Purpose of this Lecture

In this lecture, our goals are to:

1) Understand the purpose of the WPS

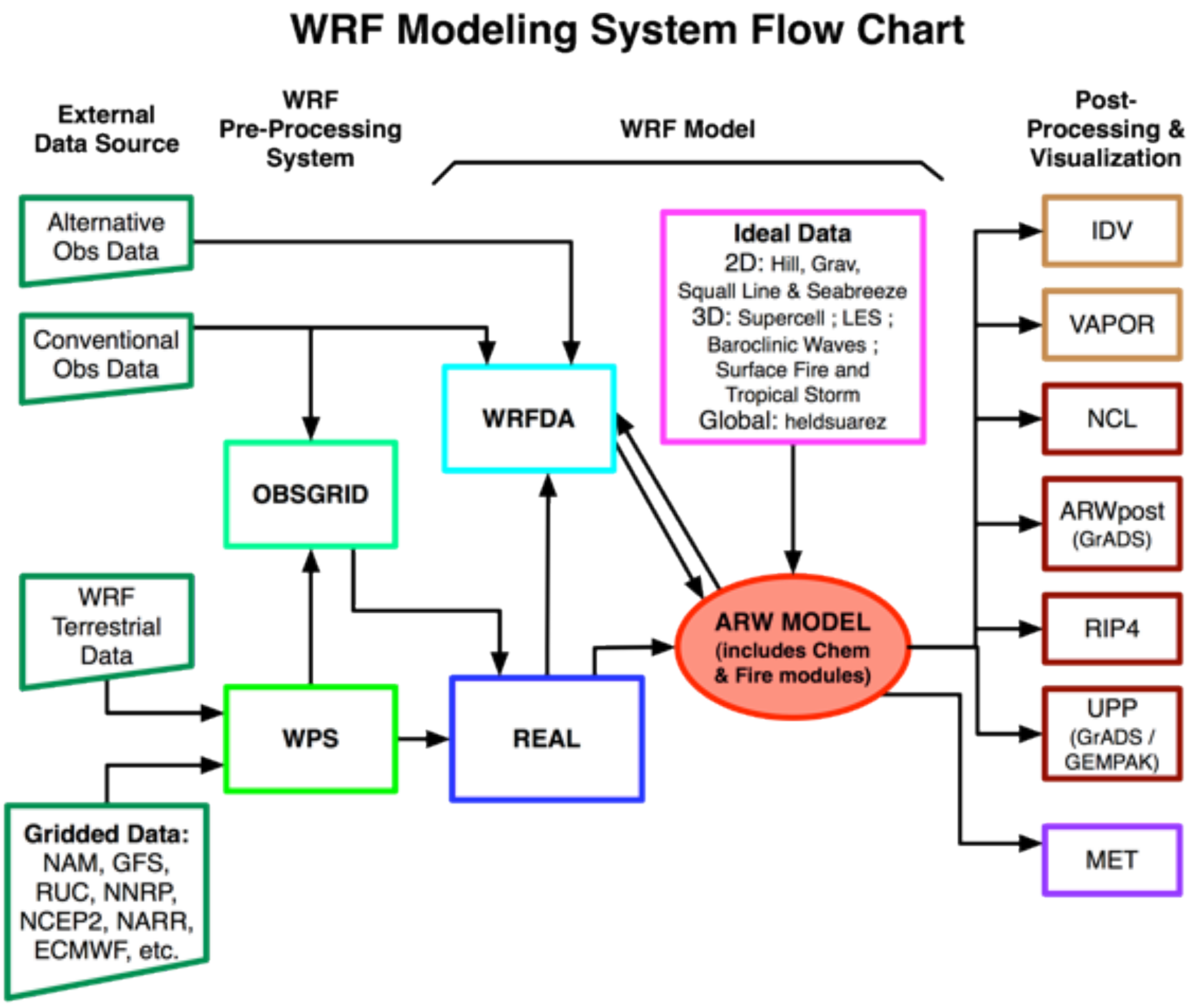
2) Learn what each component of the WPS does

3) Understand why the components work as they do

– The details of *actually running* the WPS are covered later this afternoon

– *Advanced features* of the WPS are described on Wednesday

WRF Modeling System Flowchart

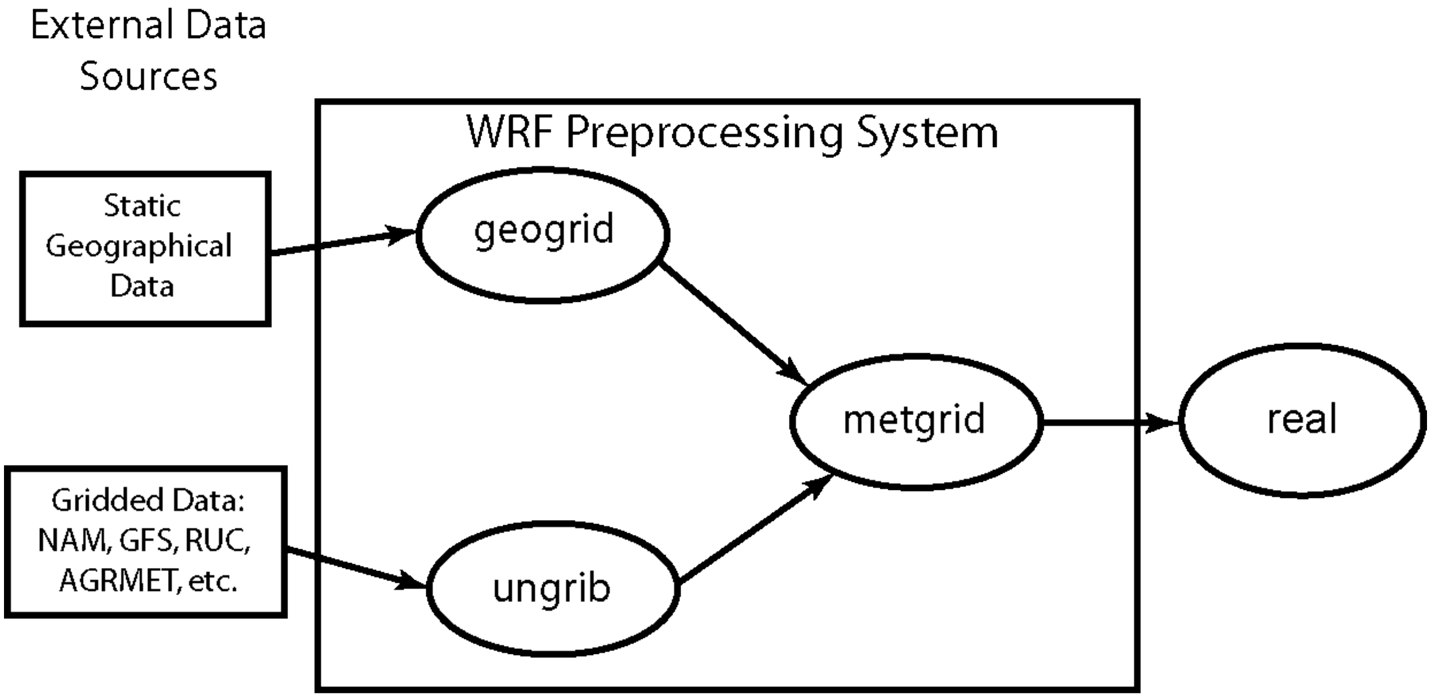

WRF Modeling System Flow Chart
External Data Source
WRF Pre-Processing System
WRF Model
Post-Processing & Visualization
Alternative Obs Data
Conventional Obs Data
WRF Terrestrial Data
Gridded Data: NAM, GFS, RUC, NNRP, NCEP2, NARR, ECMWF, etc.
OBSGRID
WPS
WRFDA
REAL
Ideal Data
2D: Hill, Grav, Squall Line & Seabreeze
3D: Supercell ; LES ; Baroclinic Waves ; Surface Fire and Tropical Storm
Global: heldsuarez
ARW MODEL (includes Chem & Fire modules)
IDV
VAPOR
NCL
ARWpost (GrADS)
RIP4
UPP (GrADS / GEMPAK)
MET

Purpose of the WPS

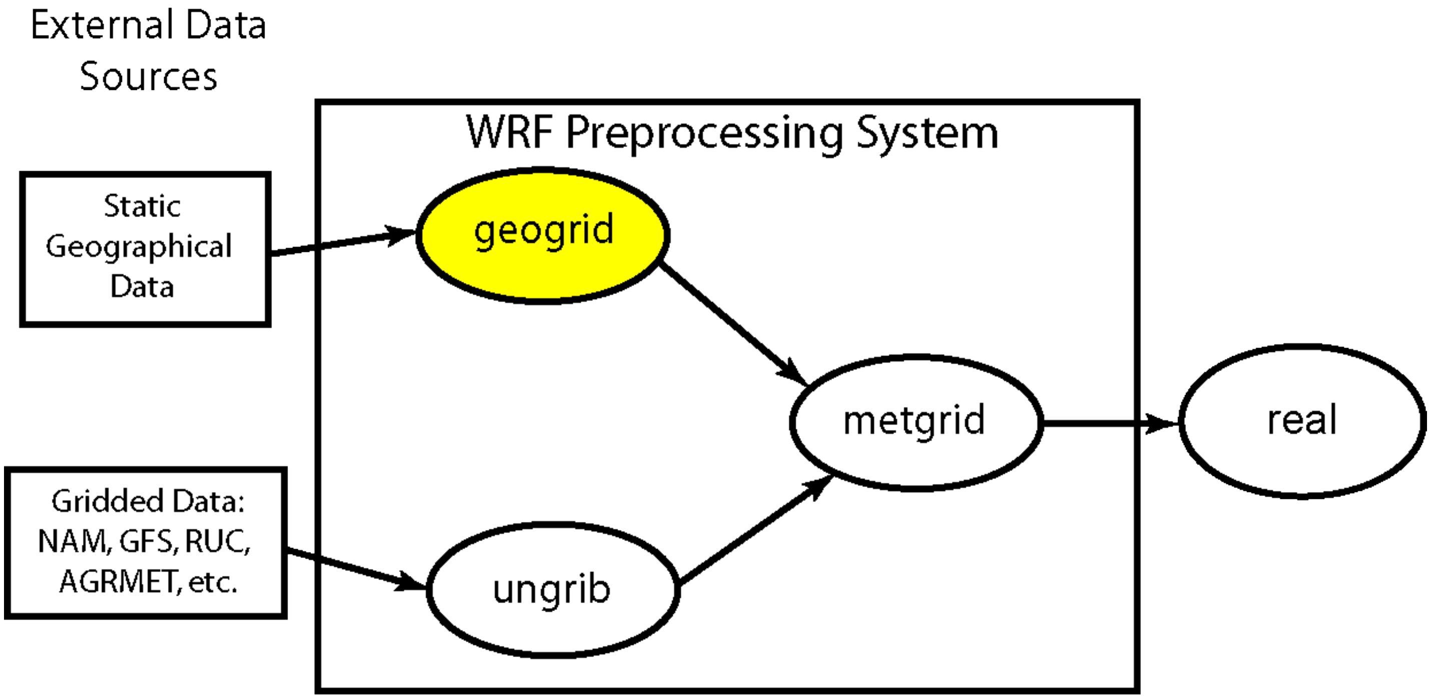
The purpose of the WPS is to prepare input to WRF for real-data simulations:

1. Defines simulation coarse domain and 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

WPS Program Flowchart



The *geogrid* program



geogrid: think geographical

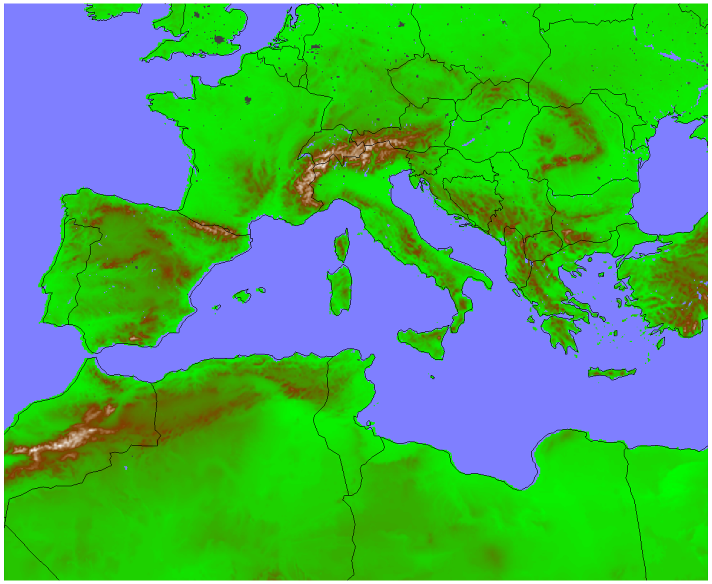
The *geogrid* program

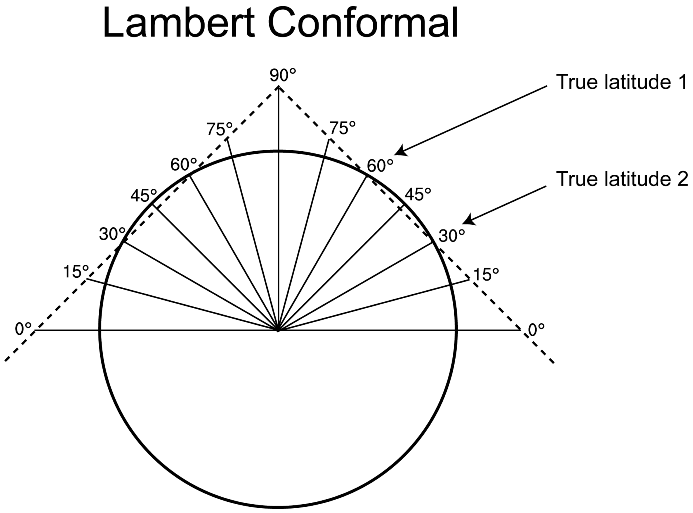
- For WRF model domains, geogrid defines:
  - Map projection (all domains must use the same projection)
  - Geographic location of domains
  - Dimensions of domains
- Geogrid provides values for static (time-invariant) fields at each model grid point
  - Compute latitude, longitude, map scale factor, 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)

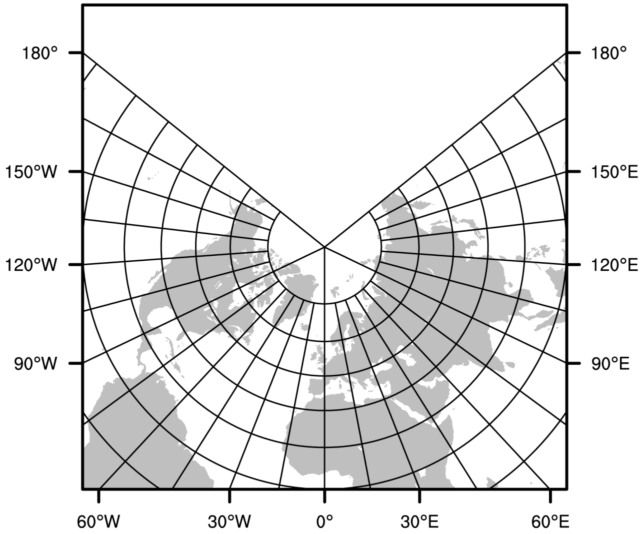
Geogrid: Defining model domains

- 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

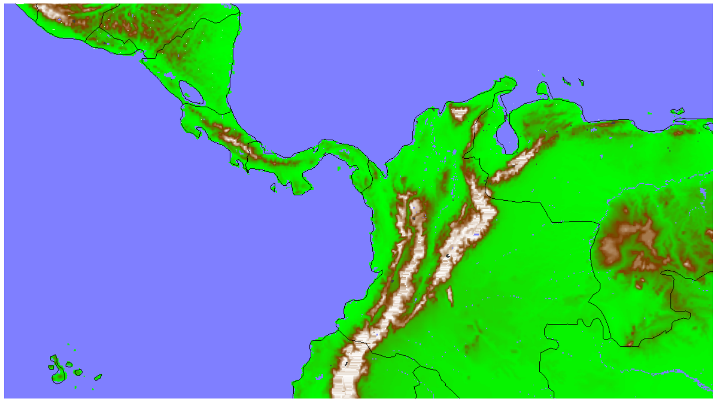




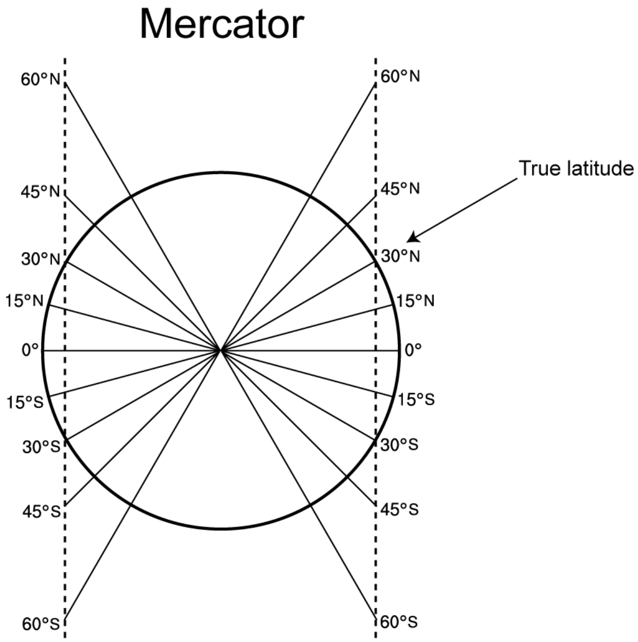


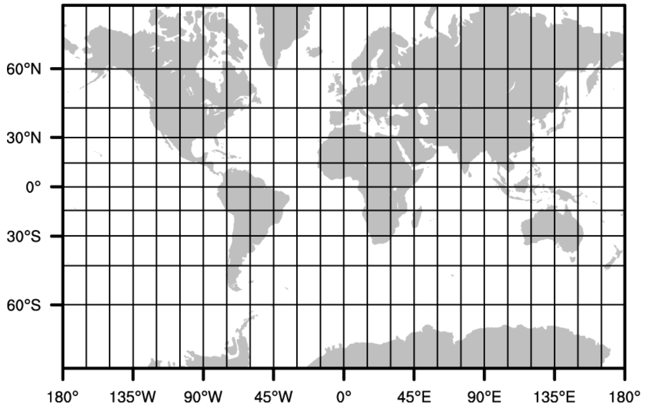
- Well-suited for mid-latitudes
- Domain cannot contain either pole
- Domain cannot be periodic in west-east direction
- Either one or two *true latitudes* may be specified
  - If two are given, the order doesn’t matter

ARW Projections: Mercator

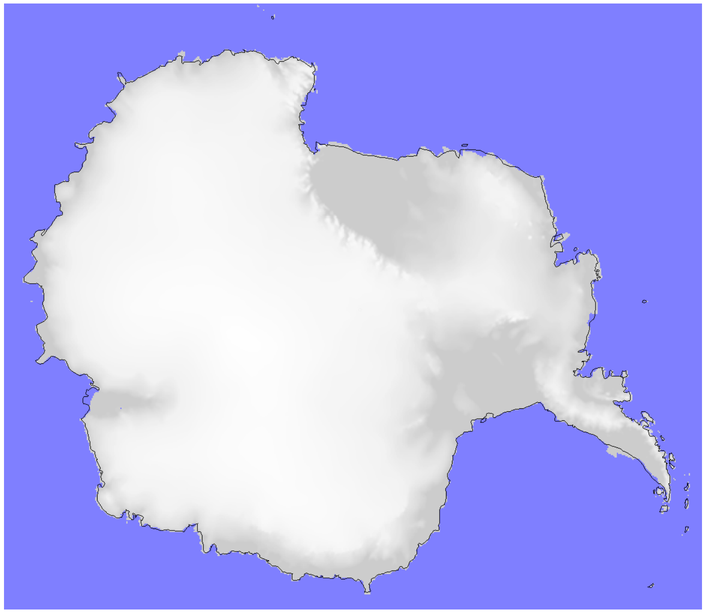


- Well-suited for low-latitudes
- May be used for “channel” domain (periodic domain in west-east direction)
- A single true latitude is specified
  - Cylinder intersects the earth’s surface at +/- truelat

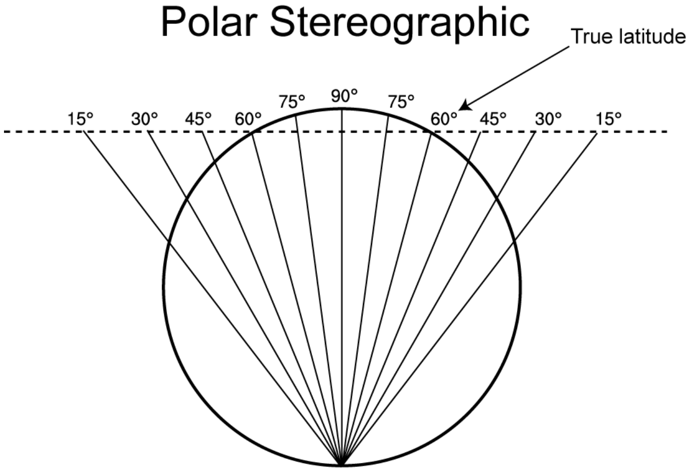


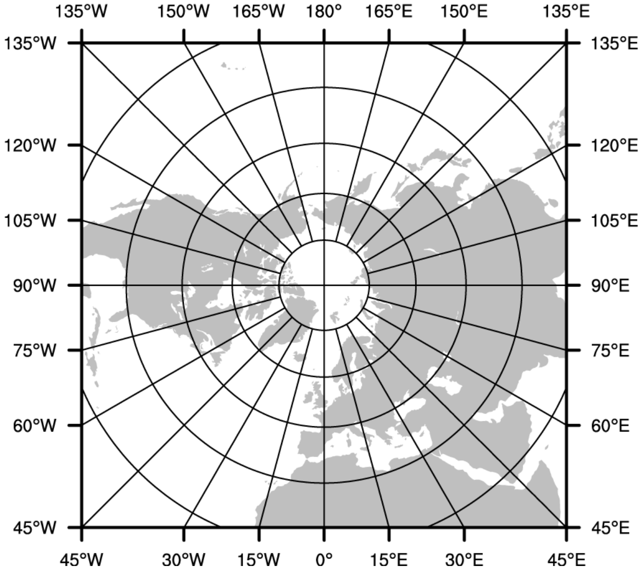


ARW Projections: Polar Stereographic

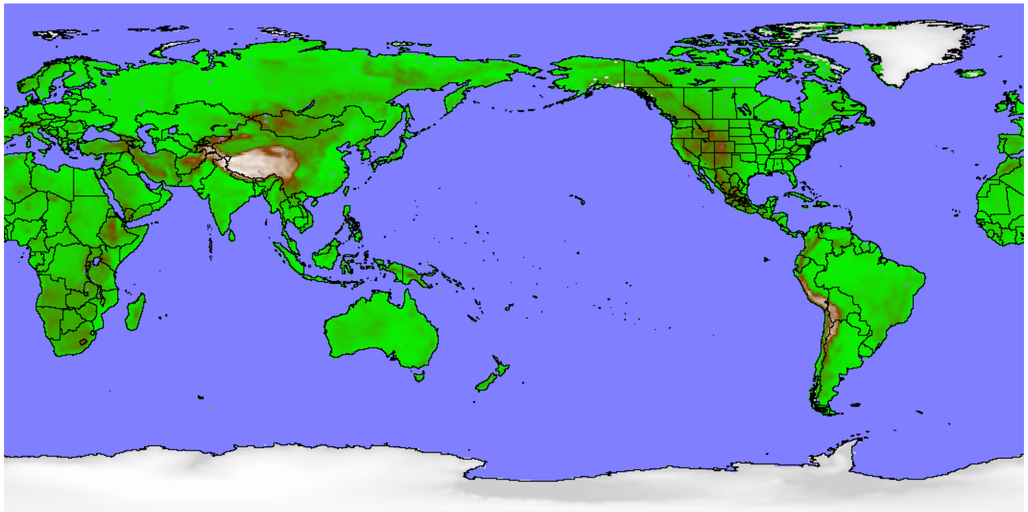


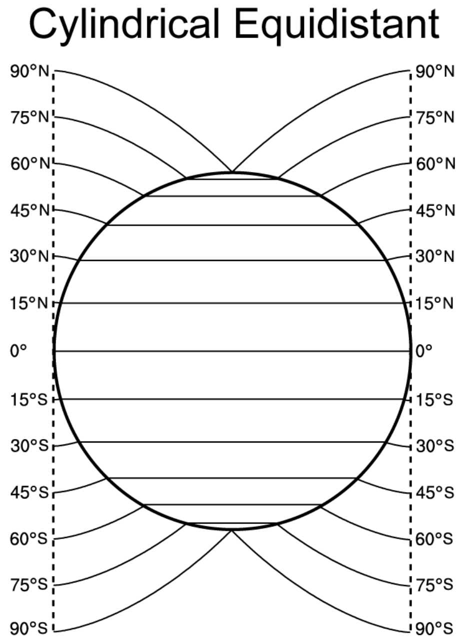
- Good for high-latitude domains, especially if domain must contain a pole
- A single true latitude is specified

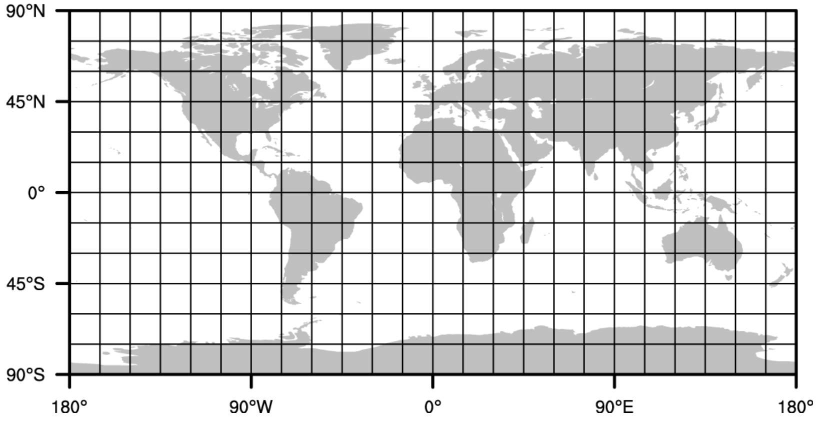




ARW Projections: Cylindrical Equidistant







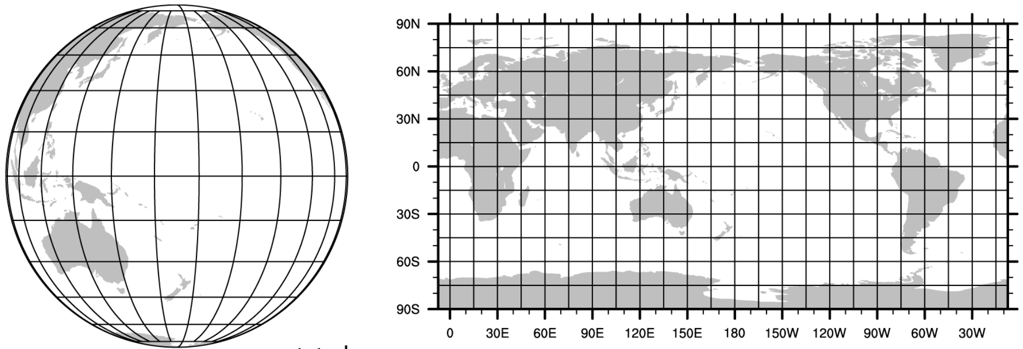
- Required for global domains
- May be used for regional domains
- Can be used in its normal or rotated aspect

Rotating the Lat-lon Grid

In certain cases, it may be desirable or necessary to rotate the poles of the projection away from the poles of the earth

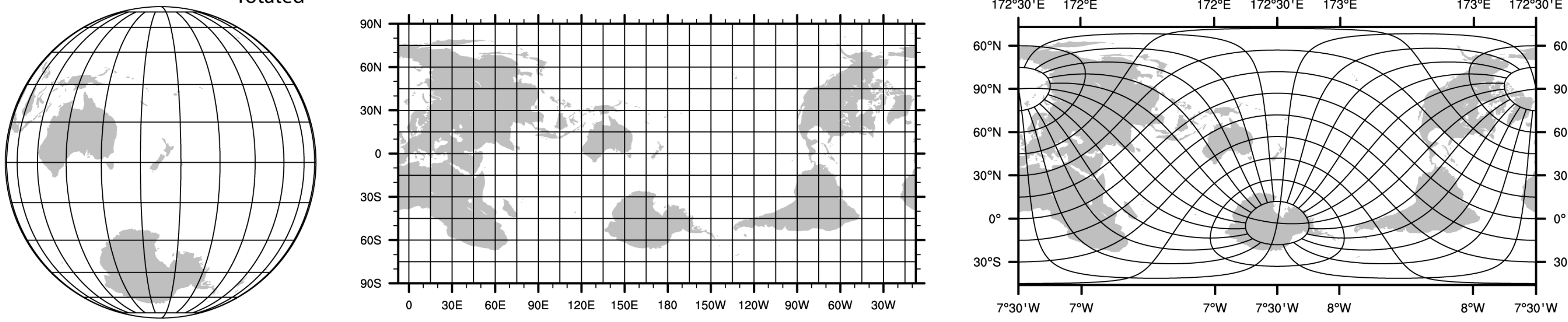
- When placing a nest over a region that would otherwise lie within a filtered region
- When using the lat-lon projection for limited area grids

See p. 3-12



unrotated

rotated



Computational grid

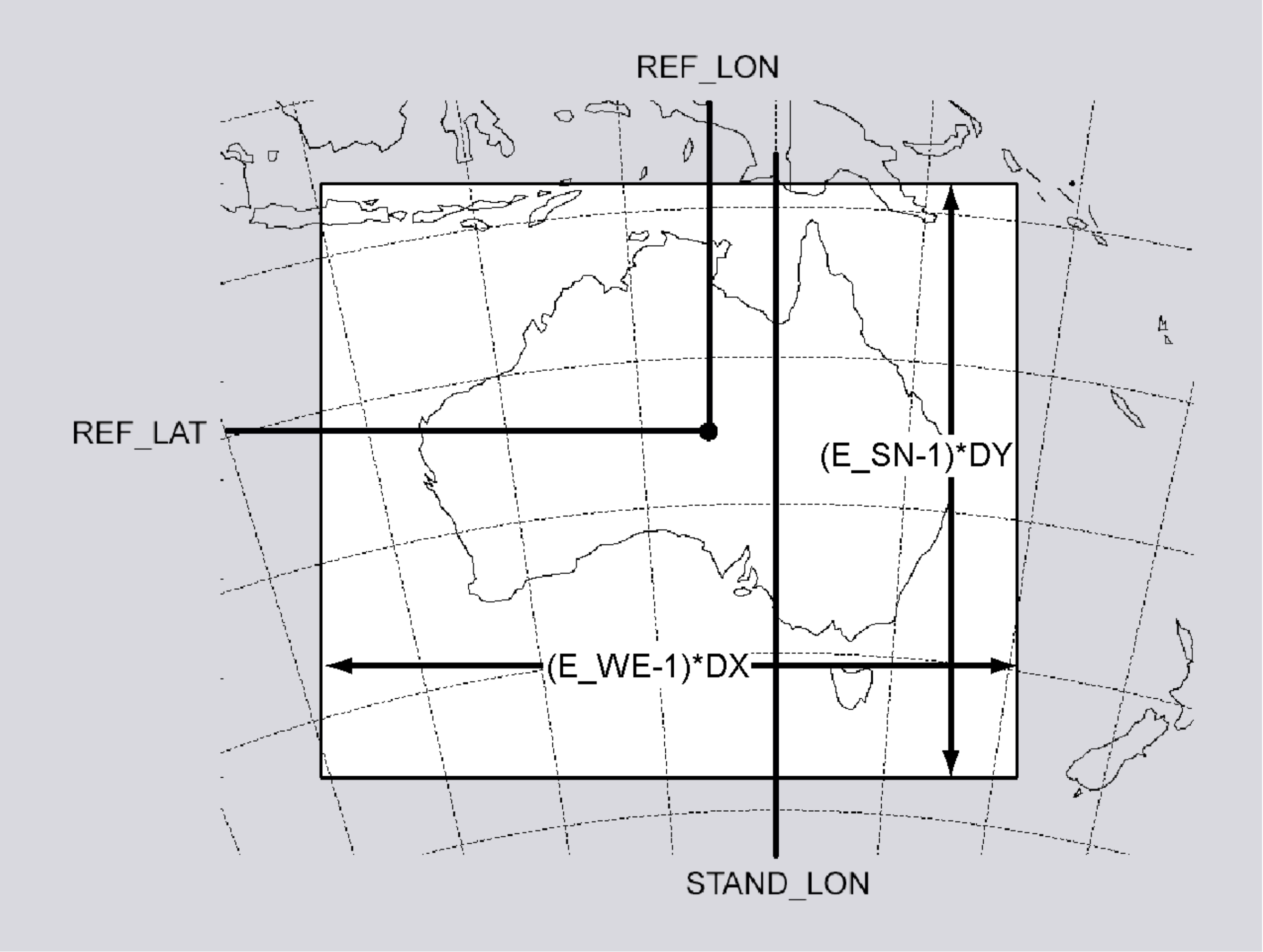
Geographic grid

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

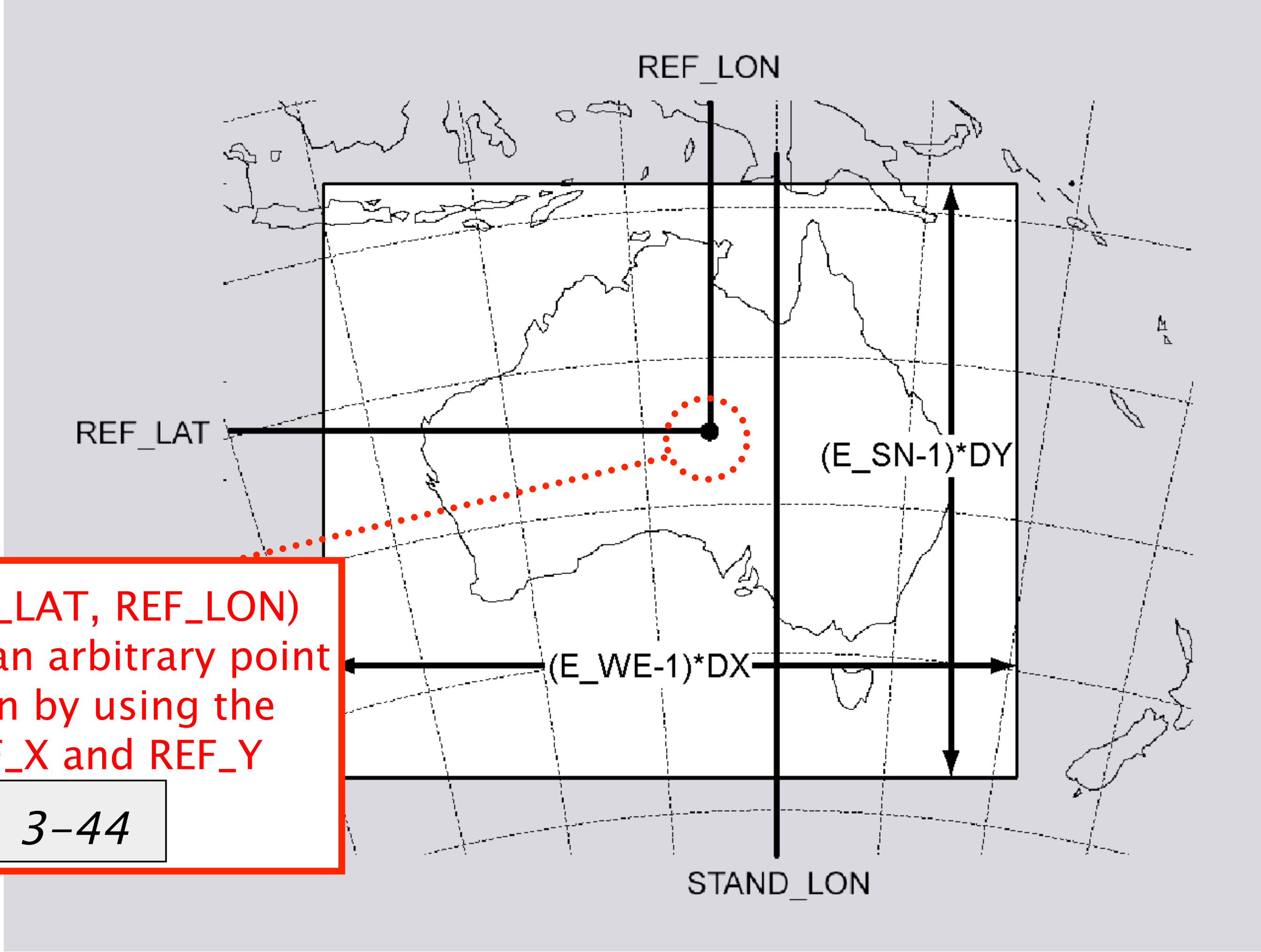


Geogrid: Defining Model Domains

- 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: Defining ARW Domains



In ARW, (REF_LAT, REF_LON) can refer to an arbitrary point in the domain by using the variables REF_X and REF_Y

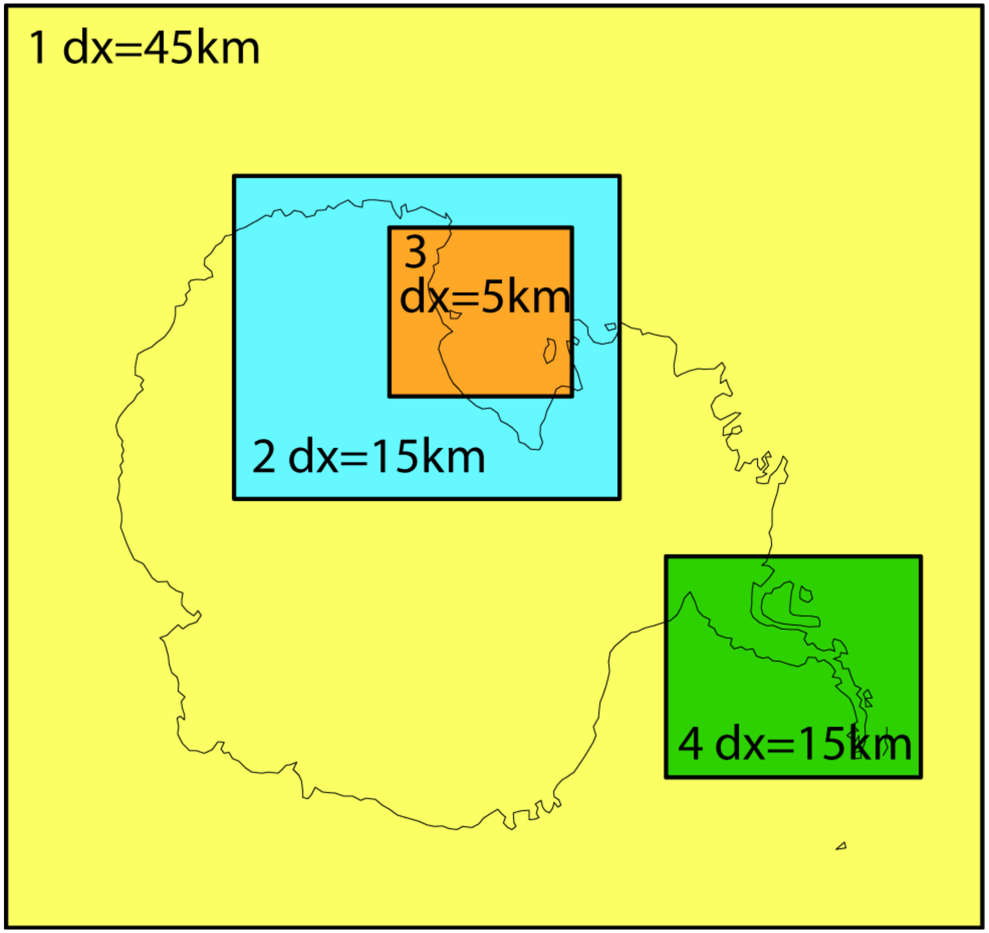
See p. 3-44

Geogrid: Nesting Basics

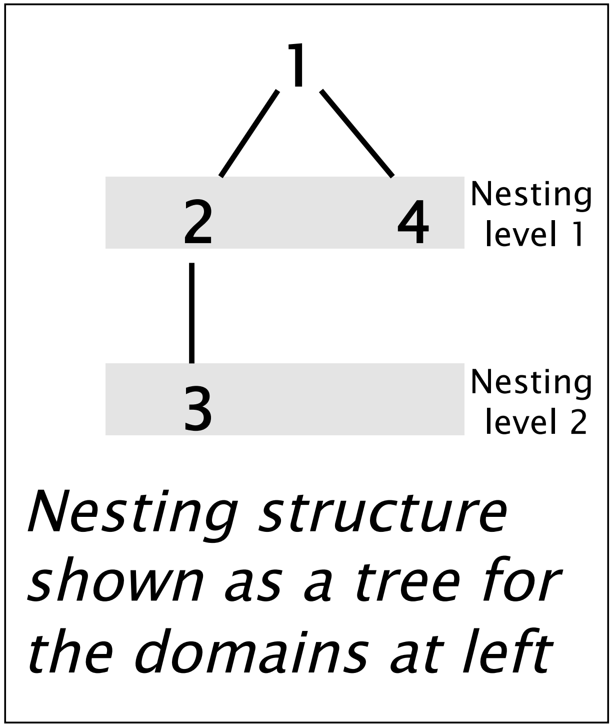
- A *nested domain* is a domain that is wholly contained within its *parent domain* and that receives information from its parent, and that may also feed information back to its parent
  - A nested domain has exactly one *parent*
  - A domain may have one or more *children*
- 2-*way nests* on the same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

Geogrid: Nesting Example

Example configuration – 4 domains



Each domain is assigned a *domain ID #*



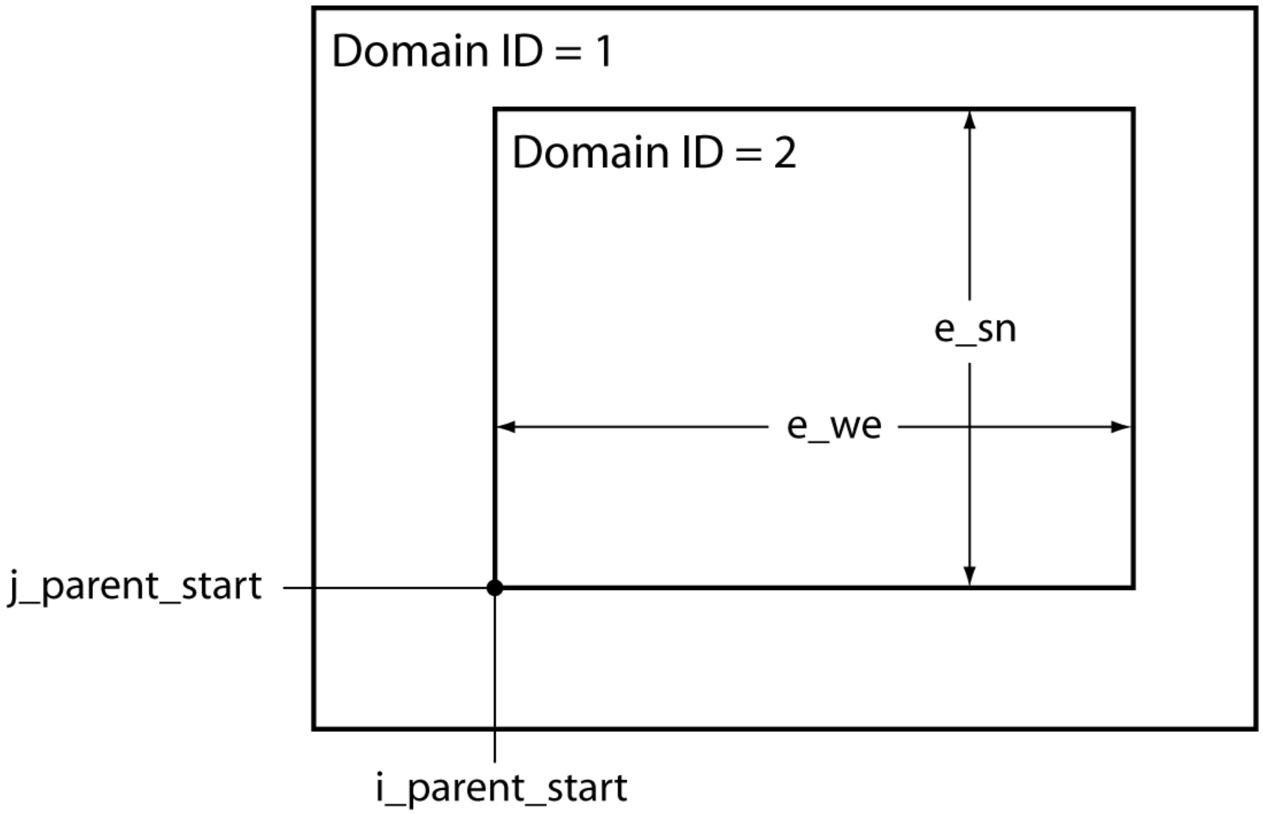
Nesting structure shown as a tree for the domains at left

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

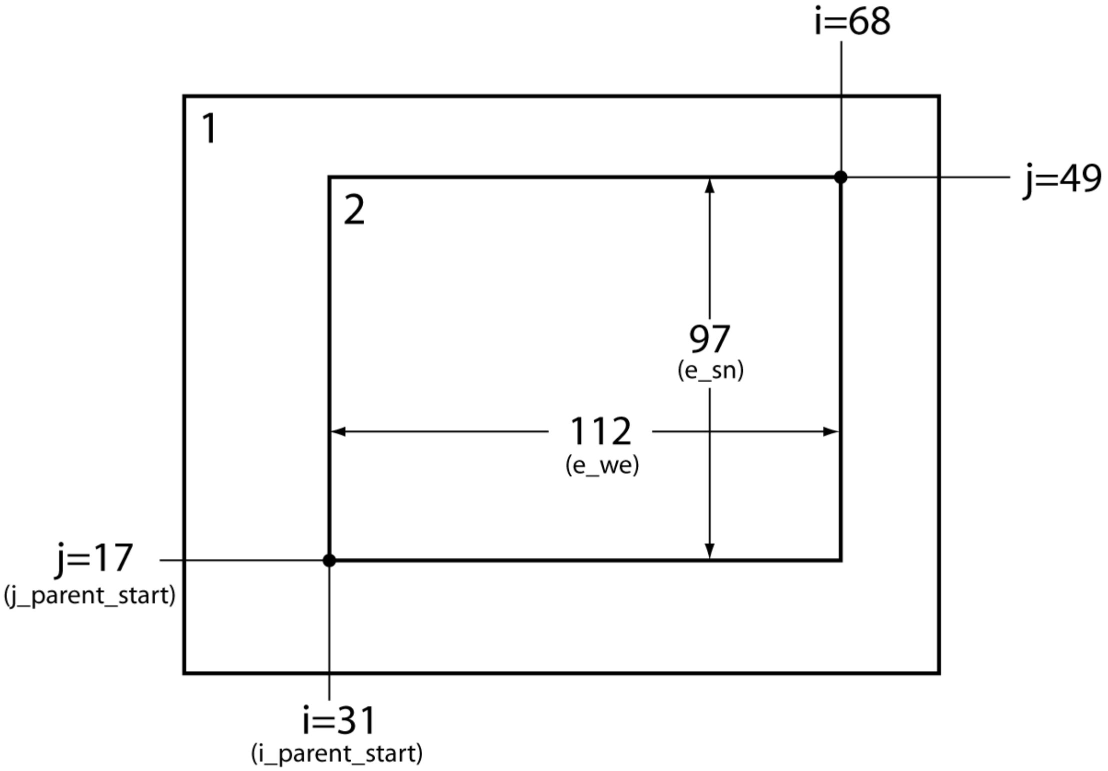
Geogrid: Defining Nested Domains



The grid spacing (*dx)* of domain 2 is determined by grid spacing of domain 1 and the *parent_grid_ratio*

Geogrid: Nesting example

Assuming *parent_grid_ratio* = 3



In ARW, nest dimensions must be

(*n** *parent_grid_ratio* + 1)

for some integer *n*

112 = 3*n+1 for n=37

97 = 3*n+1 for n=32

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: Interpolating Static Fields

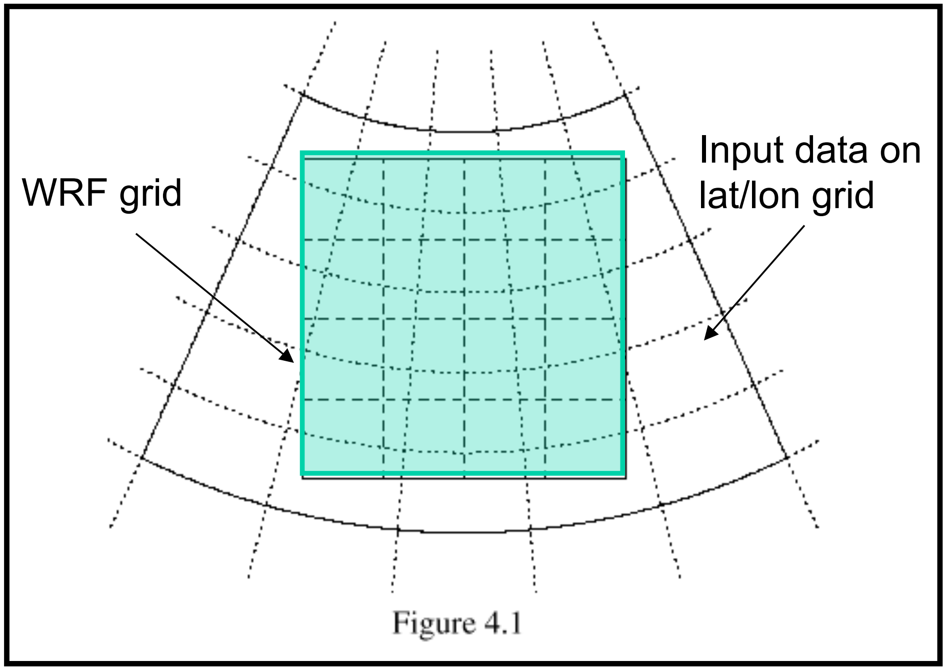


Figure 4.1

In general, source data are given on a different projection from the model grid

Geogrid: Interpolation Options

- 4-point bilinear
- 16-point overlapping parabolic
- 4-point average (simple or weighted)
- 16-point average (simple or weighted)
- Grid cell average
- Nearest neighbor
- Breadth-first search

See p. 3-55

Why have so many interpolation options?

- Different interpolators work best for different fields and different relative grid resolutions
  - Some interpolators preserve positive definiteness
  - Some interpolators produce “smoother” fields
  - Some interpolators are best suited for discrete or categorical fields
  - Some are good when going from a fine grid to a coarse grid

- Having a choice of how to interpolate fields is good!
  - We’ll see in Friday’s WPS lecture how several different options can be used for different regions of the same field

Geogrid: Program Flexibility

- The GEOGRID.TBL file determines
  1. Which fields will be produced by geogrid
  2. What sources of data will be used
  3. How the data will be interpolated/smoothed
  4. Any derived fields (e.g., dominant cat., df/dx)

- Acceptable defaults exist in GEOGRID.TBL, so user will not generally need to edit the file (*but more on this in Wednesday's WPS lecture*!)

Geogrid: Program Flexibility

- *geogrid* is flexible enough to ingest and interpolate new static fields
  - handles either continuous or categorical fields
- New data sets must be written to simple binary format
- User needs to add an entry to the file `GEOGRID.TBL`

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 #)

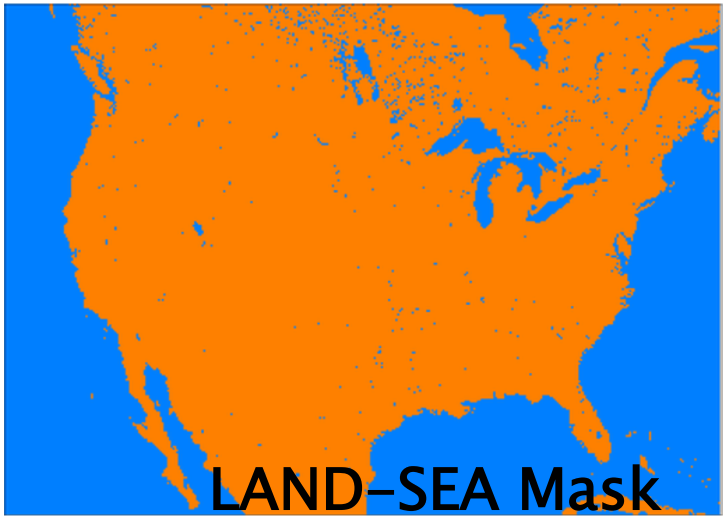
- Example:

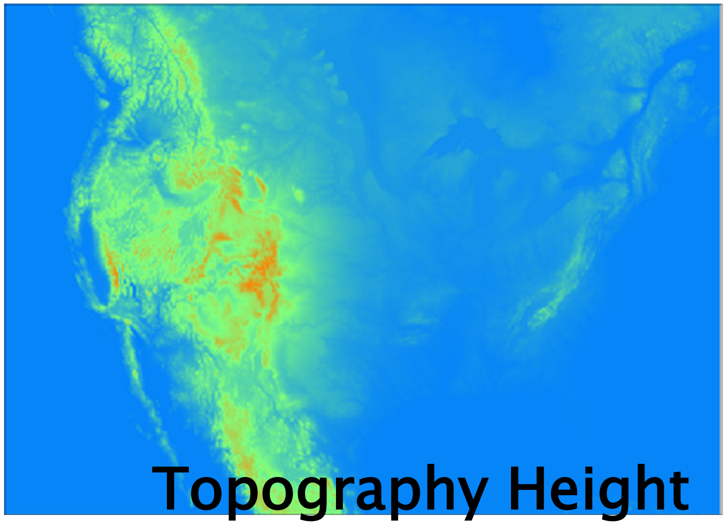
  geo_em.d01.nc

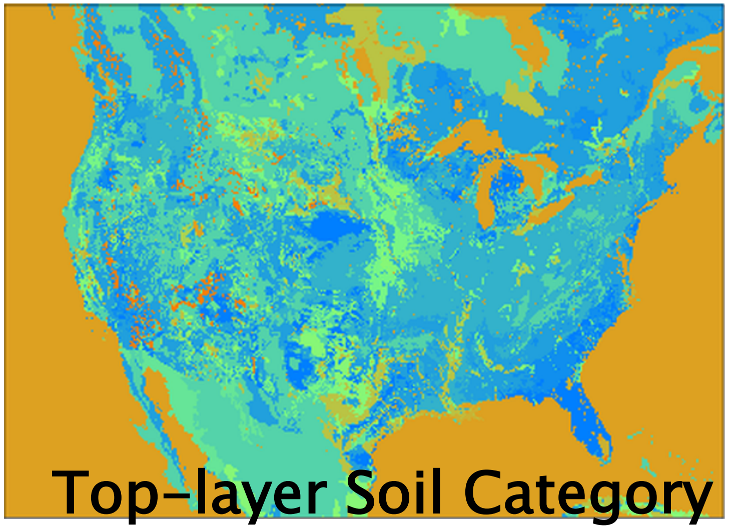
  geo_em.d02.nc (nest)

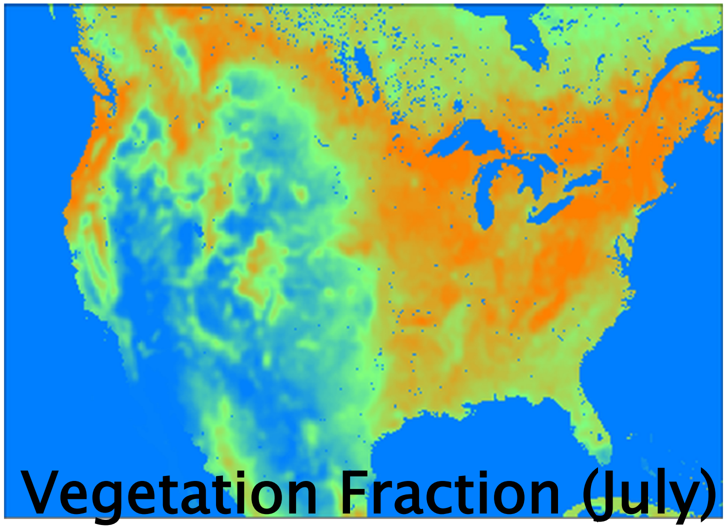
  geo_em.d03.nc (nest)

Geogrid: Example Output Fields

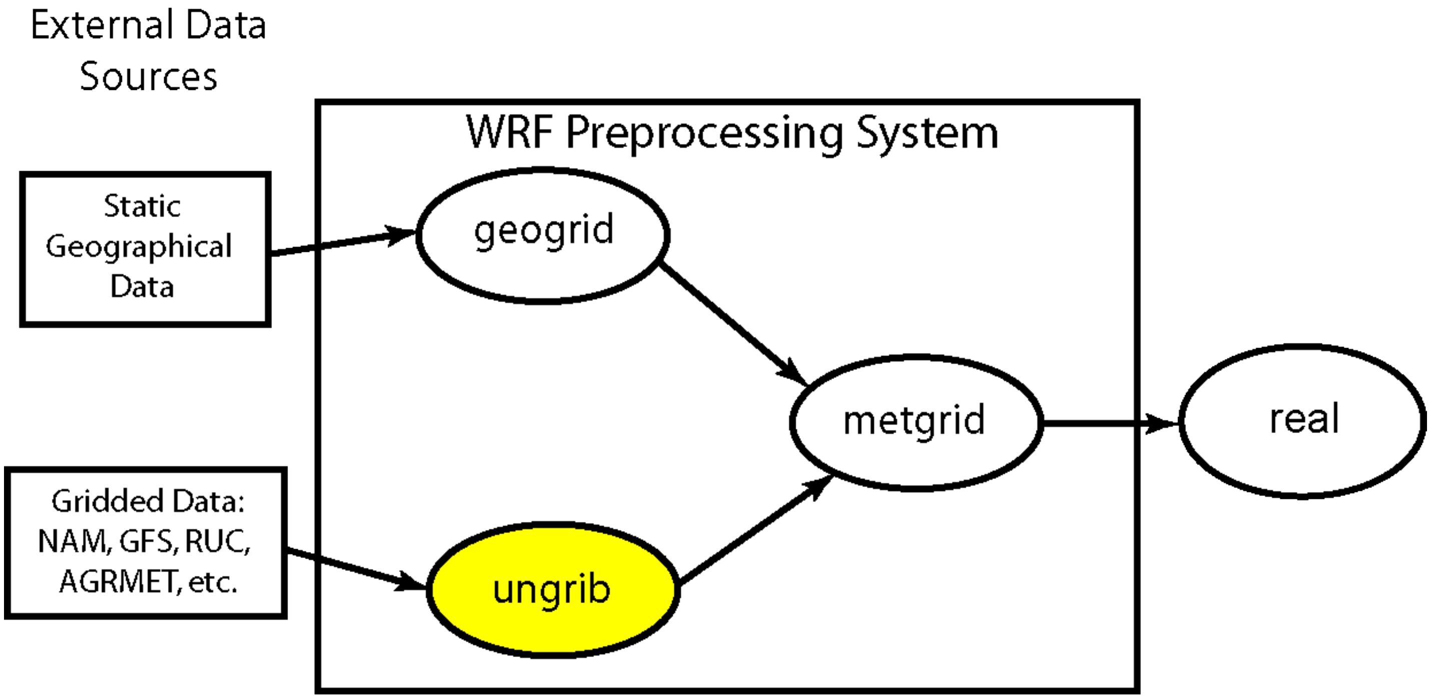

LAND-SEA Mask


Topography Height


Top-layer Soil Category


Vegetation Fraction (July)

The *ungrib* program



ungrib: think un+grib

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

Ungrib: Vtables

How does ungrib know which fields to extract?

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

```
GRIB1| Level| From |  To  | UNGRIB   |  UNGRIB | UNGRIB
Param| Type |Level1|Level2| Name     |  Units  | Description
-----+-----+-----+-----+---------+--------+----------------------------------------
  11 | 100  |   *  |      | T        | K       | Temperature
  33 | 100  |   *  |      | U        | m s-1   | U
  34 | 100  |   *  |      | V        | m s-1   | V
  52 | 100  |   *  |      | RH       | %       | Relative Humidity
   7 | 100  |   *  |      | HGT      | m       | Height
  11 | 105  |   2  |      | T        | K       | Temperature       at 2 m
  52 | 105  |   2  |      | RH       | %       | Relative Humidity at 2 m
  33 | 105  |  10  |      | U        | m s-1   | U                 at 10 m
  34 | 105  |  10  |      | V        | m s-1   | V                 at 10 m
   1 |   1  |   0  |      | PSFC     | Pa      | Surface Pressure
 130 | 102  |   0  |      | PMSL     | Pa      | Sea-level Pressure
 144 | 112  |   0  |  10  | SM000010 | kg m-3  | Soil Moist 0-10 cm below grn layer (Up)
 144 | 112  |  10  |  40  | SM010040 | kg m-3  | Soil Moist 10-40 cm below grn layer
 144 | 112  |  40  | 100  | SM040100 | kg m-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  |      | SOILCAT  | Tab4.213| Dominant soil type category
 225 |   1  |   0  |      | VEGCAT   | Tab4.212| Dominant land use category
-----+-----+-----+-----+---------+--------+----------------------------------------
```

Ungrib: GRIB2 Vtable Entries

```
| metgrid                                 |GRIB2|GRIB2|GRIB2|GRIB2|
| Description                             |Discp|Catgy|Param|Level|
+-----------------------------------------+-----------------------+
| Temperature                             |  0  |  0  |  0  | 100 |
| U                                       |  0  |  2  |  2  | 100 |
| V                                       |  0  |  2  |  3  | 100 |
| Relative Humidity                       |  0  |  1  |  1  | 100 |
| Height                                  |  0  |  3  |  5  | 100 |
| Temperature       at 2 m                |  0  |  0  |  0  | 103 |
| Relative Humidity at 2 m                |  0  |  1  |  1  | 103 |
| U                 at 10 m               |  0  |  2  |  2  | 103 |
| V                 at 10 m               |  0  |  2  |  3  | 103 |
| Surface Pressure                        |  0  |  3  |  0  |   1 |
| Sea-level Pressure                      |  0  |  3  |  1  | 101 |
| Soil Moist 0-10 cm below grn layer (Up) |  2  |  0  | 192 | 106 |
| Soil Moist 10-40 cm below grn layer     |  2  |  0  | 192 | 106 |
| Soil Moist 40-100 cm below grn layer    |  2  |  0  | 192 | 106 |
| Soil Moist 100-200 cm below gr layer    |  2  |  0  | 192 | 106 |
| Soil Moist 10-200 cm below gr layer     |  2  |  0  | 192 | 106 |
| T 0-10 cm below ground layer (Upper)    |  0  |  0  |  0  | 106 |
| T 10-40 cm below ground layer (Upper)   |  0  |  0  |  0  | 106 |
| T 40-100 cm below ground layer (Upper)  |  0  |  0  |  0  | 106 |
| T 100-200 cm below ground layer (Bottom)|  0  |  0  |  0  | 106 |
| T 10-200 cm below ground layer (Bottom) |  0  |  0  |  0  | 106 |
| Ice flag                                |  0  |  2  |  0  |   1 |
| Land/Sea flag (1=land, 0 or 2=sea)      |  2  |  0  |  0  |   1 |
| Terrain field of source analysis        |  2  |  0  |  7  |   1 |
| Skin temperature (can use for SST also) |  0  |  0  |  0  |   1 |
| Water equivalent snow depth             |  0  |  1  | 13  |   1 |
| Dominant soil type cat.(not in GFS file)|  2  |  3  |  0  |   1 |
| Dominant land use cat. (not in GFS file)|  2  |  0  | 198 |   1 |
+-----------------------------------------+-----------------------+
```

Ungrib: Vtables

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

  - *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)

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

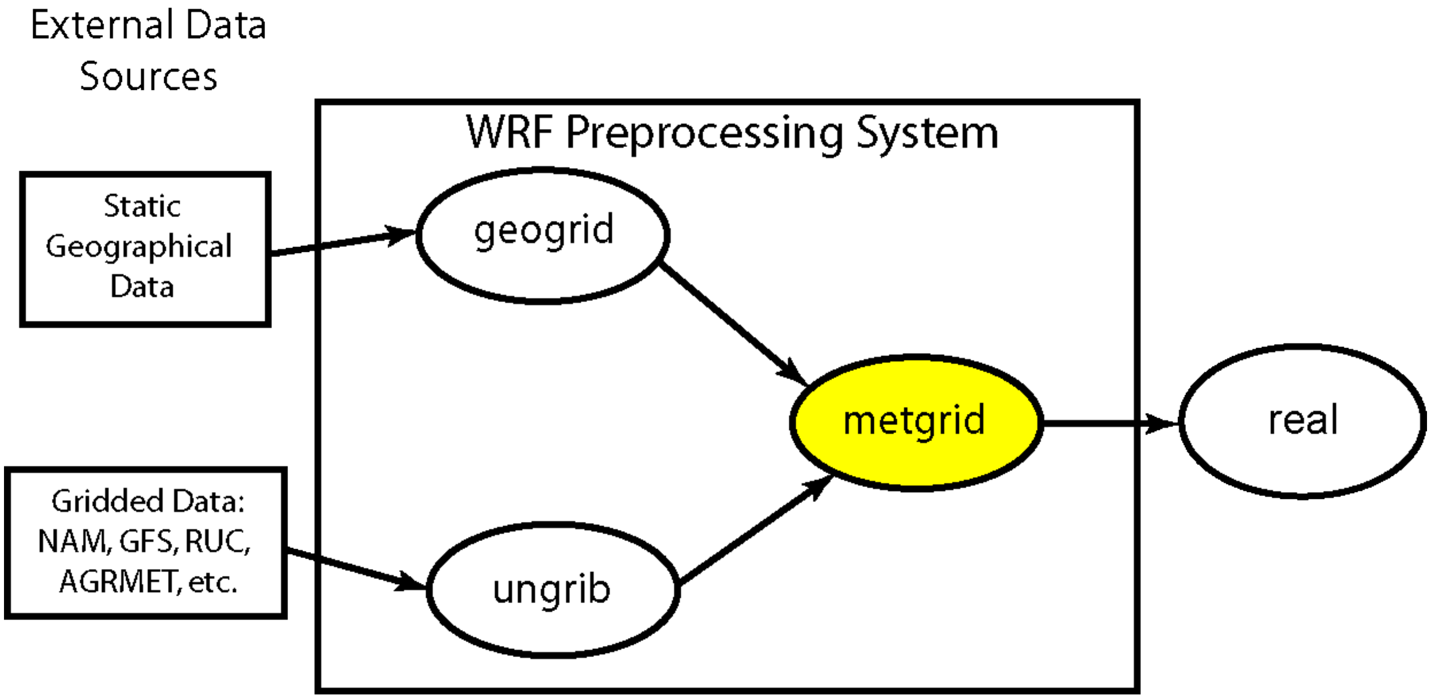
  FILE:2007-07-24_12

ungrib can also write intermediate files in the MM5 or WRF SI format! *(To allow for use of GRIB2 data with MM5, for example)*

Ungrib: Obtaining GRIB Data

- Where does one get GRIB data?
  - User’s responsibility
  - Some free data are available from NCAR and NCEP. See
  - *http://www.mmm.ucar.edu/wrf/users/*
    - > under the “Downloads” tab:
      - Some NCEP data in the past year
      - NCEP operational data available daily

The *metgrid* program



metgrid: think meteorological

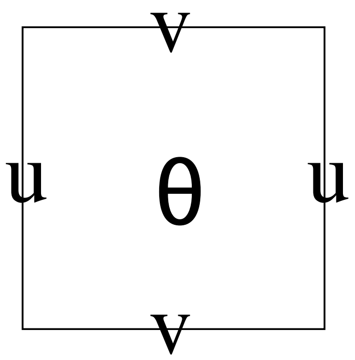
The *metgrid* program

- Horizontally interpolate meteorological data (*extracted by ungrib*) to simulation domains (*defined by geogrid*)
  - Masked interpolation for masked fields

- 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.

Metgrid: Interpolation Options*

- 4-point bilinear
- 16-point overlapping parabolic
- 4-point average (simple or weighted)
- 16-point average (simple or weighted)
- Grid cell average
- Nearest neighbor
- Breadth-first search

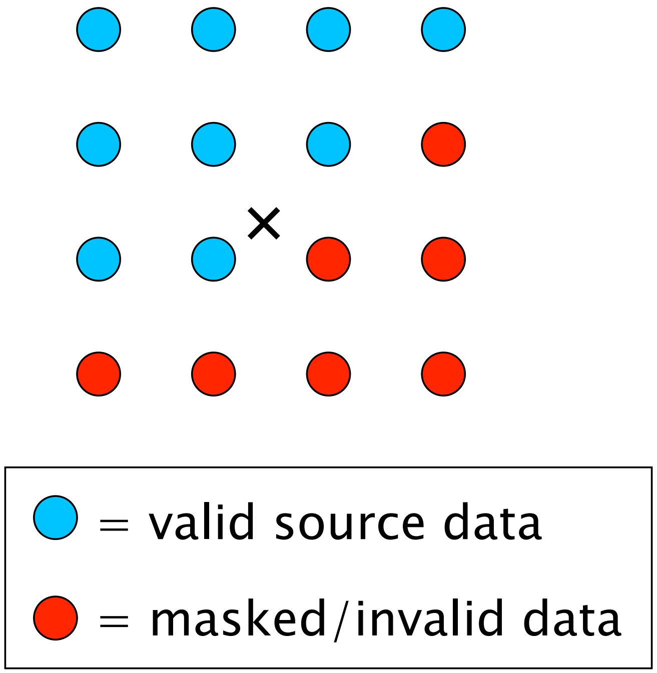
* These are the same options available for geogrid!

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., 1×10^{30}) in field itself to identify masked grid points

Metgrid: Masked Interpolation

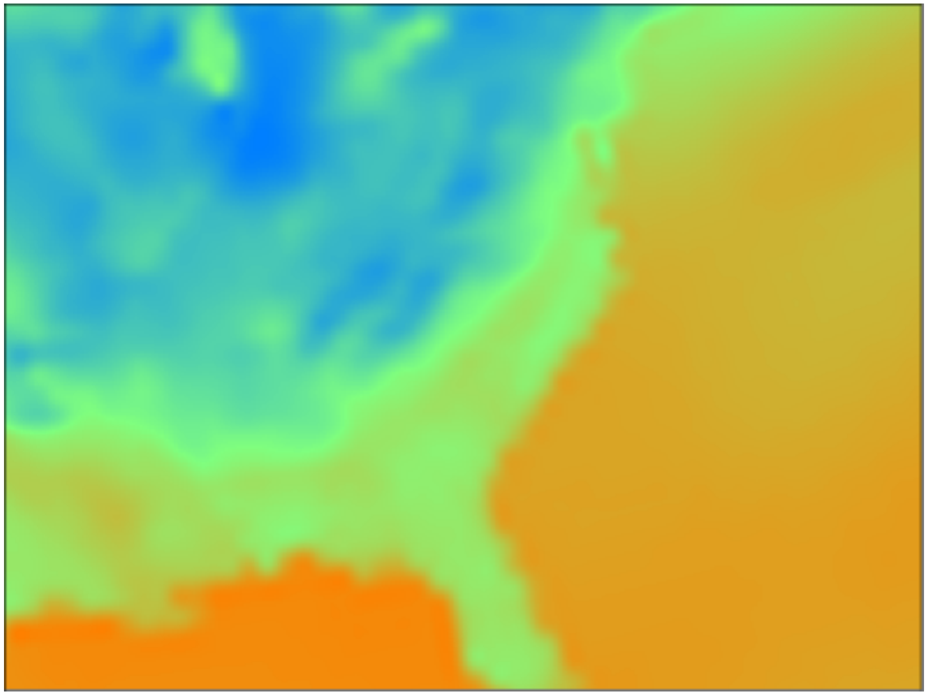


Suppose we need to interpolate to point X

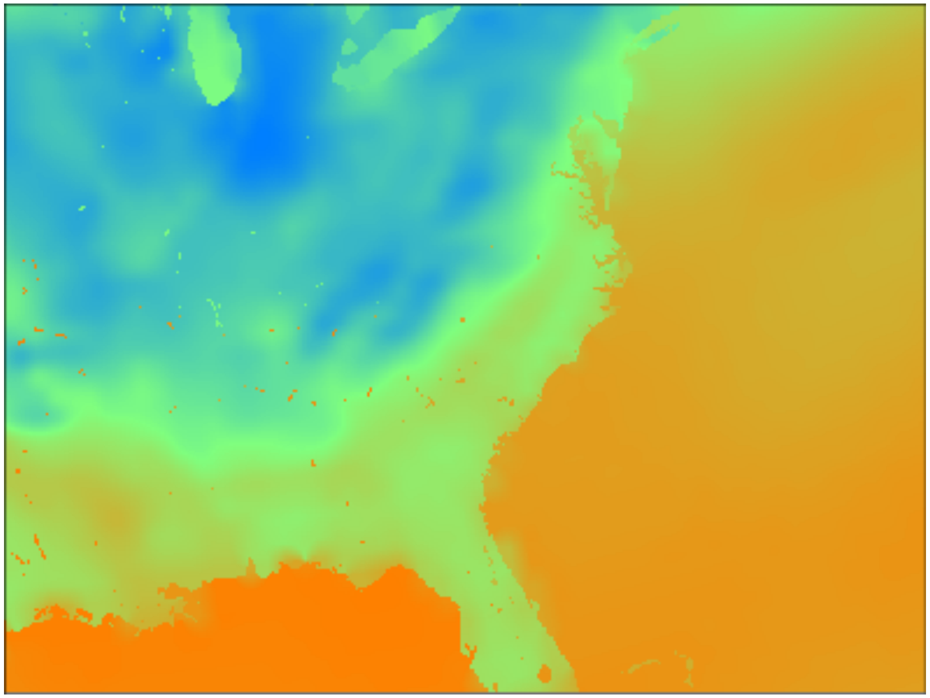
- Using red points as valid data can give a bad interpolated value!
- Masked interpolation only uses valid blue points to interpolate to X

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

Example: Masked Interpolation



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



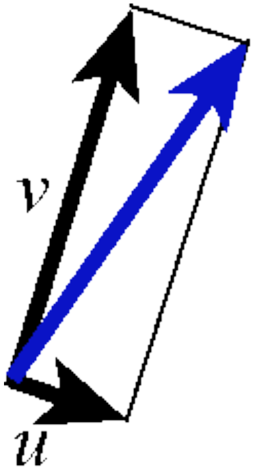
Skin temperature field interpolated using masks: GFS water points interpolated to model water points, GFS land points interpolated to model land points.

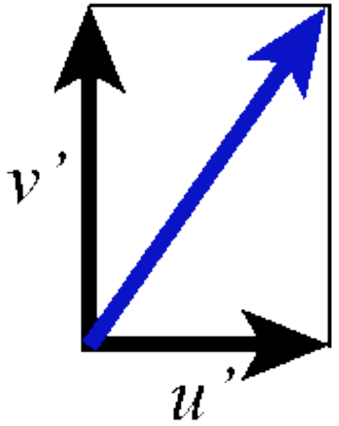
Metgrid: Wind Rotation

- 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 Flexibility

- *metgrid* is capable of interpolating both isobaric and native vertical coordinate data sets

- User may specify interpolation methods and related options in the `METGRID.TBL` file
  - `METGRID.TBL` file similar in format to the file `GEOGRID.TBL`

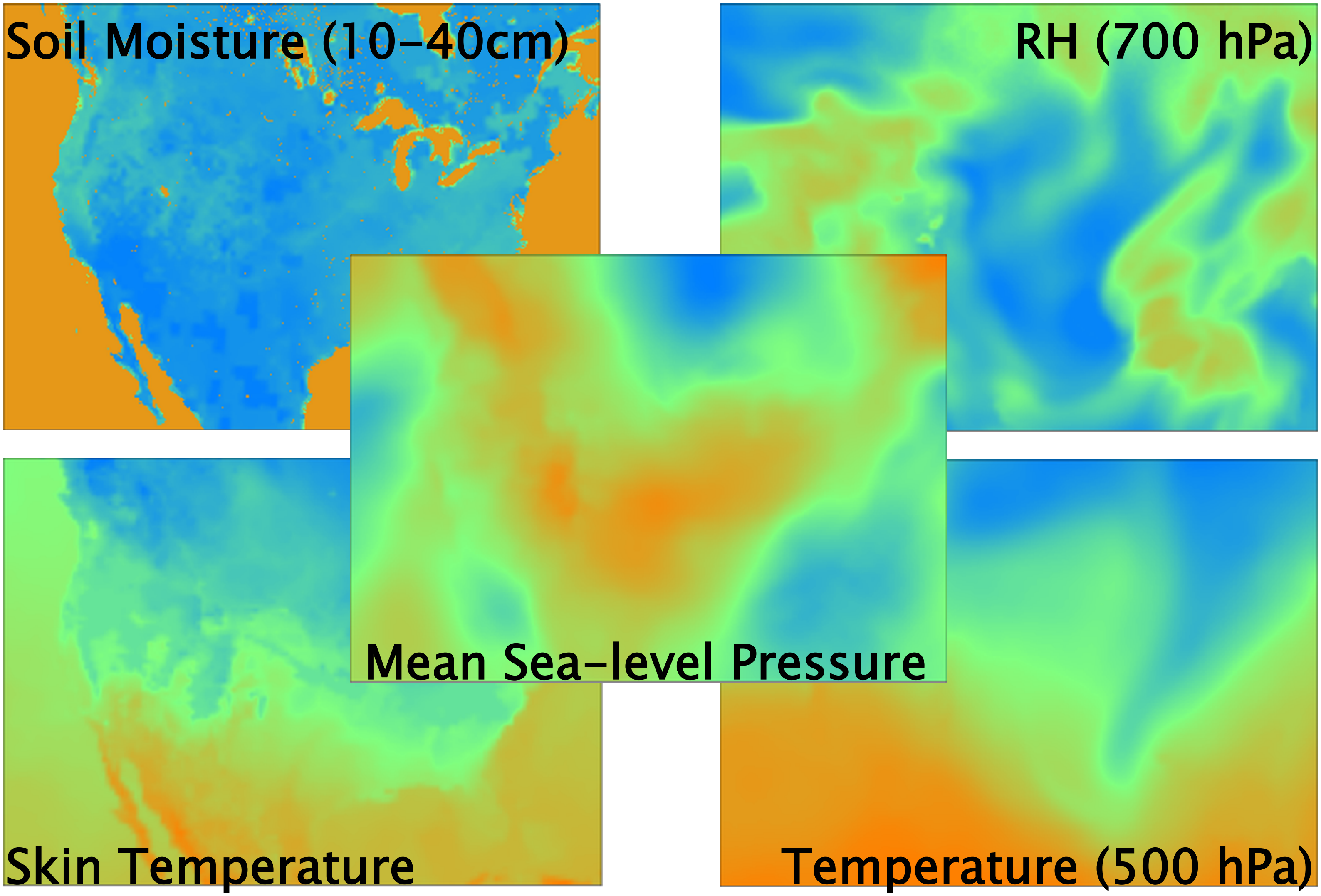
Metgrid: Program Output

- 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:

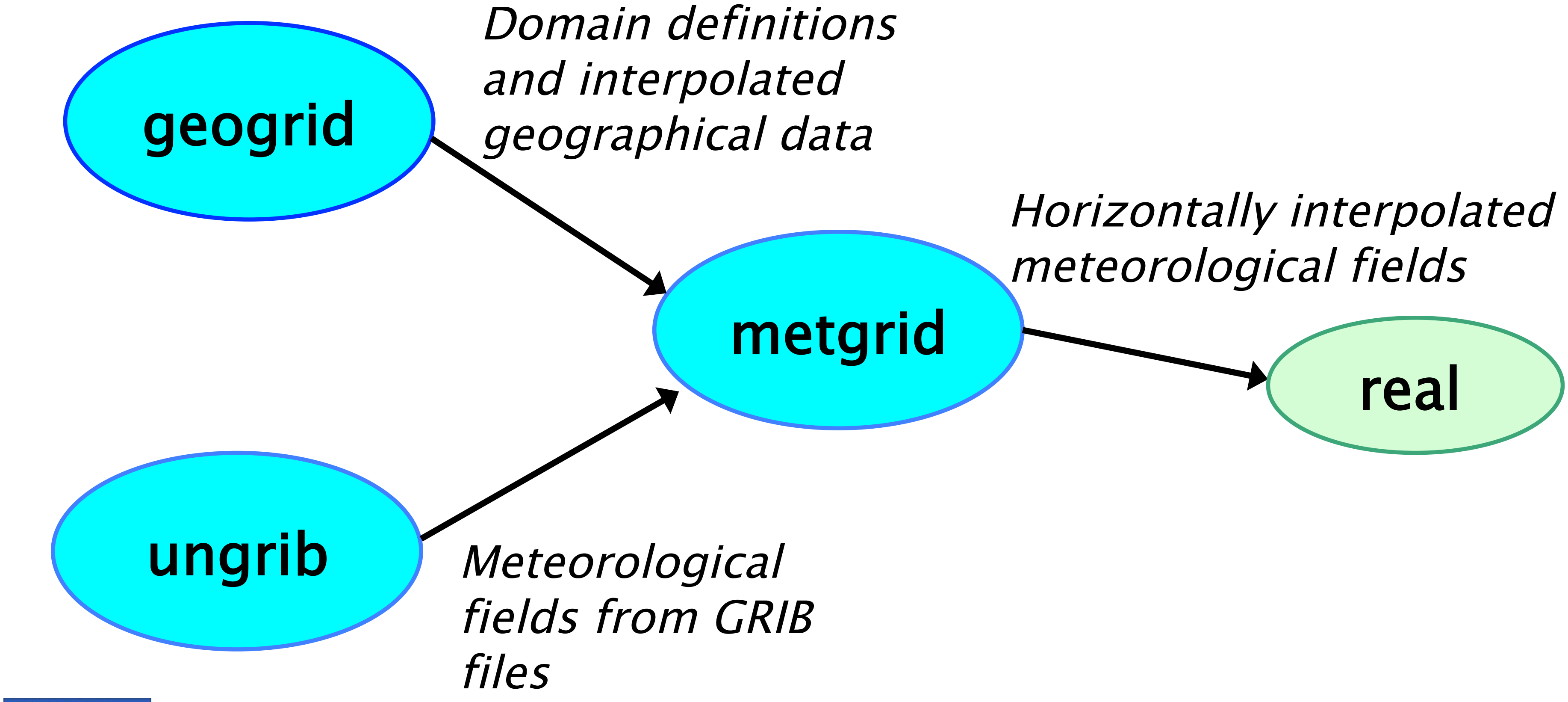
met_em.d0*n*.*YYYY-MM-DD_HH:mm:ss*.nc

(where *n* is the domain ID #)

Metgrid: Example Output



WPS Summary



geogrid

Domain definitions and interpolated geographical data

ungrib

Meteorological fields from GRIB files

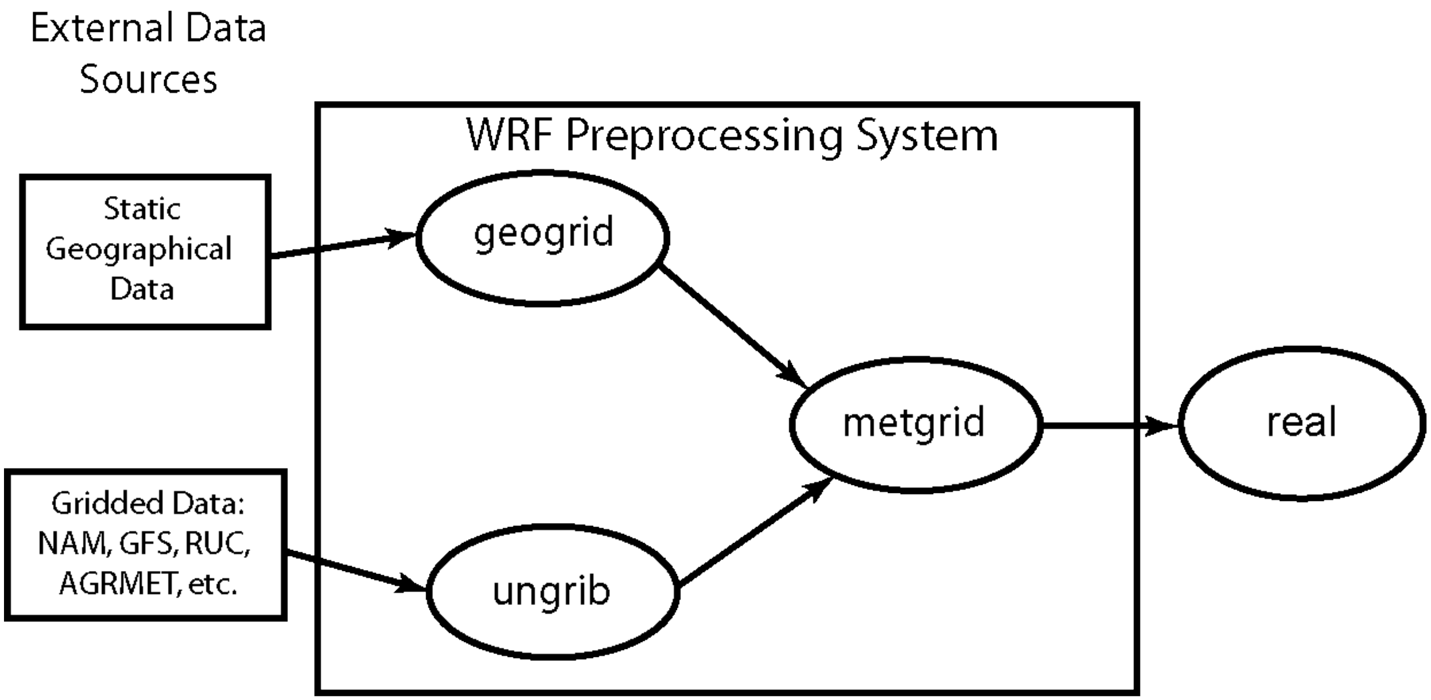
metgrid

Horizontally interpolated meteorological fields

real

And finally…

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



Questions?