# WRF Data and Utilities

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# Supported Post-processing Packages

http://www2.mmm.ucar.edu/wrf/users/docs/user_guide_V3.8/contents.html

| Package | Users' Guide Page # | Information |
|---|---|---|
| NCL | 9-2 | Graphical package<br>Supported by NCAR/CISL (wrfhelp@ucar.edu and ncl-talk@ucar.edu) |
| ARWpost | 9-29 | Converter (GrADS) (wrfhelp@ucar.edu) |
| RIP4 | 9-20 | Converter and interface to graphical Package, NCAR graphics (wrfhelp@ucar.edu) |
| UPP | 9-36 | Converter (GrADS & GEMPAK) (upp-help@ucar.edu) |
| VAPOR | 9-38 | Converter and graphical package<br>Supported by VAPOR (vapor@ucar.edu) |
| IDV | None – see unidata.ucar.edu | GRIB (from UPP)<br>GEMPAK (from wrf2gem)<br>Vis5d<br>CF compliant data (from wrf_to_cf)<br>Supported by unidata (support@unidata.ucar.edu) |
| GEMPAK | None - see: unidata.ucar.edu/software/gempak | Data from wrf2gem or UPP<br>Supported by unidata (support@unidata.ucar.edu) |

# Choosing the Right Tool

- Can it read your data?
- Will you need to pre-process the data first?
- Is it purely a visualization tool, or does it include post-processing?
- Can it handle big datasets?
- Which diagnostic/statistical functions does it have?
- How easy is it to add diagnostics?
- 3D or 2D visualization?
- Can it handle staggered grids?
- How are data below the ground handled?
- Vertical grids?
- How are model time stamps handled?
- Easy to use?
- Cost of package?
- How well supported is it?

# Data Handling

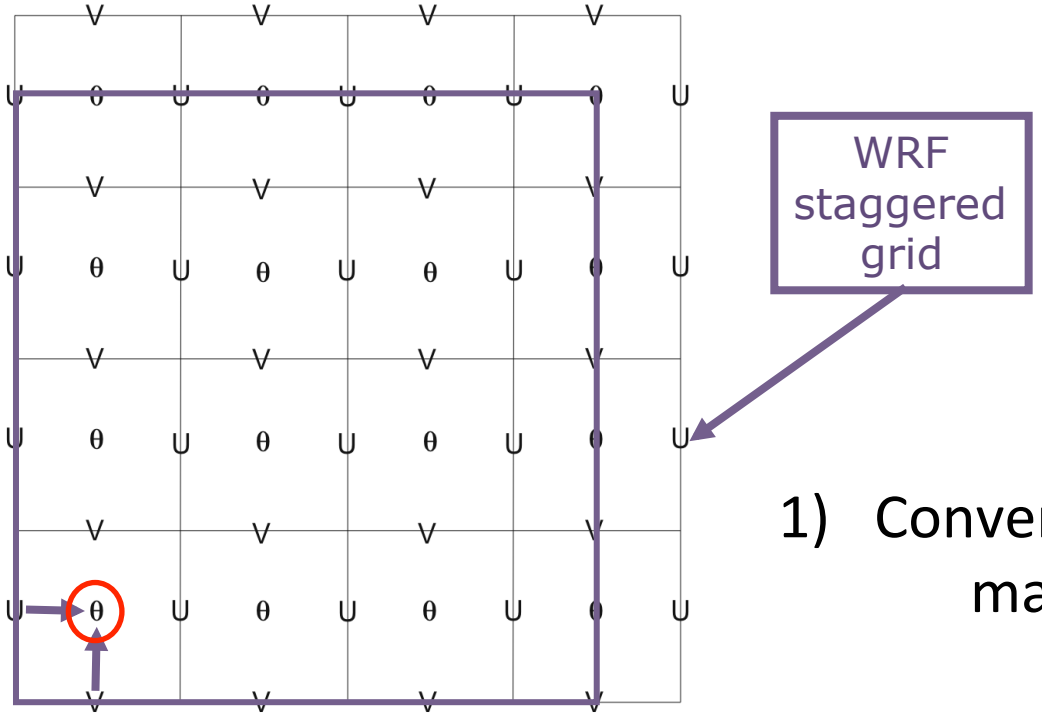
| | NCL | RIP4 | GrADS | UPP | VAPOR | IDV |
|---|---|---|---|---|---|---|
| **netCDF** | | ripdp | ARWpost | converter | converter | converter |
| **GRIB** | | | | | | |
| **ASCII** | | | | | | |
| **shapefiles** | | | | | | |
| **geogrid & metgrid output** | | | | | | |
| **intermediate file format** | ***V6.2.0*** ***V6.3.0*** | | | | | |
| **wrfinput data** | | | | | | |
| **Idealized data** | | | | | | |
| **wrfoutput** | | | | | | |
| **big data** | | | | | | |

# Post-processing

| | NCL | RIP4 | GrADS | UPP | VAPOR | IDV |
|---|---|---|---|---|---|---|
| **Post-processing** | | | | | | |
| **Data output** | | | | | | |
| **3D** | | | | | | |
| **diagnostics** | some | a lot | some | some | limited | limited |
| **Add diagnostics** | Very easy | easy | easy | Relatively easy | Not as easy | Not as easy |
| **Vertical output Coordinate** | Model pressure height | Model pressure height | Model pressure height | pressure | model | model |
| **Extrapolate Below ground** | | | | | | |

# Model Staggering

Why is a converter necessary if a package can display netCDF files?




1) Converter co-locates data to mass points

2) Converter translates variables
- e.g., “T” is not really temp. Must add 300 for actual temp (K)

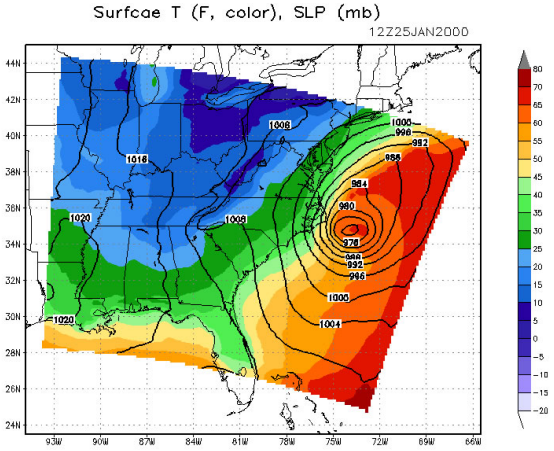
# ARWpost

# ARWpost: General Information

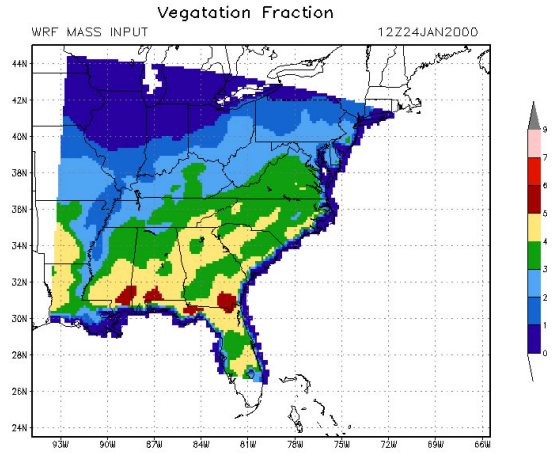
- Converter
  - Reads in wrf-arw model data, creates GrADS output files (.ctl)
  - Requires GrADS to display
  - GrADS not supported by NCAR
- GrADS software is only needed to display data, not needed to compile the code
  - http://www.iges.org/grads/grads.html
- Generate a number of graphical plots
  - Horizonal
  - Cross-section
  - skewT
  - Meteogram
  - Panel
- Download Code
  - http://www2.mmm.ucar.edu/wrf/users/download/get_sources.html
- Online Tutorial
  - http://www2.mmm.ucar.edu/wrf/users/graphics/ARWpost/ARWpost.htm

# ARWpost: Example Plots

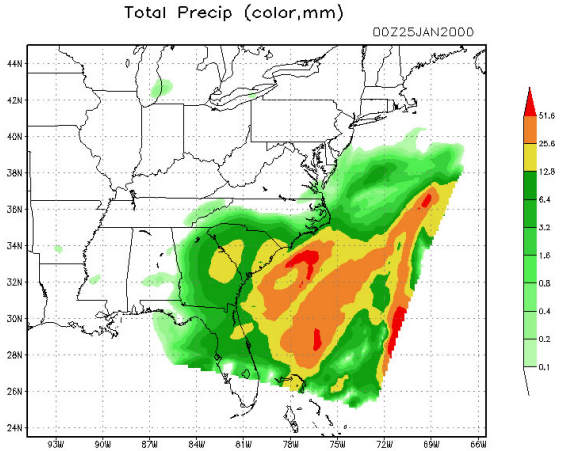
## Surface Temp



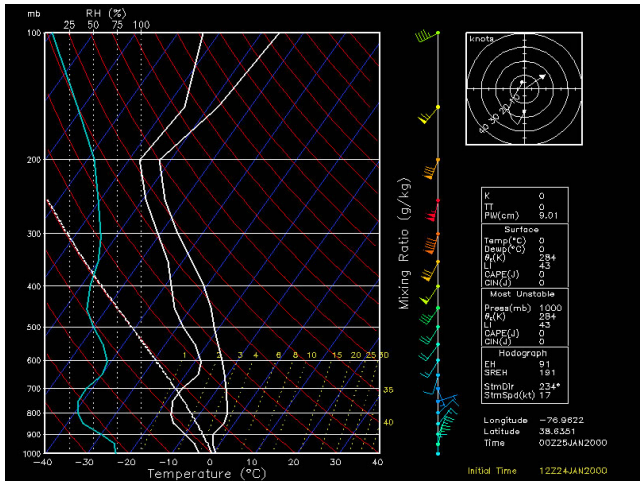

## Vegetation Fraction




## Total Precipitation

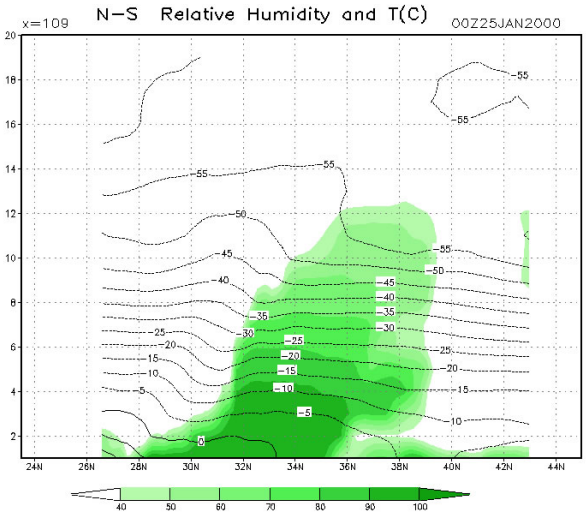


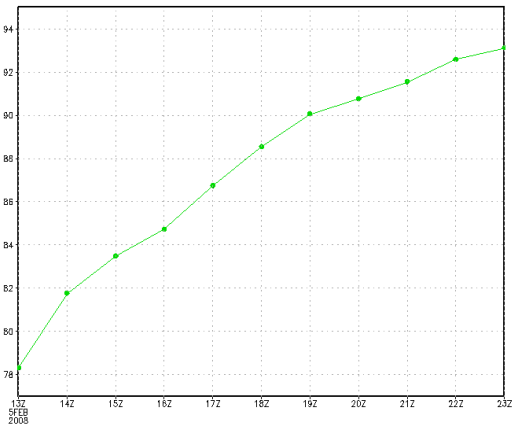

## Skew-T Diagram



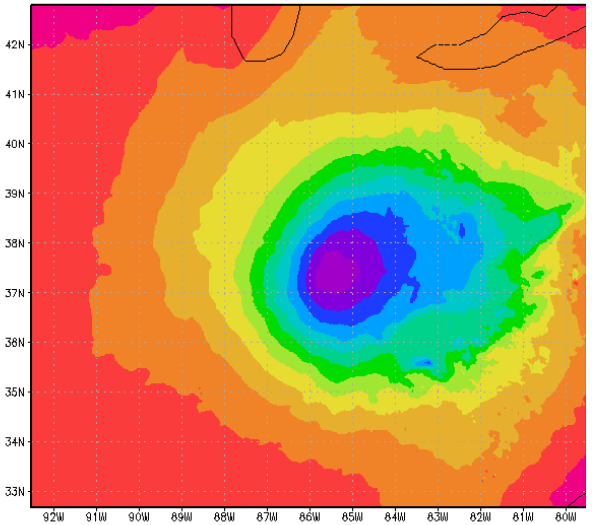
# ARWpost: Example Functions

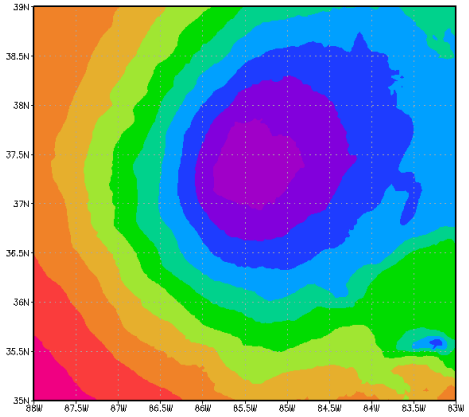
## Cross-Sections



## Zooming





# ARWpost: Diagnostics

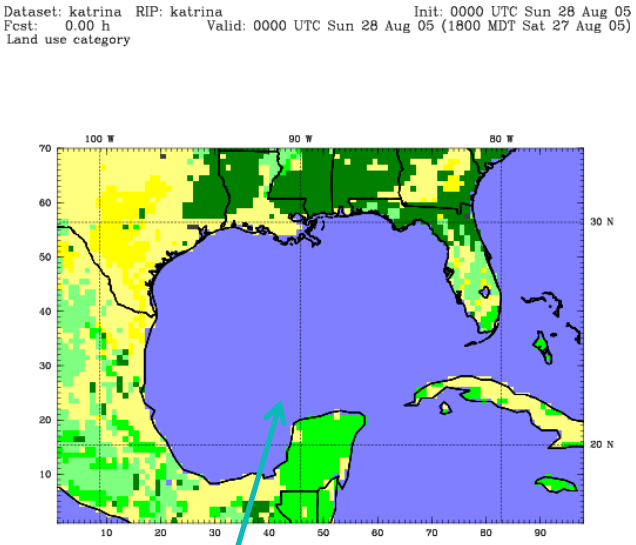
- cape – 3d cape
- cin – 3d cin
- mcape – maximum cape
- mcin – minimum cin
- clfr – low/middle/high cloud fraction
- dbz – 3d reflectivity
- max_dbz – maximum reflectivity
- geopt – geopotential
- height – model height in km
- lcl – lifting condensation level
- lfc – level of free convection
- pressure – full model pressure in hPa
- rh – relative humididy
- rh2 – 2 m relative humidity
- theta – potential temperature
- tc – temperature in degrees C
- tk – temperature in degrees K
- td – dew point temperature in degrees C
- td2 – 2m dew point temperature in degrees C
- slp – sea level pressure
- umet & vmet – winds rotated to Earth coordinates
- u10m & v10m – 10 m winds rotated to Earth coordinates
- wdir – wind direction
- wspd – wind speed coordinates
- wd10 – 10 m wind direction
- ws10 – 10 m wind speed

# ARWpost: Scripts

| Script Name | Description |
|---|---|
| cbar.gs | Plots a color bar on shaded plots |
| rgbset.gs | Allows you to add/change colors from color # 20 – 99 |
| skew.gs | Program to plot a skewT |
| plot_all.gs | Automatically finds all .ctl files in the directory and lists them so the user can pick when to use, will plot all fields chosen |
| rain.gs (real data only) | Plots total rainfall (must have data that contain fields RAINC and RAINNC) |
| cross_z.gs (real data only) | Plots a NS and EW cross section of RH and T (C) |

# RIP4

# RIP4: Example Plots

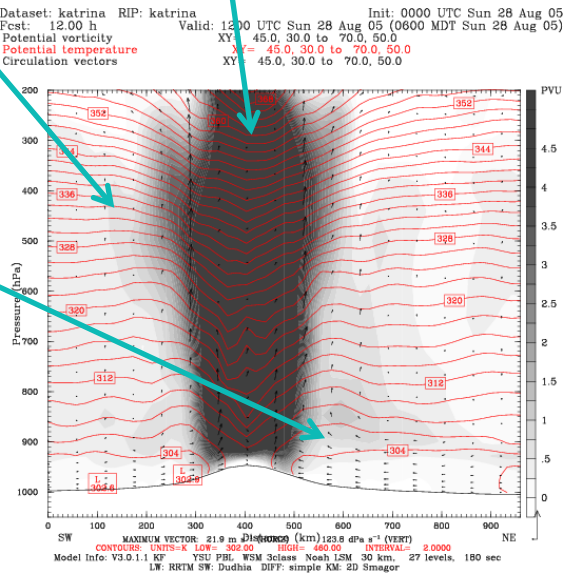


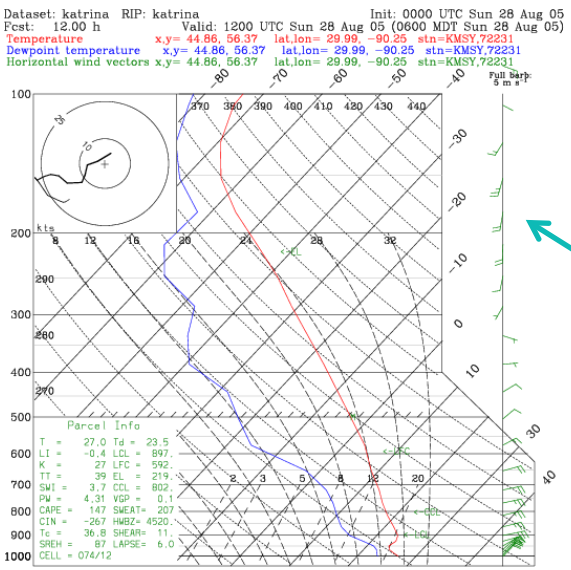

Landuse Category

Potential Temp

Potential Vorticity

Circulation Vectors

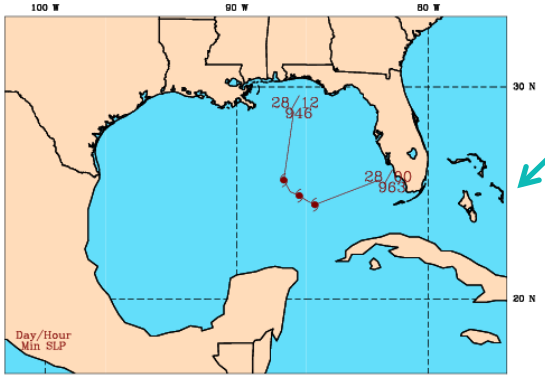


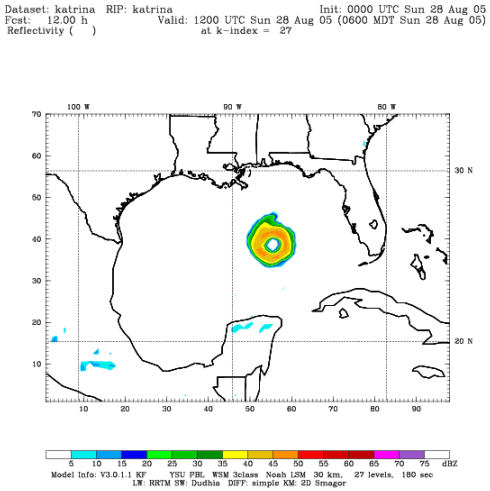




Skew-T Diagram

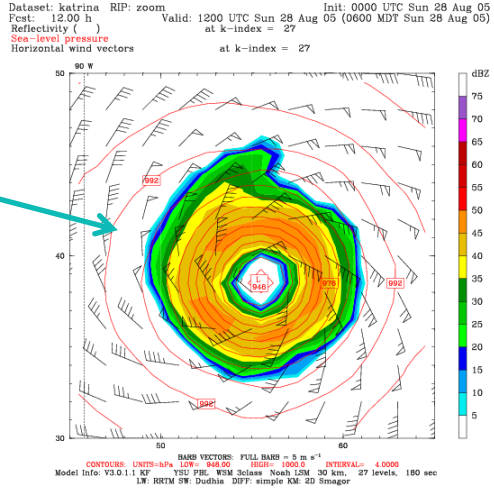
# RIP4: Example Plots


Cyclone Tracking

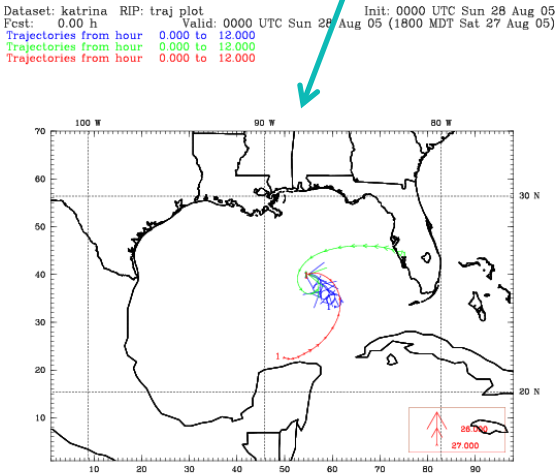


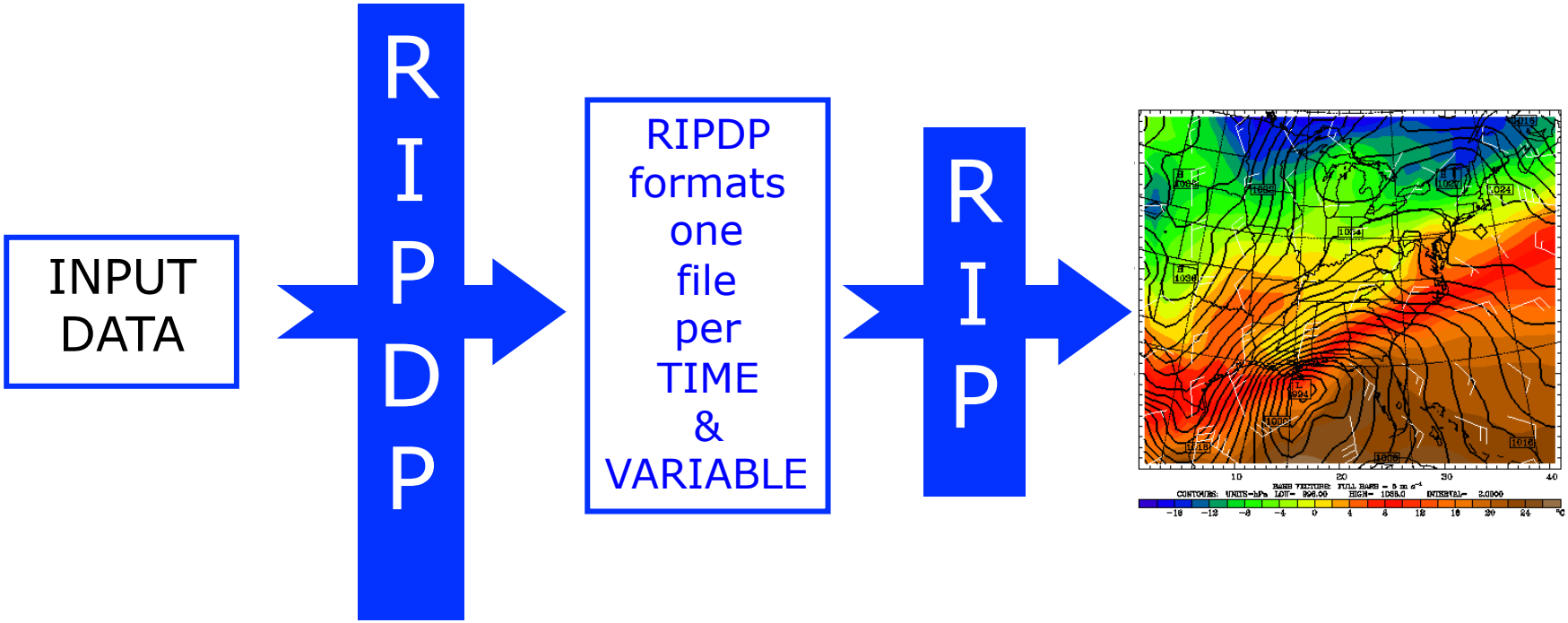

Zooming Capability




Trajectories



# RIP4: Program Flow



# RIP4: General Information

- Requires NCAR Graphics Libraries
  - http://www.ncl.ucar.edu
- Source Code
  - http://www2.mmm.ucar.edu/wrf/users/download/get_source.html
- Documentation
  - Included in program's tar file (in Doc/ directory)
  - http://www2.mmm.ucar.edu/wrf/users/docs/ripug.htm
- Online Tutorial
  - http://www2.mmm.ucar.edu/wrf/users/graphics/RIP4/RIP4.htm

# Utilities

- Graphics
- Designing a model domain
- OBSGRID
- netCDF tools
- Data
- MET

# Graphics: ImageMagick

## http://www.imagemagick.org

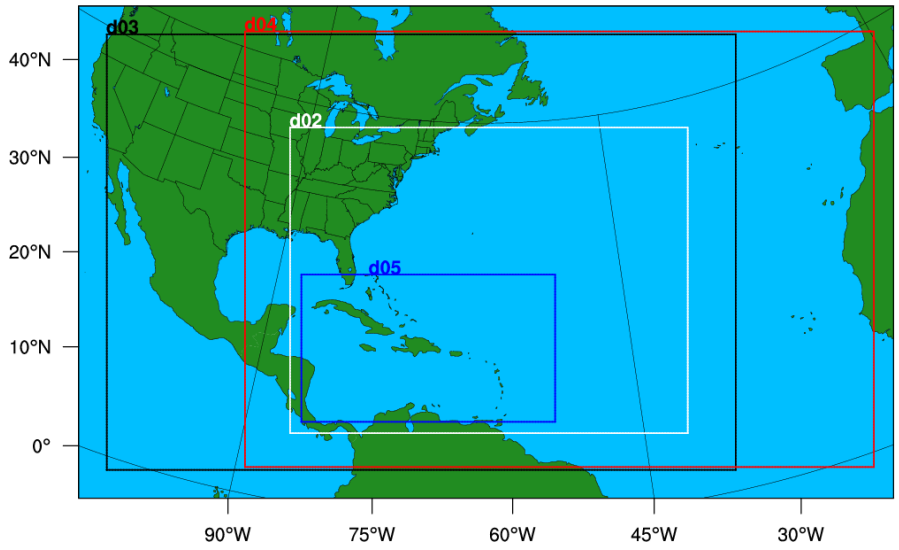
- Converts graphical files from one format to another
  *convert* *file*.pdf *file*.png
  *convert* *file*.png *file*.bmp
- Many options available
  - Rotate frames, trim white space, etc.
- Can make movies
  - Can create individual frames for each image
- Maintains high resolution – great for publishing!
- Cannot deal with .ncgm files

# Model Domain Design

```
mpres@mpFillColors  =
 (/"background","DeepSkyBlue",
 "ForestGreen","DeepSkyBlue",
 "transparent"/)


mpres@mpGridSpacingF    = 45


lnres@domLineColors     = (/
 "white", "Red" , "Red" , "Blue" /)


mpres@mpOutlineBoundarySets
 "NoBoundaries"   ; "Geophysical"
 "National"       ; "USStates"
 "GeophysicalAndUSStates"
 "AllBoundaries"
pares = True
 pmres@gsMarkerColor = "White"
 pmres@gsMarkerIndex = 16
 pmres@gsMarkerSizeF = 0.01
 gsn_polymarker(wks,mp,-77.26,38.56
 ,
                  pmres)
```

- plotgrids.ncl
  - *WPS/util/plotgrids.ncl*
  - Reads namelist information to generate plot
  - X11, png, pdf

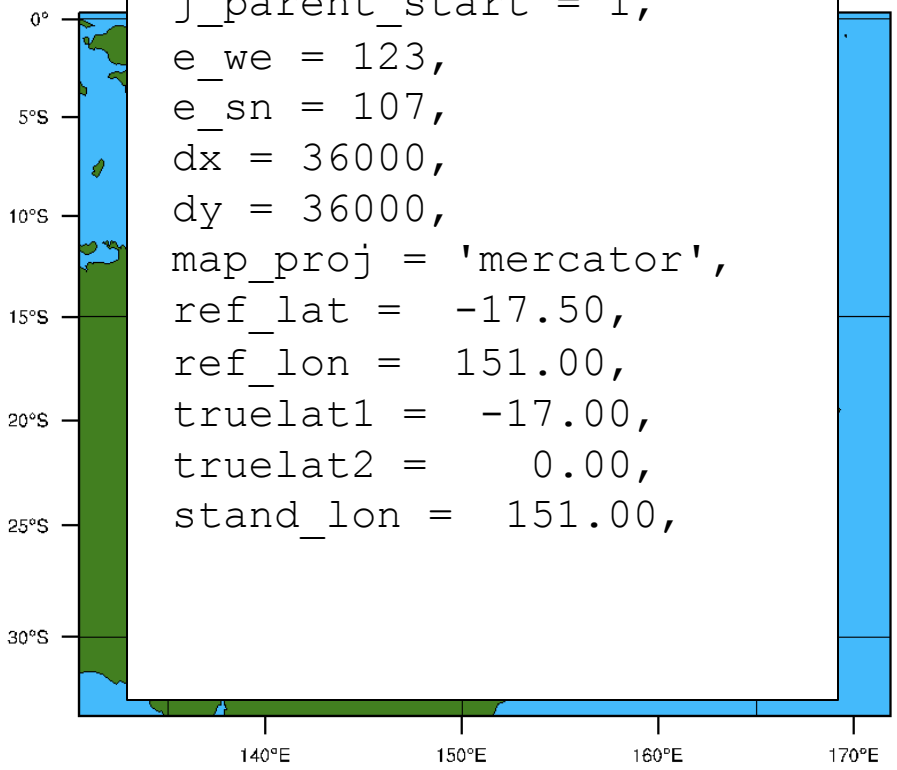
Test Domain



# Model Domain Design

```
DOMS = 1
DX = 36.
MAP = "mercator"
LAT1 = (/ -35.0, -45., -27. /)
LAT2 = (/   0., -20., -23. /)
LON1 = (/ 131., 121., 125./)
LON2 = (/ 171., 159., 131./)
parent_id = (/ 0, 1, 2 /)
parent_grid_ratio = (/ 1, 3, 3 /)
```

**design_grids.ncl**




```
Suggested namelist options
 parent_id = 0,
 parent_grid_ratio = 1,
 i_parent_start = 1,
 j_parent_start = 1,
 e_we = 123,
 e_sn = 107,
 dx = 36000,
 dy = 36000,
 map_proj = 'mercator',
 ref_lat =  -17.50,
 ref_lon =  151.00,
 truelat1 =  -17.00,
 truelat2 =    0.00,
 stand_lon =  151.00,
```

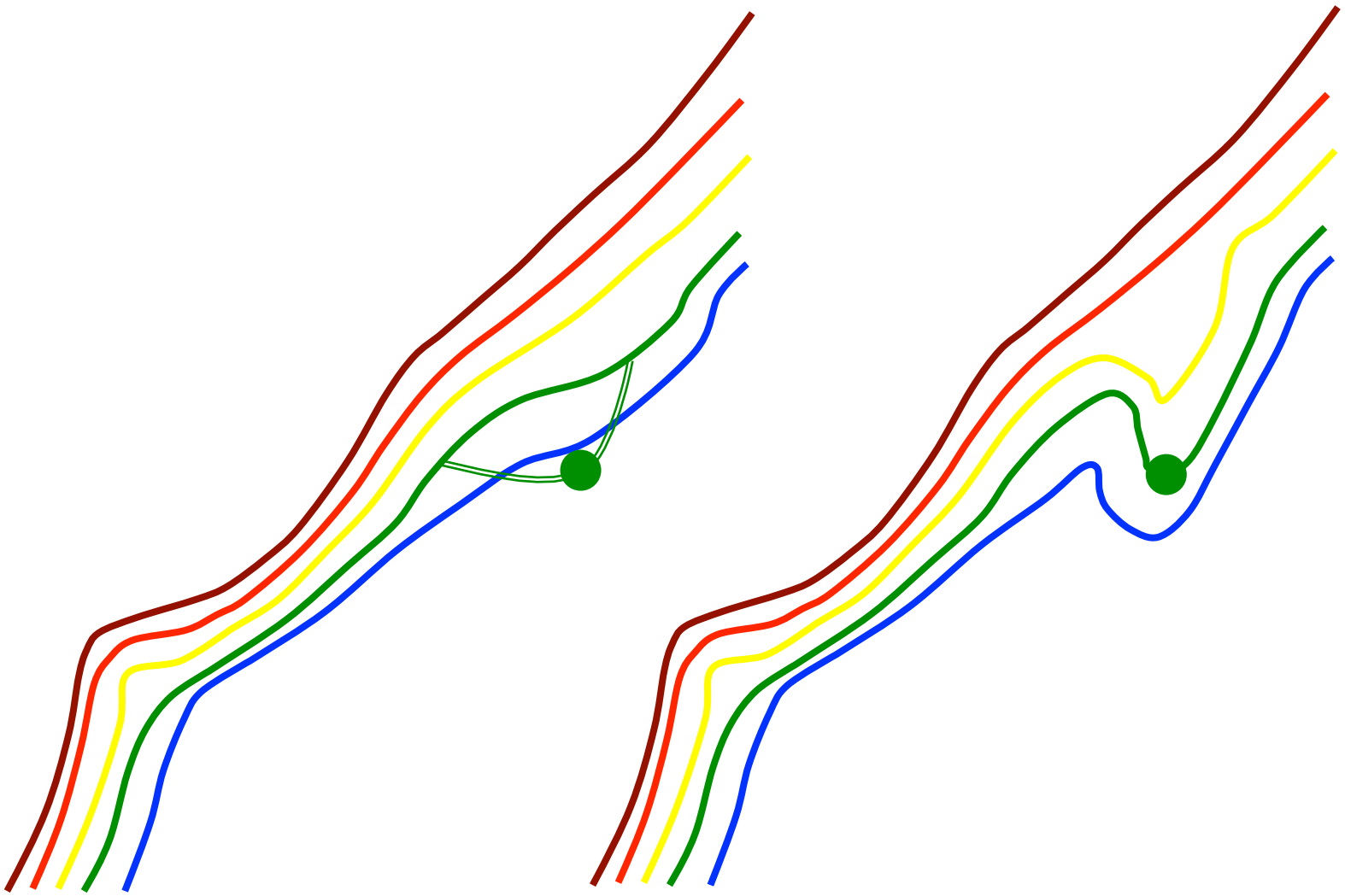
# OBSGRID

# OBSGRID

- To improve a first-guess gridded analysis by incorporating additional observational information
  - Traditionally first-guess analysis came from low-resolution global analysis and forecast grids
  - These days, higher-resolution, regional scale analyses are more readily available

- When is this method useful?
  - When using very coarse resolution first-guess input data
  - If you conducted a field campaign and have acquired very high-resolution station data (for example)

# OBSGRID: Basic Concept



# OBSGRID: How to Run

- Get the source code

  http://www2.mmm.ucar.edu/wrf/users/downloads.html
- Compile
- Prepare observation files
- Edit the namelist.oa
- Link in met_em* files from WPS
- Run the program
  - ./obsgrid.exe
- Check your output

See the WRF Users' Guide for detailed information
http://www2.mmm.ucar.edu/wrf/users/docs/user_guide_V3.8/users_guide_chap7.htm

# OBSGRID: How to Use to Run WRF

- Link the 'metoa_em*' files to WRF running directory

  ln –sf ../../../OBSGRID/metoa_em.d01.* .

- Add the following to the &time_control section of the namelist

  auxinput1_inname = "metoa_em.d<domain>.<date>"

- Run real.exe

- Run wrf.exe

# OBSGRID - Grid Nudging - Surface

- If you are interested in doing surface analysis nudging
- OBSGRID creates a file called wrfsfdda_d0*
- How to use this:
  - In &fdda, set grid_fdda = 1 and grid_sfdda = 1
  - Run real.exe and get a file called wrffdda_d01, and use with wrfsfdda_d01, wrfinput_d01, and wrfbdy_d01
  - Run wrf.exe
- For more information, refer to Jimy Dudhia's ARW Nudging talk

# OBSGRID – Observation Nudging

- Allows for input observation data & quality control
- Used if you have a large number of extra observations, and a single case study (not recommended for climate studies)
- Can get obs data from CISL (little R format)
- How to use this
  - OBSGRID creates a files called OBSDOMAIN_XXX (can concatenate files into 1: OBSDOMAIN_101)
  - In &fdda, add obs_nudge_opt = 1
  - In &time_control, add auxinput11_interval_s = *180,* auxinput11_end_h = *24*
  - Will need OBSDOMAIN_101, wrfinput_d01 and wrfbdy_d01 files
  - Run real.exe and wrf.exe as usual
- For more information, see http://www2.mmm.ucar.edu/wrf/users/wrfv3.1/How_to_run_obs_fdda.html and Jimy Dudhia's ARW Nudging talk

# NCO Tools

http://nco.sourceforge.net

- netCDF Operators are command-line programs that take netCDF (HDF and/or DAP) files as input, then operate (e.g., derive new data, compute stats, print, manipulate metadata) and output to the screen or files in various formats (text, binary, netCDF, etc.)

- ncdiff
  - Shows the differences between 2 files

```
ncdiff input1.nc input2.nc output.nc
```

- ncrcat (nc cat)
  - Writes specified variables/times to a new file

```
ncrcat -d Time,0,231 -v RAINNC wrfout* RAINNC.nc
```

- ncra (nc average)
  - Averages variables and writes to a new file

```
ncra -v OLR wrfout* -o OLR.nc
```

- ncks (nc kitchen sink)
  - Combination of all NCO tools in 1
  - Specifically nice for splitting files

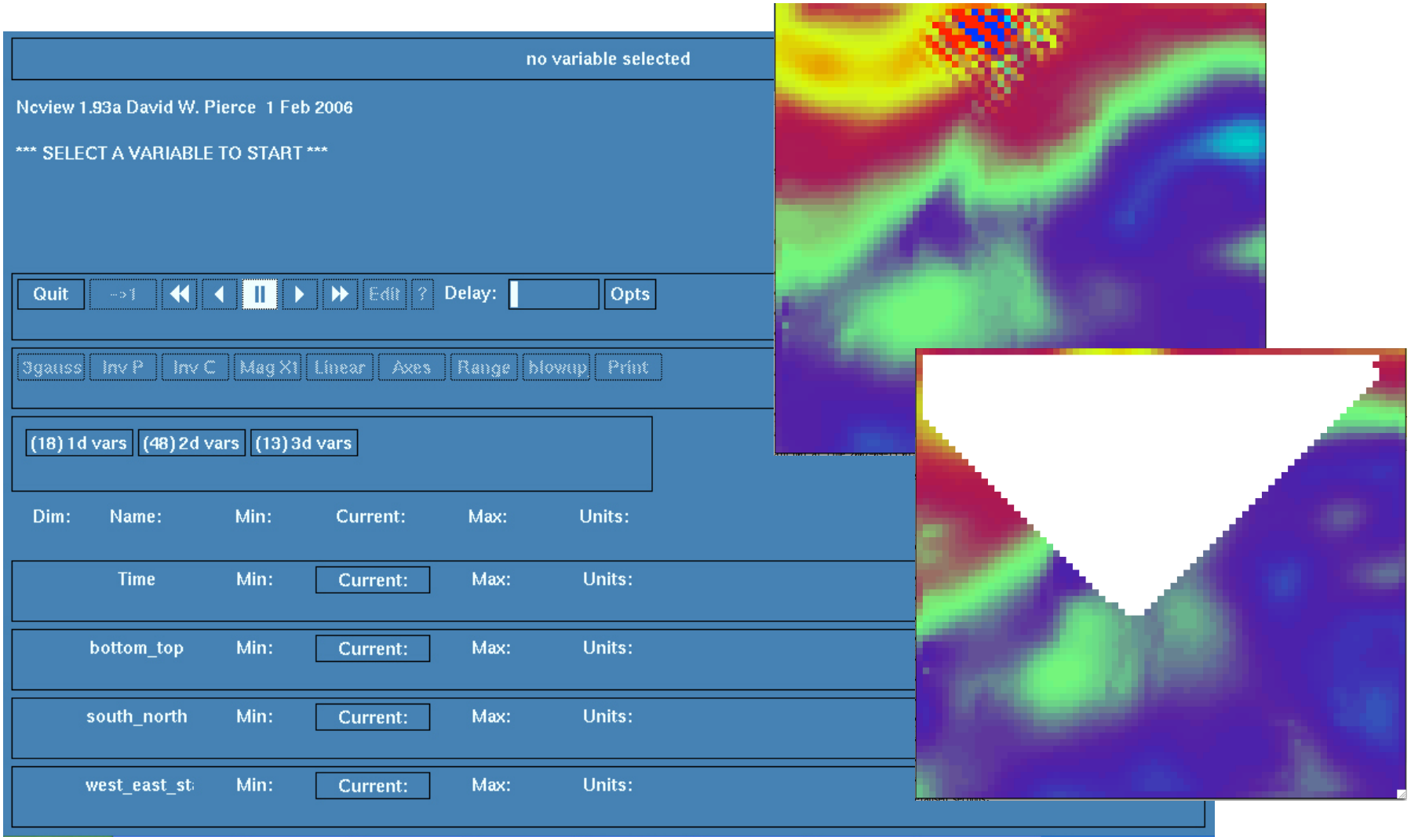
```
ncks -d Time,1,1 wrfout -o wrfout1.nc
```

# NCO Tools: Other Available Operators

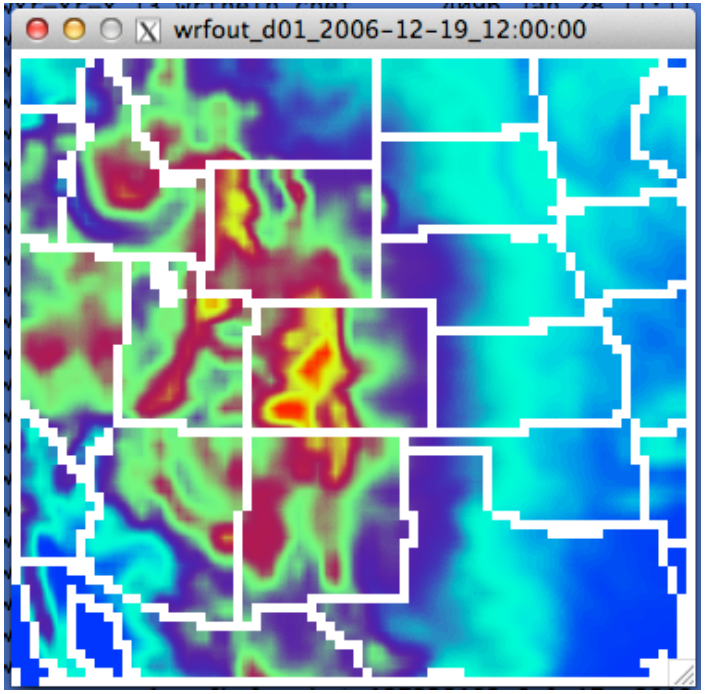
- **ncap2:** arithmetic processor
- **ncatted:** ATTribute editor
- **ncbo:** binary operator (includes ncadd, ncsubtract, ncmultiply, ncdivide)
- **ncea:** ensemble averager
- **ncecat:** ensemble conCATenator
- **ncflint:** FiLe INTerpolator
- **ncpdq:** permute dimensions quickly, pack data quietly
- **ncrename:** RENAME-er
- **ncwa:** weighted averager

# ncview

http://meteora.ucsd.edu/~pierce/ncview_home_page.html



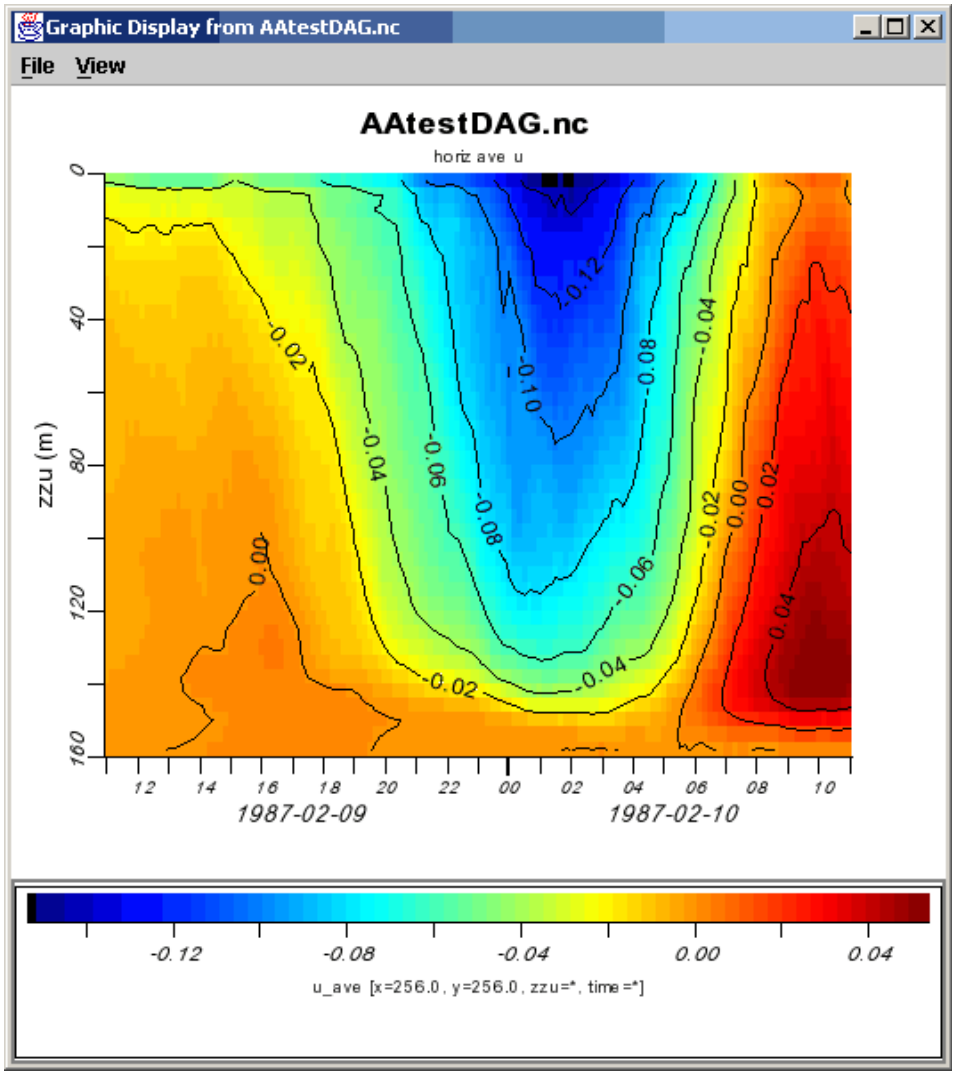
# ncview


- Beginning V3.7
- Works with wrfout* files
- Must have 1 time period per file

# ncBrowse

http://www.epic.noaa.gov/java/ncBrowse/



# ncdump

- Reads a netCDF dataset and prints information from that dataset

- `ncdump -h` *`file`*
  - Prints header (inclusive list of variables in the file)

- `ncdump -v VAR` *`file`*
  - Prints data for the variable 'VAR'

- `ncdump -v Times` *`file`*
  - Prints the times that are included in the file

# ncdump –v Times

```
netcdf wrfout_d01_2000-01-24_12:00:00 {
dimensions:
        Time = UNLIMITED ; // (3 currently)
        DateStrLen = 19 ;
        west_east = 73 ;
        south_north = 60 ;
        west_east_stag = 74 ;
        bottom_top = 27 ;
        south_north_stag = 61 ;
        bottom_top_stag = 28 ;
variables:
        char Times(Time, DateStrLen) ;
        float LU_INDEX(Time, south_north, west_east) ;
                LU_INDEX:FieldType = 104 ;
                LU_INDEX:MemoryOrder = "XY " ;
         LU_INDEX:description = "LAND USE CATEGORY" ;
                LU_INDEX:units = "" ;
                LU_INDEX:stagger = "" ;
.....
.....

global attributes:

                :TITLE = " OUTPUT FROM WRF V3.4.1 MODEL";
                :START_DATE = "2000-01-24_12:00:00" ;
                :WEST-EAST_GRID_DIMENSION = 74 ;
                :SOUTH-NORTH_GRID_DIMENSION = 61 ;
                :BOTTOM-TOP_GRID_DIMENSION = 28 ;
                :DX = 30000.f ;
                :DY = 30000.f ;
.....
.....

data:
 Times =
  "2000-01-24_12:00:00",
  "2000-01-24_18:00:00",
  "2000-01-25_00:00:00"
```

# Input Data

# Input Data: Mandatory Fields

- **3D Data (data on pressure levels, for example)**
  - Temperature
  - U and V components of wind
  - Geopotential Height
  - Relative Humidity/Specific Humidity
- **2D Data**
  - Surface pressure
  - Mean sea-level pressure
  - Skin temperature/SST
  - 2 meter temperature and relative humidity
  - 10 meter U and V components of wind
  - Soil data (temperature and moisture) and soil height
- **Recommended Fields**
  - LANDSEA mask field for input data
  - Water equivalent snow depth
  - SEAICE

# External Data Sources: Global

| Name | Resolution | Coverage | Temporal Availability | Website |
|---|---|---|---|---|
| NCEP/NCAR Reanalysis (R1/NNRP) | 209 km 6-hourly | Global | Jan 1948 – present | http://rda.ucar.edu/datasets/ds090.0 |
| NCEP/DOE Reanalysis (R2) | 209 km 6-hourly | Global | Jan 1979 – present | http://rda.ucar.edu/datasets/ds091.0 |
| ERA Interim Data | 1.125° - 0.703° 6-hourly | Global | Jan 1979 – present | http://rda.ucar.edu/datasets/ds627.0 |
| ECMWF's Operational Model Analysis | Varying | | Jan 2011 – present | http://rda.ucar.edu/datasets/ds113.0 |
| NCEP GDAS/FNL Reanalysis | 0.25° 6-hourly | Global | July 2015 – present | http://rda.ucar.edu/datasets/ds083.3 |
| GFS Real-time | 1° | Global | | ftp://ftpprd.ncep.noaa.gov/pub/data/nccf/com/gfs |
| NCEP GFS/FNL Reanalysis | 1° 6-hourly | Global | Aug 1999 – present | http://rda.ucar.edu/datasets/ds083.2 |
| GFS Gridded Model Data | 0.5° 24-hourly | Global | Dec 2002 – present | http://rda.ucar.edu/datasets/ds335.0 |
| NCEP GFS 0.25° | 0.25° 3-hourly & 12-hourly | Global | Jan 2015 – present | http://rda.ucar.edu/datasets/ds084.1 |

# External Data Sources: North America

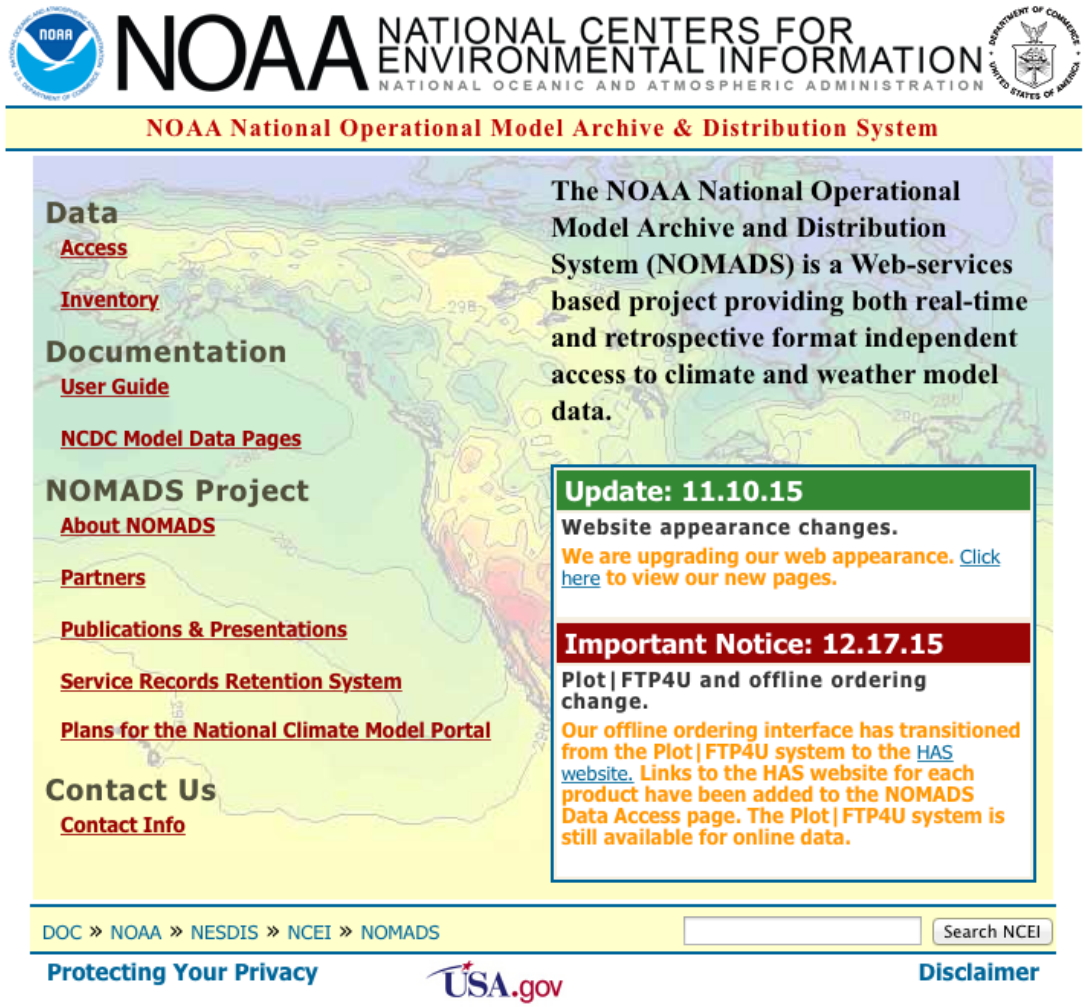
| Name | Resolution | Coverage | Temporal Availability | Website |
|---|---|---|---|---|
| NAM Real-time | 32/12 km<br>6-hourly | North America | | ftp://ftpprd.ncep.noaa.gov/pub/data/nccf/com/nam |
| NAM Analysis | 12 km<br>6-hourly | North America | Jan 2012 – present | http://rda.ucar.edu/datasets/ds609.0 |
| GCIP NCEP Eta | 40 km<br>3-hourly & 6-hourly | North America | April 1995 – present | http://rda.ucar.edu/datasets/ds609.2 |
| NCEP NARR | 32 km<br>3-hourly | North America | Nov 1979 – present | http://rda.ucar.edu/datasets/ds608.0 |

# External Data Sources: Climate

| Name | Resolution | Coverage | Temporal Availability | Website |
|---|---|---|---|---|
| NCEP Climate Forecast System Reanalysis (CFSR) | 0.3° to 2.5° 6-hourly | Global | Jan 1979 – Dec 2010 | http://rda.ucar.edu/datasets/ds093.0 |
| NCEP Climate Forecast System Reanalysis II (CFSv2) | 0.2° to 2.5° 6-hourly | Global | Jan 2011 – present | http://rda.ucar.edu/datasets/ds094.0 |
| NCAR CESM CMIP5 data (netCDF format) | 6-hourly | Global | Jan 1950 – 2100 | http://rda.ucar.edu/datasets/ds316.0 |
| NCAR CESM CMIP5 data (IM – Bias Corrected) | 6-hourly | Global | Jan 1951 – 2100 | http://rda.ucar.edu/datasets/ds316.1 |
| SST DATA | | | | |
| NCEP SST Analysis | 1° - 1/12° | Global | | http://polar.ncep.noaa.gov/sst |
| NOMAD3 SST | 1° - 0.25° | Global | Jan 1854 – present (depending which product) | http://nomads.ncdc.noaa.gov/data.php |
| NCEP & NCDC Reconstructed SST | 1° - 2° | Global | Jan 1854 – Dec 2015 | http://rda.ucar.edu/datasets/ds277.0 |

# External Data Sources: NOMADS

http://nomads.ncdc.noaa.gov




NAM
GFS
RUC
CFS
NARR
R1/R2
SST

# GRIB Data Handling

- Documents and decoders
  - GRIB1 and GRIB2

    **wgrib, wgrib2, unpackgrib2.c, grib2to1.c**

    http://rda.ucar.edu/#!GRIB

- **g1print.exe** and **g2print.exe**
  - Show data available in GRIB1 and GRIB2 files
  - Available from util/ directory in WPS

- **grib2ctl.pl**
  - Create .ctl and .idx files, so that you can plot GRIB files with GrADS
  - http://www.cpc.ncep.noaa.gov/products/wesley/grib2ctl.html

- **ncl_convert2nc**

  http://www.ncl.ucar.edu/Document/Tools/ncl_convert2nc.shtml

# Writing Intermediate File Format

- http://www2.ucar.edu/wrf/users/docs/user_guide_V3/users_guide_chap3.htm#_Writing_Meteorological_Data

- **wrf_wps_write_int**

```
FIELD = "SST"
UNITS = "K"
DESC = "Sea Surface Temperature"

opt = True
opt@map_source                = "ERA-I Data"
opt@projection                = 0
opt@startloc                  = "SWCORNER"
opt@startlon                  = 0.0
opt@startlat                  = -90.0
opt@deltalon                  = 1.25
opt@deltalat                  = 0.942408
opt@is_wind_earth_relative    = False
opt@date                      = "2015-07-26_00:00:00"
opt@level                     = 200100.

wrf_wps_wrtie_int(IM_name,FIELD,UNITS,DESC,VAR(:,:),opt)
```

# Reading Intermediate Format Files

- **wrf_wps_read_int**

**! opens file**

istatus = wrf_wps_open_int(*filename)*

**! reads header**

wrf_wps_rdhead_int(istatus,head_real,field,h
date, \
units,map_source,desc)

**! reads slab**

Slab = wrf_wps_rddata_int(istatus,nx,ny)

*! Loop until reaching the end of the file*

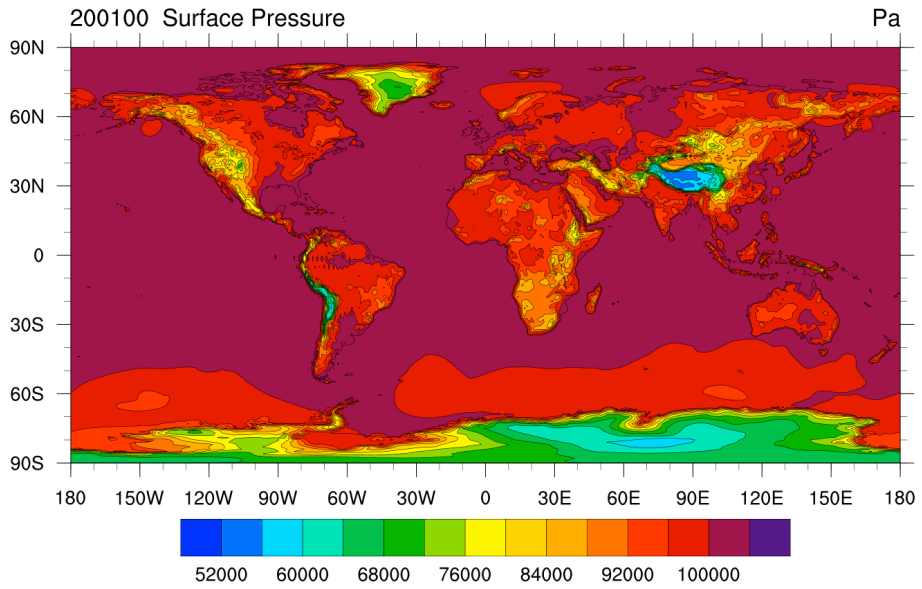
- **rd_intermediate**

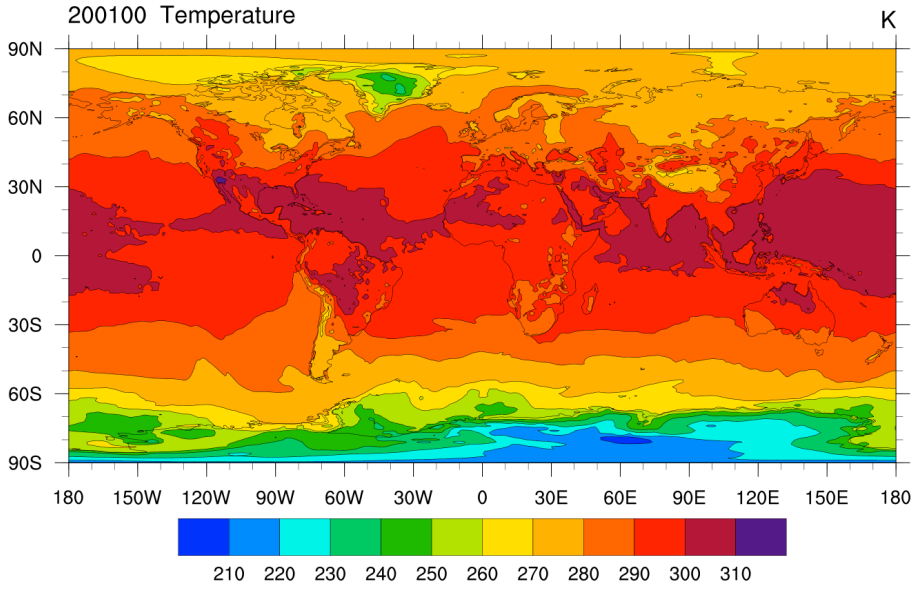
```
========================================
FIELD = TT
UNITS = K DESCRIPTION = TEMPERATURE
DATE = 2000-01-24_12:00:00 FCST = 0.000000
SOURCE = unknown model from NCEP GRID 212
LEVEL = 200100.000000
I,J DIMS = 185, 129
IPROJ = 1
   REF_X, REF_Y = 1.000000, 1.000000
   REF_LAT, REF_LON = 12.190000, -133.459000
   DX, DY = 40.635250, 40.635250
   TRUELAT1 = 25.000002
DATA(1,1) = 295.910950
========================================
```

# Utility: plotfmt

- The plotfmt program plots the fields in the ungribbed intermediate files

```
ncl plotfmt.ncl 'filename="FNL:2007-09-15_00"'
```



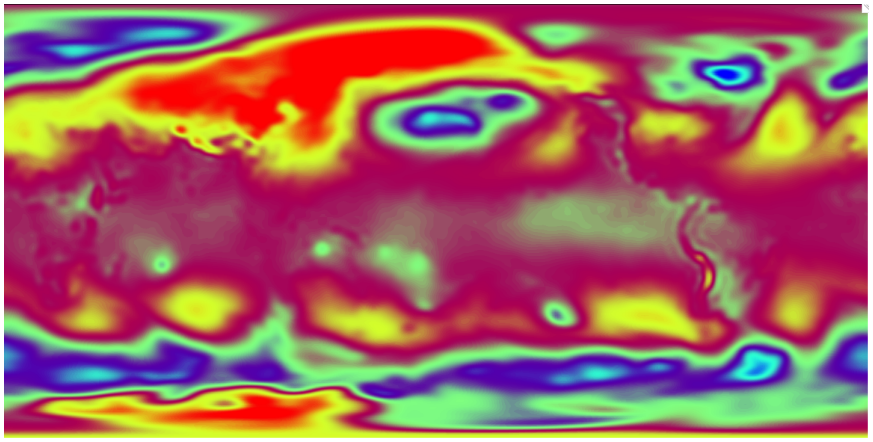



# Plotting Intermediate Files in netCDF Format

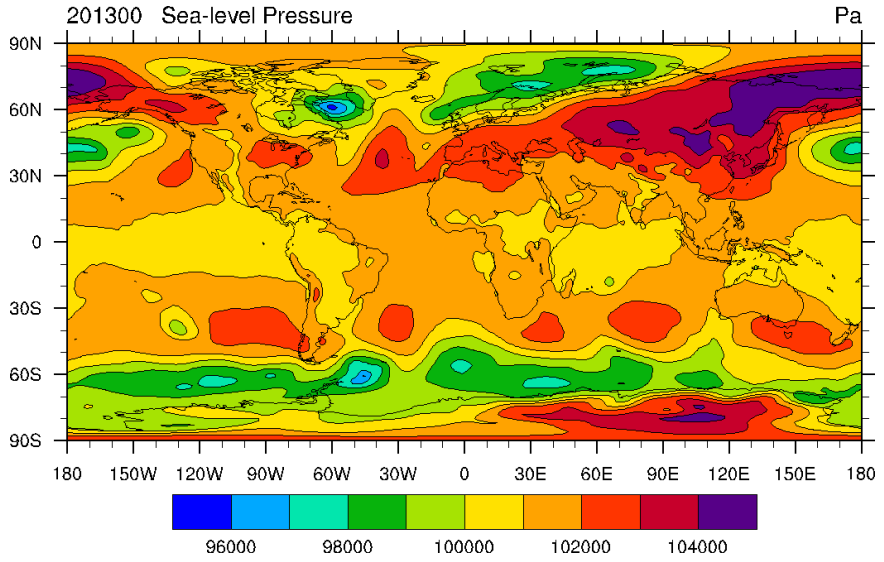
- Use the utility **int2nc.exe**
  - Converts intermediate files created by ungrib.exe to netcdf format
  - `./int2nc.exe`
- To plot: **plotfmt_nc.ncl**

```
ncl plotfmt_nc.ncl 'inputFILE="FNL:2007-09-15_00"'
```

Plot Using ncview



Plot Using plotfmt_nc.ncl



# Other Utilities

- Additional utilities
  - **read_wrf_nc**: reads WRF netCDF file, outputs various data
  - **iowrf**: thins or extracts a box from WRF netCDF files
  - **wrf_interp**: interpolates WRF output files to pressure, height-agl, height-msl, potential temp, and equivalent potential temp, and can perform underground extrapolation
  - **p_interp**: converts wrfout data to pressure levels
  - **v_interp**: adds vertical levels in WRF input and boundary files
  - **diffwrf**: performs several functions, including making comparisons of two WRF files
  - For more details on the above utilities, see:

  http://www2.mmm.ucar.edu/wrf/users/utilities/util.htm

- To download utilities:
  http://www2.mmm.ucar.edu/wrf/users/download/get_sources.html

# Special WRF Output Variables

- The WRF model outputs the state variables defined in the Registry file, and these state variables are used in the model's prognostic equations. Some of these variables are perturbation fields and therefore, the following definitions for reconstructing meteorological variables are necessary:

| | |
|---|---|
| Total geopotential | PH + PHB |
| Total geopotential height in m | (PH + PHB) / 9.81 |
| Total potential temp in K | T + 300 |
| Total pressure in mb | (P + PB) * 0.01 |
| Wind components, grid relative | U, V |
| Surface pressure in Pa | Psfc |
| Surface winds, grid relative | U10, V10 (valid at mass points) |
| Surface temp and mixing ratio | T2, Q2 |

See WRFV3/Registry/Registry.EM_COMMON for description of variables

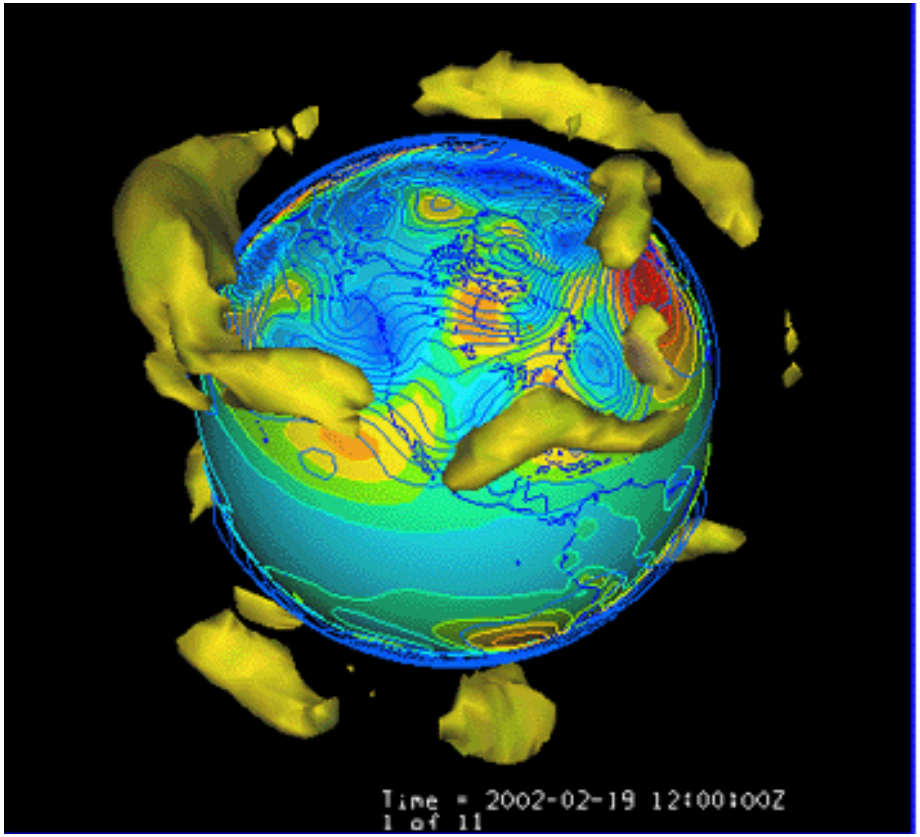
# MET Verification Software

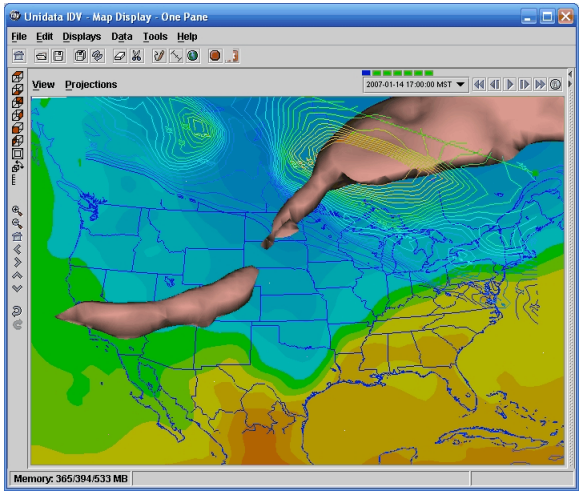
- Model Evaluation Tools (MET)
- Provides all the basics (e.g., RMSE, bias, skill scores)
- Provides
  - Advanced spatial methods (wavelets, objects)
  - Confidence intervals
- Download it
  http://www.dtcenter.org/met/users/downloads/
- Support
  met_help@ucar.edu
- Documentation
  http://www.dtcenter.org/met/users/docs/overview.php

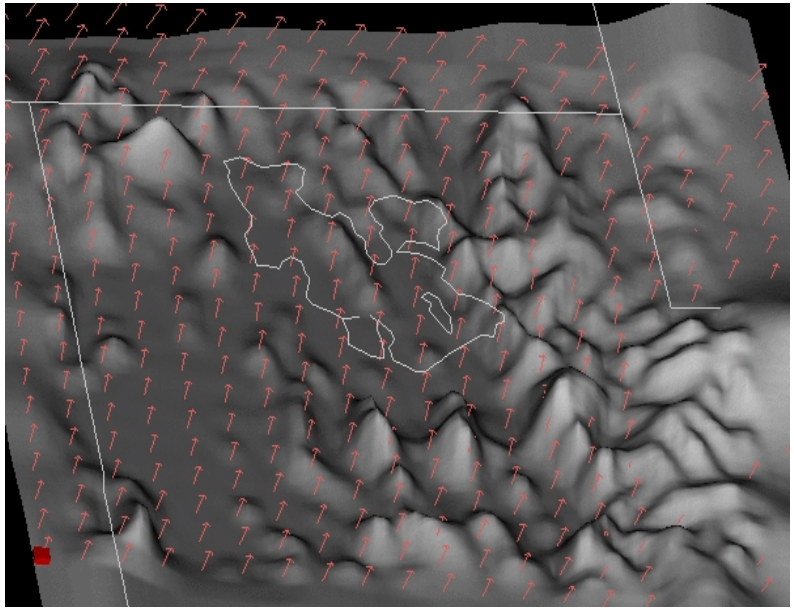
# IDV: General Information

- Integrated Data Viewer
- 2D and 3D visualization tool
- Integrate model and observational data
- Visualize and analyze post-processed WRF output
- Has ability to read in a lot of different data (e.g., aircraft data), bring in as an overlay without having to change projections
- Uses a LOT of memory!
- Developed and supported by:
  - Yuan Ho and Julien Chastang (NCAR)
  - support@unidata.ucar.edu

# IDV: Example Plots



# Questions?