Preparing for CrIS Full Spectral Resolution Radiances in the NCEP Global Forecast System

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Introduction

The Joint Polar Satellite System (JPSS) Program Office and JPSS Science Teams improved the spectral resolution of the Cross-track Infrared Sounder (CrIS) on Suomi National Polar-orbiting Partnership (SNPP). This change shortened the spectral resolution and increased the channel counts for band-2 and band-3 (midwave and shortwave regions respectively). The CrIS channel counts increased from 1305 to 2211. These data are typically identified as CrIS Full Spectral Resolution or CrIS-FSR. CrIS-FSR is expected to be the standard CrIS resolution for JPSS-1 (NOAA-20) and beyond.

To identify the two different resolutions, The National Environmental Satellite, Data, and Information Service (NESDIS) Center for Satellite Applications and Research (STAR) Algorithm Scientific Software Integration and System Transition Team (ASSIST) incorporated a new flag *MTYP* to the CrIS BUFR template. When the flag is set to *FSR* the full spectral resolution data follows. The *guard* channels were also added to the Binary Universal Form for the Representation of meteorological data (BUFR_ for anyone wanting to remove the apodization. The rest of the CrIS-FSR BUFR template remains the same as the current CrIS. NESDIS/STAR/ASSIST is generating the CrIS-FSR 2211 channel data in near real time, and they are available at: ftp://ftp.star.nesdis.noaa.gov/pub/smcd/opdb/letitias/NUCAPS/CrIS_HR_BUFR/.

The Environmental Modeling Center branch of the National Centers for Environmental Prediction (NCEP/EMC) and the Science and Technology Corporation (STC), in collaboration with other Numerical Weather Prediction (NWP)Centers, have worked out a 431 CrIS-FSR channel subset. This new subset is expected to be used to distribute CrIS-FSR data from the Regional ATOVS Retransmission Services (EARS/RARS) and Direct Broadcast sites. Recently NESDIS/STAR/ASSIST has also started generating a CrIS-FSR 431 channel subset. It is available at: ftp://ftp.star.nesdis.noaa.gov/pub/smcd/opdb/letitias/NUCAPS/CrIS_HR_BUFR_Subset/.

Hyperspectral Infrared Channel Subset Modifications

NCEP has found it difficult to use all of the channels from the various hyperspectral infrared instruments. Channels which couldn't be used in assimilation systems, for various reasons, had to be kept throughout the assimilation process. The alternative was to develop subsets for each instrument such as the Atmospheric Infrared Sounder (AIRS) 281, AIRS 325, Infrared Atmospheric Sounding Interferometer (IASI) 300, IASI 616, IASI 500, and CrIS 399. In the past, users were constrained to assimilating one of these designated subsets or receiving all of the channels. A few years ago the Community Radiative Transfer Model (CRTM) Team developed the ability to accommodate a user-defined subset of channels. This was the first step toward removing the specific channel subset constraints in the Gridpoint Statistical Interpolation (GSI) software.

The software modifications have now been incorporated into the NCEP GSI software to take advantage of these user-defined subset capabilities for the hyperspectral infrared instruments. Channel use is now defined by editing the channel entries in the *satinfo* file. If a channel is not defined in the *satinfo* file, it is basically ignored by the system. The channel is not counted for array allocations, is ignored during the read routine, and the CRTM forward model is not run. This has the potential to save memory and computer time. The GSI user community now has the capability to read the full channel files (e.g., AIRS 2378, CrIS1305, CrIS-FSR 2211, and IASI 8641) or any subset of hyperspectral infrared channels, and to assimilate and monitor only those channels suitable to their current requirements.

Review CrIS Quality Control and Thinning Routines

The current CrIS quality control procedures and spatial thinning routines were reviewed for potential improvements in quality control and performance. The design of the CrIS instrument posed some unique challenges to the way it is used, specifically the fields of view within a field of regard twist along the scan line as shown in Figure 1. A post-launch change also included adding cloud information into the BUFR file, which can be used for quality control.

Two quality control procedure changes for CrIS within the GSI were updated. All Field of View (FOV)s within a Field of Regard (FOR) are now reviewed instead of FOV=5, and the channel validity check is now last. In looking at all FOVs, the scan angle tests were updated to account for the sensor twist as shown in Figure 1. Adding all of the FOVs increased the total number of profiles by about 500 in each Global Data Assimilation System (GDAS) cycle. The channel validity check converts the radiances in the BUFR file to Brightness Temperatures, then checks to see if the Brightness Temperatures are reasonable. The time needed to convert radiances to brightness temperatures increases as the number of channels increases. Moving this conversion and validity check to be the final test allows all of the other tests to reject a profile before the time is taken to do this conversion.

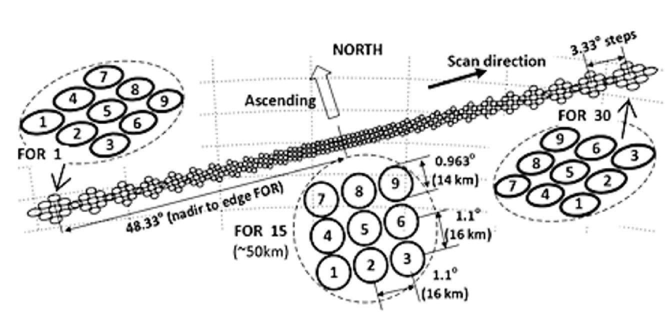

Figure 1. CrIS scan scenario. From Han et al. 2013. http://onlinelibrary.wiley.com/doi/10.1002/2013JD020344/full#jgrd50972-fig-0003.

The original NCEP GSI thinning routine chose the profile with the warmest brightness temperature within the specified grid box. Using the warmest spot created detector biases and generally produced a skewed (and biased) distribution. The warmest (and coldest) FOVs are typically at the corners (FOV 1,3,7, and 9) as shown in Figure 2. These biases led to a skewed Probability Density Function (PDF). The warmest spot technique was modified to use the model surface temperature as a baseline for clear/cloudy profiles. If the surface channel is warmer than the model surface temperature, the profile is deemed to be clear and the clear profile closest to the center of the thinning box is then chosen. If the brightness temperatures are colder than the model surface, the warmest profile is chosen.

Cloud information (cloud amount, cloud height) derived from the Visible Infrared Imaging Radiometer Suite (VIIRS) was added to the CrIS-FSR BUFR file in May 2017. This information is now part of the NCEP GSI thinning routine. The profile with the lowest clouds, or no clouds, is chosen. If the VIIRS cloud information is missing, the read_cris subroutine reverts to using the brightness temperature of a surface channel (501) to determine the clearest profile. Using the VIIRS cloud information improved the surface channel Observation – Background statistics as shown in Figure 3. The cloud information could also be biased toward specific Field of View and/or Field of Regard. To test for this we took all of the FOVs determined to be clear by the VIIRS product for 4 weeks and determined the number of clear for each FOV in a FOR. If there are no systematic biases, the clear counts of each FOV in a FOR will be equal. Subsequently, the larger scan angles are expected to have more cloud contamination than at nadir. As shown in Figure 4, there is some spread in the number of clear FOVs in a FOR near the edges and some asymmetry in the number of clear FORs but they are reasonably close.

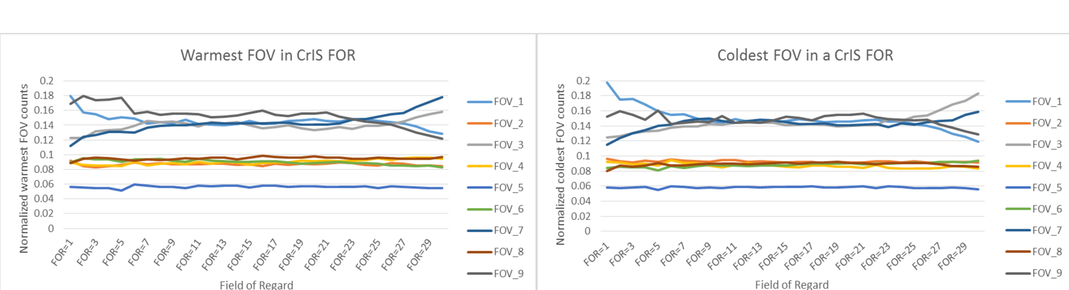

Figure 2 Probabilities of selecting the warmest (left) or coldest (right) from a specific Field of View from each Field of Regard. Corner Fields of View (FOV=1,3,7,9) have the greatest probability of being chosen. The center Field of View (FOV=5) has the least probability.

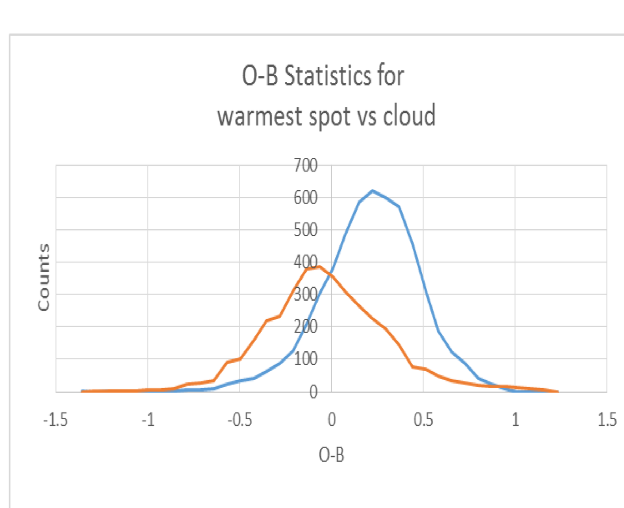

Figure 3 Observation – background statistics from using the warmest spot (blue) and using the VIIRS cloud information (gold).

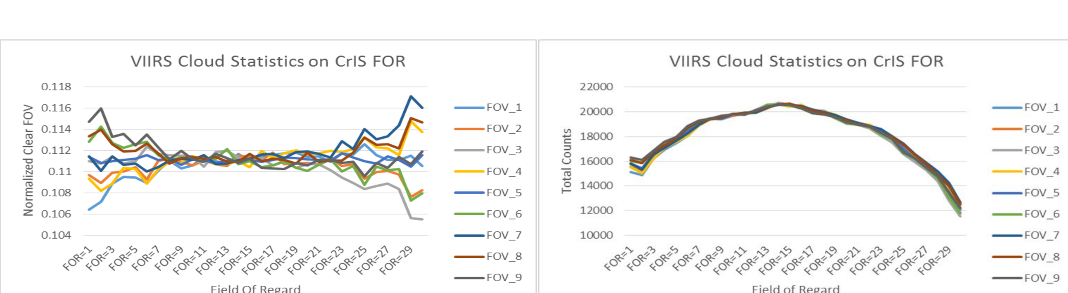

Figure 4 Statistics from mapping the VIIRS cloud information onto the CrIS FOV. Left panel is the probability a specific FOV would be clear with respect to all clear FOV within a FOR. Right panel is the number of clear FOVs within each FOR. Larger scan angles are expected to have less clear FOVs.

These three changes, using all FOVs, redesign of the distance from center of the thinning box, and using VIIRS cloud information has increased the number of profiles by ~5% and the total number of channels used by ~17%.

Review the CrIS Channel Selection Used by NCEP's GDAS

A new channel subset was developed for the CrIS-FSR by Antonia Gambacorta and Andrew Collard with input from various NWP Centers. The new channel selection has; 125 temperature, 139 surface, 19 ozone, 108 water vapor, 24 shortwave, 5 sulfur dioxide, 5 carbon monoxide and 6 methane channels. This CrIS-FSR 431 subset will replace the current CrIS 399 subset for NPP and NOAA-20.

To test the transition to CrIS-FSR a single season experiment was conducted using the NCEP lower resolution (T670) GDAS. The control used the current 82 temperature channels from the CrIS 399 subset. Our initial experiment used 94 temperature and 8 water vapor channels from the CrIS-FSR 431 subset. Adding these 8 water vapor channels has shown modest changes to the analysis and 24 hr forecast with respect to the control as shown in Figure 5. Modest increases in the number of water vapor observations were also found in other sensor like ATMS as shown in Figure 6.

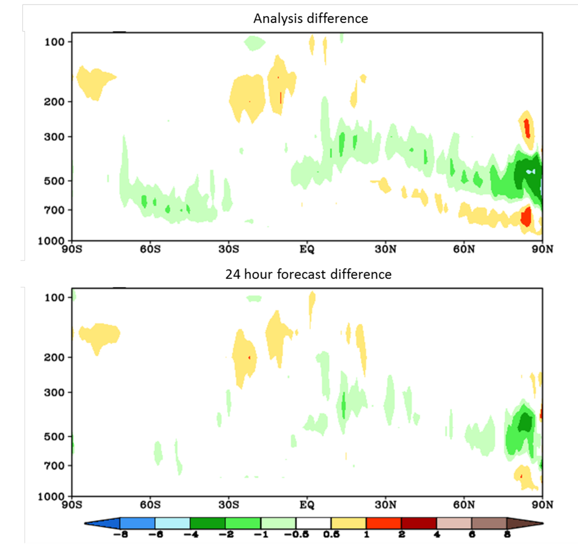

Figure 5 Average relative humidity difference in the GDAS analysis (top) and 24hr forecast (bottom) from adding 8 CrIS-FSR water vapor channels.

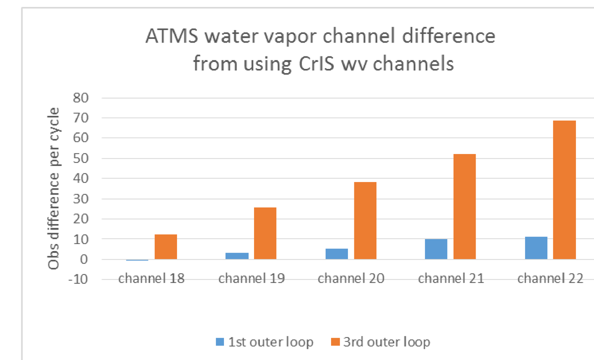

Figure 6. Increased use of ATMS water vapor channel observations when using 8 CrIS-FSR water vapor channels. Blue are extra observations passing initial QC. Gold are extra channels used in the final analysis.

NCEP is in the process of adding a new verification and diagnostic tool called the Ensemble perturbation-based Forecast Sensitivity to Observations Impact (EFSOI). The ESFOI formulation incorporates the relationship between Kalman gain and analysis – error covariance, based on an ensemble of analyses, to construct observational increments that can be projected forward in time with a forecast model, enabling an estimate of quadratic forecast error reduction due to assimilating individual observations (Kalnay et al. 2012 and Ota et al. 2013). The results presented here pertain to the estimated 24 hour quadratic forecast error reduction for the moist total energy norm described in Ehrendorfer et al. 1999. The EFSOI was computed for the last week of the control and experiment. The control has CrIS ranked 9th in the overall instrument ranking. The new channel selection moved CrIS to 5th overall as shown in Figure 7. The increase in ranking seems to be mostly due to the water vapor channels as shown in Figure 8.

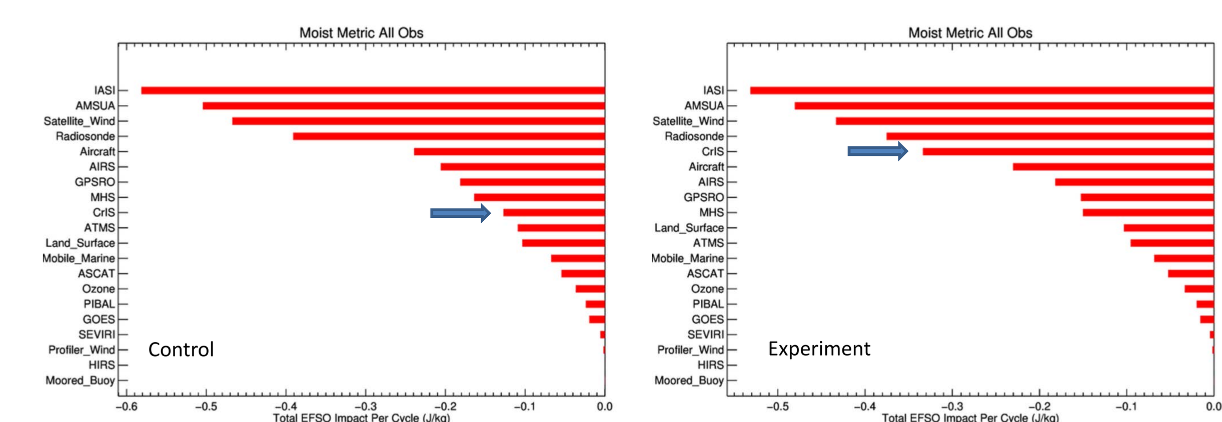

Figure 7. Total moist energy norm computed from the GDAS Ensembles (EFSOI). Left is the control where CrIS is 9th. Right is the experiment where CrIS has moved to 5th.

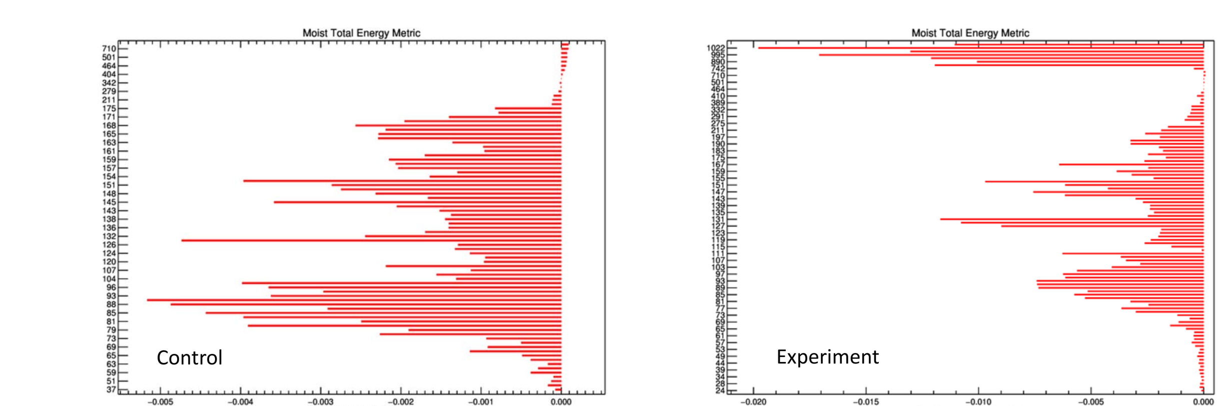

Figure 8 Per-channel moist energy norm computed from the GDAS Ensembles (EFSOI). Left is the control (82 temperature channels). Right is the experiment (94 temperature and 8 water vapor channels). The water vapor channels contribute the most to this metric. Note: vertical and horizontal scales are not identical.

Anomaly correlations are a standard metric and are mostly driven by temperature observations. Since only a few more temperature channels were added, impacts on the anomaly correlations were expected to be minimal. As shown in Figure 9, the 47 day average of 500 hPa anomaly correlations in the Northern and Southern hemispheres are mostly neutral with none being significantly different from the control.

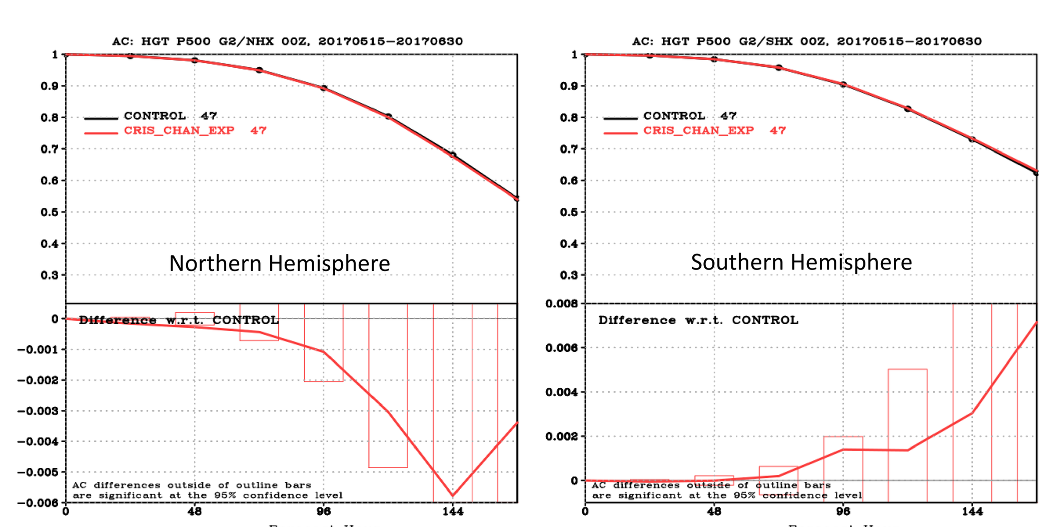

Figure 9. 500 hPa anomaly correlations in the Northern (left) and Southern (right) Hemispheres for the current CrIS channel selection (black) and a new CrIS-FSR channel selection (red).

Future Work

NWP Centers are moving toward using channel correlation matrices to characterize these channel inter-dependencies and to more effectively use various channels in their assimilation systems. The NWP Centers are showing modest forecast skill improvements by doing this. As a result, we are working to generate this matrix for CrIS-FSR. Some modifications to the matrix generation software as well as two different techniques are being investigated. Figure 10 is a CrIS-FSR correlation matrix derived from the technique NCEP/EMC currently plans to use.

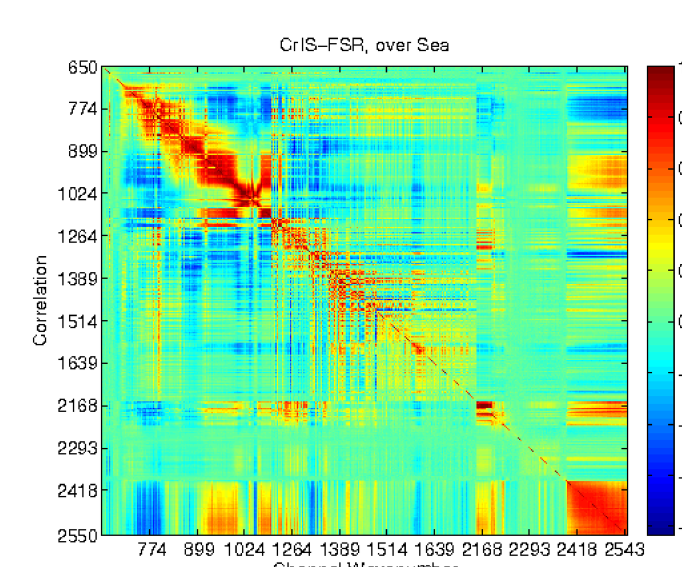

Figure 10. Channel correlation matrix for CrIS-FSR. This matrix is used by the GSI to account for various channel cross-correlations. Using this matrix allows for better characterization of each channel and thus more optimal use.

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