The WRF Pre-Processing System (WPS): Fundamental Capabilities

Michael Duda

Basic WRF Tutorial 17 – 21 July 2023





WRF Modeling System Flowchart





Overview

This lecture focuses on the basic use of the WPS to:

- Define a single simulation domain
 - The setup of *nested domains* is covered in a talk tomorrow morning
- Preprocess time-varying atmospheric and land-surface datasets
- Horizontally interpolate datasets for use as initial and boundary conditions for WRF
- Practical details of *actually running* the WPS are covered this afternoon and in a live demo tomorrow
- Advanced features of the WPS are described on Thursday



WPS Program Flowchart





The geogrid Program



geogrid: think geographical



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The geogrid Program

Let's suppose we wish to perform a simulation for the domain below...



- Where is this domain located?
- What area does the domain cover?
- How well do we resolve the atmosphere and land surface (horizontally)?
- What sources of data do we use for topography, vegetation categories, and soil categories?

Using the geogrid program, we answer these questions from the perspective of the WRF model.



The geogrid Program

- We use the geogrid program to define:
 - Map projection (all domains must use the same projection)
 - Geographic location of domains
 - Dimensions of domains
 - Horizontal resolution of domains
- Geogrid provides values for static (time-invariant) fields at each model grid point
 - Compute latitude, longitude, map scale factor, and Coriolis parameters at each grid point
 - Horizontally interpolate static terrestrial data (e.g., topography height, land use category, soil type, vegetation fraction, monthly surface albedo) from global datasets



Geogrid: Defining Model Domains

- First, we choose a map projection to use for the domains; why?
 - The real earth is (roughly) an ellipsoid
 - But WRF computational domains are defined by rectangles in the plane
- ARW can use any of the following projections:
 - 1. Lambert conformal
 - 2. Mercator
 - 3. Polar stereographic
 - 4. Latitude-longitude (for global domain, you *must* choose this projection!)



Projections: Lambert Conformal Conic



- Well-suited for mid-latitudes
- Domain cannot contain either pole
- Domain cannot be periodic in west-east direction
- Either one or two *true latitudes* may be specified
 - If two are given, the order doesn't matter





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Projections: Mercator





- Well-suited for low-latitudes
- May be used for "channel" domain (periodic domain in west-east direction)
- A single true latitude is specified
 - Cylinder intersects the earth's surface at +/- truelat

Geometric construction is tricky! https://doi.org/10.1007/s42489-022-00115-5



Projections: Polar Stereographic



- Good for high-latitude domains, especially if domain must contain a pole
- A single true latitude is specified





Projections: Cylindrical Equidistant



- Required for global domains
- May be used for regional domains
- Can be used in its normal or rotated aspect





Geogrid: Defining model domains

- Define projection of domains using a subset of the following parameters
 - MAP_PROJ: 'lambert', 'mercator', 'polar', or 'lat-lon'
 - **TRUELAT1**: First true latitude
 - TRUELAT2: Second true latitude (*only for Lambert conformal*)
 - POLE_LAT, POLE_LON: Location of North Pole in WRF computational grid (*only for 'lat-lon'*)
 - **STAND_LON**: The meridian parallel to *y*-axis
- All parameters reside in the file *namelist.wps*





Each choice of map projection and associated parameters distorts distances at a given point on the globe differently

Geographic grid distance in WRF at a point is given by

$$\Delta x_{geographical} = \Delta x_{nominal}/m$$

where *m* is a *map scale factor*.

Maximum stable timestep in WRF is determined by geographic grid distance, not nominal (i.e., namelist) grid distance!

Map scale factor is a 2-d field available in the geogrid output files

• Can easily check min/max map scale factor using, e.g., ncview!





For a nominal 12-km grid, the above projection yields grid distances from 9.9 km to 14.6 km.



For a nominal 12-km grid, the above projection yields grid distances from 11.7 to 12.1 km.



Lesson: After running geogrid.exe, check the MAPFAC_M field in the geogrid output files!

		Nev	/iew 2.1.5 ^{⊕⊕}		_		
	Nev	iew 2.1.5 Dav	id W. Pierce 18	3 Mar 2015			
variable=MAPFAC_M frame 1/1 displayed range: 0.819175 to 1.21768 none Current: (i=85, i=248) 1.21768 (x=89, y=248)							
Quit ->1 Image: Constraint of the second secon							
0.85 0.9 0.95 1 1.05 1.1 1.15 1.2 (1) 1 d vars (50) 2 d vars (8) 3 d vars							
Dim:	Name:	Min:	Current:	Max:	Units:		
Scan:	Time	0	0	0	-		
Y:	south_north	0	-Y-	248	-		
X:	west_east	0	-X-	418	-		
_							



Geogrid: Defining ARW Domains





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Geogrid: Defining ARW Domains

- Define the area covered (dimensions and location) by coarse domain using the following:
 - REF_LAT, REF_LON: The (lat,lon) location of a known location in the domain (*by default, the center point of the domain*)
 - **DX**, **DY**: Grid distance where map factor = 1
 - · For Lambert, Mercator, and polar stereographic: meters
 - . For (rotated) latitude-longitude: degrees
 - E_WE: Number of velocity points in west-east direction
 - E_SN: Number of velocity points in south–north direction

See p. 3-13 and 3-42



Geogrid: Interpolating Static Fields

- Given definitions of all computational grids, geogrid interpolates terrestrial, timeinvariant fields
 - Topography height
 - Land use categories
 - Soil type (top layer & bottom layer)
 - Annual mean soil temperature
 - Monthly vegetation fraction
 - Monthly surface albedo



Geogrid: Program Output

- The parameters defining each domain, plus interpolated static fields, are written using the WRF I/O API
 - One file per domain for ARW
- Filenames: geo_em.d0*n*.nc

(where *n* is the domain ID number)

• Example:

geo_em.d01.nc geo_em.d02.nc (nest) geo_em.d03.nc (nest)



Geogrid: Example Output Fields

Land-water mask

Top-layer dominant soil type



Topography height

Climatological vegetation fraction (January)



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The ungrib program



ungrib: think <u>un+grib</u>



What is a GRIB file, anyway?

- GRIB is a WMO standard file format for storing regularly-distributed (e.g., gridded) fields
 - "General Regularly-distributed Information in Binary"
- Fields within a GRIB file are compressed with a lossy compression
 - Think of truncating numbers to a fixed number of digits
- A record-based format
- Fields in a file are identified only by code numbers
 - These numbers must be referenced against an external table to determine the corresponding field



The ungrib program

- Reads GRIB Edition 1 and GRIB Edition 2 files
- Extracts meteorological fields
- If necessary, derives required fields from related ones
 - E.g., Compute RH from T, P, and Q
- Writes requested fields to an *intermediate* file format



How does ungrib know which fields to extract?

Using Vtables (think: <u>Variable tables</u>)

- Vtables are files that give the GRIB codes for fields to be extracted from GRIB input files
- One Vtable for each source of data
- Vtables are provided for: CFSR, ERA-Interim, GFS, NARR, and others



Ungrib: Example Vtable

GRIB1	Level	From	om To UNGRIB		UNGRIB	UNGRIB		
Param	Туре	Level1	Level2	Name	Units	Description		
+	- +· 100	+- *	+ ' '	·+	+ 	Tomporatura		
	100	*						
	100	*		U 77		24		
54 50	100			V		V Dolotino II.miditu		
5Z 7	100					Relative Humidity		
1 1	100			HGT		Height		
	105					Temperature at 2 m		
	105			KH		Relative Humidity at 2 m		
33	105			U	ms-1	U at IU m		
34	105			V	ms-l	V at 10 m		
				PSFC	Pa	Surface Pressure		
130	102			PMSL	Pa	Sea-level Pressure		
144	112	0	I TO I	SM000010	kg m-3	Soil Moist 0-10 cm below grn layer (Up)		
144	112	10	40	SM010040	kgm-3	Soil Moist 10-40 cm below grn layer		
144	112	40	100	SM040100	kgm-3	Soil Moist 40-100 cm below grn layer		
144	112	100	200	SM100200	kg m-3	Soil Moist 100-200 cm below gr layer		
85	112	0	10	ST000010	K	T 0-10 cm below ground layer (Upper)		
85	112	10	40	ST010040	K	T 10-40 cm below ground layer (Upper)		
85	112	40	100	ST040100	K	T 40-100 cm below ground layer (Upper)		
85	112	100	200	ST100200	K	T 100-200 cm below ground layer (Bottom)		
91	1	0		SEAICE	proprtn	Ice flag		
81	1	0		LANDSEA	proprtn	Land/Sea flag (1=land,2=sea in GRIB2)		
7	1	0		HGT	m	Terrain field of source analysis		
11	1	0		SKINTEMP	K	Skin temperature (can use for SST also)		
65	1	0		SNOW	kg m-2	Water equivalent snow depth		
223	1	0		CANWAT	kg m-2	Plant Canopy Surface Water		
224	1	0	i i	SOILCAT	Tab4.213	Dominant soil type category		
225	1	0		VEGCAT	Tab4.212	Dominant land use category		
+	+	+	+	+	+			



Ungrib: GRIB2 Vtables Entries

metgrid	GRIB2	GRIB2	GRIB2	GRIB2
Description	Discp	Catgy	Param	Level
<pre>> Meegind Description Temperature U V Relative Humidity Height Temperature at 2 m Relative Humidity at 2 m U at 10 m V at 10 m V at 10 m Surface Pressure Sea-level Pressure Soil Moist 0-10 cm below grn layer (Up) Soil Moist 10-40 cm below grn layer Soil Moist 10-200 cm below gr layer Soil Moist 10-200 cm below gr layer Soil Moist 10-200 cm below gr layer T 0-10 cm below ground layer (Upper) T 10-40 cm below ground layer (Upper) T 10-200 cm below ground layer (Bottom) T 10-200 cm below ground layer (Bottom) T 10-200 cm below ground layer (Bottom) I ce flag Land/Sea flag (1=Land, 0 or 2=sea) Terrain field of source analysis</pre>	Discp Discp 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	Catgy Catgy 2 2 2 2 3 3 0 1 2 1 2 1 2 1 2 1 3 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0	Param Param 0 2 3 1 5 0 1 1 2 1 1 2 1 1 1 1 1 1 1 1 1 1 1 1 1	Level 100 100 100 100 100 100 100 10
<pre> Skin temperature (can use for SST also) Water equivalent snow depth Dominant soil type cat.(not in GFS file) Dominant land use cat. (not in GFS file)</pre>	0 0 2 2	0 1 3 0	0 13 0 198	1 1 1 1



What if a data source has no existing Vtable?

Create a Vtable

- Get a listing of GRIB codes for fields in the source
 - Check documentation from originating center or use utility such as *wgrib*, *g1print*, *g2print*
- Use existing Vtable as a template
- Check documentation in Chapter 3 of the Users' Guide for more information about Vtables

See p. 3–35



Ungrib: Intermediate File Format

- After extracting fields listed in Vtable, ungrib writes those fields to intermediate format
- For meteorological data sets not in GRIB format, the user may write to intermediate format directly *See p. 3-33*
 - <u>Allows WPS to ingest new data sources</u>; basic programming required of user
 - Simple intermediate file format is easily read/written using routines from WPS (read_met_module.F and write_met_module.F)



Ungrib: Program Output

- Output files named *FILE:YYYY-MM-DD_HH*
 - YYYY is year of data in the file; MM is month;
 DD is day; HH is hour
 - All times are UTC
- Example:

FILE:2007-07-24_00 FILE:2007-07-24_06 FILE:2007-07-24_12



The *metgrid* program



metgrid: think meteorological



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The metgrid program

- Horizontally interpolate meteorological data (*extracted by ungrib*) to simulation domains (*defined by geogrid*)
 - Masked interpolation for masked fields
 - Can process both isobaric and native vertical coordinate data sets
- Rotate winds to WRF grid
 - i.e., rotate so that U-component is parallel to x-axis, V-component is parallel to y-axis



Metgrid: ARW Grid Staggering

- For ARW, wind U-component interpolated to "u" staggering
- Wind V-component interpolated to "v" staggering
- Other meteorological fields interpolated to "θ" staggering by default (*can change this!*)



A single ARW grid cell, with "u", "v", and "θ" points labeled.



- Masked fields may only have valid data at a subset of grid points
 - E.g., SST field only valid on water points
- When metgrid interpolates masked fields, it must know which points are invalid (masked)
 - Can use separate mask field (e.g., LANDSEA)
 - Can rely on special values (e.g., 1×10³⁰) in field itself to identify masked grid points





= valid source data
= masked/invalid data

Suppose we need to interpolate to point X

- Using red points as valid data can give a bad interpolated value!
- Masked interpolation only uses valid blue points to interpolate to X

Not every interpolation option can handle masked points; we'll address this issue in the advanced WPS lecture



Common fields that require masked interpolation include SST, soil moisture, and soil temperature.

Dominant category (category)



A high-resolution WRF domain centered on Pearl River Estuary.



296 296.8 297.6 298.4 299.2 300 300.8 301.6 302.4

SST data on a 0.083-degree grid, with missing data (black) over land.



296 296.8 297.6 298.4 299.2 300 300.8 301.6 302.4

SST data overlaid with land use; blue areas represent WRF water cells that must receive SST values via masked interpolation.



Masked interpolation can also be used for any field, e.g., to improve the resolution of coastlines in the field.



Skin temperature field interpolated from GFS 0.5-deg field with no mask using a sixteen-point interpolator.

Skin temperature field interpolated using masks: GFS water points interpolated to model water points, GFS land points interpolated to model land points.



Metgrid: Wind Vector Rotation

- Input wind fields (U-component + Vcomponent) are either:
 - Earth-relative: U-component = westerly component;
 V-component = southerly component
 - Relative to source grid: U-component (V-component) parallel to source model x-axis (y-axis)
- WRF expects wind components to be relative to the simulation grid



Metgrid: Wind Vector Rotation





A wind vector, shown in terms of its U and V components with respect to the source grid. The same vector, in terms of its U and V components with respect to the WRF simulation grid.

This process may require *two* rotations: one from source grid to earth grid and a second from earth grid to WRF grid



Metgrid: Constant Fields

- For short simulations, some fields may be constant
 - E.g., SST or sea-ice fraction
- Use namelist option CONSTANTS_NAME option to specify such fields:
 - CONSTANTS_NAME = 'SST_FILE:2007-07-24_00'



Metgrid: Program Output

- For coarse domain, one file per time period
 - In ARW, we also get the first time period for all nested grids
- Files contain static fields from geogrid plus interpolated meteorological fields
- Filenames:

ARW: met_em.d0n.YYYY-MM-DD_HH:mm:ss.nc
(where n is the domain ID number)



Metgrid: Example Output





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WPS Summary





And finally...

Vertical interpolation to WRF eta levels is performed in the *real* program





Questions?



Extra slides



Example:

- Nominally 27 km grid
- Lambert conformal projection
- True latitude 1 = 23.14
- True latitude 2 = 23.14

Choosing both true latitudes in the center of the WRF domain leads to maximum map scale factors of 1.0975, corresponding to a minimum physical grid distance of 27/1.0975 = 24.6 km.



Above: Contours of map scale factor (white; interval 0.01) with true latitudes (red).



We can reduce the maximum map scale factor at the expense of grid resolution...



Above: Reference projection as on previous slide; maximum grid distance is 27 km (at true latitude).



Above: The maximum map scale factor is 1.03, but the minimum is 0.924, corresponding to a physical distance of 29.2 km.



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... but if we insist that the maximum grid distance is at most 27 km, we must reduce the *nominal* grid distance to accommodate the map scale factors!





Above: Reducing the nominal grid distance to 25 km, the map scale factors of 0.924 in the center of the map correspond to a physical distance of 27.06 km.



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