CRTM improvement toward the assimilation of shortwave infrared radiances

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Background

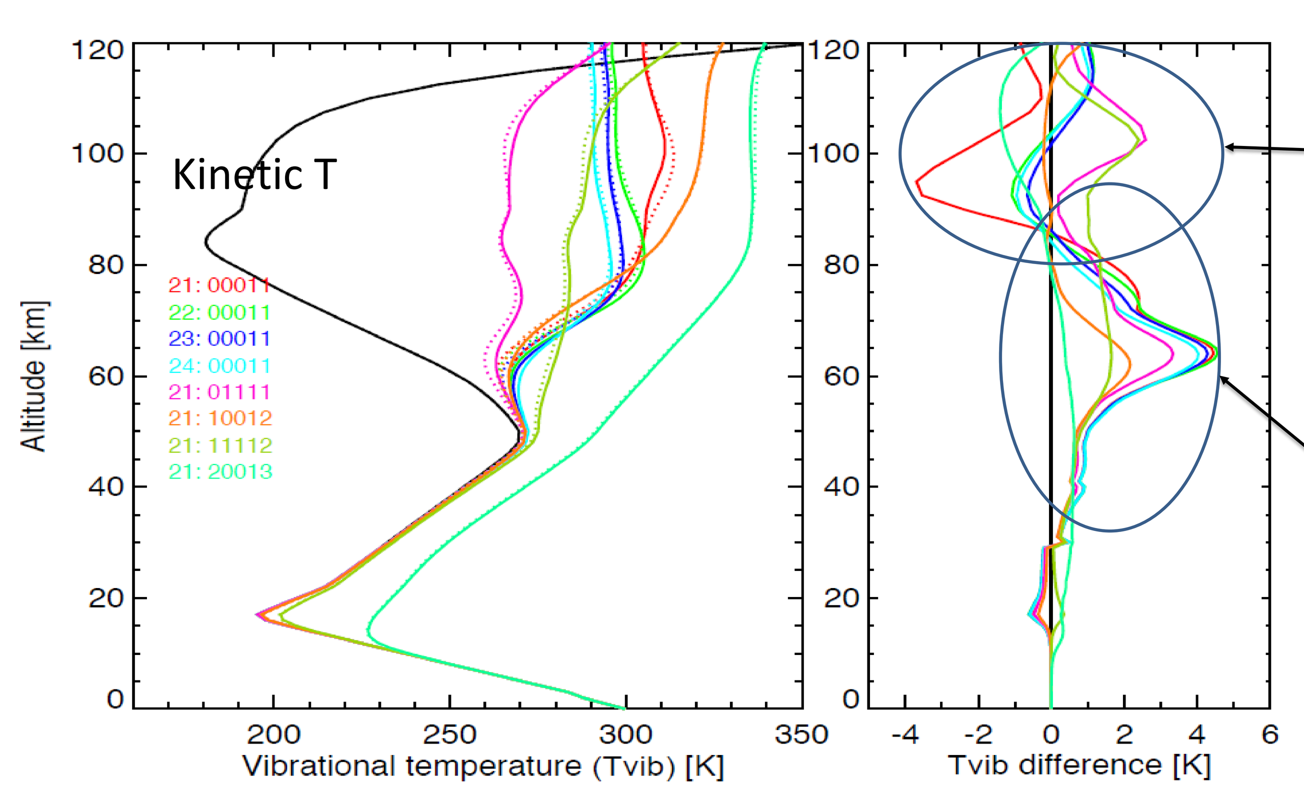
In the shortwave infrared (SWIR, approximately 3.5-4.6 um) region, there exist significant non-local thermodynamic equilibrium (non-LTE) absorption/emission in 4.3um CO_2 band and surface reflection of solar radiation. Due to the strong impact of these effects, the satellite radiances in SWIR region are not operationally assimilated in numerical weather prediction (NWP) data assimilation (DA) systems. However, satellite channels in SWIR possess unique advantage desirable for DA and retrieval algorithms. SWIR channels are “cleaner” than their counterpart in the longwave inferred (LWIR) region. The water vapor contamination is much weaker in SWIR temperature sounding channels. Also, SWIR sensors are suitable for future cubesat technology to provide an alternative and agile constellation to provide temperature profile information to NWP.

Objectives

To support the assimilation of SWIR, this study aims to enhance the non-LTE correction capability of the Community Radiative Transfer Model (CRTM), which is used operationally in the NCEP GDAS/GFS. The non-LTE correction will be revised based on the newly available vibrational temperature (Tvib) profiles from M. López-Puertas et al. (https://www.iaa.csic.es/~puertas/airs.html) and simulations using the latest version of Community Line-by-Line Model or the Line-by-Line Radiative Transfer Model (CLBLM/LBLRTM). The improvement will be validated with the Cross-track Infrared Sounder (CrIS) measurements collocated with NWP analysis data from ECMWF.

New vibrational temperature profiles

- Current CRTM non-LTE correction based on Tvibs dated back to 2003 (Y. Chen, 2013, Strow et al., 2003)
- New Tvib data are available from M. López-Puertas**.**
  - New GRANADA non-LTE model (B. Funke et al., 2012)
  - Newly derived collisional rates from MIPAS spectra (Jurado-Navarro et al., 2015)
  - Improvements involving input solar flux, line-by-line calculation of the Curtis matrices, angular integration, included HITRAN2012,…
  - Provided for 48 profiles and for 13 solar angles (old Tvibs for 6 solar angles).
  - Warmer for most energy levels, which translates to higher non-LTE radiances.



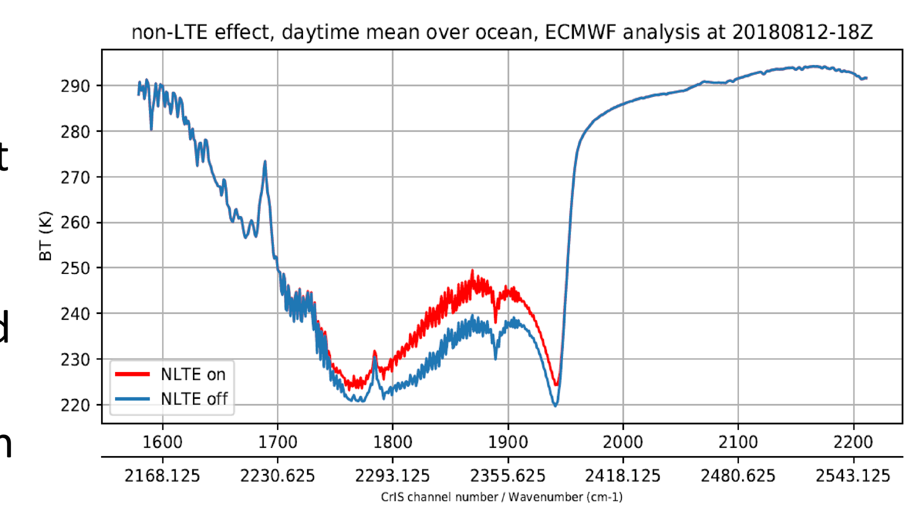
New and old are different but locations higher than instrument weighting functions

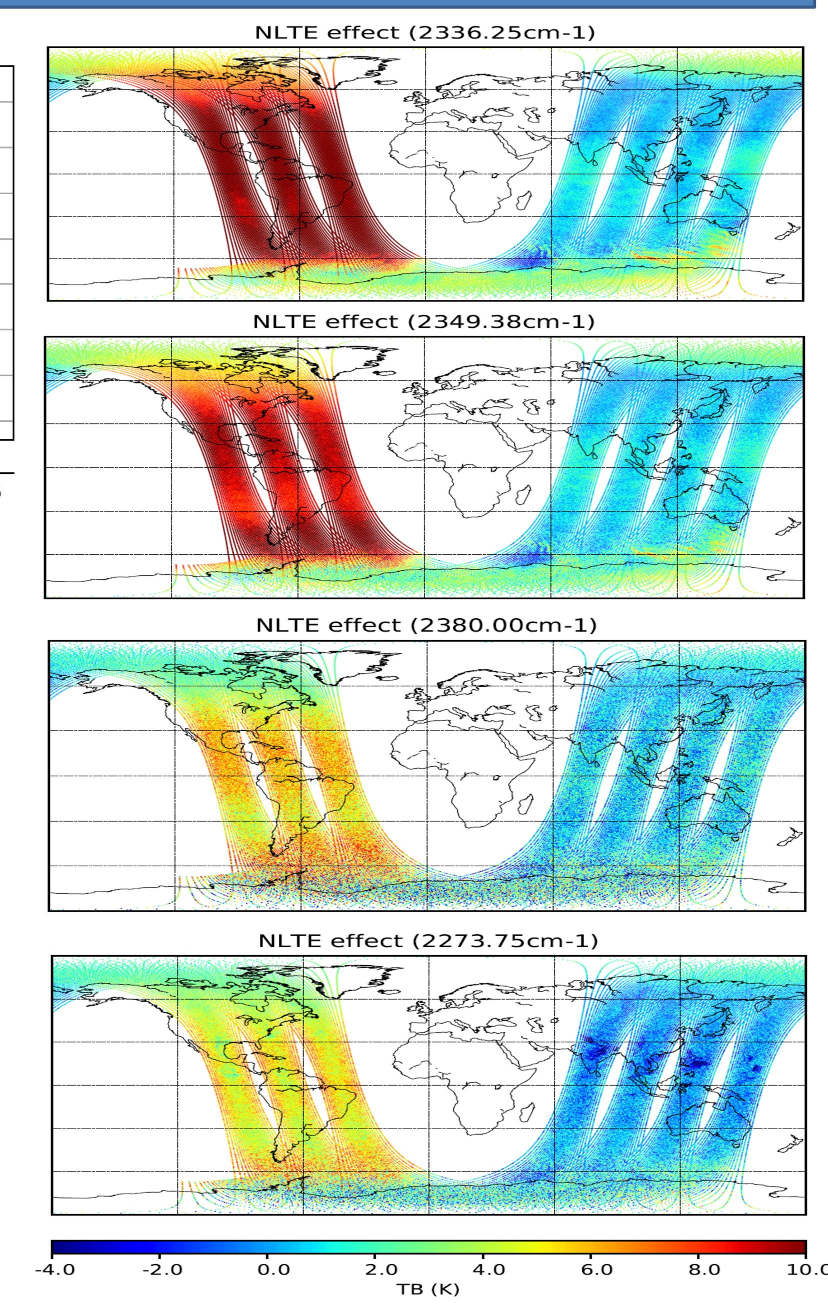
Warmer Tvibs than the pervious version.

Left panel: Example of the Tvibs in CO_2 4.3um levels. Dot lines are old Tvibs, solid lines are new Tvbis. **Right panel:** Difference between the new and the old versions. In the figure, energy levels are denoted as “2y:xxxxx”, where “y” is CO2 isotopologue ID and “xxxxxx” is level ID following HITRAN notation.

--- Courtesy of M. López-Puertas.

Non-LTE effect





Non-LTE effect seen in CO_2 4.3um bands.

Left: Difference between CrIS observation and CRTM calculation without non-LTE correction. Collocated NWP data used are the analysis from ECMWF on 8/12/2018, 18Z.

Below: Spectral location of the non-LTE effect in CrIS FSR-2211 spectrum.

- In Earth’s atmosphere, molecular state populations mainly depends on a balance between radiative and collisional processes.
- Lower atmosphere, collisional processes dominate, in LTE condition, can be described by local kinetic temperature.
- Higher atmosphere, collisions not frequent enough to thermalize the absorbed energy, in non-LTE condition, internal (vibrational, rotational …) temperatures differ from the kinetic temperature.
- Non-LTE emission in the 4.3um CO_2 band may contribute up to 10 K to obs. BT.

New non-LTE correction in CRTM

- Non-LTE calculation needs state populations (or vibrational temperatures if ignore rotational non-LTE) under non-LTE condition.
- Tvibs are difficult to obtain in operational NWP applications
- Fast models such as CRTM use additive correction

$$I_{ch}^{NLTE}(\theta_s, \theta_v) = I_{ch}^{LTE}(\theta_s, \theta_v) + \Delta I_{ch}(\theta_s, \theta_v)$$

$$\Delta I_{ch}(\theta_s, \theta_v) = c_0(\theta_s, \theta_v) + c_1(\theta_s, \theta_v) T_{up} + c_2(\theta_s, \theta_v) T_{lo}$$

Where :

θ_s - solar zenith angle ;

θ_v - view zenith angle secant;

c_i - regression coefficients;

I_{ch}^{NLTE} - Non-LTE radiance ;

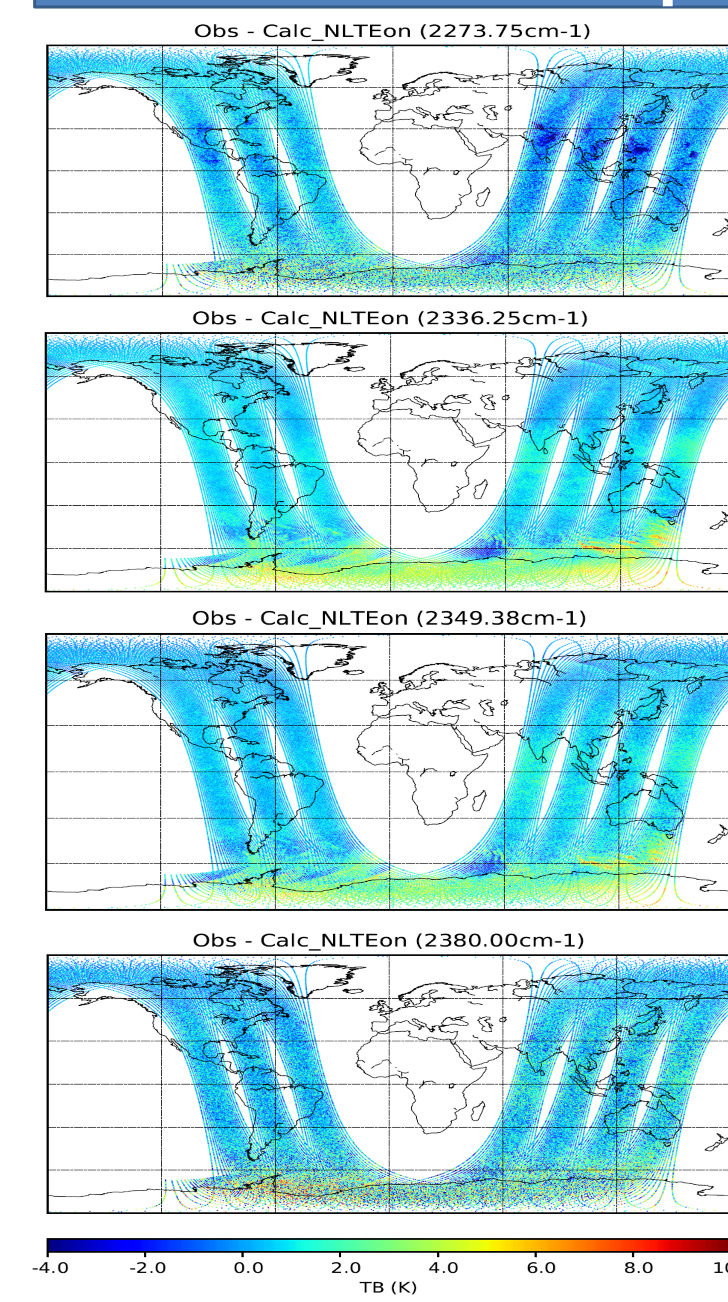
I_{ch}^{LTE} - LTE radiance;

T_{up} - upper layer mean temperature from 0.2-0.005mb and

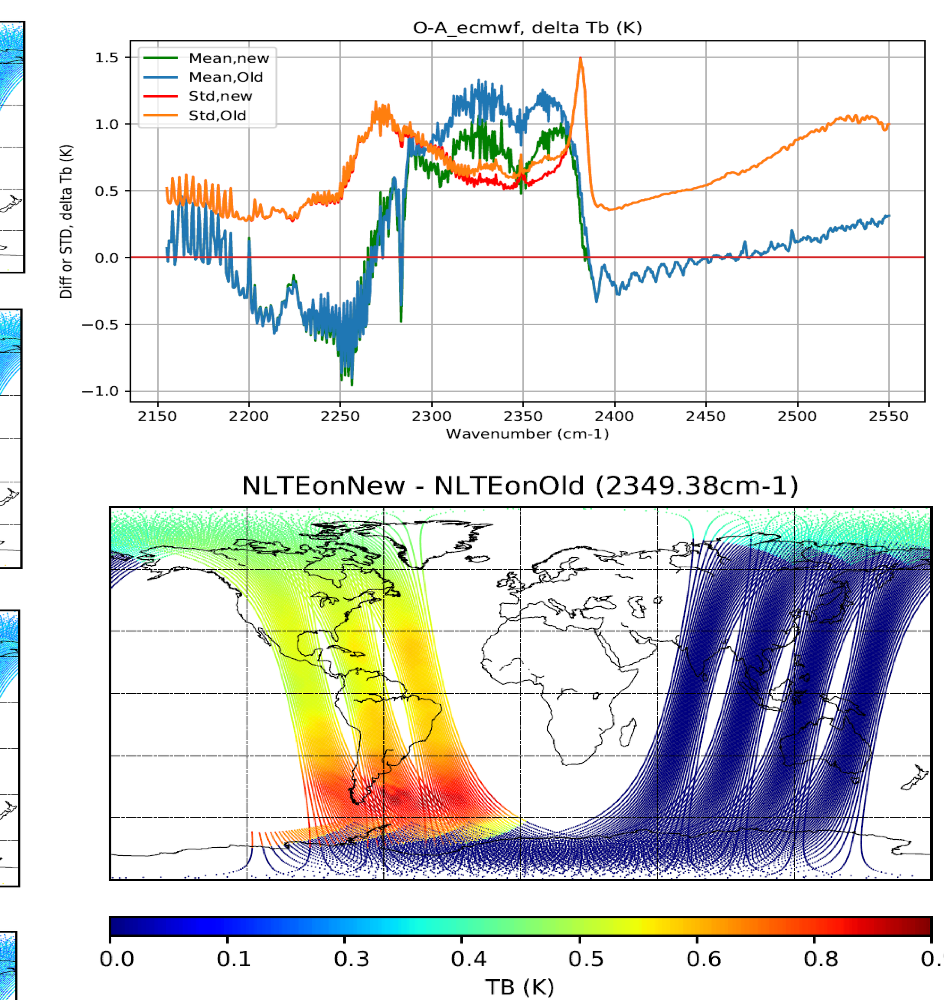
T_{lo} - lower layer mean temperature from 52-0.2mb

The regression coefficients $c_i, i = 1..3$ are obtained using line-by-line code that is capable of detailed non-LTE calculation. Step-wise regression method was used to choose the best predictor and avoid the false impact from irrelevant factors.

Results of the updated Non-LTE correction



O-A (Obs minus Analysis) on 4 CrIS FSR channels after non-LTE correction. Collocated data used are ECMWF analysis at 20180812, 18Z.



Comparison between the non-LTE corrections using the new and the old coefficients. **Upper figure**: Mean bias and standard deviation of O-A over the mid-latitude ocean after non-LTE correction. **Lower figure**: spatial distribution of the difference between the old and the new corrections. The non-LTE correction applied to daytime region only.

Summary

To support the assimilation of hyperspectral SWIR observations from CrIS, IASI, AIRS and future SWIR-only sensor in NWP, the non-LTE correction scheme applied in CRTM has been enhanced based on the newly available vibrational temperature profiles for CO2 in 4.3 um band from M. López-Puertas.

In this study, the regression coefficients of the non-LTE correction were obtained from line-by-line simulations using the CLBLM/LBLRTM model. The monochromatic radiance spectrum from simulations were Hamming apodized to match the CrIS channel radiance. Stepwise multiple linear regression was used to obtain coefficients for each CrIS channel for 13 sensor angles and 13 solar angles.

The new correction coefficients were implemented in CRTM and assessed with CrIS FSR 2211 observations collocated with NWP atmospheric data from ECMWF analysis. The results shows that the non-LTE correction based on the new Tvibs reduces the mean O-A bias by about 0.3K, and makes the O-A bias and standard deviation over mid-latitude ocean more close t the nighttime values.

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Acknowledgement: This project is funded by the NESDIS/OPPA Technology Maturation Program