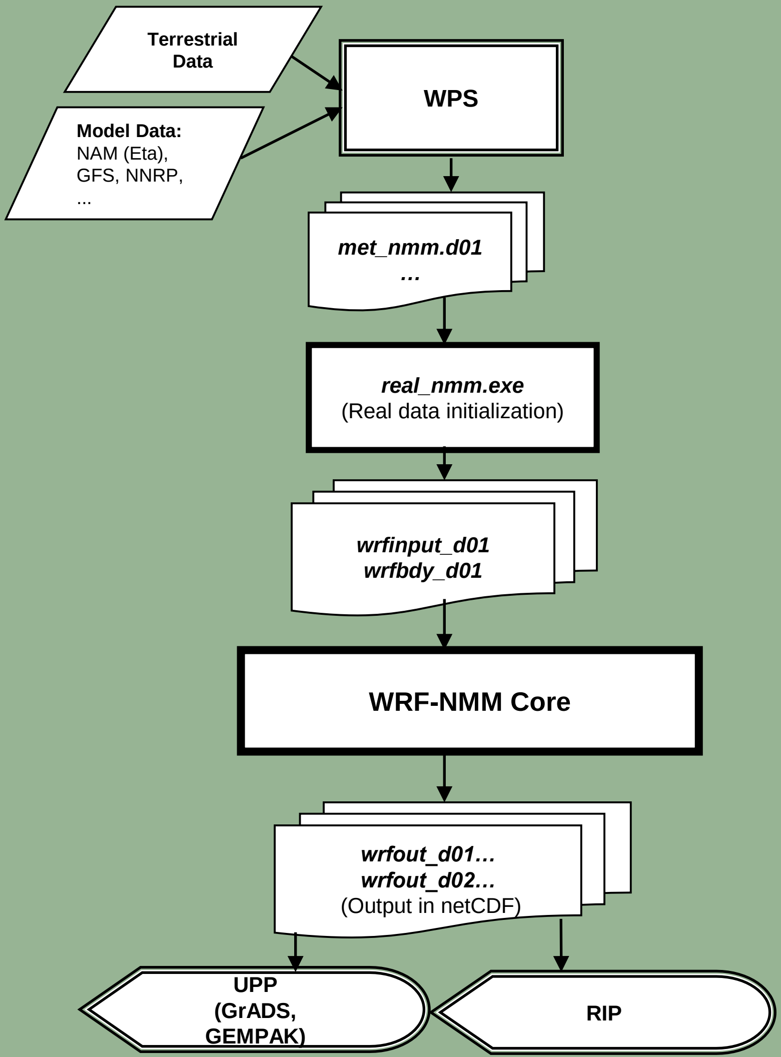
WEATHER RESEARCH & FORECASTING

NMM

Version 3 Modeling System User's Guide

April 2014

WRF-NMM FLOW CHART


Terrestrial Data
Model Data: NAM (Eta), GFS, NNRP, ...
WPS
met_nmm.d01 ...
real_nmm.exe (Real data initialization)
wrfinput_d01 wrfbdy_d01
WRF-NMM Core
wrfout_d01... wrfout_d02... (Output in netCDF)
UPP (GrADS, GEMPAK)
RIP

Developmental Testbed Center / National Centers for Environmental Prediction

Foreword

The Weather Research and Forecast (WRF) model system has two dynamic cores:

1. The Advanced Research WRF (ARW) developed by NCAR/MMM

2. The Non-hydrostatic Mesoscale Model (NMM) developed by NOAA/NCEP

The WRF-NMM User's Guide covers NMM specific information, as well as the common parts between the two dynamical cores of the WRF package. This document is a comprehensive guide for users of the WRF-NMM Modeling System, Version 3. The WRF-NMM User's Guide will be continuously enhanced and updated with new versions of the WRF code.

Please send questions to: wrfhelp@ucar.edu

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User's Guide for the NMM Core of the Weather Research and Forecast (WRF) Modeling System Version 3

(View entire document as a pdf)

User's Guide for the NMM Core of the Weather Research and Forecast (WRF) Modeling System Version 3

Chapter 1: Overview

Table of Contents

Introduction

The Nonhydrostatic Mesoscale Model (NMM) core of the Weather Research and Forecasting (WRF) system was developed by the National Oceanic and Atmospheric Adminstration (NOAA) National Centers for Environmental Prediction (NCEP). The current release is Version 3. The WRF-NMM is designed to be a flexible, state-of-the-art atmospheric simulation system that is portable and efficient on available parallel computing platforms. The WRF-NMM is suitable for use in a broad range of applications across scales ranging from meters to thousands of kilometers, including:

- Real-time NWP
- Forecast research
- Parameterization research
- Coupled-model applications
- Teaching

The NOAA/NCEP and the Developmental Testbed Center (DTC) are currently maintaining and supporting the WRF-NMM portion of the overall WRF code (Version 3) that includes:

- WRF Software Framework
- WRF Preprocessing System (WPS)
- WRF-NMM dynamic solver, including one-way and two-way nesting
- Numerous physics packages contributed by WRF partners and the research community
- Post-processing utilities and scripts for producing images in several graphics programs.

Other components of the WRF system will be supported for community use in the future, depending on interest and available resources.

The WRF modeling system software is in the public domain and is freely available for community use.

The WRF-NMM System Program Components

Figure 1 shows a flowchart for the WRF-NMM System Version 3. As shown in the diagram, the WRF-NMM System consists of these major components:

- WRF Preprocessing System (WPS)
- WRF-NMM solver
- Postprocessor utilities and graphics tools including Unified Post Processor (UPP) and Read Interpolate Plot (RIP)
- Model Evaluation Tools (MET)

WRF Preprocessing System (WPS)

This program is used for real-data simulations. Its functions include:

- Defining the simulation domain;
- Interpolating terrestrial data (such as terrain, land-use, and soil types) to the simulation domain;
- Degribbing and interpolating meteorological data from another model to the simulation domain and the model coordinate.

(For more details, see Chapter 3.)

WRF-NMM Solver

The key features of the WRF-NMM are:

- Fully compressible, non-hydrostatic model with a hydrostatic option (Janjic, 2003a).
- Hybrid (sigma-pressure) vertical coordinate.
- Arakawa E-grid.
- Forward-backward scheme for horizontally propagating fast waves, implicit scheme for vertically propagating sound waves, Adams-Bashforth Scheme for horizontal advection, and Crank-Nicholson scheme for vertical advection. The same time step is used for all terms.
- Conservation of a number of first and second order quantities, including energy and enstrophy (Janjic 1984).
- Full physics options for land-surface, planetary boundary layer, atmospheric and surface radiation, microphysics, and cumulus convection.
- One-way and two-way nesting with multiple nests and nest levels.

(For more details and references, see Chapter 5.)

The WRF-NMM code contains an initialization program (***real_nmm.exe***; see Chapter 4) and a numerical integration program (***wrf.exe***; see Chapter 5).

Unified Post Processor (UPP)

This program can be used to post-process both WRF-ARW and WRF-NMM forecasts and was designed to:

- Interpolate the forecasts from the model's native vertical coordinate to NWS standard output levels.
- Destagger the forecasts from the staggered native grid to a regular non-staggered grid.
- Compute diagnostic output quantities.
- Output the results in NWS and WMO standard GRIB1.

(For more details, see Chapter 7.)

Read Interpolate Plot (RIP)

This program can be used to plot both WRF-ARW and WRF-NMM forecasts. Some basic features include:

- Uses a preprocessing program to read model output and convert this data into standard RIP format data files.
- Makes horizontal plots, vertical cross sections and skew-T/log *p* soundings.
- Calculates and plots backward and forward trajectories.
- Makes a data set for use in the Vis5D software package.

(For more details, see Chapter 7.)

Model Evaluation Tools (MET)

This verification package can be used to evaluate both WRF-ARW and WRF-NMM forecasts with the following techniques:

- Standard verification scores comparing gridded model data to point-based observations
- Standard verification scores comparing gridded model data to gridded observations
- Object-based verification method comparing gridded model data to gridded observations

MET is developed and supported by the Developmental Testbed Center and full details can be found on the MET User's site at: *http://www.dtcenter.org/met/users*.

WRF-NMM FLOW CHART

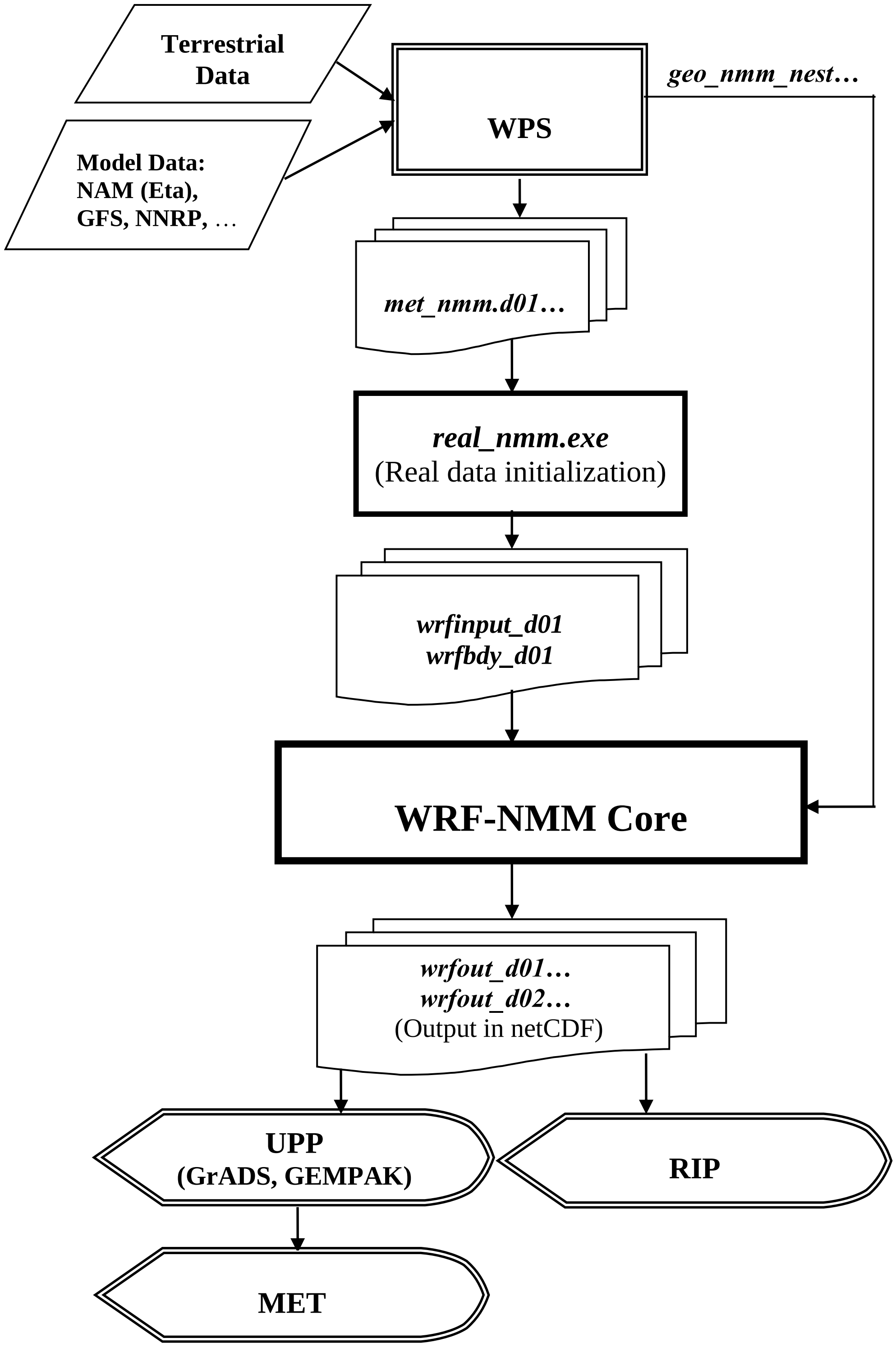


Figure 1: WRF-NMM flow chart for Version 3.

User's Guide for the NMM Core of the Weather Research and Forecast (WRF) Modeling System Version 3

Chapter 2: Software Installation

Table of Contents

Introduction

The WRF modeling system software installation is fairly straightforward on the ported platforms listed below. The model-component portion of the package is mostly self-contained. The WRF model does contain the source code to a Fortran interface to ESMF and the source to FFTPACK . Contained within the WRF system is the WRFDA component, which has several external libraries that the user must install (for various observation types and linear algebra solvers). Similarly, the WPS package, separate from the WRF source code, has additional external libraries that must be built (in support of Grib2 processing). The one external package that all of the systems require is the netCDF library, which is one of the supported I/O API packages. The netCDF libraries and source code are available from the Unidata homepage at http://www.unidata.ucar.edu (select DOWNLOADS, registration required).

The WRF model has been successfully ported to a number of Unix-based machines. WRF developers do not have access to all of them and must rely on outside users and vendors to supply the required configuration information for the compiler and loader options. Below is a list of the supported combinations of hardware and software for WRF.

Vendor	**Hardware**	**OS**	**Compiler**
Cray	XC30 Intel	Linux	Intel
Cray	XE AMD	Linux	Intel
IBM	Power Series	AIX	vendor
IBM	Intel	Linux	Intel / PGI / gfortran
SGI	IA64 / Opteron	Linux	Intel
COTS*	IA32	Linux	Intel / PGI / gfortran / g95 / PathScale
COTS	IA64 / Opteron	Linux	Intel / PGI / gfortran / PathScale
Mac	Power Series	Darwin	xlf / g95 / PGI / Intel
Mac	Intel	Darwin	gfortran / PGI / Intel
NEC	NEC	Linux	vendor
Fujitsu	FX10 Intel	Linux	vendor

* Commercial Off-The-Shelf systems

The WRF model may be built to run on a single processor machine, a shared-memory machine (that use the OpenMP API), a distributed memory machine (with the appropriate MPI libraries), or on a distributed cluster (utilizing both OpenMP and MPI). For WRF-NMM it is recommended at this time to compile either serial or utilizing distributed memory. The WPS package also runs on the above listed systems.

Required Compilers and Scripting Languages

WRF System Software Requirements

The WRF model is written in FORTRAN (what many refer to as FORTRAN 90). The software layer, RSL-LITE, which sits between WRF and the MPI interface, are written in C. Ancillary programs that perform file parsing and file construction, both of which are required for default building of the WRF modeling code, are written in C. Thus, FORTRAN 90 or 95 and C compilers are required. Additionally, the WRF build mechanism uses several scripting languages: including perl (to handle various tasks such as the code browser designed by Brian Fiedler), C-shell and Bourne shell. The traditional UNIX text/file processing utilities are used: ***make, M4, sed***, and ***awk***. If OpenMP compilation is desired, OpenMP libraries are required. The WRF I/O API also supports netCDF, PHD5 and GriB-1 formats, hence one of these libraries needs to be available on the computer used to compile and run WRF.

See Chapter 6: WRF Software (Required Software) for a more detailed listing of the necessary pieces for the WRF build.

WPS Software Requirements

The WRF Preprocessing System (WPS) requires the same Fortran and C compilers used to build the WRF model. WPS makes direct calls to the MPI libraries for distributed memory message passing. In addition to the netCDF library, the WRF I/O API libraries which are included with the WRF model tar file are also required. In order to run the WRF Domain Wizard, which allows you to easily create simulation domains, Java 1.5 or later is recommended.

Required/Optional Libraries to Download

The netCDF package is required and can be downloaded from Unidata: http://www.unidata.ucar.edu (select DOWNLOADS).

The netCDF libraries should be installed either in the directory included in the user's path to ***netCDF*** libraries or in ***/usr/local*** and its ***include***/ directory is defined by the environmental variable NETCDF. For example:

```
setenv NETCDF /path-to-netcdf-library
```

To execute netCDF commands, such as **ncdump** and **ncgen,** */path-to-netcdf/**bin*** may also need to be added to the user's path.

Hint: When compiling WRF codes on a Linux system using the PGI (Intel, g95, gfortran) compiler, make sure the netCDF library has been installed using the same PGI (Intel, g95, gfortran) compiler.

Hint: On NCAR's IBM computer, the netCDF library is installed for both 32-bit and 64-bit memory usage. The default would be the 32-bit version. If you would like to use the 64-bit version, set the following environment variable before you start compilation:

```
setenv OBJECT_MODE 64
```

If distributed memory jobs will be run, a version of MPI is required prior to building the WRF-NMM. A version of mpich for LINUX-PCs can be downloaded from: http://www-unix.mcs.anl.gov/mpi/mpich

The user may want their system administrator to install the code. To determine whether MPI is available on your computer system, try:

```
which mpif90
which mpicc
```

which mpirun

If all of these executables are defined, MPI is probably already available. The MPI ***lib/***, ***include/***, and ***bin/*** need to be included in the user's path.

Three libraries are required by the WPS ***ungrib*** program for GRIB Edition 2 compression support. Users are encouraged to engage their system administrators support for the installation of these packages so that traditional library paths and include paths are maintained. Paths to user-installed compression libraries are handled in the ***configure.wps*** file by the ***COMPRESSION_LIBS*** and ***COMPRESSION_INC*** variables. As an alternative to manually editing the ***COMPRESSION_LIBS*** and ***COMPRESSION_INC*** variables in the ***configure.wps*** file, users may set the environment variables ***JASPERLIB*** and ***JASPERINC*** to the directories holding the JasPer library and include files before configuring the WPS; for example, if the JasPer libraries were installed in ***/usr/local/jasper-1.900.1***, one might use the following commands (in csh or tcsh):

setenv JASPERLIB /usr/local/jasper-1.900.1/lib
setenv JASPERINC /usr/local/jasper-1.900.1/include

If the zlib and PNG libraries are not in a standard path that will be checked automatically by the compiler, the paths to these libraries can be added on to the JasPer environment variables; for example, if the PNG libraries were installed in ***/usr/local/libpng-1.2.29*** and the zlib libraries were installed in ***/usr/local/zlib-1.2.3***, one might use

setenv JASPERLIB "${JASPERLIB} -L/usr/local/libpng-1.2.29/lib -L/usr/local/zlib-1.2.3/lib"

setenv JASPERINC "${JASPERINC} -I/usr/local/libpng-1.2.29/include -I/usr/local/zlib-1.2.3/include"

after having previously set ***JASPERLIB*** and ***JASPERINC.***

1. JasPer (an implementation of the JPEG2000 standard for "lossy" compression)
   http://www.ece.uvic.ca/~mdadams/jasper/

   Go down to "JasPer software", one of the "click here" parts is the source.

   ./configure
   make
   make install

   Note: The GRIB2 libraries expect to find include files in ***jasper/jasper.h***, so it may be necessary to manually create a ***jasper*** subdirectory in the ***include*** directory created by the JasPer installation, and manually link header files there.

2. zlib (another compression library, which is used by the PNG library)
   http://www.zlib.net/

   Go to "The current release is publicly available here" section and download.

./configure
make
make install

3. PNG (compression library for "lossless" compression)
   http://www.libpng.org/pub/png/libpng.html

   Scroll down to "Source code" and choose a mirror site.

   ./configure
   make check
   make install

To get around portability issues, the NCEP GRIB libraries, w3 and g2, have been included in the WPS distribution. The original versions of these libraries are available for download from NCEP at http://www.nco.ncep.noaa.gov/pmb/codes/GRIB2/. The specific tar files to download are g2lib and w3lib. Because the ***ungrib*** program requires modules from these files, they are not suitable for usage with a traditional library option during the link stage of the build.

UNIX Environment Settings

Path names for the compilers and libraries listed above should be defined in the shell configuration files (such as ***.cshrc*** or ***.login***). For example:

```
set path = (    /usr/pgi/bin /usr/pgi/lib /usr/local/ncarg/bin \
                /usr/local/mpich-pgi /usr/local/mpich-pgi/bin \
                /usr/local/netcdf-pgi/bin /usr/local/netcdf-pgi/include)
setenv PGI /usr/pgi
setenv NETCDF /usr/local/netcdf-pgi
setenv NCARG_ROOT /usr/local/ncarg
setenv LM_LICENSE_FILE $PGI/license.dat
setenv LD_LIBRARY_PATH /usr/lib:/usr/local/lib:/usr/pgi/linux86/lib:/usr/local/
netcdf-pgi/lib
```

In addition, there are a few WRF-related environmental settings. To build the WRF-NMM core, the environment setting WRF_NMM_CORE is required. If nesting will be used, the WRF_NMM_NEST environment setting needs to be specified (see below). A single domain can still be specified even if WRF_NMM_NEST is set to 1. If the WRF-NMM will be built for the HWRF configuration, the HWRF environment setting also needs to be set (see below). The rest of these settings are not required, but the user may want to try some of these settings if difficulties are encountered during the build process.

In C-shell syntax:

- ***setenv WRF_NMM_CORE 1*** (explicitly turns on WRF-NMM core to build)
- ***setenv WRF_NMM_NEST 1*** (nesting is desired using the WRF-NMM core)

- ***setenv HWRF 1*** (explicitly specifies that WRF-NMM will be built for the HWRF configuration; set along with previous two environment settings)
- ***unset limits*** (especially if you are on a small system)
- ***setenv MP_STACK_SIZE 64000000*** (OpenMP blows through the stack size, set it large)
- ***setenv MPICH_F90 f90*** (or whatever your FORTRAN compiler may be called. WRF needs the bin, lib, and include directories)
- ***setenv OMP_NUM_THREADS n*** (where *n* is the number of processors to use. In systems with OpenMP installed, this is how the number of threads is specified.)

Building the WRF System for the NMM Core

Obtaining and Opening the WRF Package

The WRF-NMM source code ***tar*** file may be downloaded from:
http://www.dtcenter.org/wrf-nmm/users/downloads/

Note: Always obtain the latest version of the code if you are not trying to continue a pre-existing project. WRFV3 is just used as an example here.

Once the ***tar*** file is obtained, ***gunzip*** and ***untar*** the file.

tar –zxvf WRFV3.TAR.gz

The end product will be a ***WRFV3/*** directory that contains:

Makefile	Top-level makefile
README	General information about WRF code
README.DA	General information about WRFDA code
README.io_config	IO stream information
README.NMM	NMM specific information
README.rsl_output	Explanation of the another rsl.* output option
README.SSIB	Information about coupling WRF-ARW with SSiB
README_test_cases	Directions for running test cases and a listing of cases
README.windturbine	Describes wind turbine drag parameterization schemes
Registry/	Directory for WRF Registry file
arch/	Directory where compile options are gathered
chem/	Directory for WRF-Chem
clean	Script to clean created files and executables
compile	Script for compiling WRF code
configure	Script to configure the configure.wrf file for compile
dyn_em	Directory for WRF-ARW dynamic modules
dyn_exp/	Directory for a 'toy' dynamic core
dyn_nmm/	Directory for WRF-NMM dynamic modules
external/	Directory that contains external packages, such as those for IO, time keeping, ocean coupling interface and MPI
frame/	Directory that contains modules for WRF framework

inc/	Directory that contains include files
main/	Directory for main routines, such as wrf.F, and all executables
phys/	Directory for all physics modules
run/	Directory where one may run WRF
share/	Directory that contains mostly modules for WRF mediation layer and WRF I/O
test/	Directory containing sub-directories where one may run specific configurations of WRF - Only *nmm_real* is relevant to WRF-NMM
tools/	Directory that contains tools
var/	Directory for WRF-Var

How to Configure the WRF

The WRF code has a fairly sophisticated build mechanism. The package tries to determine the architecture on which the code is being built, and then presents the user with options to allow the user to select the preferred build method. For example, on a Linux machine, the build mechanism determines whether the machine is 32- or 64-bit, and then prompts the user for the desired usage of processors (such as serial, shared memory, or distributed memory).

A helpful guide to building WRF using PGI compilers on a 32-bit or 64-bit LINUX system can be found at:
http://www.pgroup.com/resources/tips.htm#WRF.

To configure WRF, go to the WRF (top) directory (***cd WRF***) and type:

./configure

You will be given a list of choices for your computer. These choices range from compiling for a single processor job (serial), to using OpenMP shared-memory (SM) or distributed-memory (DM) parallelization options for multiple processors.

Choices for a LINUX operating systems include:

1. Linux x86_64, PGI compiler with gcc (serial)
2. Linux x86_64, PGI compiler with gcc (smpar)
3. Linux x86_64, PGI compiler with gcc (dmpar)
4. Linux x86_64, PGI compiler with gcc (dm+sm)
5. Linux x86_64, PGI compiler with pgcc, SGI MPT (serial)
6. Linux x86_64, PGI compiler with pgcc, SGI MPT (smpar)
7. Linux x86_64, PGI compiler with pgcc, SGI MPT (dmpar)
8. Linux x86_64, PGI compiler with pgcc, SGI MPT (dm+sm)
9. Linux x86_64, PGI accelerator compiler with gcc (serial)
10. Linux x86_64, PGI accelerator compiler with gcc (smpar)
11. Linux x86_64, PGI accelerator compiler with gcc (dmpar)
12. Linux x86_64, PGI accelerator compiler with gcc (dm+sm)
13. Linux x86_64 i486 i586 i686, ifort compiler with icc (serial)

```
14. Linux x86_64 i486 i586 i686, ifort compiler with icc  (smpar)
15. Linux x86_64 i486 i586 i686, ifort compiler with icc  (dmpar)
16. Linux x86_64 i486 i586 i686, ifort compiler with icc  (dm+sm)
17. Linux x86_64 i486 i586 i686, ifort compiler with icc, SGI MPT  (serial)
18. Linux x86_64 i486 i586 i686, ifort compiler with icc, SGI MPT  (smpar)
19. Linux x86_64 i486 i586 i686, ifort compiler with icc, SGI MPT  (dmpar)
20. Linux x86_64 i486 i586 i686, ifort compiler with icc, SGI MPT  (dm+sm)
…
```

For WRF-NMM V3 on LINUX operating systems, option 3 is recommended.

Note: For WRF-NMM it is recommended at this time to compile either serial or utilizing distributed memory (DM).

Once an option is selected, a choice of what type of nesting is desired (no nesting (0), basic (1), pre-set moves (2), or vortex following (3)) will be given. For WRF-NMM, only no nesting or 'basic' nesting is available at this time, unless the environment setting HWRF is set, then (3) will be automatically selected, which will enable the HWRF vortex following moving nest capability.

Check the ***configure.wrf*** file created and edit for compile options/paths, if necessary.

Hint: It is helpful to start with something simple, such as the serial build. If it is successful, move on to build smpar or dmpar code. Remember to type 'clean –a' between each build.

Hint: If you anticipate generating a netCDF file that is larger than 2Gb (whether it is a single- or multi-time period data [e.g. model history]) file), you may set the following environment variable to activate the large-file support option from netCDF (in c-shell):
```
setenv WRFIO_NCD_LARGE_FILE_SUPPORT 1
```

Hint: If you would like to use parallel netCDF (p-netCDF) developed by Argonne National Lab (http://trac.mcs.anl.gov/projects/parallel-netcdf), you will need to install p-netCDF separately, and use the environment variable PNETCDF to set the path:
```
setenv PNETCDF path-to-pnetcdf-library
```

Hint: Since V3.5, compilation may take a bit longer due to the addition of the CLM4 module. If you do not intend to use the CLM4 land-surface model option, you can modify your `configure.wrf` file by removing `-DWRF_USE_CLM` from `ARCH_LOCAL.`

How to Compile WRF for the NMM core

To compile WRF for the NMM dynamic core, the following environment variable must be set:

setenv WRF_NMM_CORE 1

If compiling for nested runs, also set:

setenv WRF_NMM_NEST 1

Note: A single domain can be specified even if WRF_NMM_NEST is set to 1.

If compiling for HWRF, also set:

setenv HWRF 1

Once these environment variables are set, enter the following command:

./compile nmm_real

Note that entering:

./compile -h
or
./compile

produces a listing of all of the available compile options (only ***nmm_real*** is relevant to the WRF-NMM core).

To remove all object files (except those in ***external/***) and executables, type:

clean

To remove all built files in ALL directories, as well as the ***configure.wrf,*** type:

clean –a

This action is recommended if a mistake is made during the installation process, or if the ***Registry.NMM**** or ***configure.wrf*** files have been edited.

When the compilation is successful, two executables are created in ***main/***:

real_nmm.exe: WRF-NMM initialization
wrf.exe: WRF-NMM model integration

These executables are linked to ***run/*** and ***test/nmm_real/***. The ***test/nmm_real*** and ***run*** directories are working directories that can be used for running the model.

Beginning with V3.5, the compression function in netCDF4 is supported. This option will typically reduce the file size by more than 50%. It will require netCDF4 to be installed with the option `--enable-netcdf-4`. Before compiling WRF, you will need to set the environment variable NETCDF4. In a C-shell environment, type;

setenv NETCDF4 1

followed by ***configure*** and ***compile***.

More details on the WRF-NMM core, physics options, and running the model can be found in Chapter 5. WRF-NMM input data must be created using the WPS code (see Chapter 3).

Building the WRF Preprocessing System (WPS)

How to Install the WPS

The WRF Preprocessing System uses a build mechanism similar to that used by the WRF model. External libraries for ***geogrid*** and ***metgrid*** are limited to those required by the WRF model, since the WPS uses the WRF model's implementations of the I/O API; consequently, *WRF must be compiled prior to installation of the WPS* so that the I/O API libraries in the ***external*** directory of WRF will be available to WPS programs. Additionally, the ***ungrib*** program requires three compression libraries for GRIB Edition 2 support (described in the Required/Optional Libraries above) However, if support for GRIB2 data is not needed, ***ungrib*** can be compiled without these compression libraries.

Once the WPS tar file has been obtained, unpack it at the same directory level as ***WRFV3/***.

tar –zxvf WPS.tar.gz

At this point, a listing of the current working directory should at least include the directories ***WRFV3***/ and ***WPS***/. First, compile WRF (see the instructions for installing WRF). Then, after the WRF executables are generated, change to the WPS directory and issue the ***configure*** command followed by the ***compile*** command, as shown below.

cd WPS/

./configure

Choose one of the configure options listed.

./compile >& compile_wps.output

After issuing the ***compile*** command, a listing of the current working directory should reveal symbolic links to executables for each of the three WPS programs: ***geogrid.exe***, ***ungrib.exe***, and ***metgrid.exe,*** if the WPS software was successfully installed. If any of these links do not exist, check the compilation output in ***compile_wps.output*** to see what went wrong.

In addition to these three links, a ***namelist.wps*** file should exist. Thus, a listing of the WPS root directory should include:

```
arch/                                   metgrid.exe -> metgrid/src/metgrid.exe
clean                                   namelist.wps
compile                                 namelist.wps.all_options
```

compile_wps.out	***namelist.wps.fire***
configure	***namelist.wps.global***
configure.wps	***namelist.wps.nmm***
geogrid/	***README***
geogrid.exe -> geogrid/src/geogrid.exe	***ungrib/***
link_grib.csh	***ungrib.exe -> ungrib/src/ungrib.exe***
metgrid/	***util/***

More details on the functions of the WPS and how to run it can be found in Chapter 3.

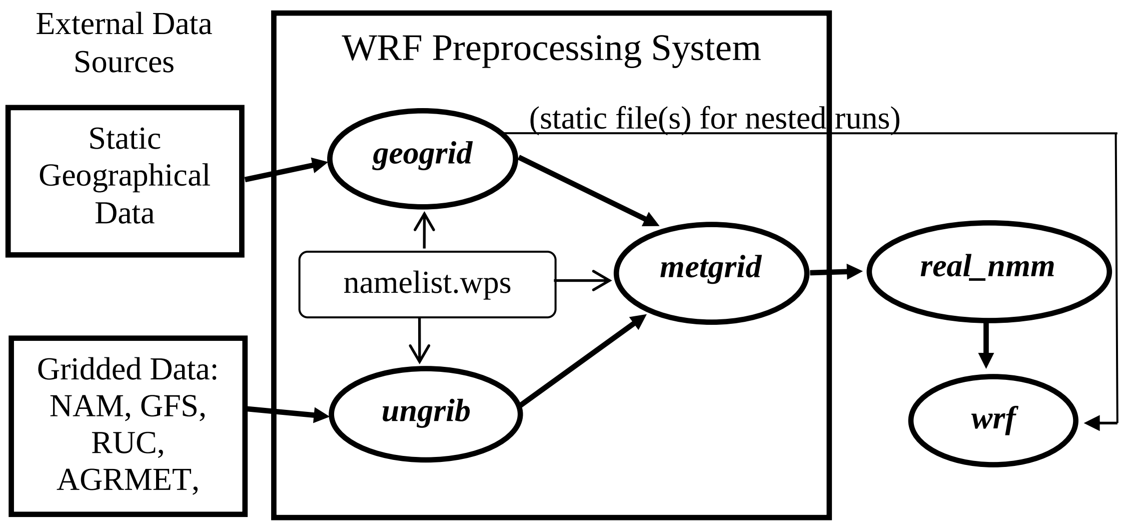
User's Guide for the NMM Core of the Weather Research and Forecast (WRF) Modeling System Version 3

Chapter 3: WRF Preprocessing System (WPS)

Table of Contents

Introduction

The WRF Preprocessing System (WPS) is a set of three programs whose collective role is to prepare input to the *real* program for real-data simulations. Each of the programs performs one stage of the preparation: *geogrid* defines model domains and interpolates static geographical data to the grids; *ungrib* extracts meteorological fields from GRIB-formatted files; and *metgrid* horizontally interpolates the meteorological fields extracted by ungrib to the model grids defined by geogrid. The work of vertically interpolating meteorological fields to WRF eta levels is performed within the *real* program.



The data flow between the programs of the WPS is shown in the figure above. Each of the WPS programs reads parameters from a common namelist file, as shown in the figure. This namelist file has separate namelist records for each of the programs and a shared namelist record, which defines parameters that are used by more than one WPS program. Not shown in the figure are additional table files that are used by individual programs. These tables provide additional control over the programs' operation, though they generally do not need to be changed by the user. The GEOGRID.TBL, METGRID.TBL, and Vtable files are explained later in this document, though for now, the user need not be concerned with them.

The build mechanism for the WPS, which is very similar to the build mechanism used by the WRF model, provides options for compiling the WPS on a variety of platforms. When MPICH libraries and suitable compilers are available, the metgrid and geogrid programs may be compiled for distributed memory execution, which allows large model domains to be processed in less time. The work performed by the ungrib program is not amenable to parallelization, so ungrib may only be run on a single processor.

Function of Each WPS Program

The WPS consists of three independent programs: *geogrid***,** *ungrib*, and *metgrid*. Also included in the WPS are several utility programs, which are described in the section on utility programs. A brief description of each of the three main programs is given below, with further details presented in subsequent sections.

Program geogrid

The purpose of geogrid is to define the simulation domains, and interpolate various terrestrial data sets to the model grids. The simulation domains are defined using information specified by the user in the “geogrid” namelist record of the WPS namelist file, namelist.wps. In addition to computing the latitude, longitude, and map scale factors at every grid point, geogrid will interpolate soil categories, land use category, terrain height, annual mean deep soil temperature, monthly vegetation fraction, monthly albedo, maximum snow albedo, and slope category to the model grids by default. Global data sets for each of these fields are provided through the WRF download page, and, because these data are time-invariant, they only need to be downloaded once. Several of the data sets are available in only one resolution, but others are made available in resolutions of 30", 2', 5', and 10'; here, " denotes arc seconds and ' denotes arc minutes. The user need not download all available resolutions for a data set, although the interpolated fields will generally be more representative if a resolution of data near to that of the simulation domain is used. However, users who expect to work with domains having grid spacings that cover a large range may wish to eventually download all available resolutions of the static terrestrial data.

Besides interpolating the default terrestrial fields, the geogrid program is general enough to be able to interpolate most continuous and categorical fields to the simulation domains. New or additional data sets may be interpolated to the simulation domain through the use of the table file, GEOGRID.TBL. The GEOGRID.TBL file defines each of the fields that will be produced by geogrid; it describes the interpolation methods to be used for a field, as well as the location on the file system where the data set for that field is located.

Output from geogrid is written in the WRF I/O API format, and thus, by selecting the NetCDF I/O format, geogrid can be made to write its output in NetCDF for easy visualization using external software packages, including ncview, NCL, and RIP4.

Program ungrib

The ungrib program reads GRIB files, "degribs" the data, and writes the data in a simple format, called the intermediate format (see the section on writing data to the intermediate format for details of the format). The GRIB files contain time-varying meteorological fields and are typically from another regional or global model, such as NCEP's NAM or GFS models. The ungrib program can read GRIB Edition 1 and, if compiled with a "GRIB2" option, GRIB Edition 2 files.

GRIB files typically contain more fields than are needed to initialize WRF. Both versions of the GRIB format use various codes to identify the variables and levels in the GRIB file. Ungrib uses tables of these codes – called Vtables, for "variable tables" – to define which fields to extract from the GRIB file and write to the intermediate format. Details about the codes can be found in the WMO GRIB documentation and in documentation from the originating center. Vtables for common GRIB model output files are provided with the ungrib software.

Vtables are provided for NAM 104 and 212 grids, the NAM AWIP format, GFS, the NCEP/NCAR Reanalysis archived at NCAR, RUC (pressure level data and hybrid coordinate data), AFWA's AGRMET land surface model output, ECMWF, and other data sets. Users can create their own Vtable for other model output using any of the Vtables as a template; further details on the meaning of fields in a Vtable are provided in the section on creating and editing Vtables.

Ungrib can write intermediate data files in any one of three user-selectable formats: WPS – a new format containing additional information useful for the downstream programs; SI – the previous intermediate format of the WRF system; and MM5 format, which is included here so that ungrib can be used to provide GRIB2 input to the MM5 modeling system. Any of these formats may be used by WPS to initialize WRF, although the WPS format is recommended.

Program metgrid

The metgrid program horizontally interpolates the intermediate-format meteorological data that are extracted by the ungrib program onto the simulation domains defined by the geogrid program. The interpolated metgrid output can then be ingested by the WRF real program. The range of dates that will be interpolated by metgrid are defined in the "share" namelist record of the WPS namelist file, and date ranges must be specified individually in the namelist for each simulation domain. Since the work of the metgrid program, like that of the ungrib program, is time-dependent, metgrid is run every time a new simulation is initialized.

Control over how each meteorological field is interpolated is provided by the METGRID.TBL file. The METGRID.TBL file provides one section for each field, and within a section, it is possible to specify options such as the interpolation methods to be used for the field, the field that acts as the mask for masked interpolations, and the grid staggering (e.g., U, V in ARW; H, V in NMM) to which a field is interpolated.

Output from metgrid is written in the WRF I/O API format, and thus, by selecting the NetCDF I/O format, metgrid can be made to write its output in NetCDF for easy visualization using external software packages, including the new version of RIP4.

Running the WPS

Note: For software requirements and how to compile the WRF Preprocessing System package, see Chapter 2.

There are essentially three main steps to running the WRF Preprocessing System:

1. Define a model coarse domain and any nested domains with *geogrid*.
2. Extract meteorological fields from GRIB data sets for the simulation period with *ungrib*.
3. Horizontally interpolate meteorological fields to the model domains with *metgrid*.

When multiple simulations are to be run for the same model domains, it is only necessary to perform the first step once; thereafter, only time-varying data need to be processed for each simulation using steps two and three. Similarly, if several model domains are being run for the same time period using the same meteorological data source, it is not necessary to run ungrib separately for each simulation. Below, the details of each of the three steps are explained.

Step 1: Define model domains with geogrid

In the root of the WPS directory structure, symbolic links to the programs geogrid.exe, ungrib.exe, and metgrid.exe should exist if the WPS software was successfully installed. In addition to these three links, a namelist.wps file should exist. Thus, a listing in the WPS root directory should look something like:

```
> ls
drwxr-xr-x 2   4096 arch
-rwxr-xr-x 1   1672 clean
-rwxr-xr-x 1   3510 compile
-rw-r--r-- 1  85973 compile.output
-rwxr-xr-x 1   4257 configure
-rw-r--r-- 1   2486 configure.wps
drwxr-xr-x 4   4096 geogrid
lrwxrwxrwx 1     23 geogrid.exe -> geogrid/src/geogrid.exe
-rwxr-xr-x 1   1328 link_grib.csh
drwxr-xr-x 3   4096 metgrid
lrwxrwxrwx 1     23 metgrid.exe -> metgrid/src/metgrid.exe
-rw-r--r-- 1   1101 namelist.wps
-rw-r--r-- 1   1987 namelist.wps.all_options
-rw-r--r-- 1   1075 namelist.wps.global
-rw-r--r-- 1    652 namelist.wps.nmm
-rw-r--r-- 1   4786 README
drwxr-xr-x 4   4096 ungrib
lrwxrwxrwx 1     21 ungrib.exe -> ungrib/src/ungrib.exe
drwxr-xr-x 3   4096 util
```

The model coarse domain and any nested domains are defined in the “geogrid” namelist record of the namelist.wps file, and, additionally, parameters in the “share” namelist record need to be set. An example of these two namelist records is given below, and the user is referred to the description of namelist variables for more information on the purpose and possible values of each variable.

```
&share
 wrf_core = 'NMM',
 max_dom = 2,
 start_date = '2008-03-24_12:00:00','2008-03-24_12:00:00',
 end_date   = '2008-03-24_18:00:00','2008-03-24_12:00:00',
 interval_seconds = 21600,
 io_form_geogrid = 2
/

&geogrid
 parent_id         =   1,   1,
 parent_grid_ratio =   1,   3,
 i_parent_start    =   1,  31,
 j_parent_start    =   1,  17,
 e_we              =  74, 112,
 e_sn              =  61,  97,
 geog_data_res     = '10m','2m',
 dx = 0.289153,
 dy = 0.287764,
 map_proj = 'rotated_ll',
 ref_lat   =  34.83,
 ref_lon   = -81.03,
 geog_data_path = '/mmm/users/wrfhelp/WPS_GEOG/'
/
```

To summarize a set of typical changes to the “share” namelist record relevant to geogrid, the WRF dynamical core must first be selected with `wrf_core`. If WPS is being run for an ARW simulation, `wrf_core` should be set to `'ARW'`, and if running for an NMM simulation, it should be set to `'NMM'`. After selecting the dynamical core, the total number of domains (in the case of ARW) or nesting levels (in the case of NMM) must be chosen with `max_dom`. Since geogrid produces only time-independent data, the `start_date`, `end_date`, and `interval_seconds` variables are ignored by geogrid. Optionally, a location (if not the default, which is the current working directory) where domain files should be written to may be indicated with the `opt_output_from_geogrid_path` variable, and the format of these domain files may be changed with `io_form_geogrid`.

In the “geogrid” namelist record, the projection of the simulation domain is defined, as are the size and location of all model grids. The map projection to be used for the model domains is specified with the `map_proj` variable and must be set to `rotated_ll` for WRF-NMM.

Besides setting variables related to the projection, location, and coverage of model domains, the path to the static geographical data sets must be correctly specified with the `geog_data_path` variable. Also, the user may select which resolution of static data geogrid will interpolate from using the `geog_data_res` variable, whose value should match one of the resolutions of data in the GEOGRID.TBL. If the full set of static data are downloaded from the WRF download page, possible resolutions include `'30s'`, `'2m'`, `'5m'`, and `'10m'`, corresponding to 30-arc-second data, 2-, 5-, and 10-arc-minute data.

Depending on the value of the `wrf_core` namelist variable, the appropriate GEOGRID.TBL file must be used with geogrid, since the grid staggerings that WPS interpolates to differ between dynamical cores. For the ARW, the GEOGRID.TBL.ARW file should be used, and for the NMM, the GEOGRID.TBL.NMM file should be used. Selection of the appropriate GEOGRID.TBL is accomplished by linking the correct file to GEOGRID.TBL in the geogrid directory (or in the directory specified by `opt_geogrid_tbl_path`, if this variable is set in the namelist).

```
> ls geogrid/GEOGRID.TBL

lrwxrwxrwx 1      15 GEOGRID.TBL -> GEOGRID.TBL.NMM
```

For more details on the meaning and possible values for each variable, the user is referred to a description of the namelist variables.

Having suitably defined the simulation coarse domain and nested domains in the namelist.wps file, the geogrid.exe executable may be run to produce domain files. In the case of ARW domains, the domain files are named `geo_em.d0N.nc`, where `N` is the number of the nest defined in each file. When run for NMM domains, geogrid produces the file `geo_nmm.d01.nc` for the coarse domain, and `geo_nmm_nest.l0N.nc` files for each nesting level `N`. Also, note that the file suffix will vary depending on the `io_form_geogrid` that is selected. To run geogrid, issue the following command:

```
> ./geogrid.exe
```

When geogrid.exe has finished running, the message

```
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!  Successful completion of geogrid.        !
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
```

should be printed, and a listing of the WPS root directory (or the directory specified by `opt_output_from_geogrid_path`, if this variable was set) should show the domain files. If not, the geogrid.log file may be consulted in an attempt to determine the possible cause of failure. For more information on checking the output of geogrid, the user is referred to the section on checking WPS output.

```
> ls
drwxr-xr-x 2      4096 arch
-rwxr-xr-x 1      1672 clean
-rwxr-xr-x 1      3510 compile
-rw-r--r-- 1     85973 compile.output
-rwxr-xr-x 1      4257 configure
-rw-r--r-- 1      2486 configure.wps
-rw-r--r-- 1   1957004 geo_nmm.d01.nc
-rw-r--r-- 1   4745324 geo_nmm.d02.nc
drwxr-xr-x 4      4096 geogrid
lrwxrwxrwx 1        23 geogrid.exe -> geogrid/src/geogrid.exe
-rw-r--r-- 1     11169 geogrid.log
-rwxr-xr-x 1      1328 link_grib.csh
drwxr-xr-x 3      4096 metgrid
lrwxrwxrwx 1        23 metgrid.exe -> metgrid/src/metgrid.exe
-rw-r--r-- 1      1094 namelist.wps
-rw-r--r-- 1      1987 namelist.wps.all_options
-rw-r--r-- 1      1075 namelist.wps.global
-rw-r--r-- 1       652 namelist.wps.nmm
-rw-r--r-- 1      4786 README
drwxr-xr-x 4      4096 ungrib
lrwxrwxrwx 1        21 ungrib.exe -> ungrib/src/ungrib.exe
drwxr-xr-x 3      4096 util
```

Step 2: Extracting meteorological fields from GRIB files with ungrib

Having already downloaded meteorological data in GRIB format, the first step in extracting fields to the intermediate format involves editing the "share" and "ungrib" namelist records of the namelist.wps file – the same file that was edited to define the simulation domains. An example of the two namelist records is given below.

```
&share
 wrf_core = 'NMM',
 max_dom = 2,
 start_date = '2008-03-24_12:00:00','2008-03-24_12:00:00',
 end_date   = '2008-03-24_18:00:00','2008-03-24_12:00:00',
 interval_seconds = 21600,
 io_form_geogrid = 2
/

&ungrib
 out_format = 'WPS',
 prefix     = 'FILE'
/
```

In the “share” namelist record, the variables that are of relevance to ungrib are the starting and ending times of the coarse domain (`start_date` and `end_date`; alternatively, `start_year`, `start_month`, `start_day`, `start_hour`, `end_year`, `end_month`, `end_day`, and `end_hour`) and the interval between meteorological data files (`interval_seconds`). In the “ungrib” namelist record, the variable `out_format` is used to select the format of the intermediate data to be written by ungrib; the metgrid program can read any of the formats supported by ungrib, and thus, any of `'WPS'`, `'SI'`, and `'MM5'` may be specified for `out_format`, although `'WPS'` is recommended. Also in the "ungrib" namelist, the user may specify a path and prefix for the intermediate files with the `prefix` variable. For example, if `prefix` were set to `'ARGRMET'`, then the intermediate files created by ungrib would be named according to AGRMET:*YYYY-MM-DD_HH*, where *YYYY-MM-DD_HH* is the valid time of the data in the file.

After suitably modifying the namelist.wps file, a Vtable must be supplied, and the GRIB files must be linked (or copied) to the filenames that are expected by ungrib. The WPS is supplied with Vtable files for many sources of meteorological data, and the appropriate Vtable may simply be symbolically linked to the file Vtable, which is the Vtable name expected by ungrib. For example, if the GRIB data are from the GFS model, this could be accomplished with

```
> ln -s ungrib/Variable_Tables/Vtable.GFS Vtable
```

The ungrib program will try to read GRIB files named GRIBFILE.AAA, GRIBFILE.AAB, …, GRIBFILE.ZZZ. In order to simplify the work of linking the GRIB files to these filenames, a shell script, link_grib.csh, is provided. The link_grib.csh script takes as a command-line argument a list of the GRIB files to be linked. For example, if the GRIB data were downloaded to the directory /data/gfs, the files could be linked with link_grib.csh as follows:

```
> ls /data/gfs
-rw-r--r-- 1  42728372 gfs_080324_12_00
-rw-r--r-- 1  48218303 gfs_080324_12_06

> ./link_grib.csh /data/gfs/gfs*
```

After linking the GRIB files and Vtable, a listing of the WPS directory should look something like the following:

```
> ls
drwxr-xr-x 2     4096 arch
-rwxr-xr-x 1     1672 clean
-rwxr-xr-x 1     3510 compile
-rw-r--r-- 1    85973 compile.output
-rwxr-xr-x 1     4257 configure
-rw-r--r-- 1     2486 configure.wps
-rw-r--r-- 1  1957004 geo_nmm.d01.nc
-rw-r--r-- 1  4745324 geo_nmm.d02.nc
drwxr-xr-x 4     4096 geogrid
lrwxrwxrwx 1       23 geogrid.exe -> geogrid/src/geogrid.exe
-rw-r--r-- 1    11169 geogrid.log
lrwxrwxrwx 1       38 GRIBFILE.AAA -> /data/gfs/gfs_080324_12_00
lrwxrwxrwx 1       38 GRIBFILE.AAB -> /data/gfs/gfs_080324_12_06
-rwxr-xr-x 1     1328 link_grib.csh
drwxr-xr-x 3     4096 metgrid
lrwxrwxrwx 1       23 metgrid.exe -> metgrid/src/metgrid.exe
-rw-r--r-- 1     1094 namelist.wps
-rw-r--r-- 1     1987 namelist.wps.all_options
-rw-r--r-- 1     1075 namelist.wps.global
-rw-r--r-- 1      652 namelist.wps.nmm
-rw-r--r-- 1     4786 README
drwxr-xr-x 4     4096 ungrib
lrwxrwxrwx 1       21 ungrib.exe -> ungrib/src/ungrib.exe
drwxr-xr-x 3     4096 util
lrwxrwxrwx 1       33 Vtable -> ungrib/Variable_Tables/Vtable.GFS
```

After editing the namelist.wps file and linking the appropriate Vtable and GRIB files, the ungrib.exe executable may be run to produce files of meteorological data in the intermediate format. Ungrib may be run by simply typing the following:

```
> ./ungrib.exe >& ungrib.output
```

Since the ungrib program may produce a significant volume of output, it is recommended that ungrib output be redirected to a file, as in the command above. If ungrib.exe runs successfully, the message

```
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!  Successful completion of ungrib.         !
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
```

will be written to the end of the ungrib.output file, and the intermediate files should appear in the current working directory. The intermediate files written by ungrib will have names of the form `FILE:`*`YYYY-MM-DD_HH`* (unless, of course, the `prefix` variable was set to a prefix other than `'FILE'`).

```
> ls
drwxr-xr-x 2       4096 arch
-rwxr-xr-x 1       1672 clean
-rwxr-xr-x 1       3510 compile
-rw-r--r-- 1      85973 compile.output
-rwxr-xr-x 1       4257 configure
-rw-r--r-- 1       2486 configure.wps
-rw-r--r-- 1  154946888 FILE:2008-03-24_12
-rw-r--r-- 1  154946888 FILE:2008-03-24_18
-rw-r--r-- 1    1957004 geo_nmm.d01.nc
-rw-r--r-- 1    4745324 geo_nmm.d02.nc
drwxr-xr-x 4       4096 geogrid
```

```
      lrwxrwxrwx 1         23 geogrid.exe -> geogrid/src/geogrid.exe
      -rw-r--r-- 1      11169 geogrid.log
      lrwxrwxrwx 1         38 GRIBFILE.AAA -> /data/gfs/gfs_080324_12_00
      lrwxrwxrwx 1         38 GRIBFILE.AAB -> /data/gfs/gfs_080324_12_06
      -rwxr-xr-x 1       1328 link_grib.csh
      drwxr-xr-x 3       4096 metgrid
      lrwxrwxrwx 1         23 metgrid.exe -> metgrid/src/metgrid.exe
      -rw-r--r-- 1       1094 namelist.wps
      -rw-r--r-- 1       1987 namelist.wps.all_options
      -rw-r--r-- 1       1075 namelist.wps.global
      -rw-r--r-- 1        652 namelist.wps.nmm
      -rw-r--r-- 1       4786 README
      drwxr-xr-x 4       4096 ungrib
      lrwxrwxrwx 1         21 ungrib.exe -> ungrib/src/ungrib.exe
      -rw-r--r-- 1       1418 ungrib.log
      -rw-r--r-- 1      27787 ungrib.output
      drwxr-xr-x 3       4096 util
      lrwxrwxrwx 1         33 Vtable ->
ungrib/Variable_Tables/Vtable.GFS
```

Step 3: Horizontally interpolating meteorological data with metgrid

In the final step of running the WPS, meteorological data extracted by ungrib are horizontally interpolated to the simulation grids defined by geogrid. In order to run metgrid, the namelist.wps file must be edited. In particular, the “share” and “metgrid” namelist records are of relevance to the metgrid program. Examples of these records are shown below.

```
&share
 wrf_core = 'NMM',
 max_dom = 2,
 start_date = '2008-03-24_12:00:00','2008-03-24_12:00:00',
 end_date   = '2008-03-24_18:00:00','2008-03-24_12:00:00',
 interval_seconds = 21600,
 io_form_geogrid = 2
/

&metgrid
 fg_name                      = 'FILE',
 io_form_metgrid              = 2,
/
```

By this point, there is generally no need to change any of the variables in the “share” namelist record, since those variables should have been suitably set in previous steps. If the "share" namelist was not edited while running geogrid and ungrib, however, the WRF dynamical core, number of domains, starting and ending times, interval between meteorological data, and path to the static domain files must be set in the “share” namelist record, as described in the steps to run geogrid and ungrib.

In the “metgrid” namelist record, the path and prefix of the intermediate meteorological data files must be given with `fg_name`, the full path and file names of any intermediate files containing constant fields may be specified with the `constants_name` variable, and the output format for the horizontally interpolated files may be specified with the `io_form_metgrid` variable. Other variables in the “metgrid” namelist record, namely, `opt_output_from_metgrid_path` and `opt_metgrid_tbl_path`, allow the user to specify where interpolated data files should be written by metgrid and where the METGRID.TBL file may be found.

As with geogrid and the GEOGRID.TBL file, a METGRID.TBL file appropriate for the WRF core must be linked in the metgrid directory (or in the directory specified by `opt_metgrid_tbl_path`, if this variable is set).

```
> ls metgrid/METGRID.TBL

lrwxrwxrwx 1      15 METGRID.TBL -> METGRID.TBL.NMM
```

After suitably editing the namelist.wps file and verifying that the correct METGRID.TBL will be used, metgrid may be run by issuing the command

```
> ./metgrid.exe
```

If metgrid successfully ran, the message

```
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!  Successful completion of metgrid.        !
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
```

will be printed. After successfully running, metgrid output files should appear in the WPS root directory (or in the directory specified by `opt_output_from_metgrid_path`, if this variable was set). These files will be named `met_em.d0N.YYYY-MM-DD_HH:mm:ss.nc` in the case of ARW domains, where `N` is the number of the nest whose data reside in the file, or `met_nmm.d01.YYYY-MM-DD_HH:mm:ss.nc` in the case of NMM domains. Here, `YYYY-MM-DD_HH:mm:ss` refers to the date of the interpolated data in each file. If these files do not exist for each of the times in the range given in the "share" namelist record, the metgrid.log file may be consulted to help in determining the problem in running metgrid.

```
> ls
drwxr-xr-x 2       4096 arch
-rwxr-xr-x 1       1672 clean
-rwxr-xr-x 1       3510 compile
-rw-r--r-- 1      85973 compile.output
-rwxr-xr-x 1       4257 configure
-rw-r--r-- 1       2486 configure.wps
-rw-r--r-- 1  154946888 FILE:2008-03-24_12
-rw-r--r-- 1  154946888 FILE:2008-03-24_18
-rw-r--r-- 1    1957004 geo_nmm.d01.nc
-rw-r--r-- 1    4745324 geo_nmm.d02.nc
drwxr-xr-x 4       4096 geogrid
lrwxrwxrwx 1         23 geogrid.exe -> geogrid/src/geogrid.exe
-rw-r--r-- 1      11169 geogrid.log
lrwxrwxrwx 1         38 GRIBFILE.AAA -> /data/gfs/gfs_080324_12_00
lrwxrwxrwx 1         38 GRIBFILE.AAB -> /data/gfs/gfs_080324_12_06
-rwxr-xr-x 1       1328 link_grib.csh
-rw-r--r-- 1    5217648 met_nmm.d01.2008-03-24_12:00:00.nc
-rw-r--r-- 1    5217648 met_nmm.d01.2008-03-24_18:00:00.nc
-rw-r--r-- 1   12658200 met_nmm.d02.2008-03-24_12:00:00.nc
drwxr-xr-x 3       4096 metgrid
lrwxrwxrwx 1         23 metgrid.exe -> metgrid/src/metgrid.exe
```

```
      -rw-r--r-- 1      65970 metgrid.log
      -rw-r--r-- 1       1094 namelist.wps
      -rw-r--r-- 1       1987 namelist.wps.all_options
      -rw-r--r-- 1       1075 namelist.wps.global
      -rw-r--r-- 1        652 namelist.wps.nmm
      -rw-r--r-- 1       4786 README
      drwxr-xr-x 4       4096 ungrib
      lrwxrwxrwx 1         21 ungrib.exe -> ungrib/src/ungrib.exe
      -rw-r--r-- 1       1418 ungrib.log
      -rw-r--r-- 1      27787 ungrib.output
      drwxr-xr-x 3       4096 util
      lrwxrwxrwx 1         33 Vtable ->
ungrib/Variable_Tables/Vtable.GFS
```

Creating Nested Domains with the WPS

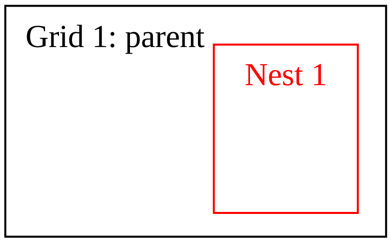
At this time, the WRF-NMM supports one-way and two-way stationary and moving (if running an HWRF configuration, see HWRF User's Guide) nests. Because the WRF-NMM nesting strategy was targeted towards the the capability of moving nests, time-invariant information, such as topography, soil type, albedo, etc. for a nest must be acquired over the entire domain of the coarsest grid even though, for a stationary nest, that information will only be used over the location where the nest is initialized.

Running the WPS for WRF-NMM nested-domain simulations is essentially no more difficult than running for a single-domain case; the ***geogrid*** program simply processes more than one grid when it is run, rather than a single grid.

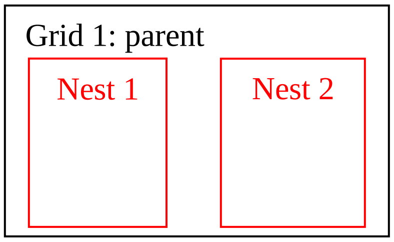
The number of grids is unlimited. Grids may be located side by side (i.e., two nests may be children of the same parent and located on the same nest level), or telescopically nested. The nesting ratio for the WRF-NMM is always 3. Hence, the grid spacing of a nest is always 1/3 of its parent.

The nest level is dependant on the parent domain. If one nest is defined inside the coarsest domain, the nest level will be one and one additional static file will be created. If two nests are defined to have the same parent, again, only one additional static file will be created.

For example:



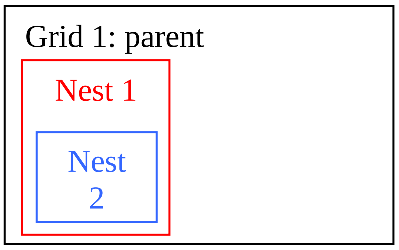
OR



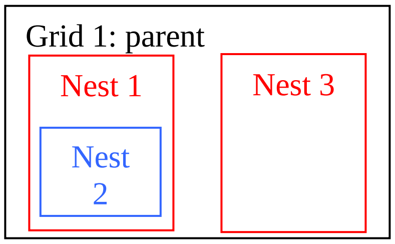
will create an output file for the parent domain: ***geo_nmm.d01.nc*** and one higher resolution output file for nest level one: ***geo_nmm_nest.l01.nc***

If, however, two telescopic nests are defined (nest 1 inside the parent and nest 2 inside nest 1), then two additional static files will be created. Even if an additional nest 3 was added at the same grid spacing as nest1, or at the same grid spacing as nest 2, there would still be only two additional static files created.

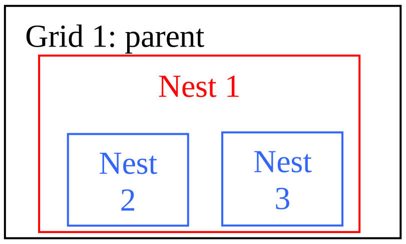
For example:



OR



OR



will create an output file for the parent domain: ***geo_nmm.d01.nc***, one output file with three times higher resolution for nest level one: ***geo_nmm_nest.l01.nc***, and one output file with nine times higher resolution for nest level two: ***geo_nmm_nest.l02.nc.***

In order to specify an additional nest level, a number of variables in the *namelist.wps* file must be given lists of values with a format of one value per nest separated by commas. The variables that need a list of values for nesting include: *parent_id*, *parent_grid_ratio*, *i_parent_start*, *j_parent_start*, *s_we*, *e_we*, *s_sn*, *e_sn*, and *geog_data_res*.

In the ***namelist.wps*,** the first change to the "***share***" namelist record is to the ***max_dom*** variable, which must be set to the total number of nests in the simulation, including the coarsest domain. Having determined the number of nests, all of the other affected namelist variables must be given a list of *N* values, one for each nest. The only other change to the "***share***" namelist record is to the starting and ending times. Here, a starting and ending time must be given for each nest, with the restriction that a nest cannot begin before its parent domain or end after its parent domain; also, it is suggested that nests be given starting and ending times that are identical to the desired starting times of the nest *when running WPS*. This is because the nests get their lateral boundary conditions from their parent domain, and thus, only the initial time for a nest needs to be processed by WPS. It is important to note that, *when running WRF*, the actual starting and ending times for all nests must be given in the WRF ***namelist.input*** file.

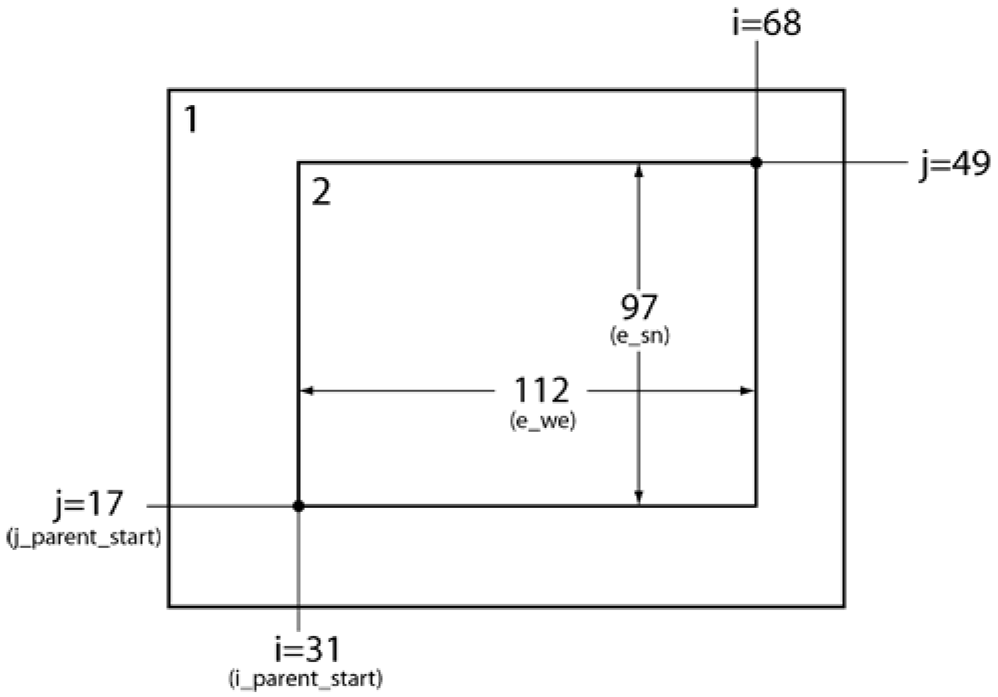
The remaining changes are to the "***geogrid***" namelist record. In this record, the parent of each nest must be specified with the ***parent_id*** variable. Every nest must be a child of exactly one other nest, with the coarse domain being its own parent. Related to the identity of a nest's parent is the nest refinement ratio with respect to a nest's parent, which is given by the ***parent_grid_ratio*** variable; this ratio determines the nominal grid spacing for a nest in relation to the grid spacing of the its parent. **Note:** This ratio must always be set to 3 for the WRF-NMM.

Next, the lower-left corner of a nest is specified as an (***i, j***) location in the nest's parent domain; this specification is done through the ***i_parent_start*** and ***j_parent_start*** variables, and the specified location is given with respect to a mass point on the E-grid. Finally, the dimensions of each nest, in grid points, are given for each nest using the ***s_we***, ***e_we***, ***s_sn***, and ***e_sn*** variables. An example is shown in the figure below, where it may be seen how each of the above-mentioned variables is found. Currently, the starting grid point values in the south-north (***s_sn***) and west-east (***s_we***) directions must be specified as 1, and the ending grid point values (***e_sn*** and ***e_we***) determine, essentially, the full dimensions of the nest.

Note: *For the WRF-NMM the variables* ***i_parent_start***, ***j_parent_start***, ***s_we***, ***e_we***, ***s_sn***, *and* ***e_sn*** *are ignored during the WPS processing because the higher resolution static files for each nest level are created for the entire coarse domain. These variables, however, are used when running the WRF-NMM model.*

Finally, for each nest, the resolution of source data to interpolate from is specified with the ***geog_data_res*** variable.

For a complete description of these namelist variables, the user is referred to the description of namelist variables.



Selecting Between USGS and MODIS-based Land Use Classifications

By default, the geogrid program will interpolate land use categories from USGS 24-category data. However, the user may select an alternative set of land use categories based on the MODIS land-cover classification of the International Geosphere-Biosphere Programme and modified for the Noah land surface model. Although the MODIS-based data contain 20 categories of land use, these categories are not a subset of the 24 USGS categories; users interested in the specific categories in either data set can find a listing of the land use classes in the section on land use and soil categories. *It must be emphasized that the MODIS-based categories should only be used with the Noah land surface model in WRF.*

The 20-category MODIS-based land use data may be selected instead of the USGS data at run-time through the `geog_data_res` variable in the “geogrid” namelist record. This is accomplished by prefixing each resolution of static data with the string “modis_30s+”. For example, in a three-domain configuration, where the `geog_data_res` variable would ordinarily be specified as

```
geog_data_res = ‘10m’, ‘2m’, ‘30s’
```

the user should instead specify

```
    geog_data_res = 'modis_30s+10m', 'modis_30s+2m', 'modis_30s+30s'
```

The effect of this change is to instruct the geogrid program to look, in each entry of the GEOGRID.TBL file, for a resolution of static data with a resolution denoted by 'modis_30s', and if such a resolution is not available, to instead look for a resolution denoted by the string following the '+'. Thus, for the GEOGRID.TBL entry for the LANDUSEF field, the MODIS-based land use data, which is identified with the string 'modis_30s', would be used instead of the '10m', '2m', and '30s' resolutions of USGS data in the example above; for all other fields, the '10m', '2m', and '30s' resolutions would be used for the first, second, and third domains, respectively. As an aside, when none of the resolutions specified for a domain in `geog_data_res` are found in a GEOGRID.TBL entry, the resolution denoted by 'default' will be used.

Selecting Static Data for the Gravity Wave Drag Scheme

The gravity wave drag by orography (GWDO) scheme in the NMM (available in version 3.1) requires fourteen static fields from the WPS. In fact, these fields will be interpolated by the geogrid program regardless of whether the GWDO scheme will be used in the model. When the GWDO scheme will not be used, the fields will simply be ignored in WRF and the user need not be concerned with the resolution of data from which the fields are interpolated. However, it is recommended that these fields be interpolated from a resolution of source data that is slightly *lower* (i.e., coarser) in resolution than the model grid; consequently, if the GWDO scheme will be used, care should be taken to select an appropriate resolution of GWDO static data. Currently, five resolutions of GWDO static data are available: 2-degree, 1-degree, 30-minute, 20-minute, and 10-minute, denoted by the strings '2deg', '1deg', '30m', '20m', and '10m', respectively. To select the resolution to interpolate from, the user should prefix the resolution specified for the `geog_data_res` variable in the "geogrid" namelist record by the string "XXX+", where XXX is one of the five available resolutions of GWDO static data. For example, in a model configuration with a 48-km grid spacing, the `geog_data_res` variable might typically be specified as

```
    geog_data_res = '10m',
```

However, if the GWDO scheme were employed, the finest resolution of GWDO static data that is still lower in resolution than the model grid would be the 30-minute data, in which case the user should specify

```
    geog_data_res = '30m+10m',
```

If none of '2deg', '1deg', '30m', or '20m' are specified in combination with other resolutions of static data in the `geog_data_res` variable, the '10m' GWDO static data will be used, since it is also designated as the 'default' resolution in the GEOGRID.TBL file. It is worth noting that, if 10-minute resolution GWDO data are to be used, but a different resolution is desired for other static fields (e.g., topography height), the user should simply omit '10m' from the value given to the `geog_data_res` variable, since specifying

```
      geog_data_res = ‘10m+30s’,
```

for example, would cause geogrid to use the 10-mintute data in preference to the 30-second data for the non-GWDO fields, such as topography height and land use category, as well as for the GWDO fields.

Using Multiple Meteorological Data Sources

The metgrid program is capable of interpolating time-invariant fields, and it can also interpolate from multiple sources of meteorological data. The first of these capabilities uses the `constants_name` variable in the `&metgrid` namelist record. This variable may be set to a list of filenames – including path information where necessary – of intermediate-formatted files which contains time-invariant fields, and which should be used in the output for every time period processed by metgrid. For example, short simulations may use a constant SST field; this field need only be available at a single time, and may be used by setting the `constants_name` variable to the path and filename of the SST intermediate file. Typical uses of `constants_name` might look like

```
&metgrid
 constants_name = '/data/ungribbed/constants/SST_FILE:2006-08-16_12'
/
```

or

```
&metgrid
 constants_name = 'LANDSEA', 'SOILHGT'
/
```

The second metgrid capability – that of interpolating data from multiple sources – may be useful in situations where two or more complementary data sets need to be combined to produce the full input data needed by `real`. To interpolate from multiple sources of time-varying, meteorological data, the `fg_name` variable in the `&metgrid` namelist record should be set to a list of prefixes of intermediate files, including path information when necessary. When multiple path-prefixes are given, and the same meteorological field is available from more than one of the sources, data from the last-specified source will take priority over all preceding sources. Thus, data sources may be prioritized by the order in which the sources are given.

As an example of this capability, if surface fields are given in one data source and upper-air data are given in another, the values assigned to the `fg_name` variable may look something like:

```
&metgrid
 fg_name = '/data/ungribbed/SFC', '/data/ungribbed/UPPER_AIR'
/
```

To simplify the process of extracting fields from GRIB files, the `prefix` namelist variable in the `&ungrib` record may be employed. This variable allows the user to control the names of (and paths to) the intermediate files that are created by ungrib. The utility of this namelist variable is most easily illustrated by way of an example. Suppose we wish to work with the North American Regional Reanalysis (NARR) data set, which is split into separate GRIB files for 3-dimensional atmospheric data, surface data, and fixed-field data. We may begin by linking all of the "3D" GRIB files using the `link_grib.csh` script, and by linking the NARR Vtable to the filename `Vtable`. Then, we may suitably edit the `&ungrib` namelist record before running ungrib.exe so that the resulting intermediate files have an appropriate prefix:

```
&ungrib
 out_format = 'WPS',
 prefix = 'NARR_3D',
/
```

After running ungrib.exe, the following files should exist (with a suitable substitution for the appropriate dates):

```
NARR_3D:2008-08-16_12
NARR_3D:2008-08-16_15
NARR_3D:2008-08-16_18
...
```

Given intermediate files for the 3-dimensional fields, we may process the surface fields by linking the surface GRIB files and changing the `prefix` variable in the namelist:

```
&ungrib
 out_format = 'WPS',
 prefix = 'NARR_SFC',
/
```

Again running ungrib.exe, the following should exist in addition to the NARR_3D files:

```
NARR_SFC:2008-08-16_12
NARR_SFC:2008-08-16_15
NARR_SFC:2008-08-16_18
...
```

Finally, the fixed file is linked with the `link_grib.csh` script, and the `prefix` variable in the namelist is again set:

```
&ungrib
 out_format = 'WPS',
 prefix = 'NARR_FIXED',
/
```

Having run ungrib.exe for the third time, the fixed fields should be available in addition to the surface and "3D" fields:

```
NARR_FIXED:1979-11-08_00
```

For the sake of clarity, the fixed file may be renamed to remove any date information, for example, by renaming it to simply `NARR_FIXED`, since the fields in the file are static. In this example, we note that the NARR fixed data are only available at a specific time, 1979 November 08 at 0000 UTC, and thus, the user would need to set the correct starting and ending time for the data in the `&share` namelist record before running ungrib on the NARR fixed file; of course, the times should be re-set before metgrid is run.

Given intermediate files for all three parts of the NARR data set, metgrid.exe may be run after the `constants_name` and `fg_name` variables in the `&metgrid` namelist record are set:

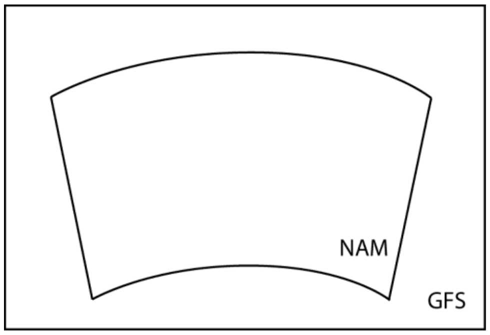
```
&metgrid
 constants_name = 'NARR_FIXED',
 fg_name = 'NARR_3D', 'NARR_SFC'
/
```

Although less common, another situation where multiple data sources would be required is when a source of meteorological data from a regional model is insufficient to cover the entire simulation domain, and data from a larger regional model, or a global model, must be used when interpolating to the remaining points of the simulation grid.

For example, to use NAM data wherever possible, and GFS data elsewhere, the following values might be assigned in the namelist:

```
&metgrid
 fg_name = '/data/ungribbed/GFS', '/data/ungribbed/NAM'
/
```

Then the resulting model domain would use data as shown in the figure below.



If no field is found in more than one source, then no prioritization need be applied by metgrid, and each field will simply be interpolated as usual; of course, each source should cover the entire simulation domain to avoid areas of missing data.

Alternative Initialization of Lake SSTs

The default treatment of sea-surface temperatures – both for oceans and lakes – in the metgrid program involves simply interpolating the SST field from the intermediate files to all water points in the WRF domain. However, if the lakes that are resolved in the WRF domain are not resolved in the GRIB data, and especially if those lakes are geographically distant from resolved water bodies, the SST field over lakes will most likely be extrapolated from the nearest resolved water bodies in the GRIB data; this situation can lead to lake SST values that are either unrealistically warm or unrealistically cold.

Without a higher-resolution SST field for metgrid to use, one alternative to extrapolating SST values for lakes is to manufacture a “best guess” at the SST for lakes. In the metgrid and real programs, this can be done using a combination of a special land use data set that distinguishes between lakes and oceans, and a field to be used as a proxy for SST over lakes. A special land use data set is necessary, since WRF’s real pre-processing program needs to know where the manufactured SST field should be used instead of the interpolated SST field from the GRIB data.

The alternative procedure for initializing lake SSTs is summarized in the following steps:

1. If they have not already been downloaded (either as a separate tar file or as part of the ‘full’ geographical data tar file), obtain the special land use data sets that distinguish between lakes and oceans. Two such data sets – based on USGS and MODIS land use categories – may be downloaded through the WRF download page. For simplicity, it is recommended to place the two directories in the same directory as the other static geographical data sets (e.g., topo_30s, soiltype_top_30s, etc.) used by geogrid, since doing so will eliminate the need to modify the GEOGRID.TBL file. If the landuse_30s_with_lakes and modis_landuse_21class_30s directories are placed in a location different from the other static data sets, it will be necessary to change the paths to these directories from relative paths to absolute paths in the GEOGRID.TBL file.

2. Before running geogrid, change the specification of `geog_data_res` in the `&geogrid` namelist record to specify either the USGS-based or the MODIS-based land use data with inland water bodies. For example, in a two-domain configuration, setting

   ```
   geog_data_res = 'usgs_lakes+10m', 'usgs_lakes+2m',
   ```

   would tell geogrid to use the USGS-based land use data for both domains, and to use the 10-minute resolution data for other static fields in domain 1 and the 2-minute resolution data for other static fields in domain 2; for MODIS-based data, `usgs_lakes` should be replaced by `modis_lakes`.

   Running geogrid should result in output files that use a separate category for inland water bodies instead of the general water category used for oceans and seas. The lake category is identified by the global attribute ISLAKE in the geogrid output files; this attribute should be set to either 28 (in the case of USGS-based data) or 21 (in the case of the MODIS-based data). See, e.g., the list of WPS output fields, where a value of -1 for ISLAKE indicates that there is no separate lake category.

3. After running the ungrib program, use the avg_tsfc.exe utility program to create an intermediate file containing a daily-average surface air temperature field, which will

be substituted for the SST field only over lakes by the real program; for more information on the avg_tsfc.exe utility, see the section on WPS utility programs.

4. Before running the metgrid program, add the TAVGSFC file created in the previous step to the specification of `constants_name` in the `&metgrid` record of the namelist.wps file.

5. Run WRF's real.exe program as usual after setting the number of land categories (`num_land_cat`) in the `&physics` record of the namelist.input file so that it matches the value of the global attribute NUM_LAND_CAT in the metgrid files. If the global attribute ISLAKE in the metgrid files indicates that there is a special land use category for lakes, the real program will substitute the TAVGSFC field for the SST field only over those grid points whose category matches the lake category; additionally, the real program will change the land use category of lakes back to the general water category (the category used for oceans), since neither the LANDUSE.TBL nor the VEGPARM.TBL files contain an entry for a lake category.

Parallelism in the WPS

If the dimensions of the domains to be processed by the WPS become too large to fit in the memory of a single CPU, it is possible to run the geogrid and metgrid programs in a distributed memory configuration. In order to compile geogrid and metgrid for distributed memory execution, the user must have MPI libraries installed on the target machine, and must have compiled WPS using one of the "DM parallel" configuration options. Upon successful compilation, the geogrid and metgrid programs may be run with the *mpirun* or *mpiexec* commands, or through a batch queuing system, depending on the machine.

As mentioned earlier, the work of the ungrib program is not amenable to parallelization, and, further, the memory requirements for ungrib's processing are independent of the memory requirements of geogrid and metgrid; thus, ungrib is always compiled for a single processor and run on a single CPU, regardless of whether a "DM parallel" configuration option was selected during configuration.

Each of the standard WRF I/O API formats (NetCDF, GRIB1, binary) has a corresponding parallel format, whose number is given by adding 100 to the io_form value (i.e., the value of `io_form_geogrid` and `io_form_metgrid`) for the standard format. It is not necessary to use a parallel io_form, but when one is used, each CPU will read/write its input/output to a separate file, whose name is simply the name that would be used during serial execution, but with a four-digit processor ID appended to the name. For example, running geogrid on four processors with `io_form_geogrid=102` would create output files named geo_em.d01.nc.0000, geo_em.d01.nc.0001, geo_em.d01.nc.0002, and geo_em.d01.nc.0003 for the coarse domain.

During distributed-memory execution, model domains are decomposed into rectangular patches, with each processor working on a single patch. When reading/writing from/to the WRF I/O API format, each processor reads/writes only its patch. Consequently, if a parallel io_form is chosen for the output of geogrid, metgrid must be run using the same number of processors as were used to run geogrid. Similarly, if a parallel io_form is chosen for the metgrid output files, the real program must be run using the same number of processors. Of course, it is still possible to use a standard io_form when running on multiple processors, in which case all data for the model domain will be distributed/collected upon input/output. As a final note, when geogrid or metgrid are run on multiple processors, each processor will write its own log file, with the log file names being appended with the same four-digit processor ID numbers that are used for the I/O API files.

Checking WPS Output

When running the WPS, it may be helpful to examine the output produced by the programs. For example, when determining the location of nests, it may be helpful to see the interpolated static geographical data and latitude/longitude fields. As another example, when importing a new source of data into WPS – either static data or meteorological data – it can often be helpful to check the resulting interpolated fields in order to make adjustments the interpolation methods used by geogrid or metgrid.

By using the NetCDF format for the geogrid and metgrid I/O forms, a variety of visualization tools that read NetCDF data may be used to check the domain files processed by geogrid or the horizontally interpolated meteorological fields produced by metgrid. In order to set the file format for geogrid and metgrid to NetCDF, the user should specify 2 as the `io_form_geogrid` and `io_form_metgrid` in the WPS namelist file (Note: 2 is the default setting for these options):

```
&share
 io_form_geogrid = 2,
/

&metgrid
 io_form_metgrid = 2,
/
```

Among the available tools, the ncdump, ncview, and new RIP4 programs may be of interest. The ncdump program is a compact utility distributed with the NetCDF libraries that lists the variables and attributes in a NetCDF file. This can be useful, in particular, for checking the domain parameters (e.g., west-east dimension, south-north dimension, or domain center point) in geogrid domain files, or for listing the fields in a file. The ncview program provides an interactive way to view fields in NetCDF files. Also, for users wishing to produce plots of fields suitable for use in publications, the new release of the RIP4 program may be of interest. The new RIP4 is capable of plotting horizontal contours, map backgrounds, and overlaying multiple fields within the same plot.

Output from the ungrib program is always written in a simple binary format (either 'WPS', 'SI', or 'MM5'), so software for viewing NetCDF files will almost certainly be of no use. However, an NCAR Graphics-based utility, *plotfmt*, is supplied with the WPS source code. This utility produces contour plots of the fields found in an intermediate-format file. If the NCAR Graphics libraries are properly installed, the plotfmt program is automatically compiled, along with other utility programs, when WPS is built.

WPS Utility Programs

Besides the three main WPS programs – geogrid, ungrib, and metgrid – there are a number of utility programs that come with the WPS, and which are compiled in the util directory. These utilities may be used to examine data files, visualize the location of nested domains, compute pressure fields, and compute average surface temperature fields.

A. avg_tsfc.exe

The avg_tsfc.exe program computes a daily mean surface temperature given input files in the intermediate format. Based on the range of dates specified in the "share" namelist section of the namelist.wps file, and also considering the interval between intermediate files, avg_tsfc.exe will use as many complete days' worth of data as possible in computing the average, beginning at the starting date specified in the namelist. If a complete day's worth of data is not available, no output file will be written, and the program will halt as soon as this can be determined. Similarly, any intermediate files for dates that cannot be used as part of a complete 24-hour period are ignored; for example, if there are five intermediate files available at a six-hour interval, the last file would be ignored. The computed average field is written to a new file named TAVGSFC using the same intermediate format version as the input files. This daily mean surface temperature field can then be ingested by metgrid by specifying 'TAVGSFC' for the `constants_name` variable in the "metgrid" namelist section.

B. mod_levs.exe

The mod_levs.exe program is used to remove levels of data from intermediate format files. The levels which are to be kept are specified in new namelist record in the namelist.wps file:

```
&mod_levs
 press_pa = 201300 , 200100 , 100000 ,
             95000 ,  90000 ,
             85000 ,  80000 ,
             75000 ,  70000 ,
             65000 ,  60000 ,
             55000 ,  50000 ,
             45000 ,  40000 ,
             35000 ,  30000 ,
             25000 ,  20000 ,
             15000 ,  10000 ,
              5000 ,   1000
/
```

Within the `&mod_levs` namelist record, the variable `press_pa` is used to specify a list of levels to keep; the specified levels should match values of `xlvl` in the intermediate format files (see the discussion of the WPS intermediate format for more information on the fields of the intermediate files). The mod_levs program takes two command-line arguments as its input. The first argument is the name of the intermediate file to operate on, and the second argument is the name of the output file to be written.

Removing all but a specified subset of levels from meteorological data sets is particularly useful, for example, when one data set is to be used for the model initial conditions and a second data set is to be used for the lateral boundary conditions. This can be done by providing the initial conditions data set at the first time period to be interpolated by metgrid, and the boundary conditions data set for all other times. If the both data sets have the same number of vertical levels, then no work needs to be done; however, when these two data sets have a different number of levels, it will be necessary, at a minimum, to remove ($m – n$) levels, where $m > n$ and m and n are the number of levels in each of the two data sets, from the data set with m levels. The necessity of having the same number of vertical levels in all files is due to a limitation in `real`, which requires a constant number of vertical levels to interpolate from.

The mod_levs utility is something of a temporary solution to the problem of accommodating two or more data sets with differing numbers of vertical levels. Should a user choose to use mod_levs, it should be noted that, although the vertical locations of the levels need not match between data sets, all data sets should have a surface level of data, and, when running real_nmm.exe and wrf.exe, the value of `p_top` must be chosen to be below the lowest top among the data sets.

C. calc_ecmwf_p.exe

In the course of vertically interpolating meteorological fields, the real program requires 3-d pressure and geopotential height fields on the same levels as the other atmospheric fields. The calc_ecmwf_p.exe utility may be used to create such these fields for use with ECMWF sigma-level data sets. Given a surface pressure field (or log of surface pressure field) and a list of coefficients A and B, calc_ecmwf_p.exe computes the pressure at an ECMWF sigma level k at grid point (i,j) as $P_{ijk} = A_k + B_k*Psfc_{ij}$. The list of coefficients used in the pressure computation can be copied from a table appropriate to the number of sigma levels in the data set from http://www.ecmwf.int/products/data/technical/model_levels/index.html. This table should be written in plain text to a file, ecmwf_coeffs, in the current working directory; for example, with 16 sigma levels, the file emcwf_coeffs would contain something like:

```
    0         0.000000      0.000000000
    1      5000.000000      0.000000000
    2      9890.519531      0.001720764
    3     14166.304688      0.013197623
    4     17346.066406      0.042217135
    5     19121.152344      0.093761623
    6     19371.250000      0.169571340
    7     18164.472656      0.268015683
    8     15742.183594      0.384274483
    9     12488.050781      0.510830879
   10      8881.824219      0.638268471
   11      5437.539063      0.756384850
   12      2626.257813      0.855612755
   13       783.296631      0.928746223
   14         0.000000      0.972985268
   15         0.000000      0.992281914
   16         0.000000      1.000000000
```

Additionally, if soil height (or soil geopotential), 3-d temperature, and 3-d specific humidity fields are available, calc_ecmwf_p.exe computes a 3-d geopotential height field, which is required to obtain an accurate vertical interpolation in the real program.

Given a set of intermediate files produced by ungrib and the file ecmwf_coeffs, calc_ecmwf_p loops over all time periods in namelist.wps, and produces an additional intermediate file, PRES:*YYYY-MM-DD_HH*, for each time, which contains pressure and geopotential height data for each full sigma level, as well as a 3-d relative humidity field. This intermediate file should be specified to metgrid, along with the intermediate data produced by ungrib, by adding 'PRES' to the list of prefixes in the `fg_name` namelist variable.

D. plotgrids.exe

The plotgrids.exe program is an NCAR Graphics-based utility whose purpose is to plot the locations of all nests defined in the namelist.wps file. The program operates on the namelist.wps file, and thus, may be run without having run any of the three main WPS programs. Upon successful completion, plotgrids produces an NCAR Graphics metafile, gmeta, which may be viewed using the idt command. The coarse domain is drawn to fill the plot frame, a map outline with political boundaries is drawn over the coarse domain, and any nested domains are drawn as rectangles outlining the extent of each nest. This utility may be useful particularly during initial placement of domains, at which time the user can iteratively adjust the locations of nests by editing the namelist.wps file, running plotgrids.exe, and determining a set of adjustments to the nest locations. *Currently, this utility does not work for ARW domains that use the latitude-longitude projection* (i.e., when `map_proj = 'lat-lon'`).

E. g1print.exe

The g1print.exe program takes as its only command-line argument the name of a GRIB Edition 1 file. The program prints a listing of the fields, levels, and dates of the data in the file.

F. g2print.exe

Similar to g1print.exe, the g2print.exe program takes as its only command-line argument the name of a GRIB Edition 2 file. The program prints a listing of the fields, levels, and dates of the data in the file.

G. plotfmt.exe

The plotfmt.exe is an NCAR Graphics program that plots the contents of an intermediate format file. The program takes as its only command-line argument the name of the file to plot, and produces an NCAR Graphics metafile, which contains contour plots of each field in input file. The graphics metafile output, gmeta, may be viewed with the idt command, or converted to another format using utilities such as ctrans.

H. rd_intermediate.exe

Given the name of a singe intermediate format file on the command line, the rd_intermediate.exe program prints information about the fields contained in the file.

WRF Domain Wizard

WRF Domain Wizard is a graphical user interface (GUI) which interacts with the WPS and enables users to easily define domains, create a ***namelist.wps*** and run ***geogrid, ungrib,*** and ***metgrid***. A helpful online tutorial can be found at: *http://wrfportal.org/DomainWizard.html*.

Writing Meteorological Data to the Intermediate Format

The role of the ungrib program is to decode GRIB data sets into a simple intermediate format that is understood by metgrid. If meteorological data are not available in GRIB Edition 1 or GRIB Edition 2 formats, the user is responsible for writing such data into the intermediate file format. Fortunately, the intermediate format is relatively simple, consisting of a sequence of unformatted Fortran writes. It is important to note that these *unformatted writes use big-endian byte order*, which can typically be specified with compiler flags. Below, we describe the WPS intermediate format; users interested in the SI or MM5 intermediate formats can first gain familiarity with the WPS format, which is very similar, and later examine the Fortran subroutines that read and write all three intermediate formats (metgrid/src/read_met_module.F90 and metgrid/src/write_met_module.F90, respectively).

When writing data to the WPS intermediate format, 2-dimensional fields are written as a rectangular array of real values. 3-dimensional arrays must be split across the vertical dimension into 2-dimensional arrays, which are written independently. It should also be noted that, for global data sets, either a Gaussian or cylindrical equidistant projection must be used, and for regional data sets, either a Mercator, Lambert conformal, polar stereographic, or cylindrical equidistant may be used. The sequence of writes used to write a single 2-dimensional array in the WPS intermediate format is as follows (note that not all of the variables declared below are used for a given projection of the data).

```
integer :: version              ! Format version (must =5 for WPS format)
integer :: nx, ny               ! x- and y-dimensions of 2-d array
integer :: iproj                ! Code for projection of data in array:
                                !       0 = cylindrical equidistant
                                !       1 = Mercator
                                !       3 = Lambert conformal conic
                                !       4 = Gaussian (global only!)
```

```
                               !       5 = Polar stereographic
real :: nlats                  ! Number of latitudes north of equator
                               !       (for Gaussian grids)
real :: xfcst                  ! Forecast hour of data
real :: xlvl                   ! Vertical level of data in 2-d array
real :: startlat, startlon     ! Lat/lon of point in array indicated by
                               !       startloc string
real :: deltalat, deltalon     ! Grid spacing, degrees
real :: dx, dy                 ! Grid spacing, km
real :: xlonc                  ! Standard longitude of projection
real :: truelat1, truelat2     ! True latitudes of projection
real :: earth_radius           ! Earth radius, km
real, dimension(nx,ny) :: slab ! The 2-d array holding the data
logical :: is_wind_grid_rel    ! Flag indicating whether winds are
                               !       relative to source grid (TRUE) or
                               !       relative to earth (FALSE)
character (len=8)  :: startloc ! Which point in array is given by
                               !       startlat/startlon; set either
                               !       to 'SWCORNER' or 'CENTER  '
character (len=9)  :: field    ! Name of the field
character (len=24) :: hdate    ! Valid date for data YYYY:MM:DD_HH:00:00
character (len=25) :: units    ! Units of data
character (len=32) :: map_source  !  Source model / originating center
character (len=46) :: desc     ! Short description of data


!  1) WRITE FORMAT VERSION
write(unit=ounit) version

!  2) WRITE METADATA
! Cylindrical equidistant
if (iproj == 0) then
      write(unit=ounit) hdate, xfcst, map_source, field, &
                        units, desc, xlvl, nx, ny, iproj
      write(unit=ounit) startloc, startlat, startlon, &
                        deltalat, deltalon, earth_radius

! Mercator
else if (iproj == 1) then
      write(unit=ounit) hdate, xfcst, map_source, field, &
                        units, desc, xlvl, nx, ny, iproj
      write(unit=ounit) startloc, startlat, startlon, dx, dy, &
                        truelat1, earth_radius

! Lambert conformal
else if (iproj == 3) then
      write(unit=ounit) hdate, xfcst, map_source, field, &
                        units, desc, xlvl, nx, ny, iproj
      write(unit=ounit) startloc, startlat, startlon, dx, dy, &
                        xlonc, truelat1, truelat2, earth_radius

! Gaussian
else if (iproj == 4) then
      write(unit=ounit) hdate, xfcst, map_source, field, &
                        units, desc, xlvl, nx, ny, iproj
      write(unit=ounit) startloc, startlat, startlon, &
                               nlats, deltalon, earth_radius

! Polar stereographic
else if (iproj == 5) then
      write(unit=ounit) hdate, xfcst, map_source, field, &
                        units, desc, xlvl, nx, ny, iproj
      write(unit=ounit) startloc, startlat, startlon, dx, dy, &
                        xlonc, truelat1, earth_radius
```

```
end if

!  3) WRITE WIND ROTATION FLAG
write(unit=ounit) is_wind_grid_rel

!  4) WRITE 2-D ARRAY OF DATA
write(unit=ounit) slab
```

Creating and Editing Vtables

Although Vtables are provided for many common data sets, it would be impossible for ungrib to anticipate every possible source of meteorological data in GRIB format. When a new source of data is to be processed by ungrib.exe, the user may create a new Vtable either from scratch, or by using an existing Vtable as an example. In either case, a basic knowledge of the meaning and use of the various fields of the Vtable will be helpful.

Each Vtable contains either seven or eleven fields, depending on whether the Vtable is for a GRIB Edition 1 data source or a GRIB Edition 2 data source, respectively. The fields of a Vtable fall into one of three categories: fields that describe how the data are identified within the GRIB file, fields that describe how the data are identified by the ungrib and metgrid programs, and fields specific to GRIB Edition 2. Each variable to be extracted by ungrib.exe will have one or more lines in the Vtable, with multiple lines for data that are split among different level types – for example, a surface level and upper-air levels. The fields that must be specified for a line, or entry, in the Vtable depends on the specifics of the field and level.

The first group of fields – those that describe how the data are identified within the GRIB file – are given under the column headings of the Vtable shown below.

```
GRIB1| Level| From |  To  |
Param| Type |Level1|Level2|
-----+------+------+------+
```

The "GRIB1 Param" field specifies the GRIB code for the meteorological field, which is a number unique to that field within the data set. However, different data sets may use different GRIB codes for the same field – for example, temperature at upper-air levels has GRIB code 11 in GFS data, but GRIB code 130 in ECMWF data. To find the GRIB code for a field, the g1print.exe and g2print.exe utility program may be used.

Given a GRIB code, the "Level Type", "From Level1", and "From Level2" fields are used to specify which levels a field may be found at. As with the "GRIB1 Param" field, the g1print.exe and g2print.exe programs may be used to find values for the level fields. The meanings of the level fields are dependent on the "Level Type" field, and are summarized in the following table.

Level	Level Type	From Level1	To Level2
Upper-air	100	*	(blank)
Surface	1	0	(blank)
Sea-level	102	0	(blank)
Levels at a specified height AGL	105	Height, in meters, of the level above ground	(blank)
Fields given as layers	112	Starting level for the layer	Ending level for the layer

When layer fields (Level Type 112) are specified, the starting and ending points for the layer have units that are dependent on the field itself; appropriate values may be found with the g1print.exe and g2print.exe utility programs.

The second group of fields in a Vtable, those that describe how the data are identified within the metgrid and real programs, fall under the column headings shown below.

```
| metgrid  | metgrid | metgrid                                 |
| Name     |  Units  | Description                             |
+----------+---------+-----------------------------------------+
```

The most important of these three fields is the "metgrid Name" field, which determines the variable name that will be assigned to a meteorological field when it is written to the intermediate files by ungrib. This name should also match an entry in the METGRID.TBL file, so that the metgrid program can determine how the field is to be horizontally interpolated. The "metgrid Units" and "metgrid Description" fields specify the units and a short description for the field, respectively; here, it is important to note that if no description is given for a field, then *ungrib will not write that field out to the intermediate files*.

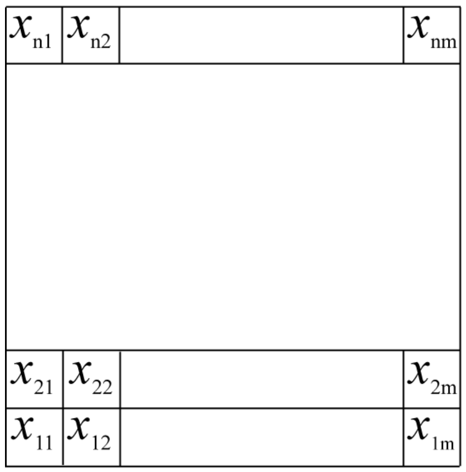
The final group of fields, which provide GRIB2-specific information, are found under the column headings below.

```
|GRIB2|GRIB2|GRIB2|GRIB2|
|Discp|Catgy|Param|Level|
+-----------------------+
```

The GRIB2 fields are only needed in a Vtable that is to be used for GRIB Edition 2 data sets, although having these fields in a Vtable does not prevent that Vtable from also being used for GRIB Edition 1 data. For example, the Vtable.GFS file contains GRIB2 Vtable fields, but is used for both 1-degree (GRIB1) GFS and 0.5-degree (GRIB2) GFS data sets. Since Vtables are provided for most known GRIB Edition 2 data sets, the corresponding Vtable fields are not described here at present.

Writing Static Data to the Geogrid Binary Format

The static geographical data sets that are interpolated by the geogrid program are stored as regular 2-d and 3-d arrays written in a simple binary raster format. Users with a new source for a given static field can ingest their data with WPS by writing the data set into this binary format. The geogrid format is capable of supporting single-level and multi-level continuous fields, categorical fields represented as dominant categories, and categorical fields given as fractional fields for each category. The most simple of these field types in terms of representation in the binary format is a categorical field given as a dominant category at each source grid point, an example of which is the 30-second USGS land use data set.



For a categorical field given as dominant categories, the data must first be stored in a regular 2-d array of integers, with each integer giving the dominant category at the corresponding source grid point. Given this array, the data are written to a file, row-by-row, beginning at the bottom, or southern-most, row. For example, in the figure above, the elements of the $n \times m$ array would be written in the order x_{11}, x_{12}, ..., x_{1m}, x_{21}, ..., x_{2m}, ..., x_{n1}, ..., x_{nm}. When written to the file, every element is stored as a 1-, 2-, 3-, or 4-byte integer in big-endian byte order (i.e., for the 4-byte integer *ABCD*, byte *A* is stored at the lowest address and byte *D* at the highest), although little-endian files may be used by setting `endian=little` in the "index" file for the data set. Every element in a file must use the same number of bytes for its storage, and, of course, it is advantageous to use the fewest number of bytes needed to represent the complete range of values in the array.

When writing the binary data to a file, no header, record marker, or additional bytes should be written. For example, a 2-byte 1000 × 1000 array should result in a file whose size is exactly 2,000,000 bytes. Since Fortran unformatted writes add record markers, *it is not possible to write a geogrid binary-formatted file directly from Fortran*; instead, it is recommended that the C routines in read_geogrid.c and write_geogrid.c (in the geogrid/src directory) be called when writing data, either from C or Fortran code.

Similar in format to a field of dominant categories is the case of a field of continuous, or real, values. Like dominant-category fields, single-level continuous fields are first organized as a regular 2-d array, then written, row-by-row, to a binary file. However, because a continuous field may contain non-integral or negative values, the storage representation of each element within the file is slightly more complex. All elements in the array must first be converted to integral values. This is done by first scaling all elements by a constant, chosen to maintain the required precision, and then removing any remaining fractional part through rounding. For example, if three decimal places of precision are required, the value -2.71828 would need to be divided by 0.001 and rounded to -2718. Following conversion of all array elements to integral values, if any negative values are found in the array, a second conversion must be applied: if elements are stored using 1 byte each, then 2^8 is added to each negative element; for storage using 2 bytes, 2^{16} is added to each negative element; for storage using 3 bytes, 2^{24} is added to each negative element; and for storage using 4 bytes, a value of 2^{32} is added to each negative element. It is important to note that no conversion is applied to positive elements. Finally, the resulting positive, integral array is written as in the case of a dominant-category field.

Multi-level continuous fields are handled much the same as single-level continuous fields. For an $n \times m \times r$ array, conversion to a positive, integral field is first performed as described above. Then, each $n \times m$ sub-array is written contiguously to the binary file as before, beginning with the smallest r-index. Categorical fields that are given as fractional fields for each possible category can be thought of as multi-level continuous fields, where each level k, $1 \leq k \leq r$, is the fractional field for category k.

When writing a field to a file in the geogrid binary format, the user should adhere to the naming convention used by the geogrid program, which expects data files to have names of the form *xstart-xend.ystart-yend*, where *xstart*, *xend*, *ystart*, and *yend* are five-digit positive integers specifying, respectively, the starting *x*-index of the array contained in the file, the ending *x*-index of the array, the starting *y*-index of the array, and the ending *y*-index of the array; here, indexing begins at 1, rather than 0. So, for example, an 800 × 1200 array (i.e., 800 rows and 1200 columns) might be named 00001-01200.00001-00800.

When a data set is given in several pieces, each of the pieces may be formed as a regular rectangular array, and each array may be written to a separate file. In this case, the relative locations of the arrays are determined by the range of *x*- and *y*-indices in the file names for each of the arrays. It is important to note, however, that *every tile in a data set must have the same* x- *and* y-*dimensions*, and that tiles of data within a data set must not overlap; furthermore, all tiles must start and end on multiples of the index ranges. For example, the global 30-second USGS topography data set is divided into arrays of dimension 1200 × 1200, with each array containing a 10-degree × 10-degree piece of the data set; the file whose south-west corner is located at (90S, 180W) is named 00001-01200.00001-01200, and the file whose north-east corner is located at (90N, 180E) is named 42001-43200.20401-21600.

If a data set is to be split into multiple tiles, and the number of grid points in, say, the *x*-direction is not evenly divided by the number of tiles in the *x*-direction, then the last column of tiles must be padded with a flag value (specified in the index file using the `missing_value` keyword) so that all tiles have the same dimensions. For example, if a data set has 2456 points in the *x*-direction, and three tiles in the *x*-direction will be used, the range of *x*-coordinates of the tiles might be 1 – 820, 821 – 1640, and 1641 – 2460, with columns 2457 through 2460 being filled with a flag value.

Clearly, since the starting and ending indices must have five digits, a field cannot have more than 99999 data points in either of the *x*- or *y*-directions. In case a field has more than 99999 data points in either dimension, the user can simply split the data set into several smaller data sets which will be identified separately to geogrid. For example, a very large global data set may be split into data sets for the Eastern and Western hemispheres.

Besides the binary data files, geogrid requires one extra metadata file per data set. This metadata file is always named 'index', and thus, two data sets cannot reside in the same directory. Essentially, this metadata file is the first file that geogrid looks for when processing a data set, and the contents of the file provide geogrid with all of the information necessary for constructing names of possible data files. The contents of an example index file are given below.

```
type = continuous
signed = yes
projection = regular_ll
dx = 0.00833333
dy = 0.00833333
known_x = 1.0
known_y = 1.0
known_lat = -89.99583
known_lon = -179.99583
wordsize = 2
tile_x = 1200
tile_y = 1200
tile_z = 1
tile_bdr=3
units="meters MSL"
description="Topography height"
```

For a complete listing of keywords that may appear in an index file, along with the meaning of each keyword, the user is referred to the section on index file options.

Description of the Namelist Variables

A. SHARE section

This section describes variables that are used by more than one WPS program. For example, the `wrf_core` variable specifies whether the WPS is to produce data for the ARW or the NMM core – information which is needed by both the geogrid and metgrid programs.

1. WRF_CORE : A character string set to either `'ARW'` or `'NMM'` that tells the WPS which dynamical core the input data are being prepared for. Default value is `'ARW'`.

2. MAX_DOM : An integer specifying the total number of domains/nests, including the parent domain, in the simulation. Default value is 1.

3. START_YEAR : A list of MAX_DOM 4-digit integers specifying the starting UTC year of the simulation for each nest. No default value.

4. START_MONTH : A list of MAX_DOM 2-digit integers specifying the starting UTC month of the simulation for each nest. No default value.

5. START_DAY : A list of MAX_DOM 2-digit integers specifying the starting UTC day of the simulation for each nest. No default value.

6. START_HOUR : A list of MAX_DOM 2-digit integers specifying the starting UTC hour of the simulation for each nest. No default value.
7. END_YEAR : A list of MAX_DOM 4-digit integers specifying the ending UTC year of the simulation for each nest. No default value.

8. END_MONTH : A list of MAX_DOM 2-digit integers specifying the ending UTC month of the simulation for each nest. No default value.

9. END_DAY : A list of MAX_DOM 2-digit integers specifying the ending UTC day of the simulation for each nest. No default value.

10. END_HOUR : A list of MAX_DOM 2-digit integers specifying the ending UTC hour of the simulation for each nest. No default value.

11. START_DATE : A list of MAX_DOM character strings of the form `'YYYY-MM-DD_HH:mm:ss'` specifying the starting UTC date of the simulation for each nest. The `start_date` variable is an alternate to specifying `start_year`, `start_month`, `start_day`, and `start_hour`, and if both methods are used for specifying the starting time, the `start_date` variable will take precedence. No default value.

12. END_DATE : A list of MAX_DOM character strings of the form `'YYYY-MM-DD_HH:mm:ss'` specifying the ending UTC date of the simulation for each nest. The `end_date` variable is an alternate to specifying `end_year`, `end_month`, `end_day`, and `end_hour`, and if both methods are used for specifying the ending time, the `end_date` variable will take precedence. No default value.

13. INTERVAL_SECONDS : The integer number of seconds between time-varying meteorological input files. No default value.

14. ACTIVE_GRID : A list of MAX_DOM logical values specifying, for each grid, whether that grid should be processed by geogrid and metgrid. Default value is `.TRUE.`.

15. IO_FORM_GEOGRID : The WRF I/O API format that the domain files created by the geogrid program will be written in. Possible options are: 1 for binary; 2 for NetCDF; 3 for GRIB1. When option 1 is given, domain files will have a suffix of .int; when option 2 is given, domain files will have a suffix of .nc; when option 3 is given, domain files will have a suffix of .gr1. Default value is 2 (NetCDF).

16. OPT_OUTPUT_FROM_GEOGRID_PATH : A character string giving the path, either relative or absolute, to the location where output files from geogrid should be written to and read from. Default value is `'./'`.

17. DEBUG_LEVEL : An integer value indicating the extent to which different types of messages should be sent to standard output. When `debug_level` is set to 0, only generally useful messages and warning messages will be written to standard output. When `debug_level` is greater than 100, informational messages that provide further runtime details are also written to standard output. Debugging messages and messages specifically intended for log files are never written to standard output, but are always written to the log files. Default value is 0.

B. GEOGRID section

This section specifies variables that are specific to the geogrid program. Variables in the geogrid section primarily define the size and location of all model domains, and where the static geographical data are found.

1. PARENT_ID : A list of MAX_DOM integers specifying, for each nest, the domain number of the nest's parent; for the coarsest domain, this variable should be set to 1. Default value is 1.

2. PARENT_GRID_RATIO : A list of MAX_DOM integers specifying, for each nest, the nesting ratio relative to the domain's parent. **This must be set to 3 for WRF-NMM.** No default value.

3. I_PARENT_START : A list of MAX_DOM integers specifying, for each nest, the x-coordinate of the lower-left corner of the nest in the parent *unstaggered* grid. For the coarsest domain, a value of 1 should be specified. No default value. **For WRF-NMM nests, see note on page 3-15.**

4. J_PARENT_START : A list of MAX_DOM integers specifying, for each nest, the y-coordinate of the lower-left corner of the nest in the parent *unstaggered* grid. For the coarsest domain, a value of 1 should be specified. No default value. **For WRF-NMM nests, see note on page 3-15.**

5. S_WE : A list of MAX_DOM integers which should all be set to 1. Default value is 1. **For WRF-NMM nests, see note on page 3-15.**

6. E_WE : A list of MAX_DOM integers specifying, for each nest, the nest's full west-east dimension. For nested domains, `e_we` must be one greater than an integer multiple of the nest's `parent_grid_ratio` (i.e., `e_ew` = *n**`parent_grid_ratio`+1 for some positive integer *n*). No default value. **For WRF-NMM nests, see note on page 3-15.**

7. S_SN : A list of MAX_DOM integers which should all be set to 1. Default value is 1. **For WRF-NMM nests, see note on page 3-15.**

8. E_SN : A list of MAX_DOM integers specifying, for each nest, the nest's full south-north dimension. For nested domains, `e_sn` must be one greater than an integer multiple of the nest's `parent_grid_ratio` (i.e., `e_sn` = *n**`parent_grid_ratio`+1 for some positive integer *n*). No default value. **For WRF-NMM nests, see note on page 3-15.**

Note: For WRF-NMM, the schematic below illustrates how ***e_we*** and ***e_sn*** apply on the E-grid:

```
H V H V H V H (V)
V H V H V H V (H)
H V H V H V H (V)
V H V H V H V (H)
H V H V H V H (V)
```

In this schematic, H represents mass variables (e.g., temperature, pressure, moisture) and V represents vector wind quantities. The (H) and (V) at the end of the row are a so-called phantom column that is used so arrays will be completely filled (***e_we***, ***e_sn***) for both mass and wind quantities, but the phantom column does not impact the integration. In this example, the x-dimension of the computational grid is 4, wheras the y-dimension is 5.By definition, ***e_we*** and ***e_sn*** are one plus the computational grid, such that, for this example, ***e_we***=5 and ***e_sn***=6. Note, also, that the number of computational rows must be odd, so the value for ***e_sn*** must always be EVEN.

9. GEOG_DATA_RES : A list of MAX_DOM character strings specifying, for each nest, a corresponding resolution or list of resolutions separated by `+` symbols of source data to be used when interpolating static terrestrial data to the nest's grid. For each nest, this string should contain a resolution matching a string preceding a colon in a `rel_path` or `abs_path` specification (see the description of GEOGRID.TBL options) in the GEOGRID.TBL file for each field. If a resolution in the string does not match any such string in a `rel_path` or `abs_path` specification for a field in GEOGRID.TBL, a default resolution of data for that field, if one is specified, will be used. If multiple resolutions match, the first resolution to match a string in a `rel_path` or `abs_path` specification in the GEOGRID.TBL file will be used. Default value is `'default'`.

10. DX : A real value specifying the grid distance in the x-direction where the map scale factor is 1. For ARW, the grid distance is in meters for the `'polar'`, `'lambert'`, and `'mercator'` projection, and in degrees longitude for the `'lat-lon'` projection; for NMM, the grid distance is in degrees longitude. Grid distances for nests are determined recursively based on values specified for `parent_grid_ratio` and `parent_id`. No default value.

11. DY : A real value specifying the nominal grid distance in the y-direction where the map scale factor is 1. For ARW, the grid distance is in meters for the `'polar'`, `'lambert'`, and `'mercator'` projection, and in degrees latitude for the `'lat-lon'` projection; for NMM, the grid distance is in degrees latitude. Grid distances for nests are determined recursively based on values specified for `parent_grid_ratio` and `parent_id`. No default value.

Note: For the rotated latitude-longitude grid used by WRF-NMM, the grid center is the equator. ***DX*** and ***DY*** are constant within this rotated grid framework. However, in a true Earth sense, the grid spacing in kilometers varies slightly between the center latitude and the northern and southern edges due to convergence of meridians away from the equator. This behavior is more notable for domains covering a wide range of latitudes. Typically, ***DX*** is set to be slightly larger than ***DY*** to counter the effect of meridional convergence, and keep the unrotated, "true earth" grid spacing more uniform over the entire grid.

The relationship between the fraction of a degree specification for the E-grid and the more typical grid spacing specified in kilometers for other grids can be approximated by considering the following schematic:

```
V -DX- H
 |      / |
DY dx DY
 | /      |
H - DX- V
```

The horizontal grid resolution is taken to be the shortest distance between two mass (H) points (diagonal – dx), while ***DX*** and ***DY*** refer to distances between adjacent H and V points. The distance between the H points in the diagram above is the hypotenuse of the triangle with legs DX and DY. Assuming 111 km/degree (a reasonable assumption for the rotated latitude-longitude grid) the grid spacing in km is approximately equal to: 111.0 * (SQRT (DX**2 + DY**2)).

12. MAP_PROJ : A character string specifying the projection of the simulation domain. For ARW, accepted projections are `'lambert'`, `'polar'`, `'mercator'`, and `'lat-lon'`; for NMM, a projection of `'rotated_ll'` must be specified. Default value is `'lambert'`.

13. REF_LAT : A real value specifying the latitude part of a (latitude, longitude) location whose (i,j) location in the simulation domain is known. For ARW, `ref_lat` gives the

latitude of the center-point of the coarse domain by default (i.e., when `ref_x` and `ref_y` are not specified). For NMM, `ref_lat` always gives the latitude to which the origin is rotated. No default value.

14. REF_LON : A real value specifying the longitude part of a (latitude, longitude) location whose (i, j) location in the simulation domain is known. For ARW, `ref_lon` gives the longitude of the center-point of the coarse domain by default (i.e., when `ref_x` and `ref_y` are not specified). For NMM, `ref_lon` always gives the longitude to which the origin is rotated. For both ARW and NMM, west longitudes are negative, and the value of `ref_lon` should be in the range [-180, 180]. No default value.

15. REF_X : A real value specifying the i part of an (i, j) location whose (latitude, longitude) location in the simulation domain is known. The (i, j) location is always given with respect to the mass-staggered grid, whose dimensions are one less than the dimensions of the unstaggered grid. Default value is (((`E_WE`-1.)+1.)/2.) = (`E_WE`/2.).

16. REF_Y : A real value specifying the j part of an (i, j) location whose (latitude, longitude) location in the simulation domain is known. The (i, j) location is always given with respect to the mass-staggered grid, whose dimensions are one less than the dimensions of the unstaggered grid. Default value is (((`E_SN`-1.)+1.)/2.) = (`E_SN`/2.).

17. TRUELAT1 : A real value specifying, for ARW, the first true latitude for the Lambert conformal projection, or the only true latitude for the Mercator and polar stereographic projections. For NMM, `truelat1` is ignored. No default value.

18. TRUELAT2 : A real value specifying, for ARW, the second true latitude for the Lambert conformal conic projection. For all other projections, `truelat2` is ignored. No default value.

19. STAND_LON : A real value specifying, for ARW, the longitude that is parallel with the y-axis in the Lambert conformal and polar stereographic projections. For the regular latitude-longitude projection, this value gives the rotation about the earth's geographic poles. For NMM, `stand_lon` is ignored. No default value.

20. POLE_LAT : For the latitude-longitude projection for ARW, the latitude of the North Pole with respect to the computational latitude-longitude grid in which -90.0° latitude is at the bottom of a global domain, 90.0° latitude is at the top, and 180.0° longitude is at the center. Default value is 90.0.

21. POLE_LON : For the latitude-longitude projection for ARW, the longitude of the North Pole with respect to the computational lat/lon grid in which -90.0° latitude is at the bottom of a global domain, 90.0° latitude is at the top, and 180.0° longitude is at the center. Default value is 0.0.

22. GEOG_DATA_PATH : A character string giving the path, either relative or absolute, to the directory where the geographical data directories may be found. This path is the

one to which `rel_path` specifications in the GEOGRID.TBL file are given in relation to. No default value.

23. OPT_GEOGRID_TBL_PATH : A character string giving the path, either relative or absolute, to the GEOGRID.TBL file. The path should not contain the actual file name, as GEOGRID.TBL is assumed, but should only give the path where this file is located. Default value is `'./geogrid/'`.

C. UNGRIB section

Currently, this section contains only two variables, which determine the output format written by ungrib and the name of the output files.

1. OUT_FORMAT : A character string set either to `'WPS'`, `'SI'`, or `'MM5'`. If set to `'MM5'`, ungrib will write output in the format of the MM5 pregrid program; if set to `'SI'`, ungrib will write output in the format of grib_prep.exe; if set to `'WPS'`, ungrib will write data in the WPS intermediate format. Default value is `'WPS'`.

2. PREFIX : A character string that will be used as the prefix for intermediate-format files created by ungrib; here, prefix refers to the string *PREFIX* in the filename *PREFIX*:*YYYY-MM-DD_HH* of an intermediate file. The prefix may contain path information, either relative or absolute, in which case the intermediate files will be written in the directory specified. This option may be useful to avoid renaming intermediate files if ungrib is to be run on multiple sources of GRIB data. Default value is `'FILE'`.

D. METGRID section

This section defines variables used only by the metgrid program. Typically, the user will be interested in the `fg_name` variable, and may need to modify other variables of this section less frequently.

1. FG_NAME : A list of character strings specifying the path and prefix of ungribbed data files. The path may be relative or absolute, and the prefix should contain all characters of the filenames up to, but not including, the colon preceding the date. When more than one `fg_name` is specified, and the same field is found in two or more input sources, the data in the last encountered source will take priority over all preceding sources for that field. Default value is an empty list (i.e., no meteorological fields).

2. CONSTANTS_NAME : A list of character strings specifying the path and full filename of ungribbed data files which are time-invariant. The path may be relative or absolute, and the filename should be the complete filename; since the data are assumed to be time-invariant, no date will be appended to the specified filename. Default value is an empty list (i.e., no constant fields).

3. IO_FORM_METGRID : The WRF I/O API format that the output created by the metgrid program will be written in. Possible options are: 1 for binary; 2 for NetCDF; 3 for GRIB1. When option 1 is given, output files will have a suffix of .int; when option 2 is given, output files will have a suffix of .nc; when option 3 is given, output files will have a suffix of .gr1. Default value is 2 (NetCDF).

4. OPT_OUTPUT_FROM_METGRID_PATH : A character string giving the path, either relative or absolute, to the location where output files from metgrid should be written to. The default value is the current working directory (i.e., the default value is `'./'`).

5. OPT_METGRID_TBL_PATH : A character string giving the path, either relative or absolute, to the METGRID.TBL file; the path should not contain the actual file name, as METGRID.TBL is assumed, but should only give the path where this file is located. Default value is `'./metgrid/'`.

6. OPT_IGNORE_DOM_CENTER : A logical value, either `.TRUE.` or `.FALSE.`, specifying whether, for times other than the initial time, interpolation of meteorological fields to points on the interior of the simulation domain should be avoided in order to decrease the runtime of metgrid. This option currently has no effect. Default value is `.FALSE.`.

Description of GEOGRID.TBL Options

The GEOGRID.TBL file is a text file that defines parameters of each of the data sets to be interpolated by geogrid. Each data set is defined in a separate section, with sections being delimited by a line of equality symbols (e.g., '==============='). Within each section, there are specifications, each of which has the form of *keyword=value*. Some keywords are required in each data set section, while others are optional; some keywords are mutually exclusive with other keywords. Below, the possible keywords and their expected range of values are described.

1. NAME : A character string specifying the name that will be assigned to the interpolated field upon output. No default value.

2. PRIORITY : An integer specifying the priority that the data source identified in the table section takes with respect to other sources of data for the same field. If a field has *n* sources of data, then there must be *n* separate table entries for the field, each of which must be given a unique value for `priority` in the range [1, *n*]. No default value.

3. DEST_TYPE : A character string, either `categorical` or `continuous`, that tells whether the interpolated field from the data source given in the table section is to be treated as a continuous or a categorical field. No default value.

4. INTERP_OPTION : A sequence of one or more character strings, which are the names of interpolation methods to be used when horizontally interpolating the field. Available

interpolation methods are: `average_4pt`, `average_16pt`, `wt_average_4pt`, `wt_average_16pt`, `nearest_neighbor`, `four_pt`, `sixteen_pt`, `search`, `average_gcell(`*r*`)`; for the grid cell average method (`average_gcell`), the optional argument *r* specifies the minimum ratio of source data resolution to simulation grid resolution at which the method will be applied; if a ratio is not specified, *r* = 0.0, and the option is used for any ratio. When a sequence of two or more methods are given, the methods should be separated by a `+` sign. No default value.

5. SMOOTH_OPTION : A character string giving the name of a smoothing method to be applied to the field after interpolation. Available smoothing options are: `1-2-1`, `smth-desmth`, and `smth-desmth_special` (ARW only). Default value is null (i.e., no smoothing is applied).

6. SMOOTH_PASSES : If smoothing is to be performed on the interpolated field, `smooth_passes` specifies an integer number of passes of the smoothing method to apply to the field. Default value is 1.

7. REL_PATH : A character string specifying the path relative to the path given in the namelist variable `geog_data_path`. A specification is of the general form *RES_STRING*:*REL_PATH*, where *RES_STRING* is a character string identifying the source or resolution of the data in some unique way and may be specified in the namelist variable `geog_data_res`, and *REL_PATH* is a path relative to `geog_data_path` where the index and data tiles for the data source are found. More than one `rel_path` specification may be given in a table section if there are multiple sources or resolutions for the data source, just as multiple resolutions may be specified (in a sequence delimited by `+` symbols) for `geog_data_res`. See also `abs_path`. No default value.

8. ABS_PATH : A character string specifying the absolute path to the index and data tiles for the data source. A specification is of the general form *RES_STRING*:*ABS_PATH*, where *RES_STRING* is a character string identifying the source or resolution of the data in some unique way and may be specified in the namelist variable `geog_data_res`, and *ABS_PATH* is the absolute path to the data source's files. More than one `abs_path` specification may be given in a table section if there are multiple sources or resolutions for the data source, just as multiple resolutions may be specified (in a sequence delimited by `+` symbols) for `geog_data_res`. See also `rel_path`. No default value.

9. OUTPUT_STAGGER : A character string specifying the grid staggering to which the field is to be interpolated. For ARW domains, possible values are `U`, `V`, and `M`; for NMM domains, possible values are `HH` and `VV`. Default value for ARW is `M`; default value for NMM is `HH`.

10. LANDMASK_WATER : One or more comma-separated integer values giving the indices of the categories within the field that represents water. When `landmask_water` is specified in the table section of a field for which `dest_type=categorical`, the LANDMASK field will be computed from the field using the specified categories as the

water categories. The keywords `landmask_water` and `landmask_land` are mutually exclusive. Default value is null (i.e., a landmask will not be computed from the field).

11. LANDMASK_LAND : One or more comma-separated integer values giving the indices of the categories within the field that represents land. When `landmask_water` is specified in the table section of a field for which `dest_type=categorical`, the LANDMASK field will be computed from the field using the specified categories as the land categories. The keywords `landmask_water` and `landmask_land` are mutually exclusive. Default value is null (i.e., a landmask will not be computed from the field).

12. MASKED : Either `land` or `water`, indicating that the field is not valid at land or water points, respectively. If the `masked` keyword is used for a field, those grid points that are of the masked type (land or water) will be assigned the value specified by `fill_missing`. Default value is null (i.e., the field is not masked).

13. FILL_MISSING : A real value used to fill in any missing or masked grid points in the interpolated field. Default value is 1.E20.

14. HALT_ON_MISSING : Either `yes` or `no`, indicating whether geogrid should halt with a fatal message when a missing value is encountered in the interpolated field. Default value is `no`.

15. DOMINANT_CATEGORY : When specified as a character string, the effect is to cause geogrid to compute the dominant category from the fractional categorical field, and to output the dominant category field with the name specified by the value of `dominant_category`. This option can only be used for fields with `dest_type=categorical`. Default value is null (i.e., no dominant category will be computed from the fractional categorical field).

16. DOMINANT_ONLY : When specified as a character string, the effect is similar to that of the `dominant_category` keyword: geogrid will compute the dominant category from the fractional categorical field and output the dominant category field with the name specified by the value of `dominant_only`. Unlike with `dominant_category`, though, when `dominant_only` is used, the fractional categorical field will not appear in the geogrid output. This option can only be used for fields with `dest_type=categorical`. Default value is null (i.e., no dominant category will be computed from the fractional categorical field).

17. DF_DX : When `df_dx` is assigned a character string value, the effect is to cause geogrid to compute the directional derivative of the field in the x-direction using a central difference along the interior of the domain, or a one-sided difference at the boundary of the domain; the derivative field will be named according to the character string assigned to the keyword `df_dx`. Default value is null (i.e., no derivative field is computed).

18. DF_DY : When `df_dy` is assigned a character string value, the effect is to cause geogrid to compute the directional derivative of the field in the y-direction using a central

difference along the interior of the domain, or a one-sided difference at the boundary of the domain; the derivative field will be named according to the character string assigned to the keyword `df_dy`. Default value is null (i.e., no derivative field is computed).

19. Z_DIM_NAME : For 3-dimensional output fields, a character string giving the name of the vertical dimension, or z-dimension. A continuous field may have multiple levels, and thus be a 3-dimensional field, and a categorical field may take the form of a 3-dimensional field if it is written out as fractional fields for each category. No default value.

Description of index Options

Related to the GEOGRID.TBL are the index files that are associated with each static data set. An index file defines parameters specific to that data set, while the GEOGRID.TBL file describes how each of the data sets should be treated by geogrid. As with the GEOGRID.TBL file, specifications in an index file are of the form *keyword=value*. Below are possible keywords and their possible values.

1. PROJECTION : A character string specifying the projection of the data, which may be either `lambert`, `polar`, `mercator`, `regular_ll`, `albers_nad83`, or `polar_wgs84`. No default value.

2. TYPE : A character string, either `categorical` or `continuous`, that determines whether the data in the data files should be interpreted as a continuous field or as discrete indices. For categorical data represented by a fractional field for each possible category, `type` should be set to `continuous`. No default value.

3. SIGNED : Either `yes` or `no`, indicating whether the values in the data files (which are always represented as integers) are signed in two's complement form or not. Default value is `no`.

4. UNITS : A character string, enclosed in quotation marks ("), specifying the units of the interpolated field; the string will be written to the geogrid output files as a variable time-independent attribute. No default value.

5. DESCRIPTION : A character string, enclosed in quotation marks ("), giving a short description of the interpolated field; the string will be written to the geogrid output files as a variable time-independent attribute. No default value.

6. DX : A real value giving the grid spacing in the x-direction of the data set. If `projection` is one of `lambert`, `polar`, `mercator`, `albers_nad83`, or `polar_wgs84`, `dx` gives the grid spacing in meters; if `projection` is `regular_ll`, `dx` gives the grid spacing in degrees. No default value.

7. DY : A real value giving the grid spacing in the y-direction of the data set. If `projection` is one of `lambert`, `polar`, `mercator`, `albers_nad83`, or `polar_wgs84`, `dy`

gives the grid spacing in meters; if `projection` is `regular_ll`, `dy` gives the grid spacing in degrees. No default value.

8. KNOWN_X : A real value specifying the i-coordinate of an (i,j) location corresponding to a (latitude, longitude) location that is known in the projection. Default value is 1.

9. KNOWN_Y : A real value specifying the j-coordinate of an (i,j) location corresponding to a (latitude, longitude) location that is known in the projection. Default value is 1.

10. KNOWN_LAT : A real value specifying the latitude of a (latitude, longitude) location that is known in the projection. No default value.

11. KNOWN_LON : A real value specifying the longitude of a (latitude, longitude) location that is known in the projection. No default value.

12. STDLON : A real value specifying the longitude that is parallel with the y-axis in conic and azimuthal projections. No default value.

13. TRUELAT1 : A real value specifying the first true latitude for conic projections or the only true latitude for azimuthal projections. No default value.

14. TRUELAT2 : A real value specifying the second true latitude for conic projections. No default value.

15. WORDSIZE : An integer giving the number of bytes used to represent the value of each grid point in the data files. No default value.

16. TILE_X : An integer specifying the number of grid points in the x-direction, *excluding any halo points*, for a single tile of source data. No default value.

17. TILE_Y : An integer specifying the number of grid points in the y-direction, *excluding any halo points*, for a single tile of source data. No default value.

18. TILE_Z : An integer specifying the number of grid points in the z-direction for a single tile of source data; this keyword serves as an alternative to the pair of keywords `tile_z_start` and `tile_z_end`, and when this keyword is used, the starting z-index is assumed to be 1. No default value.

19. TILE_Z_START : An integer specifying the starting index in the z-direction of the array in the data files. If this keyword is used, `tile_z_end` must also be specified. No default value.

20. TILE_Z_END : An integer specifying the ending index in the z-direction of the array in the data files. If this keyword is used, `tile_z_start` must also be specified. No default value

21. CATEGORY_MIN : For categorical data (`type=categorical`), an integer specifying the minimum category index that is found in the data set. If this keyword is used, `category_max` must also be specified. No default value.

22. CATEGORY_MAX : For categorical data (`type=categorical`), an integer specifying the maximum category index that is found in the data set. If this keyword is used, `category_min` must also be specified. No default value.

23. TILE_BDR : An integer specifying the halo width, in grid points, for each tile of data. Default value is 0.

24. MISSING_VALUE : A real value that, when encountered in the data set, should be interpreted as missing data. No default value.

25. SCALE_FACTOR : A real value that data should be scaled by (through multiplication) after being read in as integers from tiles of the data set. Default value is 1.

26. ROW_ORDER : A character string, either `bottom_top` or `top_bottom`, specifying whether the rows of the data set arrays were written proceeding from the lowest-index row to the highest (`bottom_top`) or from highest to lowest (`top_bottom`). This keyword may be useful when utilizing some USGS data sets, which are provided in `top_bottom` order. Default value is `bottom_top`.

27. ENDIAN : A character string, either `big` or `little`, specifying whether the values in the static data set arrays are in big-endian or little-endian byte order. Default value is `big`.

28. ISWATER : An integer specifying the land use category of water. Default value is 16.

29. ISLAKE : An integer specifying the land use category of inland water bodies. Default value is -1 (i.e., no separate inland water category).

30. ISICE : An integer specifying the land use category of ice. Default value is 24.

31. ISURBAN : An integer specifying the land use category of urban areas. Default value is 1.

32. ISOILWATER : An integer specifying the soil category of water. Default value is 14.

33. MMINLU : A character string, enclosed in quotation marks ("), indicating which section of WRF's LANDUSE.TBL and VEGPARM.TBL will be used when looking up parameters for land use categories. Default value is `"USGS"`.

Description of METGRID.TBL Options

The METGRID.TBL file is a text file that defines parameters of each of the meteorological fields to be interpolated by metgrid. Parameters for each field are defined in a separate section, with sections being delimited by a line of equality symbols (e.g., '=============='). Within each section, there are specifications, each of which has the form of *keyword*=*value*. Some keywords are required in a section, while others are optional; some keywords are mutually exclusive with other keywords. Below, the possible keywords and their expected range of values are described.

1. NAME : A character string giving the name of the meteorological field to which the containing section of the table pertains. The name should exactly match that of the field as given in the intermediate files (and, thus, the name given in the Vtable used in generating the intermediate files). This field is required. No default value.

2. OUTPUT : Either `yes` or `no`, indicating whether the field is to be written to the metgrid output files or not. Default value is `yes`.

3. MANDATORY : Either `yes` or `no`, indicating whether the field is required for successful completion of metgrid. Default value is `no`.

4. OUTPUT_NAME : A character string giving the name that the interpolated field should be output as. When a value is specified for `output_name`, the interpolation options from the table section pertaining to the field with the specified name are used. Thus, the effects of specifying `output_name` are two-fold: The interpolated field is assigned the specified name before being written out, and the interpolation methods are taken from the section pertaining to the field whose name matches the value assigned to the `output_name` keyword. No default value.

5. FROM_INPUT : A character string used to compare against the values in the `fg_name` namelist variable; if `from_input` is specified, the containing table section will only be used when the time-varying input source has a filename that contains the value of `from_input` as a substring. Thus, `from_input` may be used to specify different interpolation options for the same field, depending on which source of the field is being processed. No default value.

6. OUTPUT_STAGGER : The model grid staggering to which the field should be interpolated. For ARW, this must be one of `U`, `V`, and `M`; for NMM, this must be one of `HH` and `VV`. Default value for ARW is `M`; default value for NMM is `HH`.

7. IS_U_FIELD : Either `yes` or `no`, indicating whether the field is to be used as the wind U-component field. For ARW, the wind U-component field must be interpolated to the U staggering (`output_stagger=U`); for NMM, the wind U-component field must be interpolated to the V staggering (`output_stagger=VV`). Default value is `no`.

8. IS_V_FIELD : Either `yes` or `no`, indicating whether the field is to be used as the wind V-component field. For ARW, the wind V-component field must be interpolated to the V staggering (`output_stagger=V`); for NMM, the wind V-component field must be interpolated to the V staggering (`output_stagger=VV`). Default value is `no`.

9. INTERP_OPTION : A sequence of one or more names of interpolation methods to be used when horizontally interpolating the field. Available interpolation methods are: `average_4pt`, `average_16pt`, `wt_average_4pt`, `wt_average_16pt`, `nearest_neighbor`, `four_pt`, `sixteen_pt`, `search`, `average_gcell(`*r*`)`; for the grid cell average method (`average_gcell`), the optional argument *r* specifies the minimum ratio of source data resolution to simulation grid resolution at which the method will be applied; if a ratio is not specified, *r* = 0.0, and the option is used for any ratio. When a sequence of two or more methods are given, the methods should be separated by a `+` sign. Default value is `nearest_neighbor`.

10. INTERP_MASK : The name of the field to be used as an interpolation mask, along with the value within that field which signals masked points and an optional relational symbol, < or >. A specification takes the form *field*(?*maskval*), where *field* is the name of the field, *?* is an optional relational symbol (< or >), and *maskval* is a real value. Source data points will not be used in interpolation if the corresponding point in the *field* field is equal, greater than, or less than, the value of *maskval* for no relational symbol, a > symbol, or a < symbol, respectively. Default value is no mask.

11. INTERP_LAND_MASK : The name of the field to be used as an interpolation mask when interpolating to water points (determined by the static LANDMASK field), along with the value within that field which signals land points and an optional relational symbol, < or >. A specification takes the form *field*(?*maskval*), where *field* is the name of the field, *?* is an optional relational symbol (< or >), and *maskval* is a real value. Default value is no mask.

12. INTERP_WATER_MASK : The name of the field to be used as an interpolation mask when interpolating to land points (determined by the static LANDMASK field), along with the value within that field which signals water points and an optional relational symbol, < or >. A specification takes the form *field*(?*maskval*), where *field* is the name of the field, *?* is an optional relational symbol (< or >), and *maskval* is a real value. Default value is no mask.

13. FILL_MISSING : A real number specifying the value to be assigned to model grid points that received no interpolated value, for example, because of missing or incomplete meteorological data. Default value is 1.E20.

14. Z_DIM_NAME : For 3-dimensional meteorological fields, a character string giving the name of the vertical dimension to be used for the field on output. Default value is `num_metgrid_levels`.

15. DERIVED : Either `yes` or `no`, indicating whether the field is to be derived from other interpolated fields, rather than interpolated from an input field. Default value is `no`.

16. FILL_LEV : The `fill_lev` keyword, which may be specified multiple times within a table section, specifies how a level of the field should be filled if that level does not already exist. A generic value for the keyword takes the form *DLEVEL*:*FIELD*(*SLEVEL*), where *DLEVEL* specifies the level in the field to be filled, *FIELD* specifies the source field from which to copy levels, and *SLEVEL* specifies the level within the source field to use. *DLEVEL* may either be an integer or the string `all`. *FIELD* may either be the name of another field, the string `const`, or the string `vertical_index`. If *FIELD* is specified as `const`, then *SLEVEL* is a constant value that will be used to fill with; if *FIELD* is specified as `vertical_index`, then (*SLEVEL*) must not be specified, and the value of the vertical index of the source field is used; if *DLEVEL* is 'all', then all levels from the field specified by the `level_template` keyword are used to fill the corresponding levels in the field, one at a time. No default value.

17. LEVEL_TEMPLATE : A character string giving the name of a field from which a list of vertical levels should be obtained and used as a template. This keyword is used in conjunction with a `fill_lev` specification that uses `all` in the *DLEVEL* part of its specification. No default value.

18. MASKED : Either `land`, `water`, or `both`. Setting `MASKED` to `land` or `water` indicates that the field should not be interpolated to WRF land or water points, respectively; however, setting `MASKED` to `both` indicates that the field should be interpolated to WRF land points using only land points in the source data and to WRF water points using only water points in the source data. When a field is masked, or invalid, the static LANDMASK field will be used to determine which model grid points the field should be interpolated to; invalid points will be assigned the value given by the `FILL_MISSING` keyword. Whether a source data point is land or water is determined by the masks specified using the `INTERP_LAND_MASK` and `INTERP_WATER_MASK` options. Default value is null (i.e., the field is valid for both land and water points).

19. MISSING_VALUE : A real number giving the value in the input field that is assumed to represent missing data. No default value.

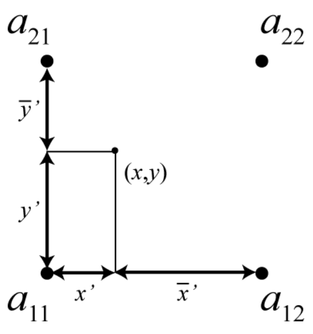
20. VERTICAL_INTERP_OPTION : A character string specifying the vertical interpolation method that should be used when vertically interpolating to missing points. Currently, this option is not implemented. No default value.

21. FLAG_IN_OUTPUT : A character string giving the name of a global attribute which will be assigned a value of 1 and written to the metgrid output if the interpolated field is to be output (output=yes). Default value is null (i.e., no flag will be written for the field).

Available Interpolation Options in Geogrid and Metgrid

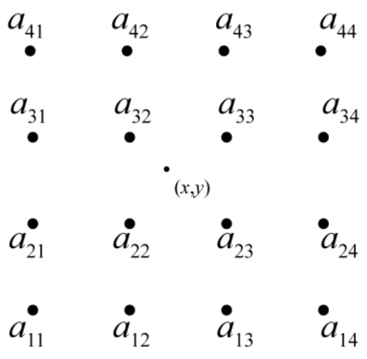
Through the GEOGRID.TBL and METGRID.TBL files, the user can control the method by which source data – either static fields in the case of geogrid or meteorological fields in the case of metgrid – are interpolated. In fact, a list of interpolation methods may be given, in which case, if it is not possible to employ the *i*-th method in the list, the (*i*+1)-st method will be employed, until either some method can be used or there are no methods left to try in the list. For example, to use a four-point bi-linear interpolation scheme for a field, we could specify `interp_option=four_pt`. However, if the field had areas of missing values, which could prevent the `four_pt` option from being used, we could request that a simple four-point average be tried if the `four_pt` method couldn't be used by specifying `interp_option=four_pt+average_4pt` instead. Below, each of the available interpolation options in the WPS are described conceptually; for the details of each method, the user is referred to the source code in the file WPS/geogrid/src/interp_options.F.

1. four_pt : Four-point bi-linear interpolation



The four-point bi-linear interpolation method requires four valid source points a_{ij}, $1 \leq i, j \leq 2$, surrounding the point (*x*,*y*), to which geogrid or metgrid must interpolate, as illustrated in the figure above. Intuitively, the method works by linearly interpolating to the *x*-coordinate of the point (*x*,*y*) between a_{11} and a_{12}, and between a_{21} and a_{22}, and then linearly interpolating to the *y*-coordinate using these two interpolated values.

2. sixteen_pt : Sixteen-point overlapping parabolic interpolation



a_{41} a_{42} a_{43} a_{44}
a_{31} a_{32} a_{33} a_{34}
(x,y)
a_{21} a_{22} a_{23} a_{24}
a_{11} a_{12} a_{13} a_{14}

The sixteen_pt overlapping parabolic interpolation method requires sixteen valid source points surrounding the point (x,y), as illustrated in the figure above. The method works by fitting one parabola to the points a_{i1}, a_{i2}, and a_{i3}, and another parabola to the points a_{i2}, a_{i3}, and a_{i4}, for row i, $1 \le i \le 4$; then, an intermediate interpolated value p_i within row i at the x-coordinate of the point is computed by taking an average of the values of the two parabolas evaluated at x, with the average being weighted linearly by the distance of x from a_{i2} and a_{i3}. Finally, the interpolated value at (x,y) is found by performing the same operations as for a row of points, but for the column of interpolated values p_i to the y-coordinate of (x,y).

3. average_4pt : Simple four-point average interpolation

The four-point average interpolation method requires at least one valid source data point from the four source points surrounding the point (x,y). The interpolated value is simply the average value of all valid values among these four points.

4. wt_average_4pt : Weighted four-point average interpolation

The weighted four-point average interpolation method can handle missing or masked source data points, and the interpolated value is given as the weighted average of all valid values, with the weight w_{ij} for the source point a_{ij}, $1 \le i, j \le 2$, given by

$$w_{ij} = \max\{0, 1 - \sqrt{(x - x_i)^2 + (y - y_j)^2}\}.$$

Here, x_i is the x-coordinate of a_{ij} and y_j is the y-coordinate of a_{ij}.

5. average_16pt : Simple sixteen-point average interpolation

The sixteen-point average interpolation method works in an identical way to the four-point average, but considers the sixteen points surrounding the point (x,y).

6. wt_average_16pt : Weighted sixteen-point average interpolation

The weighted sixteen-point average interpolation method works like the weighted four-point average, but considers the sixteen points surrounding (x,y); the weights in this method are given by

$$w_{ij} = \max\{0, 2 - \sqrt{(x - x_i)^2 + (y - y_j)^2}\},$$

where x_i and y_j are as defined for the weighted four-point method, and $1 \le i, j \le 4$.

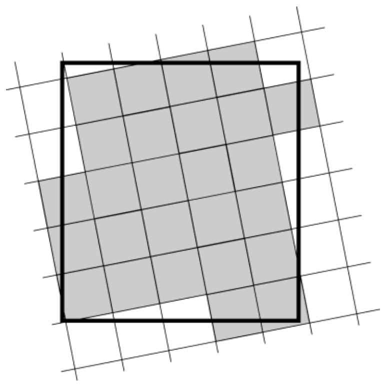
7. nearest_neighbor : Nearest neighbor interpolation

The nearest neighbor interpolation method simply sets the interpolated value at (*x*,*y*) to the value of the nearest source data point, regardless of whether this nearest source point is valid, missing, or masked.

8. search : Breadth-first search interpolation

The breadth-first search option works by treating the source data array as a 2-d grid graph, where each source data point, whether valid or not, is represented by a vertex. Then, the value assigned to the point (*x*,*y*) is found by beginning a breadth-first search at the vertex corresponding to the nearest neighbor of (*x*,*y*), and stopping once a vertex representing a valid (i.e., not masked or missing) source data point is found. In effect, this method can be thought of as "nearest *valid* neighbor".

9. average_gcell : Model grid-cell average



The grid-cell average interpolator may be used when the resolution of the source data is higher than the resolution of the model grid. For a model grid cell *Γ*, the method takes a simple average of the values of all source data points that are nearer to the center of *Γ* than to the center of any other grid cell. The operation of the grid-cell average method is illustrated in the figure above, where the interpolated value for the model grid cell – represented as the large rectangle – is given by the simple average of the values of all of the shaded source grid cells.

Land Use and Soil Categories in the Static Data

The default land use and soil category data sets that are provided as part of the WPS static data tar file contain categories that are matched with the USGS categories described in the VEGPARM.TBL and SOILPARM.TBL files in the WRF run directory.

Descriptions of the 24 land use categories and 16 soil categories are provided in the tables below.

Table 1: USGS 24-category Land Use Categories

Land Use Category	Land Use Description
1	Urban and Built-up Land
2	Dryland Cropland and Pasture
3	Irrigated Cropland and Pasture
4	Mixed Dryland/Irrigated Cropland and Pasture
5	Cropland/Grassland Mosaic
6	Cropland/Woodland Mosaic
7	Grassland
8	Shrubland
9	Mixed Shrubland/Grassland
10	Savanna
11	Deciduous Broadleaf Forest
12	Deciduous Needleleaf Forest
13	Evergreen Broadleaf
14	Evergreen Needleleaf
15	Mixed Forest
16	Water Bodies
17	Herbaceous Wetland
18	Wooden Wetland
19	Barren or Sparsely Vegetated
20	Herbaceous Tundra
21	Wooded Tundra
22	Mixed Tundra
23	Bare Ground Tundra
24	Snow or Ice

Table 2: IGBP-Modified MODIS 20-category Land Use Categories

Land Use Category	Land Use Description
1	Evergreen Needleleaf Forest
2	Evergreen Broadleaf Forest
3	Deciduous Needleleaf Forest
4	Deciduous Broadleaf Forest
5	Mixed Forests
6	Closed Shrublands
7	Open Shrublands
8	Woody Savannas
9	Savannas
10	Grasslands
11	Permanent Wetlands

12	Croplands
13	Urban and Built-Up
14	Cropland/Natural Vegetation Mosaic
15	Snow and Ice
16	Barren or Sparsely Vegetated
17	Water
18	Wooded Tundra
19	Mixed Tundra
20	Barren Tundra

Table 3: 16-category Soil Categories

Soil Category	Soil Description
1	Sand
2	Loamy Sand
3	Sandy Loam
4	Silt Loam
5	Silt
6	Loam
7	Sandy Clay Loam
8	Silty Clay Loam
9	Clay Loam
10	Sandy Clay
11	Silty Clay
12	Clay
13	Organic Material
14	Water
15	Bedrock
16	Other (land-ice)

WPS Output Fields

Below, a listing of the global attributes and fields that are written to the geogrid program's output files is given. This listing is of the output from the ncdump program when run on a typical geo_nmm.d01.nc file.

```
netcdf geo_nmm.d01 {
dimensions:
       Time = UNLIMITED ; // (1 currently)
       DateStrLen = 19 ;
       west_east = 19 ;
       south_north = 39 ;
       land_cat = 24 ;
       soil_cat = 16 ;
       month = 12 ;
variables:
       char Times(Time, DateStrLen) ;
       float XLAT_M(Time, south_north, west_east) ;
              XLAT_M:FieldType = 104 ;
```

```
                XLAT_M:MemoryOrder = "XY " ;
                XLAT_M:units = "degrees latitude" ;
                XLAT_M:description = "Latitude on mass grid" ;
                XLAT_M:stagger = "M" ;
                XLAT_M:sr_x = 1 ;
                XLAT_M:sr_y = 1 ;
        float XLONG_M(Time, south_north, west_east) ;
                XLONG_M:FieldType = 104 ;
                XLONG_M:MemoryOrder = "XY " ;
                XLONG_M:units = "degrees longitude" ;
                XLONG_M:description = "Longitude on mass grid" ;
                XLONG_M:stagger = "M" ;
                XLONG_M:sr_x = 1 ;
                XLONG_M:sr_y = 1 ;
        float XLAT_V(Time, south_north, west_east) ;
                XLAT_V:FieldType = 104 ;
                XLAT_V:MemoryOrder = "XY " ;
                XLAT_V:units = "degrees latitude" ;
                XLAT_V:description = "Latitude on velocity grid" ;
                XLAT_V:stagger = "V" ;
                XLAT_V:sr_x = 1 ;
                XLAT_V:sr_y = 1 ;
        float XLONG_V(Time, south_north, west_east) ;
                XLONG_V:FieldType = 104 ;
                XLONG_V:MemoryOrder = "XY " ;
                XLONG_V:units = "degrees longitude" ;
                XLONG_V:description = "Longitude on velocity grid" ;
                XLONG_V:stagger = "V" ;
                XLONG_V:sr_x = 1 ;
                XLONG_V:sr_y = 1 ;
        float E(Time, south_north, west_east) ;
                E:FieldType = 104 ;
                E:MemoryOrder = "XY " ;
                E:units = "-" ;
                E:description = "Coriolis E parameter" ;
                E:stagger = "M" ;
                E:sr_x = 1 ;
                E:sr_y = 1 ;
        float F(Time, south_north, west_east) ;
                F:FieldType = 104 ;
                F:MemoryOrder = "XY " ;
                F:units = "-" ;
                F:description = "Coriolis F parameter" ;
                F:stagger = "M" ;
                F:sr_x = 1 ;
                F:sr_y = 1 ;
        float LANDMASK(Time, south_north, west_east) ;
                LANDMASK:FieldType = 104 ;
                LANDMASK:MemoryOrder = "XY " ;
                LANDMASK:units = "none" ;
                LANDMASK:description = "Landmask : 1=land, 0=water" ;
                LANDMASK:stagger = "M" ;
                LANDMASK:sr_x = 1 ;
                LANDMASK:sr_y = 1 ;
        float LANDUSEF(Time, land_cat, south_north, west_east) ;
                LANDUSEF:FieldType = 104 ;
                LANDUSEF:MemoryOrder = "XYZ" ;
                LANDUSEF:units = "category" ;
                LANDUSEF:description = "24-category USGS landuse" ;
                LANDUSEF:stagger = "M" ;
                LANDUSEF:sr_x = 1 ;
                LANDUSEF:sr_y = 1 ;
        float LU_INDEX(Time, south_north, west_east) ;
```

```
                LU_INDEX:FieldType = 104 ;
                LU_INDEX:MemoryOrder = "XY " ;
                LU_INDEX:units = "category" ;
                LU_INDEX:description = "Dominant category" ;
                LU_INDEX:stagger = "M" ;
                LU_INDEX:sr_x = 1 ;
                LU_INDEX:sr_y = 1 ;
        float HCNVX(Time, south_north, west_east) ;
                HCNVX:FieldType = 104 ;
                HCNVX:MemoryOrder = "XY " ;
                HCNVX:units = "whoknows" ;
                HCNVX:description = "something" ;
                HCNVX:stagger = "M" ;
                HCNVX:sr_x = 1 ;
                HCNVX:sr_y = 1 ;
        float HSTDV(Time, south_north, west_east) ;
                HSTDV:FieldType = 104 ;
                HSTDV:MemoryOrder = "XY " ;
                HSTDV:units = "whoknows" ;
                HSTDV:description = "something" ;
                HSTDV:stagger = "M" ;
                HSTDV:sr_x = 1 ;
                HSTDV:sr_y = 1 ;
        float HASYW(Time, south_north, west_east) ;
                HASYW:FieldType = 104 ;
                HASYW:MemoryOrder = "XY " ;
                HASYW:units = "whoknows" ;
                HASYW:description = "something" ;
                HASYW:stagger = "M" ;
                HASYW:sr_x = 1 ;
                HASYW:sr_y = 1 ;
        float HASYS(Time, south_north, west_east) ;
                HASYS:FieldType = 104 ;
                HASYS:MemoryOrder = "XY " ;
                HASYS:units = "whoknows" ;
                HASYS:description = "something" ;
                HASYS:stagger = "M" ;
                HASYS:sr_x = 1 ;
                HASYS:sr_y = 1 ;
        float HASYSW(Time, south_north, west_east) ;
                HASYSW:FieldType = 104 ;
                HASYSW:MemoryOrder = "XY " ;
                HASYSW:units = "whoknows" ;
                HASYSW:description = "something" ;
                HASYSW:stagger = "M" ;
                HASYSW:sr_x = 1 ;
                HASYSW:sr_y = 1 ;
        float HASYNW(Time, south_north, west_east) ;
                HASYNW:FieldType = 104 ;
                HASYNW:MemoryOrder = "XY " ;
                HASYNW:units = "whoknows" ;
                HASYNW:description = "something" ;
                HASYNW:stagger = "M" ;
                HASYNW:sr_x = 1 ;
                HASYNW:sr_y = 1 ;
        float HLENW(Time, south_north, west_east) ;
                HLENW:FieldType = 104 ;
                HLENW:MemoryOrder = "XY " ;
                HLENW:units = "whoknows" ;
                HLENW:description = "something" ;
                HLENW:stagger = "M" ;
                HLENW:sr_x = 1 ;
                HLENW:sr_y = 1 ;
         float HLENS(Time, south_north, west_east) ;
                HLENS:FieldType = 104 ;
                HLENS:MemoryOrder = "XY " ;
                HLENS:units = "whoknows" ;
                HLENS:description = "something" ;
                HLENS:stagger = "M" ;
                HLENS:sr_x = 1 ;
                HLENS:sr_y = 1 ;
         float HLENSW(Time, south_north, west_east) ;
                HLENSW:FieldType = 104 ;
                HLENSW:MemoryOrder = "XY " ;
                HLENSW:units = "whoknows" ;
                HLENSW:description = "something" ;
                HLENSW:stagger = "M" ;
                HLENSW:sr_x = 1 ;
                HLENSW:sr_y = 1 ;
         float HLENNW(Time, south_north, west_east) ;
                HLENNW:FieldType = 104 ;
                HLENNW:MemoryOrder = "XY " ;
                HLENNW:units = "whoknows" ;
                HLENNW:description = "something" ;
                HLENNW:stagger = "M" ;
                HLENNW:sr_x = 1 ;
                HLENNW:sr_y = 1 ;
         float HANIS(Time, south_north, west_east) ;
                HANIS:FieldType = 104 ;
                HANIS:MemoryOrder = "XY " ;
                HANIS:units = "whoknows" ;
                HANIS:description = "something" ;
                HANIS:stagger = "M" ;
                HANIS:sr_x = 1 ;
                HANIS:sr_y = 1 ;
         float HSLOP(Time, south_north, west_east) ;
                HSLOP:FieldType = 104 ;
                HSLOP:MemoryOrder = "XY " ;
                HSLOP:units = "whoknows" ;
                HSLOP:description = "something" ;
                HSLOP:stagger = "M" ;
                HSLOP:sr_x = 1 ;
                HSLOP:sr_y = 1 ;
         float HANGL(Time, south_north, west_east) ;
                HANGL:FieldType = 104 ;
                HANGL:MemoryOrder = "XY " ;
                HANGL:units = "whoknows" ;
                HANGL:description = "something" ;
                HANGL:stagger = "M" ;
                HANGL:sr_x = 1 ;
                HANGL:sr_y = 1 ;
         float HZMAX(Time, south_north, west_east) ;
                HZMAX:FieldType = 104 ;
                HZMAX:MemoryOrder = "XY " ;
                HZMAX:units = "whoknows" ;
                HZMAX:description = "something" ;
                HZMAX:stagger = "M" ;
                HZMAX:sr_x = 1 ;
                HZMAX:sr_y = 1 ;
         float HGT_M(Time, south_north, west_east) ;
                HGT_M:FieldType = 104 ;
                HGT_M:MemoryOrder = "XY " ;
                HGT_M:units = "meters MSL" ;
                HGT_M:description = "Topography height" ;
                HGT_M:stagger = "M" ;
                HGT_M:sr_x = 1 ;
```

```
                HGT_M:sr_y = 1 ;
        float HGT_V(Time, south_north, west_east) ;
                HGT_V:FieldType = 104 ;
                HGT_V:MemoryOrder = "XY " ;
                HGT_V:units = "meters MSL" ;
                HGT_V:description = "Topography height" ;
                HGT_V:stagger = "V" ;
                HGT_V:sr_x = 1 ;
                HGT_V:sr_y = 1 ;
        float SOILTEMP(Time, south_north, west_east) ;
                SOILTEMP:FieldType = 104 ;
                SOILTEMP:MemoryOrder = "XY " ;
                SOILTEMP:units = "Kelvin" ;
                SOILTEMP:description = "Annual mean deep soil temperature" ;
                SOILTEMP:stagger = "M" ;
                SOILTEMP:sr_x = 1 ;
                SOILTEMP:sr_y = 1 ;
        float SOILCTOP(Time, soil_cat, south_north, west_east) ;
                SOILCTOP:FieldType = 104 ;
                SOILCTOP:MemoryOrder = "XYZ" ;
                SOILCTOP:units = "category" ;
                SOILCTOP:description = "16-category top-layer soil type" ;
                SOILCTOP:stagger = "M" ;
                SOILCTOP:sr_x = 1 ;
                SOILCTOP:sr_y = 1 ;
        float SOILCBOT(Time, soil_cat, south_north, west_east) ;
                SOILCBOT:FieldType = 104 ;
                SOILCBOT:MemoryOrder = "XYZ" ;
                SOILCBOT:units = "category" ;
                SOILCBOT:description = "16-category top-layer soil type" ;
                SOILCBOT:stagger = "M" ;
                SOILCBOT:sr_x = 1 ;
                SOILCBOT:sr_y = 1 ;
        float ALBEDO12M(Time, month, south_north, west_east) ;
                ALBEDO12M:FieldType = 104 ;
                ALBEDO12M:MemoryOrder = "XYZ" ;
                ALBEDO12M:units = "percent" ;
                ALBEDO12M:description = "Monthly surface albedo" ;
                ALBEDO12M:stagger = "M" ;
                ALBEDO12M:sr_x = 1 ;
                ALBEDO12M:sr_y = 1 ;
        float GREENFRAC(Time, month, south_north, west_east) ;
                GREENFRAC:FieldType = 104 ;
                GREENFRAC:MemoryOrder = "XYZ" ;
                GREENFRAC:units = "fraction" ;
                GREENFRAC:description = "Monthly green fraction" ;
                GREENFRAC:stagger = "M" ;
                GREENFRAC:sr_x = 1 ;
                GREENFRAC:sr_y = 1 ;
        float SNOALB(Time, south_north, west_east) ;
                SNOALB:FieldType = 104 ;
                SNOALB:MemoryOrder = "XY " ;
                SNOALB:units = "percent" ;
                SNOALB:description = "Maximum snow albedo" ;
                SNOALB:stagger = "M" ;
                SNOALB:sr_x = 1 ;
                SNOALB:sr_y = 1 ;
        float SLOPECAT(Time, south_north, west_east) ;
                SLOPECAT:FieldType = 104 ;
                SLOPECAT:MemoryOrder = "XY " ;
                SLOPECAT:units = "category" ;
                SLOPECAT:description = "Dominant category" ;
                SLOPECAT:stagger = "M" ;
                SLOPECAT:sr_x = 1 ;
                SLOPECAT:sr_y = 1 ;

// global attributes:
                :TITLE = "OUTPUT FROM GEOGRID V3.4" ;
                :SIMULATION_START_DATE = "0000-00-00_00:00:00" ;
                :WEST-EAST_GRID_DIMENSION = 19 ;
                :SOUTH-NORTH_GRID_DIMENSION = 39 ;
                :BOTTOM-TOP_GRID_DIMENSION = 0 ;
                :WEST-EAST_PATCH_START_UNSTAG = 1 ;
                :WEST-EAST_PATCH_END_UNSTAG = 19 ;
                :WEST-EAST_PATCH_START_STAG = 1 ;
                :WEST-EAST_PATCH_END_STAG = 19 ;
                :SOUTH-NORTH_PATCH_START_UNSTAG = 1 ;
                :SOUTH-NORTH_PATCH_END_UNSTAG = 39 ;
                :SOUTH-NORTH_PATCH_START_STAG = 1 ;
                :SOUTH-NORTH_PATCH_END_STAG = 39 ;
                :GRIDTYPE = "E" ;
                :DX = 0.289143f ;
                :DY = 0.287764f ;
                :DYN_OPT = 4 ;
                :CEN_LAT = 32.f ;
                :CEN_LON = -83.f ;
                :TRUELAT1 = 1.e+20f ;
                :TRUELAT2 = 1.e+20f ;
                :MOAD_CEN_LAT = 0.f ;
                :STAND_LON = 1.e+20f ;
                :POLE_LAT = 90.f ;
                :POLE_LON = 0.f ;
                :corner_lats = 26.39329f, 37.31068f, 37.31068f, 26.39329f,
26.40831f, 37.3276f, 37.29281f, 26.37742f, 0.f, 0.f, 0.f, 0.f, 0.f, 0.f, 0.f,
0.f ;
                :corner_lons = -88.78565f, -89.519f, -76.481f, -77.21435f, -
88.46474f, -89.1577f, -76.11986f, -76.89354f, 0.f, 0.f, 0.f, 0.f, 0.f, 0.f,
0.f, 0.f ;
                :MAP_PROJ = 203 ;
                :MMINLU = "USGS" ;
                :NUM_LAND_CAT = 24 ;
                :ISWATER = 16 ;
                :ISLAKE = -1 ;
                :ISICE = 24 ;
                :ISURBAN = 1 ;
                :ISOILWATER = 14 ;
                :grid_id = 1 ;
                :parent_id = 1 ;
                :i_parent_start = 0 ;
                :j_parent_start = 0 ;
                :i_parent_end = 19 ;
                :j_parent_end = 39 ;
                :parent_grid_ratio = 1 ;
                :sr_x = 1 ;
                :sr_y = 1 ;
}
```

In addition to the fields in a geogrid output file (e.g., geo_nmm.d01.nc), the following fields and global attributes will also be present in a typical output file from the metgrid program, run with the default METGRID.TBL file and meteorological data from NCEP's GFS model.

```
netcdf met_nmm.d01.2008-01-11_00\:00\:00 {
dimensions:
      Time = UNLIMITED ; // (1 currently)
      DateStrLen = 19 ;
      west_east = 19 ;
      south_north = 39 ;
      num_metgrid_levels = 27 ;
      num_sm_levels = 4 ;
      num_st_levels = 4 ;
      z-dimension0012 = 12 ;
      z-dimension0016 = 16 ;
      z-dimension0024 = 24 ;
variables:
      char Times(Time, DateStrLen) ;
      float PRES(Time, num_metgrid_levels, south_north, west_east) ;
            PRES:FieldType = 104 ;
            PRES:MemoryOrder = "XYZ" ;
            PRES:units = "" ;
            PRES:description = "" ;
            PRES:stagger = "M" ;
            PRES:sr_x = 1 ;
            PRES:sr_y = 1 ;
      float SMC_WPS(Time, num_sm_levels, south_north, west_east) ;
            SMC_WPS:FieldType = 104 ;
            SMC_WPS:MemoryOrder = "XYZ" ;
            SMC_WPS:units = "" ;
            SMC_WPS:description = "" ;
            SMC_WPS:stagger = "M" ;
            SMC_WPS:sr_x = 1 ;
            SMC_WPS:sr_y = 1 ;
      float STC_WPS(Time, num_st_levels, south_north, west_east) ;
            STC_WPS:FieldType = 104 ;
            STC_WPS:MemoryOrder = "XYZ" ;
            STC_WPS:units = "" ;
            STC_WPS:description = "" ;
            STC_WPS:stagger = "M" ;
            STC_WPS:sr_x = 1 ;
            STC_WPS:sr_y = 1 ;
      float GHT(Time, num_metgrid_levels, south_north, west_east) ;
            GHT:FieldType = 104 ;
            GHT:MemoryOrder = "XYZ" ;
            GHT:units = "m" ;
            GHT:description = "Height" ;
            GHT:stagger = "M" ;
            GHT:sr_x = 1 ;
            GHT:sr_y = 1 ;
      float SNOW(Time, south_north, west_east) ;
            SNOW:FieldType = 104 ;
            SNOW:MemoryOrder = "XY " ;
            SNOW:units = "kg m-2" ;
            SNOW:description = "Water equivalent snow depth" ;
            SNOW:stagger = "M" ;
            SNOW:sr_x = 1 ;
            SNOW:sr_y = 1 ;
      float SKINTEMP(Time, south_north, west_east) ;
            SKINTEMP:FieldType = 104 ;
            SKINTEMP:MemoryOrder = "XY " ;
            SKINTEMP:units = "K" ;
            SKINTEMP:description = "Skin temperature (can use for SST
also)" ;
            SKINTEMP:stagger = "M" ;
            SKINTEMP:sr_x = 1 ;
            SKINTEMP:sr_y = 1 ;
      float SOILHGT(Time, south_north, west_east) ;
            SOILHGT:FieldType = 104 ;
            SOILHGT:MemoryOrder = "XY " ;
            SOILHGT:units = "m" ;
            SOILHGT:description = "Terrain field of source analysis"
;
            SOILHGT:stagger = "M" ;
            SOILHGT:sr_x = 1 ;
            SOILHGT:sr_y = 1 ;
      float LANDSEA(Time, south_north, west_east) ;
            LANDSEA:FieldType = 104 ;
            LANDSEA:MemoryOrder = "XY " ;
            LANDSEA:units = "proprtn" ;
            LANDSEA:description = "Land/Sea flag (1=land, 0 or
2=sea)" ;
            LANDSEA:stagger = "M" ;
            LANDSEA:sr_x = 1 ;
            LANDSEA:sr_y = 1 ;
      float SEAICE(Time, south_north, west_east) ;
            SEAICE:FieldType = 104 ;
            SEAICE:MemoryOrder = "XY " ;
            SEAICE:units = "proprtn" ;
            SEAICE:description = "Ice flag" ;
            SEAICE:stagger = "M" ;
            SEAICE:sr_x = 1 ;
            SEAICE:sr_y = 1 ;
      float ST100200(Time, south_north, west_east) ;
            ST100200:FieldType = 104 ;
            ST100200:MemoryOrder = "XY " ;
            ST100200:units = "K" ;
            ST100200:description = "T 100-200 cm below ground layer
(Bottom)" ;
            ST100200:stagger = "M" ;
            ST100200:sr_x = 1 ;
            ST100200:sr_y = 1 ;
      float ST040100(Time, south_north, west_east) ;
            ST040100:FieldType = 104 ;
            ST040100:MemoryOrder = "XY " ;
            ST040100:units = "K" ;
            ST040100:description = "T 40-100 cm below ground layer
(Upper)" ;
            ST040100:stagger = "M" ;
            ST040100:sr_x = 1 ;
            ST040100:sr_y = 1 ;
      float ST010040(Time, south_north, west_east) ;
            ST010040:FieldType = 104 ;
            ST010040:MemoryOrder = "XY " ;
            ST010040:units = "K" ;
            ST010040:description = "T 10-40 cm below ground layer
(Upper)" ;
            ST010040:stagger = "M" ;
            ST010040:sr_x = 1 ;
            ST010040:sr_y = 1 ;
      float ST000010(Time, south_north, west_east) ;
            ST000010:FieldType = 104 ;
            ST000010:MemoryOrder = "XY " ;
            ST000010:units = "K" ;
            ST000010:description = "T 0-10 cm below ground layer
(Upper)" ;
            ST000010:stagger = "M" ;
            ST000010:sr_x = 1 ;
            ST000010:sr_y = 1 ;
      float SM100200(Time, south_north, west_east) ;
            SM100200:FieldType = 104 ;
            SM100200:MemoryOrder = "XY " ;
            SM100200:units = "kg m-3" ;
            SM100200:description = "Soil Moist 100-200 cm below gr
layer" ;
            SM100200:stagger = "M" ;
            SM100200:sr_x = 1 ;
            SM100200:sr_y = 1 ;
      float SM040100(Time, south_north, west_east) ;
            SM040100:FieldType = 104 ;
            SM040100:MemoryOrder = "XY " ;
            SM040100:units = "kg m-3" ;
            SM040100:description = "Soil Moist 40-100 cm below grn
layer" ;
            SM040100:stagger = "M" ;
            SM040100:sr_x = 1 ;
            SM040100:sr_y = 1 ;
      float SM010040(Time, south_north, west_east) ;
            SM010040:FieldType = 104 ;
            SM010040:MemoryOrder = "XY " ;
            SM010040:units = "kg m-3" ;
            SM010040:description = "Soil Moist 10-40 cm below grn
layer" ;
            SM010040:stagger = "M" ;
            SM010040:sr_x = 1 ;
            SM010040:sr_y = 1 ;
      float SM000010(Time, south_north, west_east) ;
            SM000010:FieldType = 104 ;
            SM000010:MemoryOrder = "XY " ;
            SM000010:units = "kg m-3" ;
            SM000010:description = "Soil Moist 0-10 cm below grn
layer (Up)" ;
            SM000010:stagger = "M" ;
            SM000010:sr_x = 1 ;
            SM000010:sr_y = 1 ;
      float PSFC(Time, south_north, west_east) ;
            PSFC:FieldType = 104 ;
            PSFC:MemoryOrder = "XY " ;
```

```
                PSFC:units = "Pa" ;
                PSFC:description = "Surface Pressure" ;
                PSFC:stagger = "M" ;
                PSFC:sr_x = 1 ;
                PSFC:sr_y = 1 ;
        float RH(Time, num_metgrid_levels, south_north, west_east) ;
                RH:FieldType = 104 ;
                RH:MemoryOrder = "XYZ" ;
                RH:units = "%" ;
                RH:description = "Relative Humidity" ;
                RH:stagger = "M" ;
                RH:sr_x = 1 ;
                RH:sr_y = 1 ;
        float VV(Time, num_metgrid_levels, south_north, west_east) ;
                VV:FieldType = 104 ;
                VV:MemoryOrder = "XYZ" ;
                VV:units = "m s-1" ;
                VV:description = "V" ;
                VV:stagger = "V" ;
                VV:sr_x = 1 ;
                VV:sr_y = 1 ;
        float UU(Time, num_metgrid_levels, south_north, west_east) ;
                UU:FieldType = 104 ;
                UU:MemoryOrder = "XYZ" ;
                UU:units = "m s-1" ;
                UU:description = "U" ;
                UU:stagger = "V" ;
                UU:sr_x = 1 ;
                UU:sr_y = 1 ;
        float TT(Time, num_metgrid_levels, south_north, west_east) ;
                TT:FieldType = 104 ;
                TT:MemoryOrder = "XYZ" ;
                TT:units = "K" ;
                TT:description = "Temperature" ;
                TT:stagger = "M" ;
                TT:sr_x = 1 ;
                TT:sr_y = 1 ;
        float PMSL(Time, south_north, west_east) ;
                PMSL:FieldType = 104 ;
                PMSL:MemoryOrder = "XY " ;
                PMSL:units = "Pa" ;
                PMSL:description = "Sea-level Pressure" ;
                PMSL:stagger = "M" ;
                PMSL:sr_x = 1 ;
                PMSL:sr_y = 1 ;
        float SLOPECAT(Time, south_north, west_east) ;
                SLOPECAT:FieldType = 104 ;
                SLOPECAT:MemoryOrder = "XY " ;
                SLOPECAT:units = "category" ;
                SLOPECAT:description = "Dominant category" ;
                SLOPECAT:stagger = "M" ;
                SLOPECAT:sr_x = 1 ;
                SLOPECAT:sr_y = 1 ;
        float SNOALB(Time, south_north, west_east) ;
```

```
            SNOALB:FieldType = 104 ;
            SNOALB:MemoryOrder = "XY " ;
            SNOALB:units = "percent" ;
            SNOALB:description = "Maximum snow albedo" ;
            SNOALB:stagger = "M" ;
            SNOALB:sr_x = 1 ;
            SNOALB:sr_y = 1 ;
      float GREENFRAC(Time, z-dimension0012, south_north, west_east)
;
            GREENFRAC:FieldType = 104 ;
            GREENFRAC:MemoryOrder = "XYZ" ;
            GREENFRAC:units = "fraction" ;
            GREENFRAC:description = "Monthly green fraction" ;
            GREENFRAC:stagger = "M" ;
            GREENFRAC:sr_x = 1 ;
            GREENFRAC:sr_y = 1 ;
      float ALBEDO12M(Time, z-dimension0012, south_north, west_east)
;
            ALBEDO12M:FieldType = 104 ;
            ALBEDO12M:MemoryOrder = "XYZ" ;
            ALBEDO12M:units = "percent" ;
            ALBEDO12M:description = "Monthly surface albedo" ;
            ALBEDO12M:stagger = "M" ;
            ALBEDO12M:sr_x = 1 ;
            ALBEDO12M:sr_y = 1 ;
      float SOILCBOT(Time, z-dimension0016, south_north, west_east)
;
            SOILCBOT:FieldType = 104 ;
            SOILCBOT:MemoryOrder = "XYZ" ;
            SOILCBOT:units = "category" ;
            SOILCBOT:description = "16-category top-layer soil type"
;
            SOILCBOT:stagger = "M" ;
            SOILCBOT:sr_x = 1 ;
            SOILCBOT:sr_y = 1 ;
      float SOILCTOP(Time, z-dimension0016, south_north, west_east)
;
            SOILCTOP:FieldType = 104 ;
            SOILCTOP:MemoryOrder = "XYZ" ;
            SOILCTOP:units = "category" ;
            SOILCTOP:description = "16-category top-layer soil type"
;
            SOILCTOP:stagger = "M" ;
            SOILCTOP:sr_x = 1 ;
            SOILCTOP:sr_y = 1 ;
      float SOILTEMP(Time, south_north, west_east) ;
            SOILTEMP:FieldType = 104 ;
            SOILTEMP:MemoryOrder = "XY " ;
            SOILTEMP:units = "Kelvin" ;
            SOILTEMP:description = "Annual mean deep soil
temperature" ;
            SOILTEMP:stagger = "M" ;
            SOILTEMP:sr_x = 1 ;
            SOILTEMP:sr_y = 1 ;
```

```
        float HGT_V(Time, south_north, west_east) ;
              HGT_V:FieldType = 104 ;
              HGT_V:MemoryOrder = "XY " ;
              HGT_V:units = "meters MSL" ;
              HGT_V:description = "Topography height" ;
              HGT_V:stagger = "V" ;
              HGT_V:sr_x = 1 ;
              HGT_V:sr_y = 1 ;
        float HGT_M(Time, south_north, west_east) ;
              HGT_M:FieldType = 104 ;
              HGT_M:MemoryOrder = "XY " ;
              HGT_M:units = "meters MSL" ;
              HGT_M:description = "Topography height" ;
              HGT_M:stagger = "M" ;
              HGT_M:sr_x = 1 ;
              HGT_M:sr_y = 1 ;
        float HZMAX(Time, south_north, west_east) ;
              HZMAX:FieldType = 104 ;
              HZMAX:MemoryOrder = "XY " ;
              HZMAX:units = "whoknows" ;
              HZMAX:description = "something" ;
              HZMAX:stagger = "M" ;
              HZMAX:sr_x = 1 ;
              HZMAX:sr_y = 1 ;
        float HANGL(Time, south_north, west_east) ;
              HANGL:FieldType = 104 ;
              HANGL:MemoryOrder = "XY " ;
              HANGL:units = "whoknows" ;
              HANGL:description = "something" ;
              HANGL:stagger = "M" ;
              HANGL:sr_x = 1 ;
              HANGL:sr_y = 1 ;
        float HSLOP(Time, south_north, west_east) ;
              HSLOP:FieldType = 104 ;
              HSLOP:MemoryOrder = "XY " ;
              HSLOP:units = "whoknows" ;
              HSLOP:description = "something" ;
              HSLOP:stagger = "M" ;
              HSLOP:sr_x = 1 ;
              HSLOP:sr_y = 1 ;
        float HANIS(Time, south_north, west_east) ;
              HANIS:FieldType = 104 ;
              HANIS:MemoryOrder = "XY " ;
              HANIS:units = "whoknows" ;
              HANIS:description = "something" ;
              HANIS:stagger = "M" ;
              HANIS:sr_x = 1 ;
              HANIS:sr_y = 1 ;
        float HLENNW(Time, south_north, west_east) ;
              HLENNW:FieldType = 104 ;
              HLENNW:MemoryOrder = "XY " ;
              HLENNW:units = "whoknows" ;
              HLENNW:description = "something" ;
              HLENNW:stagger = "M" ;
```

```
                HLENNW:sr_x = 1 ;
                HLENNW:sr_y = 1 ;
        float HLENSW(Time, south_north, west_east) ;
                HLENSW:FieldType = 104 ;
                HLENSW:MemoryOrder = "XY " ;
                HLENSW:units = "whoknows" ;
                HLENSW:description = "something" ;
                HLENSW:stagger = "M" ;
                HLENSW:sr_x = 1 ;
                HLENSW:sr_y = 1 ;
        float HLENS(Time, south_north, west_east) ;
                HLENS:FieldType = 104 ;
                HLENS:MemoryOrder = "XY " ;
                HLENS:units = "whoknows" ;
                HLENS:description = "something" ;
                HLENS:stagger = "M" ;
                HLENS:sr_x = 1 ;
                HLENS:sr_y = 1 ;
        float HLENW(Time, south_north, west_east) ;
                HLENW:FieldType = 104 ;
                HLENW:MemoryOrder = "XY " ;
                HLENW:units = "whoknows" ;
                HLENW:description = "something" ;
                HLENW:stagger = "M" ;
                HLENW:sr_x = 1 ;
                HLENW:sr_y = 1 ;
        float HASYNW(Time, south_north, west_east) ;
                HASYNW:FieldType = 104 ;
                HASYNW:MemoryOrder = "XY " ;
                HASYNW:units = "whoknows" ;
                HASYNW:description = "something" ;
                HASYNW:stagger = "M" ;
                HASYNW:sr_x = 1 ;
                HASYNW:sr_y = 1 ;
        float HASYSW(Time, south_north, west_east) ;
                HASYSW:FieldType = 104 ;
                HASYSW:MemoryOrder = "XY " ;
                HASYSW:units = "whoknows" ;
                HASYSW:description = "something" ;
                HASYSW:stagger = "M" ;
                HASYSW:sr_x = 1 ;
                HASYSW:sr_y = 1 ;
        float HASYS(Time, south_north, west_east) ;
                HASYS:FieldType = 104 ;
                HASYS:MemoryOrder = "XY " ;
                HASYS:units = "whoknows" ;
                HASYS:description = "something" ;
                HASYS:stagger = "M" ;
                HASYS:sr_x = 1 ;
                HASYS:sr_y = 1 ;
        float HASYW(Time, south_north, west_east) ;
                HASYW:FieldType = 104 ;
                HASYW:MemoryOrder = "XY " ;
                HASYW:units = "whoknows" ;
```

```
            HASYW:description = "something" ;
            HASYW:stagger = "M" ;
            HASYW:sr_x = 1 ;
            HASYW:sr_y = 1 ;
      float HSTDV(Time, south_north, west_east) ;
            HSTDV:FieldType = 104 ;
            HSTDV:MemoryOrder = "XY " ;
            HSTDV:units = "whoknows" ;
            HSTDV:description = "something" ;
            HSTDV:stagger = "M" ;
            HSTDV:sr_x = 1 ;
            HSTDV:sr_y = 1 ;
      float HCNVX(Time, south_north, west_east) ;
            HCNVX:FieldType = 104 ;
            HCNVX:MemoryOrder = "XY " ;
            HCNVX:units = "whoknows" ;
            HCNVX:description = "something" ;
            HCNVX:stagger = "M" ;
            HCNVX:sr_x = 1 ;
            HCNVX:sr_y = 1 ;
      float LU_INDEX(Time, south_north, west_east) ;
            LU_INDEX:FieldType = 104 ;
            LU_INDEX:MemoryOrder = "XY " ;
            LU_INDEX:units = "category" ;
            LU_INDEX:description = "Dominant category" ;
            LU_INDEX:stagger = "M" ;
            LU_INDEX:sr_x = 1 ;
            LU_INDEX:sr_y = 1 ;
      float LANDUSEF(Time, z-dimension0024, south_north, west_east)
;
            LANDUSEF:FieldType = 104 ;
            LANDUSEF:MemoryOrder = "XYZ" ;
            LANDUSEF:units = "category" ;
            LANDUSEF:description = "24-category USGS landuse" ;
            LANDUSEF:stagger = "M" ;
            LANDUSEF:sr_x = 1 ;
            LANDUSEF:sr_y = 1 ;
      float LANDMASK(Time, south_north, west_east) ;
            LANDMASK:FieldType = 104 ;
            LANDMASK:MemoryOrder = "XY " ;
            LANDMASK:units = "none" ;
            LANDMASK:description = "Landmask : 1=land, 0=water" ;
            LANDMASK:stagger = "M" ;
            LANDMASK:sr_x = 1 ;
            LANDMASK:sr_y = 1 ;
      float F(Time, south_north, west_east) ;
            F:FieldType = 104 ;
            F:MemoryOrder = "XY " ;
            F:units = "-" ;
            F:description = "Coriolis F parameter" ;
            F:stagger = "M" ;
            F:sr_x = 1 ;
            F:sr_y = 1 ;
      float E(Time, south_north, west_east) ;
```

```
                E:FieldType = 104 ;
                E:MemoryOrder = "XY " ;
                E:units = "-" ;
                E:description = "Coriolis E parameter" ;
                E:stagger = "M" ;
                E:sr_x = 1 ;
                E:sr_y = 1 ;
        float XLONG_V(Time, south_north, west_east) ;
                XLONG_V:FieldType = 104 ;
                XLONG_V:MemoryOrder = "XY " ;
                XLONG_V:units = "degrees longitude" ;
                XLONG_V:description = "Longitude on velocity grid" ;
                XLONG_V:stagger = "V" ;
                XLONG_V:sr_x = 1 ;
                XLONG_V:sr_y = 1 ;
        float XLAT_V(Time, south_north, west_east) ;
                XLAT_V:FieldType = 104 ;
                XLAT_V:MemoryOrder = "XY " ;
                XLAT_V:units = "degrees latitude" ;
                XLAT_V:description = "Latitude on velocity grid" ;
                XLAT_V:stagger = "V" ;
                XLAT_V:sr_x = 1 ;
                XLAT_V:sr_y = 1 ;
        float XLONG_M(Time, south_north, west_east) ;
                XLONG_M:FieldType = 104 ;
                XLONG_M:MemoryOrder = "XY " ;
                XLONG_M:units = "degrees longitude" ;
                XLONG_M:description = "Longitude on mass grid" ;
                XLONG_M:stagger = "M" ;
                XLONG_M:sr_x = 1 ;
                XLONG_M:sr_y = 1 ;
        float XLAT_M(Time, south_north, west_east) ;
                XLAT_M:FieldType = 104 ;
                XLAT_M:MemoryOrder = "XY " ;
                XLAT_M:units = "degrees latitude" ;
                XLAT_M:description = "Latitude on mass grid" ;
                XLAT_M:stagger = "M" ;
                XLAT_M:sr_x = 1 ;
                XLAT_M:sr_y = 1 ;

// global attributes:
                :TITLE = "OUTPUT FROM METGRID V3.4" ;
                :SIMULATION_START_DATE = "2008-01-11_00:00:00" ;
                :WEST-EAST_GRID_DIMENSION = 19 ;
                :SOUTH-NORTH_GRID_DIMENSION = 39 ;
                :BOTTOM-TOP_GRID_DIMENSION = 27 ;
                :WEST-EAST_PATCH_START_UNSTAG = 1 ;
                :WEST-EAST_PATCH_END_UNSTAG = 19 ;
                :WEST-EAST_PATCH_START_STAG = 1 ;
                :WEST-EAST_PATCH_END_STAG = 19 ;
                :SOUTH-NORTH_PATCH_START_UNSTAG = 1 ;
                :SOUTH-NORTH_PATCH_END_UNSTAG = 39 ;
                :SOUTH-NORTH_PATCH_START_STAG = 1 ;
                :SOUTH-NORTH_PATCH_END_STAG = 39 ;
```

```
            :GRIDTYPE = "E" ;
            :DX = 0.289143f ;
            :DY = 0.287764f ;
            :DYN_OPT = 4 ;
            :CEN_LAT = 32.f ;
            :CEN_LON = -83.f ;
            :TRUELAT1 = 1.e+20f ;
            :TRUELAT2 = 1.e+20f ;
            :MOAD_CEN_LAT = 0.f ;
            :STAND_LON = 1.e+20f ;
            :POLE_LAT = 90.f ;
            :POLE_LON = 0.f ;
            :corner_lats = 26.39329f, 37.31068f, 37.31068f,
26.39329f, 26.40831f, 37.3276f, 37.29281f, 26.37742f, 0.f, 0.f, 0.f,
0.f, 0.f, 0.f, 0.f, 0.f ;
            :corner_lons = -88.78565f, -89.519f, -76.481f, -
77.21435f, -88.46474f, -89.1577f, -76.11986f, -76.89354f, 0.f, 0.f,
0.f, 0.f, 0.f, 0.f, 0.f, 0.f ;
            :MAP_PROJ = 203 ;
            :MMINLU = "USGS" ;
            :NUM_LAND_CAT = 24 ;
            :ISWATER = 16 ;
            :ISLAKE = -1 ;
            :ISICE = 24 ;
            :ISURBAN = 1 ;
            :ISOILWATER = 14 ;
            :grid_id = 1 ;
            :parent_id = 1 ;
            :i_parent_start = 0 ;
            :j_parent_start = 0 ;
            :i_parent_end = 19 ;
            :j_parent_end = 39 ;
            :parent_grid_ratio = 1 ;
            :sr_x = 1 ;
            :sr_y = 1 ;
            :NUM_METGRID_SOIL_LEVELS = 4 ;
            :FLAG_METGRID = 1 ;
            :FLAG_PSFC = 1 ;
            :FLAG_SM000010 = 1 ;
            :FLAG_SM010040 = 1 ;
            :FLAG_SM040100 = 1 ;
            :FLAG_SM100200 = 1 ;
            :FLAG_ST000010 = 1 ;
            :FLAG_ST010040 = 1 ;
            :FLAG_ST040100 = 1 ;
            :FLAG_ST100200 = 1 ;
            :FLAG_SOILHGT = 1 ;
}
```

User's Guide for the NMM Core of the Weather Research and Forecast (WRF) Modeling System Version 3

Chapter 4: WRF-NMM Initialization

Table of Contents

Introduction

The ***real_nmm.exe*** portion of the code generates initial and boundary conditions for the WRF-NMM model (***wrf.exe***) that are derived from output files provided by the ***WPS.*** Inputs required for the WRF-NMM model are not restricted to WPS alone. Several variables are defined/re-defined using the ***real_nmm*** part of the routines. For instance, the WRF-NMM core uses the definition of the Coriolis parameter in ***real_nmm***, rather than that in WPS.

The ***real_nmm*** program performs the following tasks:

- Reads data from the namelist
- Allocates space
- Initializes remaining variables
- Reads input data from the WRF Preprocessing System (WPS)
- Prepares soil fields for use in the model (usually vertical interpolation to the requested levels)
- Checks to verify soil categories, land use, land mask, soil temperature, and sea surface temperature are all consistent with each other
- Vertically interpolates to the models computational surfaces.
- Generates initial condition file
- Generates lateral condition file

The ***real_nmm.exe*** program may be run as a distributed memory job, but there may be no computational speed up since this program relies heavily on I/O and does few computations.

Initialization for Real Data Cases

The ***real_nmm.exe*** code uses data files provided by the WRF Preprocessing System (WPS) as input. The data processed by the WPS typically come from a previously run, large-scale forecast model. The original data are generally in "GriB" format and are ingested into the WPS by first using ***"ftp"*** to retrieve the raw GriB data from one of the national weather agencies anonymous ftp sites.

For example, a forecast from 2005 January 23 0000 UTC to 2005 January 24 0000 UTC which has original GriB data available at 3h increments will have the following files previously generated by the WPS:

met_nmm.d01.2005-01-23_00:00:00
met_nmm.d01.2005-01-23_03:00:00
met_nmm.d01.2005-01-23_06:00:00
met_nmm.d01.2005-01-23_09:00:00
met_nmm.d01.2005-01-23_12:00:00
met_nmm.d01.2005-01-23_15:00:00
met_nmm.d01.2005-01-23_18:00:00
met_nmm.d01.2005-01-23_21:00:00
met_nmm.d01.2005-01-24_00:00:00

The convention is to use "***met_nmm"*** to signify data that are output from the WPS and used as input into the ***real_nmm.exe*** program. The "***d01"*** part of the name is used to identify to which domain this data refers. The trailing characters are the date, where each WPS output file has only a single time-slice of processed data. The WPS package delivers data that are ready to be used in the WRF-NMM system.

The following statements apply to these data:

- The data adheres to the WRF IO API.
- The data has already been horizontally interpolated to the correct grid-point staggering for each variable, and the winds are correctly rotated to the WRF model map projection.
- 3-D meteorological data required from the WPS: ***pressure***, ***u***, ***v***, ***temperature***, ***relative humidity***, ***geopotential height***
- Optional 3-D hydrometeor data may be provided to the real program at run-time, but these fields will not be used in the coarse-grid lateral boundary file. Fields named: ***QR, QC, QS, QI, QG, QH, QNI*** (mixing ratio for rain, cloud, snow, ice, graupel, hail, and number concentration) are eligible for input from the metgrid output files.
- 3D soil data from the WPS: ***soil temperature***, ***soil moisture***, ***soil liquid*** (optional, depending on physics choices in the WRF model)
- 2D meteorological data from the WPS: ***sea level pressure***, ***surface pressure***, ***surface u and v***, ***surface temperature***, ***surface relative humidity***, ***input elevation***

- 2-D meteorological optional data from WPS: ***sea surface temperature***, ***physical snow depth***, ***water equivalent snow depth***
- 2D static data for the physical surface: ***terrain elevation***, ***land use categories***, ***soil texture categories***, ***temporally-interpolated monthly data***, ***land sea mask***, ***elevation of the input model's topography***
- 2D static data for the projection: ***map factors***, ***Coriolis***, ***projection rotation***, ***computational latitude***
- constants: ***domain size***, ***grid distances***, ***date***
- The WPS data may either be isobaric or some more-generalized vertical coordinate, where each column is monotonic in pressure
- All 3-D meteorological data (wind, temperature, height, moisture, pressure) must have the same number of levels, and variables must have the exact same levels. For example, it is not acceptable to have more levels for temperature (for example) than height. Likewise, it is not acceptable to have an extra level for the horizontal wind components, but not for moisture.

Running *real_nmm.exe*:

The procedure outlined below is used for single or multiple (nested) grid runs.

1. Change to the working directory of choice (***cd test/nmm_real*** or ***cd run***).

2. Make sure the files listed below reside in or are linked to the working-directory chosen to run the model (under ***WRFV3/run***, unless otherwise noted):

CAM_ABS_DATA	
CAM_AEROPT_DATA	
co2_trans	
ETAMPNEW_DATA	
ETAMPNEW_DATA_DBL	
ETAMPNEW_DATA.expanded_rain	
GENPARM.TBL	
Grib2map.tbl	
gribmap.txt	
LANDUSE.TBL	
MPTABLE.TBL	
namelist.input	***(WRFV3/test/nmm_real)***
ozone.formatted	
ozone_lat.formatted	
real_nmm.exe	
RRTM_DATA_DBL	
RRTMG_LW_DATA	
RRTMG_LW_DATA_DBL	
RRTMG_SW_DATA	
RRTMG_SW_DATA_DBL	
SOILPARM.TBL	

tr49t85
tr67t85
URBPARM.TBL
URBPARM_UZE.TBL
VEGPARM.TBL
wrf.exe

3. Make sure the ***met_nmm.d01**** files from the WPS either reside in or are linked to the working directory chosen to run the model. If nest(s) were run, also link in the ***geo_nmm_nest**** file(s).

4. Edit the ***namelist.input*** file in the working directory for dates, domain size, time step, output options, and physics options (see Chapter 5, Description of Namelist Variables section for details).

5. The command issued to run ***real_nmm.exe*** in the working directory will depend on the operating system.

On LINUX-MPI systems, the command is:

DM parallel build:	or	Serial build:
mpirun -np n real_nmm.exe		***./real_nmm.exe >& real_nmm.out***

where "***n***" defines the number of processors to use.

For batch jobs on some IBM systems (such as NCAR's IBM), the command is:

mpirun.lsf real_nmm.exe

and for interactive runs (Interactive MPI job is not an option on NCAR IBMs), the command is:

mpirun.lsf real_nmm.exe -rmpool 1 -procs n

where ***"n"*** stands for the number of processors (CPUs) to be used.

When ***real_nmm.exe*** is successful, the following files that are used by ***wrf.exe*** should be found in the working-directory:

wrfinput_d01	(Initial conditions, single time level data.)
wrfbdy_d01	(Boundary conditions data for multiple time steps.)

To check whether the run is successful, look for "SUCCESS COMPLETE REAL_NMM INIT" at the end of the log file (e.g.., ***rsl.out.0000***, ***real_nmm.out***).

The ***real_nmm.exe*** portion of the code does not input or output any file relevant to nested domains. Initial and boundary conditions for WRF-NMM nests are interpolated down from the parent grids during the WRF model run.

More details regarding the real data test case for 2005 January 23/00 through 24/00 is given in Chapter 5, Real Data Test Case.

Considerations for Recent Releases

- Since a new simple ocean model has been included in the WRF code, the old namelist option for activating an ocean mixed layer is no longer suitable. The variable OMLCALL has been switched to SF_OCEAN_PHYSICS.
- The default behavior of the base state has been modified. Starting with release version 3.5, the isothermal temperature is no longer zero. With this change, the base state temperature no longer gets colder than 200 K (default in the Registry, though a user can override this option with a namelist setting). This fixes the problem associated with layers being too thick near the model top. A side effect of thinning-out these model layers is that users may need to increase the number of vertical levels.
- The common availability of a valid seaice field in the input provided from the metgrid program has made obsolete the option to autoconvert “cold enough” water points to seaice. By default, the temperature at which water converts to seaice is now 100 K, a temperature cold enough that the option will never be triggered.

User's Guide for the NMM Core of the Weather Research and Forecast (WRF) Modeling System Version 3

Chapter 5: WRF NMM Model

Table of Contents

Introduction

The WRF-NMM is a fully compressible, non-hydrostatic mesoscale model with a hydrostatic option (Janjic et al. 2001, Janjic 2003a,b). The model uses a terrain following hybrid sigma-pressure vertical coordinate. The grid staggering is the Arakawa E-grid. The same time step is used for all terms. The dynamics conserve a number of first and second order quantities including energy and enstrophy (Janjic 1984).

The WRF-NMM code contains an initialization program ***(real_nmm.exe***; see Chapter 4) and a numerical integration program (***wrf.exe***). The WRF-NMM model Version 3 supports a variety of capabilities. These include:

- Real-data simulations
- Non-hydrostatic and hydrostatic (runtime option)
- Full physics options
- One-way and two-way nesting
- Applications ranging from meters to thousands of kilometers
- Digital filter initialization

WRF-NMM Dynamics in a Nutshell:

Time stepping:

Horizontally propagating fast-waves:	Forward-backward scheme
Vertically propagating sound waves:	Implicit scheme

Horizontal:	Adams-Bashforth scheme
Vertical:	Crank-Nicholson scheme
TKE, water species:	Explicit, iterative, flux-corrected (called every two time steps).

Advection (space) for T, U, V:

Horizontal:	Energy and enstrophy conserving, quadratic conservative, second order
Vertical:	Quadratic conservative, second order
TKE, Water species:	Upstream, flux-corrected, positive definite, conservative

Diffusion:

Diffusion in the WRF-NMM is categorized as lateral diffusion and vertical diffusion. The vertical diffusion in the PBL and in the free atmosphere is handled by the surface layer scheme and by the boundary layer parameterization scheme (Janjic 1996a, 1996b, 2002a, 2002b). The lateral diffusion is formulated following the Smagorinsky non-linear approach (Janjic 1990). The control parameter for the lateral diffusion is the square of Smagorinsky constant.

Divergence damping:

The horizontal component of divergence is damped (Sadourny 1975). In addition, if applied, the technique for coupling the elementary subgrids of the E grid (Janjic 1979) damps the divergent part of flow.

Physics Options

WRF offers multiple physics options that can be combined in many ways. The options typically range from simple and efficient to sophisticated and more computationally costly, and from newly developed schemes to well tried schemes such as those in current operational models. All available WRF System physics package options available in WRF Version 3 are listed below. Some of these options have not yet been tested for WRF-NMM. Indication of the options that have been tested, as well as the level of the testing, is included in the discussion below.

It is recommended that the same physics be used in all grids (coarsest and nests). The only exception is that the cumulus parameterization may be activated on coarser grids and turned off on finer grids.

Microphysics (*mp_physics*)

a. Kessler scheme: A warm-rain (i.e. no ice) scheme used commonly in idealized cloud modeling studies (*mp_physics* = 1).

b. Lin et al. scheme: A sophisticated scheme that has ice, snow and graupel processes, suitable for real-data high-resolution simulations (2).

c. WRF Single-Moment 3-class scheme: A simple efficient scheme with ice and snow processes suitable for mesoscale grid sizes (3).

d. WRF Single-Moment 5-class scheme: A slightly more sophisticated version of (c) that allows for mixed-phase processes and super-cooled water (4). (This scheme has been preliminarily tested for WRF-NMM.)

e. Eta microphysics: The operational microphysics in NCEP models. A simple efficient scheme with diagnostic mixed-phase processes. For fine resolutions (< 5km) use option (5) and for coarse resolutions use option (95). (This scheme is well tested for WRF-NMM, used operationally at NCEP.)

f. Eta HWRF microphysics: Similar to Eta microphysics (e), but modified to be suitable for the tropics (85). (This scheme is well tested and used operationally at NCEP for HWRF.) New in Version 3.2.

g. WRF Single-Moment 6-class scheme: A scheme with ice, snow and graupel processes suitable for high-resolution simulations (6). (This scheme has been preliminarily tested for WRF-NMM.)

h. Goddard microphysics scheme. A scheme with ice, snow and graupel processes suitable for high-resolution simulations (7). New in Version 3.0.

i. New Thompson et al. scheme: A new scheme with ice, snow and graupel processes suitable for high-resolution simulations (8). This adds rain number concentration and updates the scheme from the one in Version 3.0. New in Version 3.1. (This scheme has been preliminarily tested for WRF-NMM.)

j. Milbrandt-Yau Double-Moment 7-class scheme (9). This scheme includes separate categories for hail and graupel with double-moment cloud, rain, ice, snow, graupel and hail. New in Version 3.2.

k. Morrison double-moment scheme (10). Double-moment ice, snow, rain and graupel for cloud-resolving simulations. New in Version 3.0.

l. Stony Brook University (Y. Lin) scheme (13). This is a 5-class scheme with riming intensity predicted to account for mixed-phase processes. New in Version 3.3.

m. WRF Double-Moment 5-class scheme (14). This scheme has double-moment rain. Cloud and CCN for warm processes, but is otherwise like WSM5. New in Version 3.1.

n. WRF Double-Moment 6-class scheme (16). This scheme has double-moment rain. Cloud and CCN for warm processes, but is otherwise like WSM6. New in Version 3.1.

o. NSSL 2-moment scheme (17, 18). This is a two-moment scheme for cloud droplets, rain drops, ice crystals, snow, graupel, and hail. It also predicts average graupel particle density, which allows graupel to span the range from frozen drops to low-density graupel. There is an additional option to predict cloud condensation nuclei (CCN, option 18) concentration (intended for idealized simulations). The scheme is intended for cloud-resolving simulations (dx <= 2km) in research applications. New in Version 3.4.

p. CAM V5.1 2-moment 5-class scheme.

q. Thompson aerosol-aware (28). This scheme considers water- and ice-friendly aerosols. A climatology dataset may be used to specify initial and boundary conditions for the aerosol variables (Thompson and Eidhammer, 2014, JAS.) New in Version 3.6.

r. HUJI (Hebrew University of Jerusalem, Israel) spectral bin microphysics, full (32) and ‘fast’ (30) versions are available since Version 3.6.

Summary of Microphysics Options

mp_physics	Scheme	Reference	Added
1	Kessler	Kessler (1969)	2000
2	Lin (Purdue)	Lin, Farley and Orville (1983, JCAM)	2000

3	WSM3	Hong, Dudhia and Chen (2004, MWR)	2004
4	WSM5	Hong, Dudhia and Chen (2004, MWR)	2004
5	Eta (Ferrier)	Rogers, Black, Ferrier, Lin, Parrish and DiMego (2001, web doc)	2000
6	WSM6	Hong and Lim (2006, JKMS)	2004
7	Goddard	Tao, Simpson and McCumber (1989, MWR)	2008
8	Thompson	Thompson, Field, Rasmussen and Hall (2008, MWR)	2009
9	Milbrandt 2-mom	Milbrandt and Yau (2005, JAS)	2010
10	Morrison 2-mom	Morrison, Thompson and Tatarskii (2009, MWR)	2008
13	SBU-YLin	Lin and Colle (2011, MWR)	2011
14	WDM5	Lim and Hong (2010)	2009
16	WDM6	Lim and Hong (2010)	2009
17	NSSL 2-mom	Mansell, Ziegler and Brunning (2010)	2012
18	NSSL 2-mom w/CCN prediction	Mansell, Ziegler and Brunning (2010)	2012
19	NSSL 1-mom		2013
21	NSSL 1-momlfo		2013
28	Thompson aerosol-aware	Thompson and Eidhammer (2014, JAS)	2014
30	HUJI SBM 'fast'	Khain et al. (2010, JAS)	2014
32	HUJI SBM full	Khain et al. (2004, JAS)	2014
85	Eta HWRF	Rogers, Black, Ferrier, Lin, Parrish and DiMego (2001, web doc)	2010
95	Eta (coarse)	Rogers, Black, Ferrier, Lin, Parrish and DiMego (2001, web doc)	2000

mp_physics	Scheme	Cores	Mass Variables	Number Variables
1	Kessler	ARW	Qc Qr	
2	Lin (Purdue)	ARW (Chem)	Qc Qr Qi Qs Qg	
3	WSM3	ARW	Qc Qr	

4	WSM5	ARW/NMM	Qc Qr Qi Qs	
5	Eta (Ferrier)	ARW/NMM	Qc Qr Qs (Qt*)	
6	WSM6	ARW/NMM	Qc Qr Qi Qs Qg	
8	Thompson	ARW/NMM	Qc Qr Qi Qs Qg	Ni Nr
9	Milbrandt 2-mom	ARW	Qc Qr Qi Qs Qg Qh	Nc Nr Ni Ns Ng Nh
10	Morrison 2-mom	ARW (Chem)	Qc Qr Qi Qs Qg	Nr Ni Ns Ng
13	SBU-YLin	ARW	Qc Qr Qi Qs	
14	WDM5	ARW	Qc Qr Qi Qs	Nn** Nc Nr
16	WDM6	ARW	Qc Qr Qi Qs Qg	Nn** Nc Nr
17	NSSL 2-mom	ARW	Qc Qr Qi Qs Qg Qh	Nc Nr Ni Ns Ng Nh
18	NSSL 2-mom +CCN	ARW	Qc Qr Qi Qs Qg Qh	Nc Nr Ni Ns Ng Nh
19	NSSL 1-mom	ARW	Qc Qr Qi Qs Qg Qh	Vg***
21	NSSL 1-momlfo	ARW	Qc Qr Qi Qs Qg	
28	Thompson aerosol-aware	ARW/NMM	Qc Qr Qi Qs Qg	Ni Nr Nwf Nif
30	HUJI fast	ARW	Qc Qr Qs Qg Qi	Nc Nr Ns Ni Ng Nn
32	HUJI full	ARW	Qc Qr Qs Qg Qh Qip Qic Qid Qnn	Nc Nr Ns Ng Nip Nic Nid Nn
85	Eta HWRF	ARW/NMM	Qc Qr Qs (Qt*)	
95	Eta (coarse)	ARW/NMM	Qc Qr Qs (Qt*)	

***** Advects only total condensates ** Nn = CCN number

Longwave Radiation (*ra_lw_physics*)

a. RRTM scheme: Rapid Radiative Transfer Model. An accurate scheme using look-up tables for efficiency. Accounts for multiple bands, trace gases, and microphysics species (*ra_lw_physics* = 1). For trace gases, the volume-mixing ratio values for CO2=330e-6, N2O=0. and CH4=0. in pre-V3.5 code; in V3.5, CO2=379e-6, N2O=319e-9 and CH4=1774e-9. See section 2.3 for time-varying option. (This scheme has been preliminarily tested for WRF-NMM.)

b. FDL scheme: Eta operational radiation scheme. An older multi-band scheme with carbon dioxide, ozone and microphysics effects (99). (This scheme is well tested for WRF-NMM, used operationally at NCEP.) ***Note:*** *If it is desired to run GFDL with a microphysics scheme other than Ferrier, a modification to module_ra_gfdleta.F is needed to comment out (!) #define FERRIER_GFDL.*

c. Modified GFDL scheme: Similar to the GFDL scheme (b) but modified to be suitable for the tropics (98). (This scheme is well tested and used operationally at NCEP for HWRF.) New in Version 3.2.

d. CAM scheme: from the CAM 3 climate model used in CCSM. Allows for aerosols and trace gases (3). It uses yearly CO2, and constant N2O (311e-9) and CH4 (1714e-9). See section 2.3 for the time-varying option.

e. RRTMG scheme. A new version of RRTM (4). It includes the MCICA method of random cloud overlap. For major trace gases, CO2=379e-6, N2O=319e-9, CH4=1774e-9. See section 2.3 for the time-varying option.

f. New Goddard scheme (5). Efficient, multiple bands, ozone from climatology. It uses constant CO2=337e-6, N2O=320e-9, CH4=1790e-9. New in Version 3.3.

g. Fu-Liou-Gu scheme (7). Multiple bands, cloud and cloud fraction effects, ozone profile from climatology and tracer gases. CO_2=345e-6. New in Version 3.4.

Shortwave Radiation (*ra_sw_physics*)

a. Dudhia scheme: Simple downward integration allowing efficiently for clouds and clear-sky absorption and scattering. When used in high-resolution simulations, sloping and shadowing effects may be considered (*ra_sw_physics* = 1). (This scheme has been preliminarily tested for WRF-NMM.)

b. Goddard shortwave: Two-stream multi-band scheme with ozone from climatology and cloud effects (2).

c. GFDL shortwave: Eta operational scheme. Two-stream multi-band scheme with ozone from climatology and cloud effects (99). (This scheme is well-tested for WRF-NMM, used operationally at NCEP.) ***Note:*** *If it is desired to run GFDL with a microphysics scheme other than Ferrier, a modification to module_ra_gfdleta.F is needed to comment out (!) #define FERRIER_GFDL.*

d. Modified GFDL shortwave: Similar to the GFDL shortwave (c), but modified to be suitable for tropics (98). (This scheme is well tested and used operationally at NCEP for HWRF.) New in Version 3.2.

e. CAM scheme: from the CAM 3 climate model used in CCSM. Allows for aerosols and trace gases (3).

f. RRTMG shortwave. A new shortwave scheme with the MCICA method of random cloud overlap (4). New in Version 3.1.

g. New Goddard scheme (5). Efficient, multiple bands, ozone from climatology. New in Version 3.3.

h. Fu-Liou-Gu scheme (7). multiple bands, cloud and cloud fraction effects, ozone profile from climatology, can allow for aerosols. New in Version 3.4.

i. Held-Suarez relaxation. A temperature relaxation scheme designed for idealized tests only (31).

j. *swrad_scat*: scattering turning parameter for *ra_sw_physics* = 1. Default value is 1, which is equivalent to 1.e-5 m^2/kg. When the value is greater than 1, it increases the scattering.

Input to radiation options

a. CAM Green House Gases: Provides yearly green house gases from 1765 to 2500. The option is activated by compiling WRF with the macro –DCLWRFGHG added in configure.wrf. Once compiled, CAM, RRTM and RRTMG long-wave schemes will see these gases. Five scenario files are available: from IPCC AR5: CAMtr_volume_mixing_ratio .RCP4.5, CAMtr_volume_mixing_ratio.RCP6, and CAMtr_volume_mixing_ratio.RCP8.5; from IPCC AR4: CAMtr_volume_mixing_ratio.A1B, and CAMtr_volume_mixing_ratio.A2. The default points to the RCP8.5 file. New in Version 3.5.

b. Climatological ozone and aerosol data for RRTMG: The ozone data is adapted from CAM radiation (ra_*_physics=3), and it has latitudinal (2.82 degrees), height and temporal (monthly) variation, as opposed to the default ozone used in the scheme that only varies with height. This is activated by the namelist option *o3input* = 2. The aerosol data is based on Tegen et al. (1997), which has 6 types: organic carbon, black carbon, sulfate, sea salt, dust and stratospheric aerosol (volcanic ash, which is zero). The data also has spatial (5 degrees in longitude and 4 degrees in latitudes) and temporal (monthly) variations. The option is activated by the namelist option *aer_opt* = 1. New in Version 3.5.

c. Aerosol input for RRTMG and Goddard radiation options (*aer_opt = 2*). Either AOD or AOD plus Angstrom exponent, single scattering albedo, and cloud asymmetry parameter can be provided via constant values from namelist or 2D input fields via auxiliary input stream 15. Aerosol type can be set too. New in V3.6.

Summary of Radiation Physics Options

ra_sw_physics	Scheme	Reference	Added
1	Dudhia	Dudhia (1989, JAS)	2000
2	Goddard	Chou and Suarez (1994, NASA Tech Memo)	2000
3	CAM	Collins et al. (2004, NCAR Tech Note)	2006
4	RRTMG	Iacono et al. (2008, JGR)	2009
5	New Goddard	Chou and Suarez (1999, NASA Tech Memo)	2011
7	FLG	Gu et al. (2011, JGR), Fu and Liou (1992, JAS)	2012
99	GFDL	Fels and Schwarzkopf (1981, JGR)	2004

ra_sw_ physics	Scheme	Cores+Chem	Microphysics Interaction	Cloud Fraction	Ozone
1	Dudhia	ARW NMM + Chem(PM2.5)	Qc Qr Qi Qs Qg	1/0	none
2	GSFC	ARW+Chem(τ)	Qc Qi	1/0	5 profiles
3	CAM	ARW	Qc Qi Qs	max-rand overlap	lat/month
4	RRTMG	ARW + Chem (τ), NMM	Qc Qr Qi Qs	max-rand overlap	1 profile or lat/month
5	New Goddard	ARW	Qc Qr Qi Qs Qg	1/0	5 profiles
7	FLG	ARW	Qc Qr Qi Qs Qg	1/0	5 profiles
99	GFDL	ARW NMM	Qc Qr Qi Qs	max-rand overlap	lat/date

ra_lw_physics	Scheme	Reference	Added
1	RRTM	Mlawer et al. (1997, JGR)	2000
3	CAM	Collins et al. (2004, NCAR Tech Note)	2006
4	RRTMG	Iacono et al. (2008, JGR)	2009

5	New Goddard	Chou and Suarez (1999, NASA Tech Memo)	2011
7	FLG	Gu et al. (2011, JGR), Fu and Liou (1992, JAS)	2012
31	Held-Suarez		2008
99	GFDL	Fels and Schwarzkopf (1981, JGR)	2004

ra_lw_ physics	Scheme	Cores+Chem	Microphysics Interaction	Cloud Fraction	Ozone	GHG
1	RRTM	ARW NMM	Qc Qr Qi Qs Qg	1/0	1 profile	constant or yearly GHG
3	CAM	ARW	Qc Qi Qs	max-rand overlap	lat/month	yearly CO2 or yearly GHG
4	RRTMG	ARW + Chem (τ), NMM	Qc Qr Qi Qs	max-rand overlap	1 profile or lat/month	constant or yearly GHG
5	New Goddard	ARW	Qc Qr Qi Qs Qg	1/0	5 profiles	constant
7	FLG	ARW	Qc Qr Qi Qs Qg	1/0	5 profiles	constant
31	Held-Suarez	ARW	none	none		none
99	GFDL	ARW NMM	Qc Qr Qi Qs	max-rand overlap	lat/date	constant

Surface Layer (*sf_sfclay_physics*)

a. MM5 similarity: Based on Monin-Obukhov with Carslon-Boland viscous sub-layer and standard similarity functions from look-up tables (*sf_sfclay_physics* = 1). (This scheme has been preliminarily tested for WRF-NMM.)

b. Eta similarity: Used in Eta model. Based on Monin-Obukhov with Zilitinkevich thermal roughness length and standard similarity functions from look-up tables (2). (This scheme is well tested for WRF-NMM, used operationally at NCEP.)

c. NCEP Global Forecasting System (GFS) scheme: The Monin-Obukhov similarity profile relationship is applied to obtain the surface stress and latent heat fluxes using a formulation based on Miyakoda and Sirutis (1986) modified for very stable and unstable situations. Land surface evaporation has three components (direct evaporation from the soil and canopy, and transpiration from vegetation) following the formulation of Pan and Mahrt (1987) (3). (This scheme has been preliminarily tested for WRF-NMM.)

d. Pleim-Xiu surface layer (7). New in Version 3.0.

e. QNSE surface layer. Quasi-Normal Scale Elimination PBL scheme's surface layer option (4). New in Version 3.1.

f. MYNN surface layer. Nakanishi and Niino PBL's surface layer scheme (5).

g. TEMF surface layer. Total Energy – Mass Flux surface layer scheme. New in Version 3.3.

h. Revised MM5 surface layer scheme (11): Remove limits and use updated stability functions. New in Version 3.4. (Jimenez et al. MWR 2012).

i. GFDL surface layer (88): (This scheme is well tested and used operationally at NCEP for HWRF.)

h. *iz0tlnd* = 1 (for *sf_sfclay_physics* = 1 or 2), Chen-Zhang thermal roughness length over land, which depends on vegetation height, 0 = original thermal roughness length in each sfclay option. New in Version 3.2.

Land Surface (*sf_surface_physics*)

a. 5-layer thermal diffusion: Soil temperature only scheme, using five layers (*sf_surface_physics* = 1).

b. Noah Land Surface Model: Unified NCEP/NCAR/AFWA scheme with soil temperature and moisture in four layers, fractional snow cover and frozen soil physics. New modifications are added in Version 3.1 to better represent processes over ice sheets and snow covered area (2). (This scheme is well tested for WRF-NMM, used operationally at NCEP.)

- In V3.6, a sub-tiling option is introduced, and it is activated by namelist *sf_surface_mosaic* = 1, and the number of tiles in a grid box is defined by namelist *mosaic_cat*, with a default value of 3.

c. RUC Land Surface Model: RUC operational scheme with soil temperature and moisture in six layers, multi-layer snow and frozen soil physics (3). (This scheme has been preliminarily tested for WRF-NMM.)

d. Pleim-Xiu Land Surface Model. Two-layer scheme with vegetation and sub-grid tiling (7). New in Version 3.0: The Pleim-Xiu land surface model (PX LSM; Pleim and Xiu 1995; Xiu and Pleim 2001) was developed and improved over the years to provide realistic ground temperature, soil moisture, and surface sensible and latent heat fluxes in mesoscale meteorological models. The PX LSM is based on the ISBA model (Noilhan and Planton 1989), and includes a 2-layer force-restore soil temperature and moisture model. the top layer is taken to be 1 cm thick, and the lower layer is 99 cm. Grid aggregate vegetation and soil parameters are derived from fractional coverage of land use categories and soil texture types. There are two indirect nudging schemes that correct biases in 2-m air temperature and moisture by dynamic adjustment of soil moisture (Pleim and Xiu, 2003) and deep soil temperature (Pleim and Gilliam, 2009).

Users should recognize that the PX LSM was primarily developed for retrospective simulation, where surface-based observations are available to inform the indirect soil nudging. While soil nudging can be disabled using the FDDA namelist.input setting "pxlsm_soil_nudge," little testing has been done in this mode, although some users have reported reasonable results. Gilliam and Pleim (2010) discuss the implementation in the WRF model and provide typical configurations for retrospective applications. If soil nudging is activated, modelers must use the Obsgrid objective re-analysis utility to produce a surface nudging file with the naming convention "wrfsfdda_d0*." Obsgrid takes WPS "met_em*" files and LittleR observation files and produces the "wrfsfdda_d0*" file. The PX LSM uses 2-m temperature and mixing ratio re-analyses from this file for the deep soil moisture and temperature nudging. If modelers want to test PX LSM in forecast mode with soil nudging activated, forecasted 2-m temperature and mixing ratio can be used with empty observation files to produce the "wrfsfdda_d0*" files, using Obsgrid, but results will be tied to the governing forecast model.

e. GFDL slab model. Used together with GFDL surface layer scheme (88). (This scheme is well tested and used operationally at NCEP for HWRF.) New in Version 3.2.

f. Noah-MP (multi-physics) Land Surface Model: uses multiple options for key land-atmosphere interaction processes (4). Noah-MP contains a separate vegetation canopy defined by a canopy top and bottom with leaf physical and radiometric properties used in a two-stream canopy radiation transfer scheme that includes shading effects. Noah-MP contains a multi-layer snow pack with liquid water storage and melt/refreeze capability and a snow-interception model describing loading/unloading, melt/refreeze, and sublimation of the canopy-intercepted snow. Multiple options are available for surface water infiltration and runoff, and groundwater transfer and storage including water table depth to an unconfined aquifer. Horizontal and vertical vegetation density can be prescribed or predicted using prognostic photosynthesis and dynamic vegetation models that allocate carbon to vegetation (leaf, stem, wood and root) and soil carbon pools (fast and slow). New in Version 3.4. (Niu et al. 2011). (This scheme has been preliminarily tested for WRF-NMM.)

g. SSiB Land Surface Model: This is the third generation of the Simplified Simple Biosphere Model (Xue et al. 1991; Sun and Xue, 2001). SSiB is developed for land/atmosphere interaction studies in the climate model. The aerodynamic resistance values in SSiB are determined in terms of vegetation properties, ground conditions and bulk Richardson number according to the modified Monin–Obukhov similarity theory. SSiB-3 includes three snow layers to realistically simulate snow processes, including destructive metamorphism, densification process due to snow load, and snow melting, which substantially enhances the model's ability for the cold season study. To use this option, *ra_lw_physics* and *ra_sw_physics* should be set to either 1, 3, or 4. The second full model level should be set to no larger than 0.982 so that the height of that level is higher than vegetation height. New in Version 3.4.

h. CLM4 (Community Land Model Version 4, Oleson et al. 2010; Lawrence et al. 2010): CLM4 was developed at the National Center for Atmospheric Research with many external collaborators and represents a state-of-the-science land surface process model. It contains sophisticated treatment of biogeophysics, hydrology, biogeochemistry, and dynamic vegetation. In CLM4, the land surface in each model grid cell is characterized into five primary sub-grid land cover types (glacier, lake, wetland, urban, and vegetated). The vegetated sub-grid consists of up to 4 plant functional types (PFTs) that differ in physiology and structure. The WRF input land cover types are translated into the CLM4 PFTs through a look-up table. The CLM4 vertical structure includes a single-layer vegetation canopy, a five-layer snowpack, and a ten-layer soil column. An earlier version of CLM has been quantitatively evaluated within WRF in Jin and Wen (2012; JGR-Atmosphere), Lu and Kueppers (2012; JGR-Atmosphere), and Subin et al. (2011; Earth Interactions) (*from Jin*). New in Version 3.5.

Urban Surface (sf_urban_physics – replacing old switch ucmcall)

a. Urban canopy model (1): 3-category UCM option with surface effects for roofs, walls, and streets.

b. BEP (2). Building Environment Parameterization: Multi-layer urban canopy model that allows for buildings higher than the lowest model levels. Only works with Noah LSM and Boulac and MYJ PBL options. New in Version 3.1.

c. BEM (3). Building Energy Model. Adds to BEP, building energy budget with heating and cooling systems. Works with same options as BEP. New in Version 3.2.

Lake Physics (sf_lake_physics)

a. CLM 4.5 lake model (1). The lake scheme was obtained from the Community Land Model version 4.5 (Oleson et al. 2013) with some modifications by Gu et al. (2013). It is a one-dimensional mass and energy balance scheme with 20-25 model layers, including up to 5 snow layers on the lake ice, 10 water layers, and 10 soil layers on the lake bottom. The lake scheme is used with actual lake points and lake depth derived from the WPS, and it also can be used with user defined lake points and lake depth in WRF (lake_min_elev and lakedepth_default). The lake scheme is independent of a land surface scheme and therefore can be used with any land surface scheme embedded in WRF. The lake scheme developments and evaluations were included in Subin et al. (2012) and Gu et al. (2013) (Subin et al. 2012: Improved lake model for climate simulations, J. Adv. Model. Earth Syst., 4, M02001. DOI:10.1029/2011MS000072; Gu et al. 2013: Calibration and validation of lake surface temperature simulations with the coupled WRF-Lake model. Climatic Change, 1-13, 10.1007/s10584-013-0978-y).

Planetary Boundary layer (*bl_pbl_physics*)

a. Yonsei University scheme: Non-local-K scheme with explicit entrainment layer and parabolic K profile in unstable mixed layer (*bl_pbl_physics* = 1). (This scheme has been preliminarily tested for WRF-NMM.)

b. Mellor-Yamada-Janjic scheme: Eta operational scheme. One-dimensional prognostic turbulent kinetic energy scheme with local vertical mixing (2). (This scheme is well-tested for WRF-NMM, used operationally at NCEP.)

c. NCEP Global Forecast System scheme: First-order vertical diffusion scheme of Troen and Mahrt (1986) further described in Hong and Pan (1996). The PBL height is determined using an iterative bulk-Richardson approach working from the ground upward whereupon the profile of the diffusivity coefficient is specified as a cubic function of the PBL height. Coefficient values are obtained by matching the surface-layer fluxes. A counter-gradient flux parameterization is included (3). (This scheme is well tested and used operationally at NCEP for HWRF.) Updated in Version 3.2.

d. MRF scheme: Older version of (a) with implicit treatment of entrainment layer as part of non-local-K mixed layer (99).

e. ACM2 PBL: Asymmetric Convective Model with non-local upward mixing and local downward mixing (7). New in Version 3.0.

f. Quasi-Normal Scale Elimination PBL (4). A TKE-prediction option that uses a new theory for stably stratified regions. New in Version 3.1. Daytime part uses eddy diffusivity mass-flux method with shallow convection (mfshconv = 1) which is added in Version 3.4.

g. Mellor-Yamada Nakanishi and Niino Level 2.5 PBL (5). Predicts sub-grid TKE terms. New in Version 3.1.

h. Mellor-Yamada Nakanishi and Niino Level 3 PBL (6). Predicts TKE and other second-moment terms. New in Version 3.1.

i. BouLac PBL (8): Bougeault-Lacarrère PBL. A TKE-prediction option. New in Version 3.1. Designed for use with BEP urban model.

j. UW (Bretherton and Park) scheme (9). TKE scheme from CESM climate model. New in Version 3.3.

k. Total Energy - Mass Flux (TEMF) scheme (10). Sub-grid total energy prognostic variable, plus mass-flux type shallow convection. New in Version 3.3.

l. *topo_wind*: Topographic correction for surface winds to represent extra drag from sub-grid topography and enhanced flow at hill tops (1) (Jimenez and Dudhia, JAMC 2012). Works with YSU PBL only. New in Version 3.4. A simpler terrain variance-related correction (2). New in Version 3.5.

Note: *Two-meter temperatures are only available when running with MYJ scheme (2).*

Summary of PBL Physics Options

bl_pbl_physics	Scheme	Reference	Added
1	YSU	Hong, Noh and Dudhia (2006, MWR)	2004
2	MYJ	Janjic (1994, MWR)	2000
3	GFS	Hong and Pan (1996, MWR)	2005
4	QNSE	Sukoriansky, Galperin and Perov (2005, BLM)	2009
5	MYNN2	Nakanishi and Niino (2006, BLM)	2009
6	MYNN3	Nakanishi and Niino (2006, BLM)	2009
7	ACM2	Pleim (2007, JAMC	2008

8	BouLac	Bougeault and Lacarrere (1989, MWR)	2009
9	UW	Bretherton and Park (2009, JC)	2011
10	TEMF	Angevine, Jiang and Mauriten (2010, MWR)	2011
12	GBM	Grenier and Bretherton (2001, MWR)	2013
99	MRF	Hong and Pan (1996, MWR)	2000

bl_pbl_ physics	Scheme	Cores	sf_sfclay_ physics	Prognostic variables	Diagnostic variables	Cloud mixing
1	YSU	ARW/ NMM	1		exch_h	QC,QI
2	MYJ	ARW/ NMM	2	TKE_PBL	EL_MYJ, exch_h	QC,QI
3	GFS (hwrf)	NMM	3			QC,QI
4	QNSE	ARW/ NMM	4	TKE_PBL	EL_MYJ, exch_h, exch_m	QC,QI
5	MYNN2	ARW	1,2,5	QKE	Tsq, Qsq, Cov, exch_h, exch_m	QC
6	MYNN3	ARW	1,2,5	QKE, Tsq, Qsq, Cov	exch_h, exch_m	QC
7	ACM2	ARW	1,7			QC,QI
8	BouLac	ARW	1,2	TKE_PBL	EL_PBL, exch_h, exch_m, wu_tur, wv_tur, wt_tur, wq_tur	QC
9	UW	ARW	2	TKE_PBL	exch_h, exch_m	QC
10	TEMF	ARW	10	TE_TEMF	*_temf	QC, QI

99	MRF	ARW/ NMM	1			QC,QI

Cumulus Parameterization (*cu_physics*)

a. Kain-Fritsch scheme: Deep and shallow convection sub-grid scheme using a mass flux approach with downdrafts and CAPE removal time scale (*cu_physics* = 1). (This scheme has been preliminarily tested for WRF-NMM.)

- kfeta_trigger = 1 – default trigger; = 2 – moisture-advection modulated trigger function [based on Ma and Tan (2009, Atmospheric Research)]. May improve results in subtropical regions when large-scale forcing is weak.

b. Betts-Miller-Janjic scheme. Operational Eta scheme. Column moist adjustment scheme relaxing towards a well-mixed profile (2). (This scheme is well tested for WRF-NMM, used operationally at NCEP.)

c. Grell-Devenyi ensemble scheme: Multi-closure, multi-parameter, ensemble method with typically 144 sub-grid members (moved to option 93 in V3.5). (This scheme has been preliminarily tested for WRF-NMM.)

e. Simplified Arakawa-Schubert scheme (4): Simple mass-flux scheme with quasi-equilibrium closure with shallow mixing scheme (and momentum transport in NMM only). Adapted for ARW in Version 3.3.

f. Grell 3D is an improved version of the GD scheme that may also be used on high resolution (in addition to coarser resolutions) if subsidence spreading (option cugd_avedx) is turned on (5). New in Version 3.0.

g. Tiedtke scheme (U. of Hawaii version) (6). Mass-flux type scheme with CAPE-removal time scale, shallow component and momentum transport. New in Version 3.3.

h. Zhang-McFarlane scheme (7). Mass-flux CAPE-removal type deep convection from CESM climate model with momentum transport. New in Version 3.3.

i. New Simplified Arakawa-Schubert (14). New mass-flux scheme with deep and shallow components and momentum transport. New in Version 3.3.

j. New Simplified Arakawa-Schubert (84). New mass-flux scheme with deep and shallow components and momentum transport. New in Version 3.4. (This scheme is well tested for HWRF, used operationally at NCEP.)

k. Grell-Freitas (GF) scheme (3): An improved GD scheme that tries to smooth the transition to cloud-resolving scales, as proposed by Arakawa et al. (2004). New in Version 3.5.

l. Old Kain-Fritsch scheme: Deep convection scheme using a mass flux approach with downdrafts and CAPE removal time scale (99). (This scheme has been preliminarily tested for WRF-NMM.)

Summary of Cumulus Parameterization Options

cu_physics	Scheme	Reference	Added
1	Kain-Fritsch	Kain (2004, JAM)	2000
2	Betts-Miller-Janjic	Janjic (1994, MWR; 2000, JAS)	2002
3	Grell-Devenyi	Grell and Devenyi (2002, GRL)	2002
4	Old SAS	(Pan and Wu 1995, Hong and Pan 1998, Pan 2003)	2010
5	Grell-3	-	2008
6	Tiedtke	Tiedtke (1989, MWR), Zhang et al. (2011, submitted)	2011
7	Zhang-McFarlane	Zhang and McFarlane (1995, AO)	2011
14	New SAS	Han and Pan (2011)	2011
84	Simplified Arakawa-Schubert	Han and Pan (2011)	2005/ 2011
93	Grell-Devenyi	Grell and Devenyi (2002, GRL)	2002
99	Old Kain-Fritsch	Kain and Fritsch (1990, JAS; 1993, Meteo. Monogr.)	2000

cu_physics	Scheme	Cores	Moisture Tendencies	Momentum Tendencies	Shallow Convection
1	Kain-Fritsch	ARW / NMM	Qc Qr Qi Qs	no	yes

2	BMJ	ARW / NMM	-	no	yes
3	GD	ARW	Qc Qi	no	no
4	Old SAS	ARW/NMM	Qc Qi	yes (NMM)	yes
5	G3	ARW	Qc Qi	no	yes
6	Tiedtke	ARW	Qc Qi	yes	yes
7	Zhang-McFarlane	ARW	Qc Qi	yes	no
14	NSAS	ARW	Qc Qr Qi Qs	yes	yes
84	SAS	ARW / NMM	Qc Qi	yes (NMM)	yes
93	GD	ARW	Qc Qi	no	no
99	Old KF	ARW	Qc Qr Qi Qs	no	no

Shallow convection option (shcu_physics)

a. *ishallow* = 1, shallow convection option on. Works together with Grell 3D scheme (cu_physics = 5) – will move to shcu_physics category in the future.

b. UW (Bretherton and Park) scheme (2). Shallow cumulus option from CESM climate model with momentum transport. New in Version 3.3.

c. GRIMS (Global/Regional Integrated Modeling System) scheme: it represents the shallow convection process by using eddy-diffusion and the pal algorithm, and couples directly to the YSU PBL scheme. New in Version 3.5.

Other physics options

a. *gwd_opt*: Gravity wave drag option. Can be activated when grid size is greater than 10 km. May be beneficial for simulations longer than 5 days and over a large domain with mountain ranges. Default *gwd_opt*=0.

b. *mommix:* Coefficient used in the calculation of momentum mixing tendency terms. Default *mommix*=0.7. Only used with old SAS cumulus scheme (4).

c. *h_diff:* Coefficient used in the calculation of horizontal momentum diffusion terms. Default *h_diff*=0.1. Only used when environment variable HWRF is set.

d. *sfenth*: Enthalpy flux factor. Default *sfenth*=1.0. Only used with GFDL surface scheme.

d. *co$_2$tf:* CO2 transmission coefficient option. Default *co$_2$tf*=0.

e. *sas_pgcon:* Convectively forced pressure gradient factor (SAS schemes 14 and 84) Default *sas_pgcon*=0.55.

f. *gfs_alpha:* Boundary layer depth factor. Default *gfs_alpha*=1 (GFS PBL scheme 3).

g. *sas_mass_flux:* Mass flux limit (SAS scheme). Default *sas_mass_flux*=$9*10^9$ (SAS scheme 84)

h. *var_ric*: Placeholder for the use of variable critical Richardson number (Ric) in GFS PBL scheme (will be available in HWRF V3.5a release). Default *var_ric*=0 to use constant Ric, else set *var_ric*=1 to use variable.

i. *coef_ric_l*: Placeholder for the coefficient used in the calculation of the variable critical Richardson number (Ric) in GFS PBL scheme. Default *coef_ric_l*=0.16.

j. *coef_ric_s*: Placeholder for the coefficient used in the calculation of the variable critical Richardson number (Ric) in GFS PBL scheme. Default *coef_ric_s*=0.25.

k. *sf_ocean_physics* = 1 (renamed from *omlcall* in previous versions): Simple ocean mixed layer model (1): 1-D ocean mixed layer model following that of Pollard, Rhines and Thompson (1972). Two other namelist options are available to specify the initial mixed layer depth (although one may ingest real mixed layer depth data) (*oml_hml0*) and a temperature lapse rate below the mixed layer (*oml_gamma*). Since V3.2, this option works with all *sf_surface_physics* options.

l. *sf_ocean_physics* = 2: New in V3.5. 3D Price-Weller-Pinkel (PWP) ocean model based on Price et al. (1994). This model predicts horizontal advection, pressure gradient force, as well as mixed layer processes. Only simple initialization via namelist variables *ocean_z, ocean_t*, and *ocean_s* is available in V3.5.

m. *isftcflx*: Modify surface bulk drag (Donelan) and enthalpy coefficients to be more in line with recent research results of those for tropical storms and hurricanes. This option also includes dissipative heating term in heat flux. It is only available for *sf_sfclay_physics* = 1. There are two options for computing enthalpy coefficients: *isftcflx* = 1: constant Z_{0q} (since V3.2) for heat and moisture; *isftcflx* = 2 Garratt formulation, slightly different forms for heat and moisture.

n. *windfarm_opt*: Wind turbine drag parameterization scheme. It represents sub-grid effects of specified turbines on wind and TKE fields. The physical charateristics of the wind farm is read in from a file and use of the manufacturers' specification is recommeded. An example of the file is provided in run/wind-turbine-1.tbl. The location of the turbines are read in from a file, windturbines.txt. See README.windturbine in WRFV3/ directory for more detail. New in Version 3.3, and in this version it only works with 2.5 level MYNN PBL option (*bl_pbl_physics*=5), and updated in V3.6.

o. Land model input options: *usemonalb*: When set to .true., it uses monthly albedo fields from geogrid, instead of table values. *rdlai2d*: When set to .true., it uses monthly LAI data from geogrid (new in V3.6) and the field will also go to wrflowinp file if *sst_update* is 1.

p. *no_mp_heating*: When set to 1, it turns off latent heating from microphysics. When using this option, *cu_physics* should be set to 0.

q. *icloud*: When set to 0, it turns off cloud effect on optical depth in shortwave radiation options 1, 4 and longwave radiation option 1, 4. Note since V3.6, this namelist also controls which cloud fraction method to use for radiation.

r. *isfflx*: When set to 0, it turns off both sensible and latent heat fluxes from the surface. This option works for *sf_sfclay_physics* = 1, 5, 7, 11.

s. *ifsnow*: When set to 0, it turns off snow effect in *sf_surface_physics* = 1.

Other dynamics options

a. *euler_adv*: Logical switch that turns on/off highly-conservative passive advection. Default *euler_adv*=.true. *(**Note:** ONLY compatible with Ferrier MP (5), else set to .false.)*

b. *codamp*: Divergence damping weighting factor (larger = more damping). Default *codamp*=6.4

c. *coac*: Horizontal diffusion weighting factor (larger = more diffusion). Default *coac*=1.6

d. *slophc*: Maximum model level slope (dZ/dy) for which horizontal diffusion is applied. Larger values applies horizontal diffusion over more mountainous terrain. Default *slophc*=6.363961e-3

e. *wp*: Off-centering weight in the updating of nonhyrostatic epsilon term in the nonhydrostatic solver. Very high-resolution runs (sub-1.5 km scale), particularly if model layers near the top of atmosphere are thick, will benefit from *wp* of about 0.10 (0.15 as an absolute upper limit) to stabilize the integration. Default *wp*=0.00

f. *vortex_tracker:* Vortex tracking algorithm for HWRF. Default *vortex_tracker*=1

g. *movemin:* Frequency with which nest tracker routine will be called in HWRF (multiples of nphs). Default *movemin*=10.

h. *nomove_freq*: To prevent noise in the output files, disable nest movement at initialization time or multiples of this interval, if this interval is set to a positive number (hours). By default, this is disabled (*nomove_freq=-1*).

Operational Configuration

Below is a summary of physics options that are well-tested for WRF-NMM and are used operationally at NCEP for the North-America Mesoscale (NAM) Model:

&physics	Identifying Number	Physics options
mp_physics (max_dom)	5	Microphysics-Ferrier
ra_lw_physics	99	Long-wave radiation - GFDL (Fels-Schwarzkopf)
ra_sw_physics	99	Short-wave radiation - GFDL (Lacis-Hansen)
sf_sfclay_physics	2	Surface-layer: Janjic scheme
sf_surface_physics	2	Noah Land Surface
bl_pbl_physics	2	Boundary-layer - Mellor-Yamada-Janjic TKE
cu_physics	2	Cumulus - Betts-Miller-Janjic scheme
num_soil_layers	4	Number of soil layers in land surface model

Description of Namelist Variables

The settings in the ***namelist.input*** file are used to configure WRF-NMM. This file should be edited to specify: dates, number and size of domains, time step, physics options, and output options. When modifying the ***namelist.input*** file, be sure to take into account the following points:

time_step: The general rule for determining the time step of the coarsest grid follows from the CFL criterion. If ***d*** is the grid distance between two neighboring points (in diagonal direction on the WRF-NMM's E-grid), ***dt*** is the time step, and ***c*** is the phase speed of the fastest process, the CFL criterion requires that:

(c*dt)/[d/sqrt(2.)] ≤1

This gives**:** **dt ≤ d/[sqrt(2.)*c]**

A very simple approach is to use ***2.25 x (grid spacing in km)*** or about ***330 x (angular grid spacing)*** to obtain an integer number of time steps per hour.

For example: If the grid spacing of the coarsest grid is 12km, then this gives *dt=27 s,* with a *dt=26 2/3 s* corresponding to 135 time steps per hour.

The following are pre-tested time-steps for WRF-NMM:

Approximate Grid Spacing (km)	**DELTA_X (in degrees)**	**DELTA_Y (in degrees)**	**Time Step (seconds)**
4	0.026726057	0.026315789	9-10s
8	0.053452115	0.052631578	18s
10	0.066666666	0.065789474	24s
12	0.087603306	0.075046904	25-30s
22	0.154069767	0.140845070	60s
32	0.222222222	0.205128205	90s

e_we and e_sn: Given WRF-NMM's E-grid staggering, the end index in the east-west direction **(*e_we*)** and the south-north direction (***e_sn***) for the coarsest grid need to be set with care and the ***e_sn*** value must be **EVEN** for WRF-NMM.

When using WPS, the coarsest grid dimensions should be set as:

e_we (namelist.input) = e_ew (namelist.wps),
e_sn (namelist.input) = e_sn (namelist.wps).

For example: The parent grid ***e_we*** and ***e_sn*** are set up as follows:

namelist.input	***namelist.wps***
e_we = 124,	***e_we*** = 124,
e_sn = 202,	***e_sn*** = 202,

Other than what was stated above, there are no additional rules to follow when choosing ***e_we*** and ***e_sn*** for nested grids.

dx and dy: For WRF-NMM, ***dx*** and ***dy*** are the horizontal grid spacing in degrees, rather than meters (unit used for WRF-ARW). Note that ***dx*** should be slightly larger than ***dy*** due to the convergence of meridians approaching the poles on the rotated grid. The grid spacing in ***namelist.input*** should have the same values as in ***namelist.wps***.

When using WPS,

> ***dx (namelist.input) = dx (namelist.wps),***
> ***dy (namelist.input) = dy (namelist.,wps).***

When running a simulation with multiple (*N*) nests, the namelist should have *N* values of ***dx***, ***dy***, ***e_we***, ***e_sn*** separated by commas.

For more information about the horizontal grid spacing for WRF-NMM, please see Chapter 3, WRF Preprocessing System (WPS).

nio_tasks_per_group: The number of ***I/O*** tasks ***(nio_tasks_per_group)*** should evenly divide into the number of compute tasks in the ***J-direction*** on the grid (that is the value of ***nproc_y***). For example, if there are 6 compute tasks in the ***J-direction***, then ***nio_tasks_per_group*** could legitimately be set to 1, 2, 3, or 6. The user needs to use a number large enough that the quilting for a given output time is finished before the next output time is reached. If one had 6 compute tasks in the ***J-direction*** (and the number in the ***I-direction*** was similar), then one would probably choose either 1 or 2 quilt tasks.

The following table provides an overview of the parameters specified in ***namelist.input***. Note that "***namelist.input***" is common for both WRF cores (WRF-ARW and WRF-NMM). Most of the parameters are valid for both cores. However, some parameters are only valid for one of the cores. Core specific parameters are noted in the table. In addition, some physics options have not been tested for WRF-NMM. Those options that have been tested are highlighted by indicating whether they have been "fully" or "preliminarily" tested for WRF-NMM.

Variable Names	**Value (Example)**	**Description**
&time_control		Time control
run_days	2	Run time in days
run_hours	0	Run time in hours Note: If run time is more than 1 day, one may use both ***run_days*** and ***run_hours*** or just ***run_hours***. e.g. if the total run length is 36 hrs, you may set ***run_days***=1, and **run_hours**=12, or ***run_days***=0, and ***run_hours***=36.
run_minutes	00	Run time in minutes

Variable Names	**Value (Example)**	**Description**
run_seconds	00	Run time in seconds
start_year (max_dom)	2005	Four digit year of starting time
start_month (max_dom)	04	Two digit month of starting time
start_day (max_dom)	27	Two digit day of starting time
start_hour (max_dom)	00	Two digit hour of starting time
start_minute (max_dom)	00	Two digit minute of starting time
start_second (max_dom)	00	Two digit second of starting time
end_year (max_dom)	2005	Four digit year of ending time
end_month (max_dom)	04	Two digit month of ending time
end_day (max_dom)	29	Two digit day of ending time
end_hour (max_dom)	00	Two digit hour of ending time
end_minute (max_dom)	00	Two digit minute of ending time
end_second (max_dom)	00	Two digit second of ending time **Note:** All end times also control when the nest domain integrations end. **Note:** All start and end times are used by ***real_nmm.exe***. One may use either ***run_days***/***run_hours*** etc. or ***end_year***/***month***/***day***/***hour*** etc. to control the length of model integration, but ***run_days***/***run_hours*** takes precedence over the end times. The program ***real_nmm.exe*** uses start and end times only.
interval_seconds	10800	Time interval between incoming real data, which will be the interval between the lateral boundary condition files. This parameter is only used by ***real_nmm.exe***.
history_interval (max_dom)	60	History output file interval in minutes
history_interval_d (max_dom)	1	history output file interval in days (integer only); used as an alternative to `history_interval`
history_interval_h (max_dom)	1	history output file interval in hours (integer only); used as an alternative to `history_interval`
history_interval_m (max_dom)	1	history output file interval in minutes (integer only); used as an alternative to `history_interval` and is equivalent to

Variable Names	Value (Example)	Description
		`history_interval`
history_interval_s (max_dom)	1	history output file interval in seconds (integer only); used as an alternative to `history_interval`
frames_per_outfile (max_dom)	1	Output times per history output file, used to split output files into smaller pieces
tstart (max_dom)	0	**This flag is only for the WRF-NMM core**. Forecast hour at the start of the NMM integration. Set to >0 if restarting a run.
analysis	.false.	**This flag is only for the HWRF configuration.** True: Nested domain will read in initial conditions from a file (instead of being initialized by interpolation from the coarse domain). False: Nested domain will get its initial condition by interpolation from the coarse domain. Will output an analysis file containing the variables with restart IO characteristics for the nested domain.
anl_outname	wrfanl_d02_yyyy-mm-dd_hh:mm:ss	specify the name of the analysis output file.
restart	.false.	Logical indicating whether run is a restart run
restart_interval	60	Restart output file interval in minutes
reset_simulation_start	F	Whether to overwrite simulation_start_date with forecast start time
io_form_history	2	Format of history file wrfout 1 = binary format (no supported post-processing software available) 2 = netCDF; 102 = split netCDF files on per processor (no supported post-processing software for split files) 4 = PHDF5 format (no supported post-processing software available) 5 = GRIB 1 10 = GRIB 2 11 = Parallel netCDF

Variable Names	**Value (Example)**	**Description**
io_form_restart	2	Format of restart file wrfrst 2 = netCDF; 102 = split netCDF files on per processor (must restart with the same number of processors)
io_form_input	2	Format of input file wrfinput_d01 2 = netCDF
io_form_boundary	2	Format of boundary file wrfbdy_d01 2 = netCDF
auxinput1_inname	***met_nmm_.d01.****<date>*	Name of input file from WPS
auxinput4_inname	***wrflowinp_d****<domain>*	Input for lower bdy file, works with ***sst_update***=1
auxinput4_interval (max_dom)	720	File interval, in minutes, for lower bdy file
debug_level	0	Control for amount of debug printouts 0 - for standard runs, no debugging. 1 - netcdf error messages about missing fields. 50,100,200,300 values give increasing prints. Large values trace the job's progress through physics and time steps.
nocolons	.false.	when set to .true. this replaces the colons with underscores in the output file names
ncd_nofill	.true.	(default) only a single write, not the write/read/write sequence (new in V3.6)
&Domains		Domain definition
time_step	18	Time step for integration of coarsest grid in integer seconds
time_step_fract_num	0	Numerator for fractional coarse grid time step
time_step_fract_den	1	Denominator for fractional coarse grid time step. Example, if you want to use 60.3 sec as your time step, set ***time_step***=60, ***time_step_fract_num***=3, and ***time_step_fract_den***=10

Variable Names	**Value (Example)**	**Description**
max_dom	1	Number of domains (1 for a single grid, >1 for nests)
s_we (max_dom)	1	Start index in x (west-east) direction (leave as is)
e_we (max_dom)	124	End index in x (west-east) direction (staggered dimension)
s_sn (max_dom)	1	Start index in y (south-north) direction (leave as is)
e_sn (max_dom)	62	End index in y (south-north) direction (staggered dimension). **For WRF-NMM this value must be even.**
s_vert (max_dom)	1	Start index in z (vertical) direction (leave as is)
e_vert (max_dom)	61	End index in z (vertical) direction (staggered dimension). This parameter refers to full levels including surface and top. Note: Vertical dimensions need to be the same for all nests.
dx (max_dom)	.0534521	Grid length in x direction, units in **degrees** for WRF-NMM.
dy (max_dom)	.0526316	Grid length in y direction, units in **degrees** for WRF-NMM.
p_top_requested	5000	P top used in the model (Pa); must be available in WPS data
ptsgm	42000.	Pressure level (Pa) in which the WRF-NMM hybrid coordinate transitions from sigma to pressure
eta_levels	1.00, 0.99, …0.00	Model eta levels. If this is not specified ***real_nmm.exe*** will provide a set of levels.
num_metgrid_levels	40	Number of vertical levels in the incoming data: type ***ncdump –h*** to find out
grid_id (max_dom)	1	Domain identifier.
parent_id (max_dom)	0	ID of the parent domain. Use 0 for the coarsest grid.
i_parent_start (max_dom)	1	Defines the LLC of the nest as this I-index of the parent domain. Use 1 for the coarsest grid.
j_parent_start (max_dom)	1	Defines the LLC of the nest in this J-index of the parent domain. Use 1 for the coarsest grid.

Variable Names	**Value (Example)**	**Description**
parent_grid_ratio (max_dom)	3	Parent-to-nest domain grid size ratio. **For WRF-NMM this ratio must be 3.**
parent_time_step_ratio (max_dom)	3	Parent-to-nest time step ratio. **For WRF-NMM this ratio must be 3.**
feedback	1	Feedback from nest to its parent domain; 0 = no feedback
smooth_option	0	no smoothing
	1	1-2-1 smoothing option for parent domain; used only with `feedback=1`
	2	(default) smoothing-desmoothing option for parent domain; used only with `feedback=1`
num_moves	-99	0: Stationary nest -99: Vortex-following moving nest throughout the entire simulation **This flag is only for the HWRF configuration.**
tile_sz_x	0	Number of points in tile x direction.
tile_sz_y	0	Number of points in tile y direction.
numtiles	1	Number of tiles per patch (alternative to above two items).
nproc_x	-1	Number of processors in x–direction for decomposition.
nproc_y	-1	Number of processors in y-direction for decomposition: If -1: code will do automatic decomposition. If >1 for both: will be used for decomposition.
&physics		Physics options
chem_opt	0	Chemistry option - not yet available
mp_physics (max_dom)	5	Microphysics options: 0. no microphysics 1. Kessler scheme 2. Lin et al. scheme 3. WSM 3-class simple ice scheme 4. WSM 5-class scheme (Preliminarily tested for WRF-NMM) 5. Ferrier (high res) scheme (Well-tested for WRF-NMM, used operationally at NCEP) 6. WSM 6-class graupel scheme (Preliminarily

Variable Names	Value (Example)	Description
		tested for WRF-NMM) 7. Goddard GCE scheme 8. Thompson graupel scheme (Preliminarily tested for WRF-NMM) 9. Milbrandt-Yau scheme (v3.2) 10. Morrison 2-moment scheme 13. SBU-YLin, 5-class scheme 14. Double moment, 5-class scheme 16. Double moment, 6-class scheme 17. NSSL 2-moment 18. NSSL 2-moment, with CCN prediction 19. NSSL 1-moment, 6-class 21. NSSL-LFO 1-moment, 6-class 28. aerosol-aware Thompson scheme with water- and ice-friendly aerosol climatology (new for V3.6); this option has 2 climatological aerosol input options: use_aero_icbs = .F. (use constant values), and use_aero_icbc = .T. (use input from WPS) 30. HUJI (Hebrew University of Jerusalem, Israel) spectral bin microphysics, fast version 32. HUJI spectral bin microphysics, full version 85. Etamp_hwrf scheme. Similar to Ferrier, modified for HWRF. (Well-tested, used operationally at NCEP for HWRF) 95. Ferrier (coarse) scheme (Well-tested for WRF-NMM, used operationally at NCEP) 98. Thompson (v3.0) scheme (Preliminarily tested for WRF-NMM)
do_radar_ref	0	allows radar reflectivity to be computed using mp-scheme- specific parameters. Currently works for `mp_physics` = 2,4,6,7,8,10,14,16 0: off 1: on
ra_lw_physics (max_dom)	99	Long-wave radiation options: 0. No longwave radiation 1. RRTM scheme (Preliminarily tested for WRF-NMM) 3. CAM scheme 4. RRTMG scheme 5. Goddard scheme 7. FLG (UCLA) scheme 31. Earth Held-Suarez forcing

Variable Names	**Value (Example)**	**Description**
		99. GFDL scheme (Well-tested for WRF-NMM, used operationally at NCEP) 98. modified GFDL scheme (Well-tested, used operationally at NCEP for HWRF)
ra_sw_physics (max_dom)	99	Short-wave radiation options: 0. No shortwave radiation 1. Dudhia scheme (Preliminarily tested for WRF-NMM) 2. Goddard short wave scheme (old) 3. CAM scheme 4. RRTMG scheme 5. Goddard scheme 7. FLG (UCLA) scheme 99. GFDL scheme (Well-tested for WRF-NMM, used operationally at NCEP) 98. modified GFDL scheme (Well-tested, used operationally at NCEP for HWRF)
nrads (max_dom)	100	**This flag is only for the WRF-NMM core**. Number of fundamental time steps between calls to shortwave radiation scheme. NCEP's operational setting: ***nrads*** is on the order of "3600/dt". For more detailed results, use: ***nrads=1800/dt***
nradl (max_dom)	100	**This flag is only for the WRF-NMM core**. Number of fundamental time steps between calls to longwave radiation scheme. Note that ***nradl*** must be set equal to ***nrads***.
tprec (max_dom)	3	**This flag is only for the WRF-NMM core**. Number of hours of precipitation accumulation in WRF output.
theat (max_dom)	6	**This flag is only for the WRF-NMM core**. Number of hours of accumulation of gridscale and convective heating rates in WRF output.
tclod (max_dom)	6	**This flag is only for the WRF-NMM core**. Number of hours of accumulation of cloud amounts in WRF output.
trdsw (max_dom)	6	**This flag is only for the WRF-NMM core**. Number of hours of accumulation of shortwave fluxes in WRF output.
trdlw (max_dom)	6	**This flag is only for the WRF-NMM core**.

Variable Names	**Value (Example)**	**Description**
		Number of hours of accumulation of longwave fluxes in WRF output.
tsrfc (max_dom)	6	**This flag is only for the WRF-NMM core**. Number of hours of accumulation of evaporation/sfc fluxes in WRF output.
pcpflg (max_dom)	.false.	**This flag is only for the WRF-NMM core**. Logical switch that turns on/off the precipitation assimilation used operationally at NCEP.
co2tf	1	**This flag is only for the WRF-NMM core.** Controls CO2 input used by the GFDL radiation scheme. 0: Read CO2 functions data from pre- generated file 1: Generate CO2 functions data internally
sf_sfclay_physics (max_dom)	2	Surface-layer options: 0. No surface-layer scheme 1. Monin-Obukhov scheme (Preliminarily tested for WRF-NMM) 2. Janjic scheme (Well-tested for WRF-NMM, used operationally at NCEP) 3. NCEP Global Forecast System scheme (Preliminarily tested for WRF-NMM) 4. QNSE 5. MYNN 7. Pleim-Xiu surface layer 10. TEMF 11. Revised MM5 surface layer scheme 88. GFDL surface layer scheme (Well-tested, used operationally at NCEP for HWRF)
iz0tlnd	0	Thermal roughness length for sfclay and myjsfc (0 - old, 1 - veg dependent Czil)
sf_surface_physics (max_dom)	99	Land-surface options: 0. No surface temperature prediction 1. Thermal diffusion scheme 2. Noah Land-Surface Model (Well-tested for WRF-NMM, used operationally at NCEP) 3. RUC Land-Surface Model (Preliminarily tested for WRF-NMM) 4. Noah-MP land-surface model (additional options under &noah_mp; preliminarily tested for WRF-NMM)

Variable Names	Value (Example)	Description
		5. CLM4 (Community Land Model Version 4) 7. Pleim-Xiu Land Surface Model (ARW only) 8. SSiB land-surface model (ARW only). Works with *ra_lw_physics* = 1, 3, 4 and *ra_sw_physics* = 1, 3, 4 88. GFDL slab land surface model (Well-tested, used operationally at NCEP for HWRF)
bl_pbl_physics (max_dom)	2	Boundary-layer options: 0. No boundary-layer 1. YSU scheme (Preliminarily tested for WRF-NMM) 2. Mellor-Yamada-Janjic TKE scheme (Well-tested for WRF-NMM, used operationally at NCEP) 3. NCEP Global Forecast System scheme (Well-tested, used operationally at NCEP for HWRF) 4. QNSE 5. MYNN 2.5 level TKE, works with ***sf_sfclay_physics***=1,2, and 5 6. MYNN 3rd level TKE, works with ***sf_sfclay_physics***=5 only 7. ACM2 scheme 8. BouLac TKE 9. Bretherton-Park/UW TKE scheme, use with sf_sfclay_physics=1,2 10. TEMF scheme 12. GBM TKE-type scheme (ARW only); use ***sf_sfclay_physics=1*** 99. MRF scheme (to be removed)
nphs (max_dom)	10	**This flag is only for WRF-NMM core**. Number of fundamental time steps between calls to turbulence and microphysics. It can be defined as: ***nphs=x/dt***, where ***dt*** is the time step (s), and ***x*** is typically in the range of 60s to 180s. (Traditionally it has been ***<u>an even number</u>***, which may be a consequence of portions of horizontal advection only being called every other time step.)
topo_wind (max_dom)	0	1=turn on topographic surface wind correction (Jimenez); requires extra input from geogrid, and works with YSU PBL scheme only (0 = off,

Variable Names	Value (Example)	Description
		default)
bl_mynn_tkebudget	1	adds MYNN tke budget terms to output
cu_physics (max_dom)	2	Cumulus scheme options: 0. No cumulus scheme (Well-tested for WRF-NMM) 1. Kain-Fritsch scheme (Preliminarily tested for WRF-NMM) 2. Betts-Miller-Janjic scheme (Well-tested for WRF-NMM, used operationally at NCEP) 3. Grell-Devenyi ensemble scheme (Preliminarily tested for WRF-NMM) 4. Simplified Arakawa-Schubert scheme (2010 operational HWRF scheme) 14. New GFS SAS from YSU (ARW only) 5. Grell 3d ensemble scheme 6. Tiedke scheme 7. Zhang-McFarlane from CESM (works with MYJ and UW PBL) 14. New GFS SAS from YSU (ARW only) 84. Simplified Arakawa-Schubert scheme (Well-tested, used operationally at NCEP for HWRF) 93. Grell-Devenyi ensemble scheme 99. Previous Kain-Fritsch scheme (Preliminarily tested for WRF-NMM)
mommix	0.7	momentum mixing coefficient (used in SAS cumulus scheme). **This flag is for the SAS scheme only.**
h_diff	0.1	Horizontal diffusion coefficient. **This flag is only for the HWRF configuration.**
sfenth	1.0	Enthalpy flux factor. **This flag is for the GFDL surface scheme only.**
ncnvc (max_dom)	10	**This flag is only for WRF-NMM core**. Number of fundamental time steps between calls to convection. ***Note that ncnvc should be set equal to nphs.***
isfflx	1	heat and moisture fluxes from the surface for real-data cases and when a PBL is used (only works with `sf_sfclay_physics=1, 5, 7, or 11`)

Variable Names	**Value (Example)**	**Description**
		1 = fluxes are on 0 = fluxes are off It also controls surface fluxes when diff_opt = 2 and km_opt = 3, and a PBL isn't used 0 = constant fluxes defined by tke_drag_coefficient and tke_heat_flux 1 = use model-computed u* and heat and moisture fluxes 2 = use model-computed u* and specified heat flux by tke_heat_flux
ifsnow	1	Snow-cover effects for "Thermal Diffusion scheme" (sf_surface_physics=1): 0. No snow-cover effect 1. With snow-cover effect
icloud	0	Cloud effect to the optical depth in the Dudhia shortwave (ra_sw_physics=1) and RRTM longwave radiation (ra_lw_physics=1) schemes. 0. No cloud effect 1. With cloud effect
swrad_scat	1	Scattering tuning parameter (default 1 is 1.e-5 m^2/kg) (only for *ra_sw_physics* = 1)
num_soil_layers	4	Number of soil layers in land surface model. Options available: 2. Pleim-Xu Land Surface Model 4. Noah Land Surface Model (Well-tested for WRF-NMM, used operationally at NCEP) 5. Thermal diffusion scheme 6. RUC Land Surface Model (Preliminarily tested for WRF-NMM)
maxiens	1	Grell-Devenyi and G3 only. **Note:** The following 5 are recommended numbers. If you would like to use any other number, consult the code, and know what you are doing.
maxens	3	G-D only
maxens2	3	G-D only
maxens3	16	G-D only
ensdim	144	G-D only.
mp_zero_out	0	For non-zero mp_physics options, to keep water vapor positive (Qv >= 0), and to set the other

Variable Names	Value (Example)	Description
		moisture fields smaller than some threshold value to zero. 0. No action is taken, no adjustment to any moist field. (conservation maintained) 1. All moist arrays, except for Qv, are set to zero if they fall below a critical value. (No conservation) 2. Qv<0 are set to zero, and all other moist arrays that fall below the critical value defined in the flag “mp_zero_out_thresh” are set to zero. (No conservation.) **For WRF-NMM, mp_zero_out MUST BE set to 0.**
gwd_opt	0	Gravity wave drag option; use with grid spacing > 10 km 0. Off (default) 1. ARW GWD on 2. NMM GWD on
sst_update	0	Option to use time-varying SST, seaice, vegetation fraction, and abledo during a model simulation (set before running ***real_nmm.exe***) 0. Off (default) 1. ***real_nmm.exe*** will create *wrflowinp_d01* file at the same time interval as the available input data. To use it in ***wrf.exe***, add *auxinput4_inname=wrflowinp_d<domain>* and *auxinput4_interval* under the ***&time_control*** namelist section
sas_pgcon	0.55	convectively forced pressure gradient factor (SAS schemes 14 and 84)
gfs_alpha	1	boundary depth factor for GFS PBL scheme (3)
var_ric	0	Placeholder for the use of variable critical Richardson number (Ric) in GFS PBL scheme (will be available in HWRF V3.5a release). Default var_ric=0 to use constant Ric, else set var_ric=1 to use variable.
coef_ric_l	0.16	Placeholder for the coefficient used in the calculation of the variable critical Richardson number (Ric) in GFS PBL scheme.
coef_ric_s	0.25	Placeholder for the coefficient used in the calculation of the variable critical Richardson

Variable Names	**Value (Example)**	**Description**
		number (Ric) in GFS PBL scheme.
sas_mass_flux	0.5	mass flux limit (SAS scheme 84)
vortex_tracker	1	Vortex Tracking Algorithm for HWRF 1. (default) follow vortex using MSLP (operational HWRF 2011 algorithm) 2. follow vortex using MSLP (revised) 3. track vortex in nest and use that result to move this domain 4. follow vortex using storm centroid 5. follow vortex using dynamic pressure 6. follow vortex using the tracking algorithm of the GFDL vortex tracker (operational HWRF 2013 algorithm, will be available in HWRF V3.5a release) . New vortex following algorithm (under development)
nomove_freq:	-1	Disable nest movement at certain intervals to prevent noise in the output files, so that nest will not move at analysis time or multiples of this interval, if this interval is set to a positive number.
movemin	5	Frequency with which nest tracker routine will be called in HWRF (multiples of nphs)
&noah_mp		***options for the Noah-MP land surface model ; see: http://www.rap.ucar.edu/research/land/technology/noahmp_lsm.php***
dveg	1	Dynamic vegetation option 1=off [LAI (Leaf Area Index) from table; FVEG (veg fraction) = shdfac (model variable for veg fraction)] 2=(default) on 3= off (LAI from table; FVEG calculated) 4= off (LAI from table; FVEG = maximum veg. fraction)
opt_crs	1	Stomatal resistance option 1=(default) Ball-Berry 2=Jarvis

Variable Names	**Value (Example)**	**Description**
opt_sfc	1	Surface layer drag coefficient calculation 1=(default) Monin-Obukhov 2=original Noah 3=MYJ consistent 4=YSU consistent
opt_btr	1	Soil moisture factor for stomatal resistance 1=Noah 2=CLM 3=SSiB
opt_run	1	1=(default) TOPMODEL with ground water 2=TOPMODEL with equilibrium water table 3=original surface and subsurface runoff (free drainage) 4=BATS (Biosphere-Atmosphere Transfer Scheme) surface and subsurface runoff (free drainage)
opt_frz	1	Supercooled liquid water option 1=(default)no iteration 2=Koren's iteration
opt_inf	1	Soil permeability option 1=(default) linear effect, more permeable 2=non-linear effect, less permeable
opt_rad	1	Radiative transfer option 1= modified two-stream 2=two-stream applied to grid cell 3=(default) two-stream applied to vegetated fraction
opt_alb	2	Ground surface albedo option 1=BATS 2=(default) CLASS (Canadian Land Surface Scheme)
opt_snf	1	Precipitation partitioning between snow and rain 1=(default) Jordan (1991) 2=BATS; snow when SFCTMP<TFRZ+2.2 3=show when SFCTMP<TFRZ
opt_tbot	2	Soil temp lower boundary condition 1=zero heat flux 2=(default) TBOT at 8m from input file
opt_stc	1	Snow/soil temperature time scheme 1=(default) semi-implicit

Variable Names	Value (Example)	Description
		2=fully-implicit
&fdda		Observation nudging (Not yet available in the WRF-NMM)
&dynamics		Dynamics options:
dyn_opt	4	4. WRF-NMM dynamics
non_hydrostatic	.true.	Whether running the model in hydrostatic or non-hydrostatic model.
euler_adv	.true.	Logical switch that turns on/off passive advection (new in v3.2 – **ONLY compatible with Ferrier MP (5), else set to .false.**)
idtadt	1	Dynamics timestep between calls to the passive advection for dynamics variables
idtadc	1	Dynamics timestep between calls to the passive advection for chemistry variables
codamp	6.4	Divergence damping weighting factor (larger = more damping)
coac	1.6	Horizontal diffusion weighting factor (larger = more diffusion)
slophc	6.364e-3	Maximum model level slope (dZ/dy) for which horizontal diffusion is applied
wp	0.15	Off-centering weight in the updating of nonhyrostatic eps
&bc_control		Boundary condition control.
spec_bdy_width	1	Total number of rows for specified boundary value nudging. **It MUST be set to 1 for WRF-NMM core.**
specified (max_dom)	.true.	Specified boundary conditions (only applies to domain 1)
&grib2		
&namelist_quilt		Option for asynchronized I/O for MPI

Variable Names	**Value (Example)**	**Description**
		applications.
nio_tasks_per_group	0	Default value is 0, means no quilting; value > 0 quilting I/O
nio_groups	1	Default is 1. May be set higher for nesting IO, or history and restart IO.
&dfi_control		Digital filter option control
dfi_opt	0	DFI option 0: No digital filter initialization 1: Digital Filter Launch (DFL) 2: Diabatic DFI (DDFI) 3: Twice DFI (TDFI) (Recommended)
dfi_nfilter	7	Digital filter type 0: uniform 1: Lanczos 2: Hamming 3: Blackman 4: Kaiser 5: Potter 6: Dolph window 7: Dolph (recommended) 8: recursive high-order
dfi_write_filtered_input	.true.	Whether to write ***wrfinput*** file with filtered model state before beginning forecast
dfi_write_dfi_history	.false.	Whether to write ***wrfout*** files during filtering integration
dfi_cutoff_seconds	3600	Cutoff period, in seconds, for filter. Should not be longer than the filter window
dfi_time_dim	1000	Maximum number of time steps for filtering period (this value can be larger than necessary)
dfi_bckstop_year	2005	Four-digit year of stop time for backward DFI integration. For a model that starts from 2005042700, this example specifies 1 hour backward integration.
dfi_bckstop_month	04	Two-digit month of stop time for backward DFI integration
dfi_bckstop_day	26	Two-digit day of stop time for backward DFI

Variable Names	**Value (Example)**	**Description**
		integration
dfi_bckstop_hour	23	Two-digit hour of stop time for backward DFI integration
dfi_bckstop_minute	00	Two-digit minute of stop time for backward DFI integration
dfi_bckstop_second	00	Two-digit second of stop time for backward DFI integration.
dfi_fwdstop_year	2005	Four-digit year of stop time for forward DFI integration. For a model that starts from 2005042700, and using the TDFI method, this example specifies the end of the 60-minute forward integration (the forward segment begins at 20050426/2330).
dfi_fwdstop_month	04	Two-digit month of stop time for forward DFI integration
dfi_fwdstop_day	27	Two-digit day of stop time for forward DFI integration
dfi_fwdstop_hour	00	Two-digit hour of stop time for forward DFI integration
dfi_fwdstop_minute	30	Two-digit minute of stop time for forward DFI integration
dfi_fwdstop_second	00	Two-digit second of stop time for forward DFI integration.
&logging		
compute_slaves_silent	.true.	Switch to enable (compute_slaves_silent=.false.) or disable (compute_slaves_silent=.true.) the wrf_message calls on the slave nodes (where the wrf_dm_on_monitor() =.false.)
io_servers_silent	.true.	Switch to enable (io_servers_silent=.false.) or disable (io_servers_silent=.true.) the wrf_message calls on the IO servers.
stderr_logging	0	Switch to enable (stderr_logging=1) or disable (stderr_logging=0) the output of stderr.

How to Run WRF for the NMM Core

Note: For software requirements for running WRF, how to obtain the WRF package and how to configure and compile WRF for the NMM core, see Chapter 2.

Note: Running a real-data case requires first successfully running the WRF Preprocessing System (WPS) (See Chapter 2 for directions for installing the WPS and Chapter 3 for a description of the WPS and how to run the package).

Running *wrf.exe*:

Note: Running ***wrf.exe*** requires a successful run of ***real_nmm.exe*** as explained in Chapter 4.

1. If the working directory used to run ***wrf.exe*** is different than the one used to run ***real_nmm.exe***, make sure ***wrfinput_d01*** and ***wrfbdy_d01,*** as well as the files listed above in the ***real_nmm.exe*** discussion, are in your working directory (you may link the files to this directory).

2. The command issued to run ***wrf.exe*** in the working directory will depend on the operating system:

On LINUX-MPI systems, the command is:

DM parallel build:	or	Serial build:
mpirun -np n wrf.exe		***./wrf.exe >& wrf.out***

where "***n***" defines the number of processors to use.

For batch jobs on some IBM systems (such as NCAR's IBM), the command is:

mpirun.lsf wrf.exe

and for interactive runs (Interactive MPI job is not an option on NCAR IBMs), the command is:

mpirun.lsf wrf.exe -rmpool 1 -procs n

where ***"n"*** stands for the number of processors (CPUs) to be used.

Checking *wrf.exe* output

A successful run of ***wrf.exe*** will produce output files with the following naming convention:

wrfout_d01_yyyy-mm-dd_hh:mm:ss

For example, the first output file for a run started at 0000 UTC, 23rd January 2005 would be:

wrfout_d01_2005-01-23_00:00:00

If multiple grids were used in the simulation, additional output files named
wrfout_d02_yyyy-mm-dd_hh:mm:ss
wrfout_d03_yyyy-mm-dd_hh:mm:ss
(…)
will be produced.

To check whether the run is successful, look for "SUCCESS COMPLETE WRF" at the end of the log file (e.g., ***rsl.out.0000***, ***wrf.out***).

The times written to an output file can be checked by typing:

ncdump -v Times wrfout_d01_2005-01-23_00:00:00

The number of ***wrfout*** files generated by a successful run of ***wrf.exe*** and the number of output times per ***wrfout*** file will depend on the output options specified in ***namelist.input*** (i.e***., frames_per_outfile*** and ***history interval***).

Restart Run

A restart run allows a user to extend a run to a longer simulation period. It is effectively a continuous run made of several shorter runs. Hence the results at the end of one or more restart runs should be identical to a single run without any restart.

In order to do a restart run, one must first create a restart file. This is done by setting namelist variable ***restart_interval*** (unit is in minutes) to be equal to or less than the simulation length in the first model run, as specified by ***run_**** variables or ***start_**** and ***end_**** times. When the model reaches the time to write a restart file, a restart file named ***wrfrst_d***<*domain*>_<*date*> will be written. The date string represents the time when the restart file is valid.

When one starts the restart run, the ***namelist.input*** file needs to be modified so that the ***start_**** time will be set to the restart time (which is the time the restart file is written). The other namelist variable that must be set is ***restart***, this variable should be set to ***.true.*** for a restart run.

In summary, these namelists should be modified:

start_*, end_*:   start and end times for restart model integration
restart: logical to indicate whether the run is a restart or not

Hint**:** Typically, the restart file is a lot bigger in size than the history file, hence one may find that even it is ok to write a single model history output time to a file in netCDF format (***frame_per_outfile=1***), it may fail to write a restart file. This is because the basic netCDF file support is only 2Gb. There are two solutions to the problem. The first is to simply set namelist option ***io_form_restart = 102*** (instead of 2), and this will force the restart file to be written into multiple pieces, one per processor. As long as one restarts the model using the same number of processors, this option works well (and one should restart the model with the same number of processors in any case). The second solution is to recompile the code using the netCDF large file support option (see section on "Installing WRF" in this chapter).

Configuring a run with multiple domains

WRF-NMM V2.2 supports stationary one-way (Gopalakrishnan et al. 2006) and two-way nesting. By setting the ***feedback*** switch in the ***namelist.input*** file to 0 or 1, the domains behave as one-way or two-way nests, respectively.   The model can handle multiple domains at the same nest level (no overlapping nest), and/or multiple nest levels (telescoping). Make sure that you compile the code with nest options turned on as described in Chapter 2.

The nest(s) can be located anywhere inside the parent domain as long as they are at least 5 parent grid points away from the boundaries of the parent grid. Similar to the coarsest domain, nests use an E-staggered grid with a rotated latitude-longitude projection.   The horizontal grid spacing ratio between the parent and the nest is 1:3, and every third point of the nest coincides with a point in the parent domain. The time step used in the nest must be 1/3 that of the parent time step.

No nesting is applied in the vertical, that is, the nest has the same number of vertical levels as its parent. Note that, while the hybrid levels of the nest and parent in sigma space coincide, the nest and the parent do not have the same levels in pressure or height space. This is due to the differing topography, and consequently different surface pressure between the nest and the parent.

Nests can be introduced in the beginning of the model forecast or later into the run. Similarly, nests can run until the end of the forecast or can be turned off earlier in the run. Namelist variables ***start_**** and ***end_**** control the starting and ending time for nests.

When a nest is initialized, its topography is obtained from the static file created for that nest level by the WPS (see Chapter 3). Topography is the only field used from the static file. All other information for the nest is obtained from the lower-resolution parent domain. Land variables, such as land-sea mask, SST, soil temperature and moisture are obtained through a nearest-neighbor approach.

To obtain the temperature, geopotential, and moisture fields for the nest initialization, the first step is to use cubic splines to vertically interpolate those fields from hybrid levels to constant pressure levels in each horizontal grid point of the parent grid. The second step is to bilinearly interpolate those fields in the horizontal from the parent grid to the nest. The third step is to use the high-resolution terrain and the geopotential to determine the surface pressure on the nest. Next, the pressure values in the nest hybrid surfaces are calculated. The final step is to compute the geopotential, temperature and moisture fields over the nest hybrid surface using a cubic spline interpolation in the vertical.

The zonal and meridional components of the wind are obtained by first performing a horizontal interpolation from the parent to the nest grid points using a bi-linear algorithm. The wind components are then interpolated in the vertical from the parent hybrid surfaces onto the nest hybrid surfaces using cubic splines.

The boundary conditions for the nest are updated at every time step of the parent domain. The outermost rows/columns of the nest are forced to be identical to the parent domain interpolated to the nest grid points. The third rows/columns are not directly altered by the parent domain, that is, their values are obtained from internal computations within the nest. The second rows/columns are a blend of the first and third rows/columns. This procedure is analogous to what is used to update the boundaries of the coarsest domain with the external data source. To obtain the values of the mass and momentum fields in the outermost row/column of the nest, interpolations from the parent grid to the nest are carried in the same manner as for nest initialization.

Most of options to start a nest run are handled through the namelist. **Note:** All variables in the ***namelist.input*** file that have multiple columns of entries need to be edited with caution.

The following are the key namelist variables to modify:

- ***start_*** and ***end_year/month/day/minute/second***: These control the nest start and end times
- ***history_interval***: History output file in minutes (integer only)
- ***frames_per_outfile***: Number of output times per history output file, used to split output files into smaller pieces
- ***max_dom***: Setting this to a number greater than 1 will invoke nesting. For example, if you want to have one coarse domain and one nest, set this variable to 2.
- ***e_we/e_sn***: Number of grid points in the east-west and north-south direction of the nest. In WPS, ***e_sw***. ***e_sn*** for the nest are specified to cover the entire domain of the coarse grid while, in file ***namelist.input***, ***e_we*** and ***e_sn*** for the nest are specified to cover the domain of the nest.
- ***e_vert***: Number of grid points in the vertical. No nesting is done in the vertical, therefore the nest must have the same number of levels as its parent.
- ***dx/dy***: grid spacing in **degrees**. The nest grid spacing must be 1/3 of its parent.
- ***grid_id***: The domain identifier will be used in the ***wrfout*** naming convention. The coarser grid must have ***grid_id*** = 1.

- ***parent_id***: Specifies the parent grid of each nest. The parents should be identified by their ***grid_id***.
- ***i_parent_start/j_parent_start***: Lower-left corner starting indices of the nest domain in its parent domain. The coarser grid should have ***parent_id*** = 1.
- ***parent_grid_ratio***: Integer parent-to-nest domain grid size ratio. **Note:** Must be 3 for the NMM.
- ***parent_time_step_ratio***: Integer parent-to-nest domain timestep ratio. **Note:** Must be 3 for the NMM. Since the timestep for the nest is determined using this variable, namelist variable ***time_step*** only assumes a value for the coarsest grid.
- ***feedback***: If feedback = 1, values of prognostic variables in the nest are fedback and overwrite the values in the coarse domain at the coincident points. 0 = no feedback.

In addition to the variables listed above, the following variables are used to specify physics options and need to have values for all domains (as many columns as domains: ***mp_physics, ra_lw_pjysics, ra_sw_physics, nrads, nradl, sf_sfclay_physics, sf_surface_physics, bl_pbl_physics, nphs, cu_physics, ncnvc***.

Note: It is recommended to run all domains with the same physics, the exception being the possibility of running cumulus parameterization in the coarser domain(s) but excluding it from the finer domain(s).

In case of doubt about whether a given variable accepts values for nested grids, search for that variable in the file ***WRFV3/Registry/Registry*** and check to see if the string ***max_doms*** is present in that line.

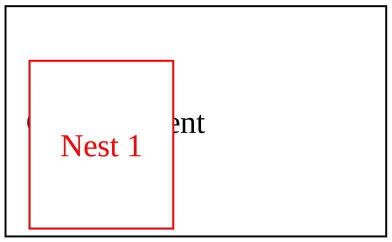
Before starting the WRF model, make sure to place the nest's time-invariant land-describing file in the proper directory.

For example, when using WPS, place the file ***geo_nmm_nest.l01.nc*** in the working directory where the model will be run. If more than one level of nest will be run, place additional files ***geo_nmm_nest.l02.nc***, ***geo_nmm_nest.l03.nc*** etc. in the working directory.

Examples:

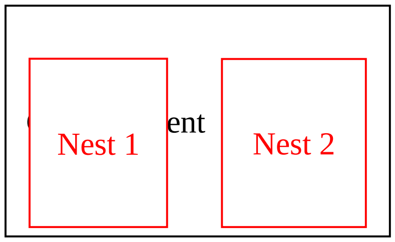
1. One nest and one level of nesting

WPS: requires file ***geo_nmm_nest.l01.nc***



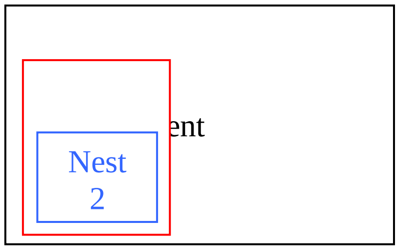
2. Two nests and one level of nesting

WPS: requires file ***geo_nmm_nest.l01.nc***



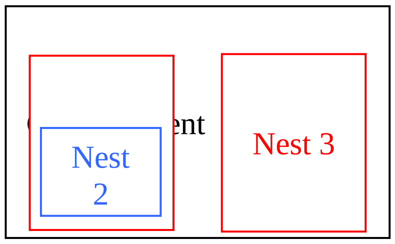
3. Two nests and two level of nesting

WPS: requires file ***geo_nmm_nest.l01.nc*** and ***geo_nmm_nest.l02.nc***

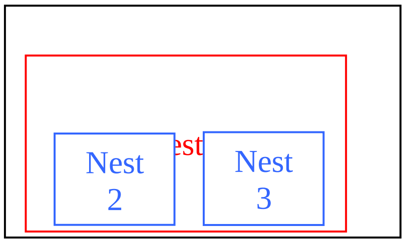


4. Three nests and two level of nesting

WPS: requires file ***geo_nmm_nest.l01.nc*** and ***geo_nmm_nest.l02.nc***



OR



After configuring the file ***namelist.input*** and placing the appropriate ***geo_nmm_nest**** file(s) in the proper directory(s), the WRF model can be run identically to the single domain runs described in Running wrf.exe.

Using Digital Filter Initialization

Digital filter initialization (DFI) is a new option in V3.2. It is a way to remove initial model imbalance as, for example, measured by the surface pressure tendency. This might be important when interested in the 0 – 6 hour simulation/forecast results. It runs a digital filter for a short model integration, backward and forward, and then starts the forecast. In the WRF implementation, this is all done in a single job. In the current release, DFI can only be used in a single domain run.

No special requirements are needed for data preparation. For a typical application, the following options are used in the ***namelist.input*** file:

dfi_opt = 3
dfi_nfilter = 7 (filter option: Dolph)
dfi_cutoff_seconds = 3600 (should not be longer than the filter window)

For time specification, it typically needs to integrate backward for 0.5 to 1 hour, and integrate forward for half of the time.

If option ***dfi_write_filtered_input*** is set to true, a filtered ***wrfinput*** file, ***wrfinput_initialized_d01***, will be produced.

If a different time step is used for DFI, one may use ***time_step_dfi*** to set it.

Using sst_update option

The WRF model physics does not predict sea-surface temperature, vegetation fraction, albedo and sea ice. For long simulations, the model provides an alternative to read in the time-varying data and update these fields. In order to use this option, one must have access to time-varying SST and sea ice fields. Twelve monthly values vegetation fraction and albedo are available from the ***geogrid*** program. Once these fields are processed via WPS, one may activate the following options in namelist record ***&time_control*** before running program ***real_nmm.exe*** and ***wrf.exe***:

sst_update = 1 in ***&physics***
io_form_auxinput4 = 2
auxinput4_inname = *"wrflowinp_d<domain>"* (created by ***real_nmm.exe***)
auxinput4_interval = 720,

Using IO Quilting

This option allows a few processors to be set alone to do output only. It can be useful and performance-friendly if the domain sizes are large, and/or the time taken to write a output time is getting significant when compared to the time taken to integrate the model in between the output times. There are two variables for setting the option:

nio_tasks_per_group: How many processors to use per IO group for IO quilting. Typically 1 or 2 processors should be sufficient for this purpose.

nio_groups: How many IO groups for IO. Default is 1.

Real Data Test Case: 2005 January 23/00 through 24/00

The steps described above can be tested on the real data set provided. The test data set is accessible from the WRF-NMM download page. Under "WRF Model Test Data", select the January data. This is a 55x91, 15-km domain centered over the eastern US.

- After running the ***real_nmm.exe*** program, the files ***wrfinput_d01*** and ***wrfbdy_d01***, should appear in the working directory. These files will be used by the WRF model.
- The ***wrf.exe*** program is executed next. This step should take a few minutes (only a 24 h forecast is requested in the ***namelist***),
- The output file ***wrfout_d01:2005-01-23_00:00:00*** should contain a 24 h forecast at 1 h intervals.

List of Fields in WRF-NMM Output

The following is edited output from the netCDF command '***ncdump***':

ncdump -h wrfout_d01_yyyy_mm_dd-hh:mm:ss

An example:

```
netcdf wrfout_d01_2008-01-11_00:00:00 {

dimensions:
        Time = UNLIMITED ; // (1 currently)
        DateStrLen = 19 ;
        west_east = 19 ;
        south_north = 39 ;
        bottom_top = 27 ;
        bottom_top_stag = 28 ;
        soil_layers_stag = 4 ;
variables:
        char Times(Time, DateStrLen) ;
        float TOYVAR(Time, bottom_top, south_north, west_east) ;
        float LU_INDEX(Time, south_north, west_east) ;
        float HBM2(Time, south_north, west_east) ;
        float HBM3(Time, south_north, west_east) ;
        float VBM2(Time, south_north, west_east) ;
        float VBM3(Time, south_north, west_east) ;
        float SM(Time, south_north, west_east) ;
        float SICE(Time, south_north, west_east) ;
        float PD(Time, south_north, west_east) ;
        float FIS(Time, south_north, west_east) ;
        float RES(Time, south_north, west_east) ;
        float T(Time, bottom_top, south_north, west_east) ;
        float Q(Time, bottom_top, south_north, west_east) ;
        float U(Time, bottom_top, south_north, west_east) ;
        float V(Time, bottom_top, south_north, west_east) ;
        float DX_NMM(Time, south_north, west_east) ;
        float ETA1(Time, bottom_top_stag) ;
        float ETA2(Time, bottom_top_stag) ;
        float PDTOP(Time) ;
        float PT(Time) ;
        float PBLH(Time, south_north, west_east) ;
        float MIXHT(Time, south_north, west_east) ;
        float USTAR(Time, south_north, west_east) ;
        float Z0(Time, south_north, west_east) ;
        float THS(Time, south_north, west_east) ;
        float QS(Time, south_north, west_east) ;
        float TWBS(Time, south_north, west_east) ;
        float QWBS(Time, south_north, west_east) ;
        float TAUX(Time, south_north, west_east) ;
        float TAUY(Time, south_north, west_east) ;
        float PREC(Time, south_north, west_east) ;
        float APREC(Time, south_north, west_east) ;
        float ACPREC(Time, south_north, west_east) ;
        float CUPREC(Time, south_north, west_east) ;
        float LSPA(Time, south_north, west_east) ;
        float SNO(Time, south_north, west_east) ;
        float SI(Time, south_north, west_east) ;
        float CLDEFI(Time, south_north, west_east) ;
        float TH10(Time, south_north, west_east) ;
        float Q10(Time, south_north, west_east) ;
        float PSHLTR(Time, south_north, west_east) ;
        float TSHLTR(Time, south_north, west_east) ;
        float QSHLTR(Time, south_north, west_east) ;
        float Q2(Time, bottom_top, south_north, west_east) ;
        float AKHS_OUT(Time, south_north, west_east) ;
        float AKMS_OUT(Time, south_north, west_east) ;
```

```
float ALBASE(Time, south_north, west_east) ;
float ALBEDO(Time, south_north, west_east) ;
float CNVBOT(Time, south_north, west_east) ;
float CNVTOP(Time, south_north, west_east) ;
float CZEN(Time, south_north, west_east) ;
float CZMEAN(Time, south_north, west_east) ;
float EPSR(Time, south_north, west_east) ;
float GLAT(Time, south_north, west_east) ;
float GLON(Time, south_north, west_east) ;
float MXSNAL(Time, south_north, west_east) ;
float RADOT(Time, south_north, west_east) ;
float SIGT4(Time, south_north, west_east) ;
float TGROUND(Time, south_north, west_east) ;
float CWM(Time, bottom_top, south_north, west_east) ;
float RRW(Time, bottom_top, south_north, west_east) ;
float F_ICE(Time, bottom_top, south_north, west_east) ;
float F_RAIN(Time, bottom_top, south_north, west_east) ;
float F_RIMEF(Time, bottom_top, south_north, west_east) ;
float CLDFRA(Time, bottom_top, south_north, west_east) ;
float SR(Time, south_north, west_east) ;
float CFRACH(Time, south_north, west_east) ;
float CFRACL(Time, south_north, west_east) ;
float CFRACM(Time, south_north, west_east) ;
int ISLOPE(Time, south_north, west_east) ;
float DZSOIL(Time, bottom_top) ;
float SLDPTH(Time, bottom_top) ;
float CMC(Time, south_north, west_east) ;
float GRNFLX(Time, south_north, west_east) ;
float PCTSNO(Time, south_north, west_east) ;
float SOILTB(Time, south_north, west_east) ;
float VEGFRC(Time, south_north, west_east) ;
float SH2O(Time, soil_layers_stag, south_north, west_east) ;
float SMC(Time, soil_layers_stag, south_north, west_east) ;
float STC(Time, soil_layers_stag, south_north, west_east) ;
float HSTDV(Time, south_north, west_east) ;
float HCNVX(Time, south_north, west_east) ;
float HASYW(Time, south_north, west_east) ;
float HASYS(Time, south_north, west_east) ;
float HASYSW(Time, south_north, west_east) ;
float HASYNW(Time, south_north, west_east) ;
float HLENW(Time, south_north, west_east) ;
float HLENS(Time, south_north, west_east) ;
float HLENSW(Time, south_north, west_east) ;
float HLENNW(Time, south_north, west_east) ;
float HANGL(Time, south_north, west_east) ;
float HANIS(Time, south_north, west_east) ;
float HSLOP(Time, south_north, west_east) ;
float HZMAX(Time, south_north, west_east) ;
float UGWDSFC(Time, south_north, west_east) ;
float VGWDSFC(Time, south_north, west_east) ;
float PINT(Time, bottom_top_stag, south_north, west_east) ;
float W(Time, bottom_top_stag, south_north, west_east) ;
float ACFRCV(Time, south_north, west_east) ;
float ACFRST(Time, south_north, west_east) ;
float SSROFF(Time, south_north, west_east) ;
float BGROFF(Time, south_north, west_east) ;
float RLWIN(Time, south_north, west_east) ;
float RLWTOA(Time, south_north, west_east) ;
float ALWIN(Time, south_north, west_east) ;
float ALWOUT(Time, south_north, west_east) ;
float ALWTOA(Time, south_north, west_east) ;
float RSWIN(Time, south_north, west_east) ;
float RSWINC(Time, south_north, west_east) ;
float RSWOUT(Time, south_north, west_east) ;
float ASWIN(Time, south_north, west_east) ;
float ASWOUT(Time, south_north, west_east) ;
float ASWTOA(Time, south_north, west_east) ;
float SFCSHX(Time, south_north, west_east) ;
float SFCLHX(Time, south_north, west_east) ;
float SUBSHX(Time, south_north, west_east) ;
float SNOPCX(Time, south_north, west_east) ;
float SFCUVX(Time, south_north, west_east) ;
float POTEVP(Time, south_north, west_east) ;
float POTFLX(Time, south_north, west_east) ;
float TLMIN(Time, south_north, west_east) ;
float TLMAX(Time, south_north, west_east) ;
float T02_MIN(Time, south_north, west_east) ;
float T02_MAX(Time, south_north, west_east) ;
float RH02_MIN(Time, south_north, west_east) ;
float RH02_MAX(Time, south_north, west_east) ;
int NCFRCV(Time, south_north, west_east) ;
int NCFRST(Time, south_north, west_east) ;
int NPHS0(Time) ;
int NPREC(Time) ;
int NCLOD(Time) ;
int NHEAT(Time) ;
int NRDLW(Time) ;
int NRDSW(Time) ;
int NSRFC(Time) ;
float AVRAIN(Time) ;
float AVCNVC(Time) ;
float ACUTIM(Time) ;
```

```
        float ARDLW(Time) ;
        float ARDSW(Time) ;
        float ASRFC(Time) ;
        float APHTIM(Time) ;
        float LANDMASK(Time, south_north, west_east) ;
        float QVAPOR(Time, bottom_top, south_north, west_east) ;
        float QCLOUD(Time, bottom_top, south_north, west_east) ;
        float QRAIN(Time, bottom_top, south_north, west_east) ;
        float QSNOW(Time, bottom_top, south_north, west_east) ;
        float SMOIS(Time, soil_layers_stag, south_north, west_east) ;
        float PSFC(Time, south_north, west_east) ;
        float TH2(Time, south_north, west_east) ;
        float U10(Time, south_north, west_east) ;
        float V10(Time, south_north, west_east) ;
        float LAI(Time, south_north, west_east) ;
        float SMSTAV(Time, south_north, west_east) ;
        float SMSTOT(Time, south_north, west_east) ;
        float SFROFF(Time, south_north, west_east) ;
        float UDROFF(Time, south_north, west_east) ;
        int IVGTYP(Time, south_north, west_east) ;
        int ISLTYP(Time, south_north, west_east) ;
        float VEGFRA(Time, south_north, west_east) ;
        float SFCEVP(Time, south_north, west_east) ;
        float GRDFLX(Time, south_north, west_east) ;
        float SFCEXC(Time, south_north, west_east) ;
        float ACSNOW(Time, south_north, west_east) ;
        float ACSNOM(Time, south_north, west_east) ;
        float SNOW(Time, south_north, west_east) ;
        float CANWAT(Time, south_north, west_east) ;
        float SST(Time, south_north, west_east) ;
        float WEASD(Time, south_north, west_east) ;
        float NOAHRES(Time, south_north, west_east) ;
        float THZ0(Time, south_north, west_east) ;
        float QZ0(Time, south_north, west_east) ;
        float UZ0(Time, south_north, west_east) ;
        float VZ0(Time, south_north, west_east) ;
        float QSFC(Time, south_north, west_east) ;
        float HTOP(Time, south_north, west_east) ;
        float HBOT(Time, south_north, west_east) ;
        float HTOPD(Time, south_north, west_east) ;
        float HBOTD(Time, south_north, west_east) ;
        float HTOPS(Time, south_north, west_east) ;
        float HBOTS(Time, south_north, west_east) ;
        float CUPPT(Time, south_north, west_east) ;
        float CPRATE(Time, south_north, west_east) ;
        float SNOWH(Time, south_north, west_east) ;
        float SMFR3D(Time, soil_layers_stag, south_north, west_east) ;
        int ITIMESTEP(Time) ;
        float XTIME(Time) ;

// global attributes:
                :TITLE = " OUTPUT FROM WRF V3.1          MODEL" ;
                :START_DATE = "2008-01-11_00:00:00" ;
                :SIMULATION_START_DATE = "2008-01-11_00:00:00" ;
                :WEST-EAST_GRID_DIMENSION = 20 ;
                :SOUTH-NORTH_GRID_DIMENSION = 40 ;
                :BOTTOM-TOP_GRID_DIMENSION = 28 ;
                :GRIDTYPE = "E" ;
                :DIFF_OPT = 1 ;
                :KM_OPT = 1 ;
                :DAMP_OPT = 1 ;
                :KHDIF = 0.f ;
                :KVDIF = 0.f ;
                :MP_PHYSICS = 5 ;
                :RA_LW_PHYSICS = 99 ;
                :RA_SW_PHYSICS = 99 ;
                :SF_SFCLAY_PHYSICS = 2 ;
                :SF_SURFACE_PHYSICS = 2 ;
                :BL_PBL_PHYSICS = 2 ;
                :CU_PHYSICS = 2 ;
                :SURFACE_INPUT_SOURCE = 1 ;
                :SST_UPDATE = 0 ;
                :SF_URBAN_PHYSICS = 0 ;
                :FEEDBACK = 0 ;
                :SMOOTH_OPTION = 2 ;
                :SWRAD_SCAT = 1.f ;
                :W_DAMPING = 0 ;
                :WEST-EAST_PATCH_START_UNSTAG = 1 ;
                :WEST-EAST_PATCH_END_UNSTAG = 19 ;
                :WEST-EAST_PATCH_START_STAG = 1 ;
                :WEST-EAST_PATCH_END_STAG = 20 ;
                :SOUTH-NORTH_PATCH_START_UNSTAG = 1 ;
                :SOUTH-NORTH_PATCH_END_UNSTAG = 39 ;
                :SOUTH-NORTH_PATCH_START_STAG = 1 ;
                :SOUTH-NORTH_PATCH_END_STAG = 40 ;
                :BOTTOM-TOP_PATCH_START_UNSTAG = 1 ;
                :BOTTOM-TOP_PATCH_END_UNSTAG = 27 ;
                :BOTTOM-TOP_PATCH_START_STAG = 1 ;
                :BOTTOM-TOP_PATCH_END_STAG = 28 ;
                :DX = 0.289143f ;
                :DY = 0.287764f ;
                :DT = 90.f ;
```

```
:CEN_LAT = 32.f ;
:CEN_LON = -83.f ;
:TRUELAT1 = 1.e+20f ;
:TRUELAT2 = 1.e+20f ;
:MOAD_CEN_LAT = 0.f ;
:STAND_LON = 1.e+20f ;
:GMT = 0.f ;
:JULYR = 2008 ;
:JULDAY = 11 ;
:MAP_PROJ = 203 ;
:MMINLU = "USGS" ;
:NUM_LAND_CAT = 24 ;
:ISWATER = 16 ;
:ISLAKE = -1 ;
:ISICE = 24 ;
:ISURBAN = 1 ;
:ISOILWATER = 14 ;
:I_PARENT_START = 1 ;
:J_PARENT_START = 1 ;}
```

Extended Reference List for WRF-NMM Dynamics and Physics

Arakawa, A., and W. H. Schubert, 1974: Interaction of a cumulus cloud ensemble with the large scale environment. Part I. *J. Atmos. Sci*., **31**, 674-701.

Chen, F., Z. Janjic and K. Mitchell, 1997: Impact of atmospheric surface-layer parameterization in the new land-surface scheme of the NCEP mesoscale Eta model. *Boundary-Layer Meteorology*, **48**

Chen, S.-H., and W.-Y. Sun, 2002: A one-dimensional time dependent cloud model. *J. Meteor. Soc. Japan*, **80**, 99–118.

Chen, F., and J. Dudhia, 2001: Coupling an advanced land-surface/ hydrology model with the Penn State/ NCAR MM5 modeling system. Part I: Model description and implementation. *Mon. Wea. Rev*., **129**, 569–585.

Chou M.-D., and M. J. Suarez, 1994: An efficient thermal infrared radiation parameterization for use in general circulation models. NASA Tech. Memo. 104606, 3, 85pp.

Dudhia, J., 1989: Numerical study of convection observed during the winter monsoon experiment using a mesoscale two-dimensional model, *J. Atmos. Sci*., **46**, 3077–3107.

Ek, M. B., K. E. Mitchell, Y. Lin, E. Rogers, P. Grunmann, V. Koren, G. Gayno, and J. D. Tarpley, 2003: Implementation of NOAH land surface model advances in the NCEP operational mesoscale Eta model. *J. Geophys. Res*., **108**, No. D22, 8851, do1:10.1029/2002JD003296.

Fels, S. B., and M. D. Schwarzkopf, 1975: The simplified exchange approximation: A new method for radiative transfer calculations. *J. Atmos. Sci*., **32**, 1475-1488.

Ferrier, B. S., Y. Lin, T. Black, E. Rogers, and G. DiMego, 2002: Implementation of a new grid-scale cloud and precipitation scheme in the NCEP Eta model. Preprints, 15th Conference on Numerical Weather Prediction, San Antonio, TX, *Amer. Meteor. Soc*., 280-283.

Gopalakrishnan, S. G., N. Surgi, R. Tuleya and Z. Janjic, 2006. NCEP's Two-way-Interactive-Moving-Nest NMM-WRF modeling system for Hurricane Forecasting. *27th Conf. On Hurric. Trop. Meteor.* Available online at http://ams.confex.com/ams/27Hurricanes/techprogram/paper_107899.htm.

Grell, G. A., 1993: Prognostic Evaluation of Assumptions Used by Cumulus Parameterizations. *Mon. Wea. Rev.*, **121**, 764-787.

Grell, G. A., and D. Devenyi, 2002: A generalized approach to parameterizing convection combining ensemble and data assimilation techniques. *Geophys. Res. Lett*., **29**(14), Article 1693.

Hong, S.-Y., J. Dudhia, and S.-H. Chen, 2004: A Revised Approach to Ice Microphysical Processes for the Bulk Parameterization of Clouds and Precipitation, *Mon. Wea. Rev*., **132**, 103–120.

Hong, S.-Y., H.-M. H. Juang, and Q. Zhao, 1998: Implementation of prognostic cloud scheme for a regional spectral model, *Mon. Wea. Rev*., **126**, 2621–2639.

Hong, S.-Y., and H.-L. Pan, 1996: Nonlocal boundary layer vertical diffusion in a medium-range forecast model, *Mon. Wea. Rev*., **124**, 2322–2339.

Janjic, Z. I., 1979: Forward-backward scheme modified to prevent two-grid-interval noise and its application in sigma coordinate models. *Contributions to Atmospheric Physics*, **52**, 69-84.

Janjic, Z. I., 1984: Non–linear advection schemes and energy cascade on semi–staggered grids. *Mon. Wea. Rev*, **112**, 1234–1245.

Janjic, Z. I., 1990: The step–mountain coordinates: physical package. *Mon. Wea. Rev*, **118**, 1429–1443.

Janjic, Z. I., 1994: The step–mountain eta coordinate model: further developments of the convection, viscous sublayer and turbulence closure schemes. *Mon. Wea. Rev*, **122**, 927–945.

Janjic, Z. I., 1996a: The Mellor-Yamada level 2.5 scheme in the NCEP Eta Model. 11th Conference on Numerical Weather Prediction, Norfolk, VA, 19-23 August 1996; *American Meteorological Society*, Boston, MA, 333-334.

Janjic, Z. I., 1996b: The Surface Layer in the NCEP Eta Model. 11th Conf. on NWP, Norfolk, VA, *American Meteorological Society*, 354–355.

Janjic, Z. I., 1997: Advection Scheme for Passive Substances in the NCEP Eta Model. Research Activities in Atmospheric and Oceanic Modeling, WMO, Geneva, CAS/JSC WGNE, 3.14.

Janjic, Z. I., 2000: Comments on "Development and Evaluation of a Convection Scheme for Use in Climate Models. *J. Atmos. Sci.*, **57**, p. 3686

Janjic, Z. I., 2001: Nonsingular Implementation of the Mellor-Yamada Level 2.5 Scheme in the NCEP Meso model. NCEP Office Note No. 437, 61 pp.

Janjic, Z. I., 2002a: A Nonhydrostatic Model Based on a New Approach. EGS XVIII, Nice France, 21-26 April 2002.

Janjic, Z. I., 2002b: Nonsingular Implementation of the Mellor–Yamada Level 2.5 Scheme in the NCEP Meso model, NCEP Office Note, No. 437, 61 pp.

Janjic, Z. I., 2003a: A Nonhydrostatic Model Based on a New Approach. *Meteorology and Atmospheric Physics*, **82**, 271-285. (Online: http://dx.doi.org/10.1007/s00703-001-0587-6).

Janjic, Z. I., 2003b: The NCEP WRF Core and Further Development of Its Physical Package. 5th International SRNWP Workshop on Non-Hydrostatic Modeling, Bad Orb, Germany, 27-29 October.

Janjic, Z. I., 2004: The NCEP WRF Core. 12.7, Extended Abstract, 20th Conference on Weather Analysis and Forecasting/16th Conference on Numerical Weather Prediction, Seattle, WA, American Meteorological Society.

Janjic, Z. I., J. P. Gerrity, Jr. and S. Nickovic, 2001: An Alternative Approach to Nonhydrostatic Modeling. *Mon. Wea. Rev.*, **129**, 1164-1178.

Janjic, Z. I., T. L. Black, E. Rogers, H. Chuang and G. DiMego, 2003: The NCEP Nonhydrostatic Meso Model (NMM) and First Experiences with Its Applications. EGS/EGU/AGU Joint Assembly, Nice, France, 6-11 April.

Janjic, Z. I, T. L. Black, E. Rogers, H. Chuang and G. DiMego, 2003: The NCEP Nonhydrostatic Mesoscale Forecasting Model. 12.1, Extended Abstract, 10th Conference on Mesoscale Processes, Portland, OR, American Meteorological Society. (Available Online).

Kain J. S. and J. M. Fritsch, 1990: A One-Dimensional Entraining/Detraining Plume Model and Its Application in Convective Parameterization. *J. Atmos. Sci*., **47**, No. 23, pp. 2784–2802.

Kain, J. S., and J. M. Fritsch, 1993: Convective parameterization for mesoscale models: The Kain-Fritcsh scheme, the representation of cumulus convection in numerical models, K. A. Emanuel and D.J. Raymond, Eds., *Amer. Meteor. Soc*., 246 pp.

Kain J. S., 2004: The Kain–Fritsch Convective Parameterization: An Update. *Journal of Applied Meteorology*, **43**, No. 1, pp. 170–181.

Kessler, E., 1969: On the distribution and continuity of water substance in atmospheric circulation, Meteor. Monogr., 32, Amer. Meteor. Soc., 84 pp.

Lacis, A. A., and J. E. Hansen, 1974: A parameterization for the absorption of solar radiation in the earth’s atmosphere. J. Atmos. Sci., 31, 118–133.

Lin, Y.-L., R. D. Farley, and H. D. Orville, 1983: Bulk parameterization of the snow field in a cloud model. J. Climate Appl. Meteor., 22, 1065–1092.

Miyakoda, K., and J. Sirutis, 1986: Manual of the E-physics. [Available from Geophysical Fluid Dynamics Laboratory, Princeton University, P.O. Box 308, Princeton, NJ 08542]

Mlawer, E. J., S. J. Taubman, P. D. Brown, M. J. Iacono, and S. A. Clough, 1997: Radiative transfer for inhomogeneous atmosphere: RRTM, a validated correlated-k model for the longwave. J. Geophys. Res., 102 (D14), 16663–16682.

Pan, H.-L. and W.-S. Wu, 1995: Implementing a Mass Flux Convection Parameterization Package for the NMC Medium-Range Forecast Model. NMC Office Note, No. 409, 40pp. [Available from NCEP/EMC, W/NP2 Room 207, WWB, 5200 Auth Road, Washington, DC 20746-4304]

Pan, H-L. and L. Mahrt, 1987: Interaction between soil hydrology and boundary layer developments. *Boundary Layer Meteor*., **38**, 185-202.

Rutledge, S. A., and P. V. Hobbs, 1984: The mesoscale and microscale structure and organization of clouds and precipitation in midlatitude cyclones. XII: A diagnostic modeling study of precipitation development in narrow cloud-frontal rainbands. *J. Atmos. Sci*., **20**, 2949–2972.

Sadourny. R., 1975: The Dynamics of Finite-Difference Models of the Shallow-Water Equations. *J. Atmos. Sci.*, **32**, No. 4, pp. 680–689.

Schwarzkopf, M. D., and S. B. Fels, 1985: Improvements to the algorithm for computing CO2 transmissivities and cooling rates. *J. Geophys. Res*., **90**, 541-550.

Schwarzkopf, M. D., and S. B. Fels, 1991: The simplified exchange method revisited: An accurate, rapid method for computations of infrared cooling rates and fluxes. *J. Geophys. Res*., **96**, 9075-9096.

Skamarock, W. C., J. B. Klemp, J. Dudhia, D. O. Gill, D. M. Barker, W. Wang and J. G. Powers, 2005: A Description of the Advanced Research WRF Version 2, NCAR Tech Note, NCAR/TN–468+STR, 88 pp. [Available from UCAR Communications, P.O. Box 3000, Boulder, CO, 80307]. Available on-line at: http://box.mmm.ucar.edu/wrf/users/docs/arw_v2.pdf)

Smirnova, T. G., J. M. Brown, and S. G. Benjamin, 1997: Performance of different soil model configurations in simulating ground surface temperature and surface fluxes. *Mon. Wea. Rev*., **125**, 1870–1884.

Smirnova, T. G., J. M. Brown, S. G. Benjamin, and D. Kim, 2000: Parameterization of cold season processes in the MAPS land-surface scheme. **J. Geophys. Res**., **105** (D3), 4077-4086.

Tao, W.-K., J. Simpson, and M. McCumber 1989: An ice-water saturation adjustment, *Mon. Wea. Rev*., **117**, 231–235.

Troen, I. and L. Mahrt, 1986: A simple model of the atmospheric boundary layer: Sensitivity to surface evaporation. *Boundary Layer Meteor*., **37**, 129-148.

Thompson, G., R. M. Rasmussen, and K. Manning, 2004: Explicit forecasts of winter precipitation using an improved bulk microphysics scheme. Part I: Description and sensitivity analysis. *Mon. Wea. Rev*., **132**, 519–542.

Wicker, L. J., and R. B. Wilhelmson, 1995: Simulation and analysis of tornado development and decay within a three-dimensional supercell thunderstorm. *J. Atmos. Sci*., **52**, 2675–2703.

User's Guide for the NMM Core of the Weather Research and Forecast (WRF) Modeling System Version 3

Chapter 6: WRF Software

Table of Contents

WRF Build Mechanism

The WRF build mechanism provides a uniform apparatus for configuring and compiling the WRF model and pre-processors over a range of platforms with a variety of options. This section describes the components and functioning of the build mechanism. For information on building the WRF code, see Chapter 2.

Required software

The WRF build relies on Perl version 5 or later and a number of UNIX utilities: csh and Bourne shell, make, M4, sed, awk, and the uname command. A C compiler is needed to compile programs and libraries in the tools and external directories. The WRF code itself is mostly standard Fortran (and uses a few 2003 capabilities). For distributed-memory processing, MPI and related tools and libraries should be installed.

Build Mechanism Components

Directory structure: The directory structure of WRF consists of the top-level directory plus directories containing files related to the WRF software framework (***frame***), the WRF model (***dyn_em***, ***dyn_nmm***, ***phys***, ***share***), configuration files ***(arch, Registry***), helper and utility programs (***tools***), and packages that are distributed with the WRF code (***external***).

Scripts: The top-level directory contains three user-executable scripts: ***configure***, ***compile***, and ***clean***. The configure script relies on a Perl script in ***arch/Config_new.pl***.

Programs: A significant number of WRF lines of code are automatically generated at compile time. The program that does this is ***tools/registry*** and it is distributed as part of the source code with the WRF model.

Makefiles: The main ***makefile*** (input to the UNIX make utility) is in the top-level directory. There are also makefiles in most of the subdirectories that come with WRF. Make is called recursively over the directory structure. Make is not directly invoked by the user to compile WRF; the ***compile*** script is provided for this purpose. The WRF build has been structured to allow "parallel make". Before the compile command, the user sets an environment variable, J, to the number of processors to use. For example, to use two processors (in csh syntax):

```
setenv J "-j 2"
```

On some machines, this parallel make causes troubles (a typical symptom is a missing mpif.h file in the frame directory). The user can force that only a single processor be used with the command:

```
setenv J "-j 1"
```

Configuration files: The ***configure.wrf*** contains compiler, linker, and other build settings, as well as rules and macro definitions used by the make utility. The ***Configure.wrf*** file is included by the Makefiles in most of the WRF source distribution (Makefiles in ***tools*** and ***external*** directories do not include ***configure.wrf***). The ***configure.wrf*** file in the top-level directory is generated each time the configure script is invoked. It is also deleted by ***clean -a.*** Thus, ***configure.wrf*** is the place to make temporary changes, such as optimization levels and compiling with debugging, but permanent changes should be made in the file ***arch/configure_new.defaults***. The ***configure.wrf*** file is composed of three files: **arch/preamble_new** ***arch/postamble_new*** and ***arch_configure_new.defaults***.

The ***arch/configure_new.defaults*** file contains lists of compiler options for all the supported platforms and configurations. Changes made to this file will be permanent. This file is used by the configure script to generate a temporary ***configure.wrf*** file in the top-level directory. The ***arch*** directory also contains the files ***preamble_new*** and ***postamble_new***, which constitute the generic parts (non-architecture specific) of the ***configure.wrf*** file that is generated by the configure script.

The ***Registry*** directory contains files that control many compile-time aspects of the WRF code. The files are named ***Registry.****core*, where *core* is either ***EM*** (for builds using the Eulerian Mass (ARW) core), ***NMM*** (for builds using the NMM core), or ***NMM_NEST*** (for builds using the NMM core with nesting capability). The configure script copies one of these to ***Registry/Registry***, which is the file that ***tools/registry*** will use as input. The choice of coredepends on settings to the **configure** script. Changes to ***Registry/Registry*** will be lost; permanent changes should be made to ***Registry.****core*. For the WRF ARW model, the file is typically **Registry.EM**. One of the keywords that the registry program understands is **include**. Some of the ARW Registry files make use of the

REGISTRY.EM_COMMON file. This reduces the amount of replicated registry information. Currently, the ***Registry.EM*** and ***Registry.EM_CHEM*** utilize this common registry file. When searching for variables previously located in a ***Registry.EM**** file, now look in ***Registry.EM_COMMON***.

Environment variables: Certain aspects of the configuration and build are controlled by environment variables: the non-standard locations of NetCDF libraries or the Perl command, which dynamic core to compile, machine-specific features, and optional build libraries (such as Grib Edition 2, HDF, and parallel netCDF).

In addition to WRF-related environment settings, there may also be settings specific to particular compilers or libraries. For example, local installations may require setting a variable like ***MPICH_F90*** to make sure the correct instance of the Fortran 90 compiler is used by the ***mpif90*** command.

How the WRF build works

There are two steps in building WRF: configuration and compilation.

Configuration: The ***configure*** script configures the model for compilation on your system. The configuration first attempts to locate needed libraries such as NetCDF or HDF and tools such as Perl. It will check for these in normal places, or will use settings from the user's shell environment. The configuration file then calls the UNIX ***uname*** command to discover what platform you are compiling on. It then calls the Perl script ***arch/Config_new.pl***, which traverses the list of known machine configurations and displays a list of available options to the user. The selected set of options is then used to create the ***configure.wrf*** file in the top-level directory. This file may be edited but changes are temporary since the file will be deleted by ***clean –a*** or overwritten by the next invocation of the ***configure*** script. The only typical option that is included on the ***configure*** command is "***-d***" (for debug). The code builds relatively quickly and has the debugging switches enabled, but the model will run very slowly since all of the optimization has been deactivated. This script takes only a few seconds to run.

Compilation: The ***compile*** script is used to compile the WRF code after it has been configured using the ***configure*** script. This ***csh*** script performs a number of checks, constructs an argument list, copies to ***Registry/Registry*** the correct ***Registry.****core* file for the core being compiled, and invokes the UNIX make command in the top-level directory. The core to be compiled is determined from the user's environment. For example, to set it for WRF-NMM core the "***setenv WRF_NMM_CORE 1"*** command should be issued. To run the WRF-NMM with a nest, the environment variable ***WRF_NMM_NEST*** should also be set to **1**. If no core is specified in the environment (by setting **WRF_*core*_CORE** to **1**) the default core is selected (currently the Eulerian Mass core for ARW). The ***makefile*** in the top-level directory directs the rest of the build, accomplished as a set of recursive invocations of make in the subdirectories of WRF. Most of these makefiles include the ***configure.wrf*** file from the top-level directory. The order of a complete build is as follows:

1. Make in ***external*** directory

    a. make in ***external/io_{grib1, grib_share, int, netcdf}*** for Grib Edition 1, binary, and NetCDF implementations of I/O API

    b. make in ***RSL_LITE*** directory to build communications layer (DM_PARALLEL only)

    c. make in ***external/esmf_time_f90*** directory to build ESMF time manager library

    d. make in ***external/fftpack*** directory to build FFT library for the global filters

    e. make in other external directories as specified by "external:" target in the ***configure.wrf*** file

2. Make in the ***tools*** directory to build the program that reads the ***Registry/Registry*** file and auto-generates files in the ***inc*** directory

3. Make in the ***frame*** directory to build the WRF framework specific modules

4. Make in the ***share*** directory to build the non-core-specific mediation layer routines, including WRF I/O modules that call the I/O API

5. Make in the ***phys*** directory to build the WRF model layer routines for physics (non core-specific)

6. Make in the ***dyn_*"*core*"** directory for core-specific mediation-layer and model-layer subroutines

7. Make in the ***main*** directory to build the main programs for WRF and symbolically link to create executable files (location depending on the build case that was selected as the argument to the compile script (e.g. compile ***em_real*** or compile ***nmm_real***)

Source files (.F and, in some of the external directories, .F90) are preprocessed to produce .f90 files, which are input to the compiler. As part of the preprocessing, Registry-generated files from the ***inc*** directory may be included. Compiling the .f90 files results in the creation of object (***.o***) files that are added to the library ***main/libwrflib.a***. Most of the ***external*** directories generate their own library file. The linking step produces the ***wrf.exe*** and ***real_nmm.exe*** executables.

The .o files and .f90 files from a compile are retained until the next invocation of the ***clean*** script. The .f90 files provide the true reference for tracking down run time errors that refer to line numbers or for sessions using interactive debugging tools such as dbx or gdb.

Registry

Tools for automatic generation of application code from user-specified tables provide significant software productivity benefits in development and maintenance of large applications such as WRF. Just for the WRF model, hundreds of thousands of lines of WRF code are automatically generated from a user-edited table, called the Registry. The Registry provides a high-level single-point-of-control over the fundamental structure of the model data, and thus provides considerable utility for developers and maintainers. It contains lists describing state data fields and their attributes: dimensionality, binding to particular solvers, association with WRF I/O streams, communication operations, and run time configuration options (namelist elements and their bindings to model control structures). Adding or modifying a state variable to WRF involves modifying a single line of a single file; this single change is then automatically propagated to scores of locations in the source code the next time the code is compiled.

The WRF Registry has two components: the Registry file (which the user may edit) and the Registry program.

The Registry file is located in the ***Registry*** directory and contains the entries that direct the auto-generation of WRF code by the Registry program. There is more than one Registry in this directory, with filenames such as ***Registry.EM*** (for builds using the Eulerian Mass/ARW core) and ***Registry.NMM(_NEST)*** (for builds using the NMM core). The WRF Build Mechanism copies one of these to the file ***Registry/Registry*** and this file is used to direct the Registry program. The syntax and semantics for entries in the Registry are described in detail in "WRF Tiger Team Documentation: The Registry" at: *http://www.mmm.ucar.edu/wrf/WG2/Tigers/Registry/***.**
The Registry program is distributed as part of WRF in the ***tools*** directory. It is built automatically (if necessary) when WRF is compiled. The executable file is ***tools/registry***. This program reads the contents of the Registry file, ***Registry/Registry***, and generates files in the ***inc*** directory. These include files are inserted (with ***cpp #include*** commands) into WRF Fortran source files prior to compilation. Additional information on these is provided as an appendix to "WRF Tiger Team Documentation: The Registry". The Registry program itself is written in C. The source files and ***makefile*** are in the ***tools*** directory.

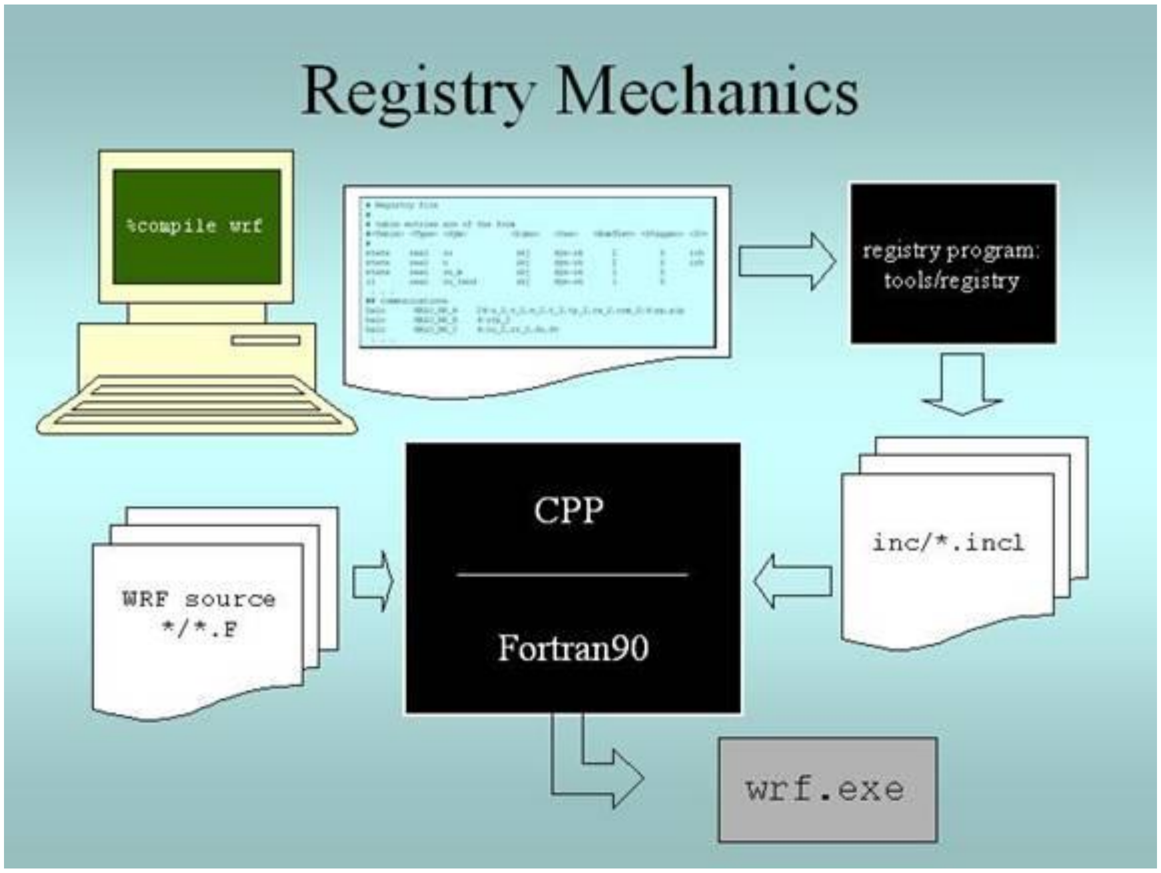


Figure 6.1: When the user compiles WRF, the Registry Program reads ***Registry/Registry***, producing auto-generated sections of code that are stored in files in the ***inc*** directory. These are included into WRF using the CPP preprocessor and the Fortran compiler.

In addition to the WRF model itself, the ***Registry/Registry*** file is used to build the accompanying preprocessors such as ***real_nmm.exe*** (for real data simulations).

Every variable that is an input or an output field is described in the Registry. Additionally, every variable that is required for parallel communication, specifically associated with a physics package, or needs to provide a tendency to multiple physics or dynamics routines is contained in the Registry. For each of these variables, the index ordering, horizontal and vertical staggering, feedback and nesting interpolation requirements, and the associated IO are defined. For most users, to add a variable into the model requires, regardless of dimensionality, only the addition of a single line to the Registry (make sure that changes are made to the correct **Registry.*core*** file, as changes to the ***Registry*** file itself are overwritten). Since the Registry modifies code for compile-time options, any change to the Registry REQUIRES that the code be returned to the original unbuilt status with the ***clean –a*** command.

The other very typical activity for users is to define new run-time options, which are handled via a Fortran namelist file ***namelist.input*** in WRF. As with the model state arrays and variables, the entire model configuration is described in the Registry. As with the model arrays, adding a new namelist entry is as easy as adding a new line in the Registry.

While the model state and configuration are by far the most commonly used features in the Registry, the data dictionary has several other powerful uses. The Registry file provides input to generate all of the communications for the distributed memory processing (halo interchanges between patches, support for periodic lateral boundaries, and array transposes for FFTs to be run in the X, Y, or Z directions). The Registry associates various fields with particular physics packages, so that the memory footprint reflects the actual selection of the options, not a maximal value.

Together, these capabilities allow a large portion of the WRF code to be automatically generated. Any code that is automatically generated relieves the developer of the effort of coding and debugging that portion of software. Usually, the pieces of code that are suitable candidates for automation are precisely those that are fraught with "hard to detect" errors, such as communications, indexing, and IO which must be replicated for hundreds of variables.

Registry Syntax

Each entry in the Registry is for a specific variable, whether it is for a new dimension in the model, a new field, a new namelist value, or even a new communication. For readability, a single entry may be spread across several lines with the traditional "\" at the end of a line to denote that the entry is continuing. When adding to the Registry, most users find that it is helpful to copy an entry that is similar to the anticipated new entry, and then modify that Registry entry. The Registry is not sensitive to spatial formatting. White space separates identifiers in each entry.

Note: Do not simply remove an identifier and leave a supposed token blank, use the appropriate default value (currently a dash character "-").

Registry Entries

The WRF Registry has the following types of entries (not case dependent):

Dimspec – Describes dimensions that are used to define arrays in the model
State – Describes state variables and arrays in the domain structure
I1 – Describes local variables and arrays in solve
Typedef – Describes derived types that are subtypes of the domain structure
Rconfig – Describes a configuration (e.g. namelist) variable or array
Package – Describes attributes of a package (e.g. physics)
Halo – Describes halo update interprocessor communications
Period – Describes communications for periodic boundary updates
Xpose – Describes communications for parallel matrix transposes
include – Similar to a CPP #include file

These ***keywords*** appear as the first word in a line of the file ***Registry*** to define which type of information is being provided. Following are examples of the more likely Registry types that users will need to understand

Registry Dimspec

The first set of entries in the Registry is the specifications of the dimensions for the fields to be defined. To keep the WRF system consistent between the dynamical cores and Chemistry, a unified ***registry.dimspec*** file is used (located in the ***Registry*** directory). This single file is included into each Registry file, with the keyword ***include***. In the example below, three dimensions are defined: i, j, and k. If you do an "***ncdump -h***" on a WRF file, you will notice that the three primary dimensions are named as "***west_east***", "***south_north***", and "***bottom_top***". That information is contained in this example (the example is broken across two lines, but interleaved).

#<Table> <Dim> <Order> <How defined>
dimspec   i   1   standard_domain
dimspec   j   3   standard_domain
dimspec   k   2   standard_domain

<Coord-axis> <Dimname in Datasets>
x   west_east
y   south_north
z   bottom_top

The WRF system has a notion of horizontal and vertical staggering, so the dimension names are extended with a "***_stag***" suffix for the staggered sizes. The list of names in the <Dim> column may either be a single unique character (for release 3.0.1.1 and prior), or the <Dim> column may be a string with no embedded spaces (such as ***my_dim***). When this dimension is used later to dimension a **`state`** or **`i1`** variable, it must be surrounded by curly braces (such as **`{`*****my_dim*****`}`**). This <Dim> variable is not case specific, so for example "**i**" is the same as an entry for "**I**".

Registry State and I1

A ***state*** variable in WRF is a field that is eligible for IO and communications, and exists for the duration of the model forecast. The ***I1*** variables (intermediate level one) are typically thought of as tendency terms, computed during a single model time-step, and then discarded prior to the next time-step. The space allocation and de-allocation for these ***I1*** variables is automatic (on the stack for the model solver). In this example, for readability, the column titles and the entries are broken into multiple interleaved lines, with the user entries in a ***bold font***.

Some fields have simple entries in the ***Registry*** file. The following is a **state** variable that is a Fortran type ***real***. The name of the field inside the WRF model is ***u_gc***. It is a three dimension array (***igj***). It has a single time level, and is staggered in the ***X*** and ***Z*** directions. This field is input only to the real program (***i1***). On output, the netCDF name is ***UU***, with the accompanying description and units provided.

#<Table> <Type> <Sym> <Dims>
state real u_gc ijg

<Use> <NumTLev> <Stagger> <IO>
dyn_nmm 1 Z i1

<DNAME> <DESCRIP> <UNITS>
"UU" "x-wind component" "m s-1"

If a variable is not staggered, a "-" (dash) is inserted instead of leaving a blank space. The same dash character is required to fill in a location when a field has no IO specification. The variable description and units columns are used for post-processing purposes only; this information is not directly utilized by the model.

When adding new variables to the ***Registry*** file, users are warned to make sure that variable names are unique. The <Sym> refers to the variable name inside the WRF model, and it is not case sensitive. The <DNAME> is quoted, and appears exactly as typed. Do not use imbedded spaces. While it is not required that the <Sym> and <DNAME> use the same character string, it is highly recommended. The `<DESCRIP>` and the `<UNITS>` are optional, however they are a good way to supply self-documentation to the Registry. Since the `<DESCRIP>` value is used in the automatic code generation, restrict the variable description to 40 characters or less.

From this example, we can add new requirements for a variable. Suppose that the variable to be added is not specific to any dynamical core. We would change the <Use> column entry of ***dyn_nmm*** to ***misc*** (for miscellaneous). The ***misc*** entry is typical of fields used in physics packages. Only dynamics variables have more than a single time level, and this introductory material is not suitable for describing the impact of multiple time periods on the registry program. For the <Stagger> option, users may select any subset from ***{X***, ***Y***, ***Z}*** or ***{-}***, where the dash character "**-**" signifies "no staggering".

The <IO> column handles file input and output, and it handles the nesting specification for the field. The file input and output uses three letters: ***i*** (input), ***r*** (restart), and ***h*** (history). If the field is to be in the input file to the model, the restart file from the model, and the history file from the model, the entry would be ***irh***. To allow more flexibility, the input and history fields are associated with streams. The user may specify a digit after the ***i*** or the ***h*** token, stating that this variable is associated with a specified stream (***1*** *through* ***9***) instead of the default (***0***). A single variable may be associated with multiple streams. Once any digit is used with the ***i*** or ***h*** tokens, the default ***0*** stream must be explicitly stated. For example, <IO> entry ***i*** and <IO> entry ***i0*** are the same. However, <IO> entry ***h1*** outputs the field to the first auxiliary stream, but does not output the field to the default history stream. The <IO> entry ***h01*** outputs the field to both the default history stream and the first auxiliary stream.

Nesting support for the model is also handled by the <IO> column. The letters that are parsed for nesting are: ***u*** (*up* as in feedback up), ***d*** (*down*, as in downscale from coarse to fine grid), ***f*** (*forcing*, how the lateral boundaries are processed), and **s** (*smoothing*). As with other entries, the best coarse of action is to find a field nearly identical to the one that you are inserting into the ***Registry*** file, and copy that line. The user needs to make the determination whether or not it is reasonable to smooth the field in the area of the coarse grid, where the fine-grid feeds back to the coarse grid. Variables that are defined over land and water, non-masked, are usually smoothed. The lateral boundary forcing is primarily for dynamics variables, and is ignored in this overview. For non-masked fields (such as wind, temperature, pressure), the downward interpolation (controlled by ***d***) and the feedback (controlled by ***u***) use default routines. Variables that are land fields (such as soil temperature ***TSLB***) or water fields (such as sea ice ***XICE***) have special interpolators, as shown in the examples below (again, interleaved for readability):

```
#<Table> <Type> <Sym> <Dims>
state    real   TSLB   ilj
state    real   XICE   ij

<Use>  <NumTLev> <Stagger>
misc      1         Z
misc      1         -

<IO>
i02rhd=(interp_mask_land_field:lu_index)u=(copy_fcnm)
i0124rhd=(interp_mask_water_field:lu_index)u=(copy_fcnm)

<DNAME>  <DESCRIP>            <UNITS>
"TSLB"   "SOIL TEMPERATURE"   "K"
"SEAICE" "SEA ICE FLAG"       ""
```

Note that the ***d*** and ***u*** entries in the <IO> section are followed by an "=" then a parenthesis enclosed subroutine, and a colon separated list of additional variables to pass to the routine. It is recommended that users follow the existing pattern: ***du*** for non-masked variables, and the above syntax for the existing interpolators for masked variables.

Registry Rconfig

The ***Registry*** file is the location where the run-time options to configure the model are defined. Every variable in the WRF namelist is described by an entry in the ***Registry*** file. The default value for each of the namelist variables is as assigned in the Registry. The standard form for the entry for two namelist variables is given (broken across lines and interleaved):

```
#<Table>  <Type>    <Sym>
rconfig  integer    run_days
rconfig  integer    start_year

<How set>          <Nentries>   <Default>
namelist,time_control      1          0
namelist,time_control  max_domains    1993
```

The keyword for this type of entry in the ***Registry*** file is ***rconfig*** (run-time configuration). As with the other model fields (such as ***state*** and ***i1***), the <Type> column assigns the Fortran kind of the variable: ***integer***, ***real***, or ***logical***. The name of the variable in the WRF namelist is given in the <Sym> column, and is part of the derived data type structure as are the ***state*** fields. There are a number of Fortran namelist records in the file ***namelist.input***. Each namelist variable is a member of one of the specific namelist records. The previous example shows that ***run_days*** and ***start_year*** are both members of the ***time_control*** record. The <Nentries> column refers to the dimensionality of the namelist variable (number of entries). For most variables, the <Nentries> column has two eligible values, either ***1*** (signifying that the scalar entry is valid for all domains) or ***max_domains*** (signifying that the variable is an array, with a value specified for each domain). Finally, a default value is given. This permits a namelist entry to be removed from the ***namelist.input*** file if the default value is acceptable.

The registry program constructs two subroutines for each namelist variable, one to retrieve the value of the namelist variable, and the other to set the value. For an integer variable named ***my_nml_var***, the following code snippet provides an example of the easy access to the namelist variables.

```
INTEGER :: my_nml_var, dom_id
CALL nl_get_my_nml_var ( dom_id , my_nml_var )
```

The subroutine takes two arguments. The first is the input integer domain identifier (for example, ***1*** for the most coarse grid, **2** for the second domain), and the second argument is the returned value of the namelist variable. The associated subroutine to set the namelist variable, with the same argument list, is ***nl_set_my_nml_var***. For namelist variables that are scalars, the grid identifier should be set to ***1***.

The ***rconfig*** line may also be used to define variables that are convenient to pass around in the model, usually part of a derived configuration (such as the number of microphysics species associated with a physics package). In this case, the <How set> column entry is ***derived***. This variable does not appear in the namelist, but is accessible with the same generated ***nl_set*** and ***nl_get*** subroutines.

Registry Halo, Period, and Xpose

The distributed memory, inter-processor communications are fully described in the ***Registry*** file. An entry in the Registry constructs a code segment which is included (with ***cpp***) in the source code. Following is an example of a ***halo*** communication (split across two lines and interleaved for readability).

#<Table> <CommName> <Core>
halo HALO_NMM_K dyn_nmm

<Stencil:varlist>
8:q2;24:t,u,v,q,w,z

The keyword is ***halo***. The communication is named in the <CommName> column, so that it can be referenced in the source code. The entry in the <CommName> column is case sensitive (the convention is to start the name with ***HALO_NMM***). The selected dynamical core is defined in the <Core> column. There is no ambiguity, as every communication in each ***Registry*** file will have the exact same <Core> column option. The last set of information is the <Stencil:varlist>. The portion in front of the "**:**" is the stencil size, and the comma-separated list afterwards defines the variables that are communicated with that stencil size. Different stencil sizes are available, and are "**;**" separated in the same <Stencil:varlist> column. The stencil sizes ***8***, ***24***, ***48*** all refer to a square with an odd number of grid cells on a side, with the center grid cell removed (***8*** = 3x3-1, ***24*** = 5x5-1, ***48*** = 7x7-1). The special small stencil ***4*** is just a simple north, south, east, west communication pattern.

The convention in the WRF model is to provide a communication immediately after a variable has been updated. The communications are restricted to the mediation layer (an intermediate layer of the software that is placed between the framework level and the model level. The model level is where developers spend most of their time. The majority of users will insert communications into the ***dyn_nmm/solve_m,m.F*** subroutine. The ***HALO_NMM_K*** communication defined in the ***Registry*** file, in the example above, is activated by inserting a small section of code that includes an automatically generated code segment into the solve routine, via standard ***cpp*** directives.

#ifdef DM_PARALLEL
#   include "HALO_NMM_K.inc"
#endif

The parallel communications are only required when the WRF code is built for distributed-memory parallel processing, which accounts for the surrounding ***#ifdef***.

The ***period*** communications are required when periodic lateral boundary conditions are selected (ARW only). The Registry syntax is very similar for ***period*** and ***halo*** communications, but the stencil size refers to how many grid cells to communicate, in a direction that is normal to the periodic boundary.

#<Table> <CommName> <Core> <Stencil:varlist>

period   PERIOD_EM_COUPLE_A   dyn_em   2:mub,mu_1,mu_2

The **xpose** (a data transpose) entry is used when decomposed data is to be re-decomposed (ARW only). This is required when doing FFTs in the x-direction for polar filtering, for example. No stencil size is necessary.

#<Table>   <CommName>   <Core>   <Varlist>
xpose   XPOSE_POLAR_FILTER_T dyn_em   t_2,t_xxx,dum_yyy

It is anticipated that many users will add to the the parallel communications portion of the Registry file (***halo*** and ***period***. It is unlikely that users will add ***xpose*** fields.

Registry Package

The ***package*** option in the ***Registry*** file associates fields with particular physics packages. Presently, it is mandatory that all 4-D arrays be assigned. Any 4-D array that is not associated with the selected physics option at run-time is either allocated, used for IO, nor communicated. All other 2-D and 3-D arrays are eligible for use with a ***package*** assignment, but that is not required.

The purpose of the ***package*** option is to allow users to reduce the memory used by the model, since only “necessary” fields are processed. An example for a microphysics scheme is given below.

#<Table> <PackageName> <NMLAssociated>   <Variables>
package   kesslerscheme   mp_physics==1   - moist:qv,qc,qr

The entry keyword is ***package***, and is associated with the single physics option listed under <NMLAssociated>. The package is referenced in the code in Fortran ***IF*** and ***CASE*** statements by the name given in the <PackageName> column, instead of the more confusing and typical ***IF (mp_physics == 1)*** approach. The <Variables> column must start with a dash character and then a blank “**- “** (for historical reasons of backward compatibility). The syntax of the <Variables> column then is a 4-D array name, followed by a colon, and then a comma-separated list of the 3-D arrays constituting that 4-D amalgamation. In the example above, the 4-D array is ***moist***, and the selected 3-D arrays are ***qv***, ***qc***, and ***qr***. If more than one 4-D array is required, a “**;**” separates those sections from each other in the <Variables> column.

In addition to handling 4-D arrays and their underlying component 3-D arrays, the ***package*** entry is able to associate generic ***state*** variables, as shown in the example following. If the namelist variable ***use_wps_input*** is set to ***1***, then the variables ***u_gc*** and ***v_gc*** are available to be processed.

#<Table> <PackageName> <NMLAssociated>   <Variables>
package   realonly   use_wps_input==1 - state:u_gc,v_gc

I/O Applications Program Interface (I/O API)

The software that implements WRF I/O, like the software that implements the model in general, is organized hierarchically, as a "software stack" (*http://www.mmm.ucar.edu/wrf/WG2/Tigers/IOAPI/IOStack.html*) . From top (closest to the model code itself) to bottom (closest to the external package implementing the I/O), the I/O stack looks like this:

- Domain I/O (operations on an entire domain)
- Field I/O (operations on individual fields)
- Package-neutral I/O API
- Package-dependent I/O API (external package)

There is additional information on the WRF I/O software architecture at *http://www.mmm.ucar.edu/wrf/WG2/IOAPI/IO_files/v3_document.htm*. The lower-levels of the stack are described in the I/O and Model Coupling API specification document at *http://www.mmm.ucar.edu/wrf/WG2/Tigers/IOAPI/index.html*.

Timekeeping

Starting times, stopping times, and time intervals in WRF are stored and manipulated as Earth System Modeling Framework (ESMF, *http://www.cisl.ucar.edu/research/2005/esmf.jsp*) time manager objects. This allows exact representation of time instants and intervals as integer numbers of years, months, hours, days, minutes, seconds, and fractions of a second (numerator and denominator are specified separately as integers). All time computations involving these objects are performed exactly, by using integer arithmetic, with the result that there is no accumulated time step drift or rounding, even for fractions of a second.

The WRF implementation of the ESMF Time Manger is distributed with WRF in the ***external/esmf_time_f90*** directory. This implementation is entirely Fortran90 (as opposed to the ESMF implementation in C++) and it is conformant to the version of the ESMF Time Manager API that was available in 2009.

WRF source modules and subroutines that use the ESMF routines do so by use-association of the top-level ESMF Time Manager module, ***esmf_mod***:

USE esmf_mod

The code is linked to the library file ***libesmf_time.a*** in the ***external/esmf_time_f90*** directory.

ESMF timekeeping is set up on a domain-by-domain basis in the routine setup_timekeeping (***share/set_timekeeping.F***). Each domain keeps its own clocks and alarms. Since the time arithmetic is exact there is no problem with clocks on separate domains getting out of synchronization.

Software Documentation

Detailed and comprehensive documentation aimed at WRF software is available at *http://www.mmm.ucar.edu/wrf/WG2/software_2.0*.

Performance

Benchmark information is available at *http://www.mmm.ucar.edu/wrf/bench*.

User's Guide for the NMM Core of the Weather Research and Forecast (WRF) Modeling System Version 3

Chapter 7: Post Processing Utilities

Table of Contents

NCEP Unified Post Processor (UPP)

UPP Introduction

The NCEP Unified Post Processor has replaced the WRF Post Processor (WPP). The UPP software package is based on WPP but has enhanced capabilities to post-process output from a variety of NWP models, including WRF-NMM, WRF-ARW, Non-hydrostatic Multi-scale Model on the B grid (NMMB), Global Forecast System (GFS), and Climate Forecast System (CFS). At this time, community user support is provided for the WRF-based systems only. UPP interpolates output from the model's native grids to National Weather Service (NWS) standard levels (pressure, height, etc.) and standard output grids (AWIPS, Lambert Conformal, polar-stereographic, etc.) in NWS and World Meteorological Organization (WMO) GRIB format. There is also an option to output fields on the model's native vertical levels. With the release of UPPv2.0, preliminary code has been introduced to output in GRIB Edition 2 (GRIB2) format. While capabilities for outputting in GRIB2 format exist within the code, these capabilities are not yet fully functional. Introductory information regarding this new output format is provided due to the influence the additions have had on the UPP package; upon full implementation of GRIB2 output capabilities, more comprehensive information will be provided. In addition, UPP incorporates the Joint Center for Satellite Data Assimilation (JCSDA) Community Radiative Transfer Model (CRTM) to compute model derived brightness temperature (T_B) for various instruments and channels. This additional feature enables the generation of simulated GOES and AMSRE products for WRF-NMM, Hurricane WRF (HWRF), WRF-ARW and GFS. For CRTM documentation, refer to http://www.orbit.nesdis.noaa.gov/smcd/spb/CRTM.

The adaptation of the original WRF Post Processor package and User's Guide (by Mike Baldwin of NSSL/CIMMS and Hui-Ya Chuang of NCEP/EMC) was done by Lígia Bernardet (NOAA/ESRL/DTC) in collaboration with Dusan Jovic (NCEP/EMC), Robert Rozumalski (COMET), Wesley Ebisuzaki (NWS/HQTR), and Louisa Nance (NCAR/RAL/DTC). Upgrades to WRF Post Processor versions 2.2 and higher were performed by Hui-Ya Chuang, Dusan Jovic and Mathew Pyle (NCEP/EMC). Transitioning of the documentation from the WRF Post Processor to the Unified Post Processor was performed by Nicole McKee (NCEP/EMC), Hui-ya Chuang (NCEP/EMC), and Jamie Wolff (NCAR/RAL/DTC). Implementation of the Community Unified Post Processor was performed by Tricia Slovacek (NCAR/RAL/DTC).

UPP Software Requirements

The Community Unified Post Processor requires the same Fortran and C compilers used to build the WRF model. In addition, the netCDF library, the JasPer library, the PNG library, Zlib, and the WRF I/O API libraries, which are included in the WRF model tar file, are also required. The JasPer library, PNG library, and Zlib are new requirements with the release of UPPv2.0, due to the addition GRIB2 capabilities. NCEP provides these necessary codes for download: http://www.nco.ncep.noaa.gov/pmb/codes/GRIB2/

The UPP has some sample visualization scripts included to create graphics using either GrADS (http://grads.iges.org/grads/grads.html) or GEMPAK (http://www.unidata.ucar.edu/software/gempak/index.html). These are not part of the UPP installation and need to be installed separately if one would like to use either plotting package.

The Unified Post Processor has been tested on IBM (with XLF compiler) and LINUX platforms (with PGI, Intel and GFORTRAN compilers).

Obtaining the UPP Code

The Unified Post Processor package can be downloaded from: http://www.dtcenter.org/wrf-nmm/users/downloads/.

Note: Always obtain the latest version of the code if you are not trying to continue a pre-existing project. UPPV2.1 is just used as an example here.

Once the ***tar*** file is obtained, ***gunzip*** and ***untar*** the file.

tar –zxvf UPPV2.1.tar.gz

This command will create a directory called ***UPPV2.1***.

UPP Directory Structure

Under the main directory of ***UPPV2.1*** reside seven subdirectories (* indicates directories that are created after the configuration step):

arch: Machine dependent configuration build scripts used to construct ***configure.upp***

bin*: Location of executables after compilation.

scripts: contains sample running scripts
- **run_unipost**: run ***unipost***, ***ndate*** and ***copygb***.
- **run_unipost andgempak**: run ***unipost***, ***copygb***, and GEMPAK to plot various fields.
- **run_unipost andgrads**: run ***unipost***, ***ndate***, ***copygb***, and GrADS to plot various fields.
- **run_unipost _frames**: run ***unipost***, ***ndate*** and ***copygb*** on a single ***wrfout*** file containing multiple forecast times.
- **run_unipost _gracet**: run ***unipost***, ***ndate*** and ***copygb*** on ***wrfout*** files with non-zero minutes/seconds.
- **run_unipost _minute**: run ***unipost***, ***ndate*** and ***copygb*** for sub-hourly ***wrfout*** files.

include*: Source include modules built/used during compilation of UPP

lib*: Archived libraries built/used by UPP

parm: Contains the parameter files, which can be modified by the user to control how the post processing is performed.

src: Contains source codes for:
- **copygb:** Source code for ***copygb***
- **ndate:** Source code for ***ndate***
- **unipost:** Source code for ***unipost***
- **lib**: Contains source code subdirectories for the UPP libraries
  - **bacio**: Binary I/O library
  - **crtm2**: Community Radiative Transfer Model library
  - **g2:** GRIB2 support library
  - **g2tmpl:** GRIB2 table support library
  - **gfsio:** GFS I/O routines
  - **ip**: General interpolation library (see ***lib/ip/iplib.doc***)
  - **nemsio**: NEMS I/O routines
  - **sfcio**: API for performing I/O on the surface restart file of the global spectral model
  - **sigio**: API for performing I/O on the sigma restart file of the global spectral model
  - **sp**: Spectral transform library (see ***lib/sp/splib.doc***)
  - **w3emc**: Library for coding and decoding data in GRIB1 format
  - **w3nco**: Library for coding and decoding data in GRIB1 format
  - **wrfmpi_stubs**: Contains some ***C*** and ***FORTRAN*** codes to genereate ***libmpi.a*** library used to replace MPI calls for serial compilation.
  - **xml**: XML support – GRIB2 parameter file

Installing the UPP Code

UPP uses a build mechanism similar to that used by the WRF model. There are two environment variables which must be set before beginning the installation: a variable to define the path to a similarly compiled version of WRF and a variable to a compatible version of netCDF. If the environment variable ***WRF_DIR*** is set by (for example),

setenv WRF_DIR */home/user/****WRFV3***

this path will be used to reference WRF libraries and modules. Otherwise, the path

../WRFV3

will be used.

In the case neither method is set, the configure script will automatically prompt you for a pathname.

To reference the netCDF libraries, the configure script checks for an environment variable (***NETCDF***) first, then the system default (***/user/local/netcdf***), and then a user supplied link (***./netcdf_links***). If none of these resolve a path, the user will be prompted by the configure script to supply a path.

If WRF was compiled with the environment variable:

```
setenv HWRF 1
```

This must also be set when compiling UPP.

Type ***configure***, and provide the required info. For example:

```
./configure
```

You will be given a list of choices for your computer.

<u>Choices for LINUX operating systems are as follows:</u>

1. Linux x86_64, PGI compiler (serial)
2. Linux x86_64, PGI compiler (dmpar)
3. Linux x86_64, Intel compiler (serial)
4. Linux x86_64, Intel compiler (dmpar)
5. Linux x86_64, Intel compiler, SGI MPT (serial)
6. Linux x86_64, Intel compiler, SGI MPT (dmpar)
7. Linux x86_64, gfortran compiler (serial)
8. Linux x86_64, gfortran compiler (dmpar)

Note*: If UPP is compiled with distributed memory, it must be linked to a dmpar compilation of WRF.*

Choose one of the configure options listed. Check the ***configure.upp*** file created and edit for compile options/paths, if necessary. For debug flag settings, the configure script can be run with a ***–d*** switch or flag.

To compile UPP, enter the following command:

```
./compile >& compile_upp.log &
```

When compiling with distributed memory (serial) this command should create 13 (14) UPP libraries in ***UPPV2.1/lib/*** (***libbacio.a***, ***libCRTM.a***, ***libg2.a***, ***libg2tmpl.a***, ***libgfsio.a***, ***libip.a***, ***(libmpi.a)***, ***libnemsio.a***, ***ibsfcio.a***, ***libsigio.a***, ***libsp.a***, ***libw3emc.a, libw3nco.a ,*** ***libxmlparse.a***) and three UPP executables in ***bin/*** (***unipost.exe***, ***ndate.exe***, and ***copygb.exe***).

To remove all built files, as well as the ***configure.upp***, type:

./clean

This action is recommended if a mistake is made during the installation process or a change is made to the configuration or build environment. There is also a ***clean –a*** option which will revert back to a pre-install configuration.

UPP Functionalities

The Unified Post Processor,

- is compatible with WRF v3.3 and higher.
- can be used to post-process WRF-ARW, WRF-NMM, NMMB, GFS, and CFS forecasts (community support provided for WRF-based forecasts).
- can ingest WRF history files (***wrfout****) in two formats: netCDF and binary.

The Unified Post Processor is divided into two parts:

1. ***Unipost***
    - Interpolates the forecasts from the model's native vertical coordinate to NWS standard output levels (e.g., pressure, height) and computes mean sea level pressure. If the requested parameter is on a model's native level, then no vertical interpolation is performed.
    - Computes diagnostic output quantities (e.g., convective available potential energy, helicity, radar reflectivity). A full list of fields that can be generated by ***unipost*** is shown in Table 3.
    - Except for new capabilities of post processing GFS/CFS and additions of many new variables, UPP uses the same algorithms to derive most existing variables as were used in WPP. The only three exceptions/changes from the WPP are:
        - ➢ Computes RH w.r.t. ice for GFS, but w.r.t. water for all other supported models. WPP computed RH w.r.t. water only.
        - ➢ The height and wind speed at the maximum wind level is computed by assuming the wind speed varies quadratically in height in the location of the maximum wind level. The WPP defined maximum wind level at the level with the maximum wind speed among all model levels.
        - ➢ The static tropopause level is obtained by finding the lowest level that has a temperature lapse rate of less than 2 K/km over a 2 km depth above it. The WPP defined the tropopause by finding the lowest level that has a mean temperature lapse rate of 2 K/km over three model layers.
    - Outputs the results in NWS and WMO standard GRIB1 format (for GRIB documentation, see http://www.nco.ncep.noaa.gov/pmb/docs/).
    - Destaggers the WRF-ARW forecasts from a C-grid to an A-grid.
    - Outputs two navigation files, ***copygb_nav.txt*** (for WRF-NMM output only) and ***copygb_hwrf.txt*** (for WRF-ARW andWRF-NMM). These files can

be used as input for ***copygb***.

- ***copygb_nav.txt:*** This file contains the GRID GDS of a Lambert Conformal Grid similar in domain and grid spacing to the one used to run the WRF-NMM. The Lambert Conformal map projection works well for mid-latitudes.
- ***copygb_hwrf.txt***: This file contains the GRID GDS of a Latitude-Longitude Grid similar in domain and grid spacing to the one used to run the WRF model. The latitude-longitude grid works well for tropics.

2. ***Copygb***
   - Destaggers the WRF-NMM forecasts from the staggered native E-grid to a regular non-staggered grid. (Since ***unipost*** destaggers WRF-ARW output from a C-grid to an A-grid, WRF-ARW data can be displayed directly without going through ***copygb***.)
   - Interpolates the forecasts horizontally from their native grid to a standard AWIPS or user-defined grid (for information on AWIPS grids, see http://www.nco.ncep.noaa.gov/pmb/docs/on388/tableb.html).
   - Outputs the results in NWS and WMO standard GRIB1 format (for GRIB documentation, see http://www.nco.ncep.noaa.gov/pmb/docs/).

In addition to ***unipost*** and ***copygb***, a utility called ***ndate*** is distributed with the Unified Post Processor tarfile. This utility is used to format the dates of the forecasts to be posted for ingestion by the codes.

Setting up the WRF model to interface with UPP

The ***unipost*** program is currently set up to read a large number of fields from the WRF model history files. This configuration stems from NCEP's need to generate all of its required operational products. A list of the fields that are currently read in by ***unipost*** is provided for the WRF-NMM in Table 1 and WRF-ARW in Table 2. Tables for the GFS and CFS fields will be added in the future. When using the netCDF or mpi binary read, this program is configured such that it will run successfully even if an expected input field is missing from the WRF history file as long as this field is not required to produce a requested output field. If the pre-requisites for a requested output field are missing from the WRF history file, ***unipost*** will abort at run time.

Take care not to remove fields from the ***wrfout*** files, which may be needed for diagnostic purposes by the UPP package. For example, if isobaric state fields are requested, but the pressure fields on model interfaces (PINT for WRF-NMM, P and PB for WRF-ARW) are not available in the history file, ***unipost*** will abort at run time. In general, the default fields available in the ***wrfout*** files are sufficient to run UPP. The fields written to the WRF history file are controlled by the settings in the Registry file (see ***Registry.EM*** or ***Registry.NMM(_NEST)*** files in the ***Registry*** subdirectory of the main ***WRFV3*** directory).

UPP is written to process a single forecast hour, therefore, having a single forecast per output file is optimal. However, UPP can be run across multiple forecast times in a single output file to extract a specified forecast hour.

Note: It is necessary to re-compile the WRF model source code after modifying the Registry file.

Table 1. *List of all possible fields read in by **unipost** for the WRF-NMM:*

T	SFCEXC	NRDSW
U	VEGFRC	ARDSW
V	ACSNOW	ALWIN
Q	ACSNOM	ALWOUT
CWM	CMC	NRDLW
F_ICE	SST	ARDLW
F_RAIN	EXCH_H	ALWTOA
F_RIMEF	EL_MYJ	ASWTOA
W	THZ0	TGROUND
PINT	QZ0	SOILTB
PT	UZ0	TWBS
PDTOP	VZ0	SFCSHX
FIS	QS	NSRFC
SMC	Z0	ASRFC
SH2O	PBLH	QWBS
STC	USTAR	SFCLHX
CFRACH	AKHS_OUT	GRNFLX
CFRACL	AKMS_OUT	SUBSHX
CFRACM	THS	POTEVP
SLDPTH	PREC	WEASD
U10	CUPREC	SNO
V10	ACPREC	SI
TH10	CUPPT	PCTSNO
Q10	LSPA	IVGTYP
TSHLTR	CLDEFI	ISLTYP
QSHLTR	HTOP	ISLOPE
PSHLTR	HBOT	SM
SMSTAV	HTOPD	SICE
SMSTOT	HBOTD	ALBEDO
ACFRCV	HTOPS	ALBASE
ACFRST	HBOTS	GLAT
RLWTT	SR	XLONG
RSWTT	RSWIN	GLON
AVRAIN	CZEN	DX_NMM
AVCNVC	CZMEAN	NPHS0
TCUCN	RSWOUT	NCLOD
TRAIN	RLWIN	NPREC
NCFRCV	SIGT4	NHEAT

NCFRST	RADOT	
SFROFF	ASWIN	
UDROFF	ASWOUT	
SFCEVP		

Note: For WRF-NMM, the period of accumulated precipitation is controlled by the ***namelist.input*** variable ***tprec***. Hence, this field in the ***wrfout*** file represents an accumulation over the time period ***tprec*INT[(fhr-Σ)/tprec]*** to fhr, where fhr represents the forecast hour and ***Σ*** is a small number. The GRIB file output by ***unipost*** and by ***copygb*** contains fields with the name of accumulation period.

Table 2. *List of all possible fields read in by* ***unipost*** *for the WRF-ARW:*

T	MUB	SFROFF
U	P_TOP	UDROFF
V	PHB	SFCEVP
QVAPOR	PH	SFCEXC
QCLOUD	SMOIS	VEGFRA
QICE	TSLB	ACSNOW
QRAIN	CLDFRA	ACSNOM
QSNOW	U10	CANWAT
QGRAUP	V10	SST
W	TH2	THZ0
PB	Q2	QZ0
P	SMSTAV	UZ0
MU	SMSTOT	VZ0
QSFC	HGT	ISLTYP
Z0	ALBEDO	ISLOPE
UST	GSW	XLAND
AKHS	GLW	XLAT
AKMS	TMN	XLONG
TSK	HFX	MAPFAC_M
RAINC	LH	STEPBL
RAINNC	GRDFLX	HTOP
RAINCV	SNOW	HBOT
RAINNCV	SNOWC	

Note: For WRF-ARW, the accumulated precipitation fields (***RAINC*** and ***RAINNC***) are run total accumulations.

UPP Control File Overview

Note: The information within this section refers exclusively to outputting files in GRIB1 format. Future releases of the UPP package will include the ability to output file in

GRIB2 format, upon which updated overviews will be provided.

The user interacts with ***unipost*** through the control file, ***parm/wrf_cntrl.parm***. The control file is composed of a header and a body. The header specifies the output file information. The body allows the user to select which fields and levels to process.

The header of the ***wrf_cntrl.parm*** file contains the following variables:

- **KGTYPE**: defines output grid type, which should always be 255.
- **IMDLTY:** identifies the process ID for AWIPS.
- **DATSET**: defines the prefix used for the output file name. Currently set to "***WRFPRS***". Note: the run_* scripts assume "***WRFPRS***" is used.

The body of the ***wrf_cntrl.parm*** file is composed of a series of line pairs similar to the following:

```
(PRESS ON MDL SFCS   ) SCAL=( 3.0)
L=(11000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000
00000 00000 00000)
```

where,

- The top line specifies the variable (e.g. PRESS) to process, the level type (e.g. ON MDL SFCS) a user is interested in, and the degree of accuracy to be retained (SCAL=3.0) in the GRIB output.
  - SCAL defines the precision of the data written out to the GRIB format. Positive values denote decimal scaling (maintain that number of significant digits), while negative values describe binary scaling (precise to 2^{SCAL}; i.e., SCAL=-3.0 gives output precise to the nearest 1/8). Because ***copygb*** is unable to handle binary precision at this time, negative numbers are discouraged.
  - A list of all possible output fields for ***unipost*** is provided in Table 3. This table provides the full name of the variable in the first column and an abbreviated name in the second column. The abbreviated names are used in the control file. Note that the variable names also contain the type of level on which they are output. For instance, temperature is available on "model surface" and "pressure surface".
- The second line specifies the levels on which the variable is to be posted. "0" indicates no output at this level and "1" indicates output the variable specified on the top line at the level specified by the position of the digit and the type of level defined for this variable. For flight/wind energy fields, a "2" may be specified, such that "2" requests AGL and "1" requests MSL.

Controlling which variables *unipost* outputs

To output a field, the body of the control file needs to contain an entry for the appropriate variable and output for this variable must be turned on for at least one level (see "*Controlling which levels unipost outputs*"). If an entry for a particular field is not yet available in the control file, two lines may be added to the control file with the appropriate entries for that field.

Controlling which levels *unipost* outputs

The second line of each pair determines which levels ***unipost*** will output. Output on a given level is turned off by a "0" or turned on by a "1".

- For isobaric output, 47 levels are possible, from 2 to 1013 hPa (*2, 5, 7, 10, 20, 30, 50, 70 mb and then every 25 mb from 75 to 1000 mb*). The complete list of levels is specified in ***sorc/unipost/CTLBLK.f***.
    - Modify specification of variable LSMDEF to change the number of pressure levels: LSMDEF=47
    - Modify specification of SPLDEF array to change the values of pressure levels:

    (/200.,500.,700.,1000.,2000.,3000.
    &,5000.,7000.,7500.,10000.,12500.,15000.,17500.,20000., …/)
- For model-level output, all model levels are possible, from the highest to the lowest.
- When using the Noah LSM, the *soil layers* are 0-10 cm, 10-40 cm, 40-100 cm, and 100-200 cm.
- When using the RUC LSM, the *soil levels* are 0 cm, 5 cm, 20 cm, 40 cm, 160 cm, and 300 cm. For the RUC LSM it is also necessary to turn on two additional output levels in the ***wrf_cntrl.parm*** to output 6 levels rather than the default 4 layers for the Noah LSM.
- For PBL layer averages, the levels correspond to 6 layers with a thickness of 30 hPa each.
- For flight level, the levels are 30 m, 50 m, 80 m, 100 m, 305 m, 457 m, 610 m, 914 m,1524 m,1829 m, 2134 m, 2743 m, 3658 m, 4572 m, and 6000 m.
- For AGL RADAR Reflectivity, the levels are 4000 and 1000 m.
- For surface or shelter-level output, only the first position of the line needs to be turned on.
    - For example, the sample control file ***parm/wrf_cntrl.parm*** has the following entry for surface dew point temperature:

```
(SURFACE DEWPOINT    ) SCAL=( 4.0)
L=(00000 00000 00000 00000 00000 00000 00000 00000 00000 00000
00000 00000 00000 00000)
```

Based on this entry, surface dew point temperature will not be output by ***unipost***. To add this field to the output, modify the entry to read:

```
(SURFACE DEWPOINT    ) SCAL=( 4.0)
L=(10000 00000 00000 00000 00000 00000 00000 00000 00000 00000
00000 00000 00000 00000)
```

Running UPP

Six scripts for running the Unified Post Processor package are included in the tar file:

run_unipost
run_unipostandgrads
run_unipostandgempak
run_unipost_frames
run_unipost_gracet
run_unipost_minute

<u>Before running any of the above listed scripts, perform the following instructions:</u>

1. ***cd*** to your ***DOMAINPATH*** directory.

2. Make a directory to put the UPP results.

    mkdir postprd

3. Make a directory to put a copy of ***wrf_cntrl.parm*** file.

    mkdir parm

4. Copy over the default ***UPPV2.1/parm/wrf_cntrl.parm*** to your working directory to customize ***unipost***.

5. Edit the ***wrf_cntrl.parm*** file to reflect the fields and levels you want ***unipost*** to output.

6. Copy over the (***UPPV2.1/scripts/run_unipost****) script of your choice to the ***postprd/***.

7. Edit the run script as outlined below.

Once these directories are set up and the edits outlined above are completed, the scripts can be run interactively from the ***postprd*** directory by simply typing the script name on the command line.

Overview of the scripts to run the UPP

Note: It is recommended that the user refer to the ***run_unipost**** scripts in the ***script/*** while reading this overview.

1. Set up variables:
   TOP_DIR: top level directory for source codes (***UPPV2.1*** and ***WRFV3***)
   DOMAINPATH: directory where UPP will be run from
   WRFPATH: path to your WRFV3 build; defaults to the environment variable used during the installation with the configure script
   UNI_POST_HOME: path to your UPPV2.1 build
   POSTEXEC: path to your UPPV2.1 executables

Note: The scripts are configured such that ***unipost*** expects the WRF history files (***wrfout**** files) to be in ***wrfprd/***, the ***wrf_cntrl.parm*** file to be in ***parm/*** and the postprocessor working directory to called ***postprd/***, all under ***DOMAINPATH***.

2. Specify dynamic core being run (“NMM” or “ARW”)

3. Specify the forecast cycles to be post-processed
   startdate: YYYYMMDDHH of forecast cycle
   fhr: first forecast hour
   lastfhr: last forecast hour
   incrementhr: increment (in hours) between forecast files (Do not set to 0 or the script will loop continuously)

4. Set naming convention for prefix and extension of output file name
   i. ***comsp*** is the initial string of the output file name (by default it is not set (and the prefix of the output file will be the string set in ***wrf_cntrl.parm*** **DATSET**), if set it will concatenate the setting to the front of the string specified in ***wrf_cntrl.parm*** **DATSET**)
   ii. ***tmmark*** is used for the file extension (in ***run_unipost***, *tmmark=tm00,* if not set it is set to .*GrbF*)

5. Set up how many domains will be post-processed
   For runs with a single domain, use “for domain d01”.
   For runs with multiple domains, use “for domain d01 d02 .. d*nn*”

6. Create namelist ***itag*** that will be read in by ***unipost.exe*** from stdin (unit 5). This namelist contains 5 lines:
   i. Name of the WRF output file to be posted.
   ii. Format of WRF model output (netcdf, binary or binarympiio).
   iii. Format of UPP output (grib1 or grib2)
   iv. Forecast valid time (not model start time) in WRF format (the forecast time desired to be post-processed).
   v. Dynamic core used (NMM or NCAR).

   Note: With the addition of GRIB2 output capabilities, a fifth line has been added to the namelist. If the third line (i.e., UPP output type) is not set, UPP will default the output file format to “grib1”.

7. Run ***unipost*** and check for errors.
   - The execution command in the distributed scripts is for a single processor: ./***unipost.exe > outpost 2>&1***.
   - To run ***unipost*** using mpi (dmpar compilation), the command line should be:
     - LINUX-MPI systems: ***mpirun -np N unipost.exe > outpost 2>&1*** (Note: on some systems a host file also needs to be specified: ***–machinefile*** “***host***”)

- IBM: ***mpirun.lsf unipost.exe < itag > outpost***

8. Set up grid to post to (see full description under "Run ***copygb***" below)
   copygb is run with a pre-defined AWIPS grid
   gridno: standard AWIPS grid to interpolate WRF model output to
   copygb ingests a kgds definition on the command line
   copygb ingests the contents of file ***copygb_gridnav.txt*** or ***copygb_hwrf.txt*** through variable ***nav***

9. Run ***copygb*** and check for errors.
   copygb.exe –xg"grid [kgds]" input_file output_file
   where ***grid*** refers to the output grid to which the native forecast is being interpolated.

   The output grid can be specified in three ways:

   i. As the grid id of a pre-defined AWIPS grid:

      copygb.exe -g${gridno} -x input_file output_file

      For example, using grid 218:
      copygb.exe -xg"218" WRFPRS_$domain.${fhr} wrfprs_$domain .${fhr}

   ii. As a user defined standard grid, such as for grid 255:

      copygb.exe –xg"255 kgds" input_file output_file

      where the user defined grid is specified by a full set of kgds parameters determining a GRIB GDS (grid description section) in the ***W3fi63*** format. Details on how to specify the kgds parameters are documented in file ***lib/w3lib/w3fi71.f***. For example:

      copygb.exe -xg" 255 3 109 91 37719 -77645 8 -71000 10433 9966 0 64 42000 42000" WRFPRS_$domain.${fhr} wrfprs_$domain.${fhr}

   iii. Specifying output grid as a file: When WRF-NMM output in is processed by ***unipost***, two text files ***copygb_gridnav.txt*** and ***copygb_hwrf.txt*** are created. These files contain the GRID GDS of a Lambert Conformal Grid (file ***copygb_gridnav.txt***) or lat/lon grid (***copygb_hwrf.txt***) similar in domain and grid spacing to the one used to run the WRF-NMM model. The contents of one of these files are read into variable ***nav*** and can be used as input to ***copygb.exe***.

      copygb.exe -xg"$nav" input_file output_file

      For example, when using "***copygb_gridnav.txt"*** for an application the steps include:

read nav < 'copygb_gridnav.txt'
export nav
copygb.exe -xg"${nav}" WRFPRS_$domain.${fhr}
wrfprs_$domain.${fhr}

If scripts ***run_unipostandgrads*** or ***run_unipostandgempak*** are used, additional steps are taken to create image files (see **Visualization** section below).

Upon a successful run, ***unipost*** and ***copygb*** will generate output files ***WRFPRS_d****nn.hh* and ***wrfprs_d****nn.hh*, respectively, in the post-processor working directory, where "*nn*" refers to the domain id and "*hh*" denotes the forecast hour. In addition, the script ***run_unipostandgrads*** will produce a suite of gif images named ***variablehh_GrADS.gif***, and the script ***run_unipostandgempak*** will produce a suite of gif images named ***variablehh.gif***.

If the run did not complete successfully, a log file in the post-processor working directory called ***unipost_dnn.hh.out***, where "*nn*" is the domain id and "*hh*" is the forecast hour, may be consulted for further information.

It should be noted that ***copygb*** is a flexible program that can accept several command line options specifying details of how the horizontal interpolation from the native grid to the output grid should be performed. Complete documentation of ***copygb*** can be found at:
http://www.dtcenter.org/met/users/support/online_tutorial/METv4.0/copygb/copygb.txt

Visualization with UPP

GEMPAK

The GEMPAK utility ***nagrib*** is able to decode GRIB files whose navigation is on any non-staggered grid. Hence, GEMPAK is able to decode GRIB files generated by the Unified Post Processing package and plot horizontal fields or vertical cross sections.

A sample script named ***run_unipostandgempak***, which is included in the ***scripts*** directory of the tar file, can be used to run ***unipost***, ***copygb***, and plot the following fields using GEMPAK:

- ***Sfcmap_dnn_hh.gif:*** mean SLP and 6 hourly precipitation
- ***PrecipType_dnn_hh.gif:*** precipitation type (just snow and rain)
- ***850mbRH_dnn_hh.gif:*** 850 mb relative humidity
- ***850mbTempandWind_dnn_hh.gif:*** 850 mb temperature and wind vectors
- ***500mbHandVort_dnn_hh.gif:*** 500 mb geopotential height and vorticity
- ***250mbWindandH_dnn_hh.gif:*** 250 mb wind speed isotacs and geopotential height

This script can be modified to customize fields for output. GEMPAK has an online users

guide at
http://www.unidata.ucar.edu/software/gempak/help_and_documentation/manual/.

In order to use the script ***run_unipostandgempak***, it is necessary to set the environment variable ***GEMEXEC*** to the path of the GEMPAK executables. For example,

```
setenv GEMEXEC /usr/local/gempak/bin
```

Note: For GEMPAK, the precipitation accumulation period for WRF-NMM is given by the variable ***incrementhr*** in the ***run_unipostandgempak*** script.

GrADS

The GrADS utilities ***grib2ctl.pl*** and ***gribmap*** are able to decode GRIB files whose navigation is on any non-staggered grid. These utilities and instructions on how to use them to generate GrADS control files are available from:
http://www.cpc.ncep.noaa.gov/products/wesley/grib2ctl.html.

The GrADS package is available from: http://grads.iges.org/grads/grads.html.
GrADS has an online User's Guide at: http://grads.iges.org/grads/gadoc/ and a list of basic commands for GrADS can be found at:
http://grads.iges.org/grads/gadoc/reference_card.pdf.

A sample script named ***run_unipostandgrads***, which is included in the ***scripts*** directory of the Unified Post Processing package, can be used to run ***unipost***, ***copygb***, and plot the following fields using GrADS:

- ***Sfcmaphh_dnn_GRADS.gif***: mean SLP and 6-hour accumulated precipitation.
- ***850mbRHhh_dnn_GRADS.gif***: 850 mb relative humidity
- ***850mbTempandWindhh_dnn_GRADS.gif***: 850 mb temperature and wind vectors
- ***500mbHandVorthh_dnn_GRADS.gif***: 500 mb geopotential heights and absolute vorticity
- ***250mbWindandHhh_dnn_GRADS.gif***: 250 mb wind speed isotacs and geopotential heights

In order to use the script ***run_unipostandgrads***, it is necessary to:

1. Set the environmental variable ***GADDIR*** to the path of the GrADS fonts and auxiliary files. For example,

   ```
   setenv GADDIR /usr/local/grads/data
   ```

2. Add the location of the GrADS executables to the ***PATH***. For example

   ```
   setenv PATH /usr/local/grads/bin:$PATH
   ```

3. Link script ***cbar.gs*** to the post-processor working directory. (This scripts is provided in UPP package, and the ***run_unipostandgrads*** script makes a link from ***scripts/*** to ***postprd/***.) To generate the plots above, GrADS script ***cbar.gs*** is invoked. This script can also be obtained from the GrADS library of scripts at http://grads.iges.org/grads/gadoc/library.html.

Note: For GrADS, the precipitation accumulation period for WRF-NMM is plotted over the subintervals of the ***tprec*** hour (set in ***namelist.input***).

Fields produced by *unipost*

Table 3 lists basic and derived fields that are currently produced by ***unipost***. The abbreviated names listed in the second column describe how the fields should be entered in the control file (***wrf_cntrl.parm***).

Table 3: *Fields produced by* ***unipost*** *(column 1), abbreviated names used in the* ***wrf_cntrl.parm*** *file (column 2), corresponding GRIB identification number for the field (column 3), and corresponding GRIB identification number for the vertical coordinate (column 4).*

Field Name	Name In Control File	Grib ID	Vertical Level
Radar reflectivity on model surface	RADAR REFL MDL SFCS	211	109
Pressure on model surface	PRESS ON MDL SFCS	1	109
Height on model surface	HEIGHT ON MDL SFCS	7	109
Temperature on model surface	TEMP ON MDL SFCS	11	109
Potential temperature on model surface	POT TEMP ON MDL SFCS	13	109
Dew point temperature on model surface	DWPT TEMP ON MDL SFC	17	109
Specific humidity on model surface	SPEC HUM ON MDL SFCS	51	109
Relative humidity on model surface	REL HUM ON MDL SFCS	52	109
Moisture convergence on model surface	MST CNVG ON MDL SFCS	135	109
U component wind on model surface	U WIND ON MDL SFCS	33	109
V component wind on model surface	V WIND ON MDL SFCS	34	109
Cloud water on model surface	CLD WTR ON MDL SFCS	153	109
Cloud ice on model surface	CLD ICE ON MDL SFCS	58	109
Rain on model surface	RAIN ON MDL SFCS	170	109
Snow on model surface	SNOW ON MDL SFCS	171	109
Cloud fraction on model surface	CLD FRAC ON MDL SFCS	71	109

Omega on model surface	OMEGA ON MDL SFCS	39	109
Absolute vorticity on model surface	ABS VORT ON MDL SFCS	41	109
Geostrophic streamfunction on model surface	STRMFUNC ON MDL SFCS	35	109
Turbulent kinetic energy on model surface	TRBLNT KE ON MDL SFC	158	109
Richardson number on model surface	RCHDSN NO ON MDL SFC	254	109
Master length scale on model surface	MASTER LENGTH SCALE	226	109
Asymptotic length scale on model surface	ASYMPT MSTR LEN SCL	227	109
Radar reflectivity on pressure surface	RADAR REFL ON P SFCS	211	100
Height on pressure surface	HEIGHT OF PRESS SFCS	7	100
Temperature on pressure surface	TEMP ON PRESS SFCS	11	100
Potential temperature on pressure surface	POT TEMP ON P SFCS	13	100
Dew point temperature on pressure surface	DWPT TEMP ON P SFCS	17	100
Specific humidity on pressure surface	SPEC HUM ON P SFCS	51	100
Relative humidity on pressure surface	REL HUMID ON P SFCS	52	100
Moisture convergence on pressure surface	MST CNVG ON P SFCS	135	100
U component wind on pressure surface	U WIND ON PRESS SFCS	33	100
V component wind on pressure surface	V WIND ON PRESS SFCS	34	100
Omega on pressure surface	OMEGA ON PRESS SFCS	39	100
Absolute vorticity on pressure surface	ABS VORT ON P SFCS	41	100
Geostrophic streamfunction on pressure surface	STRMFUNC ON P SFCS	35	100
Turbulent kinetic energy on pressure surface	TRBLNT KE ON P SFCS	158	100
Cloud water on pressure surface	CLOUD WATR ON P SFCS	153	100
Cloud ice on pressure surface	CLOUD ICE ON P SFCS	58	100
Rain on pressure surface	RAIN ON P SFCS	170	100
Snow water on pressure surface	SNOW ON P SFCS	171	100
Total condensate on pressure surface	CONDENSATE ON P SFCS	135	100
Mesinger (Membrane) sea level	MESINGER MEAN SLP	130	102

pressure			
Shuell sea level pressure	SHUELL MEAN SLP	2	102
2 M pressure	SHELTER PRESSURE	1	105
2 M temperature	SHELTER TEMPERATURE	11	105
2 M specific humidity	SHELTER SPEC HUMID	51	105
2 M mixing ratio	SHELTER MIX RATIO	53	105
2 M dew point temperature	SHELTER DEWPOINT	17	105
2 M RH	SHELTER REL HUMID	52	105
10 M u component wind	U WIND AT ANEMOM HT	33	105
10 M v component wind	V WIND AT ANEMOM HT	34	105
10 M potential temperature	POT TEMP AT 10 M	13	105
10 M specific humidity	SPEC HUM AT 10 M	51	105
Surface pressure	SURFACE PRESSURE	1	1
Terrain height	SURFACE HEIGHT	7	1
Skin potential temperature	SURFACE POT TEMP	13	1
Skin specific humidity	SURFACE SPEC HUMID	51	1
Skin dew point temperature	SURFACE DEWPOINT	17	1
Skin Relative humidity	SURFACE REL HUMID	52	1
Skin temperature	SFC (SKIN) TEMPRATUR	11	1
Soil temperature at the bottom of soil layers	BOTTOM SOIL TEMP	85	111
Soil temperature in between each of soil layers	SOIL TEMPERATURE	85	112
Soil moisture in between each of soil layers	SOIL MOISTURE	144	112
Snow water equivalent	SNOW WATER EQUIVALNT	65	1
Snow cover in percentage	PERCENT SNOW COVER	238	1
Heat exchange coeff at surface	SFC EXCHANGE COEF	208	1
Vegetation cover	GREEN VEG COVER	87	1
Soil moisture availability	SOIL MOISTURE AVAIL	207	112
Ground heat flux - instantaneous	INST GROUND HEAT FLX	155	1
Lifted index—surface based	LIFTED INDEX—SURFCE	131	101
Lifted index—best	LIFTED INDEX—BEST	132	116
Lifted index—from boundary layer	LIFTED INDEX—BNDLYR	24	116
CAPE	CNVCT AVBL POT ENRGY	157	1
CIN	CNVCT INHIBITION	156	1
Column integrated precipitable water	PRECIPITABLE WATER	54	200
Column integrated cloud water	TOTAL COLUMN CLD WTR	136	200
Column integrated cloud ice	TOTAL COLUMN CLD	137	200

	ICE		
Column integrated rain	TOTAL COLUMN RAIN	138	200
Column integrated snow	TOTAL COLUMN SNOW	139	200
Column integrated total condensate	TOTAL COL CONDENSATE	140	200
Helicity	STORM REL HELICITY	190	106
U component storm motion	U COMP STORM MOTION	196	106
V component storm motion	V COMP STORM MOTION	197	106
Accumulated total precipitation	ACM TOTAL PRECIP	61	1
Accumulated convective precipitation	ACM CONVCTIVE PRECIP	63	1
Accumulated grid-scale precipitation	ACM GRD SCALE PRECIP	62	1
Accumulated snowfall	ACM SNOWFALL	65	1
Accumulated total snow melt	ACM SNOW TOTAL MELT	99	1
Precipitation type (4 types) – instantaneous	INSTANT PRECIP TYPE	140	1
Precipitation rate - instantaneous	INSTANT PRECIP RATE	59	1
Composite radar reflectivity	COMPOSITE RADAR REFL	212	200
Low level cloud fraction	LOW CLOUD FRACTION	73	214
Mid level cloud fraction	MID CLOUD FRACTION	74	224
High level cloud fraction	HIGH CLOUD FRACTION	75	234
Total cloud fraction	TOTAL CLD FRACTION	71	200
Time-averaged total cloud fraction	AVG TOTAL CLD FRAC	71	200
Time-averaged stratospheric cloud fraction	AVG STRAT CLD FRAC	213	200
Time-averaged convective cloud fraction	AVG CNVCT CLD FRAC	72	200
Cloud bottom pressure	CLOUD BOT PRESSURE	1	2
Cloud top pressure	CLOUD TOP PRESSURE	1	3
Cloud bottom height (above MSL)	CLOUD BOTTOM HEIGHT	7	2
Cloud top height (above MSL)	CLOUD TOP HEIGHT	7	3
Convective cloud bottom pressure	CONV CLOUD BOT PRESS	1	242
Convective cloud top pressure	CONV CLOUD TOP PRESS	1	243
Shallow convective cloud bottom pressure	SHAL CU CLD BOT PRES	1	248
Shallow convective cloud top pressure	SHAL CU CLD TOP PRES	1	249

Deep convective cloud bottom pressure	DEEP CU CLD BOT PRES	1	251
Deep convective cloud top pressure	DEEP CU CLD TOP PRES	1	252
Grid scale cloud bottom pressure	GRID CLOUD BOT PRESS	1	206
Grid scale cloud top pressure	GRID CLOUD TOP PRESS	1	207
Convective cloud fraction	CONV CLOUD FRACTION	72	200
Convective cloud efficiency	CU CLOUD EFFICIENCY	134	200
Above-ground height of LCL	LCL AGL HEIGHT	7	5
Pressure of LCL	LCL PRESSURE	1	5
Cloud top temperature	CLOUD TOP TEMPS	11	3
Temperature tendency from radiative fluxes	RADFLX CNVG TMP TNDY	216	109
Temperature tendency from shortwave radiative flux	SW RAD TEMP TNDY	250	109
Temperature tendency from longwave radiative flux	LW RAD TEMP TNDY	251	109
Outgoing surface shortwave radiation - instantaneous	INSTN OUT SFC SW RAD	211	1
Outgoing surface longwave radiation - instantaneous	INSTN OUT SFC LW RAD	212	1
Incoming surface shortwave radiation - time-averaged	AVE INCMG SFC SW RAD	204	1
Incoming surface longwave radiation - time-averaged	AVE INCMG SFC LW RAD	205	1
Outgoing surface shortwave radiation - time-averaged	AVE OUTGO SFC SW RAD	211	1
Outgoing surface longwave radiation - time-averaged	AVE OUTGO SFC LW RAD	212	1
Outgoing model top shortwave radiation - time-averaged	AVE OUTGO TOA SW RAD	211	8
Outgoing model top longwave radiation - time-averaged	AVE OUTGO TOA LW RAD	212	8
Incoming surface shortwave radiation - instantaneous	INSTN INC SFC SW RAD	204	1
Incoming surface longwave radiation - instantaneous	INSTN INC SFC LW RAD	205	1
Roughness length	ROUGHNESS LENGTH	83	1
Friction velocity	FRICTION VELOCITY	253	1
Surface drag coefficient	SFC DRAG COEFFICIENT	252	1
Surface u wind stress	SFC U WIND STRESS	124	1
Surface v wind stress	SFC V WIND STRESS	125	1
Surface sensible heat flux - time-averaged	AVE SFC SENHEAT FX	122	1
Ground heat flux - time-averaged	AVE GROUND HEAT FX	155	1

Surface latent heat flux - time-averaged	AVE SFC LATHEAT FX	121	1
Surface momentum flux - time-averaged	AVE SFC MOMENTUM FX	172	1
Accumulated surface evaporation	ACC SFC EVAPORATION	57	1
Surface sensible heat flux – instantaneous	INST SFC SENHEAT FX	122	1
Surface latent heat flux - instantaneous	INST SFC LATHEAT FX	121	1
Latitude	LATITUDE	176	1
Longitude	LONGITUDE	177	1
Land sea mask (land=1, sea=0)	LAND/SEA MASK	81	1
Sea ice mask	SEA ICE MASK	91	1
Surface midday albedo	SFC MIDDAY ALBEDO	84	1
Sea surface temperature	SEA SFC TEMPERATURE	80	1
Press at tropopause	PRESS AT TROPOPAUSE	1	7
Temperature at tropopause	TEMP AT TROPOPAUSE	11	7
Potential temperature at tropopause	POTENTL TEMP AT TROP	13	7
U wind at tropopause	U WIND AT TROPOPAUSE	33	7
V wind at tropopause	V WIND AT TROPOPAUSE	34	7
Wind shear at tropopause	SHEAR AT TROPOPAUSE	136	7
Height at tropopause	HEIGHT AT TROPOPAUSE	7	7
Temperature at flight levels	TEMP AT FD HEIGHTS	11	103
U wind at flight levels	U WIND AT FD HEIGHTS	33	103
V wind at flight levels	V WIND AT FD HEIGHTS	34	103
Freezing level height (above mean sea level)	HEIGHT OF FRZ LVL	7	4
Freezing level RH	REL HUMID AT FRZ LVL	52	4
Highest freezing level height	HIGHEST FREEZE LVL	7	204
Pressure in boundary layer (30 mb mean)	PRESS IN BNDRY LYR	1	116
Temperature in boundary layer (30 mb mean)	TEMP IN BNDRY LYR	11	116
Potential temperature in boundary layers (30 mb mean)	POT TMP IN BNDRY LYR	13	116
Dew point temperature in boundary layer (30 mb mean)	DWPT IN BNDRY LYR	17	116
Specific humidity in boundary layer (30 mb mean)	SPC HUM IN BNDRY LYR	51	116
RH in boundary layer (30 mb mean)	REL HUM IN BNDRY LYR	52	116

Moisture convergence in boundary layer (30 mb mean)	MST CNV IN BNDRY LYR	135	116
Precipitable water in boundary layer (30 mb mean)	P WATER IN BNDRY LYR	54	116
U wind in boundary layer (30 mb mean)	U WIND IN BNDRY LYR	33	116
V wind in boundary layer (30 mb mean)	V WIND IN BNDRY LYR	34	116
Omega in boundary layer (30 mb mean)	OMEGA IN BNDRY LYR	39	116
Visibility	VISIBILITY	20	1
Vegetation type	VEGETATION TYPE	225	1
Soil type	SOIL TYPE	224	1
Canopy conductance	CANOPY CONDUCTANCE	181	1
PBL height	PBL HEIGHT	221	1
Slope type	SLOPE TYPE	222	1
Snow depth	SNOW DEPTH	66	1
Liquid soil moisture	LIQUID SOIL MOISTURE	160	112
Snow free albedo	SNOW FREE ALBEDO	170	1
Maximum snow albedo	MAXIMUM SNOW ALBEDO	159	1
Canopy water evaporation	CANOPY WATER EVAP	200	1
Direct soil evaporation	DIRECT SOIL EVAP	199	1
Plant transpiration	PLANT TRANSPIRATION	210	1
Snow sublimation	SNOW SUBLIMATION	198	1
Air dry soil moisture	AIR DRY SOIL MOIST	231	1
Soil moist porosity	SOIL MOIST POROSITY	240	1
Minimum stomatal resistance	MIN STOMATAL RESIST	203	1
Number of root layers	NO OF ROOT LAYERS	171	1
Soil moist wilting point	SOIL MOIST WILT PT	219	1
Soil moist reference	SOIL MOIST REFERENCE	230	1
Canopy conductance - solar component	CANOPY COND SOLAR	246	1
Canopy conductance - temperature component	CANOPY COND TEMP	247	1
Canopy conductance - humidity component	CANOPY COND HUMID	248	1
Canopy conductance - soil component	CANOPY COND SOILM	249	1
Potential evaporation	POTENTIAL EVAP	145	1
Heat diffusivity on sigma surface	DIFFUSION H RATE S S	182	107
Surface wind gust	SFC WIND GUST	180	1
Convective precipitation rate	CONV PRECIP RATE	214	1

Radar reflectivity at certain above ground heights	RADAR REFL AGL	211	105
MAPS Sea Level Pressure	MAPS SLP	2	102
Total soil moisture	TOTAL SOIL MOISTURE	86	112
Plant canopy surface water	PLANT CANOPY SFC WTR	223	1
Accumulated storm surface runoff	ACM STORM SFC RNOFF	235	1
Accumulated baseflow runoff	ACM BSFL-GDWR RNOFF	234	1
Fraction of frozen precipitation	FROZEN FRAC CLD SCHM	194	1
GSD Cloud Base pressure	GSD CLD BOT PRESSURE	1	2
GSD Cloud Top pressure	GSD CLD TOP PRESSURE	1	3
Averaged temperature tendency from grid scale latent heat release	AVE GRDSCL RN TMPTDY	241	109
Averaged temperature tendency from convective latent heat release	AVE CNVCT RN TMPTDY	242	109
Average snow phase change heat flux	AVE SNO PHSCNG HT FX	229	1
Accumulated potential evaporation	ACC POT EVAPORATION	228	1
Highest freezing level relative humidity	HIGHEST FRZ LVL RH	52	204
Maximum wind pressure level	MAX WIND PRESS LEVEL	1	6
Maximum wind height	MAX WIND HGHT LEVEL	7	6
U-component of maximum wind	U COMP MAX WIND	33	6
V-component of maximum wind	V COMP MAX WIND	34	6
GSD cloud base height	GSD CLD BOT HEIGHT	7	2
GSD cloud top height	GSD CLD TOP HEIGHT	7	3
GSD visibility	GSD VISIBILITY	20	1
Wind energy potential	INSTN WIND POWER AGL	126	105
U wind at 80 m above ground	U WIND AT 80M AGL	49	105
V wind at 80 m above ground	V WIND AT 80M AGL	50	105
Graupel on model surface	GRAUPEL ON MDL SFCS	179	109
Graupel on pressure surface	GRAUPEL ON P SFCS	179	100
Maximum updraft helicity	MAX UPDRAFT HELICITY	236	106
Maximum 1km reflectivity	MAX 1km REFLECTIVITY	235	105
Maximum wind speed at 10m	MAX 10m WIND SPEED	229	105
Maximum updraft vertical velocity	MAX UPDRAFT VERT VEL	237	101
Maximum downdraft vertical velocity	MAX DNDRAFT VERT VEL	238	101

Mean vertical velocity	MEAN VERT VEL	40	108
Radar echo top in KDT	ECHO TOPS IN KFT	7	105
Updraft helicity	UPDRAFT HELICITY PRM	227	106
Column integrated graupel	VERT INTEG GRAUP	179	200
Column integrated maximum graupel	MAX VERT INTEG GRAUP	228	200
U-component of 0-1km level wind shear	U COMP 0-1 KM SHEAR	230	106
V-component of 0-1km level wind shear	V COMP 0-1 KM SHEAR	238	106
U-component of 0-6km level wind shear	U COMP 0-6 KM SHEAR	239	106
V-component of 0-6km level wind shear	V COMP 0-6 KM SHEAR	241	106
Total precipitation accumulated over user-specified bucket	BUCKET TOTAL PRECIP	61	1
Convective precipitation accumulated over user-specified bucket	BUCKET CONV PRECIP	63	1
Grid-scale precipitation accumulated over user-specified bucket	BUCKET GRDSCALE PRCP	62	1
Snow accumulated over user-specified bucket	BUCKET SNOW PRECIP	65	1
Model level fraction of rain for Ferrier’s scheme	F_rain ON MDL SFCS	131	109
Model level fraction of ice for Ferrier’s scheme	F_ice ON MDL SFCS	132	109
Model level riming factor for Ferrier’s scheme	F_RimeF ON MDL SFCS	133	109
Model level total condensate for Ferrier’s scheme	CONDENSATE MDL SFCS	135	109
Height of sigma surface	HEIGHT OF SIGMA SFCS	7	107
Temperature on sigma surface	TEMP ON SIGMA SFCS	11	107
Specific humidity on sigma surface	SPEC HUM ON S SFCS	51	107
U-wind on sigma surface	U WIND ON SIGMA SFCS	33	107
V-wind on sigma surface	V WIND ON SIGMA SFCS	34	107
Omega on sigma surface	OMEGA ON SIGMA SFCS	39	107
Cloud water on sigma surface	CLOUD WATR ON S SFCS	153	107
Cloud ice on sigma surface	CLOUD ICE ON S SFCS	58	107
Rain on sigma surface	RAIN ON S SFCS	170	107
Snow on sigma surface	SNOW ON S SFCS	171	107
Condensate on sigma surface	CONDENSATE ON S SFCS	135	107
Pressure on sigma surface	PRESS ON SIG SFCS	1	107

Turbulent kinetic energy on sigma surface	TRBLNT KE ON S SFCS	158	107
Cloud fraction on sigma surface	CLD FRAC ON SIG SFCS	71	107
Graupel on sigma surface	GRAUPEL ON S SFCS	179	107
LCL level pressure	LIFT PCL LVL PRESS	141	116
LOWEST WET BULB ZERO HEIGHT	LOW WET BULB ZERO HT	7	245
Leaf area index	LEAF AREA INDEX	182	1
Accumulated land surface model precipitation	ACM LSM PRECIP	154	1
In-flight icing	IN-FLIGHT ICING	186	100
Clear air turbulence	CLEAR AIR TURBULENCE	185	100
Wind shear between shelter level and 2000 FT	0-2000FT LLWS	136	106
Ceiling	CEILING	7	215
Flight restritction	FLIGHT RESTRICTION	20	2
Instantaneous clear sky incoming surface shortwave	INSTN CLR INC SFC SW	161	1
Pressure level riming factor for Ferrier's scheme	F_RimeF ON P SFCS	133	100
Model level vertical volocity	W WIND ON MDL SFCS	40	109
Brightness temperature	BRIGHTNESS TEMP	213	8
Average albedo	AVE ALBEDO	84	1
Ozone on model surface	OZONE ON MDL SFCS	154	109
Ozone on pressure surface	OZONE ON P SFCS	154	100
Surface zonal momentum flux	SFC ZONAL MOMEN FX	124	1
Surface meridional momentum flux	SFC MERID MOMEN FX	125	1
Average precipitation rate	AVE PRECIP RATE	59	1
Average convective precipitation rate	AVE CONV PRECIP RATE	214	1
Instantaneous outgoing longwave at top of atmosphere	INSTN OUT TOA LW RAD	212	8
Total spectrum brightness temperature	BRIGHTNESS TEMP NCAR	118	8
Model top pressure	MODEL TOP PRESSURE	1	8
Composite rain radar reflectivity	COMPOSITE RAIN REFL	165	200
Composite ice radar reflectivity	COMPOSITE ICE REFL	166	200
Composite radar reflectivity from convection	COMPOSITE CONV REFL	167	200
Rain radar reflecting angle	RAIN RADAR REFL AGL	165	105
Ice radar reflecting angle	ICE RADAR REFL AGL	166	105
Convection radar reflecting angle	CONV RADAR REFL AGL	167	105
Model level vertical velocity	W WIND ON P SFCS	40	100

Column integrated super cool liquid water	TOTAL COLD LIQUID	168	200
Column integrated melting ice	TOTAL MELTING ICE	169	200
Height of lowest level super cool liquid water	COLD LIQ BOT HEIGHT	7	253
Height of highest level super cool liquid water	COLD LIQ TOP HEIGHT	7	254
Richardson number planetary boundary layer height	RICH NO PBL HEIGHT	7	220
Total column shortwave temperature tendency	TOT COL SW T TNDY	250	200
Total column longwave temperature tendency	TOT COL LW T TNDY	251	200
Total column gridded temperature tendency	TOT COL GRD T TNDY	241	200
Total column convective temperature tendency	TOT COL CNVCT T TNDY	242	200
Radiative flux temperature tendency on pressure level	RADFLX TMP TNDY ON P	216	100
Column integrated moisture convergence	TOT COL MST CNVG	135	200
Time averaged clear sky incoming UV-B shortwave	AVE CLR INC UV-B SW	201	1
Time averaged incoming UV-B shortwave	AVE INC UV-B SW	200	1
Total column ozone	TOT COL OZONE	10	200
Average low cloud fraction	AVE LOW CLOUD FRAC	71	214
Average mid cloud fraction	AVE MID CLOUD FRAC	71	224
Average high cloud fraction	AVE HIGH CLOUD FRAC	71	234
Average low cloud bottom pressure	AVE LOW CLOUD BOT P	1	212
Average low cloud top pressure	AVE LOW CLOUD TOP P	1	213
Average low cloud top temperature	AVE LOW CLOUD TOP T	11	213
Average mid cloud bottom pressure	AVE MID CLOUD BOT P	1	222
Average mid cloud top pressure	AVE MID CLOUD TOP P	1	223
Average mid cloud top temperature	AVE MID CLOUD TOP T	11	223
Average high cloud bottom pressure	AVE HIGH CLOUD BOT P	1	232
Average high cloud top pressure	AVE HIGH CLOUD TOP P	1	233
Average high cloud top temperature	AVE HIGH CLOUD TOP T	11	233
Total column relative humidity	TOT COL REL HUM	52	200

Cloud work function	CLOUD WORK FUNCTION	146	200
Temperature at maximum wind level	MAX WIND TEMPERATURE	11	6
Time averaged zonal gravity wave stress	AVE Z GRAVITY STRESS	147	1
Time averaged meridional gravity wave stress	AVE M GRAVITY STRESS	148	1
Average precipitation type	AVE PRECIP TYPE	140	1
Simulated GOES 12 channel 2 brightness temperature	GOES TB – CH 2	213	8
Simulated GOES 12 channel 3 brightness temperature	GOES TB – CH 3	214	8
Simulated GOES 12 channel 4 brightness temperature	GOES TB – CH4	215	8
Simulated GOES 12 channel 5 brightness temperature	GOES TB – CH5	216	8
Cloud fraction on pressure surface	CLD FRAC ON P SFCS	71	100
U-wind on theta surface	U WIND ON THETA SFCS	33	113
V-wind on theta surface	V WIND ON THETA SFCS	34	113
Temperature on theta surface	TEMP ON THETA SFCS	11	113
Potential vorticity on theta surface	PV ON THETA SFCS	4	113
Montgomery streamfunction on theta surface	M STRMFUNC ON THETA	37	113
	S STAB ON THETA SFCS	19	113
Relative humidity on theta surface	RH ON THETA SFCS	52	113
U wind on constant PV surface	U WIND ON PV SFCS	33	117
V wind on constant PV surface	V WIND ON PV SFCS	34	117
Temperature on constant PV surface	TEMP ON PV SFCS	11	117
Height on constant PV surface	HEIGHT ON PV SFCS	7	117
Pressure on constant PV surface	PRESSURE ON PV SFCS	1	117
Wind shear on constant PV surface	SHEAR ON PV SFCS	136	117
Planetary boundary layer cloud fraction	PBL CLD FRACTION	71	211
Average water runoff	AVE WATER RUNOFF	90	1
Planetary boundary layer regime	PBL REGIME	220	1
Maximum 2m temperature	MAX SHELTER TEMP	15	105
Minimum 2m temperature	MIN SHELTER TEMP	16	105
Maximum 2m RH	MAX SHELTER RH	218	105
Minimum 2m RH	MIN SHELTER RH	217	105
Ice thickness	ICE THICKNESS	92	1
Shortwave tendency on pressure surface	SW TNDY ON P SFCS	250	100

Longwave tendency on pressure surface	LW TNDY ON P SFCS	251	100
Deep convective tendency on pressure surface	D CNVCT TNDY ON P SF	242	100
Shallow convective tendency on pressure surface	S CNVCT TNDY ON P SF	244	100
Grid scale tendency on pressure surface	GRDSCL TNDY ON P SFC	241	100
	VDIFF MOIS ON P SFCS	249	100
Deep convective moisture on pressure surface	D CNVCT MOIS ON P SF	243	100
Shallow convective moisture on pressure surface	S CNVCT MOIS ON P SF	245	100
Ozone tendency on pressure surface	OZONE TNDY ON P SFCS	188	100
Mass weighted potential vorticity	MASS WEIGHTED PV	139	100
Simulated GOES 12 channel 3 brightness count	GOES BRIGHTNESS-CH 3	221	8
Simulated GOES 12 channel 4 brightness count	GOES BRIGHTNESS-CH 4	222	8
Omega on theta surface	OMEGA ON THETA SFCS	39	113
Mixing height	MIXHT HEIGHT	67	1
Average clear-sky incoming longwave at surface	AVE CLR INC SFC LW	163	1
Average clear-sky incoming shortwave at surface	AVE CLR INC SFC SW	161	1
Average clear-sky outgoing longwave at surface	AVE CLR OUT SFC LW	162	1
Average clear-sky outgoing longwave at top of atmosphere	AVE CLR OUT TOA LW	162	8
Average clear-sky outgoing shortwave at surface	AVE CLR OUT SFC SW	160	1
Average clear-sky outgoing shortwave at top of atmosphere	AVE CLR OUT TOA SW	160	8
Average incoming shortwave at top of atmosphere	AVE INC TOA SW	204	8
Tranport wind u component	TRANSPORT U WIND	33	220
Transport wind v component	TRANSPORT V WIND	34	220
Sunshine duration	SUNSHINE DURATION	191	1
Field capacity	FIELD CAPACITY	220	1
ICAO height at maximum wind level	ICAO HGHT MAX WIND	5	6
ICAO height at tropopause	ICAO HGHT AT TROP	5	7
Radar echo top	RADAR ECHO TOP	240	200
Time averaged surface Visible	AVE IN SFC VIS SW BE	166	1

beam downward solar flux			
Time averaged surface Visible diffuse downward solar flux	AVE IN SFC VIS SW DF	167	1
Time averaged surface Near IR beam downward solar flux	AVE IN SFC IR SW BE	168	1
Time averaged surface Near IR diffuse downward solar flux	AVE IN SFC IR SW DF	169	1
Average snowfall rate	AVE SNOWFALL RATE	64	1
Dust 1 on pressure surface	DUST 1 ON P SFCS	240	100
Dust 2 on pressure surface	DUST 2 ON P SFCS	241	100
Dust 3 on pressure surface	DUST 3 ON P SFCS	242	100
Dust 4 on pressure surface	DUST 4 ON P SFCS	243	100
Dust 5 on pressure surface	DUST 5 ON P SFCS	244	100
Equilibrium level height	EQUIL LEVEL HEIGHT	7	247
Lightning	LIGHTNING	187	1
Goes west channel 2 brightness temperature	GOES W TB – CH 2	241	8
Goes west channel 3 brightness temperature	GOES W TB – CH 3	242	8
Goes west channel 4 brightness temperature	GOES W TB – CH 4	243	8
Goes west channel 5 brightness temperature	GOES W TB – CH 5	244	8
In flight icing from NCAR’s algorithm	NCAR IN-FLIGHT ICING	168	100
Specific humidity at flight levels	SPE HUM AT FD HEIGHT	51	103
Virtual temperature based convective available potential energy	TV CNVCT AVBL POT EN	202	1
Virtual temperature based convective inhibition	TV CNVCT INHIBITION	201	1
Ventilation rate	VENTILATION RATE	241	220
Haines index	HAINES INDEX	250	1
Simulated GOES 12 channel 2 brightness temperature with satellite angle correction	GOESE TB-2 NON NADIR	213	8
Simulated GOES 12 channel 3 brightness temperature with satellite angle correction	GOESE TB-3 NON NADIR	214	8
Simulated GOES 12 channel 4 brightness temperature with satellite angle correction	GOESE TB-4 NON NADIR	215	8
Simulated GOES 12 channel 5 brightness temperature with satellite angle correction	GOESE TB-5 NON NADIR	216	8

Simulated GOES 11 channel 2 brightness temperature with satellite angle correction	GOESW TB-2 NON NADIR	241	8
Simulated GOES 11 channel 3 brightness temperature with satellite angle correction	GOESW TB-3 NON NADIR	242	8
Simulated GOES 11 channel 4 brightness temperature with satellite angle correction	GOESW TB-4 NON NADIR	243	8
Simulated GOES 11 channel 5 brightness temperature with satellite angle correction	GOESW TB-5 NON NADIR	244	8
Pressure at flight levels	PRESS AT FD HEIGHTS	1	103
Simulated AMSR-E channel 9 brightness temperature	AMSRE TB – CH 9	176	8
Simulated AMSR-E channel 10 brightness temperature	AMSRE TB – CH 10	177	8
Simulated AMSR-E channel 11 brightness temperature	AMSRE TB – CH 11	178	8
Simulated AMSR-E channel 12 brightness temperature	AMSRE TB – CH 12	179	8
SSMI channel 4 brightness temperature	SSMI TB – CH 4	176	8
SSMI channel 5 brightness temperature	SSMI TB – CH 5	177	8
SSMI channel 6 brightness temperature	SSMI TB – CH 6	178	8
SSMI channel 7 brightness temperature	SSMI TB – CH 7	179	8
Time-averaged percentage snow cover	TIME AVG PCT SNW CVR	238	1
Time-averaged surface pressure	TIME AVG SFC PRESS	1	1
Time-averaged 10m temperature	TIME AVG TMP AT 10M	11	105
Time-averaged mass exchange coefficient	TAVG MASS EXCH COEF	185	1
Time-averaged wind exchange coefficient	TAVG WIND EXCH COEF	186	1
Temperature at 10m	TEMP AT 10 M	11	105
Maximum U-component wind at 10m	U COMP MAX 10 M WIND	253	105
Maximum V-component wind at 10m	V COMP MAX 10 M WIND	254	105

RIP4

RIP Introduction

RIP (which stands for Read/Interpolate/Plot) is a Fortran program that invokes NCAR Graphics routines for the purpose of visualizing output from gridded meteorological data sets, primarily from mesoscale numerical models. It can also be used to visualize model input or analyses on model grids.

RIP has been under continuous development since 1991, primarily by Mark Stoelinga at both NCAR and the University of Washington. It was originally designed for sigma-coordinate-level output from the PSU/NCAR Mesoscale Model (MM4/MM5), but was generalized in April 2003 to handle data sets with any vertical coordinate, and in particular, output from both the WRF-NMM and WRF-ARW modeling systems.

It is strongly recommended that users read the complete RIP User's Guide found at: http://www.mmm.ucar.edu/wrf/users/docs/ripug.pdf. A condensed version is given here for a quick reference.

RIP Software Requirements

The program is designed to be portable to any UNIX system that has a Fortran 77 or Fortran 90 compiler and the NCAR Graphics library (preferably 4.0 or higher). The NetCDF library is also required for I/O.

RIP Environment Settings

An important environment variable for the RIP system is ***RIP_ROOT***. ***RIP_ROOT*** should be assigned the path name of the directory where all the RIP program and utility files (*color.tbl*, *stationlist*, *.ascii* files, *psadilookup.dat*) will reside. The natural choice for the ***RIP_ROOT*** directory is the ***RIP*** subdirectory that is created after the RIP tar file is unpacked. For simplicity, define ***RIP_ROOT*** in one of the UNIX start-up files. For example, add the following to the shell configuration file (such as **.login** or **.cshrc**):

```
setenv RIP_ROOT /path-to/RIP
```

Obtaining the RIP Code

The RIP4 package can be downloaded from: http://www.dtcenter.org/wrf-nmm/users/downloads.

Once the ***tar*** file is obtained, ***gunzip*** and ***untar*** the file.

```
tar –zxvf RIP4_v4.4.TAR.gz
```

This command will create a directory called ***RIP***.

RIP Directory Structure

Under the main directory of ***RIP*** reside the following files and subdirectories:
:

- **CHANGES**, a text file that logs changes to the RIP tar file.
- **Doc**/, a directory that contains documentation of RIP, most notably the HTML version of the Users' Guide that you are now reading (*ripug.htm*).
- **Makefile**, the top-level make file used to compile and link RIP.
- **README**, a text file containing basic information on running RIP.
- **color.tbl**, a file that contains a table defining the colors you want to have available for RIP plots.
- **eta_micro_lookup.dat**, a file that contains "look-up" table data for the Ferrier microphysics scheme.
- **psadilookup.dat**, a file that contains "look-up" table data for obtaining temperature on a pseudoadiabat.
- **sample_infiles**/, a directory that contains sample user input files for RIP and related programs. These files include *bwave.in*, *grav2d_x.in*, *hill2d.in*, *qss.in*, *rip_sample.in*, *ripdp_wrfarw_sample.in*, *ripdp_wrfnmm_sample.in*, *sqx.in*, *sqy.in*, *tabdiag_sample.in*, and *tserstn.dat*.
- **src**/, a directory that contains all of the source code files for RIP, RIPDP, and several other utility programs. Most of these are Fortran 77 source code files with extension *.f*. In addition, there are:
    - a few *.h* and *.c* files, which are C source code files.
    - *comconst*, *commptf*, *comvctran*, and *CMASSI.comm*, which are include files that contain common blocks that are used in several routines in RIP.
    - *pointers*, an include file that contains pointer declarations used in some of the routines in RIP.
    - *Makefile*, a secondary make file used to compile and link RIP.
- **stationlist**, a file containing observing station location information.

Installing the RIP Code

RIP uses a build mechanism similar to that used by the WRF model. First issue the ***configure*** command, followed by the ***compile*** command.

./configure

Choose one of the configure options listed. Check the ***configure.rip*** file created and edit for compile options/paths, if necessary.

./compile >& compile_rip.log &

A successful compilation will result in the creation of several object files and executables in the ***RIP/src*** directory. The makefile is also set up to create symbolic links in the ***RIP*** directory to the actual executables in the ***RIP/src*** directory.

To remove all built files, as well as the ***configure.rip***, type:

> ***clean***

This action is recommended if a mistake is made during the installation process.

RIP Functionalities

RIP can be described as "quasi-interactive". You specify the desired plots by editing a formatted text file. The program is executed, and an NCAR Graphics CGM file is created, which can be viewed with any one of several different metacode translator applications. The plots can be modified, or new plots created, by changing the user input file and re-executing RIP. Some of the basic features of the program are outlined below:

- Uses a preprocessing program (called RIPDP) which reads model output, and converts this data into standard RIP format data files that can be ingested by RIP.
- Makes Lambert Conformal, Polar Stereographic, Mercator, or stretched-rotated-cyllindrical-equidistant (SRCE) map backgrounds, with any standard parallels.
- Makes horizontal plots of contours, color-filled contours, vectors, streamlines, or characters.
- Makes horizontal plots on model vertical levels, as well as on pressure, height, potential temperature, equivalent potential temperature, or potential vorticity surfaces.
- Makes vertical cross sections of contours, color-filled contours, full vectors, or horizontal wind vectors.
- Makes vertical cross sections using vertical level index, pressure, log pressure, Exner function, height, potential temperature, equivalent potential temperature, or potential vorticity as the vertical coordinate.
- Makes skew-*T*/log *p* soundings at points specified as grid coordinates, lat/lon coordinates, or station locations, with options to plot a hodograph or print sounding-derived quantities.
- Calculates backward or forward trajectories, including hydrometeor trajectories, and calculates diagnostic quantities along trajectories.
- Plots trajectories in plan view or vertical cross sections.
- Makes a data set for use in the Vis5D visualization software package.
- Allows for complete user control over the appearance (color, line style, labeling, etc.) of all aspects of the plots.

RIP Data Preparation (RIPDP)

RIP does not ingest model output files directly. First, a preprocessing step, RIPDP (which stands for RIP Data Preparation), must be executed which converts the model output data files to RIP-format data files. The primary difference between these two types of files is that model output is in NetCDF or GRIB format and may contain all times and all variables in a single file (or a few files), whereas RIP data has each variable at each time in a separate file in binary format.

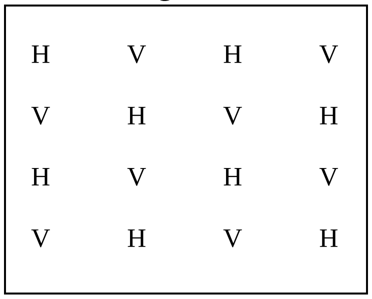
RIPDP reads in a model output file (or files), and separates out each variable at each time. There are several basic variables that RIPDP expects to find, and these are written out to files with names that are chosen by RIPDP (such as *uuu*, *vvv*, *prs*, etc.). These are the variable names that RIP users are familiar with. However, RIPDP can also process unexpected variables that it encounters in model output data files, creating RIP data file names for these variables from the variable name that is stored in the model output file metadata.

When you run ***make***, it should produce executable programs called ***ripdp_mm5***, ***ripdp_wrfarw***, and ***ripdp_wrfnmm***. Although these are three separate programs, they serve the same purpose, and only ***ripdp_wrfnmm*** will be described here.

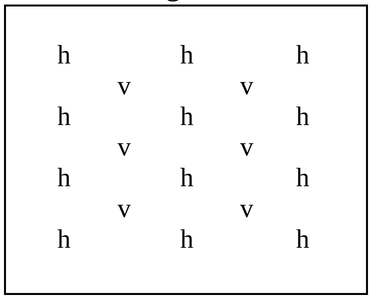
The WRF-NMM model uses a rotated latitude/longitude projection on the E-grid, both of which introduce special challenges for processing and plotting WRF-NMM data. RIPDP and RIP have been modified to handle the rotated latitude/longitude projection, however, the grid staggering in WRF-NMM requires additional data processing.

Because of its developmental history with the MM5 model, RIP is inextricably linked with an assumed B-grid staggering system. Therefore, the easiest way to deal with E-grid data is to make it look like B-grid data. This can be done in two ways, either of which the user can choose.

E-grid



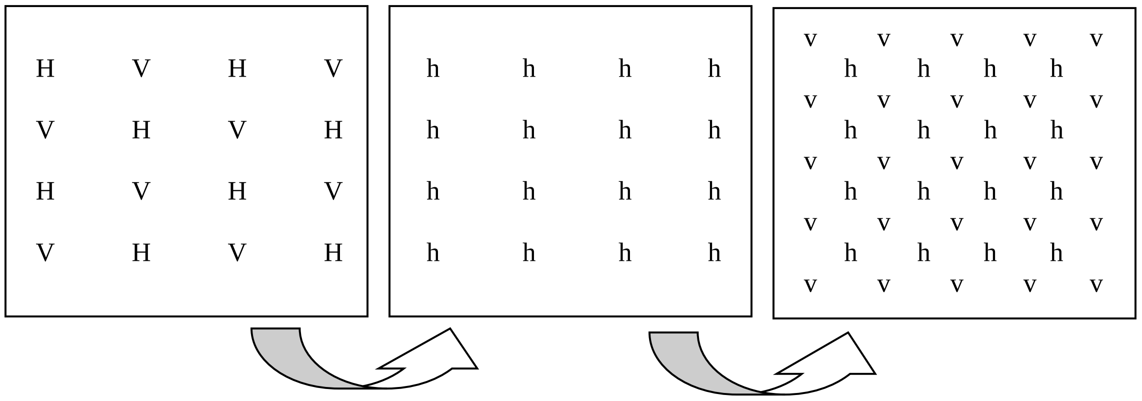
B-grid



In the first method (*iinterp=0*), we define a B-grid in which its mass (h) points collocate with all the mass (H) and velocity (V) points in the E-grid, and the B-grid's velocity (v) points are staggered in the usual B-grid way (see illustration below). The RIPDP-created data files retain only the E-grid data, but then when they are ingested into RIP, the E-grid H-point data are transferred directly to overlapping B-grid mass points, and non-overlapping B-grid mass points and all velocity points are interpolated from the E-grid's

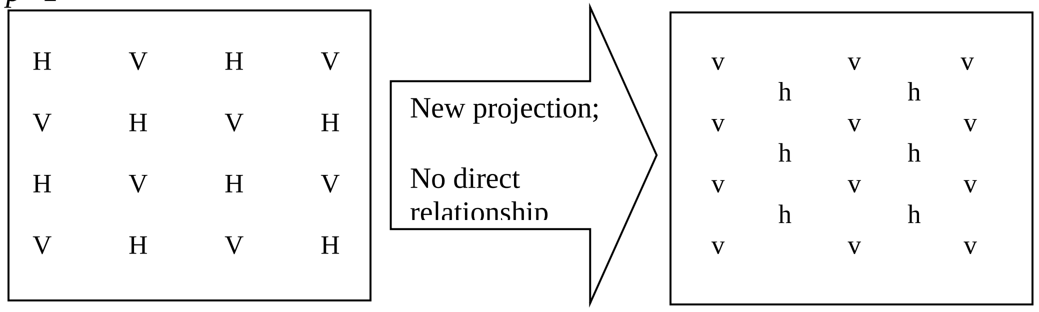
H and V points. This is the best way to retain as much of the exact original data as possible, but effectively doubles the number of horizontal grid points in RIP, which can be undesirable.

iinterp = 0



The second method (*iinterp=1*) is to define a completely new B-grid that has no relation to the E-grid points, possibly (or even preferably) including a different map background, but presumably with substantial overlap between the two grids, and a horizontal resolution similar to the effective resolution of the E-grid. The E-grid data is then bilinearly interpolated to the new B-grid in RIPDP and the new B-grid data is then written out to the RIPDP output data files. With this method, the fact that the original data was on the E-grid is completely transparent to the RIP plotting program.

iinterp=1



It should be noted that if *iinterp=1* is set, grid points in the new domain that are outside the original E-grid domain will be assigned a "missing value" by RIPDP. RIP (the plotting program) handles "missing value" data inconsistently. Some parts of the code are designed to deal with it gracefully, and other parts are not. Therefore, it is best to make sure that the new domain is entirely contained within the original E-grid domain. Unfortunately, there is no easy way to do this. RIPDP does not warn you when your new domain contains points outside the original E-grid. The best way to go about it is by trial and error: define an interpolation domain, run RIPDP, then plot a 2-D dot-point field such as map factor on dot points (*feld=dmap*) in color contours and see if any points do not get plotted. If any are missing, adjust the parameters for the interpolation domain and try again.

RIPDP Namelist

The namelist file for RIPDP contains the namelist ***&userin***. All of the ***&userin*** namelist variables are listed below. Each variable has a default value, which is the value this variable will take if its specification is omitted from the namelist. Additional details for each namelist variable can be found in Chapter 3 of the full RIP User's Guide.

Variable Name	**Default Value**	**Description**
ptimes	9.0E+09	Times to process. This can be a string of times or a series in the form of A,*-B*,*C*, which is interpreted as "times from hour *A* to hour *B*, every *C* hours".
ptimeunits	' h'	Units of *ptimes*. This can be either 'h' (for hours), 'm' (for minutes), or 's' (for seconds).
iptimes	99999999	Times to process in the form of 8-digit "mdate" times (i.e. YYMMDDHH). A value of 99999999 indicates *ptimes* is being used instead.
tacc	1.0	Time tolerance, in seconds. Any times encountered in the model output that are within *tacc* seconds of one of the times specified in *ptimes* or *iptimes* will be processed.
discard	' '	Names of variables that, if encountered in the model data file, will not be processed.
retain	' '	Names of variables that, if encountered in the model data file, should be processed, even though the user specified ***basic*** on the ***ripdp_wrfnmm*** command line.
iinterp	0	**NMM Only:** Method for defining B-grid (described above) 0 = Collocated high-density B-grid 1 = Interpolate to a new B-grid

If ***iinterp=1*** then the following namelist variables must also be set for the indicated domain on which the new B-grid will be based.

Variable Name	**Default Value**	**Description**
dskmcib	50.0	Grid spacing, in km, of the centered domain.
miycorsib, mjxcorsib	100	Grid points in the *y* and *x* directions, respectively, of the centered domain.
nprojib	1	Map projection number (0: none/ideal, 1: LC, 2: PS, 3: ME, 4: SRCE) of the centered domain.
xlatcib, xloncib	45.0, -90.0	Central latitude and longitude, respectively, for the centered domain.
truelat1ib, truelat2ib	30.0, 60.0	Two true latitudes for the centered domain.
miyib, mjxib	75	Number of grid points in the *y* and *x* directions, respectively, of the fine domain.
yicornib, xjcornib	25	Centered domain *y* and *x* locations, respectively, of the lower left corner point of the fine domain.
dskmib	25.0	Grid spacing, in km, of the fine domain.

An example of a namelist input file for ***ripdp_wrfnmm***, called ***ripdp_wrfnmm_sample.in***, is provided in the RIP tar file in the ***sample_infiles*** directory.

Running RIPDP

RIPDP has the following usage:

ripdp_wrfnmm *-n namelist_file model-data-set-name [**basic|all**] data_file_1 data_file_2 data_file_3 ...*

In order to provide the user more control when processing the data, a namelist needs to be specified by means of the *-n* option, with *namelist_file* specifying the path name of the file containing the namelist.

The argument *model-data-set-name* can be any string you choose, that uniquely defines the model output data set. It will be used in the file names of all the new RIP data files that are created.

The ***basic*** option causes ***ripdp_wrfnmm*** to process only the basic variables that RIP requires, whereas ***all*** causes ***ripdp_wrfnmm*** to process all variables encountered in the model output file. It produces files for those variables using the variable name provided in the model output to create the file name. If ***all*** is specified, the *discard* variable can be used in the RIPDP namelist to prevent processing of unwanted variables. However, if ***basic*** is specified, the user can request particular other fields (besides the basic fields) to be processed by setting a *retain* variable in the RIPDP namelist.

Finally, *data-file-1*, *data-file-2*, ... are the path names (either full or relative to the current working directory) of the model data set files, in chronological order. If model output exists for nested domains, RIPDP must be run for each domain separately and each run must be given a new *model-data-set-name*.

When the program is finished, a large number of files will have been created that will reside in the current working directory. This is the data that will be accessed by RIP to produce plots. See Appendix C in the full RIP user's guide for a description of how these files are named and the format of their contents.

RIP User Input File (UIF)

Once the RIP data has been created with RIPDP, the next step is to prepare the user input file (UIF) for RIP. This file is a text file which tells RIP what plots you want and how they should be plotted. A sample UIF, called ***rip_sample.in***, is provided in the RIP tar file.

A UIF is divided into two main sections. The first section specifies various general parameters about the set up of RIP in a namelist format. The second section is the plot specification section, which is used to specify what plots will be generated.

a. The namelist section

The first namelist in the UIF is called ***&userin***. A description of each variable is shown below. Each variable has a default value, which is the value this variable will take if its specification is omitted from the namelist. Additional details for each namelist variable can be found in Chapter 4 of the full RIP User's Guide.

Variable Name	**Default Value**	**Description**
idotitle, title	1, 'auto'	Control the first part of the first title line.
titlecolor	'def.foreground'	Specifies the color for the text in the title.
iinittime	1	If flag = 1, the initial date and time (in UTC) will be printed in the title.
ifcsttime	1	If flag = 1, the forecast lead time (in hours) will be printed in the title.
ivalidtime	1	If flag = 1, the valid date and time (in both UTC and local time) will be printed in the title.
inearesth	0	If flag = 1, plot valid time as two digits rather than 4 digits.
timezone	-7.0	Offset from Greenwich time (UTC) for the local time zone.
iusdaylightrule	1	If flag = 1, apply daylight saving rule.
ptimes	9.0E+09	Times to process. This can be a string of times or a series in the form of A,-*B*,*C*, which is interpreted as "times from hour *A* to hour *B*, every *C*

		hours".
ptimeunits	' h'	Units of *ptimes*. This can be either 'h' (for hours), 'm' (for minutes), or 's' (for seconds).
iptimes	99999999	Times to process in the form of 8-digit "mdate" times (i.e. YYMMDDHH). A value of 99999999 indicates *ptimes* is being used instead.
tacc	1.0	Time tolerance, in seconds. Any times encountered in the model output that are within *tacc* seconds of one of the times specified in *ptimes* or *iptimes* will be processed.
flmin, ***frmax***, ***fbmin***, and ***ftmax***	0.05,0.95,0.10,0.90	Left frame limit, right frame limit, bottom frame limit, and top frame limit, respectively.
ntextq	0	Text quality specifier [0=high; 1=medium; 2=low].
ntextcd	0	Text font specifier [0=complex (Times); 1=duplex (Helvetica)].
fcoffset	0.0	Change initial time to something other than output initial time.
idotser	0	If flag = 1, generate time series ASCII output files (no plots).
idescriptive	1	If flag = 1, use more descriptive plot titles.
icgmsplit	0	If flag = 1, split metacode into several files.
maxfld	10	Reserve memory for RIP.
itrajcalc	0	If flag = 1, turns on trajectory calculation (use ***&trajcalc*** namelist as well).
imakev5d	0	If flag = 1, generates output for Vis5D.
rip_root	'/dev/null'	Over-ride the path name specified in UNIX environment variable ***RIP_ROOT***.

The second namelist in the UIF is called ***&trajcalc***. This section is ignored by RIP if *itrajcalc*=0. Trajectory calculation mode and use of the ***&trajcalc*** namelist are described in the Calculating and Plotting Trajectories with RIP section and in Chapter 6 of the full RIP User's Guide.

b. The plot specification table

The plot specification table (PST) provides user control over particular aspects of individual frames and overlays. The basic structure of the PST is as follows. The first line of the PST is a line of consecutive equal signs. This line, as well as the next two lines, is ignored–they are simply a banner that indicates a PST. Following that there are several groups of one or more lines separated by a full line of equal signs. Each group of lines is a frame specification group (FSG), because it describes what will appear in a frame. A frame is defined as one frame of metacode. Each FSG must be ended with a full line of equal signs–that is how RIP knows that it has reached the end of the FSG. (Actually, RIP only looks for four consecutive equal signs, but the equal signs are continued to the end of the line for cosmetic purposes.) Each line within the FSG is a plot specification line (PSL), because it describes what will appear in a plot. A plot is defined as one call to a major plotting routine (e.g. a contour plot, a vector plot, a map background, etc.). Hence, a FSG that has three PSLs in it will result in a frame that has three overlaid plots.

Each PSL contains several plot specification settings (PSSs), of the form

keyword = value [,value,value,...]

where *keyword* is a 4-character code word that refers to a specific aspect of the plot. Some keywords need one value, some need two, and some need an arbitrary number of values. Keywords that require more than one value should have those values separated by commas. All the PSSs within a PSL must be separated by semicolons, but the final PSS in a PSL must have no semicolon after it–this is how RIP identifies the end of the PSL. Any amount of white space (i.e., blanks or tabs) is allowed anywhere in a PSS or PSL, because all white space will be removed after the line is read into RIP. The use of white space can help make your PST more readable. The order of the PSSs in a PSL does not matter, though the common convention is to first specify the *feld* keyword, then the *ptyp* keyword, and then other keywords in no particular order.

A PSL may be as long as 240 characters, including spaces. However, if you want to keep all your text within the width of your computer screen, then a "greater than" symbol (>) at the end of the line can be used to indicate that the PSL will continue onto the next line. You may continue to the next line as many times as you want for a PSL, but the total length of the PSL cannot exceed 240 characters.

Any line in the PST can be commented out, simply by putting a pound sign (#) anywhere in the line (at the beginning makes the most sense). Note that the pound sign only comments out the line, which is not necessarily the same as the PSL. If the PSL is continued onto another line, both lines must be commented out in order to comment out the entire PSL. A partial PSL will likely cause a painful error in RIP. If all the PSLs in a FSG are commented out, then the line of equal signs at the end of the FSG should also be commented out.

There is a special keyword, *incl*, which allows the user to tell RIP to insert (at run time) additional information from another file into the plot specification table. This capability makes it easier to repeat large sections of plot specification information in a single input file, or to maintain a library of "canned" plot specifications that can be easily included in different input files. The *incl* keyword is described in more detail in Appendix A in the full RIP User's Guide.

Each keyword has a variable associated with it in the program, and this variable may be of type integer, real, character, logical, or array. The keywords that are associated with a real variable expect values that are of Fortran floating point format. The keywords that are associated with an integer variable also expect values that are of Fortran floating point format because they are initially read in as a floating point number, and then rounded (not truncated) to the nearest integer. The keywords that are associated with a character variable expect values that are character strings. They should NOT be in single quotes, and should also not have any blank characters, commas, or semicolons in them. The keywords that are associated with a logical variable should not have any value. They are set as .FALSE. by default, and simply the fact that the keyword appears will cause the associated variable to be set to .TRUE.. The keywords that are associated with an array (of any type) may expect more than one value. The values should be separated by commas, as mentioned above.

All keywords are set to a default value prior to the reading of the PST. With regard to the default setting of keywords, there are two basic types of keywords; those that "remember" their values, and those that "forget" their values. The type that remembers its value is set to its default value only at the outset, and then it simply retains its value from one PSL to the next (and even from one FSG to the next) unless it is explicitly changed by a PSS. The type that forgets its value is reset to its default value after every PSL. Keywords that remember are primarily those that deal with location (e.g. the subdomain for horizontal plots, the vertical coordinate and levels for horizontal plots, cross section end points, etc.).

This section has described the basic rules to follow in creating the PST. Appendix A in the full RIP User's Guide provides a description of all of the available keywords, in alphabetical order.

Running RIP

Each execution of RIP requires three basic things: a RIP executable, a model data set and a user input file (UIF). Assuming you have followed the procedures outlined in the previous sections, you should have all of these. The UIF should have a name of the form *rip-execution-name.in*, where *rip-execution-name* is a name that uniquely defines the UIF and the set of plots it will generate. The syntax for the executable, ***rip***, is as follows:

rip *[-f] model-data-set-name rip-execution-name*

In the above, *model-data-set-name* is the same *model-data-set-name* that was used in creating the RIP data set with the program ***ripdp***. The *model-data-set-name* may also include a path name relative to the directory you are working in, if the data files are not in your present working directory. Again, if nested domains were run, ***rip*** will be run for each domain separately. The *rip-execution-name* is the unique name for this RIP execution, and it also defines the name of the UIF that RIP will look for. The intended syntax is to exclude the *.in* extension in *rip-execution-name*. However, if you include it by mistake, RIP will recognize it and proceed without trouble. The ***–f*** option causes the standard output (i.e., the textual print out) from RIP to be written to a file called *rip-execution-name.out*. Without the ***–f*** option, the standard output is sent to the screen. The standard output from RIP is a somewhat cryptic sequence of messages that shows what is happening in the program execution.

As RIP executes, it creates either a single metacode file or a series of metacode files, depending on whether or not *icgmsplit* was set to 0 or 1 in the ***&userin*** namelist. If only one file was requested, the name of that metacode file is *rip-execution-name.cgm*. If separate files were requested for each plot time, they are named *rip-execution-name.cgmA*, *rip-execution-name.cgmB*, etc.

Although the metacode file has a *.cgm* suffix, it is not a standard computer graphics metacode (CGM) file. It is an NCAR CGM file that is created by the NCAR Graphics plotting package. It can be viewed with any of the standard NCAR CGM translators, such as ***ctrans***, ***ictrans***, or ***idt***.

A common arrangement is to work in a directory that you've set up for a particular data set, with your UIFs and plot files (*.cgm* files) in that directory, and a subdirectory called ***data*** that contains the large number of RIP data files

Calculating and Plotting Trajectories with RIP

Because trajectories are a unique feature of RIP and require special instructions to create, this section is devoted to a general explanation of the trajectory calculation and plotting utility. RIP deals with trajectories in two separate steps, each of which requires a separate execution of the program.

a. Trajectory calculation

The first step is trajectory calculation, which is controlled exclusively through the namelist. No plots are generated in a trajectory calculation run. In order to run RIP in trajectory calculation mode, the variable ***itrajcalc*** must be set to 1 in the ***&userin*** namelist. All other variables in the ***&userin*** part of the namelist are ignored. The ***&trajcalc*** part of the namelist contains all the information necessary to set up the trajectory calculation run. The following is a description of the variables that need to be set in the ***&trajcalc*** section:

Variable Name	**Description**
rtim	The release time (in forecast hours) for the trajectories.
ctim	The completion time (in forecast hours) for the trajectories. Note: If *rtim<ctim*, trajectories are forward. If *rtim>ctim*, trajectories are backward.
dtfile	The time increment (in seconds) between data files.
dttraj	The time step (in seconds) for trajectory calculation.

vctraj	The vertical coordinate of values specified for *zktraj*. ‘s’: *zktraj* values are model vertical level indices ‘p’: *zktraj* values are pressure values, in mb ‘z’: *zktraj* values are height values, in km ‘m’: *zktraj* values are temperature values, in C ‘t’: *zktraj* values are potential temperature values, in K ‘e’: *zktraj* values are equivalent potential temperature values, in K
ihydrometeor	If flag=1, trajectory calculation algorithm uses the hydrometeor fall speed instead of the vertical air velocity.
xjtraj,yitraj	*x* and *y* values (in grid points) of the initial positions of the trajectories.
zktraj	Vertical location of the initial points of the trajectories.

It is also possible to define a 3D array of trajectory initial points, without having to specify the [x,y,z] locations of every point. The grid can be of arbitrary horizontal orientation. To define the grid, you must specify the first seven values of *xjtraj* as follows: The first two values should be the *x* and *y* values of the lower left corner of the trajectory horizontal grid. The next two values should be the *x* and *y* values of another point defining the positive x-axis of the trajectory grid (i.e., the positive x-axis will point from the corner point to this point). The fifth value should be the trajectory grid spacing, in model grid lengths. The final two values should be the number of points in the *x* and *y* directions of the trajectory horizontal grid. The first value of *xjtraj* should be negative, indicating that a grid is to be defined (rather than just individual points), but the absolute value of that value will be used. Any *yitraj* values given are ignored. The *zktraj* values specify the vertical levels of the 3D grid to be defined. Note that any vertical coordinate may still be used if defining a 3D grid of trajectories.

If no diagnostic quantities along the trajectories are desired, the PST is left blank (except that the first three lines comprising the PST banner are retained). If diagnostic quantities are desired, they can be requested in the PST (although no plots will be produced by these specifications, since you are running RIP in trajectory calculation mode). Since no plots are produced, only a minimum of information is necessary in the PST. In most cases, only the *feld* keyword needs to be set. For some fields, other keywords that affect the calculation of the field should be set (such as *strm*, *rfst*, *crag*, *crbg*, *shrd*, *grad*, *gdir*, *qgsm*, *smcp*, and *addf*). Keywords that only affect how and where the field is plotted can be omitted.

Any of the diagnostic quantities listed in Appendix B of the full RIP User’s Guide can be calculated along trajectories, with the exception of the Sawyer-Eliassen diagnostics. Each desired diagnostic quantity should be specified in its own FSG (i.e. only one *feld*= setting between each line of repeated equal signs). The only exception to this is if you are using the *addf* keyword. In that case, all of the plot specification lines (PSLs) corresponding to the fields being added (or subtracted) should be in one FSG.

Once the input file is set up, RIP is run as outlined in the Running RIP section. Since no plots are generated when RIP is run in trajectory calculation mode, no *rip-execution-name.cgm* file is created. However, two new files are created that are not in a regular (non-trajectory-calculation) execution of RIP. The first is a file that contains the positions of all the requested trajectories at all the trajectory time steps, called *rip-execution-name.traj*. The second is a file that contains requested diagnostic quantities along the trajectories at all data times during the trajectory period, called *rip-execution-name.diag*. The *.diag* file is only created if diagnostic fields were requested in the PST.

b. Trajectory plotting

Once the trajectories have been calculated, they can be plotted in subsequent RIP executions. Because the plotting of trajectories is performed with a different execution of RIP than the trajectory calculation, the plotting run should have a different *rip-execution-name* than any previous trajectory calculation runs.

Trajectories are plotted by including an appropriate PSL in the PST. There are three keywords that are necessary to plot trajectories, and several optional keywords. The necessary keywords are *feld*, *ptyp*, and *tjfl*. Keyword *feld* should be set to one of five possibilities: *arrow*, *ribbon*, *swarm*, *gridswarm*, or *circle* (these fields are described in detail below). Keyword *ptyp* should be set to either *ht* (for "horizontal trajectory plot") or *vt* (for "vertical (cross section) trajectory plot"). And keyword *tjfl* tells RIP which trajectory position file you want to access for the trajectory plot.

As mentioned above, there are four different representations of trajectories, as specified by the *feld* keyword:

- ***feld=arrow***: This representation shows trajectories as curved arrows, with arrowheads drawn along each trajectory at a specified time interval. If the plot is a horizontal trajectory plot (*ptyp=ht*), the width of each arrowhead is proportional to the height of the trajectory at that time. If the plot is a vertical (cross section) trajectory plot (*ptyp=vt*), the width of each arrowhead is constant. The arrowhead that corresponds to the time of the plot is boldened.
- ***feld=ribbon***: This representation shows trajectories as curved ribbons, with arrowheads drawn along each trajectory at a specified time interval. If the plot is a horizontal trajectory plot (*ptyp=ht*), the width of each arrowhead, and the width of the ribbon, is proportional to the height of the trajectory at that time. If the plot is a vertical (cross section) trajectory plot (*ptyp=vt*), the width of each arrowhead (and the ribbon) is constant. The arrowhead that corresponds to the time of the plot is boldened.
- ***feld=swarm***: This representation shows a group of trajectories attached to each other by straight lines at specified times. The trajectories are connected to each other in the same order at each time they are plotted, so that the time evolution of a material curve can be depicted. Swarms can be plotted either as horizontal or vertical trajectory plots (*ptyp=ht* or *ptyp=vt*).

- ***feld=gridswarm***: This is the same as *swarm*, except it works on the assumptioin that part or all of the trajectories in the position file were initially arranged in a row-oriented 2-D array, or "gridswarm". The evolution of this gridswarm array is depicted as a rectangular grid at the initial time, and as a deformed grid at other specified times. The gridswarm being plotted can have any orientation in 3D space, although the means to create arbitrarily oriented gridswarms when RIP is used in trajectory calculation mode are limited. Creative use of the "3D grid of trajectories" capability descirbed above under the description of *zktraj* can be used to initialize horizontal gridswarms of arbitrary horizontal orientation (but on constant vertical levels).
- ***feld=circle***: This representation shows the trajectories as circles located at the positions of the trajectories at the current plotting time, in which the diameter of the circles is proportional to the net ascent of the trajectories (in terms of the chosen vertical coordinate) during the specified time interval. It is only available as a horizontal trajectory plot (*ptyp=ht*).

See “Keywords”, in Appendix A in the full RIP User’s Guide for more details on optional keywords that affect trajectory plots.

c. Printing out trajectory positions

Sometimes, you may want to examine the contents of a trajectory position file. Since it is a binary file, the trajectory position file cannot simply be printed out. However, a short program is provided in the ***src/*** directory in the RIP tar file called ***showtraj.f***, which reads the trajectory position file and prints out its contents in a readable form. The program should have been compiled when you originally ran ***make***, and when you run ***showtraj***, it prompts you for the name of the trajectory position file to be printed out.

d. Printing out diagnostics along trajectories

As mentioned above, if fields are specified in the PST for a trajectory calculation run, then RIP produces a *.diag* file that contains values of those fields along the trajectories. This file is an unformatted Fortran file, so another program is required to view the diagnostics. Among the Fortran files included in the ***src*** directory in the RIP tar file is ***tabdiag.f*** which serves this purpose. It is compiled when ***make*** is run.

In order to use the program, you must first set up a special input file that contains two lines. The first line should be the column headings you want to see in the table that will be produced by ***tabdiag***, with the entire line enclosed in single quotes. The second line is a Fortran I/O format string, also enclosed in single quotes, which determines how the diagnostic values are printed out. An example of an input file for ***tabdiag*** is included in the RIP tar file, called ***tabdiag.in***.

Once the input file is set up, ***tabdiag*** is run as follows:

> ***tabdiag*** *diagnostic-output-file tabdiag-input-file*

The result will be a text file with a table for each trajectory, showing the time evolution of the diagnostic quantities. Some adjustment of the column headings and format statement will probably be necessary to make it look just right.

Creating Vis5D Dataset with RIP

Vis5D is a powerful visualization software package developed at the University of Wisconsin, and is widely used by mesoscale modelers to perform interactive 3D visualization of model output. Although it does not have the flexibility of RIP for producing a wide range of 2D plot types with extensive user control over plot details, its 3D visualization capability and fast interactive response make it an attractive complement to RIP.

A key difference between RIP and Vis5D is that RIP was originally developed specifically for scientific diagnosis and operational display of mesoscale modeling system output. This has two important implications: (1) The RIP system can ingest model output files, and (2) RIP can produce a wide array of diagnostic quantities that mesoscale modelers want to see. Thus, it makes sense to make use of these qualities to have RIP act as a bridge between a mesoscale model and the Vis5D package. For this reason, a Vis5D-format data-generating capability was added to RIP. With this capability, you can create a Vis5D data set from your model data set, including any diagnostic quantities that RIP currently calculates.

The Vis5D mode in RIP is switched on by setting *imakev5d*=1 in the ***&userin*** namelist in the UIF. All other variables in the ***&userin*** part of the namelist are ignored. No plots are generated in Vis5D mode. The desired diagnostic quantities are specified in the PST with only a minimum of information necessary since no plots are produced. In most cases, only the *feld* keyword needs to be set, and vertical levels should be specified with *levs* (in km) for the first field requested. The vertical coordinate will automatically be set to 'z', so there is no need to set *vcor=z*. The levels specified with *levs* for the first requested field will apply to all 3D fields requested, so the *levs* specification need not be repeated for every field. You are free to choose whatever levels you wish, bearing in mind that the data will be interpolated from the data set's vertical levels to the chosen height levels.

For some fields, other keywords that affect the calculation of the field should be set (such as *strm*, *rfst*, *crag*, *crbg*, *shrd*, *grad*, *gdir*, *qgsm*, *smcp*, and *addf*). Keywords that only affect how and where the field is plotted can be omitted. Any of the diagnostic quantities listed in Appendix B in the full RIP User’s Guide can be added to the Vis5D data set, with the exception of the Sawyer-Eliassen diagnostics. Each desired diagnostic quantity should be specified in its own FSG (i.e. only one *feld*= setting between each line of repeated equal signs). The only exception to this is if you are using the *addf* keyword. In that case, all of the plot specification lines (PSLs) corresponding to the fields being added (or subtracted) should be in one FSG.

Once the user input file is set up, RIP is run as outlined in the Running RIP section. Since no plots are generated when RIP is run in Vis5D mode, no *rip-execution-name.cgm* file is created. However, a file is created with the name *rip-execution-name.v5d*. This file is the Vis5D data set which can be used by the Vis5D program to interactively display your model data set.

The map projection information will automatically be generated by RIP and be included in the Vis5D data set. Therefore, you don't have to explicitly request *feld=map* in the PST. However, there are some complications with converting the map background, as specified in RIP, to the map background parameters required by Vis5D. Currently, RIP can only make the conversion for Lambert conformal maps, and even that conversion does not produce an exact duplication of the correct map background.

Vis5D also has its own terrain data base for producing a colored terrain-relief map background--you don't need to specifically request *feld=ter* to get this. However, if you want to look at the actual model terrain as a contour or color-filled field, you should add *feld=ter* to your PST.