Current and Future Plans for Post-Processing and Verification of Numerical Weather Prediction Models at the NOAA Environmental Modeling Center

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NOAA/NWS/NCEP

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National Weather Service (NWS) Vision and Mission

Vision

Build a Weather-Ready Nation where Society is prepared for & responds to Weather-Dependent Events

Mission

The National Weather Service (NWS) provides weather, water, & climate forecasts & warnings for the United States, its territories, adjacent waters & ocean areas, for the protection of life & property & the enhancement of the national economy. NWS data & products form a national information database & infrastructure which can be used by other governmental agencies, the private sector, the public, & the global community.

Impact-based Decision Support Services (IDSS)

Courtesy: U.S. Army National Guard

What is IDSS?

Timely and relevant forecasts, watches, and warnings are major strengths of the National Weather Service (NWS). However, NWS core partners have ever-changing and complex decisions to make that require a higher level of service to ensure public safety and the effective use of resources. This higher level of service that NWS provides is called "Impact-based Decision Support Services," or "IDSS." **IDSS is forecast advice and interpretative services to assist core partners' decision-making when weather, water, or climate has a direct impact on the protection of lives and property.**

Ready • Responsive • Resilient

Building a Weather-Ready Nation

Building a Weather-Ready Nation requires strong partnerships. NWS professionals work hand-in-hand with core partners at local, tribal, state and national levels to help ensure decision-makers have accurate, reliable and trustworthy weather, water and climate information needed to meet a joint mission to protect life and property. As part of the Weather, Water, and Climate Enterprise, we also can't do this alone with each part playing an important role collectively working to meet this mission.

Government | Emergency Management | Academia | America's Weather and | Broadcast Media

> "[NWS support] has revolutionized the emergency management community – from a reactive posture to proactive mitigation of impending extreme events."

Eric Wagge
Hennepin County (MN) Emergency Manager

EMC Reorganization: May 2017

- Why did EMC reorganize?
  - Shift from legacy multi-models to unified modeling framework
  - Break down stovepipes (e.g., no more separate models and pre-/post-processing applications for separate Global, Meso and Marine branches)
  - Address gaps/shortfalls (e.g., DA, V&V/diagnostics, systems engineering)
    - Bring together functions for consistency and greater efficiency
  - Create new management structure to more effectively manage EMC as an integrated system, rather than as a collection of separate models
  - *Bottom line: EMC reorg is designed to more effectively manage model development and operations for the* ***new unified modeling framework***

Environmental Modeling Center (EMC)

Environmental Modeling Center

Director

Deputy Director

Director's Office Staff: Budget, HR, Admin

Verification, Post-processing and Product Generation Branch

Modeling and Data Assimilation Branch

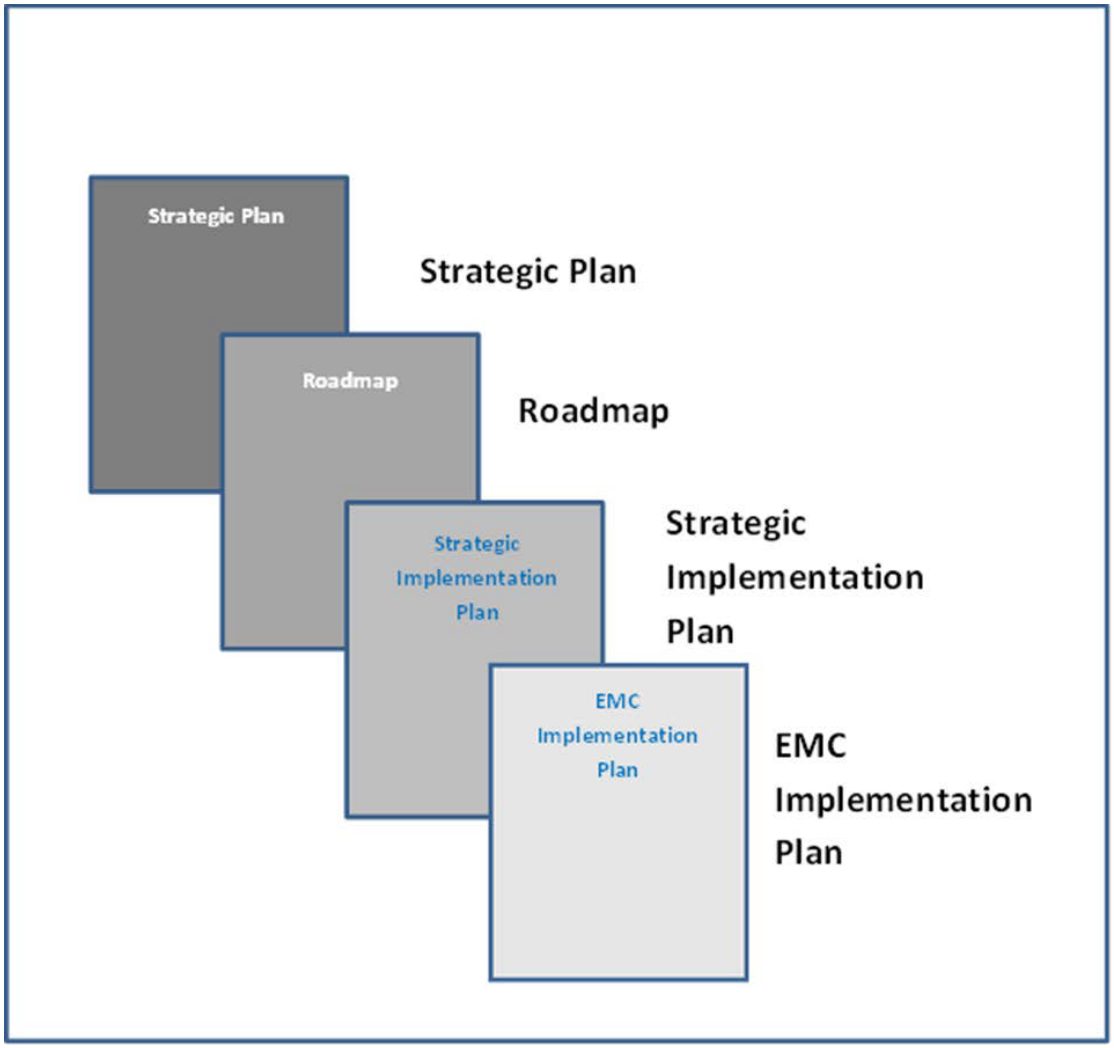
Engineering and Implementation Branch

Data Assimilation and Quality Control Group

Model Physics Group

Model Dynamics and Coupling Group

Unified Forecast System Planning



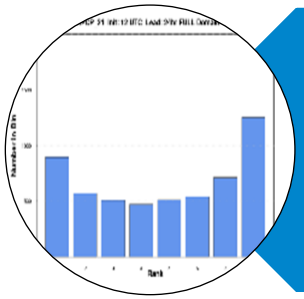
VPPPG Branch Introduction

Verification, Post-Processing, and Product Generation – Est. May 2017

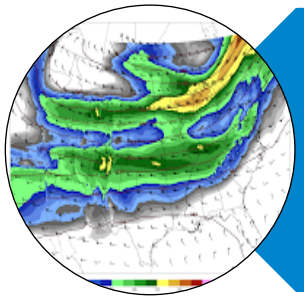
  - Consolidates verification and evaluation functions to more efficiently and consistently support all modeling groups.
  - Also removes evaluation functions from model science chain of command, ensuring ***independent*** evaluations
- Functions (from new functional statement) include:
  - Conduct **diagnostic verification studies** of model performance on weather and climate time and space scales;
  - Processing and quality control of **observations**;
  - **Evaluation of new observing systems** for the atmosphere, ocean, land surface and cryosphere;
  - Data impact studies to evaluate potential improvements in forecast skill with new or improved observing systems;
  - **Ensemble products** using models from EMC and external partners;
  - **Post-processing of model output** and **generation of products** for use by internal and external users and partners.

VPPPG Branch Core Mission

Observation Processing



Verification and Validation



Post-Processing and Products

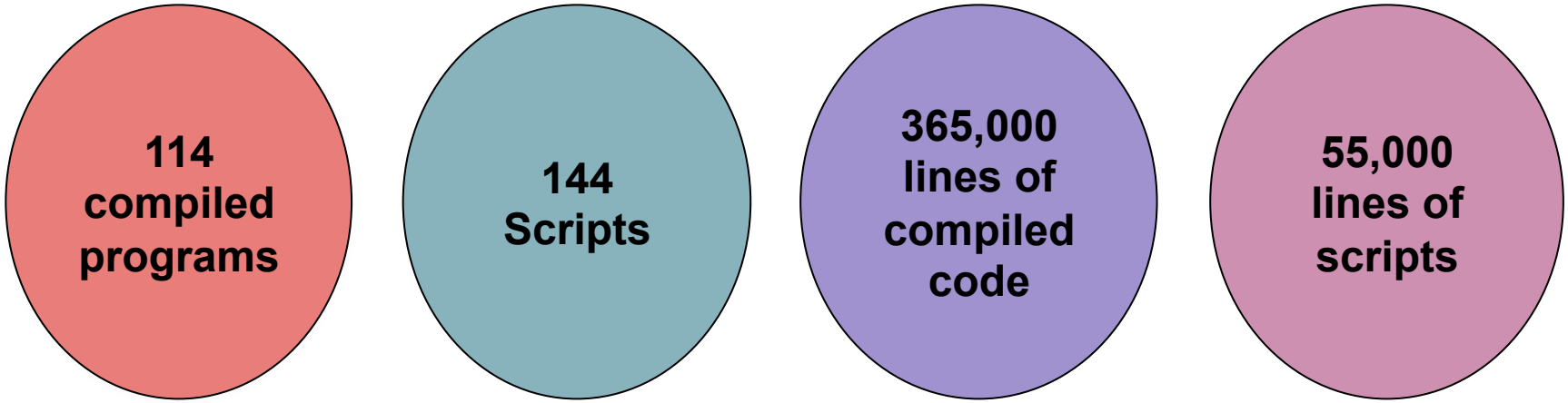
Observation Processing

Problem:

- Majority of code written in FORTRAN77 during the 1980's and 1990's
- Software has become patchworked and difficult to learn, however it is reliable
- New data sources take much time to integrate into software
- Partners (ECMWF) are using new data sources that EMC can't integrate due to integration time
- Software is not parallelized or ready for future large data sets and WoF-type processing

Solution:

- Engineer with Python, create modular code using Python libraries and modern techniques
- Store observations in a high performance geospatial database structure
- Reduce time for new data set integration from months to weeks



Ongoing EMC ObsProc engagement with international groups

- WMO Interprogramme Expert Team on Codes Maintenance (IPET-CM)
  - Supports, manages and enhances BUFR and GRIB code forms
  - Meets annually (next in Germany, May 2018)
- WMO Expert Team on Aircraft-Based Observations (ET-ABO)
  - Supports, manages and enhances worldwide aircraft-based observing system
  - Meets annually (next TBD)
- WMO Task Team on WIGOS Data Quality Monitoring System (TT-WDQMS)
  - Develops real-time monitoring, evaluation and incident resolution standards for the WMO Integrated Global Observing System (WIGOS)
  - Meets annually (next in December 2018)
- Global Data Exchange (GODEX-NWP)
  - Facilitates and coordinates observational data discovery and exchange between major worldwide NWP centers
  - Meets biennially (next in India, November 2018)

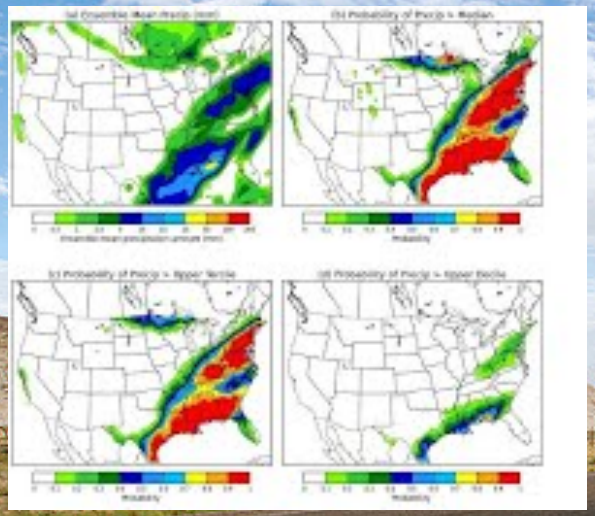
Ongoing EMC ObsProc engagement with national groups

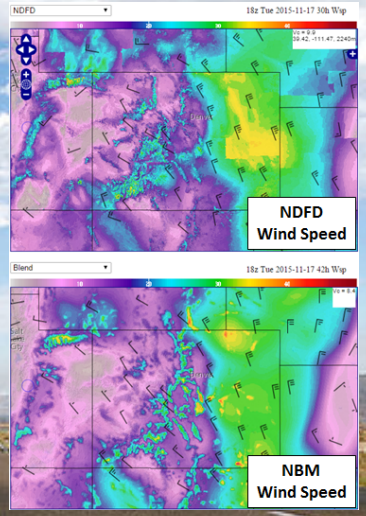
- OFCM Working Group for Observational Data (WG-OD)
  - Facilitates and coordinates observational data discovery and exchange between U.S. national NWP centers, including resolution of data management and processing issues
  - Meets weekly (via telecon)

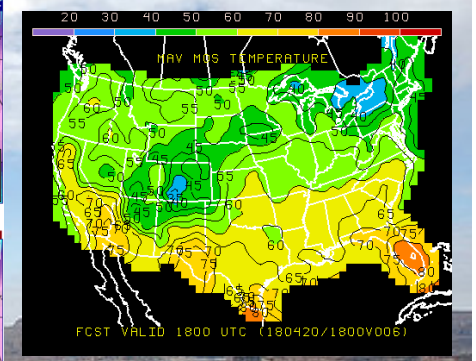
- OFCM Working Group for Cooperative Support and Backup (WG-CSAB)
  - Parent body of WG-OD
  - EMC ObsProc directly participates through its chairing of the WG-OD
  - Meets semi-annually (next in Monterey, September 2018)

- OFCM Committee for Operational Processing Centers (COPC)
  - Executive-level parent body of WG-OD and WG-CSAB
  - EMC ObsProc directly participates through its chairing of the WG-OD
  - Meets semi-annually (next in Omaha, May 2018)

NWP Post-Processing







Environmental Modeling Center

- Value added and derived products (CAPE, etc.)

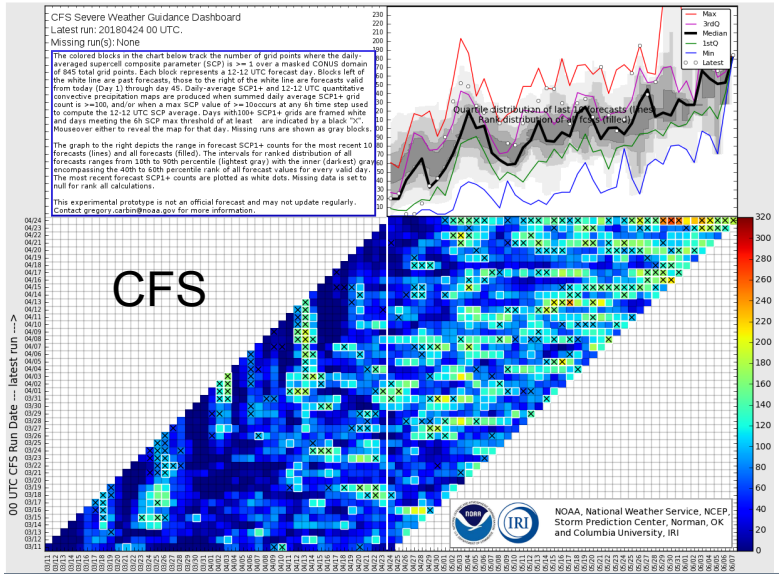
Meteorological Development Laboratory

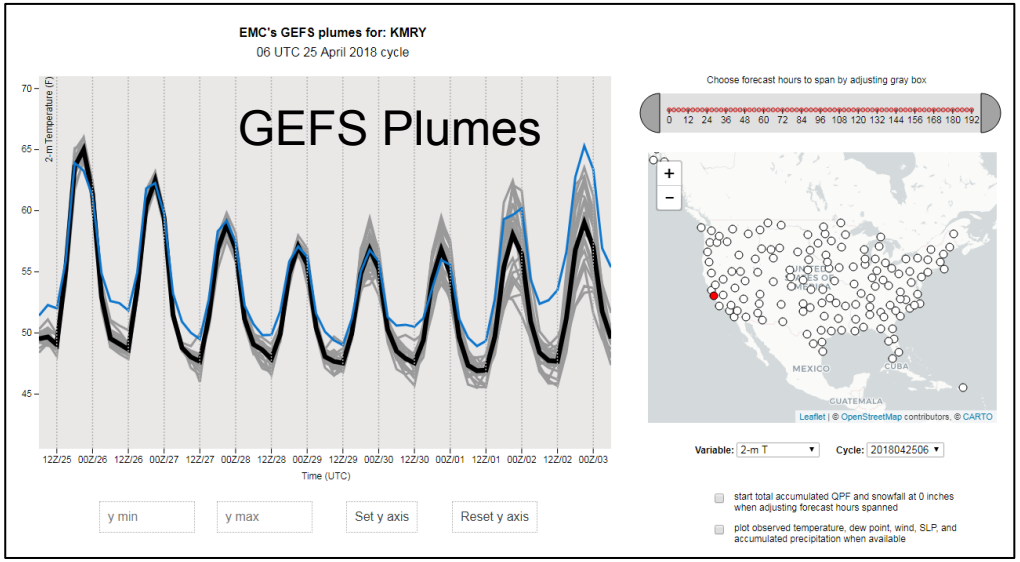
- Machine Learning
- National Blend
- Model Output Statistics (MOS)

Unified Post Processor

- The NCEP Unified Post Processor post-processes output from a variety of NWP models, including WRF-NMM, WRF-ARW, Non-hydrostatic Multi-scale Model on the B grid (NMMB), Global Forecast System (GFS), and Climate Forecast System (CFS)
- UPP interpolates output from the model's native grids to
  - National Weather Service (NWS) standard levels (pressure, height, etc.) and
  - standard output grids (AWIPS, Lambert Conformal, polar-stereographic, etc.) in NWS and World Meteorological Organization (WMO) GRIB format.
  - model's native vertical levels
- UPP incorporates the Joint Center for Satellite Data Assimilation (JCSDA) Community Radiative Transfer Model (CRTM) to compute model derived brightness temperature (TB) for various instruments and channels.

Non-Traditional Post-processing





ENSEMBLE SITUATIONAL AWARENESS TABLES

NOAA / NATIONAL WEATHER SERVICE

NAEFS ESAT

WFO Western U.S. Table May 19, 2016 00Z Run

			Z	T	U	V	WSP	SLP	Q	PW	IVT
0	Thu 19th	00Z	10	MIN	97.5	1	90	97.5	2.5	90	97.5
6		06Z	10	0.5	97.5	1	90	10	10	90	90
12		12Z	10	0.5	99	99	97.5	2.5	2.5	10	97.5
18		18Z	10	MIN	97.5	97.5	97.5	2.5	10	1	97.5
24	Fri 20th	00Z	10	MIN	99	97.5	97.5	1	1	10	99
30		06Z	2.5	MIN	99.5	99	99	1	1	97.5	99
36		12Z	1	0.5	99	MAX	99.5	0.5	2.5	90	99
42		18Z	0.5	MIN	99	MAX	MAX	0.5	97.5	10	99
48	Sat 21st	00Z	0.5	1	99	MAX	MAX	1	99	97.5	99
54		06Z	1	1	2.5	MAX	MAX	1	97.5	97.5	99
60		12Z	2.5	1	97.5	MAX	99.5	2.5	99	90	99
66		18Z	2.5	1	97.5	99.5	99	2.5	99	90	97.5
72	Sun 22nd	00Z	10	1	97.5	99.5	99	10	2.5	90	97.5
78		06Z	97.5	10	97.5	99.5	97.5	97.5	99	90	97.5
84		12Z	10	2.5	97.5	99	90	97.5	99	10	90
90		18Z	2.5	10	97.5	97.5	97.5	2.5	10	10	90
96	Mon 23rd	00Z	2.5	10	97.5	90	97.5	1	10	AVG	90
102		06Z	2.5	10	97.5	90	90	1	1	10	AVG	AVG
108		12Z	2.5	10	90	90	90	10	10	10	AVG
114		18Z	10	10	97.5	90	97.5	10	2.5	10	AVG

ECMWF ESAT

WFO Western U.S. Table May 19, 2016 00Z Run

			Z	T	U	V	WSP	SLP	Q	PW	IVT
0	Thu 19th	00Z	10	MIN	99.5	0.5	99.5	99.5	2.5	99.5	90
6		06Z	10	0.5	99.5	MIN	MAX	2.5	99	10	97.5
12		12Z	10	0.5	99.5	MIN	MAX	2.5	99	MIN	99
18		18Z	10	MIN	MAX	MIN	MAX	2.5	0.5	0.5	99
24	Fri 20th	00Z	2.5	MIN	MAX	0.5	MAX	0.5	MIN	1	99.5
30		06Z	1	MIN	MAX	99.5	MAX	0.5	0.5	0.5	99.5
36		12Z	0.5	MIN	MAX	99.5	MAX	MIN	1	10	99
42		18Z	0.5	MIN	99.5	MAX	MAX	0.5	0.5	2.5	99.5
48	Sat 21st	00Z	0.5	MIN	99.5	MAX	99.5	0.5	MIN	97.5	99.5
54		06Z	0.5	MIN	MAX	MAX	99.5	1	99	99	99.5
60		12Z	2.5	0.5	99.5	MAX	99.5	2.5	1	97.5	97.5
66		18Z	2.5	MIN	99.5	MAX	99.5	97.5	99.5	10	99.5
72	Sun 22nd	00Z	2.5	2.5	99.5	MAX	99.5	99.5	MAX	99	99.5
78		06Z	99.5	2.5	99	MAX	99.5	99.5	99.5	97.5	99
84		12Z	2.5	10	MAX	99.5	MAX	99	1	10	97.5
90		18Z	2.5	1	99.5	99.5	99.5	99	0.5	10	90
96	Mon 23rd	00Z	1	10	99	97.5	97.5	2.5	10	10	AVG
102		06Z	1	10	99.5	90	97.5	2.5	97.5	10	AVG
108		12Z	1	10	97.5	10	97.5	2.5	10	2.5	90
114		18Z	2.5	1	99	90	99.5	2.5	1	10	90

NAEFS ESAT ARCHIVE

WFO Western U.S. Table May 19, 2016 00Z Run

			Z	T	U	V	WSP	SLP	Q	PW	IVT
0	Thu 19th	00Z	10	MIN	97.5	1	90	97.5	2.5	90	97.5
6		06Z	10	0.5	97.5	1	90	10	10	90	90
12		12Z	10	0.5	99	99	97.5	2.5	2.5	10	97.5
18		18Z	10	MIN	97.5	97.5	97.5	2.5	10	1	97.5
24	Fri 20th	00Z	10	MIN	99	97.5	97.5	1	1	10	99
30		06Z	2.5	MIN	99.5	99	99	1	1	97.5	99
36		12Z	1	0.5	99	MAX	99.5	0.5	2.5	90	99
42		18Z	0.5	MIN	99	MAX	MAX	0.5	97.5	10	99
48	Sat 21st	00Z	0.5	1	99	MAX	MAX	1	99	97.5	99
54		06Z	1	1	2.5	MAX	MAX	1	97.5	97.5	99
60		12Z	2.5	1	97.5	MAX	99.5	2.5	99	90	99
66		18Z	2.5	1	97.5	99.5	99	2.5	99	90	97.5
72	Sun 22nd	00Z	10	1	97.5	99.5	99	10	2.5	90	97.5
78		06Z	97.5	10	97.5	99.5	97.5	97.5	99	90	97.5
84		12Z	10	2.5	97.5	99	90	97.5	99	10	90
90		18Z	2.5	10	97.5	97.5	97.5	2.5	10	10	90
96	Mon 23rd	00Z	2.5	10	97.5	90	97.5	1	10	AVG	90
102		06Z	2.5	10	97.5	90	90	1	1	10	AVG	AVG
108		12Z	2.5	10	90	90	90	10	10	10	AVG
114		18Z	10	10	97.5	90	97.5	10	2.5	10	AVG

NAEFS D(PROG)/DT

Western U.S. Table May 19, 2016 00Z Run

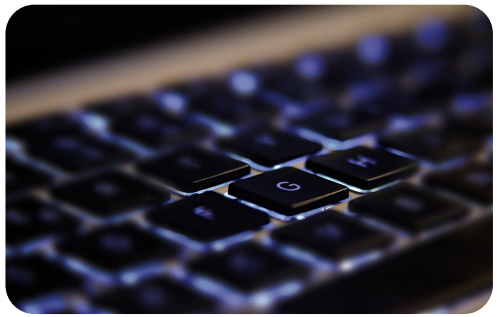
			Z	T	U	V	WSP	SLP	Q	PW	IVT
0	Thu 19th	00Z	10	MIN	97.5	1	90	97.5	2.5	90	97.5
12		12Z	10	0.5	99	99	97.5	2.5	2.5	10	97.5
24	Fri 20th	00Z	2.5	MIN	99.5	97.5	97.5	1	0.5	10	99
36		12Z	1	0.5	99	MAX	99.5	0.5	2.5	90	99
48	Sat 21st	00Z	0.5	0.5	99	MAX	MAX	0.5	99	10	99
60		12Z	2.5	0.5	2.5	MAX	99.5	2.5	99	10	99
72	Sun 22nd	00Z	10	1	97.5	99.5	99	10	2.5	90	97.5
84		12Z	10	2.5	97.5	99.5	90	97.5	99.5	10	90
96	Mon 23rd	00Z	2.5	10	97.5	90	97.5	1	10	AVG	90
108		12Z	2.5	10	90	90	90	10	10	10	AVG
120	Tue 24th	00Z	10	10	90	90	90	AVG	10	AVG	AVG
132		12Z	10	10	90	90	90	10	10	10	AVG
144	Wed 25th	00Z	10	10	90	90	90	10	AVG	90
156		12Z	99	10	90	90	90	99.5	10	10	90
168	Thu 26th	00Z	MAX	10	90	AVG	AVG	MAX	10	AVG	90
180		12Z	MAX	10	AVG	AVG	AVG	MAX	AVG	AVG	AVG
192	Fri 27th	00Z	99.5	10	90	AVG	90	99.5	AVG	AVG	AVG
204		12Z	97.5	10	AVG	AVG	AVG	99.5	90	10	AVG
216	Sat 28th	00Z	AVG	97.5	90	AVG	AVG	AVG	AVG	10	AVG
228		12Z	AVG	90	AVG	AVG	AVG	AVG	AVG	AVG	AVG

New FV3GFS Variables

Composite and 1km radar reflectivity
Instantaneous precipitation type
Simulated GOES
Isobaric snow every 50 hPa
Isobaric cloud ice every 50 hPa
Isobaric rain every 50 hPa
Isobaric graupel every 50 hPa
Isobaric specific humidity every 50 hPa
Isobaric DZDT every 50 hPa
20, 30, 40, 50 m AGL wind
Height at 0.4, 15, 40 hPa
Temperature at 0.4, 15, 40 hPa
Vorticity at 0.4, 15, 40 hPa
Ozone at 0.4, 15, 40, 500, 700, 850, 1000 hPa
3D cloud fraction

Weather Information Statistical Post Processing System

- What is it? Software to statistically post process numerical weather prediction data.



Community

Ideas sourced from the global weather enterprise

Support NGGPS

Technology

Python

NetCDF

Git

Data

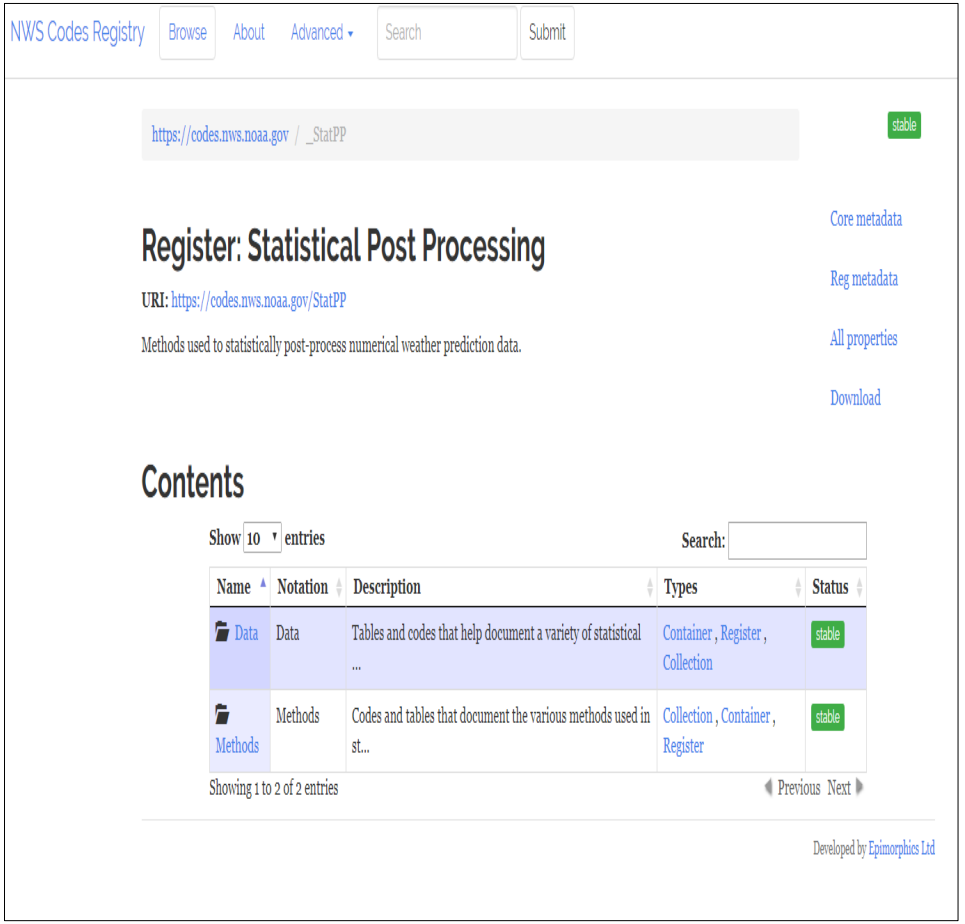
Metadata

Widely accepted standards (ISO, WMO, OGC)

NetCDF-CF

Foundation of WISPS: The Data Model

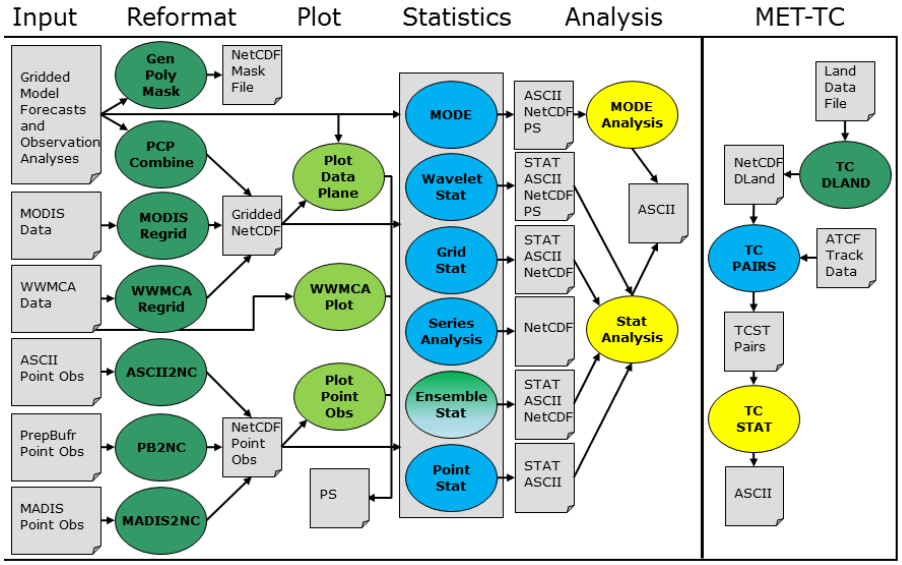
- Data tells a story
- NetCDF-CF conventions
- codes.nws.noaa.gov
- Internal Metadata



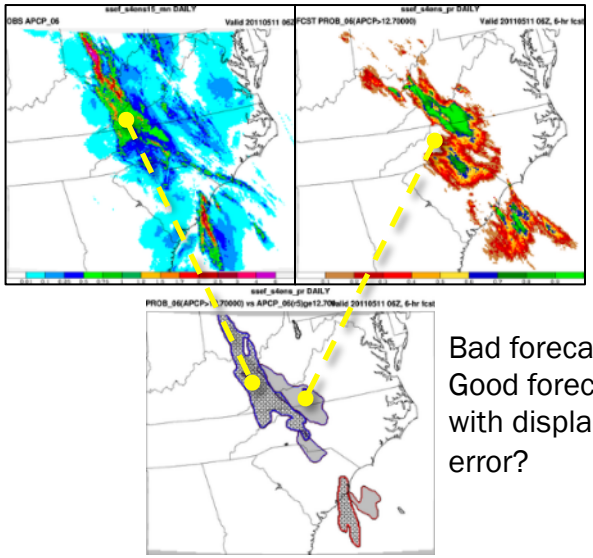
Verification Software

MET Model Evaluation Tools

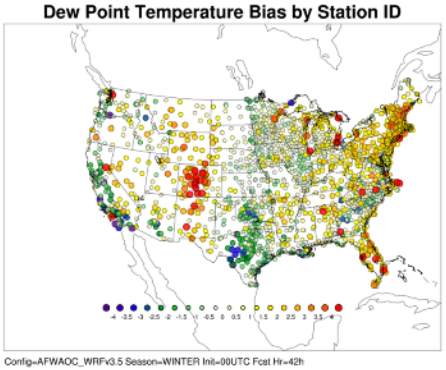
- Originally developed to replicated the EMC mesoscale verification system
- **Over 85 traditional statistics** using both point and gridded datasets
- 15 interpolation methods
- Computation of confidence intervals
- Able to read in GRIB1, GRIB2 and CF-compliant NetCDF
- Applied to many spatial and temporal scales
- 3500+ users, both US & Int'l



Object Based and Spatial Methods

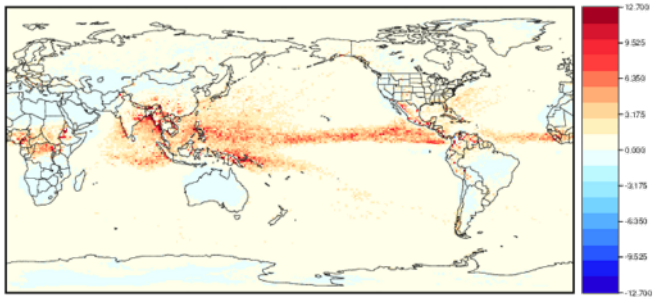


Bad forecast or Good forecast with displacement error?

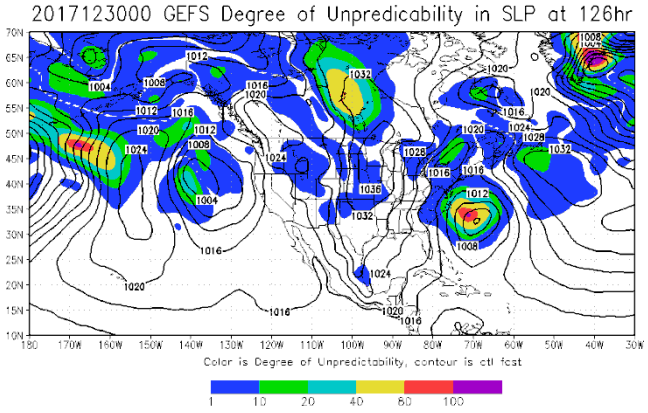


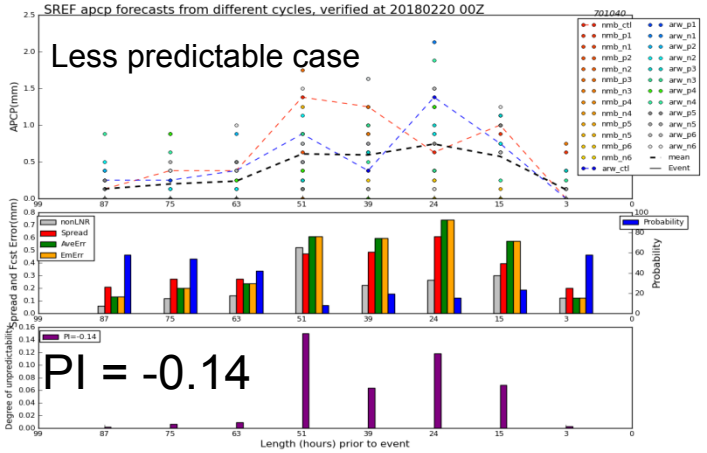
Geographical Representation of Errors

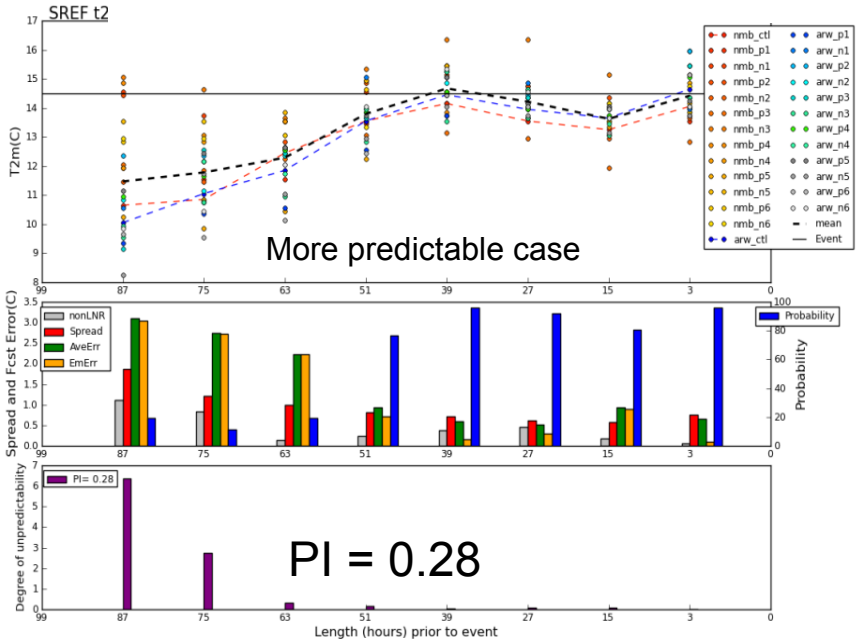
90th Percentile of difference between two models

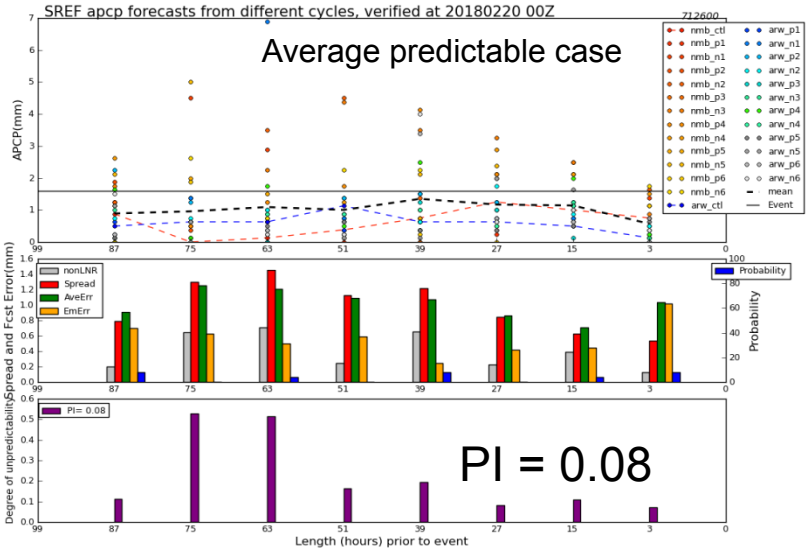


Ensemble Metrics: Predictability Index (Jun Du)









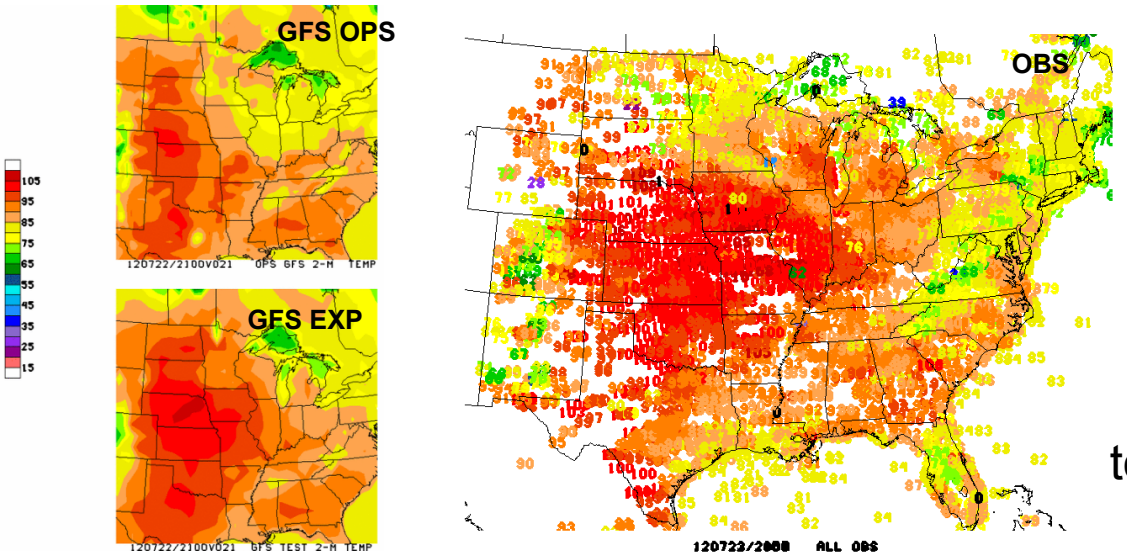
Model Evaluation Group

- **OUTREACH** – the MEG serves as the "customer service" function of EMC with webinars, direct communication, and visits to WFOs
- Provides daily examination of model performance from the perspective of the forecasting community
- Organized evaluation of EMC parallels and experiments
- **Provides critical feedback to modelers and branch chiefs and keeps customers "in the loop" regarding model changes, verification, and forecast issues**
- Provides streamlined feedback to outside users with model concerns – EMC is listening to customer/stakeholder feedback
- Can rapidly generate critical case studies (2012 Mid-Atlantic derecho, Superstorm Sandy, 2013 El Reno tornado/OKC flood,, 2016 IAH and BTR floods, 2016 Matthew, 2017 PDX surprise snow,2017 Harvey, Irma, and Maria)

Model Evaluation Group

- **Participation and presenters from other NCEP centers, NWS regional/ local offices, ESRL, GFDL, other customers**
  - **Webinar held each Thursday at 11:30 Eastern Time: open to all. To get on MEG listserv, contact**

    Geoff Manikin (geoffrey.manikin@noaa.gov)
- **Model changes have already been implemented, and more are being tested in response to MEG concerns**



Example of changes made to GFS in response to concerns raised by MEG

FV3GFS Evaluation Metrics

METRIC	LEVEL(s)	VERIFICATION METHOD	VERIFICATION DATA
Anomaly Height Correlation and Dieoff Curves	500 mb	grid-to-grid	GFS analysis
RMSE of T, q, u, v	Full vertical profile	grid-to-obs	Raob Data
Bias of T, q, u, v	Full vertical profile	grid-to-obs	Raob Data
Precipitation Equitable Threat Score	Surface	grid-to-grid	Stage IV Analysis
Precipitation Bias	Surface	grid-to-grid	Stage IV Analysis
2-m T, Td RMS and Bias	Surface	grid-to-obs	METARS
10-m u,v RMS and Bias	Surface	grid-to-obs	METARS
Tropical Cyclone Track & Intensity Errors	Surface	Cyclone tracker data - to obs	NHC track summaries
3-hr Areal-average Precipitation	Surface	grid-to-grid	Stage IV Analysis
Precipitation MODE Scores	Surface	grid-to-grid	Stage IV Analysis
Lat-lon and Zonal Mean Wind Plots	250, 850 mb	grid-to-grid	GFS analysis
Sfc-based and most unstable cape	Computed through column	grid-to-obs	Raob Data
Visibility RMS and Bias	Surface	grid-to-obs	METARS
Cloud Ceiling RMS and Bias	Surface	grid-to-obs	METARS
Wind MODE Scores	250 mb	grid-to-grid	GFS analysis

Emerging CAM Metrics

Forecast Field	Vertical Attribute	Temporal Attribute	Validation Source	Deterministic Methodology	Ensemble Methodology	Deterministic Scores	Ensemble Scores	Deterministic Stratifications	Ensemble Stratifications
Simulated Reflectivity	Composite	Instantaneous	MRMS Mosaic Composite	Grid-to-Grid	Neighborhood probability	CSI, BIAS, FSS, POD, FAR, AUR, Performance Diagram	Briar Score, Briar Skill Score (other ensemble reference), Reliability, Sharpness, CRPS, CRPSS (other ensemble reference)	Forecast Length [0-36 hr], Threshold [25,30,35,40,45,50 dBZ, percentiles], Scale [03, 40 km], Domain [W and E CONUS]	Neighborhoods [10, 20, 40, 80 km, +/- 1hr in time], Smoothing [? km], Probabilities [0, 5, 10, ...100]
Updraft Helicity	2-5, 0-3 km AGL	Hourly Maximum	Storm Reports	Surrogate Severe	Max neighborhood probability	FSS, AUR	Briar Score, Briar Skill Score (other ensemble reference), Reliability, Sharpness, CRPS, CRPSS (other ensemble reference)	Forecast Length [0-36 hr], Threshold [25,50,75 m^2/s^2, percentiles], Scale [03, 40 km], Domain [W and E CONUS]	Time Windows [4, 24 hr], Neighborhoods [80 km], Smoothing [120 km sigma], Probabilities [0, 5, 10, ...100]
Updraft Helicity	2-5, 0-3 km AGL	Hourly Minimum	Storm Reports	Surrogate Severe	Max neighborhood probability	FSS, AUR	Briar Score, Briar Skill Score (other ensemble reference), Reliability, Sharpness, CRPS, CRPSS (other ensemble reference)	Forecast Length [0-36 hr], Threshold [25,50,75 m^2/s^2, percentiles], Scale [03, 40 km], Domain [W and E CONUS]	Time Windows [4, 24 hr], Neighborhoods [80 km], Smoothing [120 km sigma], Probabilities [0, 5, 10, ...100]
Reflectivity	-10C	Hourly Maximum	MRMS Mosaic -10C	Grid-to-Grid	Probability matched mean, point probability, neighborhood probability	CSI, BIAS	Briar Score, Briar Skill Score (other ensemble reference), Reliability, Sharpness, CRPS, CRPSS (other ensemble reference)	Forecast Length [0-36 hr], Threshold [25,35,45 dBZ], Scale [03, 40 km], Domain [W and E CONUS]	Neighborhoods [40 km], Smoothing [? km], Probabilities [0, 5, 10, ...100]

VPPPG Branch FY18 Plans

- FY18 Plans:
  - FV3GFS and RAPv4/HRRRv3 Evaluation through Model Evaluation Group (MEG)
  - Continue to move towards using MET+ (Model Evaluation Tools) software exclusively for all verification
  - Web site consolidation, create a plan to move all EMC verification and post-processed graphics into a more organized structure
  - Begin looking towards vetted CAM verification methods
  - Community Metrics workshop: July 30 – Aug 1, 2018 @ NCWCP
  - Create plans to re-engineer Observation Processing and Unified Post Processing Software

Community Metrics Workshop

- Community Workshop on Metrics for Verification and Validation of NWP models
  - July 30th – August 1st, 2018
  - National Center for Weather and Climate Prediction in College Park, MD
  - Meeting is ahead of NGGPS SIP workshop

- Purpose: Create a community plan for:
  - real-time and historical NWP verification metrics, focus on CAMs, coupled models, ensembles
  - validation of model components and decision process for model improvements

Community Metrics Workshop

- Community Workshop on Metrics for Verification and Validation of NWP model
  - Registration now open at:

https://dtcenter.org/events/2018/2018-dtc-community-unified-forecast-system-test-plan-metrics-workshop/registration

Thanks for Your Time.

Any Questions?