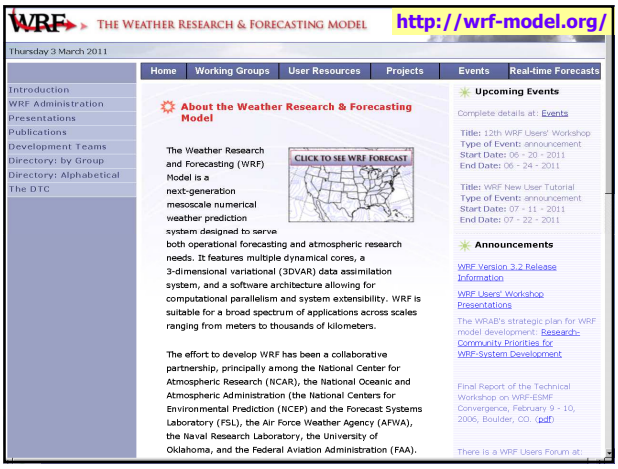
WRF Overview

WRF THE WEATHER RESEARCH & FORECASTING MODEL



Outline

- What is WRF and why use it...?
- ARW Dynamics
- Modeling System Components
- Pre-processing – WPS
- Initialization
- Running WRF
- Post-processing and Verification

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What is WRF...?

- Weather Research and Forecasting Model
- Operational forecasting and atmospheric research
- 'Community Model'
- Developed by NCAR and NOAA
- Current Version – 3.2: released April 2009
- Next Version – 3.3: due in March 2011

Numerical Weather Prediction

ACM 40520

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What is WRF…?

- Non-hydrostatic model
- Terrain-following hydrostatic pressure coordinate
- Arakawa C-grid staggering
- Runge-Kutta 2nd and 3rd order time integration schemes
- 2nd to 6th order advection schemes
- Semi-implicit acoustic step off-centering
- ARW and NMM dynamical cores.

What is WRF…?

- Advanced Research WRF (ARW) and Nonhydrostatic Mesoscale Model (NMM) are both dynamical cores
  - Dynamical core includes advection, pressure-gradients, Coriolis, buoyancy, filters, diffusion and time-stepping.
- Both use Eulerian mass dynamical cores with terrain-following vertical coordinates
- Both share physics, software framework, and parts of the pre- and post-processing systems.

ARW or NMM…?

- ARW and NMM
  - Atmospheric physics research
  - Case-study research
  - Real-time NWP and forecast system research
  - Data assimilation research
  - Teaching dynamics and NWP
- ARW only
  - Regional climate and seasonal time-scale research
  - Coupled-chemistry applications
  - Global simulations
  - Idealized simulations at many scales (e.g. convection, baroclinic waves, large eddy simulations)

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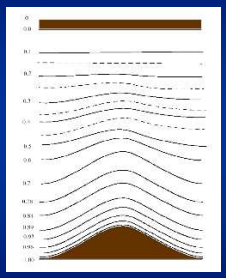
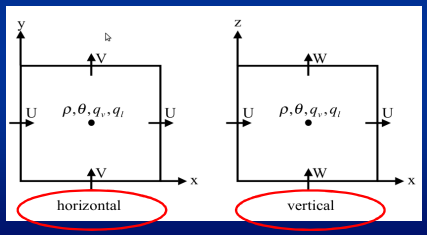
ARW Dynamics – Key Features

- Equations:
  - Fully compressible
  - Non-hydrostatic
  - Scalar conservative
- Vertical Coordinate:
  - Mass-based terrain following coordinate
  - Top of model is a constant pressure surface



ARW Dynamics – Key Features

- Horizontal Grid
  - Arakawa C-grid staggering



ARW Dynamics – Key Features

- **Prognostic Variables:**
  - Velocity componets u, v
  - Vertical velocity w, potential temp, geopotential, surface pressure
- **Time Integration:**
  - 3rd order Runge-Kutta scheme

$$\phi^{*} = \phi^{t} + \frac{\Delta t}{3} R\left(\phi^{t}\right)$$
$$\phi^{**} = \phi^{t} + \frac{\Delta t}{2} R\left(\phi^{*}\right)$$
$$\phi^{t+\Delta t} = \phi^{t} + \Delta t\, R\left(\phi^{**}\right)$$

ARW Dynamics – Key Features

- **Spatial Discretization**
  - 2nd to 6th order advection options in horizontal and vertical
- **Turbulent Mixing and Model Filters**
  - Divergence damping, sub-grid scale turbulence formulation
- **Initial Conditions**
  - 3 dimensional for real cases
  - Digital filtering initialization (DFI)

ARW Dynamics – Key Features

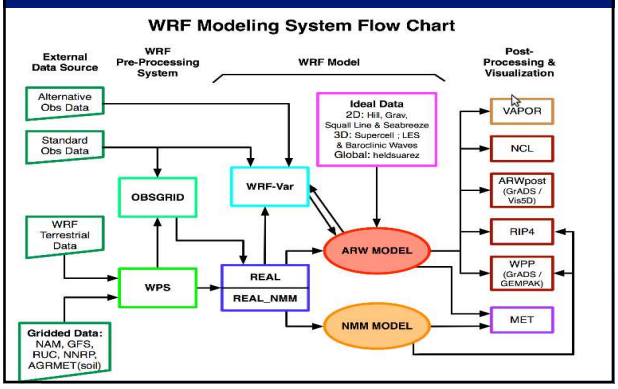
- **Lateral Boundary Conditions**
  - Periodic, open, symmetric
- **Top Boundary Conditions**
  - Gravity wave absorbing
  - Constant pressure level
  - Rigid lid option
- **Bottom Boundary Conditions**
  - Physical or free-slip

ARW Dynamics – Key Features

- **Earth's rotation**
  - Full Coriolis terms included
- **Mapping to Sphere**
  - Four supported map projections
- **Nesting**
  - One-way and two-way nesting
  - Static or moving grids
- **Nudging**
  - Grid analysis and observation nudging capabilities

Outline

WRF Modeling System



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- **Pre-processing – WPS**
- Initialization
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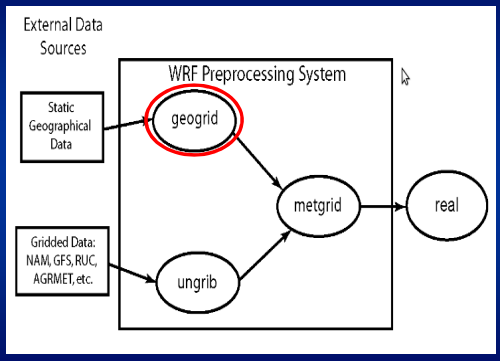
WRF Preprocessing System

- **The purpose of the WPS is to prepare input to WRF for real-data simulations. It:**
  - **Defines simulation domain and ARW nested domains**
  - **Computes latitude, longitude, map scale factor and Coriolis parameters at every grid point**
  - **Interpolates time invariant terrestrial data to simulation grids (e.g. terrain height and soil type)**
  - **Interpolates time-varying meteorological fields from another model onto simulation domains**

WRF Preprocessing System



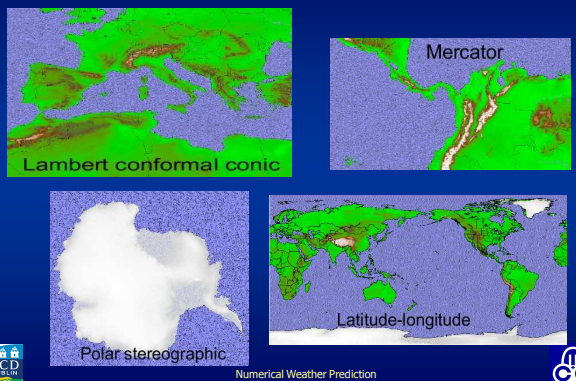
WPS – The *geogrid* program

- **Geogrid defines:**
  - **Map projection**
  - **Geographic location of domains**
  - **Dimensions of domains**
- **Geogrid provides:**
  - **Values for static fields at each model grid point**
  - **Computes latitude, longitude, map scale factor and Coriolis parameters at each grid point**
  - **Horizontally interpolates static terrestrial data (e.g. topography, height, land use category, soil type, vegetation fraction, monthly surface albedo)**

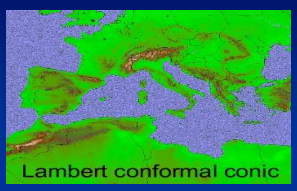
WPS – The *geogrid* program

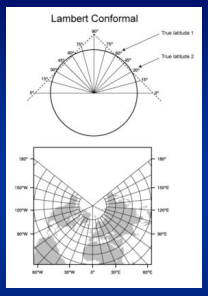
- **First, choose a map projection**
  - **Why? - The Earth is roughly ellipsoidal, but WRF computational domains are defined by rectangles on a plane**
- **ARW can use the following projections**
  - **Lambert conformal**
  - **Mercator**
  - **Polar stereographic**
  - **Latitude-longitude**

ARW Projections



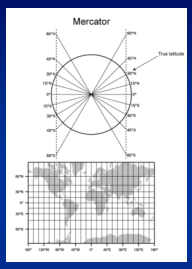
ARW Projections – Lambert Conformal





- Well-suited for mid-latitudes
- Domain cannot contain either pole
- Domain cannot be periodic in west-east direction
- One or two *true latitudes* may be specified

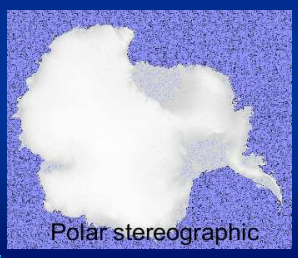
ARW Projections - Mercator

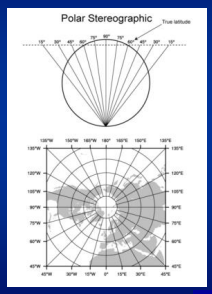


- Well-suited for low latitudes
- May be used for periodic domain in west-east direction
- A single true latitude is specified

ARW Projections – Polar Stereographic

- Good for high-latitude domains (including pole)
- A single true latitude is specified

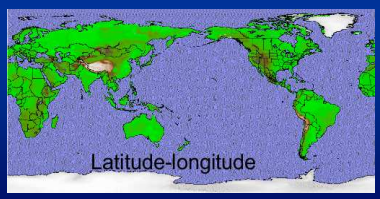




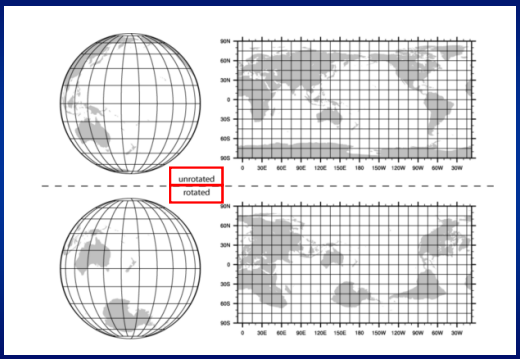
ARW Projections - Latitude-Longitude

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

[Rotation involves moving the poles of the projection away from the geographical poles]



ARW Projections - Latitude-Longitude

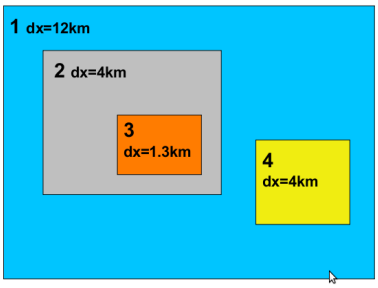


ARW Dynamics – Nesting

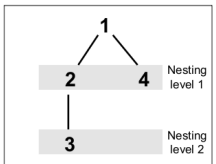
- A nested domain is wholly contained within its parent domain and receives information from its parent.
- It may also feed information back to its parent [2-way nesting]
- A nested domain has exactly one parent
- A domain may have one or more children
- 2-way nests on the same nesting level must not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

ARW Dynamics – Nesting

Example configuration – 4 domains



Each domain is assigned a *domain ID #*

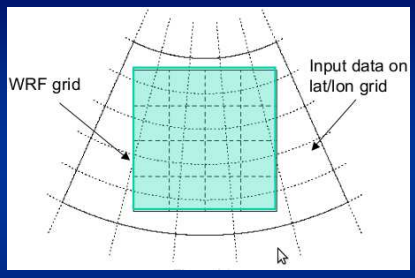


Nesting structure shown as a tree for the domains at left

Geogrid: Interpolating Static Fields

- ***Geogrid*** **interpolates terrestrial, time-invariant fields:**
  - **Topography height**
  - **Land use categories**
  - **Soil type (top layer and bottom layer)**
  - **Annual mean soil temperature**
  - **Monthly vegetation fraction**
  - **Monthly surface albedo**

Geogrid: Interpolating Static Fields



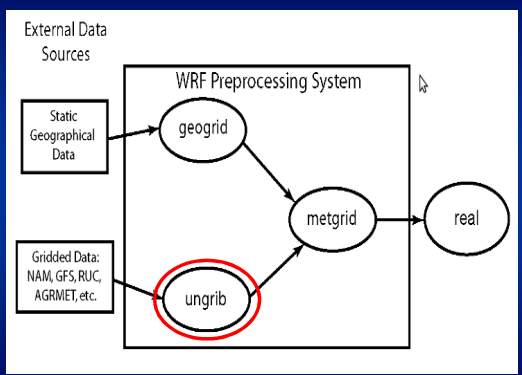
- **Normally, source data are given on a different projection from the model grid**

Geogrid: Interpolating Static Fields

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 neighbour**
- **Breadth-first search**

WRF Preprocessing System



The *ungrib* program

- **What is a GRIB file?**
- **WMO standard file format for storing regulary distributed fields**
- **General Regularly-distributed Information in Binary**
- **Fields are compressed with a lossy compression**
  [Think of truncating numbers to a fixed number of digits]

- **Fields in file are identified by code number**
- **These numbers are referenced against an external table to determing the corresponding field**

The *ungrib* program

- What does it do?
  - Reads in GRIB data
  - Extracts meteorological fields
  - Derives required fields if necessary
    - e.g. Computes RH from T, P and Q
  - Writes requested fields to an intermediate file format.

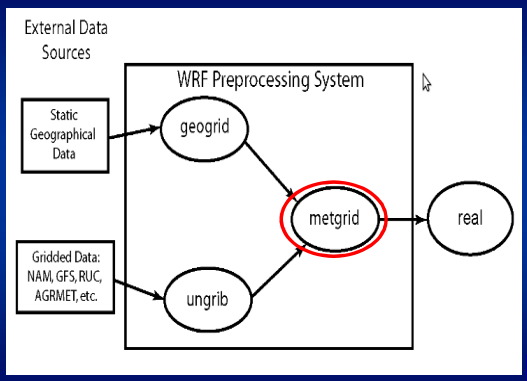
How does ungrib know which fields to extract?

- From vtables …

The *ungrib* program - Vtables

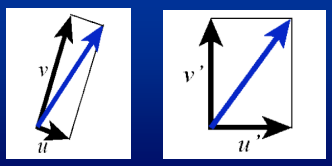
GRIB1 Param	Level Type	From Level1	To Level2	UNGRIB Name	UNGRIB Units	UNGRIB Description
11	100	*		T	K	Temperature
33	100	*		U	m s-1	U
34	100	*		V	m s-1	V
52	100	*		RH	%	Relative Humidity
7	100	*		HGT	m	Height
11	105	2		T	K	Temperature at 2 m
52	105	2		RH	%	Relative Humidity at 2 m
33	105	10		U	m s-1	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

WRF Preprocessing System



The *metgrid* program

- Horizontally interpolates meteorological data, extracted by *ungrib*, to simulation domains, defined by *geogrid*
- Rotates winds to WRF grid
  - i.e. rotates so that U-component is parallel to x-axis, V-component parallel to y-axis

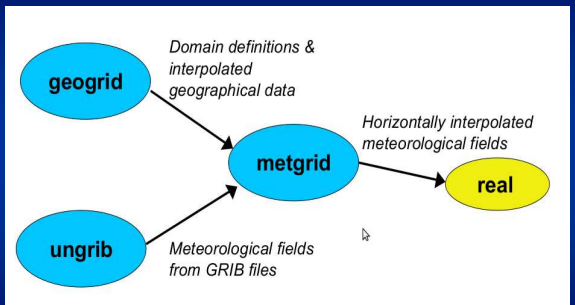


Metgrid: Interpolating Static Fields

Interpolation options [same options as for geogrid]

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

WPS Summary



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Initialization

- ideal.exe
  - Program for controlled (idealized) scenarios
  - Examples include 2-D and 3-D idealized cases, with or without topography, with or without an initial thermal perturbation.
- real.exe
  - Program for real data cases
  - Interpolates the intermediate files generated by *metgrid.exe* in the vertical, creates boundary and initial condition files and does some consistency checks.

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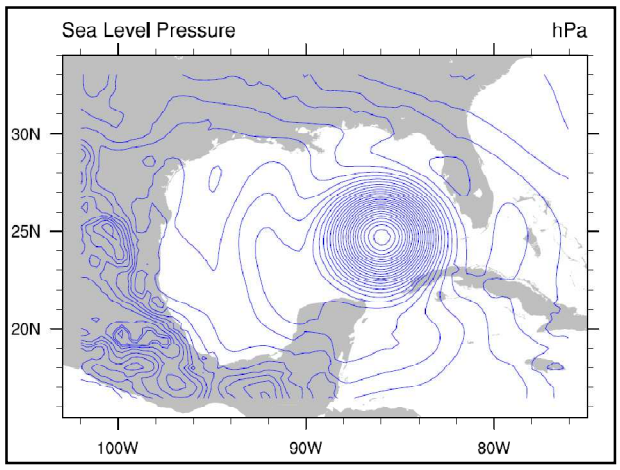
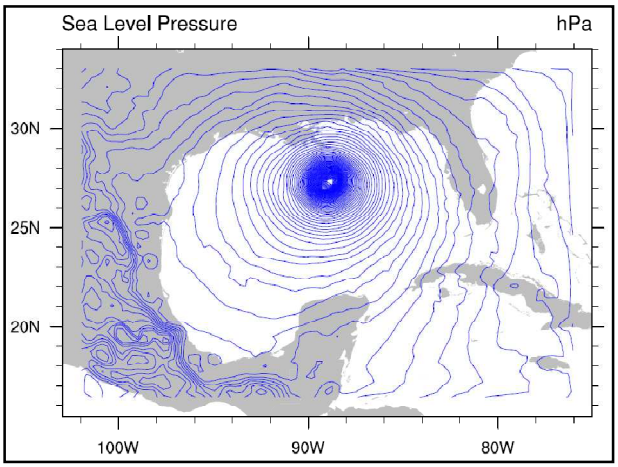
Running WRF

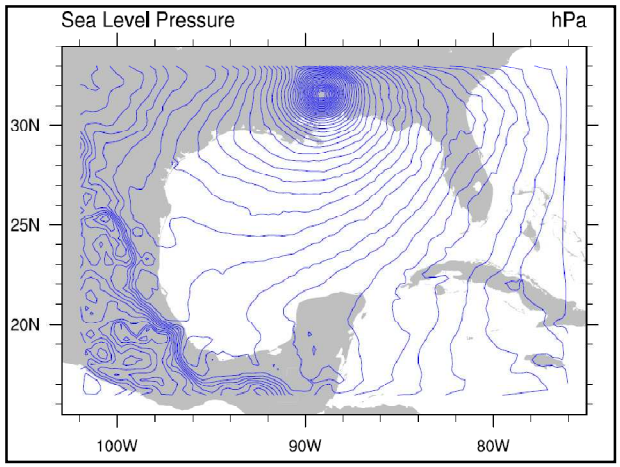
- cd into run/ directory
- Link WPS output files to directory for real-data cases
- Edit *namelist.input* for appropriate grid and time of case
- Run initialization program *real.exe*
- Run model executable *wrf.exe*

Running WRF

Simulation of Hurricane Katrina







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Post processing - Graphics

Several graphical packages available

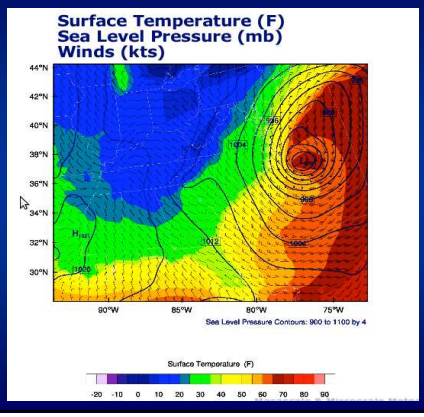
- NCL
- ARWpost
- RIP4
- VAPOR
- IDV

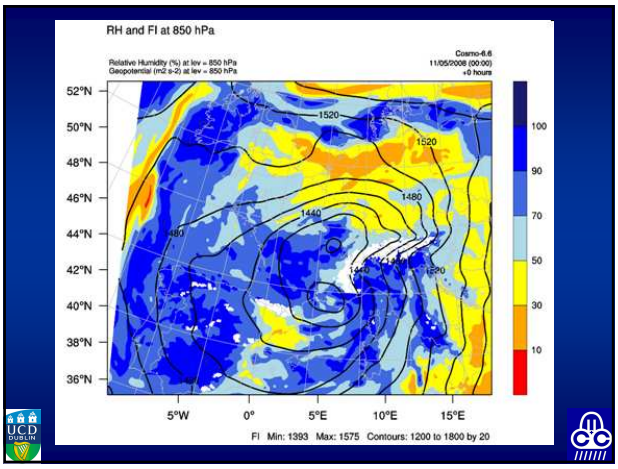
NCL Graphics

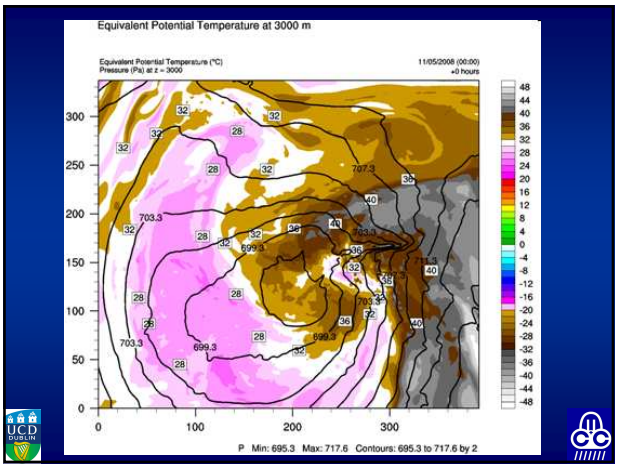
- NCAR Command Language
- Reads in WRF-ARW data directly
- Generates a number of graphical plots using scripts
  - e.g. Horizontal, cross-section, skewT, meteogram, panel

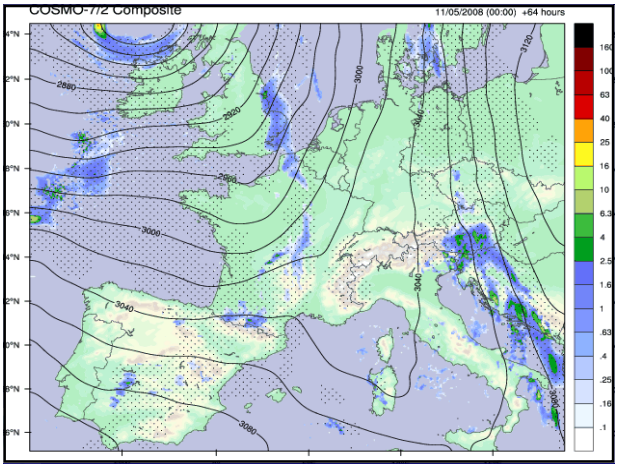
```
load "$NCARG_ROOT/lib/ncarg/nclscripts/wrf/WRFUserARW.ncl"

begin

  ; Open graphical output
  ; Open input file(s)

  ; Read variables

  ; Set up plot resources & Create plots
  ; Output graphics

end
```

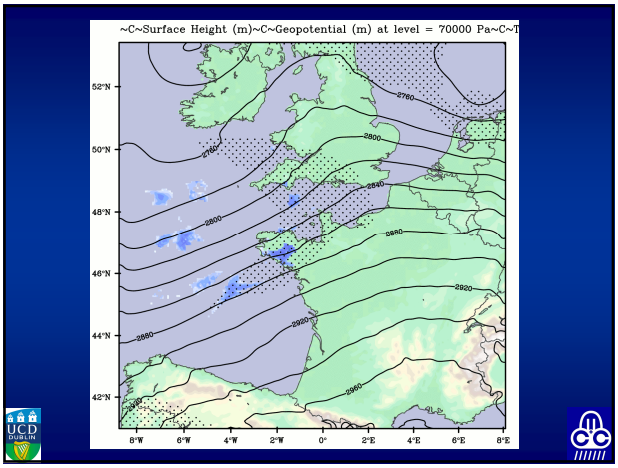
NCL Graphics











Post-processing and Verification

- **MET verification software**
  - Model Evaluation Tools
  - All the basics – RMSE, bias, skill scores
  - Advanced spatial methods (wavelets, objects)
  - Confidence intervals
- **Additional Information:**
- http://www.mmm.ucar.edu/wrf/users/docs/user_guide_V3.1/contents.html
- http://www.mmm.ucar.edu/wrf/users/docs/arw_v3.pdf

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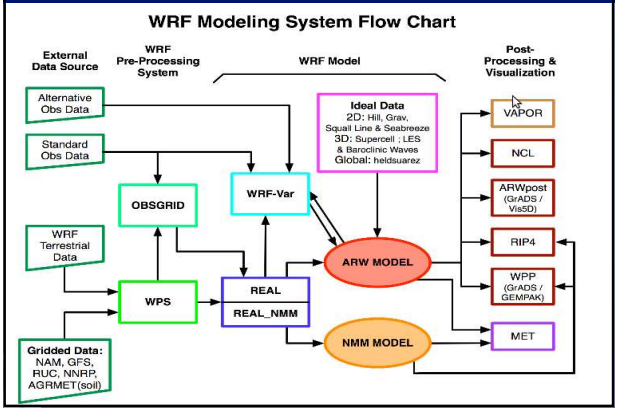

Thank you