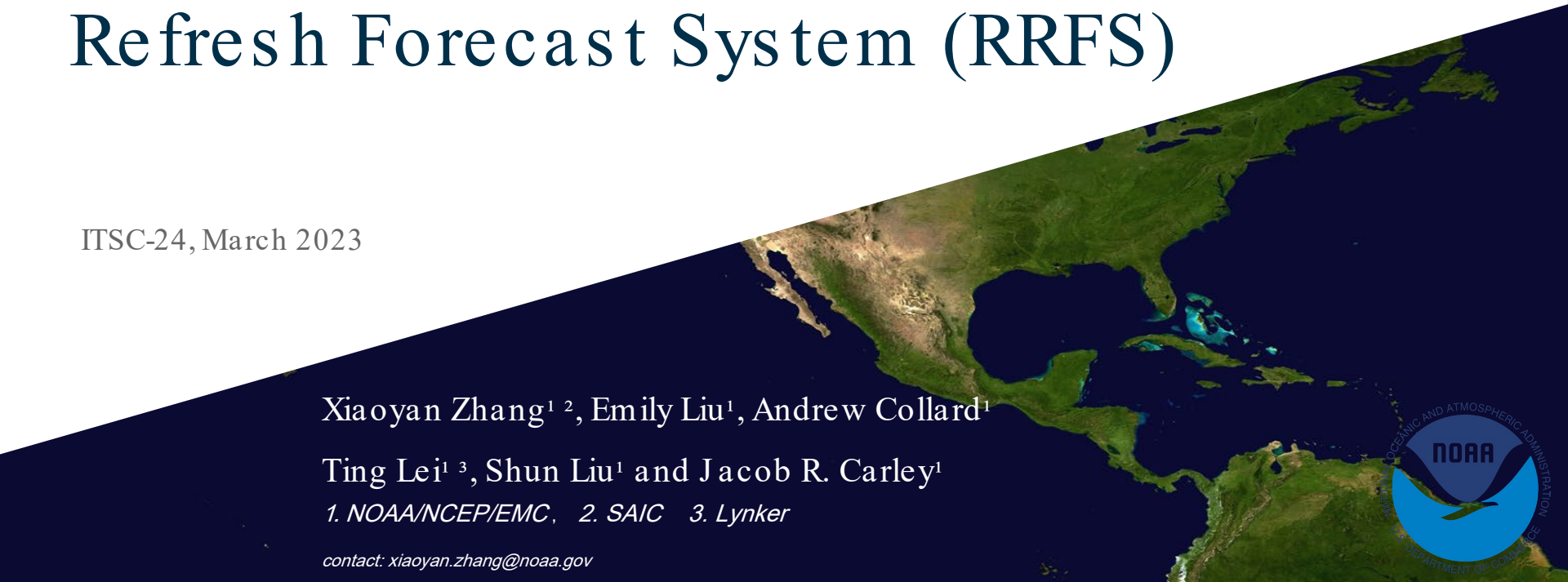
Satellite Bias Correction in NOAA's Next Generation Regional Model - Rapid Refresh Forecast System (RRFS)

ITSC-24, March 2023



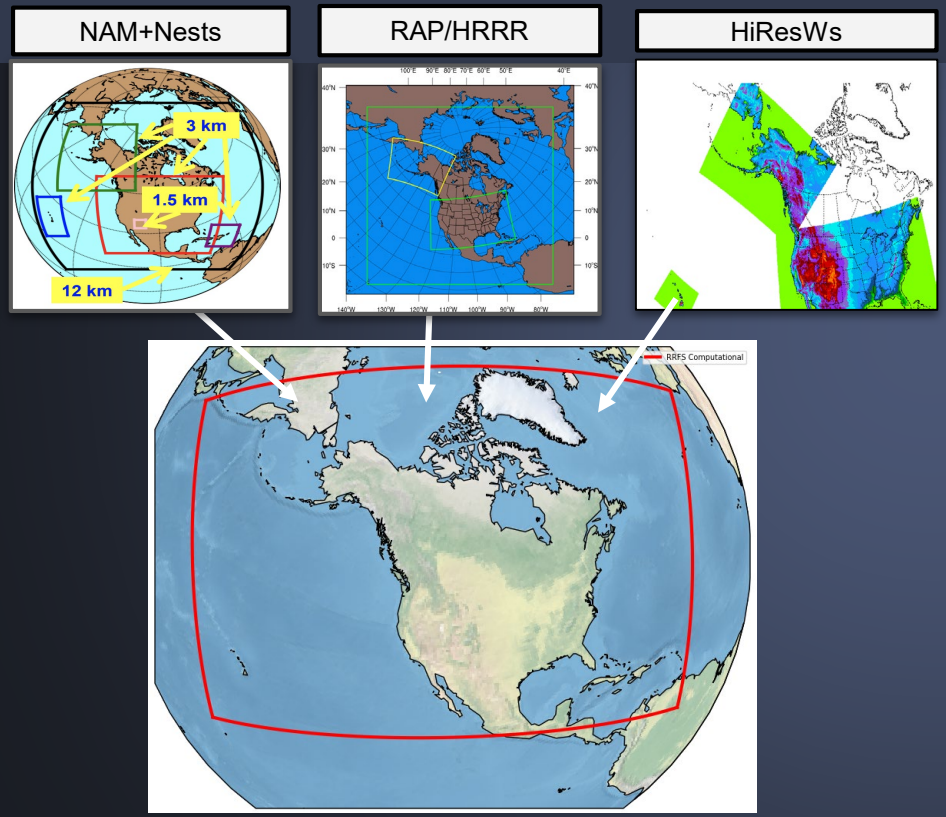
Xiaoyan Zhang[1 2], Emily Liu[1], Andrew Collard[1]

Ting Lei[1 3], Shun Liu[1] and Jacob R. Carley[1]

1. NOAA/NCEP/EMC, 2. SAIC 3. Lynker

contact: xiaoyan.zhang@noaa.gov

NOAA Regional Models



RRFSv1 Computational Domain

Next Generation Regional Model RRFS

- Based on the FV3 dynamical core Limited Area Model (LAM) capability
- Convection-allowing (~3 km grid spacing)
- Model grid 3950x2700
- 65 vertical layers with 2-mb model top
- GSI Hybrid 3DEnVar assimilation (30-40 members)
- Rapidly updated (hourly)
- Deterministic forecasts to 18h every hour
- Ensemble forecasts to 60h every 6 hours
- Implementation Fall, 2024

RRFS realtime parallel testing

Data assimilation cycling strategy

Satellite Data Tested in RRFS

AMSU-A
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
METOP-A Channels 1-6, 9-10, 15
METOP-B Channels 8-13
METOP-C Channels 1-10, 15

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

ABI
GOES-16 Channels 8-10 (CSR)

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

CRIS
NOAA-NPP CrIS 72 Channels
NOAA-20 CrIS 72 Channels

IASI
IASI METOP-A 98 Channels
IASI METOP-B 98 Channels
IASI METOP-C 98 Channels

SSMIS
F17 Channel 5-7

Objectives

- Re-address the bias correction of satellite radiance within this new RRFS system by evaluating the performance of existing bias correction initialization and cycle strategies
- Compare cycling bias coefficients independently in the RRFS by adopting bias coefficients from the global model (GFS)

Variational Bias Correction (VarBC)

(Dee, 2004; Auligné et al. 2007, Zhu .et al. 2014)

Linear predictor model for bias in each channel:

$$\mathbf{b}(\mathbf{x}, \beta) = \sum_{i=0}^{N_p} \beta_i \mathbf{p}_i(\mathbf{x})$$

Cost function:

J_b: background constraint for x J_β: background constraint for β

$$J(\mathbf{x}, \boldsymbol{\beta}) = (\mathbf{x}_b - \mathbf{x})^T \mathbf{B}_x^{-1} (\mathbf{x}_b - \mathbf{x}) + (\boldsymbol{\beta}_b - \boldsymbol{\beta})^T \mathbf{B}_\beta^{-1} (\boldsymbol{\beta}_b - \boldsymbol{\beta}) + [\mathbf{y} - \mathbf{b}(\mathbf{x}, \beta) - h(\mathbf{x})]^T \mathbf{R}^{-1} [\mathbf{y} - \mathbf{b}(\mathbf{x}, \beta) - h(\mathbf{x})]$$

J_o: bias-corrected observation constraint

$\mathbf{B}_\beta^{(j)} = diag(\boldsymbol{\sigma}^2_{\beta i,j}, ..., \boldsymbol{\sigma}^2_{\beta n,j})$

$\boldsymbol{\sigma}^2_\beta$ is set to be the estimate of the analysis-error variance of the predictor from the previous analysis cycle, which is automatically adjusted within GSI **without proportion to** the number of radiance data. However, there is a threshold (obs number < 20) in GSI to control if the variance will be updated from the analysis cycle.

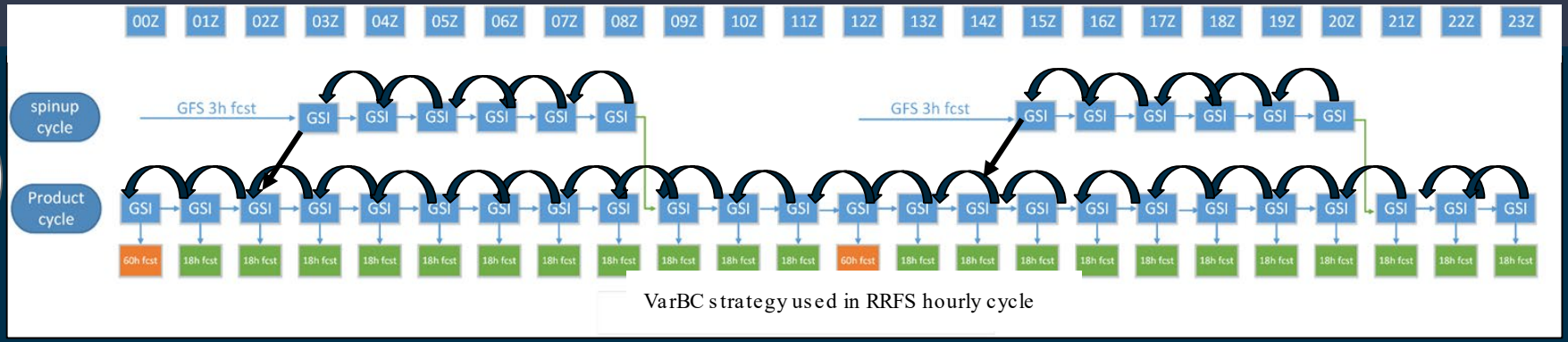
Bias correction experiments

Retrospective testing (May 11-19, 2021) for 3-km CONUS domain

Experiment Name	Initialisation type	Initialisation bias coefficient	Cycle update
1. Exp: bias0	Cold start	Zero	Hourly
2. Exp: biasg	Warm start	Global	Hourly
3. Exp: biasgl	Warm start	Global	Fixed

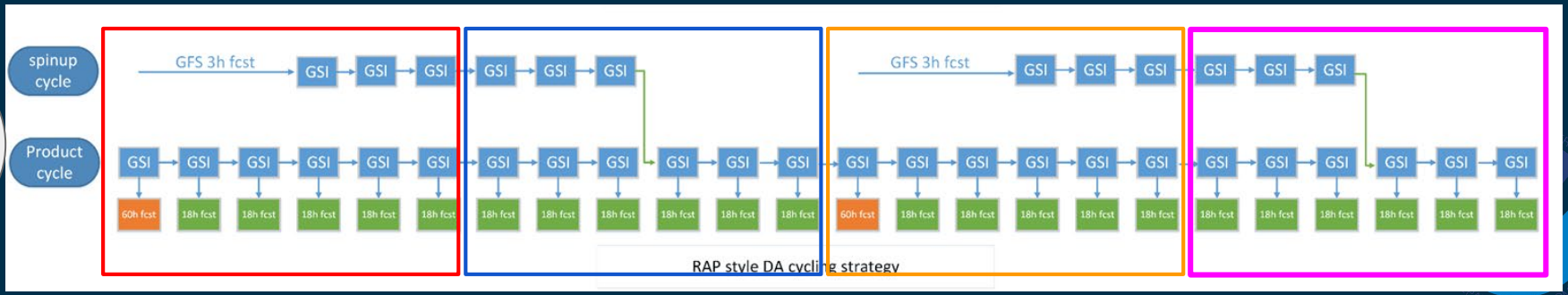
RRFS DA bias correction cycle strategy

1
2



VarBC strategy used in RRFS hourly cycle

3



RAP style DA cycling strategy

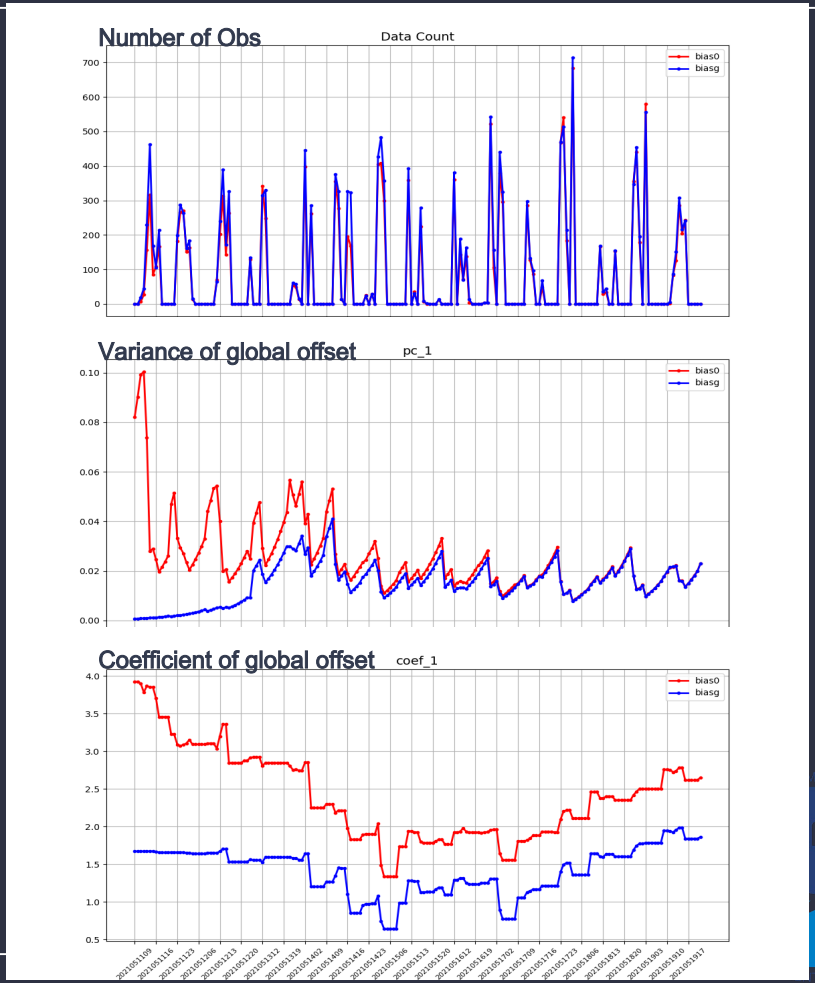
Time series of amsua_n19 channel 1:

- Number of data
- Background error variance of global offset
- Bias coefficient of global offset

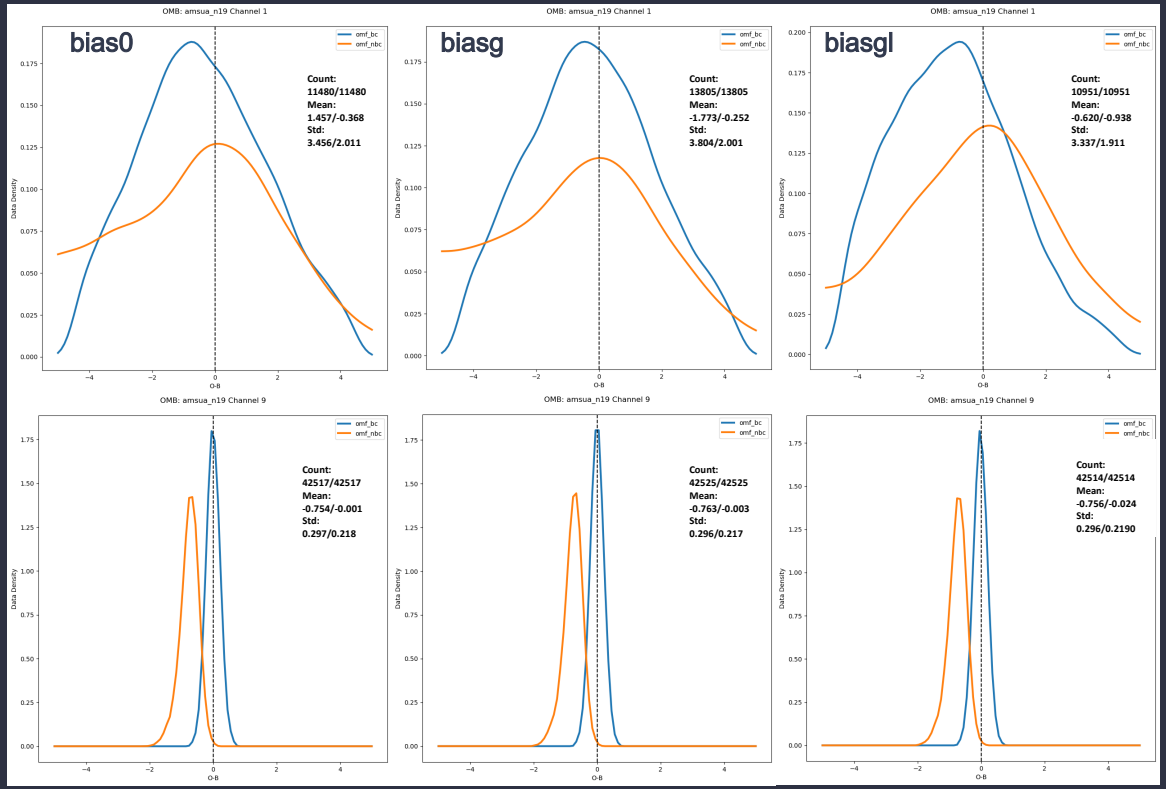
The background variance is the estimate of the analysis error variance of the predictor coefficient from previous analysis cycle. Large background variance leads to a large adjustment to the predictor coefficient. The adjustment of bias coefficient largely correlated to observation number in regional DA

In GSI, when the data amount less than certain threshold (<20), the background variance multiplied by the factor (1.1)

The adjustment of bias coefficient Initialized from zero or from global has the same trend when spin-up settled.

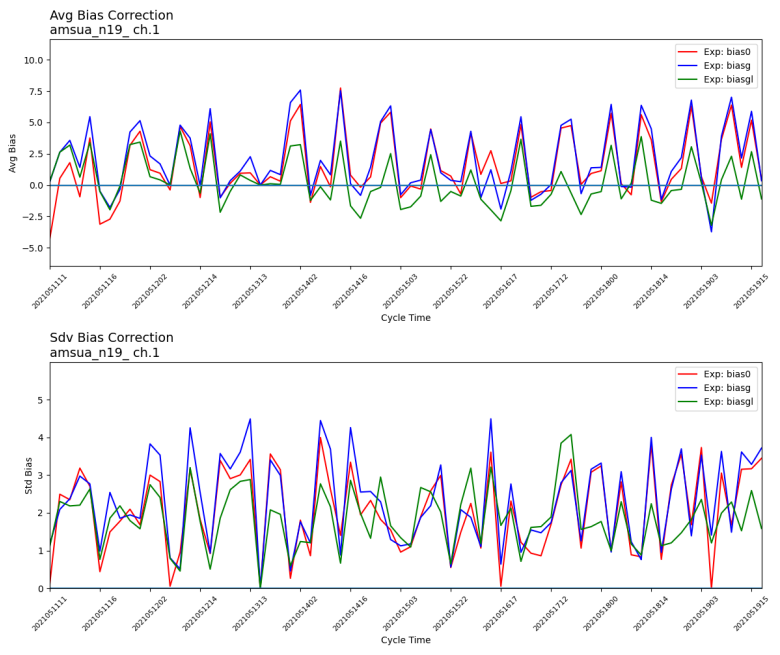


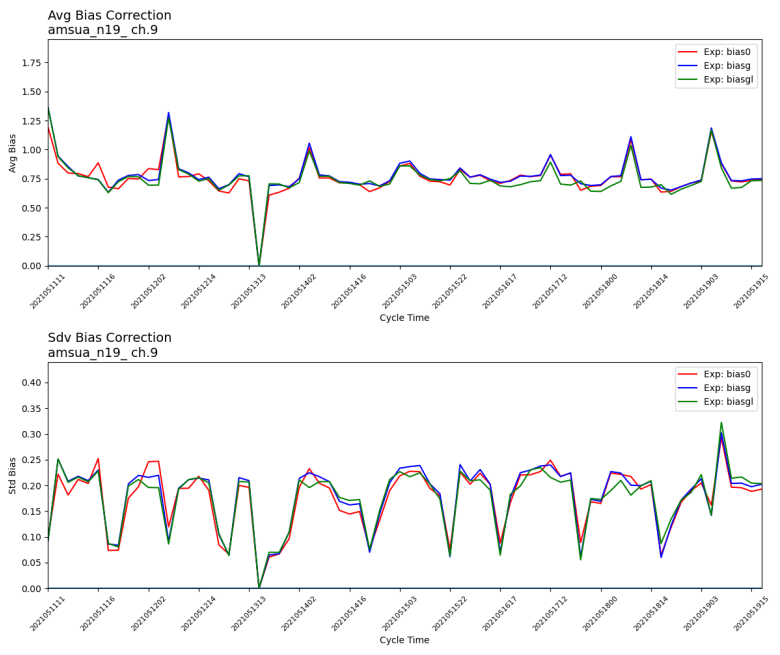
O-B histogram of amsua_n19 channel 1 & 9 before and after bias correction



- The O-B fit after bias correction is different among three experiments of surface channel.
- The O-B of surface channel has larger cold bias with bias corrected from fixed global bias coefficient
- For higher peaking channel, the three bias correction strategies performed very similar.

Total bias time series of amsua_n19 channel 1& 9

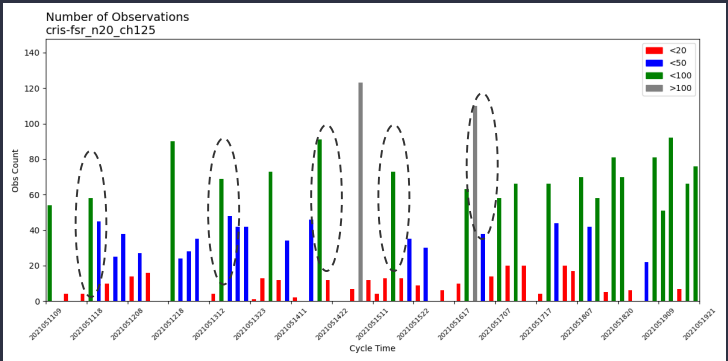


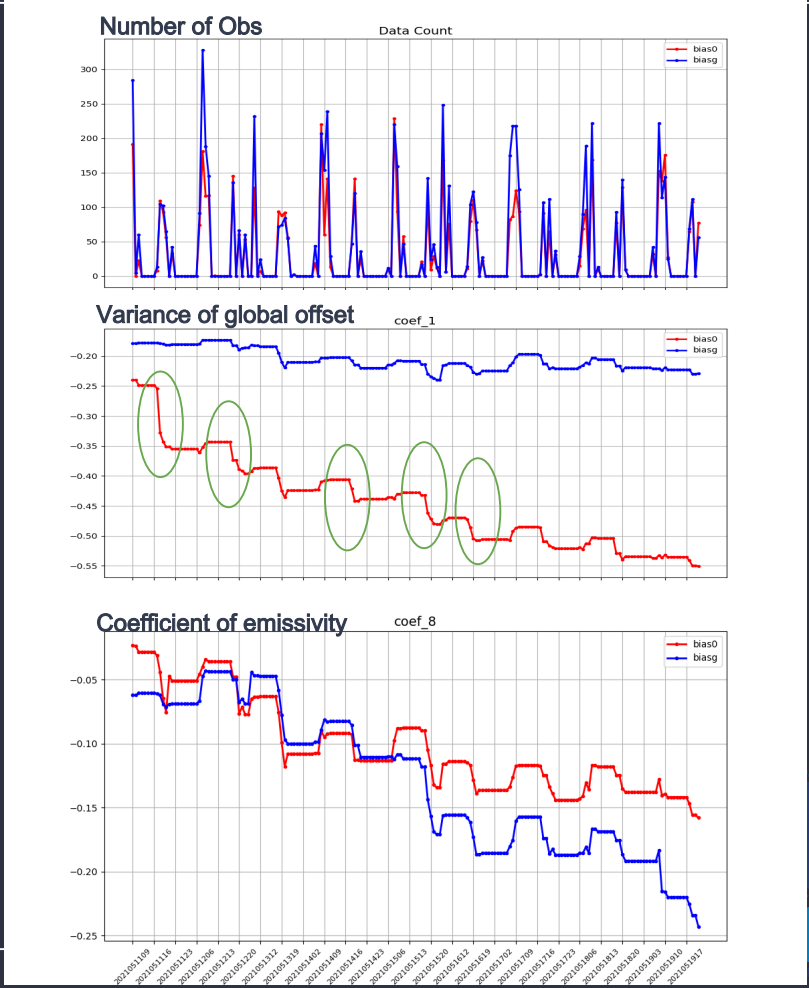


In the RRFS system, the bias estimate is highly variable in time, but global system bias estimate is relatively less variable, especially for near-surface channel.

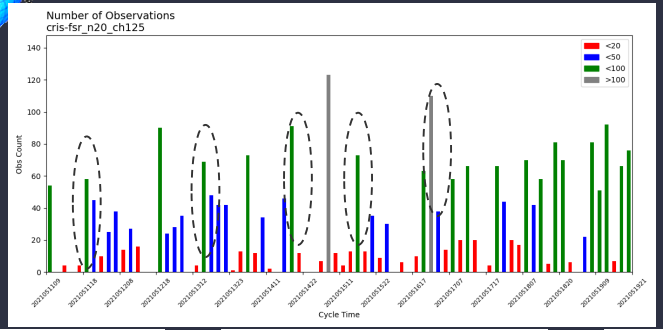
Issue in CrIS_N20 channel 125:

- Bias coefficient continued drifting, and the coefficient dropped dramatically at a certain time when the data count increased.
- Surface emissivity coefficient has the same drifting problem as global offset term.

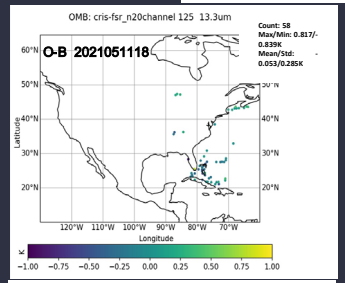


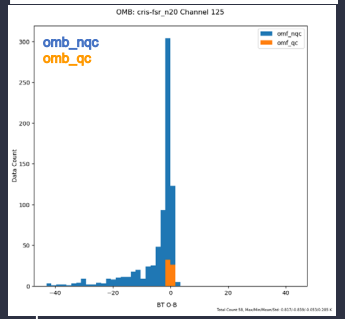


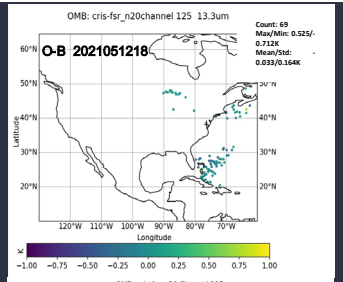
Issue in CrIS_N20 channel 125 Cont.

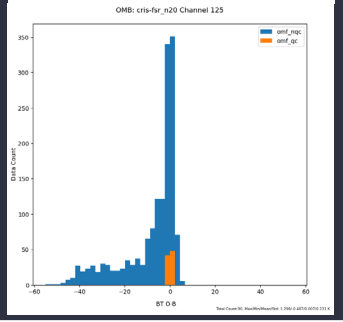


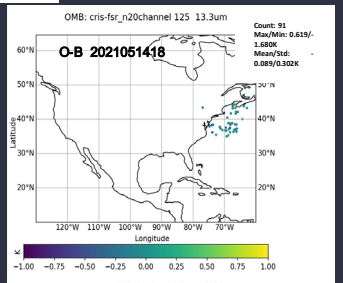
- The time of bias coefficient dropped significantly corresponding to the time of most data over the ocean
- GSI QC rejects all CrIS obs over non-sea surfaces with a surface-to-space transmittance > 2%.

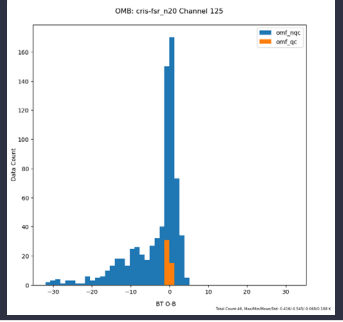


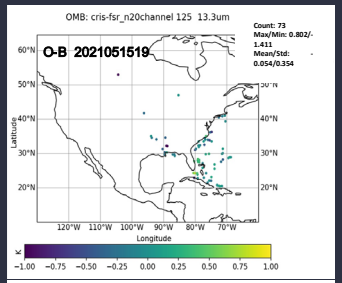


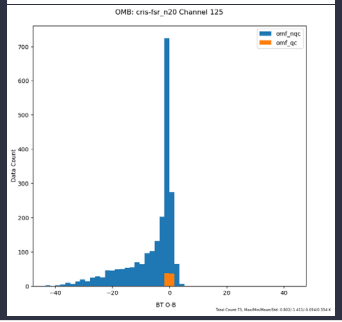


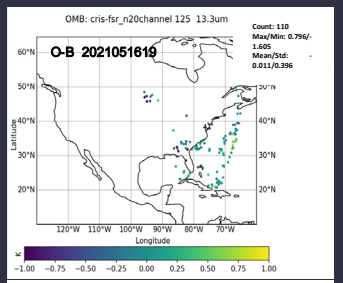


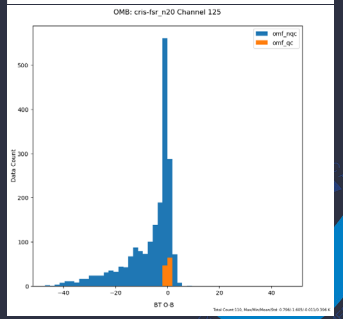






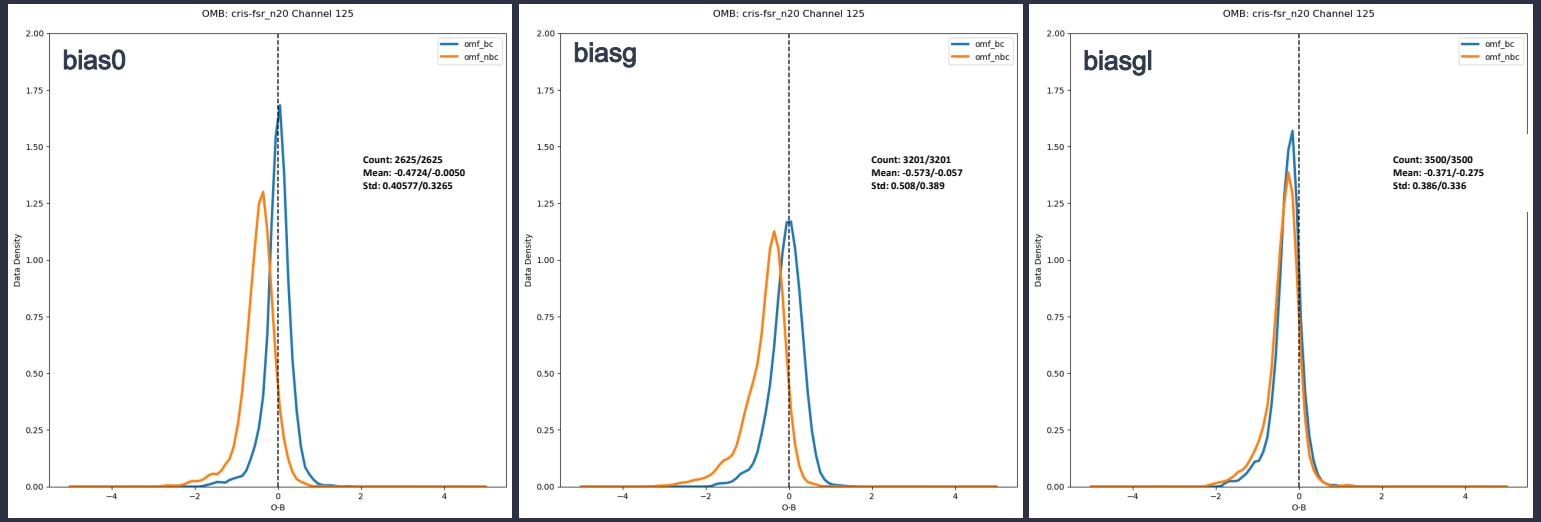






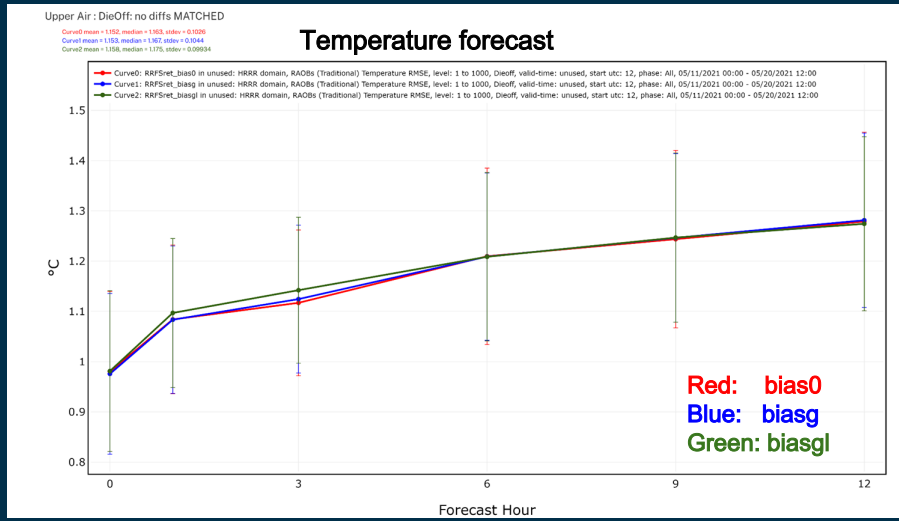
O-B histogram with/without bias correction of cris_n20 channel 125

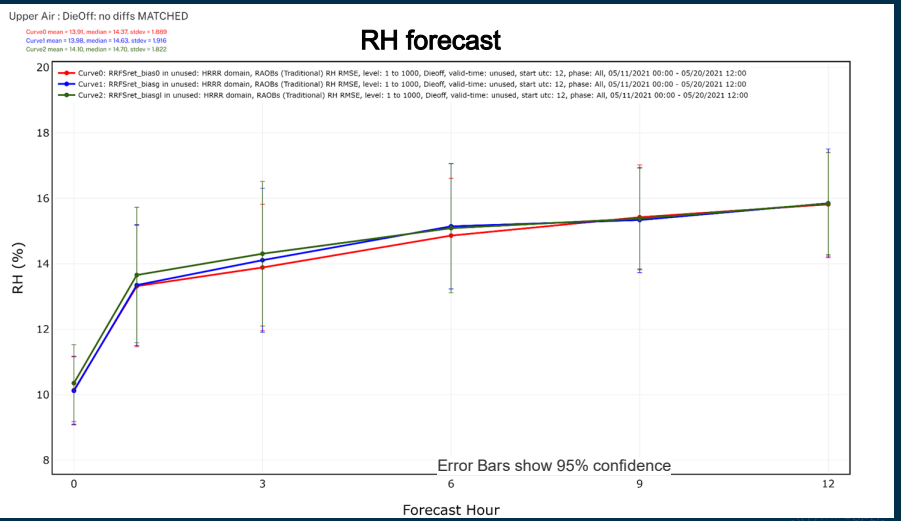
before and after bias correction



- The experiment initialized the bias coefficient from zero has the best O-B fit
- Coefficient adjustment drifting issue do not make the bias correction to a wrong direction

Bias correction impact on 12-hour Forecast

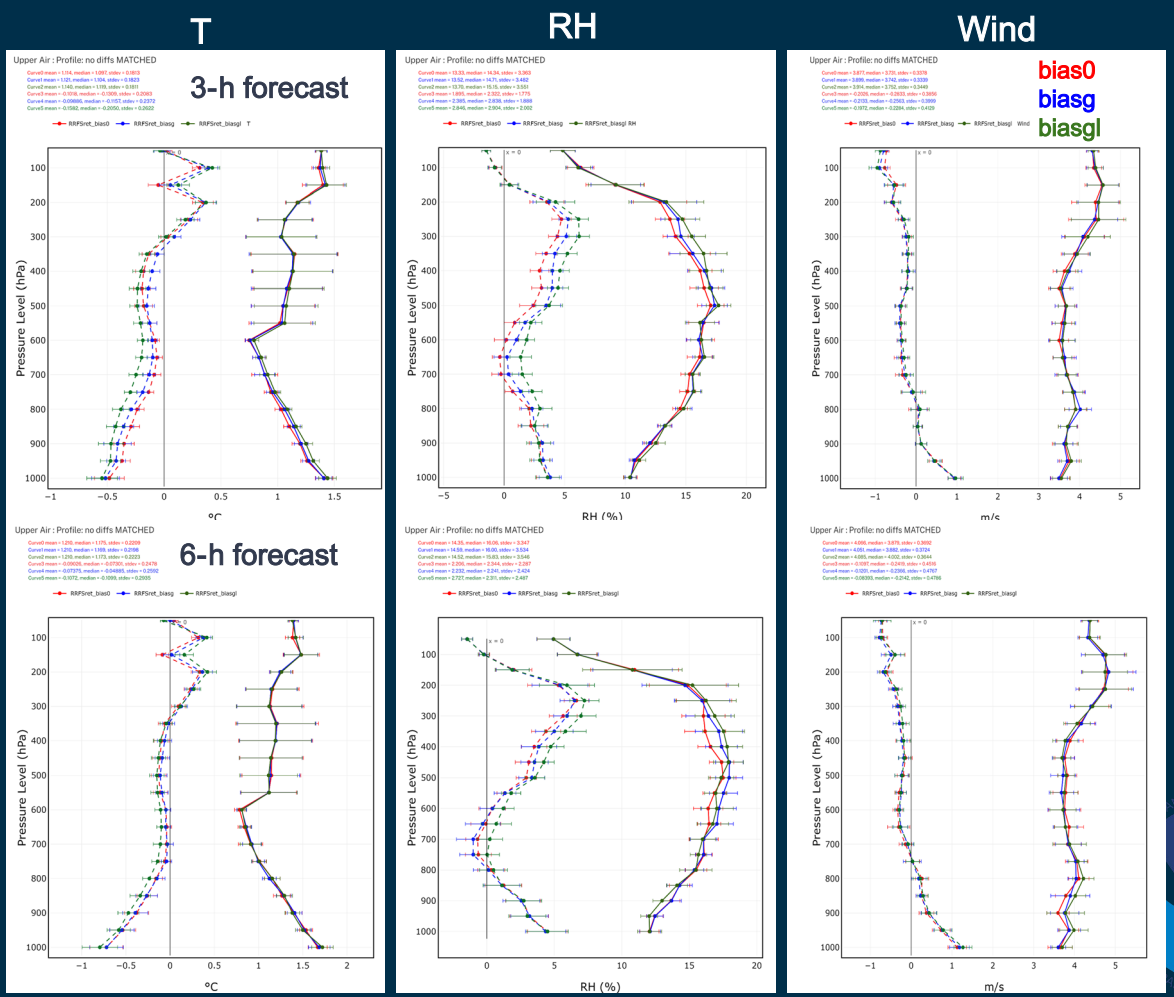




- The experiment initialized the bias coefficient from zero has the best forecast for temperature 1-6 hours forecast, for RH 1-9 hours forecast.
- Wind forecast is very similar from all experiments, the figure is omitted here.

Upper Air Forecast Verification RMSE & Bias

Experiment bias0 has the best 3/ 6-hour forecast for RH in middle and upper troposphere; there is better temperature forecast at lower troposphere.



Summary

- Three bias correction initialization and cycle strategies were assessed in RRFS
  - The best forecast performance for temperature and relative humidity was by cycling a bias coefficient independently in the RRFS hourly analysis cycle, and initializing the bias coefficient from zero
  - The forecast Initialized the bias coefficient from global bias coefficient is slightly worse than from zero bias coefficient, but much better than adopt the fixed global bias coefficient without cycle in RRFS
- The VarBC scheme in GSI can automatically adjust the bias coefficient error variance without proportion to the number of radiance data. It can handle properly the situation of small number of observation available in the hourly RRFS analysis cycle; but more effort is needed to address bias correction when the data distribution is over an inconsistent surface from cycle to cycle
- Based on the results of this study, the VarBC of operational RRFS will cycle the bias coefficient with hourly cycling strategy and initialization of zero

Thank You!

Questions/Comments?