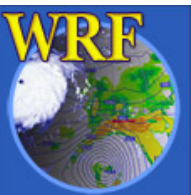




# The WRF Preprocessing System: Description of General Functions

Michael Duda



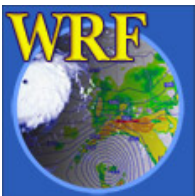
# Purpose of this Lecture

---

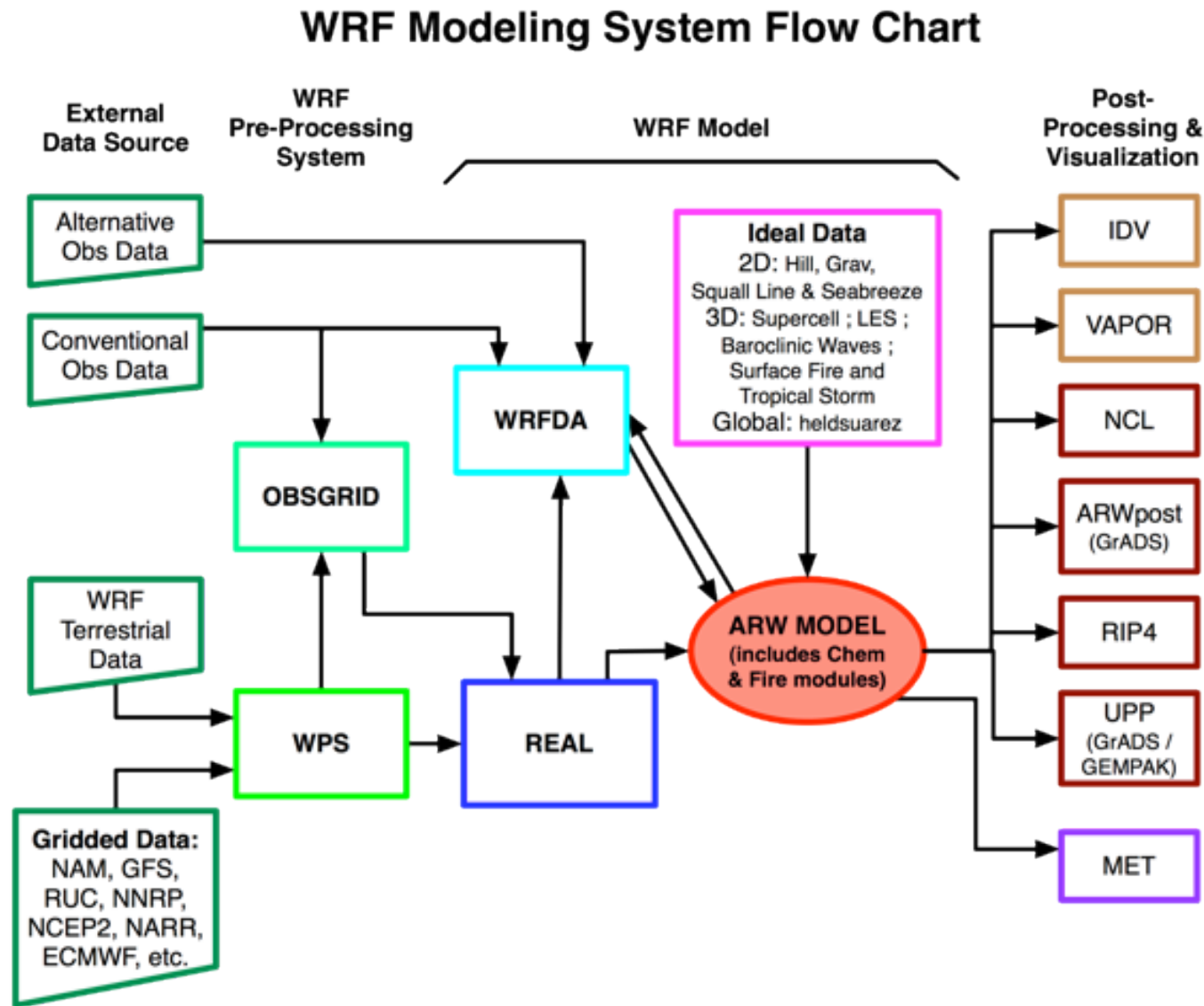
In this lecture, our goals are to:

- 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 this afternoon
- *Advanced features* of the WPS are described on Thursday



# WRF Modeling System Flowchart

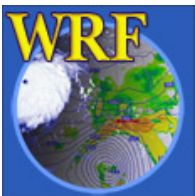


# Purpose of the WPS

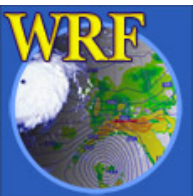
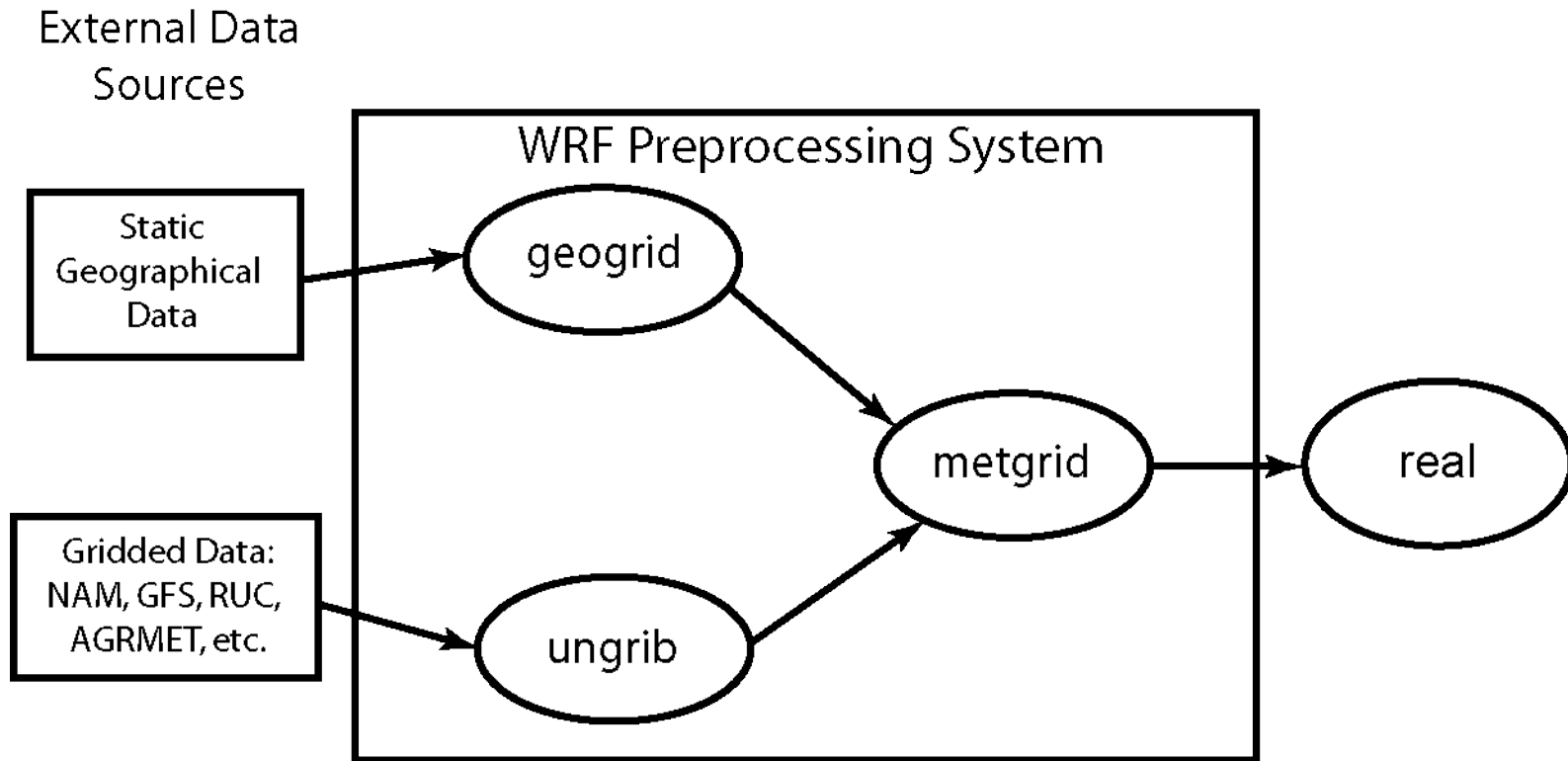
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The purpose of the WPS is to prepare input to WRF for real-data simulations:

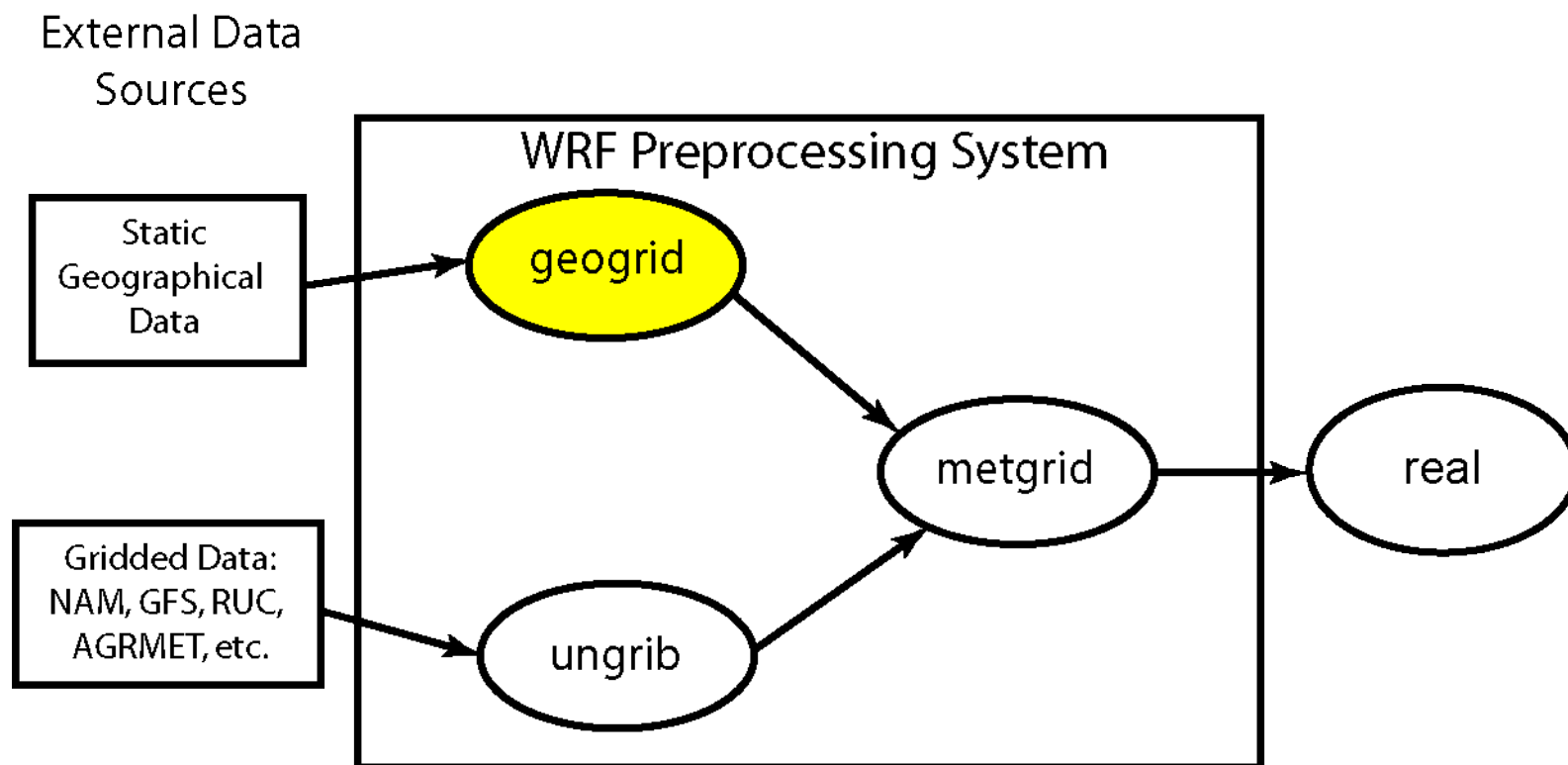
1. Defines simulation coarse domain and ARW nested domains
2. Computes latitude, longitude, map scale factors, and Coriolis parameters at every grid point
3. Interpolates time-invariant terrestrial data to simulation grids (e.g., terrain height and soil type)
4. Interpolates time-varying meteorological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



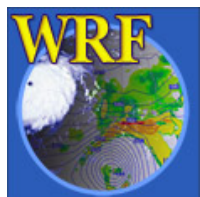
# WPS Program Flowchart



# The *geogrid* program



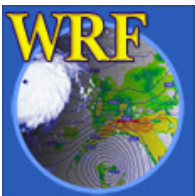
geogrid: think geographical



# The *geogrid* program

---

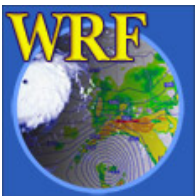
- For WRF model domains, geogrid defines:
  - Map projection (all domains must use the same projection)
  - Geographic location of domains
  - Dimensions of domains
- Geogrid provides values for static (time-invariant) fields at each model grid point
  - Compute latitude, longitude, map scale factor,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

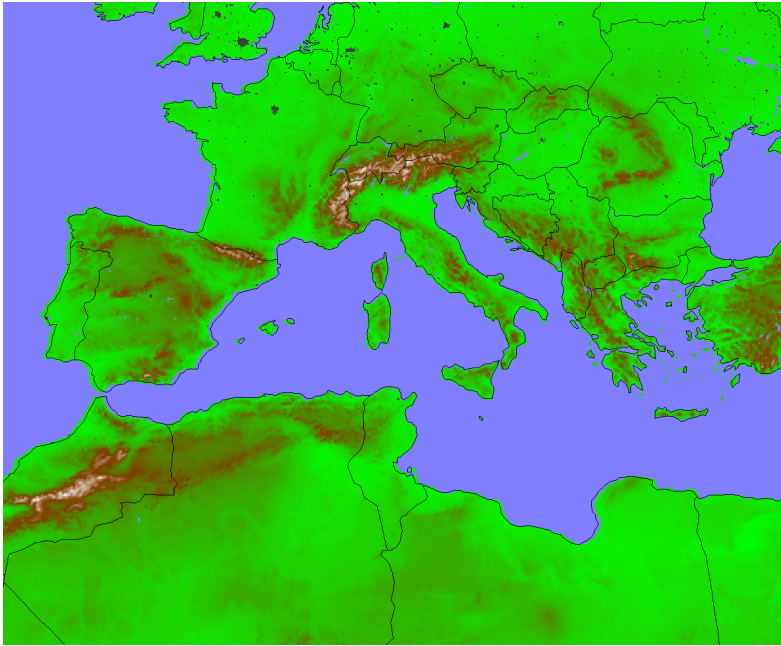
---

- 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!)

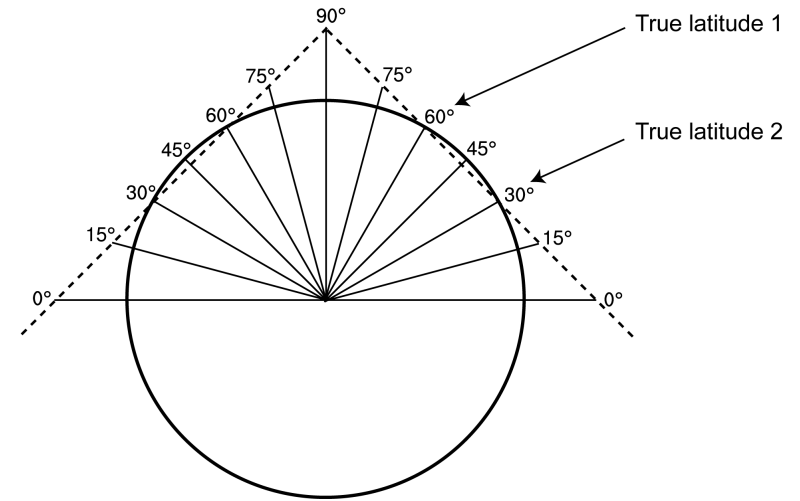




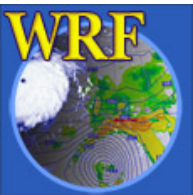
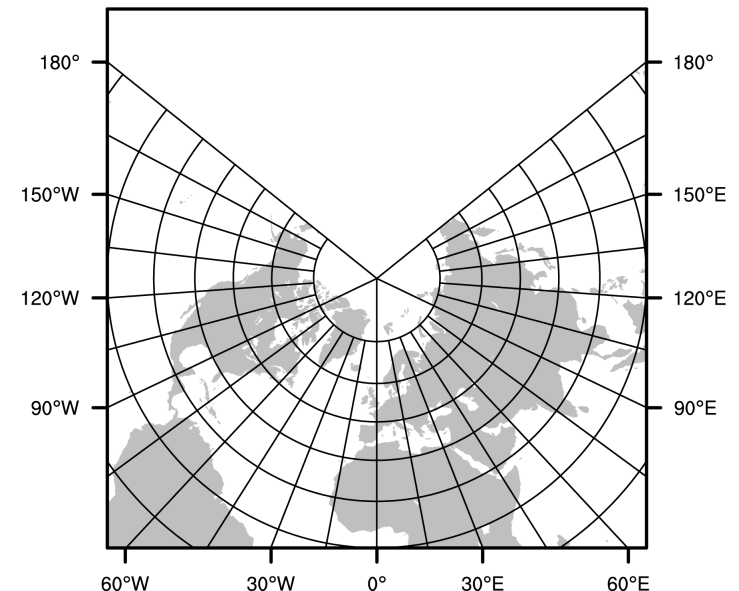
# ARW Projections: Lambert Conformal



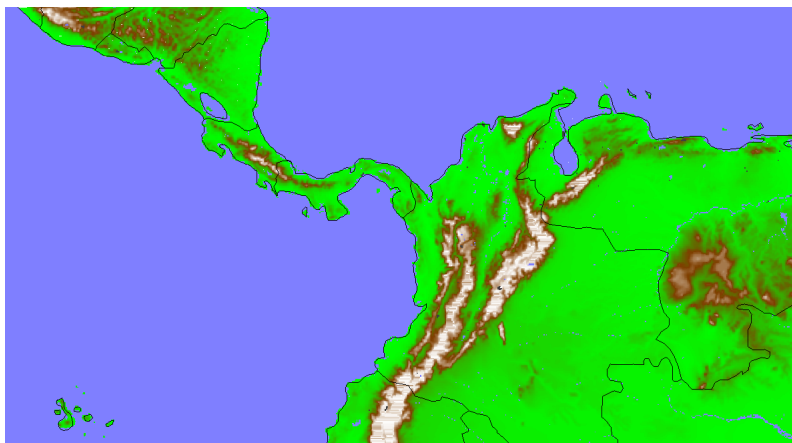
Lambert Conformal



- 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

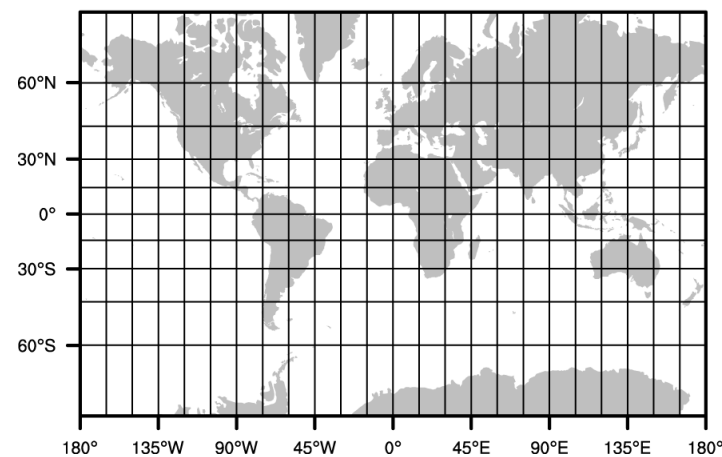
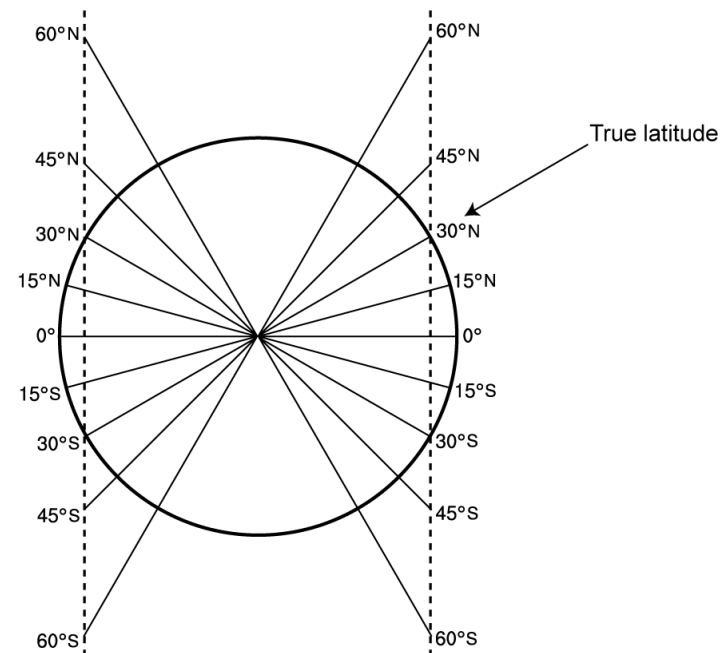


# ARW Projections: Mercator

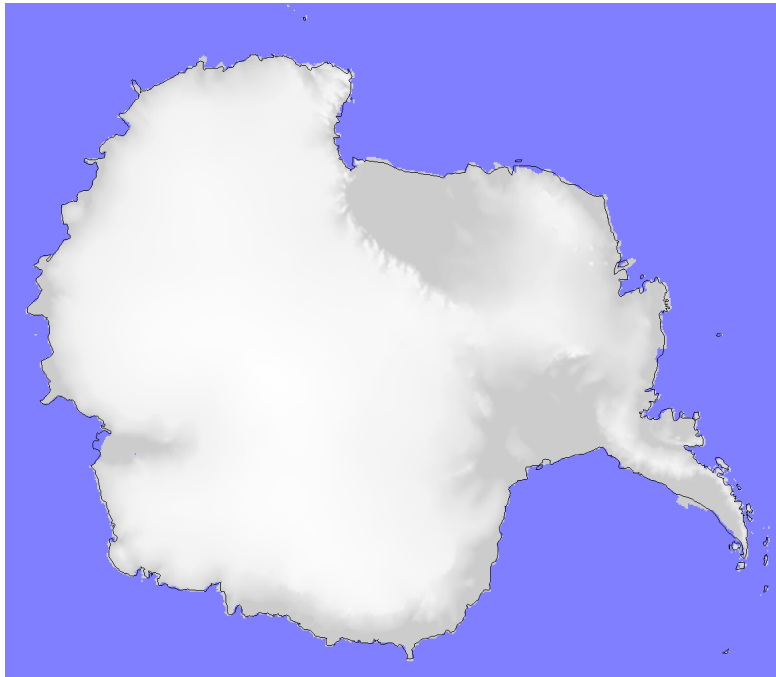


- Well-suited for low-latitudes
- May be used for “channel” domain (periodic domain in west-east direction)
- A single true latitude is specified
  - Cylinder intersects the earth’s surface at +/- truelat

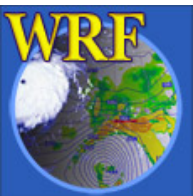
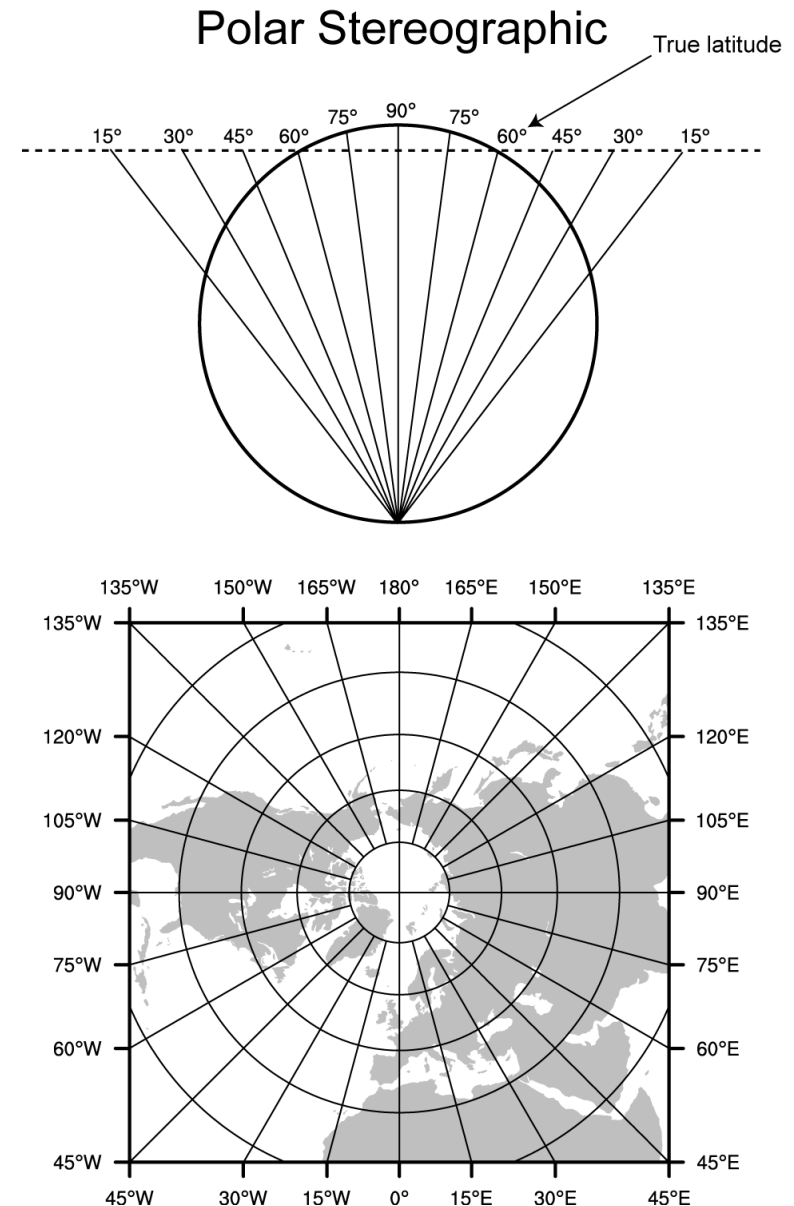
Mercator



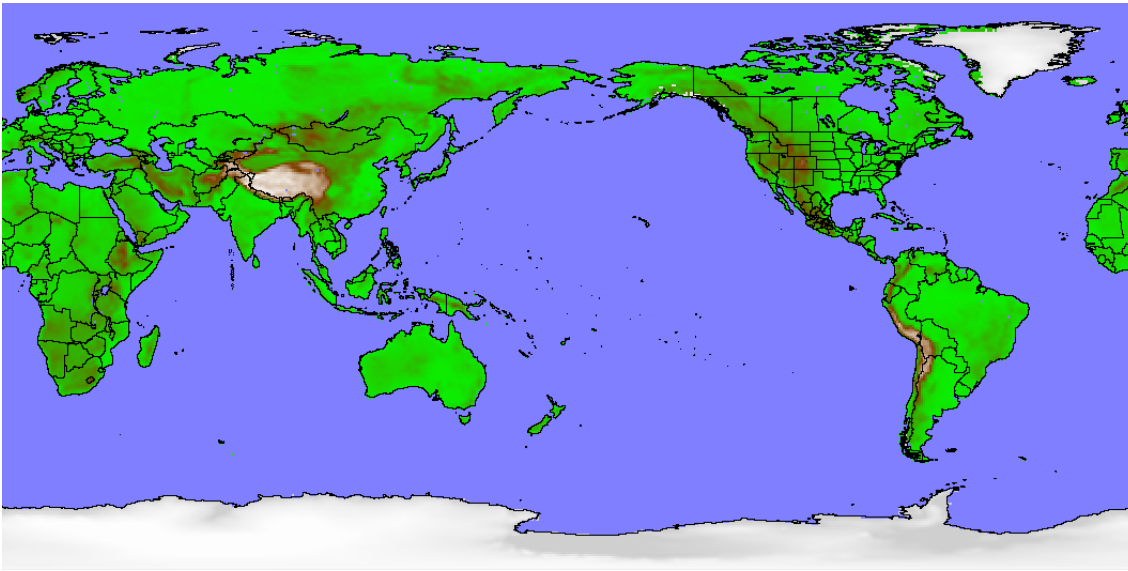
# ARW Projections: Polar Stereographic



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

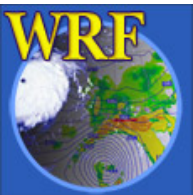
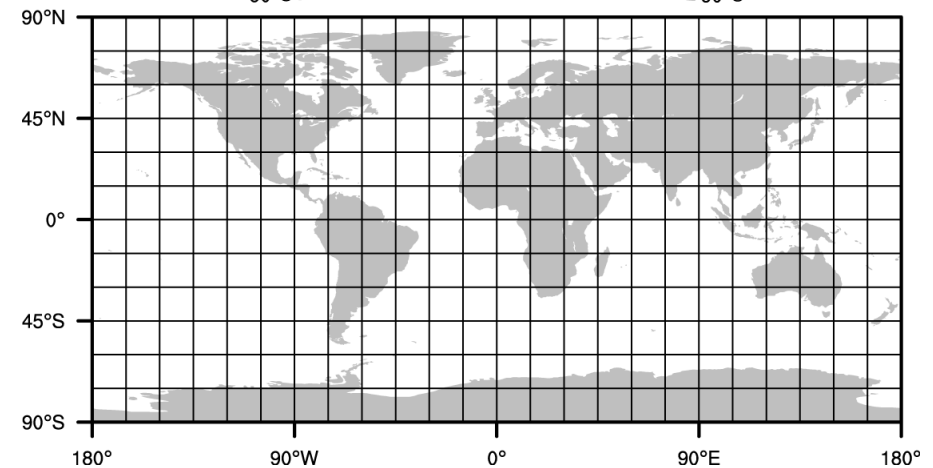
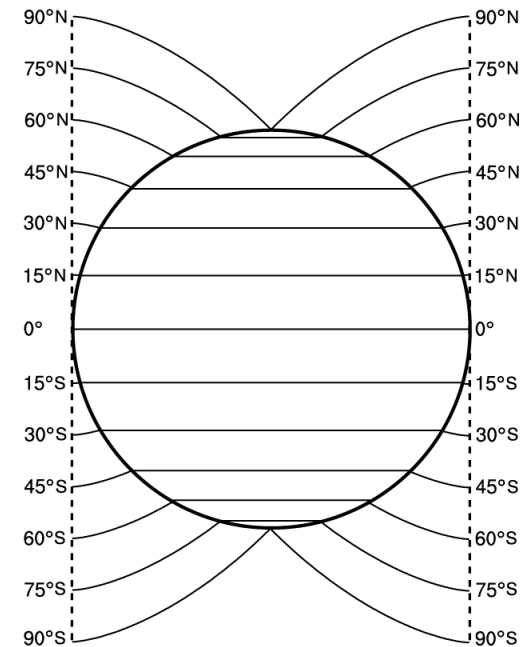


# ARW Projections: Cylindrical Equidistant



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

Cylindrical Equidistant



# 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

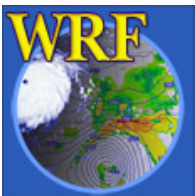
$$\Delta x_{\text{geographical}} = \Delta x_{\text{nominal}} / m$$

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!

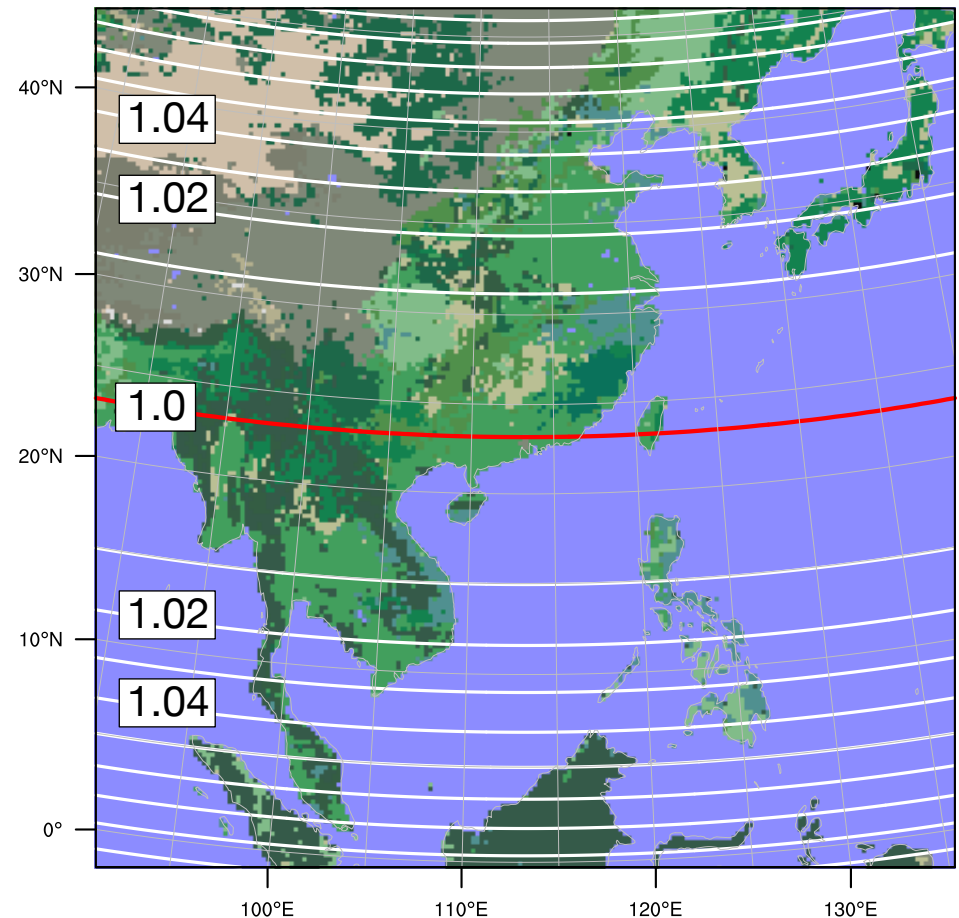


# Why do map projections matter?

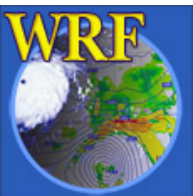
## Example:

- 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.*



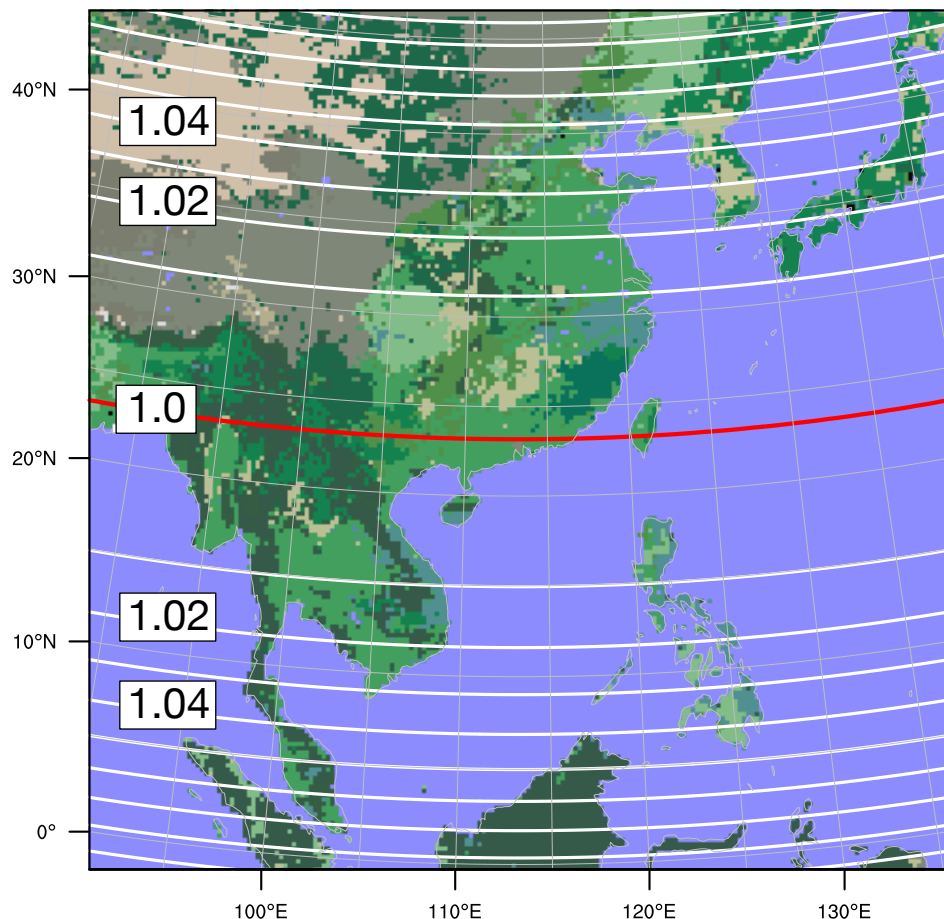
*Above: Contours of map scale factor (white; interval 0.01) with true latitudes (red).*



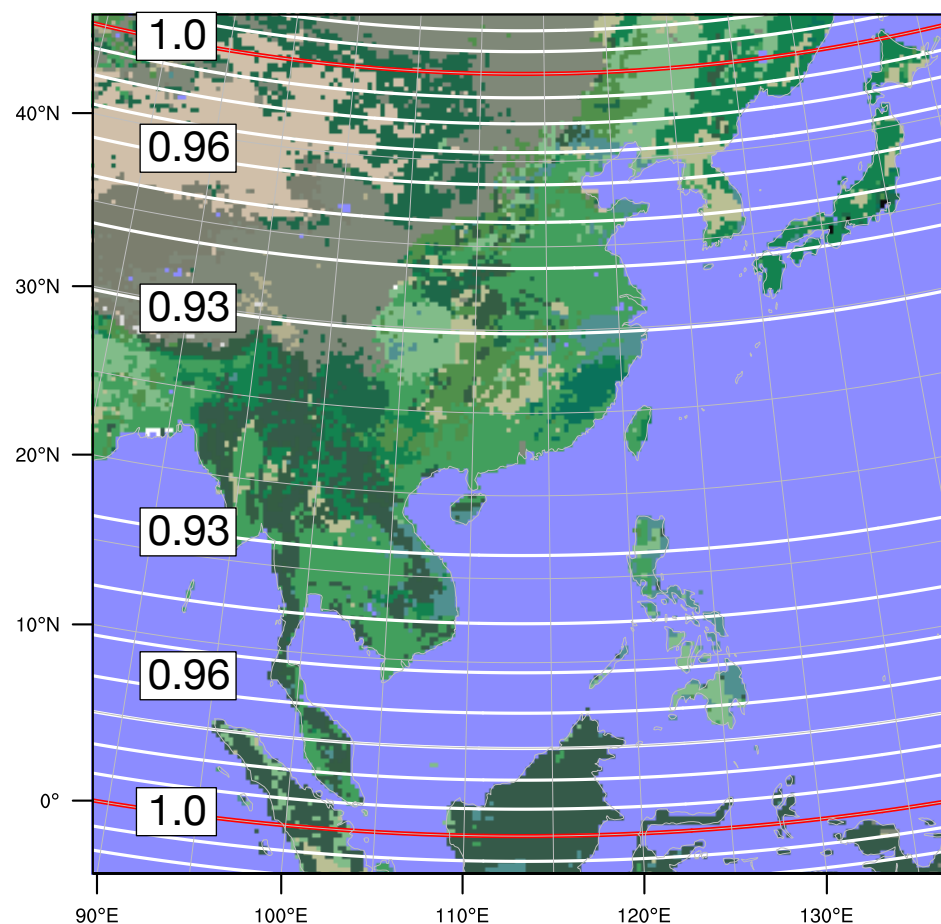


# Why do map projections matter?

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).*

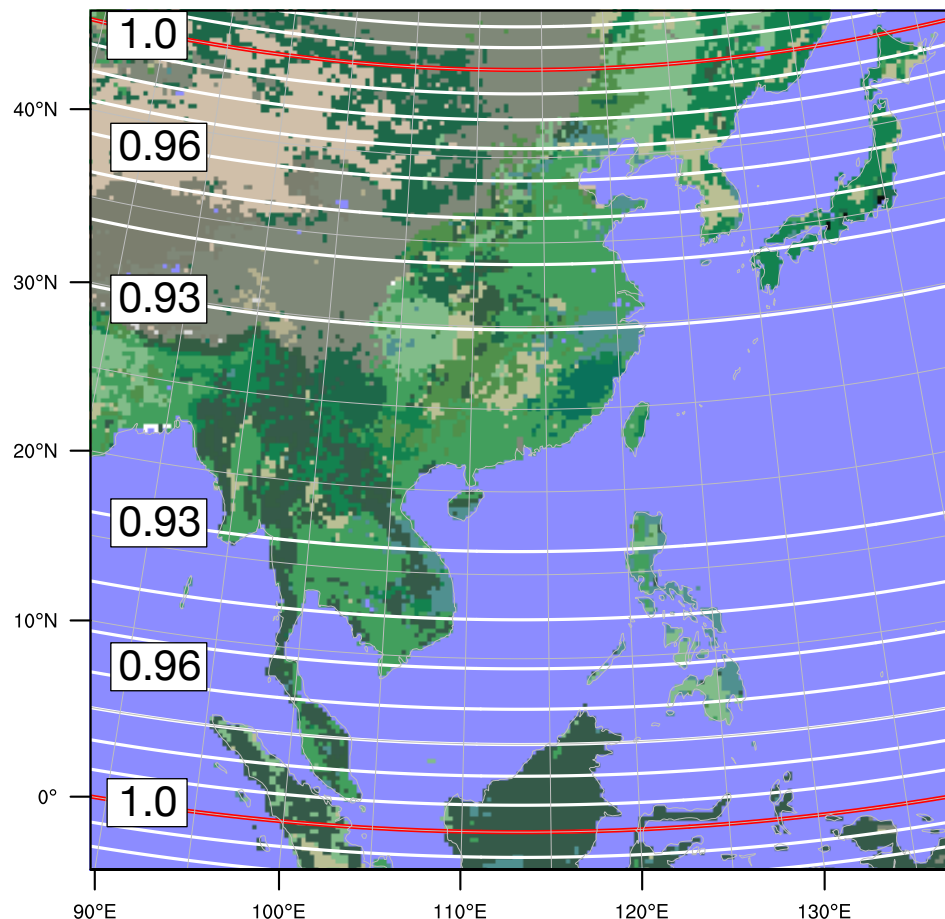


*Above: The maximum map scale factor is 1.03, but the minimum is 0.924, corresponding to a physical distance of 29.2 km.*

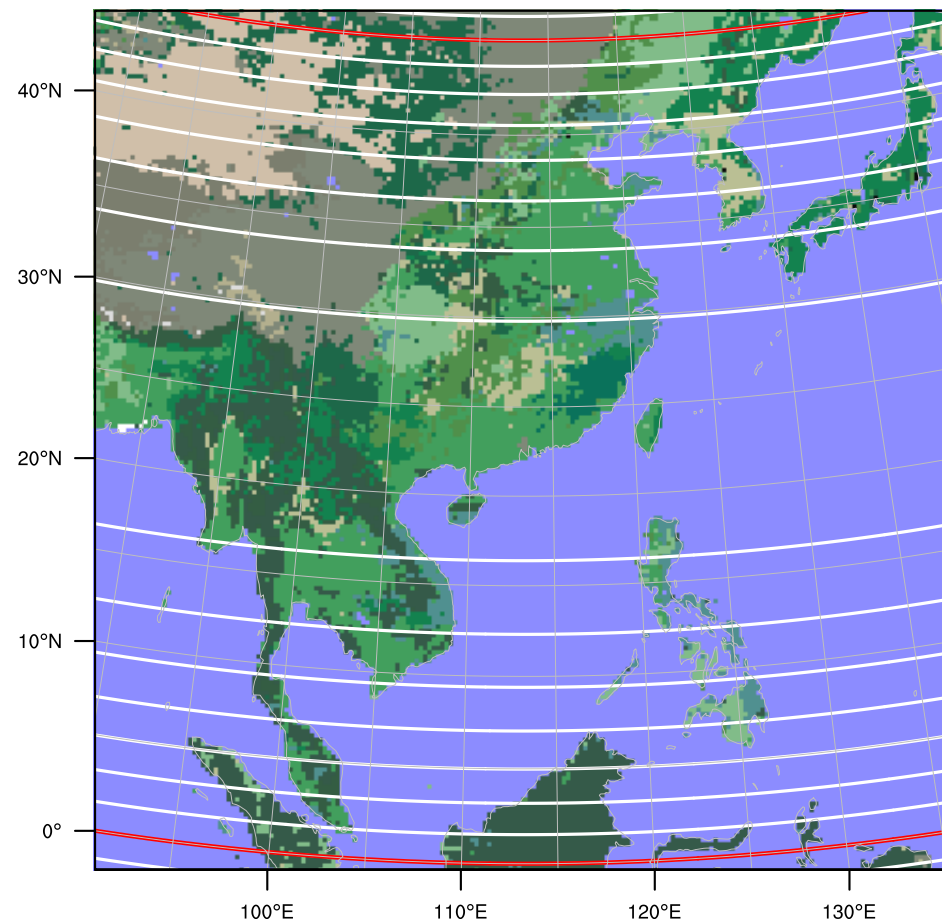


# Why do map projections matter?

... 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: With a nominal grid distance of 27 km, the map scale factors of 0.924 in the center of the map correspond to a physical distance of 29.2 km.



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.



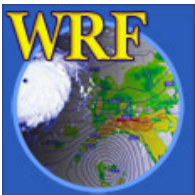


# Geogrid: Defining Model Domains

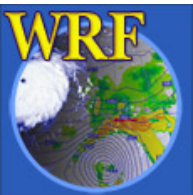
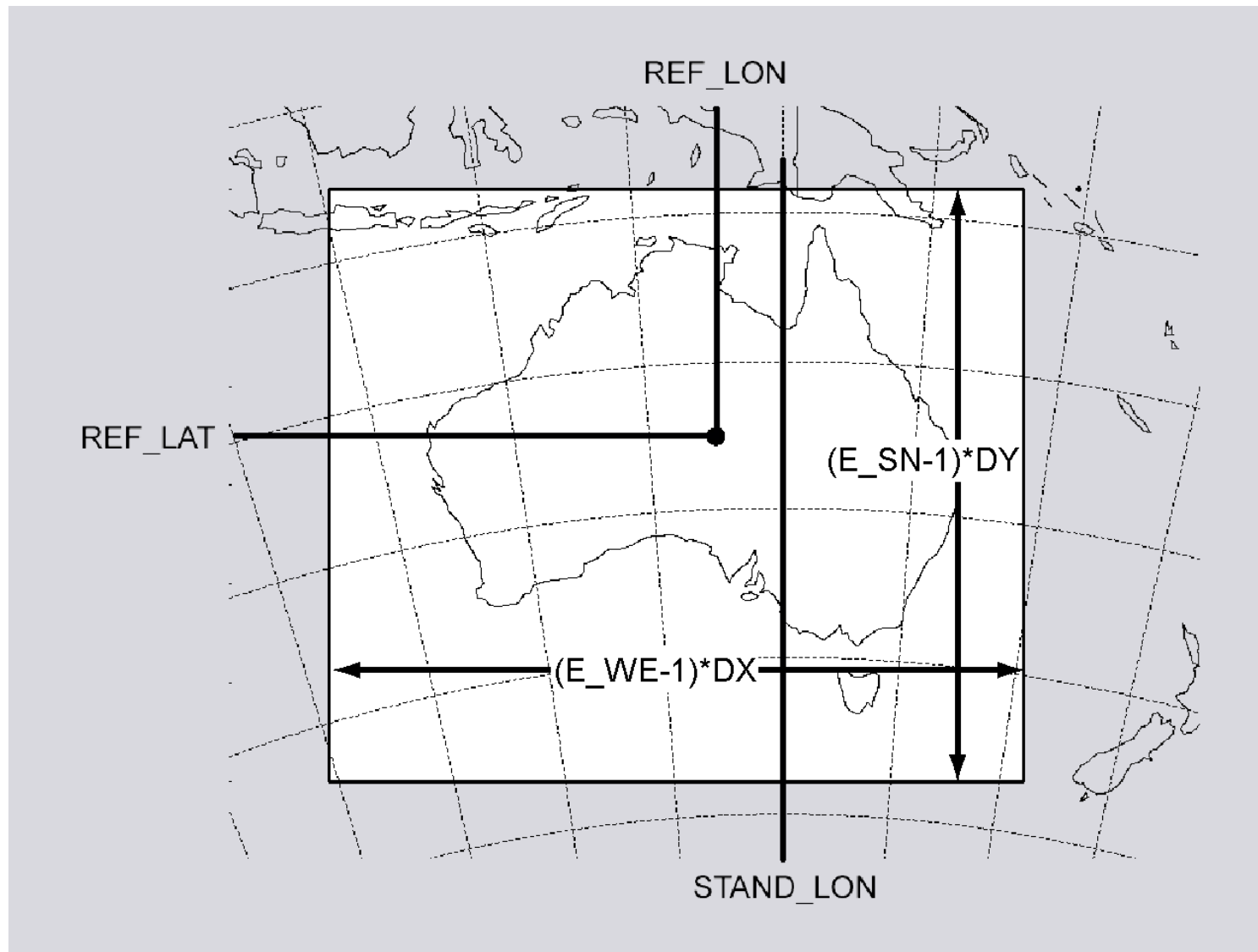
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- Define projection of domains using a subset of the following parameters
  - MAP\_PROJ: 'lambert', 'mercator', 'polar', or 'lat-lon'
  - TRUELAT1: First true latitude
  - TRUELAT2: Second true latitude (*only for Lambert conformal*)
  - POLE\_LAT, 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

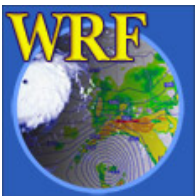


# Geogrid: Defining Model Domains

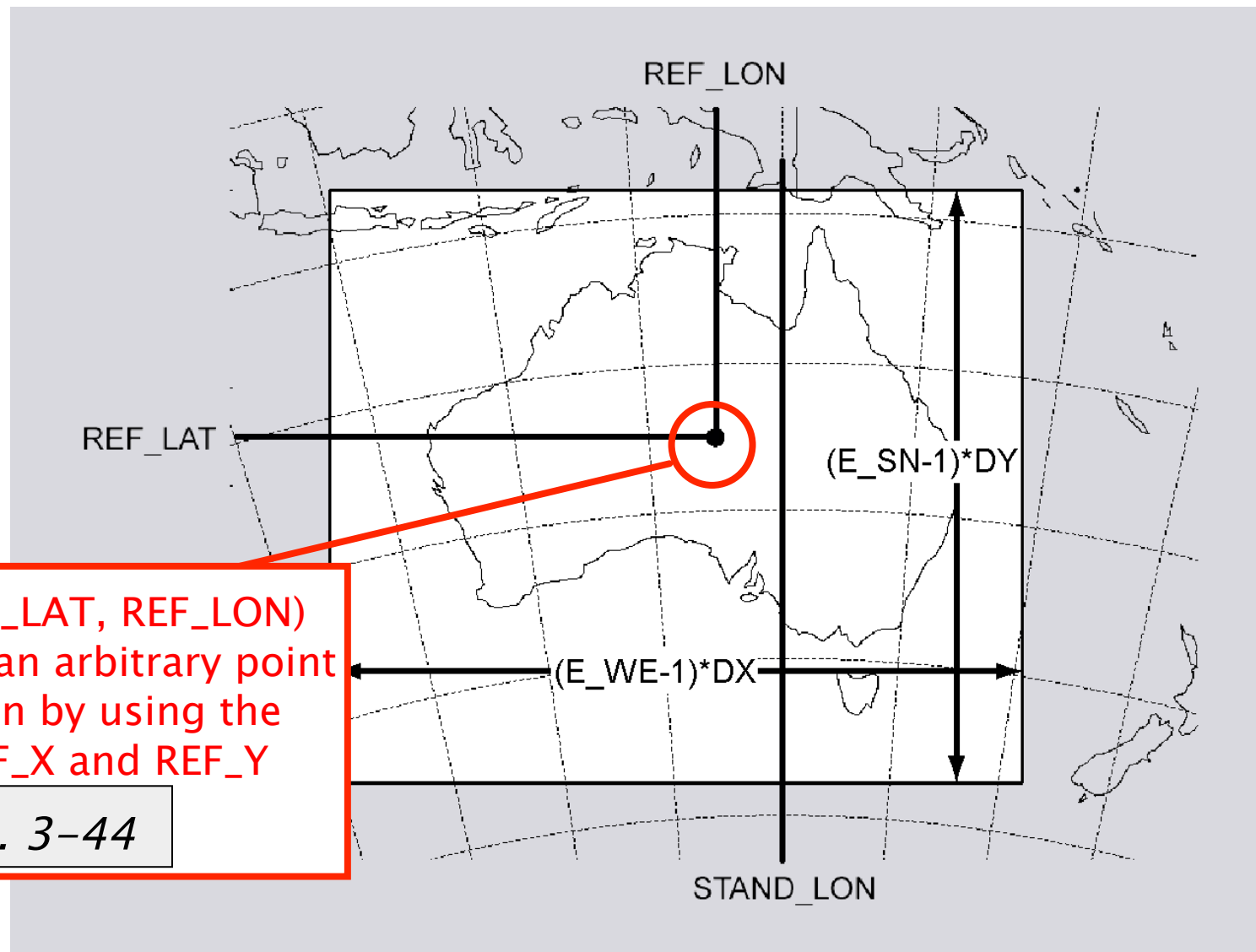
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- Define the area covered (dimensions and location) by coarse domain using the following:
  - **REF\_LAT, REF\_LON:** The (lat,lon) location of a known location in the domain (*by default, the center point of the domain*)
  - **DX, DY:** Grid distance 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*

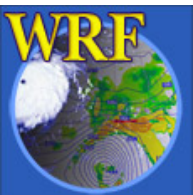


# Geogrid: Defining ARW Domains



In ARW, ( $REF\_LAT$ ,  $REF\_LON$ ) can refer to an arbitrary point in the domain by using the variables  $REF\_X$  and  $REF\_Y$

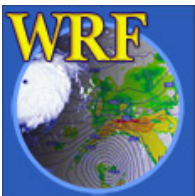
*See p. 3-44*



# Geogrid: Nesting Basics

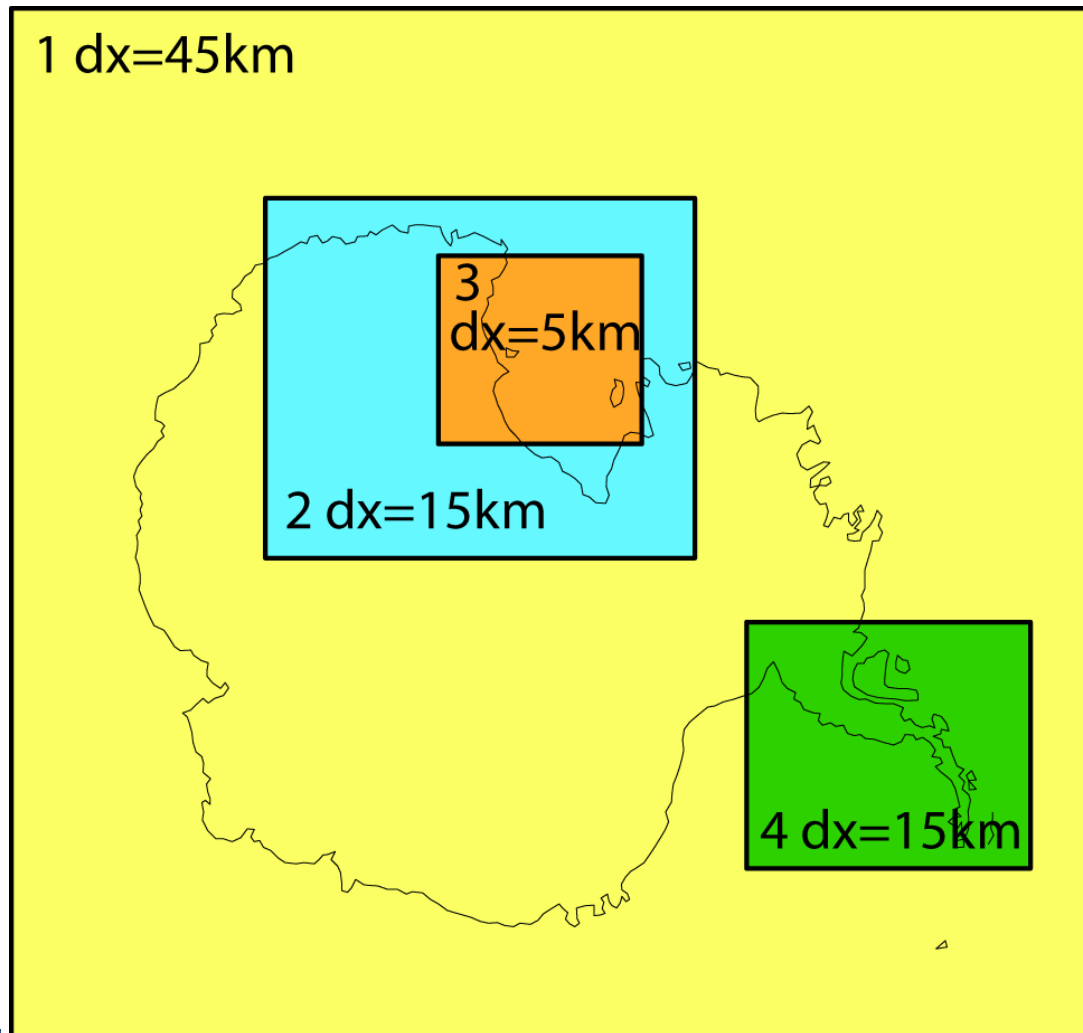
---

- 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!

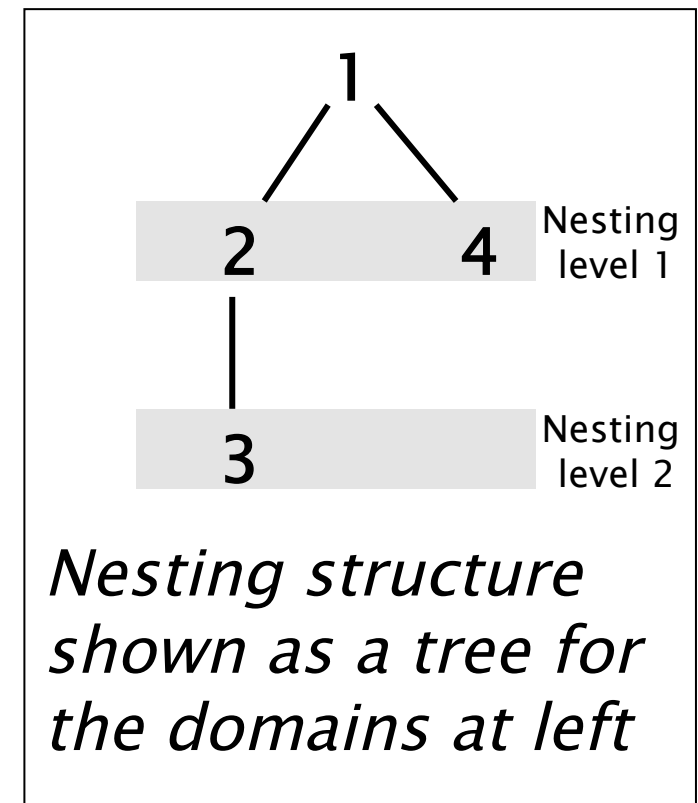


# Geogrid: Nesting Example

Example configuration – 4 domains



Each domain is assigned a *domain ID #*



# Geogrid: Defining Nested Domains

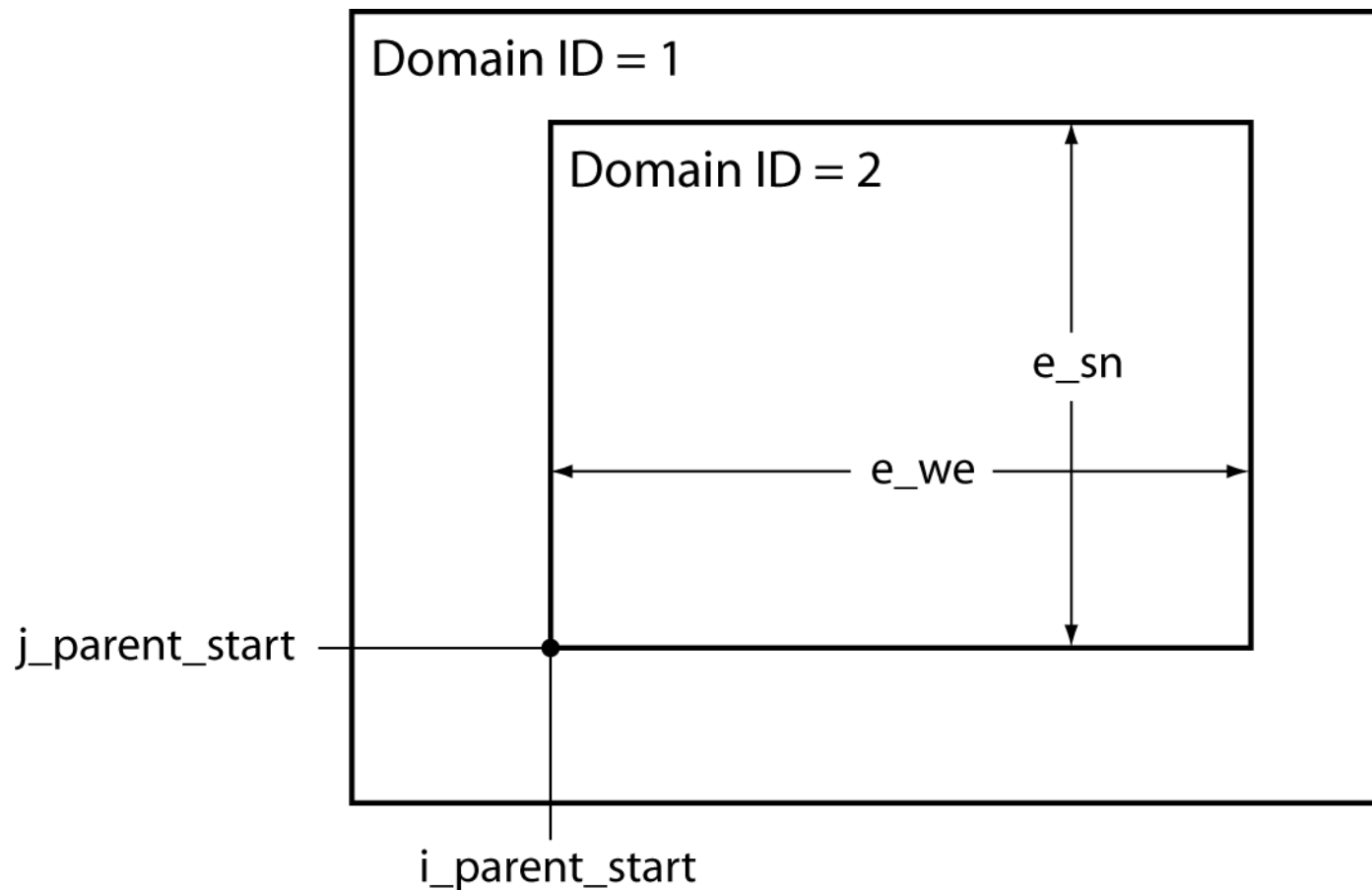
---

- 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

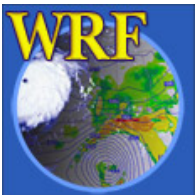
*See p. 3-20 and 3-42*



# Geogrid: Defining Nested Domains



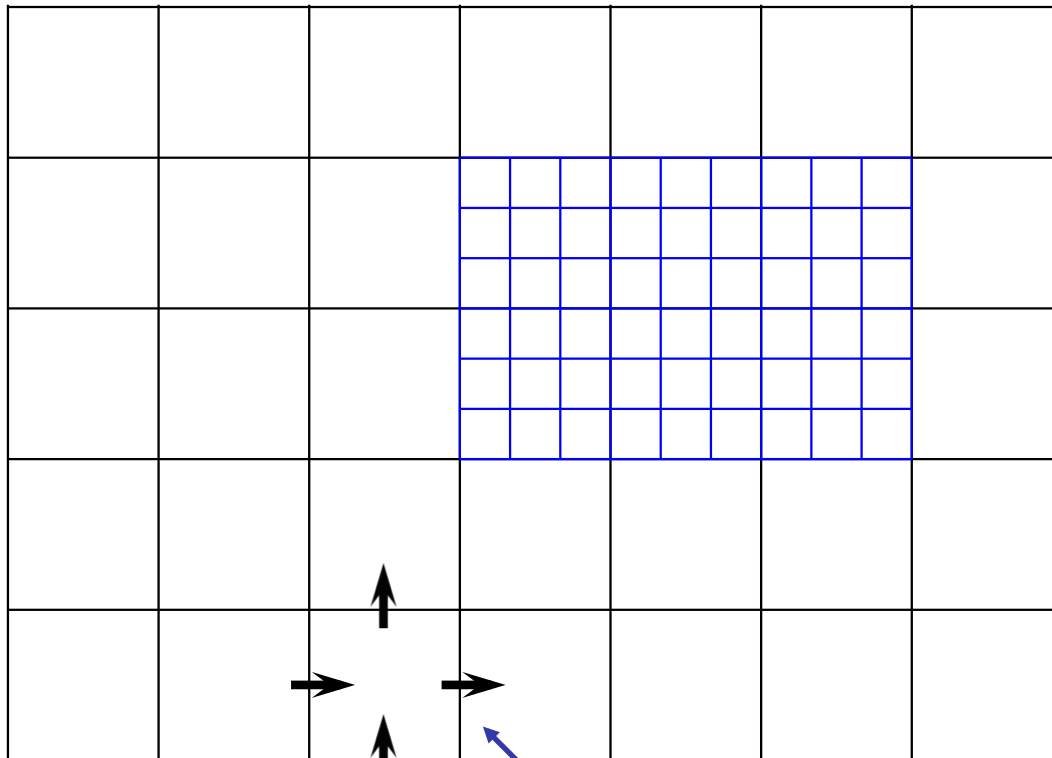
The grid spacing ( $dx$ ) of domain 2 is determined by grid spacing of domain 1 and the *parent\_grid\_ratio*





# 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*.

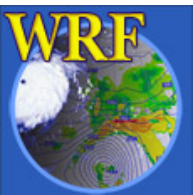


Therefore, in ARW, nest dimensions must satisfy

$$\frac{e\_we - 1}{parent\_grid\_ratio} = n_i$$

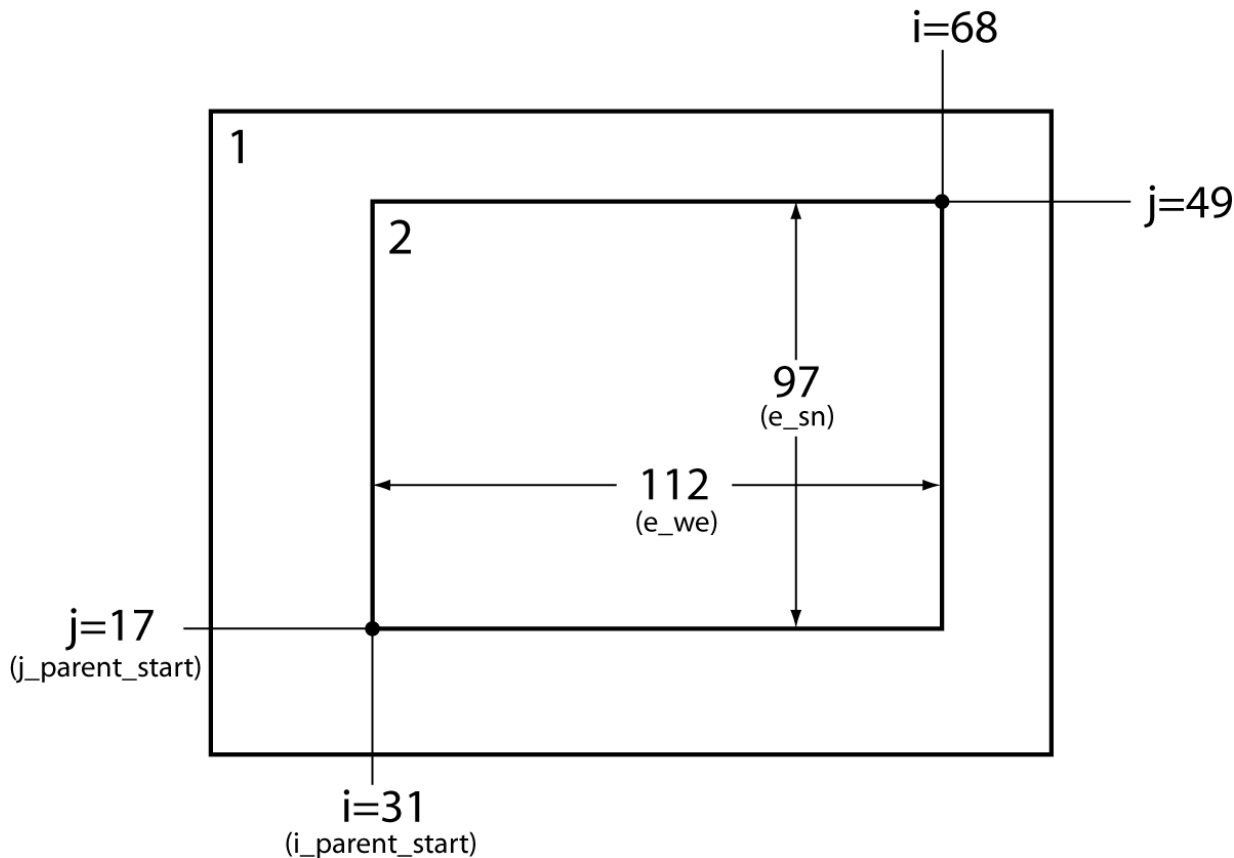
$$\frac{e\_sn - 1}{parent\_grid\_ratio} = n_j$$

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



# Geogrid: Nesting example

Assuming *parent\_grid\_ratio* = 3

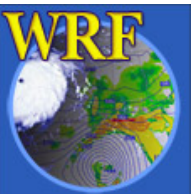


In ARW, nest dimensions must satisfy

$$\frac{e_{we} - 1}{parent\_grid\_ratio} = n_i$$

$$\frac{e_{sn} - 1}{parent\_grid\_ratio} = n_j$$

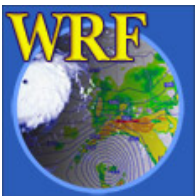
where  $n_i$  and  $n_j$  are any integers.



# Geogrid: Interpolating Static Fields

---

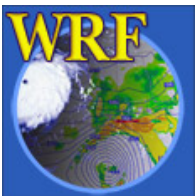
- Given definitions of all computational grids, geogrid interpolates terrestrial, time-invariant fields
  - Topography height
  - Land use categories
  - Soil type (top layer & bottom layer)
  - Annual mean soil temperature
  - Monthly vegetation fraction
  - Monthly surface albedo



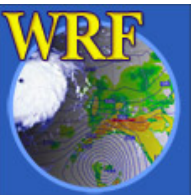
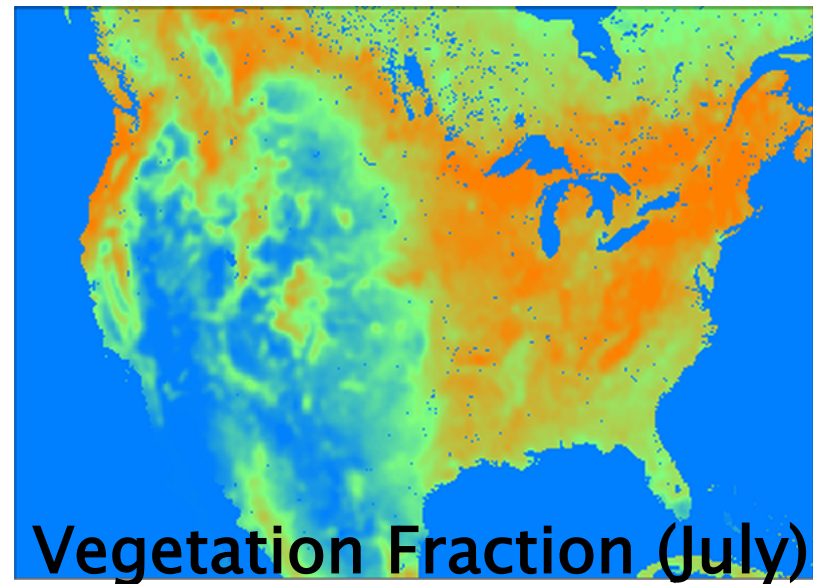
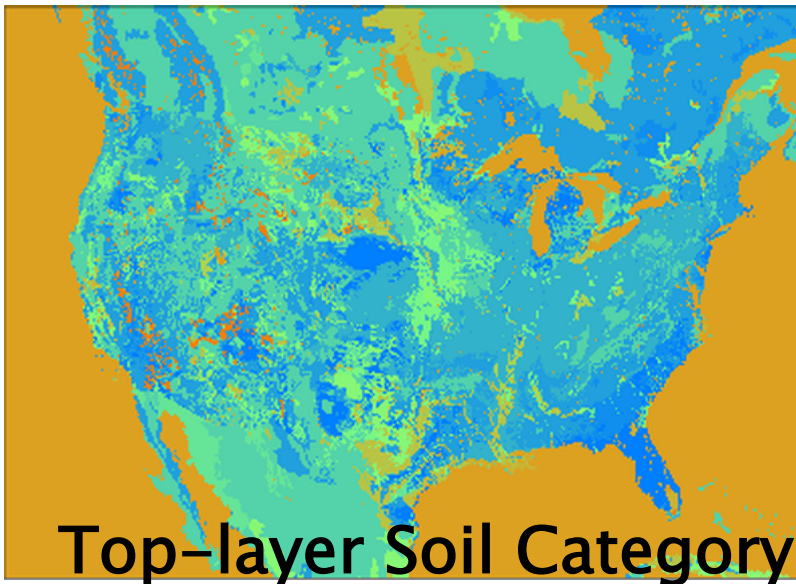
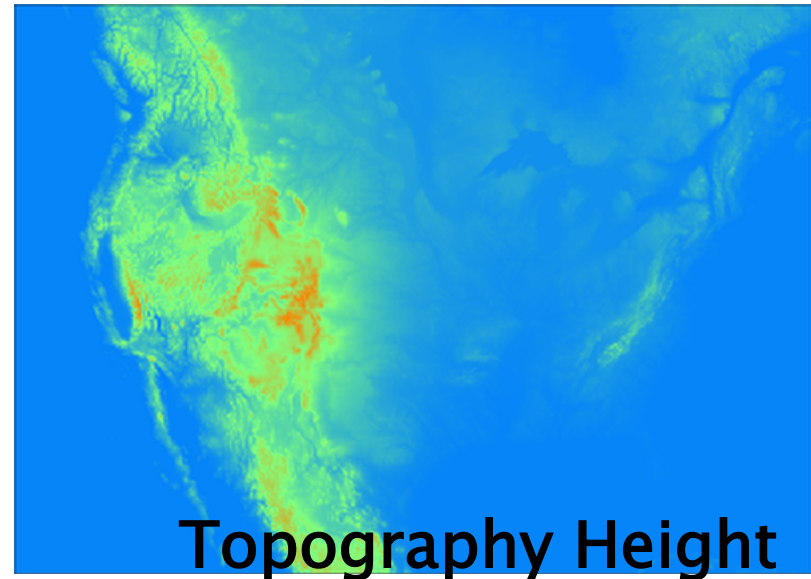
# Geogrid: Program Output

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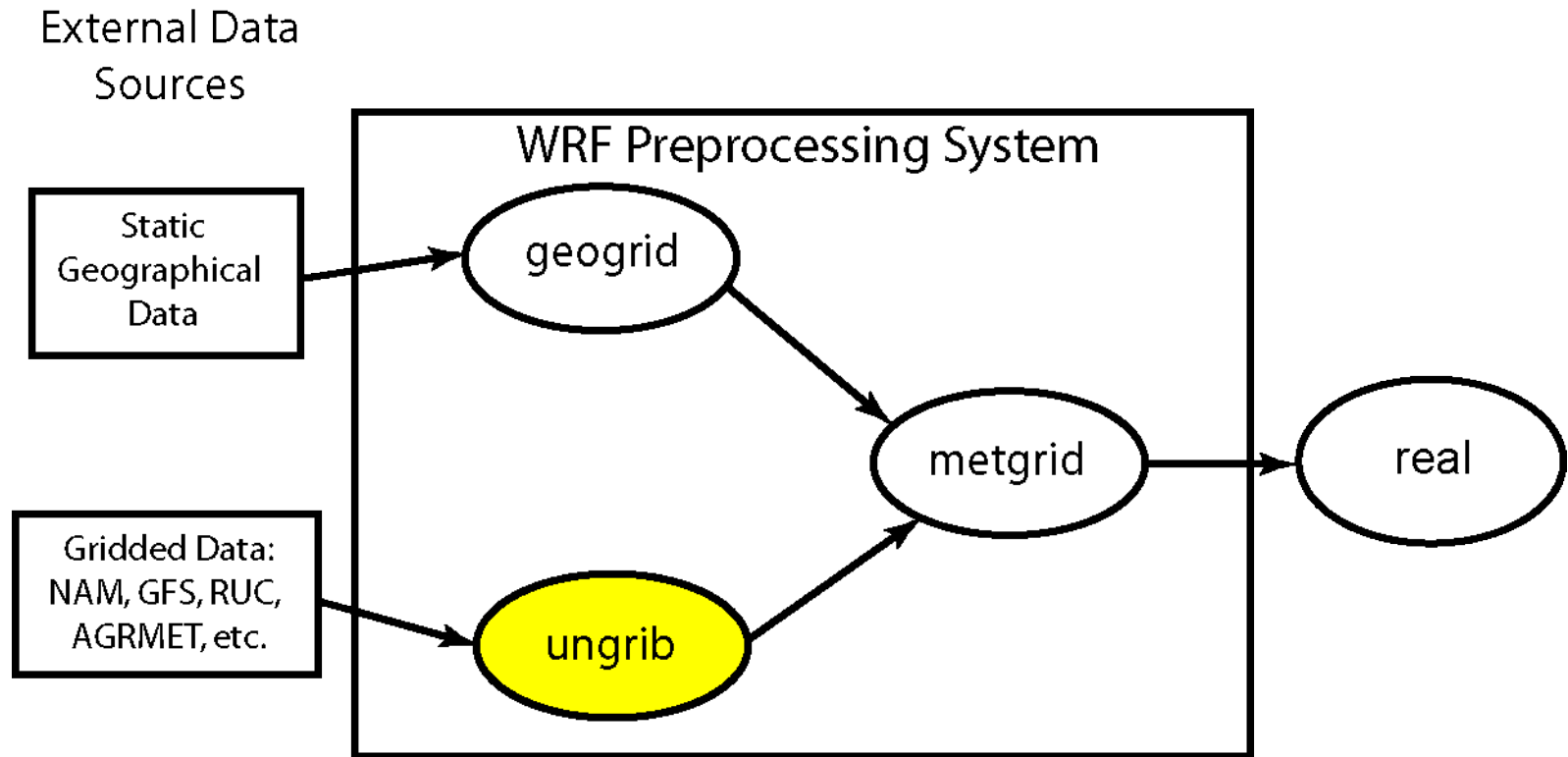
- The parameters defining each domain, plus interpolated static fields, are written using the WRF I/O API
  - One file per domain for ARW
- Filenames: `geo_em.d0n.nc`  
(where  $n$  is the domain ID number)
- Example:
  - `geo_em.d01.nc`
  - `geo_em.d02.nc` (nest)
  - `geo_em.d03.nc` (nest)



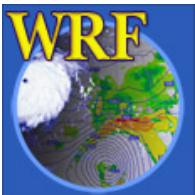
# Geogrid: Example Output Fields



# The *ungrib* program



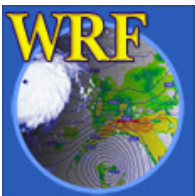
ungrib: think un+grib



# What is a GRIB file, anyway?

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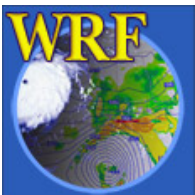
- GRIB is a WMO standard file format for storing regularly-distributed (e.g., gridded) fields
  - “General Regularly-distributed Information in Binary”
- Fields within a GRIB file are compressed with a lossy compression
  - Think of truncating numbers to a fixed number of digits
- A record-based format
- 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





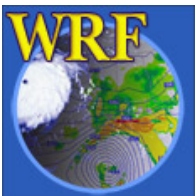
# Ungrib: Vtables

---

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



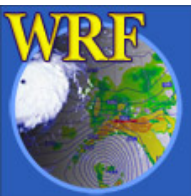
# Ungrib: Example Vtable

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

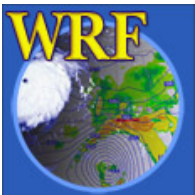
---

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. 3–35



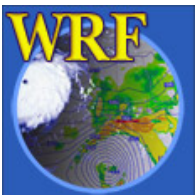
# Ungrib: Intermediate File Format

---

- 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*

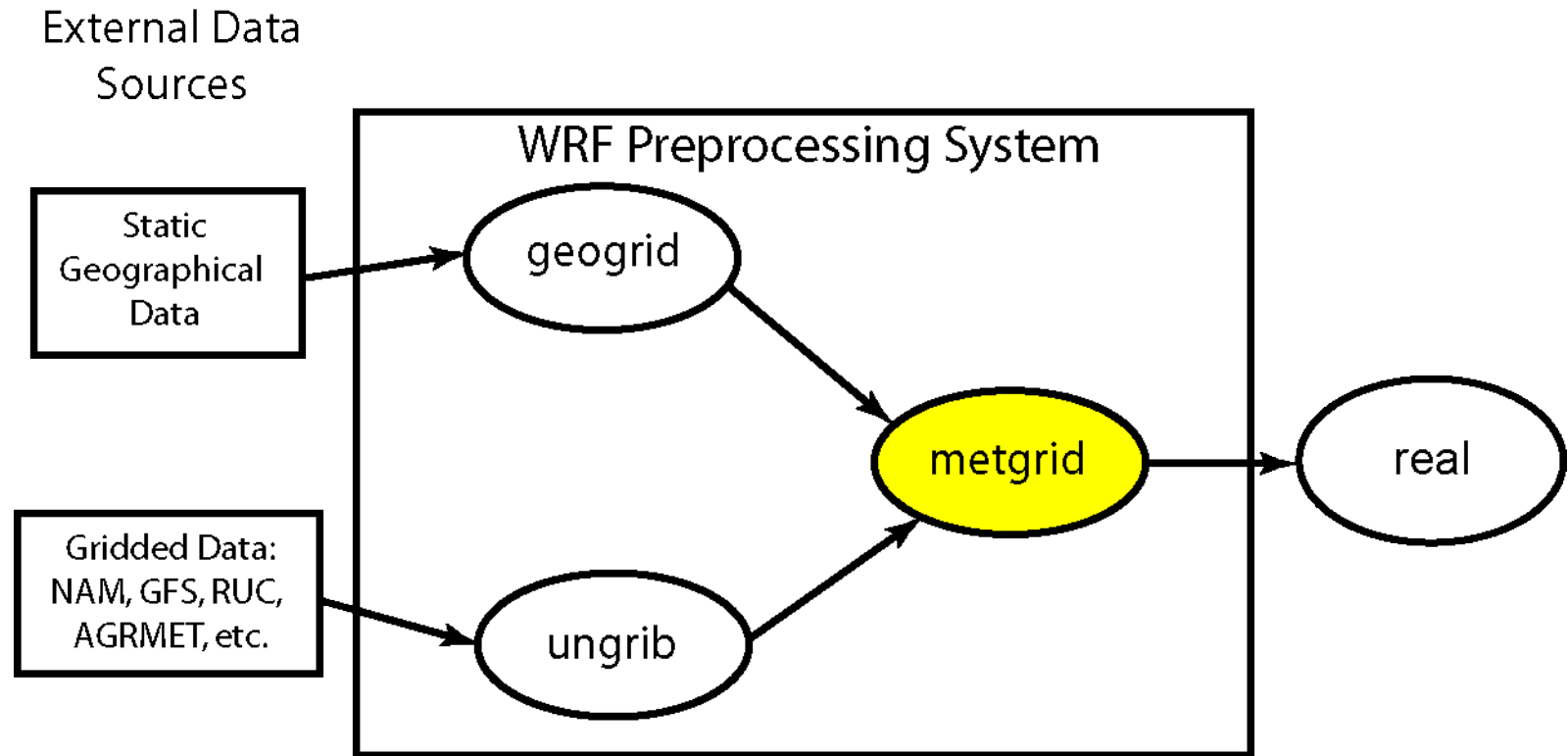
*FILE:2007-07-24\_06*

*FILE:2007-07-24\_12*

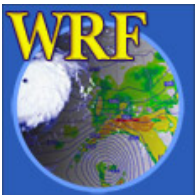
ungrib can also write intermediate files in the MM5 or WRF SI format!  
*(To allow for use of GRIB2 data with MM5, for example)*



# The *metgrid* program



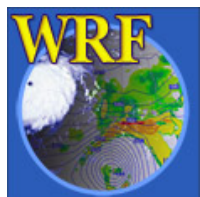
metgrid: think meteorological



# The *metgrid* program

---

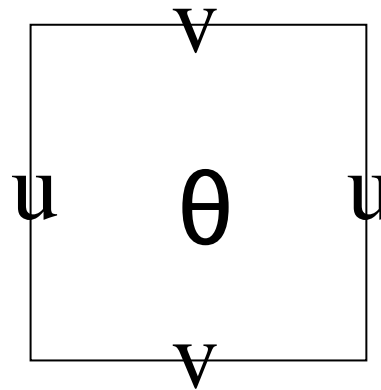
- Horizontally interpolate meteorological data (*extracted by ungrib*) to simulation domains (*defined by geogrid*)
  - Masked interpolation for masked fields
  - *Can process both isobaric and native vertical coordinate data sets*
- Rotate winds to WRF grid
  - i.e., rotate so that U-component is parallel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



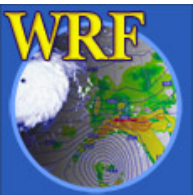


# Metgrid: ARW Grid Staggering

- For ARW, wind U-component interpolated to “u” staggering
- Wind V-component interpolated to “v” staggering
- Other meteorological fields interpolated to “ $\theta$ ” staggering by default (*can change this!*)



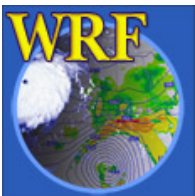
*A single ARW grid cell, with “u”, “v”, and “ $\theta$ ” points labeled.*



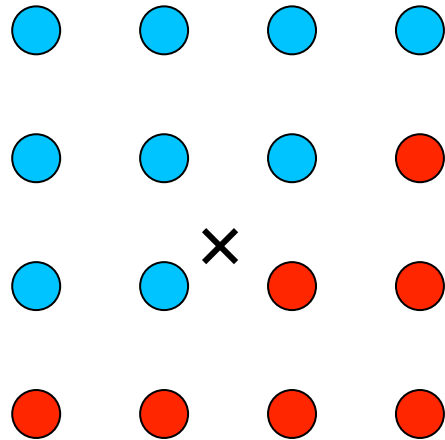
# Metgrid: Masked Interpolation

---

- *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

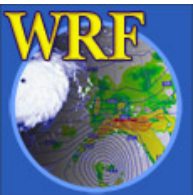


● = valid source data  
● = masked/invalid data

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

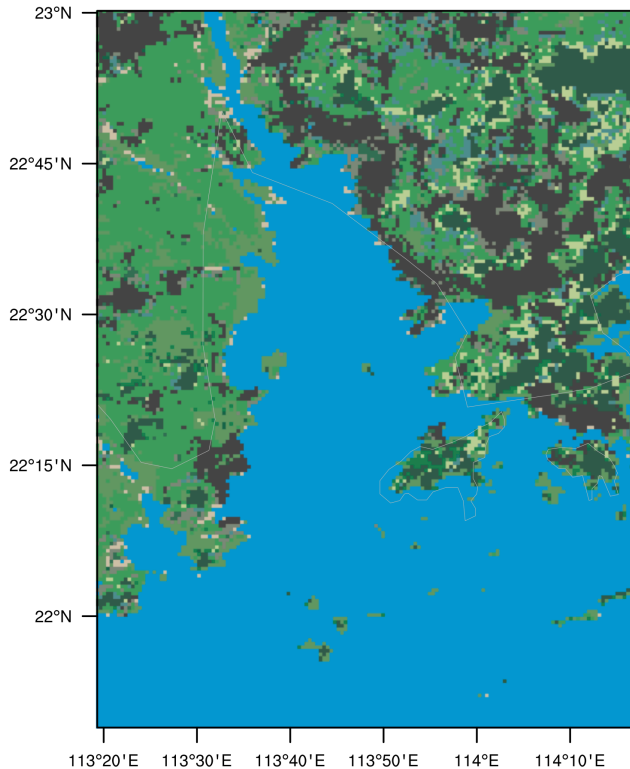
*Not every interpolation option can handle masked points; we'll address this issue in the advanced WPS lecture*



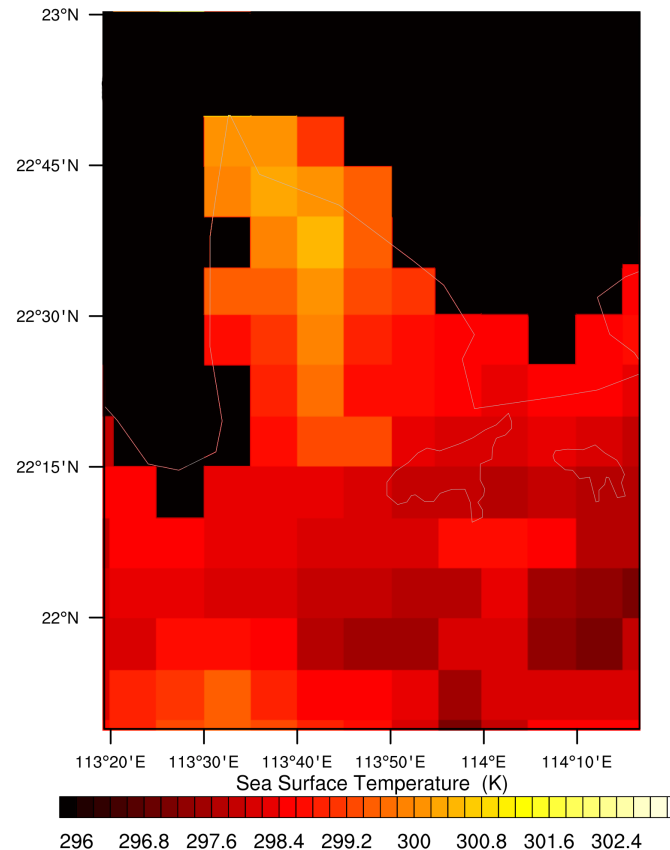
# Metgrid: Masked Interpolation

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

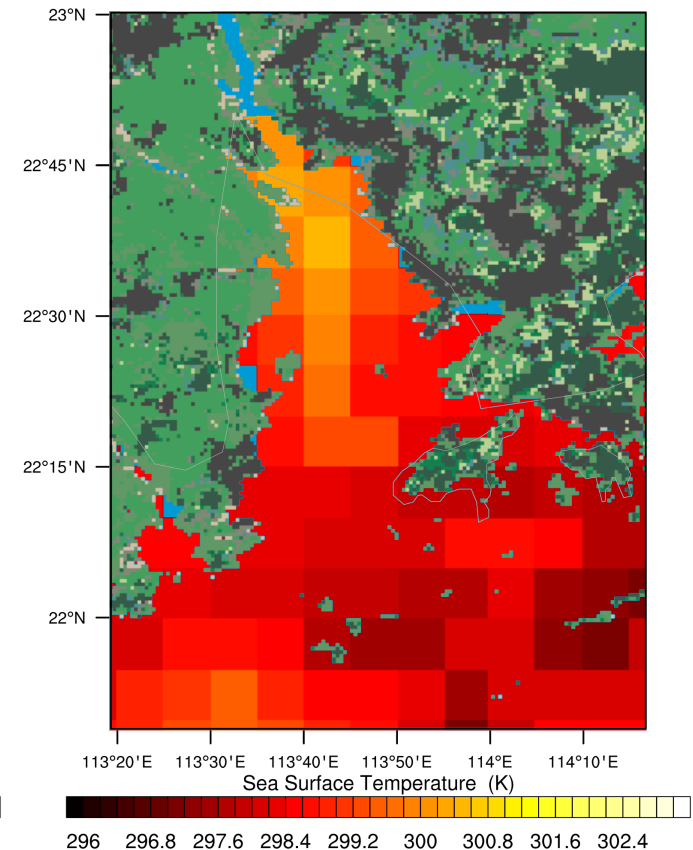
Dominant category (category)



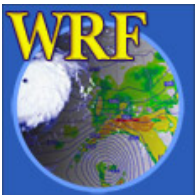
A high-resolution WRF domain centered on Pearl River Estuary.



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

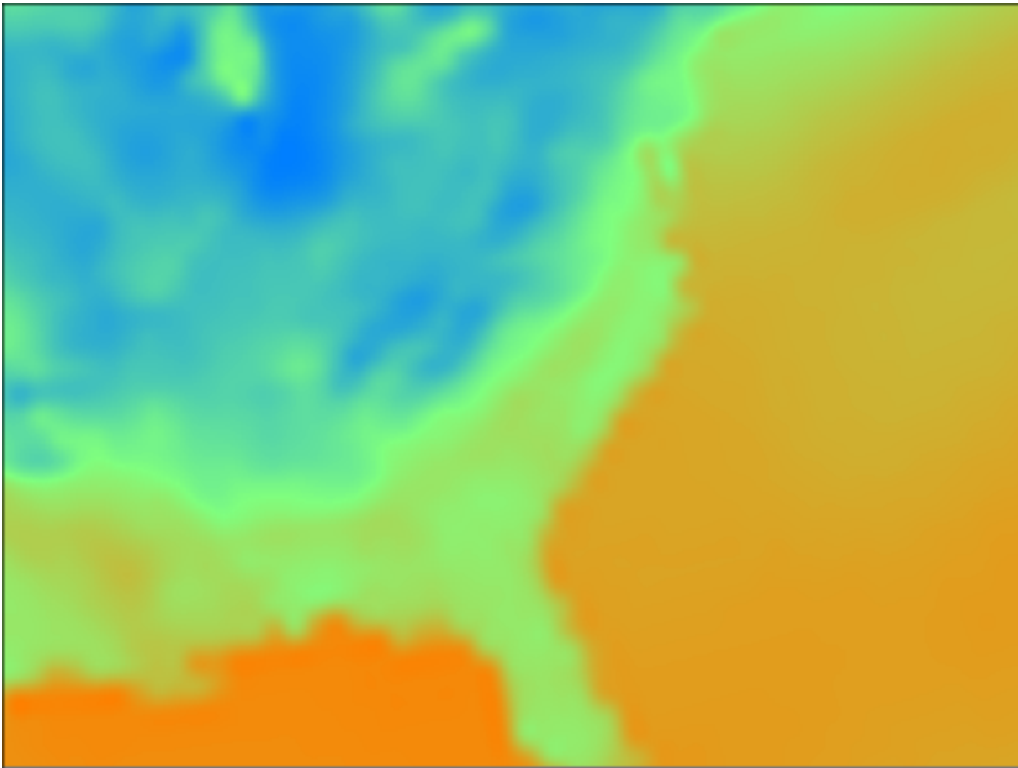


SST data overlaid with land use; blue areas represent WRF water cells that must receive SST values via masked interpolation.

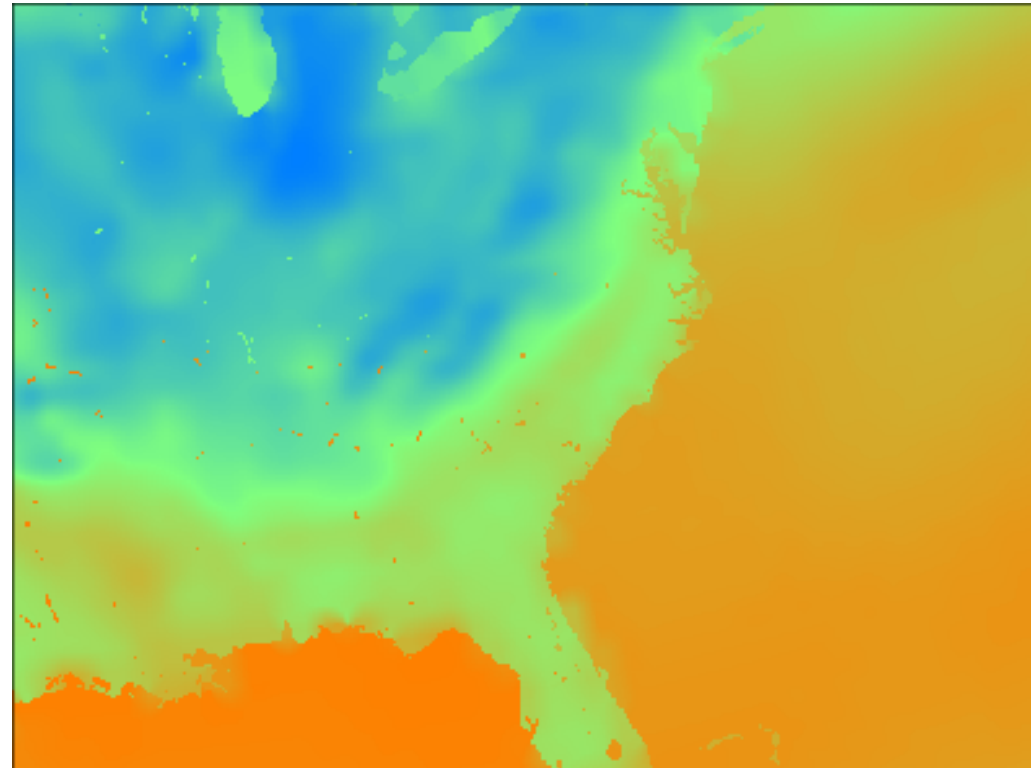


# Metgrid: Masked Interpolation

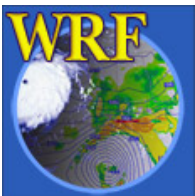
Masked interpolation can also be used for any field, e.g., to improve the resolution of coastlines in the field.



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



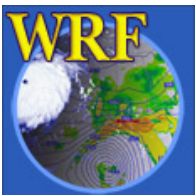
Skin temperature field interpolated using masks: GFS water points interpolated to model water points, GFS land points interpolated to model land points.



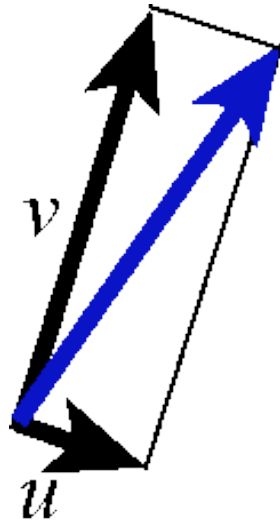
# Metgrid: Wind Rotation

---

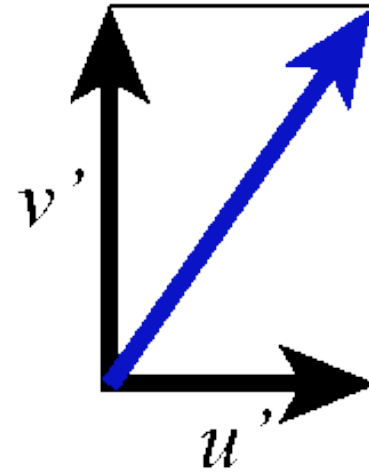
- Input wind fields (U-component + V-component) are either:
  - **Earth-relative:** U-component = westerly component; V-component = southerly component
  - **Relative to source grid:** U-component (V-component) parallel to source model x-axis (y-axis)
- WRF expects wind components to be relative to the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



# Metgrid: Wind Rotation Example

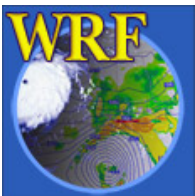


A wind vector, shown in terms of its U and V components with respect to the source grid.



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

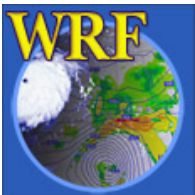
This process may require *two* rotations: one from source grid to earth grid and a second from earth grid to WRF grid



# Metgrid: Constant Fields

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- 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

---

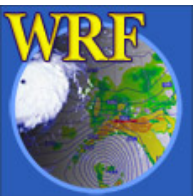
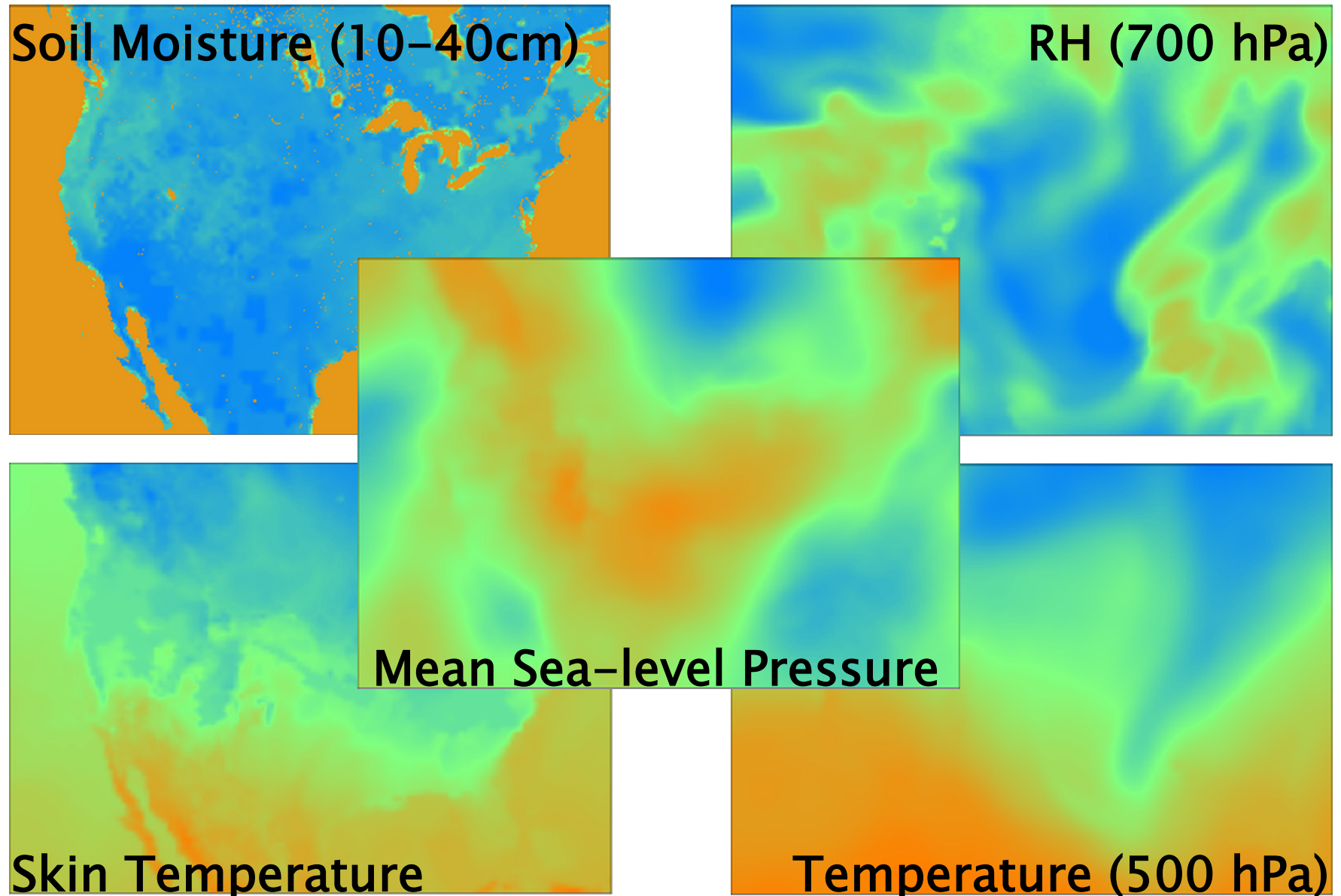
- For coarse domain, one file per time period
  - In ARW, we also get the first time period for all nested grids
- Files contain static fields from geogrid plus interpolated meteorological fields
- Filenames:

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

(where  $n$  is the domain ID number)

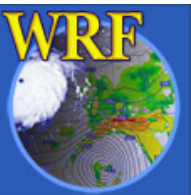
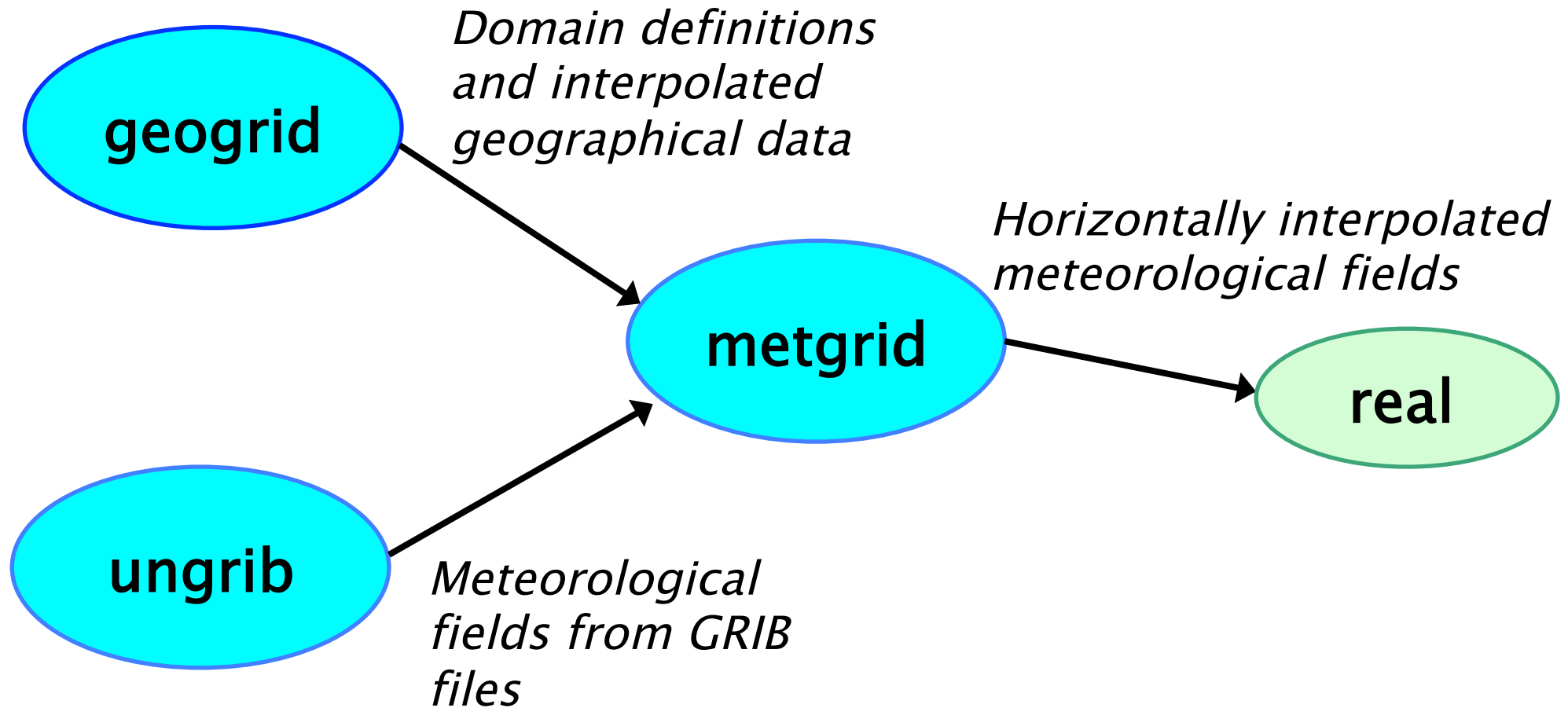


# Metgrid: Example Output



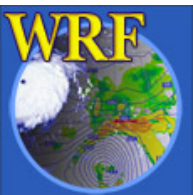
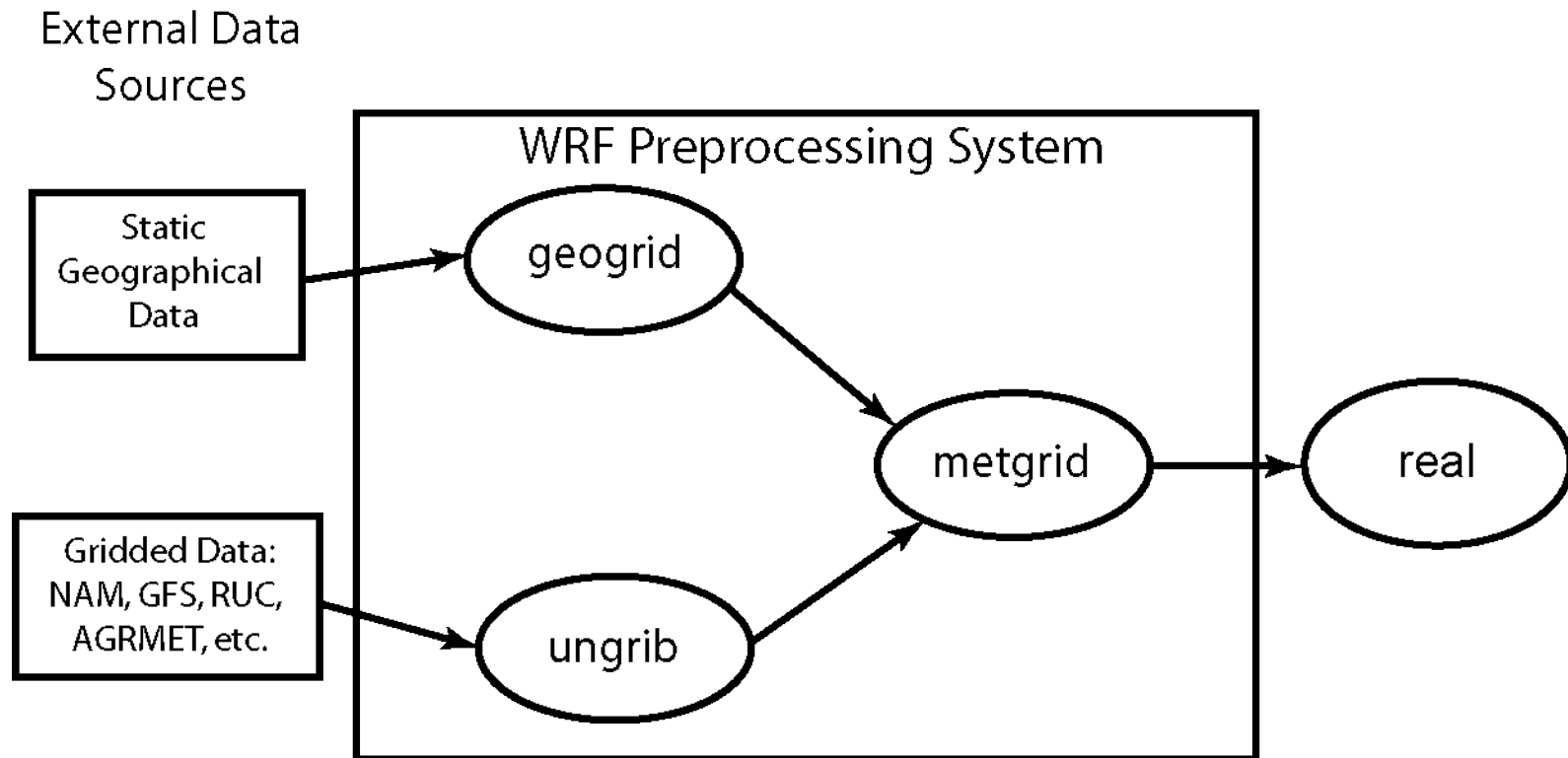
# WPS Summary

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# And finally...

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



# Questions?

