Progress and Plan for Satellite Radiance Assimilation in the NCEP Global Data Assimilation System

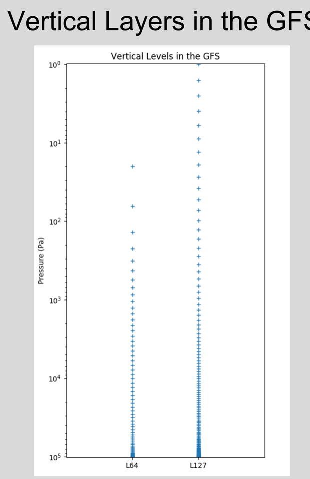
Emily, Huichun Liu[1], Daryl Kleist[1], Catherine Thomas[1], Jeffrey Whitaker[2], Cory Martin[4],
Kristen Bathmann[3], Andrew Collard[3], Haixia Liu[3], Scott Sieron[3], Xu Li[3], Iliana Genkova[3], Louis Kouvaris[3],

[1]NOAA/NWS/NCEP/EMC [2]NOAA/ESRL/PSD [3]IMSG @ NOAA/NWS/NCEP/EMC [4]Redline @ NOAA/NWS/NCEP/EMC

Recent Major Upgrades (GFS v16.0 and GFS v16.1) to Data Assimilation

- Increased model layers from 64 to 127 and raising the model top from 55 km to 80 km
  - New background error as well as ensemble and balance related changes
- ❖ **Forecast Initialization & Balance : 4D Incremental Analysis Update (IAU) + TLNMC**
- Replace EnSRF with Modulated-ensemble LETKF, including model space localization and linearized observation operator
- Reduced humidity increments in the stratosphere
- Variational Quality Control (VarQC) redesign with Hilbert Curve
- ❖ **Correlated observation error for radiances from IR Hyperspectral sensors**
- ❖ **AMSU-A channel 14 and AMTS Channel 15 without bias correction**
- ❖ **Geostationary radiances – ABI GOES-16, SEVIRI MeteoSat-8, and AHI Himawari-8**
- ❖ **AVHRR from MetOp-B and NOAA-19 for Near Sea Surface Temperature (NSST) analysis**
- Additional GPSRO from MetOp-C, GRAS, and more Cosmic-2)
- Commercial GPSRO
- High-density Aircraft Observations

Vertical Layers in the GFS

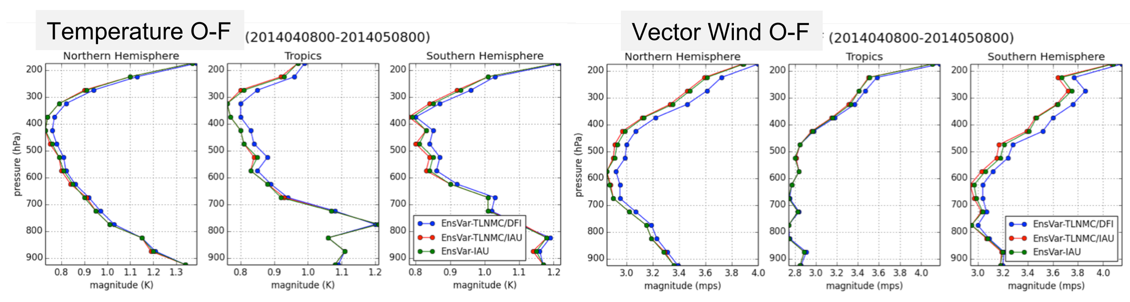


L64 L127

❖ Upgrades related to Radiance Assimilation

4D Incremental Analysis Update (IAU) Jeffrey Whitaker

Low resolution trials of IAU with/without Tangent Linear Normal Mode Constraint (TLNMC)



4D IAU has several benefits:
- It reduces imbalances introduced by discontinuous analysis step, localization, and imperfect background error covariances, ….etc.
- It helps spin up non-updated state variables (such as clouds).

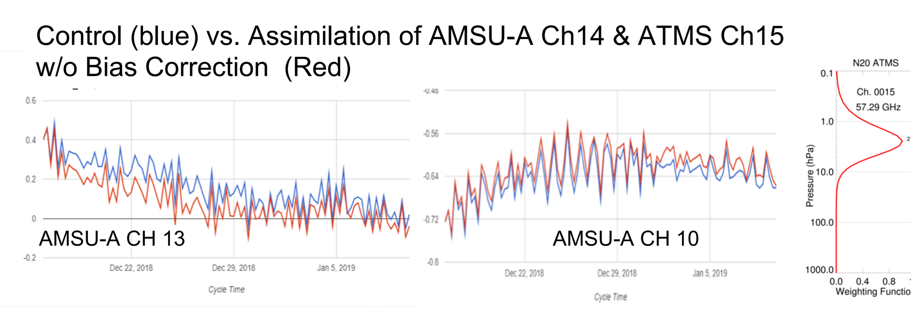
- Digital Filter Initialization (DFI) with TLNMC is the worst performing.
- IAU+TLNMC is best performing.

Note: GFSv15 utilized TLNMC only. Previous version of GFS used DFI.

Reference: A four-dimensional incremental analysis update for the ensemble Kalman filter. Lili Lei and Jeffrey Whitaker, Monthly Weather Review, 2016 (DOI: 10.1175/MWR-D-15-0246.1)

New Satellite Channels Yanqiu Zhu (NASA, GMAO)

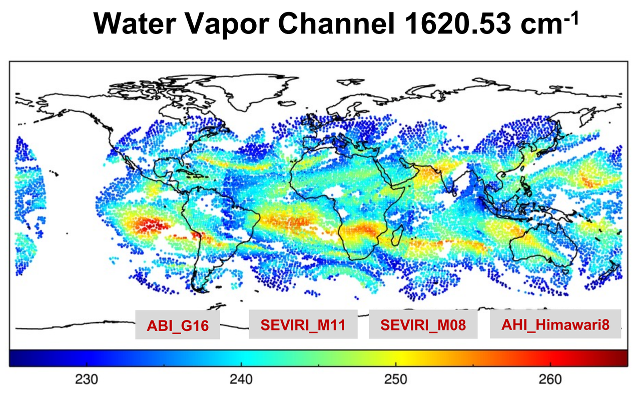
Control (blue) vs. Assimilation of AMSU-A Ch14 & ATMS Ch15 w/o Bias Correction (Red)



- With the model top increased, we can turn on assimilation of two highest pealing channels, 14 and 15 in AMSU-A and ATMS, respectively.
- No bias correction applied to prevent aliasing the model bias to observations.
- The reduced departures for other high-peaking channels indicate improved forecast field in the upper atmosphere.

Assimilation of Geostationary Clear-Sky Radiances (CSR) Haixia Liu

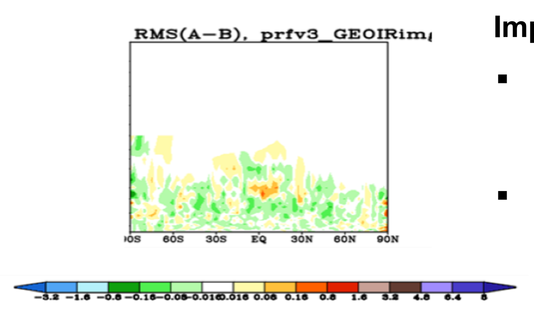
Water Vapor Channel 1620.53 cm^{-1}



CSR is the averaged brightness temperature from clear pixels within a 16x16 pixels segment (15x15 for ABI).

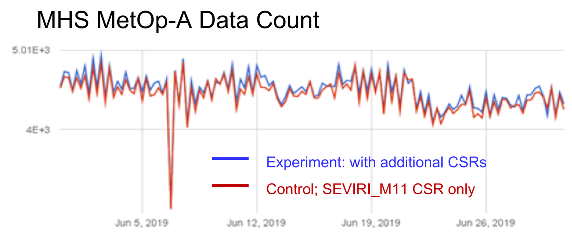
- CSR is thinned to 145 km in GSI.
- Additional cloud detection to remove potential cloud-contaminated data
- Moisture channels (6.2-7.35 μm) from ABI GOES-16, SEVIRI MeteoSat-8 & -11, and AHI Himawari-8 are assimilated.
- Control: SEVIRI M11 only

  Experiment: Control + ABI G16 + SEVIRI M08 + AHI Himarari-8



Impact of CSR
- Moisture increments are much small with additional CSR assimilated.
- This indicates improved moisture field.

MHS MetOp-A Data Count

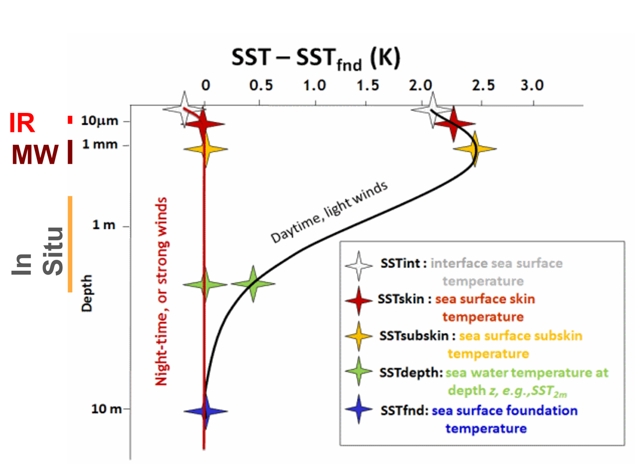


The number of MHS radiances assimilated are increases with additional CSR assimilated.

Assimilation of AVHRR for Near Sea Surface Temperature (NSST) Analysis Xu Li

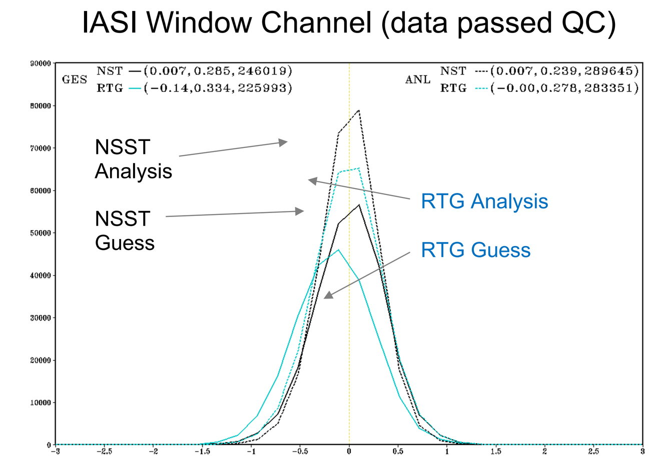
NSST Profile

High wind speed conditions or during the night (red)
Low wind speed during the day (black)



- Foundation temperature is the analysis variable.
- Diurnal warming and sub-layer cooling T-Profile are simulated by NSST Model in the cycling of GFS.
- NSST T-Profile for atmospheric model and CRTM
- The input surface temperature to CRTM depends on instrument type
  - IR – temperature at 0.015 mm
  - MW – temperature at 1.0 mm
- Satellite radiances: AVHRR, AIRS, CrIS IASI, AMSU-A and ATMS are used in NSST along with in-situ observations to constrain the foundation temperature.
- The use of radiances in NSST analysis leads to better NSST profiles and this, in turn, improves the radiance assimilation.

IASI Window Channel (data passed QC)

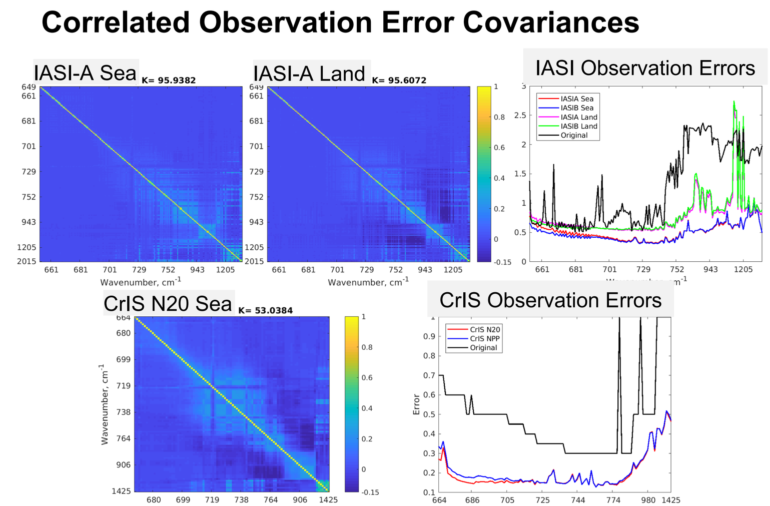


Using the NSST at 0.015 mm for IASI in CRTM leads to more data passed quality control and better residual statistics.

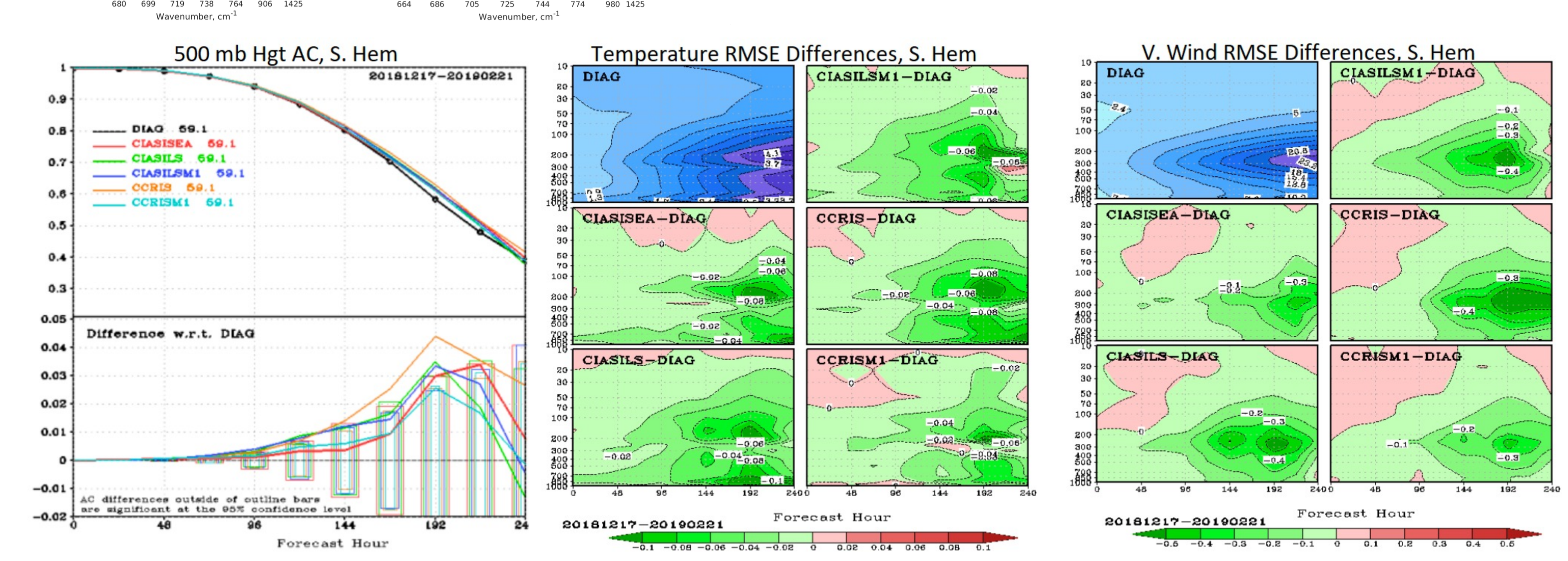
Correlated Observation Error for IR Hyperspectral Radiances

Kristen Bathmann and Andrew Collard

Correlated Observation Error Covariances



- Spectrally correlated observation error matrices for IASI and CrIS are estimated with the Desrosiers diagnostics.
- Infrared observations have different error characteristics over land, therefore, errors over land and ocean are estimated separately.
- The estimated R matrices are reconditioned by raising the smallest eigenvalues to a threshold and then empirically tuned inflation factors are applied to the diagonals.
- The correlated observation error estimation leads to reduced errors in the diagonals. This error reduction results in tighter cloud detection and thus prevents the sub-optimal analysis caused by the assimilation of potentially cloud-contaminated radiances.



- IASI is assimilated with correlated error over land and sea, with separate matrices over these surfaces. CrIS is assimilated with correlated observation error over sea only.
- Correlated error has a positive forecast impact, especially in the southern hemisphere.
- Accounting for correlated error over land improved the NWP impact as well as IASI residual statistics.
- Significant improvements were found in the temperature forecast biases at 1000 hPa, likely a result of improved cloud detection.

Planned Upgrades to Radiance Data Assimilation

- GOES-17 ABI CSR – Haixia Liu
- NPP OMPS-LP (UV and VIS blended) – Louis Kouvaris
- NOAA-20 OMPS-TC (OMPS-NP retrievals not consistent with those from NPP in tropics) – Louis Kouvaris & Haixia Liu
- Use top 5 layers retrieved ozone due to extended model layers and top – Louis Kouvaris & Haixia Liu
- Revised correlated observation errors for IASI over land/sea and CrIS over sea – Kristen Bathmann
- ❖ **Assimilate antenna-corrected AMSU-A, MHS, and ATMS brightness temperature (SDR)** – Scott Sieron
- ❖ **Precipitation-affected AMSU-A & ATMS radiances** – Emily Liu & Scott Sieron
- All-sky assimilation of GMI – Scott Sieron & Emily Liu
- Stereo AMVs (GOES/GOES, GOES/Himawari) – Iliana Genkova
- Leo-Geo AMVs – Iliana Genkova
- GOES-17 mitigated AMVs – Iliana Genkova
- VIIRS and AVHRR for near sea surface temperature (NSST) analysis with revised thinning – Xu Li
- Updated utilization of ASCAT winds – Emily Liu

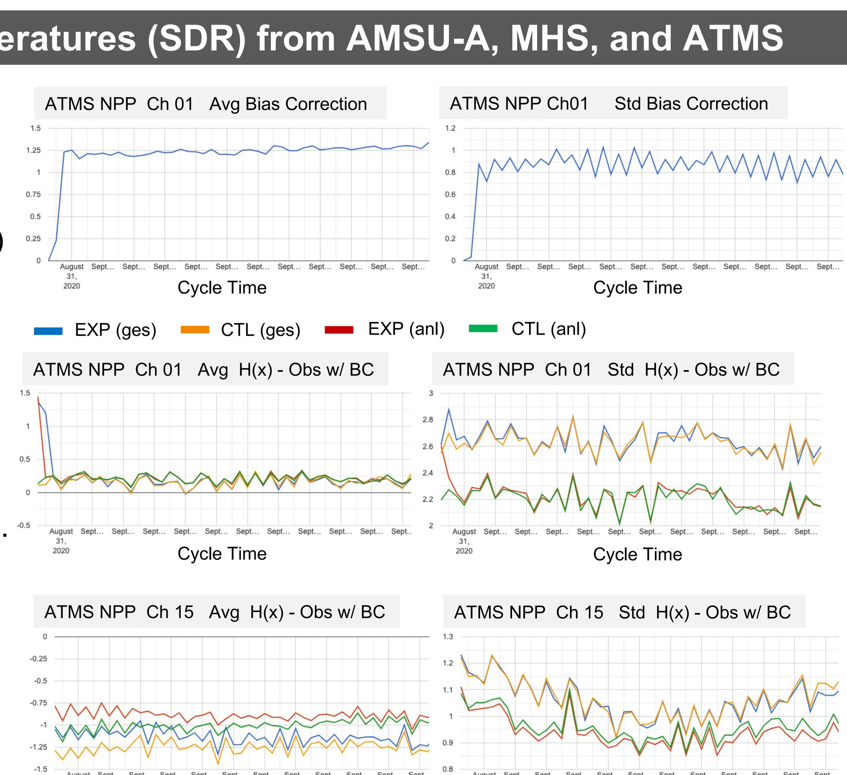
Assimilation of Antenna-Corrected Brightness Temperatures (SDR) from AMSU-A, MHS, and ATMS Scott Sieron

Background

Observations from GTS and NESDIS
- Normal feed - antenna temperatures (Ta, TDR)
- DBNet - antenna-corrected (AC) brightness temperatures (Tb, SDR)

GSI Analysis (Operational: CTL) --- assimilate TDR
- Tb from DBNet is converted to Ta for assimilation (AC removed)
- The variational bias correction (BC) takes care the inconsistency between Ta observations and simulated Tb from background.

GSI Analysis (Experimental: EXP) – assimilate SDR
- Ta from normal feed is converted to Tb for assimilation (AC applied).
- Spin up bias correction coefficients from zero.
- GSI has a built-in self-initialization using the quasi-mode of all data.
- Adaptive background error variances for bias predictor coefficients are based on the Hessian (analysis error) from the previous cycle.
- Experiment is on-going; will assess the impact to forecast.



Bias correction spun up to steady estimations within 4 cycles.

The residual statistics with bias correction indicates that the control and experiment agree with each other.

Highest peaking channel has no bias correction applied to prevent aliasing model bias into observation.

In operational system, Ta is assimilated without antenna correction ---> less optimal.

The antenna correction bring the observations closer to the simulated Tb.

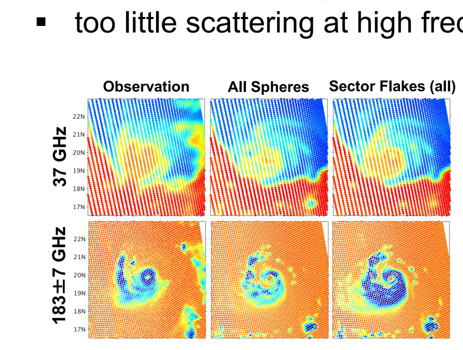
Assimilation of Precipitation-Affected AMSU-A & ATMS Radiances

Emily, Huichun Liu & Scott Sieron

New Features
- Use antenna-corrected brightness temperature for AMSU-A and ATMS radiance assimilation
- Improve CRTM accuracy under scattering conditions
- Enhance CRTM to handle fractional cloud coverage
- Use CRTM cloud optical table consistent with model particle size distribution (under testing)
- Augment GSI control variable to include precipitating hydrometers
- Calculate GFDL cloud fraction at each observation footprint
- Enhance data quality control
- Assess the impact of precipitation-affected radiances

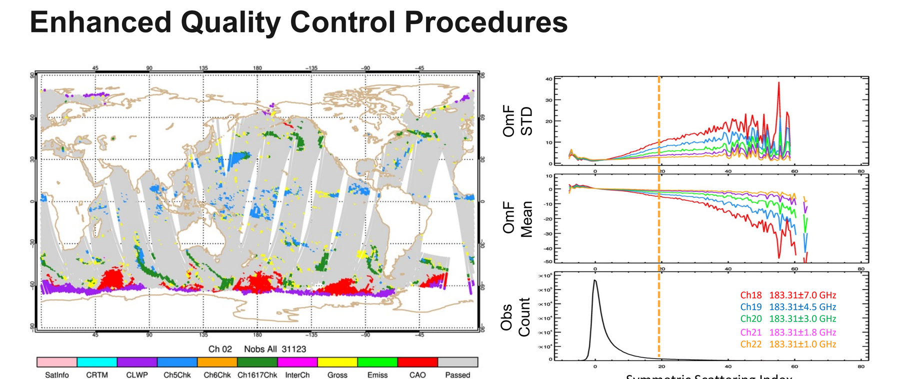
New Cloud Optical Property Table

Using scattering table for spherical particle leads to systematic errors:
- too much scattering at low frequencies
- too little scattering at high frequencies



Credit: Figures and information from Yinghui Lu, Penn State

Enhanced Quality Control Procedures

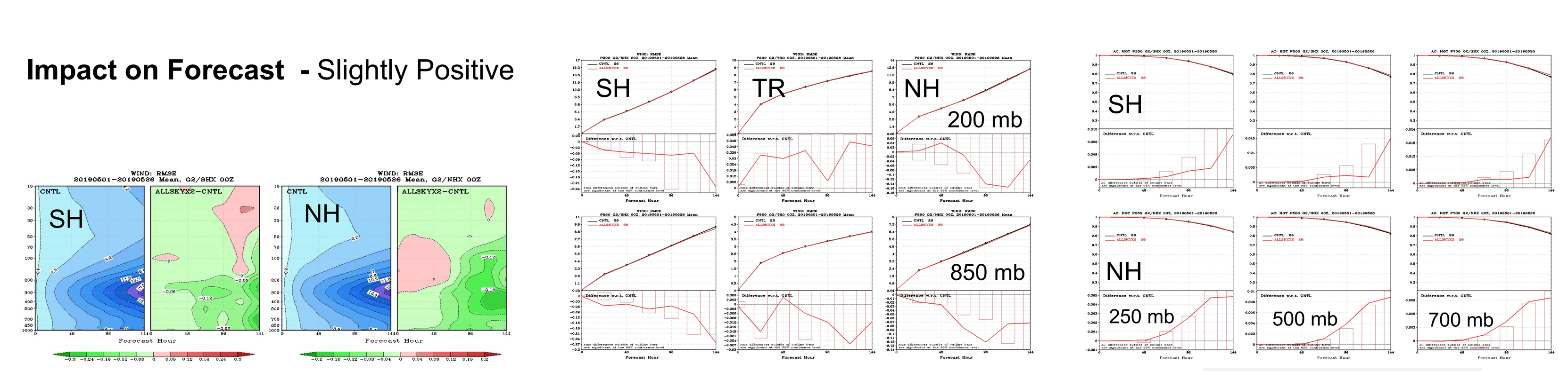


- New LUTs generated by integrating scattering properties over exponential GFDL PSD.
- Use scattering properties of sector snowflakes in Liu (2008) scattering database.
- Replace sphere snow particles in model with sector snowflakes.

  One sphere snow is replaced by multiple sector snowflakes of the same size to preserve total mass of particles within each size bin.

- Relax precipitation screening by remove 54.5 GHz precipitation check to allows precipitation affected radiances.
- Screen observations affected by strong convective situations by:
  - Enhancing cloud effect ΔBT check using 53.6 GHz
  - Using symmetric scattering index derived from 90 and 150 GHz
- CAO (Cold Air Outbreak) – screen out the CAO area where the forecast model tend to produce too much ice cloud.

Impact on Forecast - Slightly Positive



Vector Wind RMSE Vector Wind RMSE Anomaly Correlation