Spectral Correlations to Estimate Non-local Thermal Equilibrium (SCENTE)

--An alternative way to quantify NLTE radiances

Zhenglong Li, Paul Menzel, Jim Jung, Agnes Lim, Jun Li, Manuel López-Puertas, Sergio DeSouza-Machado, L. Larrabee Strow

CIMSS/SSEC, University of Wisconsin-Madison, Madison, Wisconsin

CIMSS

INTERNATIONAL ATOVS WORKING GROUP

SSEC

Outlines

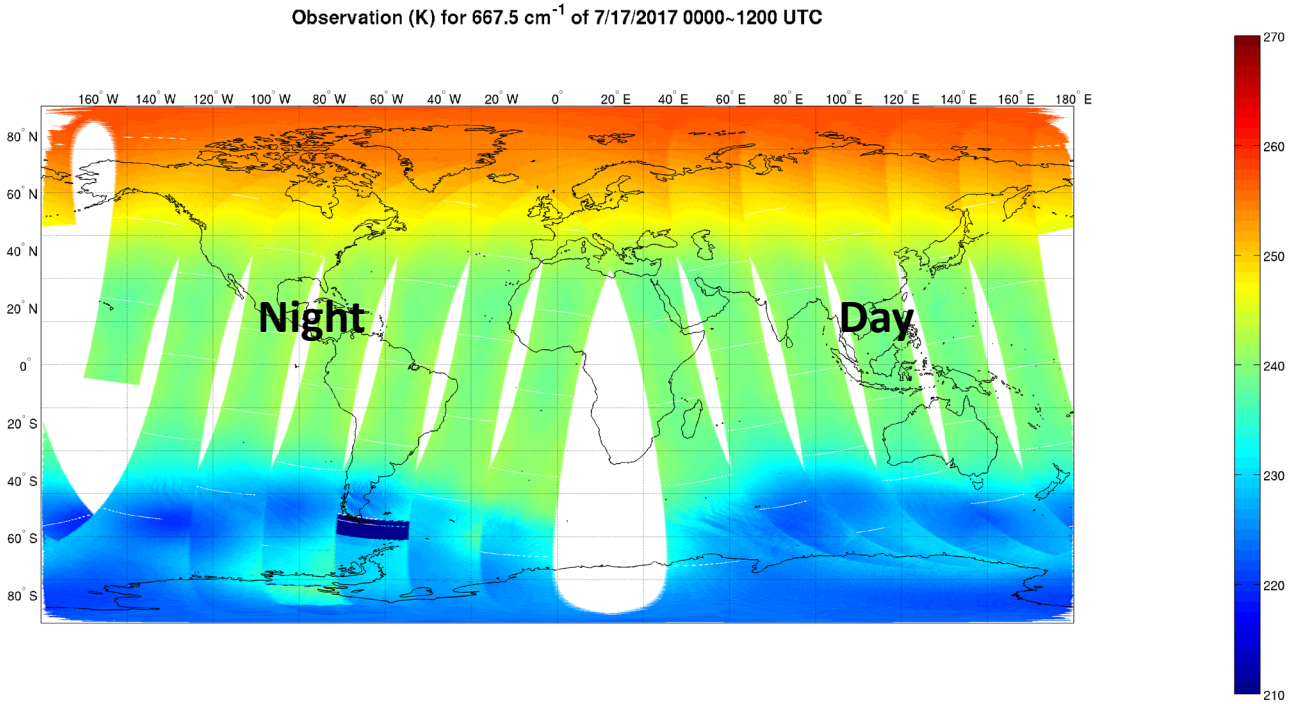
- Background and motivations
- NLTE demonstration
- Methodology of SCENTE
- Evaluation
- Summary

Background and motivations

- Shortwave (SW) CO2 band radiances are more sensitive to temperature than longwave (LW) CO2 radiances
- None of the NWP centers is assimilating SW CO2 radiances
- Part of the reason: 4.3 micron CO2 band transitions are populated by both local thermodynamic equilibrium (LTE) and non-LTE (NLTE)
- Primary mechanism for NLTE is solar pumping; **nighttime has NLTE as well, though it is not as significant and not understood well.**
- SCENTE helps improve the applications of SW radiances from CrIS, IASI, and AIRS.
- IR CubeSat highly depends on how good the applications of SW CO2 bands are

CrIS FSR Observation of LW

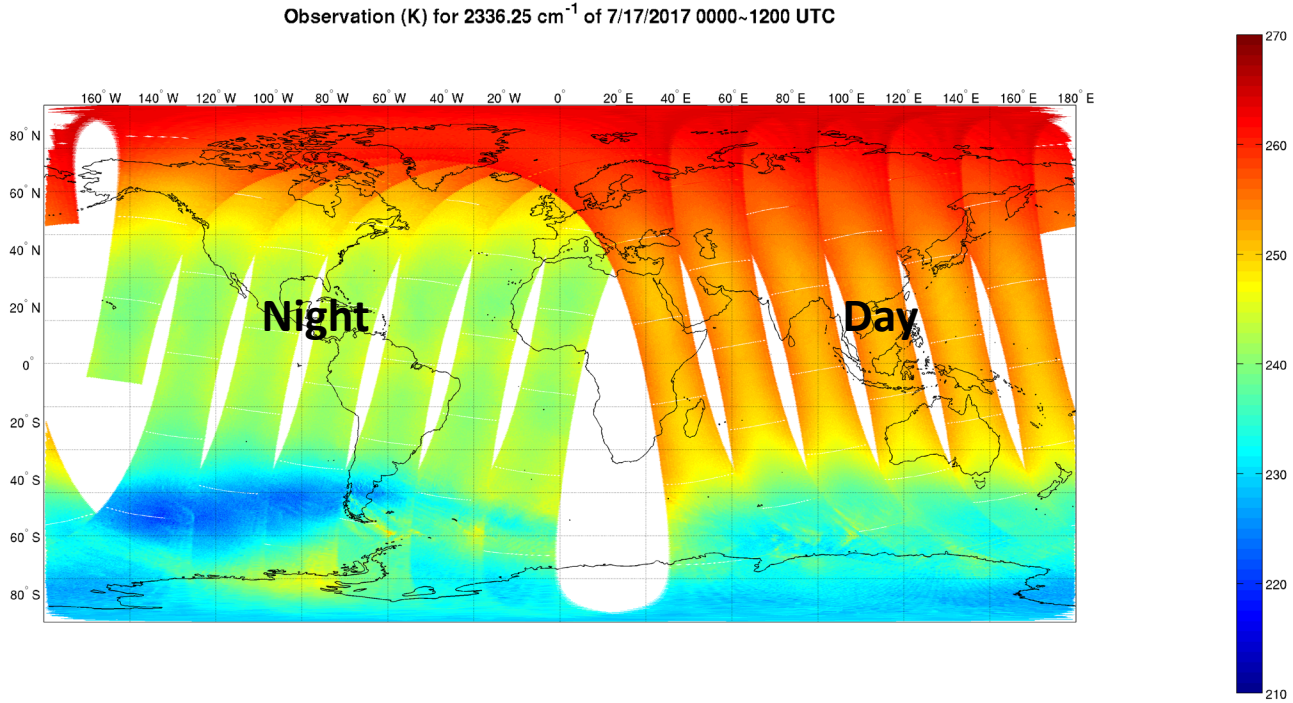
00 – 12 UTC
07/17/2017



This CrIS FSR LW channel peaks in lower mesosphere, and covers a decent amount of stratosphere. Radiance is considered NLTE free.

CrIS FSR Observation of SW

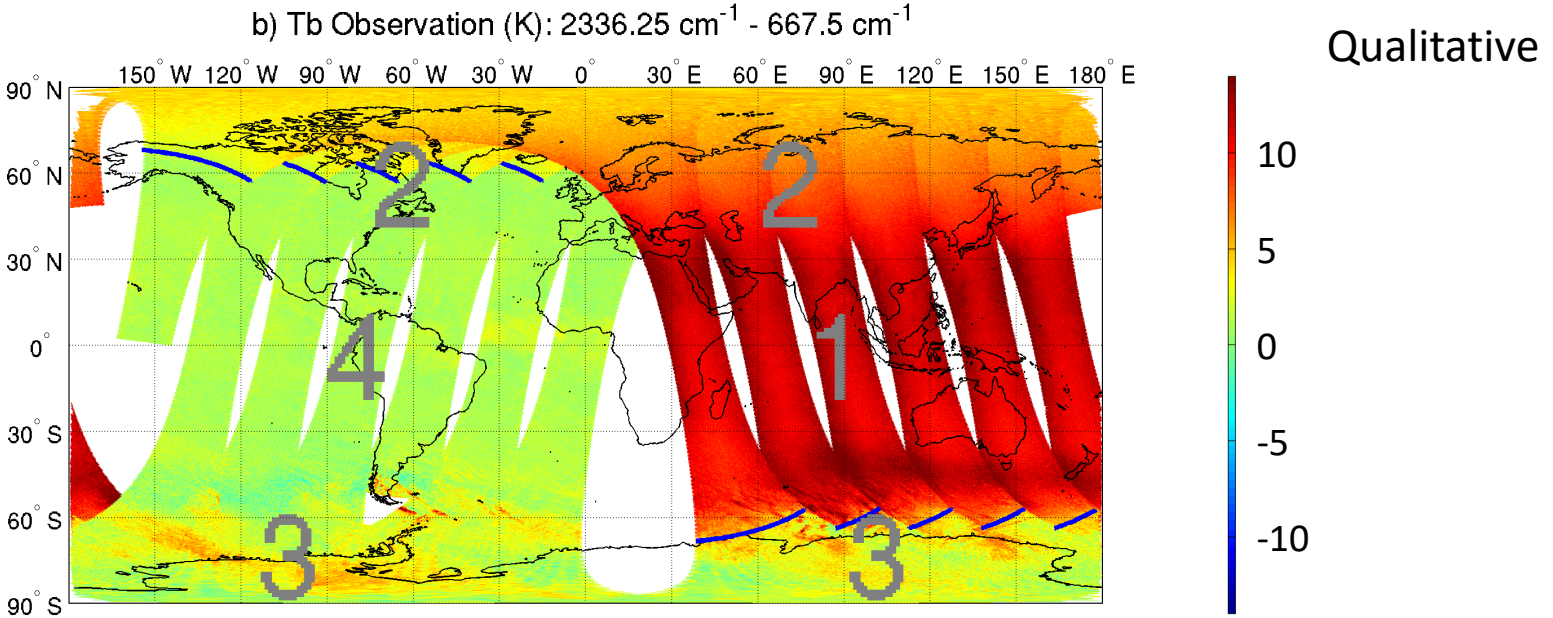
00 – 12 UTC
07/17/2017



Similar CrIS FSR SW channel peaking around the same altitude, but affected by NLTE.

CrIS FSR NLTE Observations : SW - LW

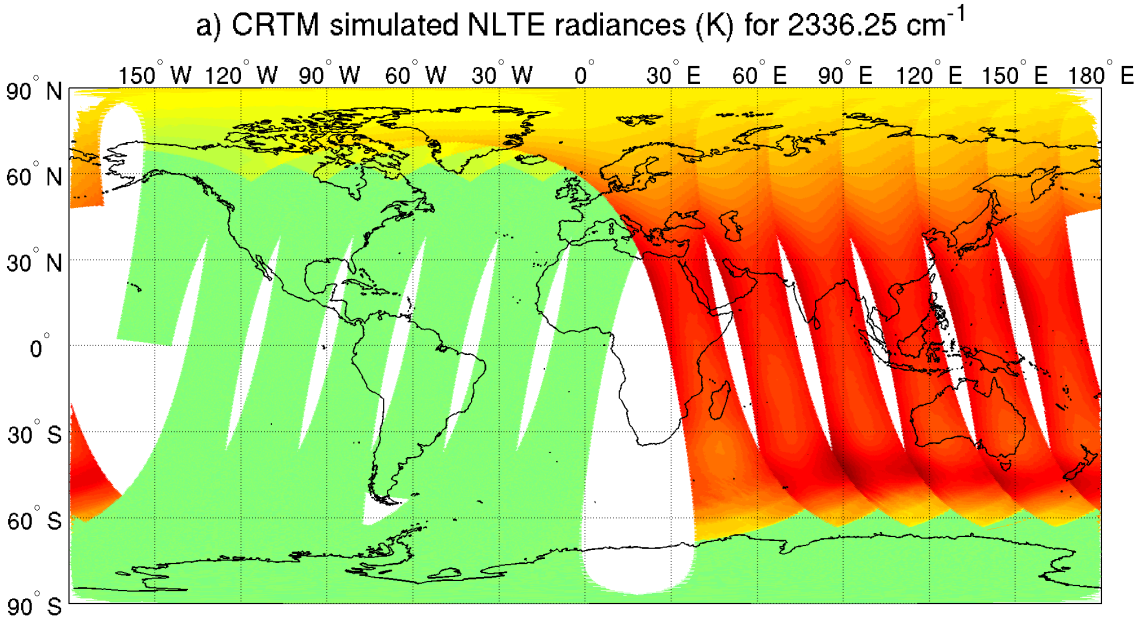
00 – 12 UTC
07/17/2017



1. Daytime tropics and mid-latitudes: strong NLTE radiances ---- known NLTE effects
2. North pole and high latitudes: mostly daytime, NLTE gradually decrease with solar zenith angle (SZA)
3. South pole and high latitudes: mostly nighttime, many areas with positive values, not smooth around terminator ---- evidence of nighttime NLTE
4. Nighttime in tropics and mid-latitudes: no obvious NLTE

Simulated NLTE by CRTM

00 – 12 UTC
07/17/2017



V 2.1.3
ODPS

Known NLTE features:

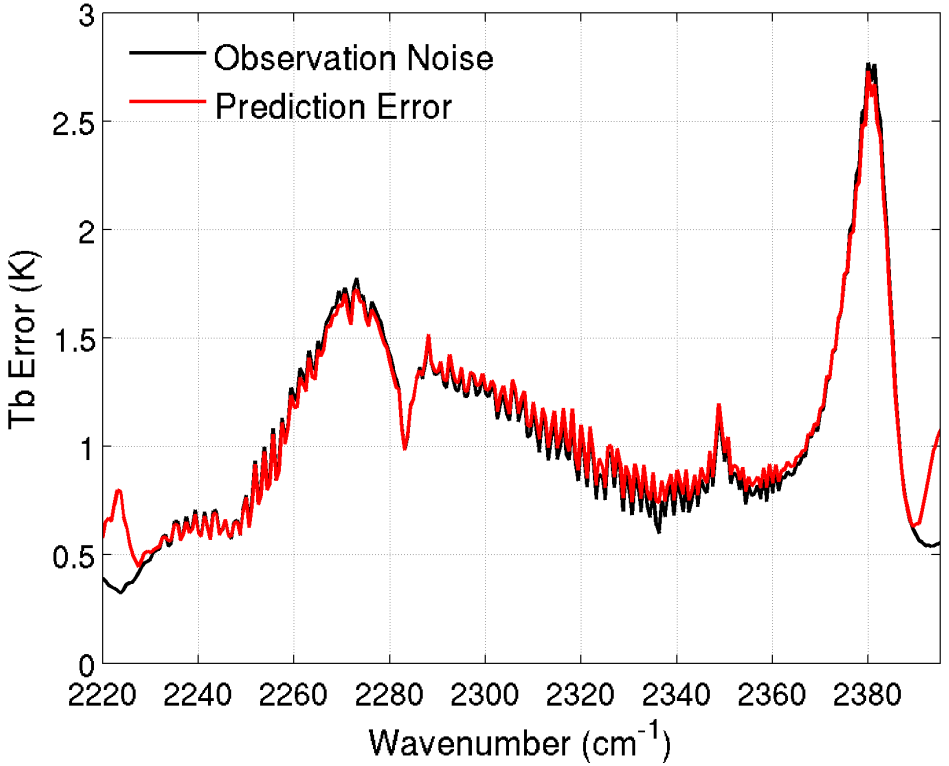
- NLTE decreases with SZA
- NLTE increases with local zenith angle (LZA)

Questionable NLTE features:

- Immediate shut-off at terminator (SZA=90deg)
- Lack of nighttime NLTE

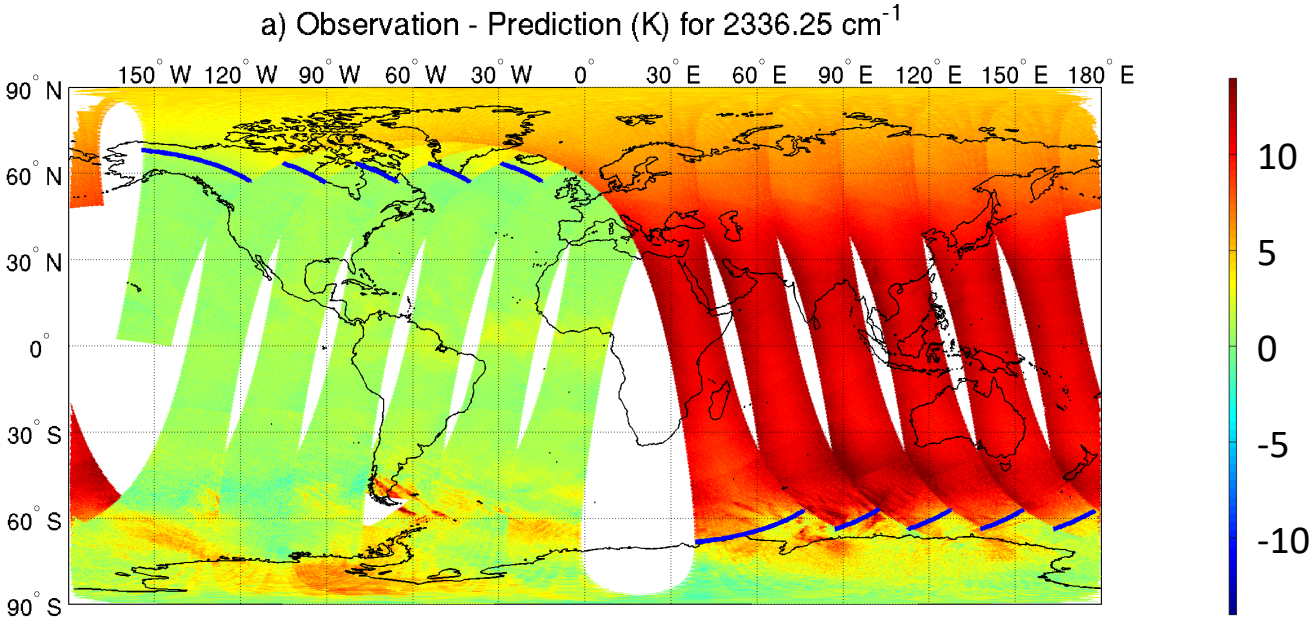
Estimate NLTE from SW+LW

- Both SW and LW are observing the same atmosphere; they are highly correlated;
- SW radiances can be predicted from LW if there is no NLTE;
- LW is not affected by NLTE;
- The difference between the prediction and observations should be a good quantification of NLTE
- Figure on the right also shows 149 SW channels can be predicted from LW;
- Training uses simulated radiance; coefficients will be applied to real data.



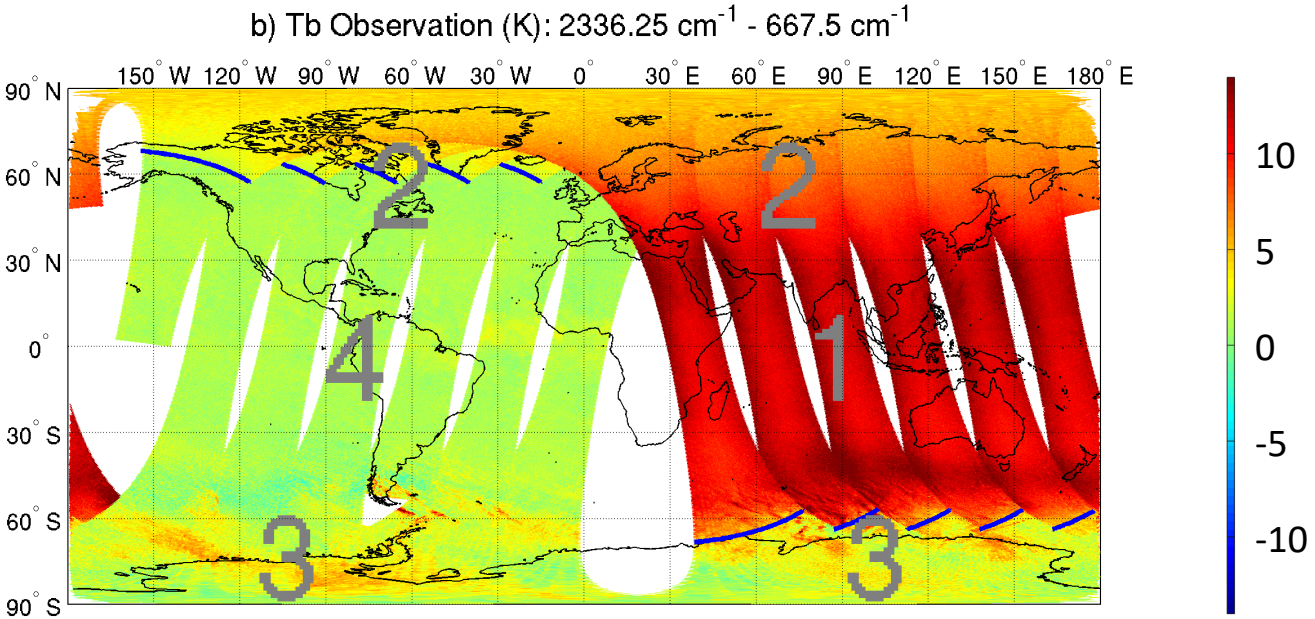
Simulation using 15704 profiles from SeeBor database

Quantitatively Estimated NLTE by SCENTE

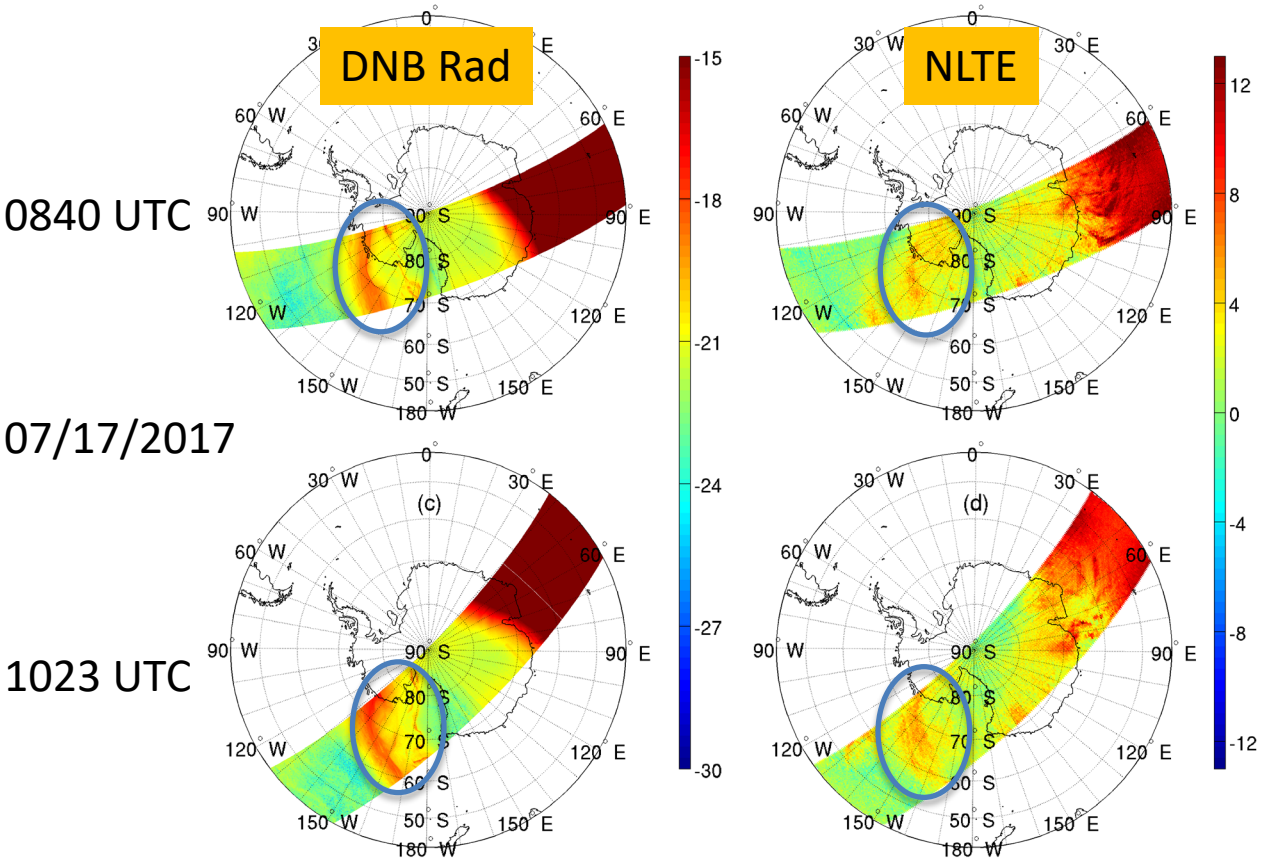


1. Daytime tropics and mid-latitudes: strong NLTE radiances ---- known NLTE effects
2. North pole and high latitudes: mostly daytime, NLTE gradually decrease with solar zenith angle (SZA)
3. South pole and high latitudes: mostly nighttime, many areas with positive values, not smooth around terminator ---- evidence of nighttime NLTE
4. Nighttime in tropics and mid-latitudes: no obvious NLTE

NLTE in CrIS Observation: SW - LW



Nighttime NLTE and Auroras



- Strong auroral activities are one type of mechanism of nighttime NLTE
- Left two panels show auroras from logarithm of VIIRS day/night band (DNB) radiances
- Right panels show SCENTE captures those strong NLTE signals related to auroras
- What caused NLTE inhomogeneousness near terminator?

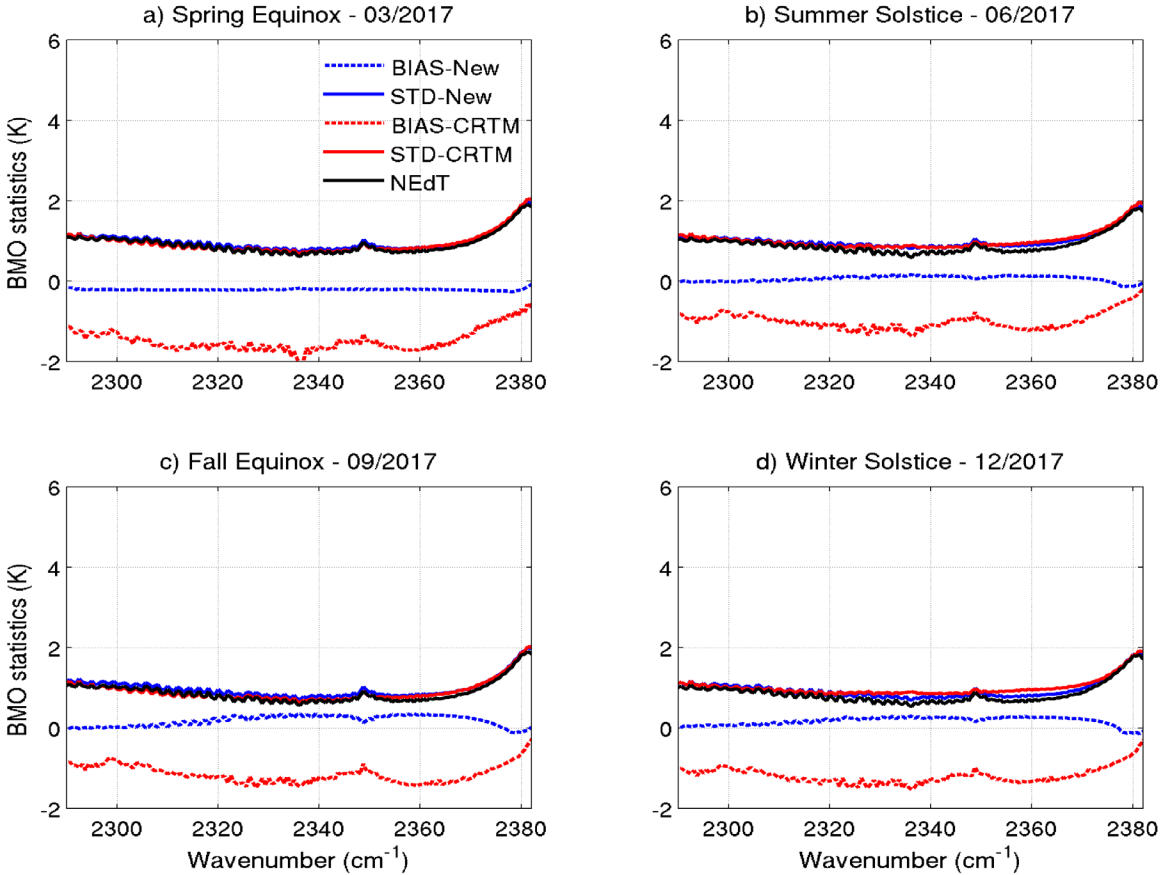
Statistical evaluation strategy

- Focus on statistics of Calculation – Observation. Calculation has two parts
  - LTE radiances from ECMWF analysis using CRTM
  - NLTE radiances (correction part) from CRTM (daytime with NLTE and nighttime without NLTE) or SCENTE

- Four datasets representing 4 seasons
  - Spring Equinox: March 21-22, 2017
  - Summer Solstice: June 21-22, 2017
  - Fall Equinox: September 21-22, 2017
  - Winter Solstice: December 21-22, 2017

- No screen out of observations except bad observations
  - Land and water
  - clear and cloudy
  - polar and non-polar
  - homogeneous and non-homogeneous
  - nadir and off-nadir

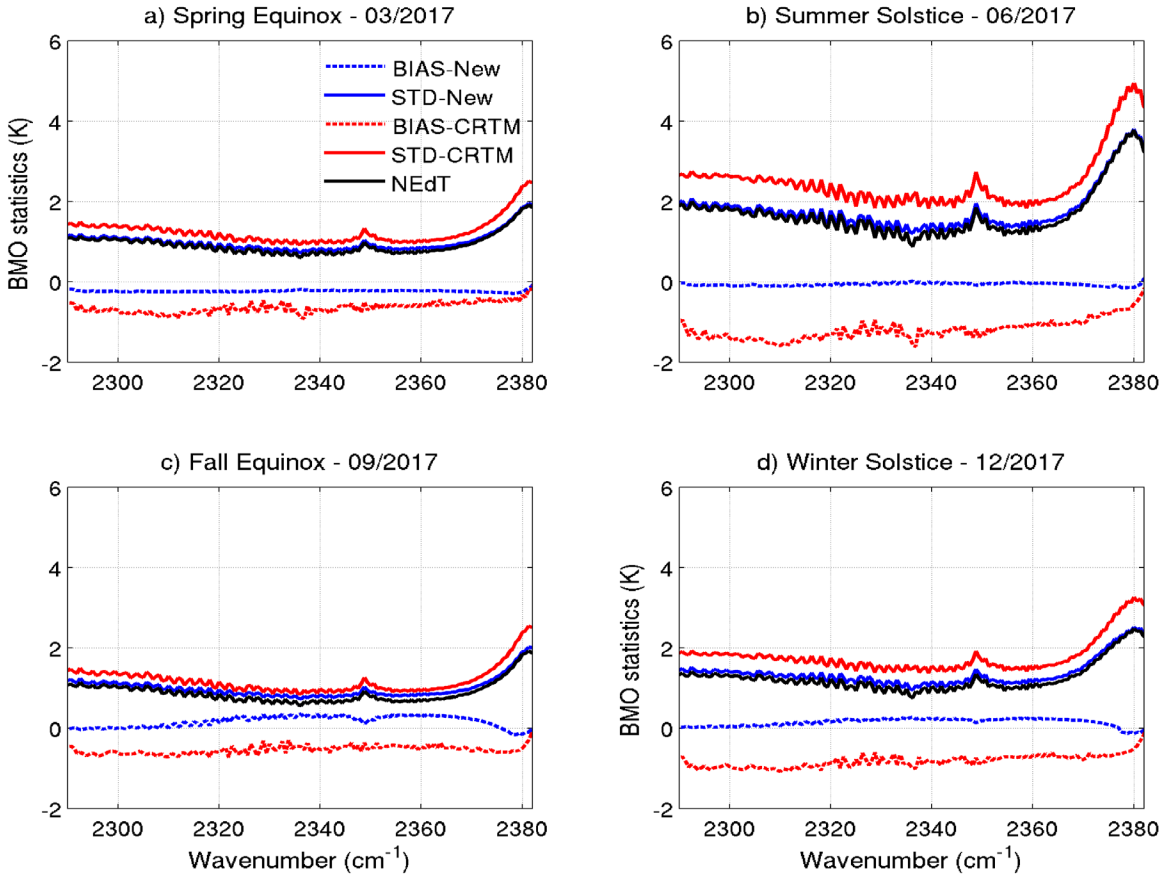
Daytime (SZA < 90 deg)



- Both methods depict daytime NLTE well in terms of STD
- SCENTE has small biases with little seasonal variation
- CRTM has strong negative biases with substantial seasonal variation

Calc - Obs

Nighttime (SZA > 90 deg)



- SCENTE has smaller STD than CRTM, comparable to NEdT
- SCENTE has small biases with little seasonal variation and little diurnal variation
- CRTM strong negative biases have substantial seasonal and substantial diurnal variations
- Nighttime is likely not NLTE free

Calc - Obs

Summary

- A statistical method, the Spectral Correction to Estimate NLTE (SCENTE) is developed.

- SCENTE is applied to process four seasons of CrIS FSR data. Evaluations of Calc - Obs show that
  - SCENTE has STD close to NEdT in both day and nighttime, CRTM STD is close to NEdT in daytime, but larger in nighttime, indicating possible nighttime NLTE
  - CRTM has strong negative biases in both day and nighttime, with substantial seasonal and diurnal variations
  - Although SCENTE has small biases in O-B with little seasonable and diurnal variations, *it does have positive biases of 0.5 – 1.0 K in the estimated NLTE between 30S and 30N. That is because CRTM LTE simulation has a negative bias of 0.5 – 1.0 K.*
  - *CRTM underestimates NLTE by 0.5 to 1.0 K between 60°S and 60°N.*
  - Evidence is provided to aurora related nighttime NLTE, and daytime could also be subject to aurora related NLTE
  - Other mechanisms could also lead to nighttime NLTE, and NLTE near terminator

- *One static set of coefficients can be used to process all four seasons*

- Applications: alternative and complementary to RTM simulation; help improve the application of SW radiances in assimilation or retrievals through
  - quality control; very important for nighttime and around terminator
  - NLTE bias correction, can be applied to SW only