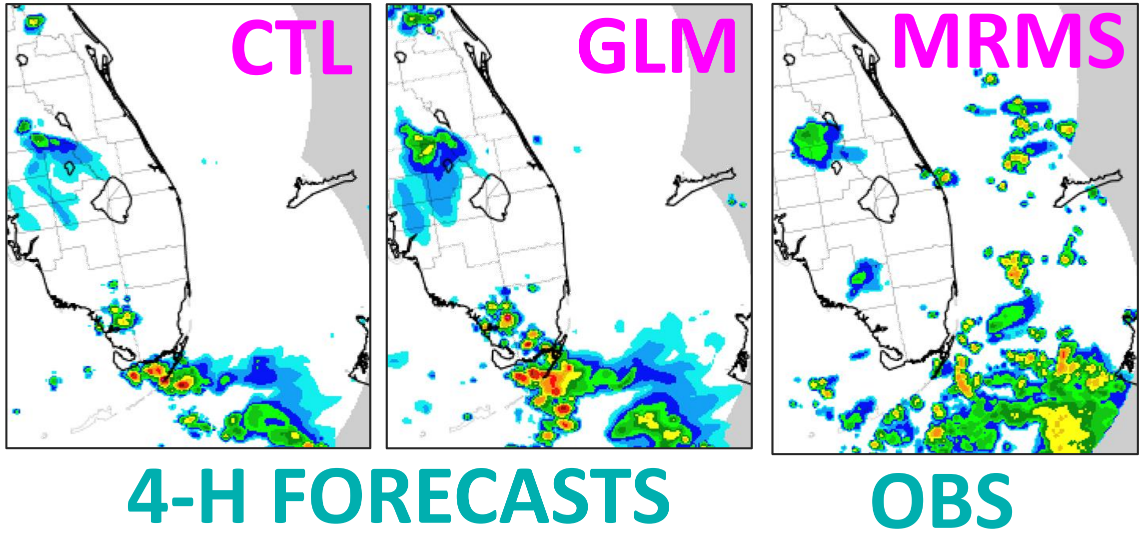
Satellite data use at NOAA/ESRL for Rapid Refresh analysis and forecast systems

Geostationary
- **GOES cloud-top pressure**
- **AMVs (GOES16*)**
- **IMS snow cover product**

Experimental / future
- **GLM lightning data**
- **Cloud-top cooling rate**
- **Polar orbiter cloud products**
- **AOD, Smoke Mask (NESDIS)**
- **Soil moisture**

Polar Orbiters
- **VIIRS Fire Radiative Power***
- **VIIRS Green Vegetation Fractions**
- **IMS snow cover product**



Amanda Back, CIRA NOAA/ESRL (amanda.back@noaa.gov)

Satellite data use at NOAA/ESRL for Rapid Refresh analysis and forecast systems

Decision-making for new data inclusion

- Do we **know** that this product **exists**?
- Will the data be **operationally available** at **low latency**?
- Will use of the data increase **computation time** (e.g., expensive pre-processing)?
- Does evidence indicate its use will be **impactful** (e.g., inclusion in global model)?
- Do we have the **resources** to **test** the data, and, if applicable, **develop algorithms**?
- Do tests indicate the data ingest is **beneficial** (improved skill score; improved forecasts for stakeholders, such as aviation)?
- Are the data **reliable**?

Satellite data use at NOAA/ESRL for Rapid Refresh analysis and forecast systems

Resources

- More **people** and **computer time** needed to **thoroughly test** products, even those that already exist/are known to us
- Good products come online but much **work to leverage** (bias/error, obs. operator/adjustment scheme, long testing time periods, …)
- **Pipeline** to **operations**

Ongoing or future needs for satellite data use

Quality/bias correction

- **Expensive to develop** our own bias correction
- **Error reporting** (esp. retrievals)
- **Reliability**/QC

Communication

- **Centralized location** to share new products; not "ad hoc"
- **Documentation** for all products including **error** and **methodology**

Satellite data use at NOAA/ESRL for Rapid Refresh analysis and forecast systems

Connecting Models and Observations

Land/sea surface

- Need high-res, real-time
- 1-km **snow cover**
- Fractional **sea ice**
- Higher-resolution **green. fraction**

Ongoing or future needs for satellite data use

Info. in the vertical

- Many sat. products are **2D**
- Model fields are **3D**
- Cloud-top pressure (for ex.) 2D but gives **useful height info**

Model assessment

- Tools needed for **global models** especially
- **Classification/ML** for, e.g., stratiform vs. convective precipitation
- **Product error information**

Global, Convective-scale products

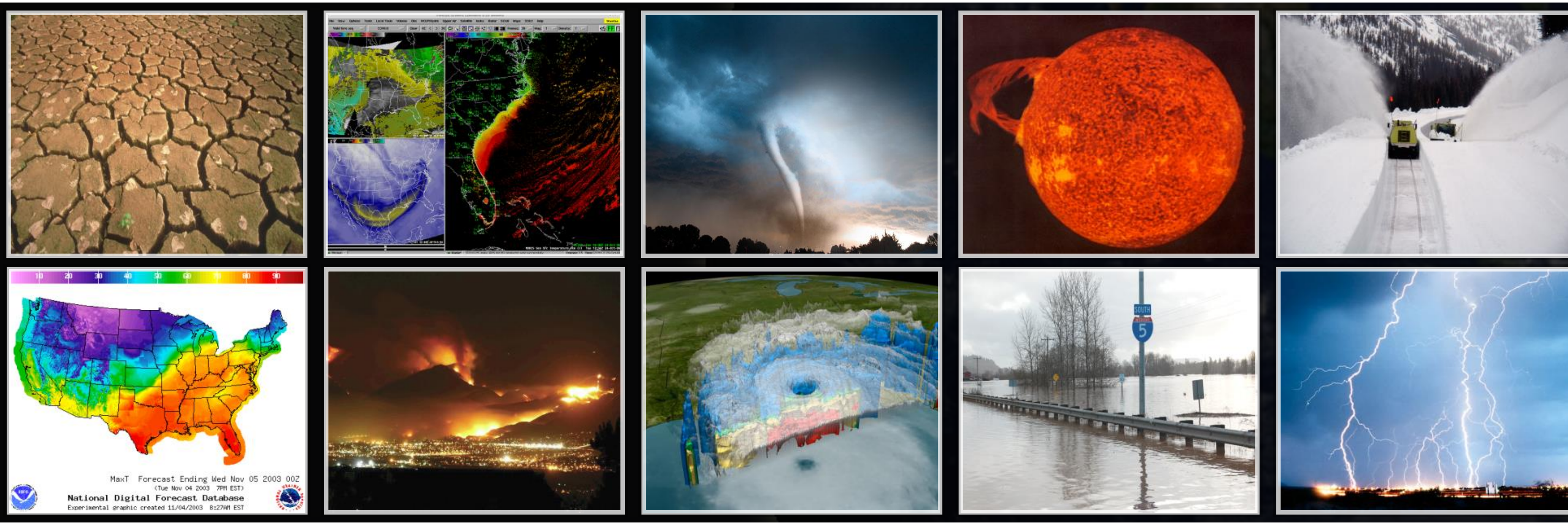
- RR-**HI** and RR-**PR**
- **Global** RR
- **IOPs/field campaigns** to **validate** satellite products?

Satellite data use at NOAA/ESRL for Rapid Refresh analysis and forecast systems

More chances to learn about satellite data use for RR systems

- Tues, 1:15 pm: **Smoke and Fire** Panel (R. Ahmadov)
- Weds, 10:30 am: **Clouds and Winds** Panel (S. Weygandt)
- Weds, 4:45 pm, poster session:
  - **Use of satellite cloud product data for HRRR and RTMA cloud analysis** (S. Weygandt)
  - **Assimilation of GOES-16 ABI, N20 CrIS-FSR/ATMS (including Direct Broadcast) in RAP version 5** (H. Lin)
  - **Assimilation of GOES-R GLM Lightning Data and Cloud-Top Cooling Information in HRRR** (A. Back)
- https://**rapidrefresh.noaa.gov**

NWP and Assimilation (Geophysical Parameters)



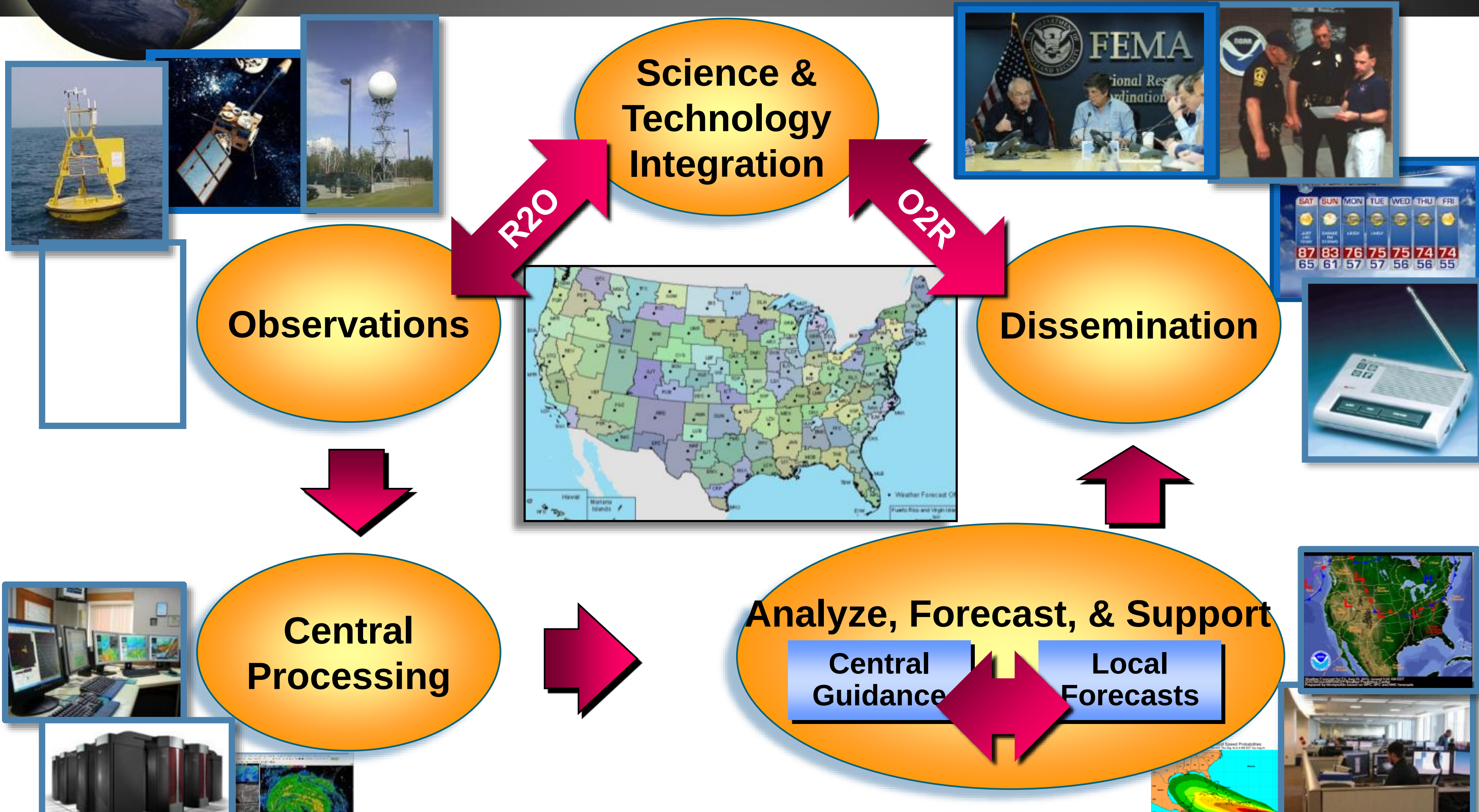
James G. (Jim) Yoe

NOAA/NWS National Centers for Environmental Prediction

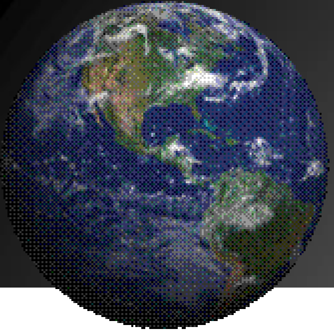
Satellite Proving Ground Summit

College Park, MD - February 24, 2020

Background - NWS Infrastructure Based on:
The Forecast Process



***Also defines the NWS Portfolio Process**



My “User” Perspective

- **What I Do (my job)**
  - **Coordinate Obs, ST/I for National Centers (9 of them)**
  - **Research Transition Manager for NCEP**
    - **Joint Center for Satellite Data Assimilation**
    - **Develop, Test, & Demonstrate methods/infrastructure to Accelerate/Improve use of satellite data**
- **What I Want to Accomplish (my mission)**
  - **Improve Service Delivery:**
    - **Assimilate more (sat) obs better for more accurate NWP**
      - **More useful forecast products at Centers, WFOs, RFCs**
        - **Improved Decision Support to government agencies, individual citizens, and everyone in between**

Geophysical Parameters

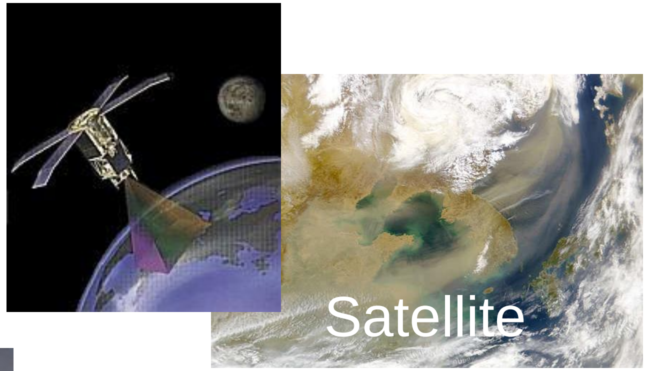
- Radio Occultation Profiles (bending angle)
- Atmospheric Motion Vectors (Geo and Polar)
- Surface properties (Land, Ocean, Cryosphere)
  - Ocean Surface Winds, Altimetry
- Vertical profiles of horizontal wind (DWL)
- Atmospheric Chemistry and Aerosols

Challenges

- **Recognized and Addressed**
  - **O2R is necessary for R2O**
  - **Acceleration requires common tools, efforts**
- **Recognized but not Addressed**
  - **DA Development and Testing requires ever more HPC**
- **What I Lose Sleep Over**
  - **O2R is NOT sufficient for R2O**
    - **Obs, DA, & Model compete for implementation**
    - **Faster planned dev of DA(JEDI), model (UFS via EPIC) and obs (small sats, commercial) not complemented on implementation side**

Motivation – Navy Requirements for EO/Aerosol Research

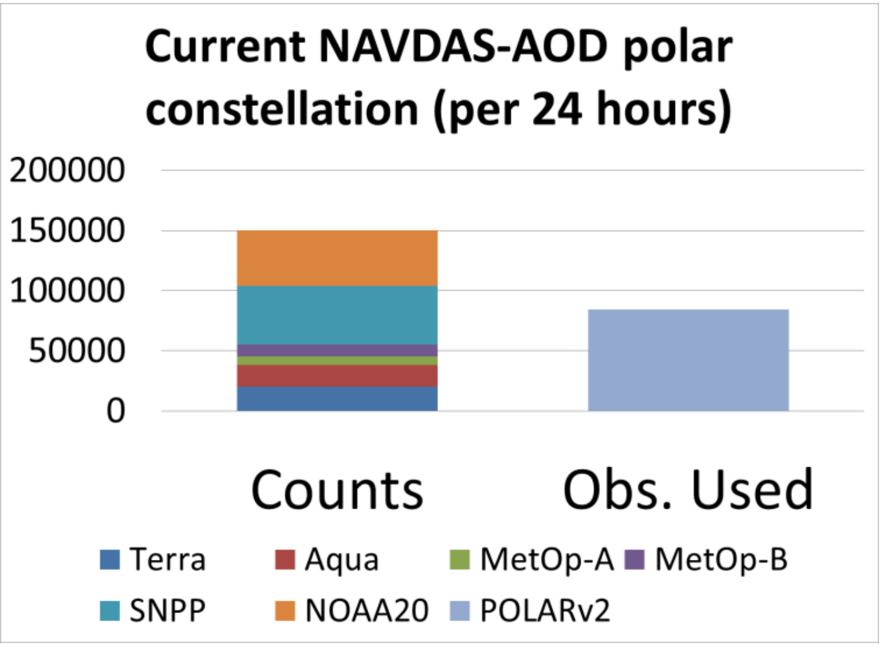
- Atmospheric environment (aerosols, clouds) can have a significant impact on visibility and EO conditions:
    - Passive sensors: Visibility for operations; EO/IR sensors, satellite sensors
    - Active sensors: Directed energy; laser communications; laser radar; precision guided munitions illumination

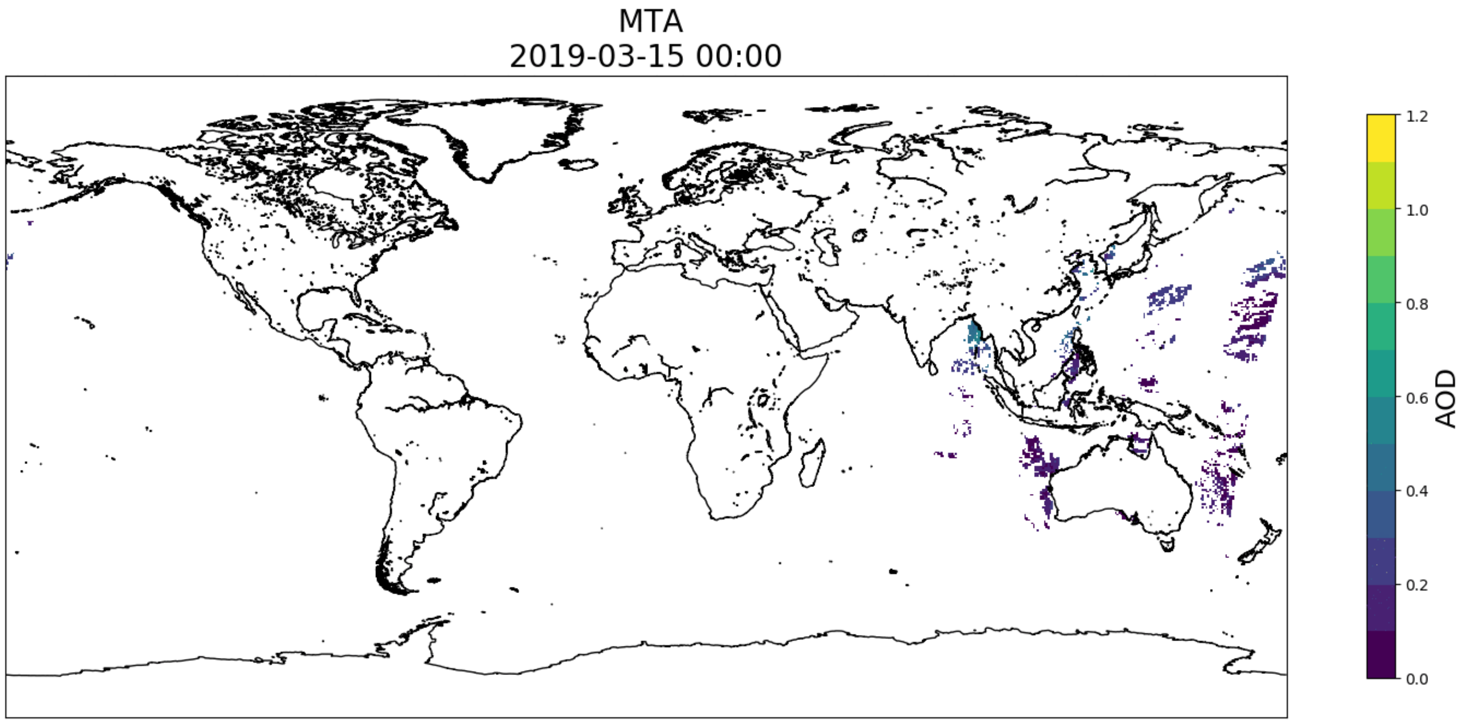


Goal: Measure, model, and predict the impact of the environment on naval operations, and EO/IR sensors and weapon systems

Current LEO Constellation for Aerosol DA

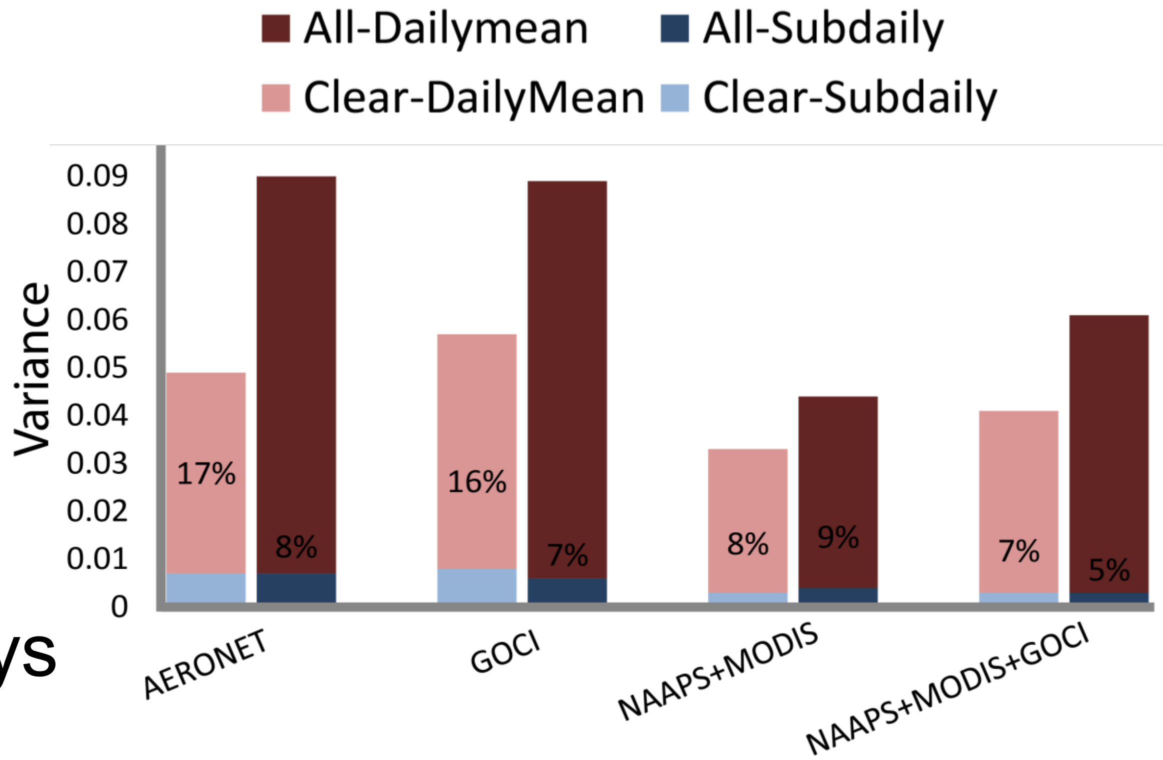
- MODIS: Terra+Aqua, Collection 6.1 Dark Target + Deep Blue
- VIIRS: NOAA Enterprise AOD, NPP (preparing to use N20)
- AVHRR: ACSPO MetOp-A and MetOp-B, ocean-only
- 6-hourly 3DVAR: There is redundancy, but less than you'd think!





Contribution of GEO to Aerosol Model Skill

- AERONET observations over East Asia during Sping 2016
- GOCI (Yonsei v2 AOD) and NAAPS sampled to match
- "subdaily anomaly" calculated by subtracting daily mean at each location from each observation
- "Clear" excludes partially cloudy days

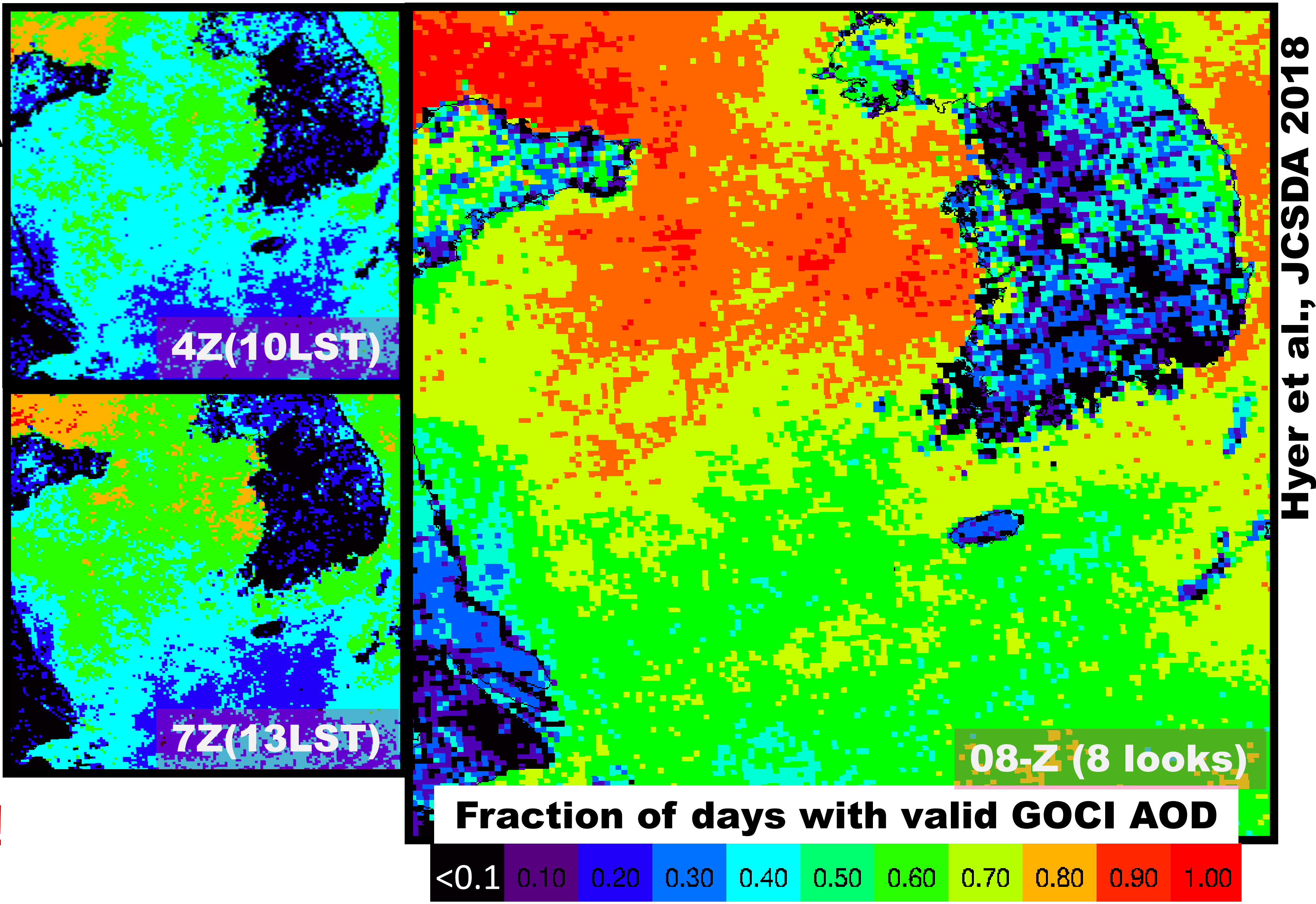


Hyer et al., JCSDA 2018

1. **Subdaily variation is a 10-20% residual in this region**
2. **Satellite observations show similar variance to AERONET**
3. **NAAPS global model has smaller variance overall, much less subdaily variance (more with GOCI)**
4. **Daily mean matters most-- does GEO give a better daily mean?**

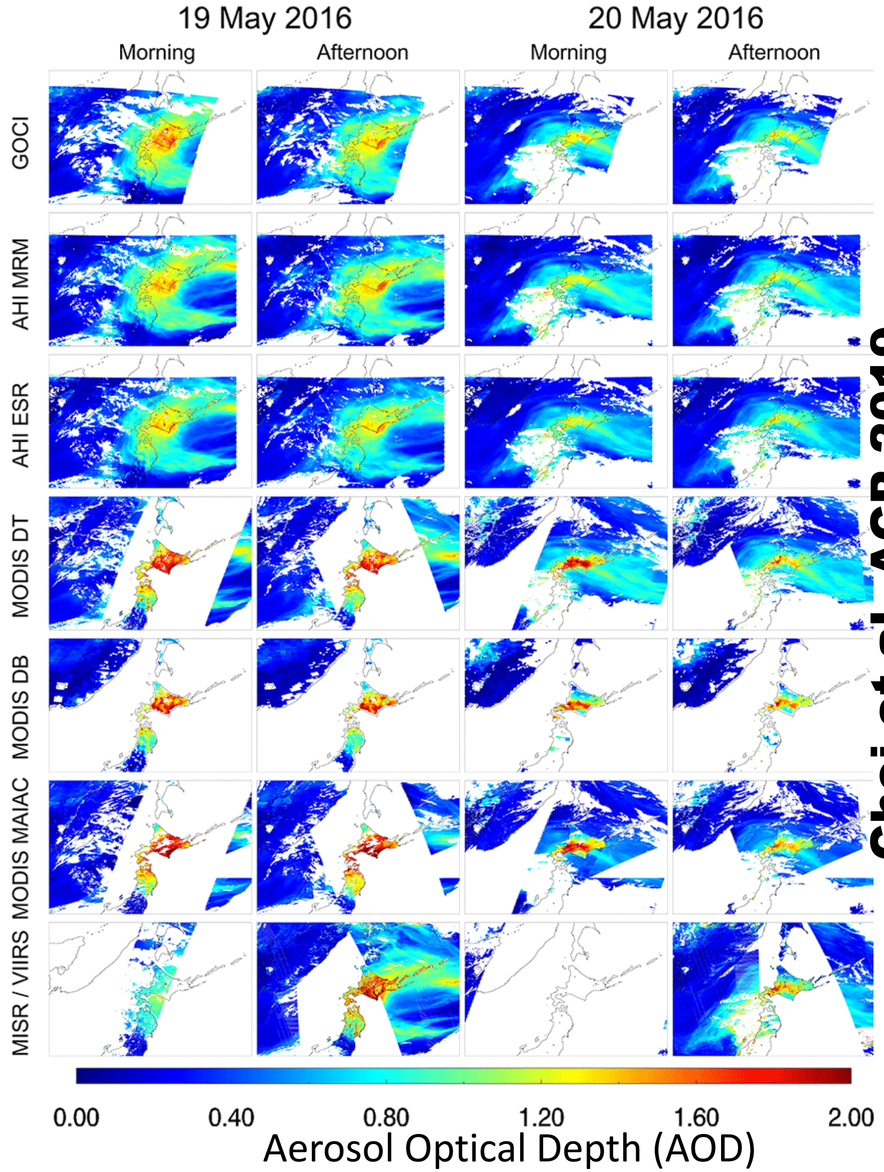
Contribution of GEO to Aerosol Model Skill

- GOCI (Yonsei v2 AOD) filtered using built-in QA
- Upper left: 10LST
  - (AM LEO orbit)
- Lower left: 13LST
  - (PM LEO orbit)
- Right: Use entire day
- Repeat looks drastically increase available coverage!
- Large benefits available even for coarse models!



Choosing satellite products for Assimilation

- Lots of products available-- top to bottom at right: GOCI, AHI MRM, AHI ESR, MODIS DT, MODIS DB, MODIS MAIAC, MISR(left), VIIRS SNPP Enterprise (right)
- Are they available in near real-time?
  - Research products push the science, NRT products get used for operations
- Do they verify well?
  - Optimally independent verification including comparison with current
- Do they include information to refine uncertainty estimates?

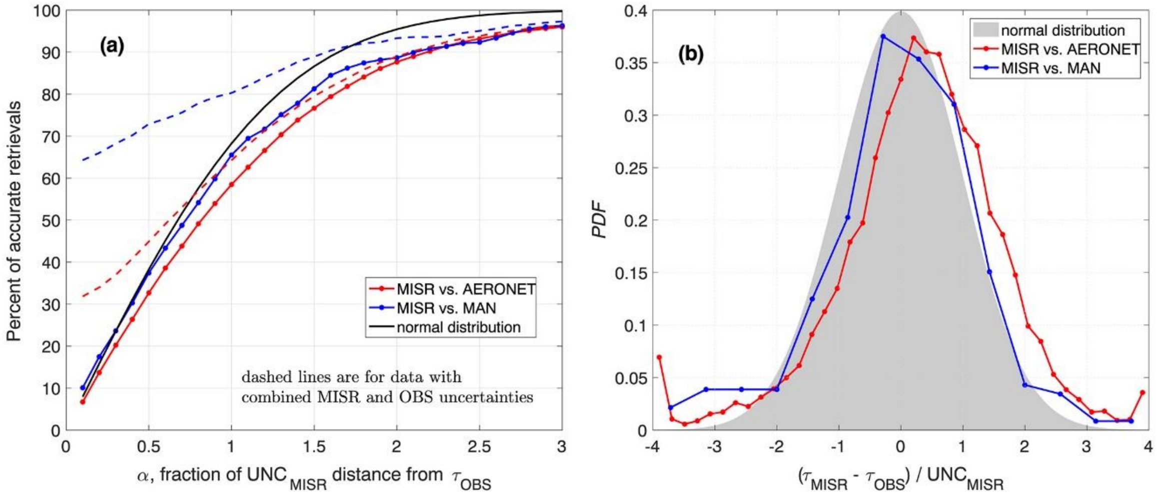


Choi et al. ACP 2019

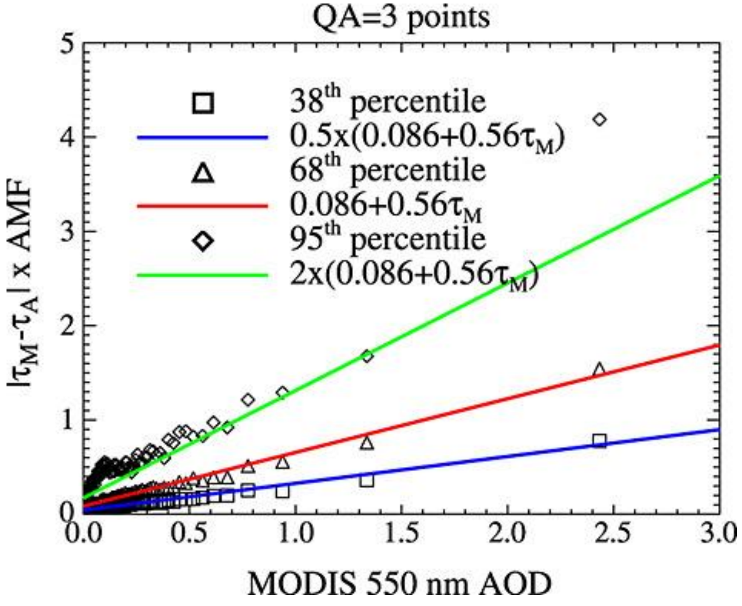
Satellite product uncertainty-- and its validation!

U.S. NAVAL RESEARCH LABORATORY

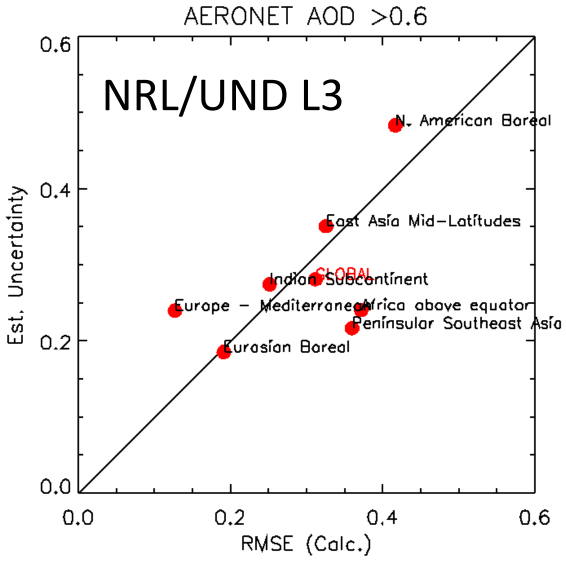
- Uncertainty comes from many sources– many not readily stratified
- The mathematics of radiance inversion for retrieval generates an uncertainty
  - MISR uses this directly to estimate per-pixel uncertainty (Witek et al., top figures)
- Uncertainty can also be empirically estimated from verification
  - Some MODIS products include this (Sayer et al., bottom left)
  - Stratifies only by retrieved AOD and AMF
- Can we make a skillful uncertainty resolved on ancillary characteristics?
  - (example: by region, bottom right)



Witek et al. JGR 2019



Sayer et al. JGR 2013



Final Slide

1. Resolution and uncertainty trade off for many types of retrieval– who will manage that tradeoff (developer or user)?
2. Improving satellite retrievals is a job that evolves-- but does not end!
3. Information into the model is a function of ability to resolve uncertainty– data assimilation must always “assume the worst” about the observations!

THANK YOU!

NWP/Data Assimilation Part II: Geophysical Parameters

Kyle Hilburn

24-Feb-2020

Challenges

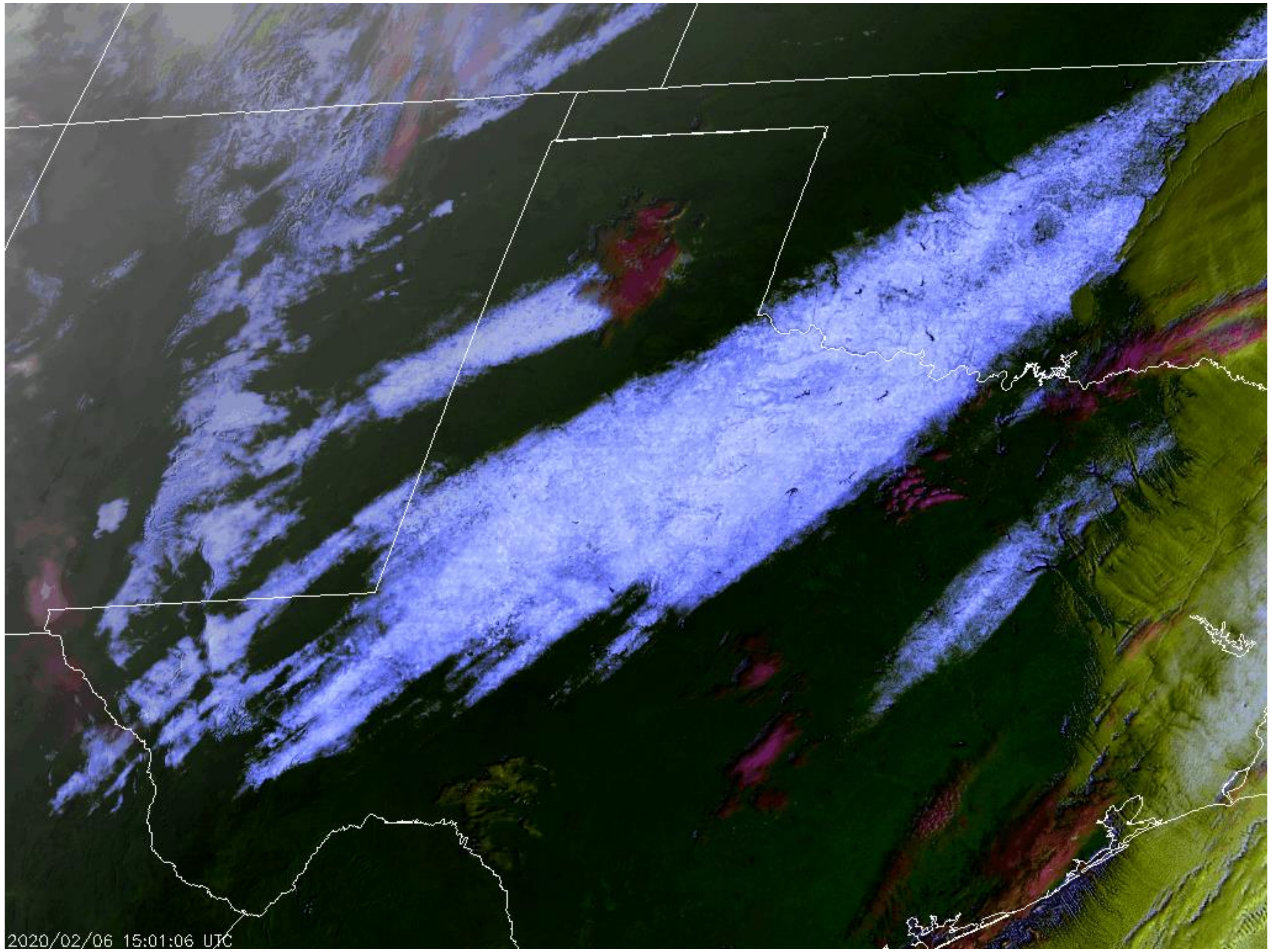
- Observations
  - Big data: many small improvements from a large number of observations makes for a big total improvement
- Models
  - Coupling: more Earth System components means many more interactions
- Data assimilation
  - Algorithms: becoming more complex and application dependent

Opportunities

- Observations
  - GOES-R Series: untapped potential for snow, dust, smoke, and fire
  - Unmet need: latent heating for convective-scale forecasting in locations lacking good ground-based radar coverage
  - Other technologies (e.g., hyperspectral, UV, …)
- Data assimilation
  - Machine learning
    - Humans develop imagery, machine learning uses imagery
    - Forward operator
    - Data fusion

Untapped Potential: Snow Cover

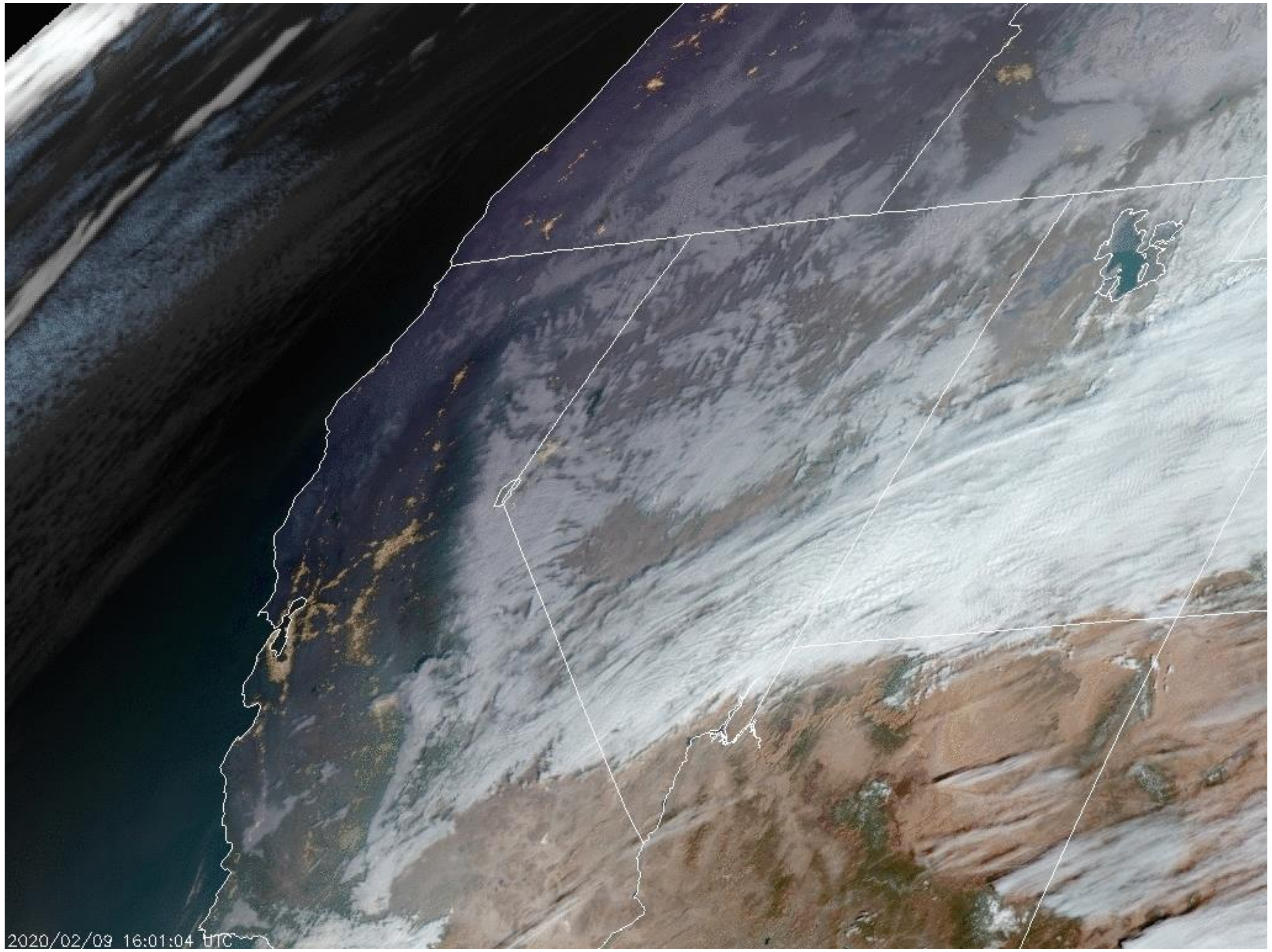
Melting snow over Texas
GOES-16 CIRA Snow-Cloud/Layers



http://rammb.cira.colostate.edu/ramsdis/online/loop_of_the_day/

Untapped Potential: Blowing Dust

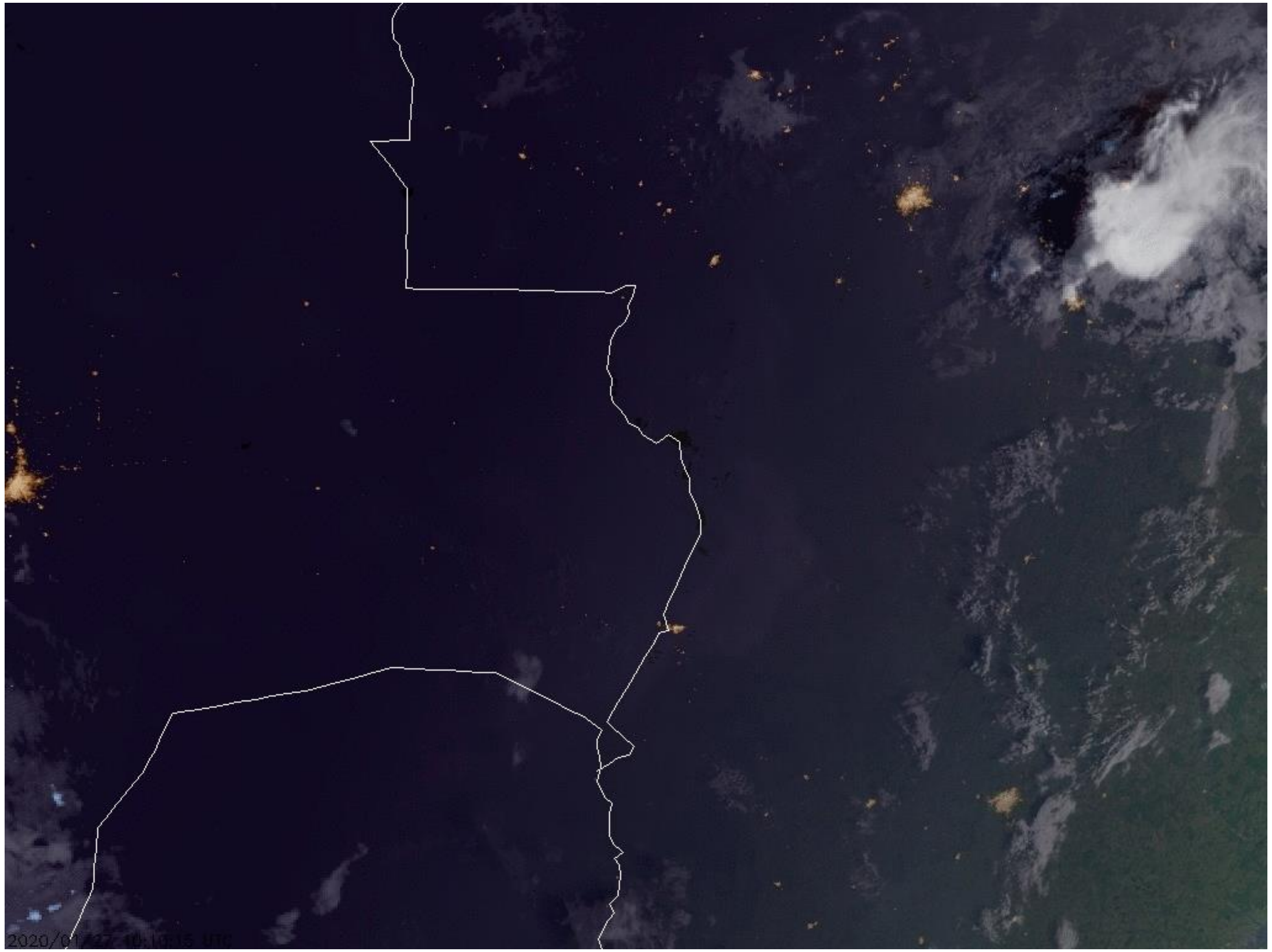
High winds loft dust from dry lake beds in Nevada
GOES-16 CIRA GeoColor



http://rammb.cira.colostate.edu/ramsdis/online/loop_of_the_day/

Untapped Potential: Smoke Dispersion

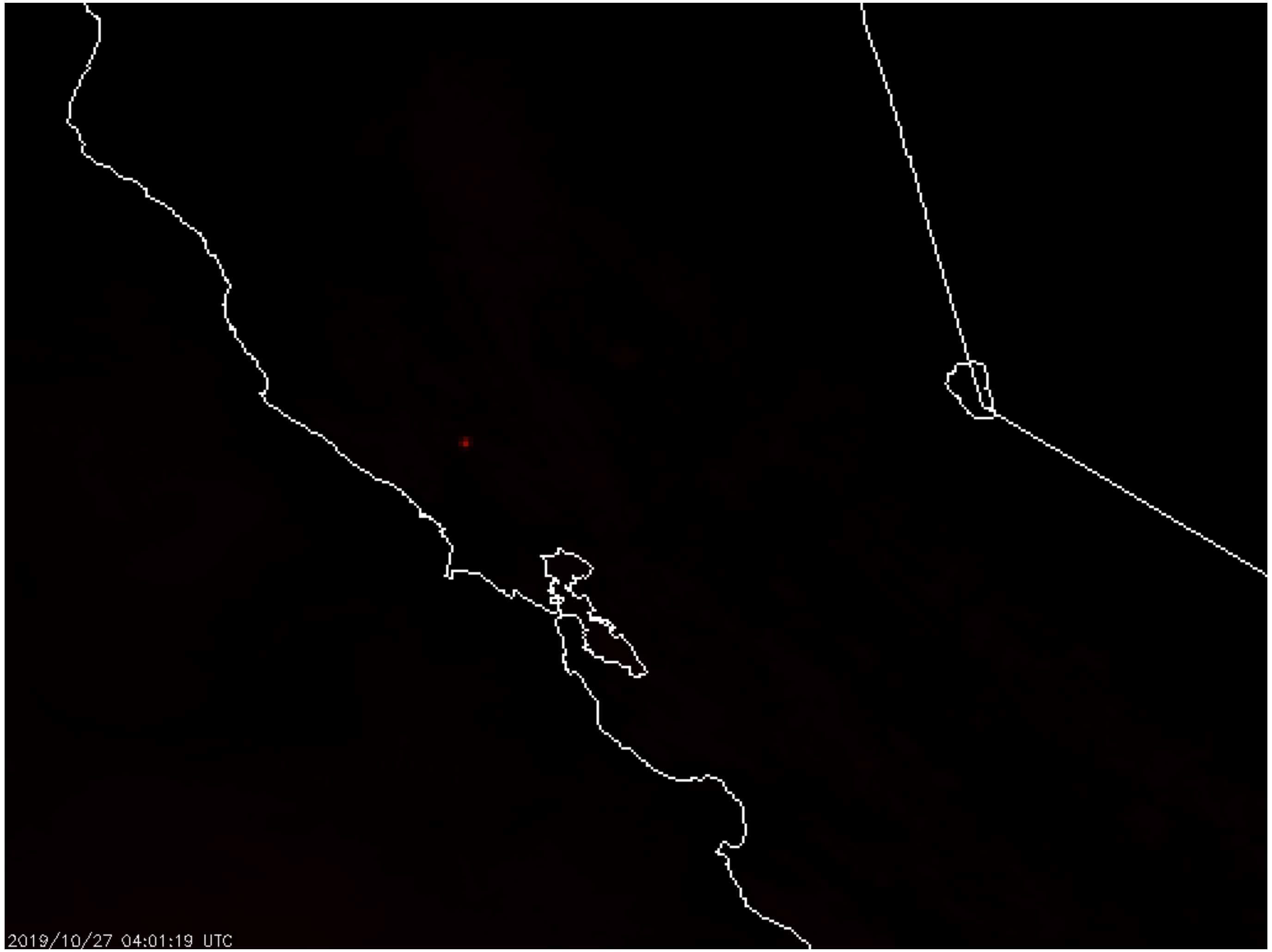
Smoke ingested by convection over Bolivia, Brazil, and Paraguay
GOES-16 CIRA GeoColor



http://rammb.cira.colostate.edu/ramsdis/online/loop_of_the_day/

Untapped Potential: Fire Temperature

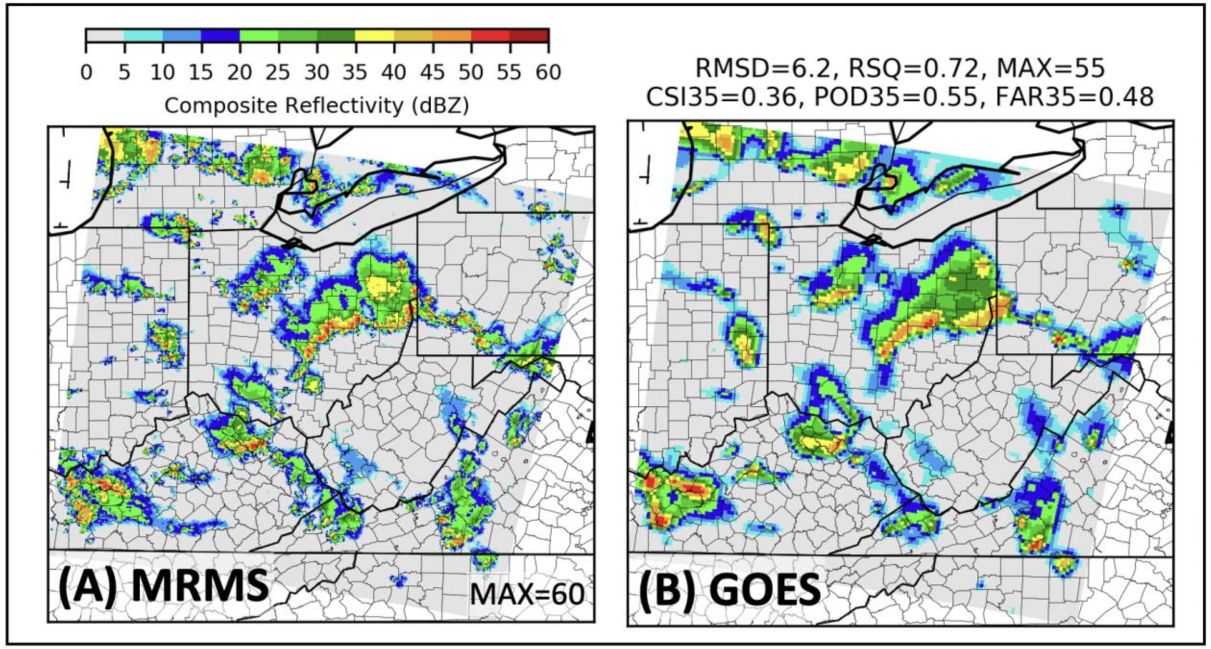
Explosive growth of the Kincaid Fire
GOES-17 Fire Temperature RGB



http://rammb.cira.colostate.edu/ramsdis/online/loop_of_the_day/

Unmet Need: Latent Heating for Convective-Scale Forecasting

- Data assimilation
  - Radiance assimilation
  - Machine learning
- Machine learning
  - Convolutional neural networks
  - Experiments: channel withholding, 1x1 filters, synthetic inputs
  - Attribution methods: LRP
- Poster 27: Using Machine Learning to Assimilate Precipitating Pixel Information from GOES ABI and GLM



<u>Conclusions</u>

1) Information content in image gradients
2) Data fusion of lightning and radiances

Discussion Questions

- To users: do you see potential benefits from assimilation of GOES-R Series snow cover, blowing dust, smoke dispersion, or fire temperature?
  - And what data assimilation strategies would be needed to include such observations in your models?

Improving rapidly-developing storm prediction by assimilating high-resolution GOES-16 ABI Infrared water vapor and cloud sensitive radiances:
issues and challenges

Xuguang Wang, Aaron Johnson
Krishna Chandramouli
Multiscale data Assimilation and Predictability (**MAP**) laboratory
School of Meteorology, University of Oklahoma

Collaborators:

Jason Otkin (CIMSS, U. Wisconsin)
Thomas Jones (CIMMS, U. Oklahoma)
Jefferey S. Whitaker (NOAA/ESRL/PSD)
Yanqiu Zhu (NCEP/EMC)

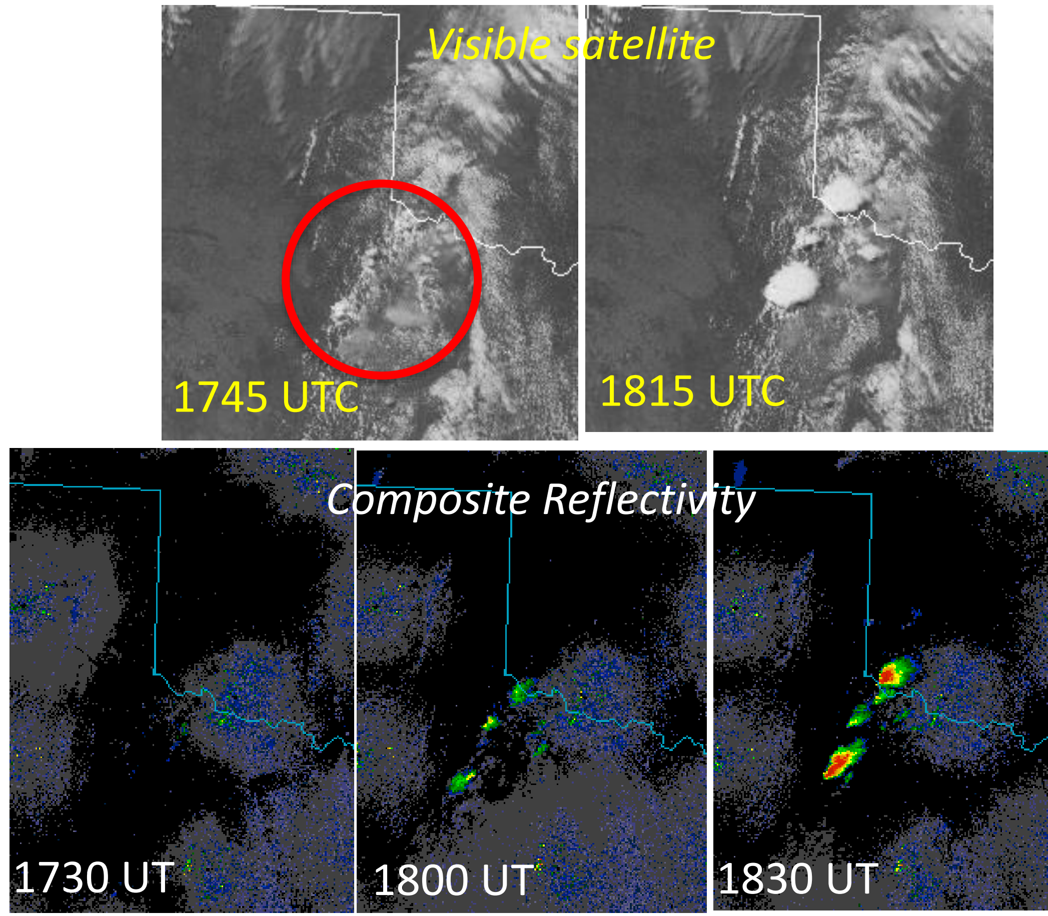
24 Feb. 2020

JPSS GOES PGRR summit, College Park, MA

Background and motivation

- Direct radar reflectivity assimilation has shown good results for already-initiated storms (e.g., Dowell et al. 2011; Johnson et al. 2015; Wang and Wang 2017).

- High resolution ABI obsrvations can be complementary to radar observations and if assimilated can add lead time to NWP of rapidly developing storms (e.g., Cintineo et al. 2016).



May 18 2017

Challenges of assimilating GOES-16 clear air and cloudy radiances in convection allowing models

- Issues of numerical models
- Bias (model and obs.) correction
- Observation error estimation (operator error, representativeness error, etc.)
- Effective assimilation of multiple channels
- QC during DA
- Data assimilation algorithm advancement to treat nonlinearity and multiscale

Research and Development made so far

- We have implemented ABI clear air and cloudy radiance assimilation in GSI-EnKF with various methods to enhance the assimilation.

  - additive noise inflation to treat model issue
  - adaptive obs. error estimation
  - understanding impact of assimilating different ABI channels (channel 9 vs. channel 10)
  - comparing different bias correction predictors/methods.

GOES-16 products used

Bias correction predictor

ABI band	Approx central wavelength (µm)	FWHM at 50% minimum (µm)	FWHM at 50% maximum (µm)	Subpoint pixel spacing	Descriptive name
1	0.47	0.45	0.49	1	Blue
2	0.64	0.60	0.68	0.5	Red
3	0.864	0.847	0.882	1	Vegetation
4	1.373	1.366	1.380	2	Cirrus
5	1.61	1.59	1.63	1	Snow/ice
6	2.24	2.22	2.27	2	Cloud particle size
7	3.90	3.80	3.99	2	Shortwave window
8	6.19	5.79	6.59	2	Upper-level water vapor
9	6.93	6.72	7.14	2	Midlevel water vapor
10	7.34	7.24	7.43	2	Lower/midlevel water vapor
11	8.44	8.23	8.66	2	Cloud-top phase
12	9.61	9.42	9.80	2	Ozone
13	10.33	10.18	10.48	2	Clean longwave window
14	11.21	10.82	11.60	2	Longwave window
15	12.29	11.83	12.75	2	Dirty longwave window
16	13.28	12.99	13.56	2	CO_2

Table 1. ABI FMI spectral attributes [band number, center wavelength, 50% full width at half maximum (FWHM) minimum–FWHM maximum, approximate subpoint ground sampling distance, and name].

Schmit et al. (2017)

Assimilated

Parallax correction

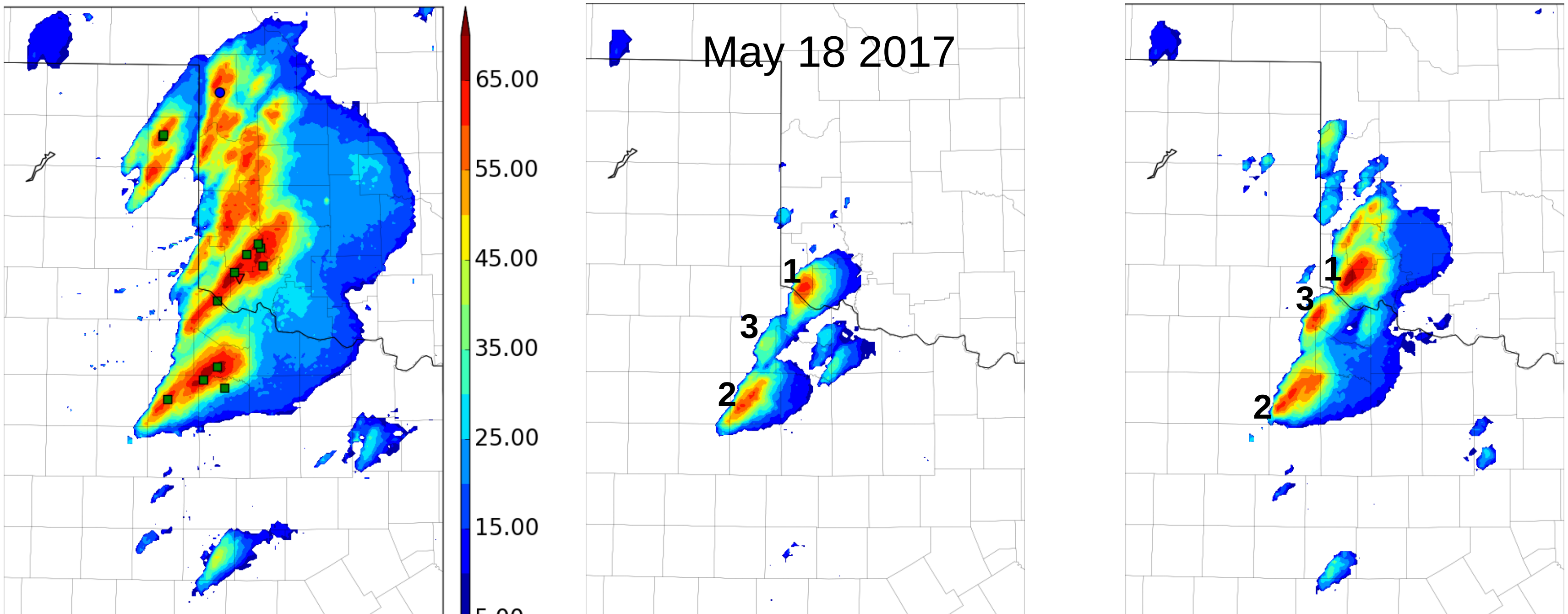
Table 4. List of GOES-R ABI-derived baseline products. Also included are other attributes, such as the geographical coverage, horizontal resolution, and product refresh rate.

Baseline product	Product geographic coverage	Product horizontal resolution	Refresh rate/coverage time (mode 3)
Aerosol detection (including smoke and dust)	CONUS FD Mesoscale	2 km	CONUS: 15 min FD: 15 min Mesoscale: 15 min
Aerosol optical depth	CONUS FD	2 km	CONUS: 5 min FD: 15 min
Volcanic ash: Detection and height	FD	2 km	FD: 15 min
Cloud and moisture imagery	CONUS FD Mesoscale	2 km, with finer day-time observations	CONUS: 5 min FD: 15 min Mesoscale: 30 s
Cloud optical depth	CONUS: for optical depth > 1 FD: for optical depth > 1	CONUS: 2 km FD: 4 km	CONUS: 15 min FD: 15 min
Cloud particle size distribution	CONUS FD Mesoscale	2 km	CONUS: 5 min FD: 15 min Mesoscale: 5 min
Cloud-top phase	CONUS FD Mesoscale	2 km	CONUS: 5 min FD: 15 min Mesoscale: 5 min
Cloud-top height	CONUS FD Mesoscale	CONUS: 10 km FD: 10 km Mesoscale: 4 km	CONUS: 60 min FD: 60 min Mesoscale:5 min
Cloud-top pressure	CONUS FD	10 km	CONUS: 60 min FD: 60 min
Cloud-top temperature	FD Mesoscale	2 km	FD: 15 min Mesoscale: 5 min
Hurricane intensity	FD	2 km	FD: 30 min
Rainfall rate/quantitative precipitation estimation (QPE)	FD	2 km	FD: 15 min
Legacy vertical moisture profile	CONUS FD Mesoscale	10 km	CONUS: 30 min FD: 60 min Mesoscale: 5 min
Legacy vertical temperature profile	CONUS FD Mesoscale	10 km	CONUS: 30 min FD: 60 min Mesoscale: 5 min
Derived stability indices [convective available potential energy (CAPE), lifted index, K index, Showalter index, total totals]	CONUS FD Mesoscale	10 km	CONUS: 30 min FD: 60 min Mesoscale: 5 min
Total precipitable water	CONUS FD Mesoscale	10 km	CONUS: 30 min FD: 60 min Mesoscale: 5 min
Clear-sky masks	CONUS FD Mesoscale	2 km	CONUS: 15 min FD: 15 min Mesoscale: 5 min

Schmit et al. (2017)

Removal of partial cloudy pixels

Case Overview



*Observed maximum composite reflectivity during **1800-2000** UTC*

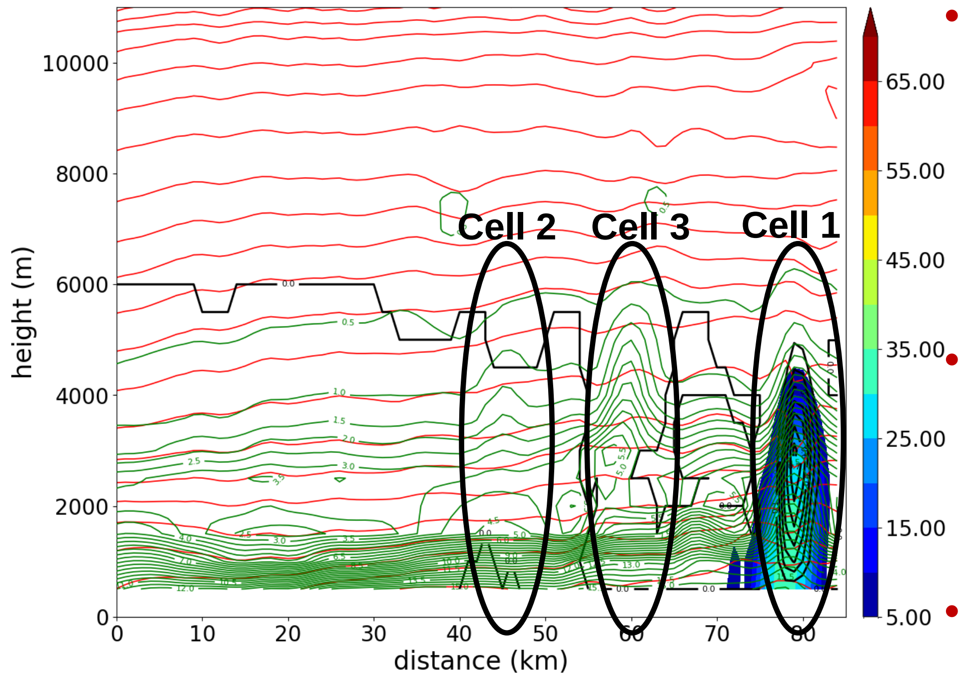
*Observed maximum composite reflectivity during **1800-1830** UTC*

*Observed maximum composite reflectivity during **1830-1900** UTC*

- Two long-track supercells were observed in southwestern OK and north-central TX.
- Interested in predicting storm scale details and individual convective cells.
- Cell 1 initiated first and had the longest track and a tornado.
- Cell 2 developed next, and also intensified quickly into a long-lived supercell.
- Cell 3 developed last, eventually weakening as it followed the path of cell 1 and ingested cooler air.

Additive Noise Inflation Implementation

Radar and Ch. 10 DA: 1830 UTC cycle

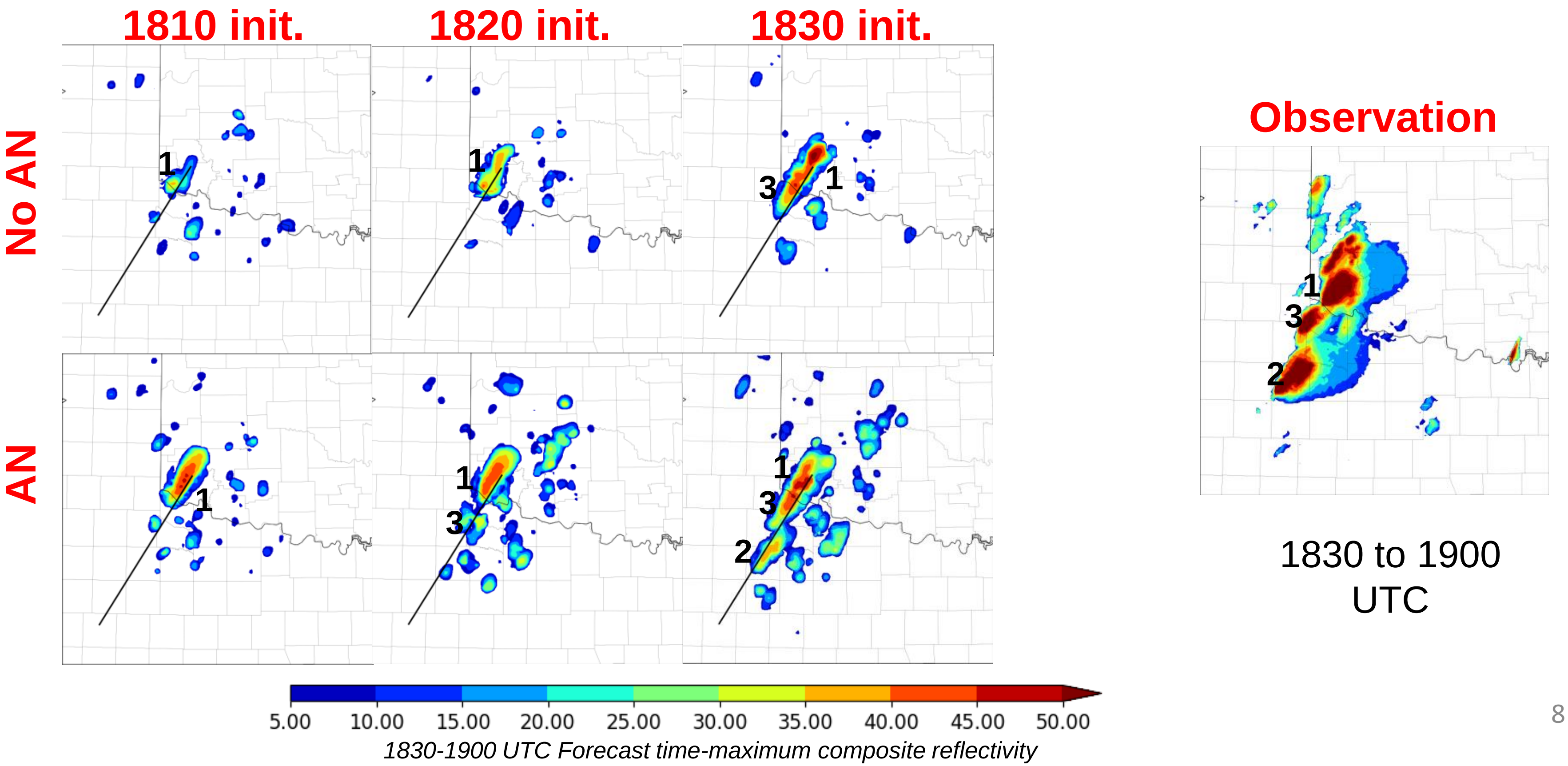


Ensemble mean background of reflectivity (shaded, potential temperature (red contour), water vapor (green contour), and total cloud (black contour).

- Ensemble based DA cannot add cloud or precipitation hydrometeors to locations where all first guess members predicted zero values of these variables, even if they are implied by the radiance observations.
- Zero background error variance for these variables prevents the southern storm(s) (e.g. cell 2) from being produced during ABI DA cycling
- Analogous approach to radar reflectivity DA, an additive noise inflation approach is adopted where observations indicate cloud but background indicates clear air.

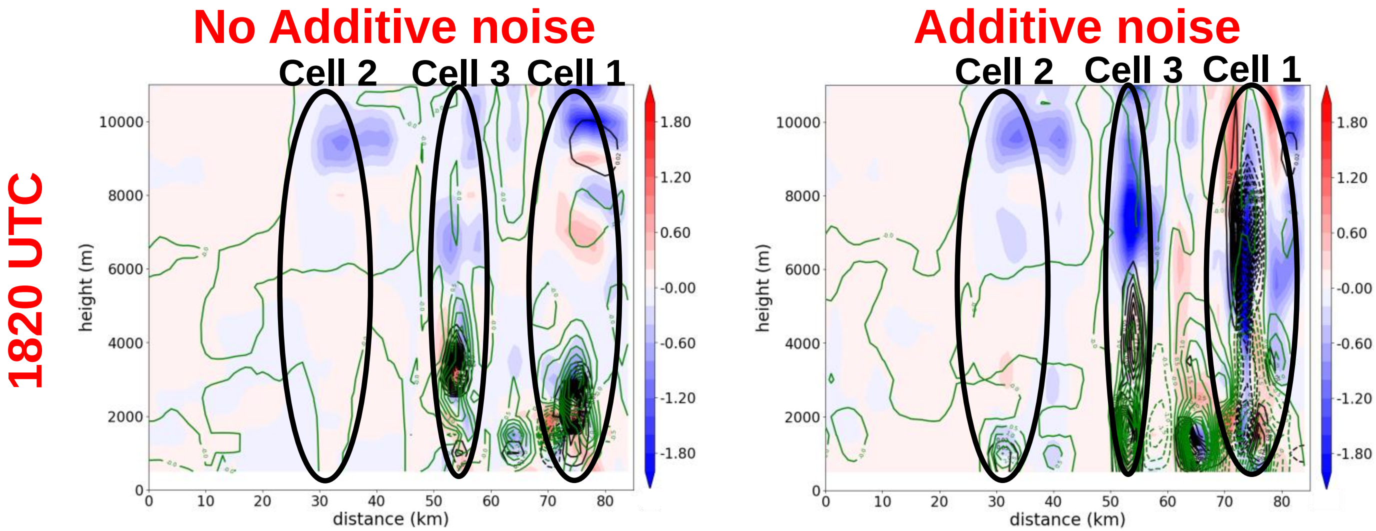
Additive Noise Inflation Impact on Channel 10 ABI DA

- Verification of time-maximum (using output files every 5 minutes) composite reflectivity during the 1830 to 1900 UTC period.
- The implementation of AN allows all storms be well forecast in the 1830 UTC initialization.
- The northern storms are able to be forecast with greater lead time. Southern storms captured at 1830 init.
- Further optimizations to the AN implementation is still ongoing.



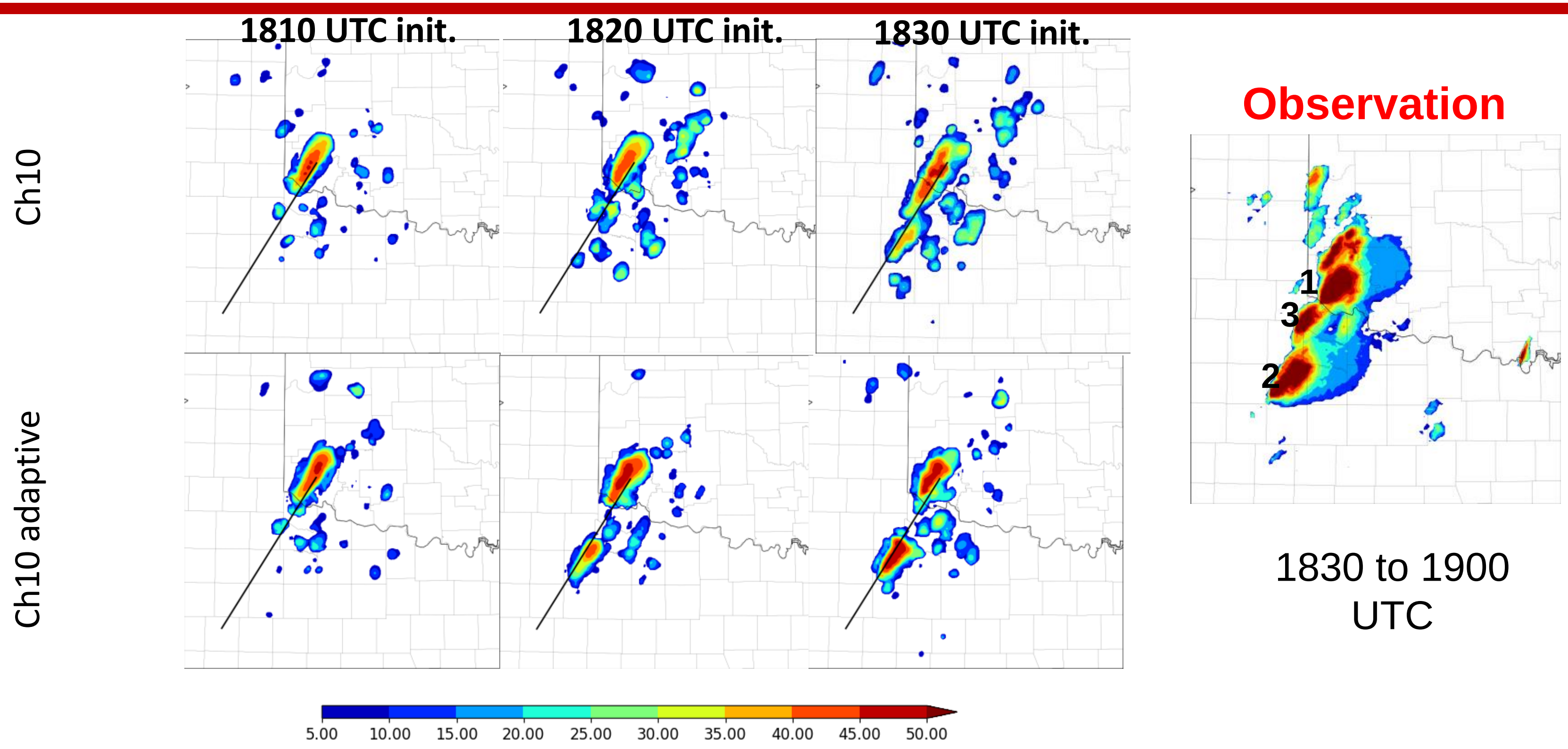
Cross Section Diagnostics on Additive Noise Inflation (Ch10)

Cross sections of DA increment to potential temperature (shaded), water vapor (green contour), and total cloud hydrometeor (black contour)



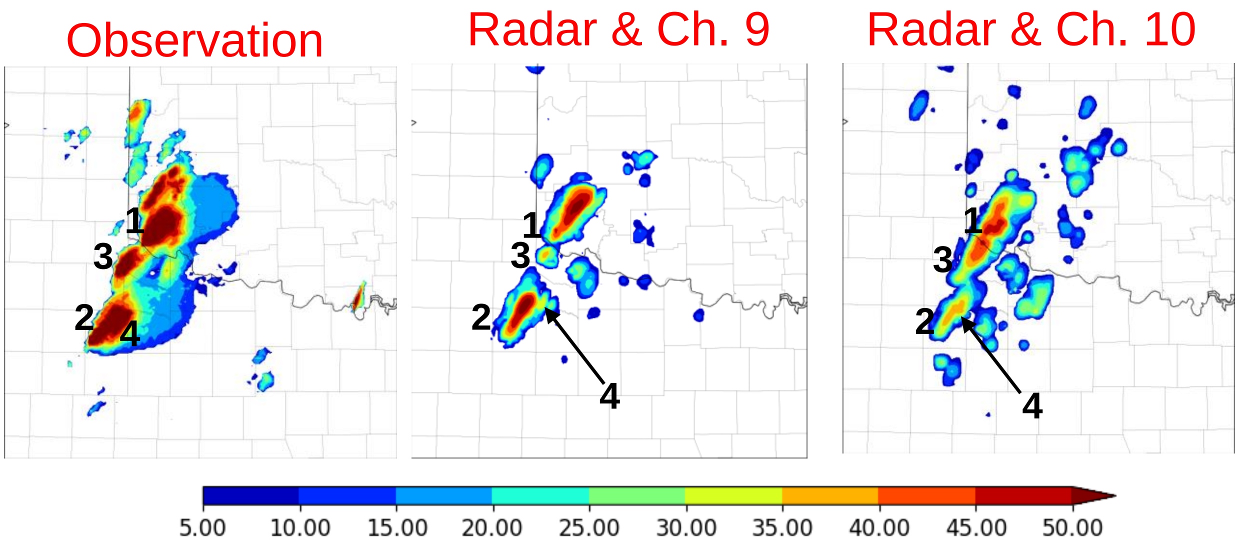
- Additive noise allows the increments to produce deeper storms in northern two cells.
- Additive noise allows DA to start spinning up the southern storm in the 1820 UTC cycle

Impact of adaptive obs. error estimation



- Ob error estimated from o-b as a function of symmetric cloud amount
- The forecasts are generally improved by using adaptive ob error estimation, especially in the southern storm.

Ch9 vs Ch10 ABI DA impact



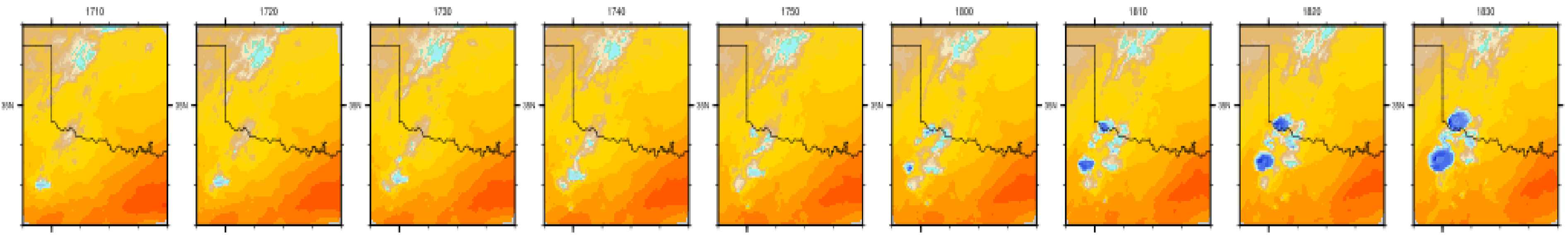
Forecast time-maximum composite reflectivity

- Ch10 better captures cell 3 likely because Ch10 can see the early stages of low-level cloud development more clearly than Ch 9.

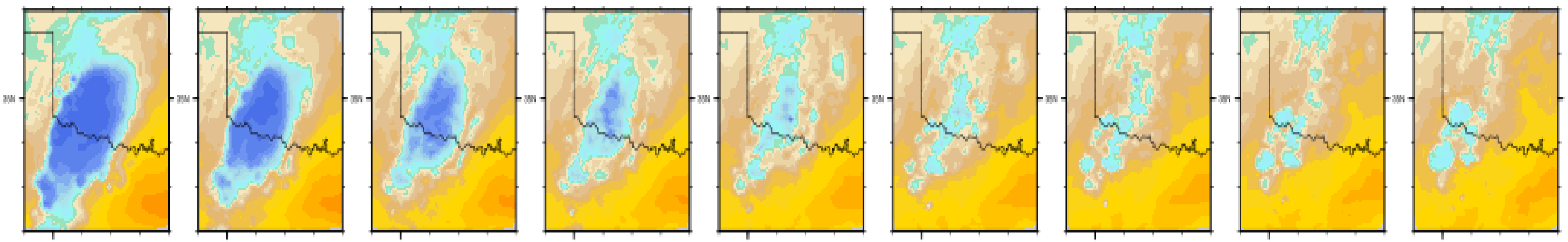
- Ch9 better captures cell 1& 2 likely because of better spun-up ensemble covariance structure

Challenge of bias correction

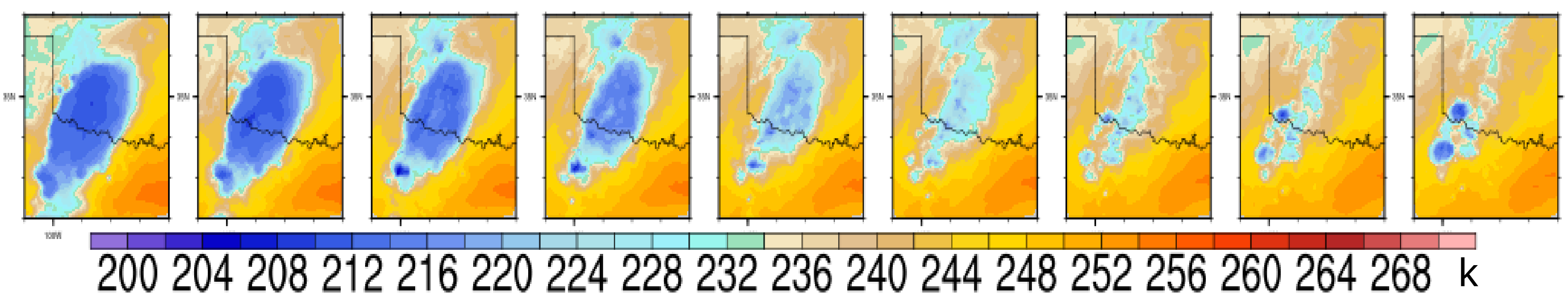
Channel 9 BT Observation at times from 1710 to 1830 UTC



Channel 9 BT analysis : Observed BT predictor at times from 1710 to 1830 UTC



Channel 9 BT analysis : Simulated BT predictor at times from 1710 to 1830 UTC



Ozone Data Assimilation at NCEP

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Why Ozone Data Assimilation?

- Ozone data assimilation provides a global 3D distribution of ozone.
- Ozone observations from satellite instruments are important to constrain the ozone field in global model.
- Accurate knowledge of the ozone distribution has potential to improve temperature forecasts in stratosphere.
- The time evolution of ozone contains wind information.
- Ozone analyses initialize ozone forecasts which are used for surface UV forecasts.

O3 products used operationally at NCEP

Actively Assimilated

- OMPS version 8 nadir profiler (NP) and nadir mapper (NM) from NPP
- OMI_AURA (total column)

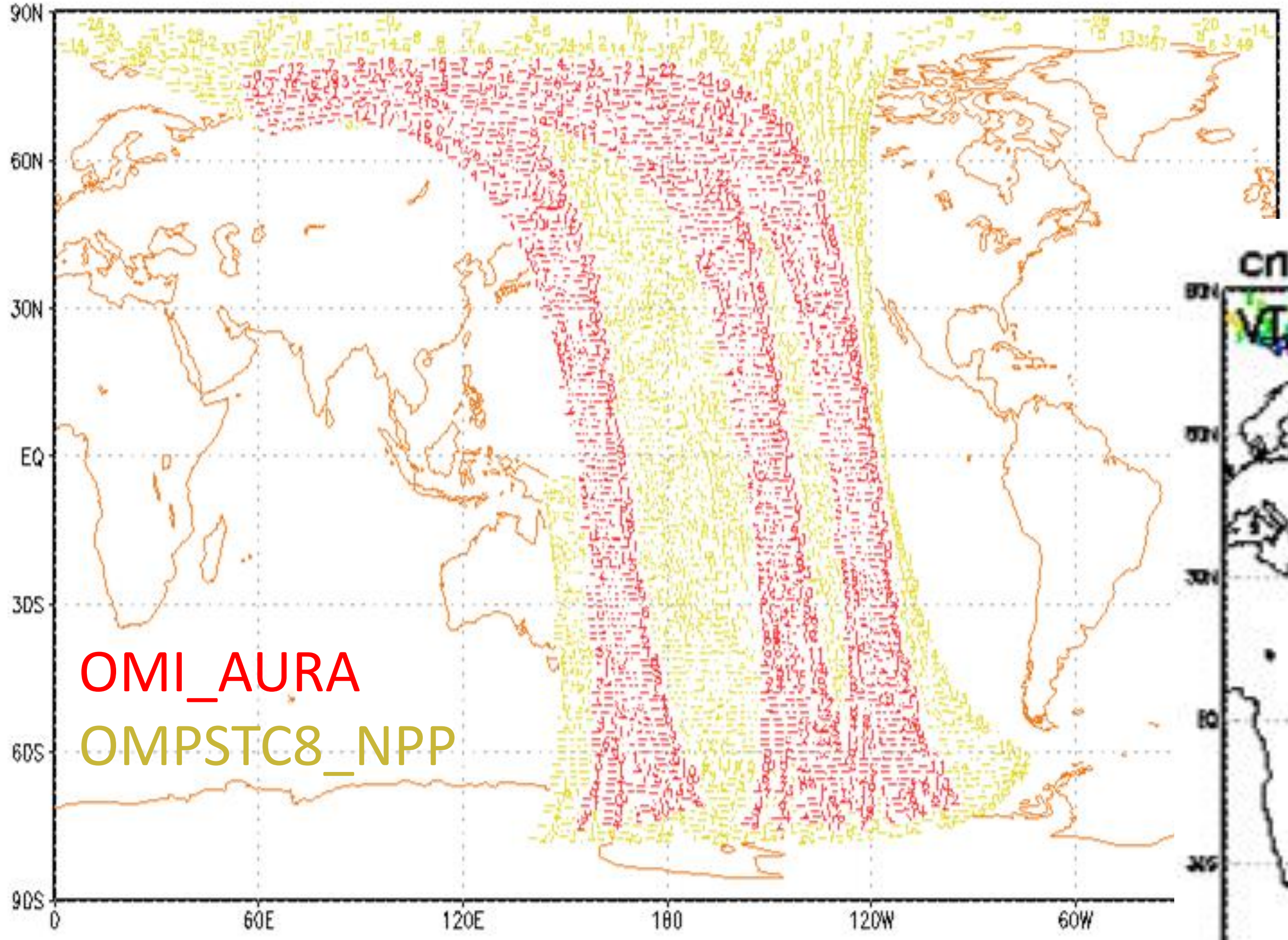
Passively Monitored

- SBUV_N19 version 8 nadir profiler
- GOME from Metop-A and Metop-B

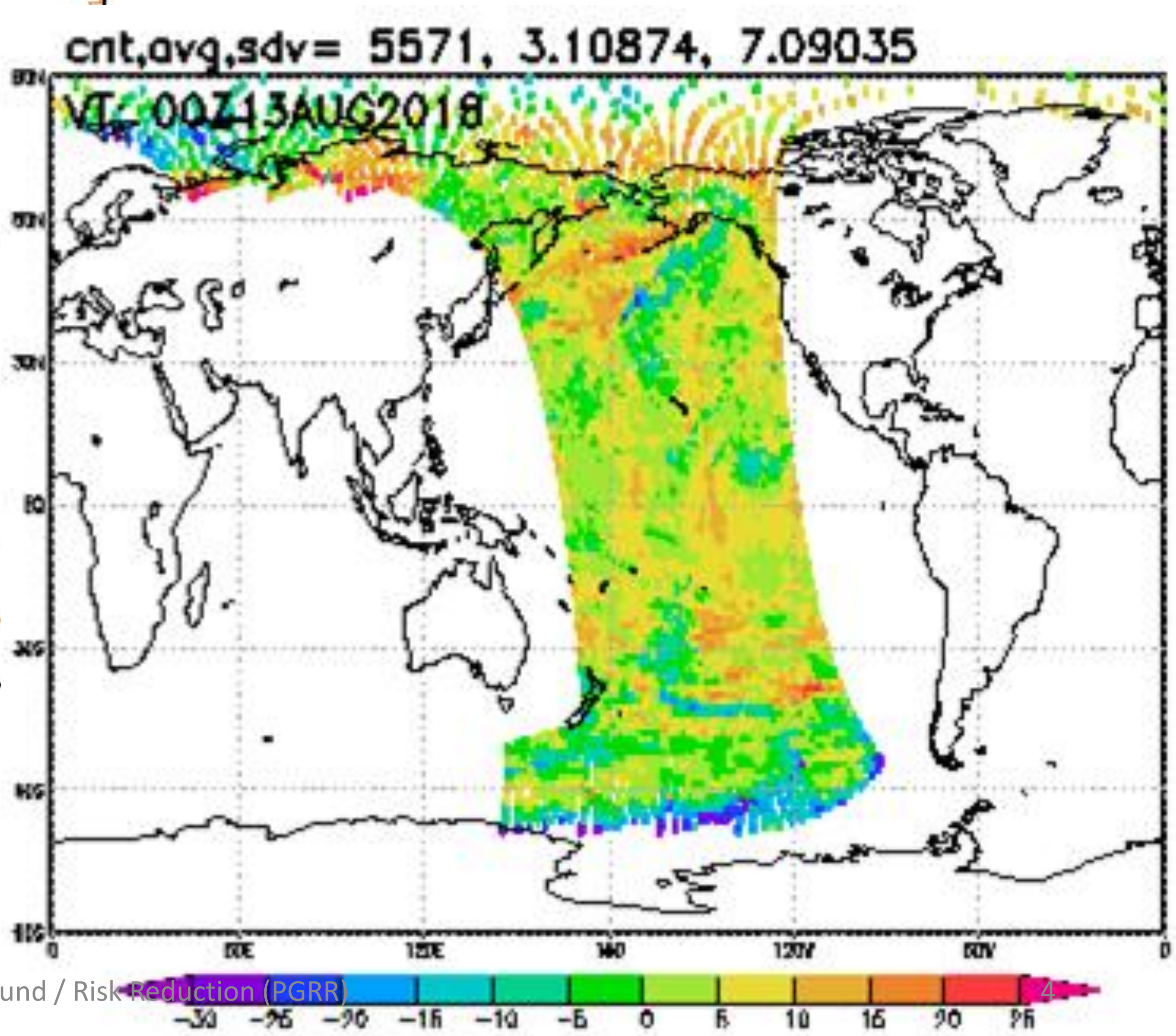
To be used in future

- OMPS limb profiler (LP): under evaluation and can be monitored in the pre-implementation parallels
- OMPS NP and NM from N20

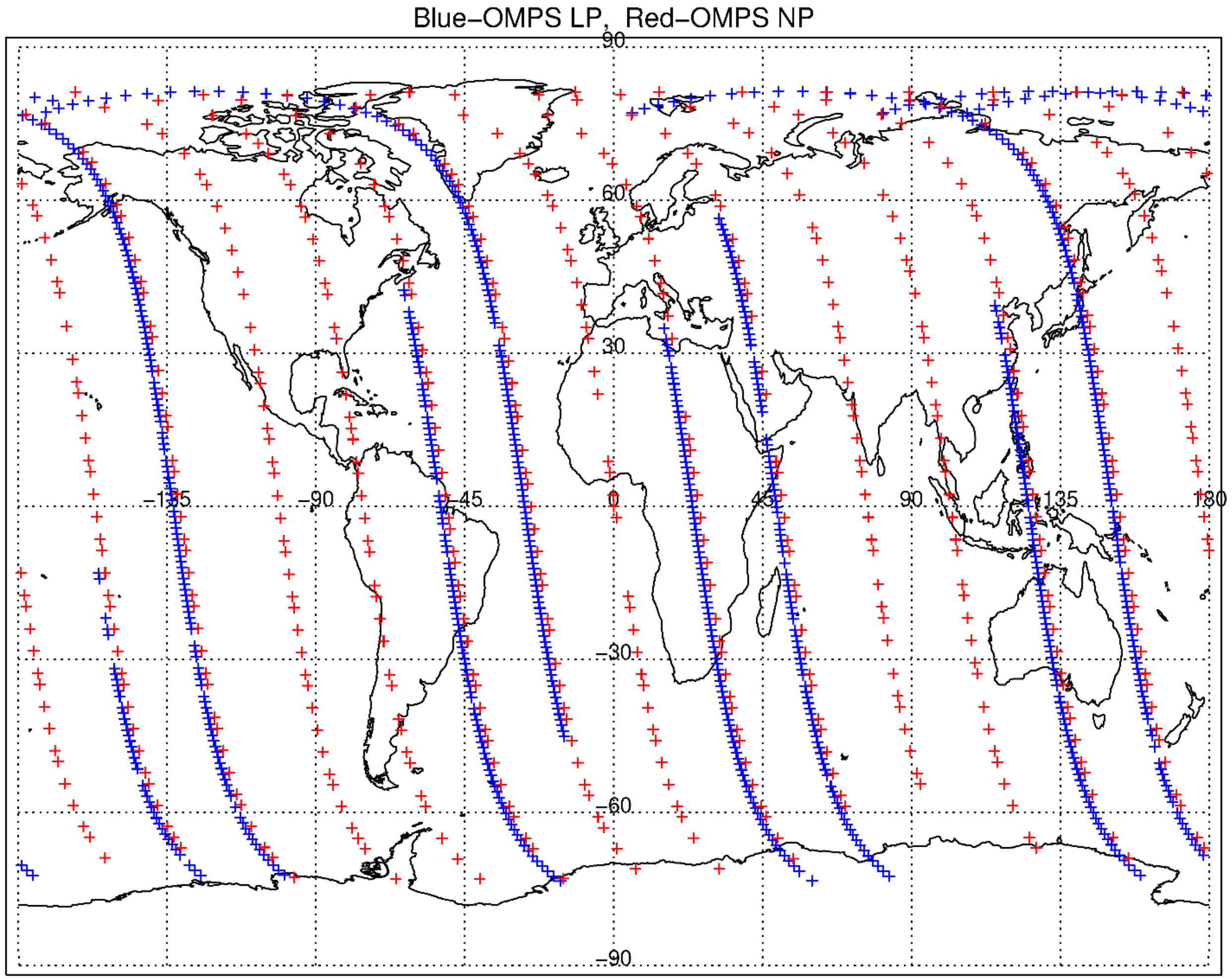
total column O3 data coverage



OmF from OMPS nadir mapper



- OMPS nadir mapper has better coverage than OMI_AURA.

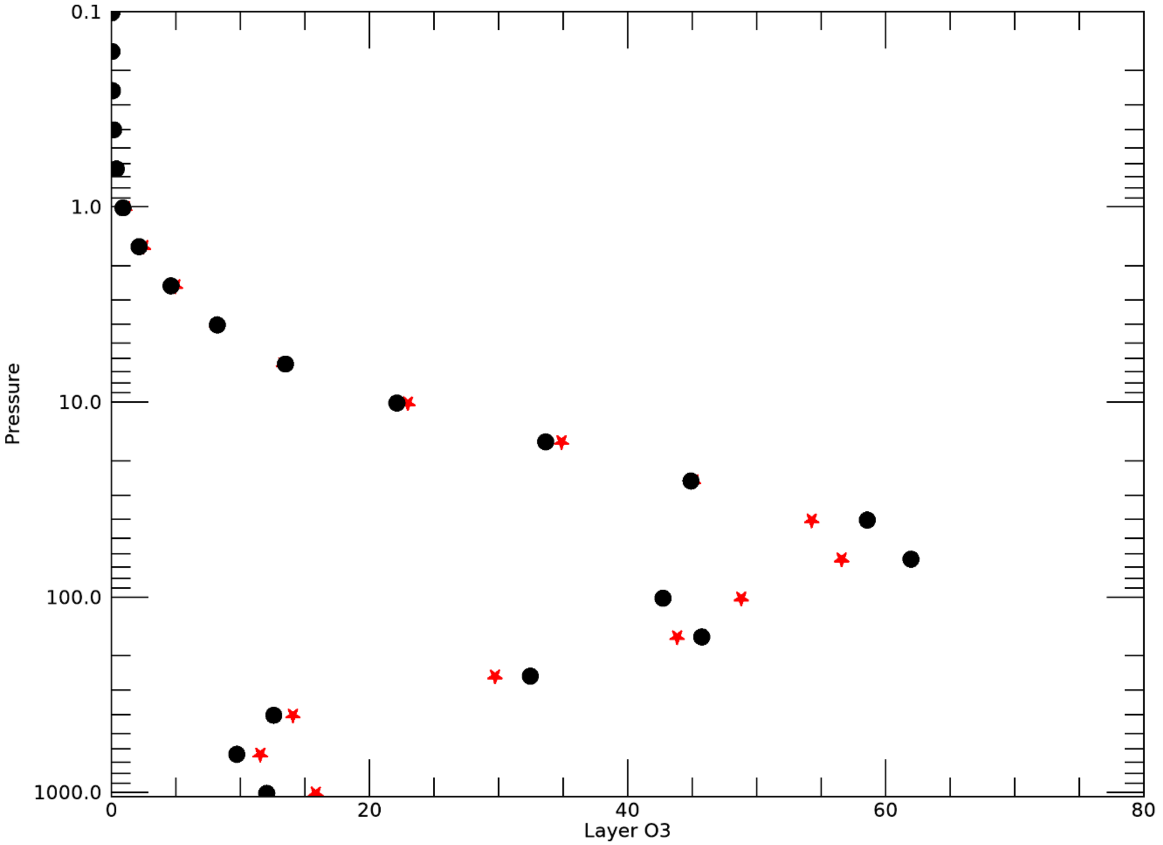


OMPS profiler daily data coverage

blue: limb profiler

red: nadir profiler

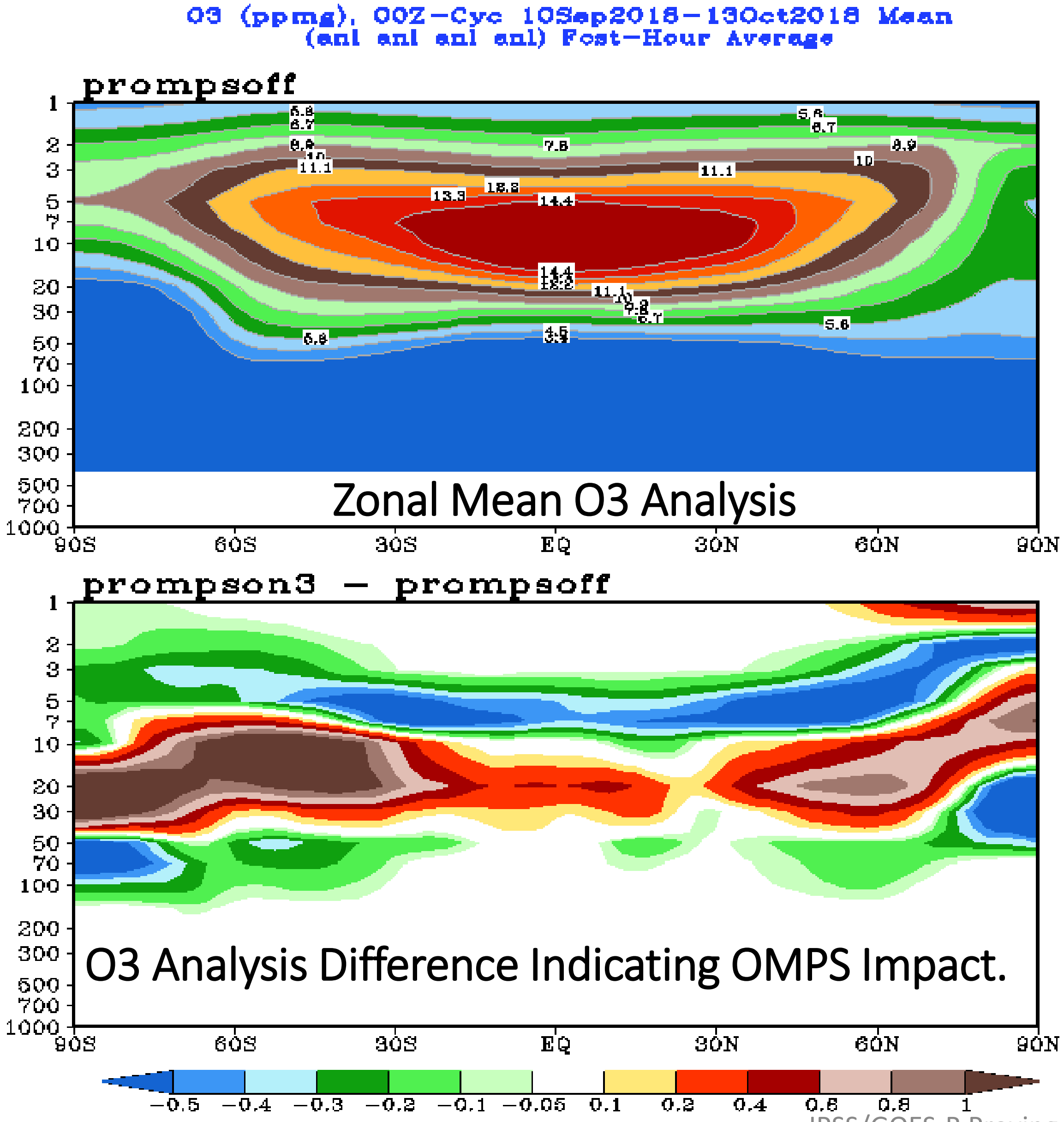
Obs from OMPS nadir profiler VS FCST



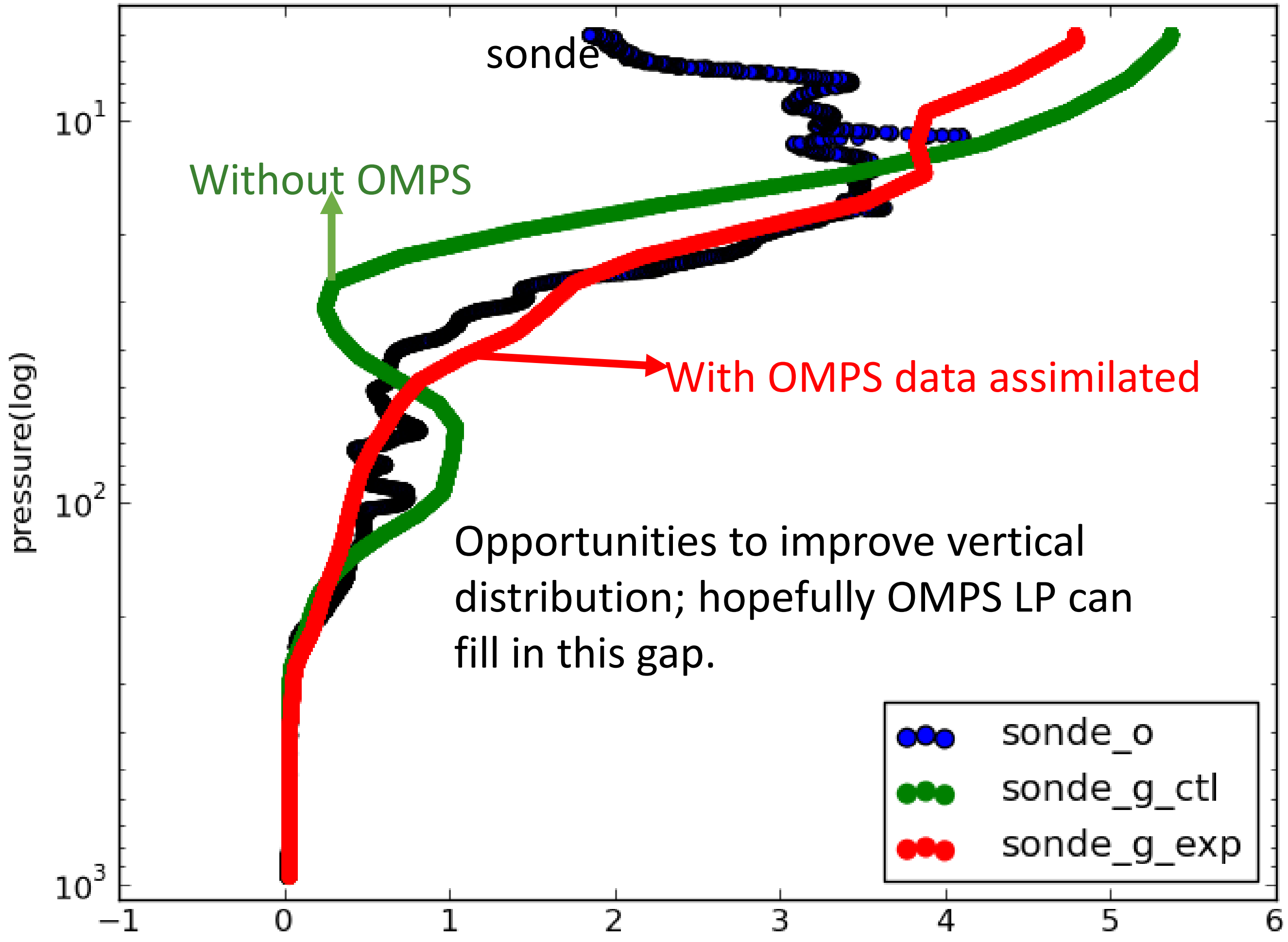
OMPS_NPP Assimilation

- Quality Controls (QC) for OMPS
  - QC for nadir profiler (NP):
    - Only accept total ozone error code 0 or 2 (high sza)
    - Only accept profile ozone error code 0, 1 (high sza) or 7(stray light correction applied)
  - QC for total column ozone from nadir mapper (NM):
    - only accept flags 0, 1, flag 2 is high SZA data which is not used
    - remove the data in which the C-pair algorithm (331 and 360 nm) is used
- Thinning for OMPS NM:
  - the product resolution is 50kmx50km but thinned to 150kmx150km

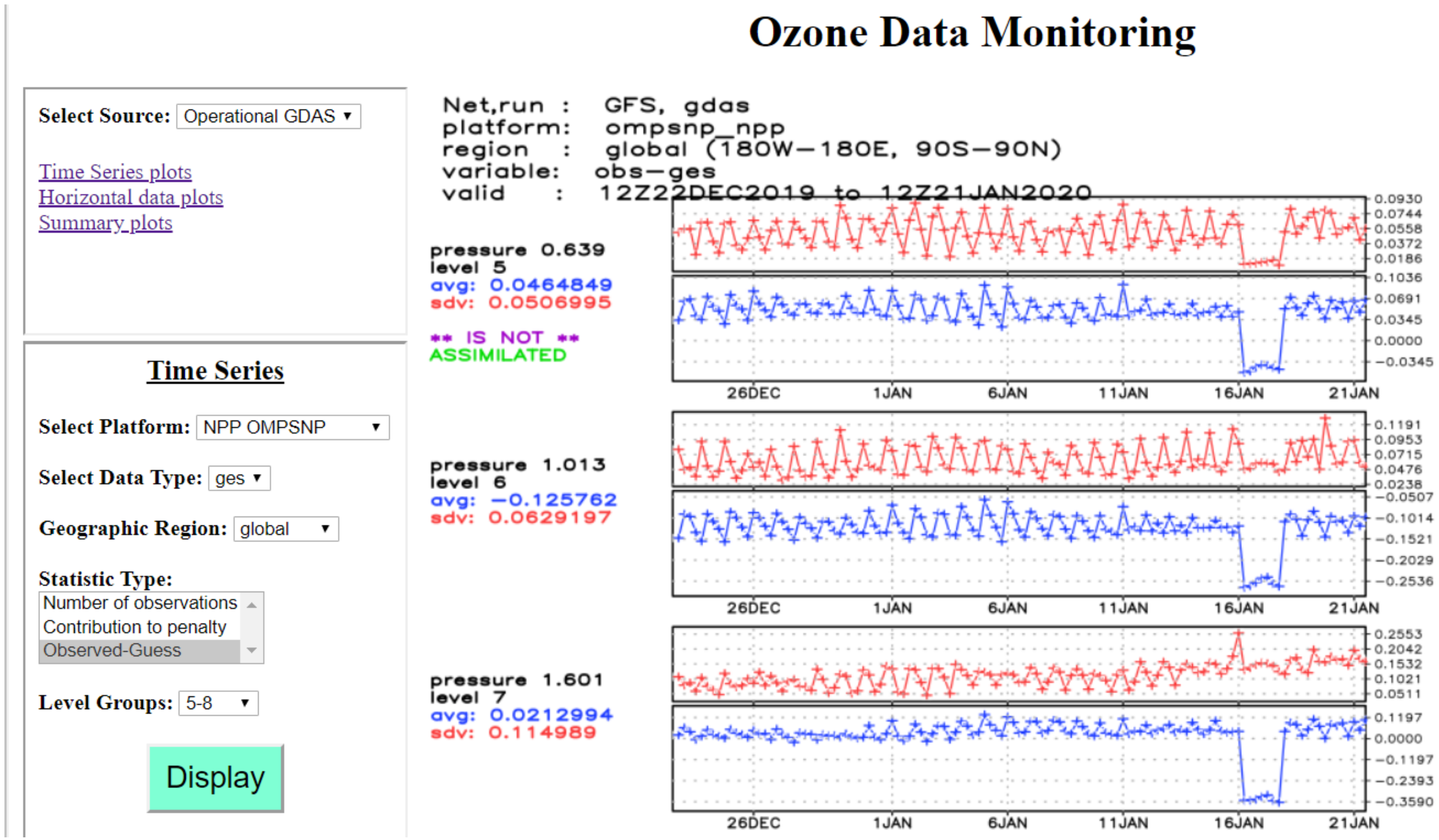
Impact of OMPS_NPP Assimilation



Comparison with independent O3 sounding



Ozone Data Assimilation Monitoring



dramatic changes in these time series indicate changes in quality of ozone data

Challenges and Questions

- Lack independent ozone sounding data for validation.

- Recent development of CRTM on direct simulation of the UV radiances. Any work done on direct UV radiance assimilation?

- Further improvement on ozone analysis: finer horizontal and vertical structures. What are the potential benefits in users' applications?