Introduction to WRF

Model framework

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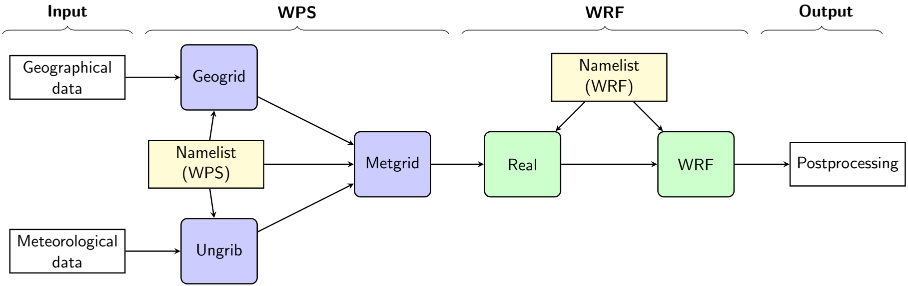
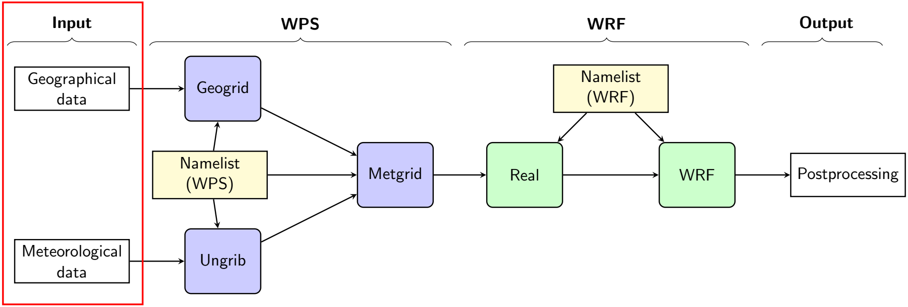
March 20, 2018

Lecture topics

1. WRF components and its workflow
2. Domain configurations and nesting
3. Vertical resolution and η-levels
4. Temporal resolution and the time step contraint

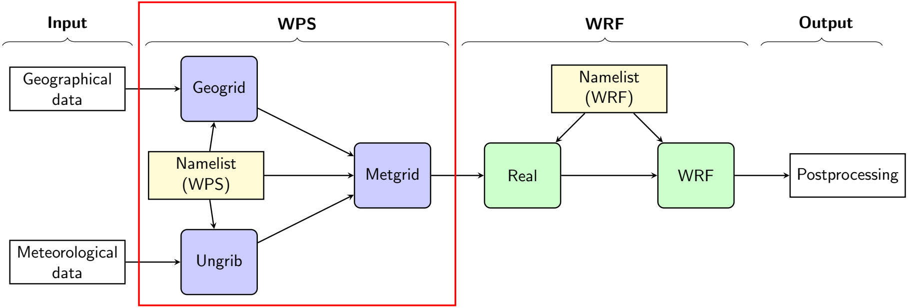
1. WRF components and its workflow





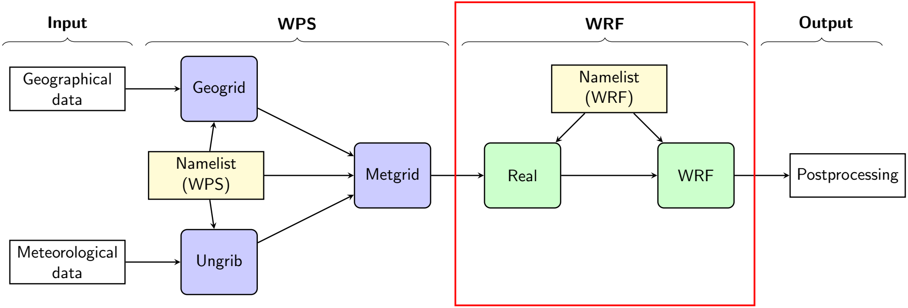
Input to preprocessing:

- Geographical data: topography, type of vegetation, albedo, lake depths, soil types
- Meteorological boundary conditions: pressure and surface variables, e.g. Cloud cover, potential vorticity, humidity, temperature, wind direction and magnitude, etc.

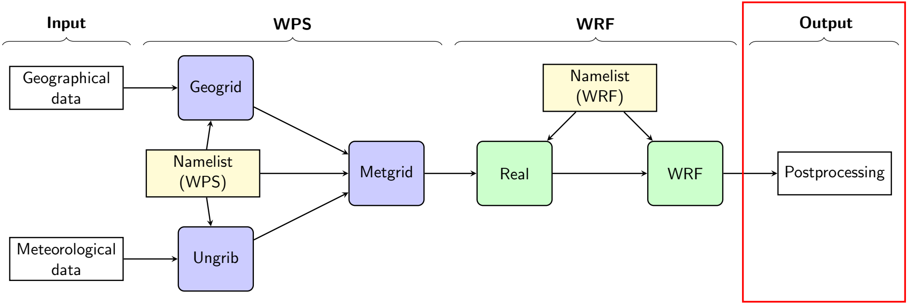


WRF preprocessing system (WPS):

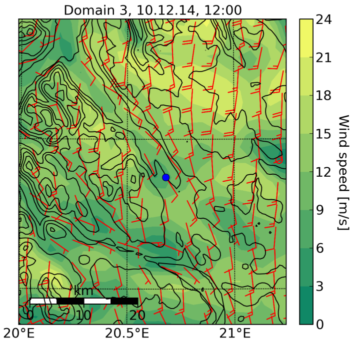
- Namelist (WPS): Controls the WPS framework like core, simulation time, domains and input data.
- Geogrid: Interpolating the terrestrial input data.
- Ungrib: Unpacking and the meteorological input data and makes them readable.
- Metgrid: Horizontally interpolating the meteorological data onto the simulation domain.

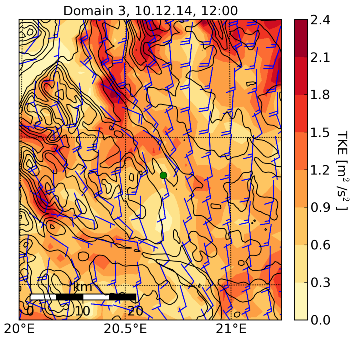


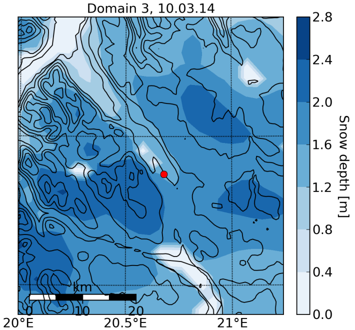
- Namelist (WRF): Defining all the simulation parameters. All parameters and physical options are specified in this script.
- Real: Vertically interpolates the meteorological fields to the model grid. The output of `Real.exe` is fully interpolated 4-dimensional simulation data.
- WRF: The 4-D interpolated boundary values is simulated using WRF's dynamical solver.

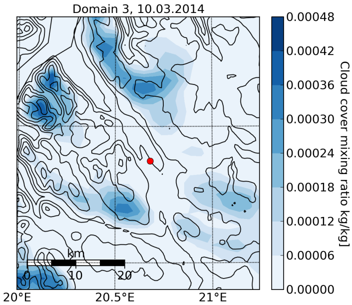


Postprocessing:
The output of the WRF model is NetCDF files containing more than 150 variables.

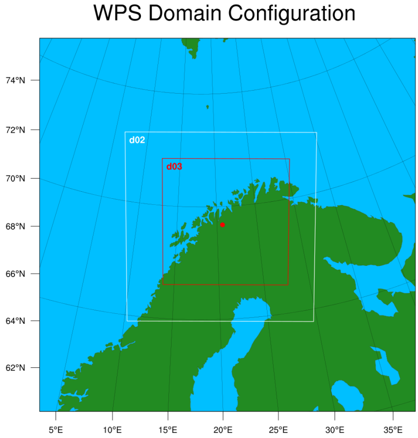

Domain 3, 10.12.14, 12:00
km
0
10
20
20°E
20.5°E
21°E
Wind speed [m/s]
0
3
6
9
12
15
18
21
24

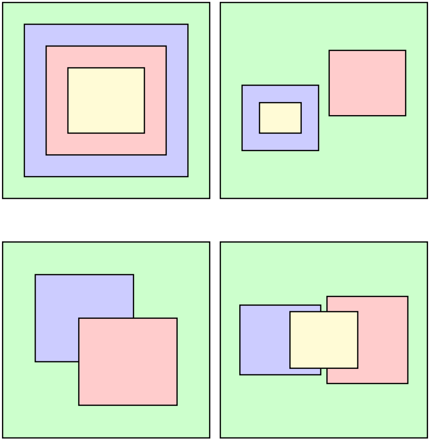

Domain 3, 10.12.14, 12:00
km
0
10
20
20°E
20.5°E
21°E
TKE [m^2/s^2]
0.0
0.3
0.6
0.9
1.2
1.5
1.8
2.1
2.4


Domain 3, 10.03.14
km
0
10
20
20°E
20.5°E
21°E
Snow depth [m]
0.0
0.4
0.8
1.2
1.6
2.0
2.4
2.8


Domain 3, 10.03.2014
km
0
10
20
20°E
20.5°E
21°E
Cloud cover mixing ratio kg/kg]
0.00000
0.00006
0.00012
0.00018
0.00024
0.00030
0.00036
0.00042
0.00048

2. Domain configurations and nesting



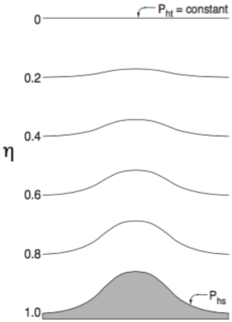


3. Vertical resolution and η-levels

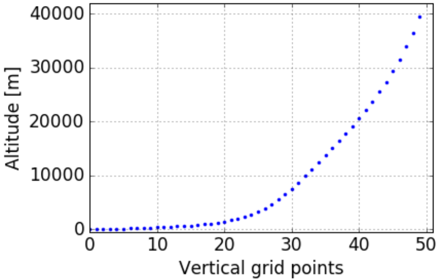
The η vertical coordinate was first defined by Mesinger [1984]. The ground surface is the first η-coordinate. The subsequent coordinates are pressure based and normalized. The η-levels in the WRF model is given in Skamarock et al. [2005] as:

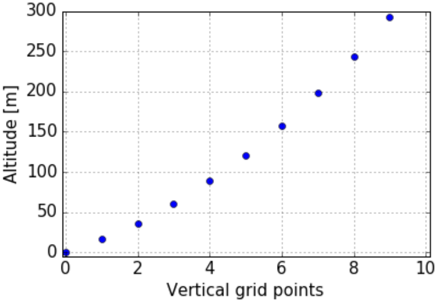
$$\eta = \frac{p_h - p_{ht}}{\mu_d},$$

where $\mu_d = p_{hs} - p_{ht}$. p_h is hydrostatic component of the pressure. p_{hs} and p_{ht} is pressure along the surface and the top boundary respectively.



The figure above illustrates the height coordinates in the WRF model. Image from Skamarock et al. [2008].


Altitude [m]
40000
30000
20000
10000
0
0
10
20
30
40
50
Vertical grid points


Altitude [m]
300
250
200
150
100
50
0
0
2
4
6
8
10
Vertical grid points

4. Temporal resolution and the time step contraint I

The Courant-Fredrichs-Lewy (CFL) condition is a time step constraint condition for convergence of an ordinary differential equation. For the case of determining the time step constraint for a wind simulation where the horizontal wind speed is $\boldsymbol{u}$ and the simulation domain has a spatial discrete grid spacing of Δx, the CFL condition can be expressed as

$$0 \leq \frac{\boldsymbol{u}\Delta t}{\Delta x} \leq 1. \tag{1}$$

The Courant number in one dimension is defined as

$$Cr = \frac{u\Delta t}{\Delta x} \tag{2}$$

according to Skamarock et al. [2008].
The maximum Courant numbers for one-dimensional linear advection is obtained from Wicker and Skamarock [2002] and tabulated below. The extension in two and three dimensions is done by multiplying the time step by a factor $1/\sqrt{2}$ and $1/\sqrt{3}$ respectively [Wicker and Skamarock, 2002].

4. Temporal resolution and the time step contraint II

Time scheme	Spatial order			
	3rd	4th	5th	6th
Leapfrog	*Unstable*	0.72	*Unstable*	0.62
RK2	0.88	*Unstable*	0.30	*Unstable*
RK3	1.61	1.26	1.42	1.08

According to the maximum time step for the RK3 integration in 3-D applications, the time step should satisfy

$$\Delta t_{max} < \frac{Cr}{\sqrt{3}} \cdot \frac{\Delta x}{\boldsymbol{u}_{max}}, \tag{3}$$

here Cr denotes the Courant number
For the ARW core of WRF, it is advised that the maximum time step should be approximately 6 times the grid distance of the largest domain in kilometers [Skamarock et al., 2008].

List of useful programs if running on Windows

- Putty
- Xming
- MATLAB
- Python (if time)

For running jobs on Stallo, one need a Stallo-account. To get this one can follow this guide:
`https://hpc-uit.readthedocs.io/en/latest/account/uitquota.html`

References I

F Mesinger. A blocking technique for representation of mountains in atmospheric models. *Riv. Meteor. Aeronaut.*, 44:195–202, 1984.

William C Skamarock, Joseph B Klemp, Jimy Dudhia, David O Gill, Dale M Barker, Wei Wang, and Jordan G Powers. A description of the advanced research wrf version 2. Technical report, National Center For Atmospheric Research Boulder Co Mesoscale and Microscale Meteorology Div, 2005.

William C Skamarock, Joseph B Klemp, Jimy Dudhia, David O Gill, Dale M Barker, Wei Wang, and Jordan G Powers. A description of the advanced research wrf version 3. Technical report, DTIC Document, June 2008.

Louis J Wicker and William C Skamarock. Time-splitting methods for elastic models using forward time schemes. *Monthly Weather Review*, 130(8):2088–2097, 2002.