Modeling and Data Assimilation for UFS Applications

NATIONAL WEATHER SERVICE

JPSS/GOES-R Proving Ground Risk Reduction Summit, 24 February 2020

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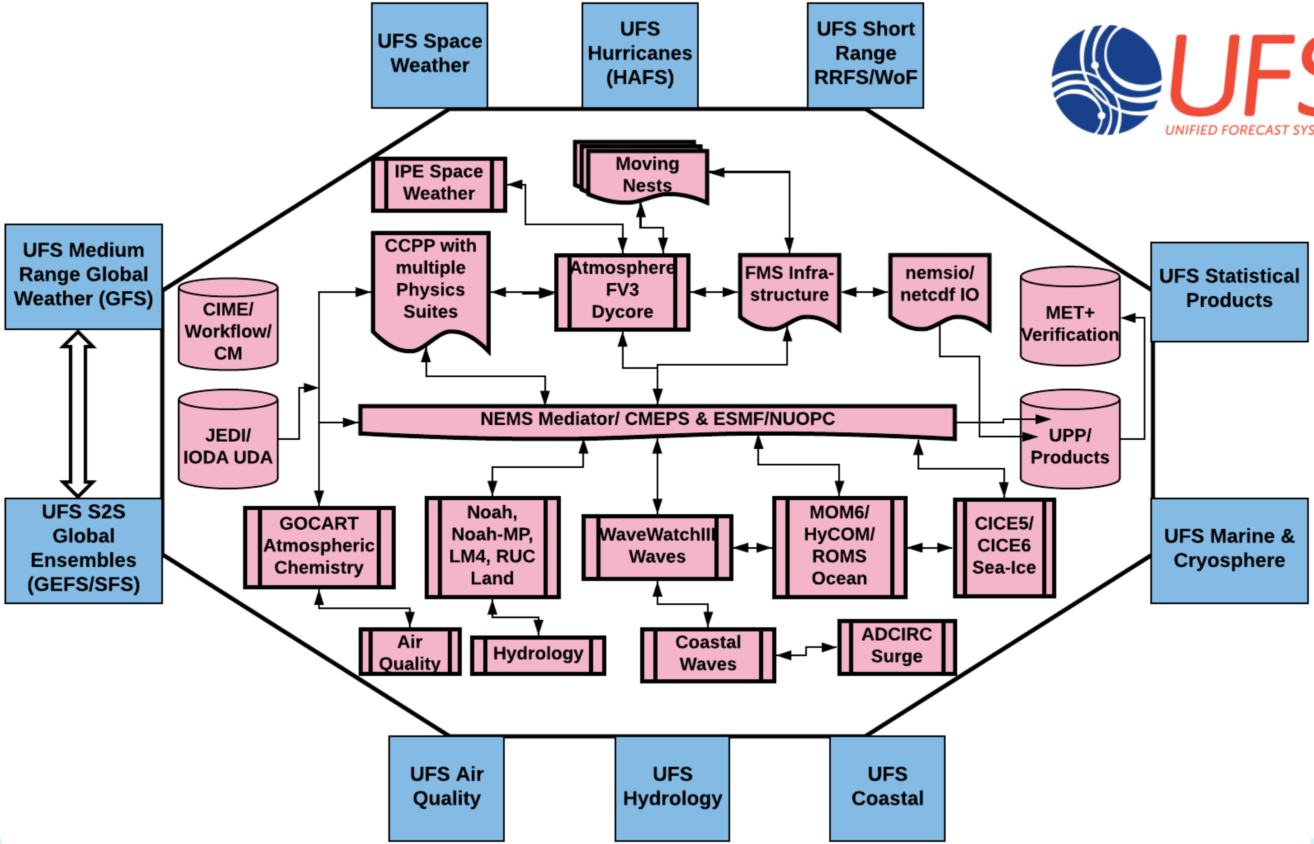
NPS Transitioning to UFS Applications

Conceptual UFS applications in production covering all NPS applications.

Components of UFS are configured to develop distinct applications while maintaining the dependencies between the applications and products



Timelines for transitioning NPS to UFS Applications (planned)

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	WCOSS Moratorium								GFSv17/ GEFSv13			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																		

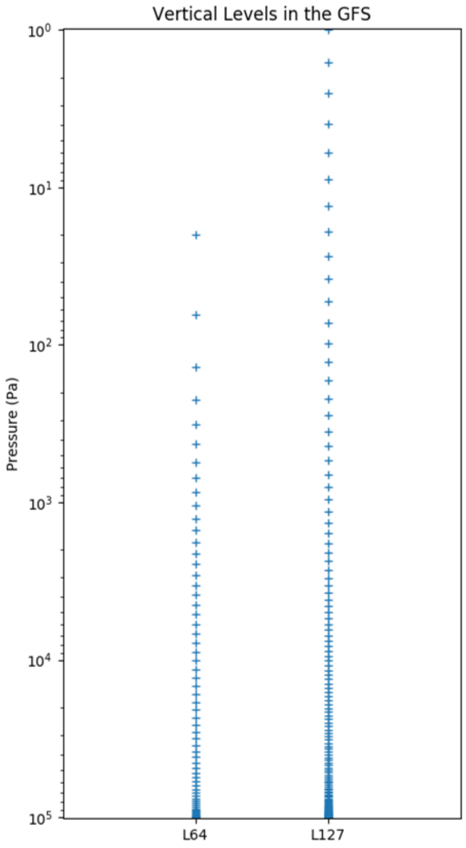
Recent and Planned Upgrades to the GFS

- 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
  - Correlated observation errors
  - VarQC re-design
  - LDAS

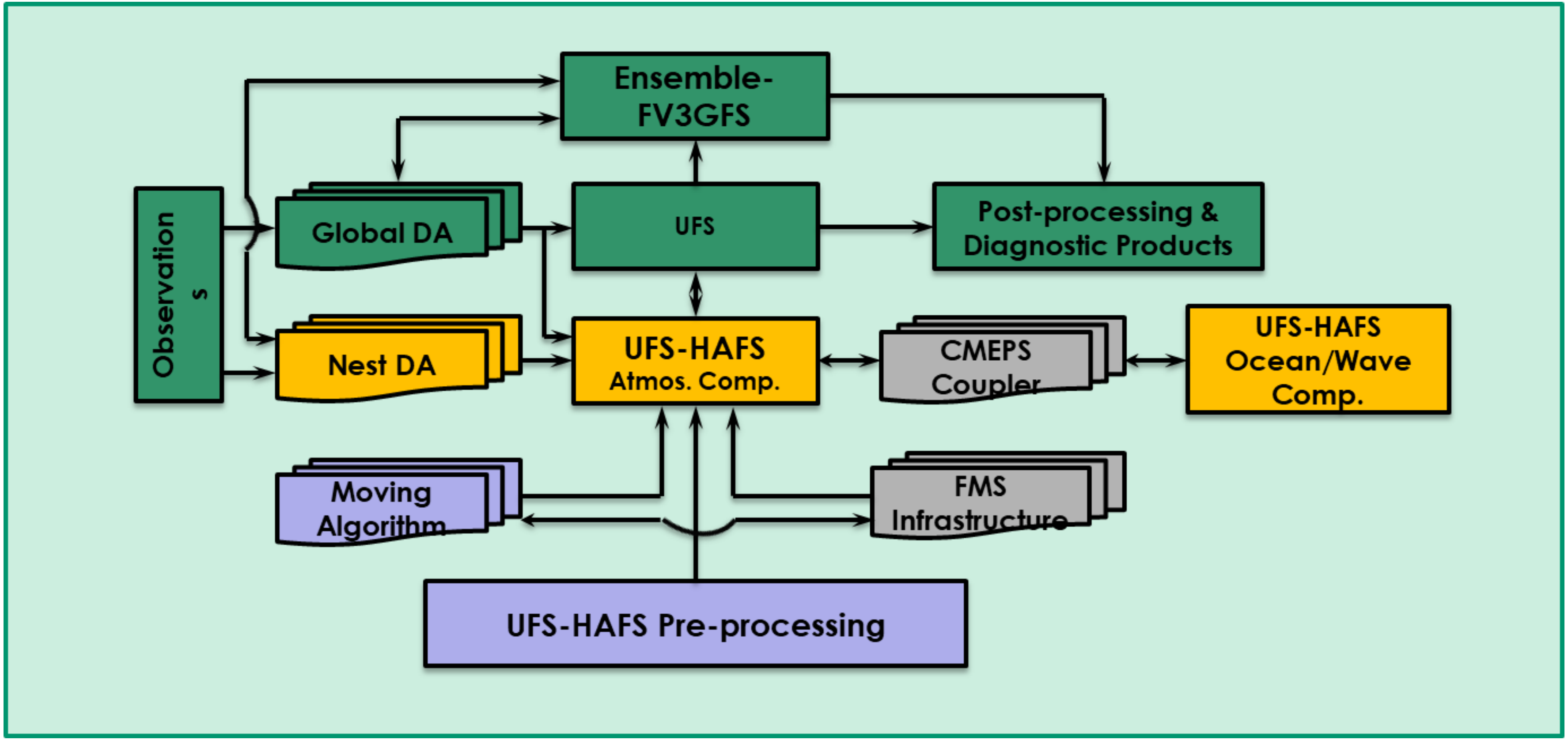
GFSv16 Data Assimilation Upgrades

- The GFSv16 will move from 64 layers to 127 layers, raising the model top from **55 km** to **80 km**.

- 4D Incremental Analysis Update (IAU)
- **Replace EnSRF with LETKF (including model space localization and linearized obs operator)**
- Intra-channel correlated observation errors for radiances
- **Additional channels (*A*** *MSU-A ch14 and ATMS ch15, clear-sky radiances from Meteosat 8 (SEVIRI), Himawari 8 (AHI), GOES-16 ABI)*
- Variational Quality Control update
- **New observations**
- “GLDAS”
- **Reduced humidity increments in stratosphere**
- Improved NSST



UFS-HAFS Strategic Roadmap

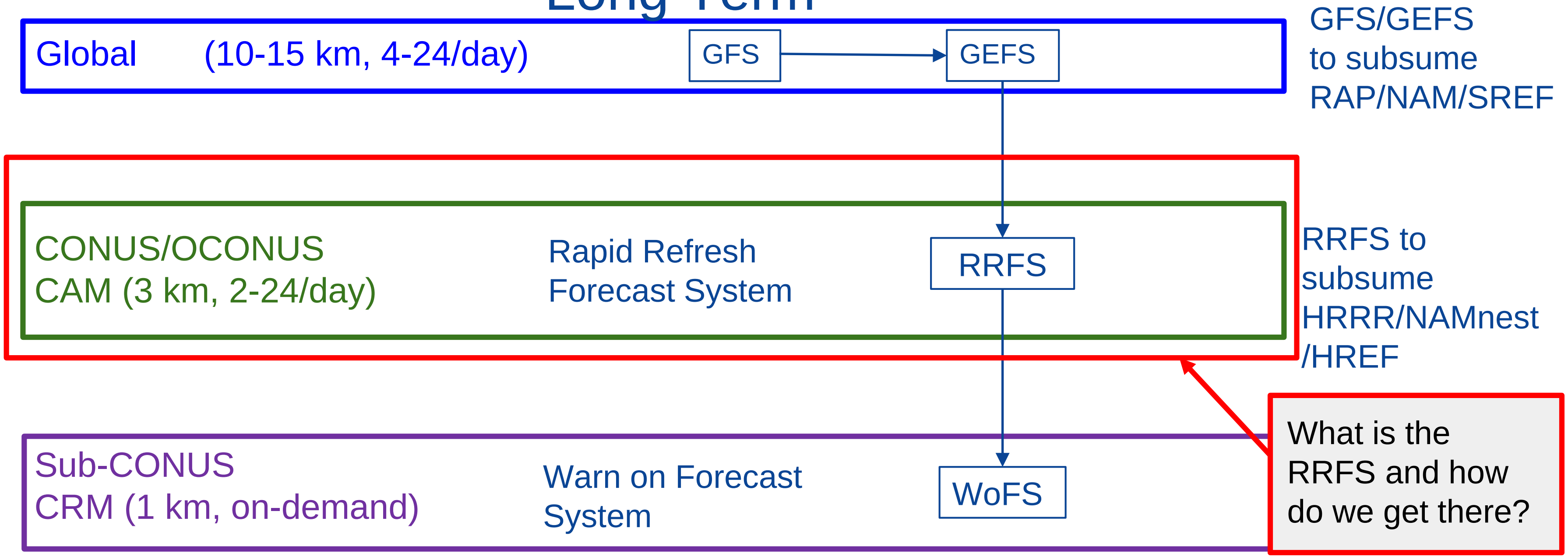


Data Assimilation for Hurricane Models

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2020+
GSI-based DA											
GSI hybrid											
P3 Doppler velocity											
Dropsondes (partial)											
Global Hawk dropsondes											
Warm-start HWRF ensemble											
SLP from TCVitals											
Satellite radiances/winds (D03)											
Flight-level obs.											
Fully-cycled DA (EnKF/GSI)											
SFMR											
Dropsondes (all with drift)											
G-IV Doppler velocity											
Stochastic physics (DA)											
Spectral filter for increments											
Dynamic obs. errors for recon											
WSR-88D Doppler velocity											
Clearsky radiance data (more channels)											
All sky radiance data (inner core)											

UFS: Simplification of Regional Model Production Suite

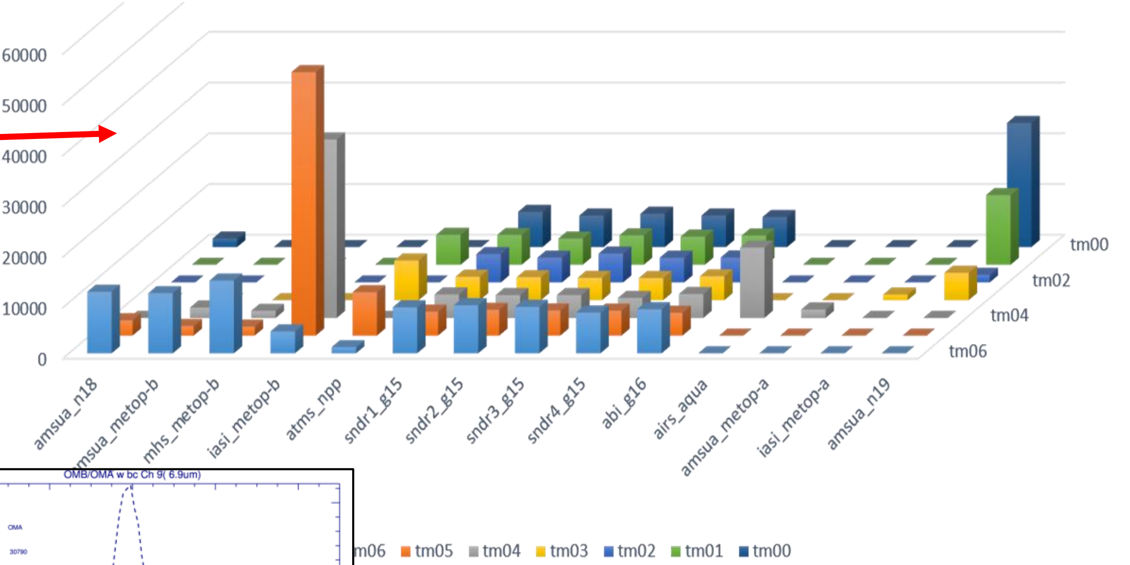
Long Term

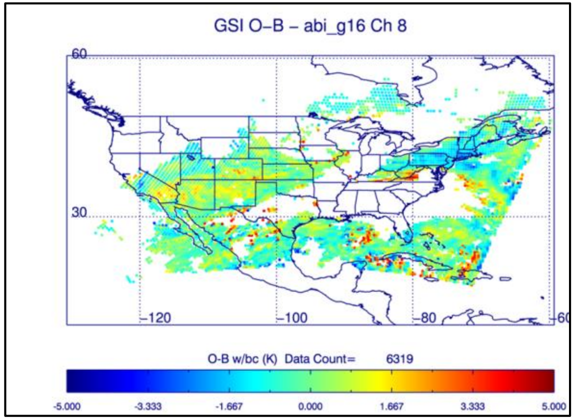


*Material courtesy of C. Alexander

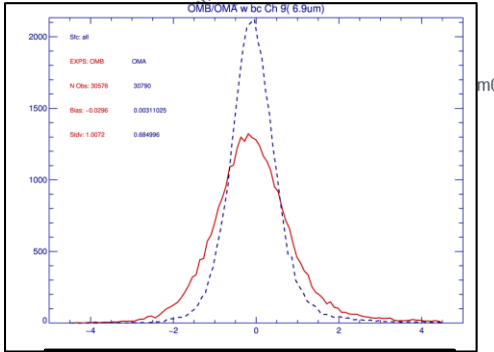
Ongoing Radiance DA Development

- *Hourly* assimilation of radiances
  - Same data as GFS
- Using radiance data through Regional ATOVS Retransmission Service (RARS) to reduce the data latency
- Bias corrections for all satellite instruments are estimated within the regional system

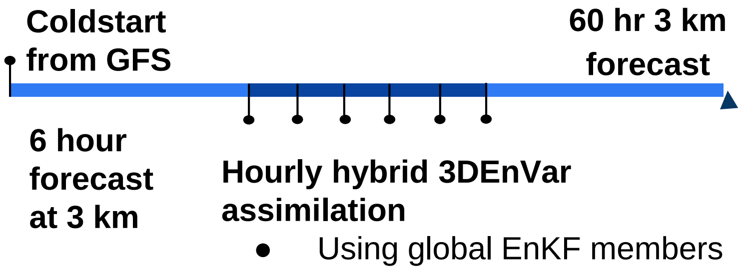




GOES-16 O-Bs



GOES-16 O-Bs and O-As *with* bias correction



Satellite Data Assimilation at the GMAO

Will McCarty
Global Modeling and Assimilation Office
NASA Goddard Space Flight Center

24 February 2020

JPSS/GOES-R Proving Ground Risk Reduction Summit

Introduction

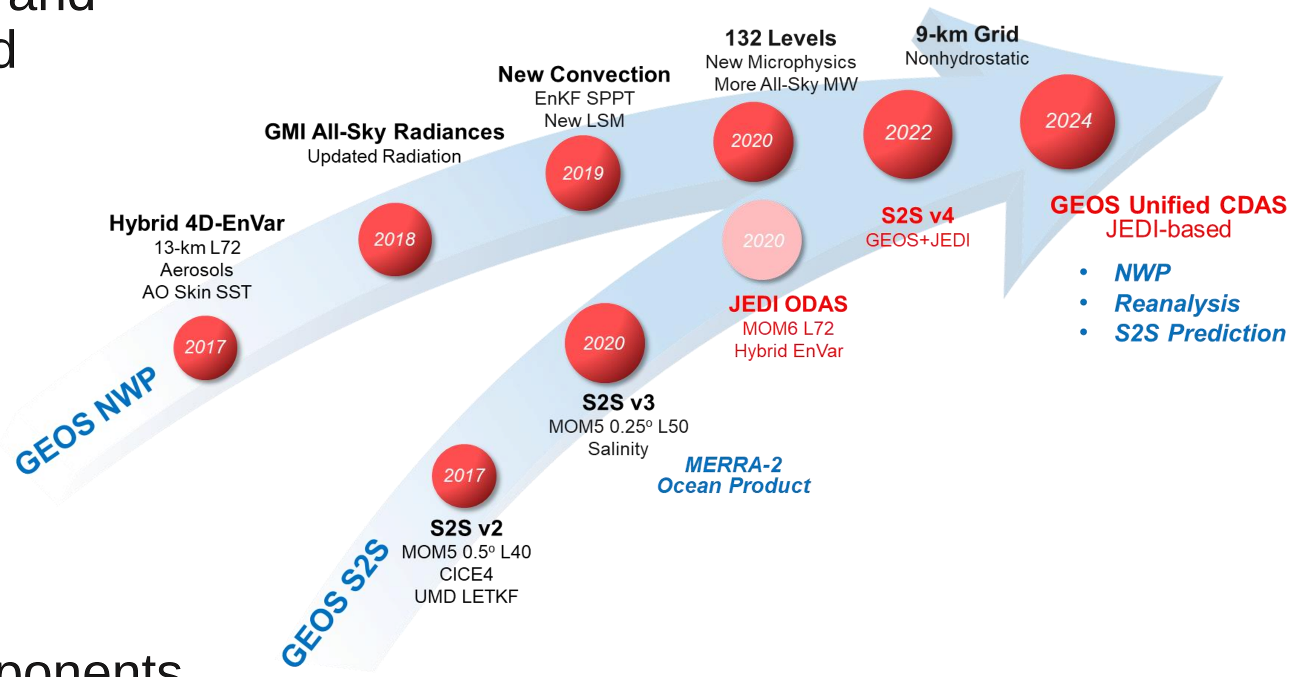
GMAO's core mission is to enhance the value of NASA's observations to understand, analyze and predict changes in the physics, chemistry and biology of the Earth system

We do this:

- Historically: Reanalysis
- Currently: Forward Processing; S2S
- Future: Targeted research, e.g. OSSEs as a decision support tool

Our goal is to collapse the earth system components to a common modeling and assimilation infrastructure

- Fundamental to this goal is the capability of analyzing the four dimensional atmospheric state



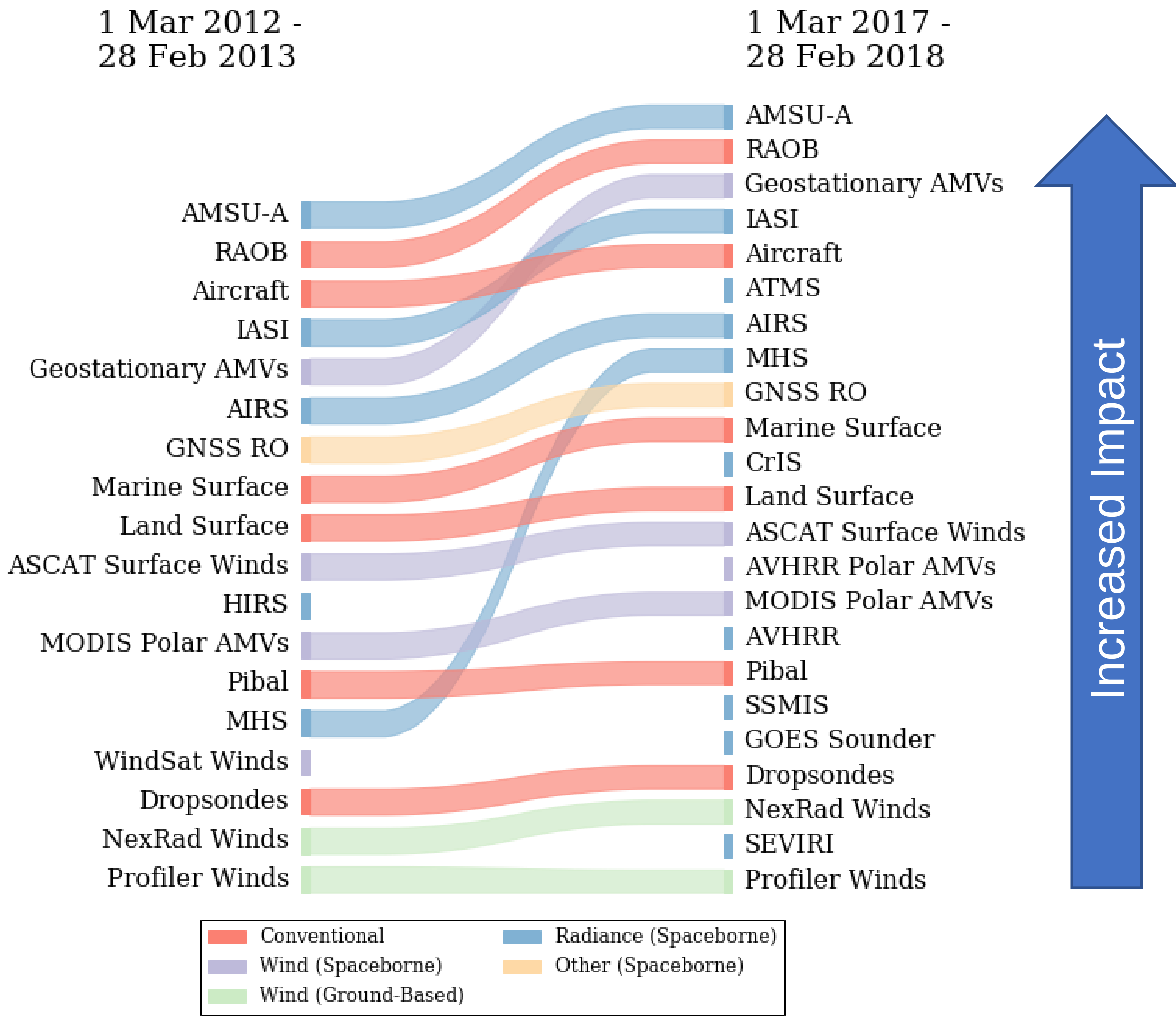
Current State of Radiance Assimilation

Forward processing developments

- ‘New observations’ – and system developments – are considered ‘updates’
- Ultimately constrained by near-real-time availability

Advances in the observing system are apparent through FSOI metric

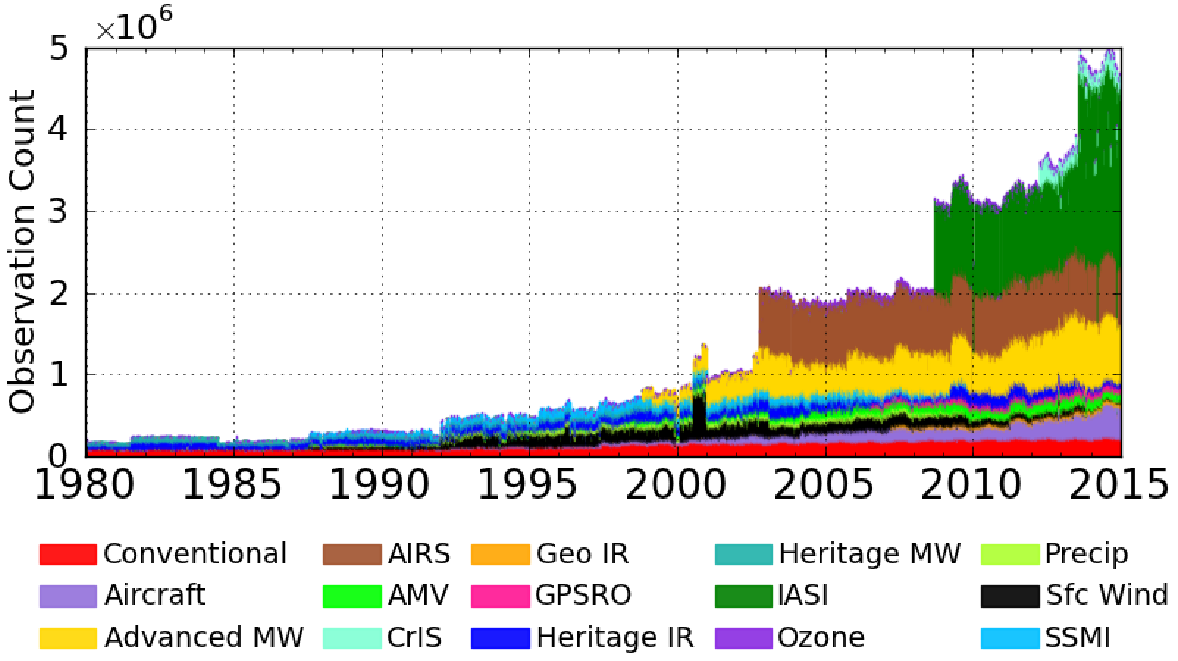
- Observing System resilience
- Notable differences:
  - Geostationary Atmospheric Motion Vectors (AMVs) & IASI jump w/ advances in observing systems
  - MHS with change in metric
- AMSU-A & RAOB still the most important observing systems by this metric
- This plot predates NOAA-20



Applying Current Methods to Historical Observations

Much of our FP development is aimed at transition to reanalysis

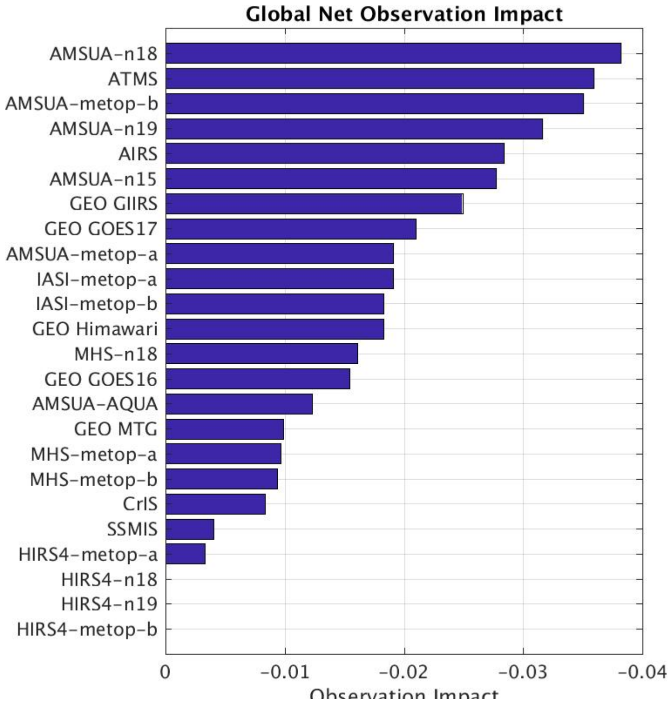
- FP advancements are performed with reanalysis in mind
  - New data not only feeds FP, but also adds to the retrospective observation baseline
  - The FP starting point is implicitly the beginning of baseline
  - Evaluate feasibility of backfilling observation to include entire data record
- Reanalysis systems do not have a NRT constraint
  - Provides additional motivation to consider observations beyond the scope of operational systems
- The hyperspectral IR still accounts for the largest single type of data
  - Only to increase w/ MTG-S IRS; IASI-NG; NOAA-21, etc.



The Future of Radiance Assimilation

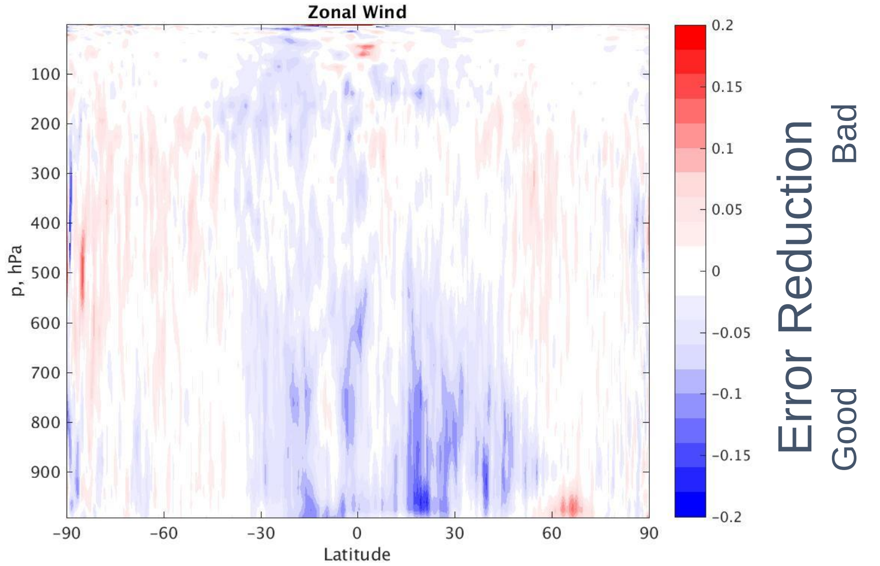
The GMAO has a full Global OSSE capability, which can serve as a tool (in a toolbox of tools) to investigate future observing system architectures

- Recent assessment of a constellation of MTG-S IRS-like instruments showed that the GEOS would be consistent w/ other infrared sounding instruments
- Also validated the 'tracer effect' via improved temporal resolution as large impacts were seen in wind metrics



OSSEs however are limited

- Today's approaches
- Today's observations
- Simulated data too perfect
- Errors difficult to model



Outstanding Questions

Radiance Assimilation is hard

– JEDI hopefully leads towards better cross-agency and extra-agency collaboration

What is the future of all-sky assimilation?

– Many results illustrate the utility of the 183 GHz water vapor measurements that are affected by ice

– What about 118 GHz temperature?

– What role will observations > 200 GHz play? (e.g. Metop-SG ICI)

– All-sky in the IR/Vis?

Spatial/Spectral/Temporal Resolution in the infrared

– How much spectral information is too much spectral information?

– Spatial thinning/hole hunting/etc.?

– Chemistry radiance assimilation in the future?

Other questions

– Station keeping/the early-AM orbits

– The role of small satellites in the future

NOAA

Satellite and Information Service

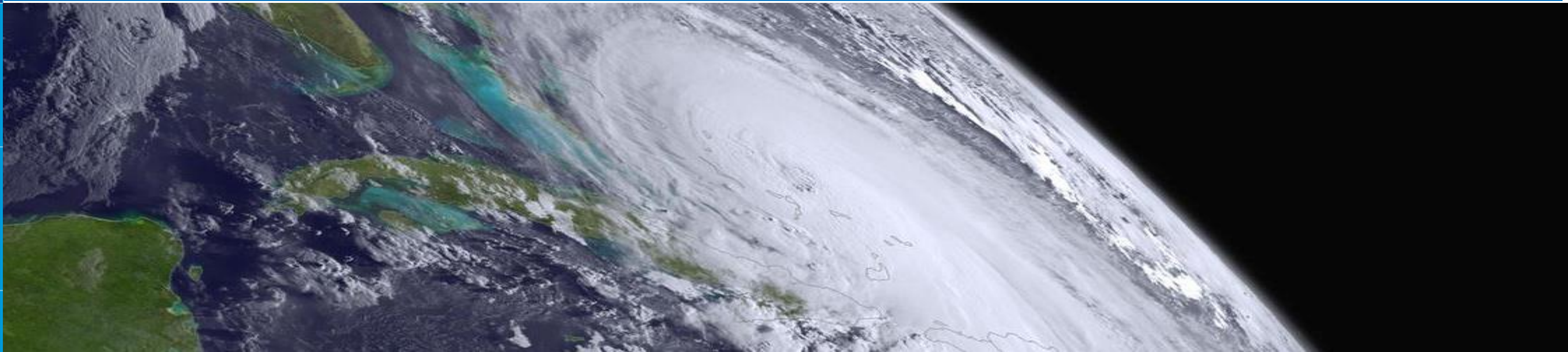
24 Feb 2020

NESDIS Support to NWP Radiance Assimilation

Kevin Garrett

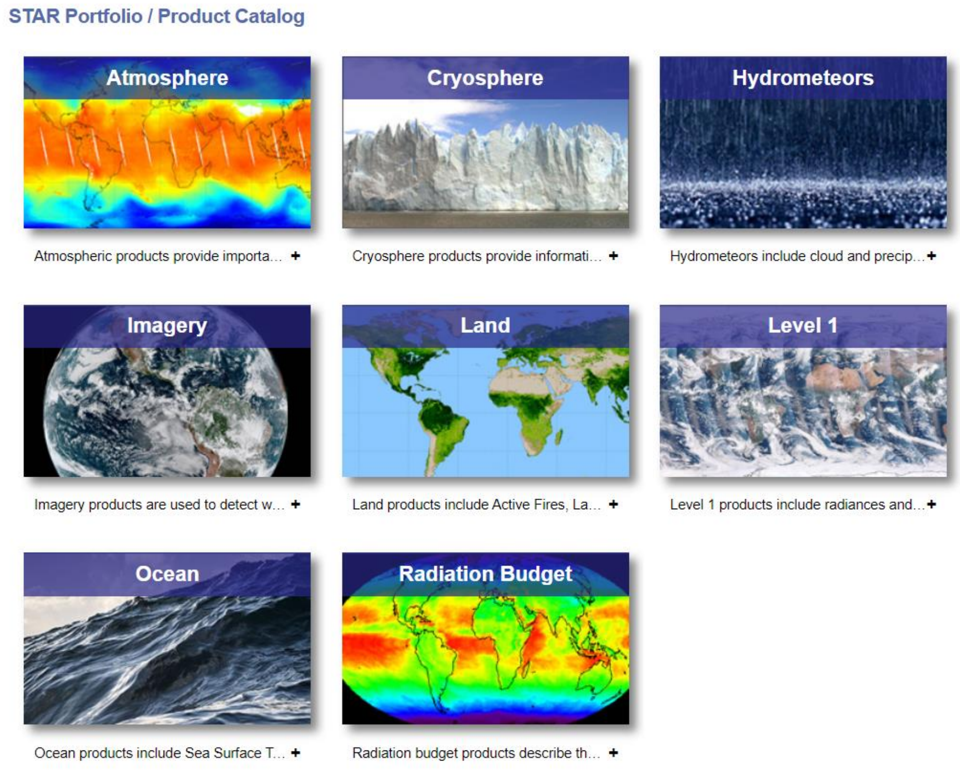
NOAA/NESDIS Center for Satellite Applications and Research

JPSS/GOES-R Proving Ground/Risk Reduction Summit, February 24-28, 2020, College Park, Maryland



NESDIS Development Supporting NWP

- Radiance product development, TDR/SDR, applied in:
  - Direct assimilation
- Level 2 product development, EDR, applied in:
  - Direct assimilation (e.g. AMV, AOD)
  - Quality control
  - Boundary conditions
- BUFR toolkit development
- Forward operator development
- Data assimilation satellite data integration
  - New sensors, optimization, next generation architecture studies
  - External funding (CIs, JCSDA)



STAR Product Catalog
https://www.star.nesdis.noaa.gov/portfolio/productCatalog.php

JPSS/GOES-R data exploitation in NOAA NWP

Assimilation status in NOAA Data Assimilation/NWP

	FV3GFS	HWRF/HAFS	RAP/HRRR	WoF	Ocean DA	Land DA
GOES-R Radiances						
GOES-R GLM						
GOES-R Cloud Top Cooling Rate						
Enterprise Cloud						
SST						
LST						
AMVs						
JPSS ATMS Radiances						
JPSS CrIS Radiances						
JPSS VIIRS Radiances						
JPSS Ozone						
Smoke, Fire						
AOD						
JPSS Green Vegetation Fraction						
GCOM-W1 AMSR2 Radiances						
GCOM-W1 AMSR2 Soil Moisture						

Optimization level

Operational

Non-operational

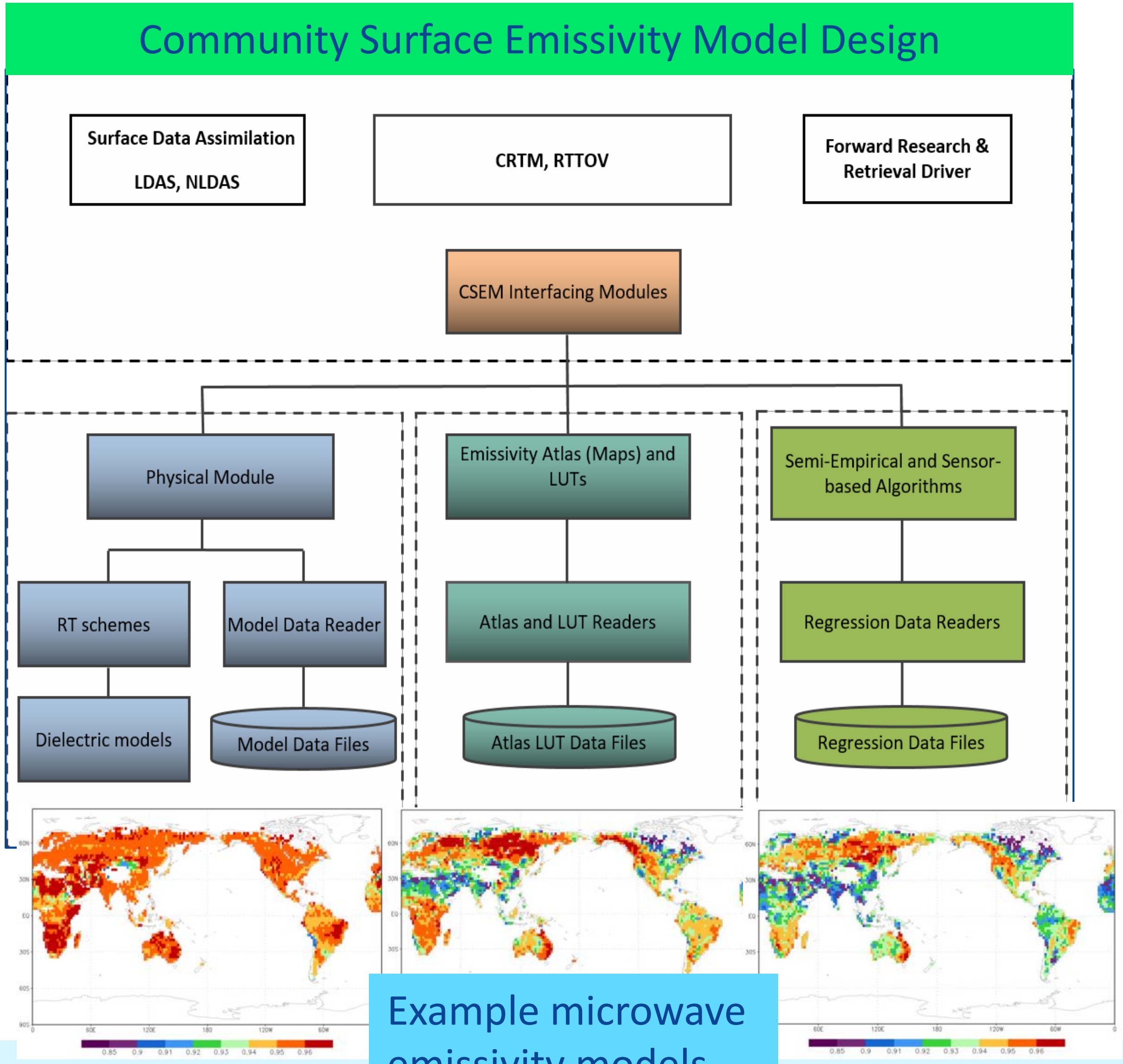
Input

n/a

CRTM development: all-sky/all-surface DA

Need more advanced forward modeling of satellite radiances:

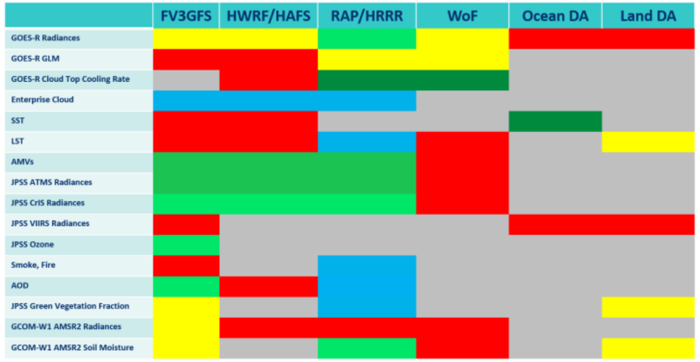
- Under cloudy/scattering conditions
  - Spectrally consistent optical properties
  - Vectorized RT
  - Evolving model (prior) states, CAM DA
- Under aerosol conditions
  - Global/regional forecast models coupled with chemistry models (e.g. CMAQ)
- Where atmosphere is not opaque
  - More accurate surface handling, land/ocean/cryosphere, L-band to UV
  - Coupled land-atmosphere, sea-ice/ocean-atmosphere assimilation



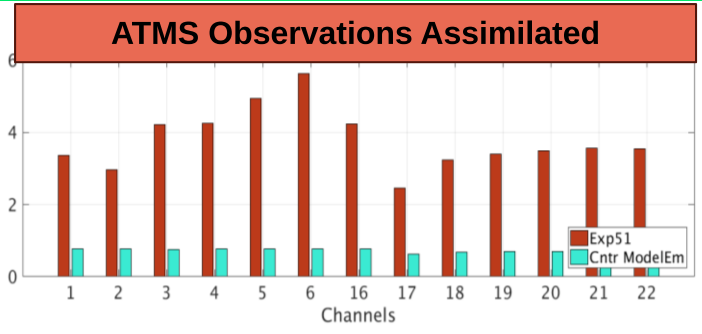
Example microwave emissivity models

Satellite radiance assimilation development

- Emphasis on maximizing observation impacts on NWP analysis and forecast
- Gaps highlight the unmet needs for NWP users
- Establish priorities based on potential impact and value
- Need to work closely with partners on all aspects of DA value chain- data delivery, QC, operators, integration



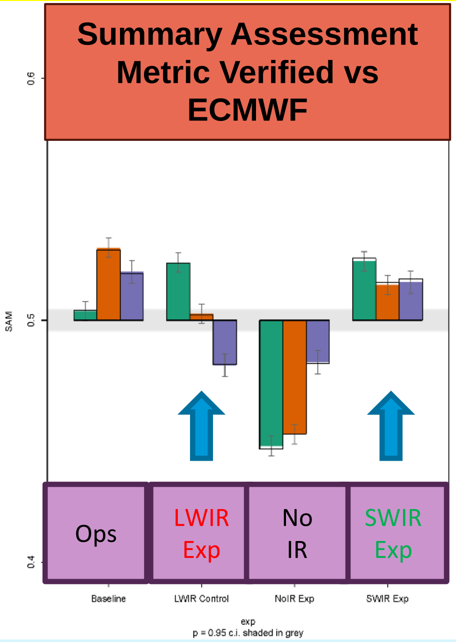
Land Sensitive Radiance Assimilation



Implementation of emissivity control variable, updated QC, new emissivity background:

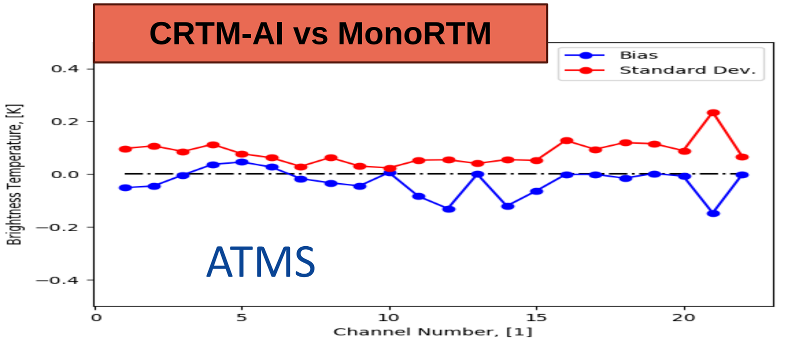
➢Plot: 5-10x more (red) ATMS land obs assimilated per GDAS cycle

Hyperspectral Shortwave IR Assimilation



- Implement new QC, observation errors for SWIR
- Assess/improve CRTM in SW reg.
- Run impact experiments and compare to LW
- Transition to Operations

New Techniques to Maximize Satellite Impacts



Explore new AI/ML techniques to overcoming current challenges in radiance assimilation

➢Thinning, QC, forward operators (all-sky), post-forecast correction

Satellite radiance assimilation for rapidly updating regional and global models

Connecting Models and Observations

Hourly RAP / HRRR radiance assimilation

- AMSU-A (RARS)
- MHS (RARS)
- IASI (DB, RARS)
- ATMS (DB, RARS)
- CrIS (FSR*) (DB, RARS)
- GOES-16 ABI Radiance data*
- AIRS, SSMIS,GOES-15 sounder

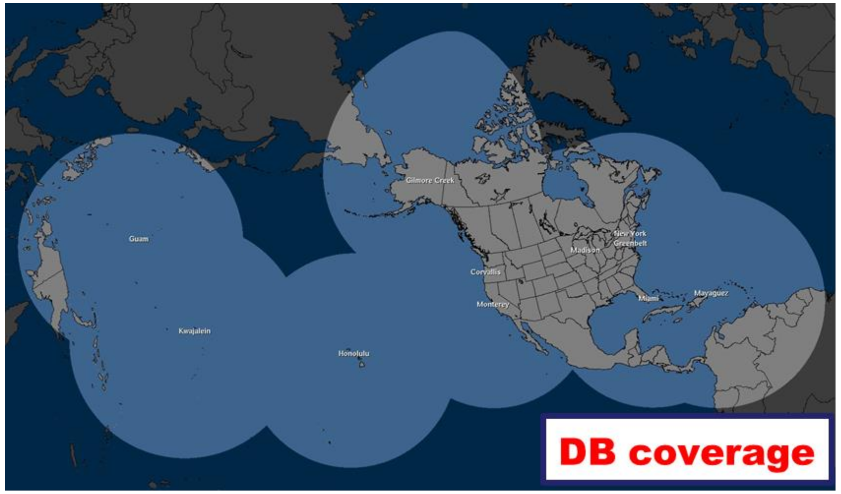
→ **HRRR-AK radiance DA***

* = in RAPv5, HRRRv4

DB = Direct Broadcast

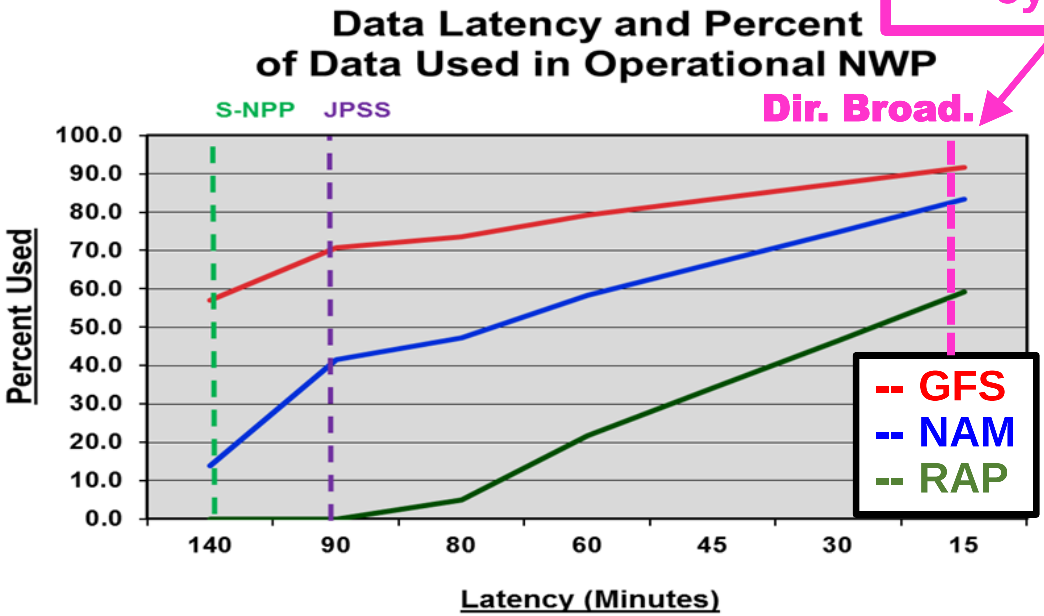
RARS = Regional ATOVs Retransmission Service

See **Amanda Back** presentation in next panel discussion for summary of RAP/HRRR **satellite product assimilation**



25 min. Observation data cutoff for RAP/HRRR

Direct Broadcast data critical for hourly cycling



Steve Weygandt, NOAA/ESRL – Haidao Lin, NOAA/ESRL, CIRA

Satellite radiance assimilation for rapidly updating regional and global models

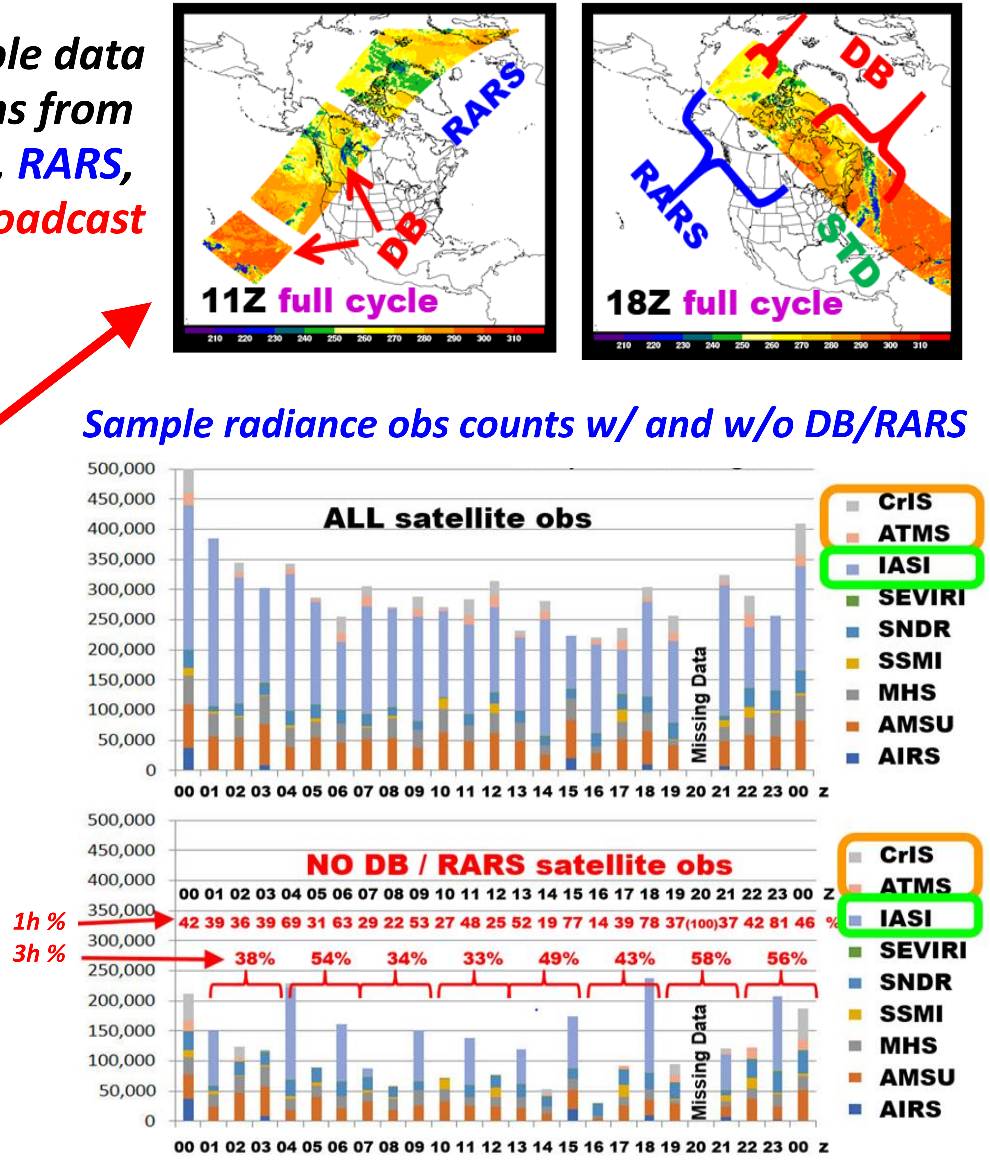
Connecting Models and Observations

Challenges and questions

- Will the data be **operationally available** at **low enough latency** for rapidly updating? **(direct broadcast critical for hourly updating)**
- Can we improve on the **bias correction** for regional models?
- What degree of **channel selection** is needed for regional models compared to global models (because of the lower model top)?

Sample data swaths from Standard, RARS, Direct Broadcast

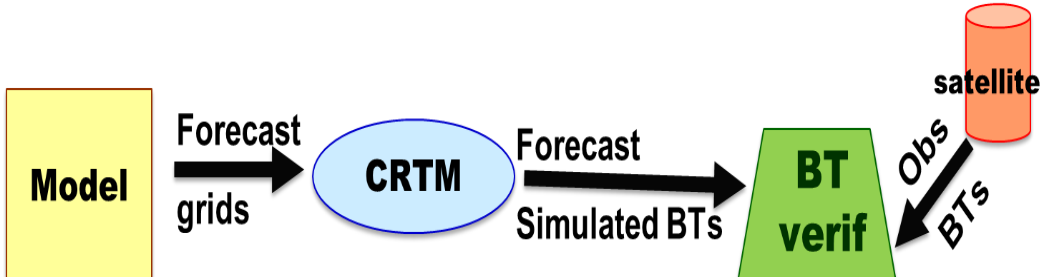
Sample radiance obs counts w/ and w/o DB/RARS



Satellite radiance assimilation for rapidly updating regional and global models

Connecting Models and Observations

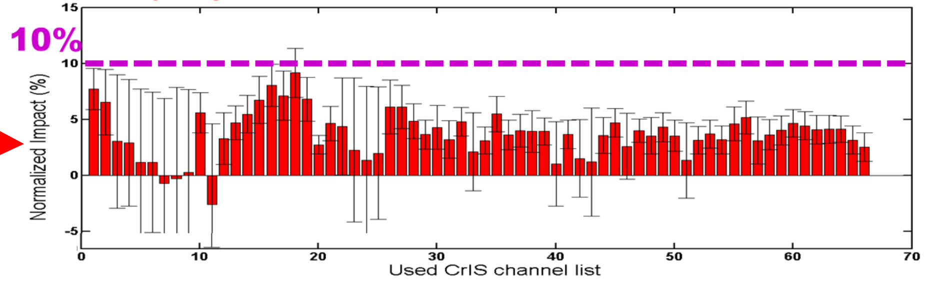
Challenges and questions



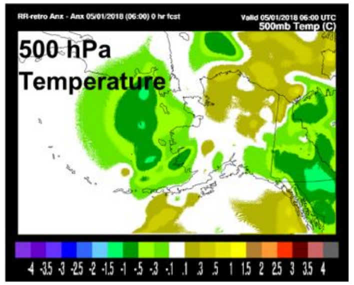
CrIS BT verification process

- Quantifying regional radiance assimilation impact for data rich and data poor regions? **(use of satellite radiance-based verification approaches?)**
- Application for storm-scale models **(inclusion in 3-km HRRR-AK for 2020, and RRFS - Rapid Refresh Forecast System - in 2023)**
- Timing for introduction of enhancements (all-sky radiance, evolution to JEDI)

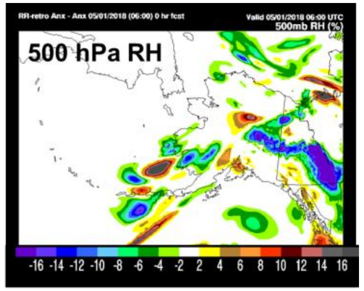
Percent impact in 6-h RAP forecasts from denying DB and RARS on CrIS BT verification



Radiance data impact in 3-km HRRR/AK



Sample analysis difference (A-A) from inclusion of radiance data



Satellite radiance assimilation for rapidly updating regional and global models

Science / Technical Issues

- All sky radiances
- Transition to JEDI
- Quality control issues
- CRTM enhancements
- Correlated observation errors
- Regional bias correction issues

Evolving / future needs for satellite radiance DA

Monitoring / Assessment

- Further streamlining of sensor/channel monitoring
- Increased FSOI evaluation
- Further application of novel radiance data verification techniques

Coordination / Communication

- Further streamlining of data processing and formatting for operational DA
- Coordination of code development for current and new sensors within JEDI

Global Rapid Refresh Models

- Work toward global hourly updating
- Data availability / latency issues
- Better integration of radiance and product assimilation

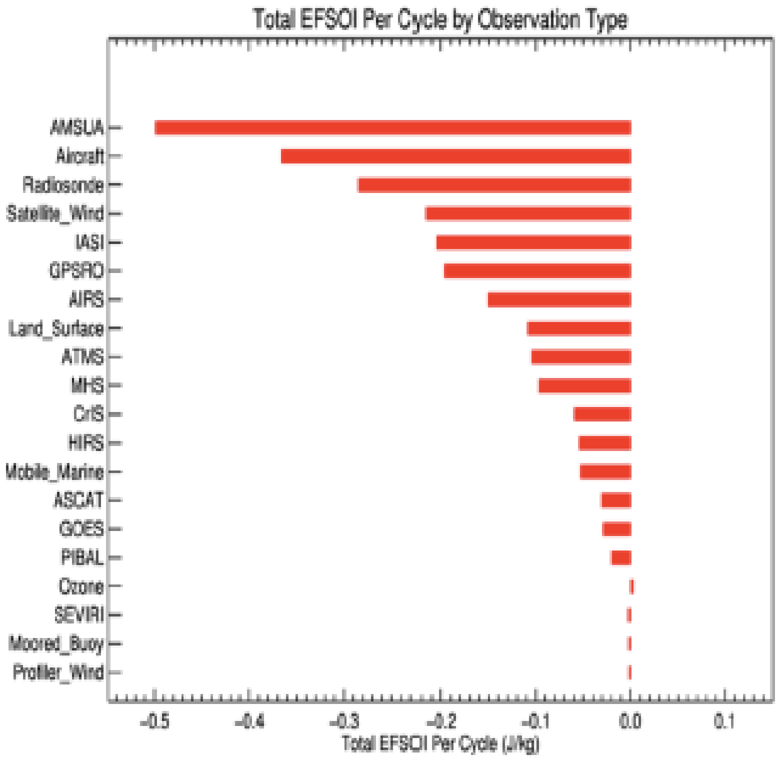
Connecting Models and Observations

Use of Radiances in Global Data Assimilation at NOAA/NCEP

Andrew Collard
IMSG@NOAA/NCEP/EMC

Radiance Data Used in the NCEP Global Model

Ensemble Forecast Sensitivity to Observation Impact (EFSOI)



Total EFSOI impacts per cycle based on EnSRF products from a low resolution 4DEnVar configuration of the 2016 GSM GFS. (Courtesy of David Groff)

Microwave:

AMSU-A: NOAA-15, 18, 19, MetOp-A/B/C, Aqua

ATMS: S-NPP, NOAA-20

MHS: NOAA-18, 19, MetOp-A/B/C

SSMIS: DMSP-F17

Saphir: Megha-Tropiques

Infrared:

AIRS: Aqua

IASI: MetOp-A/B

CrIS: S-NPP, NOAA-20

SEVIRI: Meteosat-11 (Meteosat-8, Himawari-9 and GOES-16/17 infrared imagers coming soon!)

AVHRR: MetOp-A, NOAA-18

RED=All Sky Over Sea

Recent and Upcoming Changes to the Global Data Assimilation System.

12th June 2019 Global Model Upgrade

- Forecast model is now based around the Finite-Volume Cubed-Sphere dynamical core.
- All-sky radiance assimilation for ATMS
- Add moisture sensitive channels for IASI and CrIS.
- Implement channels 5 and 6 for SEVIRI on Meteosat-11.
- Assimilate radiances from Saphir on Megha-Tropiques.
- OMPS Nadir Sounder assimilated
- Metop-B ASCAT winds assimilated.
- NOAA-20 CrIS, AMSU-A and MHS radiances as well as GOES-16 AMVs included prior to this upgrade
- Improvements to the use of climatology in Near Sea-Surface temperature analysis.

November 2019 Data Upgrade

- Assimilate radiance from MetOp-C AMSU-A and MHS
- Assimilate GOES-17 AMVs
- Assimilate KOMPSAT-5 GPSRO and prepare to monitor COSMIC-2

January 2021 Global Model Package (GFS v16)

- Upgrade is primarily to increase the number of model levels from 64 to 127.
- Introduction of correlated observation errors for IASI and CrIS
- Use of water vapor channels for Meteosat-8, Himawari-9 and GOES-16 infrared imagers.
- Inclusion of sub-gridscale cloud and cloud fraction for microwave all-sky radiances.
- Assimilation of AMSU-A Ch 14 and ATMS Ch. 15
- NOAA-20 VIIRS winds and more aggressive use of ASCAT winds
- Increased use of aircraft data including LATAM and TAMDAR
- 4D-Incremental Analysis Update and replace EnSRF with LETKF

Future Work

- All-sky infrared assimilation
- Extension of all-sky assimilation to precipitating conditions.
- Microwave all-sky assimilation over land surfaces.
- Getting ready for MTG-IRS.
- JEDI

Important Areas of Development in Next Decade

- Expansion of all-sky assimilation to:
  - All surfaces (coupled DA)
  - Other frequencies (Infrared, maybe visible?)
- Increased use of high-temporal frequency observations
  - Wind increments through tracing effect in DA

Challenges and Opportunities on the Data Side

- Retention of high-value measurements:
  - Threat to microwave frequencies through RFI
  - Retention of the 15µm band for infrared sounders
  - Co-located imagers
- Optimal use of high-volume datasets
  - MTG-IRS
- GPSRO and Doppler Winds
  - Not radiance data – but likely to be increasingly significant.