Reduced Global Sea Surface Temperature Biases from Upgrades to the CRTM Infrared Sea Surface Emissivity Model

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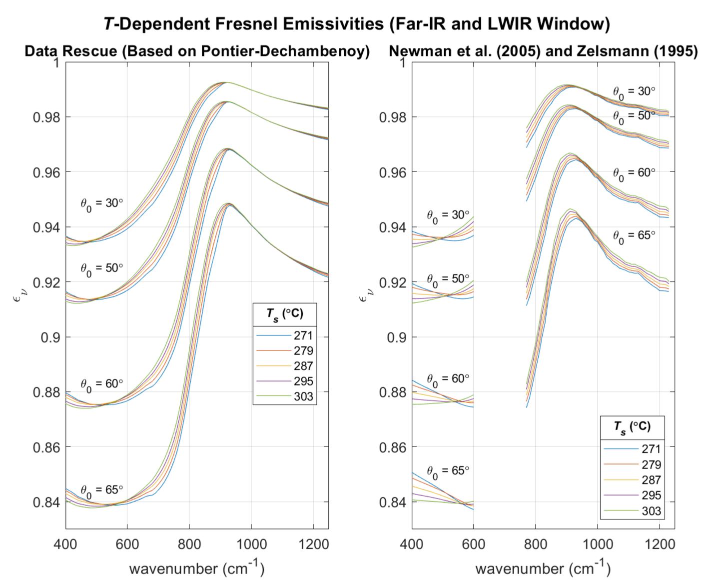
Introduction

The National Centers for Environmental Prediction's (NCEP) Global Forecast System (FV3GFS) has an observed, consistent cold Sea Surface Temperature (SST) bias in colder waters (Liu et al. 2017). Recent upgrades to the Community Radiative Transfer Model's (CRTM) Infrared Sea Surface Emissivity (IRSSE) model (Nalli et al. 2022, Nalli et al. 2023) now includes a thermal infrared (TIR) emissivity temperature dependency (based on newly rescued temperature-dependent optical constants) to reduce these SST biases. The current default and new IRSSE models are referenced as Nalli_V1.2 and Nalli_V2.2 respectively throughout this poster. These changes (Nalli_V2.2) will be available in the CRTM_V3.0 release.

Several changes to NCEP's FV3GFS data assimilation and quality control procedures were developed to help exploit the emissivity temperature dependency in the CRTM's new IRSSE model. This poster outlines the expected reduction in errors in the global radiance assimilation and improvements to FV3GFS near surface temperature biases in the analysis and forecasts when implemented.

The new IRSSE model (Nalli_V2.2) and modest changes to the assimilation procedures show improvements to the ocean surface and near surface temperature biases within the FV3GFS analysis and forecasts over the current operational configuration.

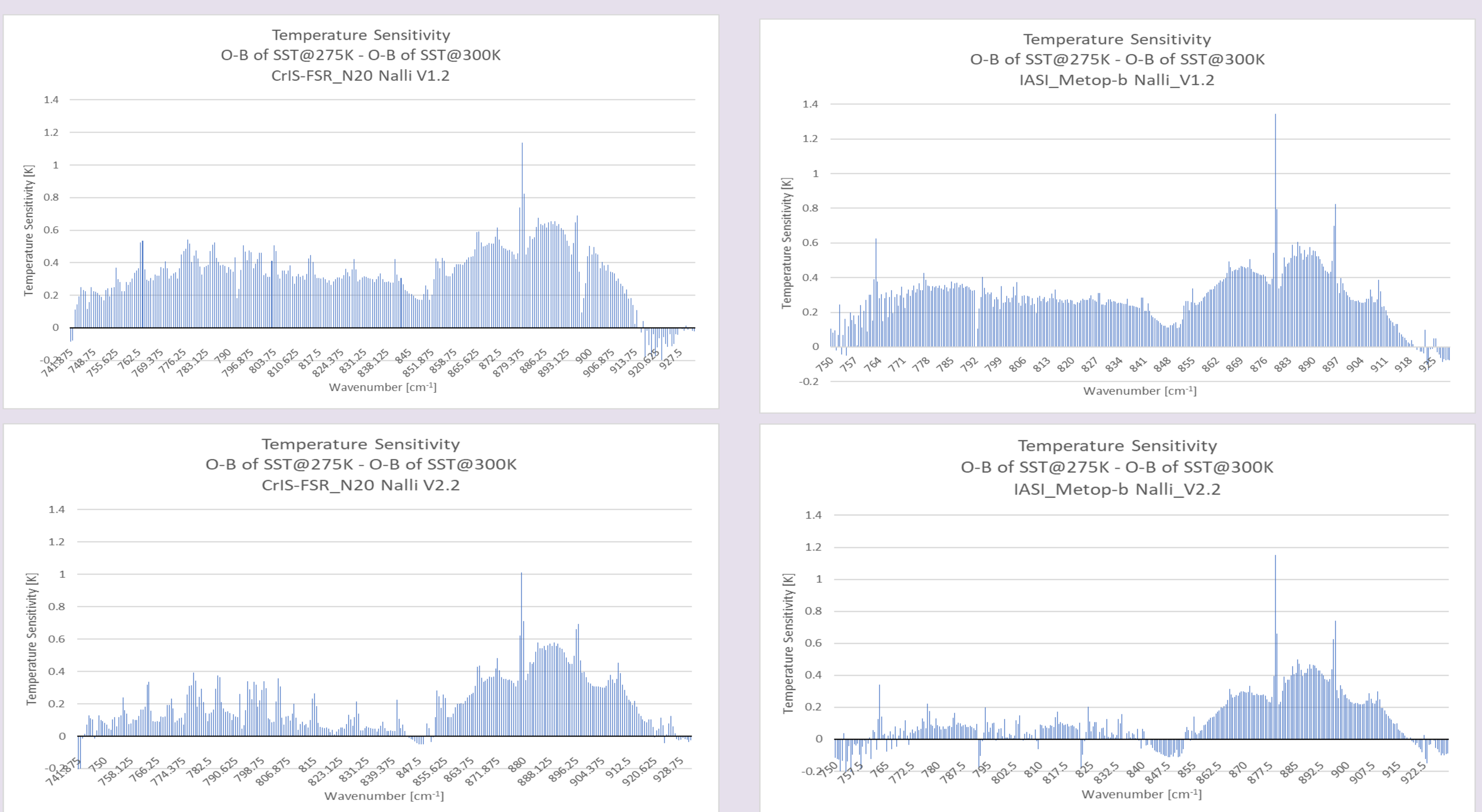


Comparison of flat-surface spectral emissivites at 4 different zenith observing angles within the longwave TIR (LWIR) to far-IR (FIR) regions. The left panel shows the results of the Nalli et al. (2022) data rescue. The right panel is based on the Newman et al. (2005) data set and results from Zelsmann (1995) extending into the far-IR region. Subtle but significant differences are noted above 900 cm^{-1} where the Newman data generally predict lower emissivities along with more temperature dependence (Nalli et al. 2022), and are limited to the longwave infrared region.

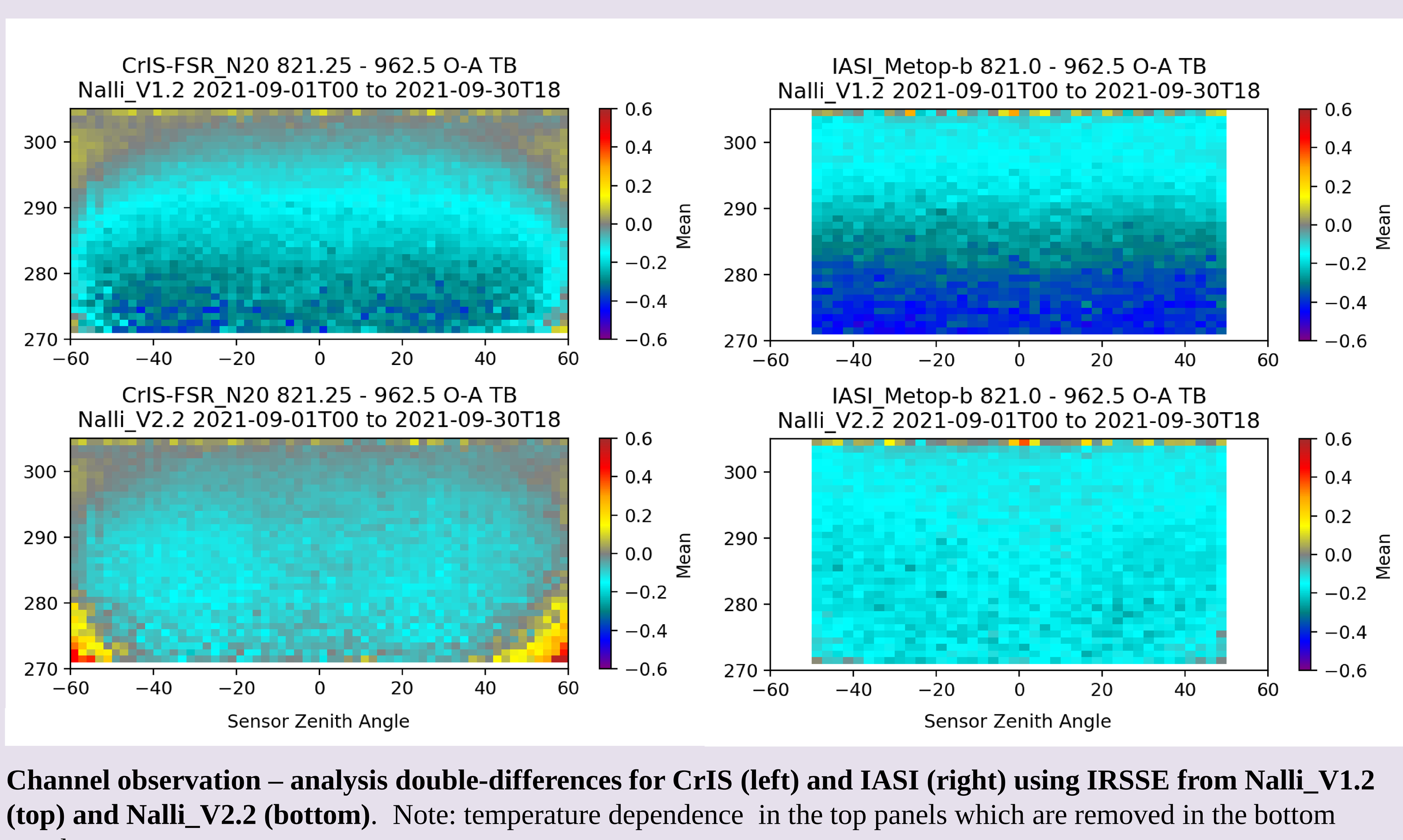
Quantifying the thermal infrared ocean emissivity spectral dependency

Two methods are used to quantify the spectral dependency;

- average observation – background differences between sea surface temperatures of 275K and 300K for each CrIS and IASI channel between 750 and 920 cm^{-1} (upper group)
- observation – analysis differences between a channel with the temperature dependency and a channel without (channel double difference) (lower group)

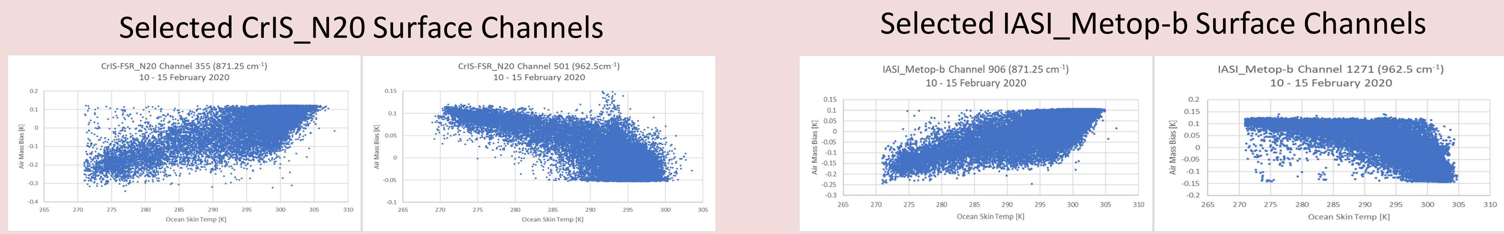


Spectral (average observation – background) at 275K – (average observation – background) at 300K for CrIS (left) and IASI (right) using IRSSE from Nalli_V1.2 (top) and Nalli_V2.2 (bottom). Nalli_V2.2 significantly reduces the spectral sea surface temperature dependence observed in Nalli_V1.2. The spectral region between 900 – 920 cm^{-1} still shows a temperature dependence was determined to be an absorbing region of chlorofluorocarbons CFC-11 and CFC-12 along with nitric acid (HNO_3). These trace gases are not accounted for in these versions of NCEP's FV3GFS.



Channel observation – analysis double-differences for CrIS (left) and IASI (right) using IRSSE from Nalli_V1.2 (top) and Nalli_V2.2 (bottom). Note: temperature dependence in the top panels which are removed in the bottom panels.

Initial tests with the new IRSSE, Nalli_V2.2, produced less than expected results. On further investigation, we found issues with the air mass portion of the bias correction on the surface channels. The surface temperature dependence was being accounted for by the bias correction and applied to both channels with and without the temperature dependence. Because the temperature dependence is correlated with latitude, the differences are seen both as latitude and temperature. To resolve this problem, the air mass portion of the bias correction was turned off.



Values of the air mass bias correction from NCEP's FV3GFS on selected CrIS_N20 and IASI_Metop-b surface channels. Bias values are with respect to surface temperature. 1st and 3rd panels are channels with temperature dependent emissivity, right 2nd and 4th panels are channels without temperature dependent emissivity.

Experiment Configuration

- NCEP's FV3GFS_V15 (20210801 – 20210930)
  - CRTM_V2.4_beta
  - Nalli_V1.2 (control) vs Nalli_V2.2 (experiment) Infrared Sea Surface Emissivity models
- NCEP's FV3GFS_V16.3 (20220601 – 20220830)
  - CRTM_V3.0_beta
  - Nalli_V1.2 (control) vs Nalli_V2.2 (experiment) Infrared Sea Surface Emissivity models
- Instruments affected
  - AVHRR (N18, N19, Metop-b, Metop-c)
  - CrIS (NPP, N21)
  - IASI (Metop-b, Metop-c)
  - VIIRS (NPP, N20)
- The experiment (Nalli_V2.2) has the air mass bias correction turned off for channels from 920 – 1030 cm-1

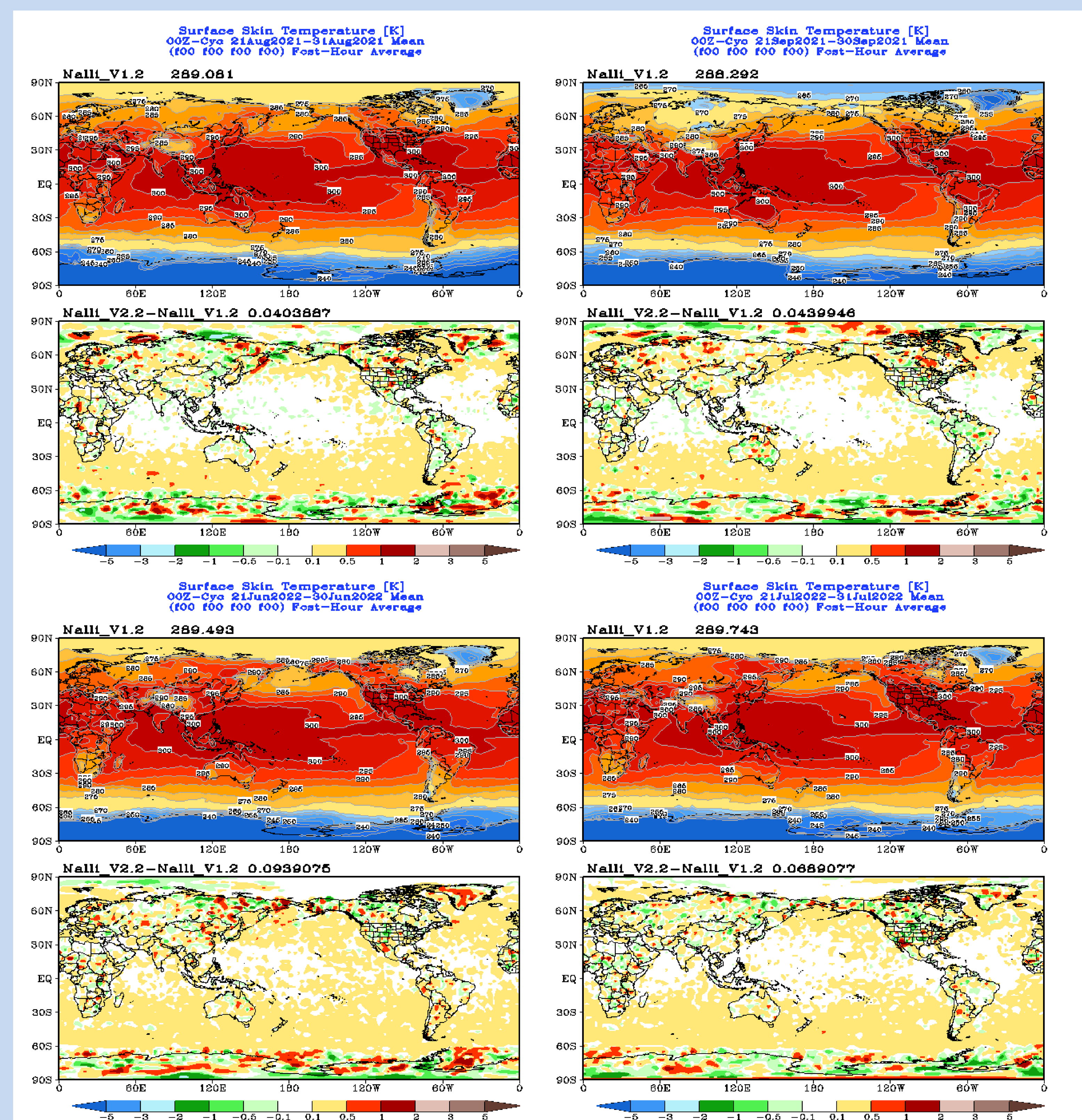
Summary

A new thermal-to-far Infrared Sea Surface Emissivity (IRSSE) model was developed by Nalli et al. (2023) to account for the ocean surface temperature dependency on emissivity. This new IRSSE will be available in CRTM_V3.0.

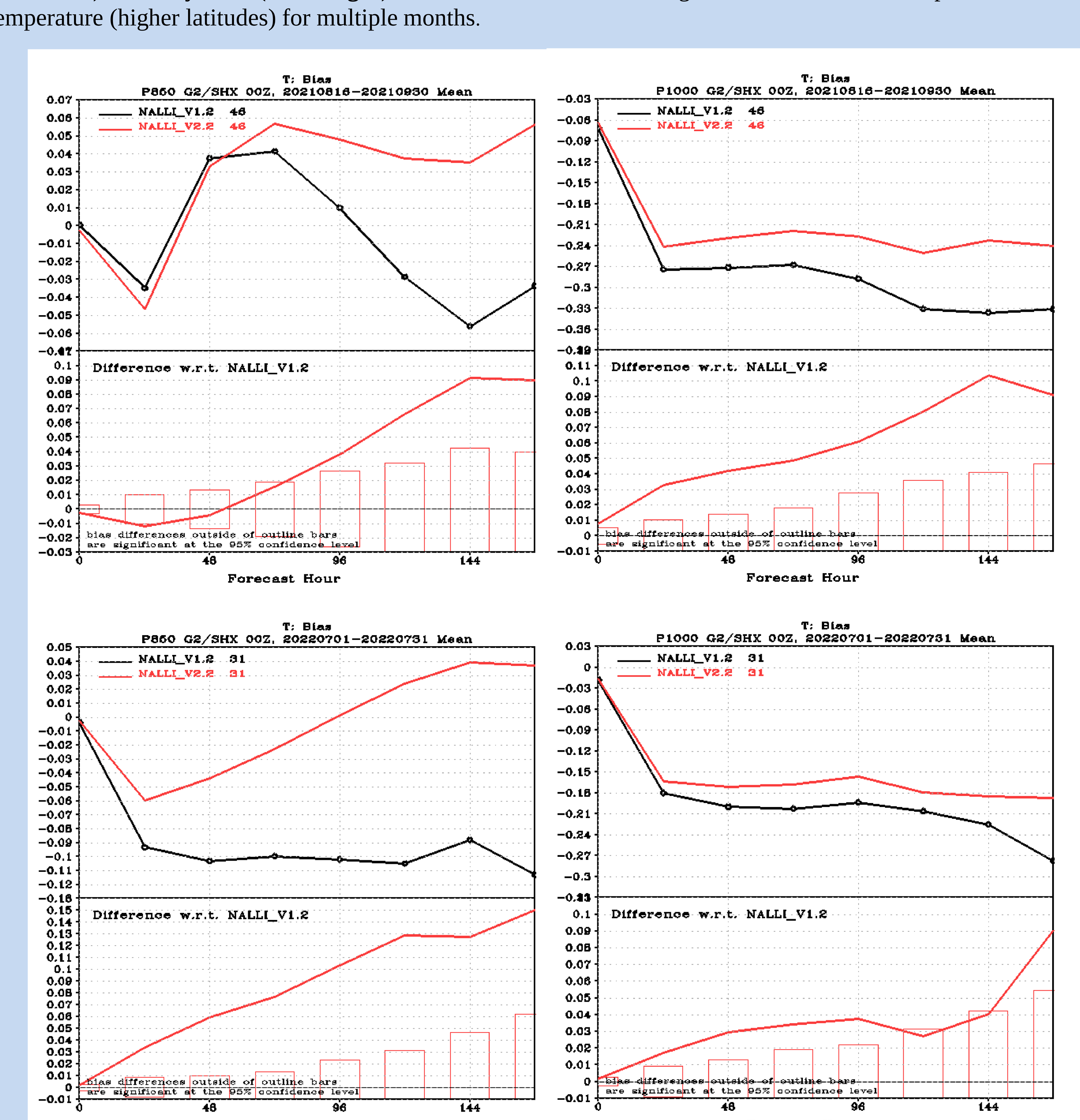
The full spectral resolution CrIS and IASI data were used to quantify which channels, and to what extent, the emissivity temperature had. Theory suggests the 800 – 900 cm^{-1} regions have the greatest dependency. The 900 – 920 cm^{-1} region dependency was determined to be other trace gases. Improvements in the 800 – 900 cm^{-1} region were verified after the emissivity temperature dependence was applied. More consistent results between channels with and without the temperature dependence were verified using an observation – background channel double difference.

A closer look at the initial test indicated issues with the air mass bias correction terms for surface channels. The airs mass terms were improperly accounting for the emissivity temperature dependence. Corrections were being made to channels with no emissivity temperature dependence. Channels with the emissivity temperature dependence did not get an adequate correction. Removal of the air mass portion of the bias correction for channels that do not have and emissivity temperature dependence improved the overall fit statistics.

Changes to the ocean surface temperature in the analysis between Nalli_V1.2 and Nalli_V2.2 are consistent with expectations. The colder ocean temperatures (higher latitudes) are now warmer by up to 0.5K. These surface and near surface temperatures in the analysis are maintained throughout the 7 day forecasts.



10 day average surface temperature for August 2021 (upper left) September 2021 (upper right), June 2022 (lower left) and July 2022 (lower right). All show consistent warming of the ocean surface temperatures at colder temperature (higher latitudes) for multiple months.



Forecast time series of temperature at 850 hPa (left) and 1000 hPa (right) for 202108 (top) and 202207 (bottom) in the Southern Hemisphere. These plots show the lowest model layers are consistently warmer using the new IRSSE model. These results are hemispheric averages (20° -80° south latitude) and include all surface types.

References

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