The WRF Preprocessing System: Description of General Functions

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Purpose of this Lecture

In this lecture, our goals are to:

1) Understand the purpose of the WPS
2) Learn what each component of the WPS does
3) Understand why the components work as they do

- The details of actually running the WPS are covered this afternoon
- Advanced features of the WPS are described on Thursday

Purpose of the WPS

The purpose of the WPS is to prepare input to WRF for real-data simulations:

1. Defines simulation coarse domain and ARW nested domains
2. Computes latitude, longitude, map scale factors, and Coriolis parameters at every grid point
3. Interpolates time-invariant terrestrial data to simulation grids (e.g., terrain height and soil type)
4. Interpolates time-varying meteorological fields from another model onto simulation domains
The geogrid program

For WRF model domains, geogrid defines:
- Map projection (all domains must use the same projection)
- Geographic location of domains
- Dimensions 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)

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!)
ARW Projections: Lambert Conformal

- 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

ARW 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 +/- true lat

ARW Projections: Polar Stereographic

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

ARW Projections: Cylindrical Equidistant

- Required for global domains
- May be used for regional domains
- Can be used in its normal or rotated aspect
Why do map projections matter?

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

$$\Delta x_{\text{geographical}} = \frac{\Delta x_{\text{nominal}}}{m}$$

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!

**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

$$\frac{27}{1.0975} = 24.6 \text{ km}.$$
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`

See p. 3-9 and 3-43

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: Nesting Basics

- A **nested domain** is a domain that is wholly contained within its **parent domain** and that receives information from its parent, and that may also feed information back to its parent
  - A nested domain has exactly one **parent**
  - A domain may have one or more **children**
- **2-way nests** on the same **nesting level** must not overlap in coverage!

Geogrid: Defining Nested Domains

- Define the dimensions and location of nested domains using:
  - **PARENT_ID**: Which domain is the parent?
  - **PARENT_GRID_RATIO**: What is the ratio of grid spacing in parent to grid spacing in this nest?
  - **I_PARENT_START**: i-coordinate in parent of this nest’s lower–left corner
  - **J_PARENT_START**: j-coordinate in parent of this nest’s lower–left corner
  - **E_WE**: Number of velocity points in west–east direction
  - **E_SN**: Number of velocity points in south–north direction

See p. 3–20 and 3–42

Geogrid: Defining Nested Domains

The grid spacing ($dx$) of domain 2 is determined by grid spacing of domain 1 and the **parent_grid_ratio**
**Geogrid: Defining Nested Domains**

A nested domain must cover an integer number of parent-domain grid cells, and *e_we* and *e_sn* represent the number of velocity-staggered points.

Therefore, in ARW, nest dimensions must satisfy

\[
\frac{e_{\text{we}} - 1}{\text{parent\_grid\_ratio}} = n_i \\
\frac{e_{\text{sn}} - 1}{\text{parent\_grid\_ratio}} = n_j
\]

where *n_i* and *n_j* are any integers.

**Geogrid: Nesting example**

Assuming *parent\_grid\_ratio* = 3

In ARW, nest dimensions must satisfy

\[
\frac{e_{\text{we}} - 1}{\text{parent\_grid\_ratio}} = n_i \\
\frac{e_{\text{sn}} - 1}{\text{parent\_grid\_ratio}} = n_j
\]

where *n_i* and *n_j* are any integers.

**Geogrid: Interpolating Static Fields**

- Given definitions of all computational grids, geogrid interpolates terrestrial, time-invariant 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.d0n.nc`
    (where *n* is the domain ID number)
  - Example:
    - `geo_em.d01.nc`
    - `geo_em.d02.nc` (nest)
    - `geo_em.d03.nc` (nest)
The WRF Users’ Basic Tutorial
25 – 29 July 2016, Boulder, CO

Geogrid: Example Output Fields

- LAND–SEA Mask
- Topography Height
- Top-layer Soil Category
- Vegetation Fraction (July)

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

- Read GRIB Edition 1 and GRIB Edition 2 files
- Extract meteorological fields
- If necessary, derive required fields from related ones
  - E.g., Compute RH from T, P, and Q
- Write requested fields to an intermediate file format
Using Vtables (think: Variable tables)

- 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: NAM 104, NAM 212, GFS, AGRMET, and others

### Ungrib: Example Vtable

<table>
<thead>
<tr>
<th>Field</th>
<th>GRIB2</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>T</td>
<td>K</td>
<td>Temperature</td>
</tr>
<tr>
<td>U</td>
<td>m s⁻¹</td>
<td>U</td>
</tr>
<tr>
<td>V</td>
<td>m s⁻¹</td>
<td>V</td>
</tr>
<tr>
<td>RH</td>
<td>%</td>
<td>Relative Humidity</td>
</tr>
<tr>
<td>HGT</td>
<td>m</td>
<td>Height</td>
</tr>
<tr>
<td>T</td>
<td>m</td>
<td>Terrain field of source analysis</td>
</tr>
<tr>
<td>V</td>
<td>m s⁻¹</td>
<td>V at 10 m</td>
</tr>
<tr>
<td>PMSL</td>
<td>Pa</td>
<td>Sea-level Pressure</td>
</tr>
<tr>
<td>PSFC</td>
<td>Pa</td>
<td>Surface Pressure</td>
</tr>
<tr>
<td>V</td>
<td>m s⁻¹</td>
<td>V at 10 m</td>
</tr>
<tr>
<td>U</td>
<td>m s⁻¹</td>
<td>U</td>
</tr>
<tr>
<td>T</td>
<td>K</td>
<td>Temperature</td>
</tr>
<tr>
<td>HGT</td>
<td>m</td>
<td>Height</td>
</tr>
<tr>
<td>RH</td>
<td>%</td>
<td>Relative Humidity</td>
</tr>
<tr>
<td>T</td>
<td>m</td>
<td>Terrain field of source analysis</td>
</tr>
</tbody>
</table>

### Ungrib: Vtables

#### Ungrib: GRIB2 Vtable Entries

<table>
<thead>
<tr>
<th>Description</th>
<th>GRIB2</th>
<th>GRIB2</th>
<th>GRIB2</th>
<th>GRIB2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>U</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relative Humidity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature at 2 m</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relative Humidity at 2 m</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>U</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface Pressure</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sea-level Pressure</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil Moist 0-10 cm below grn layer (Up)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil Moist 10-40 cm below grn layer</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil Moist 5-40 cm below grn layer</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil Moist 100-200 cm below grn layer</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T 0-10 cm below ground layer (Upper)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T 10-40 cm below ground layer (Upper)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T 40-100 cm below ground layer (Upper)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T 100-200 cm below ground layer (Bottom)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T 10-200 cm below ground layer (Bottom)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ice flag</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Land/Sea flag (1=land, 0 or 2=sea)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Terrain field of source analysis</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skin temperature (can use for SST also)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water equivalent snow depth</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dominant soil type cat. (not in GFS files)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dominant land use cat. (not in GFS files)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Ungrib: GRIB1 Vtable Entries

<table>
<thead>
<tr>
<th>Description</th>
<th>GRIB1</th>
<th>Level1</th>
<th>Level2</th>
<th>Name</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td></td>
<td></td>
<td></td>
<td>V</td>
<td>m s⁻¹</td>
</tr>
<tr>
<td>U</td>
<td></td>
<td></td>
<td></td>
<td>U</td>
<td>m s⁻¹</td>
</tr>
<tr>
<td>V</td>
<td></td>
<td></td>
<td></td>
<td>V</td>
<td>m s⁻¹</td>
</tr>
<tr>
<td>Relative Humidity</td>
<td></td>
<td></td>
<td></td>
<td>RH</td>
<td>%</td>
</tr>
<tr>
<td>Height</td>
<td></td>
<td></td>
<td></td>
<td>HGT</td>
<td>m</td>
</tr>
<tr>
<td>Temperature at 2 m</td>
<td></td>
<td></td>
<td></td>
<td>T</td>
<td>m</td>
</tr>
<tr>
<td>Relative Humidity at 2 m</td>
<td></td>
<td></td>
<td></td>
<td>RH</td>
<td>%</td>
</tr>
<tr>
<td>U</td>
<td></td>
<td></td>
<td></td>
<td>U</td>
<td>m s⁻¹</td>
</tr>
<tr>
<td>V</td>
<td></td>
<td></td>
<td></td>
<td>V</td>
<td>m s⁻¹</td>
</tr>
</tbody>
</table>

### Ungrib: Vtables

What if a data source has no existing Vtable?

- Get a listing of GRIB codes for fields in the source
  - Check documentation from originating center or use utility such as wgr, g1print, g2print
- Use existing Vtable as a template
- Check documentation in Chapter 3 of the Users’ Guide for more information about Vtables
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
  - Allows WPS to ingest new data sources; 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)

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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

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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: think meteorological
### 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.

### Metgrid: Masked Interpolation

- **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., $1 \times 10^{-30}$) in field itself to identify masked grid points

### Metgrid: Masked Interpolation

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.

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

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

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

- Input wind fields (U-component + V-component) 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 Rotation Example

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

- RH (700 hPa)
- Skin Temperature
- Temperature (500 hPa)
- Mean Sea-level Pressure
- Soil Moisture (10-40cm)

WPS Summary

- geogrid
  - Domain definitions and interpolated geographical data
- metgrid
  - Horizontally interpolated meteorological fields
- ungrb
  - Meteorological fields from GRIB files
- real

And finally…

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

External Data Sources

- WRF Preprocessing System
  - metgrid
  - real
  - ungrb
  - Grided Data: NAM, GFS, RUC, AGRMET, etc.
  - Static Geographical Data
  - geogrid
Questions?