The WRF Preprocessing System: Description of General Functions

Michael Duda

WRF and WRF-Chem Workshop and Tutorial
7 – 10 December 2015, Nansha, Guangzhou, China

*NCAR is sponsored by the National Science Foundation

Purpose of this Lecture

In this lecture, our goals are to:

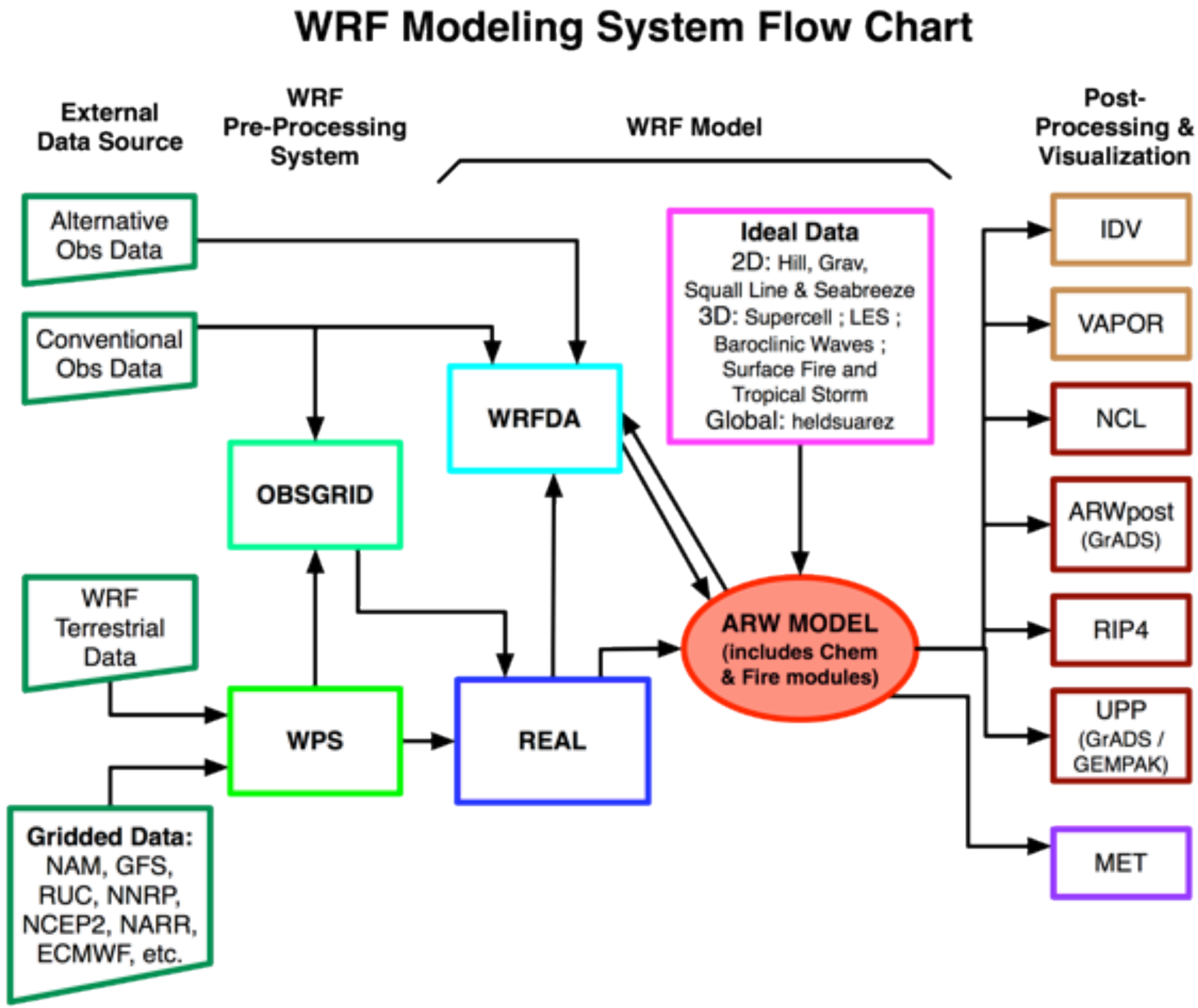
1) Understand the purpose of the WPS

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 Wednesday

WRF Modeling System Flowchart

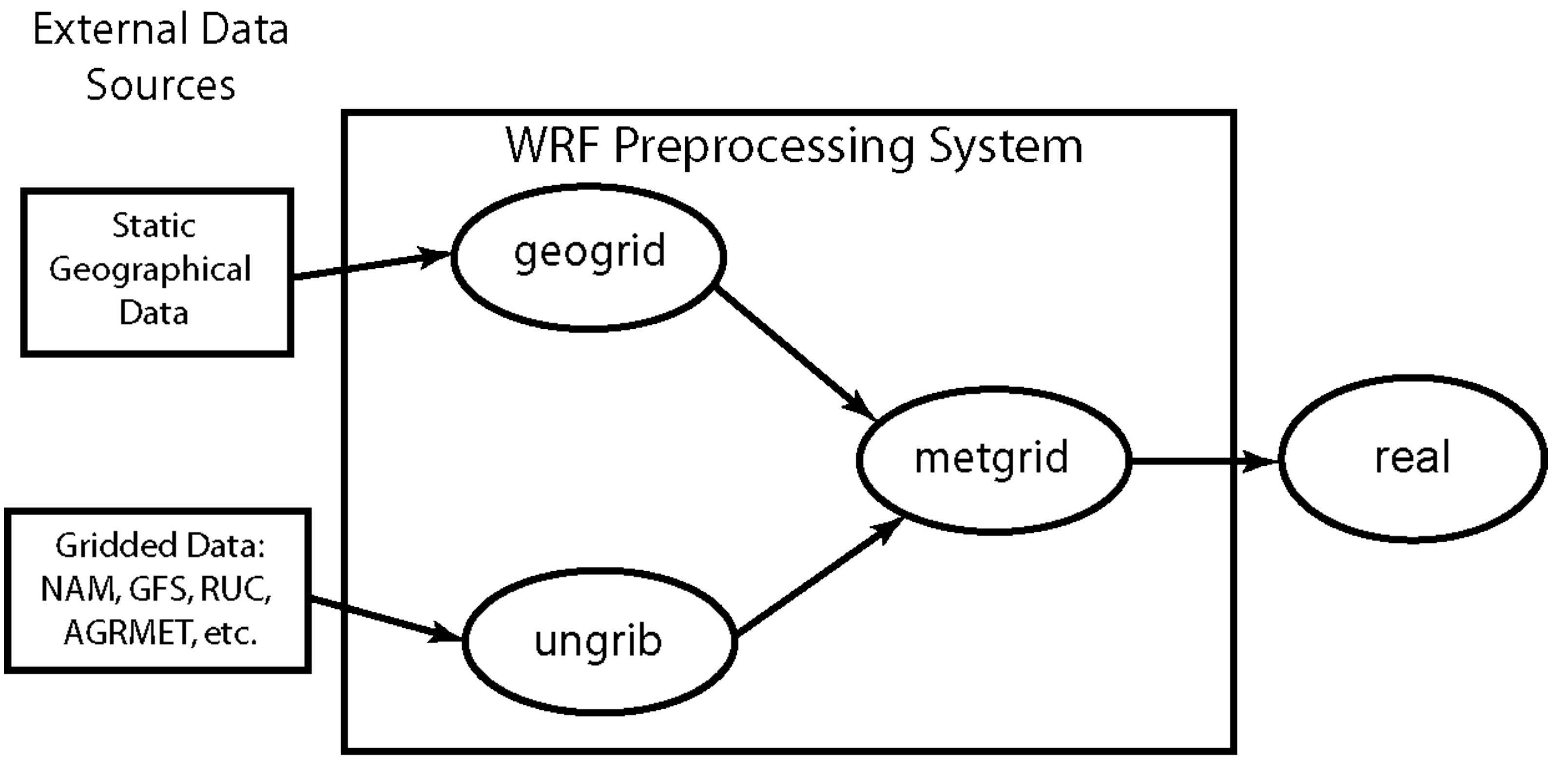


Purpose of the WPS

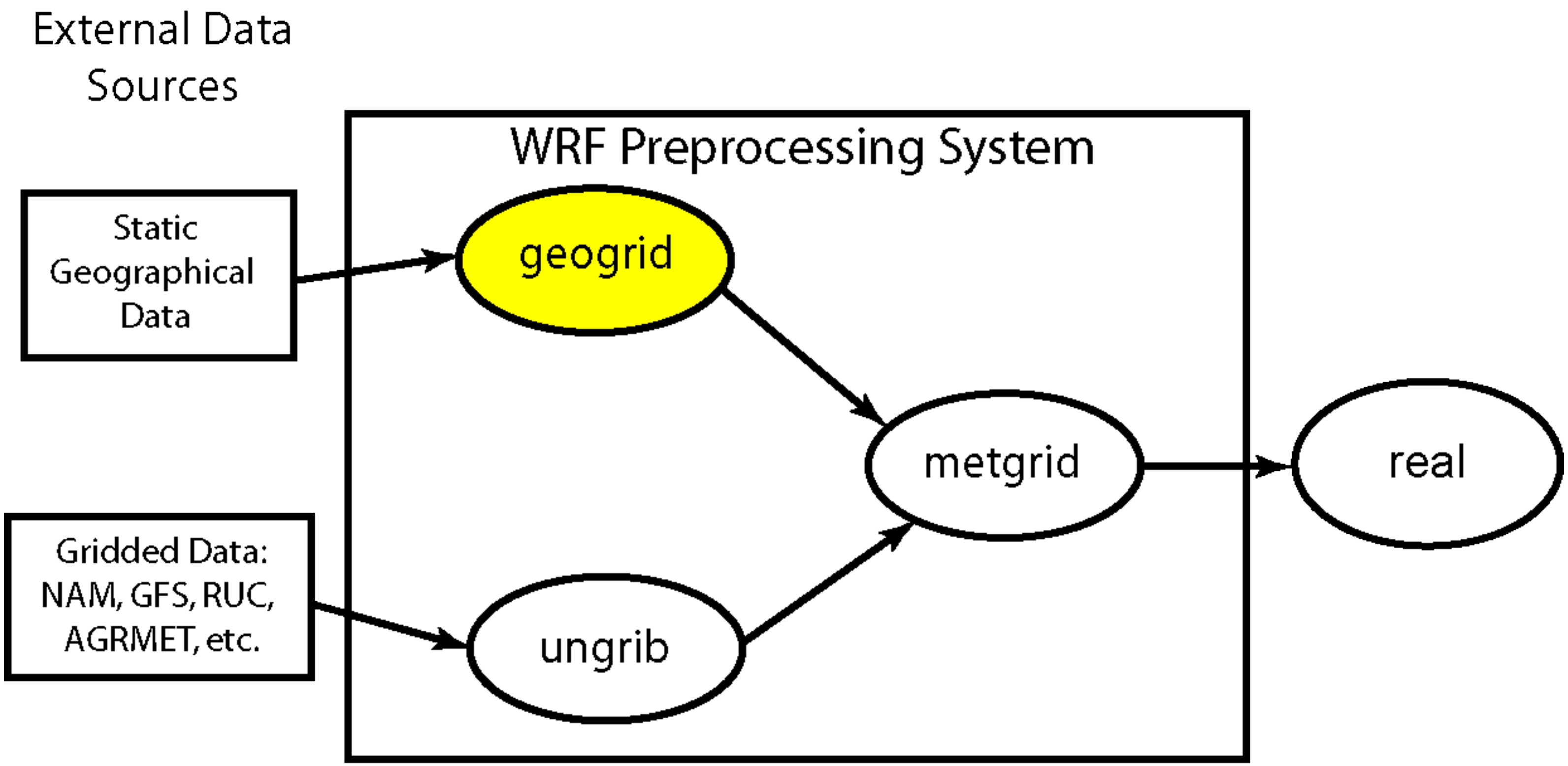
The purpose of the WPS is to prepare input to WRF for real-data simulations:

1. Defines simulation 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 <u>geo</u>graphical

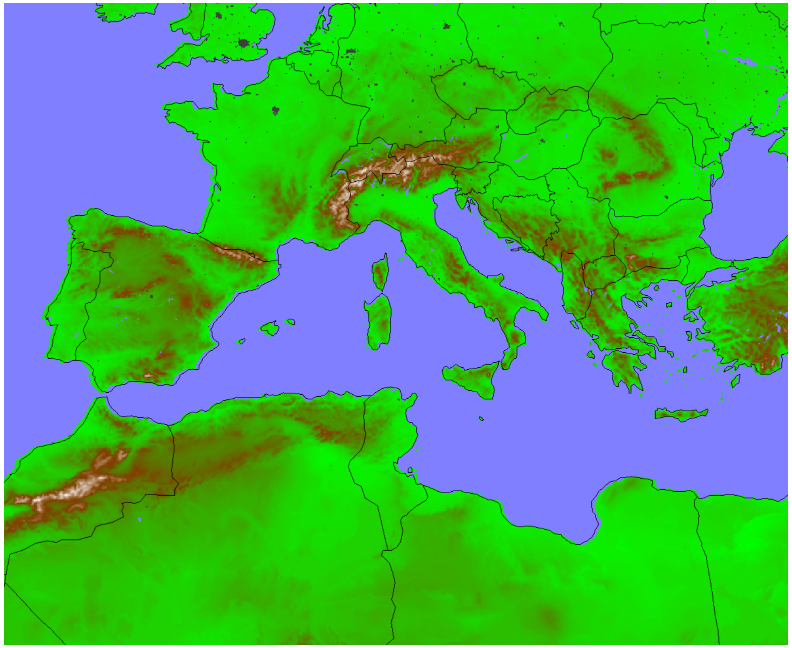
The *geogrid* program

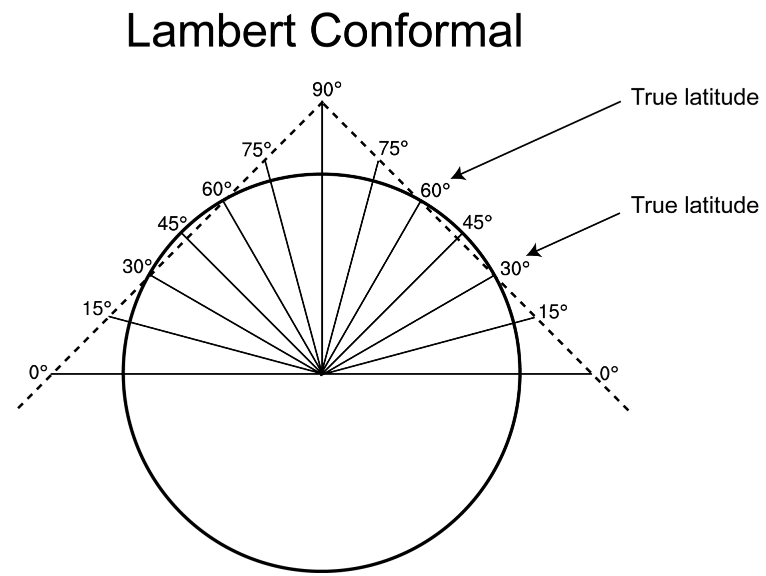
- For WRF model domains, geogrid defines:
  - Map projection (all domains must use the same projection)
  - Geographic location of domains
  - Dimensions of domains
- Geogrid provides values for static (time-invariant) fields at each model grid point
  - Compute latitude, longitude, map scale factor,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

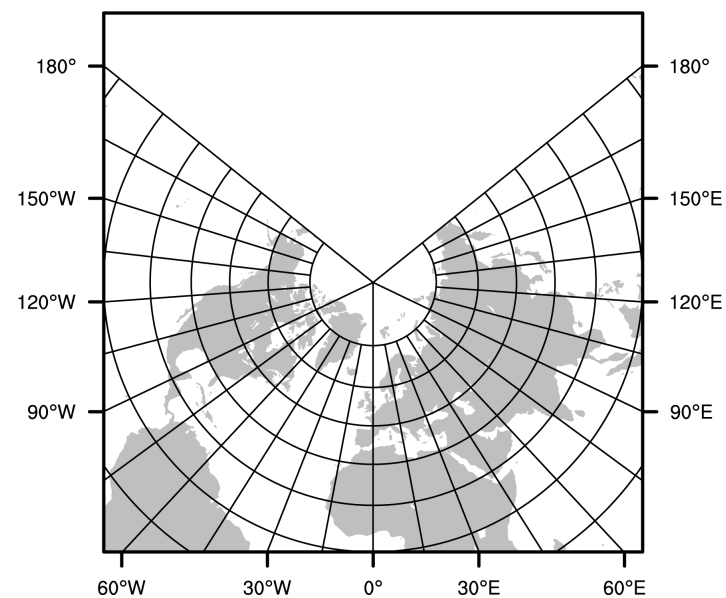
- First, we choose a map projection to use for the domains; why?
  - The real earth is (roughly) an ellipsoid
  - But WRF computational domains are defined by rectangles in the plane
- ARW can use any of the following projections:
  1. Lambert conformal
  2. Mercator
  3. Polar stereographic
  4. Latitude-longitude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

ARW Projections: Lambert Conformal

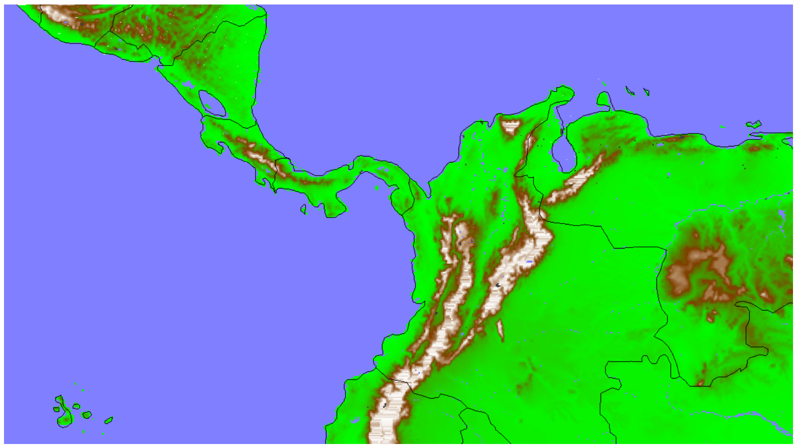


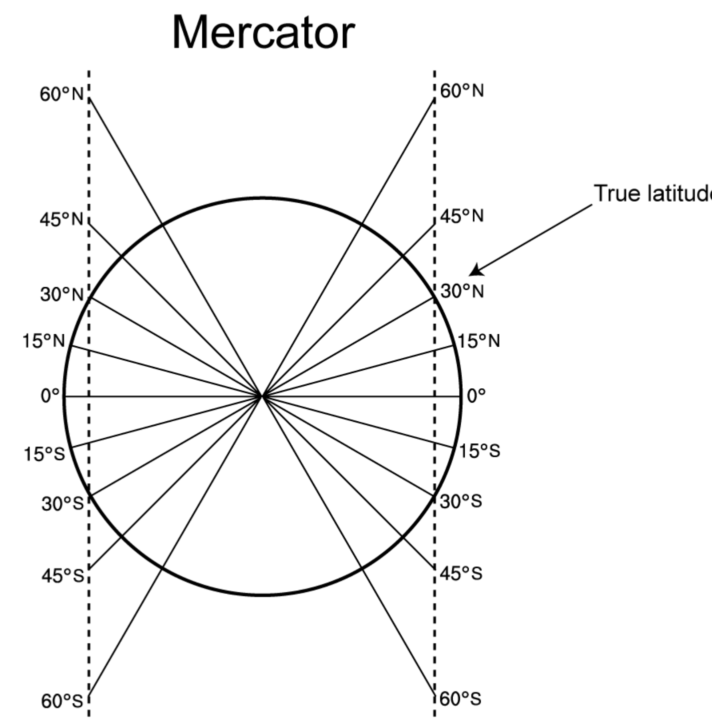


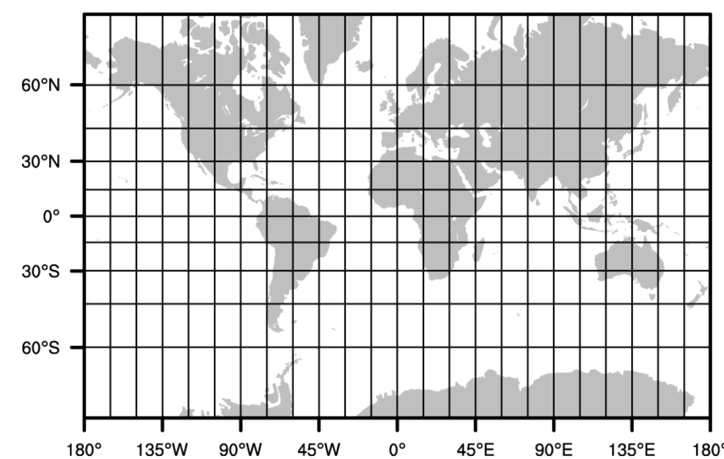
- Well-suited for mid-latitudes
- Domain cannot contain either pole
- Domain cannot be periodic in west-east direction
- Either one or two *true latitudes* may be specified
  - If two are given, the order doesn't matter



ARW Projections: Mercator

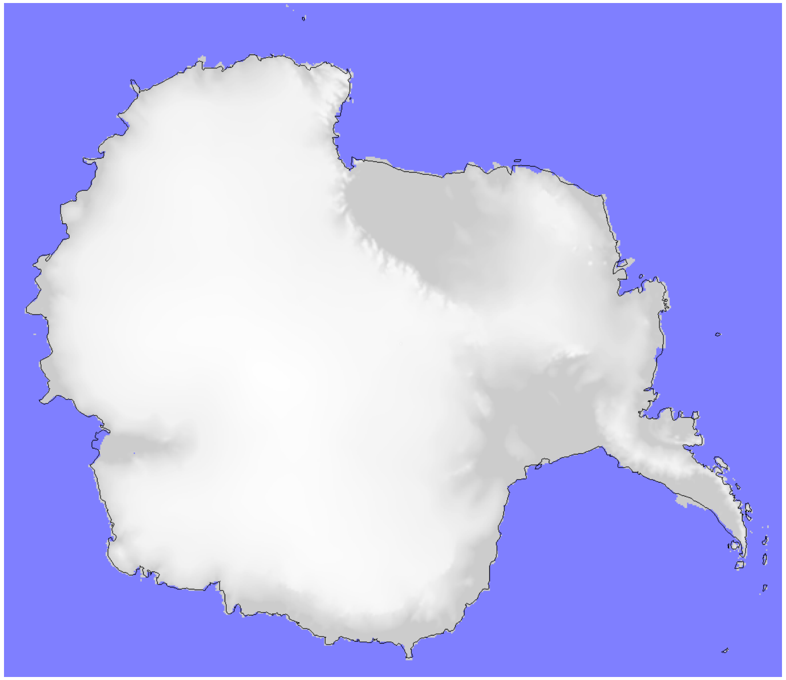


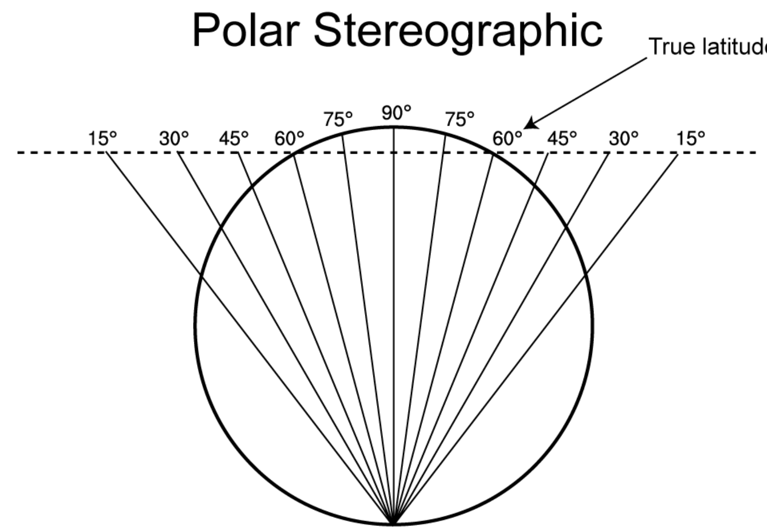


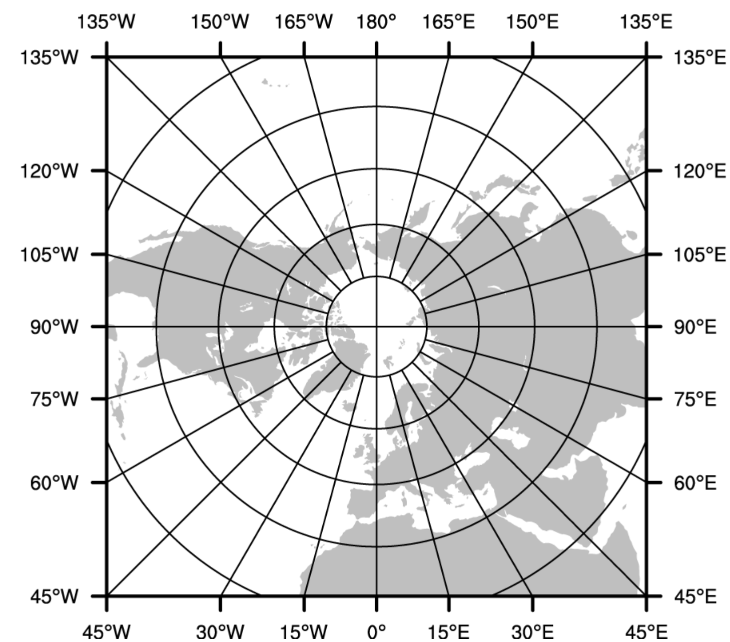


- Well-suited for low-latitudes
- May be used for “channel” domain (periodic domain in west-east direction)
- A single true latitude is specified
  - Cylinder intersects the earth’s surface at +/- truelat

ARW Projections: Polar Stereographic

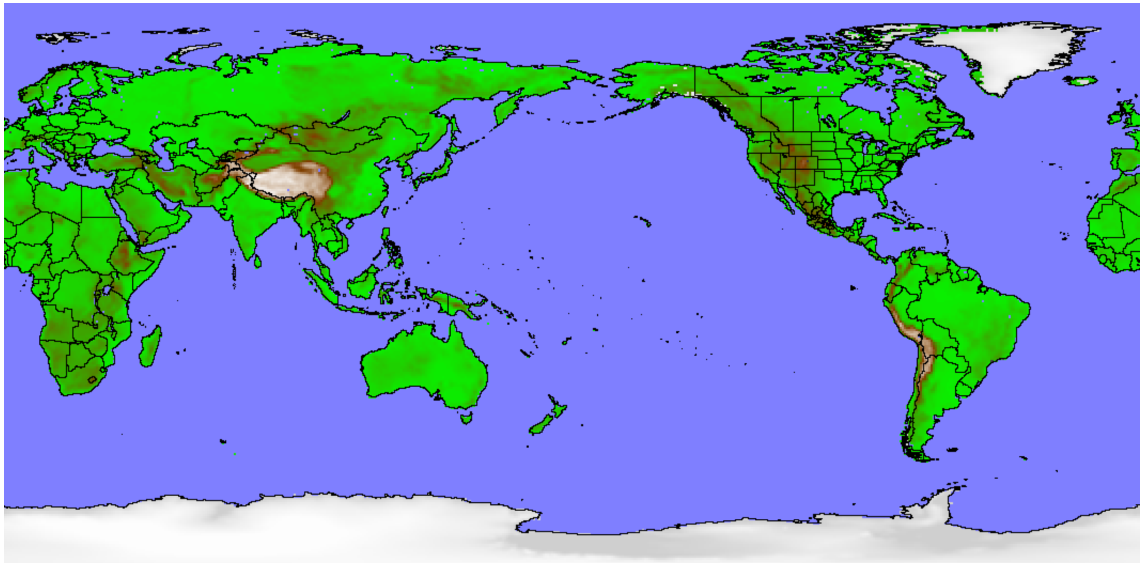


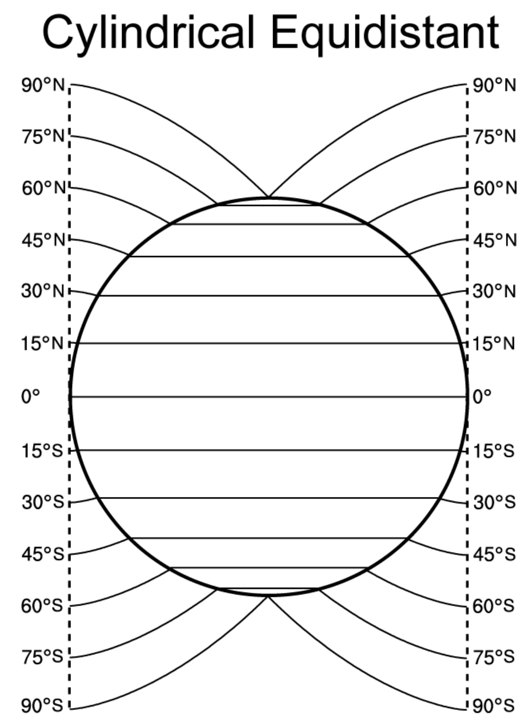


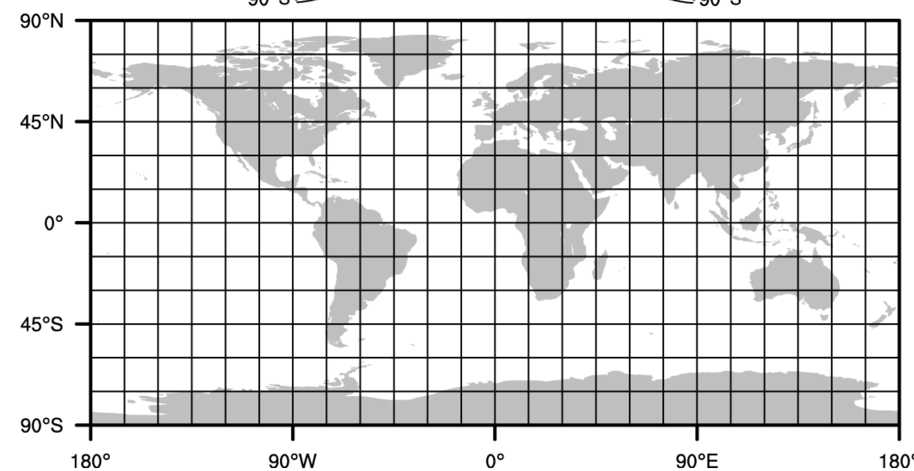


- Good for high-latitude domains, especially if domain must contain a pole
- A single true latitude is specified

ARW Projections: Cylindrical Equidistant







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

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

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

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

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

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

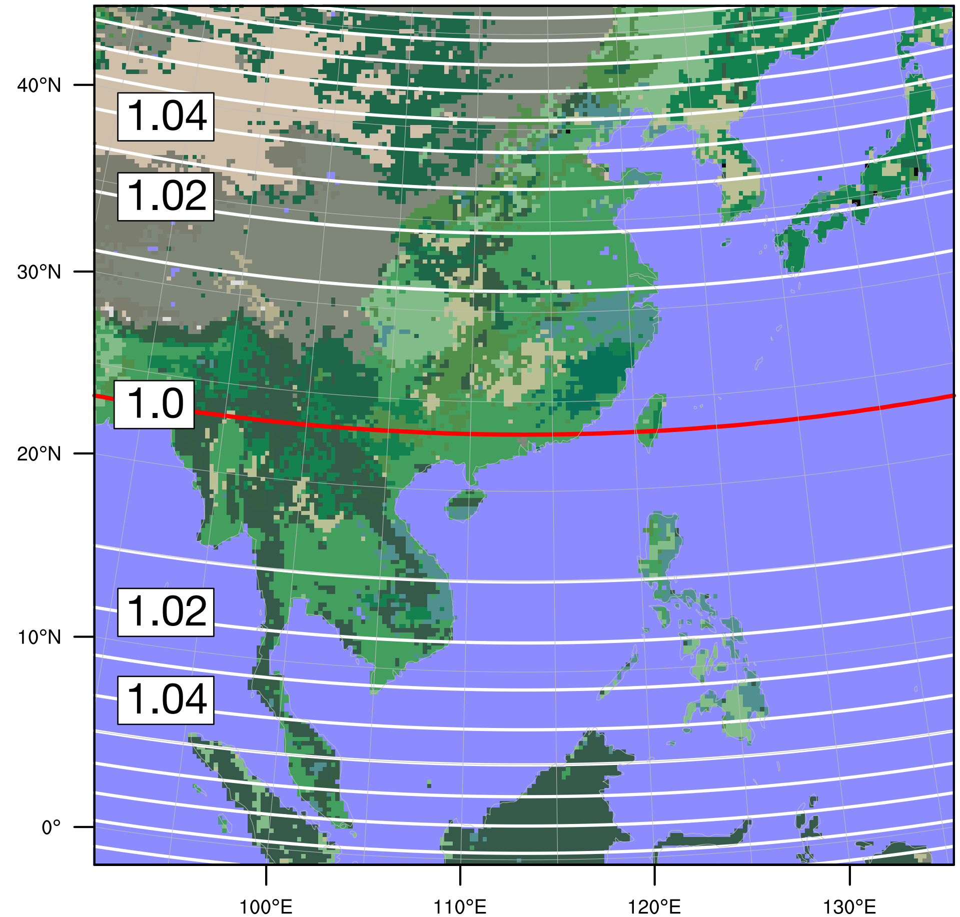
- Can easily check min/max map scale factor using, e.g., ncview!

Why do map projections matter?

Example:

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

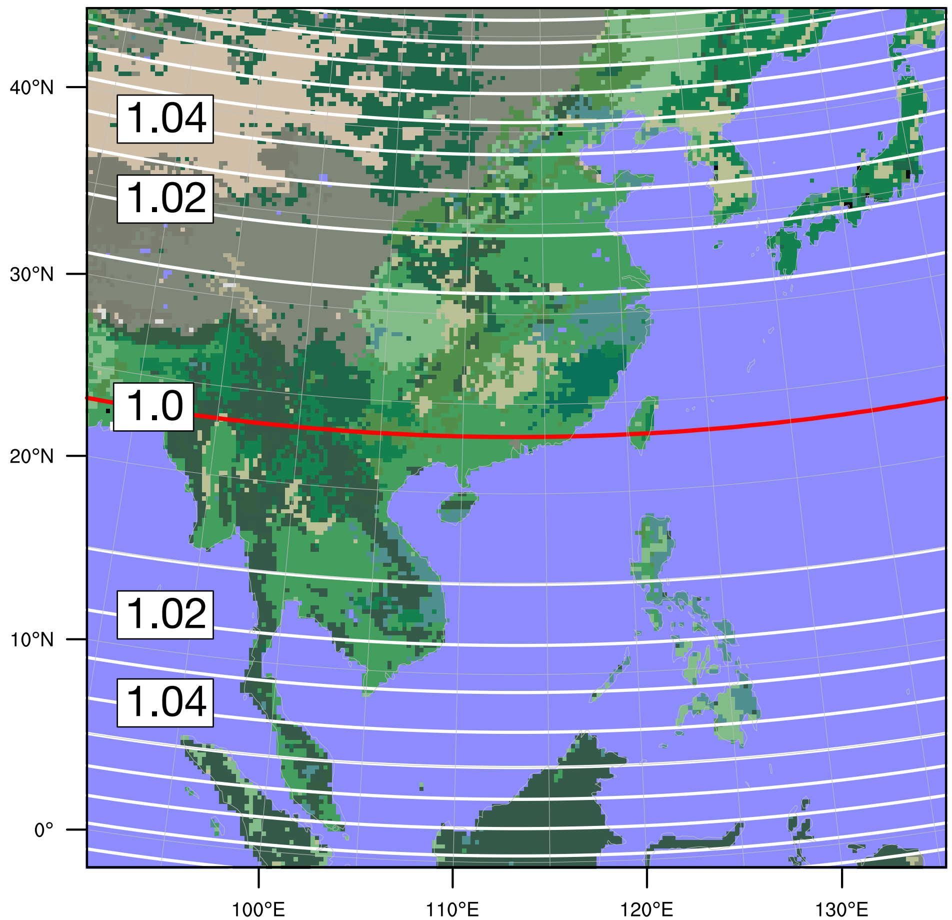
Choosing both true latitudes in the center of the WRF domain leads to maximum map scale factors of 1.0975, corresponding to a *minimum physical grid distance of 27/1.0975 = 24.6 km.*



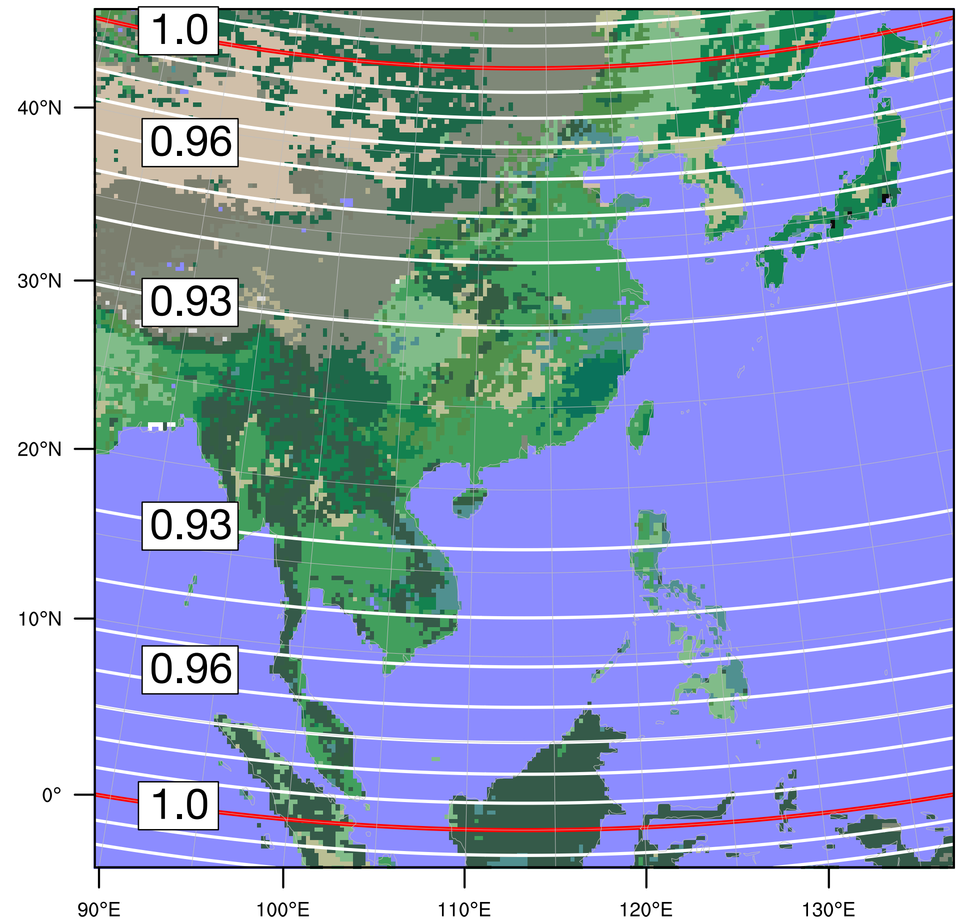
Above: Contours of map scale factor (white; interval 0.01) with true latitudes (red).

Why do map projections matter?

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



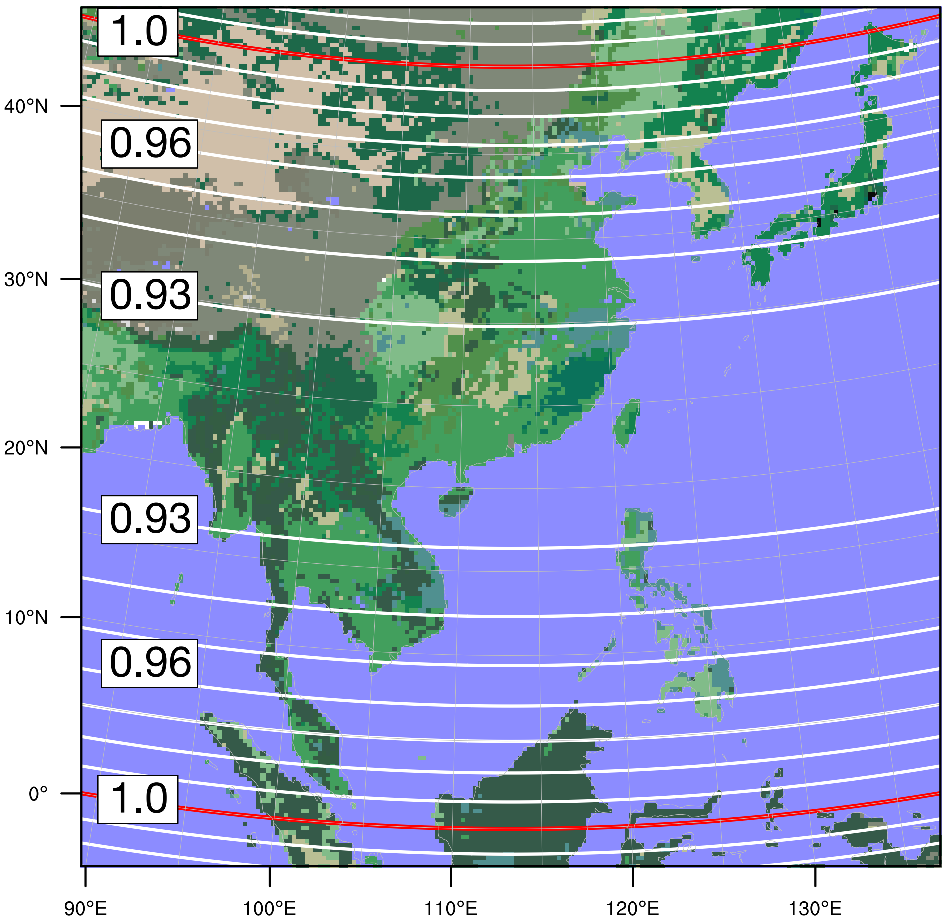
Above: Reference projection as on previous slide; maximum grid distance is 27 km (at true latitude).



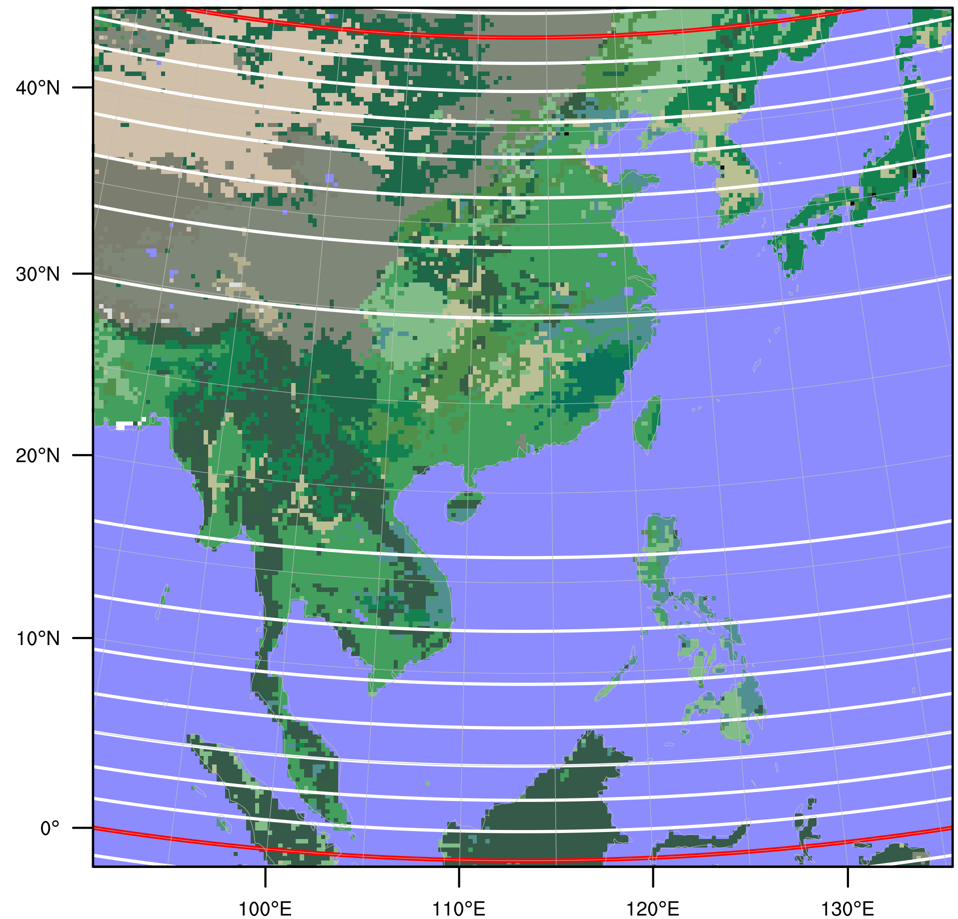
Above: The maximum map scale factor is 1.03, but the minimum is 0.924, corresponding to a physical distance of 29.2 km.

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.



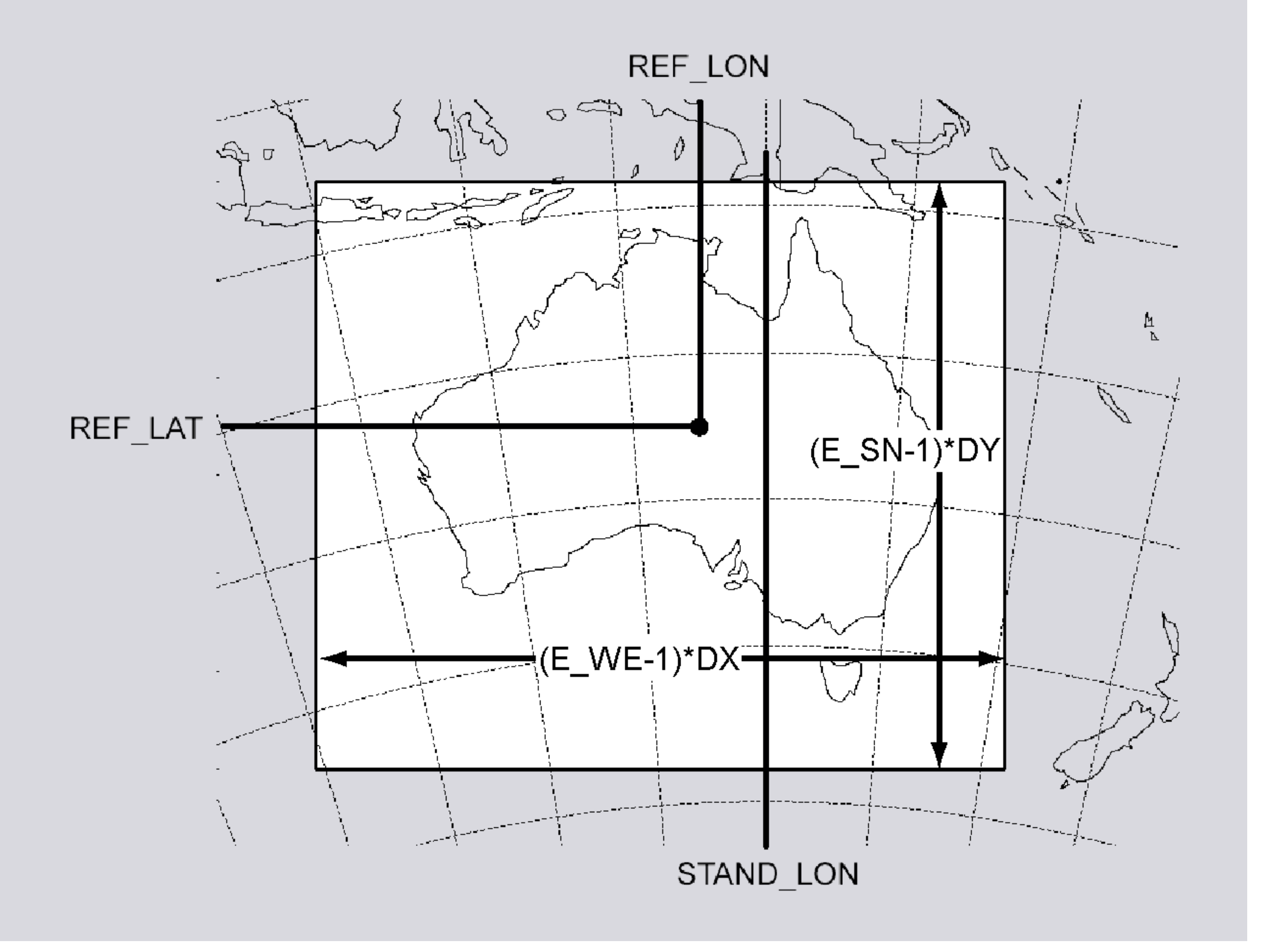
Above: Reducing the nominal grid distance to 25 km, the map scale factors of 0.924 in the center of the map correspond to a physical distance of 27.06 km.

Geogrid: Defining Model Domains

- 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

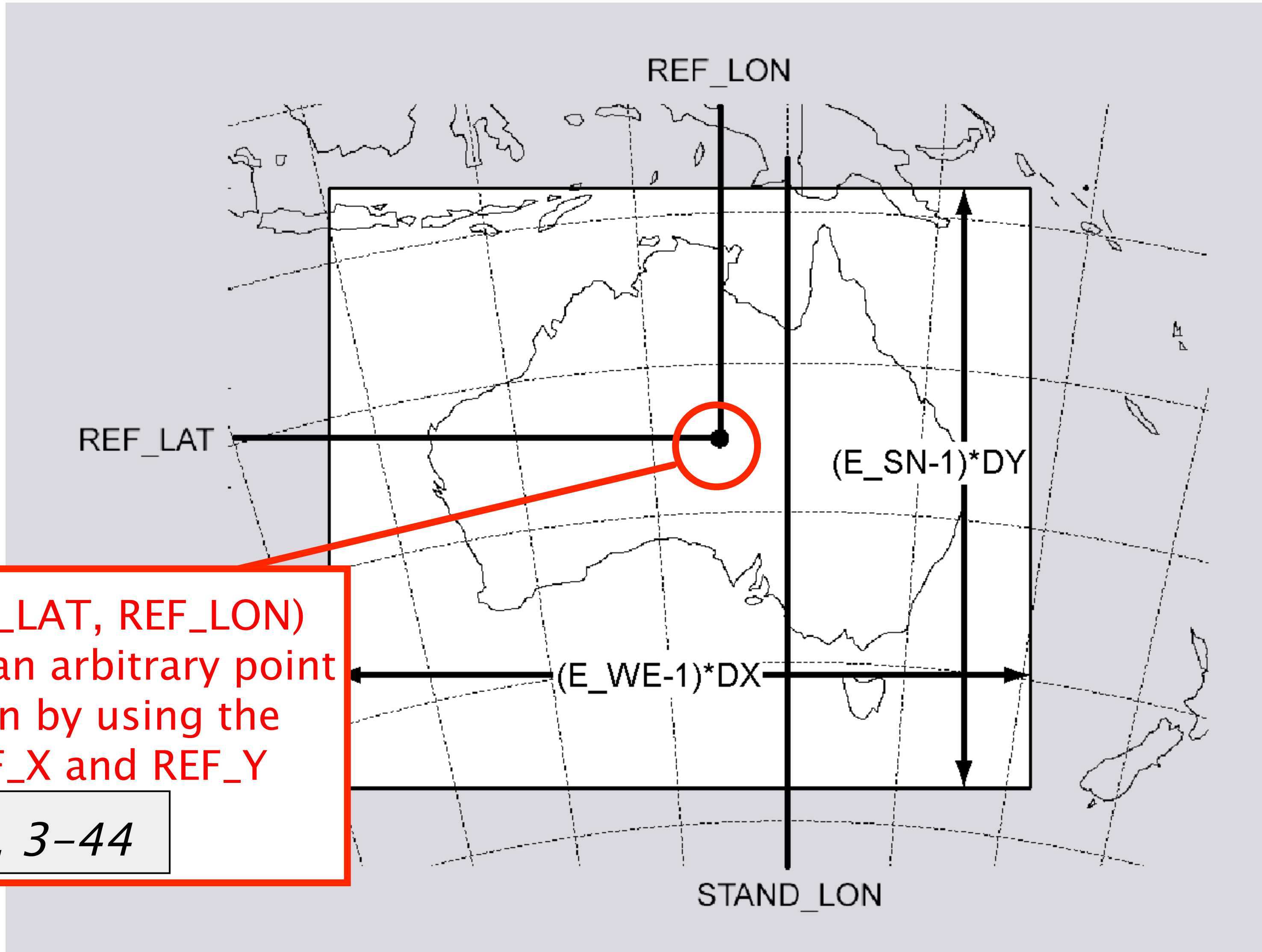


Geogrid: Defining Model Domains

- 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

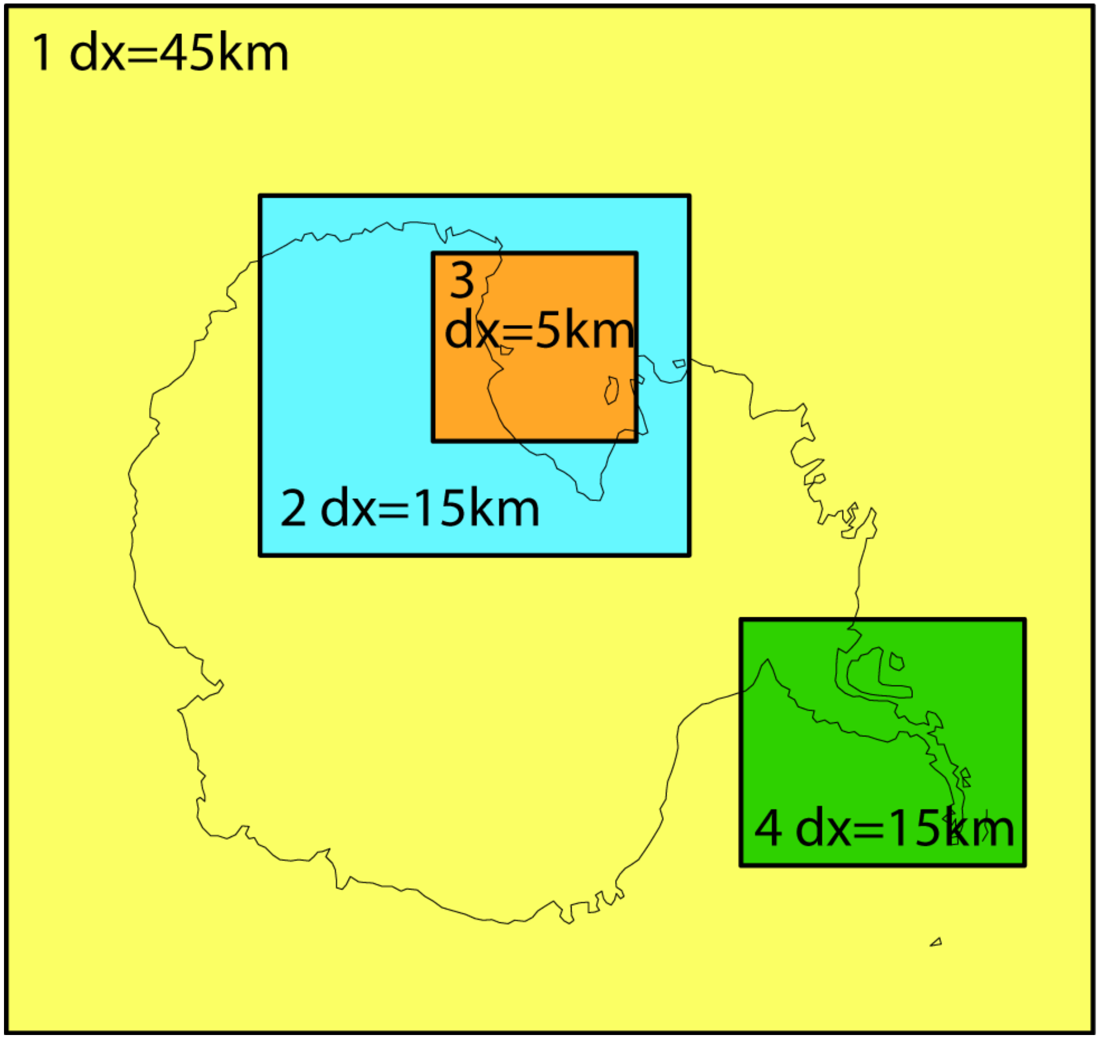
See p. 3-44

Geogrid: Nesting Basics

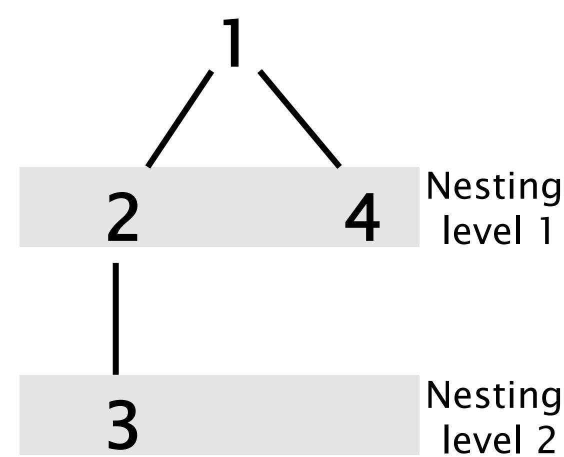
- A *nested domain* is a domain that is wholly contained within its *parent domain* and that receives information from its parent, and that may also feed information back to its parent
  - A nested domain has exactly one *parent*
  - A domain may have one or more *children*
- 2-*way nests* on the same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

Geogrid: Nesting Example

Example configuration – 4 domains



Each domain is assigned a *domain ID #*



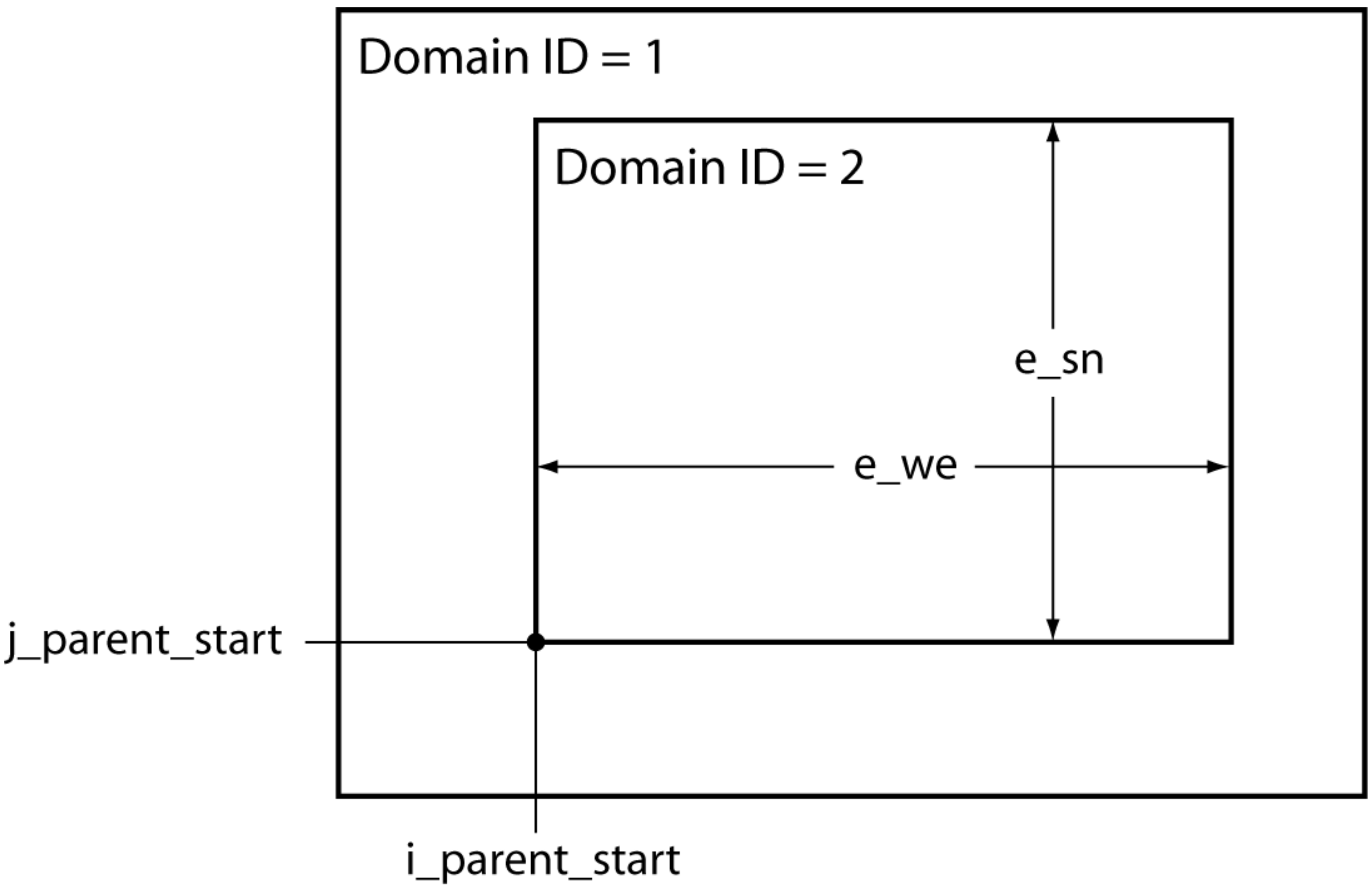
Nesting structure shown as a tree for the domains at left

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

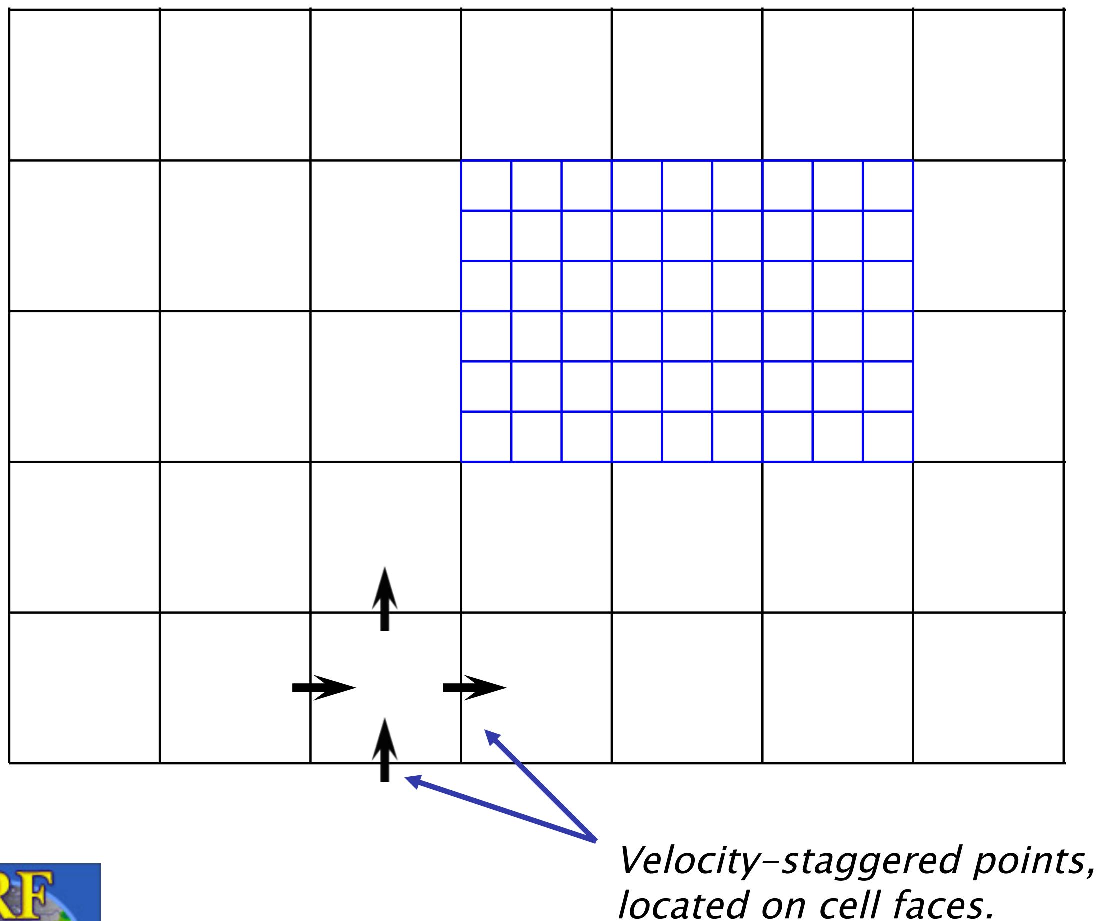
Geogrid: Defining Nested Domains



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

Geogrid: 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

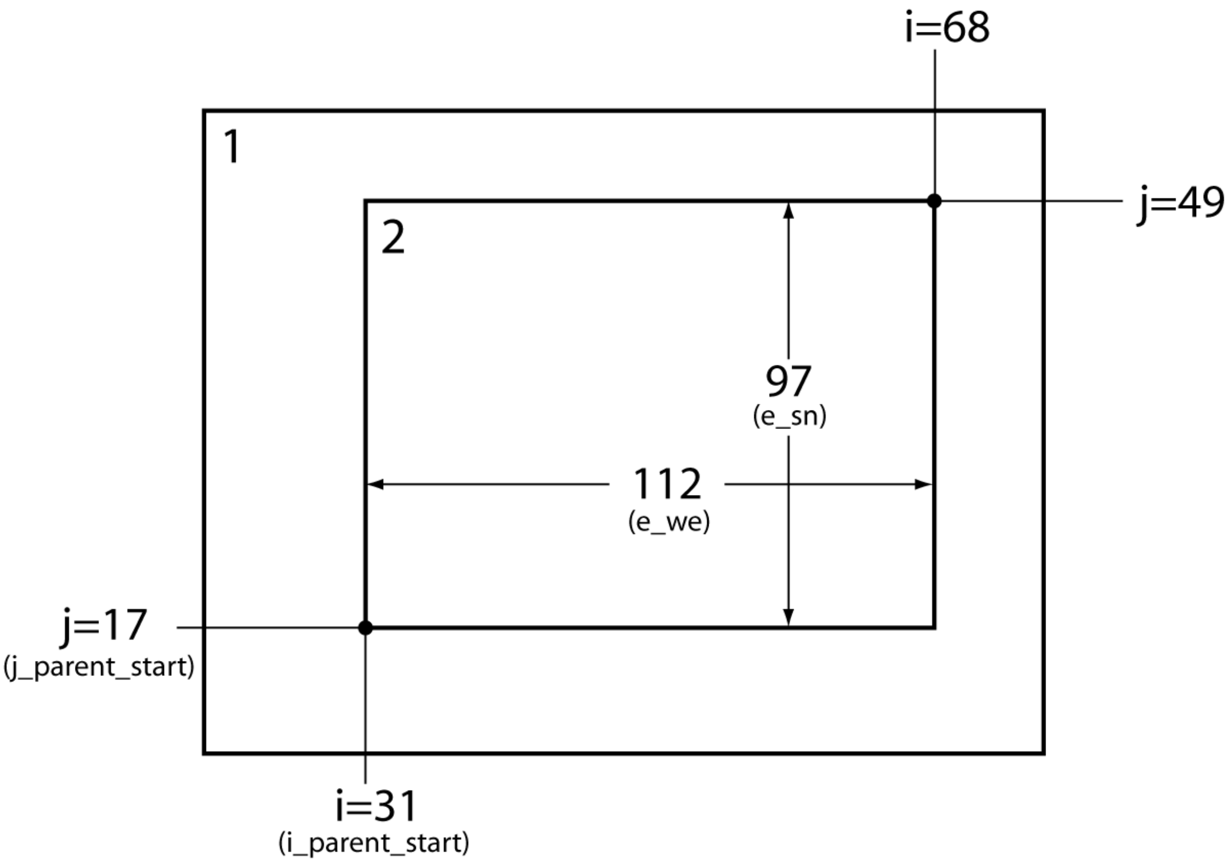
$$\frac{e\_we - 1}{parent\_grid\_ratio} = n_i$$

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

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

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

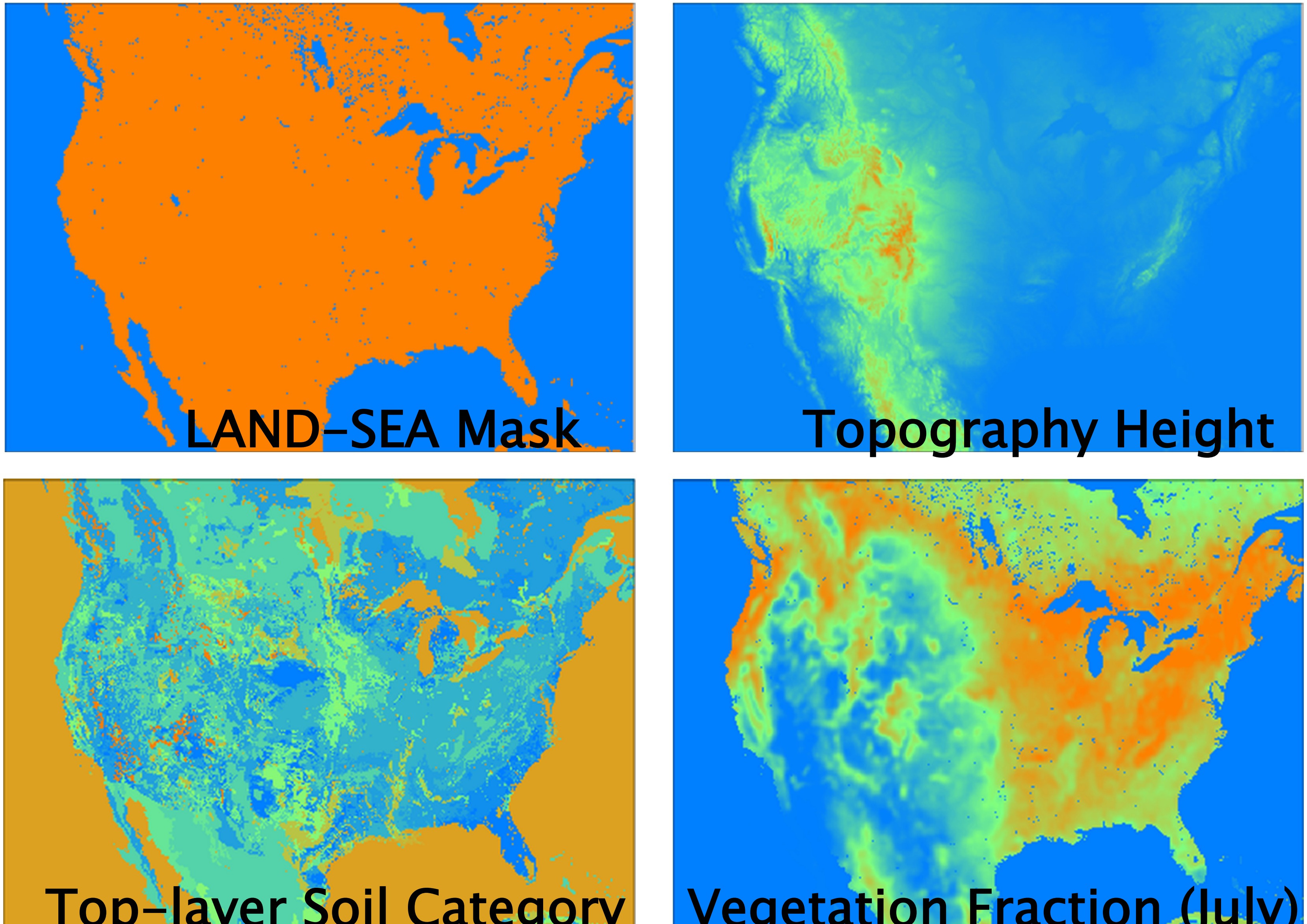
  (where *n* is the domain ID number)
- Example:

  geo_em.d01.nc

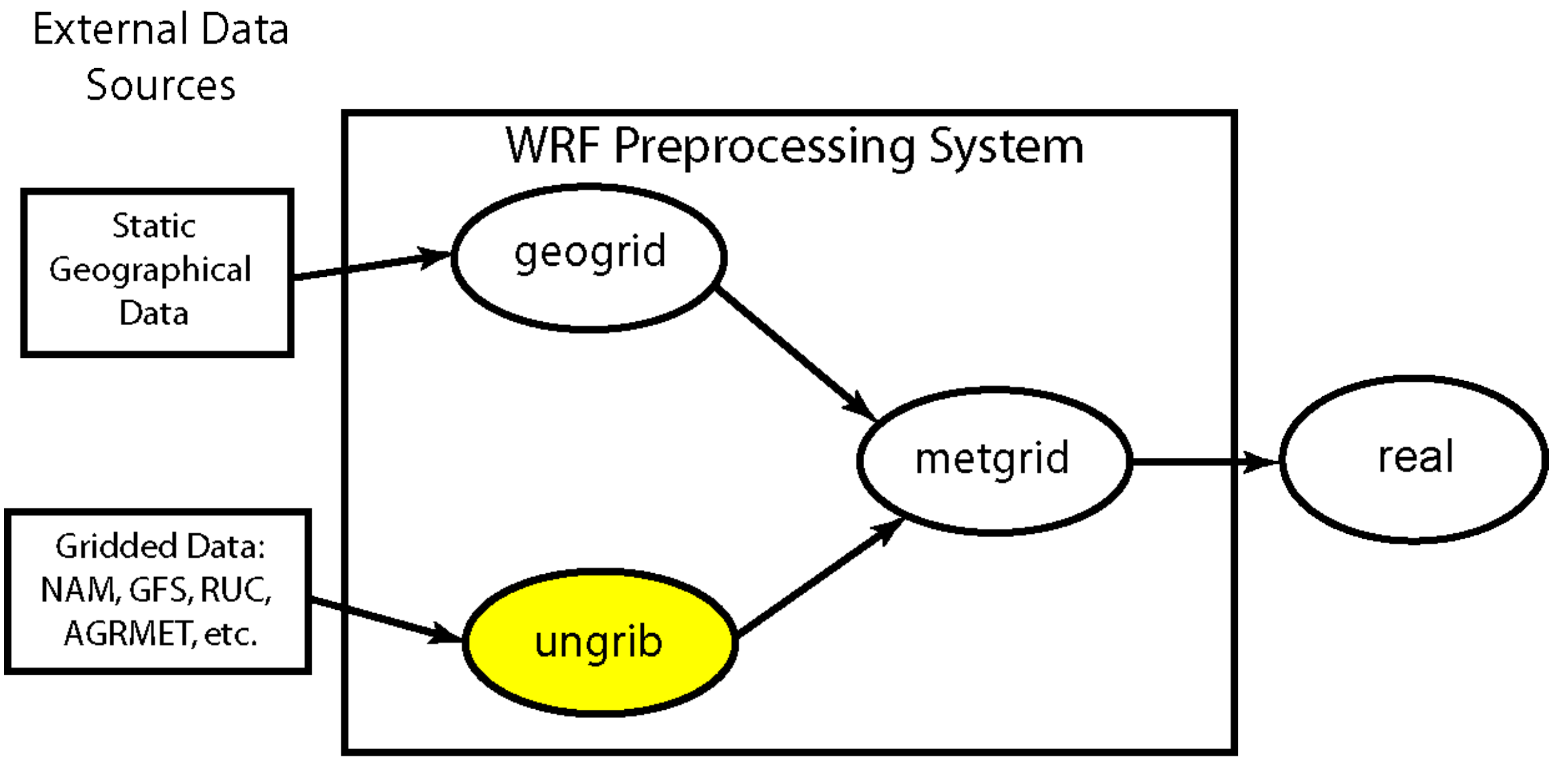
  geo_em.d02.nc (nest)

  geo_em.d03.nc (nest)

Geogrid: Example Output Fields



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 Description	GRIB2 Discp	GRIB2 Catgy	GRIB2 Param	GRIB2 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:

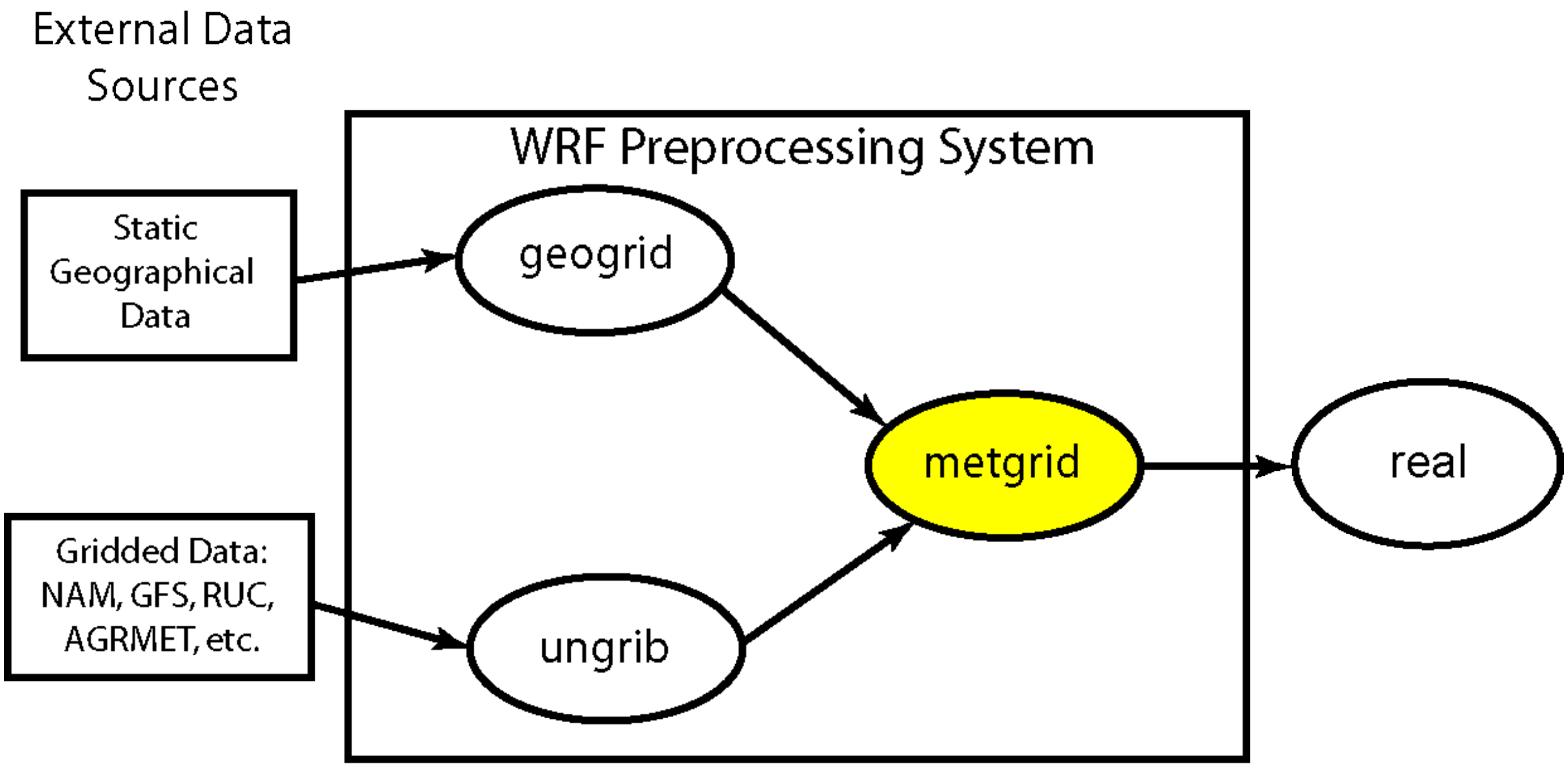
  FILE:2007-07-24_00

  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



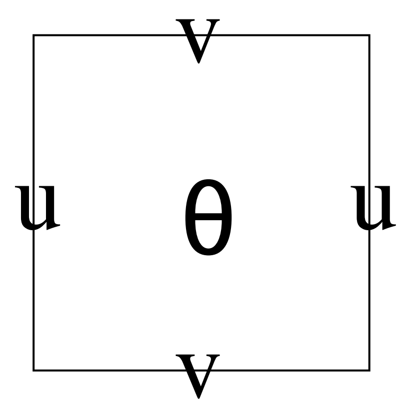
metgrid: think <u>met</u>eorological

The *metgrid* program

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

Metgrid: ARW Grid Staggering

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

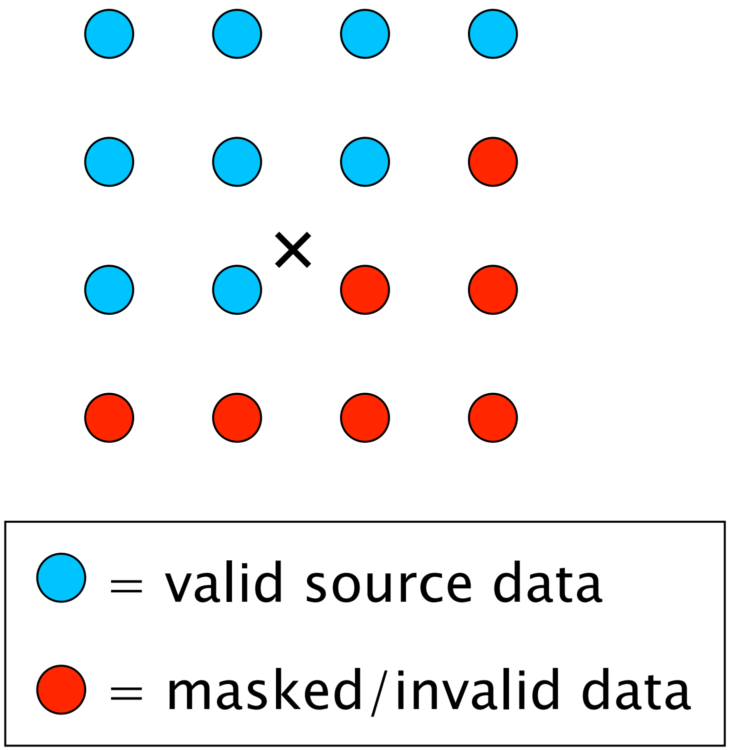


A single ARW grid cell, with “u”, “v”, and “θ” points labeled.

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



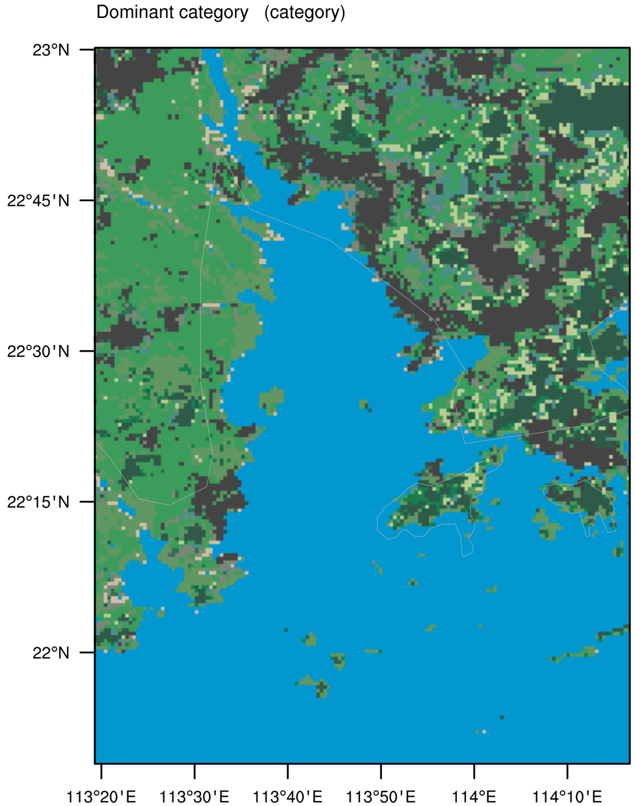
Suppose we need to interpolate to point X

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

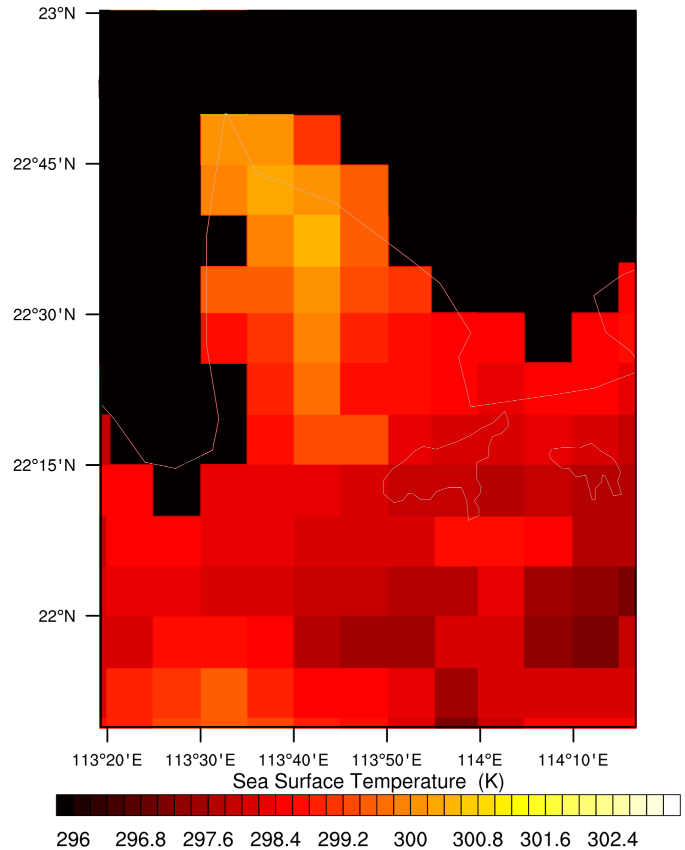
Not every interpolation option can handle masked points; we'll address this issue in the advanced WPS lecture

Metgrid: Masked Interpolation

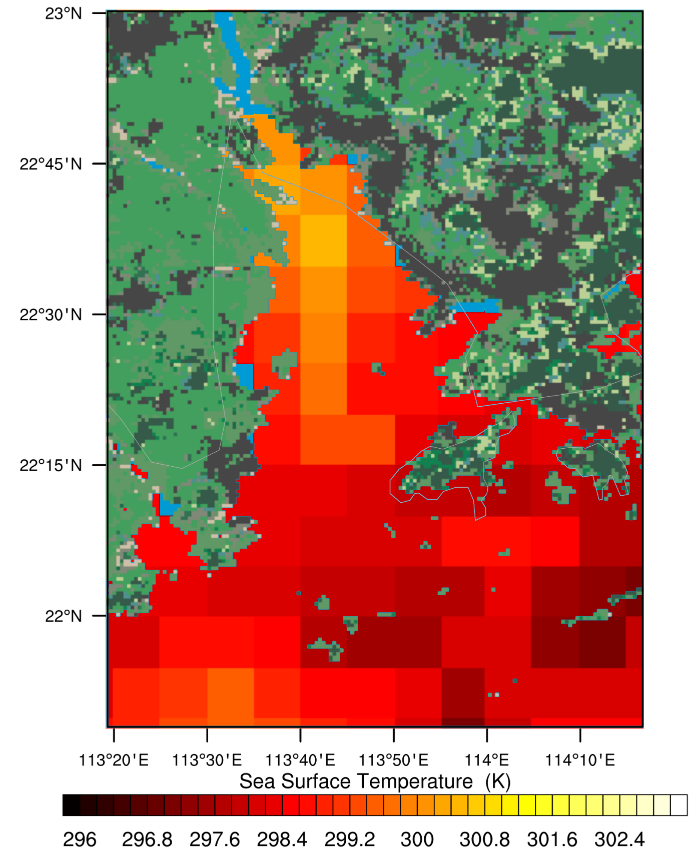
Common fields that require masked interpolation include SST, soil moisture, and soil temperature.



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



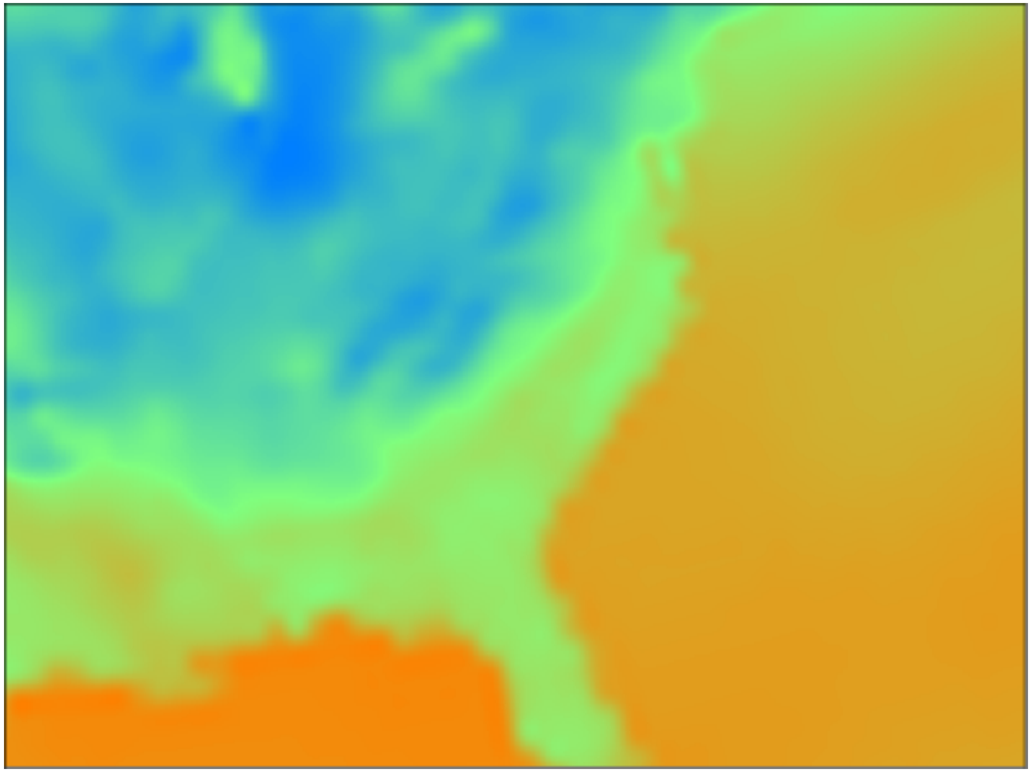
SST data on a 0.083-degree grid, with missing data (black) over land.



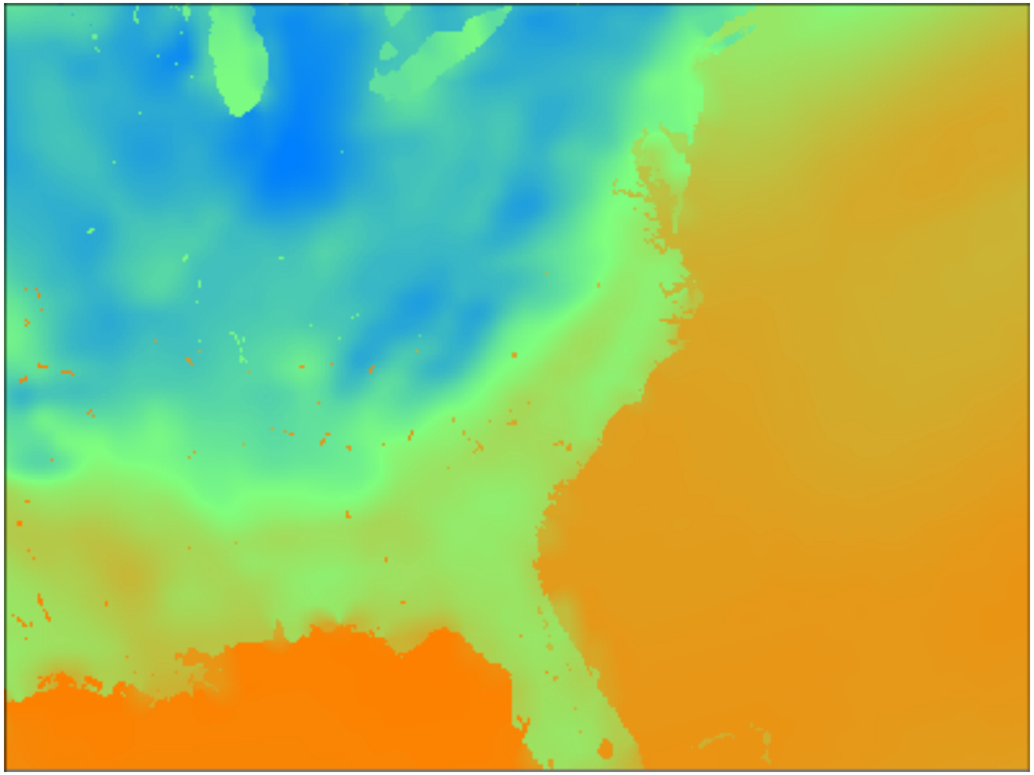
SST data overlaid with land use; blue areas represent WRF water cells that must receive SST values via masked interpolation.

Metgrid: Masked Interpolation

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



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



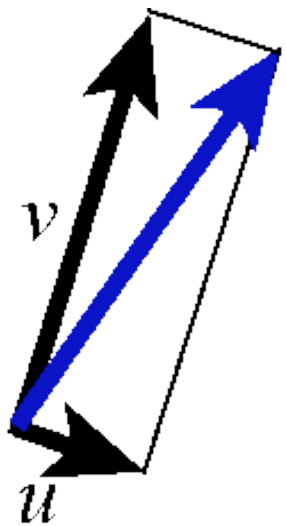
Skin temperature field interpolated using masks: GFS water points interpolated to model water points, GFS land points interpolated to model land points.

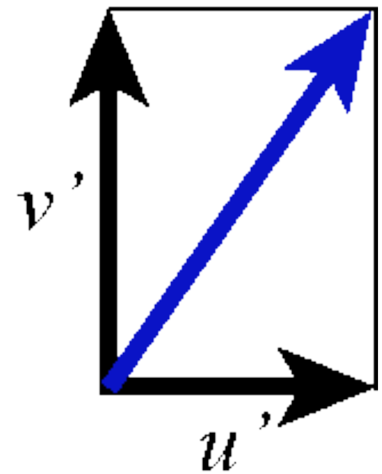
Metgrid: Wind Rotation

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

- WRF expects wind components to be relative to the simulation grid

Metgrid: Wind Rotation Example





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

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

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

Metgrid: Constant Fields

- For short simulations, some fields may be constant
  - E.g., SST or sea-ice fraction

- Use namelist option `CONSTANTS_NAME` option to specify such fields:
  - `CONSTANTS_NAME = 'SST_FILE:2007-07-24_00'`

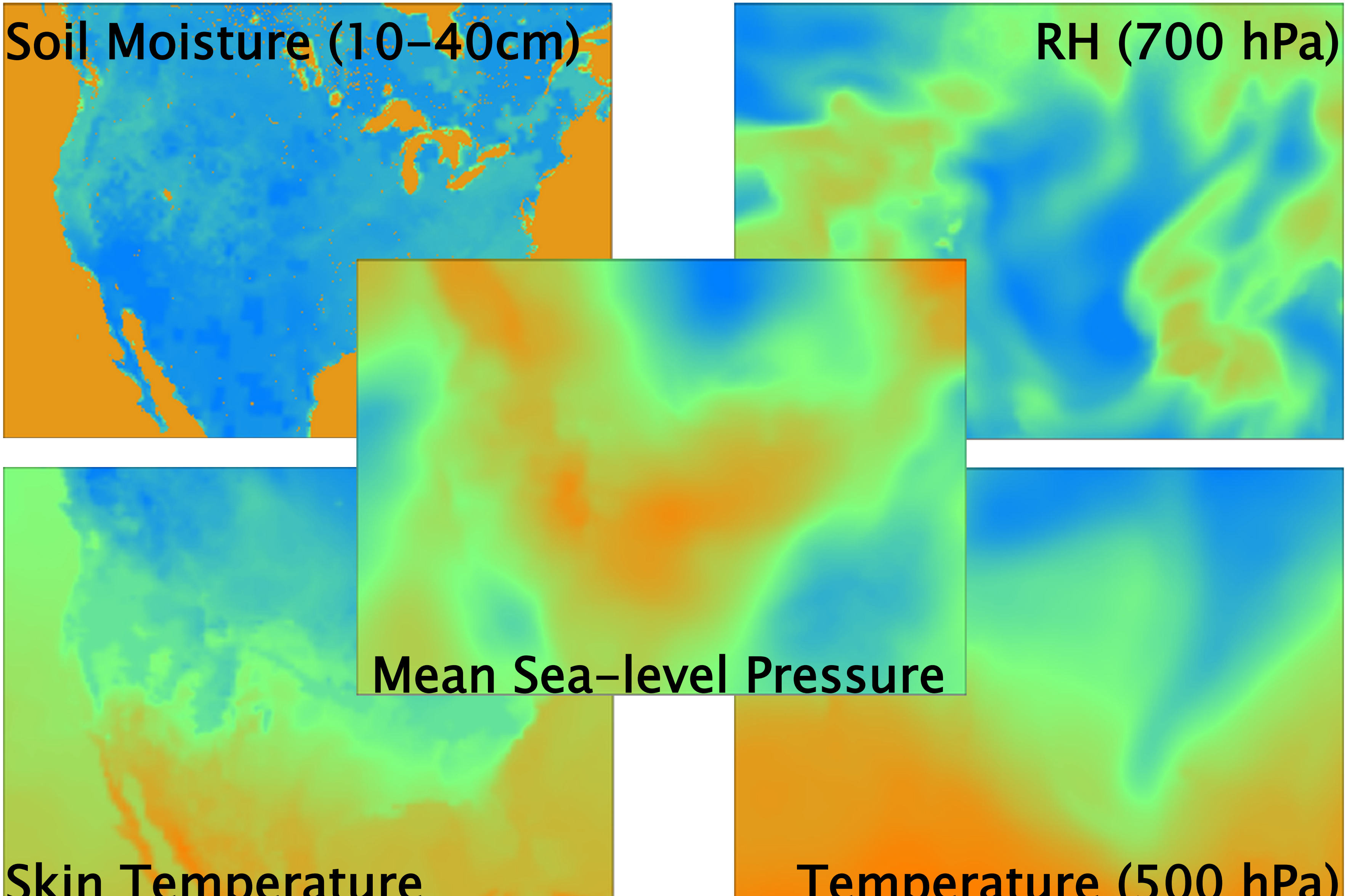
Metgrid: Program Output

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

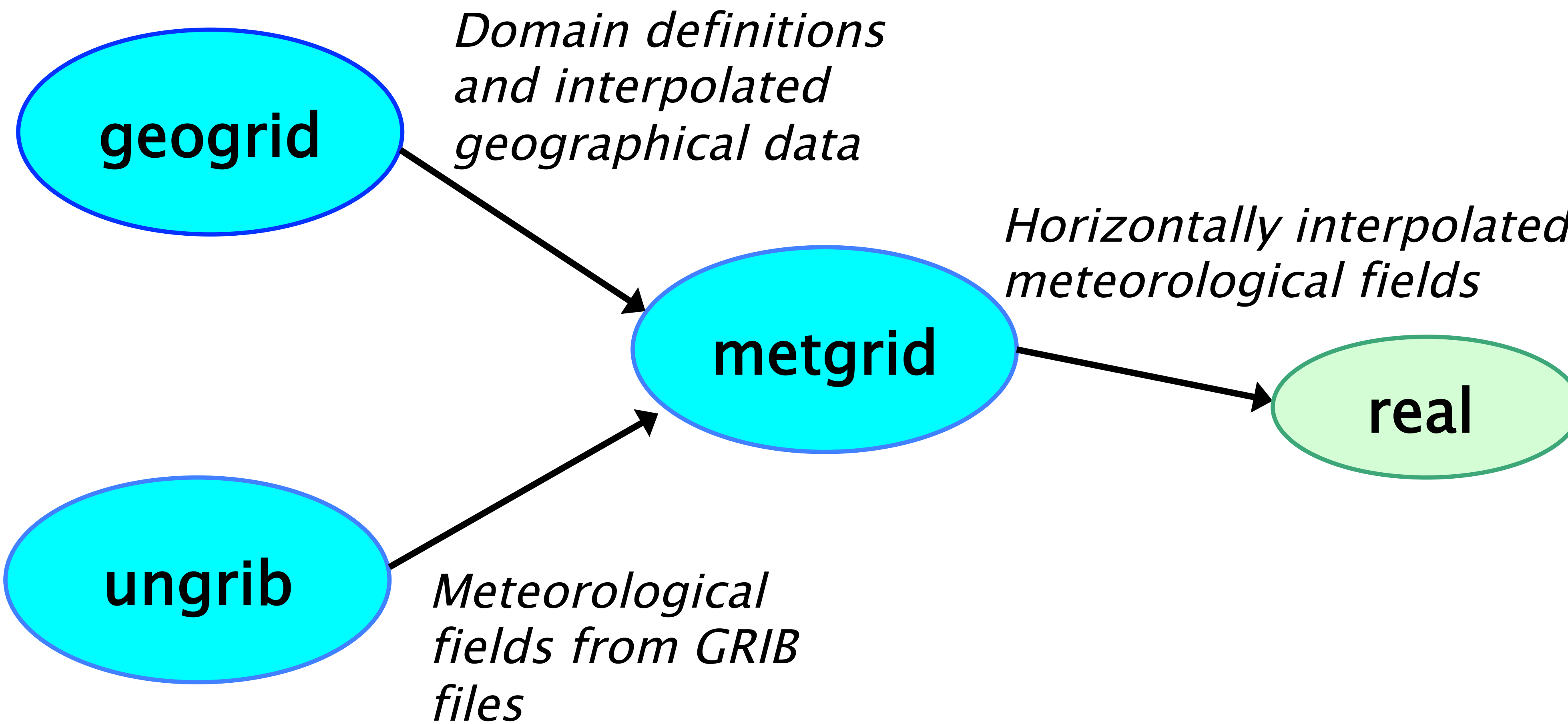
ARW: `met_em.d0`*`n`*`.`*`YYYY-MM-DD_HH:mm:ss`*`.nc`

(where *n* is the domain ID number)

Metgrid: Example Output



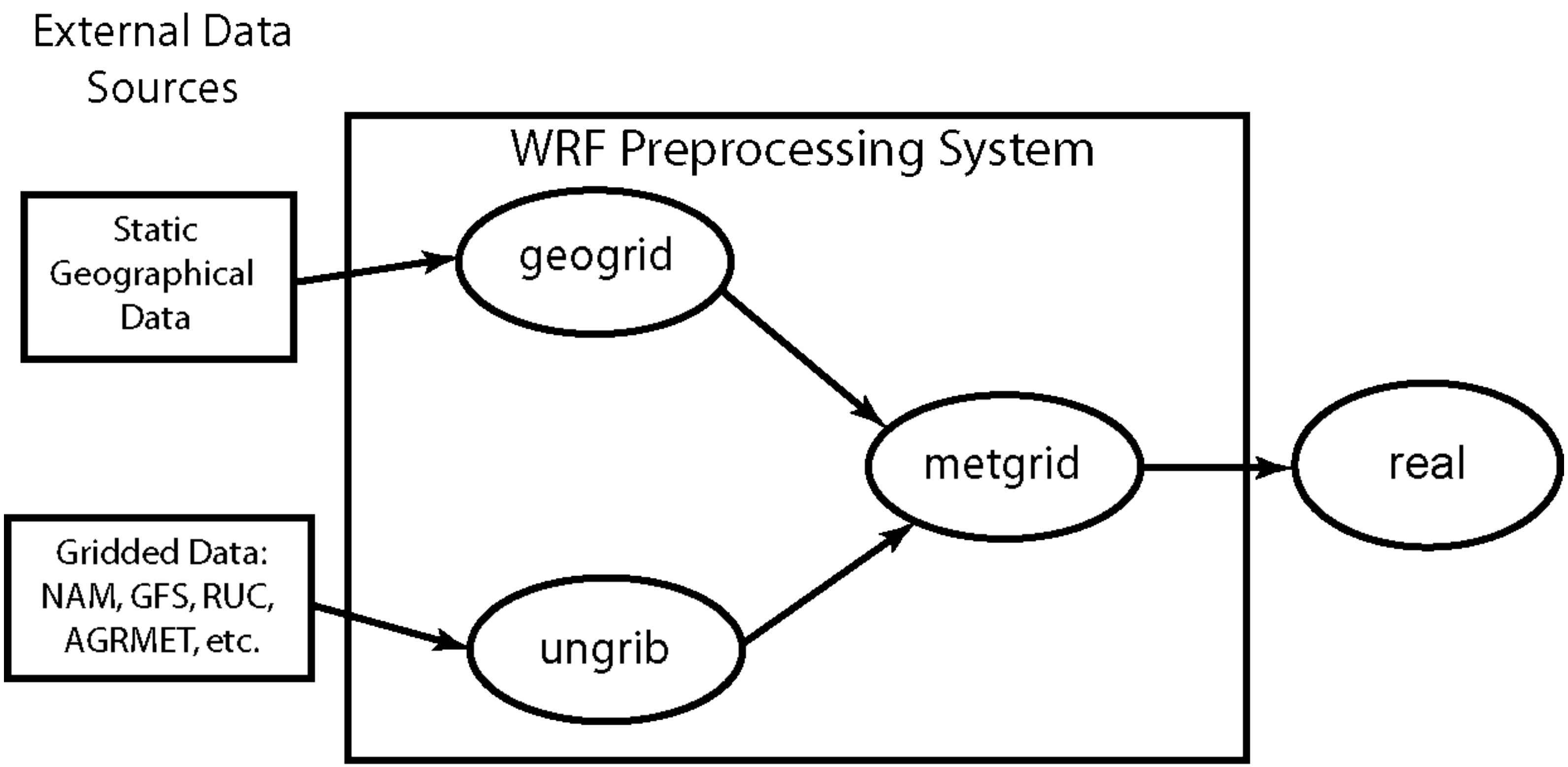
WPS Summary



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

And finally…

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



Questions?