WRF Data Assimilation System

Xin Zhang Xiang-Yu Huang

NCAR Earth System Laboratory

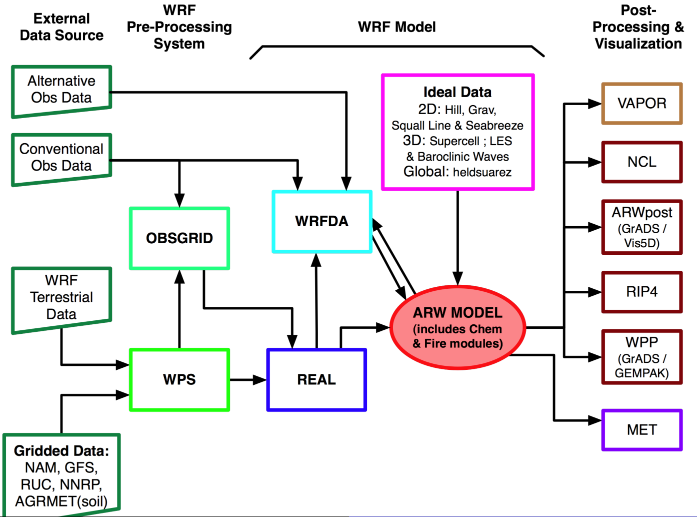
6th East Asia WRF Tutorial, SNU

NCAR is sponsored by the National Science Foundation

What is WRFDA ?

- WRFDA : A Data Assimilation system for WRF (ARW) model
  - Variational and Ensemble methods
  - Used for both research and operational data analysis
- It is a supported community model, i.e. a free and shared resource with distributed development and centralized support

WRF Modeling System Flow Chart


External Data Source
WRF Pre-Processing System
WRF Model
Post-Processing & Visualization
Alternative Obs Data
Conventional Obs Data
WRF Terrestrial Data
Gridded Data: NAM, GFS, RUC, NNRP, AGRMET(soil)
OBSGRID
WPS
WRFDA
REAL
Ideal Data
2D: Hill, Grav, Squall Line & Seabreeze
3D: Supercell ; LES & Baroclinic Waves
Global: heldsuarez
ARW MODEL (includes Chem & Fire modules)
VAPOR
NCL
ARWpost (GrADS / Vis5D)
RIP4
WPP (GrADS / GEMPAK)
MET

WRFDA formulation

$$J = \frac{1}{2}(\mathbf{x} - \mathbf{x}_b)^T \mathbf{B}^{-1} (\mathbf{x} - \mathbf{x}_b) + \frac{1}{2}[\mathbf{y}_o - H(\mathbf{x})]^T \mathbf{R}^{-1} [\mathbf{y}_o - H(\mathbf{x})]$$

Define the first guess of the n^{th} outer loop: $\mathbf{x}_{n-1}$, note: $\mathbf{x}_0 = \mathbf{x}_b$

$$\begin{aligned} J = {} & \frac{1}{2}(\mathbf{x}_n - \mathbf{x}_{n-1} + \mathbf{x}_{n-1} - \mathbf{x}_b)^T \mathbf{B}^{-1} (\mathbf{x}_n - \mathbf{x}_{n-1} + \mathbf{x}_{n-1} - \mathbf{x}_b) \\ & + \frac{1}{2}[\mathbf{y}_o - H(\mathbf{x}_n)]^T \mathbf{R}^{-1} [\mathbf{y}_o - H(\mathbf{x}_n)] \end{aligned}$$

Define analysis increment of n^{th} outer loop: $\delta\mathbf{x}_n = \mathbf{x}_n - \mathbf{x}_{n-1}$

$$\begin{aligned} J = {} & \frac{1}{2}(\delta\mathbf{x}_n + \mathbf{x}_{n-1} - \mathbf{x}_b)^T \mathbf{B}^{-1} (\delta\mathbf{x}_n + \mathbf{x}_{n-1} - \mathbf{x}_b) \\ & + \frac{1}{2}[\mathbf{y}_o - H(\mathbf{x}_{n-1} + \delta\mathbf{x}_n)]^T \mathbf{R}^{-1} [\mathbf{y}_o - H(\mathbf{x}_{n-1} + \delta\mathbf{x}_n)] \end{aligned}$$

Define innovation : $\mathbf{d}_n = \mathbf{y}_o - H_{n-1}(\mathbf{x}_{n-1})$

$$J = \frac{1}{2}(\delta\mathbf{x}_n + \mathbf{x}_{n-1} - \mathbf{x}_b)^T\mathbf{B}^{-1}(\delta\mathbf{x}_n + \mathbf{x}_{n-1} - \mathbf{x}_b) + \frac{1}{2}[\mathbf{d}_n - \mathbf{H}_{n-1}(\delta\mathbf{x}_n)]^T\mathbf{R}^{-1}[\mathbf{d}_n - \mathbf{H}_{n-1}(\delta\mathbf{x}_n)]$$

$\mathbf{H}_{n-1} = \frac{\partial H_{n-1}}{\partial \mathbf{x}_{n-1}}$ is the tangent linear observational operator
To find the $\delta\mathbf{x}_n$ which lead J to minimium:

$$\nabla_{\delta\mathbf{x}_n} J = 0$$

$$\nabla_{\delta\mathbf{x}_n} J = \mathbf{B}^{-1}(\delta\mathbf{x}_n + \mathbf{x}_{n-1} - \mathbf{x}_b) - \mathbf{H}_{n-1}^T\mathbf{R}^{-1}(\mathbf{d}_n - \mathbf{H}_{n-1}(\delta\mathbf{x}_n))$$

At the minimium, $\nabla_{\delta \mathbf{x}_n} J$ vanishes:

$$(\mathbf{B}^{-1} + \mathbf{H}_{n-1}^T \mathbf{R}^{-1} \mathbf{H}_{n-1}) \delta \mathbf{x}_n = \mathbf{H}_{n-1}^T \mathbf{R}^{-1} \mathbf{d}_n - \mathbf{B}^{-1} (\mathbf{x}_{n-1} - \mathbf{x}_b)$$

Then

$$\delta \mathbf{x}_n = (\mathbf{B}^{-1} + \mathbf{H}_{n-1}^T \mathbf{R}^{-1} \mathbf{H}_{n-1})^{-1} [\mathbf{H}_{n-1}^T \mathbf{R}^{-1} \mathbf{d}_n - \mathbf{B}^{-1} (\mathbf{x}_{n-1} - \mathbf{x}_b)]$$

With the Woodbury Matrix Identity formulation:

$$(\mathbf{A} + \mathbf{UCV})^{-1} = \mathbf{A}^{-1} - \mathbf{A}^{-1} \mathbf{U} (\mathbf{C}^{-1} + \mathbf{V} \mathbf{A}^{-1} \mathbf{U})^{-1} \mathbf{V} \mathbf{A}^{-1}$$

$$(\mathbf{B}^{-1} + \mathbf{H}_{n-1}^T \mathbf{R}^{-1} \mathbf{H}_{n-1})^{-1} = \mathbf{B} - \mathbf{B} \mathbf{H}_{n-1}^T (\mathbf{R} + \mathbf{H}_{n-1} \mathbf{B} \mathbf{H}_{n-1}^T)^{-1} \mathbf{H}_{n-1} \mathbf{B}$$

WRFDA formulation

$$\begin{aligned}\delta \mathbf{x}_n =& [\mathbf{B} - \mathbf{B}\mathbf{H}_{n-1}^T(\mathbf{R} + \mathbf{H}_{n-1}\mathbf{B}\mathbf{H}_{n-1}^T)^{-1}\mathbf{H}_{n-1}\mathbf{B}] \\ & [\mathbf{H}_{n-1}^T\mathbf{R}^{-1}\mathbf{d}_n - \mathbf{B}^{-1}(\mathbf{x}_{n-1} - \mathbf{x}_b)]\end{aligned}$$

$$\begin{aligned}\delta \mathbf{x}_n =& \mathbf{B}\mathbf{H}_{n-1}^T(\mathbf{R} + \mathbf{H}_{n-1}\mathbf{B}\mathbf{H}_{n-1}^T)^{-1}[\mathbf{d}_n + \mathbf{H}_{n-1}(\mathbf{x}_{n-1} - \mathbf{x}_b)] \\ & - (\mathbf{x}_{n-1} - \mathbf{x}_b)\end{aligned}$$

Please note that the new analysis is :

$$\mathbf{x}_a = \delta \mathbf{x} + \mathbf{x}_{n-1}$$

For first outer loop, $\mathbf{x}_0 = \mathbf{x}_b$ and $\mathbf{d} = \mathbf{y}_o - H(\mathbf{x}_b)$

$$J = \frac{1}{2}\delta\mathbf{x}^T\mathbf{B}^{-1}\delta\mathbf{x} + \frac{1}{2}(\mathbf{d} - \mathbf{H}\delta\mathbf{x})^T\mathbf{R}^{-1}(\mathbf{d} - \mathbf{H}\delta\mathbf{x})$$

$$\nabla_{\delta\mathbf{x}}J = \mathbf{B}^{-1}\delta\mathbf{x} - \mathbf{H}^T\mathbf{R}^{-1}(\mathbf{d} - \mathbf{H}\delta\mathbf{x})$$

$$\delta\mathbf{x} = \mathbf{B}\mathbf{H}^T(\mathbf{R} + \mathbf{H}\mathbf{B}\mathbf{H}^T)^{-1}\mathbf{d}$$

B in WRFDA

- Partly for preconditioning reasons:
  $\mathbf{B} = \mathbf{U}\mathbf{U}^T$ with $\mathbf{U} = \mathbf{U}_p$
- Horizontal transform $(\mathbf{U}_h)$ is via
  - Regional - recursive filters
  - Global - power spectrum
- Vertical transform $(\mathbf{U}_v)$ is via
  - cv3 - recursive filters
  - cv5&6 - via EOF
- Physical transformation $(\mathbf{U}_p)$ depends upon the choice of the analysis control variable

Cost function in WRFDA

- Define: $\delta\mathbf{x} = \mathbf{U}\mathbf{v}$
- $\mathbf{v}$ is the analysis increment in control variable space
  - streamfunction
  - unbalanced velocity potential
  - unbalanced temperature
  - RH
  - unbalanced surface pressure
- The actual cost function in WRFDA :

$$J = \frac{1}{2}\mathbf{v}^T\mathbf{v} + \frac{1}{2}(\mathbf{d} - \mathbf{H}\mathbf{U}\mathbf{v})^T\mathbf{R}^{-1}(\mathbf{d} - \mathbf{H}\mathbf{U}\mathbf{v})$$

$$\mathbf{x}_a = \mathbf{U}\mathbf{v} + \mathbf{x}_{n-1}$$

Prepare the BE

$$J = \frac{1}{2}\mathbf{v}^T\mathbf{v} + \frac{1}{2}(\mathbf{d} - \mathbf{H}\mathbf{U}\mathbf{v})^T\mathbf{R}^{-1}(\mathbf{d} - \mathbf{H}\mathbf{U}\mathbf{v})$$

- Nominally, $\mathbf{B} = \mathbf{U}\mathbf{U}^T$ is the background error covariance
- For initial testing, default background error statistics may be used
    - be.dat file (CV option 5) from test case tar file can only be used with the case of online tutorial
    - be.dat.cv3 (CV option 3) from source code tar file can be used for general test domains, tuning is still needed for satisfied performance
- Ultimately, **B** should be specific to the particular model domain (and season)

Prepare the Background

$$J = \frac{1}{2}\mathbf{v}^T\mathbf{v} + \frac{1}{2}(\mathbf{d} - \mathbf{H}\mathbf{U}\mathbf{v})^T\mathbf{R}^{-1}(\mathbf{d} - \mathbf{H}\mathbf{U}\mathbf{v})$$

$$\mathbf{U}\mathbf{v} = \mathbf{x} - \mathbf{x}_b$$

- In cold-start mode: accomplished by running the WPS and real programs
  - The background is the wrfinput_d01 file
- In cycling mode: the output of the WRF model
  - WRF can output wrfinput-formatted files used for cycling

Prepare the Observations & Errors

$$J = \frac{1}{2}\mathbf{v}^T\mathbf{v} + \frac{1}{2}(\mathbf{d} - \mathbf{HUv})^T\mathbf{R}^{-1}(\mathbf{d} - \mathbf{HUv})$$

$$\mathbf{d} = \mathbf{y} - H(\mathbf{x}_b)$$

- Conventional observation input for WRFDA is supplied through
  - Little_R format, observation preprocessor, OBSPROC
  - Prepbufr format data directly
- Observation error covariance also provided by OBSPROC (R is a diagonal matrix)
- Separate input file (ASCII) for radar, both reflectivity and radial velocity
- Separate input file for satellite radiances, BUFR format

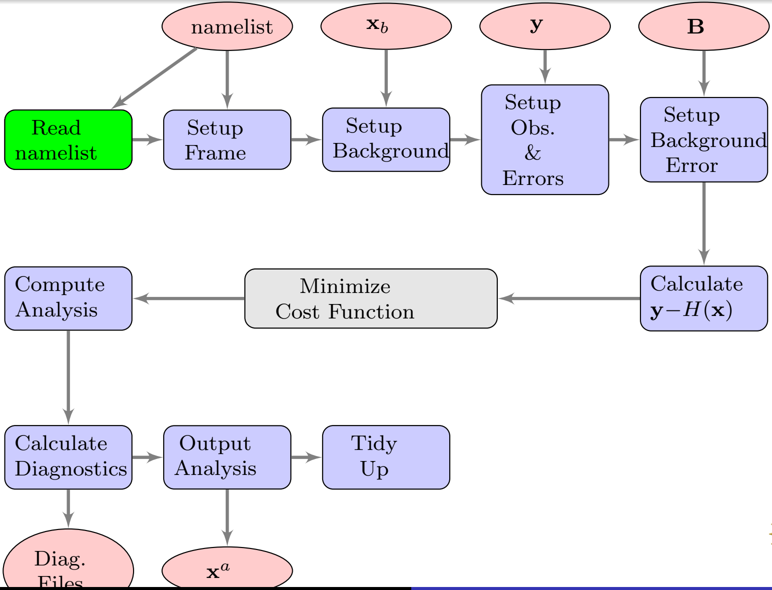
Run WRFDA

$$J = \frac{1}{2}\mathbf{v}^T\mathbf{v} + \frac{1}{2}(\mathbf{d} - \mathbf{HU}\mathbf{v})^T\mathbf{R}^{-1}(\mathbf{d} - \mathbf{HU}\mathbf{v})$$

- H is the observational operator, which calculate the counterpart of observations in model space
- Conjuagate gradient method
- Try to find a $\mathbf{v}$, which minimizes J and then $\mathbf{x}_a = \mathbf{U}\mathbf{v} + \mathbf{x}_{n-1}$

Update Boundary Condition

- After creating an analysis, $\mathbf{x}_a$, we have changed the initial conditions for the model
- However, tendencies in wrfbdy_d01 file are valid for background, $\mathbf{x}_b$
- The update_bc program adjusts these tendencies based on the difference $\mathbf{x}_a - \mathbf{x}_b$
- Of course, if $\mathbf{x}_a$ was produced for reasons other than running WRF, there is probably not a need to update boundary conditions



namelist

$\mathbf{x}_b$

$\mathbf{y}$

$\mathbf{B}$

Read namelist

Setup Frame

Setup Background

Setup Obs. & Errors

Setup Background Error

Calculate $\mathbf{y}-H(\mathbf{x})$

Minimize Cost Function

Compute Analysis

Calculate Diagnostics

Output Analysis

Tidy Up

Diag. Files

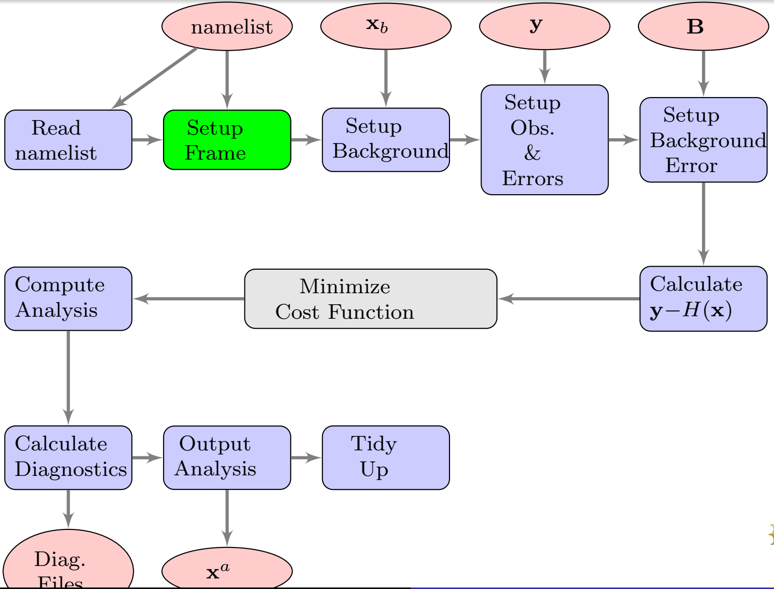
$\mathbf{x}^a$

Read namelist

- Reads WRFDA data assimilation options from *namelist.input* file
- Performs consistency checks between namelist options.

```
Calling order:
da_wrfvar_main ==> call da_wrfvar_init1, da_wrfvar_init2 ==> call initial_config


Calling subroutines:
da_wrfvar_main.f90 ==> da_wrfvar_init1.inc, da_wrfvar_init2.inc ==> module_configure.F
```

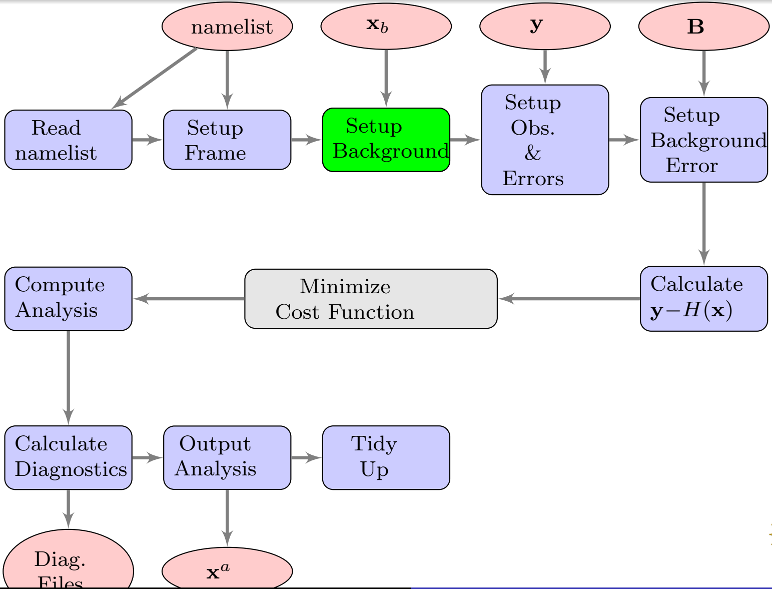

namelist
$\mathbf{x}_b$
$\mathbf{y}$
$\mathbf{B}$
Read namelist
Setup Frame
Setup Background
Setup Obs. & Errors
Setup Background Error
Calculate $\mathbf{y}-H(\mathbf{x})$
Minimize Cost Function
Compute Analysis
Calculate Diagnostics
Output Analysis
Tidy Up
Diag. Files
$\mathbf{x}^a$

Setup Frame

- Use WRF framework distributed memory capability to initialize tile, memory, patch dimensions, etc.

```
Calling order:
da_wrfvar_main ==> call da_wrfvar_init2 ==> call alloc_and_configure_domain
da_wrfvar_main ==> call da_wrfvar_run.inc ==> call da_wrfvar_interface ==> call da_solve
 ==> call da_solve_init


Calling subroutines:
da_wrfvar_main.f90 ==> da_wrfvar_init2.inc ==> module_domain.F
da_wrfvar_main.f90 ==> da_wrfvar_run.inc ==> da_wrfvar_interface.inc ==> da_solve.inc
==> da_solve_init.inc
```

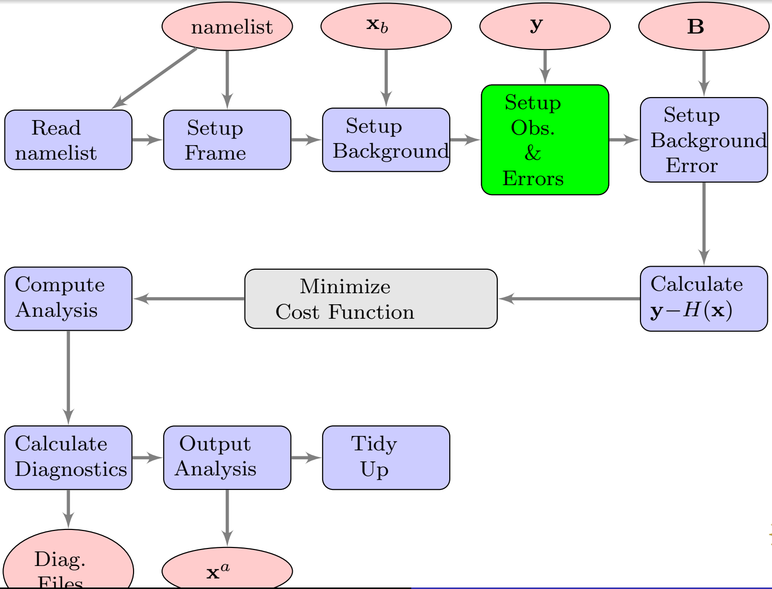

namelist
$\mathbf{x}_b$
$\mathbf{y}$
$\mathbf{B}$
Read namelist
Setup Frame
Setup Background
Setup Obs. & Errors
Setup Background Error
Calculate $\mathbf{y}-H(\mathbf{x})$
Minimize Cost Function
Compute Analysis
Calculate Diagnostics
Output Analysis
Tidy Up
Diag. Files
$\mathbf{x}^a$

Setup Background

- Reads the first-guess file
- Extracts fields used by WRFDA
- Creates background FORTRAN 90 derived data type xb etc.

```
Calling order:
da_wrfvar_main ==> call da_wrfvar_init2 ==> call da_med_initialdata_input
da_wrfvar_main ==> call da_wrfvar_run ==> call da_wrfvar_interface ==> call da_solve
==>call da_setup_firstguess
```

```
Calling subroutines:
da_wrfvar_main.f90 ==> da_wrfvar_init2.inc ==> da_med_initialdata_input.inc
da_wrfvar_main.f90 ==> da_wrfvar_run.inc ==> da_wrfvar_interface.inc ==> da_solve.inc
==>da_setup_firstguess.inc
```

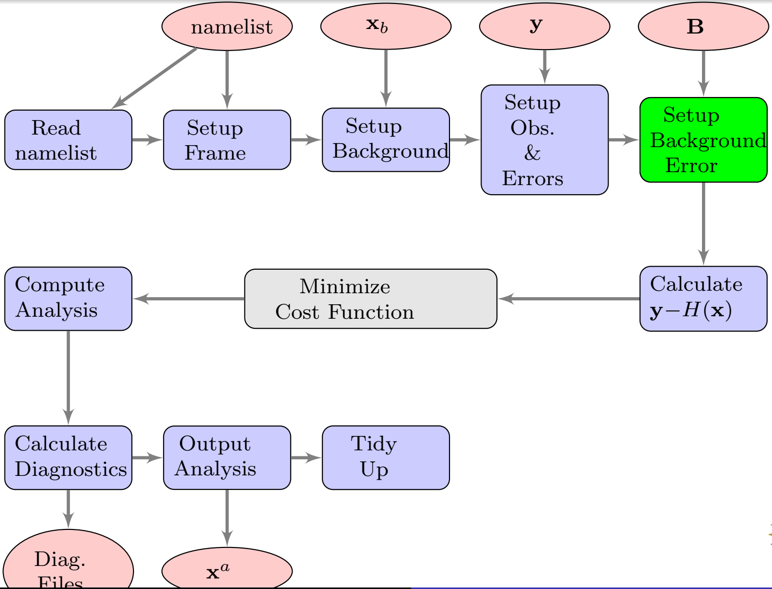

namelist
$\mathbf{x}_b$
$\mathbf{y}$
$\mathbf{B}$
Read namelist
Setup Frame
Setup Background
Setup Obs. & Errors
Setup Background Error
Calculate $\mathbf{y}-H(\mathbf{x})$
Minimize Cost Function
Compute Analysis
Calculate Diagnostics
Output Analysis
Tidy Up
Diag. Files
$\mathbf{x}^a$

Setup Observations & Errors

- Reads in observations
- Assign observational error
- Creates observation FORTRAN 90 derived data type *ob*
- Domain and time check

```
Calling order:
da_wrfvar_main ==> call da_wrfvar_run ==> call da_wrfvar_interface ==> call da_solve
==>call da_setup_obs_structures
```

```
Calling subroutines:
da_wrfvar_main.f90 ==> da_wrfvar_run.inc ==> da_wrfvar_interface.inc ==> da_solve.inc
==>da_setup_obs_structures.inc
```

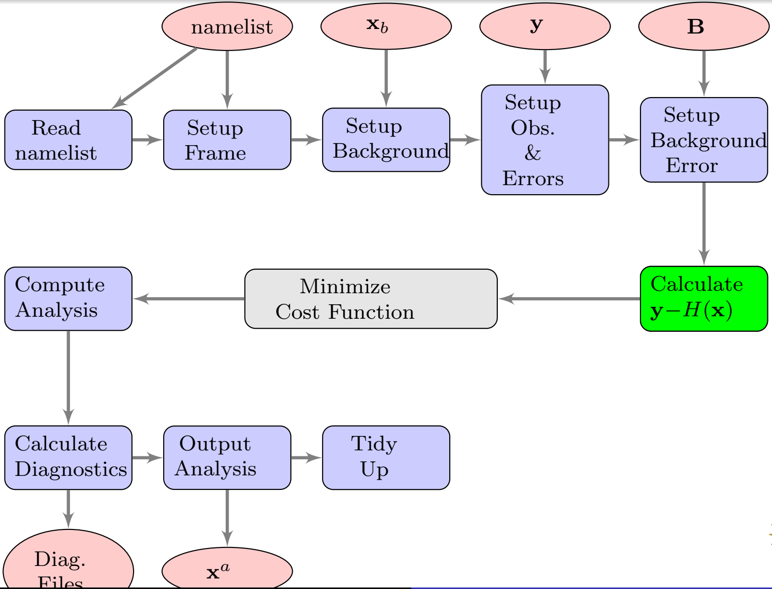

namelist
$\mathbf{x}_b$
$\mathbf{y}$
$\mathbf{B}$
Read namelist
Setup Frame
Setup Background
Setup Obs. & Errors
Setup Background Error
Calculate $\mathbf{y} - H(\mathbf{x})$
Minimize Cost Function
Compute Analysis
Calculate Diagnostics
Output Analysis
Tidy Up
Diag. Files
$\mathbf{x}^a$

Setup Background Error

- Reads in background error statistics
- Extracts necessary quantities: eigenvectors, eigenvalues, lengthscales, regression coefficients, etc.
- Creates background error FORTRAN 90 derived data type *be*
- Reference :**Online BE Documents**

```
Calling order:
da_wrfvar_main ==> call da_wrfvar_run ==> call da_wrfvar_interface ==> call da_solve
==>call da_setup_background_errors
```

```
Calling subroutines:
da_wrfvar_main.f90 ==> da_wrfvar_run.inc ==> da_wrfvar_interface.inc ==> da_solve.inc
==>da_setup_background_errors.inc
```

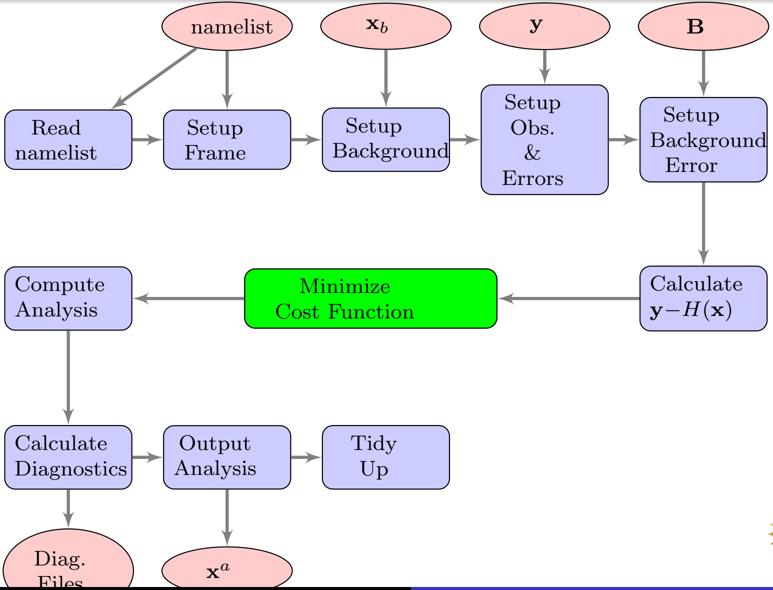

namelist
$\mathbf{x}_b$
$\mathbf{y}$
$\mathbf{B}$
Read namelist
Setup Frame
Setup Background
Setup Obs. & Errors
Setup Background Error
Calculate $\mathbf{y} - H(\mathbf{x})$
Minimize Cost Function
Compute Analysis
Calculate Diagnostics
Output Analysis
Tidy Up
Diag. Files
$\mathbf{x}^a$

Calculate Innovation

- Calculates model equivalent of observations through interpolation and change of variable
- Computes observation minus first guess $(\mathbf{y} - H(\mathbf{x}))$ value
- Creates innovation vector FORTRAN 90 derived data type iv

```
Calling order:
da_wrfvar_main ==> call da_wrfvar_run ==> call da_wrfvar_interface ==> call da_solve
==>call da_get_innov_vector, da_allocate_y
```

```
Calling subroutines:
da_wrfvar_main.f90 ==> da_wrfvar_run.inc ==> da_wrfvar_interface.inc ==> da_solve.inc
==>da_get_innov_vector.inc, da_allocate_y.inc
```


namelist
$\mathbf{x}_b$
$\mathbf{y}$
$\mathbf{B}$
Read namelist
Setup Frame
Setup Background
Setup Obs. & Errors
Setup Background Error
Calculate $\mathbf{y}-H(\mathbf{x})$
Minimize Cost Function
Compute Analysis
Calculate Diagnostics
Output Analysis
Tidy Up
Diag. Files
$\mathbf{x}^a$

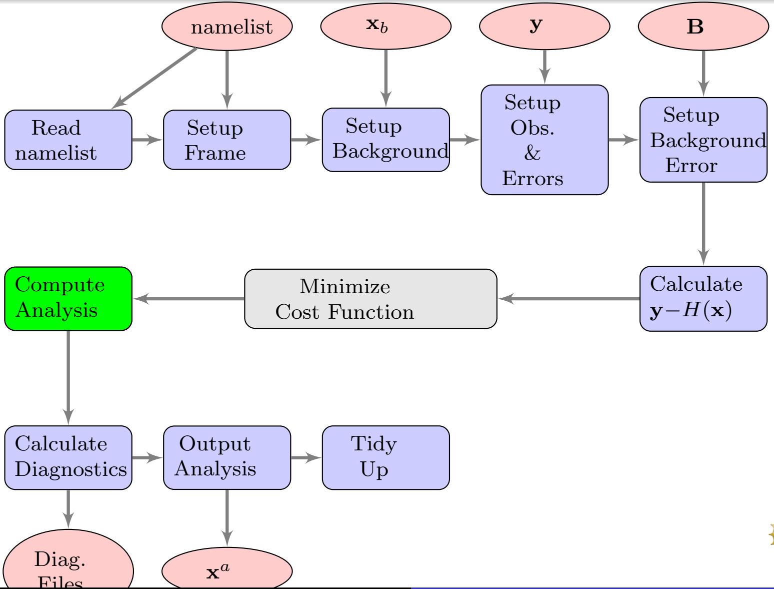
Minimization

Use conjugate gradient method

- Initializes analysis increments to zero
- Computes cost function (if desired)
- Computes gradient of cost function
- Uses cost function and gradient to calculate new value of analysis control variable

```
Calling order:
da_wrfvar_main ==> call da_wrfvar_run ==> call da_wrfvar_interface ==> call da_solve
==>call da_minimise_cg


Calling subroutines:
da_wrfvar_main.f90 ==> da_wrfvar_run.inc ==> da_wrfvar_interface.inc ==> da_solve.inc
==>da_minimise_cg.inc
```

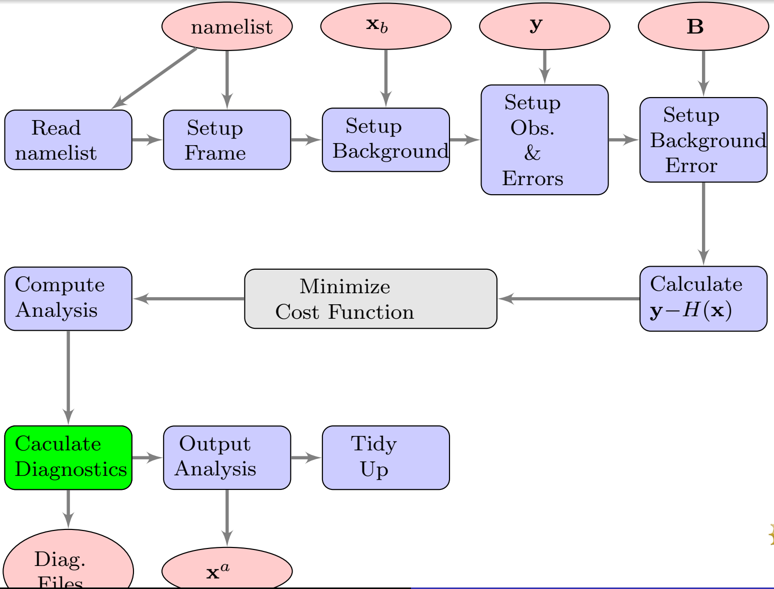

namelist
$\mathbf{x}_b$
$\mathbf{y}$
$\mathbf{B}$
Read namelist
Setup Frame
Setup Background
Setup Obs. & Errors
Setup Background Error
Calculate $\mathbf{y} - H(\mathbf{x})$
Minimize Cost Function
Compute Analysis
Calculate Diagnostics
Output Analysis
Tidy Up
Diag. Files
$\mathbf{x}^a$

Compute Analysis

- Once WRFDA has found a converged control variable, convert control variable to model space analysis increments
- Calculate:
  analysis = first-guess + analysis increment
- Performs consistency checks, e.g., remove negative humidity etc.
- Optionally, do outer loop

```
Calling order:
da_wrfvar_main ==> call da_wrfvar_run ==> call da_wrfvar_interface ==> call da_solve
==>call da_transfer_xatoanalysis
```

```
Calling subroutines:
da_wrfvar_main.f90 ==> da_wrfvar_run.inc ==> da_wrfvar_interface.inc ==> da_solve.inc
==>da_transfer_xatoanalysis.inc
```

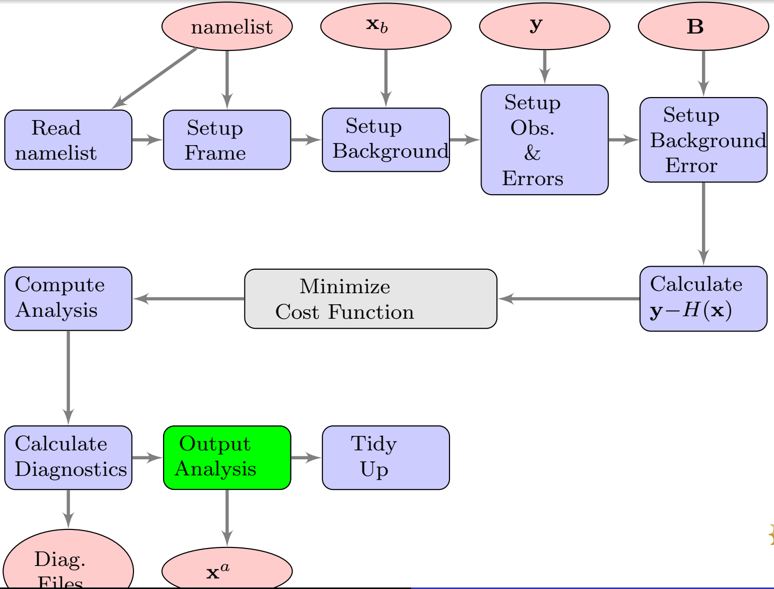

namelist
$\mathbf{x}_b$
$\mathbf{y}$
$\mathbf{B}$
Read namelist
Setup Frame
Setup Background
Setup Obs. & Errors
Setup Background Error
Calculate $\mathbf{y}-H(\mathbf{x})$
Minimize Cost Function
Compute Analysis
Caculate Diagnostics
Output Analysis
Tidy Up
Diag. Files
$\mathbf{x}^a$

Calculate Diagnostics

- Output $\mathbf{y} - H(\mathbf{x}_b)$, $\mathbf{y} - H(\mathbf{x}^a)$ statistics for all observation types and variables
- Compute $\mathbf{x}^a - \mathbf{x}_b$ (analysis increment) statistics for all model variables and levels
- Statistics include minimum, maximum (and their locations), mean and standard deviation.

```
Calling order:
da_wrfvar_main ==> call da_wrfvar_run ==> call da_wrfvar_interface ==> call da_solve
==> call da_write_diagnostics


Calling subroutines:
da_wrfvar_main.f90 ==> da_wrfvar_run.inc ==> da_wrfvar_interface.inc ==> da_solve.inc
==> da_write_diagnostics.inc
```

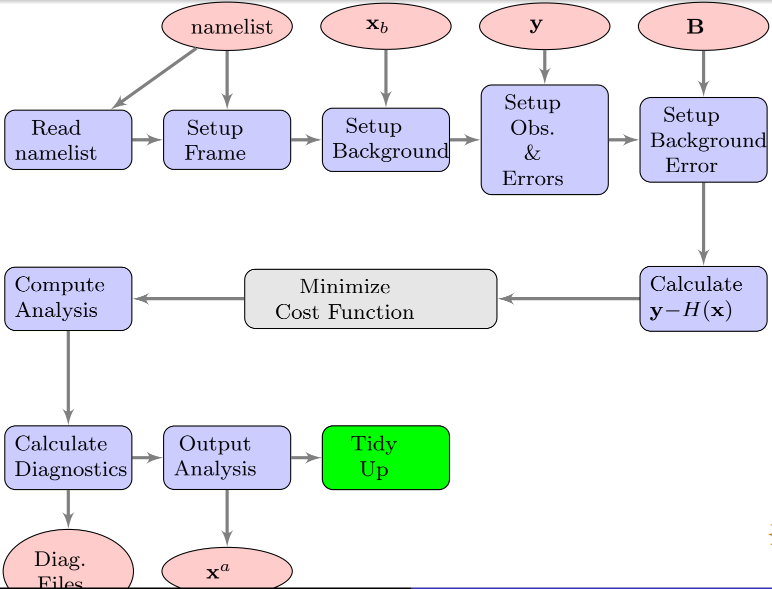

namelist
$\mathbf{x}_b$
$\mathbf{y}$
$\mathbf{B}$
Read namelist
Setup Frame
Setup Background
Setup Obs. & Errors
Setup Background Error
Calculate $\mathbf{y}-H(\mathbf{x})$
Minimize Cost Function
Compute Analysis
Calculate Diagnostics
Output Analysis
Tidy Up
Diag. Files
$\mathbf{x}^a$

Output Analysis

- Outputs analysis in native model format.

```
Calling order:
da_wrfvar_main ==> call da_wrfvar_run ==> call da_wrfvar_interface ==> call da_solve
==> call da_med_initialdata_output


Calling subroutines:
da_wrfvar_main.f90 ==> da_wrfvar_run.inc ==> da_wrfvar_interface.inc ==> da_solve.inc
==> da_med_initialdata_output.inc
```

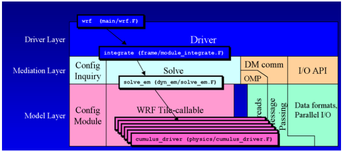

namelist
$\mathbf{x}_b$
$\mathbf{y}$
$\mathbf{B}$
Read namelist
Setup Frame
Setup Background
Setup Obs. & Errors
Setup Background Error
Calculate $\mathbf{y}-H(\mathbf{x})$
Minimize Cost Function
Compute Analysis
Calculate Diagnostics
Output Analysis
Tidy Up
Diag. Files
$\mathbf{x}^a$

Tidy Up

- Deallocate dynamically-allocated arrays, structures, etc.
- Timing information
- Clean end to WRFDA

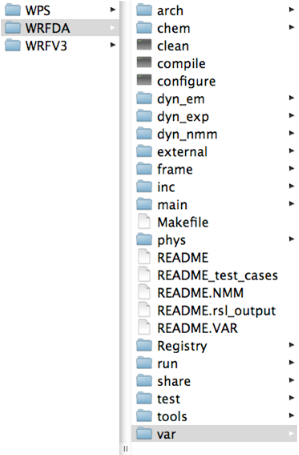
```
Calling subroutines:
da_wrfvar_main.f90 ==> da_wrfvar_run.inc ==> da_wrfvar_interface.inc ==> da_solve.inc
==> deallocate ....
```

WRFDA Software Framework



- WRFDA relies on the WRF Software framework for
  - Distributed memory parallelism (halo exchanges, etc.)
  - Input/Output of first guess and analysis files
  - Parallel transposes
- WRFDA also uses
  - The WRF Registry mechanism to handle definitions of fields, halos, type, package and transposes (Registry.wrfvar)
  - The WRF build system (clean, configure, compile)

WRFDA Code Organization

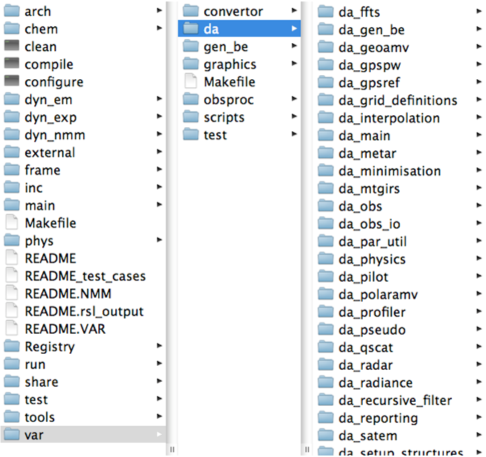


```
WPS      ▸   arch              ▸
WRFDA    ▸   chem              ▸
WRFV3    ▸   clean
             compile
             configure
             dyn_em            ▸
             dyn_exp           ▸
             dyn_nmm           ▸
             external          ▸
             frame             ▸
             inc               ▸
             main              ▸
             Makefile
             phys              ▸
             README
             README_test_cases
             README.NMM
             README.rsl_output
             README.VAR
             Registry          ▸
             run               ▸
             share             ▸
             test              ▸
             tools             ▸
             var               ▸
```

Remarks

Besides the directories for WRF, the WRFDA tar file contains a *var* directory, which holds all of the WRFDA code

WRFDA Code Organization



- arch
- chem
- clean
- compile
- configure
- dyn_em
- dyn_exp
- dyn_nmm
- external
- frame
- inc
- main
- Makefile
- phys
- README
- README_test_cases
- README.NMM
- README.rsl_output
- README.VAR
- Registry
- run
- share
- test
- tools
- var

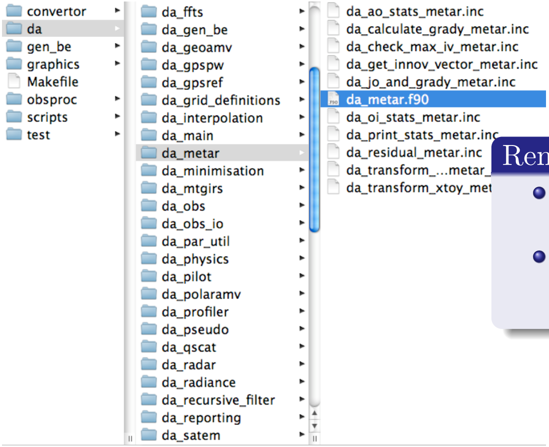
- convertor
- da
- gen_be
- graphics
- Makefile
- obsproc
- scripts
- test

- da_ffts
- da_gen_be
- da_geoamv
- da_gpspw
- da_gpsref
- da_grid_definitions
- da_interpolation
- da_main
- da_metar
- da_minimisation
- da_mtgirs
- da_obs
- da_obs_io
- da_par_util
- da_physics
- da_pilot
- da_polaramv
- da_profiler
- da_pseudo
- da_qscat
- da_radar
- da_radiance
- da_recursive_filter
- da_reporting
- da_satem
- da_setup_structures

Remarks

Generally, each subdirectory of *da* contains a Fortran module with the same name

WRFDA Code Organization



```
convertor
da
gen_be
graphics
Makefile
obsproc
scripts
test
```

```
da_ffts
da_gen_be
da_geoamv
da_gpspw
da_gpsref
da_grid_definitions
da_interpolation
da_main
da_metar
da_minimisation
da_mtgirs
da_obs
da_obs_io
da_par_util
da_physics
da_pilot
da_polaramv
da_profiler
da_pseudo
da_qscat
da_radar
da_radiance
da_recursive_filter
da_reporting
da_satem
```

```
da_ao_stats_metar.inc
da_calculate_grady_metar.inc
da_check_max_iv_metar.inc
da_get_innov_vector_metar.inc
da_jo_and_grady_metar.inc
da_metar.f90
da_oi_stats_metar.inc
da_print_stats_metar.inc
da_residual_metar.inc
da_transform_...metar_
da_transform_xtoy_met
```

Remarks

- da_metar.f90 contains a Fortran module
- Each .inc file corresponds to a subroutine within the module

How to add a new observation in WRFDA

A example of adding TAMDAR data, contributed by Dr. Hongli Wang

```
1. define_structures
     da/da_define_structures/da_deallocate_y.inc
     da/da_define_structures/da_zero_y.inc
     da/da_define_structures/da_deallocate_observations.inc
     da/da_define_structures/da_allocate_y.inc
     da/da_define_structures/da_allocate_observations.inc
     da/da_define_structures/da_define_structures.f90
     da/da_setup_structures/da_setup_obs_structures.inc
     da/da_setup_structures/da_setup_structures.f90
2. da_obs_io
     da/da_obs_io/da_search_obs.inc
     da/da_obs_io/da_write_filtered_obs.inc
     da/da_obs_io/da_read_obs_ascii.inc
     da/da_obs_io/da_scan_obs_ascii.inc
     da/da_obs_io/da_obs_io.f90
3. da_obs
     da/da_obs/da_random_omb_all.inc
     da/da_obs/da_add_noise_to_ob.inc
     da/da_obs/da.obs.f90
     da/da_obs/da_count_filtered_obs.inc
     da/da_obs/da_transform_xtoy_adj.inc
     da/da_obs/da_use_obs_errfac.inc
     da/da_obs/da_fm_decoder.inc
```

How to add a new observation in WRFDA, cont'd

```
     da/da_obs/da_fill_obs_structures.inc
     da/da_obs/da_transform_xtoy.inc
4. da_tamdar
     da/da_tamdar/da_ao_stats_tamdar.inc
     da/da_tamdar/da_calculate_grady_tamdar.inc
     da/da_tamdar/da_check_max_iv_tamdar.inc
     da/da_tamdar/da_get_innov_vector_tamdar.inc
     da/da_tamdar/da_jo_and_grady_tamdar.inc
     da/da_tamdar/da_jo_tamdar_uvtq.inc
     da/da_tamdar/da_oi_stats_tamdar.inc
     da/da_tamdar/da_print_stats_tamdar.inc
     da/da_tamdar/da_residual_tamdar.inc
     da/da_tamdar/da_tamdar.f90
     da/da_tamdar/da_transform_xtoy_tamdar.inc
     da/da_tamdar/da_transform_xtoy_tamdar_adj.inc
5. da_minimisation
     da/da_minimisation/da_calculate_grady.inc
     da/da_minimisation/da_calculate_residual.inc
     da/da_minimisation/da_minimisation.f90
     da/da_minimisation/da_get_innov_vector.inc
     da/da_minimisation/da_get_var_diagnostics.inc
     da/da_minimisation/da_jo_and_grady.inc
     da/da_minimisation/da_write_diagnostics.inc
 6. control/regestry/compile
     da/da_control/da_control.f90
     Registry/Registry.wrfvar
     da/Makefile
```

How to add a new observation in WRFDA, cont'd

```
7. da_test
      da/da_test/da_check_xtoy_adjoint_tamdar.inc
      da/da_test/da_test.f90
      da/da_test/da_check_xtoy_adjoint.inc
      da/da_test/da_get_y_lhs_value.inc
8. obsproc
      obsproc/src/3dvar_obs.F90
      obsproc/src/fm_decoder.F90
      obsproc/src/sort_platform.F90
      obsproc/src/module_decoded.F90
      obsproc/src/module_write.F90
      obsproc/src/module_complete.F90
      obsproc/src/module_duplicate.F90
      obsproc/src/platform_interface.inc
      obsproc/src/module_namelist.F90
      obsproc/src/module_err_afwa.F90
      obsproc/src/module_per_type.F90
      obsproc/src/module_qc.F90
      Registry/Registry.wrfvar
tamdar_sfc
      da/da_define_structures/da_define_structures.f90
      da/da_control/da_control.f90
      da/da_define_structures/da_allocate_y.inc
      da/da_define_structures/da_deallocate_observations.inc
      da/da_define_structures/da_deallocate_y.inc
      da/da_define_structures/da_zero_y.inc
```

Quick Start

- Supported compilation mechanisms
  - Serial
  - Distributed-memory(dm)
  - Shared-memory(sm) (use with cautions, thread safe compiler only–IBM XLF)
  - hybrid (dm+sm) (use with cautions)
- Supported platforms
  - IBM: XLF
  - Linux: PGI, IFORT, GFORTRAN (higher version needed,V4.4.0 tested)
  - Macintosh intel: PGI, G95, GFORTRAN (higher version needed,V4.4.0 tested)
- Included libraries
  - CRTM 2.0.2
  - BUFR, BLAS and LAPACK

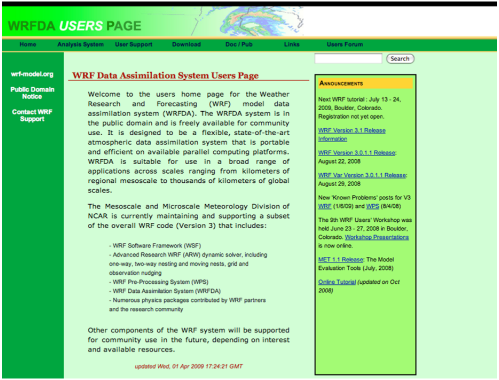
- Install NetCDF (V3.6 above) with THE SAME COMPILER you will choose to compile WRFDA codes.
- Setup the environmental variable
  - csh, tcsh : setenv NETCDF *your_netcdf_path*
  - bash, ksh : export NETCDF=*your_netcdf_path*
- cd WRFDA
- ./clean -a
- ./configure (-d) wrfda (-d : compile with debug mode)
- ./compile all_wrfvar
- 42 executables should be generated under var/build directory

Upgraded to Mac OS X Snow Leopard Users

- PGI (v10.3.0, 64-bit), G95(v4.0.3, 32-bit), GFORTRAN(v4.4.0, default is 32-bit, '-m64' needed for 64-bit) have been tested.
- gcc, g++ are verision 4.2.1, default is 64-bit, '-m32' needed for 32-bit.
- NetCDF library should be re-install with appropriate compiler and option.
- V3.4 configure is able to produce configure.wrf for PGI and G95.
- For GFORTRAN compiler, '-m64' should be added to SFC,SCC, CCOMP in configure.wrf manually.
- Prepbufr and Bufr format data have problem to be read on Snow Leopard system.

Online WRFDA Resources

WRFDA has a dedicated page, similar to the ARW Users page:
WRFDA User Page



WRF Data Assimilation System Users Page

Welcome to the users home page for the Weather Research and Forecasting (WRF) model data assimilation system (WRFDA). The WRFDA system is in the public domain and is freely available for community use. It is designed to be a flexible, state-of-the-art atmospheric data assimilation system that is portable and efficient on available parallel computing platforms. WRFDA is suitable for use in a broad range of applications across scales ranging from kilometers of regional mesoscale to thousands of kilometers of global scales.

The Mesoscale and Microscale Meteorology Division of NCAR is currently maintaining and supporting a subset of the overall WRF code (Version 3) that includes:

- WRF Software Framework (WSF)
- Advanced Research WRF (ARW) dynamic solver, including one-way, two-way nesting and moving nests, grid and observation nudging
- WRF Pre-Processing System (WPS)
- WRF Data Assimilation System (WRFDA)
- Numerous physics packages contributed by WRF partners and the research community

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

updated Wed, 01 Apr 2009 17:24:21 GMT

Announcements

Next WRF tutorial : July 13 - 24, 2009, Boulder, Colorado. Registration not yet open.

WRF Version 3.1 Release Information

WRF Version 3.0.1.1 Release: August 22, 2008

WRF Var Version 3.0.1.1 Release: August 29, 2008

New 'Known Problems' posts for V3 WRF (1/6/09) and WPS (8/4/08)

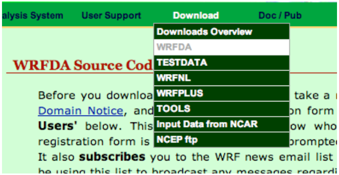
The 9th WRF Users' Workshop was held June 23 - 27, 2008 in Boulder, Colorado. Workshop Presentations is now online.

MET 1.1 Release: The Model Evaluation Tools (July, 2008)

Online Tutorial *(updated on Oct 2008)*

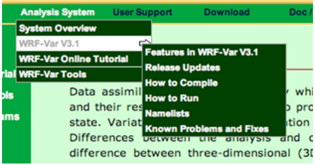
Online Resources

From the WRFDA page, one can access:

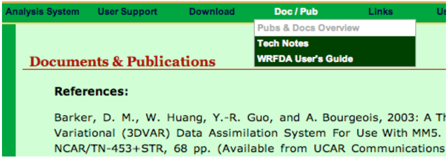


WRFDA Source Cod

Before you downloa take a
Domain Notice, and on form
Users' below. This ow who
registration form is prompte
It also **subscribes** you to the WRF news email list
be using this list to broadcast any messages regardi



Data assimil whi
and their res pro
state. Variat tion
Differences between the analysis and c
difference between three-dimensional (3D



Documents & Publications

References:

Barker, D. M., W. Huang, Y.-R. Guo, and A. Bourgeois, 2003: A Th
Variational (3DVAR) Data Assimilation System For Use With MM5.
NCAR/TN-453+STR, 68 pp. (Available from UCAR Communications

Thank You

The NESL Mission is:
To advance understanding of weather, climate, atmospheric composition and processes;
To provide facility support to the wider community; and,
To apply the results to benefit society.

NCAR is sponsored by the National Science Foundation