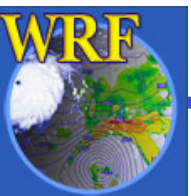


The WRF Preprocessing System: Description of General Functions

Michael Duda



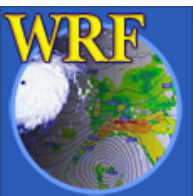
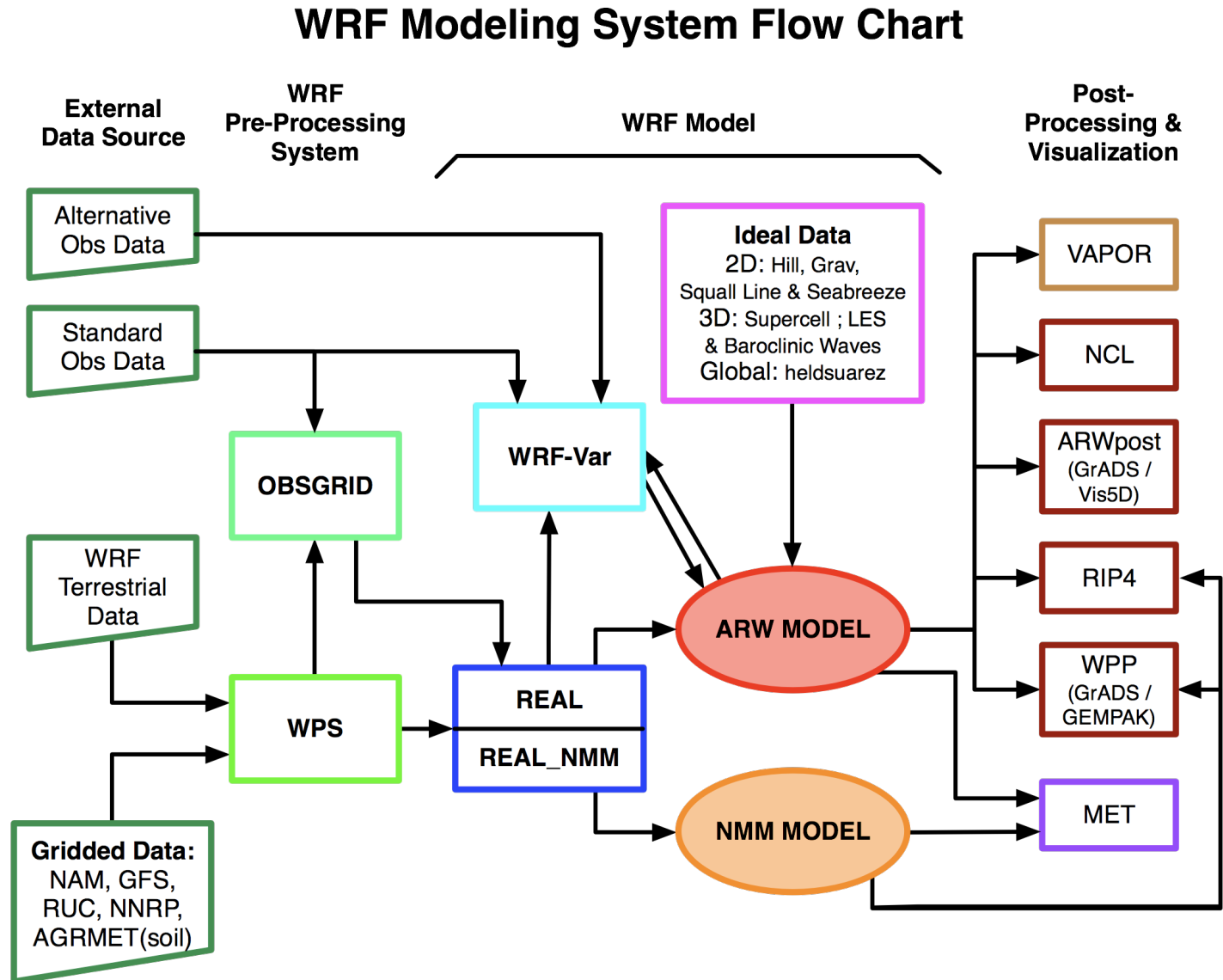
Purpose of this Lecture

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 in the second WPS lecture
 - *Advanced usage* of the WPS is covered in the third lecture



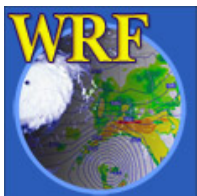
WRF Modeling System Flowchart



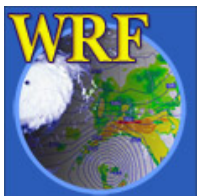
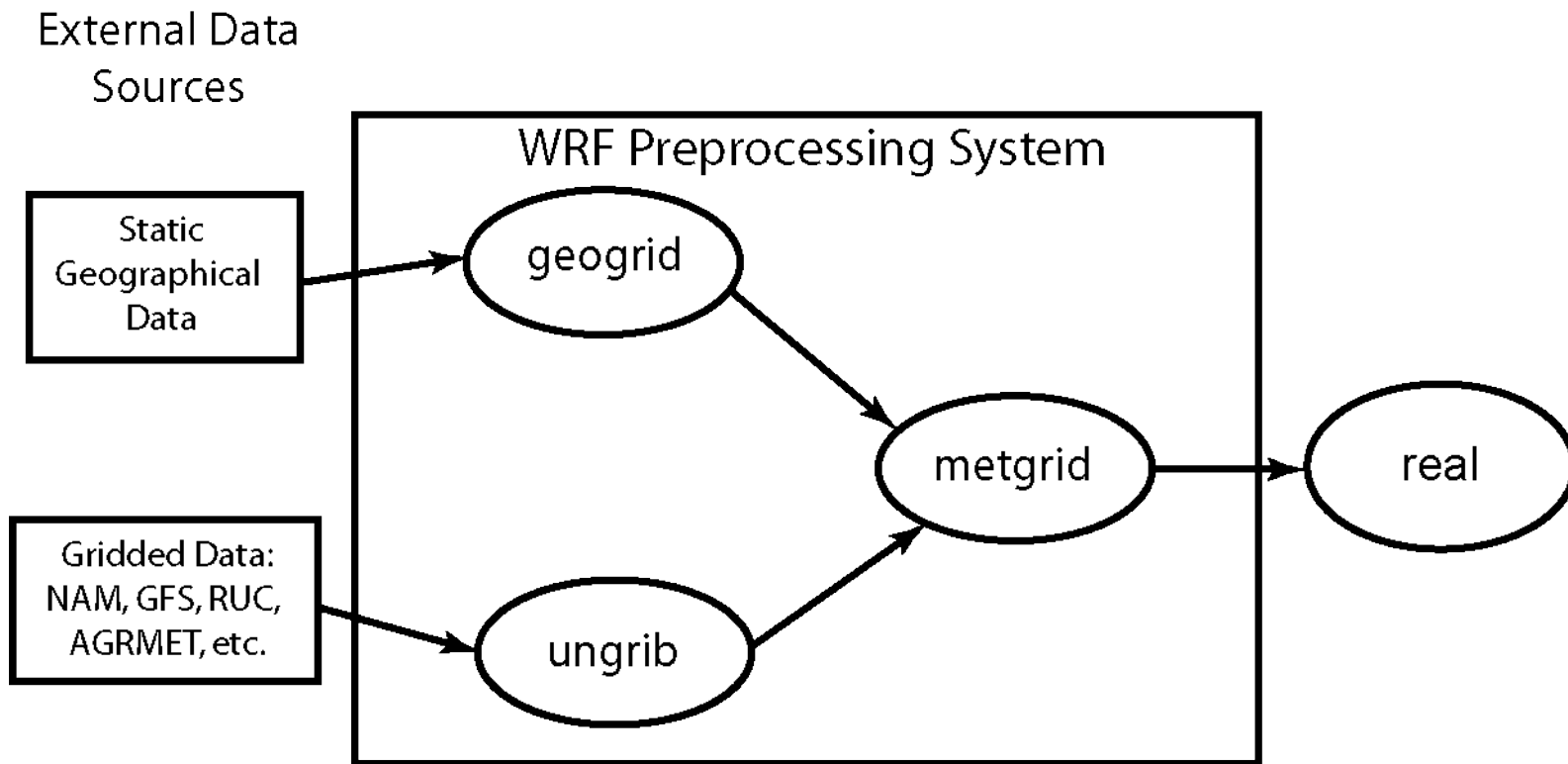
Purpose of the WPS

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

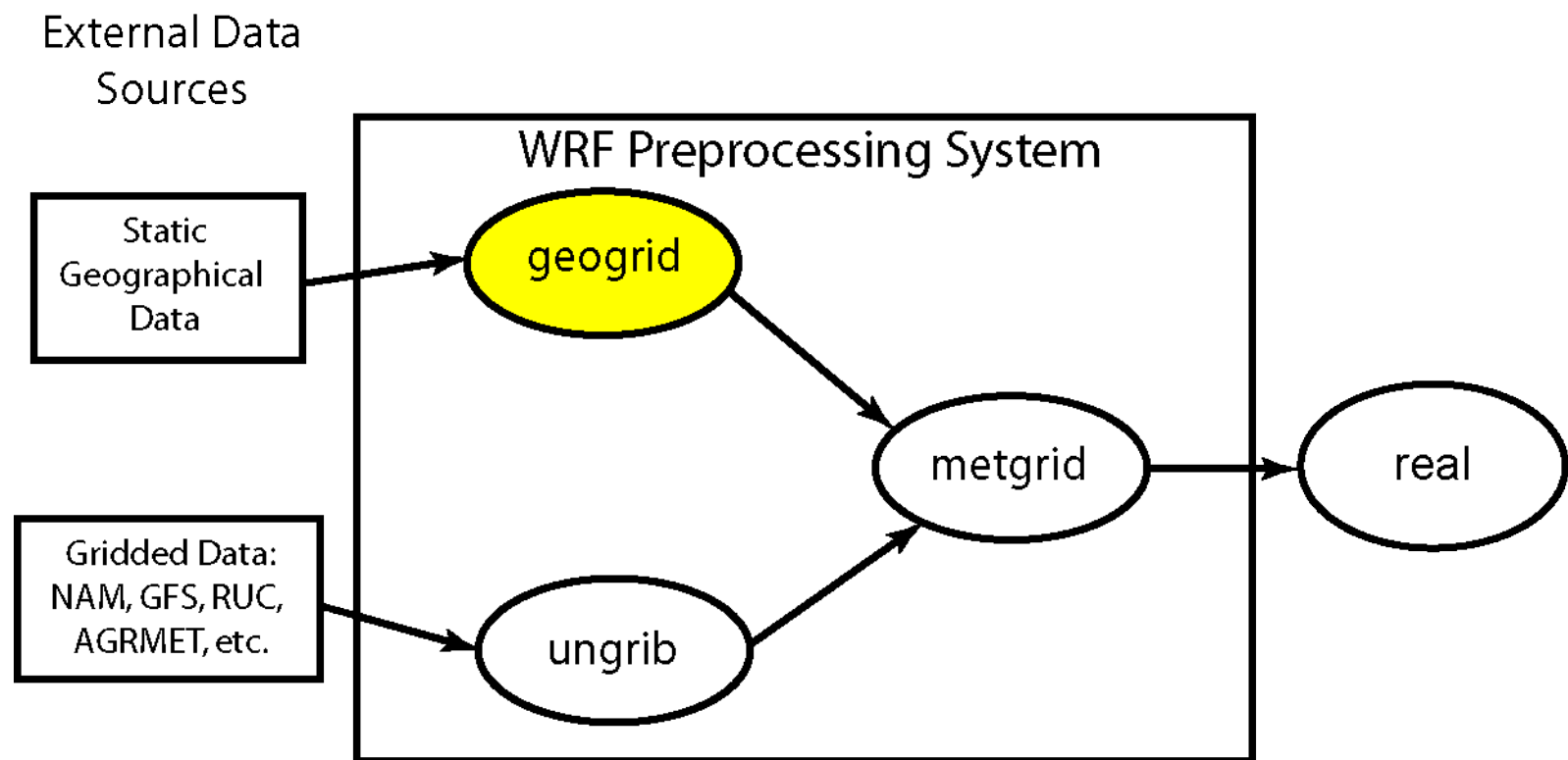
1. Defines simulation domain and ARW nested domains
2. Computes latitude, longitude, map scale factors, and Coriolis parameters at every grid point
3. Interpolates time-invariant terrestrial data to simulation grids (e.g., terrain height and soil type)
4. Interpolates time-varying meteorological fields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



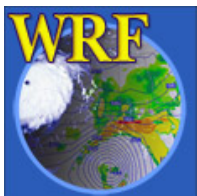
WPS Program Flowchart



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)

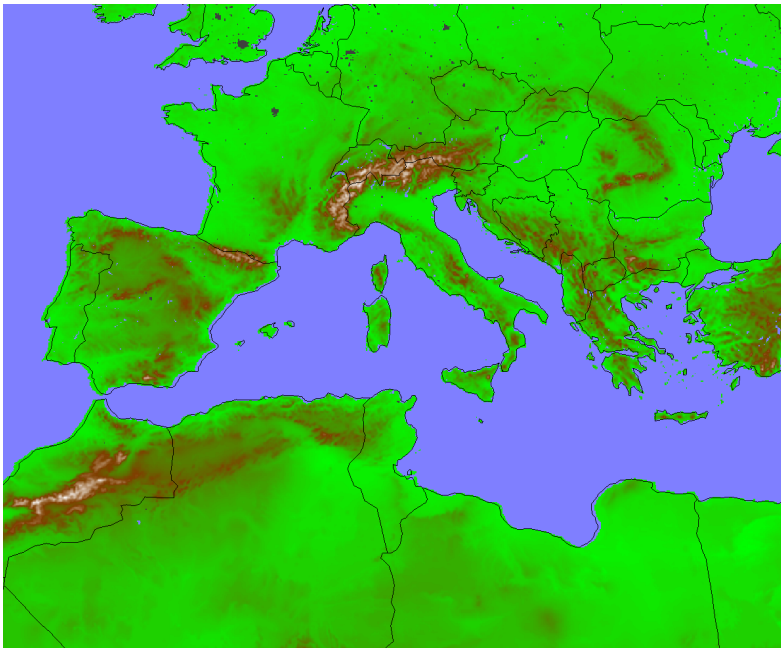


Geogrid: Defining model domains

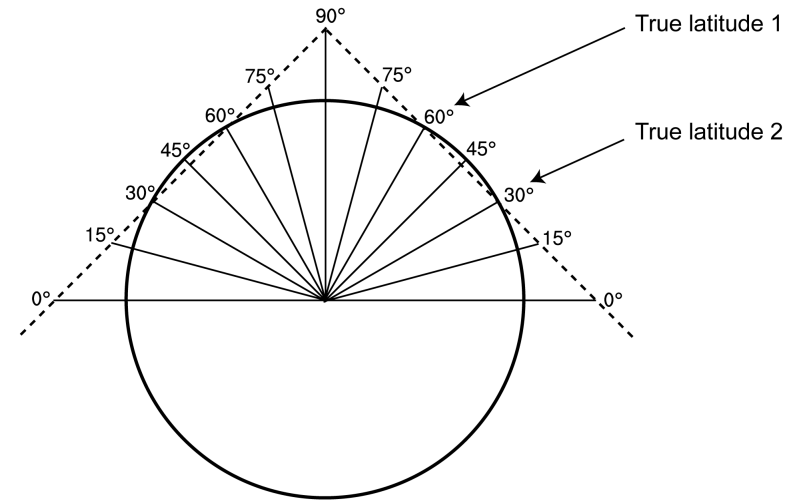
- First, we choose a map projection to use for the domains; why?
 - The real earth is (roughly) an ellipsoid
 - But WRF computational domains are defined by rectangles in the plane
- NMM uses a rotated latitude–longitude projection
- ARW can use any of the following projections:
 1. Lambert conformal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



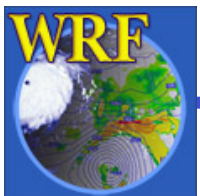
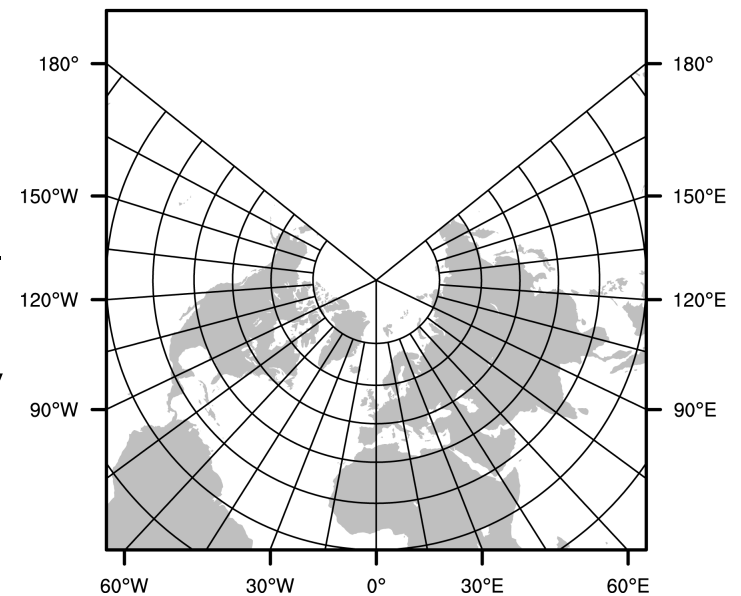
ARW Projections: Lambert Conformal



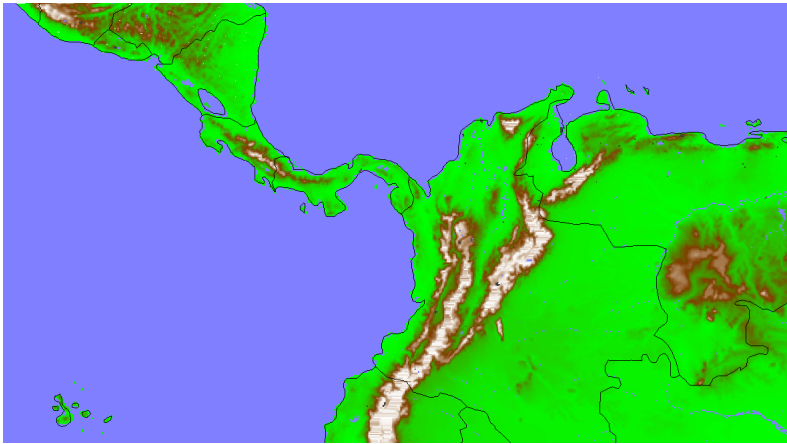
Lambert Conformal



- 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

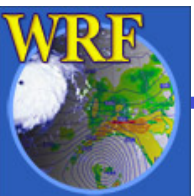
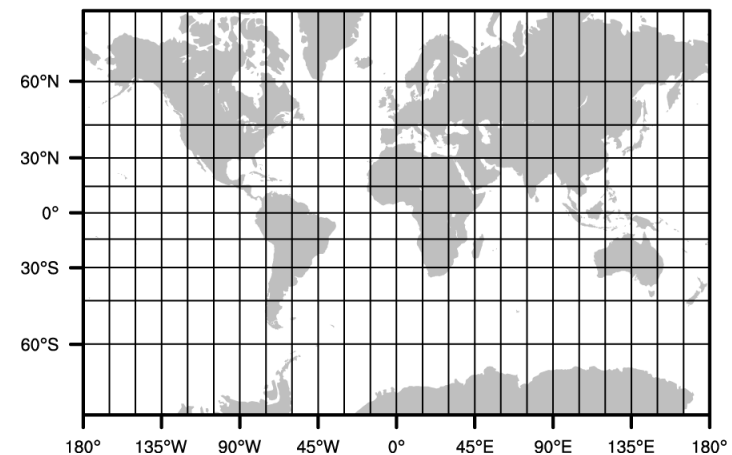
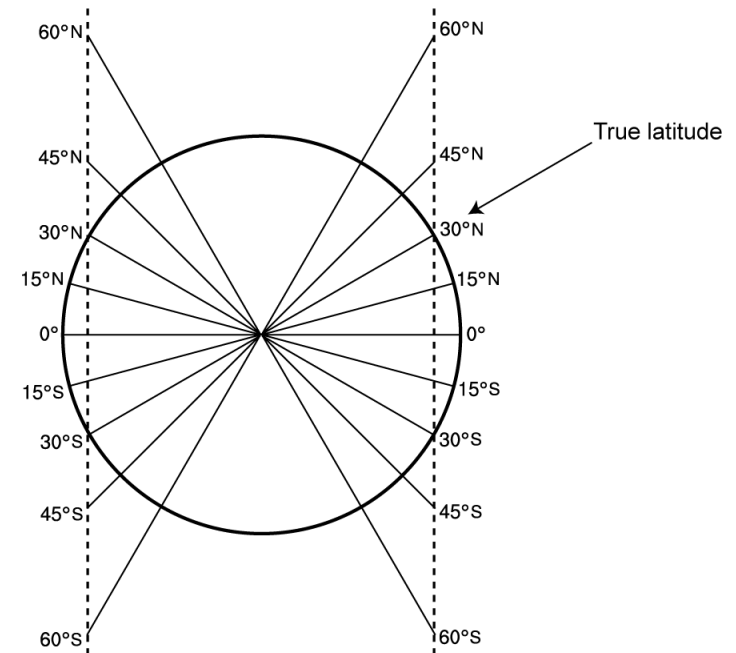


ARW Projections: Mercator

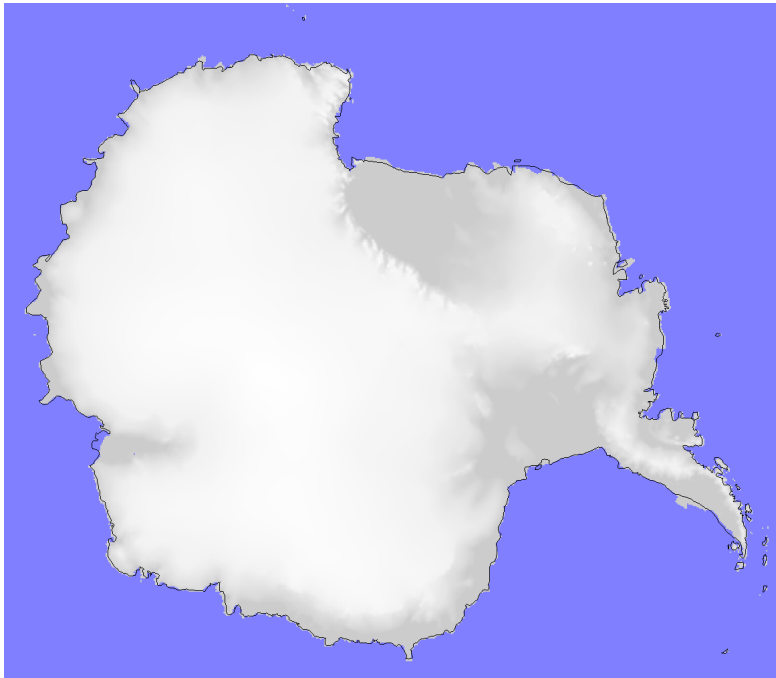


- Well-suited for low-latitudes
- May be used for “channel” domain (periodic domain in west–east direction)
- A single true latitude is specified
 - Cylinder intersects the earth’s surface at \pm truelat

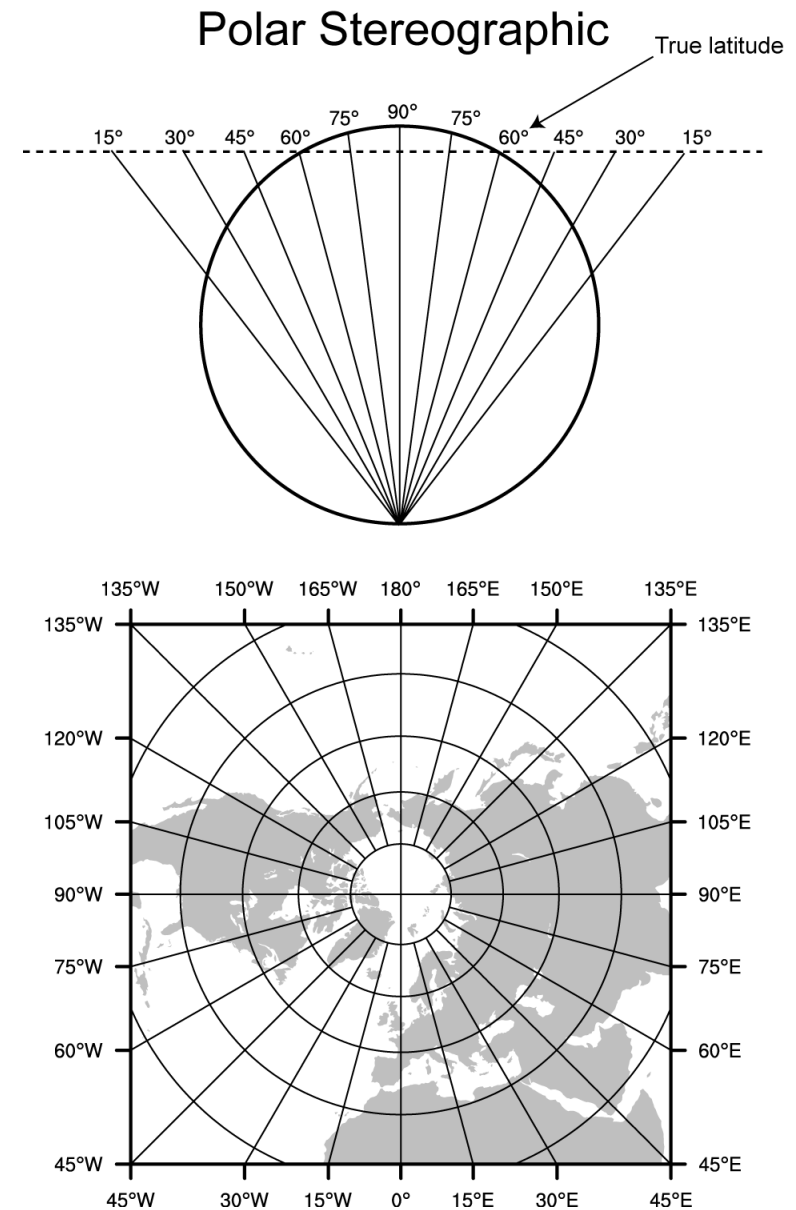
Mercator



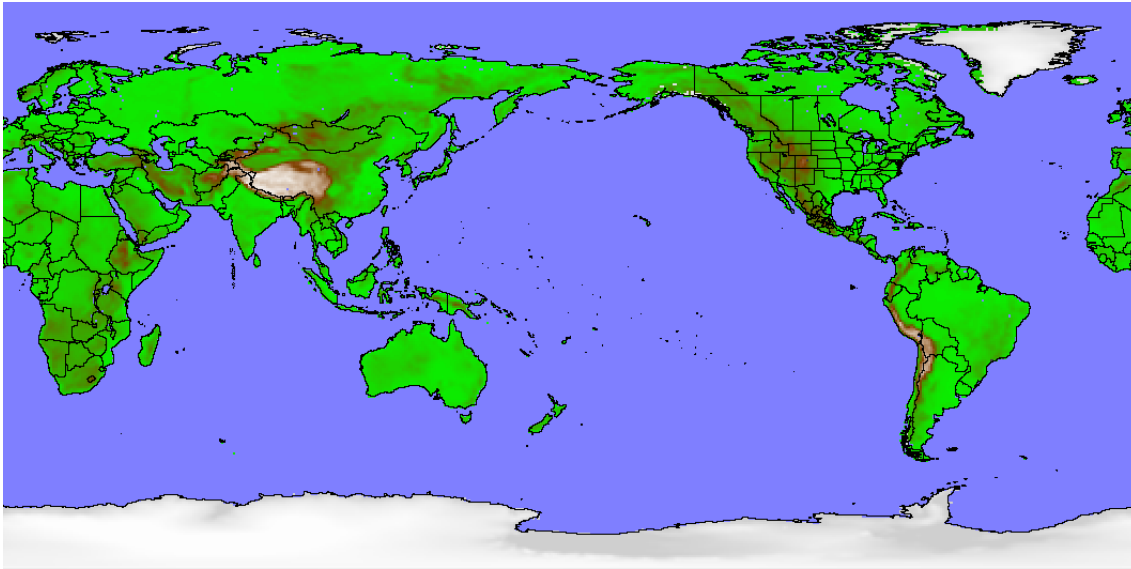
ARW Projections: Polar Stereographic



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

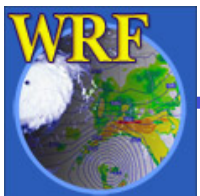
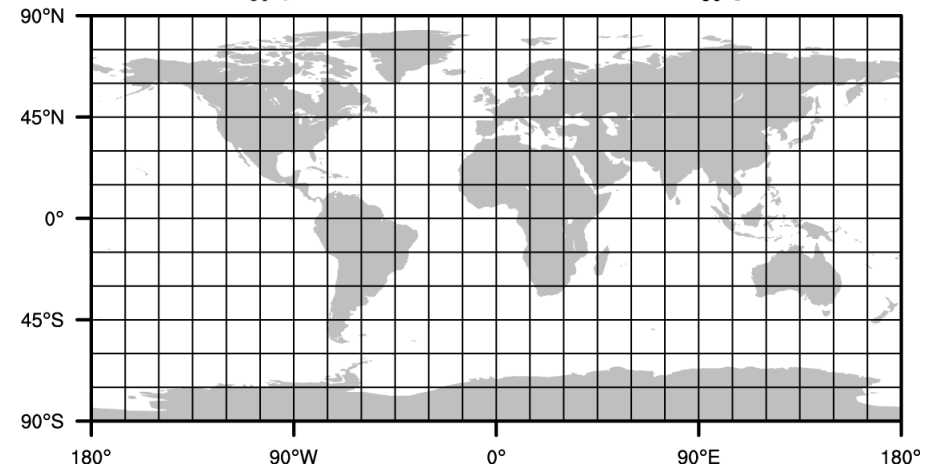
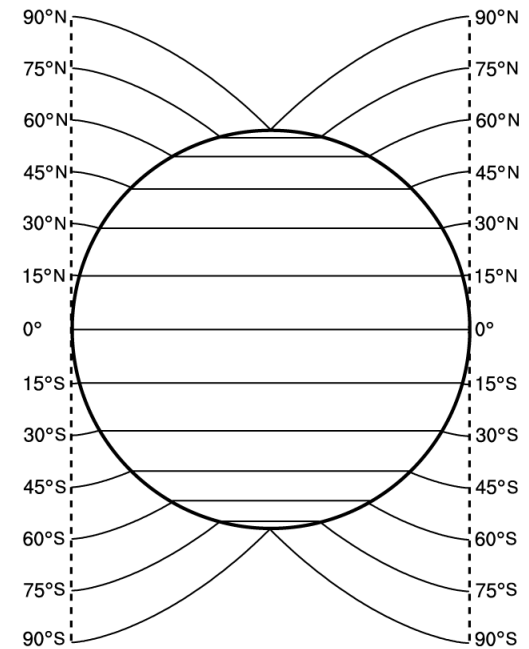


ARW Projections: Cylindrical Equidistant



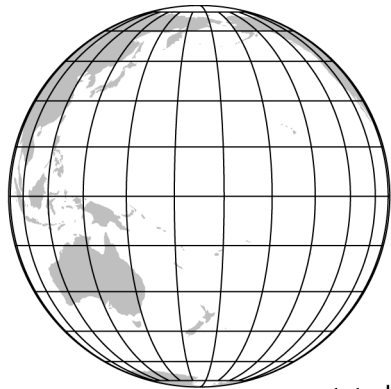
- Required for global domains
- Can be used for regional domains
- Can be used in its normal or rotated aspect

Cylindrical Equidistant

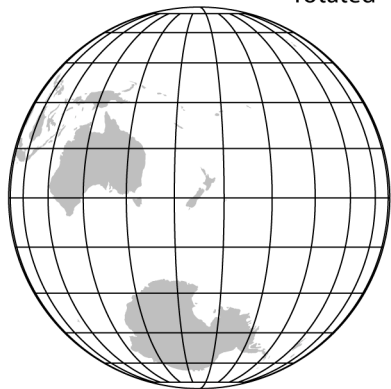
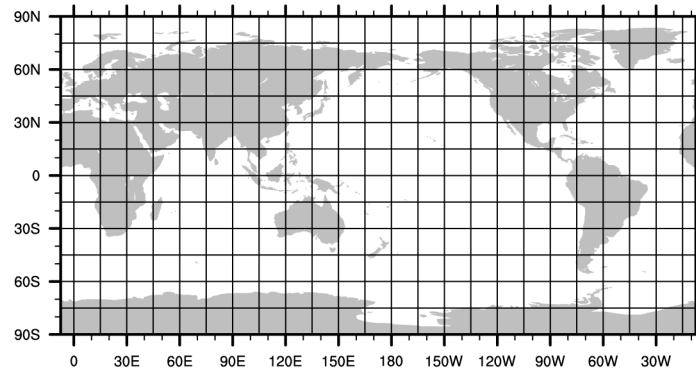


ARW Projections: Rotating the Lat-Ion Grid

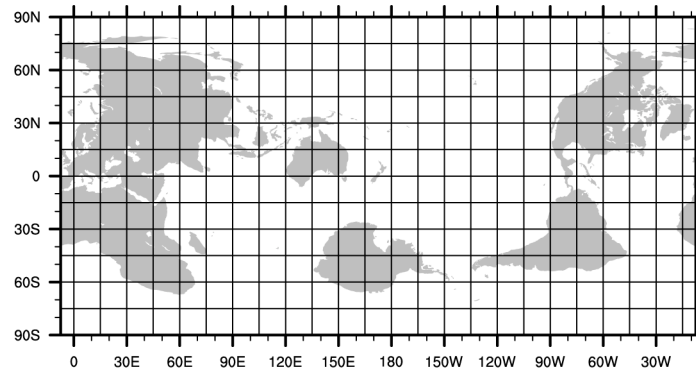
In certain cases, it may be desirable or necessary to rotate the poles of the projection away from the poles of the earth



unrotated



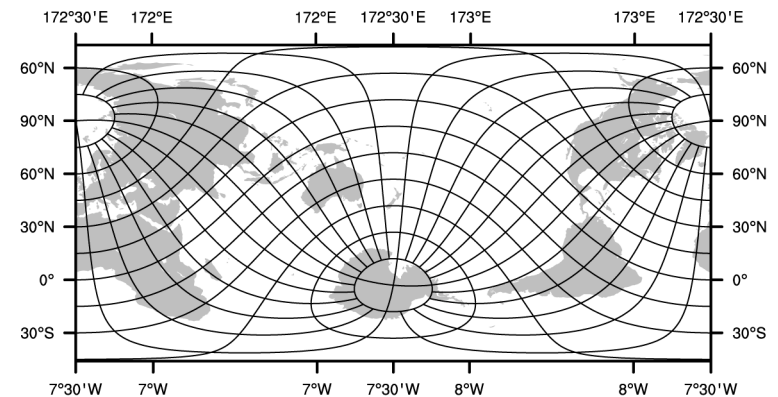
rotated



Computational grid

- 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. 3-11

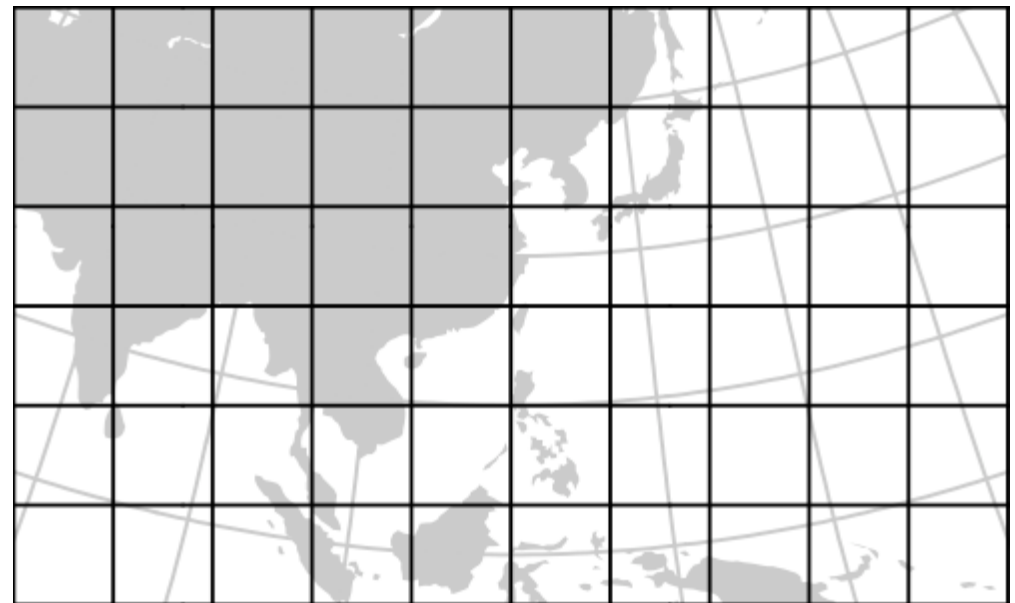
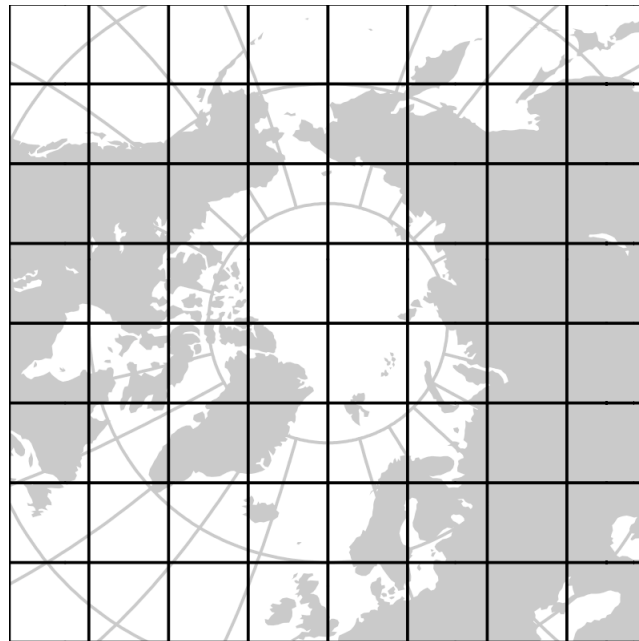
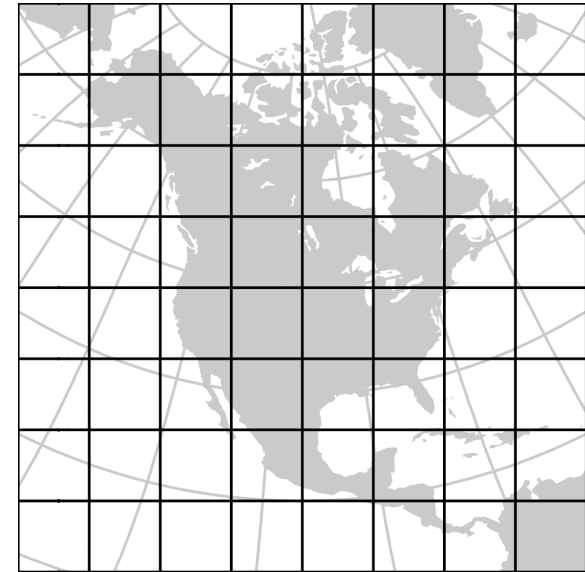


Geographic grid



NMM Projection: Rotated Lat-Lon

- Can be used for any region
 - Polar, equatorial, mid-latitude
- Earth is rotated so that geographic location of interest is located at 0° lat, 0° lon
 - User simply specifies geographic point to appear in the center of the domain



Geogrid: Defining Model Domains

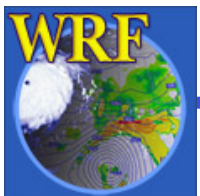
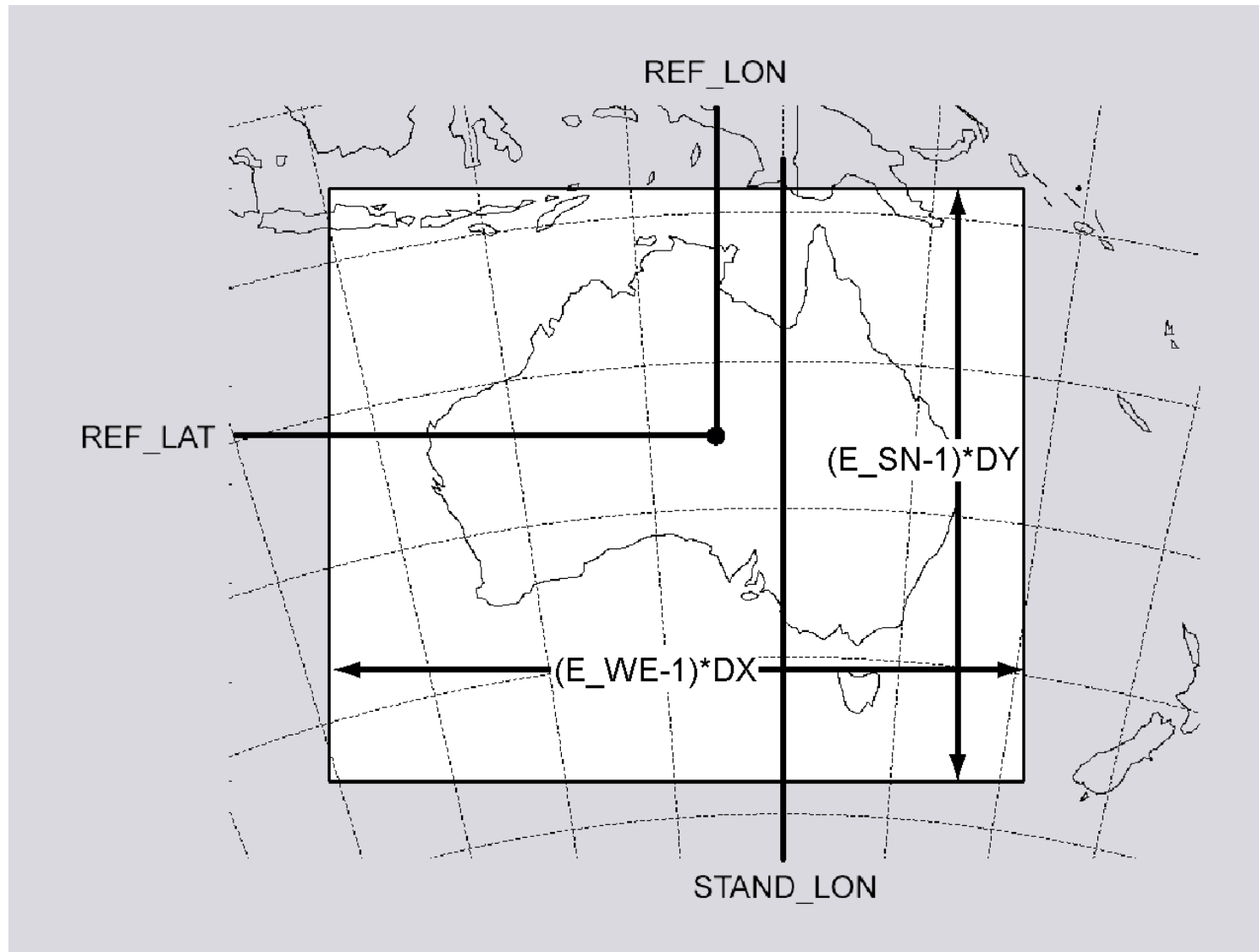
- Define projection of domains using a subset of the following parameters
 - **MAP_PROJ**: 'lambert', 'mercator', 'polar', 'lat-lon', or 'rotated_ll'
 - * {
 - **TRUELAT1**: First true latitude
 - **TRUELAT2**: Second true latitude (*only for Lambert conformal*)
 - **POLE_LAT, POLE_LON**: Location of 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*

*ARW only

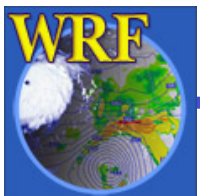
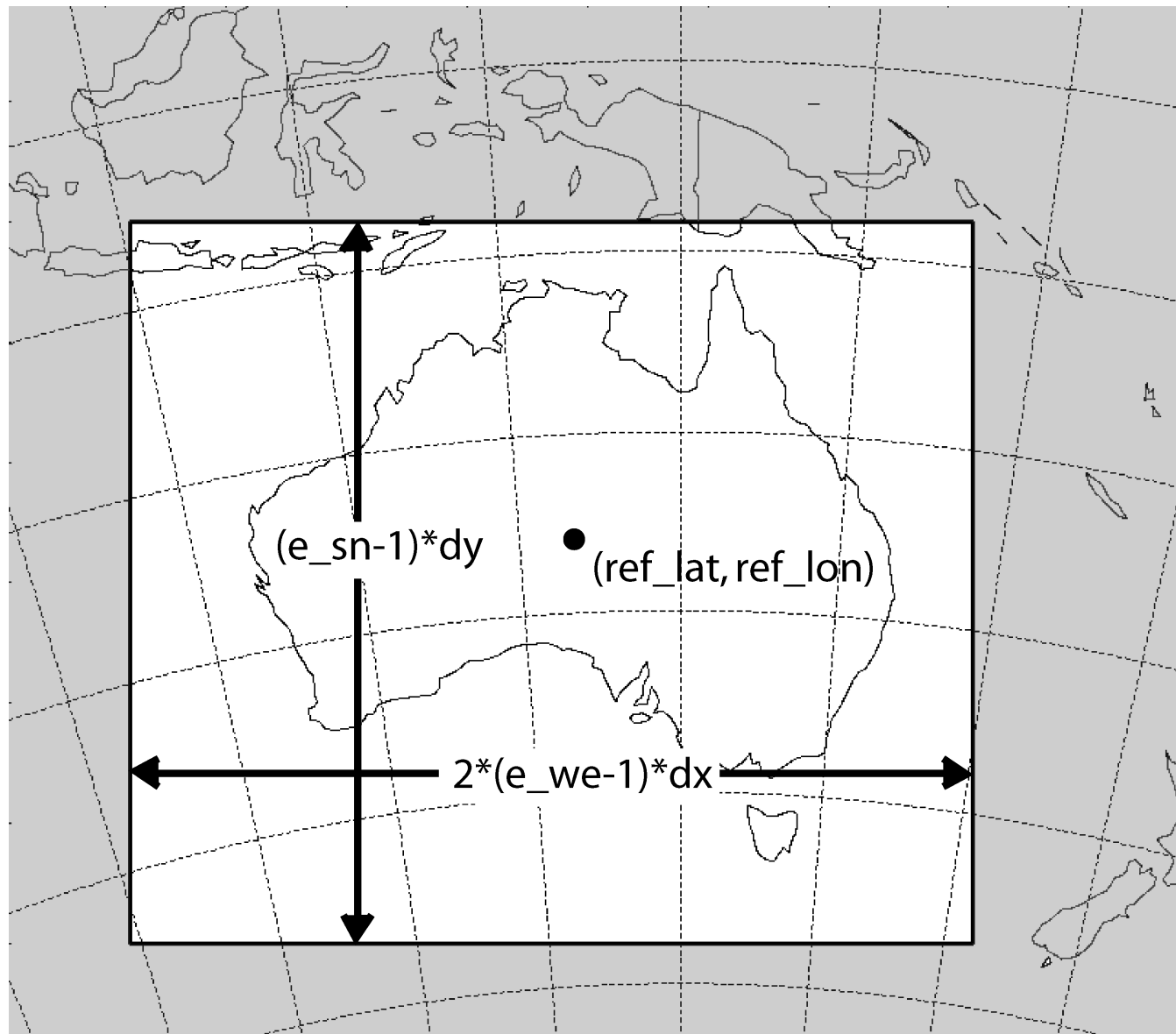
See p. 3-9 and 3-40



Geogrid: Defining ARW Domains



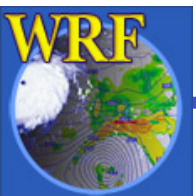
Geogrid: Defining NMM Domains



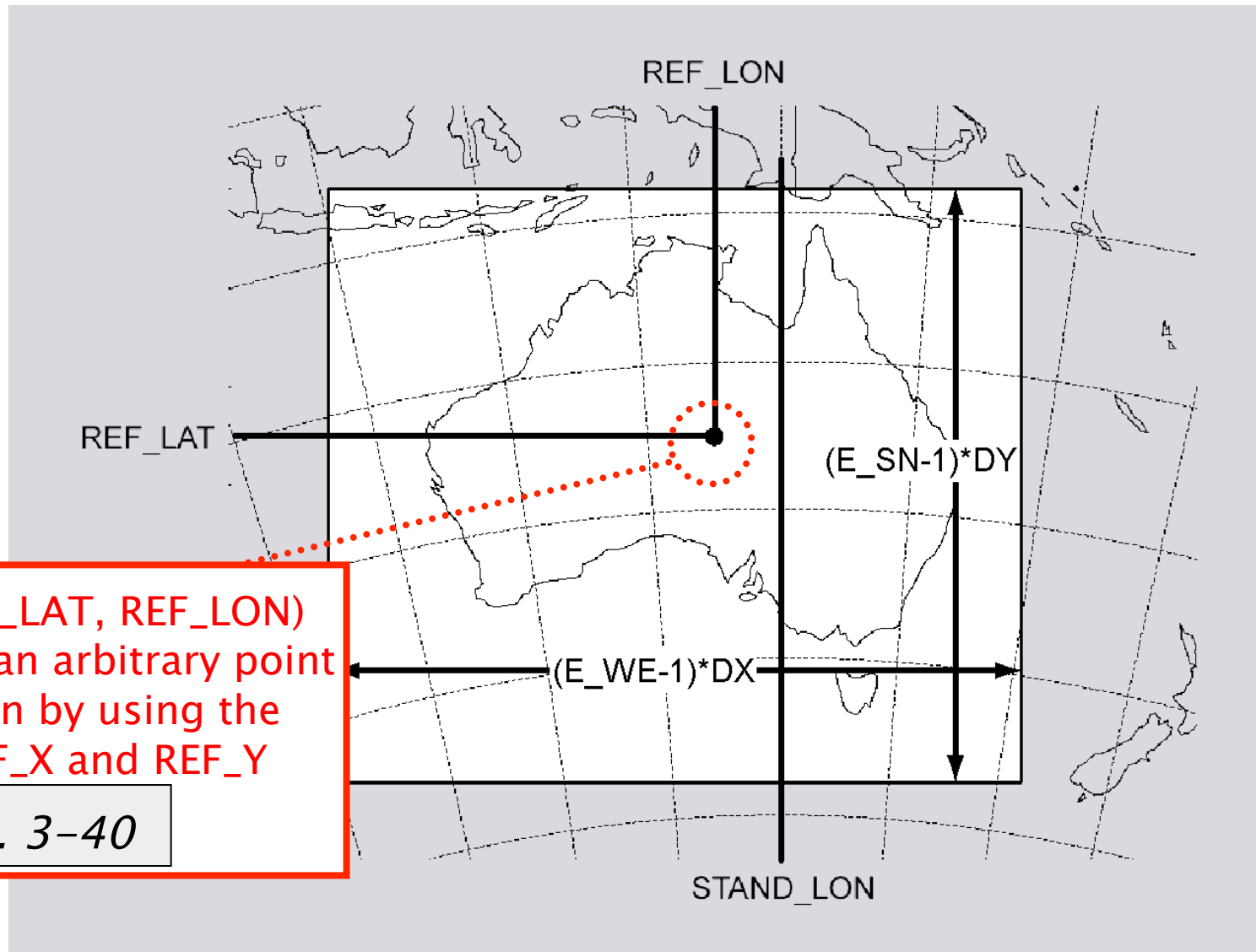
Geogrid: Defining Model Domains

- 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 for ARW; number of mass points in odd rows for NMM
 - E_SN: Number of velocity points in south–north direction for ARW; number of rows for NMM

See p. 3–12 and 3–39

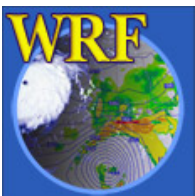


Geogrid: Defining ARW Domains



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. 3-40



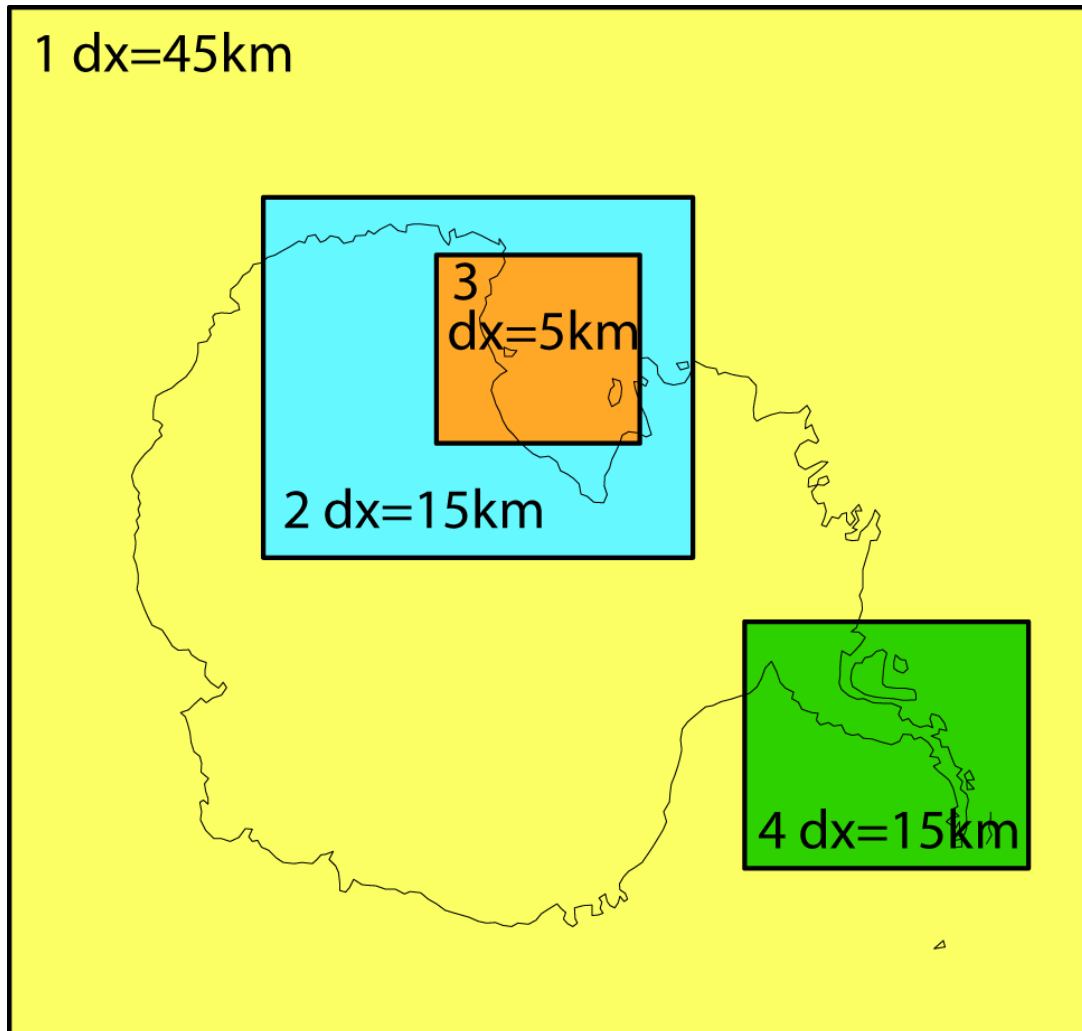
Geogrid: Nesting Basics

- 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!

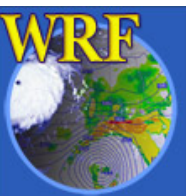
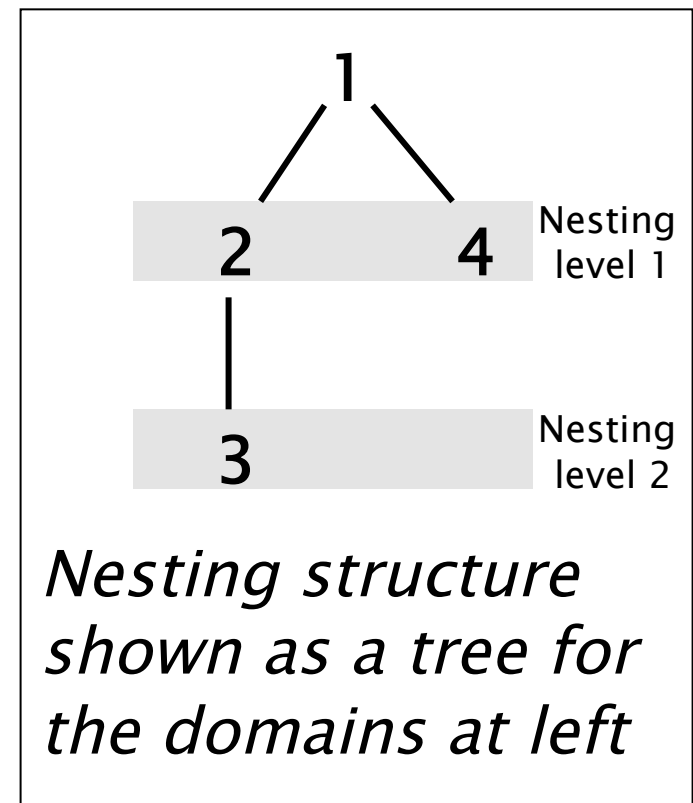


Geogrid: Nesting Example

Example configuration – 4 domains



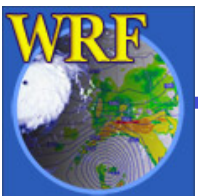
Each domain is assigned a *domain ID #*



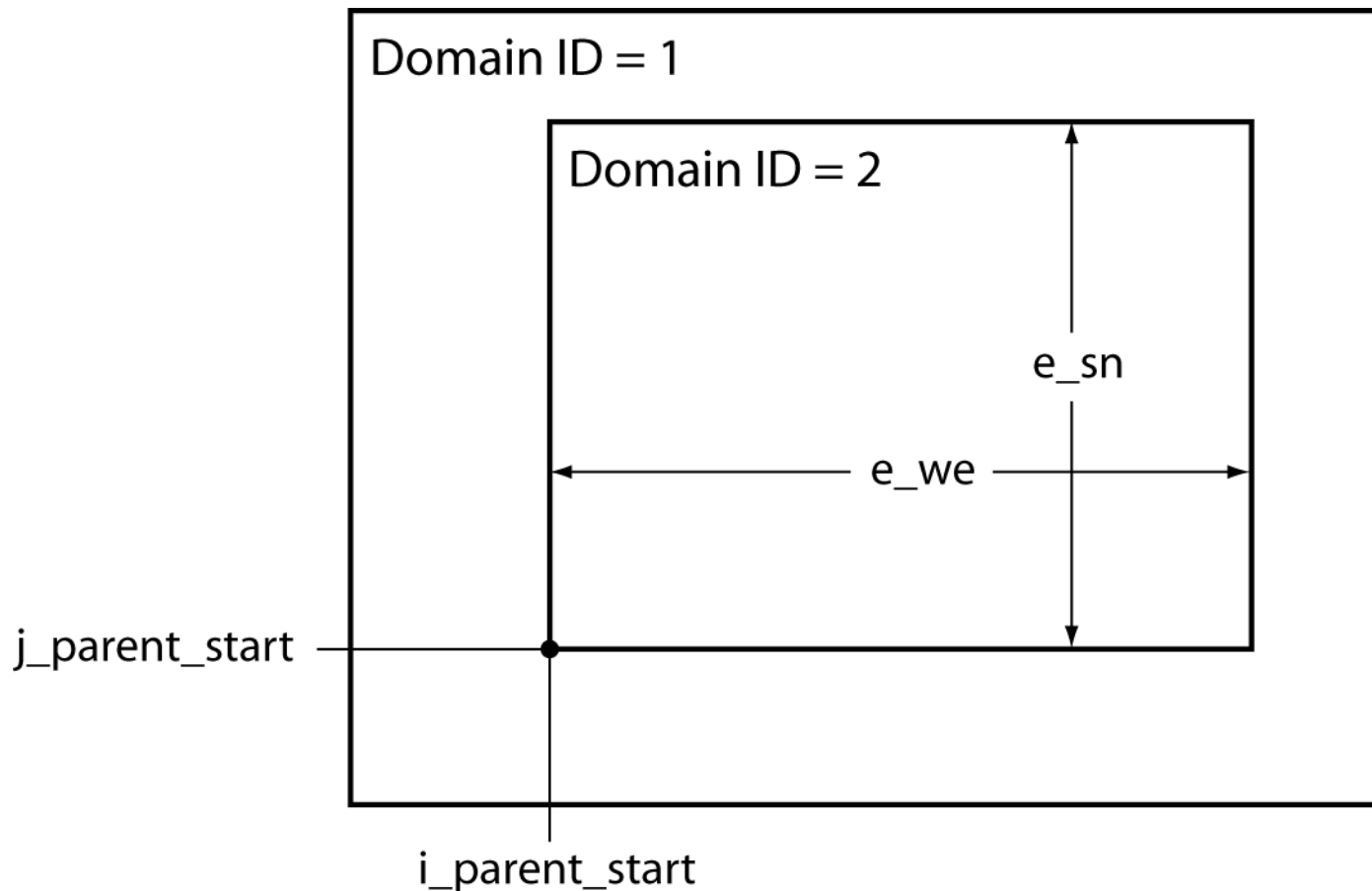
Geogrid: Defining Nested Domains

- 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. 3-18 and 3-38



Geogrid: Defining Nested Domains



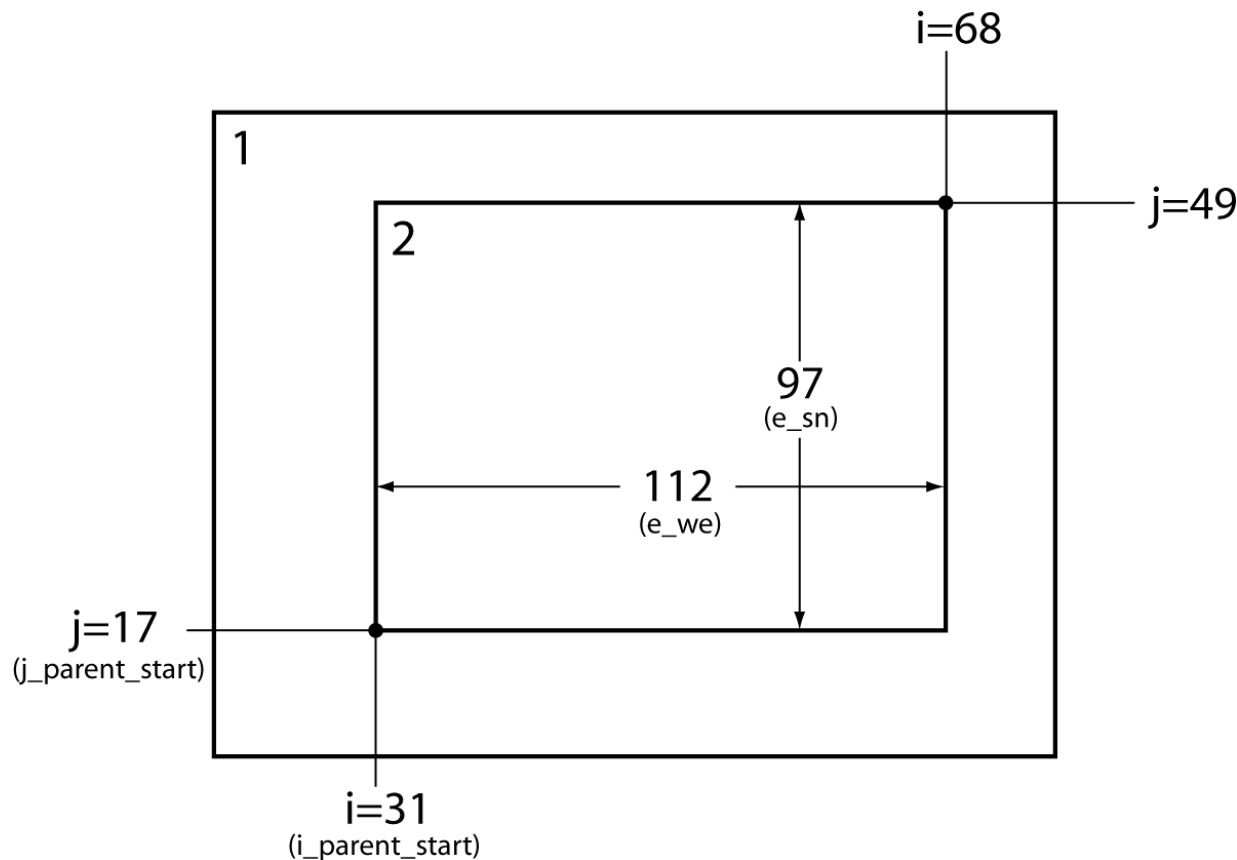
The grid spacing (dx) of domain 2 is determined by grid spacing of domain 1 and the *parent_grid_ratio*

NB: For NMM, the parent_grid_ratio is always 3!



Geogrid: Nesting example

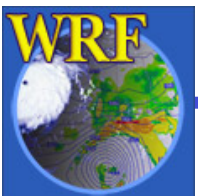
Assuming *parent_grid_ratio* = 3



In ARW, nest dimensions must be $(n * \text{parent_grid_ratio} + 1)$ for some integer n

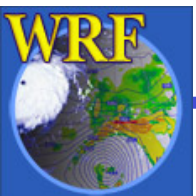
$$112 = 3 * n + 1 \text{ for } n=37$$

$$97 = 3 * n + 1 \text{ for } n=32$$

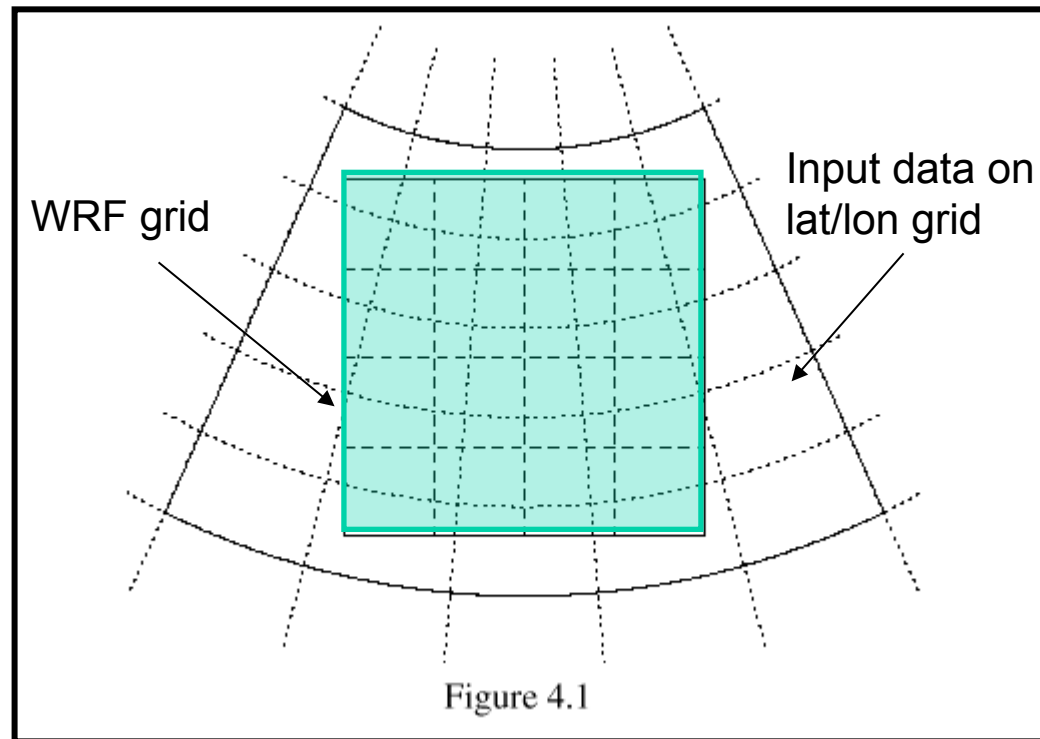


Geogrid: Interpolating Static Fields

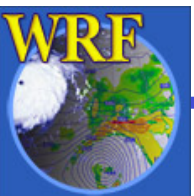
- Given definitions of all computational grids, geogrid interpolates terrestrial, time-invariant fields
 - Topography height
 - Land use categories
 - Soil type (top layer & bottom layer)
 - Annual mean soil temperature
 - Monthly vegetation fraction
 - Monthly surface albedo



Geogrid: Interpolating Static Fields



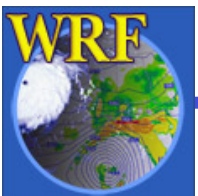
In general, source data are given on a different projection from the model grid



Geogrid: Interpolation Options

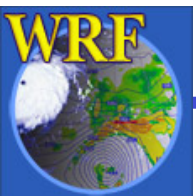
- 4-point bilinear
- 16-point overlapping parabolic
- 4-point average (simple or weighted)
- 16-point average (simple or weighted)
- Grid cell average
- Nearest neighbor
- Breadth-first search

See p. 3-51



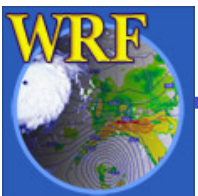
Why have so many interpolation options?

- 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 the third WPS lecture how several different options can be used for different regions of the same field



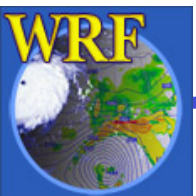
Geogrid: Program Flexibility

- 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 the third WPS lecture!*)



Geogrid: Program Flexibility

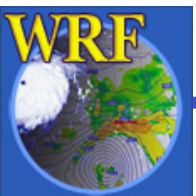
- *geogrid* is flexible enough to ingest and interpolate new static fields
 - handles either continuous or categorical fields
- New data sets must be written to simple binary format
- User needs to add an entry to the file
GEOGRID.TBL



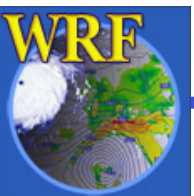
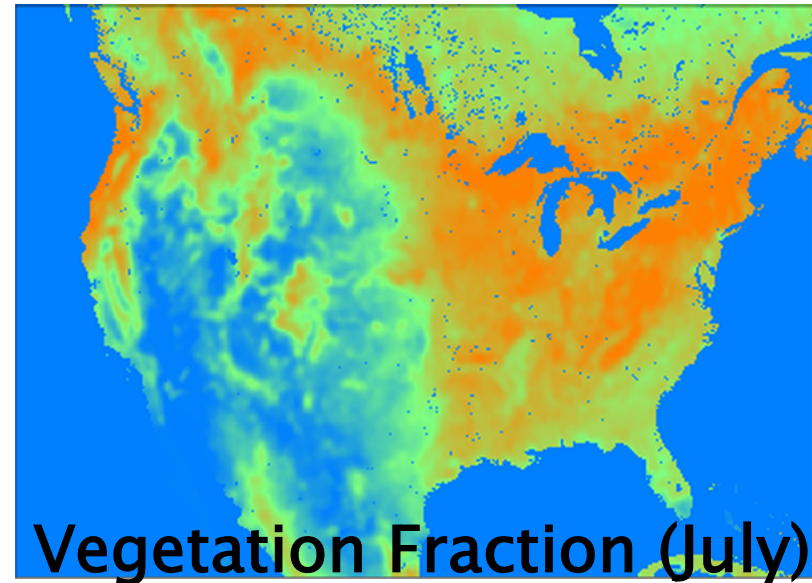
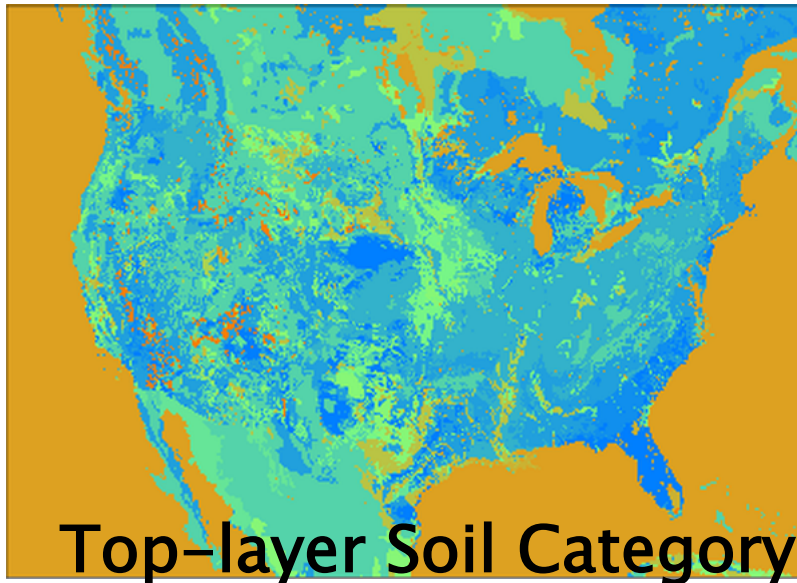
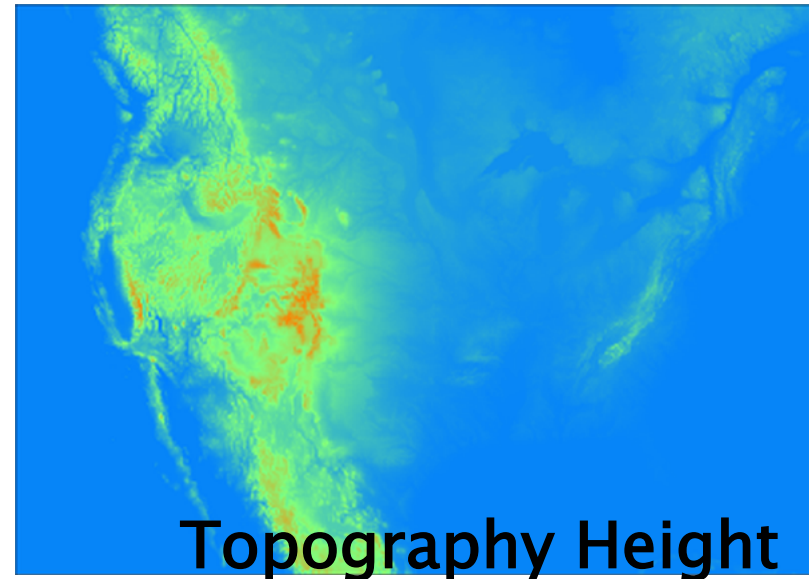
Geogrid: Program Output

- The parameters defining each domain, plus interpolated static fields, are written using the WRF I/O API
 - One file per domain for ARW
 - One file per *nesting level* for NMM
- Filenames: `geo_em.d0n.nc` , or
`geo_nmm.d01.nc`, `geo_nmm_nest.l0k.nc`
(where *n* is the domain ID # and *k* is the nest level)
- Example:

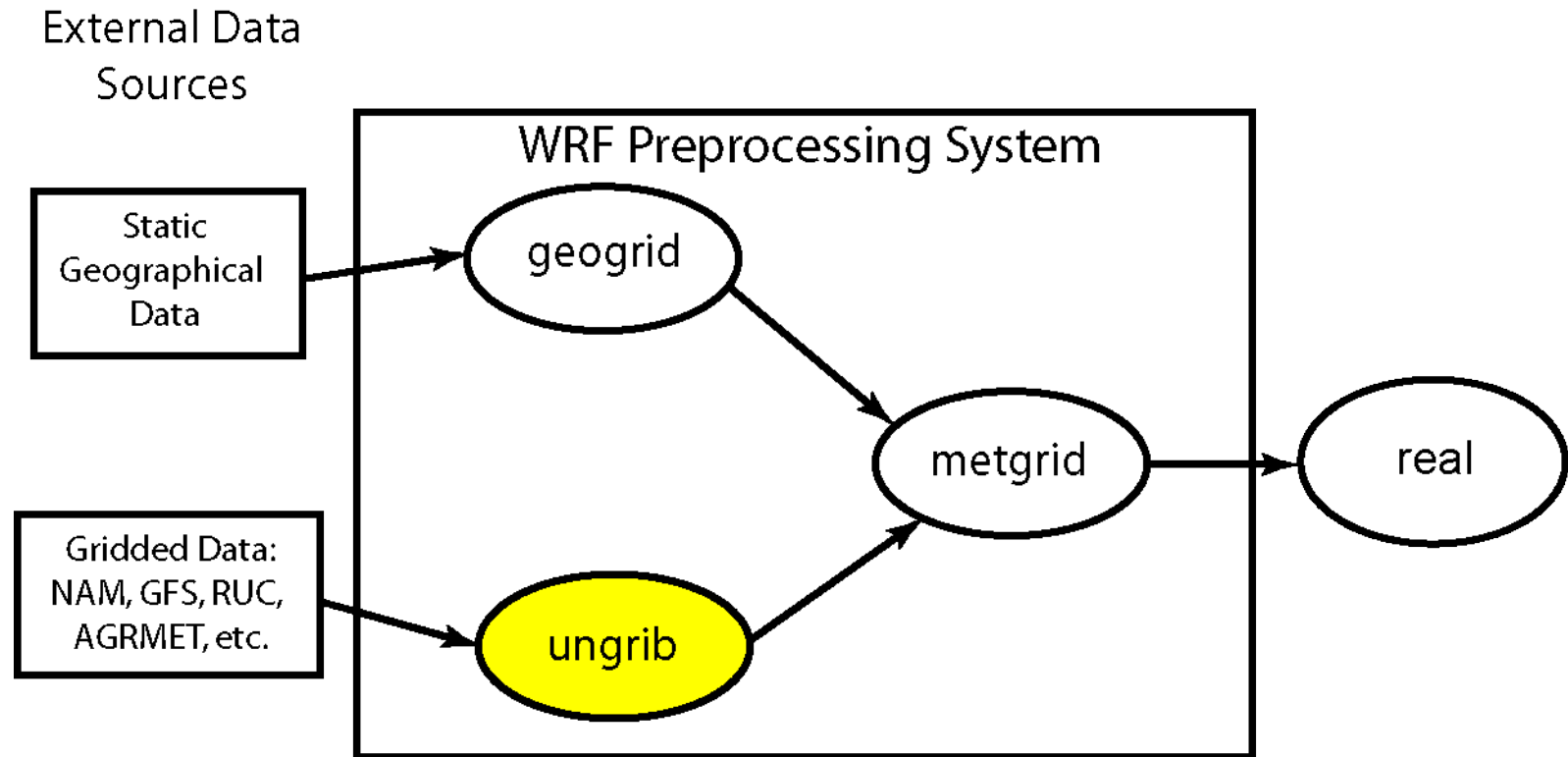
<code>geo_em.d01.nc</code>	<code>geo_nmm.d01.nc</code>
<code>geo_em.d02.nc</code> (nest)	<code>geo_nmm_nest.l01.nc</code> (nest level)
<code>geo_em.d03.nc</code> (nest)	<code>geo_nmm_nest.l02.nc</code> (nest level)



Geogrid: Example Output Fields



The *ungrib* program

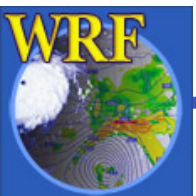


ungrib: think un+grib



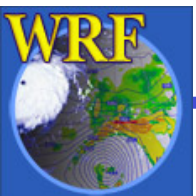
What is a GRIB file, anyway?

- 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

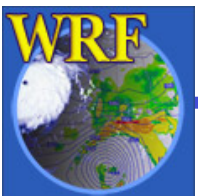


Ungrib: Vtables

How does ungrib know which fields to extract?

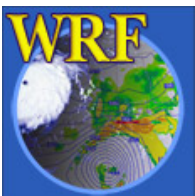
Using Vtables (think: Variable tables)

- 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



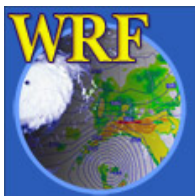
Ungrib: Example Vtable

GRIB1 Param	Level Type	From Level1	To Level2	UNGRIB Name	UNGRIB Units	UNGRIB 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

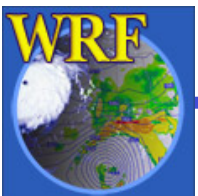
See p. 3–32



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](#))

See p. 3–30



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

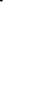
- Example:

FILE:2007-07-24_00

FILE:2007-07-24_06

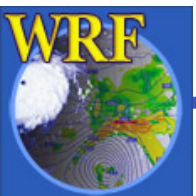
FILE:2007-07-24_12

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

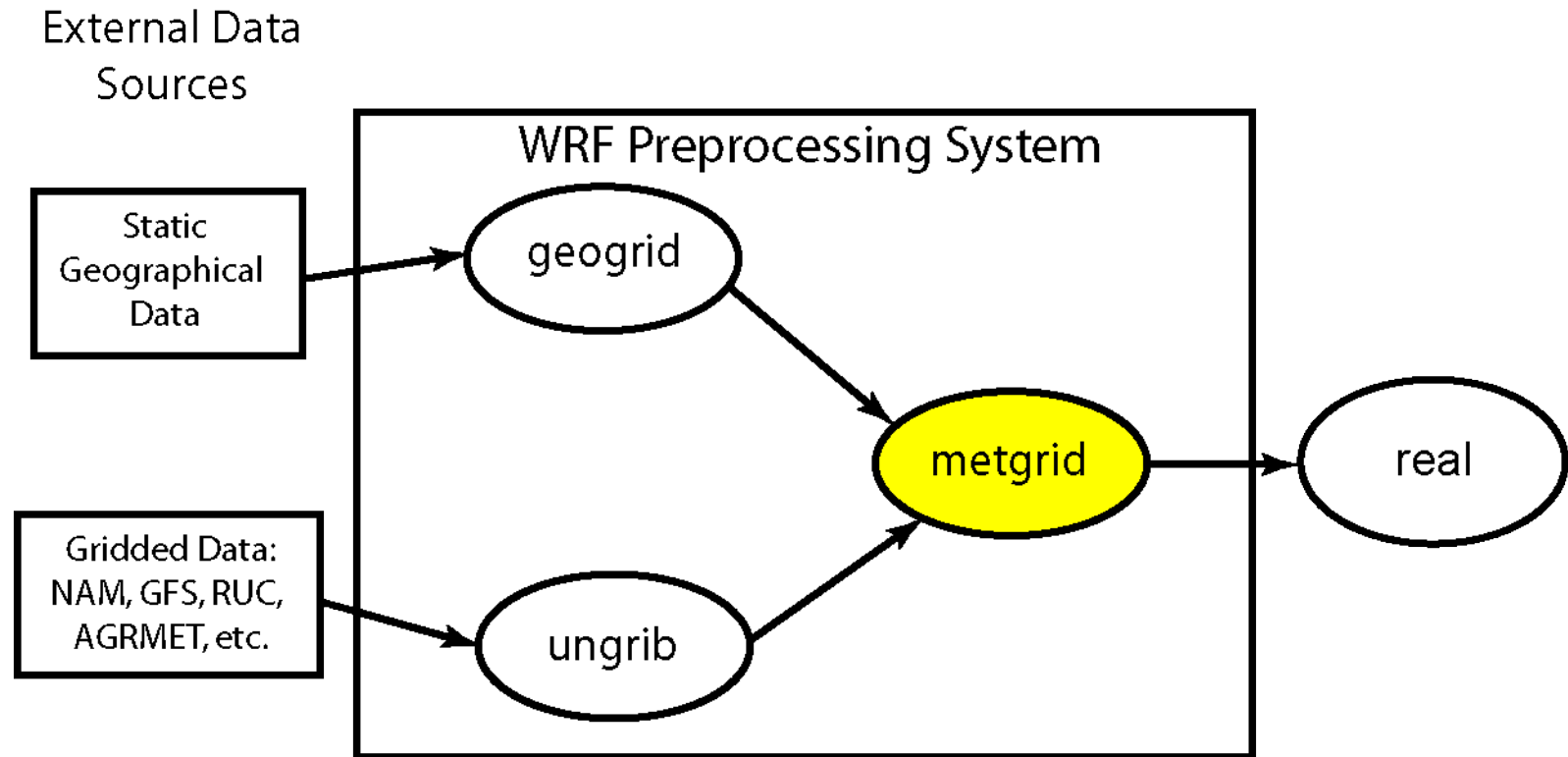


Ungrib: Obtaining GRIB Data

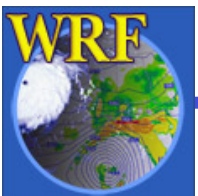
- Where does one get GRIB data?
 - User's responsibility
 - Some free data are available from NCAR and NCEP. See
 - <http://www.mmm.ucar.edu/wrf/users/>
 - > under the “Downloads” tab:
 - Some NCEP data in the past year
 - NCEP operational data available daily



The *metgrid* program

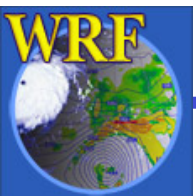


metgrid: think meteorological



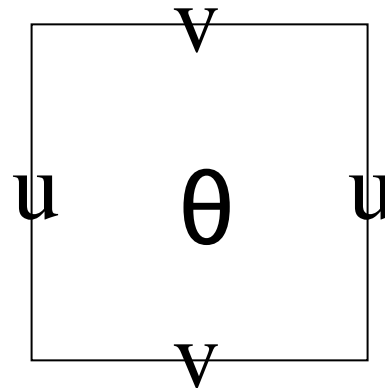
The *metgrid* program

- 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

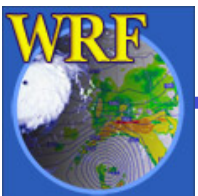


Metgrid: ARW Grid Staggering

- 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!*)

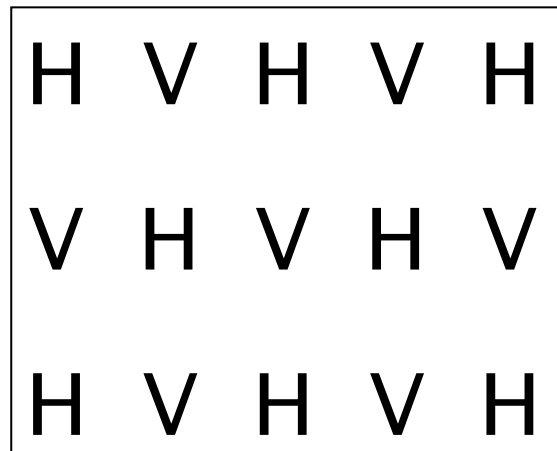


A single ARW grid cell, with “u”, “v”, and “ θ ” points labeled.

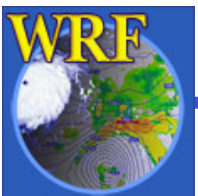


Metgrid: NMM Grid Staggering

- For NMM, wind U– and V–components interpolated to “V” staggering
- Other meteorological fields interpolated to “H” staggering by default (*can change this!*)



An NMM grid showing “V”, and “H” points.



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!

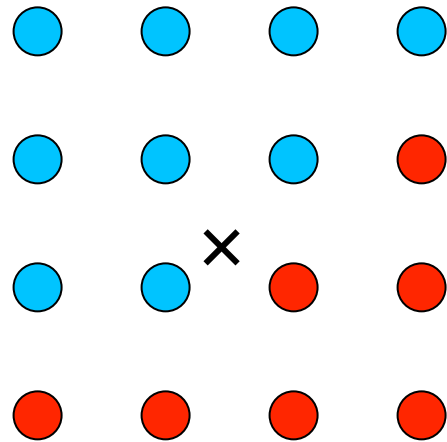


Metgrid: Masked Interpolation

- *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

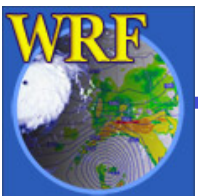


- = valid source data
- = masked/invalid data

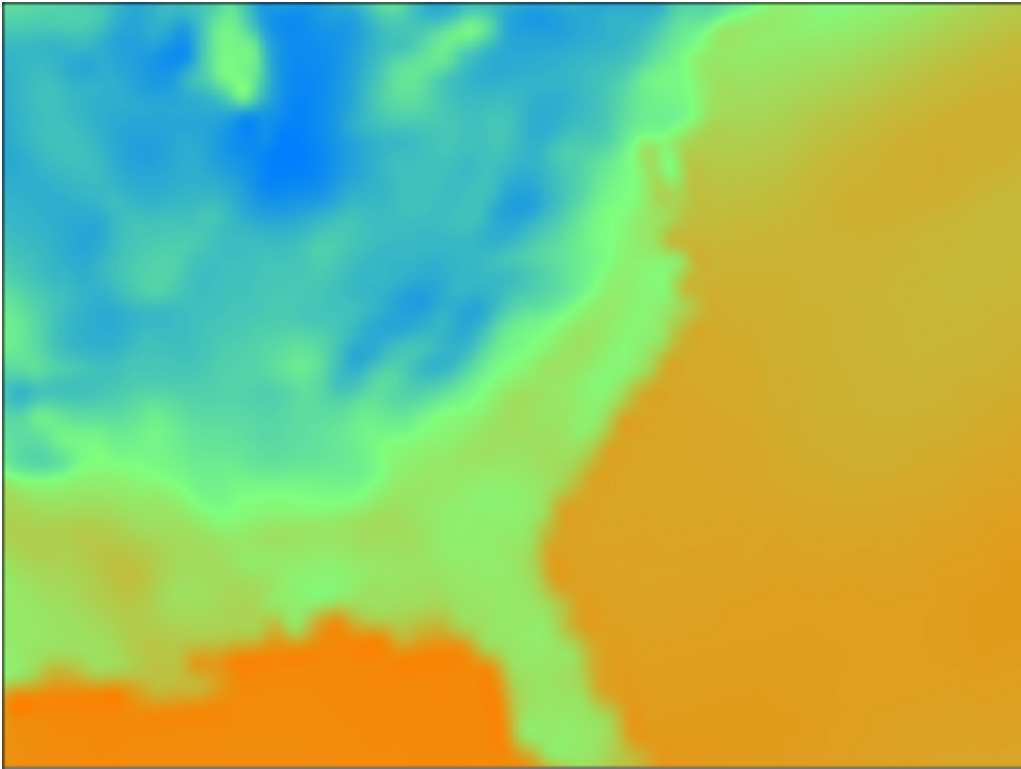
Suppose we need to interpolate to point X

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

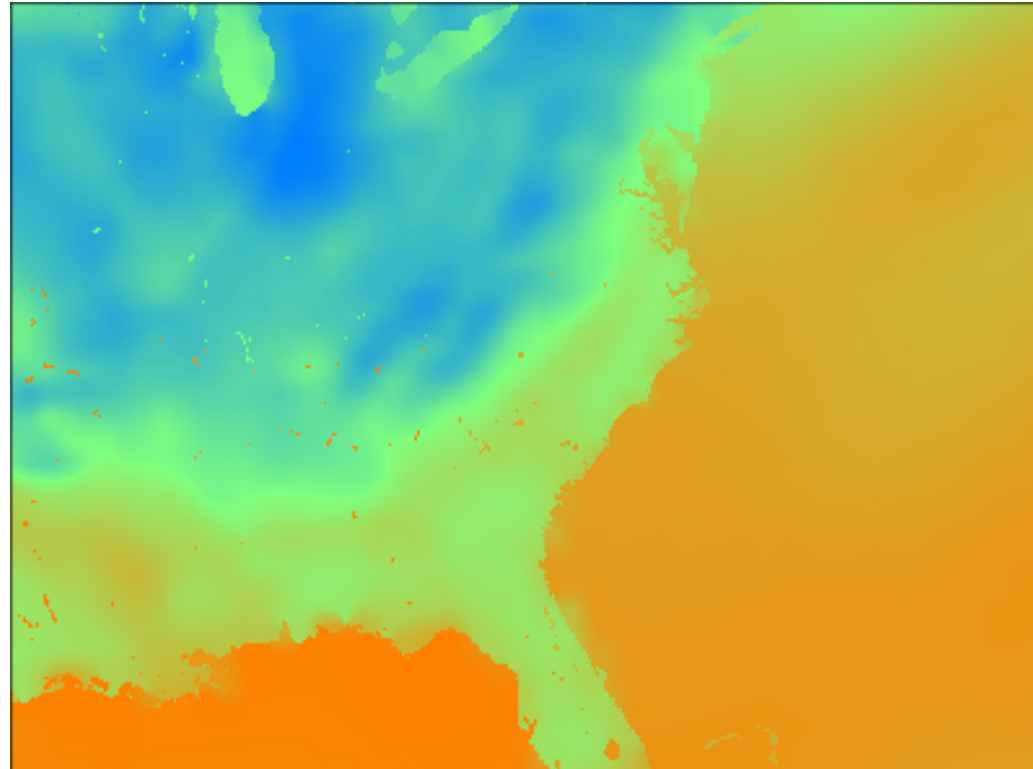
Not every interpolation option can handle masked points; we'll address this issue in the third lecture



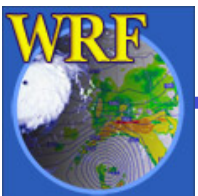
Example: Masked Interpolation



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.

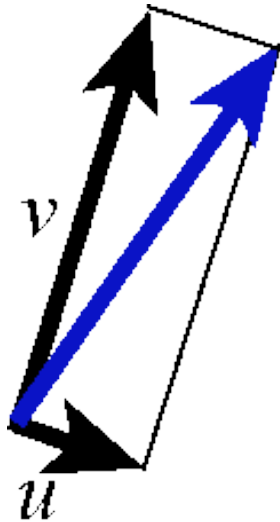


Metgrid: Wind Rotation

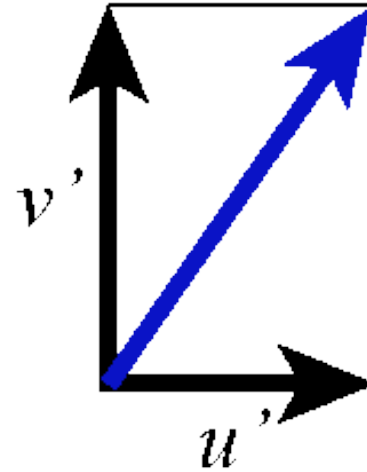
- Input wind fields (U-component + V-component) are either:
 - **Earth-relative:** U-component = westerly component; V-component = southerly component
 - **Relative to source grid:** U-component (V-component) parallel to source model x-axis (y-axis)
- WRF expects wind components to be relative to the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



Metgrid: Wind Rotation Example

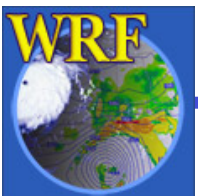


A wind vector, shown in terms of its U and V components with respect to the source grid.



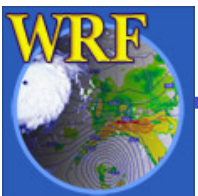
The same vector, in terms of its U and V components with respect to the WRF simulation grid.

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



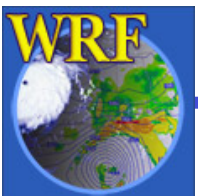
Metgrid: Constant Fields

- 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



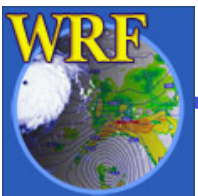
Metgrid: Program Output

- 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:

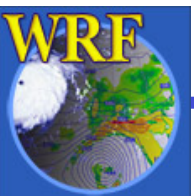
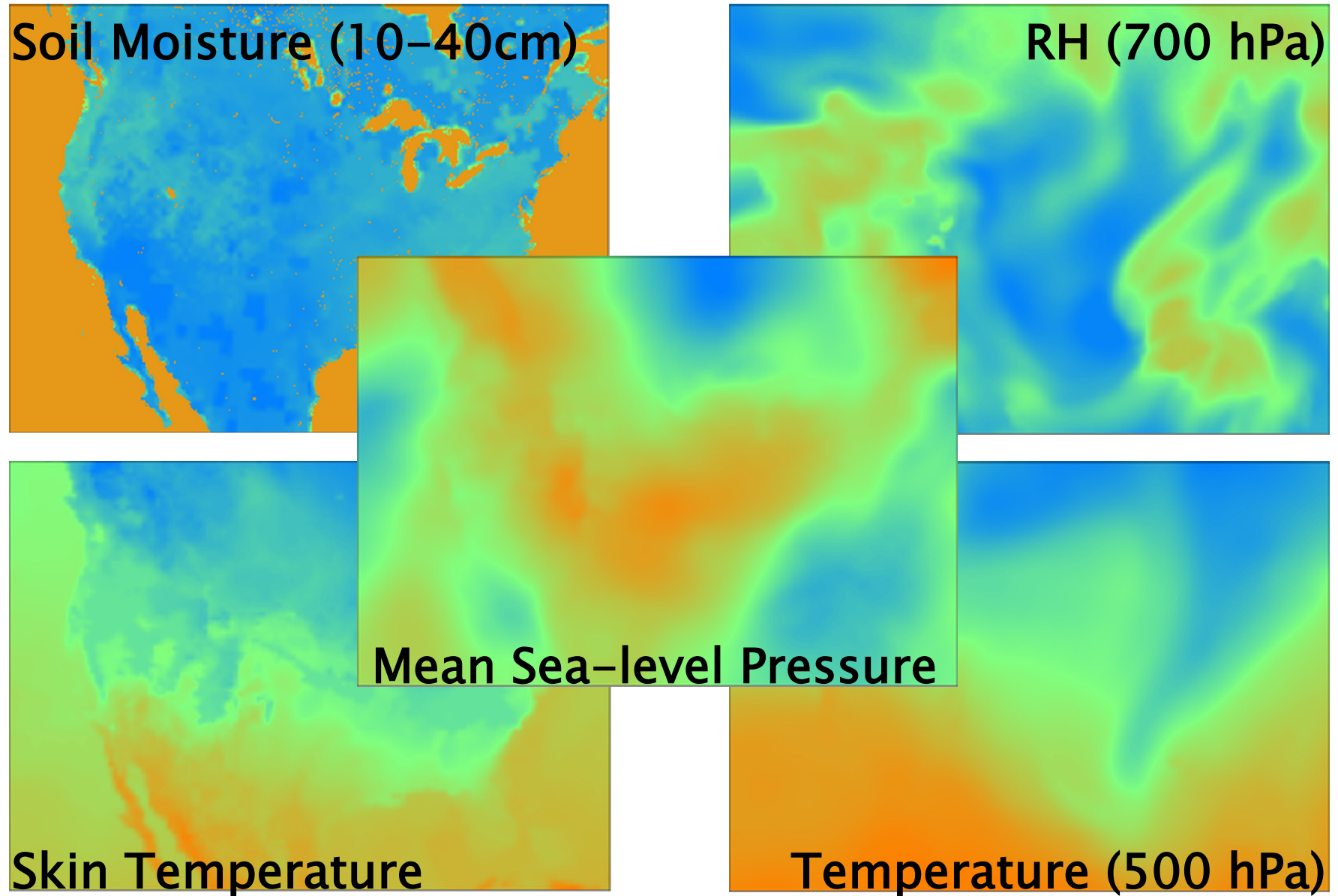
ARW: `met_em.d0n.YYYY-MM-DD_HH:mm:ss.nc`

(where n is the domain ID #)

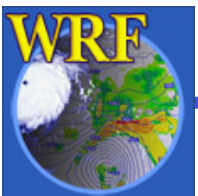
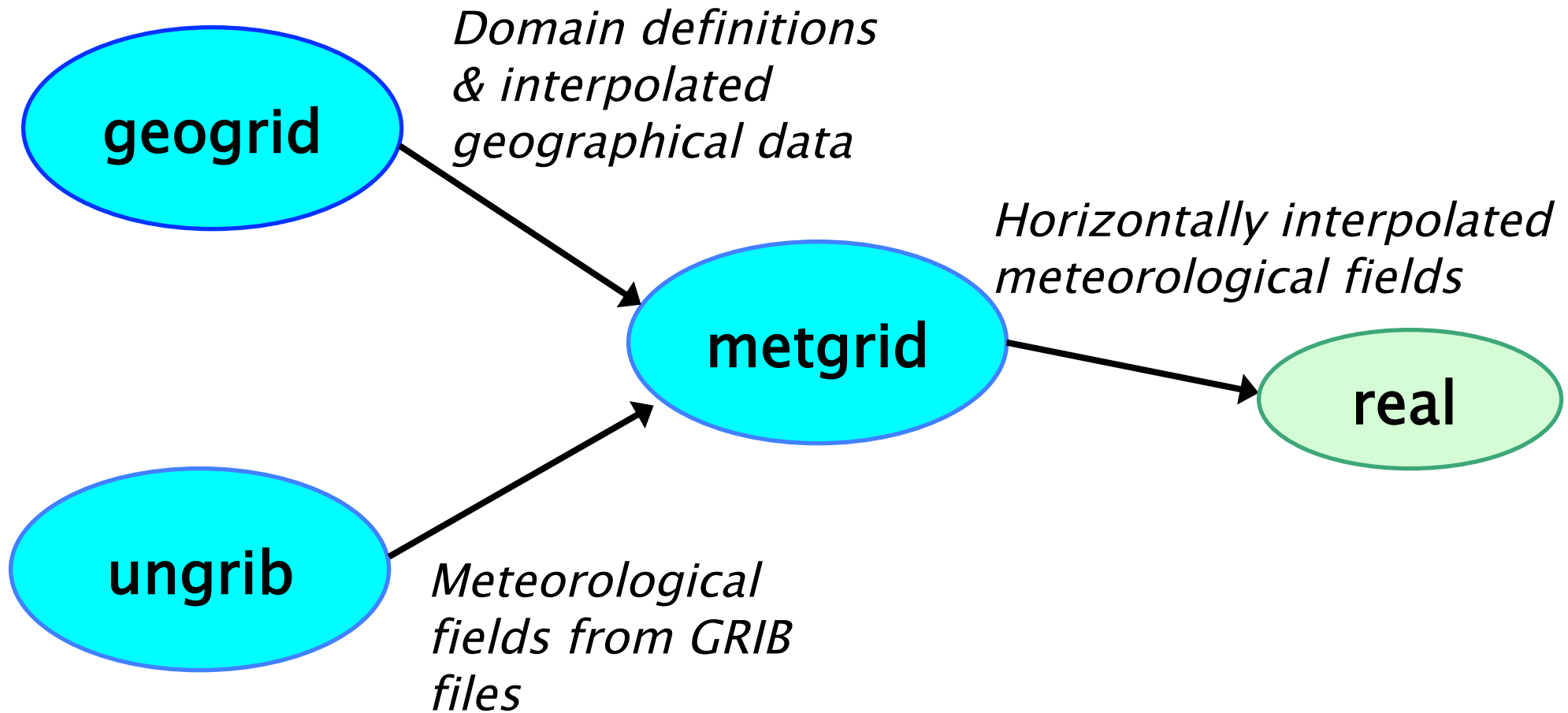
NMM: `met_nmm.d01.YYYY-MM-DD_HH:mm:ss.nc`



Metgrid: Example Output

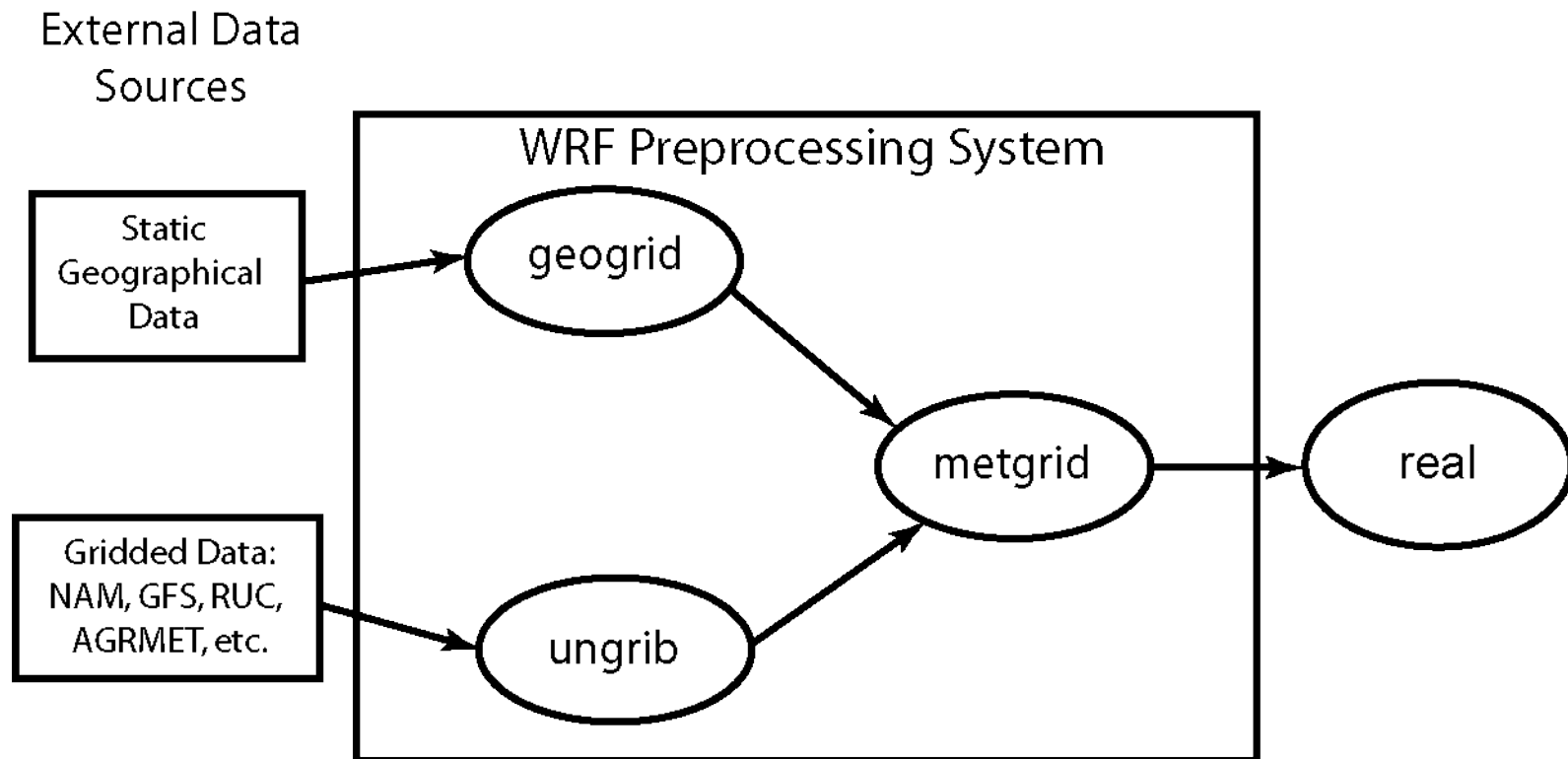


WPS Summary



And finally...

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



Questions?

