Exploring Satellite Bias Correction Methodologies for Numerical Weather Prediction within Theoretical and Operational Frameworks

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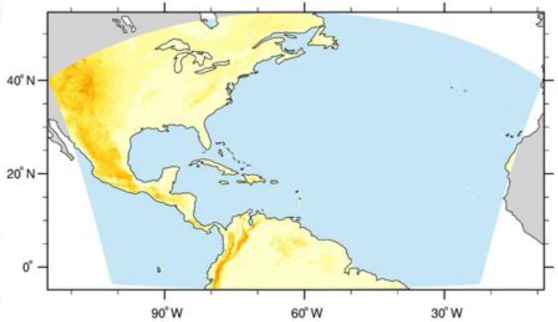
Motivation

- Satellite radiance assimilation requires bias correction
- Limited area models are often unable to perform bias estimation, and thus adopt bias correction parameters from an externally trained model
- **Satellite radiance bias specification is strongly model dependent, as bias correction methods cannot easily separate model and observation biases**
- Our research: test a fully-cycling clear-sky radiance bias correction method for Hurricane Analysis and Forecast System (HAFS) model

HAFS/GSI Data Assimilation

- FV3-SAR
- 6 km horizontal grid spacing
- 81 vertical levels, model top of 2 hpa
- GFSv16 Input Data, boundary conditions
- **3DEnVar every 6 hours; 80 ens members borrowed from GDAS**
- Community Radiative Transfer Model (CRTM; Liu and Weng 2006)
- Tested over 5-week period during peak 2020 TC season



GSI Clear-sky VarBC

Bias-corrected prior

$$\tilde{h}(\mathbf{x}, \beta) = h(\mathbf{x}) + b(\mathbf{x}, \beta)$$

Original obs-space prior

Bias model

$$b(\mathbf{x}, \beta) = \beta_0 + \sum_{k=1}^{N_p} \beta_k p_k(\mathbf{x})$$

Weighted sum of BC predictors

- Bias correction applied to the measurement operator $h(\mathbf{x})$
- For "online" experiment, weights (β_k) are estimated each analysis via variational framework (VarBC)
- For control experiment, these weights are adopted from external model (GDAS)

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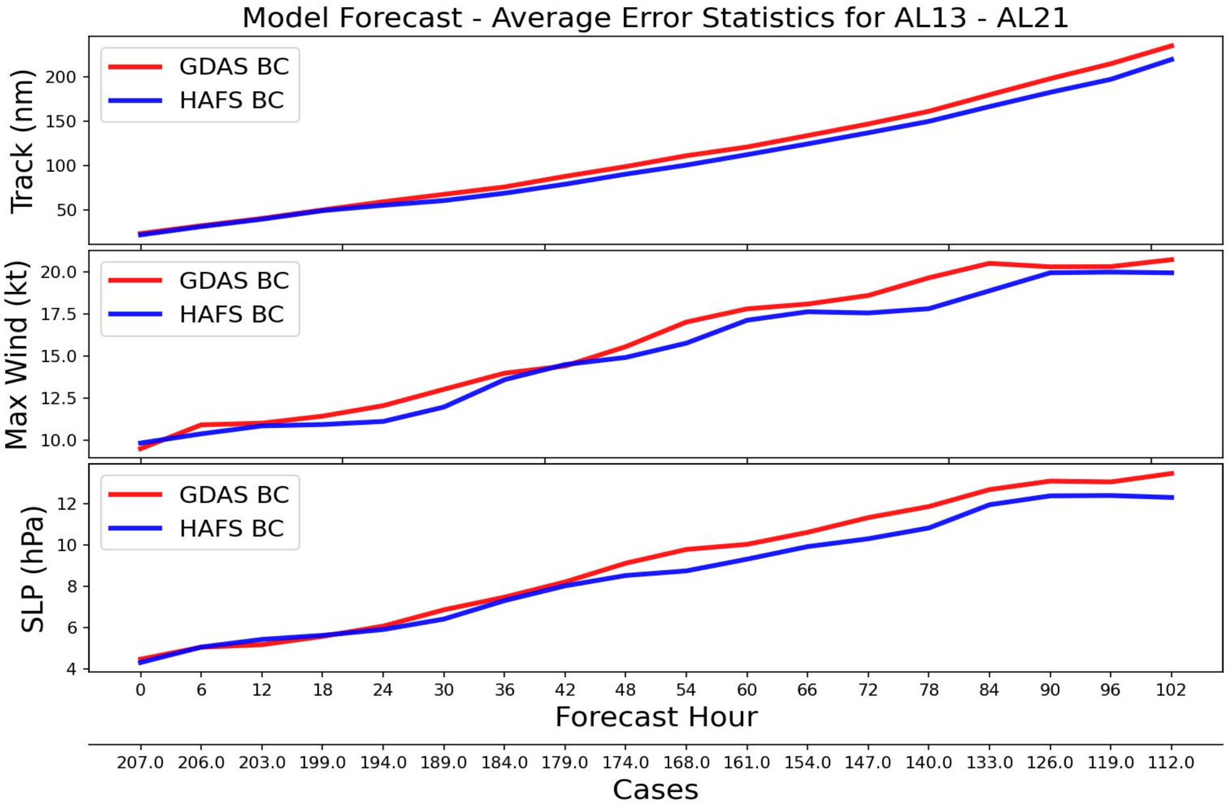
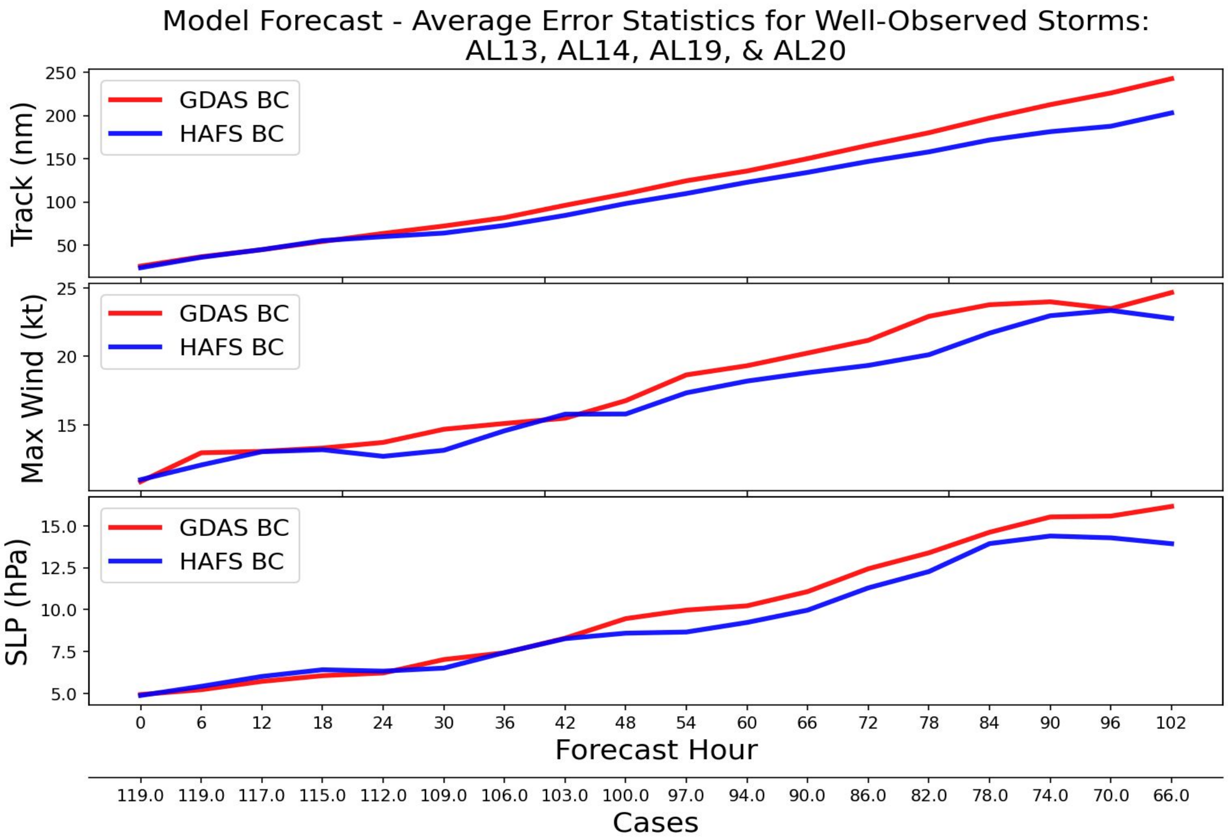


- Online bias correction approach leads to improvements in TC track & intensity forecasting



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- Improvement strengthens for storms with aircraft reconnaissance flight data

For more detail, check out:

"Implications of Self-Contained Radiance Bias Correction for Data Assimilation within the Hurricane Analysis and Forecasting System (HAFS)"

Joseph Knisely and Jonathan Poterjoy

Weather and Forecasting (Early Online Release)

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Current Research

- Bias correction schemes like VarBC correct to a model background
- With zero model error/bias, observation bias correction would be trivial
- **When undiagnosed model bias is present, bias correction schemes tend to experience "bias reinforcement" (Dee 2005)**
- **By correcting model bias independently of obs bias correction, we can mitigate model bias reinforcement**
- Strategy: first correct model bias with analysis increment statistics, then correct obs with innovation statistics

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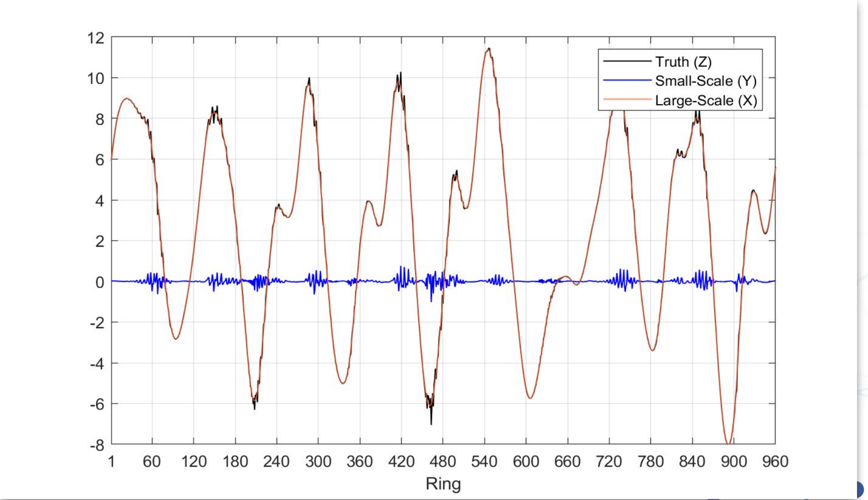
Lorenz 2005 Model III

- Simulates scalar quantity at one level and one latitude (Lorenz 2005)
- **Model III simulates smooth planetary waves w/ small-scale activity superposed**
- *X* describes large-scale, *Y* describes small-scale
- Replicates physical processes such as advection, damping, constant forcings, etc.



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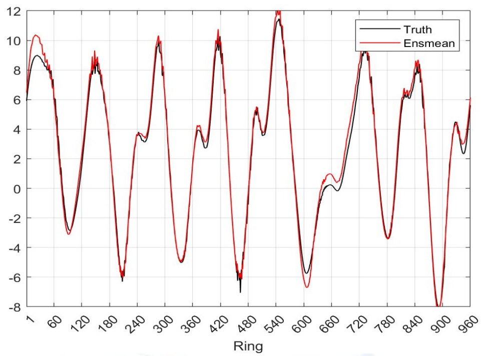
DA & Sources of Bias

- 500 ens member EnKF (Whitaker and Hamill 2001)
- Localization/inflation tuned to achieve optimal spread

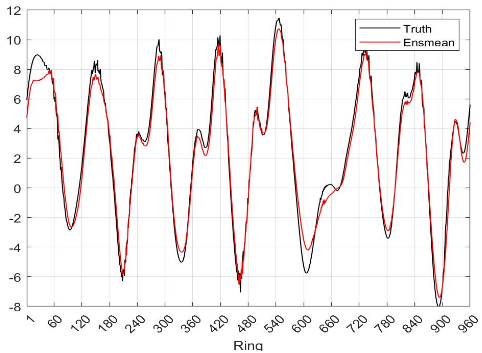
Experiments are designed to simulate challenges in NWP, such as:

- Sparse and/or biased obs
- Land/ocean disparity
- “Anchor” obs
- Model bias
- Representativeness error

(a)



(b)



Panels (a) and (b) display results from experiments with high and low model bias, respectively

Bias Correction (BC) Techniques

- Analysis increment and innovation statistics are collected over equivalent training period
- Statistics time-averaged and smoothed via Savitzky–Golay filter

We examine 3 additive bias correction techniques:

- Model BC: model-space prior $\mathbf{x}_{(i)}$ + analysis increments (*A*-*B*)
- Obs BC: obs-space prior $h(\mathbf{x})$ + innovations (*O*-*B*)
- Obs BC: obs-space prior $h(\mathbf{x})$ + residuals (*O*-*A*)

Bias Correction (BC) Techniques (cont.)

In addition, we performed experiments in which we correct model bias and obs bias independently:

- First, we use a biased model with unbiased obs assimilated
- Second, we bias correct the model and introduce biased obs
- Third, we maintain the bias corrected model and bias correct the obs using innovation statistics from 2nd experiment

1st	Biased Model	Unbiased Obs
2nd	Bias Corrected Model	Biased Obs
3rd	Bias Corrected Model	Bias Corrected Obs

Summary & UFS Applications

- Our candidate technique has demonstrated success in improving forecast accuracy over benchmark experiments
- We continue to refine the methodology within an idealized framework, aiming to replicate known challenges for assimilating satellite radiances
- This method is scalable to NWP systems, relying only on time-averaged analysis increment and innovation statistics
- Next steps: implementation of candidate technique in HAFS DA configuration, in combination with other novel DA methodologies developed at UMD (Poterjoy and Kurosawa 2022; Kurosawa and Poterjoy 2023; Knisely and Poterjoy 2023)

Supplemental Material

VarBC Cost-function

$$J(\mathbf{x}, \beta) = \frac{1}{2}(\mathbf{x} - \mathbf{x}_b)^T \mathbf{B}_{\mathbf{x}}^{-1} (\mathbf{x} - \mathbf{x}_b)$$
$$+ \frac{1}{2}(\beta - \beta_b)^T \mathbf{B}_{\beta}^{-1} (\beta - \beta_b)$$
$$+ \frac{1}{2}[\mathbf{y} - \tilde{h}(\mathbf{x}, \beta)]^T \mathbf{R}^{-1} [\mathbf{y} - \tilde{h}(\mathbf{x}, \beta)],$$

Zhu et al. 2014