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 correction applied to the measurement operator $h(x)$
- For “online” experiment, weights ($\beta_k$) are estimated each analysis via variational framework (VarBC)
- For control experiment, these weights are adopted from external model (GDAS)
Online bias correction approach leads to improvements in TC track & intensity forecasting
• 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)
DOI: 10.1175/WAF-D-23-0027.1
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.
Lorenz 2005 Model III

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

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 $x_{(i)}$ + analysis increments ($A-B$)
- Obs BC: obs-space prior $h(x)$ + innovations ($O-B$)
- Obs BC: obs-space prior $h(x)$ + residuals ($O-A$)
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 2\textsuperscript{nd} experiment
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

\[
J(x, \beta) = \frac{1}{2} (x - x_b)^T B_x^{-1} (x - x_b) \\
+ \frac{1}{2} (\beta - \beta_b)^T B_\beta^{-1} (\beta - \beta_b) \\
+ \frac{1}{2} [y - \tilde{h}(x, \beta)]^T R^{-1} [y - \tilde{h}(x, \beta)],
\]

Zhu et al. 2014