Improving CrIS Infrared Assimilation in the GEOS Atmospheric Data Assimilation System

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Motivation

CrIS has been an integral part of the global observing system in NWP. While CrIS has provided an improvement in forecast skill owing to direct assimilation of observed radiances, it has not had as strong an impact in GEOS atmospheric data assimilation system (GEOS-ADAS), or in the GDAS/GFS data assimilation system compared with the US Naval Research Lab's NAVDAS-AR, or ECMWF's global systems. Both the GEOS ADAS and GDAS utilize the Gridpoint Statistical Interpolation analysis system (GSI), and the same cloud detection scheme for all hyperspectral sounders and is suboptimal for CrIS. The GMAO has recently observed failed cloud detection has resulted in some strong degradation in Forecast Sensitivity Observation Impact (FSOI). These channels typically peak in the lower stratosphere but have sensitivity into the troposphere making them sensitive to clouds. A short-term solution has been developed which uses a tighter gross check to reduce some of the more obvious cloud contaminated observations. In addition to CrIS, some similar FSOI degradation has been observed with some AIRS and IASI lower stratospheric sensitive channels as well. A similar gross check modification is shown for IASI and AIRS. A more long-term solution would be to explore a different cloud detection scheme (replace GSI's minimum residual method), or perhaps replacing or supplementing longwave channels with equivalent shortwave channels with sharper peaking weighting functions. A few of these channels have slightly shorter tails and may be less susceptible to cloud contamination, however, they may have higher noise along with NLTE effects present.

Summer 2022 - Something Troublesome Appears in GEOS-FP…

Looking at Figure 1, starting in May of 2022, several relatively large spikes in FSOI (positive indicating the observation degrades the forecast) appear for CrIS observations. A particularly strong spike appears on July 26, 2022, in globally accumulated FSOI for NPP and NOAA 20 (Panels A and B, respectively). This spike appears to be concentrated in the southern hemisphere for NPP and NOAA 20 (Panels C and D, respectively). When accumulating FSOI by channel, it was observed that assimilated stratospheric channels between channel 69 and 76 were particularly strong, along with tropospheric channels 112-114. A simple spatial plot of FSOI accumulated for channel 74 shown in Figure 2, shows what appears to be a cloud signature. In Figure 3, the bias correction for this channel seems to contribute to the problem by bias correcting a cloudy region making it more difficult for the GSI cloud detection to QC out the observations.

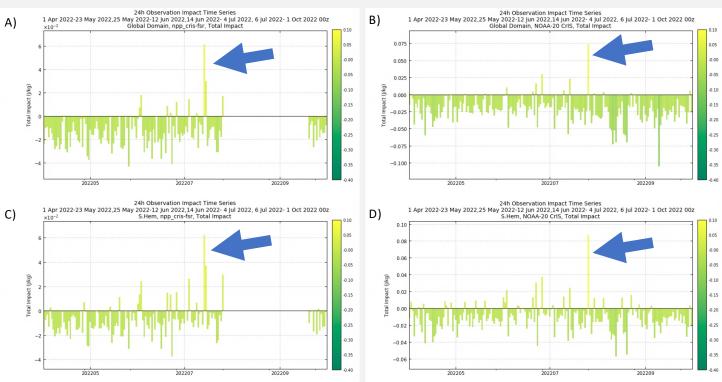

Figure 1: Time series plots of Total CrIS FSOI per analysis cycle. Panels A and B are combined global values for NPP and NOAA 20 platforms, respectively. Panels C and D are combined values in the southern hemisphere for NPP and NOAA 20, respectively

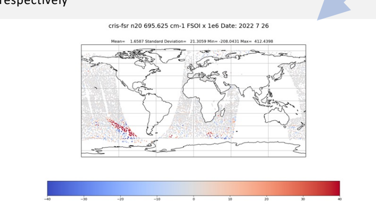

Figure 2: Spatial plot of FSOI in µJ/kg red region indicates cloudy region mistaken for clear

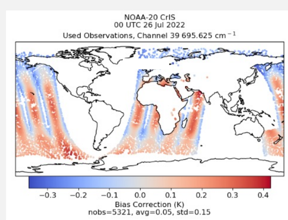

Figure 3: Bias correction applied to assimilated observations on July 26, 2022

Developing Temporary Solution - Gross Check

The GSI which is at the core of GEOS-ADAS and GDAS provides a gross check which is the smaller of 3 times the observation error or a prescribed limit. This prescribed limit for assimilated CrIS channels is typically set to 2.0 K. As a stopgap measure to minimize obvious cloud getting past QC measures, this limit was set to a value of 0.4 K. This limit was determined by looking at histograms of channels which appeared to have skewed distributions for lower stratospheric/upper tropospheric channels. The 0.4 K limit was chosen as a balance between removing undesirable obvious cloud, and not modifying the penalty or observation count drastically. Data storage and processing restrictions require testing of this gross check to be applied to a lower resolution GEOS model of C360 (~25 km) vs C720 (~12.5 km) in FP. Here the results are filtered to GEOS-FP's FSOI output using an O-B filter value of 0.4 K.

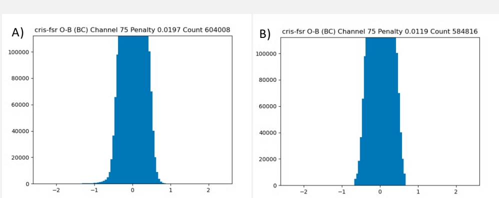

Figure 4: Histograms of all O-B for CrIS channel 75 for month of July 2022. Before applying 0.4K threshold (Panel A) and after (Panel B). Panel B shows the removal of a long cold tail but maintains a similar observation count and penalty.

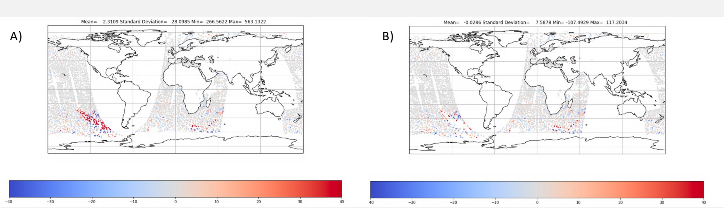

Figure 5: Map of FSOI before applying 0.4 K gross check (Panel A) and after applying gross check threshold (Panel B)

FSOI From Initial Experiments

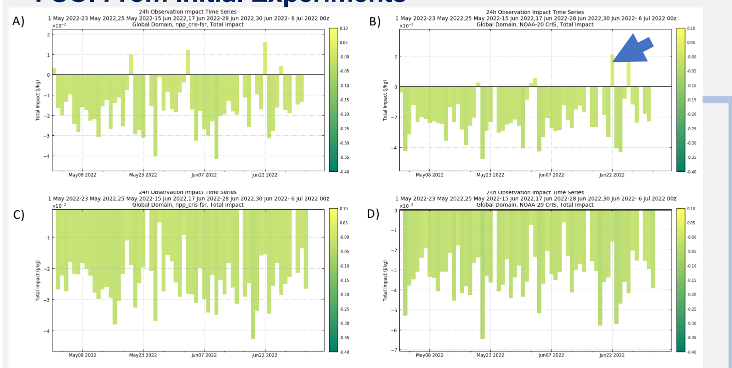

Figure 6: Time series plots of Total CrIS FSOI per analysis cycle. Panels A and B are combined global values for NPP and NOAA 20 platforms using control, respectively. Panels C and D are global values for NPP and NOAA 20 using the modified gross check.

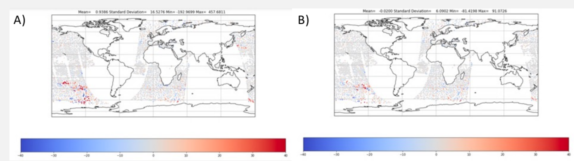

Figure 7: Map of CrIS N20 Channel 70 FSOI (uJ/kg) for June 22, 2022 for Control (Panel A) and modified gross check (Panel B)

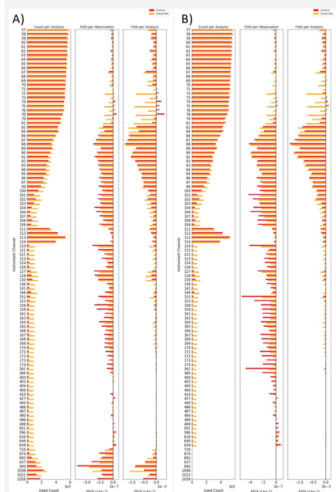

Figure 8: Chanel plot of CrIS NOAA 20 Control (Panel A) and CrIS NPP (Panel B) averaged over 2 months of experiment

Two experiments are conducted using a C360 resolution model run a control using the standard GEOS-ADAS configuration and a second experiment with a modified gross check.

Figure 6 Shows timeseries plots of FSOI for the control (Panels A & B), and experiment using the modified gross check (Panels C & D). It is clear several undesirable positive values in FSOI are reduced in the experiment with the modified gross check applied. Figure 7 shows a reduction in cloud signatures appearing in FSOI between the control (Panel A) and experiment (Panel B). While the signature is drastically reduced, it is not removed completely.

Figure 8 shows a per channel breakdown of assimilated data counts, FSOI per observation and FSOI per analysis. Red bars indicate the control, and orange indicates the experiment. Large improvements in FSOI per analysis are clearly observed for channels 69-76 where the modified gross check was applied, and little to no improvement for channels 112-114 where the modified gross check was also applied. An increase in counts for surface sensitive channels in the experiment were due to an additional fix selecting cloud detection channels reduced a systematic bias drift.

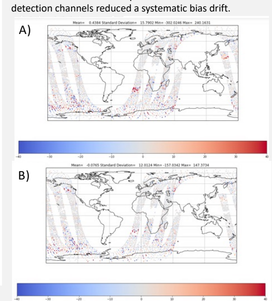

Figure 9: Map of FSOI Channel 157 on AIRS Control (Panel A) and applying a modified gross check (Panel B)

With this work a question arises: Does this phenomenon appear in other hyperspectral sensors? Applying the same methodology used for CrIS, similar effects were observed in lower stratospheric and upper tropospheric sensing channels on AIRS and IASI as well. Figure 9 shows an assimilation cycle with a similar threshold applied to channel 157 of AIRS in Panel B, while no threshold is applied in Panel A.

Opportunity to leverage SWIR?

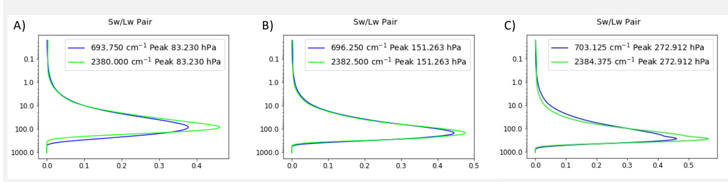

Figure 10: Example weighting functions for similarly peaking lower stratospheric/upper tropospheric sensing channels in the longwave infrared and shortwave infrared for CrIS using a US Standard Atmosphere

Recent developments in assimilating select CrIS CO_2 R-branch channels (See Poster by Burrows et al. and talk by Jones et al. this session) show that it is at least feasible to assimilate these SWIR channels. In Figure 10, the blue curves show LWIR currently used in the GEOS-ADAS, with the green curves representing similarly peaking SWIR channels. Given the LWIR channels in the GEOS-ADAS are poorly screened for clouds, there may be some benefit to using some of these SWIR channels which have sharper peaks and shorter tails into the troposphere limiting cloud contamination. However, the SWIR does have some significant disadvantages such as the need to account for non-local thermodynamic equilibrium effects, higher noise, and scene dependent noise. Nonetheless, supplementing LWIR with SWIR is something worth investigating.

Summary

Here a short-term mitigation strategy for additional cloud screening measures using a gross check has been presented. Additional work is needed to improve or replace the GSI cloud detection algorithm such that this temporary fix is no longer necessary. Another potential easy fix would be to turn off certain predictors in the bias correction as it appears the bias correction seems to over correct (see Figure 3). Potential avenues for research include leveraging recent work in the SWIR to supplement or replace select LWIR channels sensing the lower stratosphere, and alternative cloud detection algorithms.

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