Data Assimilation for the Unified Forecast System: Plans for GFS Version 16 and Progress with JEDI

EMMDA, Delhi, India
Monday, 24 February 2020

NATIONAL WEATHER SERVICE

Daryl Kleist (NOAA/NWS/NCEP/EMC)
Chief, Data Assimilation and QC Group
On behalf of the entire EMC data assimilation team and collaborators

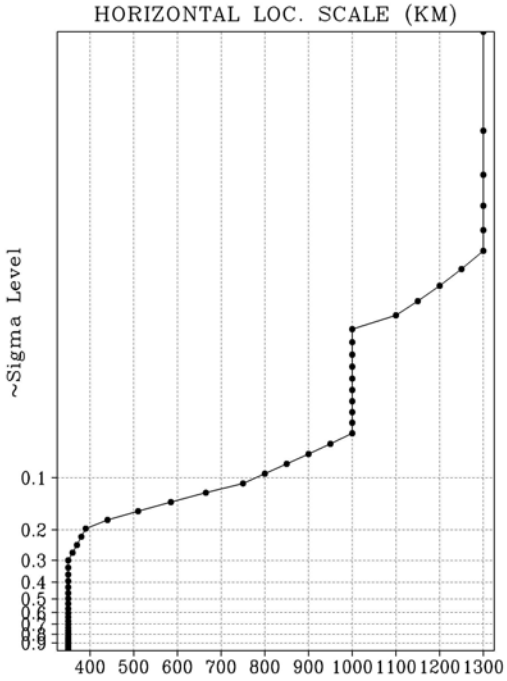
Current Operational GDAS (Hybrid 4DEnVar)

$$J(\mathbf{x}'_c, \mathbf{a}) = \beta_c \frac{1}{2}(\mathbf{x}'_c)^{\mathrm{T}}\mathbf{B}_c^{-1}(\mathbf{x}'_c) + \beta_e \frac{1}{2}\mathbf{a}^{\mathrm{T}}\mathbf{L}^{-1}\mathbf{a} + \frac{1}{2}\sum_{k=1}^{K}(\mathbf{H}_k\mathbf{x}'_{(t)k} - \mathbf{y}'_k)^{\mathrm{T}}\mathbf{R}_k^{-1}(\mathbf{H}_k\mathbf{x}'_{(t)k} - \mathbf{y}')$$

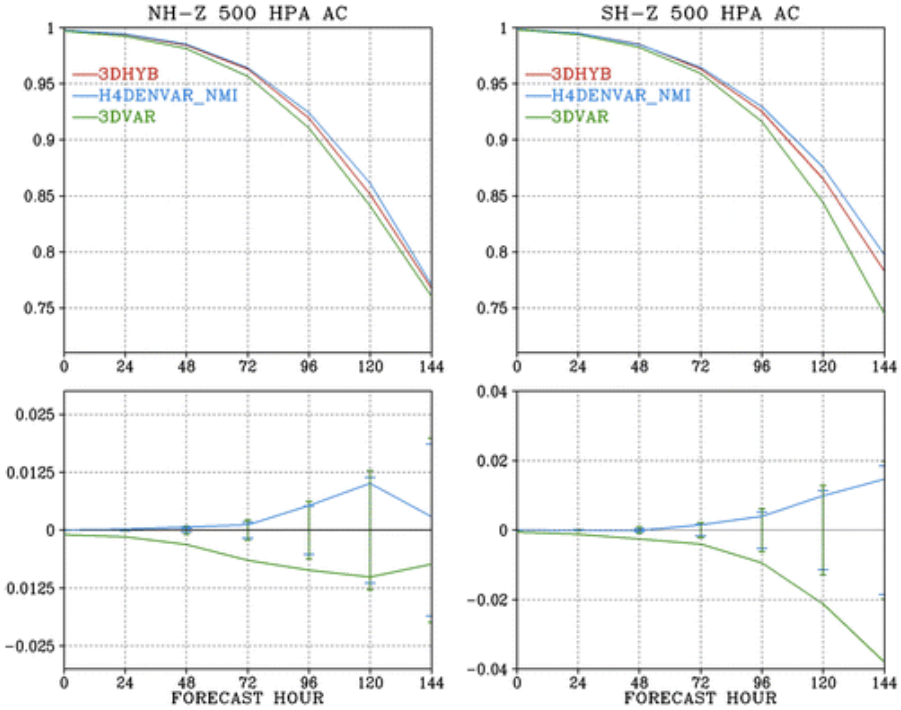
$$\mathbf{z} = \mathbf{B}^{-1}\mathbf{x}'_c \qquad \mathbf{v} = \mathbf{L}^{-1}\mathbf{a}$$

C768L64 (~12km) FV3-based GFS

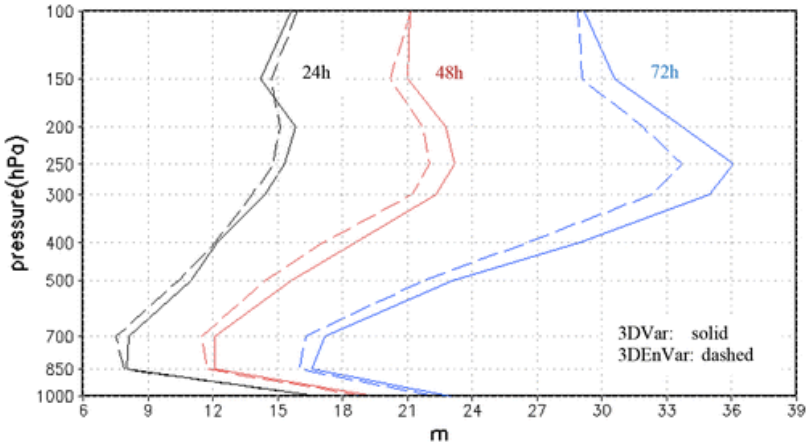
- 80 member ***C384L64 (~25km)*** EnSRF for data assimilation
- Level-dependent localization
- Stochastic physics to represent model uncertainty (SPPT, ~~*SKEB*~~, SHUM) – Since January 2015 + RTPS (no more additive perturbations)
- Analysis increment at ensemble resolution
- Ensemble perturbations centered about hybrid analysis
  - Ensemble mean state estimate replaced



Ensemble Importance for Forecast Skill

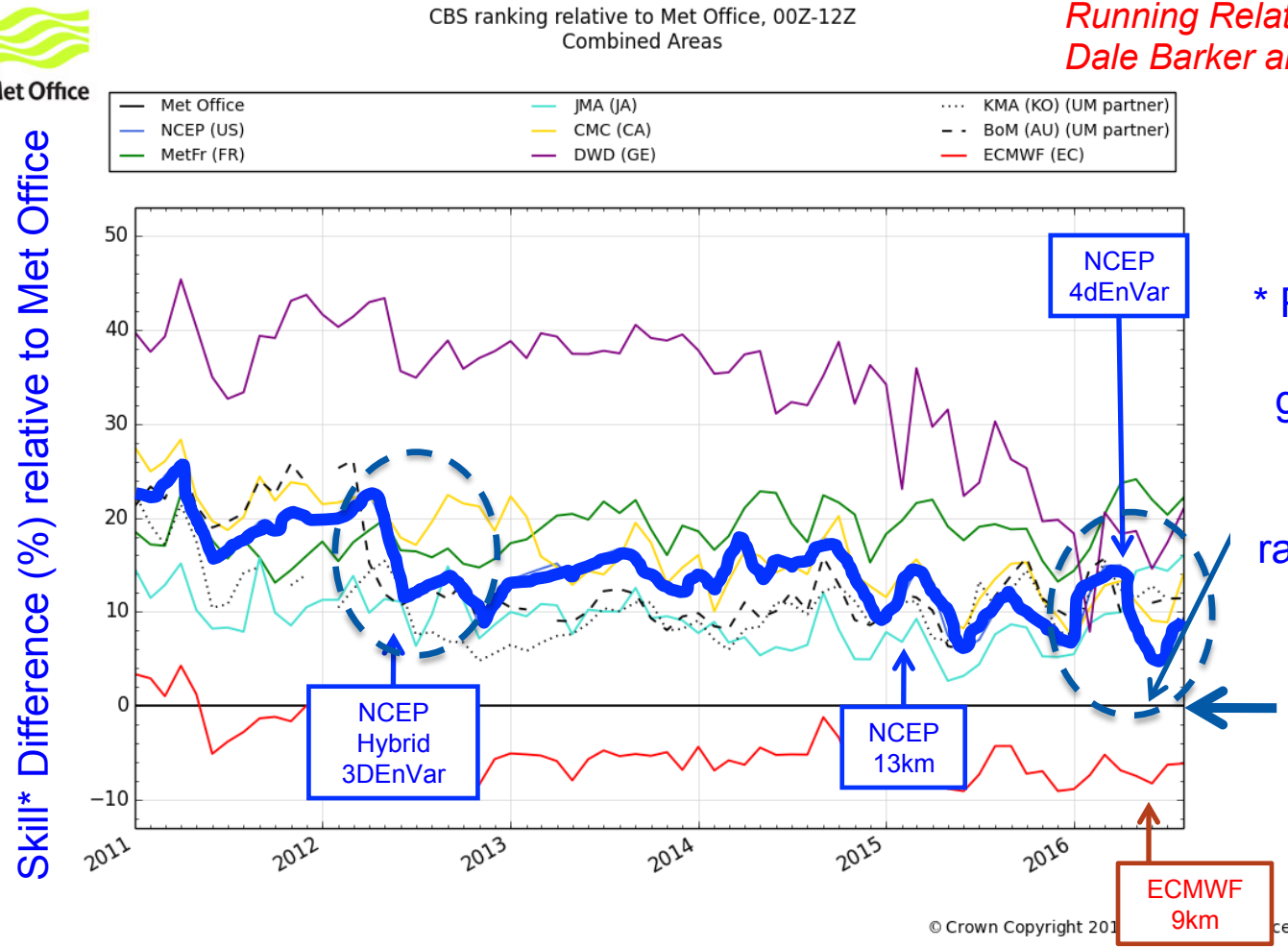


Kleist and Ide (2015), Fig. 10: OSSE based study. Comparison of skill from **3DVar**, **Hyb 3DEnVar**, and **Hyb 4DEnVar** for simulated August 2005.



Wu et al. (2017), Fig. 10: Impact of using global ensemble perturbations in regional hybrid EnVar (forecast fits to geop. height, radiosondes). This has also been realized in other regional systems at NOAA (RA

Running Relative NWP Index, Courtesy Dale Barker and Gilbert Brunet

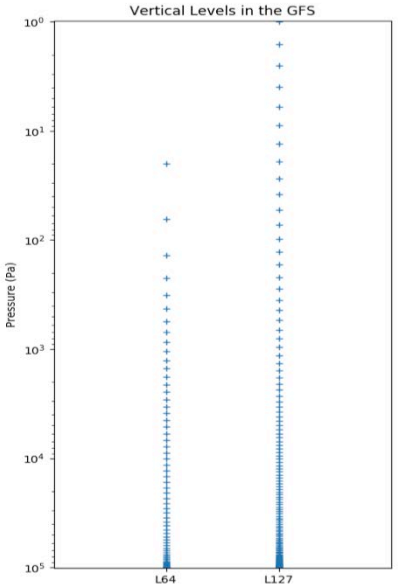


PS37

* Parameters: Surface pressure, 500hPa geopotential height, 250hPa/850hPa Winds; Forecast ranges from T+24h to T+120h

Recent and Planned Upgrades to the GFS

- GFSv15.1 (June 2019)
  - ***Initial implementation of FV3-based GFS***
  - Increase analysis increment & ensemble resolution
  - No DFI
- GFSv15.2 (November 2019)
  - Observation changes: GOES-17 AMVs, KOMPSAT-5 GPS, METOP-C AMSU-A and MHS
  - NSST Updates
- GFSv15.3 (TBD)
  - Observation changes: COSMIC-2, METOP-C GRAS and IASI
- GFSv16 (Early 2021)
  - GSI-based Hybrid 4DEnVar
  - **127 Layers, ~80km model top +** Updated physics
  - Modulated-ensemble LETKF (model space localization)
  - 4D-IAU
  - Inter-channel correlated observation errors
  - VarQC re-design
  - LDAS
  - New / Additional Observations
  - SKEB



Background Errors for L127

(Cathy Thomas)

Experimented with two methods of generating the static background error:

NMC method

- Preliminary lagged pair database (24 - 48 hour forecasts)
- Initialized from MERRA initial conditions to mitigate issues above current GFS top
- 2 months of forecasts, one winter and one summer, 00z only

Ensemble perturbation method

- Ensemble forecast database
- 6 hour forecasts
- 80 ensemble members
- 2 months of cycling, one winter and one summer
- Upper layers had increased damping

Acknowledgements:

- *MERRA conversion utility was provided by Valery Yudin (CU-CIRES)*
- *The NMC_Bkerror utility was updated to read NEMSIO by Razvan Stefanescu (Spire)*

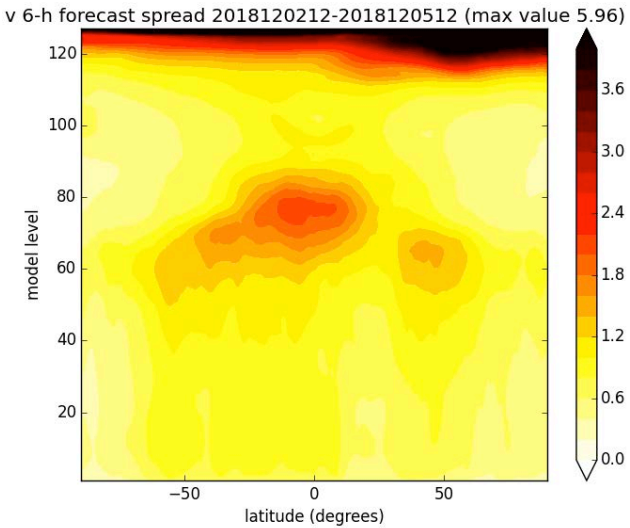
Ensemble Spread at Model Top

(Cathy Thomas & Jeff Whitaker)

Initial attempts at cycling (with ensemble) were poor due to large spread in upper layers. Needed to modify divergence damping and Rayleigh damping.

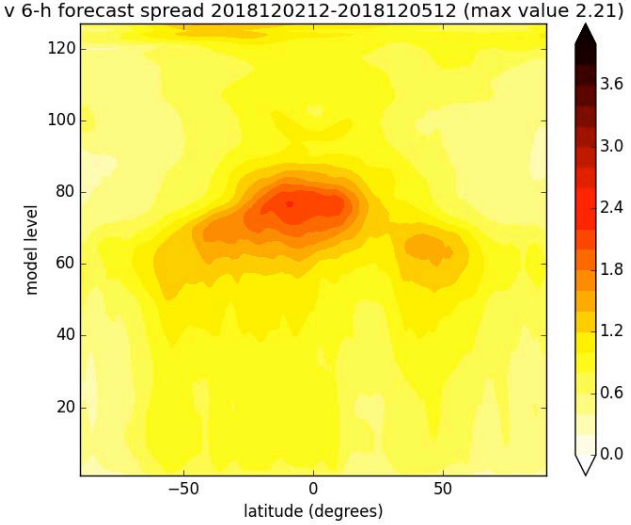
Ensemble Spread (v) for 6-h Forecast

Default, initial settings



Ensemble Spread (v) for 6-h Forecast

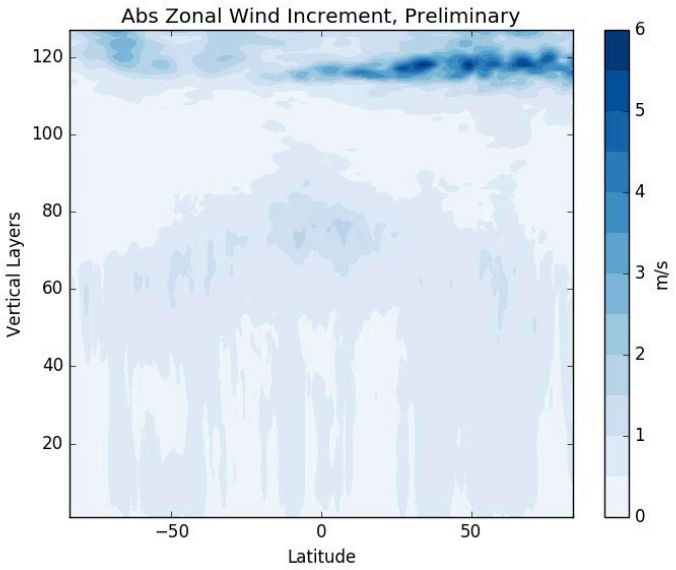
After modifying damping



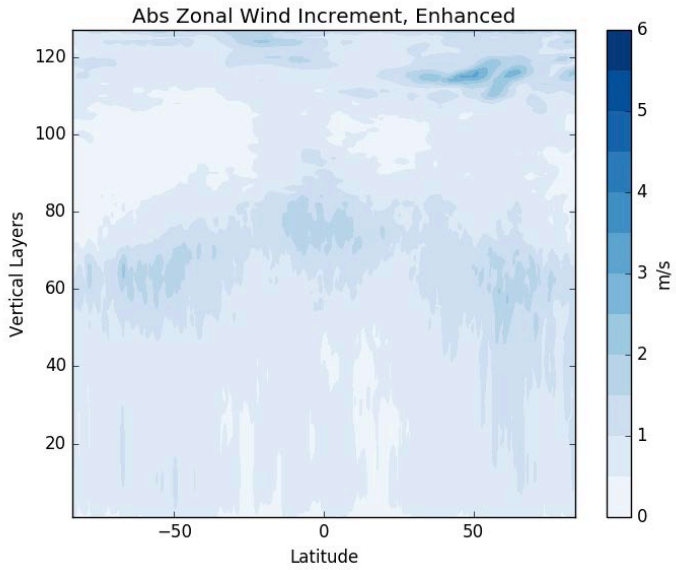
Analysis Increments for L127

(Cathy Thomas)

Preliminary NMC static B and original ensemble spread



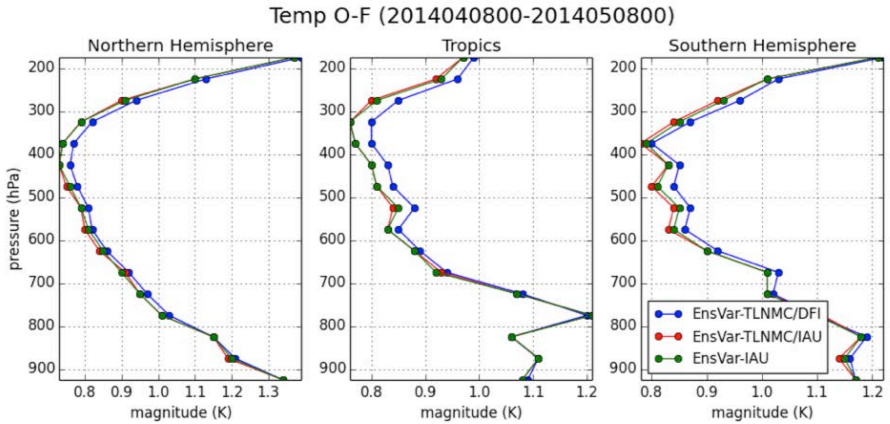
Ensemble-generated static B and damped ensemble spread

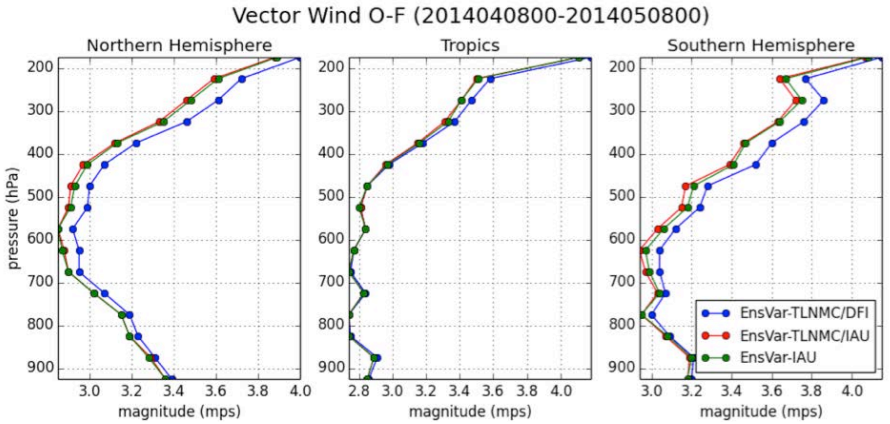


Modifications to both the static and ensemble background errors have greatly reduced the size of the analysis increments at the model top where there are no constraining observations.

Incremental Analysis Update

(Lili Lei & Jeff Whitaker)



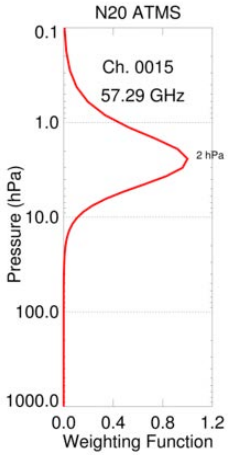


Low resolution trials of IAU (with/without TLNMC). Background fits to observations for Temperature (left) and Vector Wind (right).

Digital Filter Initialization (DFI) with TLNMC is the worst performing

IAU+TLNMC is best performing

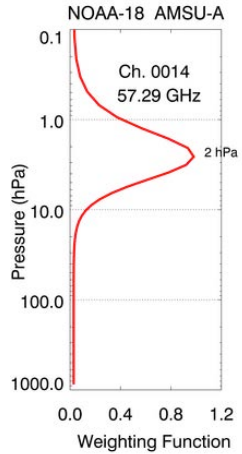
GFSv15 utilizes TLNMC only. Prior versions of GFS used DFI.



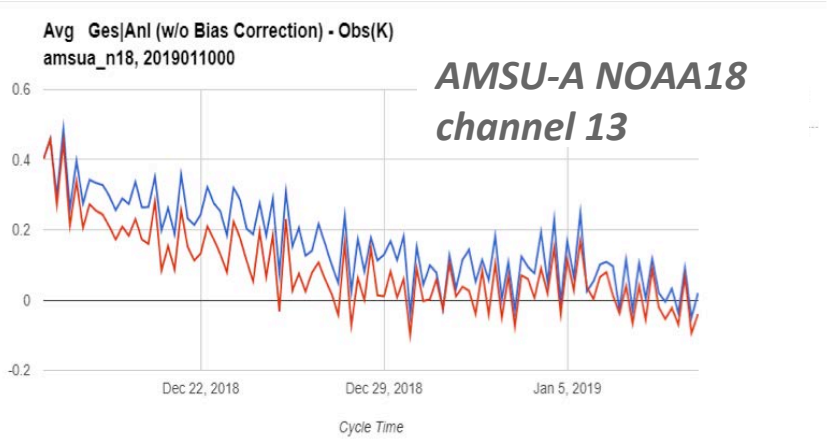
New Satellite Channels

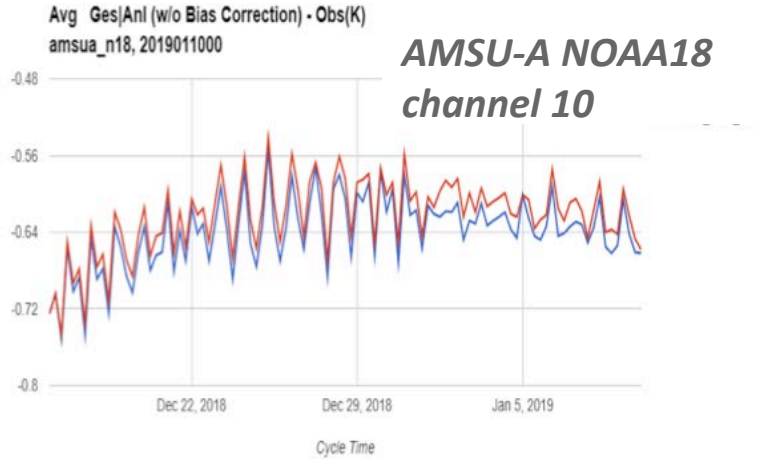
(Yanqui Zhu)

With increased model top, turn on assimilation of two new, high-peaking channels (AMSU-A ch14 and ATMS ch15)



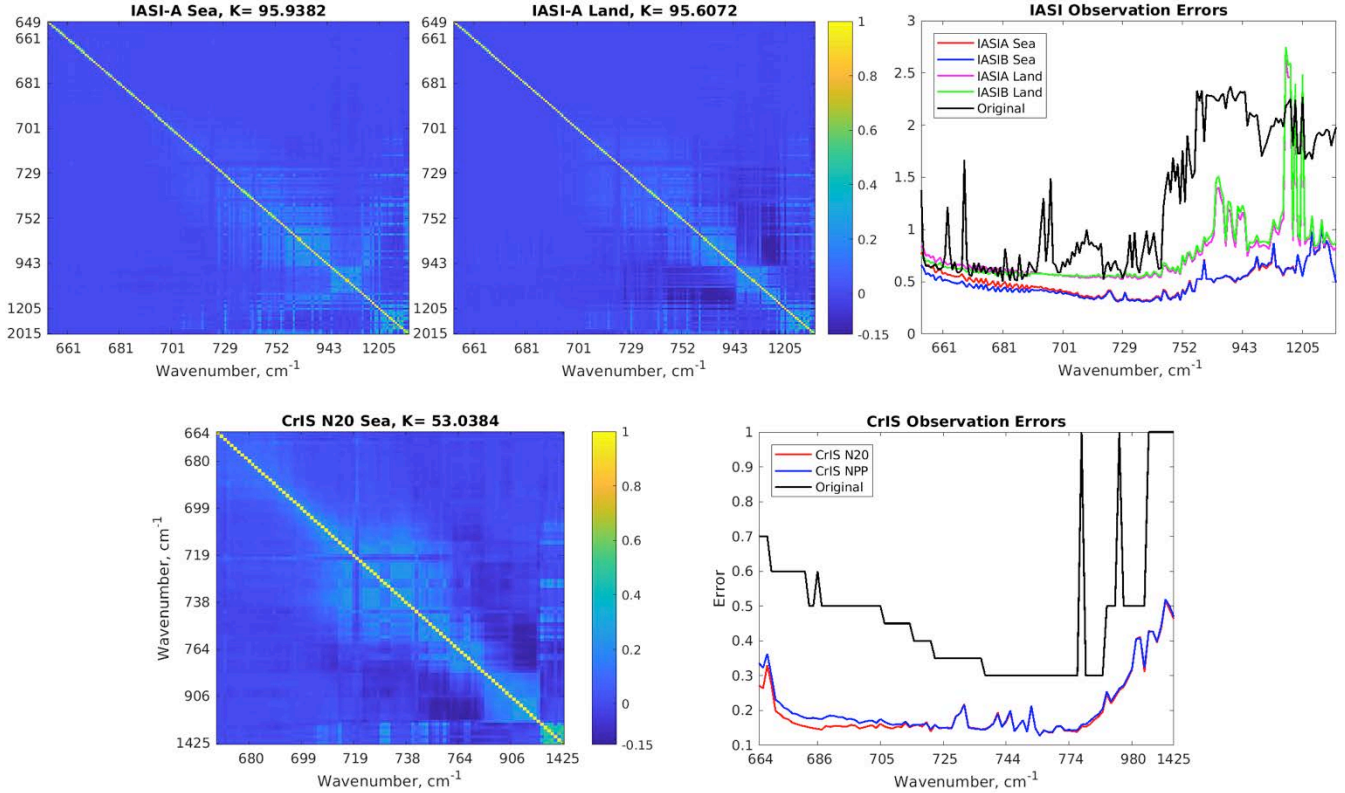
Control (blue line) **vs.** assimilation of AMSU-A ch 14 & ATMS ch 15 **w/o** bias correction (red line).



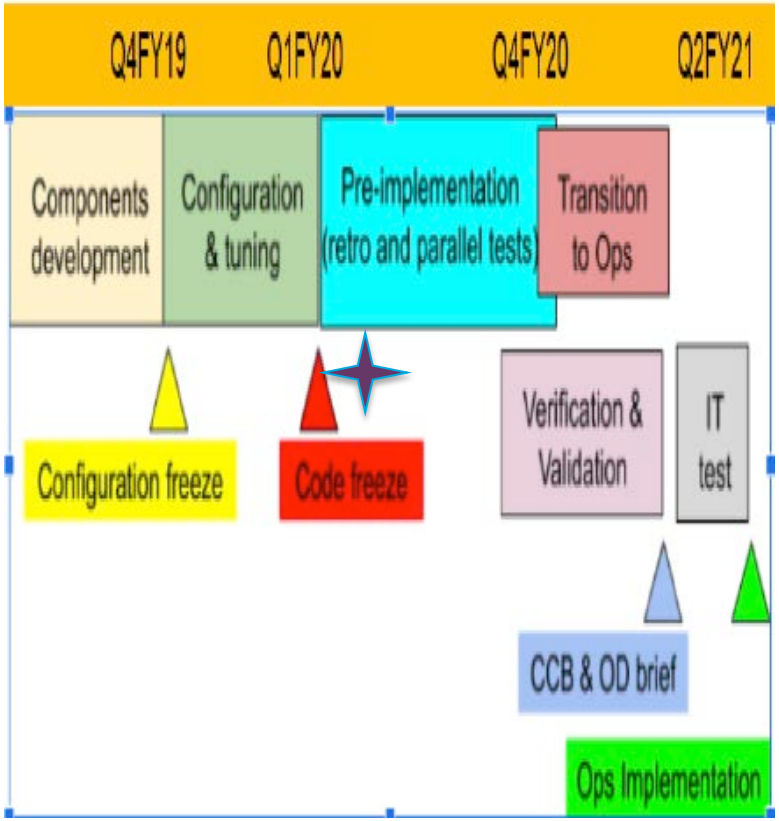


Interchannel Correlated Observation Error

(Kristen Bathmann)



Implementation Plan & Schedule



Retrospective forecasts start: March 1, 2020

Retrospective forecasts complete: July 1, 2020

MEG Evaluation Kickoff webinar: July 23, 2020

Field Evaluation: August 1, 2020 - September 15, 2020

MEG Evaluation Briefing: September 10, 2020

Field Recommendations due: September 21, 2020

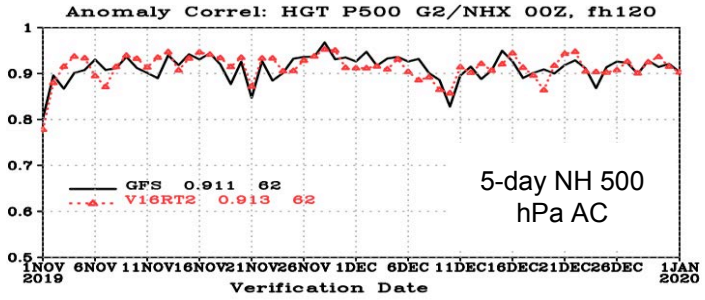
NCEP Director Brief: October 1, 2020

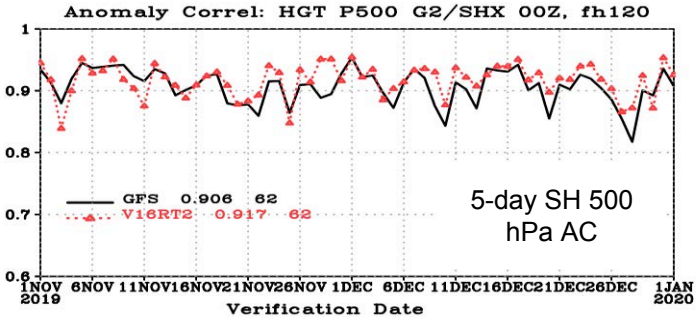
Code delivery to NCO: October 20, 2020

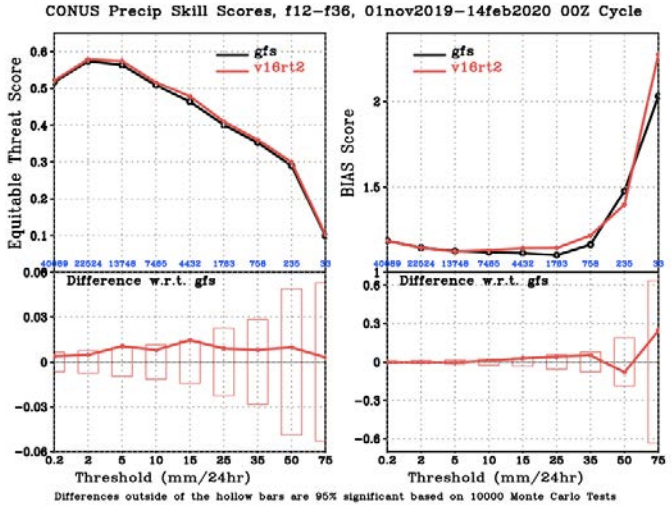
NCO 30-Day IT Test begins: December 21, 2020 (tentative)

(Very) Preliminary 127L Package Results

- Prototype, near-real time run at full resolution since ~November 1, 2019.
  - *Not a clean comparison as things are being folded in as they are ready in the run-up to starting official experiments.*
  - *Includes model and assimilation package components, including physics changes.*







CONUS QPF ETS and Bias Scores (Day 1)

And beyond…

GFSv17/GEFSv13

- Combined package, fully ***coupled*** components
- Planning to leverage/transition to JEDI (at least what's ready for implementation)

Algorithms

- Hybrid 4DVar/4DEnVar study
- Supplement with rapid update (hourly) cycling / overlapping windows?
- Coupled DA
- Further exploitation of ensemble information

JEDI

- Need to start redirecting internal efforts toward JEDI development
- Will be the backbone for performing DA in the "Unified Forecast System"
- Much work remains for transition & testing operational viability

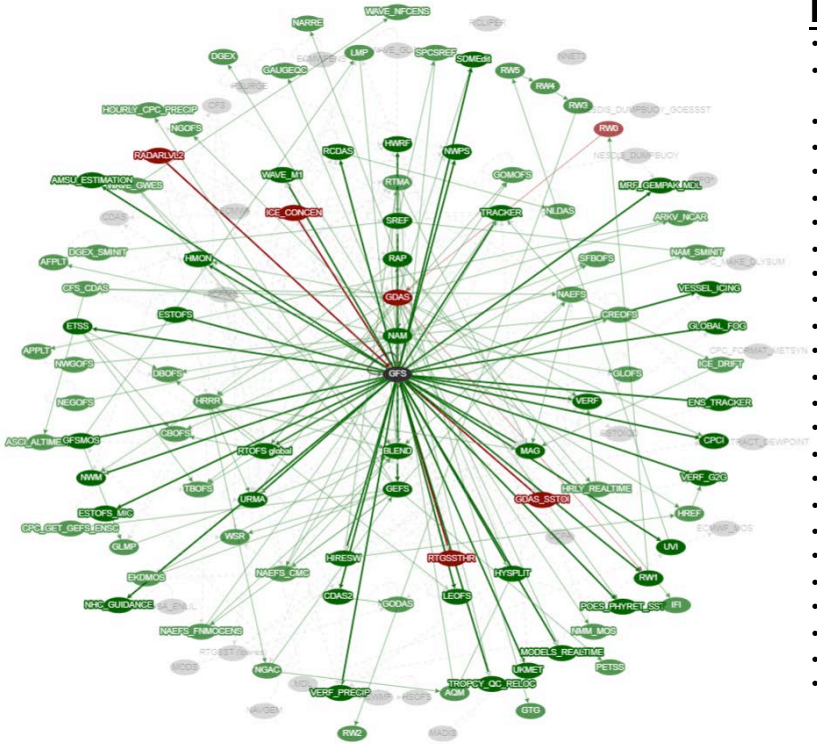
Reanalysis and Reforecast

- Need to stand up sustained effort

Programmatic Changes:

Evolution of Production Suite
Unified Forecast System
JEDI

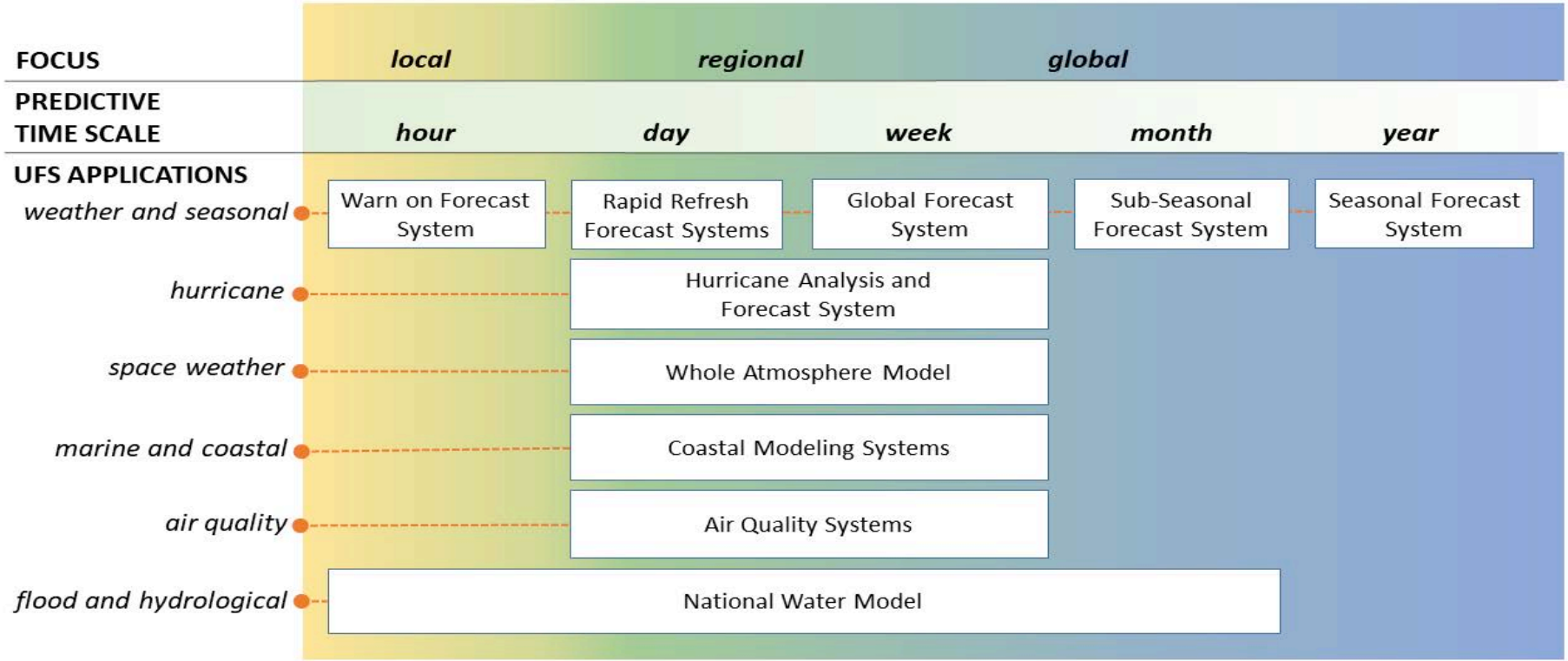
Current State of NCEP Production Suite



Distinct Modeling Systems of NPS:

- AQM: CMAQ North American Air Quality Model (84 hrs)
- CFS: Spectral model coupled to ocean and ice & weakly coupled DA for seasonal forecasts (9 months)
- GDAS/GFS: FV3 based atmospheric model with GSI based DA (16 days, medium range)
- GEFS: Spectral model with 21 member ensemble (16 days)
- HiRes Window: Regional NMMB (72 hrs)
- HREF: Ensembles of WRF ARW and NMMB (72 hrs)
- HRRR/RAP: Regional WRF ARW with ensemble DA (36 hrs)
- HWRF: Regional WRF NMM-E hurricane model coupled to ocean and waves (126 hrs)
- HMON: Regional NMMB hurricane model coupled to ocean (126 hrs)
- HySPLIT: Regional on-demand dust/smoke/volcanic ash prediction
- NAM: NMMB North American Mesoscale Model (84 hrs)
- NAM Nests: High-Resolution NMMB Nests (84 hrs)
- NWPS: SWAN Near Shore Wave Prediction System
- NGAC: Global Spectral Model for Aerosols (5 days)
- NLDAS: Regional Land Data Assimilation System
- NAEFS: North American Ensemble Forecast System (GEFS+Canadian Ensembles)
- NWM: WRF Hydro for Water Prediction (5 days)
- RTMA/URMA: Regional Mesoscale Analysis
- RTOFS: HyCOM Global Ocean Model (5 days)
- SREF: Short Range Ensemble with WRF ARW, NMMB (84 hrs)
- Waves: Global multigrid WaveWatch III Model (10 days)
- Wave Ensembles: Global WaveWatch III Ensembles (10 days)
- Great Lakes: WaveWatch III for great lakes (10 days)
- Space Weather: Global Spectral Whole Atmosphere Model
- Space Weather: WSA EnLil Solar Wind Predition Model

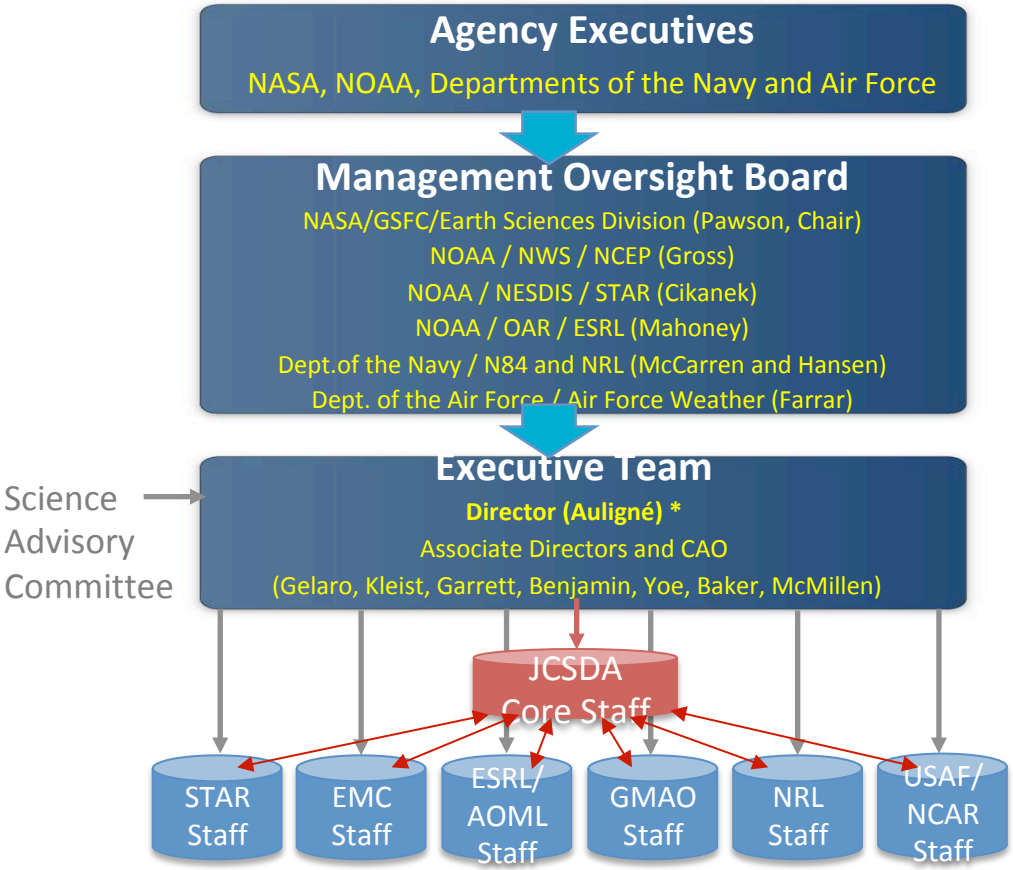
NPS Transitioning to UFS Applications



Toward a simpler, UFS-based Production Suite (notional)

NPS Modeling System	Current Version	Q1 FY 20	Q2 FY 20	Q3 FY 20	Q4 FY 20	Q1 FY 21	Q2 FY 21	Q3FY 21 - Q2FY22 MORATORIUM	Q3 FY 22	Q4 FY 22	Q1 FY 23	Q2 FY 23	Q3 FY 23	Q4 FY 23	Q1 FY 24	Q2 FY 24	Q3 FY 24	Q4 FY 24	UFS Application
Global Weather & Global Analysis	GFS/ GDASv15						GFSv16									v17/GEFSv			UFS Medium Range & Sub-Seasonal
Global Waves	GWMv3																		
Global Weather Ensembles	GEFSv11				GEFSv12														
Global Wave Ensembles	GWESv3																		
Global Aerosols	NGAC v2																		
Short-Range Regional Ensembles	SREFv7																		
Global Ocean & Sea-Ice	RTOFSv1.2					RTOFSv2					RTOFSv3								UFS Marine & Cryosphere
Global Ocean Analysis	GODASv2										GODASv3								
Seasonal Climate	CDAS/ CFSv2																	SFSv1	UFS Seasonal
Regional Hurricane 1	HWRFv12			HWRFv13					HAFSv1				HAFSv2				HAFSv3		UFS Hurricane
Regional Hurricane 2	HMONv2			HMONv3															
Regional High Resolution CAM 1	HiRes Window v7											RRFSv1				RRFSv2			UFS Short-Range Regional HiRes CAM & Regional Air Quality
Regional High Resolution CAM 2	NAM nests/ Fire Wxv4																		
Regional High Resolution CAM 3	RAPv4/ HRRRv3			RAPv5/ HRRRv4															
Regional HiRes CAM Ensemble	HREFv2				HREFv3														
Regional Mesoscale Weather	NAMv4																		
Regional Air Quality	CMAQv5								CMAQv6										
Regional Surface Weather Analysis	RTMA/ URMA v2.7			RTMA/ URMA v2.8									3DRTMA/ URMAv3						
Atmospheric Transport & Dispersion	HySPLITv7								HySPLIT v8								HySPLIT v9		UFS Air Quality & Dispersion
Coastal & Regional Waves	NWPSv1.2			NWPS v1.3					NWPS v1.4						RWPSv1				UFS Coastal
Great Lakes	GLWUv3.4								GLWUv4								GLWUv5		UFS Lakes
Regional Hydrology	NWMv2					NWMv3							NWMv4						UFS Hydrology
Space Weather 1	WAM/IPEv1																	WAMv2	UFS Space Weather
Space Weather 2	ENLILv1																		

JCSDA Concept of Operations



Joint Center for Satellite Data Assimilation
Operating Plan 2019

110 staff (54 FTEs)
In-kind: 19 FTEs
Core (UCP): 35 FTEs

JEDI Objectives

The ***Joint Effort for Data assimilation Integration (JEDI)*** is a collaborative development between JCSDA partners.

Develop a unified data assimilation system:

- From toy models to Earth system coupled models
- Unified observation (forward) operators (UFO)
- For research and operations (including R2O/O2R)
- Share as much as possible without imposing one approach

Joint Effort for Data Assimilation Integration (JEDI)

Generic interfaces

- Models: several atmospheric models, ocean, sea-ice
- Observations: radiosondes, aircraft, CRTM, marine

Generic solvers

15+ variational including hybrid-4DVar, *EnKF*

OOPS
(Object Oriented Prediction System)
Full data assimilation generic algorithms

IODA
(Interface for Observation Data Access)
Performs all the I/O of the observations.
Allows for all kinds of operators

UFO
(Unified Forward Operator)
The 'app-store' of model-agnostic observation operators

JOINT CENTER FOR SATELLITE DATA ASSIMILATION

NO. 66, Winter 2020

JCSDA Quarterly

NOAA | NASA | US NAVY | US AIR FORCE

https://doi.org/10.25923/rb19-0q26

IN THIS ISSUE

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The Joint Effort for Data Assimilation Integration (JEDI)

Joint Effort for Data Assimilation Integration (JEDI) Design and Structure

Status of Model Interfacing in the Joint Effort for Data Assimilation Integration (JEDI)

Observations in the Joint Effort for Data Assimilation Integration (JEDI) -

NEWS IN THIS QUARTER

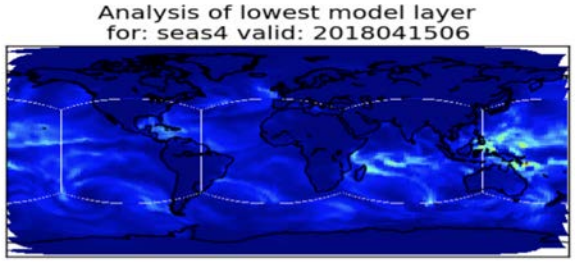
The Joint Effort for Data Assimilation Integration (JEDI)

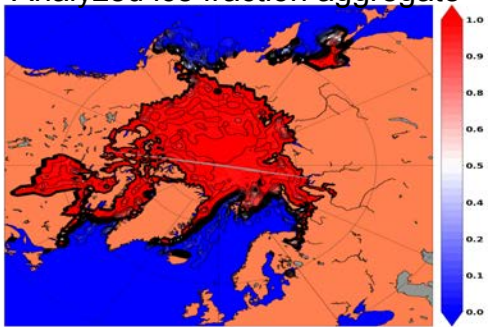
Data Assimilation Challenges

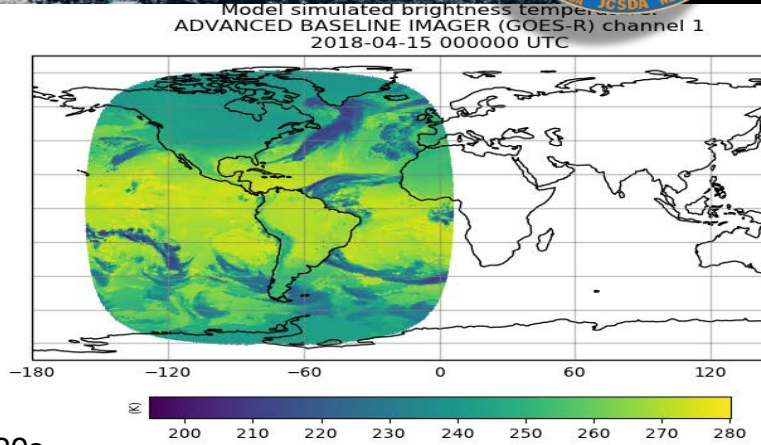
All partners of the Joint Center for Satellite Data Assimilation (JCSDA) run data assimilation algorithms applied to their own models and applications. In 2001, the JCSDA was created to accelerate and improve the use of new satellite observing systems into each member's data assimilation system. As Earth-observing systems constantly evolve and new systems are launched, continuous scientific developments for exploiting the full potential of the data are necessary. Given the cost and limited lifetime of new observing systems, it is important that this process happens quickly. This effort has been successful and continues to be; but, as the context evolves, new challenges emerge.

jcsda.org/newsletters

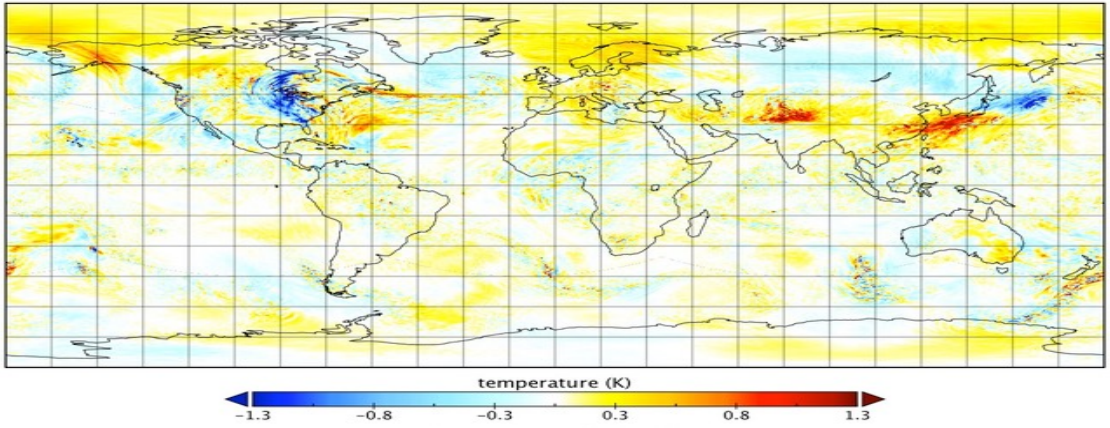
JEDI: One System with Multiple Configurations



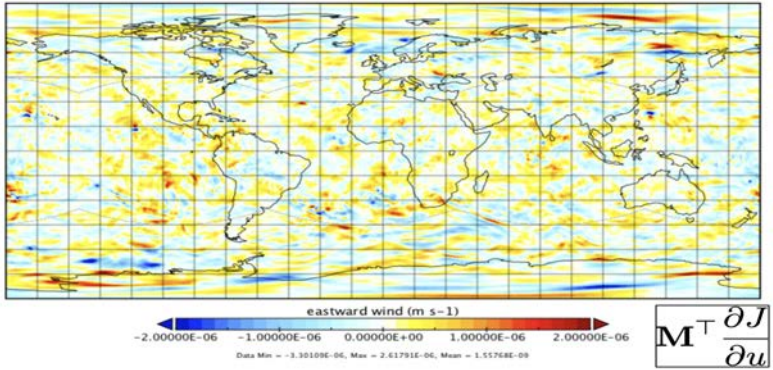




200 hPa T increment propagated 24h by GFSv15 on AWS (1,728 cores) in 7min20s

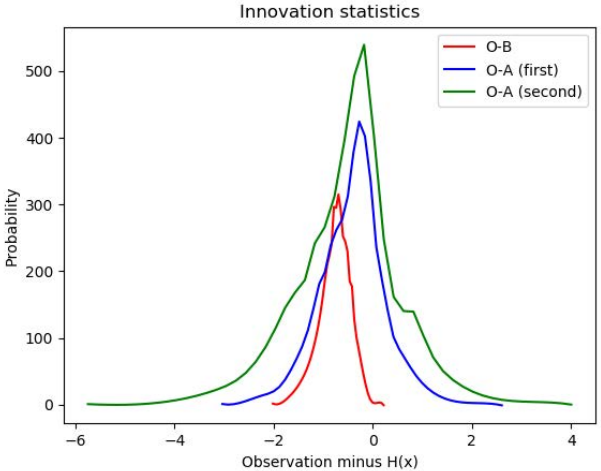


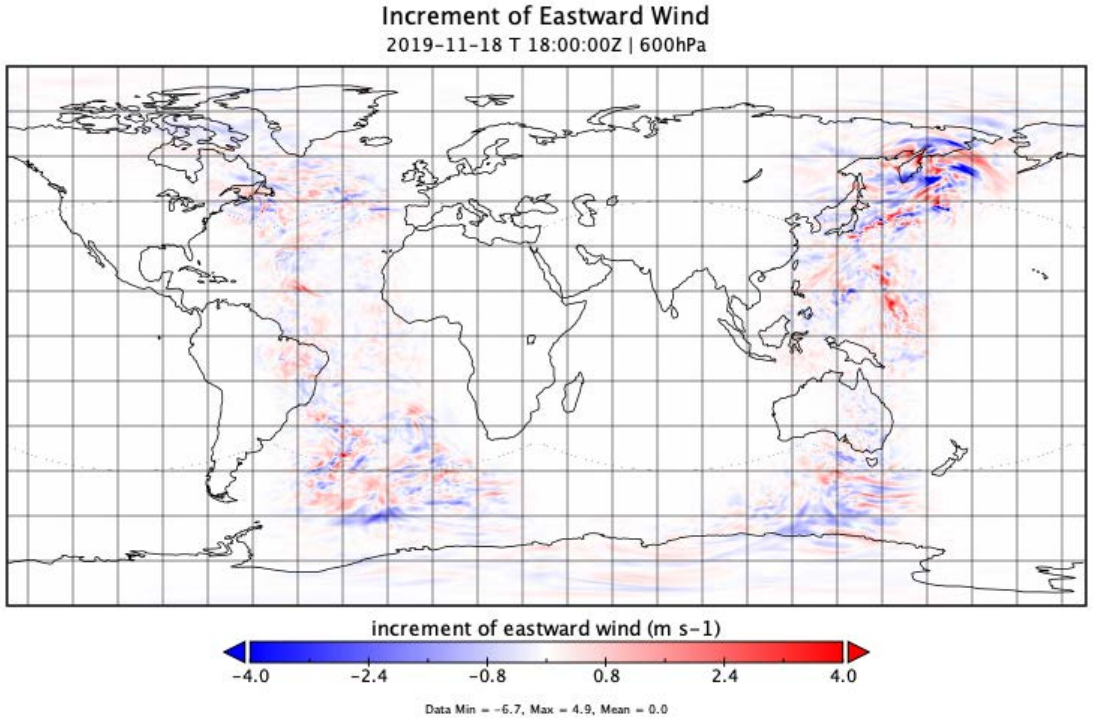
Adjoint Sensitivity to initial conditions @500 hPa



In core data assimilation – Hybrid 4DVar

- C768 background (from ops) and forecast.
- Native grid and resolution observer.
- Pure ensemble B matrix from C384 (25km) 40 member ensemble (from ops).
- C192 (50km) increment.
- All AMSU-A NOAA 19 (~20,000 obs).
- 3 hour window
- 2 outer loops **in-core**.
- BUMP for localization, interpolation etc.





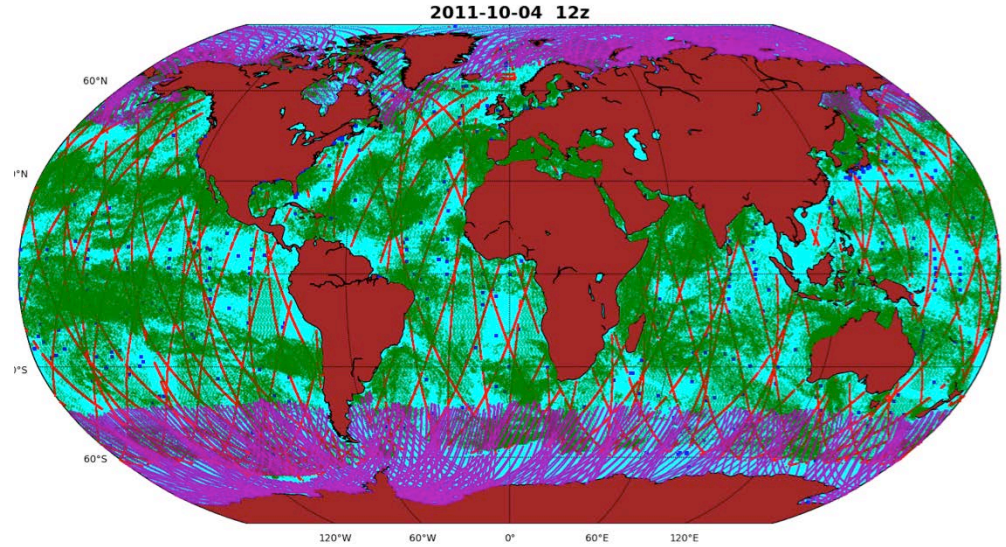
D. Holdaway/JCSDA

Daily Ocean Analysis (Largely JEDI-based)

Oct 1, 2011 – Nov 1, 2011

Assimilated Observations

Sea Surface Temperature: AVHRR and Windsat
Absolute Dynamic Topography: Altimeters
Ice Concentration: SSMI and SSMIS
In-situ Temperature: Argo, CTD, XBT, TAO, PIRATA, RAMA



1 Million Observations per day

Summary and Moving Forward

Ensembles now integral part of operational data assimilation across scales

- Background error representation
- Initial perturbations from DA for ensemble prediction system (not covered in this talk)

Major paradigm shift under way

- Open development, community modeling
- Consolidation of production suite into applications based on UFS code base
- Coupled modeling and data assimilation across scales

Public Releases

- UFS global weather application (github, March 2020)
- JEDI – Iniital public release, June 2020

Thank you!


UFS
UNIFIED FORECAST SYSTEM


EPIC
EARTH
PREDICTION
INNOVATION
CENTER