Inclusion Surface Emissivity as an Analysis Variable in Assimilation of Surface-Sensitive Microwave Observations Over Land in a 1D-EnVar System

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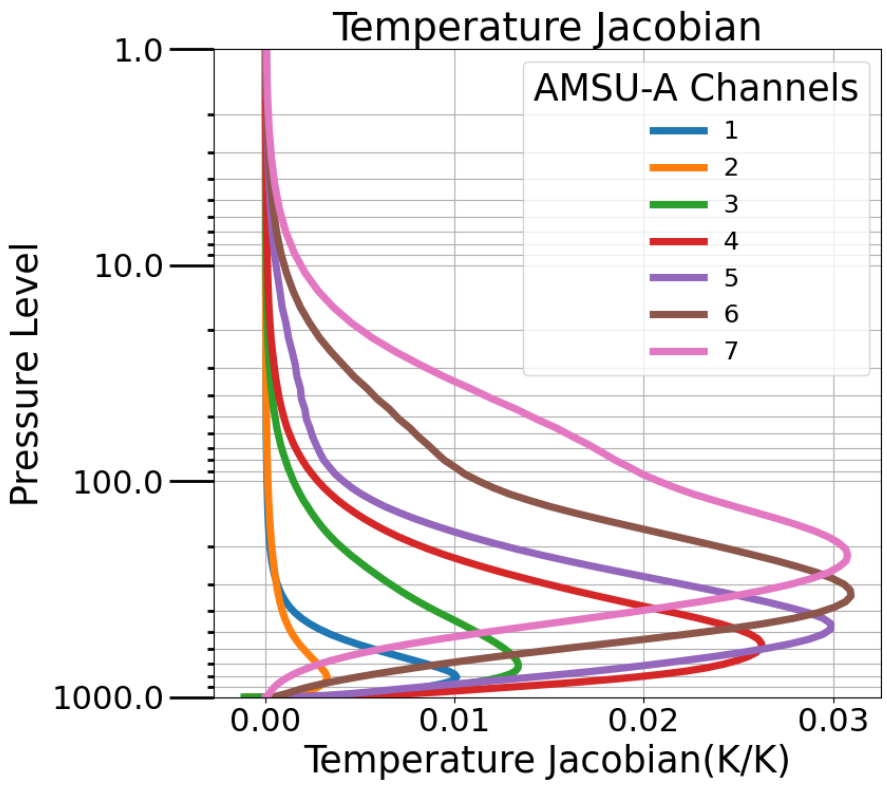
Assimilation of Surface-Sensitive Radiance Observations Over Land

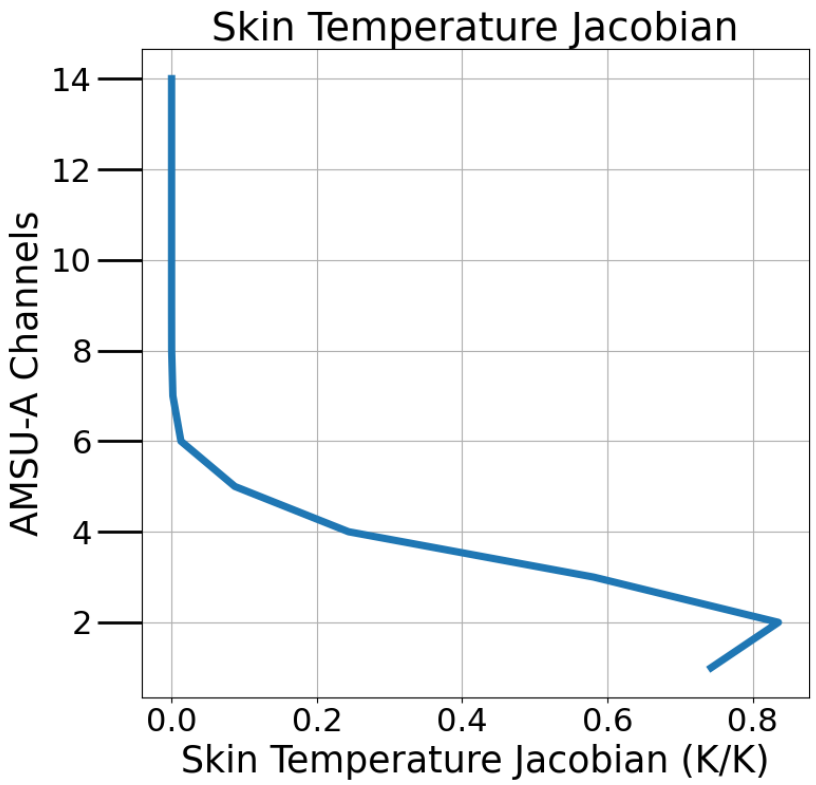
- **Motivation:** Environment and Climate Change Canada (ECCC) assimilates only surface-sensitive AMSU-A channels (4 & 5) over ocean to improve atmospheric temperature.
- **Challenge**: Surface emissivity over land are poorly known and potentially have large errors, limiting effectiveness of assimilating of such observations.
- **Objective**: Evaluate potential of assimilating surface sensitive AMSU-A channels over land by correcting surface emissivity.
  - Including surface emissivity as analysis variable and accounting for its error statistics in **B**-matrix.

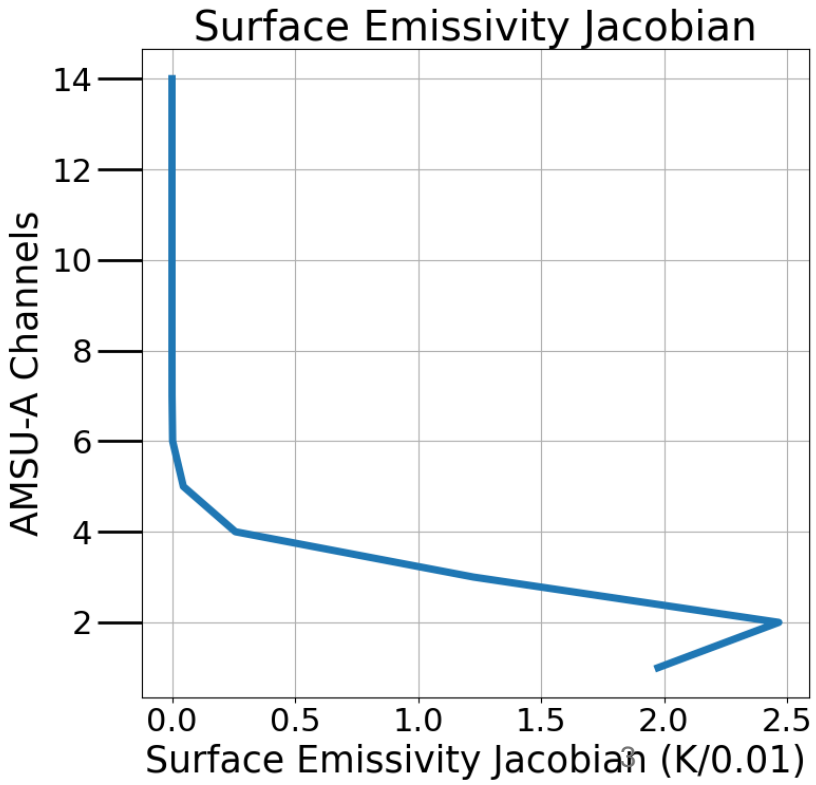
Jacobian of Surface Sensitive AMSU-A Observations

Brightness temperature sensitivity from surface emissivity, air and skin temperature

AMSU-A Channels	Air Temperature Sensitivity	Skin Temperature and Emissivity Sensitivity
Ch 6 – 14	Strong sensitivity in lower stratosphere and upper troposphere	None
Ch 4 and 5	Strong sensitivity in the low and-mid troposphere.	Weak
Ch 1 – 3	Weak	Strong







Fixed Surface Emissivity Approach

- **Estimitated variables**: $\mathrm{T_{air}}$ and $\mathrm{T_{skin}}$
- **Analysis Increment:**

$$\Delta \mathbf{x}_a = \mathbf{B}\mathbf{H}_x^T \left(\mathbf{H}_x \mathbf{B} \mathbf{H}_x^T + \left(\bar{\mathbf{H}}_e \mathbf{E} \bar{\mathbf{H}}_e^T + \mathbf{R}_m \right) \right)^{-1} \left(\mathbf{y}_{obs} - H(\mathbf{x}_b, \mathbf{e}_{atlas}) \right)$$

Background Error Covariances

Background Error Covariances in Observation Space

Observation Error Covariances

- Error Contribution of Surface Emissivity in observation space ($\bar{\mathbf{H}}_e \mathbf{E} \bar{\mathbf{H}}_e^T$)
  - Represented in Observation Error Covariances, along with observation measurement errors ($\mathbf{R}_m$)

Correcting Surface Emissivity Approach

- **Estimitated variables**: T_{air}, T_{skin} and surface emissivity
- **Analysis Increment**:

$$\begin{bmatrix}\Delta \mathbf{x}_a \\ \Delta \mathbf{e}_a\end{bmatrix} = \begin{bmatrix}\mathbf{B} & 0 \\ 0 & \mathbf{E}\end{bmatrix} \begin{bmatrix}\mathbf{H}_x^T \\ \mathbf{H}_e^T\end{bmatrix} \left(\left(\mathbf{H}_x \mathbf{B} \mathbf{H}_x^T + \mathbf{H}_e \mathbf{E} \mathbf{H}_e^T \right) + \mathbf{R}_m \right)^{-1} \left(\mathbf{y}_{obs} - H(\mathbf{x}_b, \mathbf{e}_b) \right)$$

Background Error Covariances

Background Error Covariances in Observation Space

Observation Error Covariances

- Surface Emissivity Errors Covariances ($\mathbf{E}$)
  - Represented in Background Error Covariances
- Error Contribution of Surface Emissivity in Observation Space ($\bar{\mathbf{H}}_e \mathbf{E} \bar{\mathbf{H}}_e^T$)
  - Represented in Background Error Covariances in Observation Space

Radiance Observation Bias Correction

- Operational bias correction at ECCC:
  - **Channel 6-14**: Includes scenes over both sea and land.
  - **Channel 4 and 5**: Includes scenes only over sea.
- Applying additional bias correction for channels over land surfaces:

AMSU-A Channels	**Bias Correction Predictors**
4 and 5	• FOV • Land Surface Type (Local day/night) • Latitude band dependent constant
6-14	• Latitude band dependent constant

- Note: Latitude band dependent constant predictors computed based on analysis generated by assimilating radiosonde with inflated **B** matrix.

Experimental Setup

- **Setup:** Assimilating AMSU-A observations using 1D EnVar system
  - 1D profiles is co-located at AMSU-A observation location.
  - Only over land.
  - Between 60°N and 20°S to exclude most profiles over ice/snow cover and regions with sparse radiosonde (required for bias correction and verification).
  - Exclude profiles with surface elevation > 1 km.
- **Inputs:**
  - **Background**: Global Deterterministic Prediction System short-term forecast.
  - **Observation**: AMSU-A observations.
  - **Surface emissivity parameter (Fixed Emissivity Approach)**: CNRM microwave surface emissivity atlas.
  - **Surface emissivity background (Correcting Emissivity Approach):** CNRM microwave surface emissivity atlas.
- **Verification**:
  - **Period**: June 1st – June 30th , 2022
  - Verified against analysis generated by assimilating radiosonde.
  - Only 1D profiles within 0.25° lat/lon of radiosonde locations included verification.
  - Over 3000 1D profiles are used in verification

Results: Impact of Fixed Emissivity Approach

Assessment: Reduction in RMSE of analysis relative to the background.

- Verified against the analysis generated by assimilating only radiosonde

$$\text{RMSE Reduction \%} = \frac{\text{RMSE}_{\text{background}} - \text{RMSE}_{\text{analysis}}}{\text{RMSE}_{\text{background}}} \text{x100\%}$$

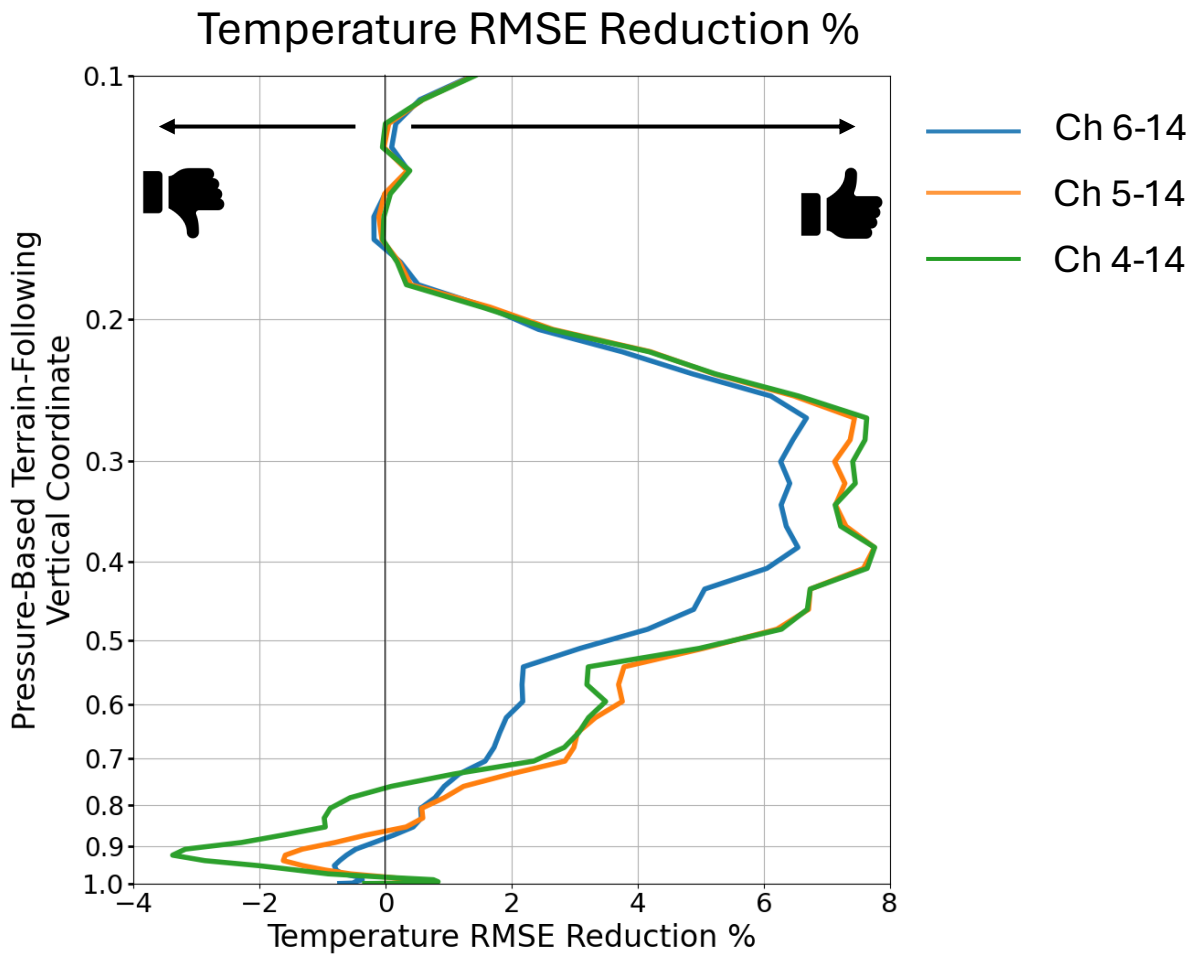
Results

Mid-Troposphere:

- RMSE improved by assimilating channels 5-14 and 4-14, relative to channels 6-14.

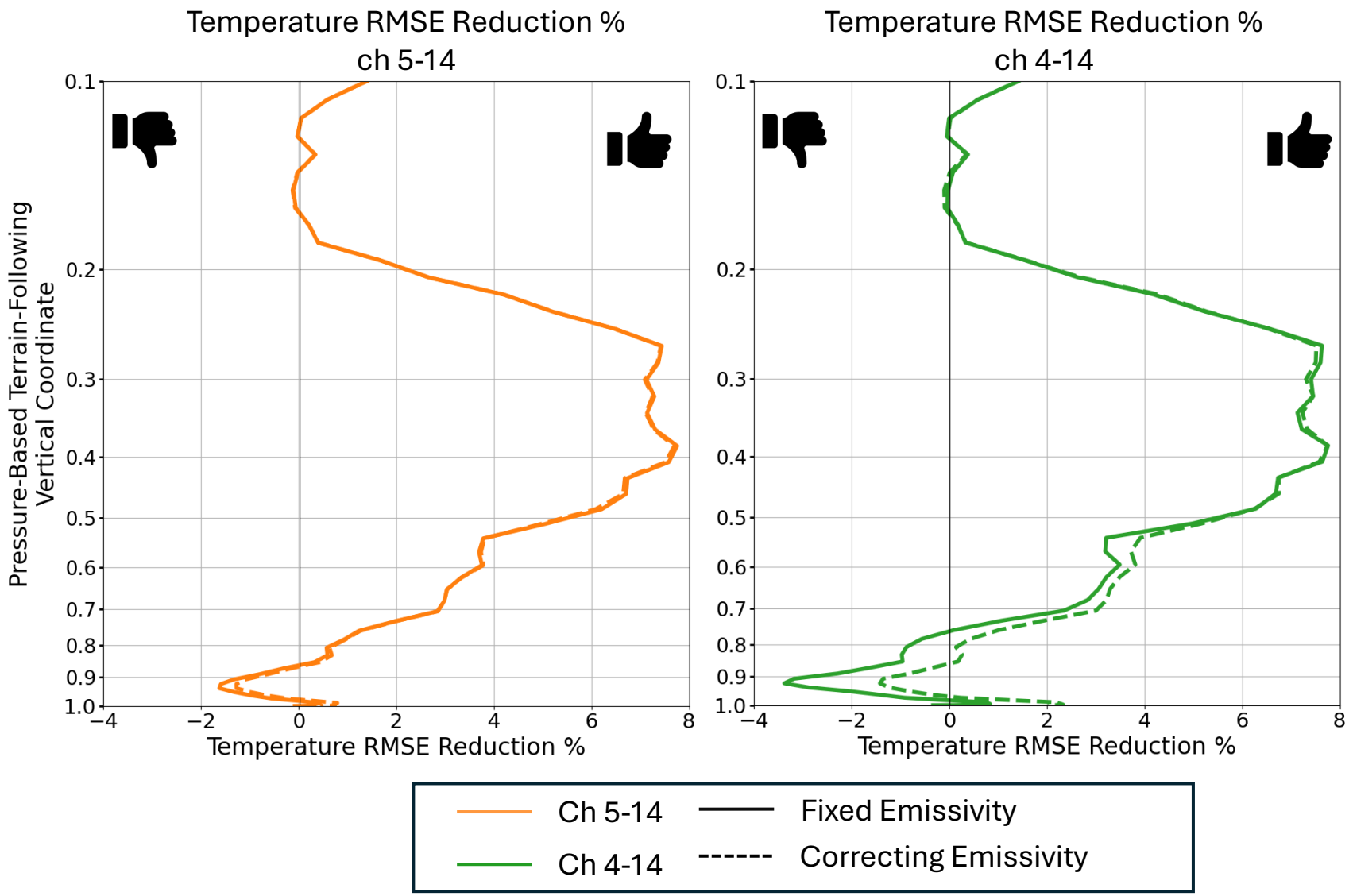
Lower-Troposphere:

- Degraded RMSE by assimilating channels 5-14 and 4-14, relative to channels 6-14.



Pressure Levels (hPa) ≈ Pressure Based Terrain Following Vertical Coordinate X 1000

Results: Impact of Correcting Emissivity Approach



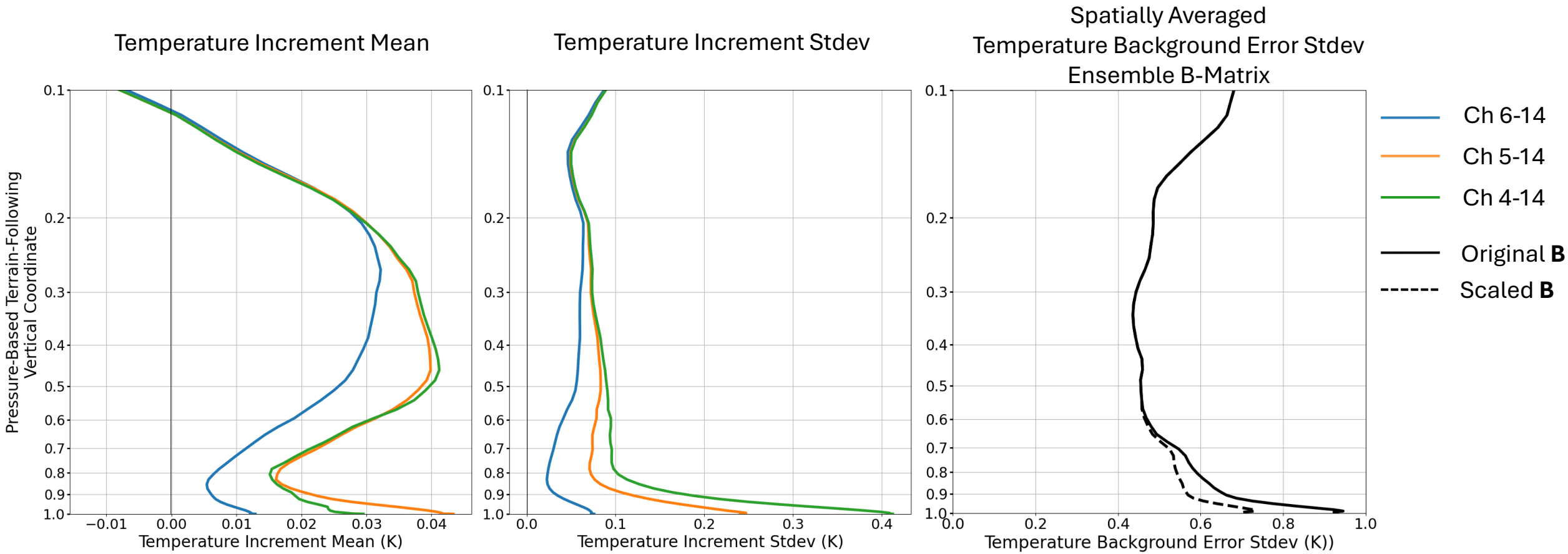
Assimilating ch 5-14:

- Minimal RMSE improvement in the lower troposphere.

Assimilating ch 4-14:

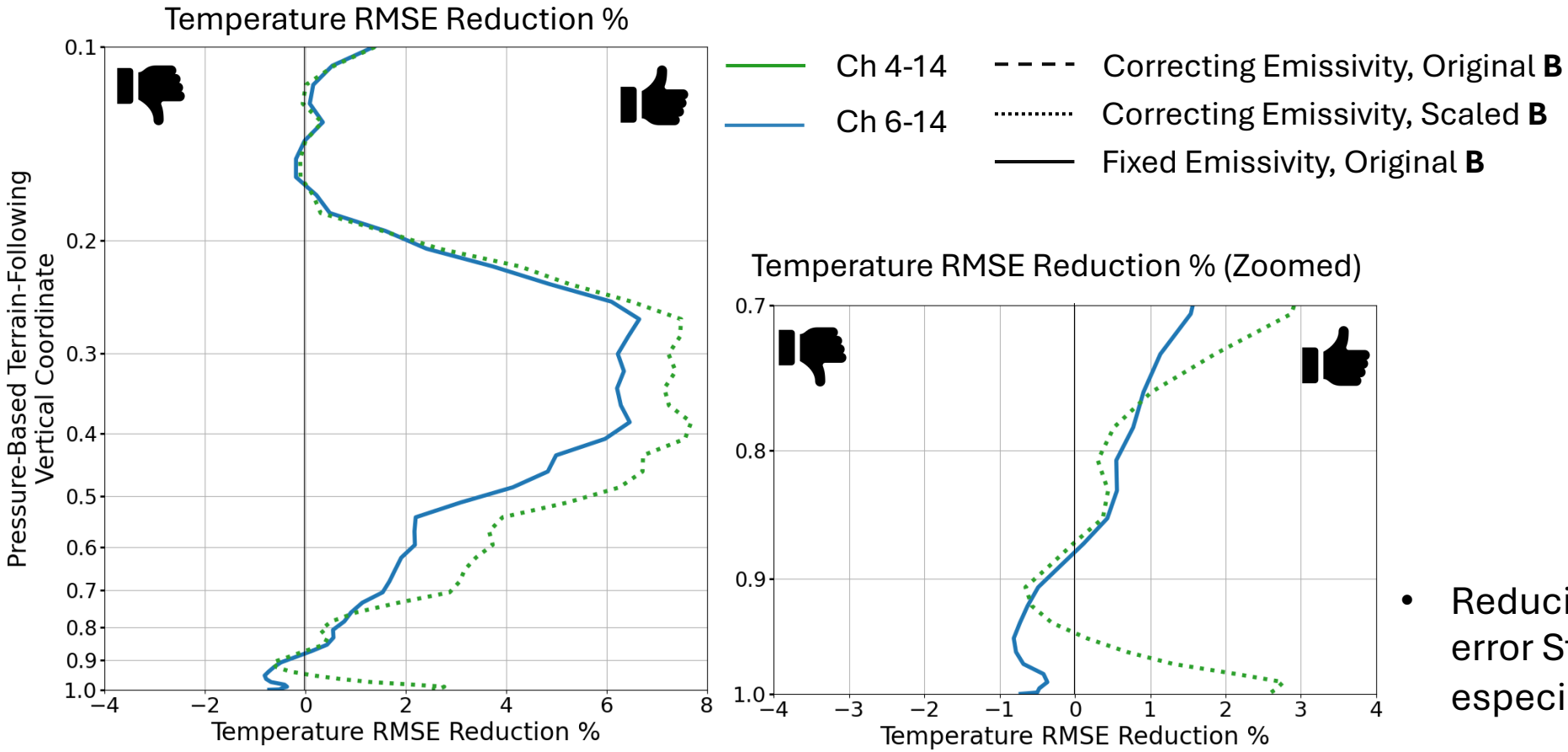
- RMSE improvement in mid troposphere and planetary boundary layer (PBL), especially at near-surface.
- But, still negative RMSE reduction % in the lower troposphere – Why?

Tuning of Ensemble-Based **B**-Matrix



- The large increment in the lower troposphere could be due to inaccurate estimate of the ensemble-based **B** matrix near surface and lower troposphere
- **Potential Solution:** Reduced temperature background error Stdev for lower troposphere in ensemble-based **B**-matrix.

Impact of **B**-matrix tuning



- Reducing temperature background error Stdev improves RMSE at PBL, especially at near-surface.

Summary:

1. Using correcting emissivity approach
2. Tuning of **B**-Matrix
3. Assimilating channels 4-14

- Improved RMSE within troposphere, especially within PBL, compared to only assimilating channels 6-14.

Conclusion

- Assimilating AMSU-A channel 4-14 while using correcting emissivity approach and scaling **B**-Matrix lead to improved RMSE, relative to assimilating only channels 6-14.
- Improvement is prominent within PBL and near-surface.
- **Disclaimer**:
  - The verifying analysis also used for bias correction, potentially exaggerating improvement of mean error but improvement of Stddev error remains representative (not shown)

Future Work

1. Further exploration of the **B**-matrix tuning and evaluating impact in full 4D EnVar Assimilation System
2. Tuning of the **R**-matrix
3. A comparison with idealized 1D EnVar study (Wang et al, 2025)
4. Uses emissivity retrieval instead of atlas in the Fixed Emissivity Approach.
5. Apply these approaches in 4D EnVar Assimilation system.

Thank you!

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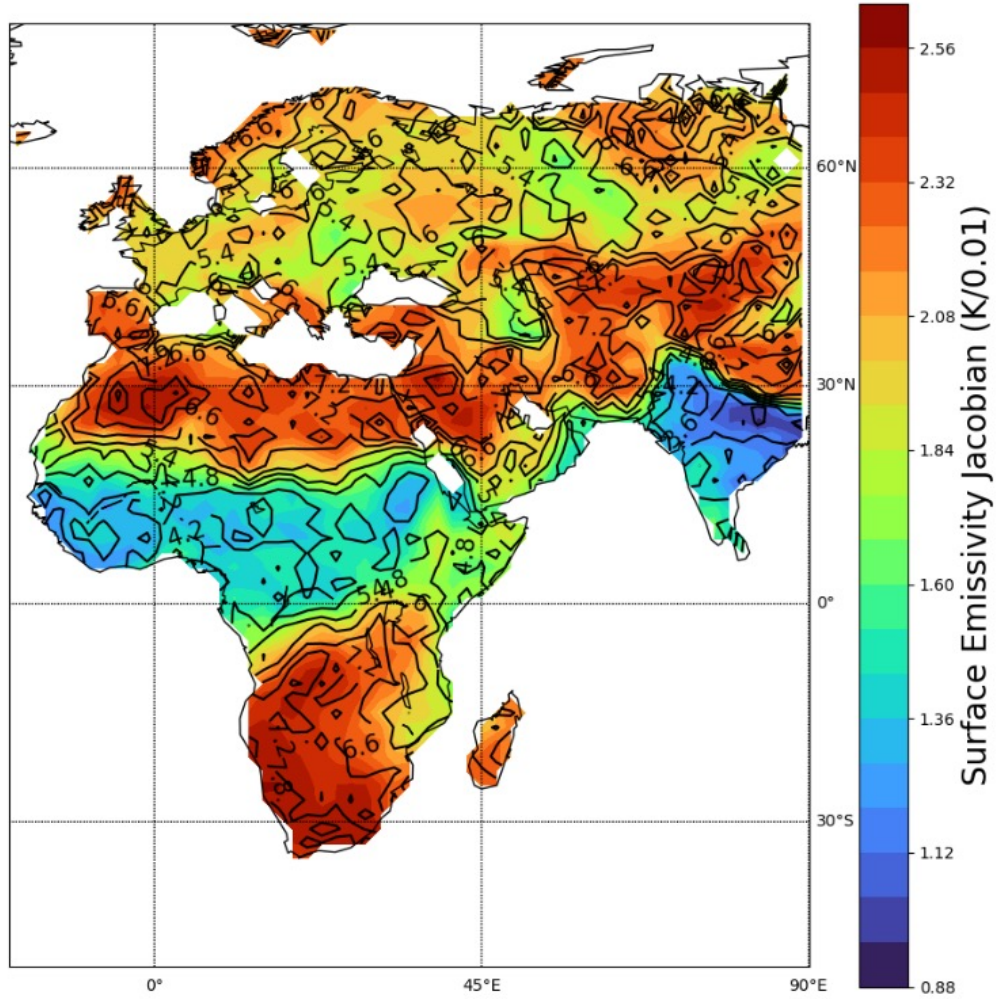
Wang, Z.Q., Buehner, M. and Huang, Y., 2025. **Idealized study of representing spatial and temporal variations in the error contribution of surface emissivity for assimilating surface-sensitive microwave radiance observations over land**. *Quarterly Journal of the Royal Meteorological Society*, p.e4948.

Fixed vs Correcting Surface Emissivity Approaches

- The formula of the analysis increment $\Delta\mathbf{x}_a$ in fixed and correcting emissivity approaches are nearly identical, except for:
  - **Fixed Emissivity Approach**: an average surface emissivity Jacobian is used to represent the error contribution of surface emissivity ($\bar{\mathbf{H}}_e\mathbf{E}\bar{\mathbf{H}}_e^T$) for the assimilation of all observation location and time
  - **Correcting Emissivity Approach**: profile-specific surface emissivity Jacobians is used to compute the error contribution of surface emissivity ($\mathbf{H}_e\mathbf{E}\mathbf{H}_e^T$) for corresponding individual observation location and time.

(Necessary to assimilation surface-sensitive AMSU-A channels)



Colored Contour: Surface Emissivity Jacobian
Line Contour: Error contribution of surface emissivity in observation space

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