Rapid Refresh Forecast System (RRFS) Data Assimilation System

NATIONAL WEATHER SERVICE

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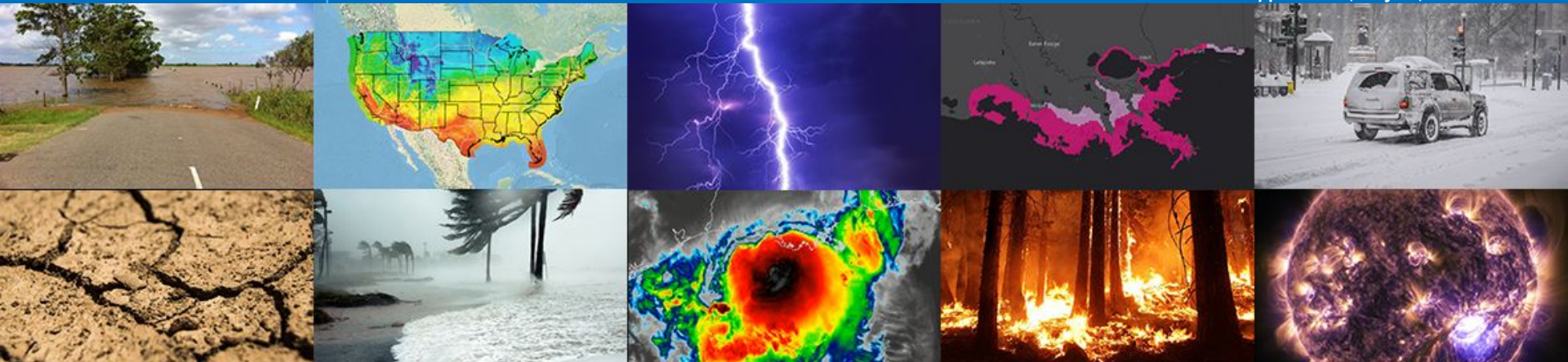
NOAA'S SATELLITE APPLICATIONS SYMPOSIUM SERIES: Severe Weather and Hurricane Applications, July 16, 2025



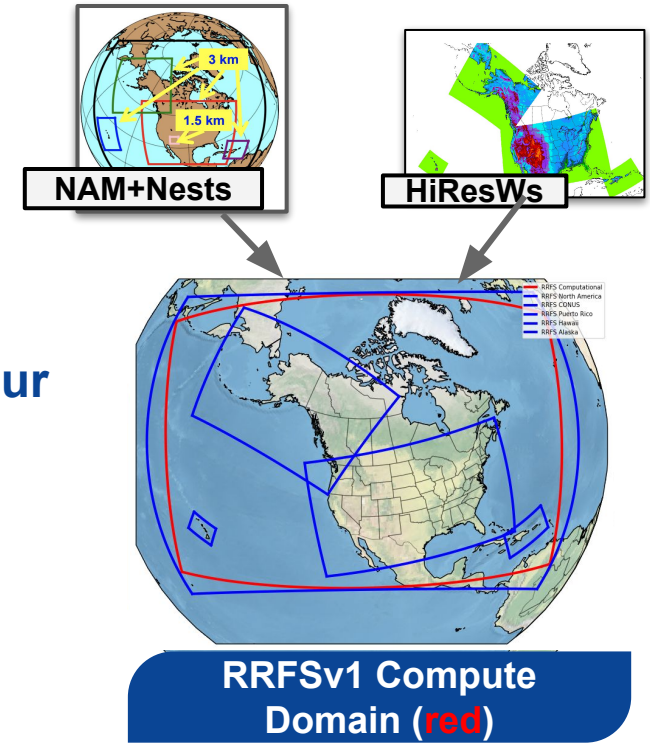
OUTLINE

- Rapid Refresh Forecast System (RRFS) overview
- RRFS Data Assimilation System (RDAS)
- RDAS cycling strategy
- Observations used in RDAS
- Satellite data assimilation in RRFS
- Overview of RDAS (MPAS+JEDI) for RRFSv2

Rapid Refresh Forecast System (RRFS)

A UFS Application

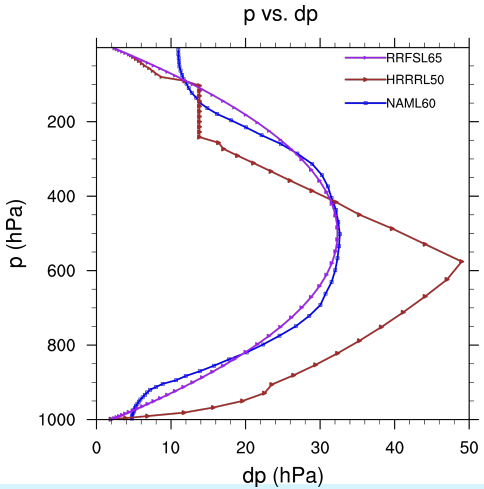
- **FV3 dynamical core Limited Area Model**
- **Hourly updated**
- **3 km grid spacing over North America**
- **65 vertical layers**
- **Hybrid 3DEnVar assimilation (30 members)**
- **Includes Smoke & Dust**
- **Deterministic forecasts to *at least* 18h every hour**
- **Det & Ens forecasts to 60h every 6 hours**
  - 12 total RRFS members
    - 6 on-time + 6 t-6h (plus 2 HRRR TL members for CONUS/AK)
    - Membership count drops at longer leads



RRFS Physics and Vertical Resolution

Physics	SCHEME	REFERENCE
PBL/Turbulence	MYNN-EDMF	Olson et al. (2019)
Surface Layer	MYNN	Olson et al. (2021)
Microphysics	Thompson-Eidhammer	Thompson and Eidhammer (2014)
Climatological Aerosols	Thompson-Eidhammer	Thompson and Eidhammer (2014)
Smoke and Dust	RAVE fire data, FENGSA scheme for dust	Ahmadov et al., Freitas et al., 2010
Shallow Convection	MYNN-EDMF	Olson et al. (2019) Angevine et al. (2020)
Deep Convection	Grell-Freitas	Grell and Freitas (2014)
Gravity Wave Physics	Small Scale and Turbulent Orographic Gravity-Wave & Form Drag	Beljaars et al. (2004) Tsiringakis et al. (2017) Toy et al. (2021)
Land Model	RUC LSM	Smirnova et al. (1997, 2000, 2016)
Large Lakes	FVCOM	Fujisaki-Manome et al. (2020)
Small Lakes	CLM Lake	Subin et al. (2012), Mallard et al. (2015), Benjamin et al. (2022)
Long and Short Wave Radiation	RRTMG	Iacono et al. (2008), Mlawer (1997)

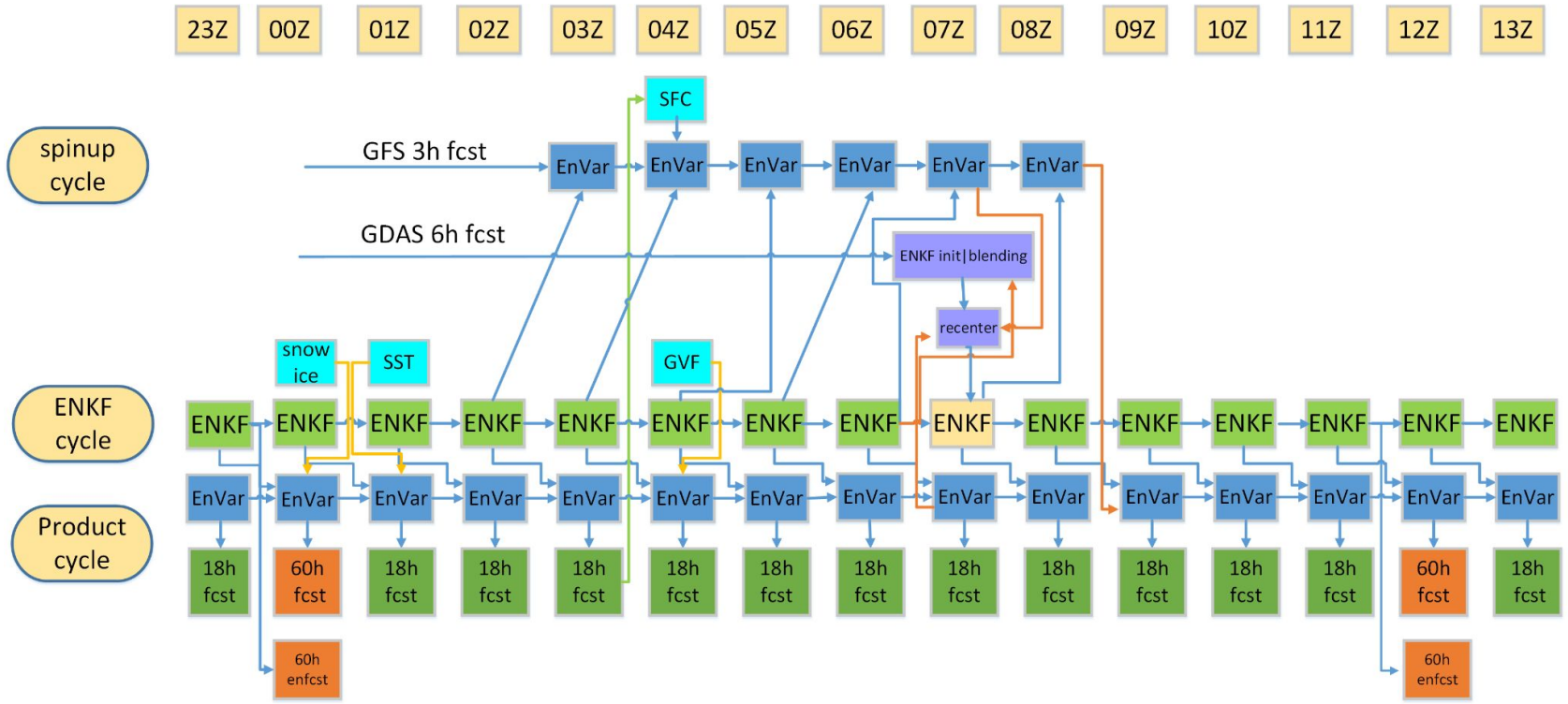
Parameter	RRFS	HRRRv4	NAMv4
Number of levels	65	50	60
Lowest level (m)	8	8	20
Top (hPa)	2	20	2



RRFS Data Assimilation System (RDAS)

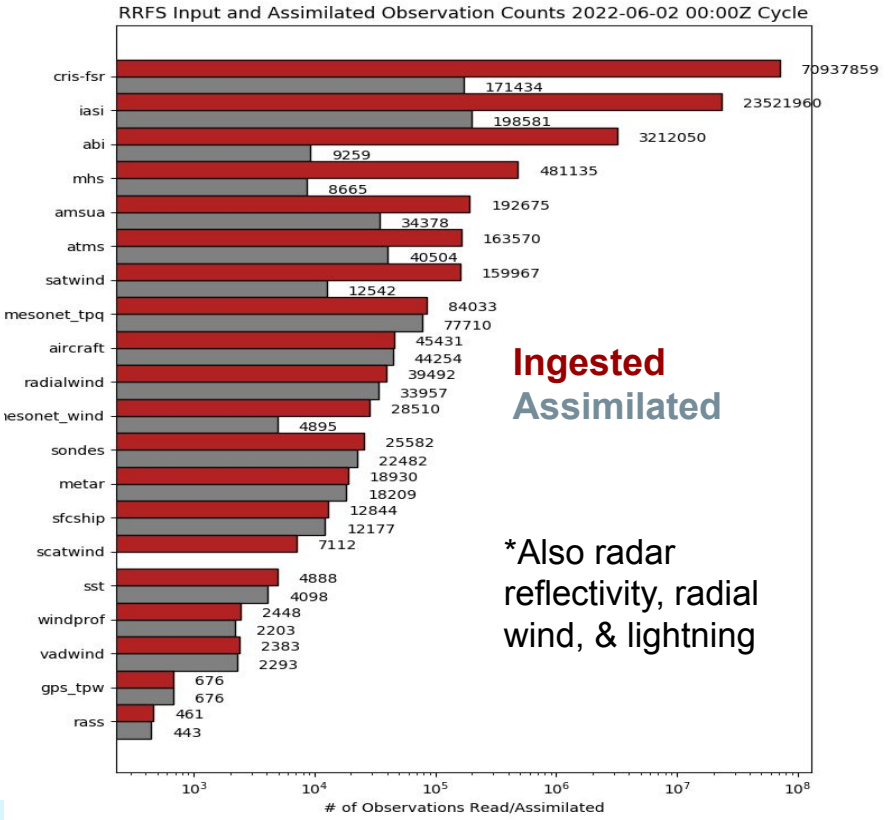
Deterministic DA Spin-up Cycle	• 03z-08z and 15z-20z • Cold start at 03z and 15z and hybrid EnVar with 80 GDAS ensemble members • hourly cycled 04z-08z and 16-20z with Hybrid EnVar with 30 regional ensemble member
Deterministic DA Product cycle	• Hybrid EnVar with 30 regional ensemble members • hourly cycled from 00z to 23z
Ensemble DA EnKF cycle	• EnKF • hourly cycled from 00z to 23z

RDAS cycling strategy

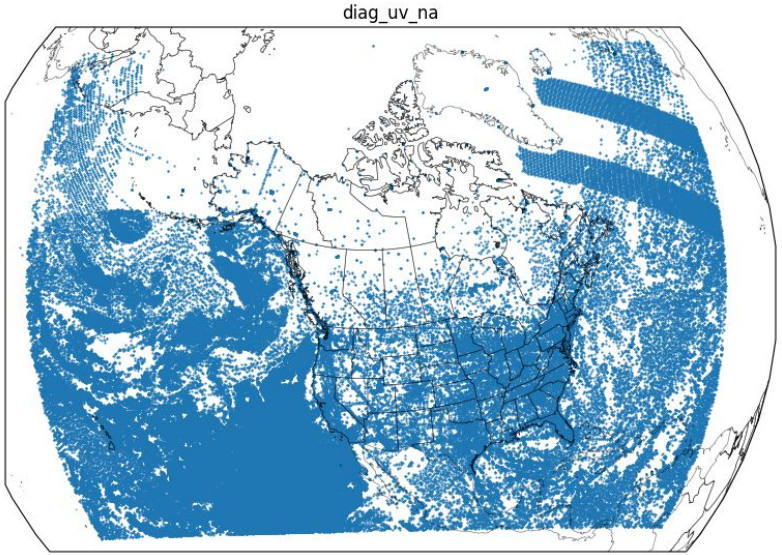


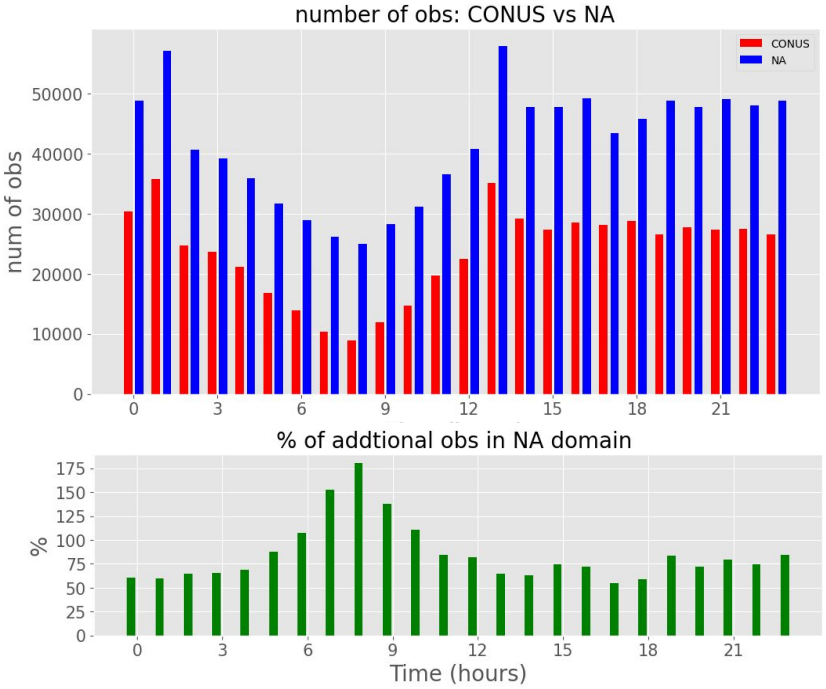
Observations used in RDAS

Obs Platform	Variables
METAR, Mesonet, Buoy, C-Man, Ship	T, moisture, W, ps, ceiling, vis
Rawinsonde	T, moisture, W
NEXRAD Radar	dBZ, rw, VAD W, REF
Lightning	Flash Extent Density
Aircraft	T, moisture, W
GOES-16/18/19	ABI, AMVs, cloud top pres. & T
Polar Orbiters	Radiances (AMSUA, MHS, ATMS, CRIS, IASI, SSMIS)



RRFS observations: CONUS vs NA





wind observations

Satellite Data in RRFS

- Satellite radiances assimilation
  - especially valuable for limited-area convective model over data-sparse areas like oceans, mountains, and rural regions
  - High-frequency hourly DA cycles in RRFS benefit from the near-continuous coverage geostationary satellite radiances, enhances the system's responsiveness to rapidly evolving mesoscale weather systems
  - Properly assimilate cloud-sensitive radiance channels improves: **Vertical humidity profiles, Cloud water and ice fields, Cloud-top properties**
  - Convective-scale models rely on accurate representation of small-scale atmospheric features.Improved radiance assimilation leads to better:
    - Timing and location of convective storms
    - Quantitative Precipitation Forecasts (QPF)
    - Prediction of severe weather (e.g., thunderstorms, flash floods)
- AMV wind assimilation
- Regional Hourly Advanced Baseline Imager (ABI) and Visible Infrared Imaging Suite (VIIRS) emissions, RAVE RAVE for smoke and dust initialization

Status of Satellite Radiance DA in RRFS V1

- Assimilates a similar set of polar-orbiting satellites as GDAS, but under **clear-sky conditions only**
- The same **quality control (QC)** and **bias correction (BC)** methods as GDAS
- BC coefficients and error variances are **updated hourly**
- Uses radiance channels below the **2 mb model top**
- Implements a **finer thinning mesh** of **60 km**
- Supports **high spatial (3-km)** and **high temporal (hourly)** data assimilation

AMSU-A
METOP-B Channels 8-13
METOP-C Channels 1-10, 15
NOAA-15 Channels 1-5, 7-10, 15
NOAA-18 Channels 1-4, 6-7, 10, 15
NOAA-19 Channels 1-6, 9-10, 15

MHS
METOP-B Channels 1-5
METOP-C Channels 1-5
NOAA-18 Channel 1-5
NOAA-19 Channels 1-2, 4-5

ABI
GOES-18 Channels 8-10 (CSR)
GOES-19 Channels 8-10 (CSR) (in plan)
GOES-16 Channels 8-10 (CSR)

ATMS
NOAA-20 Channels 1-11, 16-22
NOAA-21 Channels 1-11, 16-22
NOAA-NPP Channels 1-11,16-22

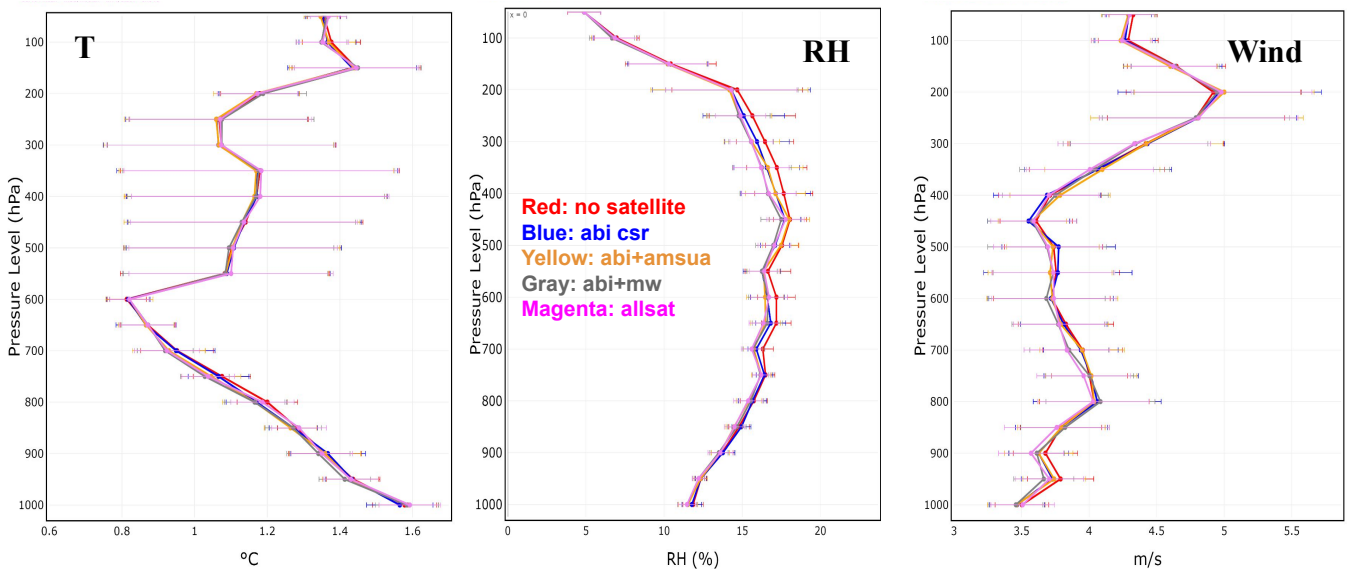
CRIS
NOAA-20 CrIS 98 Channels
NOAA-21 CrIS 98 Channels
NOAA-NPP CrIS 98 Channels

IASI
IASI METOP-B 141 Channels
IASI METOP-C 141 Channels

SSMIS
F17 Channel 5-7

* All satellite radiance data are assimilated under **cleary-sky** condition in RRFSV1
* Shaded color indicated satellites that have been discontinued

Impact Study for Satellite Radiance DA in RRFS V1.0



6-h Forecast **RMSE**

Validate from

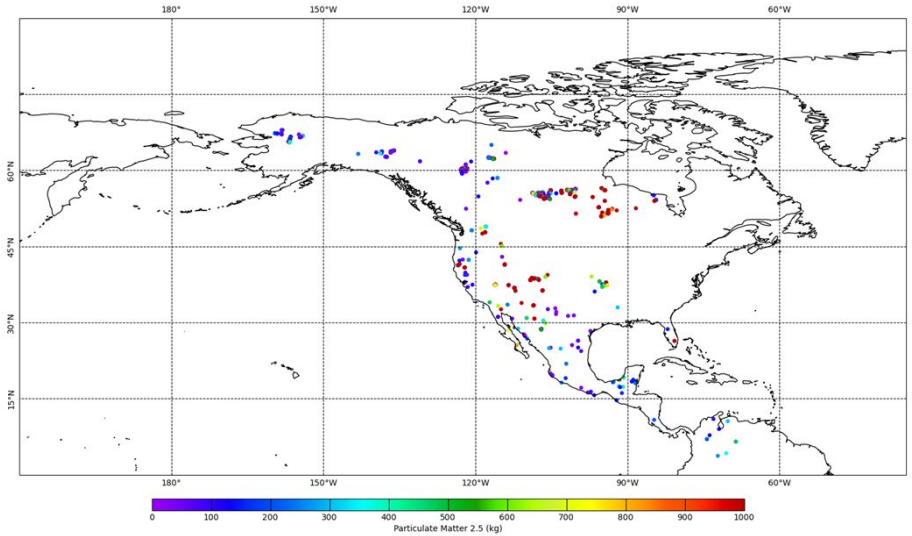
20210511 00Z to

20210520 18z

- Satellite radiance data has more positive impacts on moisture forecast than temperature and wind compared with only assimilating conventional data
- ABI data has the most important positive impact for middle level moisture forecast

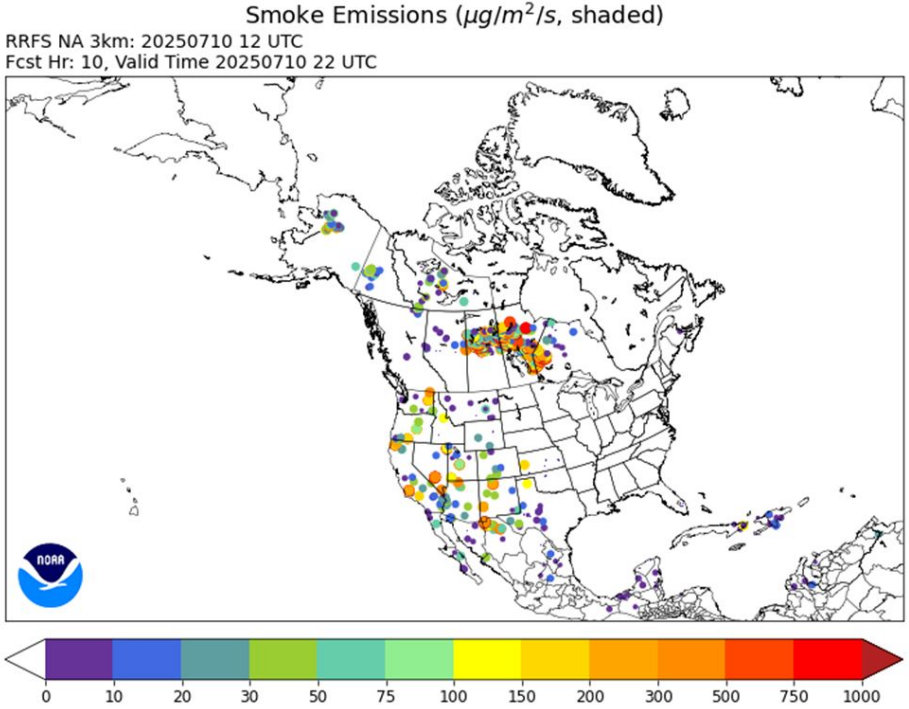
Smoke and Dust initialization with RAVE data

RAVE product: PM2.5



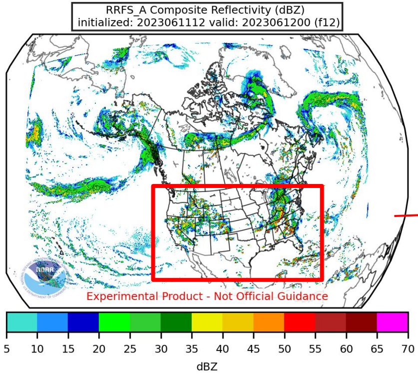
Source : https://www.ospo.noaa.gov/products/land/rave/

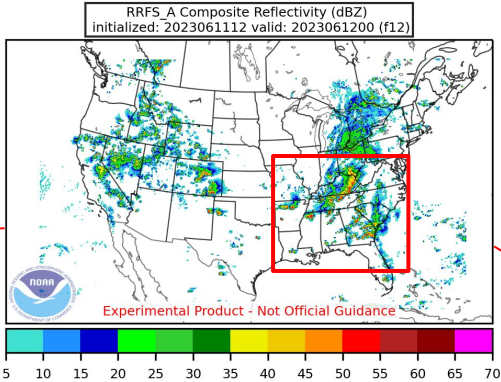
Provided by Dr. Partha Bhattacharjee

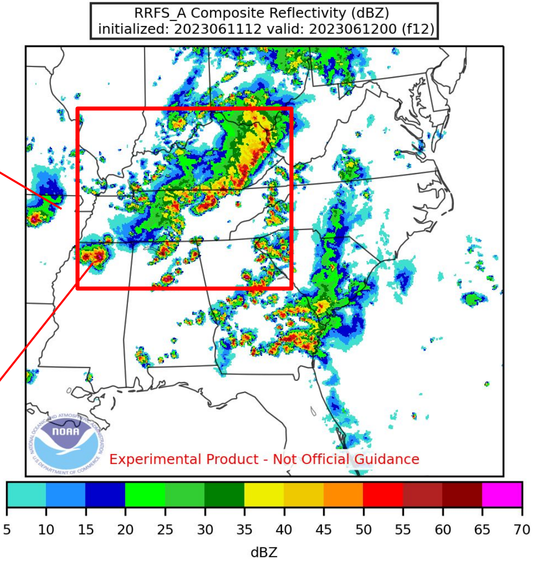


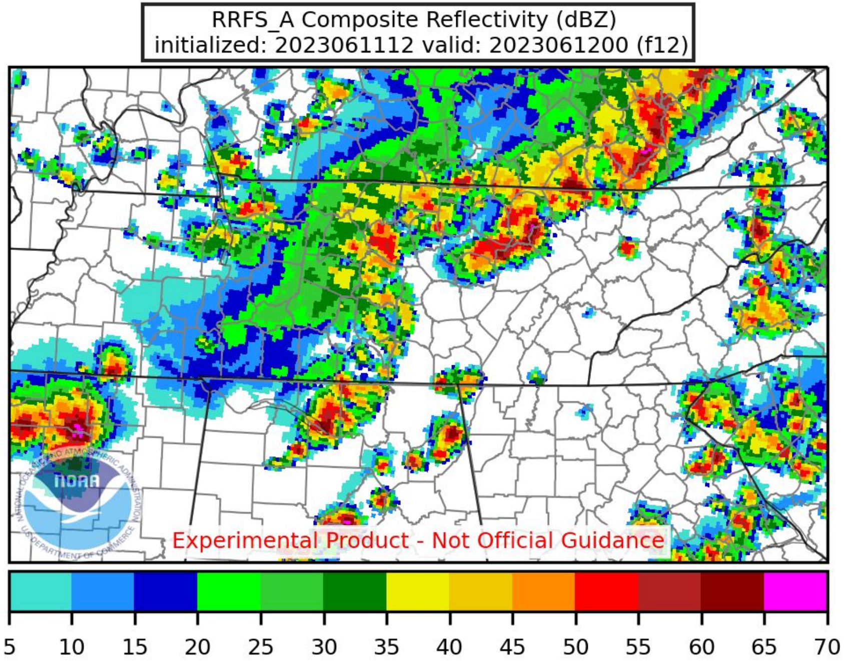
Source : https://rapidrefresh.noaa.gov/RRFS-SD/

North America 3 km Domain



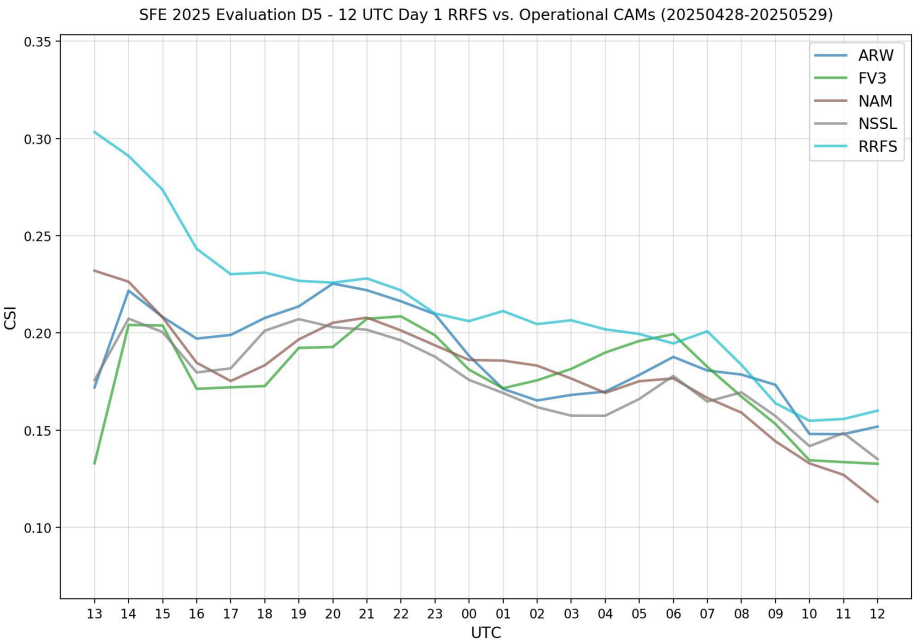


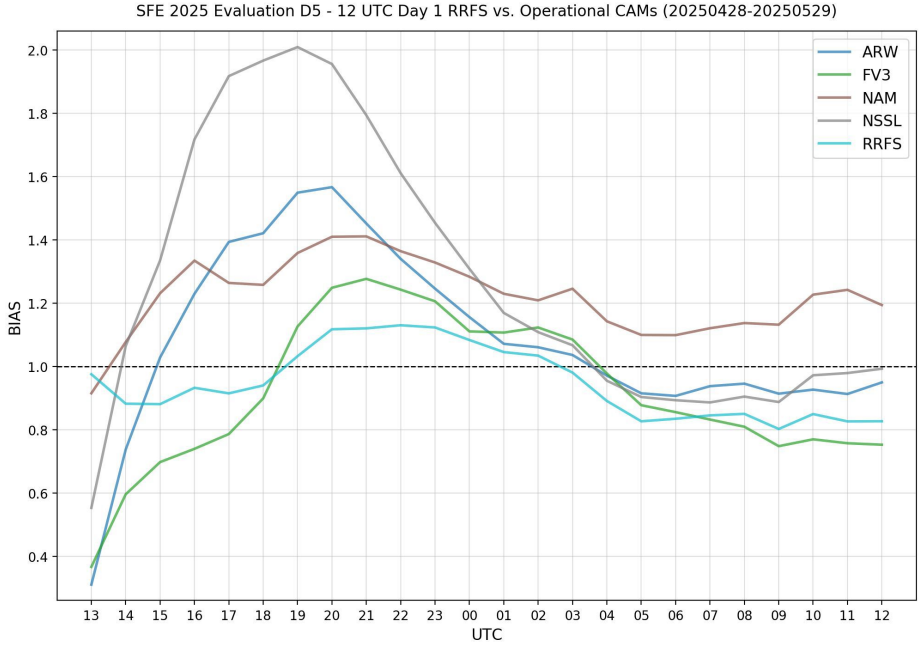




HWT Spring Forecasting Experiment

2025 5-week evaluation RRFS vs. Operational CAMs (20250428 - 20250529)





HWT wrap-up discussion

RDAS for RRFSv2

- **Regional convection-allowing ensemble forecast system built upon** MPAS (Model for Prediction Across Scales) and JEDI
  - Jointly developed by EMC, GSL, UFS community, NCAR, JCSDA, NSSL, …
  - All key components are based on the community systems
  - Workflow evolves to meet operation requirements
- **Challenges of MPAS-JEDI:**
  - UFO validation and development.
  - Background error covariance for MPAS-JEDI
  - DA algorithm validation.
  - Computational performance
    - MPAS vs FV3
    - JEDI vs GSI

All regional DA features from RRFS version 1 will be ported or further developed to RRFS version 2

Radiance DA in RRFSV2 (MPAS+JEDI)

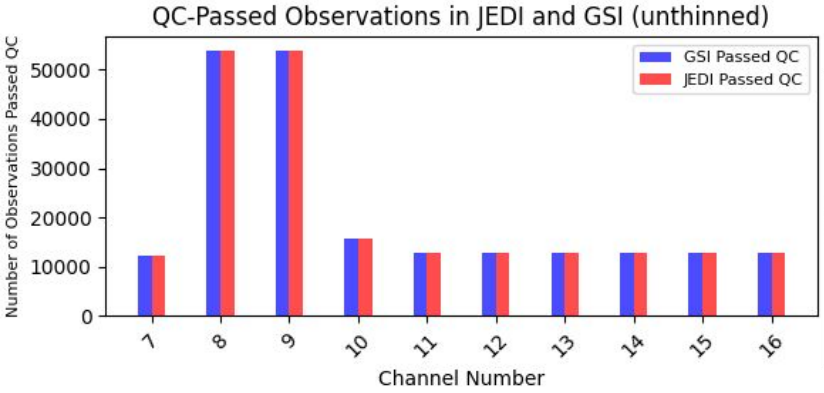
Instrument	Platform(s)	BUFR2IODA Conversion	YAML Config	Obs Available in IODA	Assimilation Tested	Status/Notes
AMSU-A	MetOp_b/c	✅ Completed	✅Drafted	✅ Yes	✅ Partial	YAMLs not yet finalized
ATMS	NPP, NOAA-20/21	✅ Completed	✅ Final	✅ Yes	✅ Completed	Working as expected
CrIS	NPP, NOAA-20/21	✅ Completed	✅ Partial	✅ Yes	✅ Partial	YAML and obs not yet finalized
ABI	GOES-16/18	✅ Completed	✅ Final	✅ Yes	✅ Completed	Working as expected
MHS	MetOp_b/c	⬜ Pending	⬜ No	⬜ No	⬜ No	Planned after AMSU-A
IASI	MetOp_b/c	⬜ Pending	⬜ No	⬜ No	⬜ No	Planned after CrIS

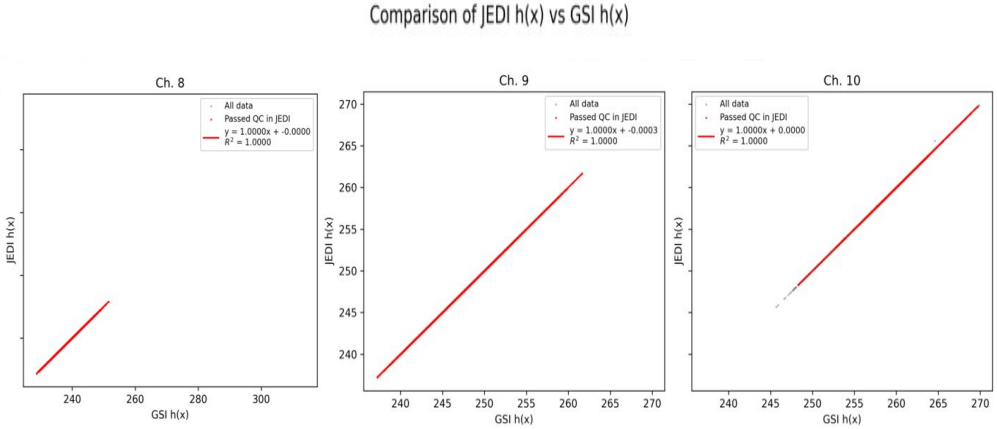
Legend:

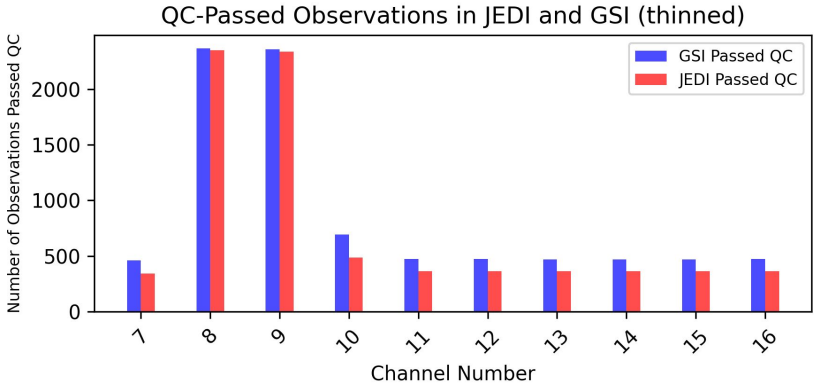
✅ = Complete or working
⬜ = Not started / pending

GOES-16 ABI Channel 8 HofX Comparison: JEDI vs. GSI

QC filter comparison between JEDI and GSI over CONUS





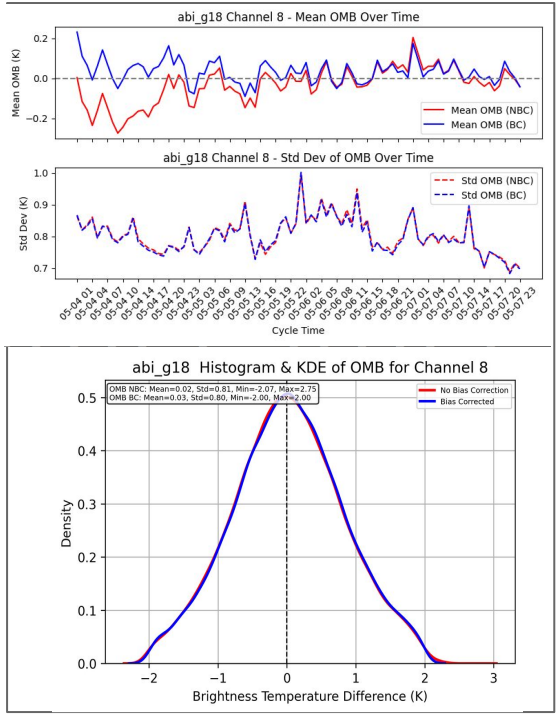


- Using the same ABI data and background:
  - Without thinning: The number of observations passing quality control (QC) is identical between JEDI and GSI across all channels.
  - With thinning: Slightly fewer observations pass QC in JEDI compared to GSI, due to differences in the thinning algorithms used by the two systems.

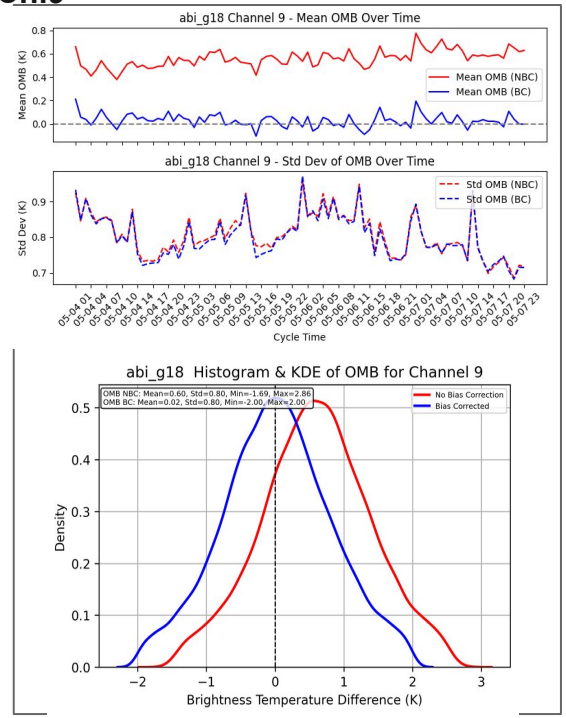
RRFSV2 baseline 1 Retro Experiment

ABI OMB: 4-Day Time Series & Histograms (With vs. Without BC)

Ch.8



Ch.9



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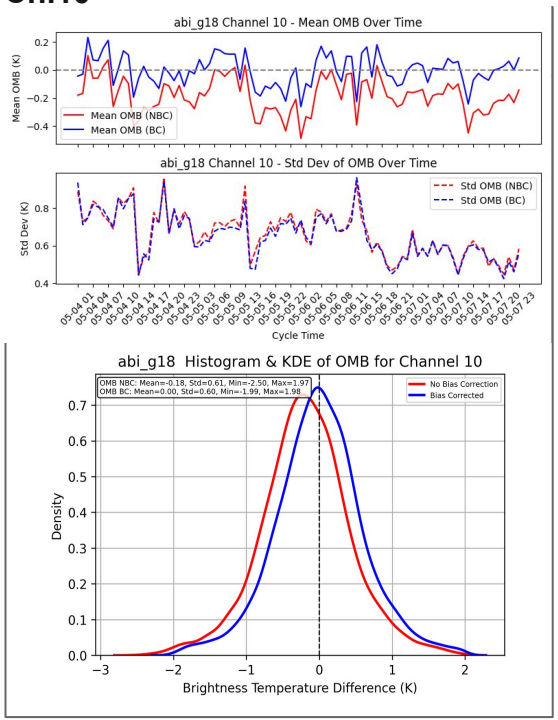

- Bias correction **reduces mean OMB** across Channels || **Standard deviation of OMB** is generally smaller with BC
- Time series show more stable and centered OMB after correction || **Histograms** reveal tighter and more symmetric OMB distribution with BC

Summary and Conclusion

- RDAS for RRFSv1
  - RDAS developed for RRFSv1 with the advanced DA techniques
    - RRFSv1 will be implemented in the early of 2026
  - Satellite observations and products play important role in improving RRFS forecast skill over NA domain with high rapid updated cycling strategy

- RDAS for RRFSv2
  - Worked on transitioning DA functions in RRFSv1 to RRFSv2
  - Extend clear-sky ABI radiance assimilation to all-sky conditions in RRFSv2
  - Expand ATMS and AMSU-A cloudy radiance assimilation to include precipitation-affected scenes

Thank you!