Development and research of assimilating GOES-16 ABI all-sky radiance observations in FV3-LAM using hybrid EnVar

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All-sky infrared radiance observations from the GOES-16 Advanced Baseline Imager (ABI) provide high-resolution information about water vapor and cloud hydrometeors.

These observations are complementary to radar reflectivity such that they can provide information in non-precipitating regions.

Additional development and research of assimilating ABI all-sky radiances are needed in convection-allowing models for operational RRFS implementation.

The primary goal of this UFS-R2O project is to develop and test the GOES ABI all-sky radiance data assimilation for FV3-LAM hybrid EnVar data assimilation system toward improving Rapid Refresh Forecast System (RRFS) analyses and forecasts.

Specific objectives include:

- Part I: Develop and test ABI all-sky radiance DA capabilities in the RRFS hybrid EnVar system.
- Part II: Evaluate the impact of assimilating ABI all-sky radiances for multiple severe weather events.
Part I: Development and testing of GOES16 ABI all-sky radiance DA capabilities in the RRFS hybrid EnVar system
First attempt for cycled assimilation of both synoptic/mesoscale and storm-scale observations with EnVar for FV3-LAM (Gasperoni* et al. 2022)

Direct radar reflectivity assimilation follows the approach of Wang* and Wang (2017) and Wang* and Wang (2021) from OU MAP

*denote OU MAP student or early career scientist
Testing of the newly developed cycled hybrid EnVar FV3-LAM DA system for direct assimilation of radar observations
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27 May 2021 case

20 dBZ

30 dBZ

45 dBZ

FSS

Forecast hours

FSS

Forecast hours

FSS

Forecast hours

NORADAR
RADAR
We have made many development to the fully-cycled EnVar system to support the assimilation of ABI all-sky radiance observations, including:

- **Inflation:**
  - Additive noise for cloud affected obs. that are clear sky in the model (Johnson* et al. 2022)
  - Adaptive RTPS inflation

- **Forward operator**
  - Calculation for effective radii in CRTM following Thompson microphysics scheme

- **Obs. bias correction, error estimation and pre-processing**
  - Online, nonlinear bias correction using radar anchoring (Chandramouli* et al. 2022)
  - Adaptive observation error (Johnson* et al. 2022)
  - Adaptive thinning for ABI observations
  - Remove partly cloudy pixels (Saunders and Kriebel (1988))

- **EnVar solver improvement**
  - Addition of $T_b$ as a control variable to improve convergence (following Wang and Wang 2017)
• Follows Johnson* et al. (2022)

• Adding perturbations to $T$, $q$, $u$, and $v$ at locations where obs. are cloudy ($C_o > 2$ K) but background is clear ($C_f < 2$ K)

• Appropriately selected inflation helps spin-up shallow clouds
• Relaxation to prior spread (RTPS) inflates the analysis ensemble back to some percentage of the prior spread (Whitaker and Hamill 2012)

\[ x_i^{\prime a} \leftarrow x_i^{\prime a} \left( \alpha \frac{\sigma^b - \sigma^a}{\sigma^a} + 1 \right) \]

• RTPS needs to be adaptively tuned for FV3-LAM given its over convection

• Appropriately selected RTPS inflation reduce spurious precip., increase spread of \( T_b \), and improve suppression of spurious clouds and convection
DA system development for ABI assimilation: addition of $T_b$ as a control variable to improve EnVar convergence

- We find that assimilating all-sky radiances often leads to an imbalance in the gradient of the cost function caused by the tangent linear ($H$) being much larger for some cloud hydrometeors, which therefore prevents efficient convergence

$$\nabla_a J = A^{-1}a + D^T H^T R^{-1} (Hx' - y'^o)$$

- We propose an alternative method following Wang* and Wang (2017) wherein $T_b$ is added as a control variable, which leads to a more efficient convergence
DA system development for ABI assimilation: addition of $T_b$ as a control variable to improve EnVar convergence

- The new approach improves increments to $T_b$ and dBZ, especially in regions of spurious convection and cloud cover
- These benefits grow throughout the DA period and are maintained throughout the entire forecast period
Part II: Evaluating the impact of assimilating ABI all-sky radiances for multiple severe weather events
Benefits of assimilating ABI observations: synoptic-scale cloud features

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- Assimilating ABI obs. better analyzes location and temp. of cloud tops in the stratus deck
Benefits of assimilating ABI observations: faster spin-up of ongoing supercell

RADAR+ABI experiment spins up KS supercell ~ 2 h sooner than RADAR experiment
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Benefits of assimilating ABI observations: top-down suppression of spurious convection

- Assimilating radar observations does not remove hydrometeors in anvil associated with spurious convection
- Including the ABI observations during DA better removes these spurious anvil clouds (though not entirely)
Cycled DA impacts of assimilating radar and ABI observations in FV3-LAM

- Assimilating ABI observations improves fit to dBZ observations during earlier cycles due to better spin-up of convection
- Assimilating ABI observations significantly improve background fit to ABI observations
Some benefits from assimilating ABI observations continue into the forecast period, especially for localized convection.

Forecast impacts are smaller for $T_b$ as all experiments produce too cold anvils that are larger than the observed system.

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Forecast impacts are smaller for $T_b$ as all experiments produce too cold anvils that are larger than the observed system (FV3-LAM model bias issue).
Summary

- GOES16 ABI all sky radiance DA capabilities are developed for FV3-LAM for RRFS implementation

- Assimilation of ABI all sky radiance on top of the radar observations improves the synoptic scale cloud features, facilitates the spin up of the ongoing convection, and assists suppressing spurious convection during the analysis.

- Benefits of assimilating ABI all sky radiance are carried over to the forecast period, especially for localized convection

- Benefits for brightness temperature ($T_b$) forecasts are smaller than for radar reflectivity likely due to FV3-LAM model biases

- Spurious convection in FV3-LAM can greatly reduce analysis increments for $T_b$ due to large anvil clouds reducing ensemble spread

- Ongoing work will continue R&D and work with NOAA to incorporate ABI all sky radiance DA for future RRFS implementation