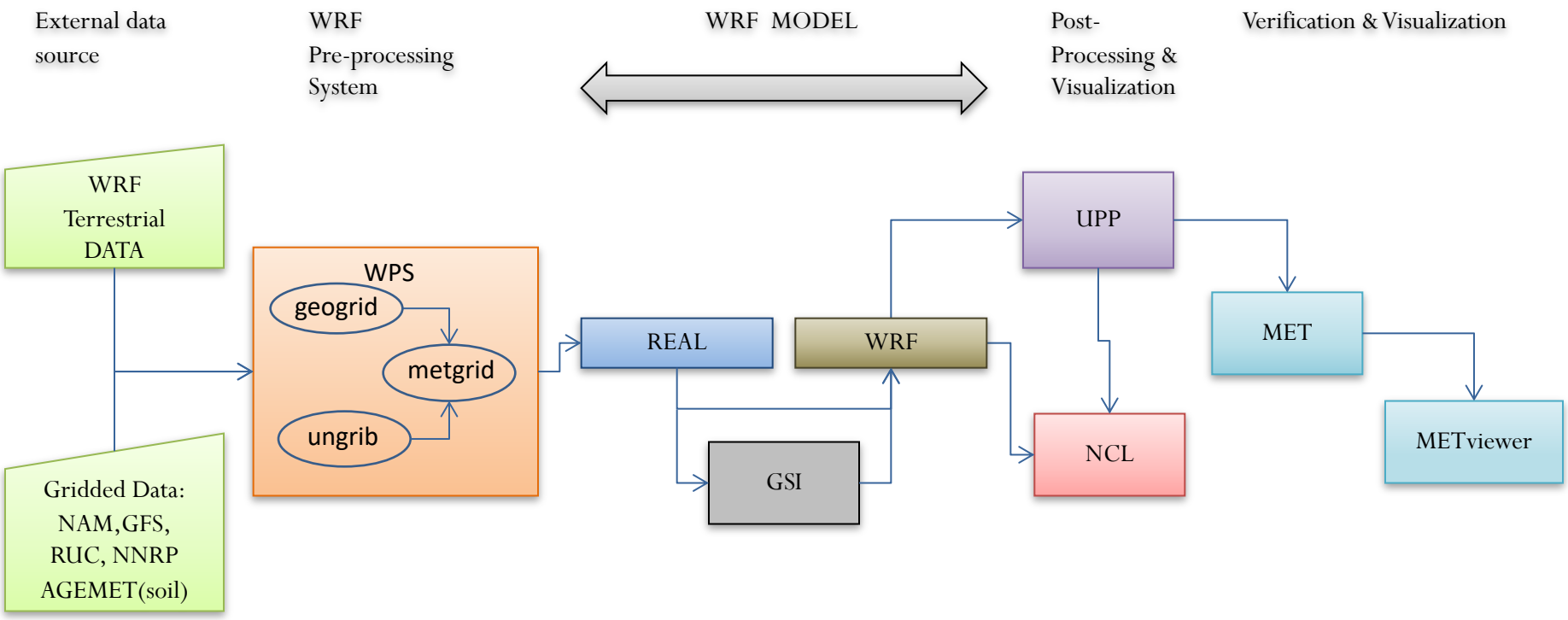
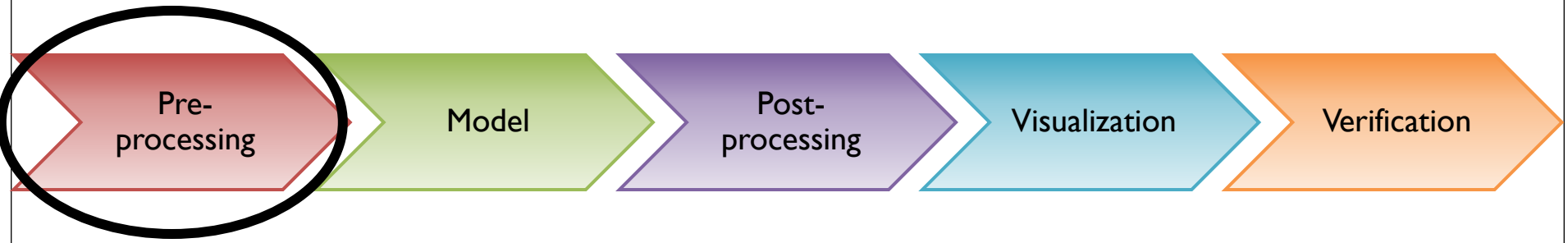
Introduction to containerized NWP system and case study overview

Introduction to containerized NWP system components

WPS, GSI, WRF, UPP, NCL, MET, METviewer



WRF Preprocessing System (WPS)



What is WPS?

- The WRF Preprocessing System (WPS) takes existing 4-d atmospheric data from GRIB-format files and interpolates it onto the user's specified WRF domain grid.
  - Initial conditions: 3-dimensional wind, temperature, geopotential height and RH, 2-dimensional surface pressure
  - Boundary conditions for the parent domain for the full length of the forecast
  - Commonly used input datasets are forecast output from GFS, or re-analysis datasets from NCEP or ECMWF

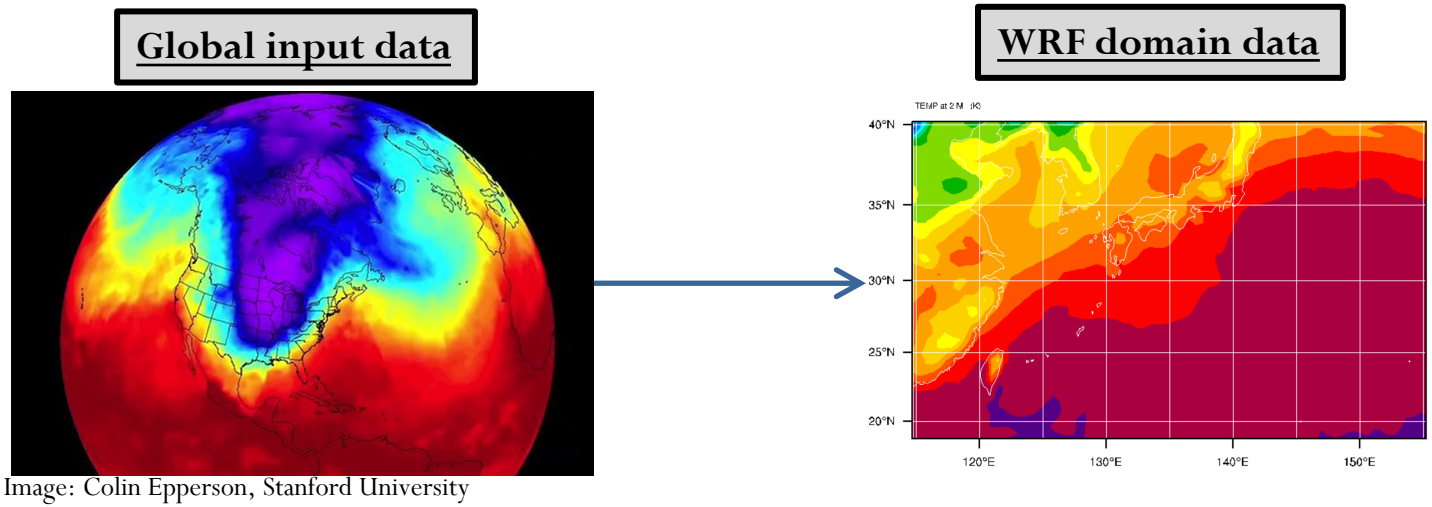
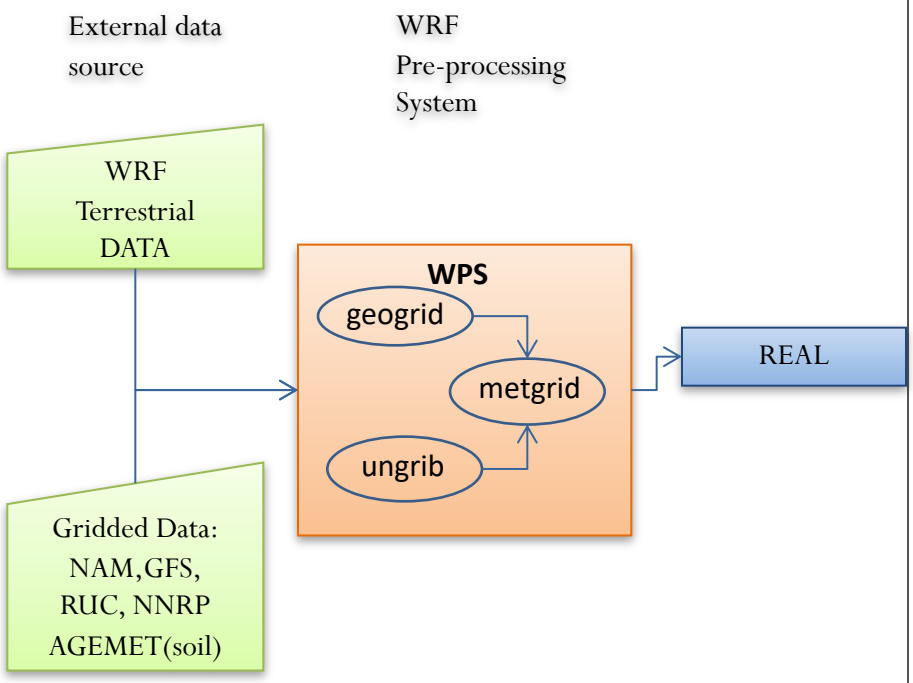


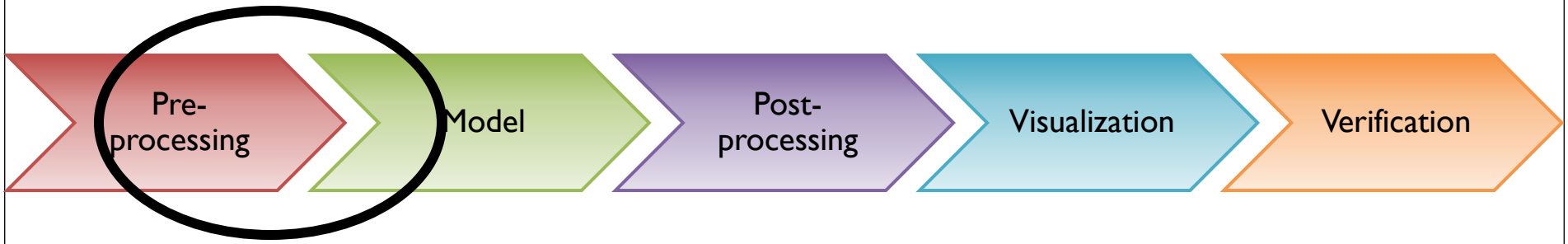
Image: Colin Epperson, Stanford University

Function of WPS components

- geogrid.exe (think **geo**graphical)
  - Define size/location of coarse domain and interpolate static terrestrial fields to coarse-domain and nested-domain grids
- ungrib.exe
  - Extract meteorological fields from GRIB files
- metgrid.exe (think **met**eorological)
  - Horizontally interpolate meteorological fields (from ungrib) to coarse grid (defined by geogrid)

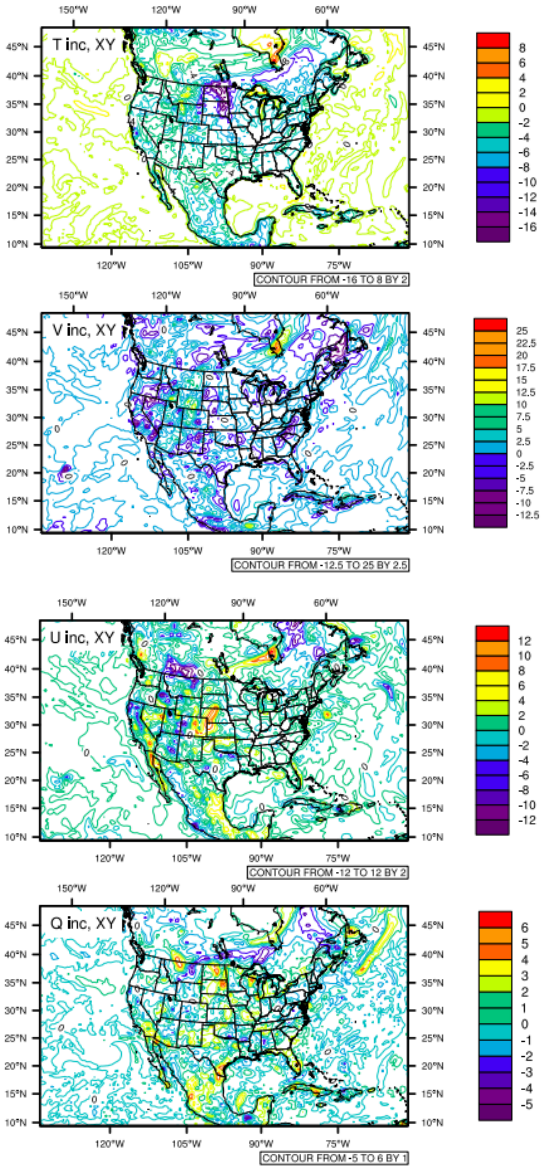


Gridpoint Statistical Interpolation (GSI) data assimilation



What is GSI?

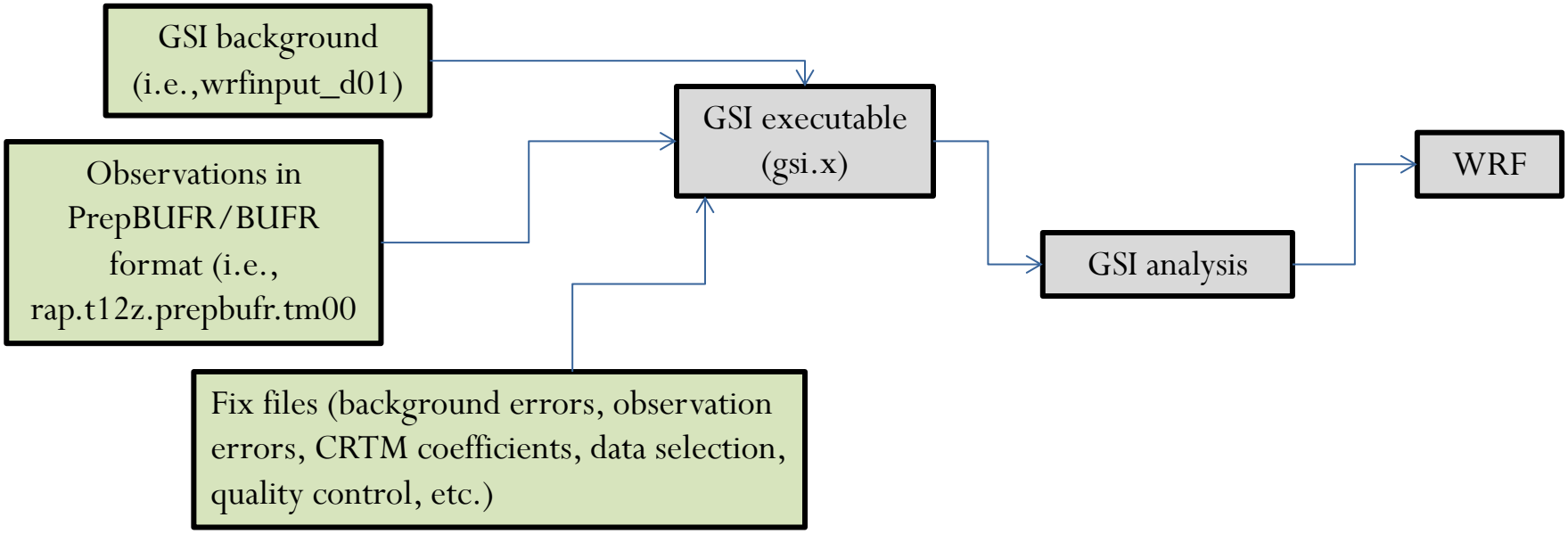
- Gridpoint Statistical Interpolation (GSI) is the operational data assimilation system being used at NOAA and NCEP-EMC, and can be applied for global and regional analysis, and can also serve as the observation operators for the Ensemble Kalman Filter (EnKF)
- In short, data assimilation takes a forecast (aka, first guess or background field) and modifies the model state based on observations.
  - The difference between the forecast and the observations at the initial time is called the innovation.
  - After applying a weighting function to the innovation and correcting the forecast, an analysis, or best estimate of the initial stat, is created.



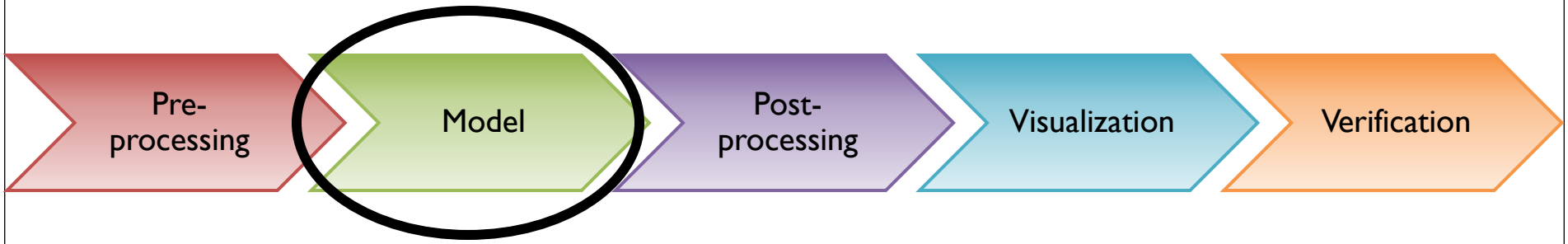
GSI analysis increment (analysis-background) after assimilating conventional observations

What does GSI do?

- For WRF applications, GSI can use the output from real.exe (i.e., wrfinput_d01) as the background field, and update it using the various observations. The updated background field – so called GSI analysis – can then be used as the initial conditions for WRF forecasts
- GSI can also use the WRF forecast files (i.e., wrfout_d01_<yyyymm-dd_hh:mm:ss>) as the background fields and update it for further forecasts.
- The observations can include conventional observations, satellite radiance, GPS radio occultations, etc.



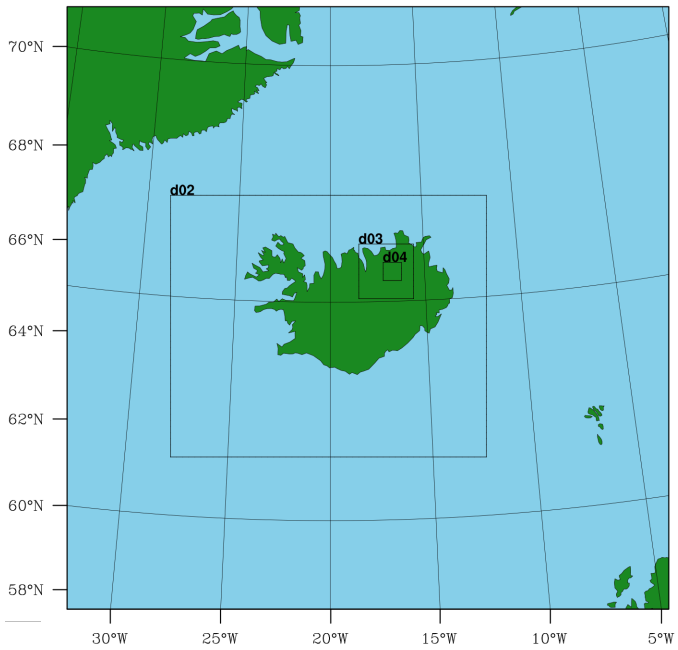
Weather Research and Forecasting (WRF) model



What is WRF?

- The Weather Research and Forecasting (WRF) model is a numerical weather prediction model for weather research and forecasting
- Two dynamical cores, both non-hydrostatic
  - Advanced Research WRF (ARW), most commonly used
  - Nonhydrostatic Mesoscale Model (NMM), used in some operational forecasting systems
- Highly configurable, but also caters to less advanced users
  - e.g. 26 different microphysics schemes, 10 surface layer schemes, etc.
  - "Suites" of widely-used and tested scheme combinations are provided for casual users
  - Most options can be easily changed at runtime (no re-compilation required)
- Typically run for regional domains, although a global capability exists
  - One parent domain gets its initial and boundary conditions from the WRF Preprocessing System (WPS)
  - Can also have one or more child domains that get their boundary conditions from the parent domain

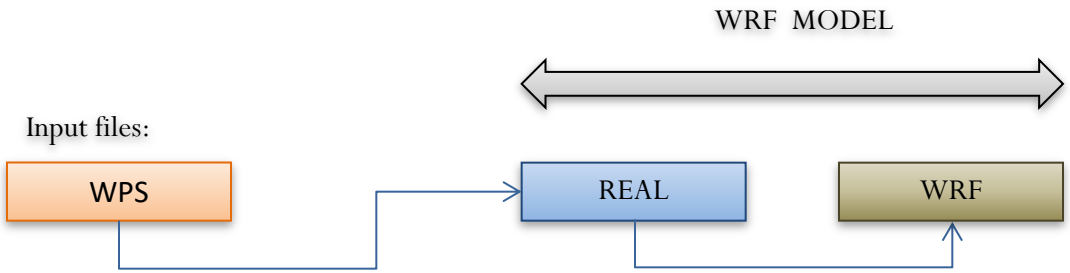
Example domain with nests



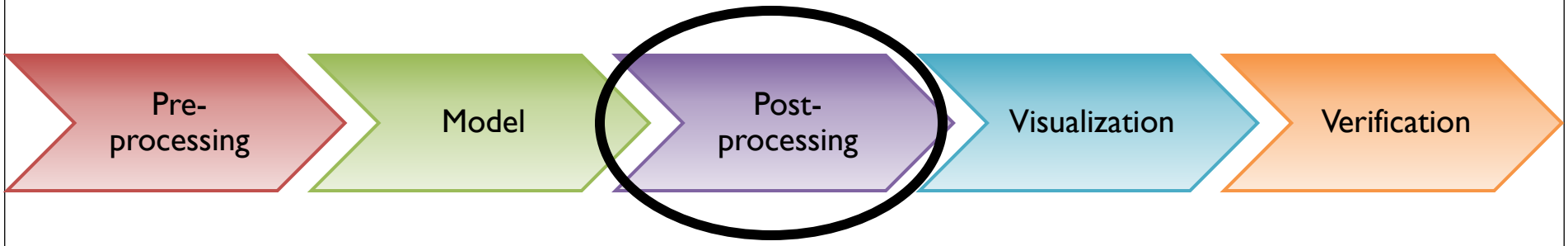
Grid	Resolution	Size
1	16 km	99x99
2	4 km	208x172
3	1 km	136x128
4	250 m	160x160

Function of WRF components

- real.exe
  - Generation of initial state for each of the requested domains
  - Creation of a lateral boundary file for the most coarse domain
  - Vertical interpolation for 3d meteorological fields and for sub-surface soil data
- wrf.exe
  - Forecast model integration through time



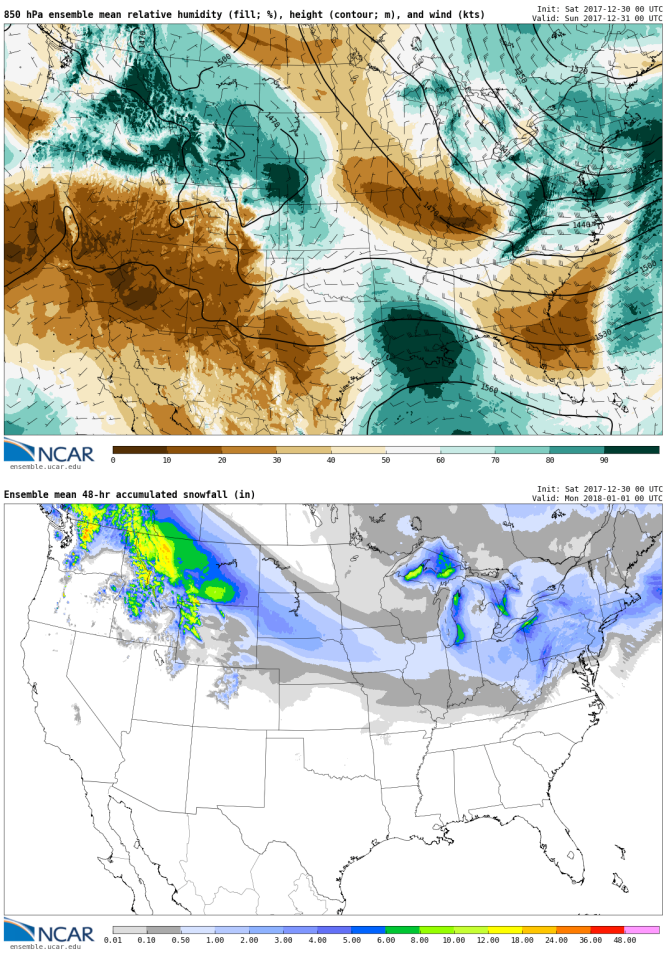
Unified Post Processor (UPP)



What is UPP?

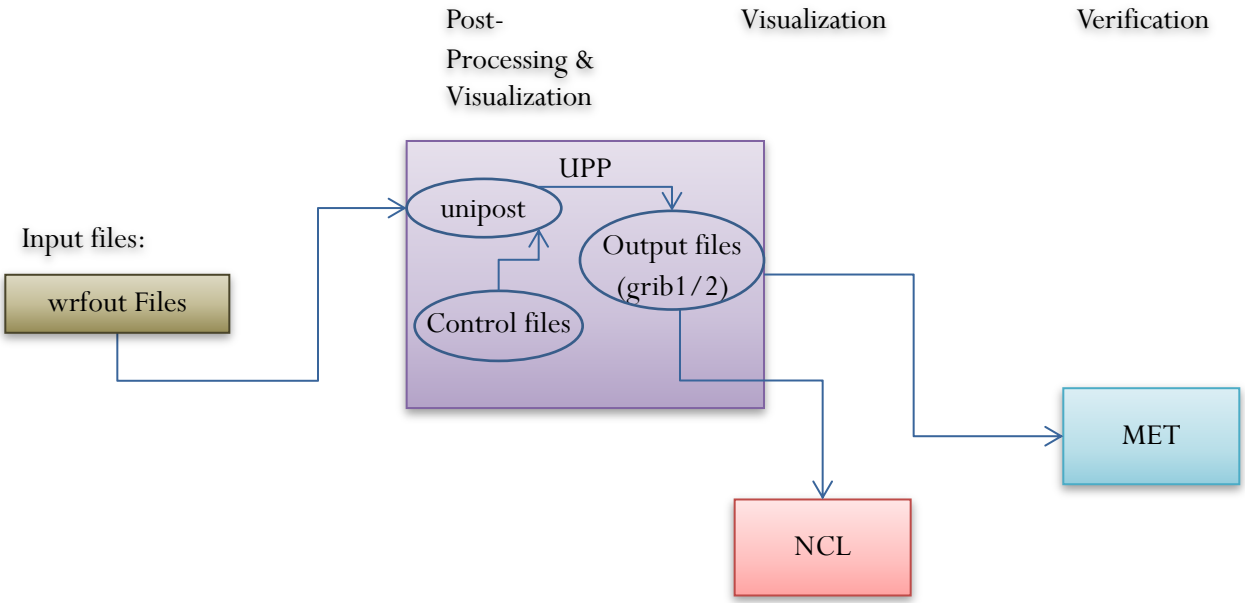
- The Unified Post-Processor (UPP) is a post-processor for WRF and other models
  - Developed at the National Centers for Environmental Prediction (NCEP) for use in its operational forecasting
  - Also available for community use and development with WRF
- Processes raw model output to more useful forms
  - Produces hundreds of products like those used operationally
    - T, Z, humidity, wind, cloud water, cloud ice, rain, and snow on isobaric levels
    - SLP + shelter level T, humidity, and wind fields
    - Precipitation-related fields
    - PBL-related fields
    - Diagnostic products (i.e. RH, radar reflectivity, CAPE)
    - Radiative/Surface fluxes 7) Cloud related fields 8) Aviation products
    - Synthetic satellite products
  - Creates output that can be plotted with your favorite visualization tool

Example plots from NCAR Ensemble

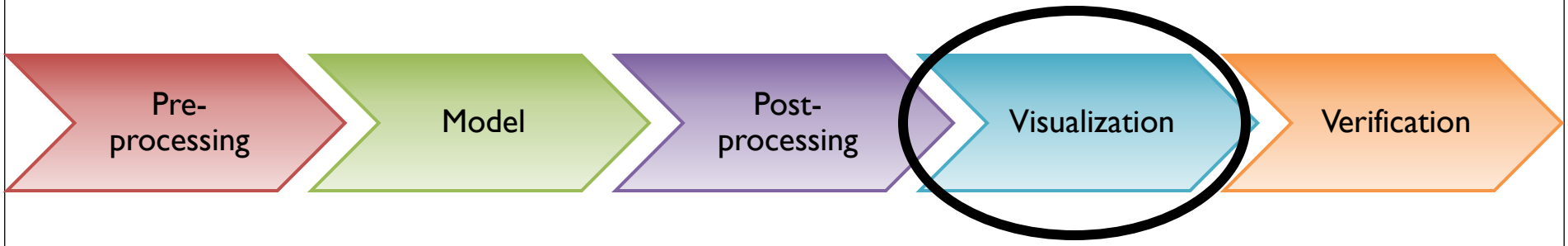


Function of UPP component

- unipost.exe
  - Performs vertical interpolation from model levels/surfaces onto isobaric, height, and other levels/surfaces
  - Calculated derived quantities/diagnostic fields
  - Destaggers wind onto mass points



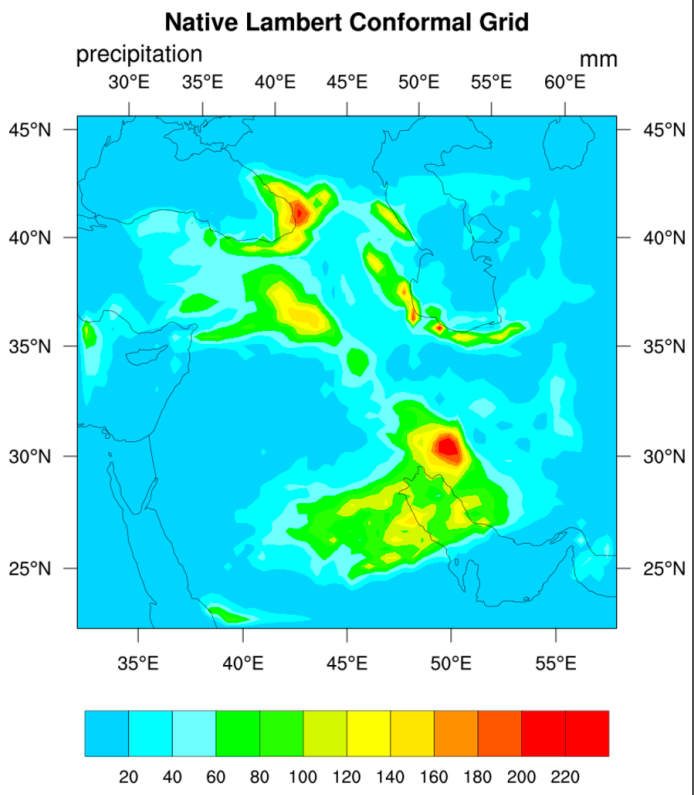
NCAR Command Language (NCL) visualization



What is NCL?

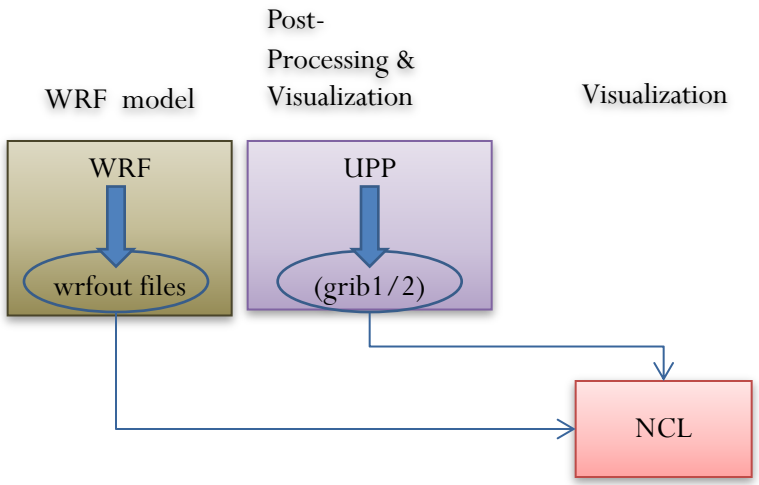
- The NCAR Command Language
  - An interpreted (scripting) language for creating visualizations of geoscientific data
  - Designed and maintained by the Computational & Information Systems Laboratory (CISL)
  - Can read and write a bunch of different formats (netCDF, HDF4, binary, and ASCII data) and can read many more (HDF5, GRIB1/GRIB2)
  - Supports calling of C and Fortran external routines
  - More info: https://www.ncl.ucar.edu/overview.shtml

Example NCL contour plot

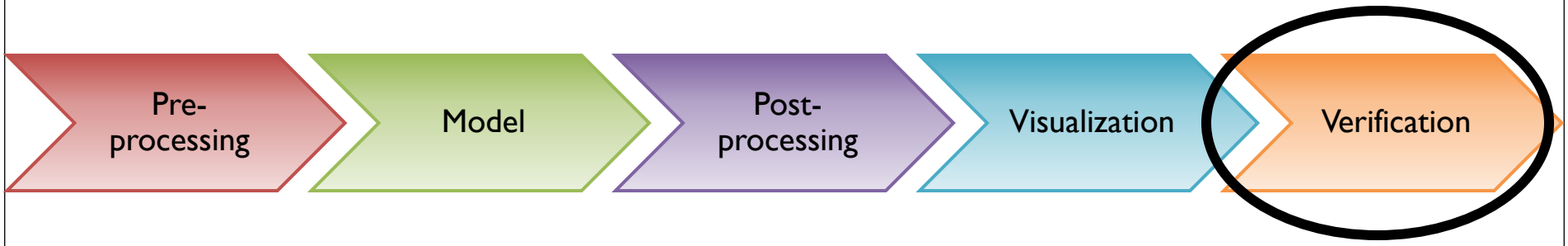


Function of NCL component

- NCL
  - Reads wrfout files created by WRF
    - Calculates derived/accumulated variables (if necessary)
    - Creates plots of one or more variables
  - Can also read grib files created by UPP



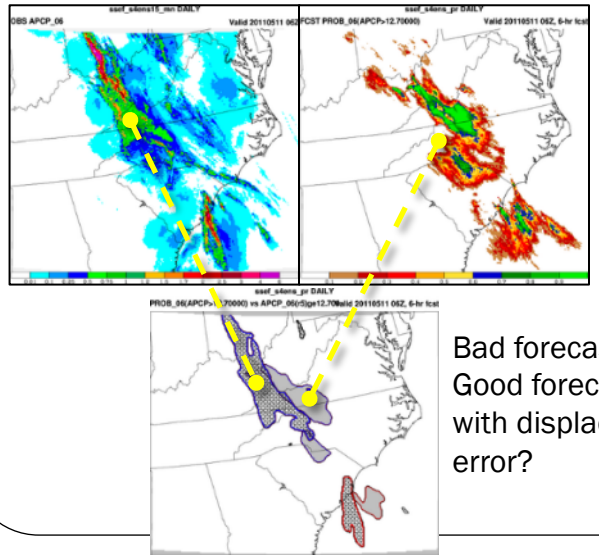
Model Evaluation Tools (MET) verification and visualization (METviewer)



What is MET?

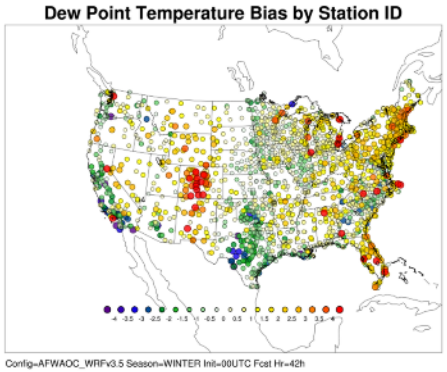
- MET is freely available community verification package supported by the DTC
  - Suite of verification tools with over 70 statistics using both point and gridded datasets
  - Full suite of standard statistics with cutting-edge statistics regularly added
  - Computation of confidence intervals
  - Multiple interpolation methods
  - Regridding within the tools and ability to apply complex masking

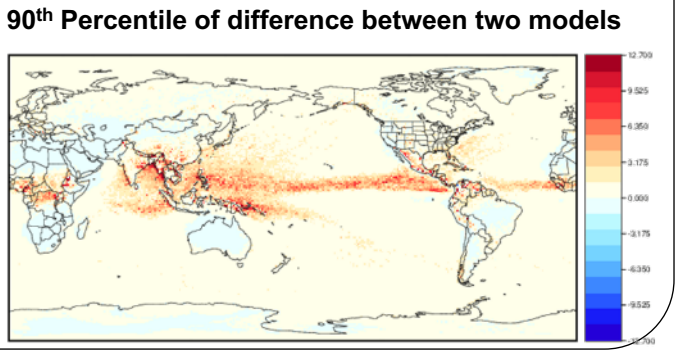
Object Based and Spatial Methods



Bad forecast or Good forecast with displacement error?

Geographical Representation of Errors



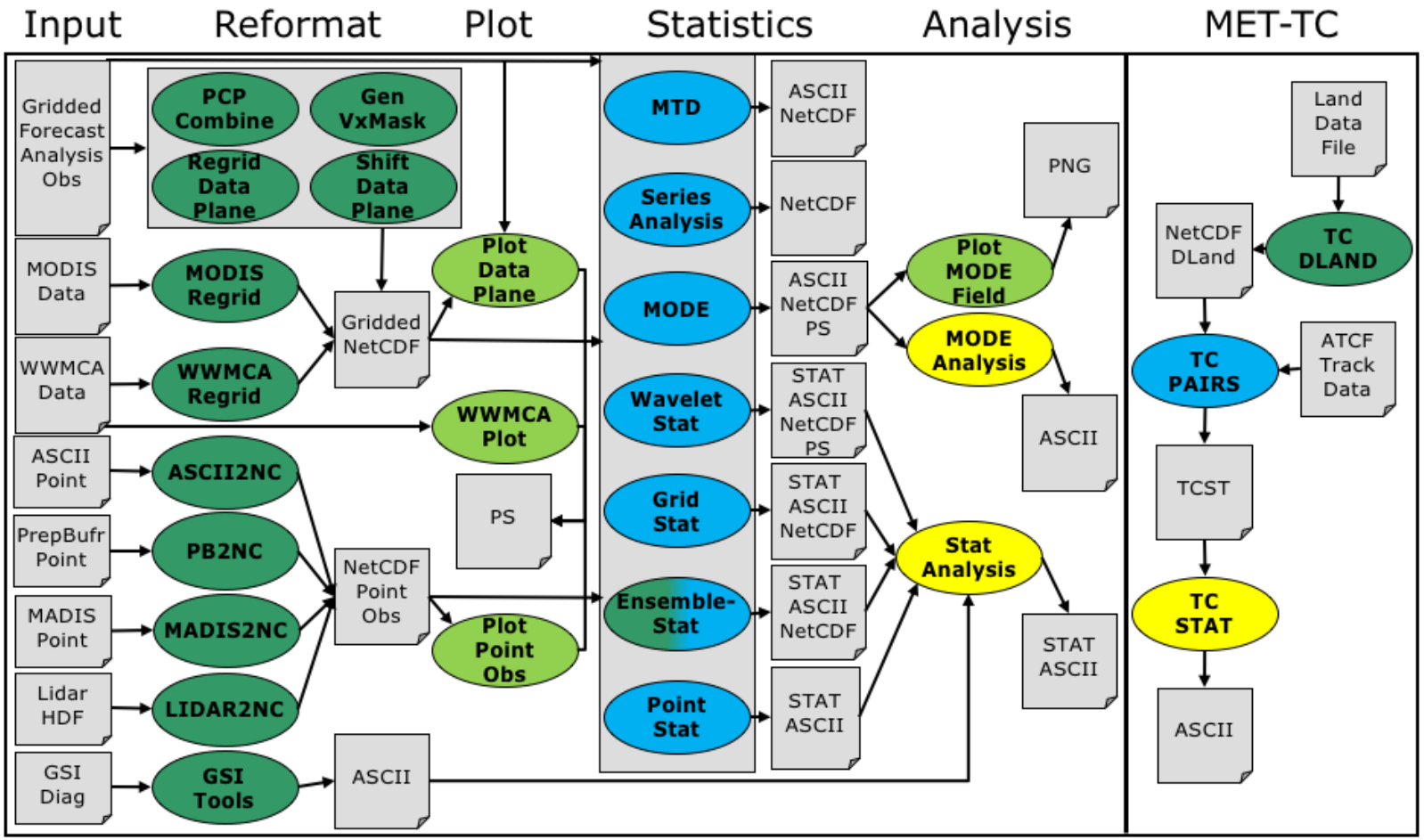


Function of MET

MET includes tools for:

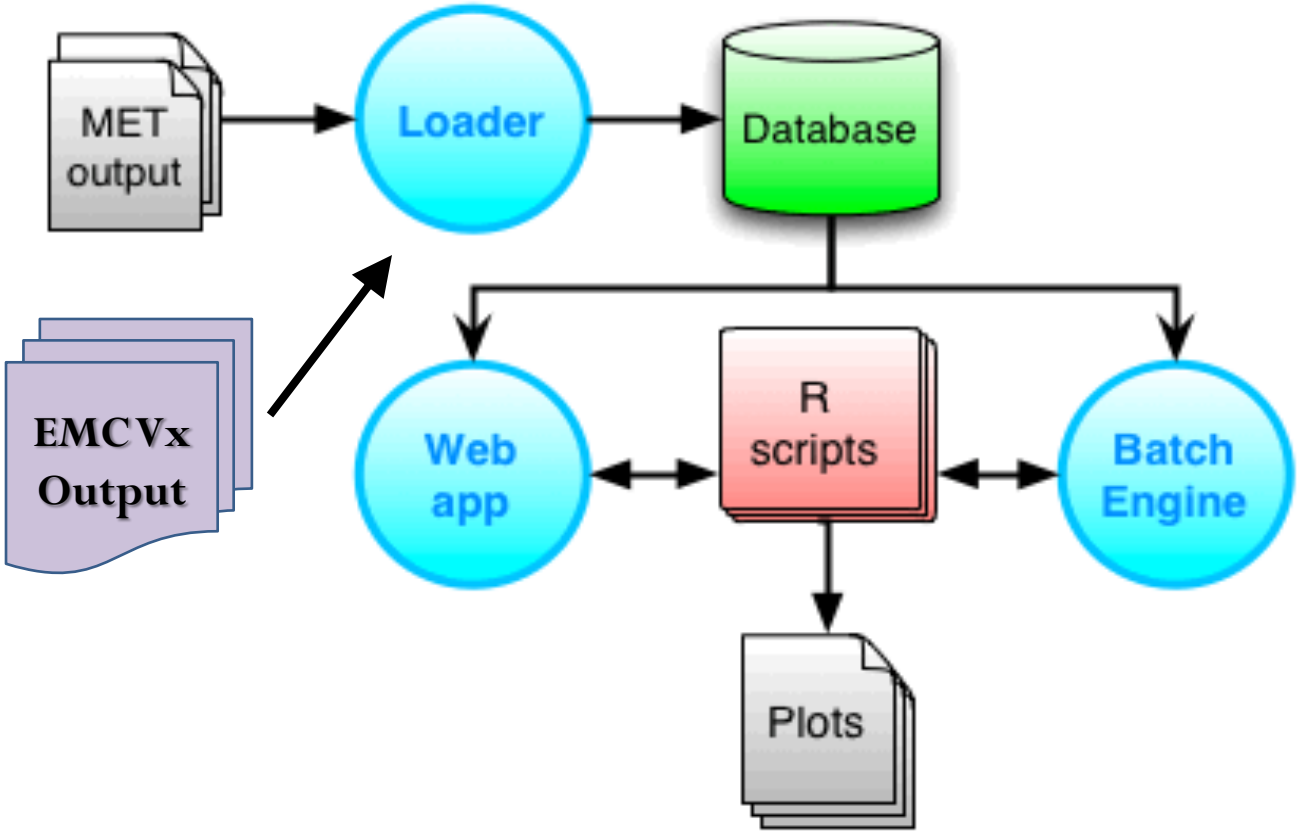
- reformatting (dark green)
- plotting (light green)
- calculating statistics (blue)
- statistical analysis (yellow)
- tropical cyclone verification (MET-TC)

Components Overview



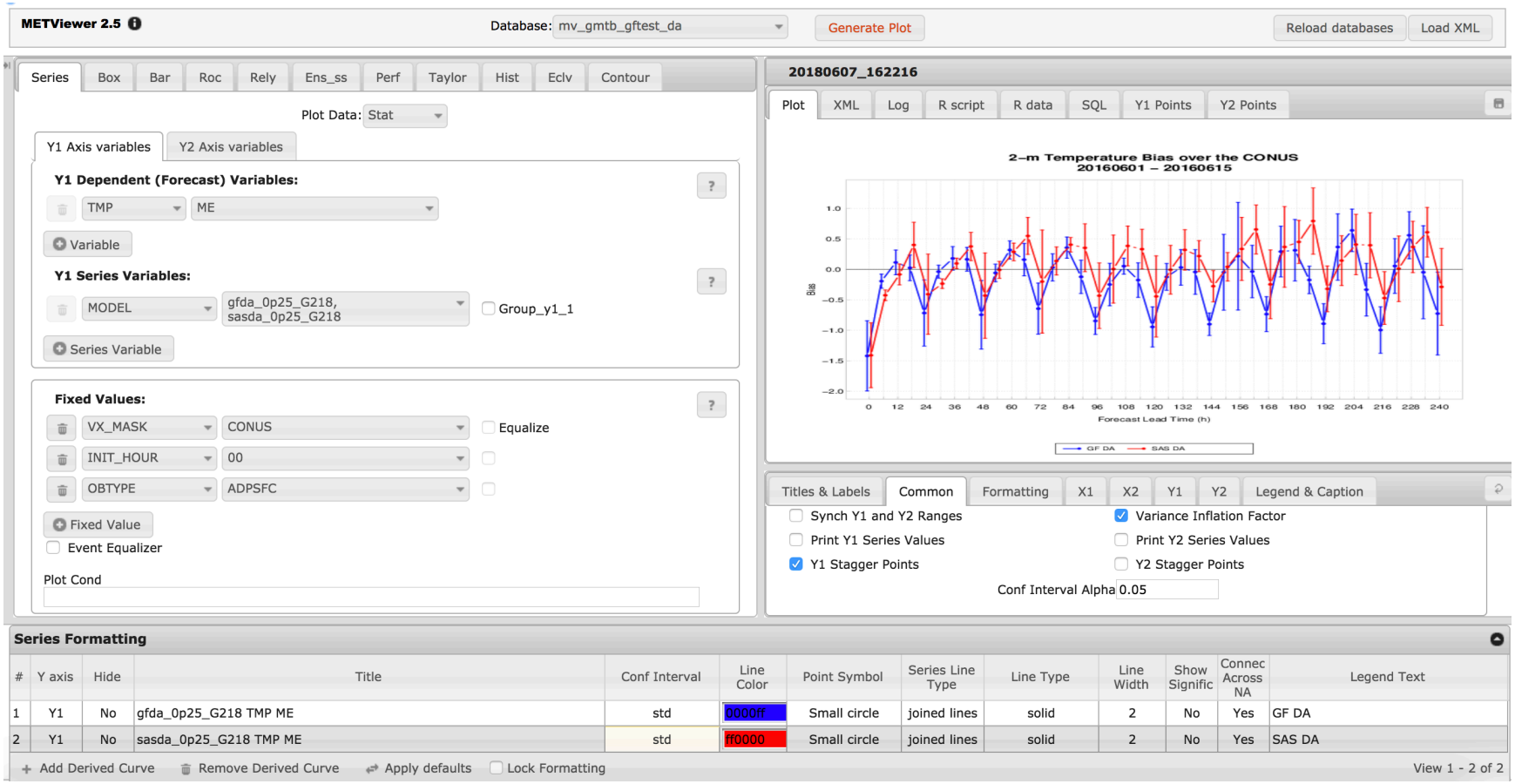
What is METviewer?

- Database and display analysis tool
  - **Packages**: Java, Apache/Tomcat, MySQL, R statistics



METviewer

Plotting example

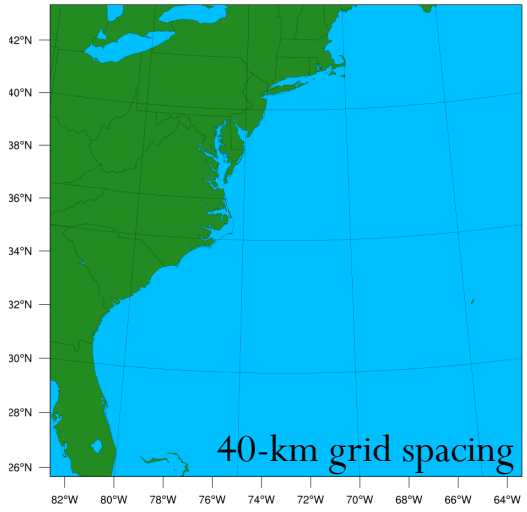


Software Packages Links

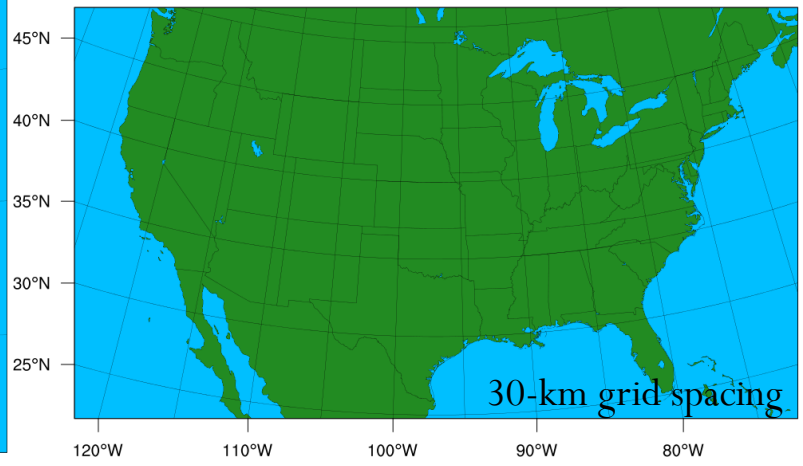
- WPS and WRF
  - Users' Page: http://www2.mmm.ucar.edu/wrf/users
  - Online Tutorial: http://www2.mmm.ucar.edu/wrf/OnLineTutorial
- GSI
  - Users' Page: https://dtcenter.org/com-GSI/users
  - Online Tutorial: https://dtcenter.org/com-GSI/users/tutorial/index.php
- UPP
  - Users' Page: https://dtcenter.org/community-code/unified-post-processor-upp
  - Online Tutorial: https://dtcenter.org/community-code/unified-post-processor-upp/upp-online-tutorial-uppv4-0
- NCL
  - Users' Page: http://www.ncl.ucar.edu
- MET
  - Users' Page: https://dtcenter.org/community-code/model-evaluation-tools-met
  - Online Tutorial: https://dtcenter.org/community-code/model-evaluation-tools-met/online-tutorial

Case Study Overview

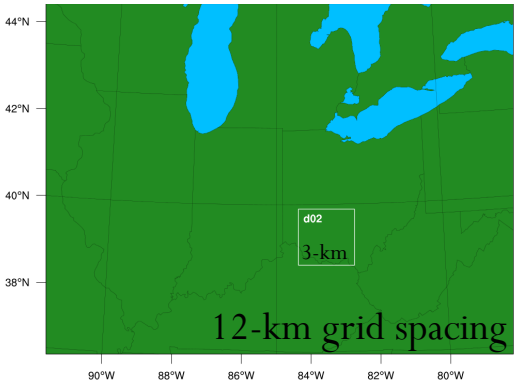
Hurricane Sandy
(Initialized on 27 Oct. 2012)



Snow case across mid-Atlantic
(Initialized on 23 Jan. 2016)



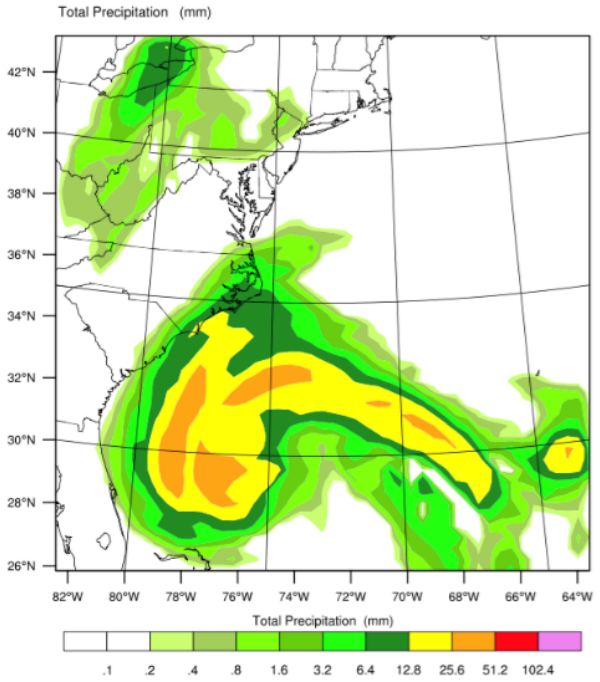
Derecho event
(Initialized on 29 June 2012)



What cases are provided?

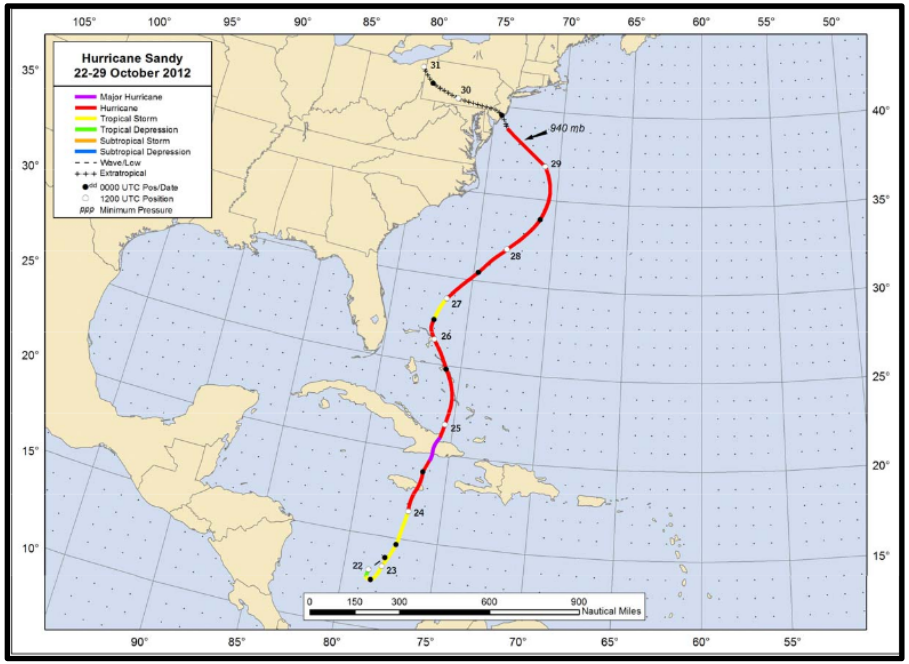
- Three cases with full datasets are provided in current inventory
  - Hurricane Sandy (Initialized on 27 Oct. 2012)
    - 40-km domain centered over East Coast (6-h forecast)
  - Snow case across the mid-Atlantic region (Initialized on 23 Jan. 2016)
    - 30-km CONUS domain (24-h forecast)
  - Derecho event over the Eastern CONUS (Initialized on 29 June 2012)
    - 12-km parent domain with 3-km nest over southern Ohio (24-h forecast)

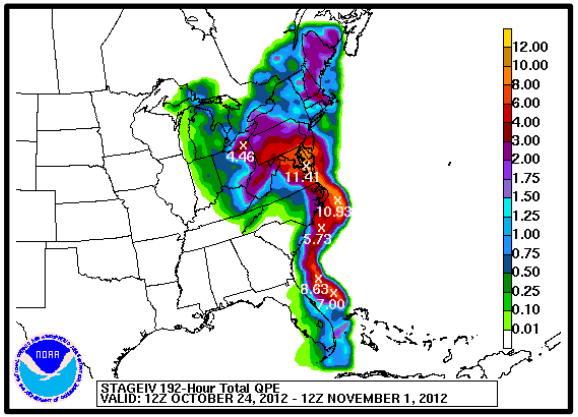
Total precip for Hurricane Sandy model forecast



Sandy Event Background

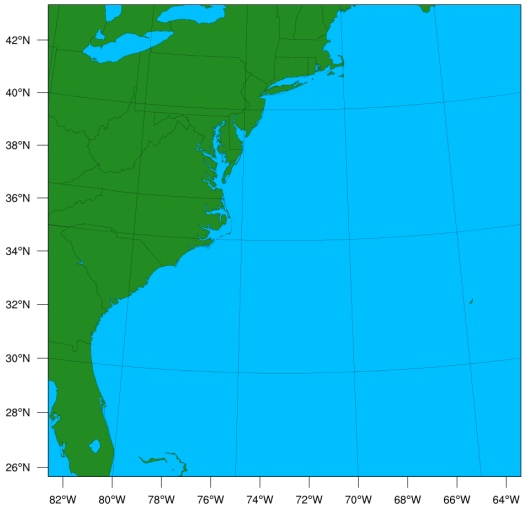
- Most deadly and destruction hurricane during the 2012 Atlantic hurricane season
  - 230 direct/indirect fatalities
  - Category 1 over Jamaica
  - Impacted Cuba as a Category 3
  - Weakened to a Category 1 over the Bahamas
  - Curved northwest and came onshore in New Jersey with hurricane force winds (no longer tropical)





Sandy Event Output

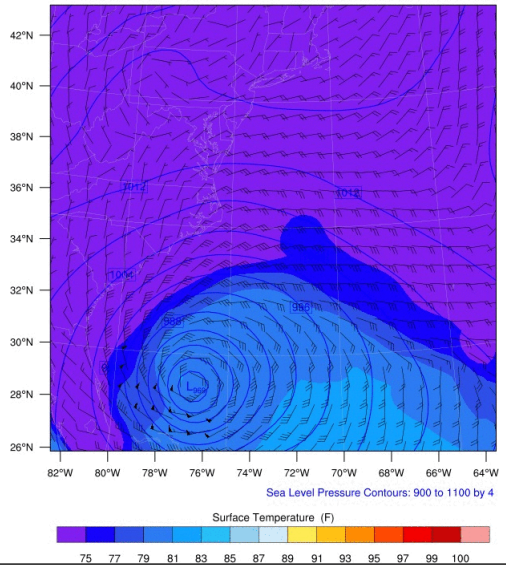
WPS Domain Configuration



REAL-TIME WRF

Init: 2012-10-27_12:00:00
Valid: 2012-10-27_12:00:00

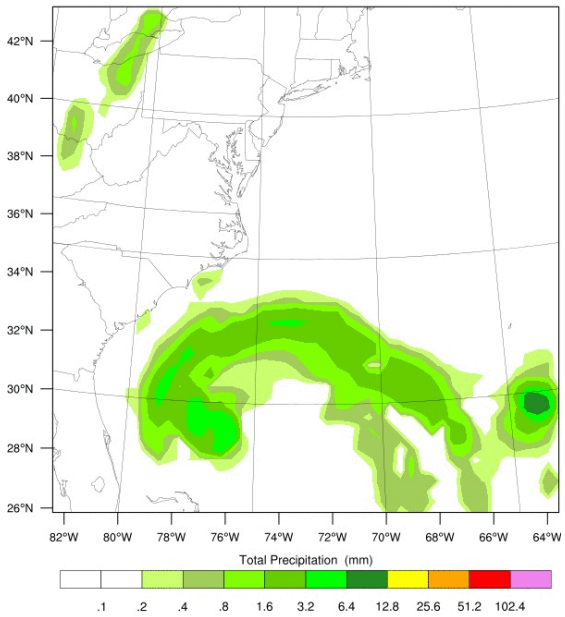
Surface Temperature (F)
Sea Level Pressure (hPa)
Wind (kts)



REAL-TIME WRF

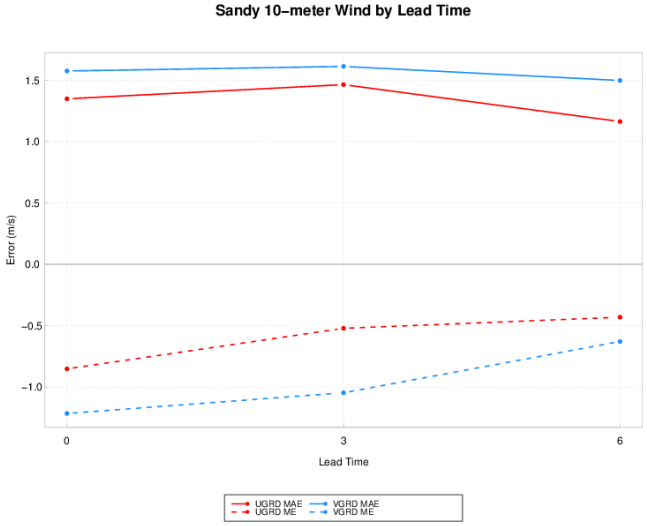
Init: 2012-10-27_12:00:00
Valid: 2012-10-27_13:00:00

Total Precipitation (mm)

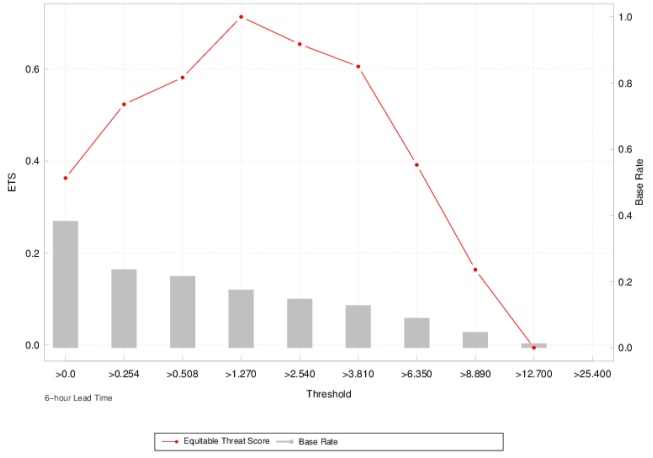


OUTPUT FROM WRF V3.9.1.1 MODEL
WE = 50 ; SN = 50 ; Levels = 60 ; Dis = 40km ; Phys Opt = 4 ; PBL Opt = 1 ; Cu Opt = 1

Sandy 10–meter Wind by Lead Time

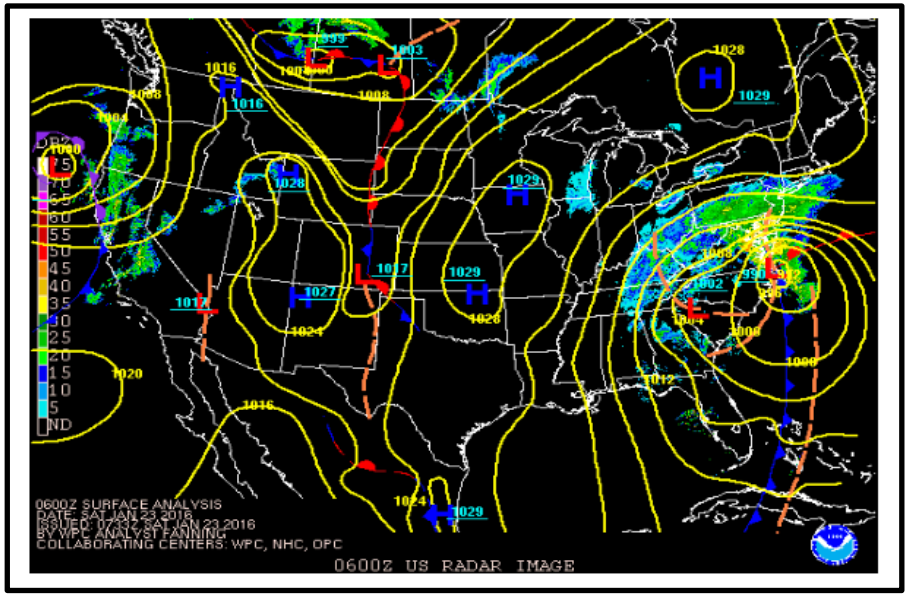


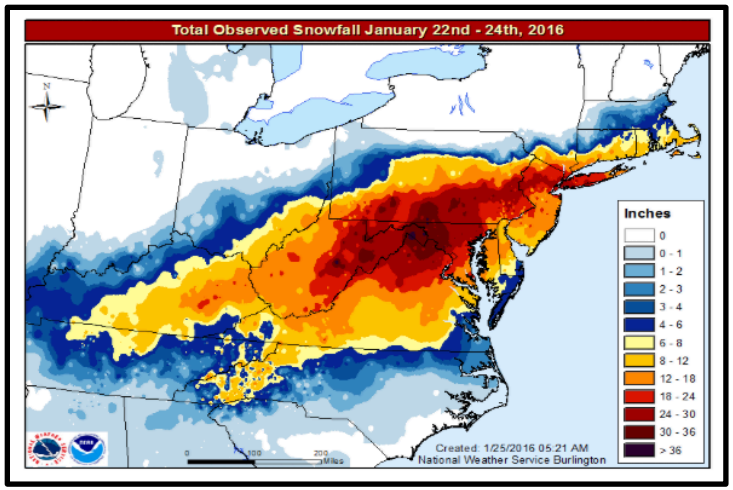
Sandy 3–hourly APCP ETS by Threshold



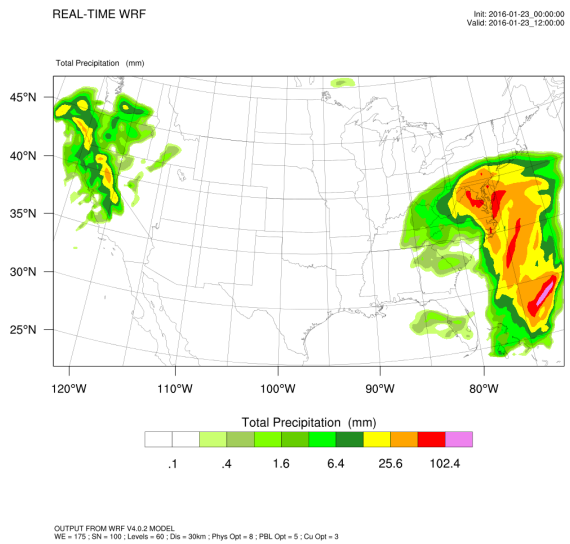
Snow Event Background

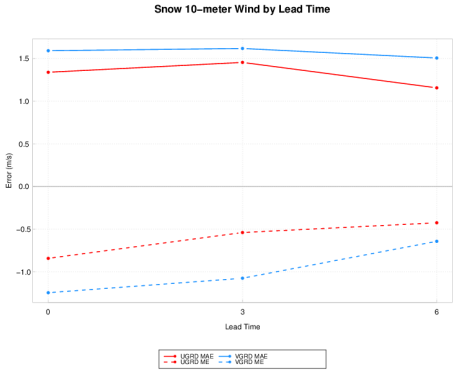
- Classic set-up for a major winter storm
  - Developed near the Gulf Coast and strengthened rapidly as it moved slowly up the coast
  - Produced significant amounts of snow, sleet, and freezing rain
  - Maximum amounts of 30-42” of snow in the mountains near the border of VA/WV/MD



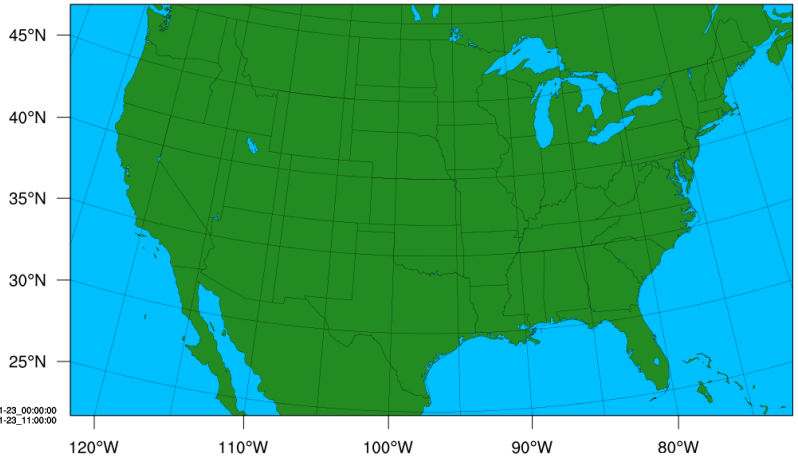


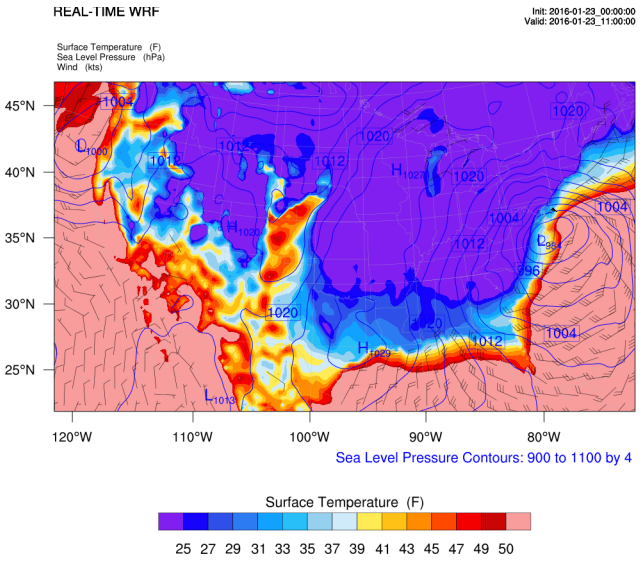
Snow Event Output

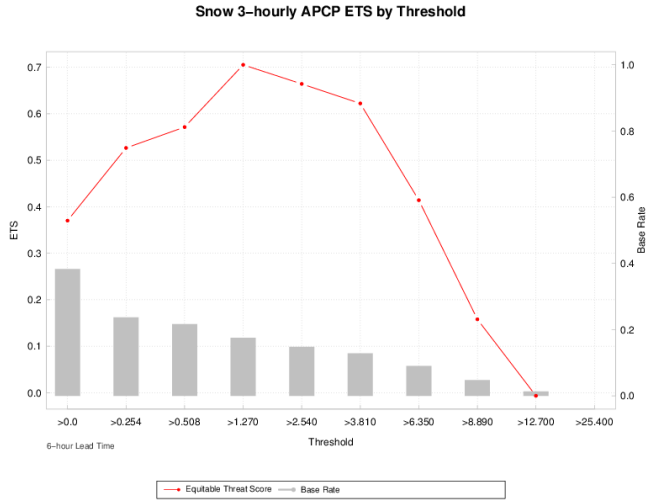




WPS Domain Configuration

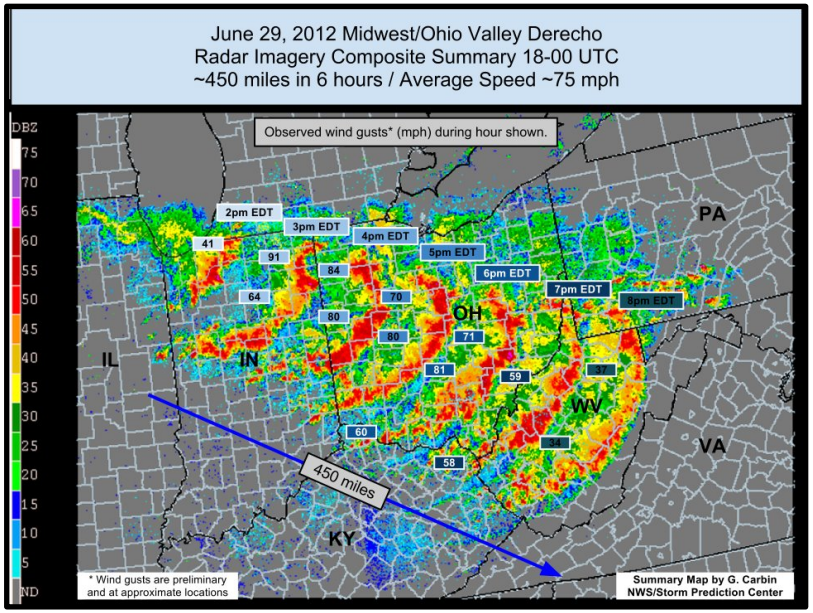


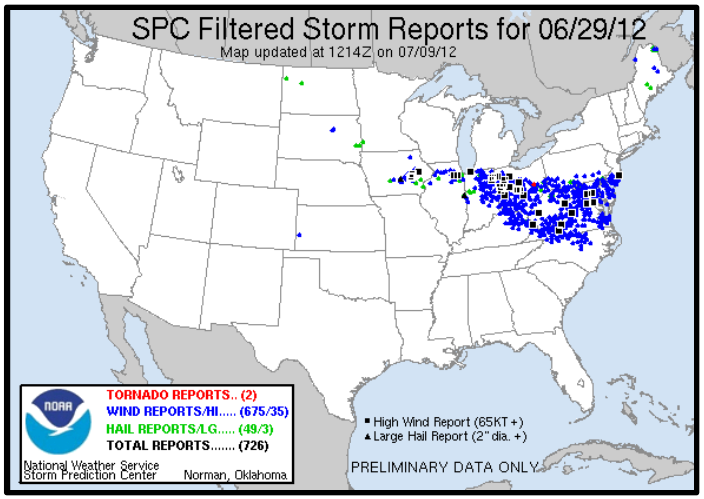




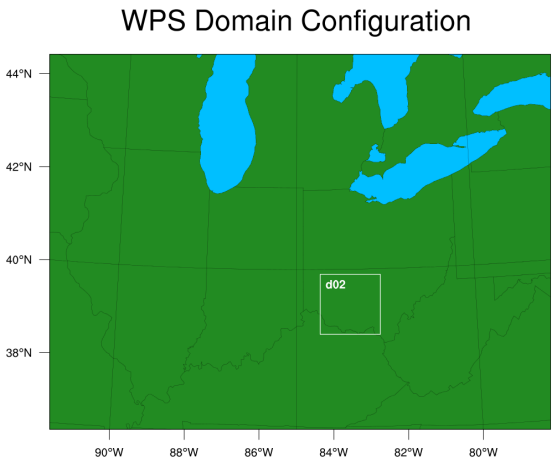
Derecho Event Background

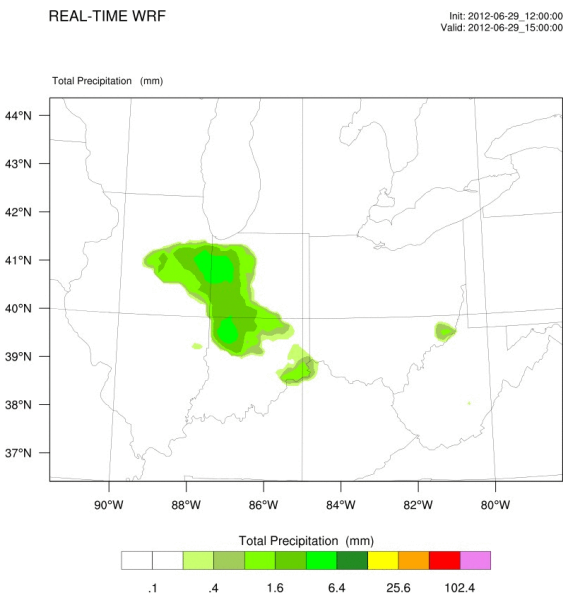
- Progressive derecho originated in Midwest, moved ESE across the Ohio Valley into the Mid-Atlantic
  - Traversed over 700 miles over 10 states
  - 13 deaths directly associated with storm
  - 4 million lost power
- Operational forecast guidance:
  - Global Forecast System (GFS) and NAM did not provide much forecast assistance more than 24 hours out from the event
  - High-Resolution Rapid Refresh (HRRR) model forecast an MCS to move through impacted area on morning of 29 June 2012 → *however, previous performance by HRRR did not allow for much confidence in forecast*

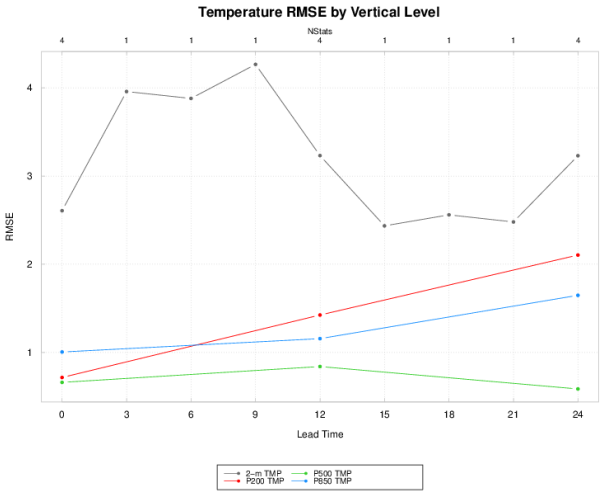


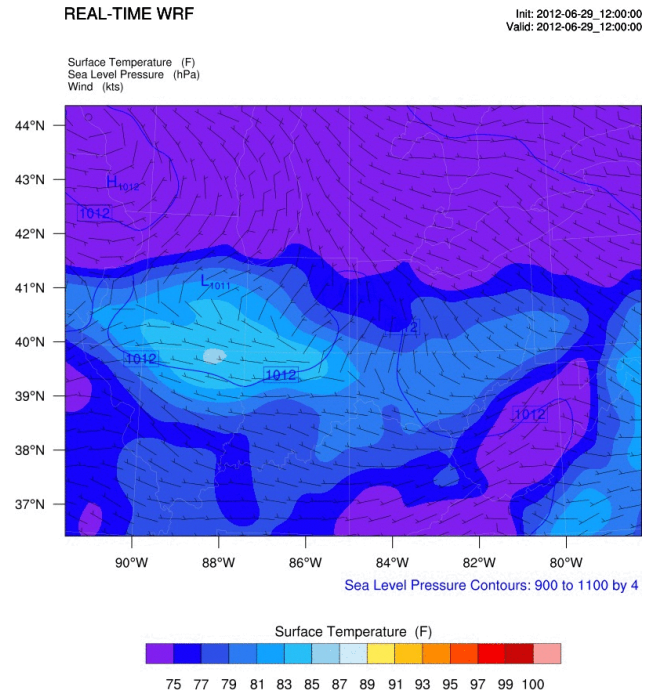


Derecho Event Output

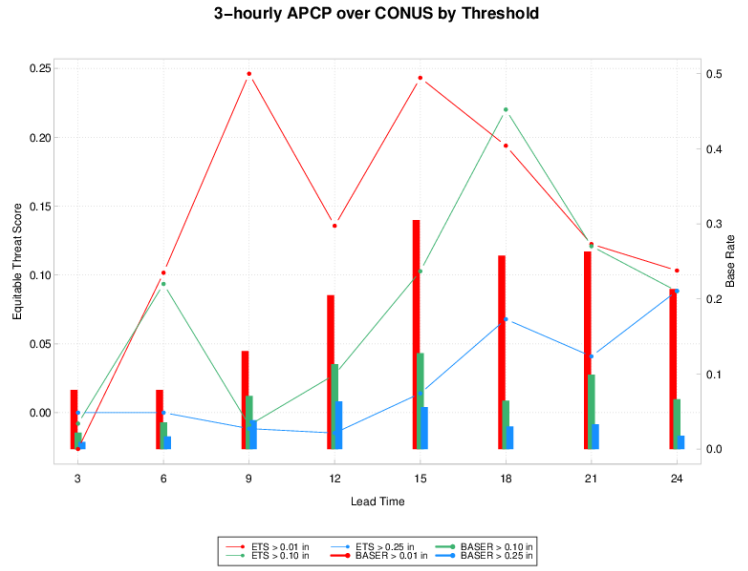








OUTPUT FROM WRF V3.9.1.1 MODEL
WE = 101 ; SN = 76 ; Levels = 51 ; Dis = 12km ; Phys Opt = 8 ; PBL Opt = 5 ; Cu Opt = 3

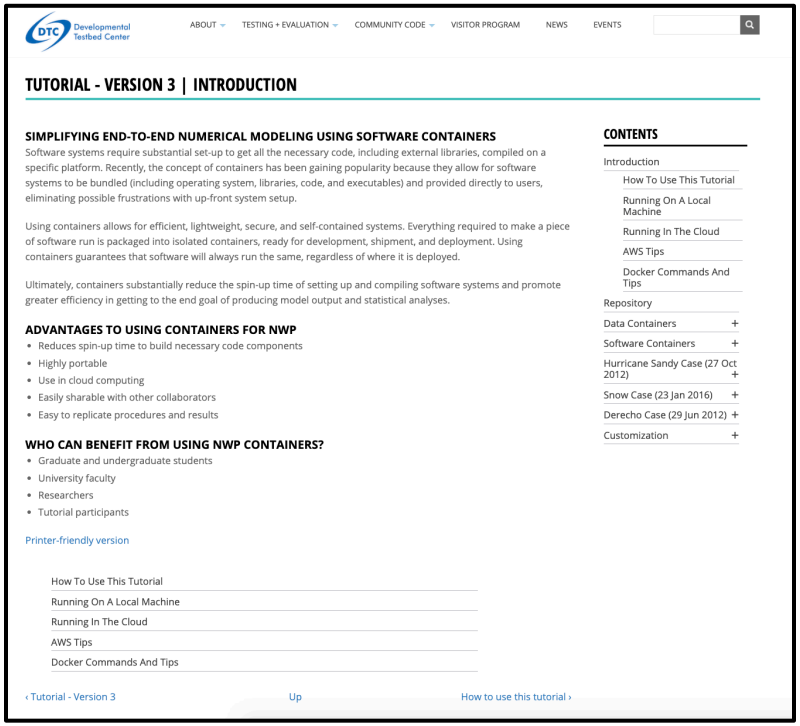


Online Tutorial

Step-by-step instructions for

- accessing/building software and data containers on a local machine or cloud computing platform

- running available case studies



https://dtcenter.org/tutorial-version-3/introduction