Evaluating CrIS Shortwave Infrared Observations in the NOAA Global Data Assimilation System: Impacts and Recommendations

Contact info: erin.jones@noaa.gov

Erin Jones[1,2,3], Nadia Smith[4], Kevin Garrett[3], Kayo Ide[2], Chris Barnet[4], Sid Boukabara[3]

Contributions from: Bryan Karpowicz (GESTAR, NASA GMAO)

1. CISESS
2. University of Maryland
3. NOAA/NESDIS/STAR
4. STC

1. Background and Motivation

The Cross-track Infrared Sounder (CrIS) instrument is a hyperspectral infrared (IR) instrument which provides radiance measurements of the atmospheric column with 2211 channels in three bands: longwave (LW, 650 – 1095 cm^{-1}), midwave (MW, 1210 – 1750 cm^{-1}), and shortwave (SW, 2155 – 2500 cm^{-1}). Historically, numerical weather prediction (NWP) centers have had a strong preference for the use of LW observations from hyperspectral IR sensors (e.g. CrIS, AIRS, IASI) in global data assimilation (DA) and NWP, because it's necessary to account for things like non-local thermodynamic equilibrium (NLTE) and solar reflectance when using SW observations.

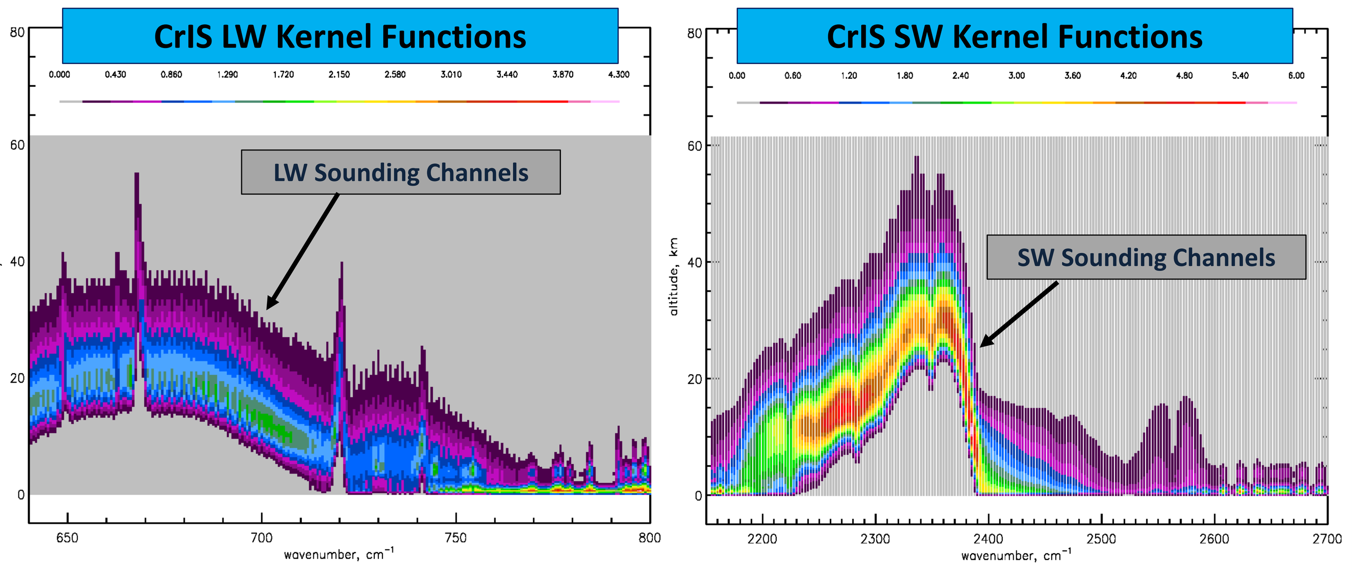

Figure 2. Temperature kernel functions (mid-latitude) for CO_2-sensitive regions of CrIS LW and SW bands. The CrIS SW R-branch kernel function is more narrow (indicates higher vertical resolution) and more sensitive than its LW counterpart.

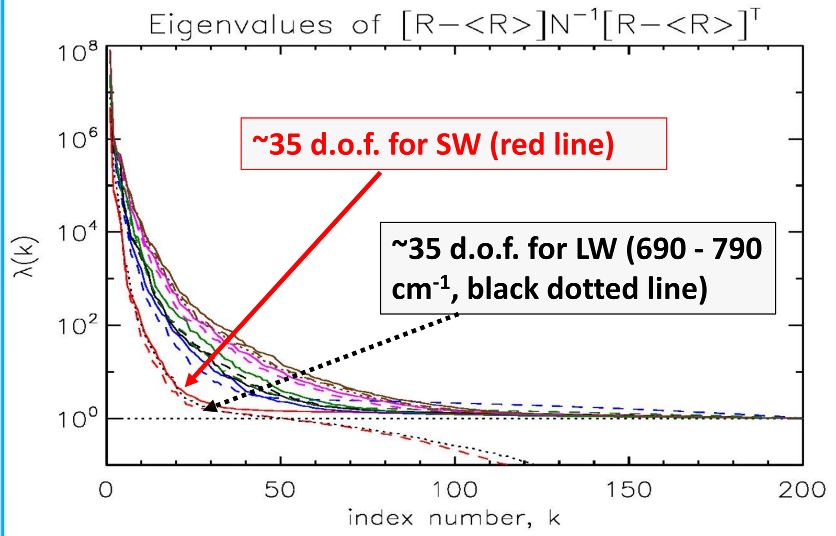

Figure 1. Information provided by subsets of the CrIS-FSR 431 channel set; computed outside of the DA system.

Recent advances in radiative transfer (RT) models can mitigate some the challenges of using SW observations in DA and NWP. There are several potential benefits to pursuing the use of SW observations in DA for global NWP. At NOAA, and for CrIS specifically, some of these are:

- **Some CrIS SW channels are highly sensitive to temperature with little interference from water vapor and trace gases**
- **The amount of information provided by the SW channels in NOAA's CrIS full spectral resolution (FSR) 431 channel set is comparable to that provided a majority of the operationally assimilated CrIS LW channels**
- **CrIS SW observations are readily available from SNPP and NOAA-20; minimal modifications are required to ingest and assimilate them in the NOAA Global Data Assimilation System (GDAS)**
- **Assimilating CrIS LW + MW + SW bands together has potential to enhance positive impacts of assimilating CrIS**
- **Interest exists among small-sat manufacturers to produce CrIS SW-like and/or SW-only hyperspectral IR instruments**
- **LW and MW bands on instruments like CrIS can fail, as has been seen with SNPP CrIS**

2. Using CrIS Shortwave Observations in the GDAS

Assimilating CrIS SW observations in the NOAA GDAS required a few enhancements to the DA quality control (QC) and errors in order to account for inherent differences between CrIS's LW and SW bands:

- **The QC check that flagged and de-weighted (or removed) daytime CrIS observations over water from channels with wavenumbers greater than 2000 cm^{-1} was replaced with a sun glint check for surface sensitive CrIS SW channels**
- **Cloud detection QC for CrIS SW channels was changed to be dependent on CrIS SW observations, and not CrIS LW observations**
- **A scene-dependent observation error was implemented for high peaking, cold, and typically noisy (owing to the radiance to brightness temperature conversion) CrIS SW channels; impacts weighting and gross check**

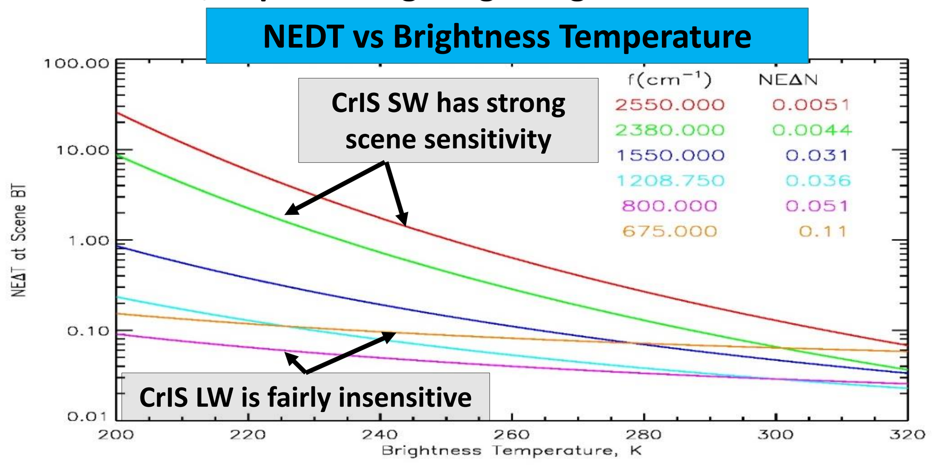

Figure 3. The non-linearity of the Planck function leads to a higher uncertainty in the radiance to brightness temperature conversion (performed in the GDAS) for CrIS SW observations in colder scenes. This effect is not as noticeable in the LW.

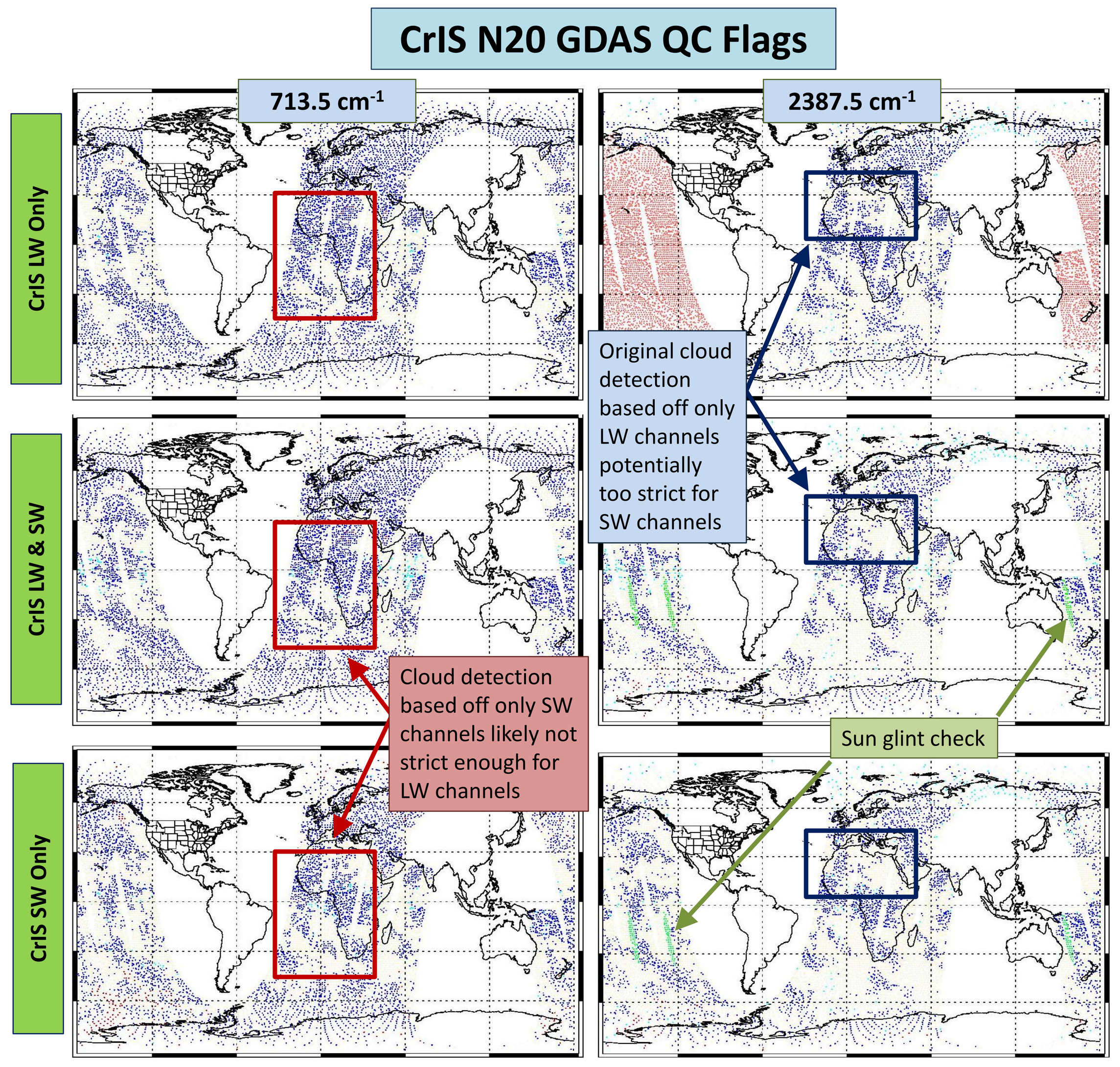

Figure 4. QC Flags for one cycle of the GDAS from experiments assimilating CrIS data in three configurations: LW-only (top), LW + SW (middle), and SW-only (bottom). The LW-only example uses no enhancements for the assimilation of CrIS SW observations; the SW-only example uses enhanced QC procedures and scene-dependent errors for CrIS SW channels, but does not treat CrIS LW and SW cloud detection QC separately (SW channels only are used for cloud detection for all CrIS channels). The LW + SW example uses QC and error enhancements for CrIS SW channels, but all original QC and error procedures for CrIS LW channels.

Initial tests assimilating CrIS LW and SW observations together indicate that QC changes made for CrIS SW channels (namely using CrIS SW channels in cloud detection) may not be appropriate for the assimilation of CrIS LW data. This has been addressed by allowing CrIS LW channels to be used for cloud detection QC of CrIS LW observations and CrIS SW channels to be used for cloud detection QC of CrIS SW observations.

3. Analysis and Forecast Impacts

To evaluate the analysis and forecast impacts of assimilating CrIS SW observations, 52 SW channels from SNPP and NOAA-20 CrIS were assimilated in SW-only and LW+SW (CrIS SW channels used on top of all CrIS channels normally assimilated operationally at NOAA) configurations in the NOAA Finite Volume Cubed Sphere Global Forecast System (FV3GFS) / GDAS, with enhancements for the QC and error specification for CrIS SW observations. A LW-only experiment was performed using operationally assimilated CrIS channels as a baseline for comparison, and experiments were run at 00Z for 20181201 – 20190131.

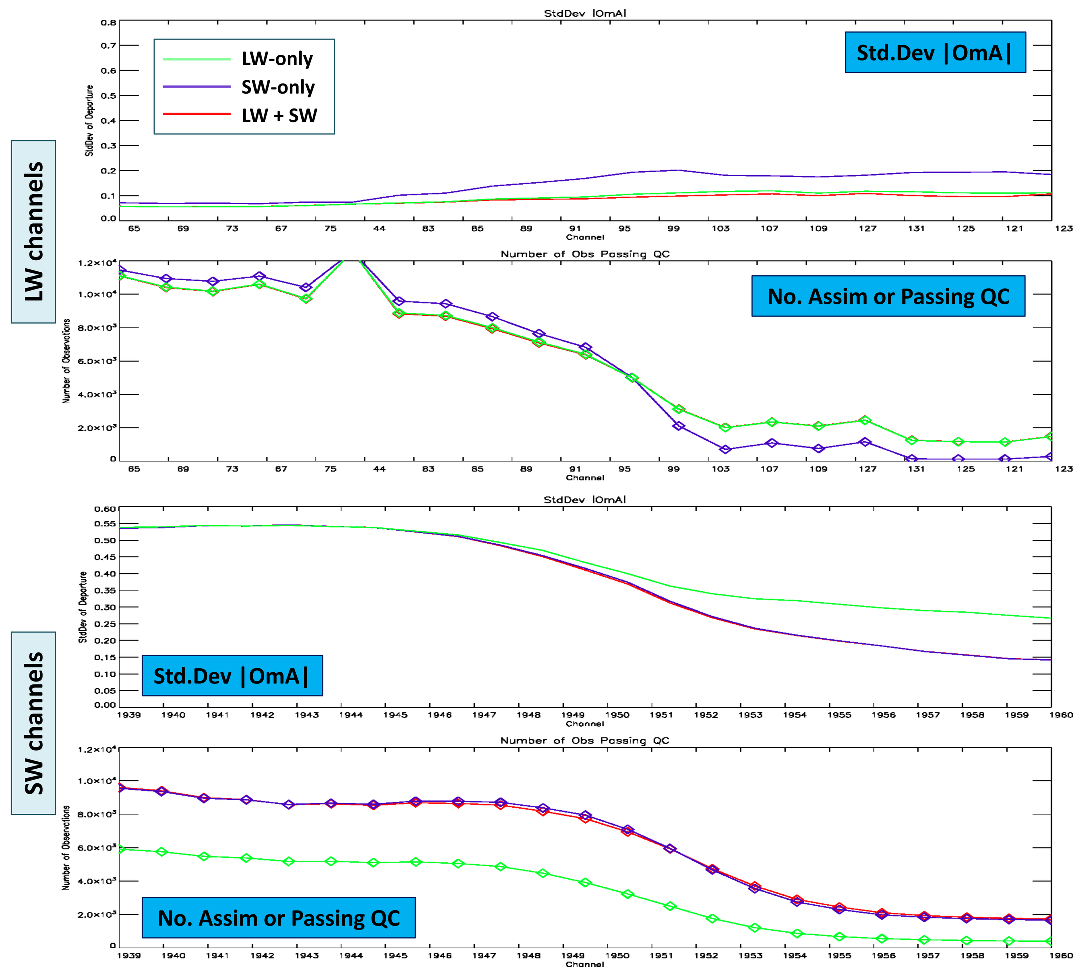

Figure 5. Mean standard deviation of |OmA| and number of observations assimilated (or passing QC, if monitored) for SW R-branch channels (bottom panels) and their LW "equivalents" (top panels) for one month of the LW-only (green line), SW-only (blue line), and LW+SW (red line) experiments. Note similar performance for LW channels in LW-only and LW+SW experiments, and similar performance for SW channels in SW-only and LW+SW experiments.

|OmA| and |OmB| (not shown) statistics for CrIS observations were compared from the three experiments. Enhancements to CrIS SW QC and observation errors improve |OmA| statistics for CrIS SW channels in the SW-only and LW+SW experiments, and do not appear to degrade performance of CrIS LW channels in the LW+SW experiment.

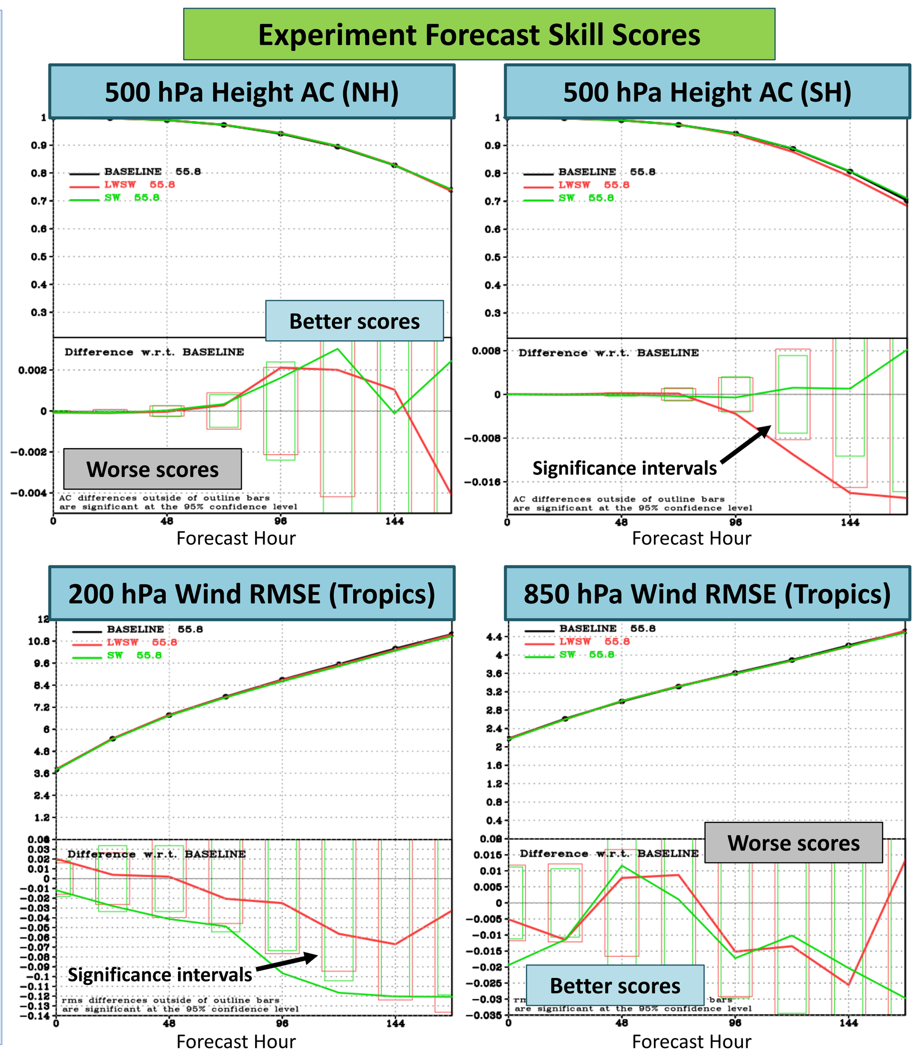

Figure 6. Forecast skill scores for LW-only (Baseline, black line), LW +SW (LWSW, red line), and SW-only (SW, green line) experiments. 500 hPa anomaly correlation (AC) scores (top) for Northern and Southern Hemispheres, and tropical wind root mean square error (RMSE) scores at 200 hPa and 850 hPa. Experiment forecasts are verified at 1° resolution against ECMWF analyses at 00Z. Larger AC scores and smaller RMSE scores are more favorable. Note the SW-only experiment typically has best performance overall, but differences between the three experiments are not significant for most variables and at most lead times.

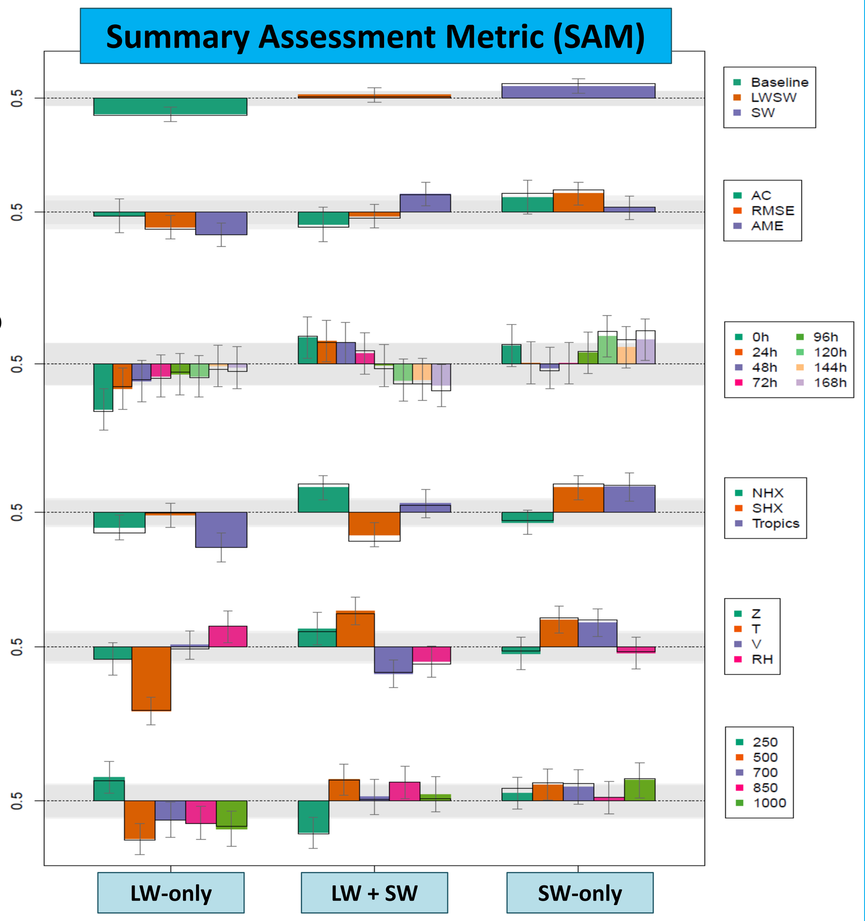

Figure 7. Summary Assessment Metric (SAM, Hoffman et al., 2018) overall forecast skill score for LW-only, LW + SW, and SW-only experiments. Assessments, from top to bottom, for overall skill, skill based on metric, skill by forecast lead time, skill by region, skill by variable, and skill by pressure level.

Experiments were verified against ECMWF. The best overall performance was seen for the SW-only experiment when comparing forecast skill metrics; good performance is seen in the LW+SW for some variables, lead times, etc., though work is ongoing to see how the assimilation of CrIS LW and SW observations together can be improved.

5. Conclusions and Future Work

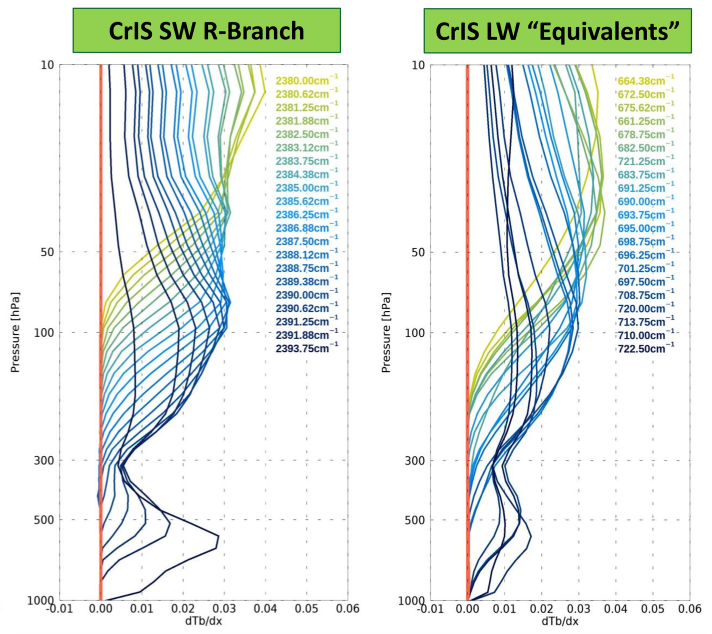

Figure 8. Average temperature weighting functions for CrIS SW R-branch channels and their CrIS LW "equivalents." Assessment performed using the SARTA radiative transfer model.

Experiments thus far at NOAA STAR have shown that assimilating CrIS SW channels in the NOAA GDAS is possible, and can add value to FV3GFS forecasts. Recommendations for assimilating CrIS SW observations include:

- **Employing the use of a scene-dependent observation error, at a minimum for SW channels of wavenumber less than 2386 cm^{-1}**
- **QCing surface-sensitive SW data for sun glint over water in daytime**
- **Using CrIS SW channels for SW cloud detection**

Work with CrIS SW is still relatively new, and there is much still left to do. Initial results assimilating CrIS LW and SW observations together suggest that there may be some issues unaccounted for when using CrIS SW channels with channels from CrIS's other two bands. Of note is the fact that work still needs to be been done to use correlated observation errors for CrIS SW.

Work is ongoing to assess the sensitivities and performance of the full CrIS 2211 channel set, including CrIS MW channels. This assessment will seek inform an improved channel selection for the assimilation of CrIS data. Current and future areas of focus include:

- **The extension of correlated observation errors to CrIS SW, and to channels not within NOAA'S CrIS 431 channel set**
- **The assessment of channels from the CrIS 2211 channel set**
- **The exploration of using CrIS SW N_2O channels (lower scene-to-scene variability than high peaking R-branch channels)**
- **The optimization of GDAS QC and errors for CrIS LW and MW channels, and further optimization for CrIS SW, if needed for the concurrent assimilation of CrIS LW (and MW) channels**
- **The performance of new experiments to assess the impact of assimilating CrIS 2211 data on FV3GFS forecasts**

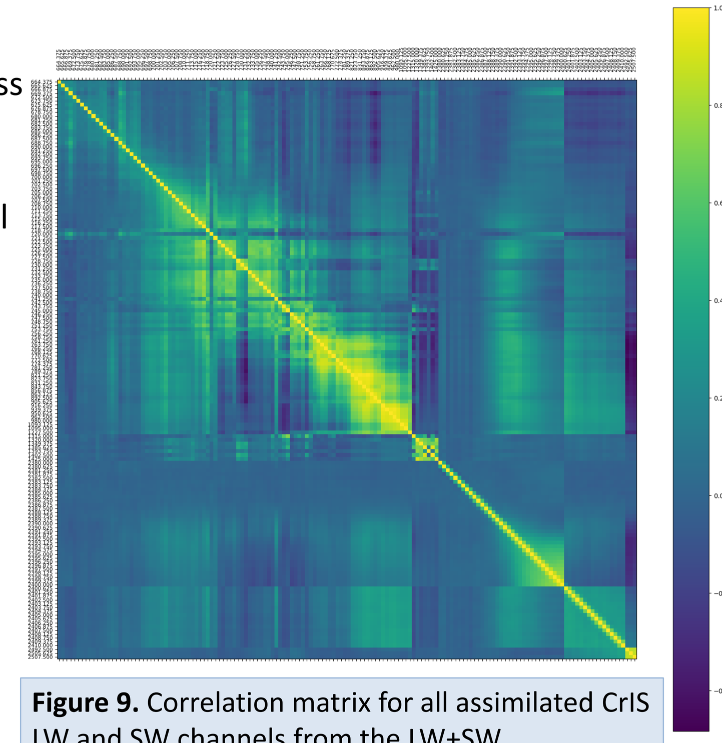

Figure 9. Correlation matrix for all assimilated CrIS LW and SW channels from the LW+SW experiment. Lowest wavenumbers are at top left.

Manuscripts profiling work done thus far at NOAA/STAR and STC to assess and assimilate CrIS SW observations are currently in production.