

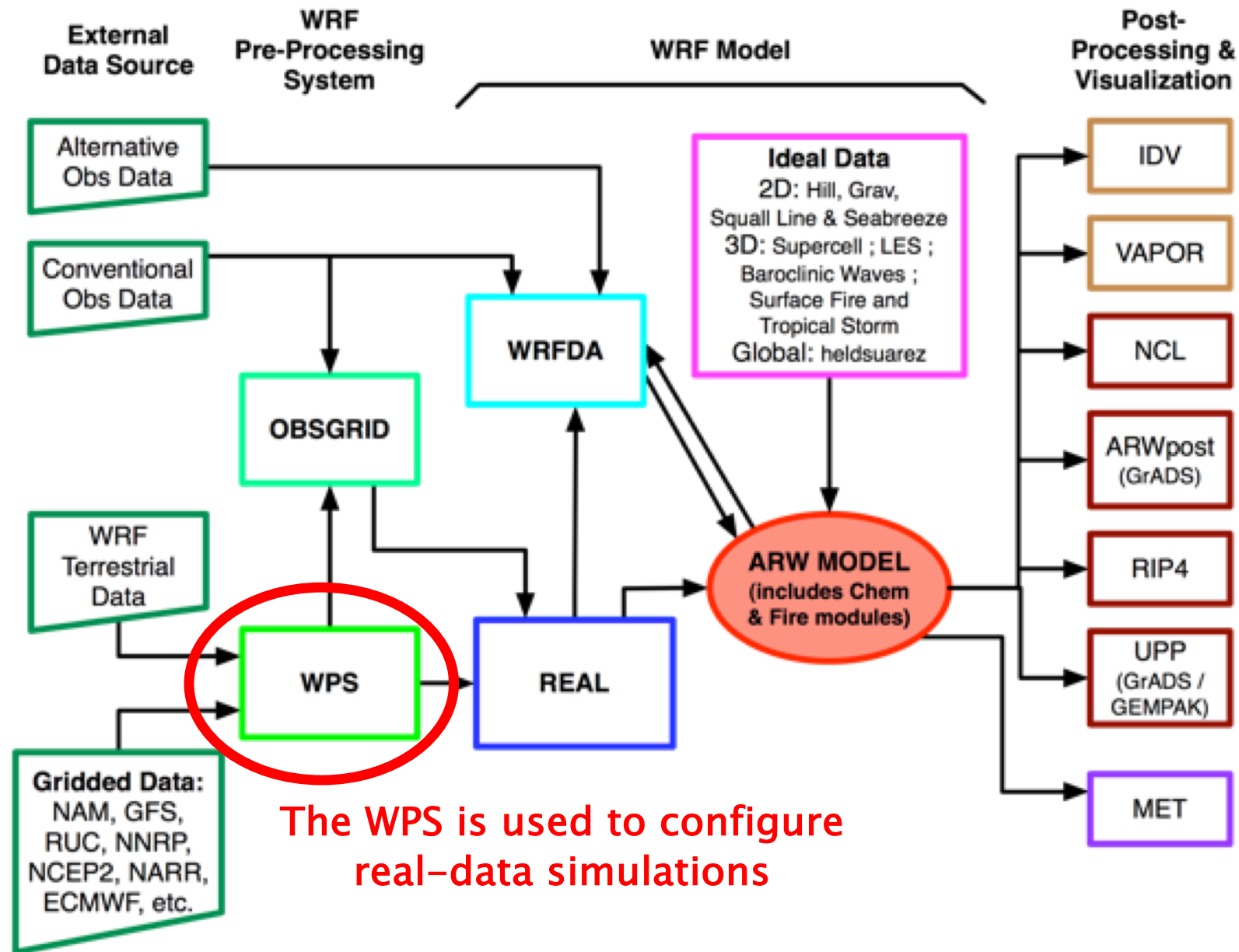
The WRF Pre-Processing System (WPS): Fundamental Capabilities

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*Winter WRF Tutorial
27 – 31 January 2020*



WRF Modeling System Flowchart

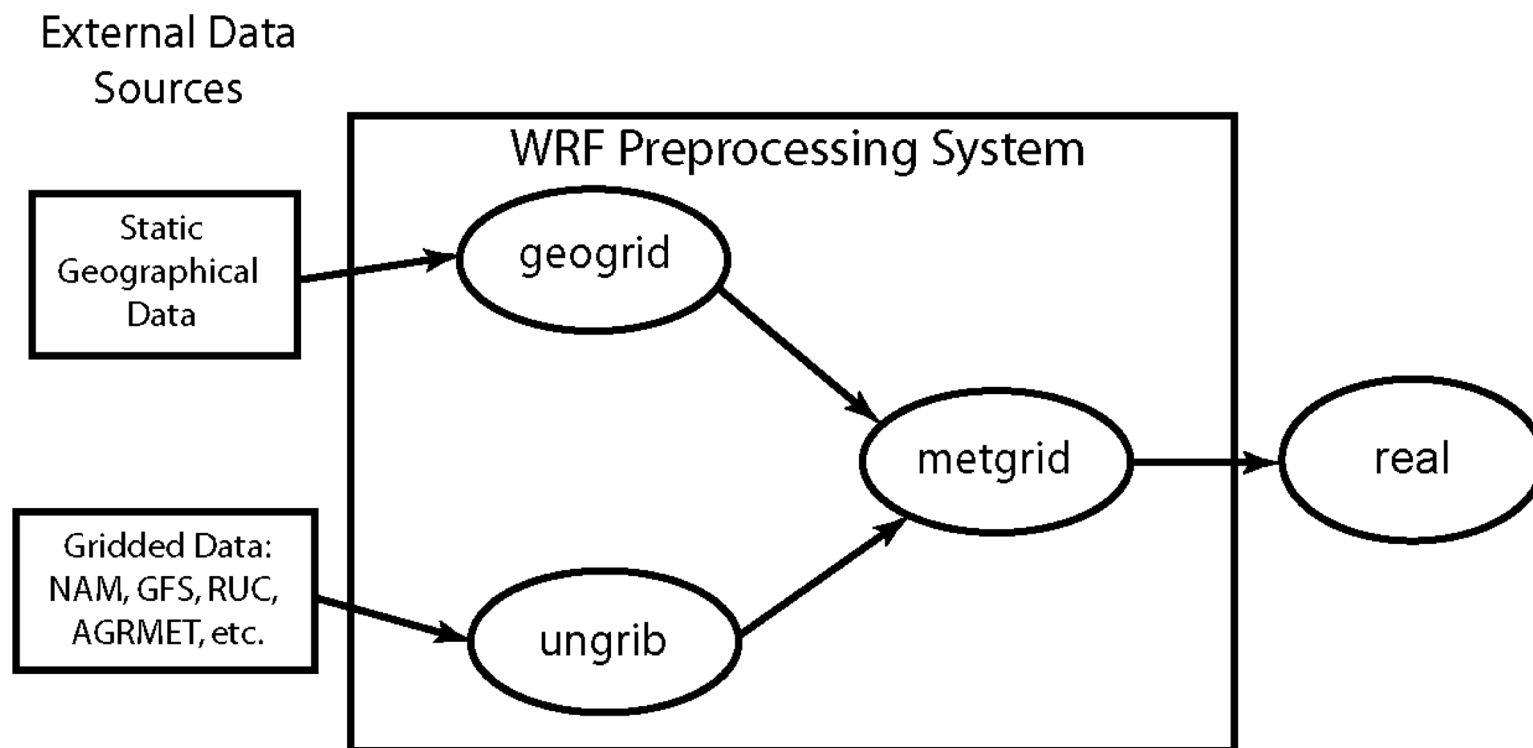


Overview

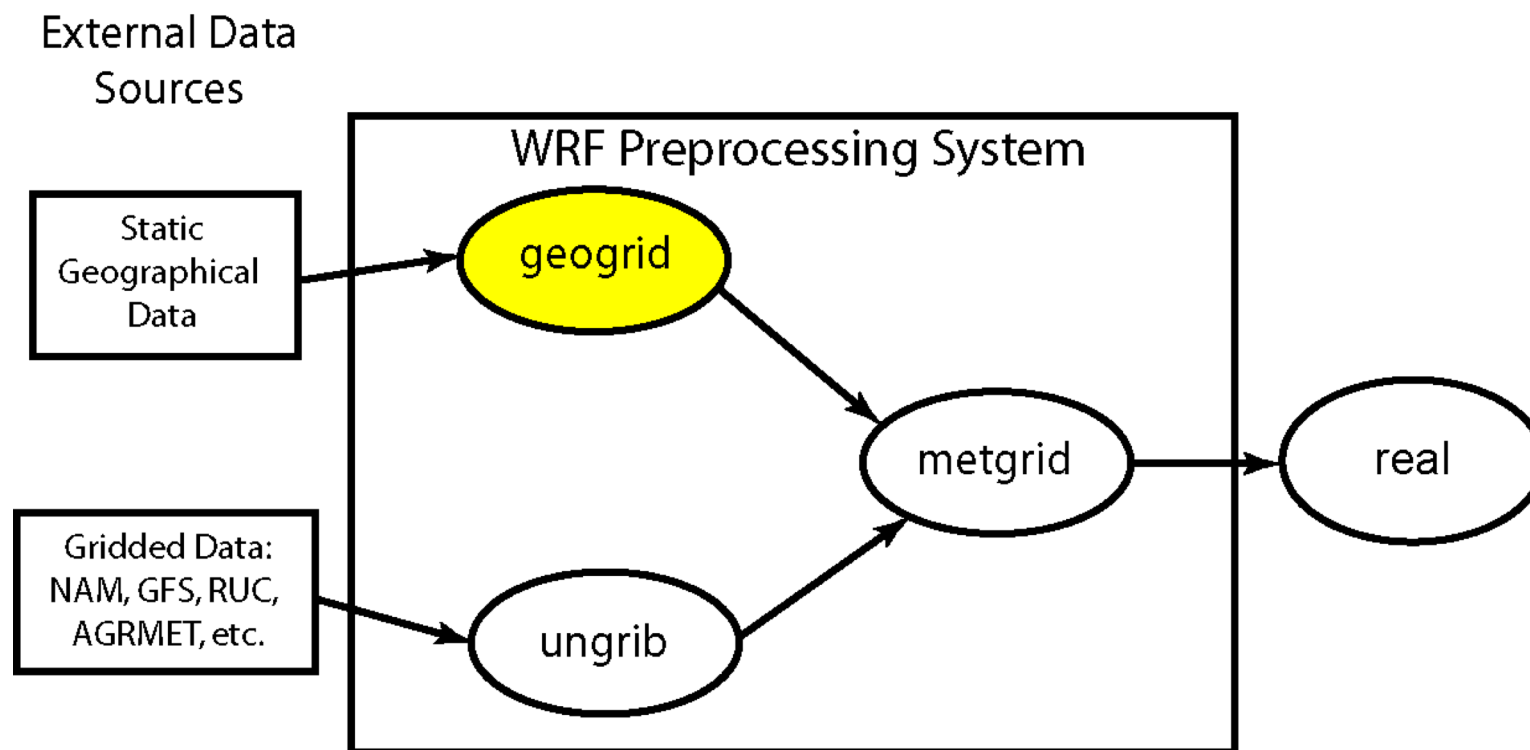
This lecture focuses on the basic use of the WPS to:

- Define a single simulation domain
 - The setup of *nested domains* is covered in a talk tomorrow morning
 - Preprocess time-varying atmospheric and land-surface datasets
 - Horizontally interpolate datasets for use as initial and boundary conditions for WRF
-
- Practical details of *actually running* the WPS are covered this afternoon and in a live demo tomorrow
 - *Advanced features* of the WPS are described on Wednesday

WPS Program Flowchart



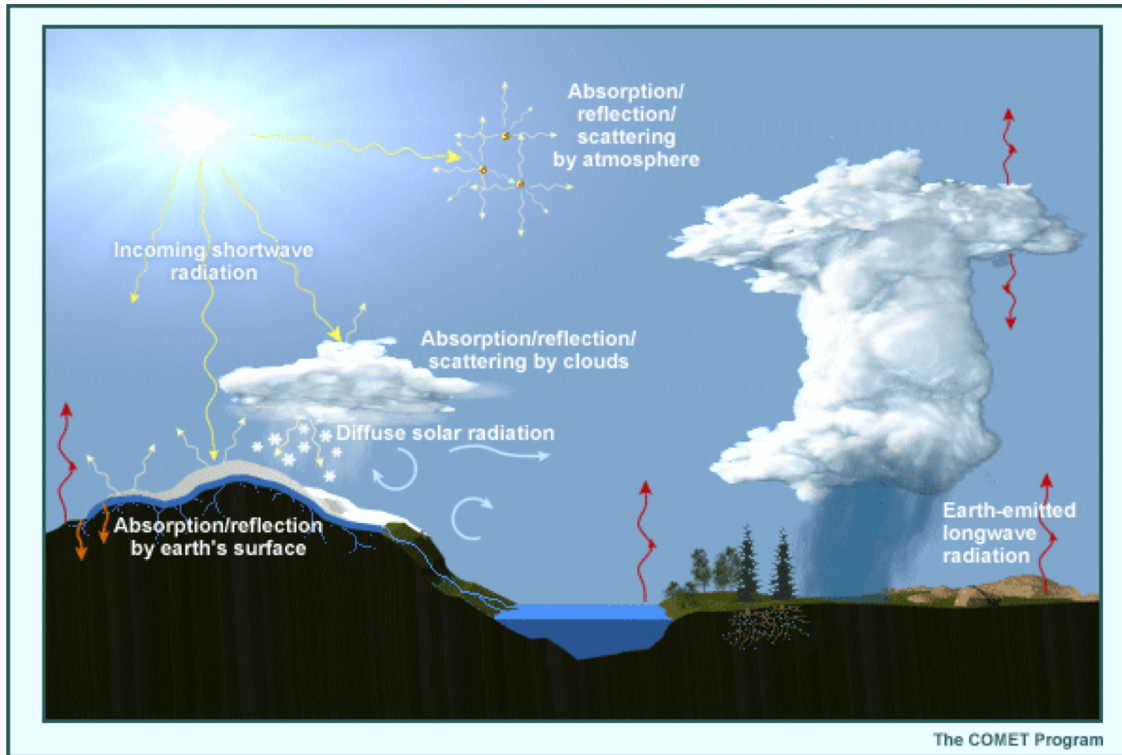
The *geogrid* Program



geogrid: think geographical

The *geogrid* Program

Let's suppose we wish to perform a simulation for the domain below...



- Where is this domain located?
- What area does the domain cover?
- How well do we resolve the atmosphere and land surface (horizontally)?
- What sources of data do we use for topography, vegetation categories, and soil categories?

Using the *geogrid* program, we answer these questions from the perspective of the WRF model.

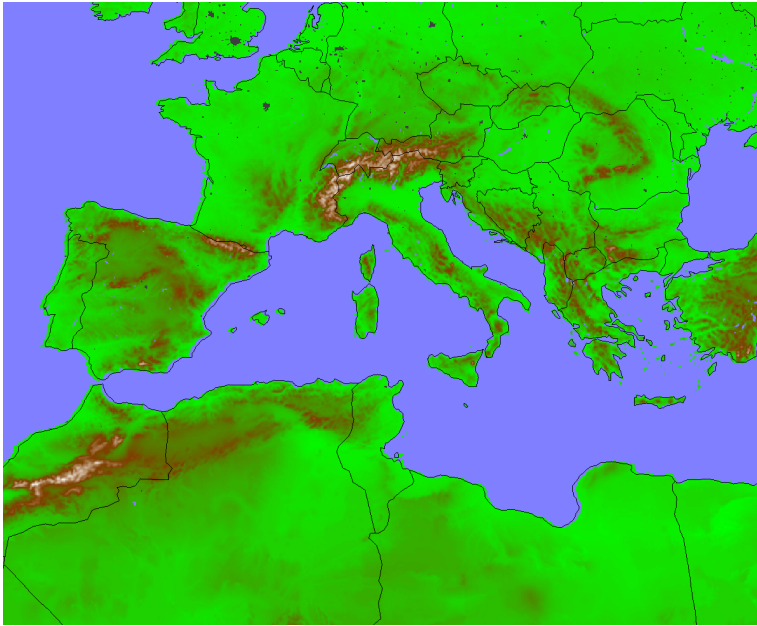
The *geogrid* Program

- We use the geogrid program to define:
 - Map projection (all domains must use the same projection)
 - Geographic location of domains
 - Dimensions of domains
 - Horizontal resolution 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) from global datasets

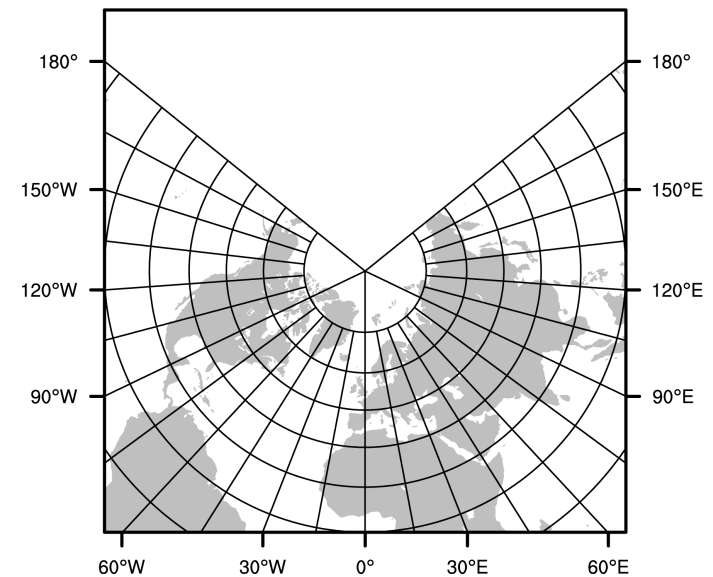
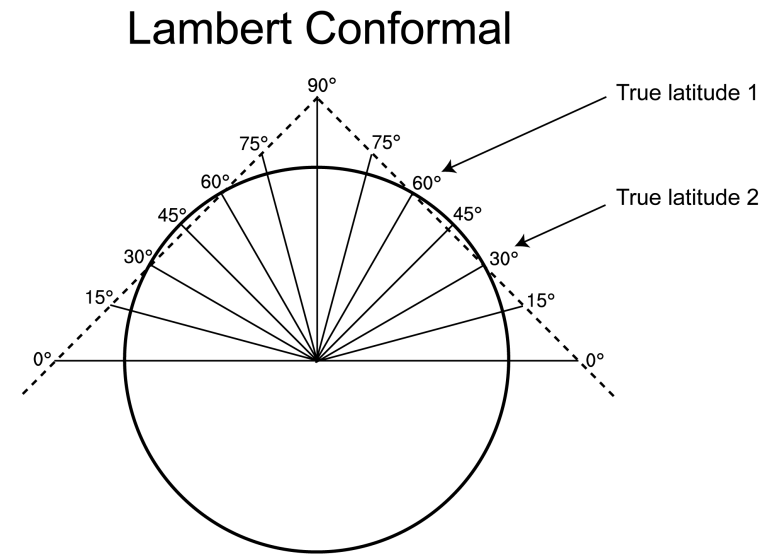
Geogrid: Defining Model Domains

- 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!)

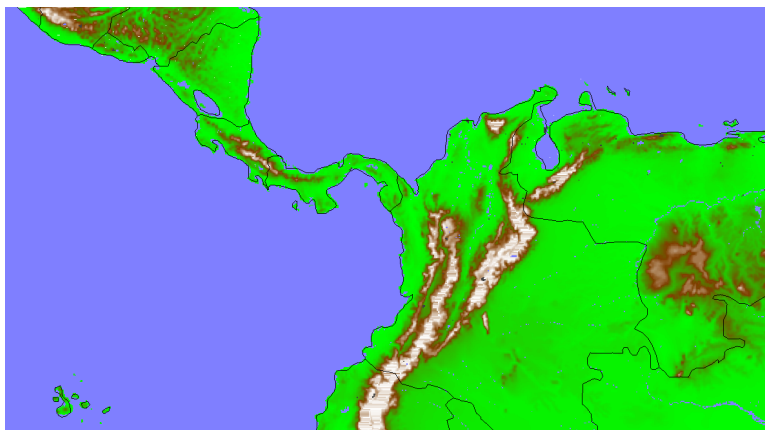
Projections: Lambert Conformal Conic



- 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

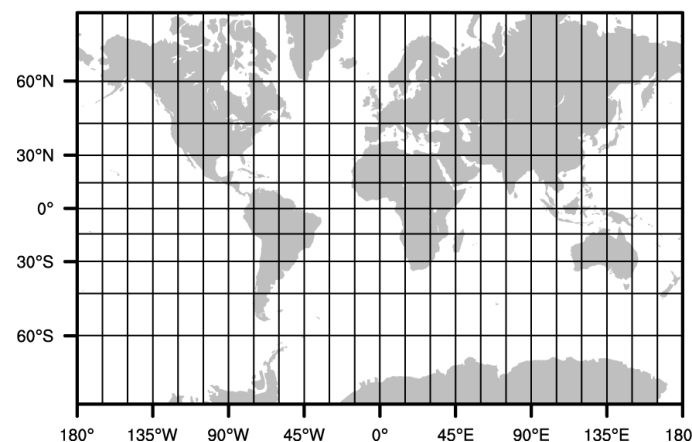
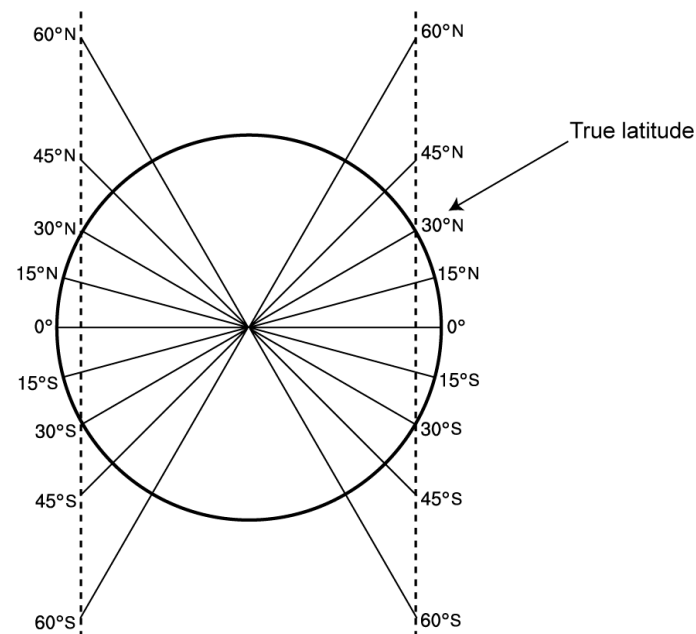


Projections: Mercator

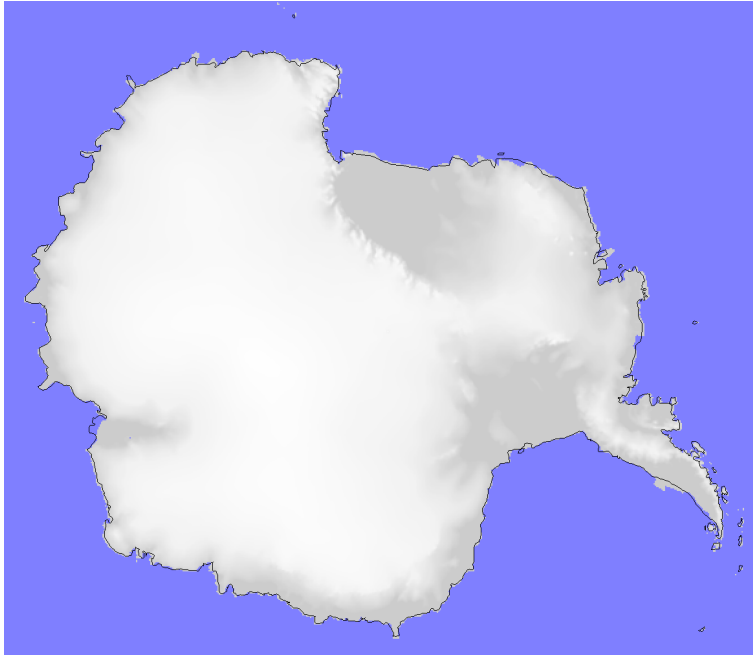


- Well-suited for low-latitudes
- May be used for “channel” domain (periodic domain in west-east direction)
- A single true latitude is specified
 - Cylinder intersects the earth’s surface at +/- truelat

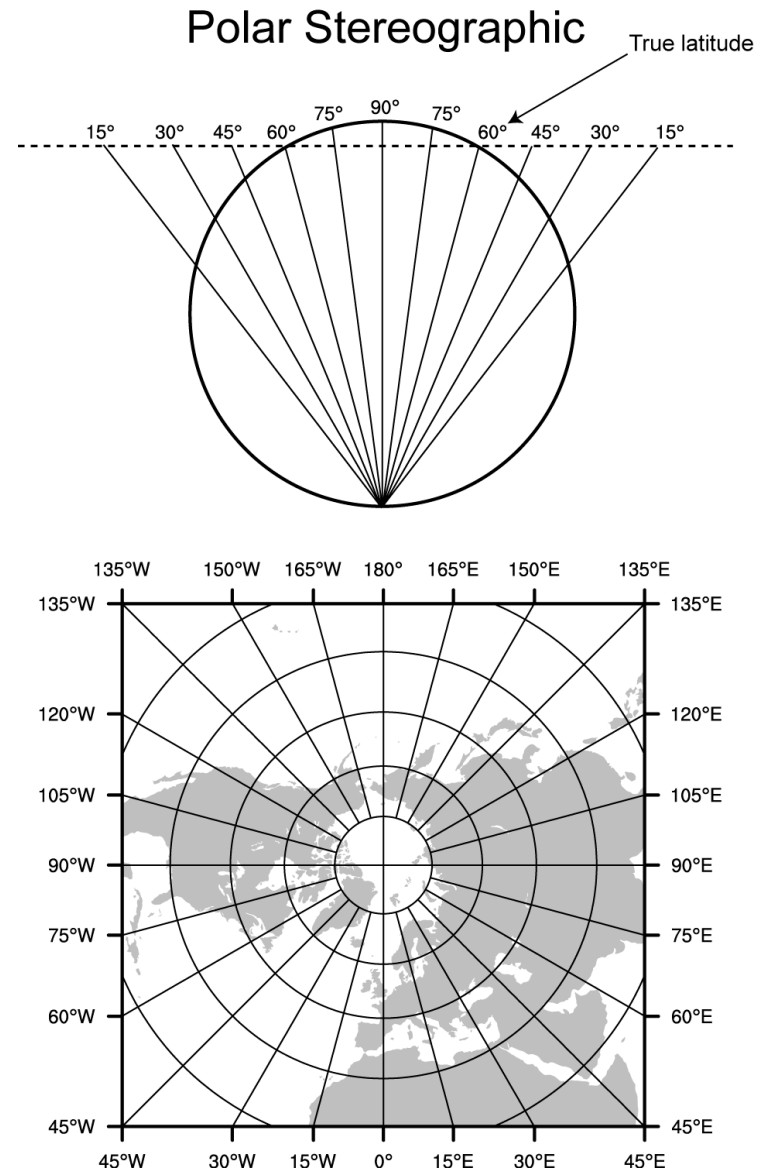
Mercator



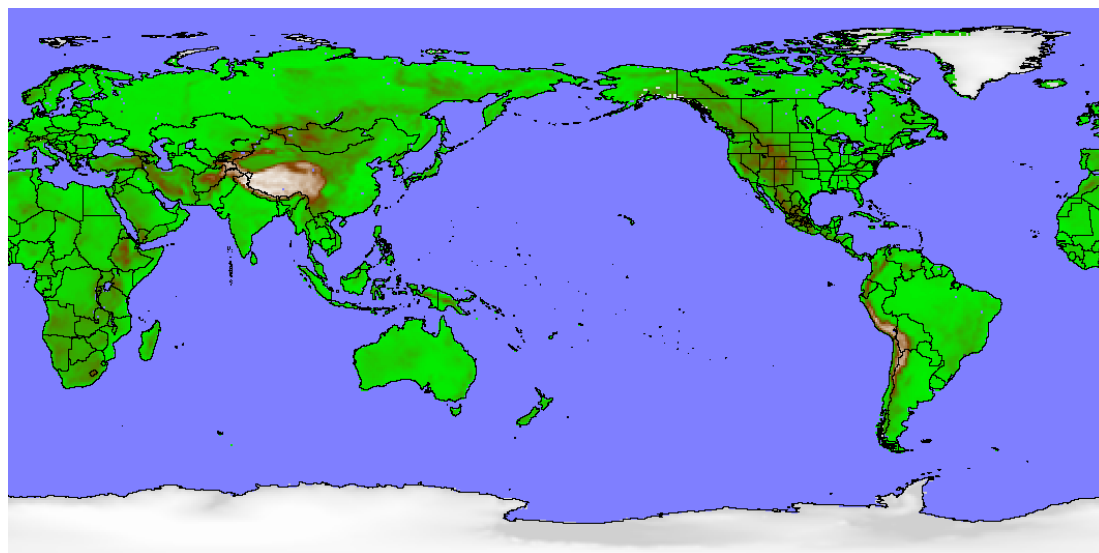
Projections: Polar Stereographic



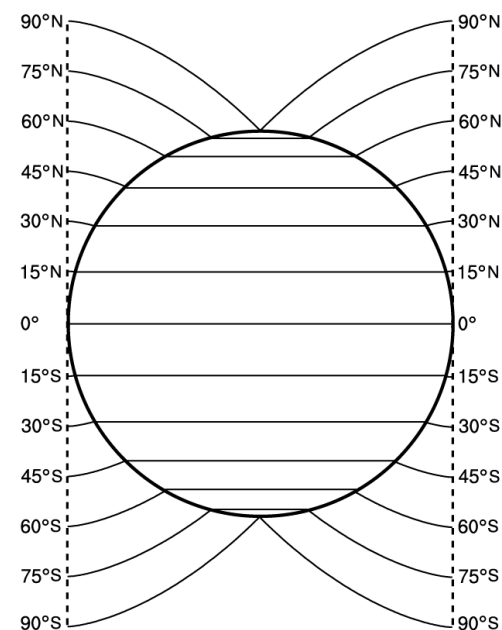
- Good for high-latitude domains, especially if domain must contain a pole
- A single true latitude is specified



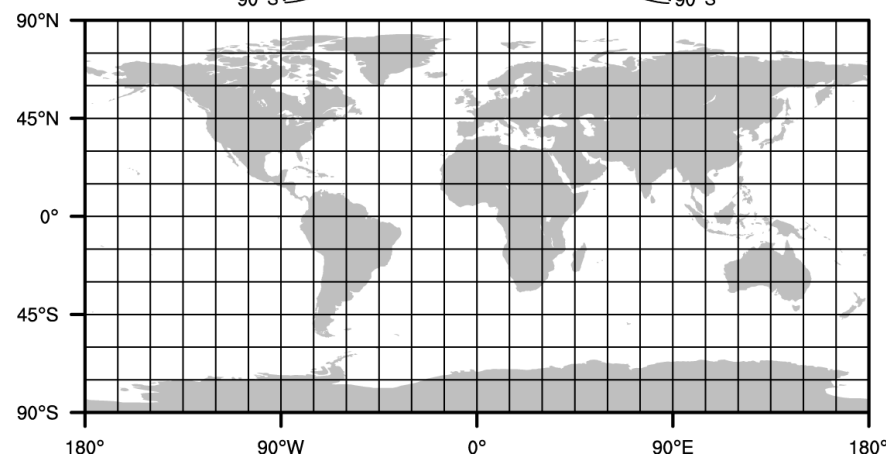
Projections: Cylindrical Equidistant



Cylindrical Equidistant



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



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

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*.

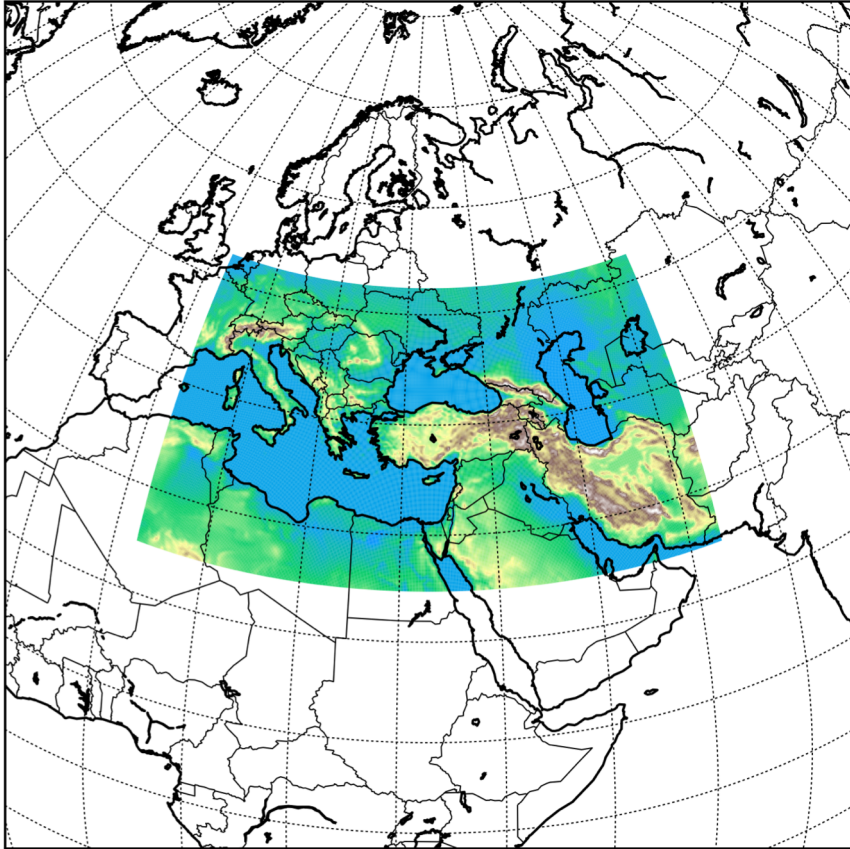
Maximum stable timestep in WRF is determined by geographic grid distance, not nominal (i.e., namelist) grid distance!

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!

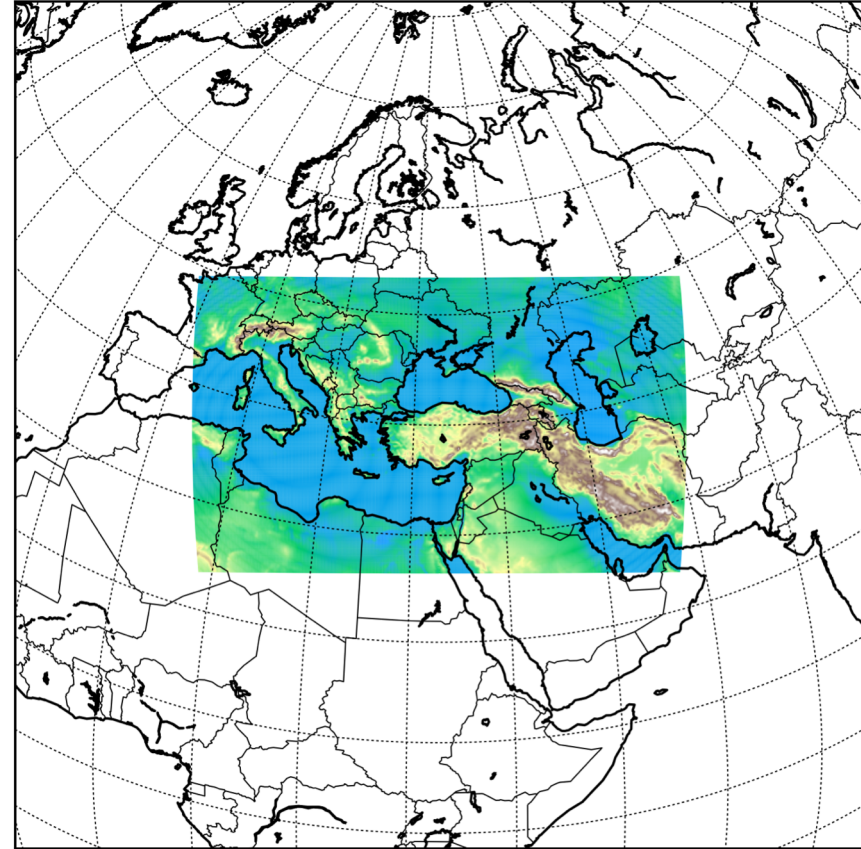
Why do map projections matter?

Mercator projection, $\phi_1 = 42.0$, $0.819 \leq m \leq 1.218$



For a nominal 12-km grid, the above projection yields grid distances from 9.9 km to 14.6 km.

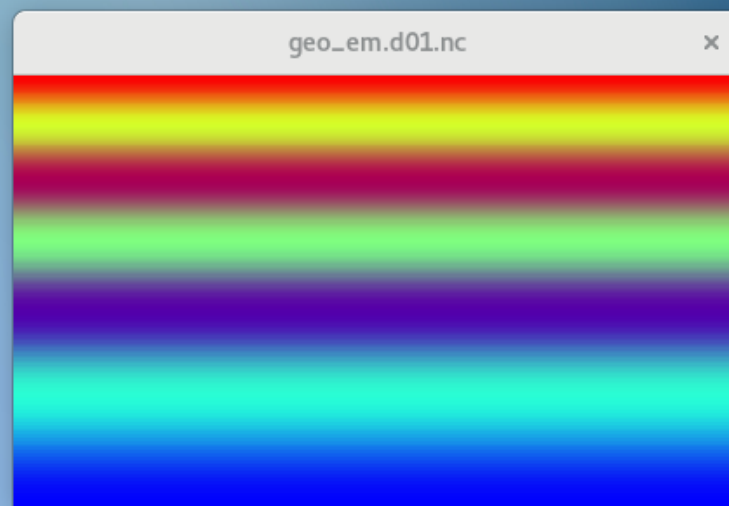
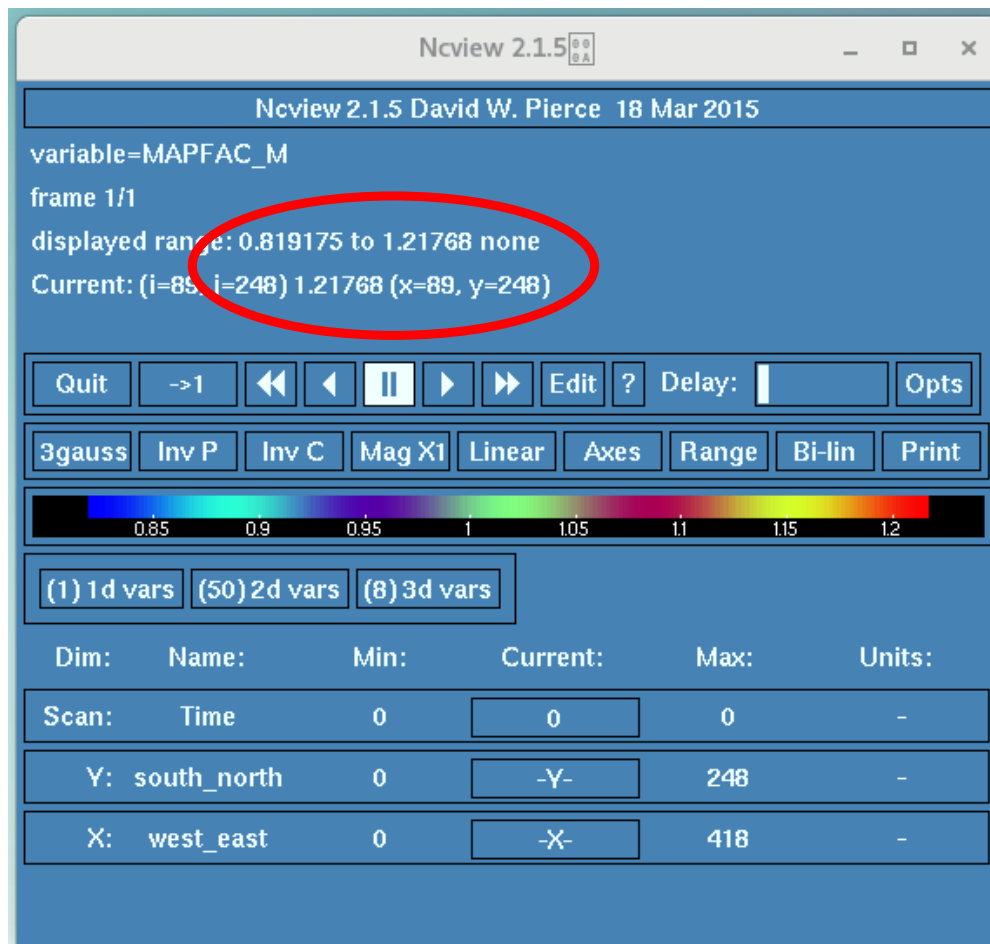
Lambert conformal projection, $\phi_1, \phi_2 = 30.0, 47.5$, $0.988 \leq m \leq 1.023$



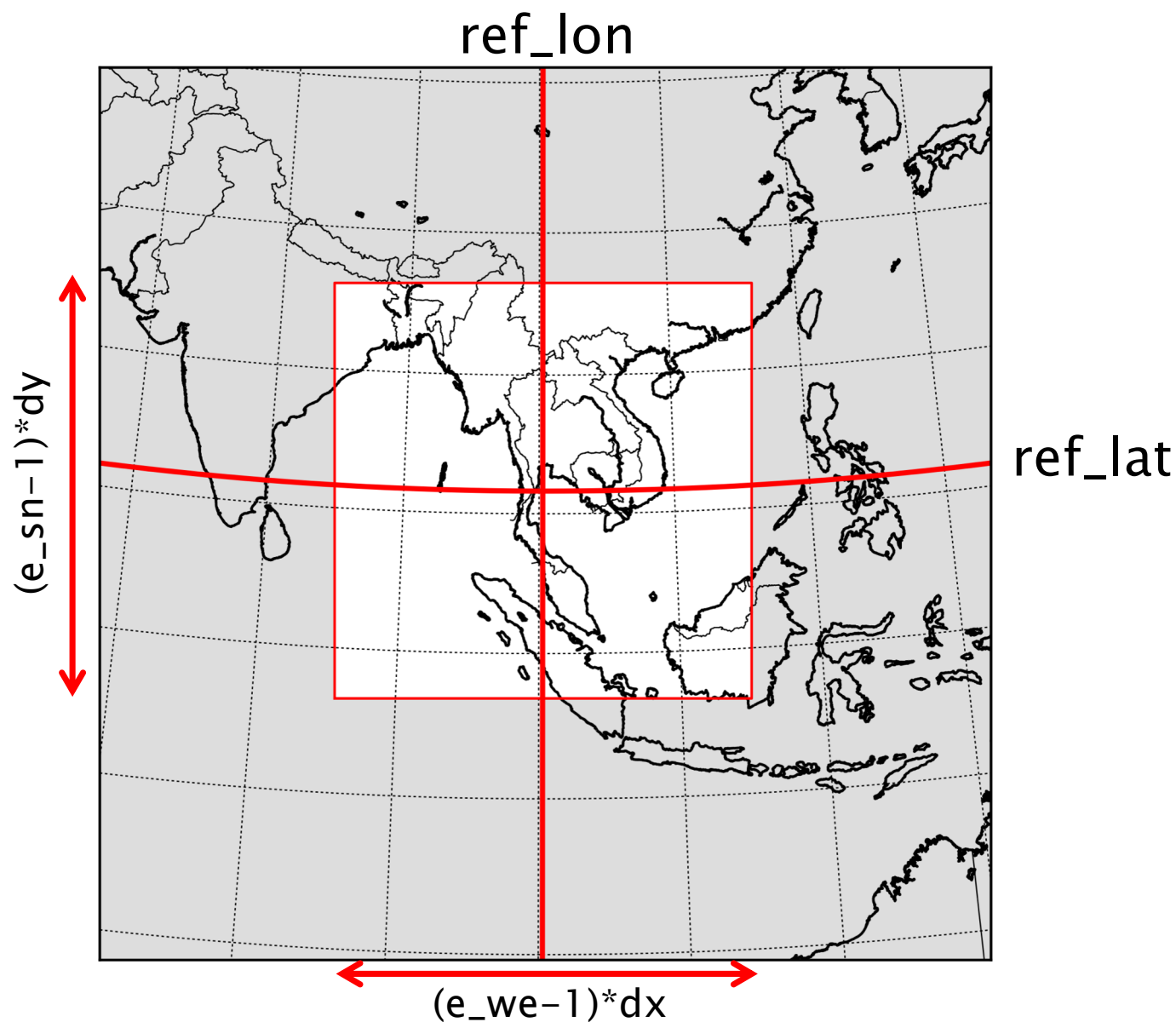
For a nominal 12-km grid, the above projection yields grid distances from 11.7 to 12.1 km.

Why do map projections matter?

Lesson: After running geogrid.exe, check the MAPFAC_M field in the geogrid output files!



Geogrid: Defining ARW Domains



Geogrid: Defining ARW Domains

- Define the area covered (dimensions and location) by coarse domain using the following:
 - **REF_LAT, REF_LON:** The (lat,lon) location of a known location in the domain (*by default, the center point of the domain*)
 - **DX, DY:** Grid distance where map factor = 1
 - For Lambert, Mercator, and polar stereographic: **meters**
 - For (rotated) latitude–longitude: **degrees**
 - **E_WE:** Number of velocity points in west–east direction
 - **E_SN:** Number of velocity points in south–north direction

See p. 3–13 and 3–42

Geogrid: Interpolating *Static* Fields

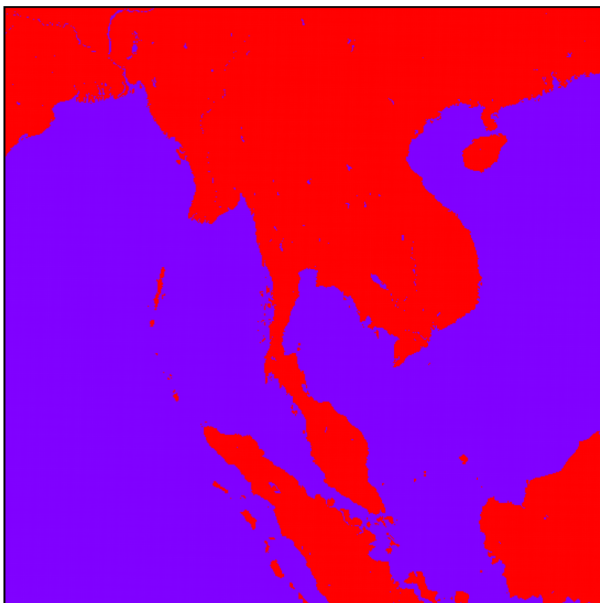
- Given definitions of all computational grids, geogrid interpolates terrestrial, time-invariant fields
 - Topography height
 - Land use categories
 - Soil type (top layer & bottom layer)
 - Annual mean soil temperature
 - Monthly vegetation fraction
 - Monthly surface albedo

Geogrid: Program Output

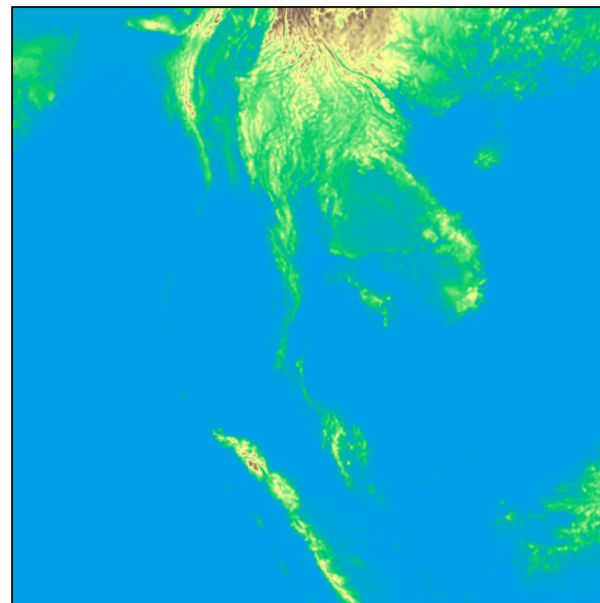
- The parameters defining each domain, plus interpolated static fields, are written using the WRF I/O API
 - One file per domain for ARW
- Filenames: `geo_em.d0 n .nc`
(where n is the domain ID number)
- Example:
 - `geo_em.d01.nc`
 - `geo_em.d02.nc` (nest)
 - `geo_em.d03.nc` (nest)

Geogrid: Example Output Fields

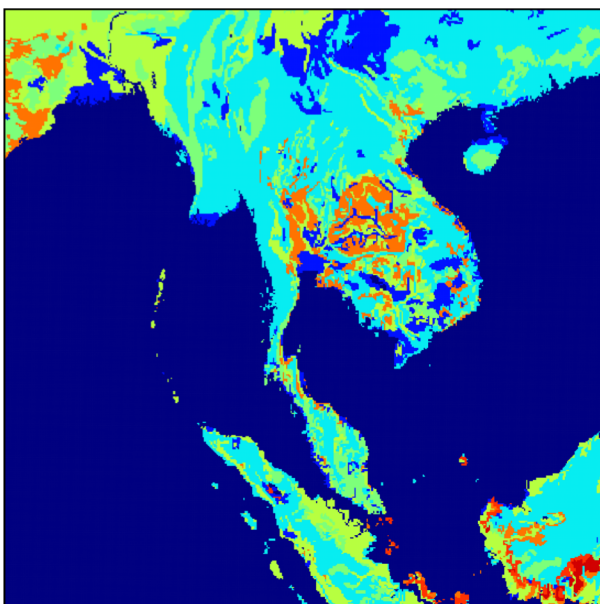
Land-water
mask



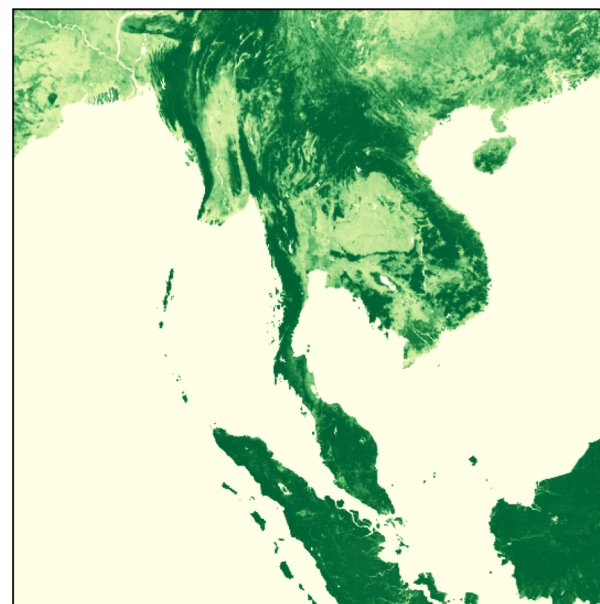
Topography
height



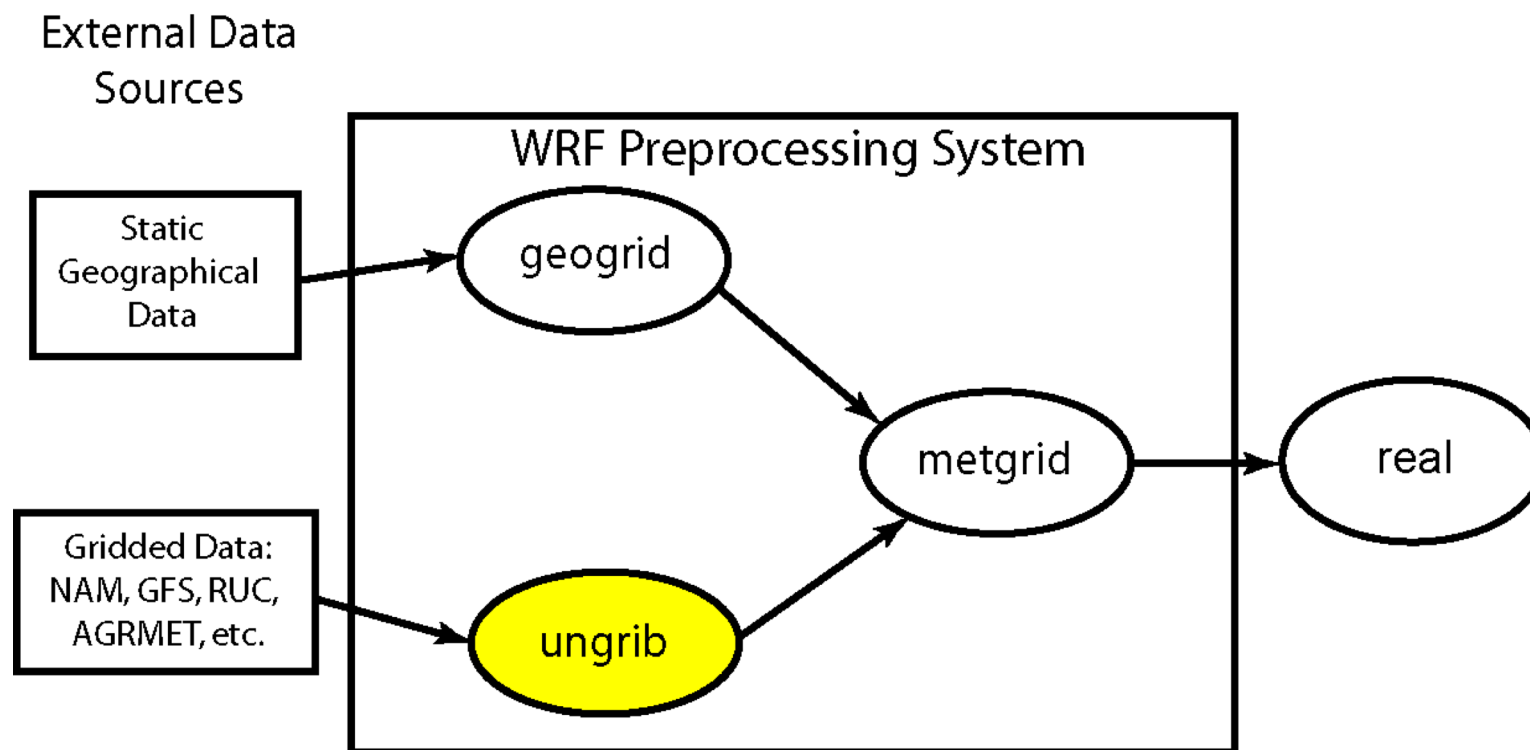
Top-layer
dominant
soil type



Climatological
vegetation
fraction
(January)



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

- Reads GRIB Edition 1 and GRIB Edition 2 files
- Extracts meteorological fields
- If necessary, derives required fields from related ones
 - E.g., Compute RH from T, P, and Q
- Writes 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: CFSR, ERA-Interim, GFS, NARR, 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		SKINTMP	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 Vtables 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

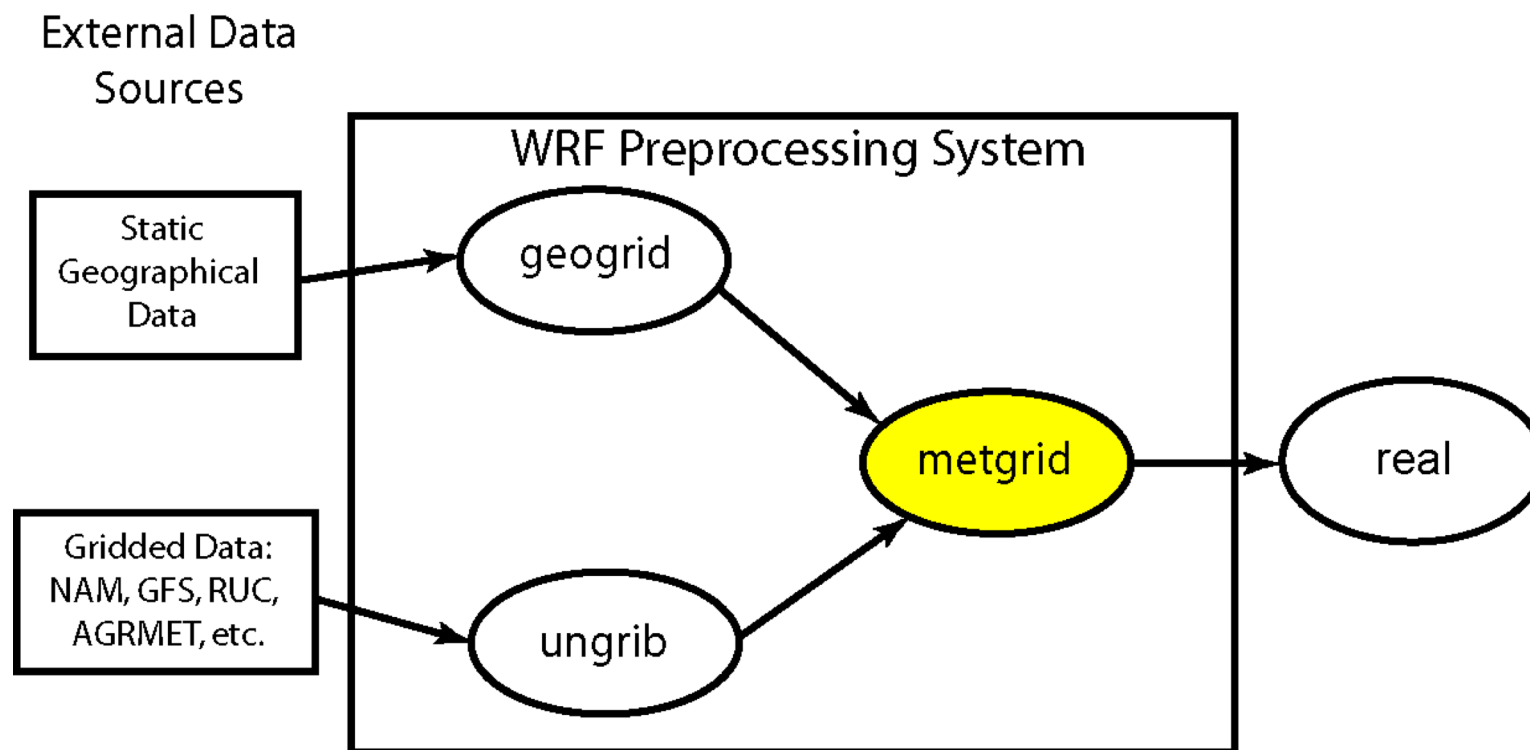
- Output files named *FILE:YYYY-MM-DD_HH*
 - *YYYY* is year of data in the file; *MM* is month; *DD* is day; *HH* is hour
 - All times are UTC
- Example:

FILE:2007-07-24_00

FILE:2007-07-24_06

FILE:2007-07-24_12

The *metgrid* program



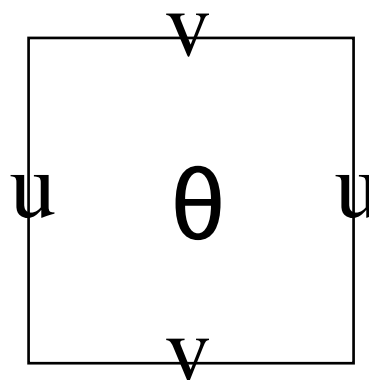
metgrid: think meteorological

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 “ θ ” staggering by default (*can change this!*)

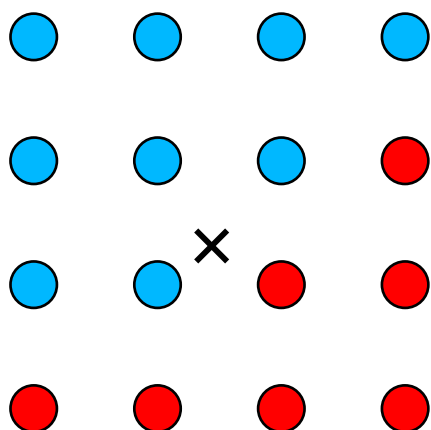


A single ARW grid cell, with “u”, “v”, and “ θ ” points labeled.

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



- Blue circle = valid source data
- Red circle = masked/invalid data

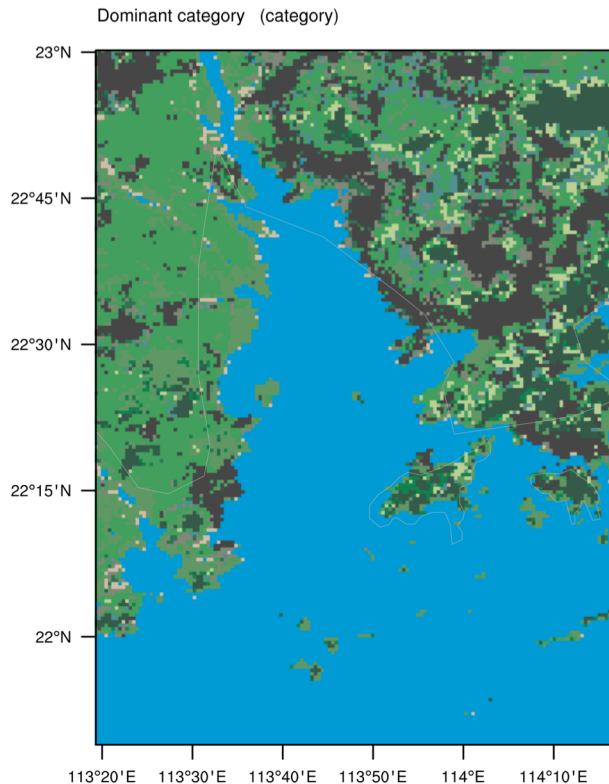
Suppose we need to interpolate to point X

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

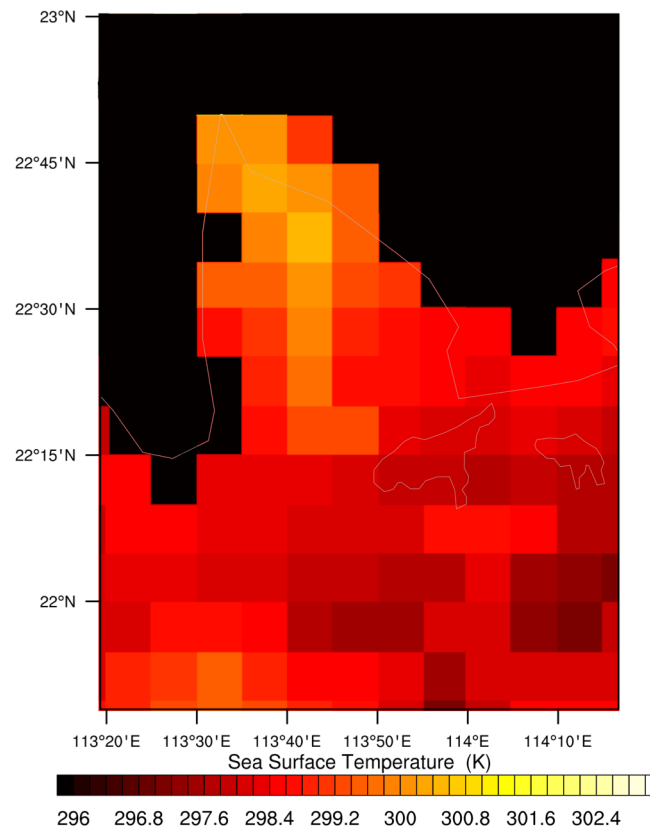
Not every interpolation option can handle masked points; we'll address this issue in the advanced WPS lecture

Metgrid: Masked Interpolation

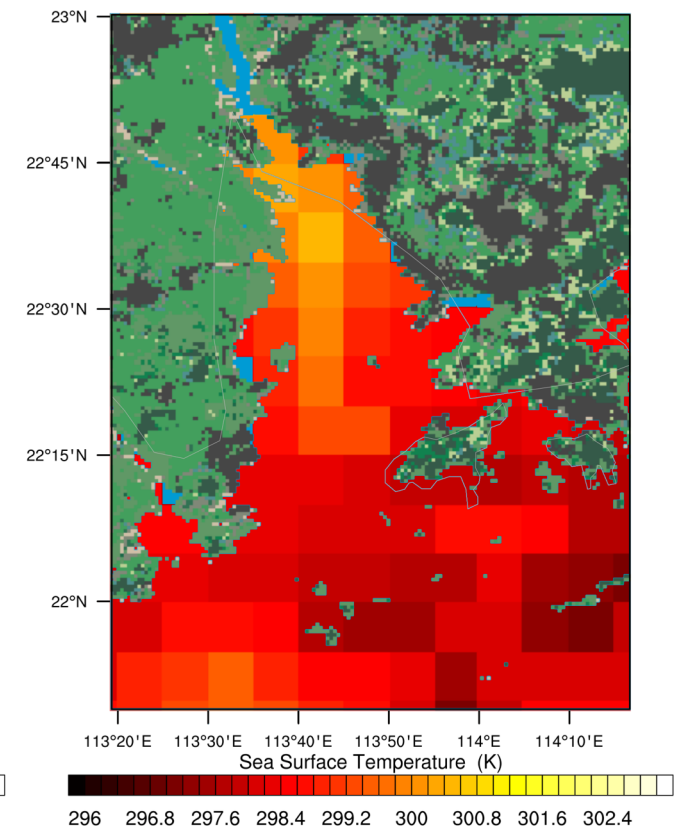
Common fields that require masked interpolation include SST, soil moisture, and soil temperature.



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



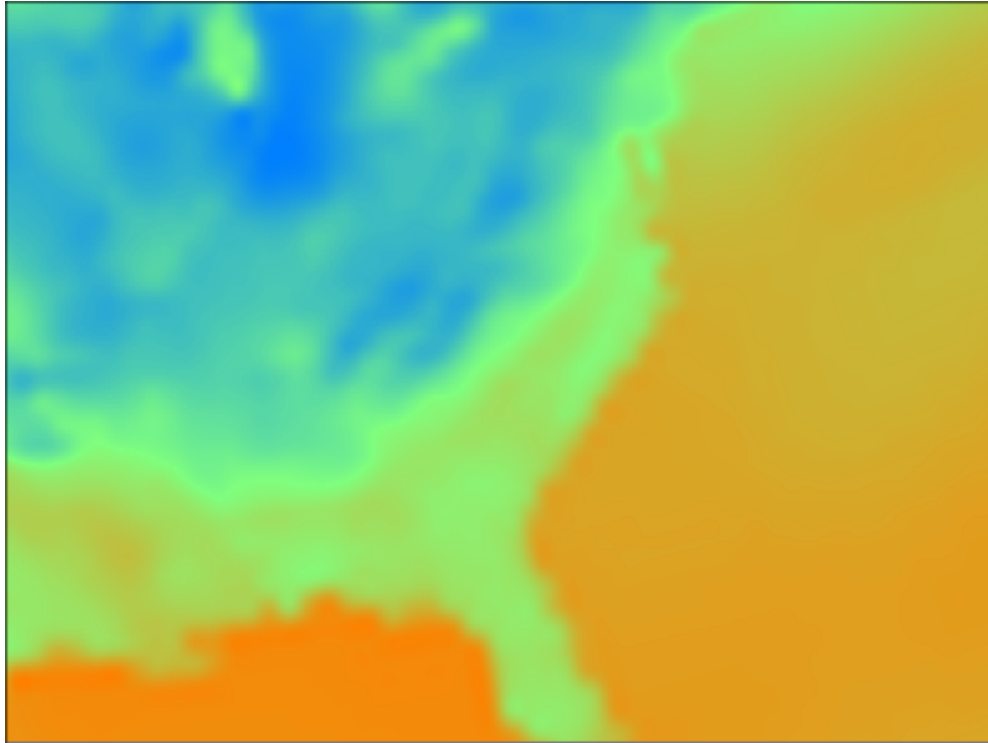
SST data on a 0.083-degree grid, with missing data (black) over land.



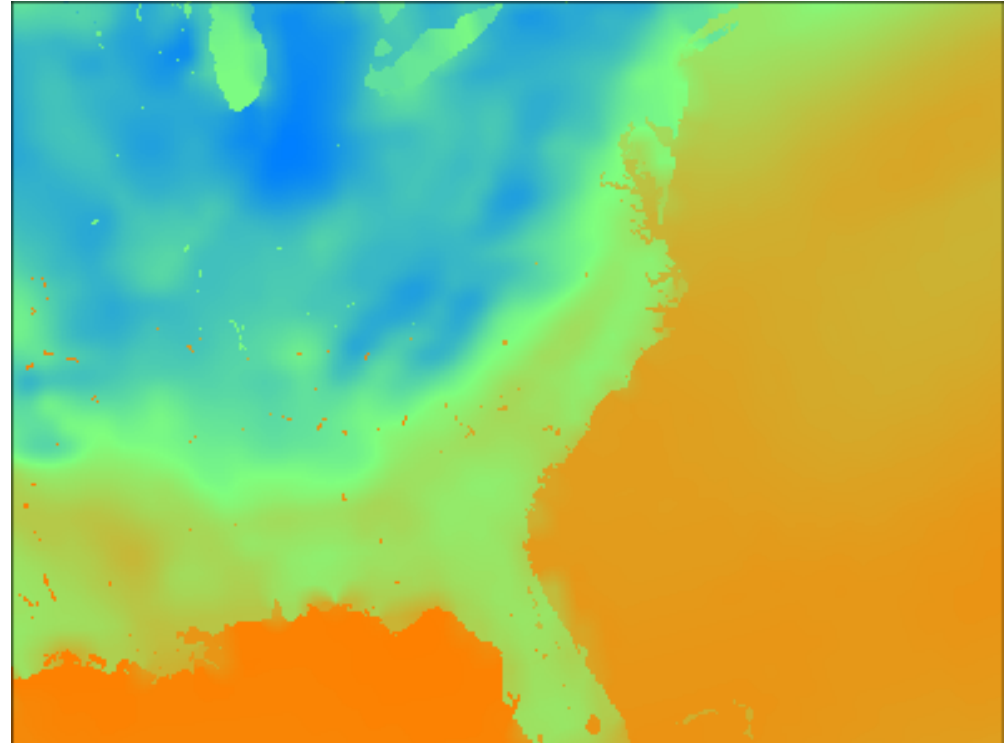
SST data overlaid with land use; blue areas represent WRF water cells that must receive SST values via masked interpolation.

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.

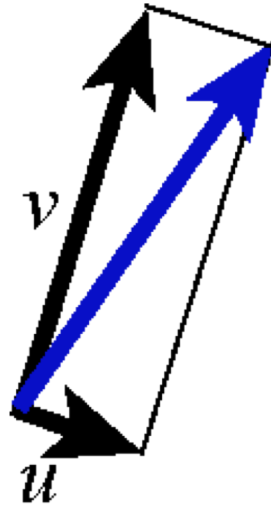


Skin temperature field interpolated using masks: GFS water points interpolated to model water points, GFS land points interpolated to model land points.

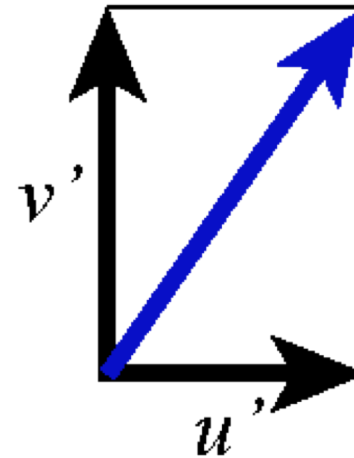
Metgrid: Wind Vector Rotation

- 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 Vector Rotation



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



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

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

Metgrid: Constant Fields

- For short simulations, some fields may be constant
 - E.g., SST or sea-ice fraction
- Use namelist option `CONSTANTS_NAME` option to specify such fields:
 - `CONSTANTS_NAME = 'SST_FILE:2007-07-24_00'`

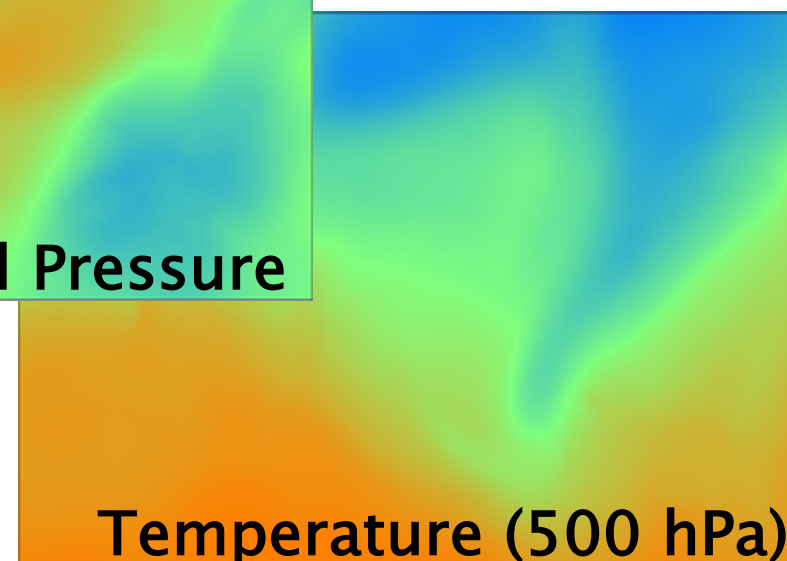
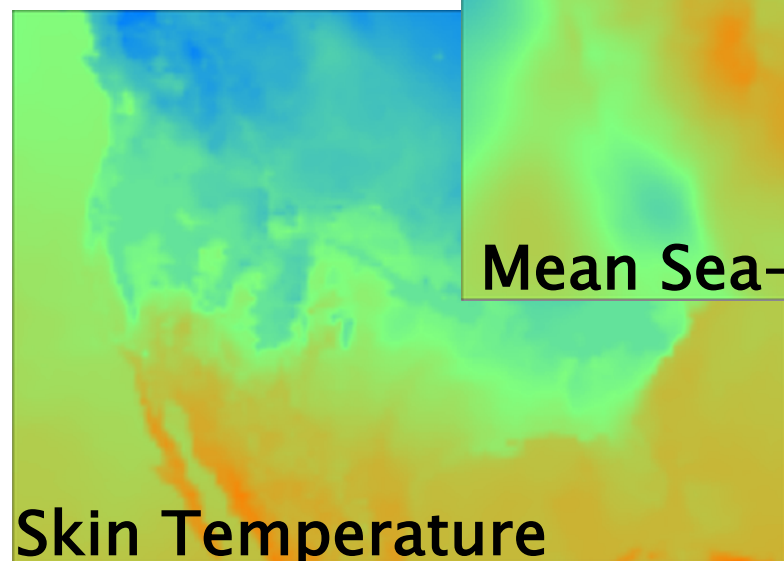
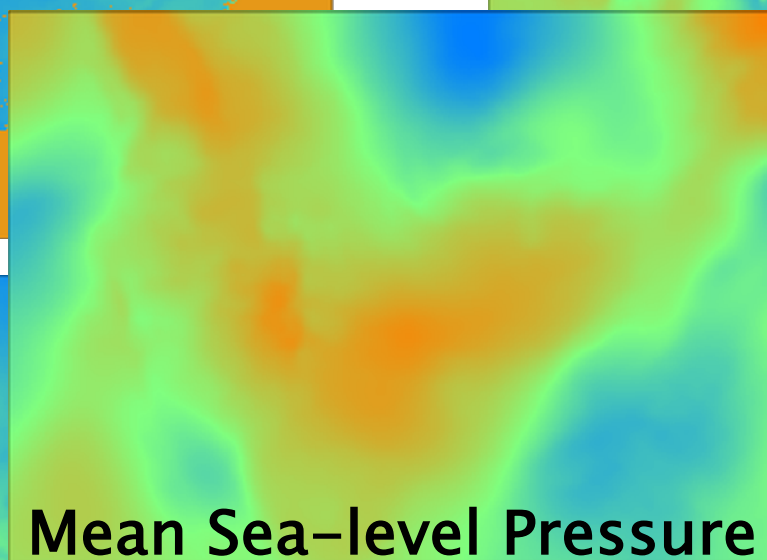
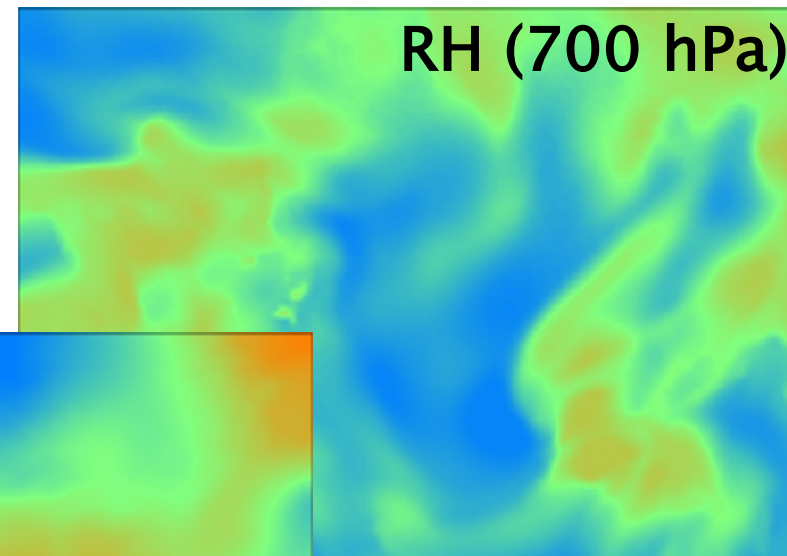
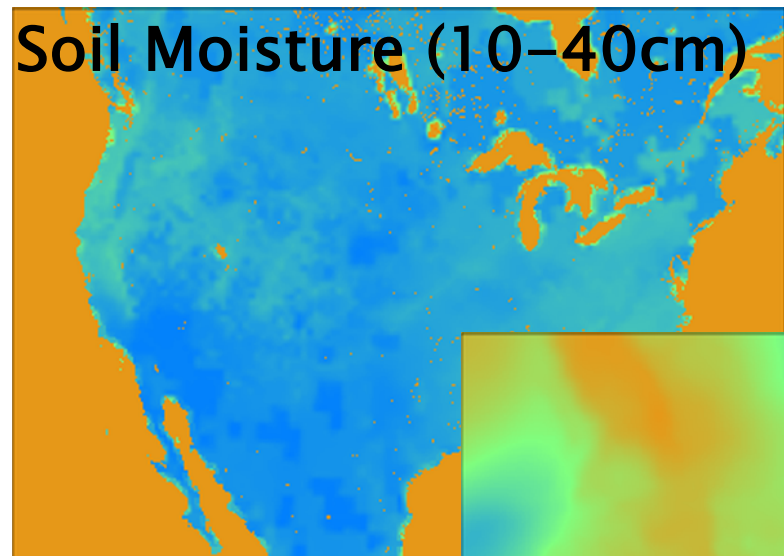
Metgrid: Program Output

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

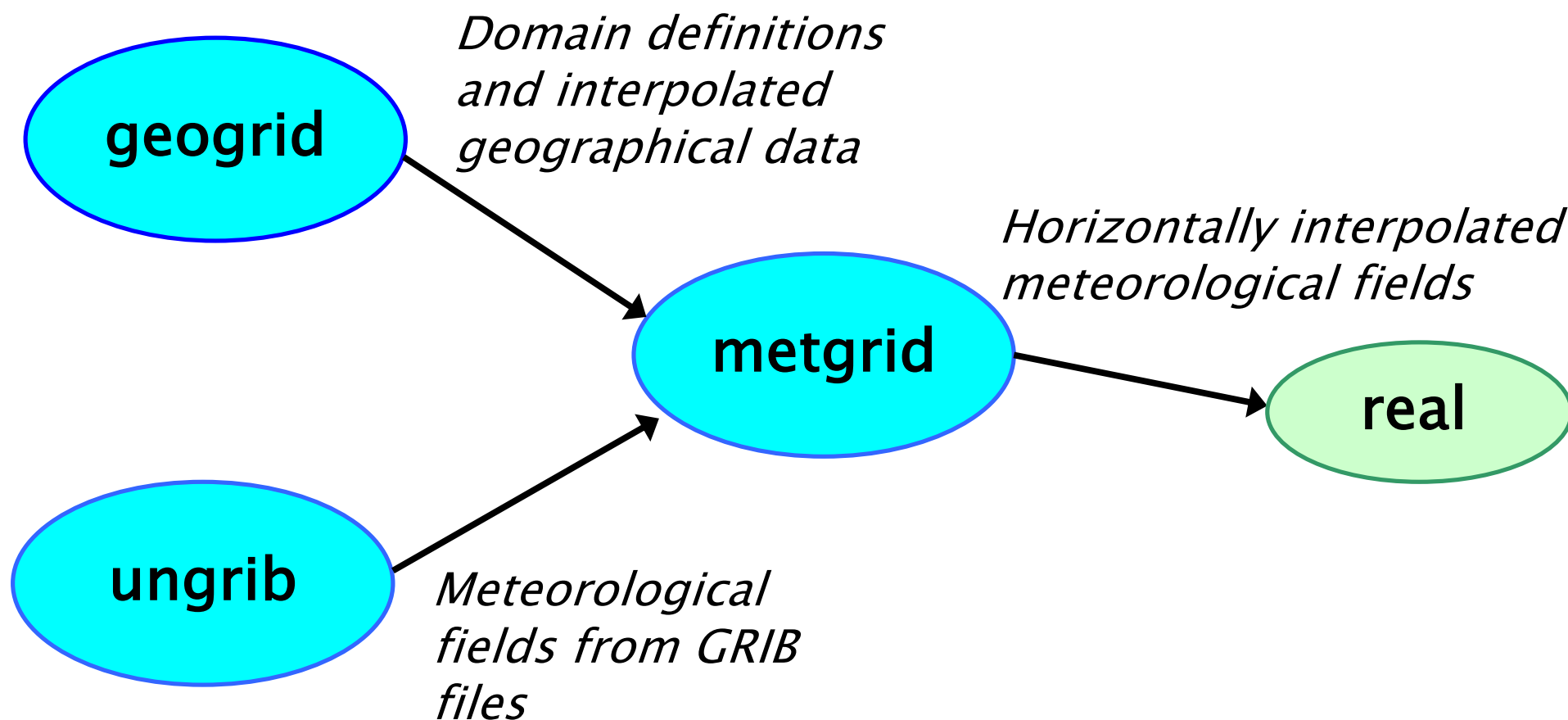
ARW: `met_em.d0n.YYYY-MM-DD_HH:mm:ss.nc`

(where n is the domain ID number)

Metgrid: Example Output

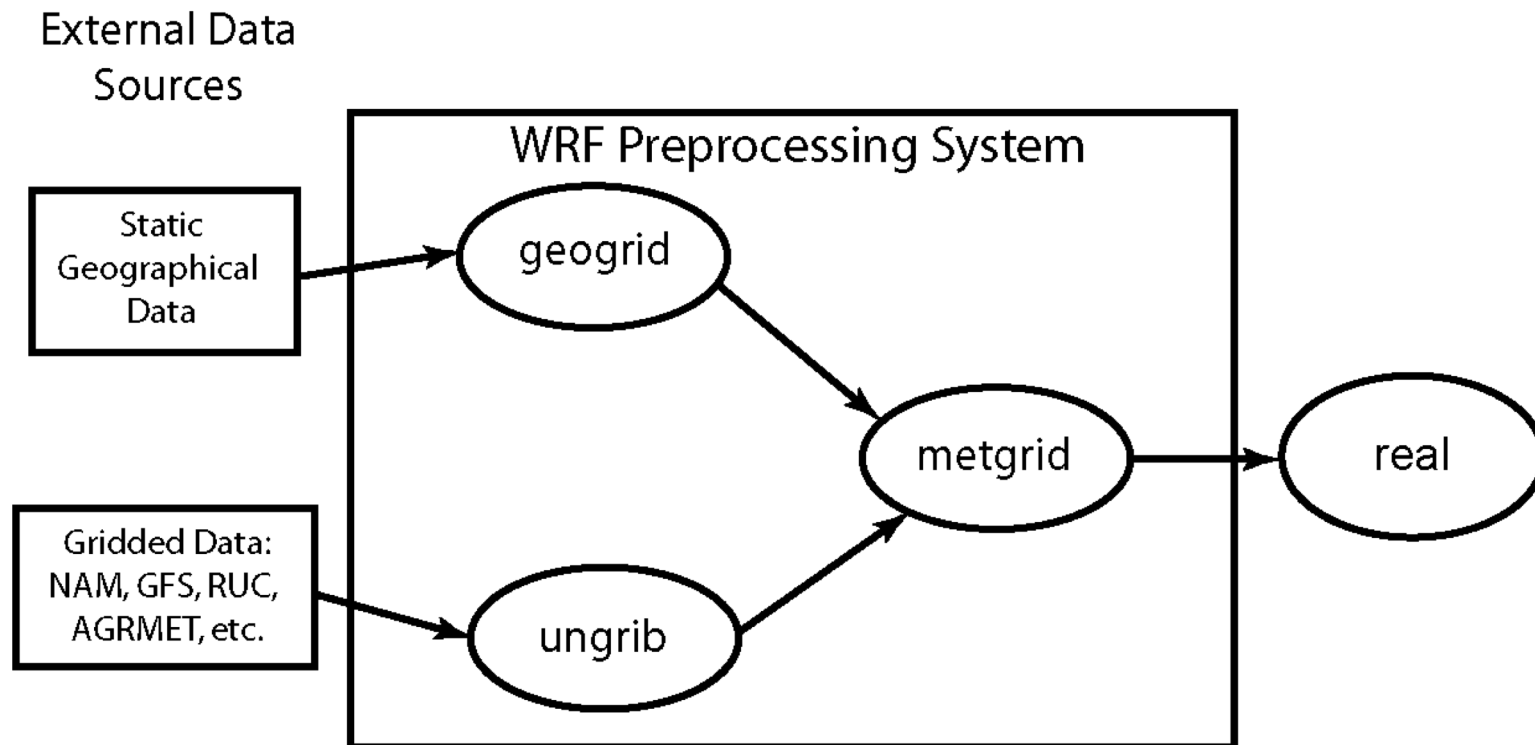


WPS Summary



And finally...

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



Questions?

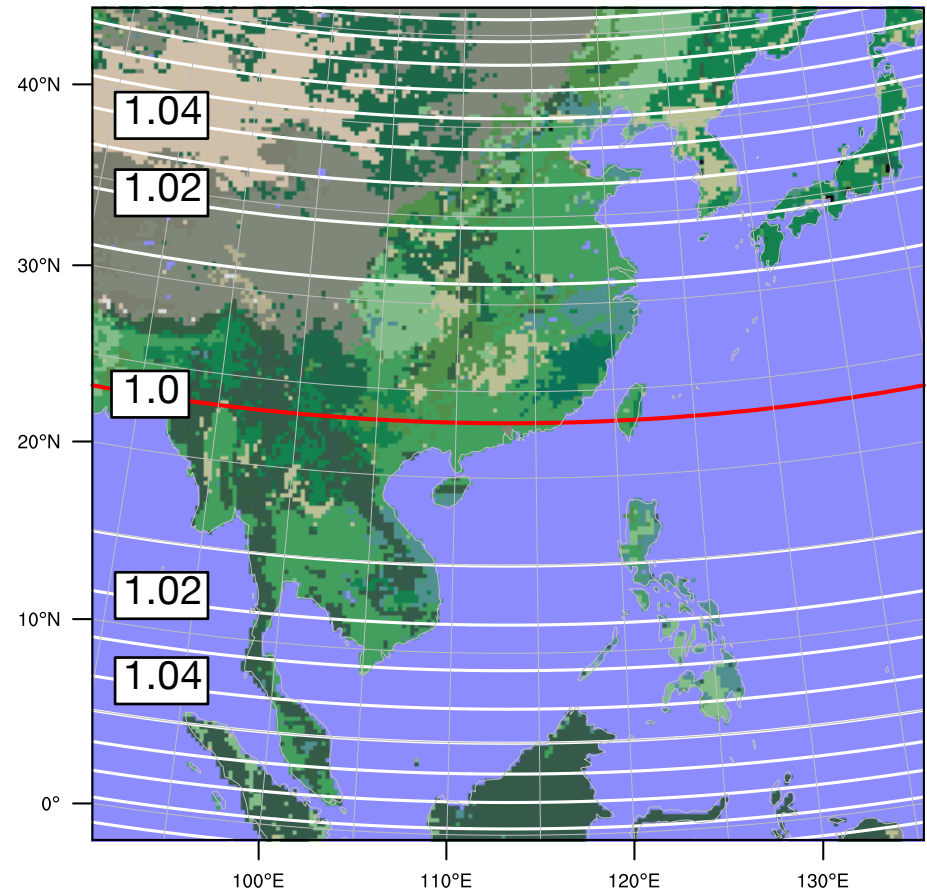
Extra slides

Why do map projections matter?

Example:

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

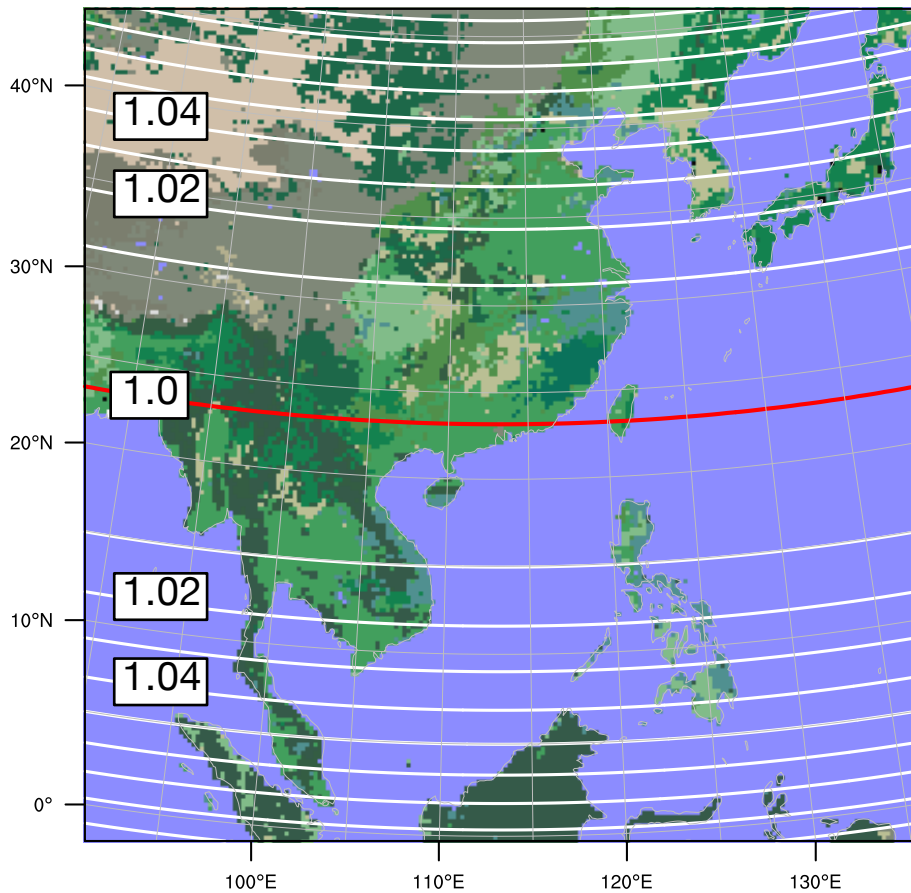
Choosing both true latitudes in the center of the WRF domain leads to maximum map scale factors of 1.0975, corresponding to a *minimum physical grid distance of $27/1.0975 = 24.6$ km.*



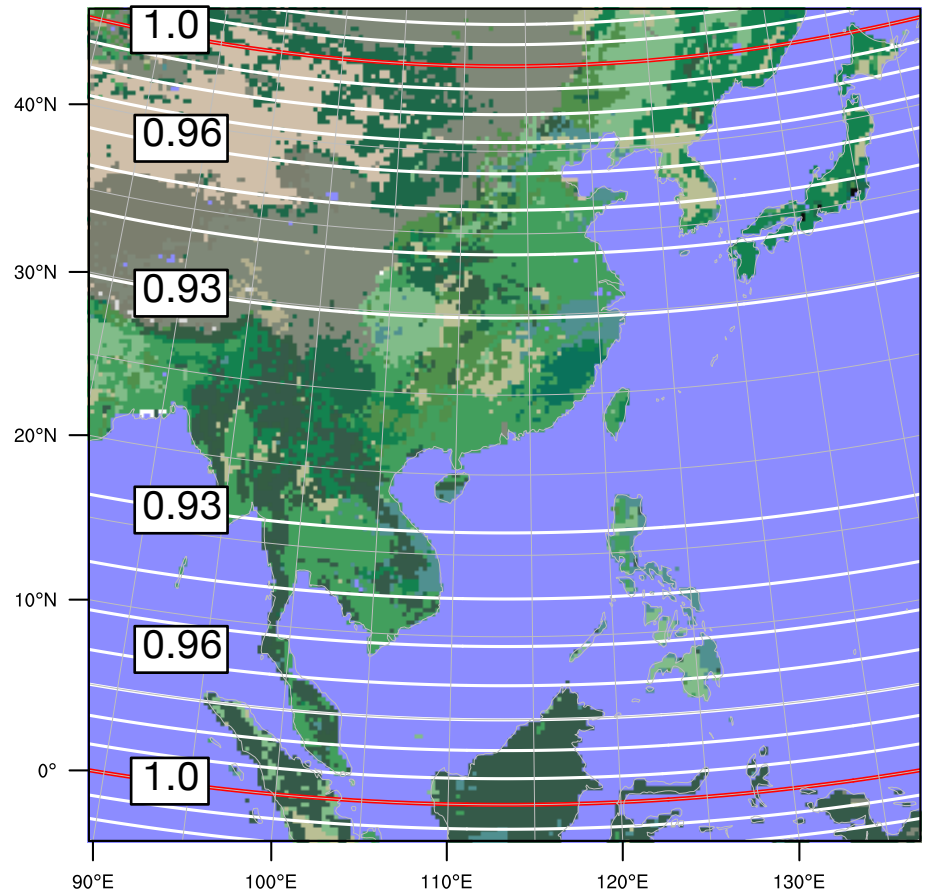
Above: Contours of map scale factor (white; interval 0.01) with true latitudes (red).

Why do map projections matter?

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



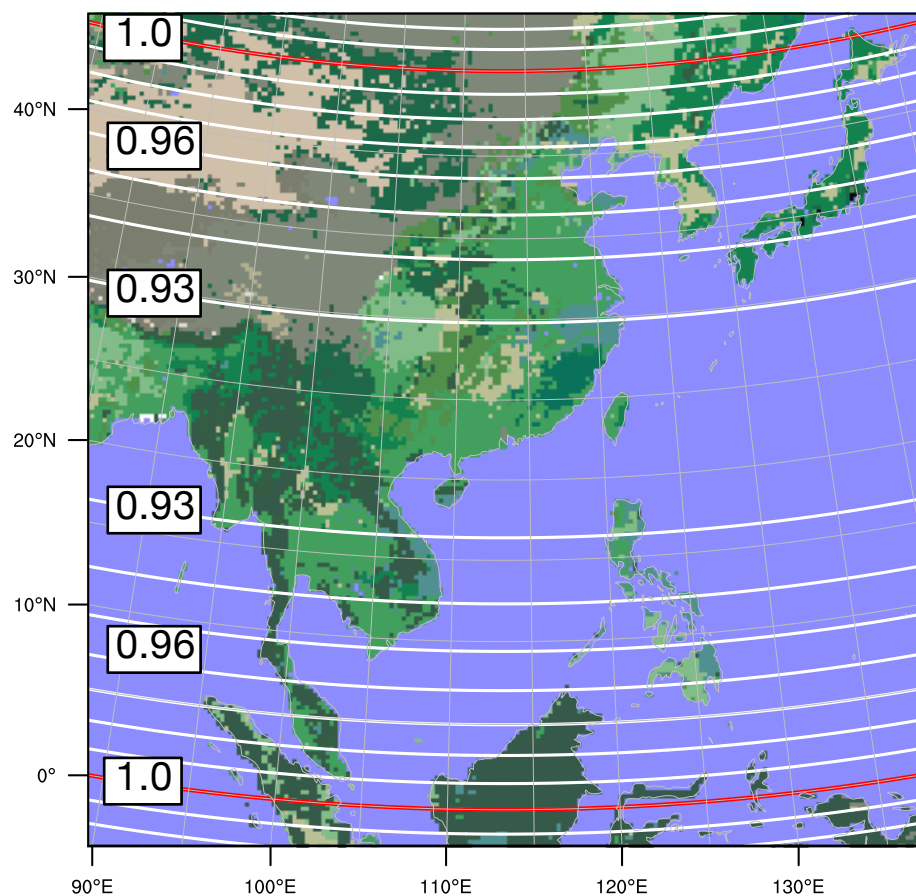
Above: Reference projection as on previous slide; maximum grid distance is 27 km (at true latitude).



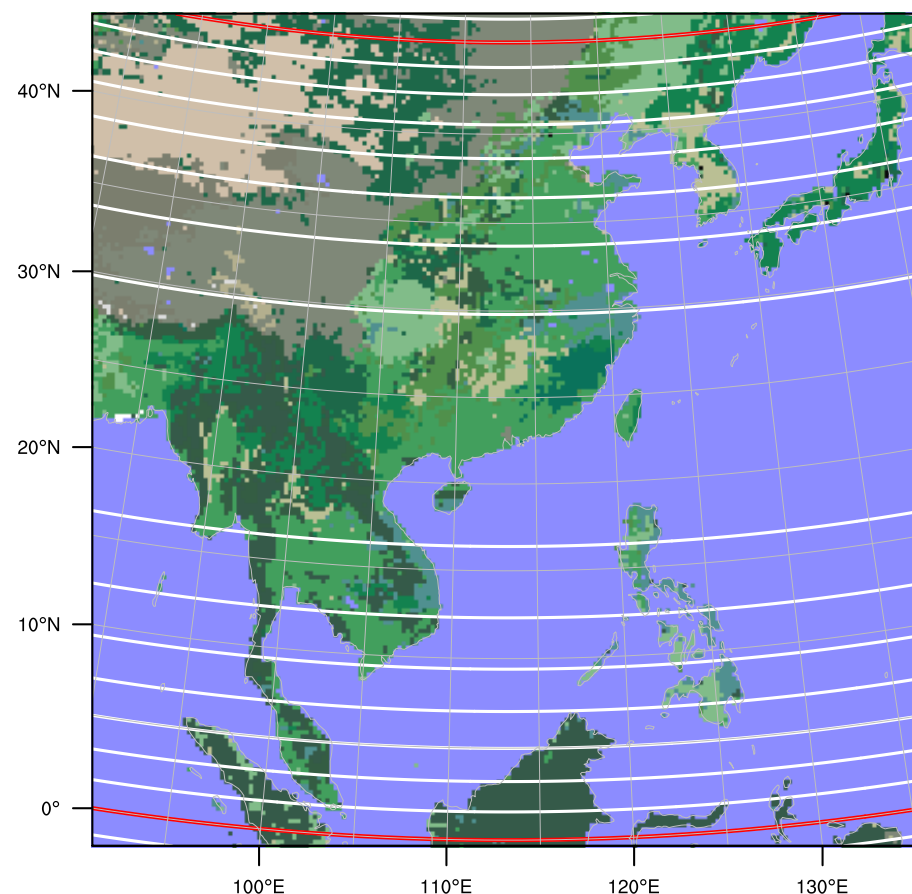
Above: The maximum map scale factor is 1.03, but the minimum is 0.924, corresponding to a physical distance of 29.2 km.

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.