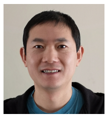
Challenges in CrIS shortwave radiance assimilation



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1. Background

1.1 Why shortwave infrared (SWIR)?

SWIR radiance use in NWP models is limited:

- Longwave infrared (LWIR) at 15μm CO_2 absorption band very successful
- SWIR has more T sensitivity and less contaminated by Q and O_3
- No operational centers are assimilating SWIR radiances

1.2 Challenges in SWIR assimilation

- One major issue: Non-local Thermodynamic Equilibrium (NLTE) effects; may add more than 10 K to observed brightness temperature (BT)
- Cannot avoid NLTE effects: Figure 1 shows that all SWIR sounding channels are affected by NLTE effects and only 6 channels with NLTE smaller than 0.1K
- Cannot avoid daytime SWIR radiances: need to be more cautious for nighttime, as will be shown in section 3.4.
- CRTM can simulate NLTE effects with major limitations
  - Underestimate of NLTE effects by 0.76K (Li et al., 2020)
  - No nighttime NLTE (associated with aurora activities)
  - large and unexplained discrepancies between observation (O) and background (B) at high latitudes during winter
- CRTM new coefficients improve NLTE simulation but still with underestimation
- Large day/night discrepancies in O-B bias, making it difficult to assimilate SWIR radiances in both daytime and nighttime

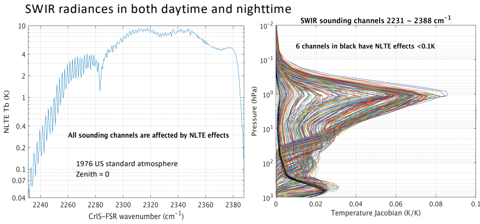

Figure 1. (left) CRTM simulated NLTE effects in BT (K) (CRTM simulated BT with NLTE effects turned on minus turned off) of all 250 SWIR sounding channels not or weakly affected by the surface and (right) Temperature Jacobians.

1.3 Recent progress in NLTE estimates

- Spectral Correlations to Estimate Non-local Thermal Equilibrium (SCENTE, Li et al. 2020) provides accurate NLTE estimates
- Better agreement between O and B
- Effective in both daytime and nighttime
- Overestimate of NLTE effects due to the use of CRTM in training

1.4 Questions and objective

- How to remove the bias in SCENTE NLTE estimates?
- How to use SCENTE NLTE to remove bias in CRTM NLTE simulation?
- How to quality control SWIR radiances to remove observations poorly simulated by CRTM in both daytime and nighttime?
- Objective: remove/minimize the day/night discrepancy in the O-B bias caused by the CRTM NLTE simulation, so that it is possible to assimilate SWIR radiances in both day and night

2. Data and tools

- CrIS full spectral resolution (FSR) sensor data record (SDR) data from SNPP and NOAA-20 for 2020
- ECMWF analysis as background
- CRTM with old (released version) and new (research version using revised vibrational temperature profiles) NLTE coefficients

3. Methodology

3.1 SCENTE NLTE estimates

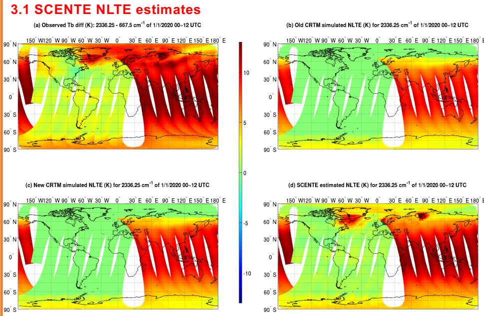

Figure 2. (a) The observed CrIS FSR BT differences between 2336.25 cm^{-1} and 667.5 cm^{-1} (former minus the latter), (b) CRTM simulated NLTE effects in BT (K) (CRTM simulated BT with NLTE effects turned on minus turned off) using old coefficients and (c) new coefficients, and (d) SCENTE estimated NLTE radiances converted to BT (K) from channel of 2336.25 cm^{-1} from 00 - 12 UTC on 1/1/2020. The large differences in (a) are caused by NLTE effects. The CRTM simulation is based on Version 2.1.3 with ODPS coefficients, with ECMWF analysis as input, and daytime (solar zenith angle ≤ 90°) including NLTE effects. The ascending orbits on right half of the imagery are mostly in daytime, and the descending observations are mostly in nighttime. The locations with discontinuity in (b) and (c) are the terminators.

3.2 Bias correction of SCENTE NLTE estimates

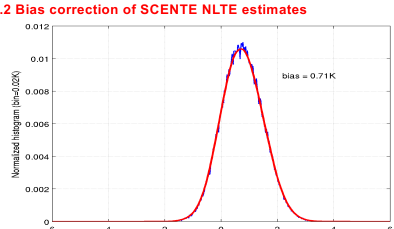

Figure 3. The normalized histogram of SCENTE NLTE estimates for all nighttime CrIS-FSR/SNPP field of views between 90°s and 75°s and from September 22 to October 27, 2020 for channel of 2320.625 cm^{-1}. The blue line is the original histogram and the red line is smoothed with 30 points average.

Without more accurate independent NLTE radiance measurements, it is difficult to directly estimate the bias in the SCENTE NLTE estimates. However, it is known that for most of time in nighttime there are no NLTE effects. So when SCENTE is applied to nighttime observations, the estimated NLTE radiances should be 0. Any systematic deviation from 0 indicates possible bias. The bias is determined as the most frequent value of SCENTE NLTE, or the mode of the histogram as shown in Figure 3. Further filtering to remove outliers due to nighttime NLTE effects are shown in Figure 4. The same bias is removed from the daytime SCENTE NLTE estimates.

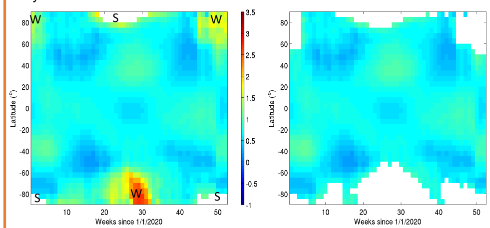

Figure 4. The bias in SCENTE NLTE estimates for CrIS-FSR/SNPP channel of 2320.625 cm^{-1} as a function of time and latitude (left) before and (right) after outlier removal. Nighttime only. W: winter; S: summer.

3.3 Bias correction of CRTM NLTE simulation

The bias corrected SCENTE NLTE estimates are used as reference to bias correct daytime CRTM NLTE simulation using simple linear regression technique. Figure 5 shows that the bias correction:

- Significantly reduces the O-A bias for both old and new CRTM coefficients
- Substantially reduces the O-A standard deviation difference for both old and new CRTM coefficients
- Works equally effectively on both sets of CRTM coefficients
- Figure 6 shows that the bias correction of CRTM NLTE simulation is only weakly sensitive to the temperature profile error.

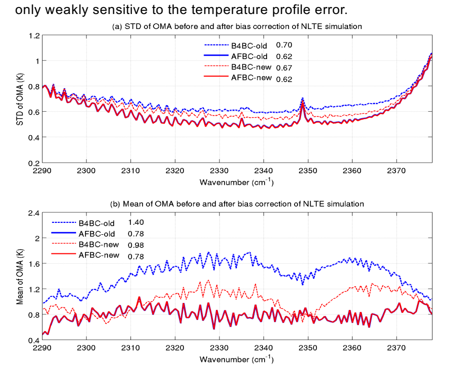

Figure 5. (a) The standard deviation (STD) and (b) the mean of observation minus analysis (O-A) for CrIS-FSR SWIR channels that are affected by daytime NLTE effects. The analysis is calculated using CRTM with NLTE effects turned on. The ECMWF analysis provides surface and atmospheric information. Note that the solid blue and red lines are overlapping with each other on both panels. Numbers show the spectrally mean value. Data from 2020.

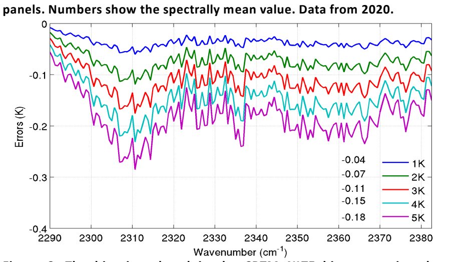

Figure 6. The bias introduced in the CRTM NLTE bias correction due to uncertainty in the temperature profile. The 1976 US standard atmosphere with both satellite and solar zenith angles set as 0. The numbers in front of the legends are the spectrally mean values of each line.

3.4 Quality control

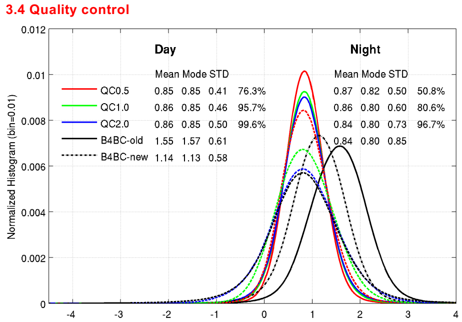

Figure 7. The normalized histograms of CrIS-FSR/SNPP OMA for the channel of 2320.625 cm^{-1}. The solid lines are for daytime and dashed lines for nighttime. Red/green/blue lines uses fixed thresholds of 0.5K, 1.0K, and 2.0K to reject observations. The black lines are for daytime before the bias correction using old (solid) and new (dash dotted) coefficients, and after the bias correction (dashed).

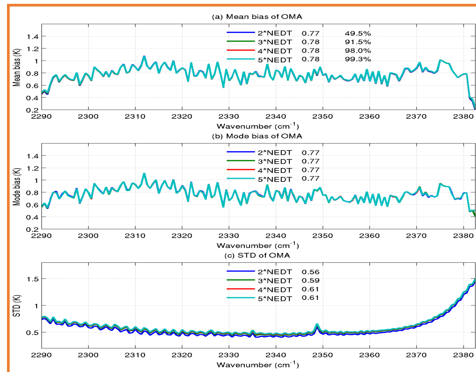

Figure 8. The spectra of (a) mean bias, (b) mode bias, and (c) standard deviation (STD) of observation minus analysis (O-A) for the SWIR channels with different thresholds for quality controls. The first column of values after the legend shows the spectral mean. The second column of values in (a) shows the yields. Note for mean and mode biases, all spectra overlap with each other.

Quality control aims to remove SWIR radiances that are affected by NLTE effects and poorly simulated by CRTM, even with the bias correction. It is based on the comparison of the bias corrected SCENTE NLTE estimates and bias corrected CRTM NLTE simulation. Figures 7 and 8 show that

- The bias correction of CRTM NLTE simulation is effective to bring the daytime bias much closer to nighttime bias
- Smaller threshold for quality control does not affect the bias much but significantly reduces the standard deviation of O-A and yields

Table 1 shows that

- The quality control is effective on rejecting radiances with large bias and standard deviation of O-A
- Same threshold rejects higher percentage of nighttime observations, likely due to nighttime NLTE effects, indicating more caution is needed for nighttime SWIR radiance assimilation

Table 1. The spectral mean of mean bias, mode bias, STD of O-A from daytime and nighttime as well as the yields for observations rejected by the quality control.

Thresholds	Mean bias (K)		Mode bias (K)		STD (K)		Yield (%)	
	Day	Night	Day	Night	Day	Night	Day	Night
2*NEdT	0.79	0.76	0.77	0.75	0.67	0.95	50.5	96.1
3*NEdT	0.86	0.89	0.80	0.76	0.83	1.03	8.5	27.9
4*NEdT	1.03	1.22	0.88	0.81	1.02	1.24	2.0	5.4
5*NEdT	1.24	1.60	0.97	0.90	1.14	1.46	0.7	1.7

4. Evaluation

Detailed comparison between day and night shows that the day/night discrepancies in O-A bias is reasonably small for different seasons (Table 2), different zenith angles (Table 3), and different latitudes (Table 4).

Table 2. The spectral mean of mean bias, mode bias, STD of O-A from daytime and nighttime in different seasons.

Seasons	Mean bias (K)		Mode bias (K)		STD (K)	
	Day	Night	Day	Night	Day	Night
FMA	0.71	0.66	0.70	0.71	0.59	0.91
MJJ	0.74	0.66	0.75	0.71	0.58	0.94
ASO	0.84	0.75	0.83	0.81	0.62	0.90
NDJ	0.83	0.80	0.79	0.76	0.56	0.93

Table 3. Similar to Table 2 but for different satellite zeniths

Satellite zenith angles (°)	Mean bias (K)		Mode bias (K)		STD (K)	
	Day	Night	Day	Night	Day	Night
0-15	0.74	0.62	0.74	0.66	0.61	0.94
15-30	0.79	0.69	0.78	0.72	0.60	0.92
30-45	0.81	0.76	0.80	0.78	0.58	0.91
>45	0.76	0.78	0.74	0.82	0.56	0.90

Table 4. Similar to Table 2 but for latitudes

Latitude range (°)	Mean bias (K)		Mode bias (K)		STD (K)	
	Day	Night	Day	Night	Day	Night
-90 ~ -60	0.73	0.76	0.64	0.68	0.69	0.95
-60 ~ -30	0.77	0.63	0.69	0.58	0.57	0.77
-30 ~ 30	0.74	0.87	0.76	0.91	0.55	0.80
30 ~ 60	0.79	0.59	0.79	0.62	0.54	0.75
60 ~ 90	0.71	0.68	0.75	0.68	0.61	0.82

5. Summary and future plan

- NLTE effects affect all SWIR sounding channels that are weakly or not affected by the surface, and must be accounted for in radiative transfer models in order to assimilate daytime SWIR radiances
- A bias correction scheme is developed to remove the underestimate in CRTM NLTE simulation
- A quality control is developed to remove shortwave infrared radiances that are poorly simulated by CRTM in both daytime and nighttime
- Evaluations show that the bias correction and quality control can bring the daytime bias of O-A closer to nighttime and are equally effective on both sets of CRTM coefficients
- The quality control rejects higher percentage of nighttime observations, indicating more caution is needed for nighttime SWIR radiance assimilation
- Eliminating and minimizing the day/night discrepancies in O-A bias paves the path toward shortwave infrared radiance assimilation
- Methodology is currently being implemented into NCEP DA system for testing
- A manuscript is in preparation

6. Acknowledgement

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