Validation of CRTM using Observation and RTTOV

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2019 International Workshop on Radiative Transfer Models for Satellite Data Assimilation

Outline

- Introduction and Motivation
- Overview of differences between CRTM and RTTOV
- Validation of CRTM under scattering conditions for MW sensors
  - Surface Reflectivity
  - Jacobians
- Validation of CRTM under clear-sky conditions for IR sensors
  - Surface Emissivity over Ocean
  - Input Profile Check
  - Simulation of ABI
- Summary

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Introduction and Motivation

- CRTM and RTTOV are each called from the GSI data assimilation system using the same model background fields and compared both with each other and with observations (i.e., the innovation).
- This allows direct comparison between model calculations for a wide range of atmospheric scenarios.
- Differences may be:
  - Deficiencies in one or both models
  - Errors in implementation of the model
  - Opportunities for improvement.

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Overview of Differences CRTM and RTTOV

Features	CRTM	RTTOV
Interface	▪ Unified interface for all sensors and conditions ▪ (MW-IR-VIS)	▪ Separate interfaces for MW ad IR sensors under all-sky conditions (e.g. RTTOV-SCATT for MW, RTTOVCLD for IR) ▪ Discrete Ordinates Method (DOM) multiple-scattering solver for thermal emission and solar radiation ▪ MFASIS for fast visible cloud scattering parameterization ▪ Principal components
Hydrometeor Types	▪ Six types: water, ice, rain, snow and hail and graupel	▪ Four types: cloud water, ice, rain, snow (MW) ▪ Six types: two stratus, three cumulus, one cirrus (IR)
Total Cloud Cover	▪ Four cloud overlapping schemes available	▪ Hydrometeor weighted average overlap (MW) ▪ Maximum-random overlap (IR)
Fractional Cloud	▪ Two-column radiance calculation	▪ Two-column radiance calculation (MW) ▪ Streams method (IR) – six columns (for six cloud types)
RT Solver	▪ Thermal emission for clear-sky and non-precipitating clouds ▪ Advanced Adding and Doubling scheme for scattering conditions	▪ Delta-Eddington approximation (MW) ▪ Single-stream RTE with scaling of cloud optical thickness to account for the scattering effect (IR) ▪ Discrete ordinates method (IR/VIS)

Overview of Differences CRTM and RTTOV (contd.)

Features	CRTM	RTTOV
Hydrometeor Optical Properties for MW	All hydrometeors – sphere; modified gamma Mie solution Constant density for each hydrometeor type LUT for bulk mass extinction and scattering coefficient and Legendre phase function coefficients, as a function of frequency, temperature, hydrometeor type and effective radius	Cloud water/ice – sphere; gamma Rain – sphere; Marshall – Palmer Snow – sector; Field Mie solution (sphere); DDA (non-spherical) Constant density for each hydrometeor type LUT for volume extinction coefficient, single scattering albedo and average asymmetry, as a function of frequency, temperature, hydrometeor type and hydrometeor water content
Hydrometeor Optical Properties for IR	Similar to MW except for cloud ice Cloud ice – hexagonal columns; gamma Mie solution – sphere FDTD/GO – non-spherical	Water clouds – sphere; modified gamma Ice clouds – ensemble of shapes & PSDs Mie solution – sphere Baran database – function of IWC & temperature

Overview of CRTM and RTTOV (contd.) Transmittance Coefficients

- Transmittance coefficients for the regression based transmittance model are solved by applying the diverse profiles of atmosphere states and the corresponding transmittances computed from the LBL model
- Due to the variability of water vapor in space and time, water vapor is more challenging than other gases to fit in a regression-based, fast RT model and produce smooth, physically representative Jacobian profiles
- Transmittance Models
  - **ODPS** (Optical Depth at Pressure Space) – fit the effective channel transmittance using the prescribed pressure levels
  - **ODAS** (Optical Depth at Absorber Space) – fit the effective channel transmittance with the prescribed integrated absorber amount levels
- RTTOV - ODPS for all variable gases
- CRTM
  - ODAS for water vapor and OPDS for all other variable gases
  - A polynomial function is applied to the regression coefficients to improve the water vapor Jacobians (Compact OPTRAN).
- ODAS generates more accurate fast RT transmittance than ODPS for water vapor

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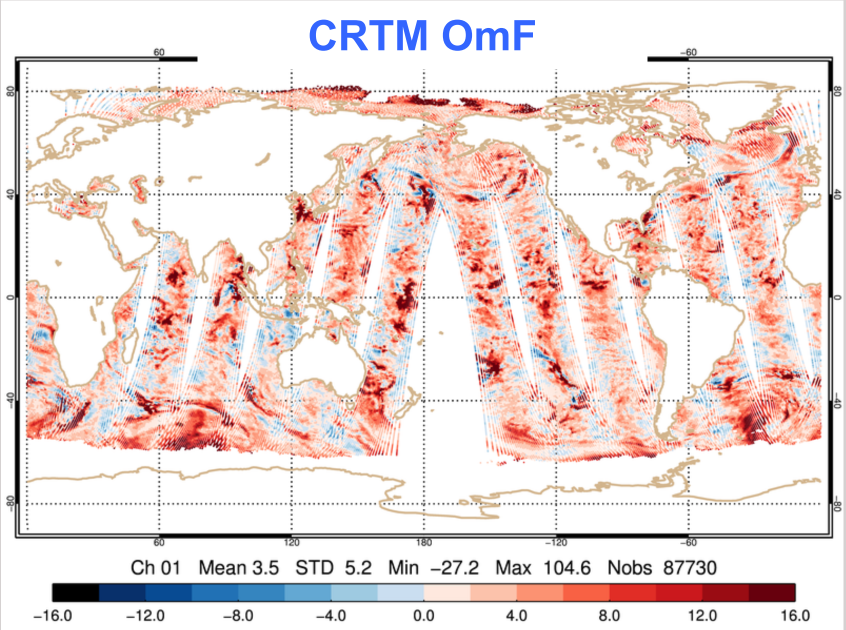
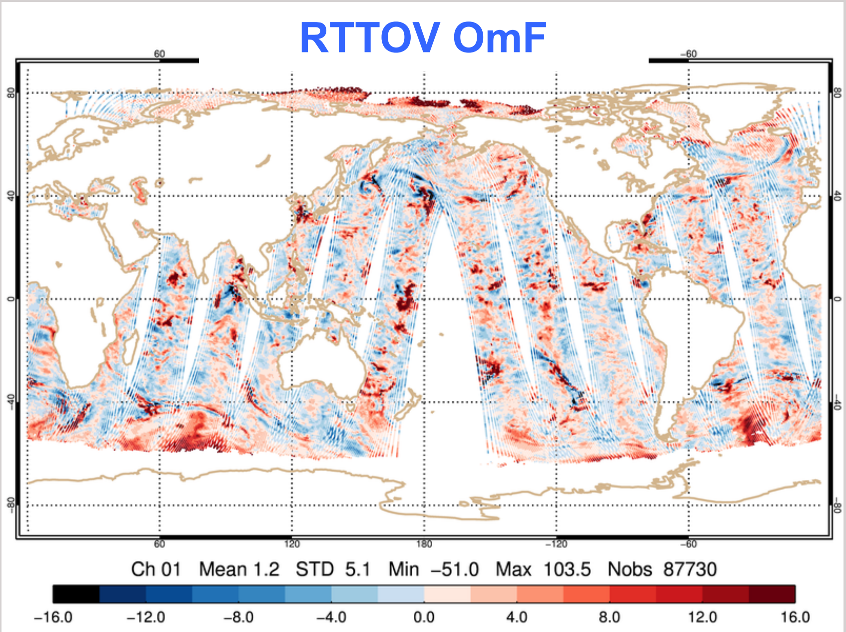
Validation of CRTM under scattering conditions

- The current all-sky assimilation at NCEP/EMC is for non-precipitating clouds as precipitating hydrometeor profiles are not available from the current model.
- To facilitate the move to include these extra variables (available in the soon-to-be-implemented FV3GFS model), we compare CRTM and RTTOV scattering calculations….

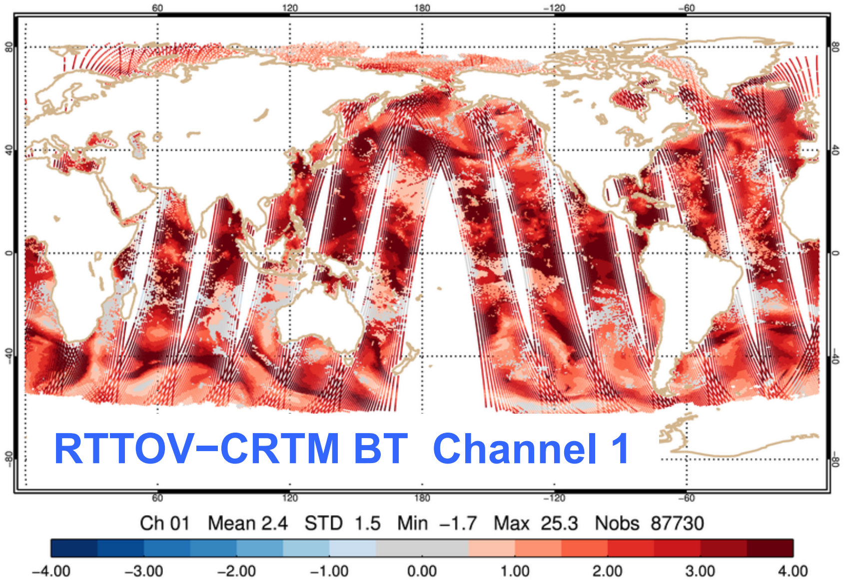
Evaluate CRTM under Scattering Conditions Issue





- The calculated CRTM BTs have systematic biases for surface sensitive channels (1-5, and 15) at locations where ADA solver is involved.
- The CRTM BTs are too cold in general

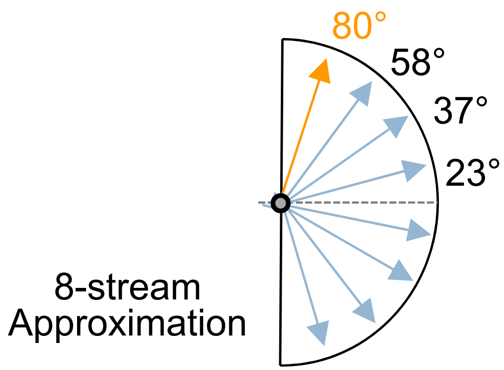
Evaluate CRTM under Scattering Condition　　Enhancement



- It is found that the off-diagonal terms of the surface reflectivity matrix is zero so that there is no diffuse radiation being reflected towards the viewing direction
- A proper surface emissivity model to work with multiple scattering algorithm is necessary
- For non-scattering RT, a reflection correction is used to account for the diffuse radiation.

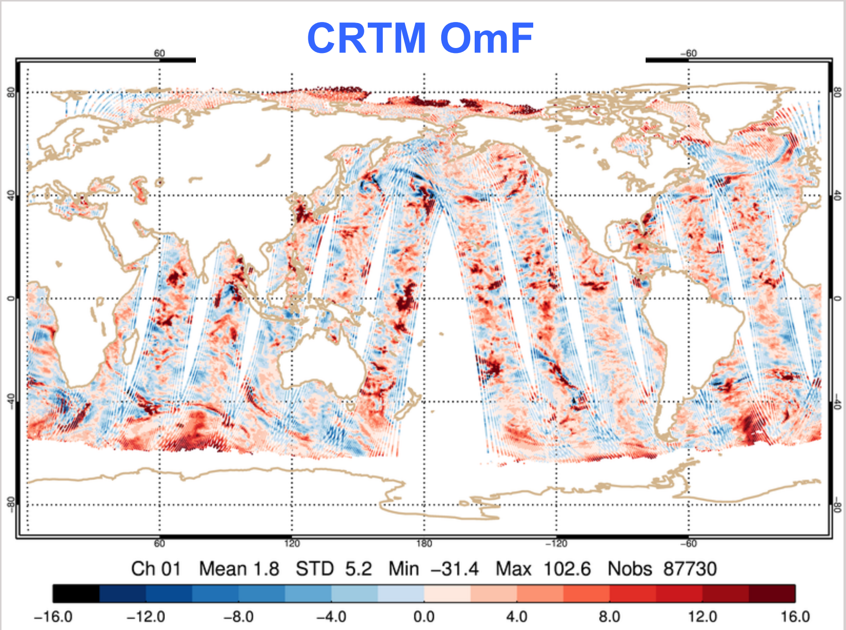
The **work-around** to reduce the biases:

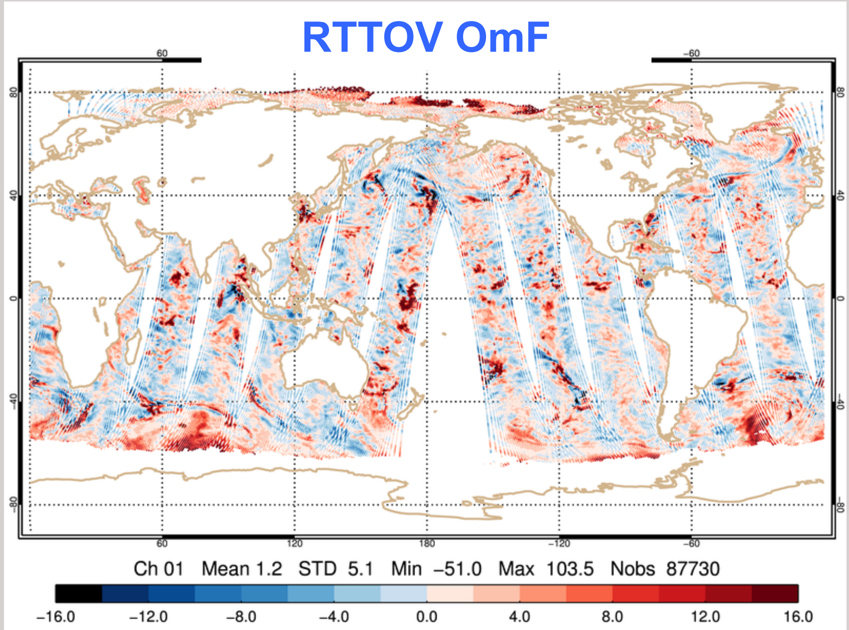
- Reflection correction is included in conjunction with ADA solver and the correction is only applied to stream angles ≤ 60˚
- Stream angles > 60˚ are taken as 60˚ when ADA is on.
- The bi-directional reflectance distribution function (BRDF) for MW will be developed to replace the work-around.



Evaluate CRTM under Scattering Condition

Validation w/ RTTOV



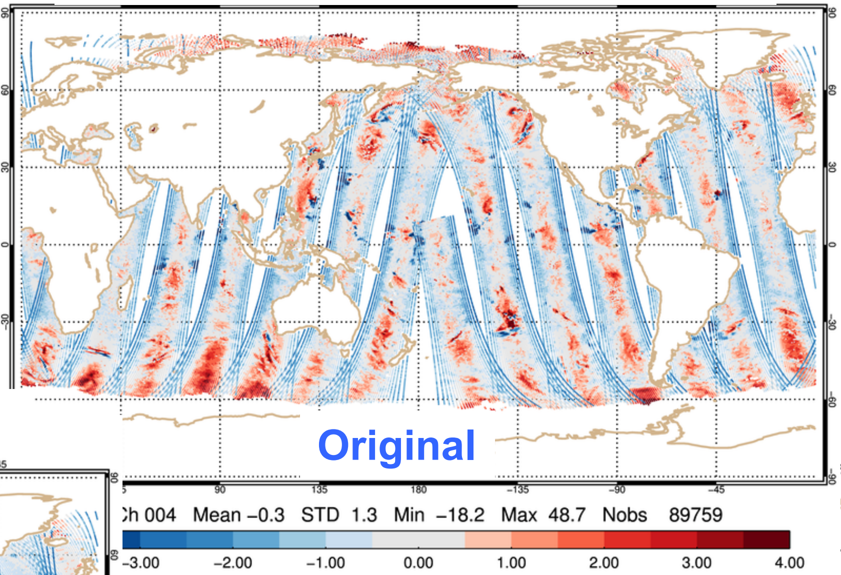


The resulting CRTM BTs with the work-around are comparable to RTTOV BTs for all channels in AMSU-A

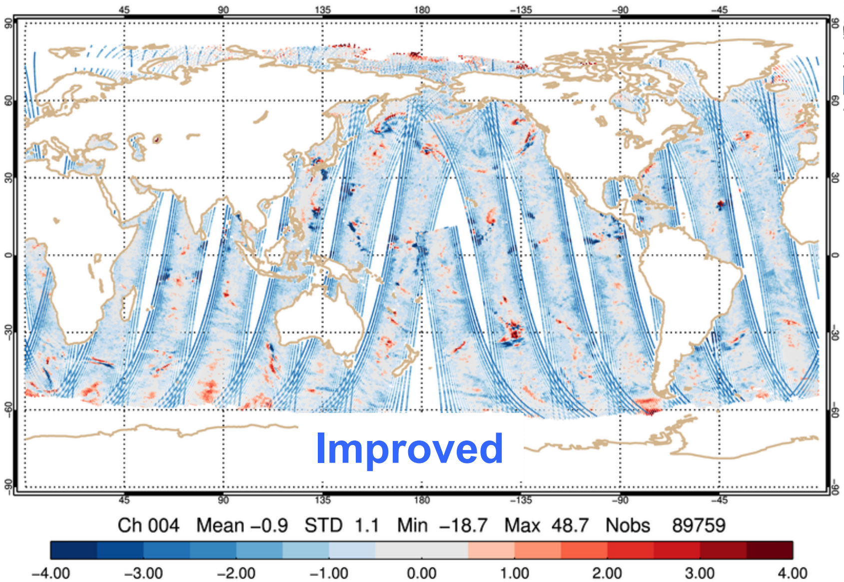
Enhancement of CRTM   Validation w/ Obs

AMSU-A
Channel 04

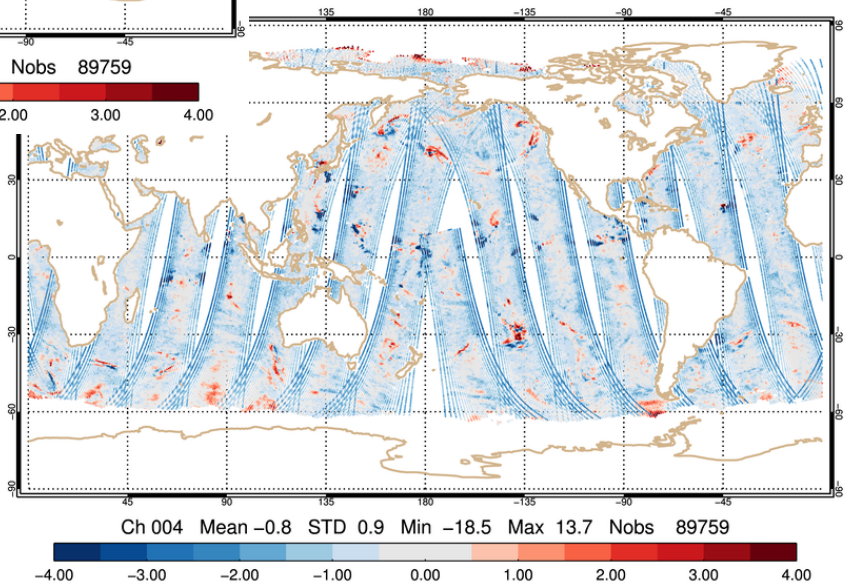
CRTM OmF



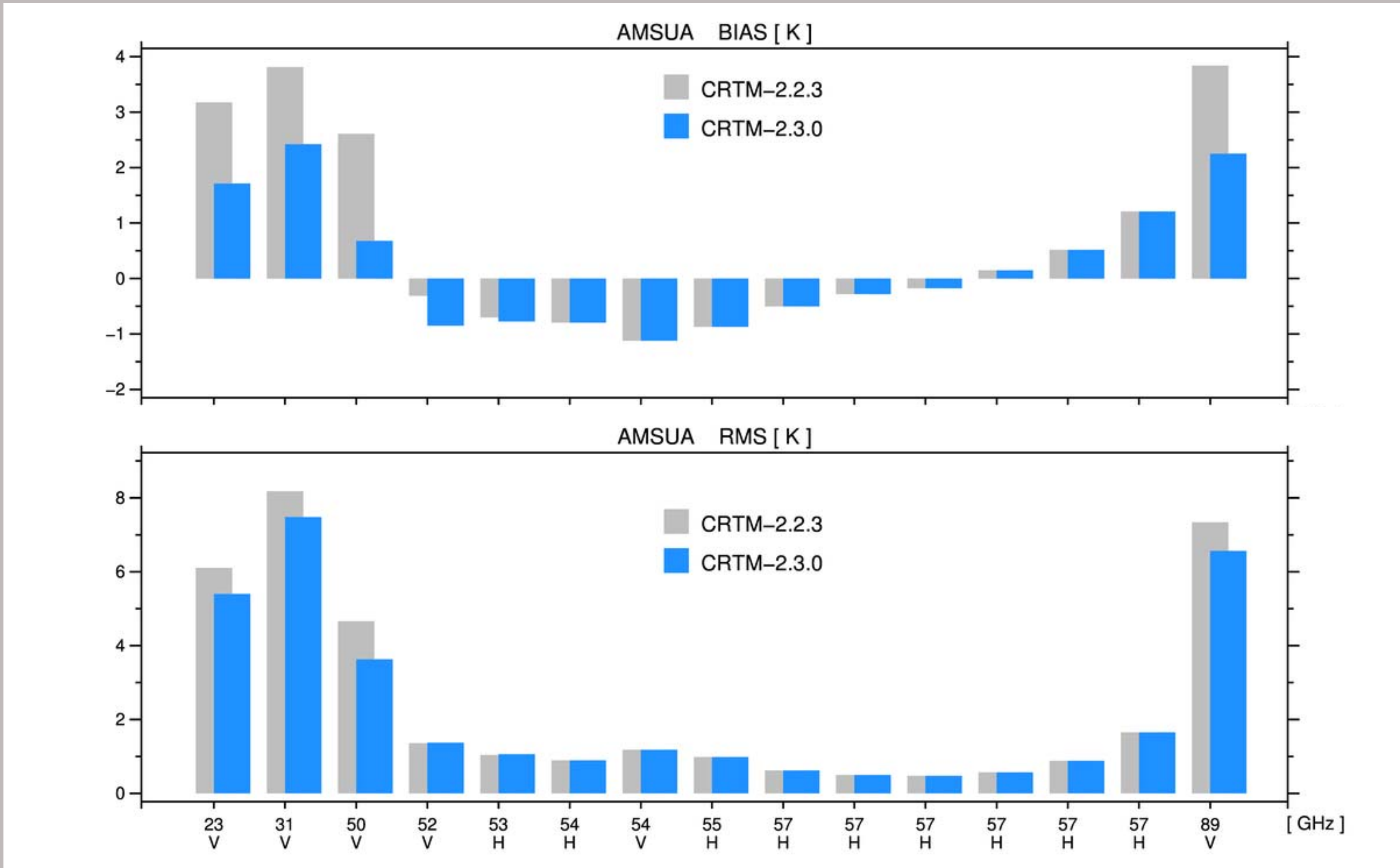
CRTM OmF



RTTOV OmF

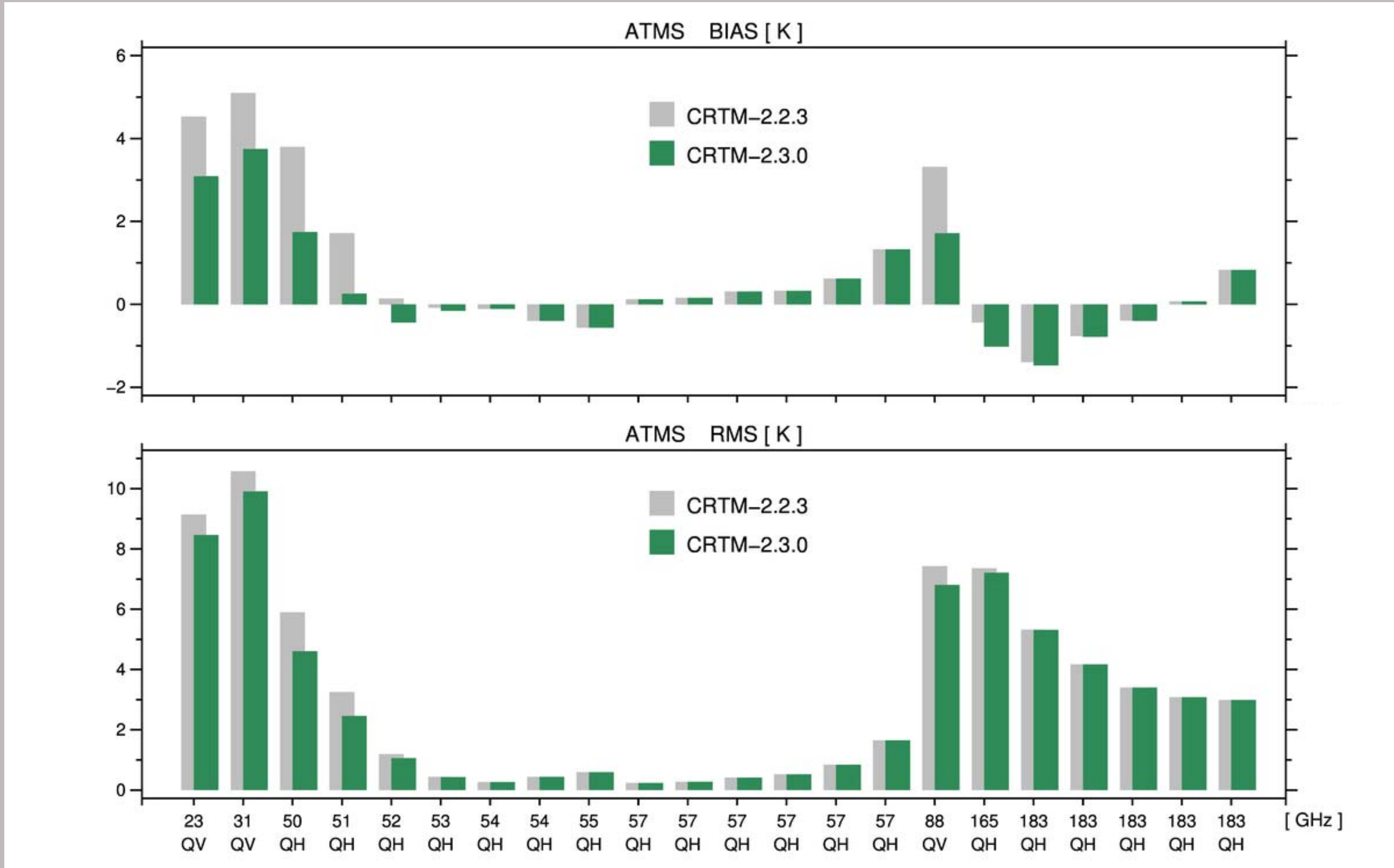


Evaluate CRTM under Scattering Condition   Validation w/ Obs



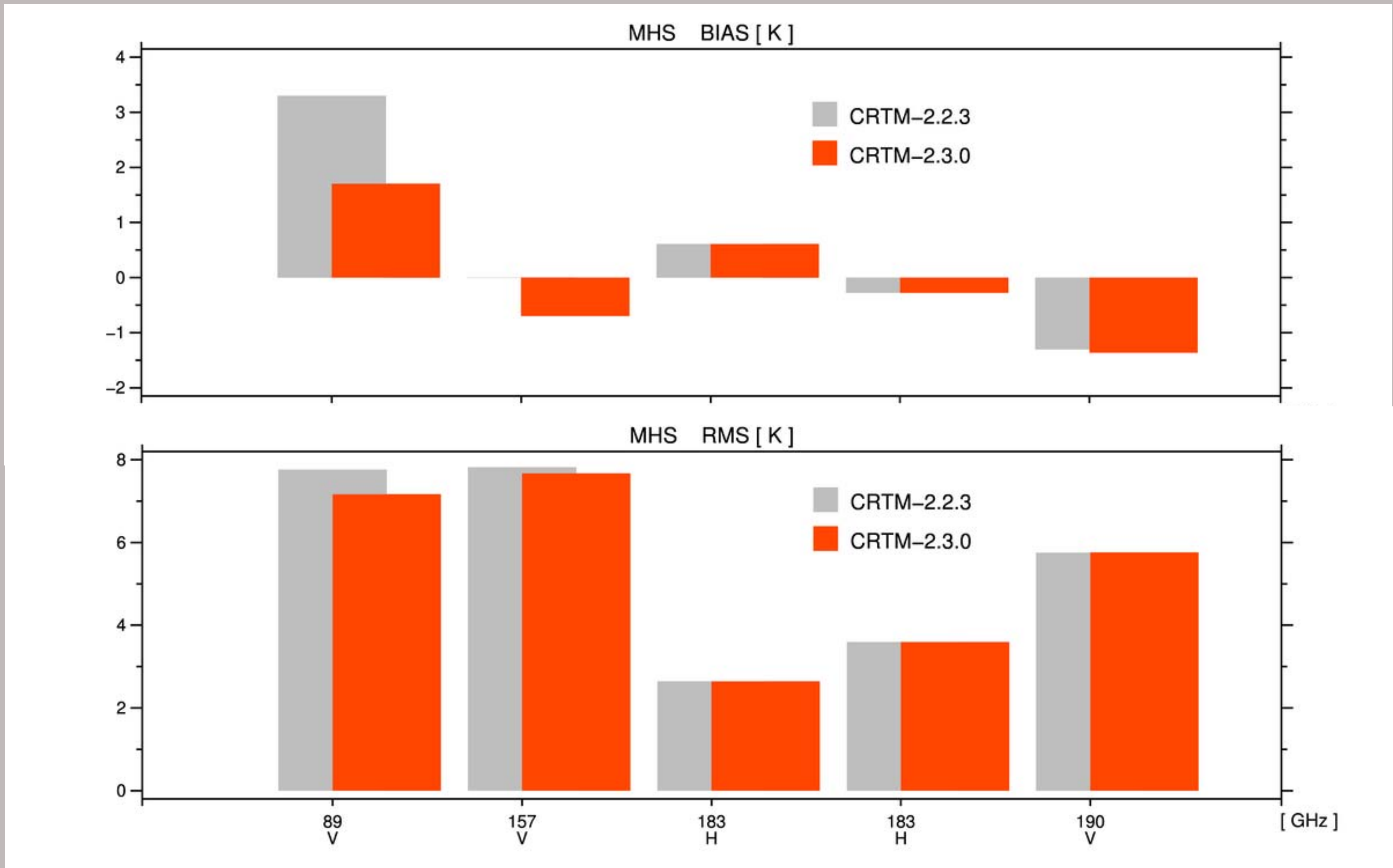
AMSU-A

Evaluate CRTM under Scattering Condition   Validation w/ Obs



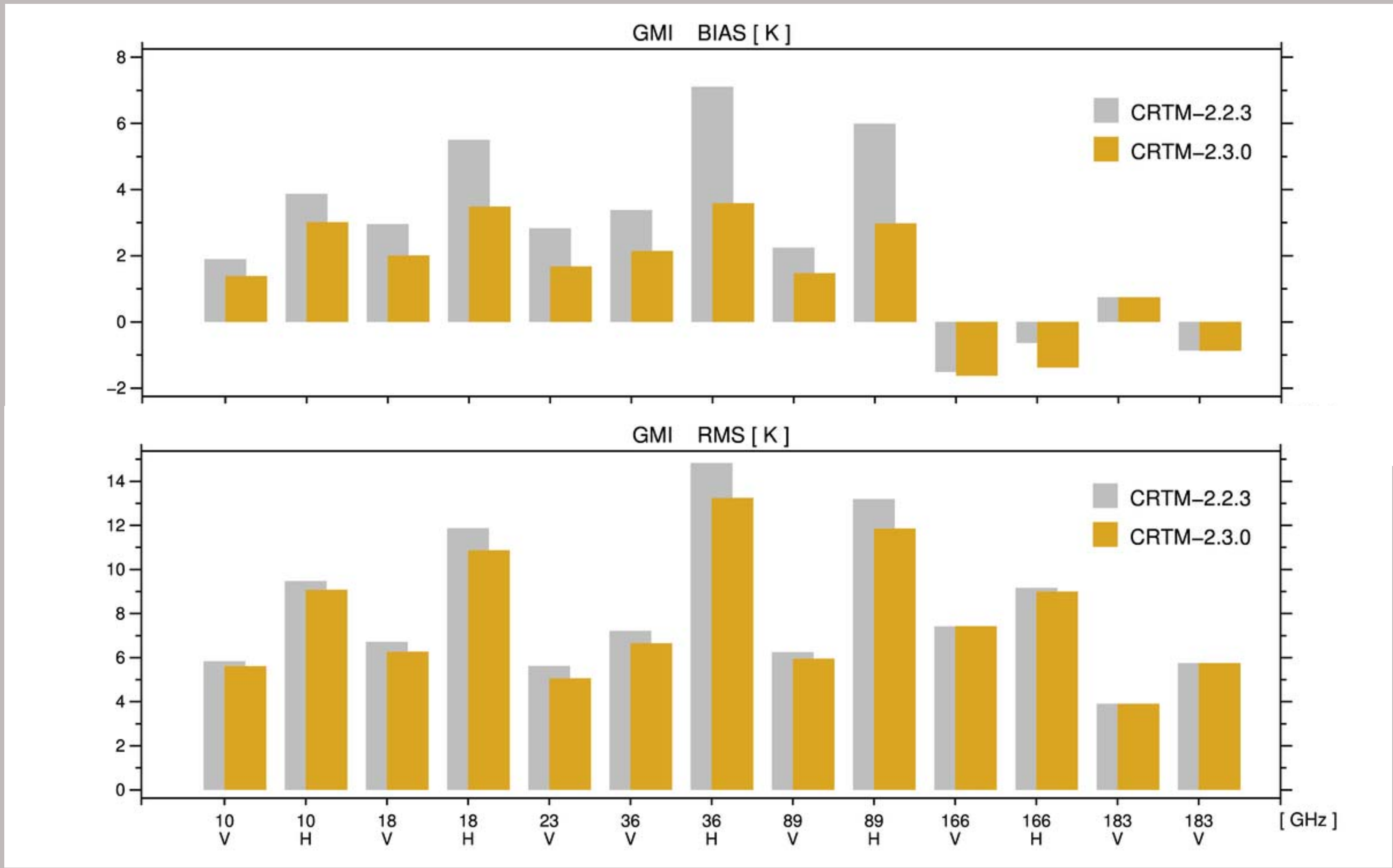
ATMS

Evaluate CRTM under Scattering Condition   Validation w/ Obs



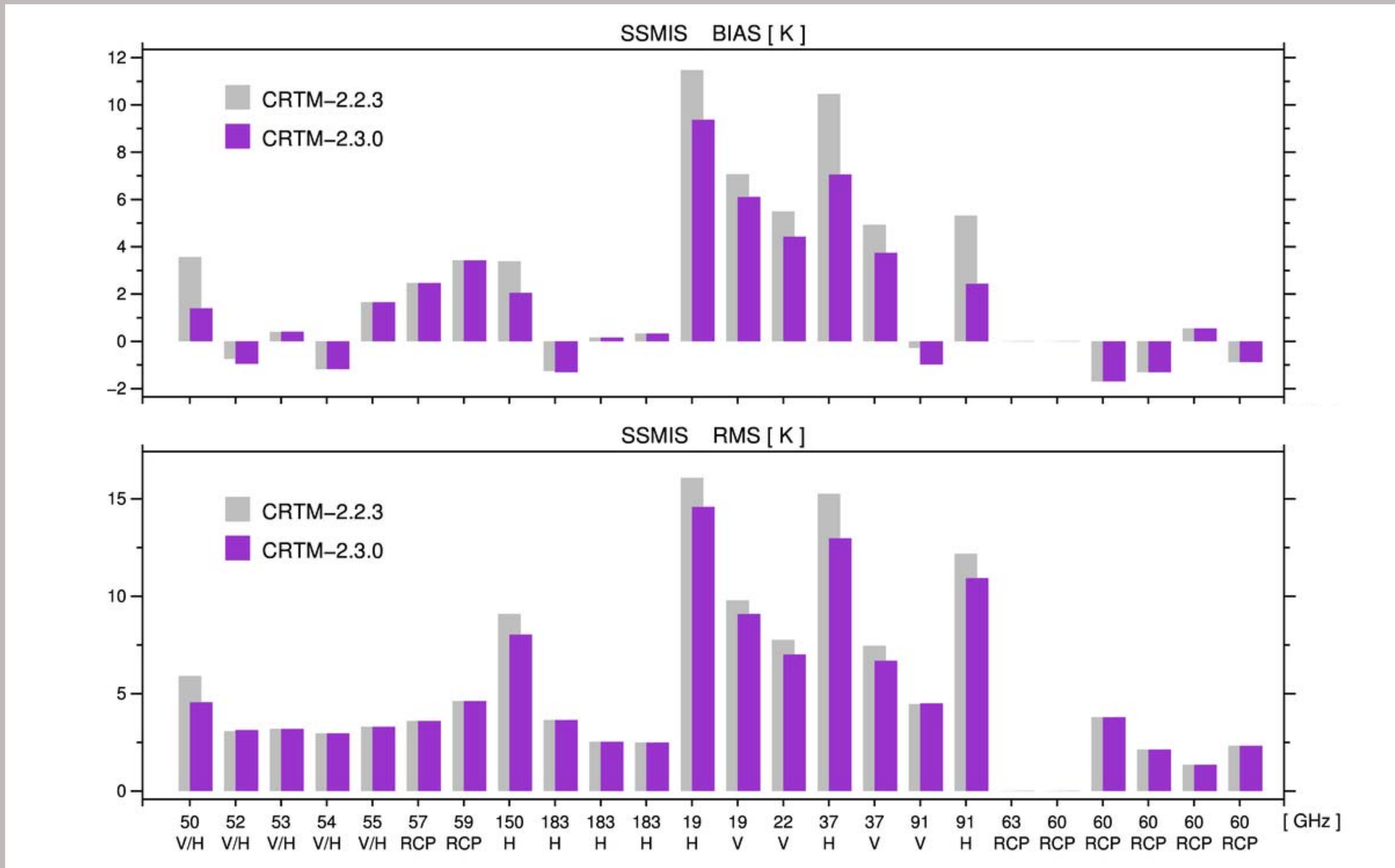
MHS

Evaluate CRTM under Scattering Condition Validation w/ Obs



GMI

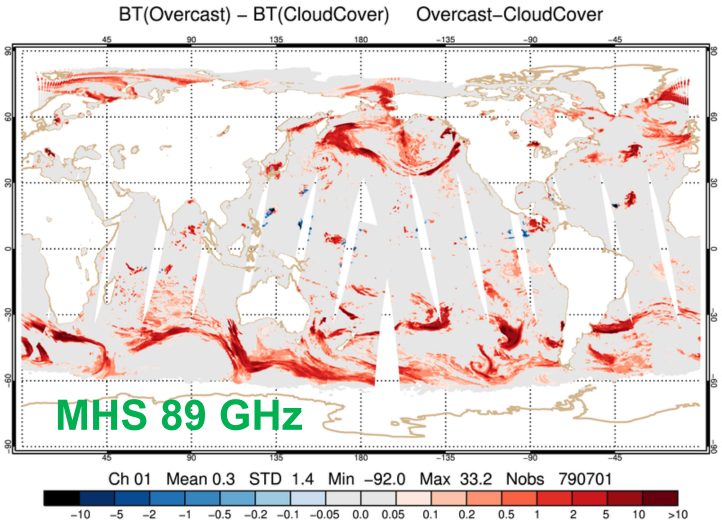
Evaluate CRTM under Scattering Condition Validation w/ Obs

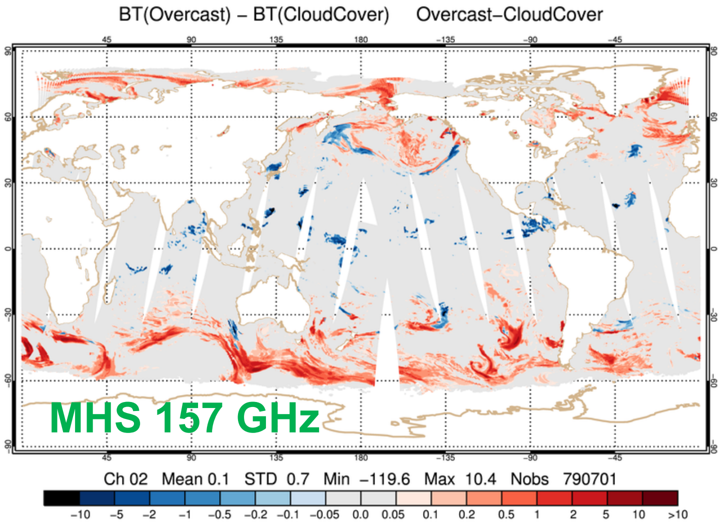


SSMIS

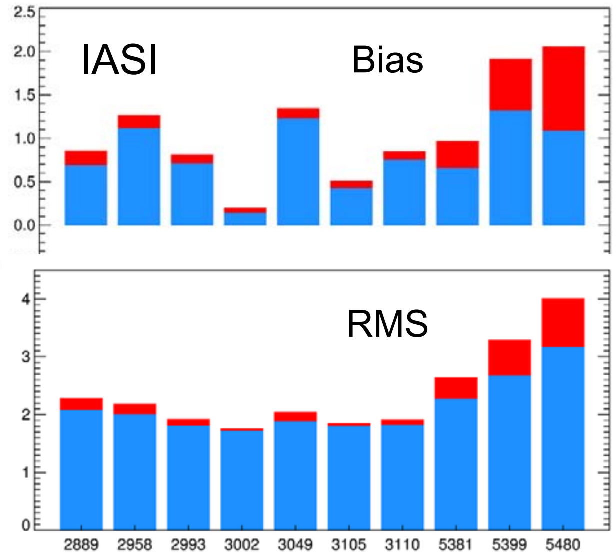
Enhancement of CRTM   Impact of Fractional Cloud Coverage

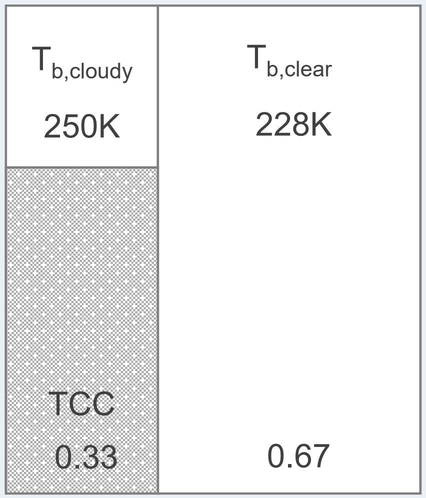
- The impact of fractional cloud coverage on BT can be significant when precipitation is involved
- For high frequency channels, the impact could be over 100 K
- Significant impact for small-scale cloud and precipitation in convective region





Overcast vs. Fractional





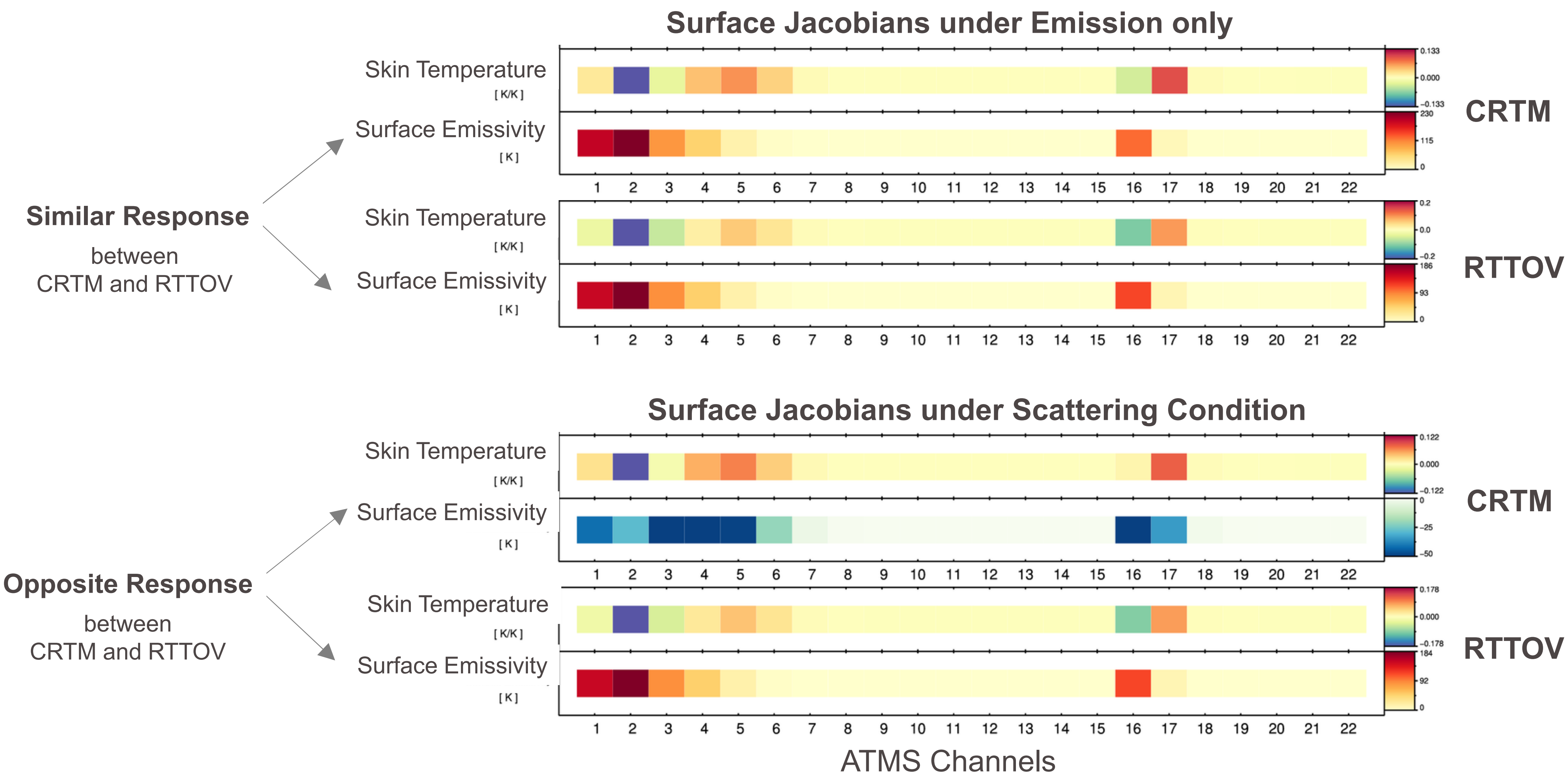
MHS 89 GHz

$T_{b,overcast}$ = 245K ⟶ T_b = 235K

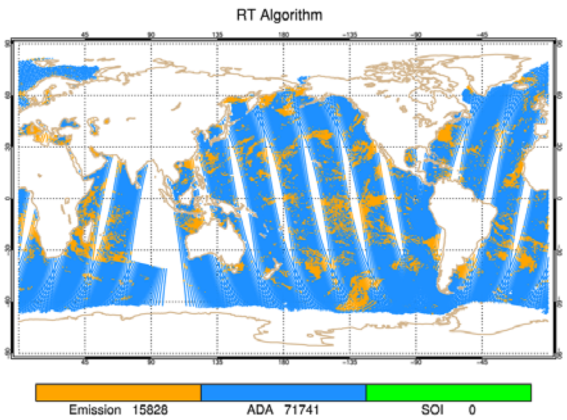
$$T_b = (1 - TCC) \times T_{b,clear} + TCC \times T_{b,cloudy}$$

$$T_b = (1 - 0.33) \times 228 + 0.33 \times 250 = 235$$

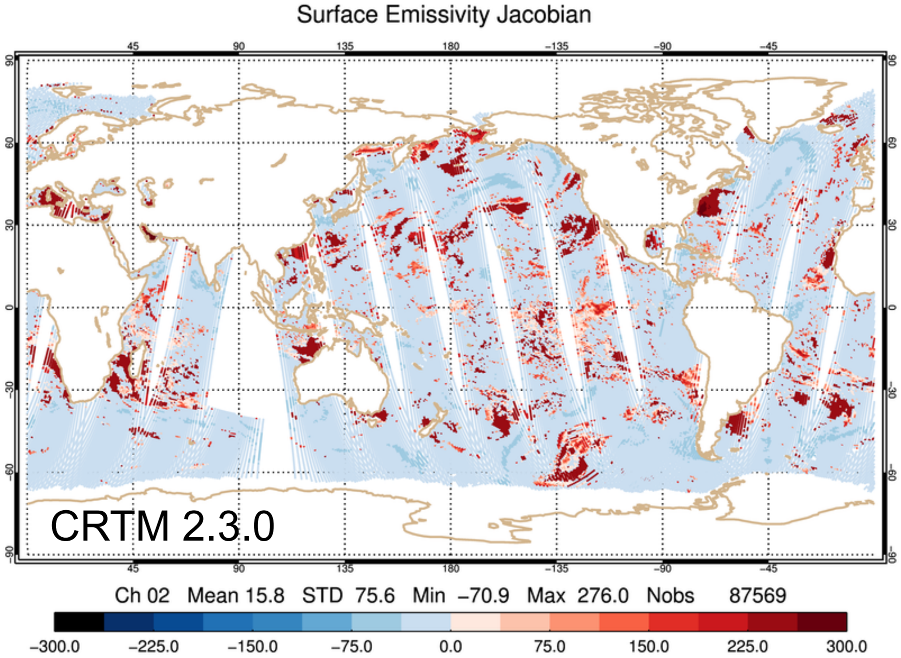
Surface Emissivity Jacobian CRTM vs. RTTOV



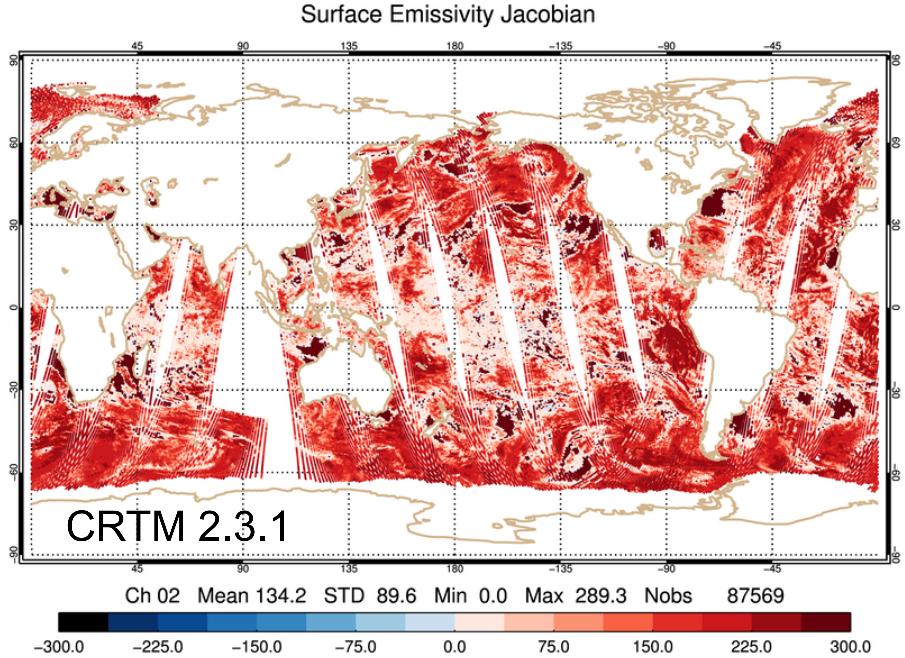
Surface Emissivity Jacobian — Unphysical Response and the Fix



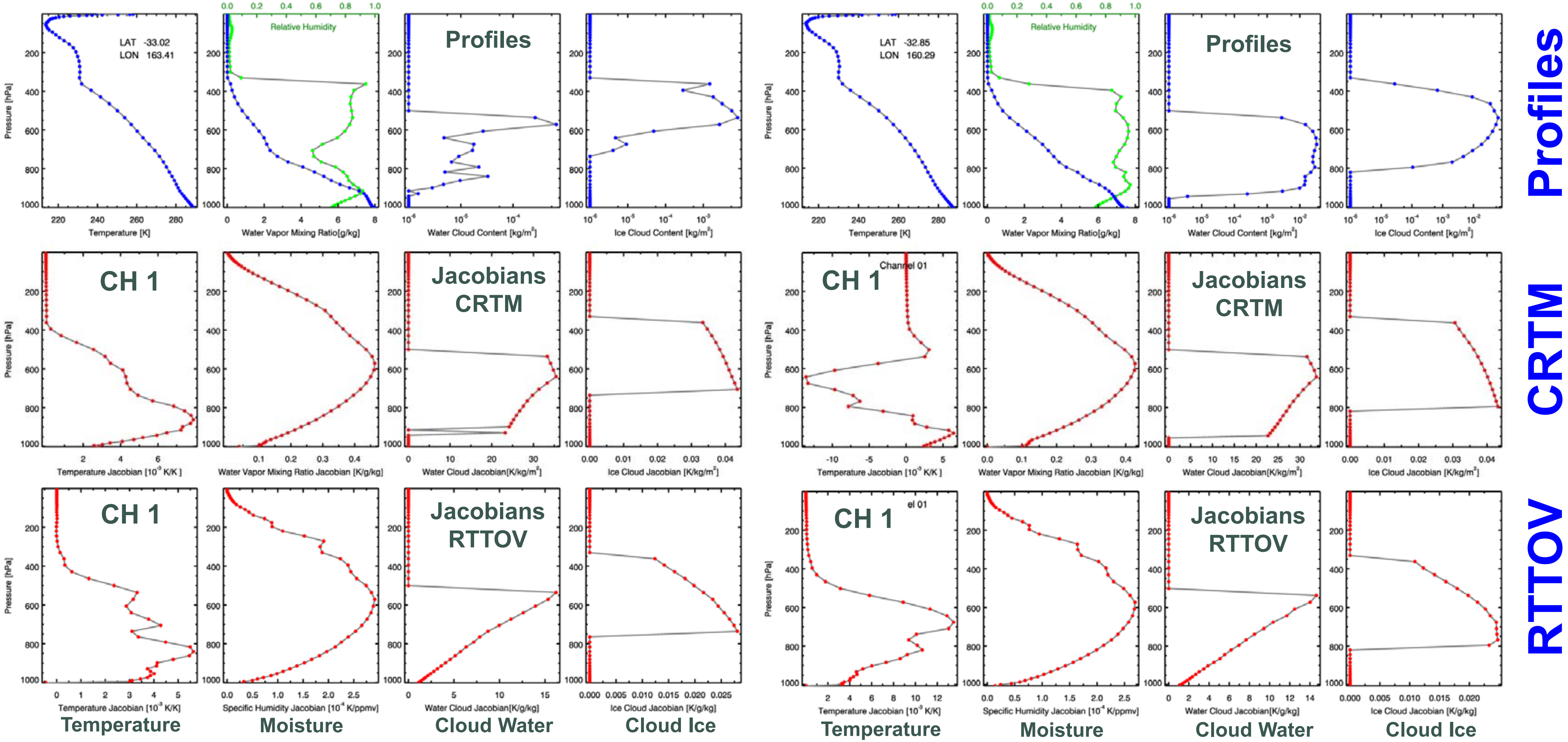
- Unphysical response occurs under scattering condition where ADA is used (blue area)
- This was found to be an output logic error under scattering condition in CRTM and has been corrected for CRTM 2.3.1 release
- The quality of the surface emissivity Jacobian is crucial for the radiance data quality control and bias correction procedures in GSI analysis



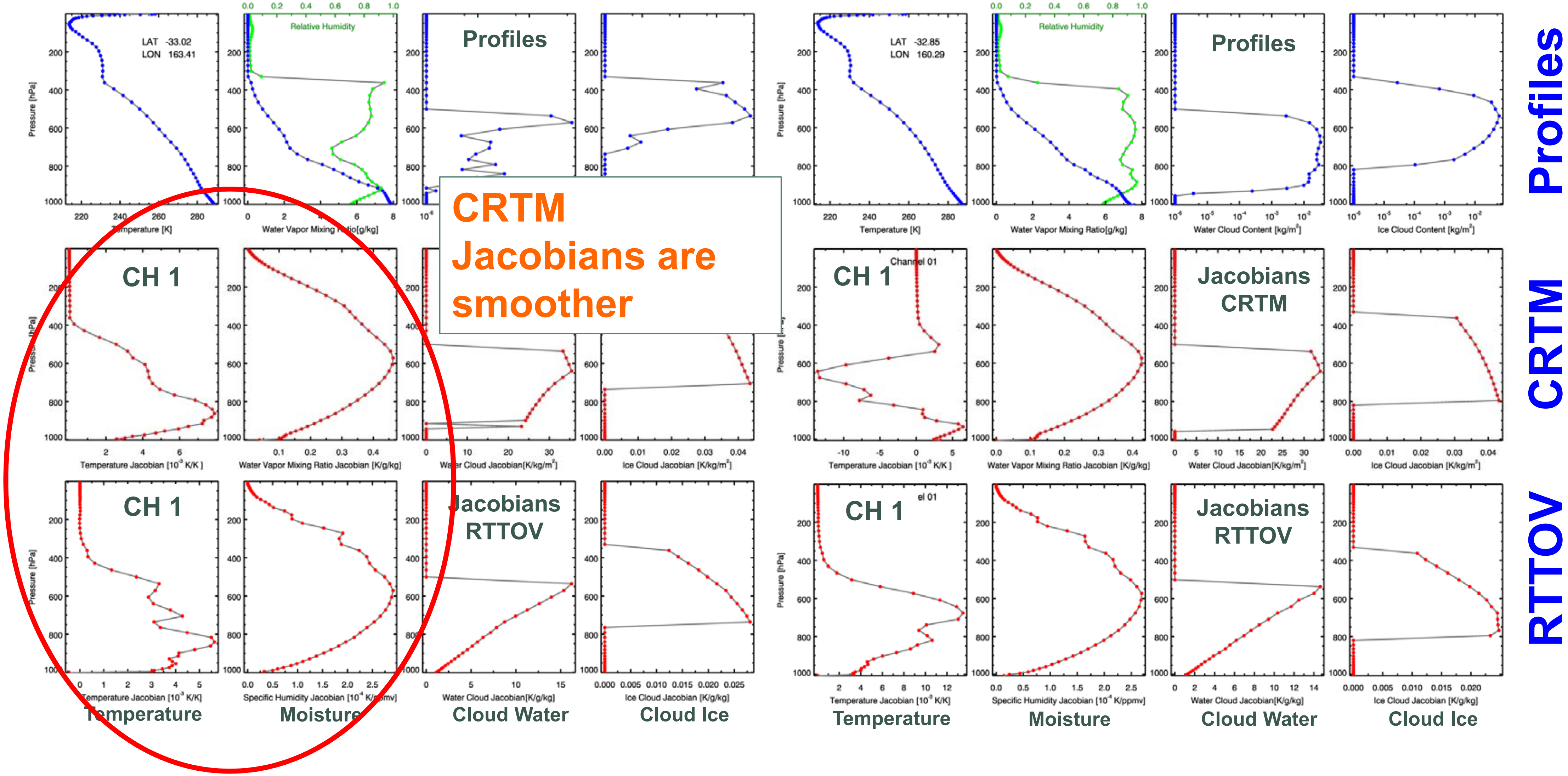
AMSUA Channel 02



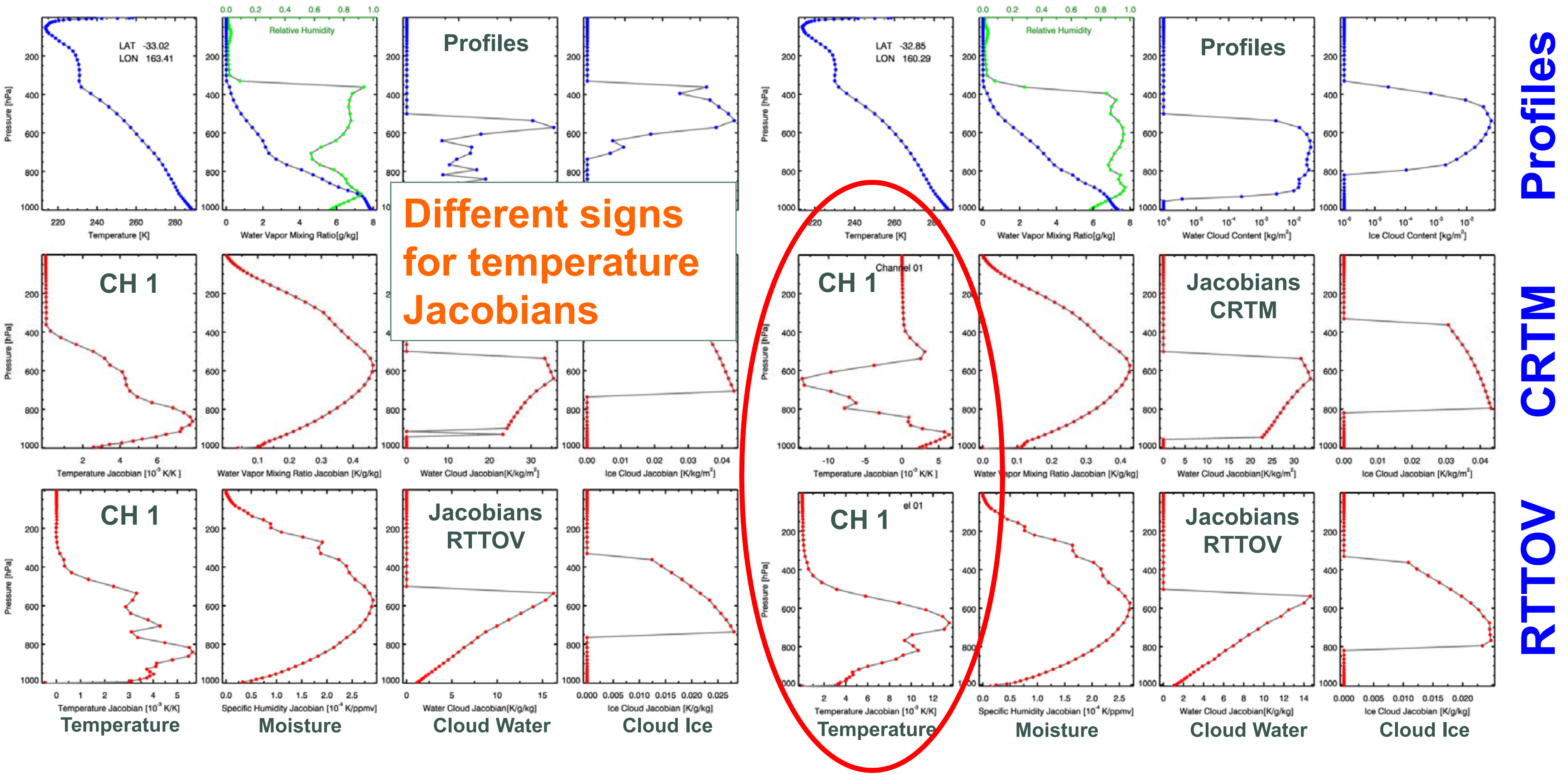
Comparing Jacobians   Optically Thin vs. Thick Clouds



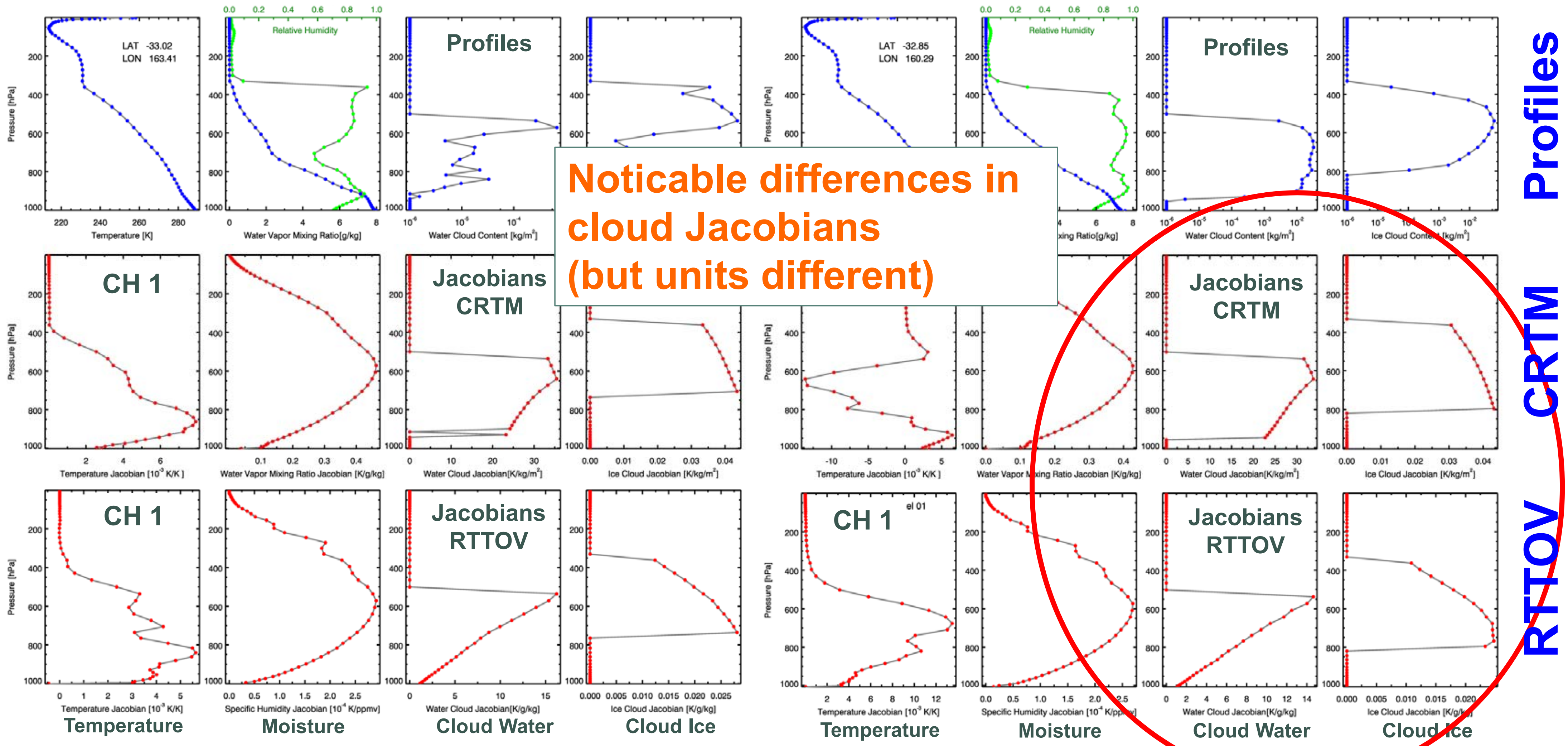
Comparing Jacobians   Optically Thin vs. Thick Clouds



Comparing Jacobians Optically Thin vs. Thick Clouds



Comparing Jacobians Optically Thin vs. Thick Clouds



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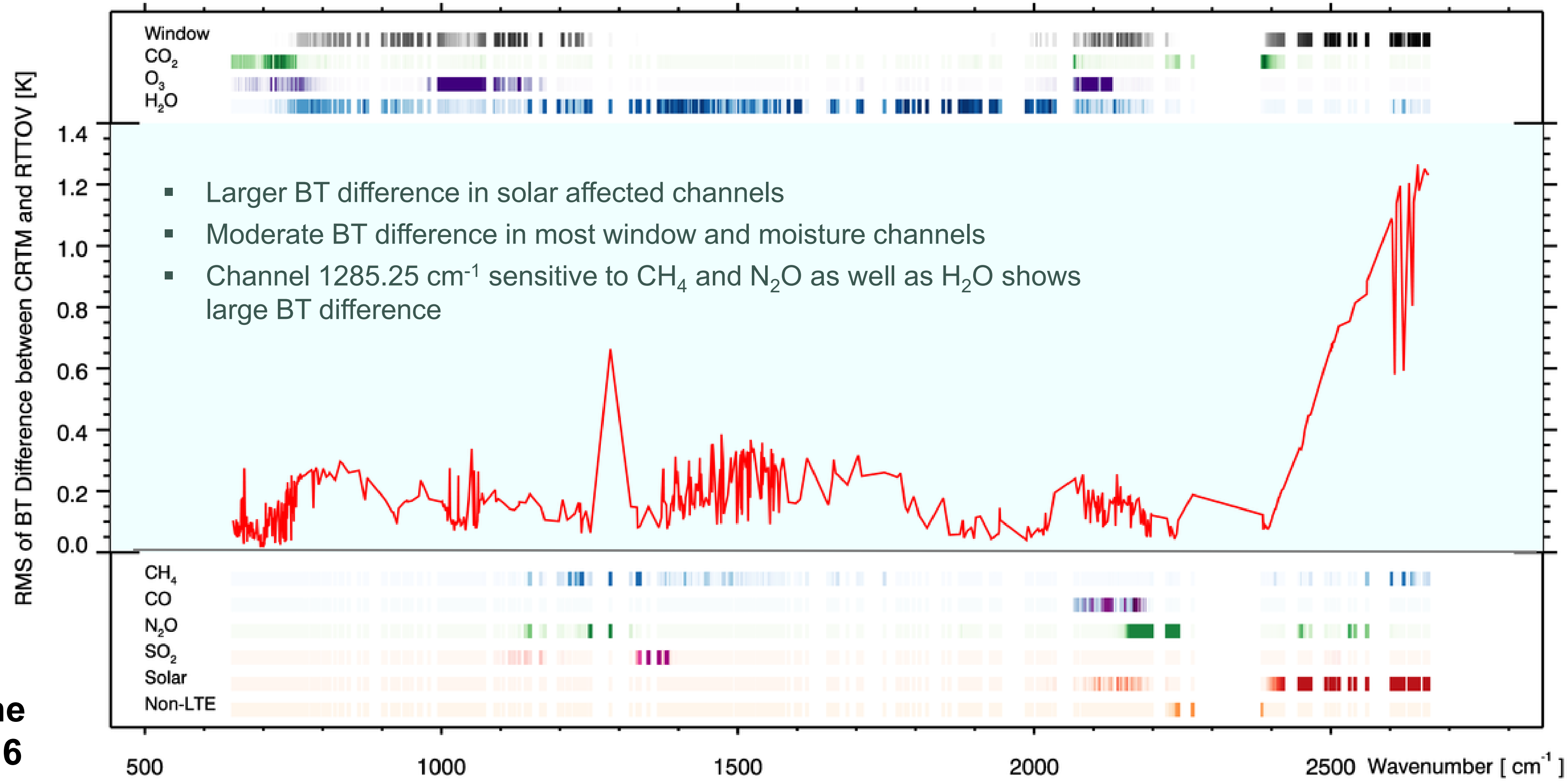
Evaluate CRTM for Clear-sky IASI   Compare with RTTOV

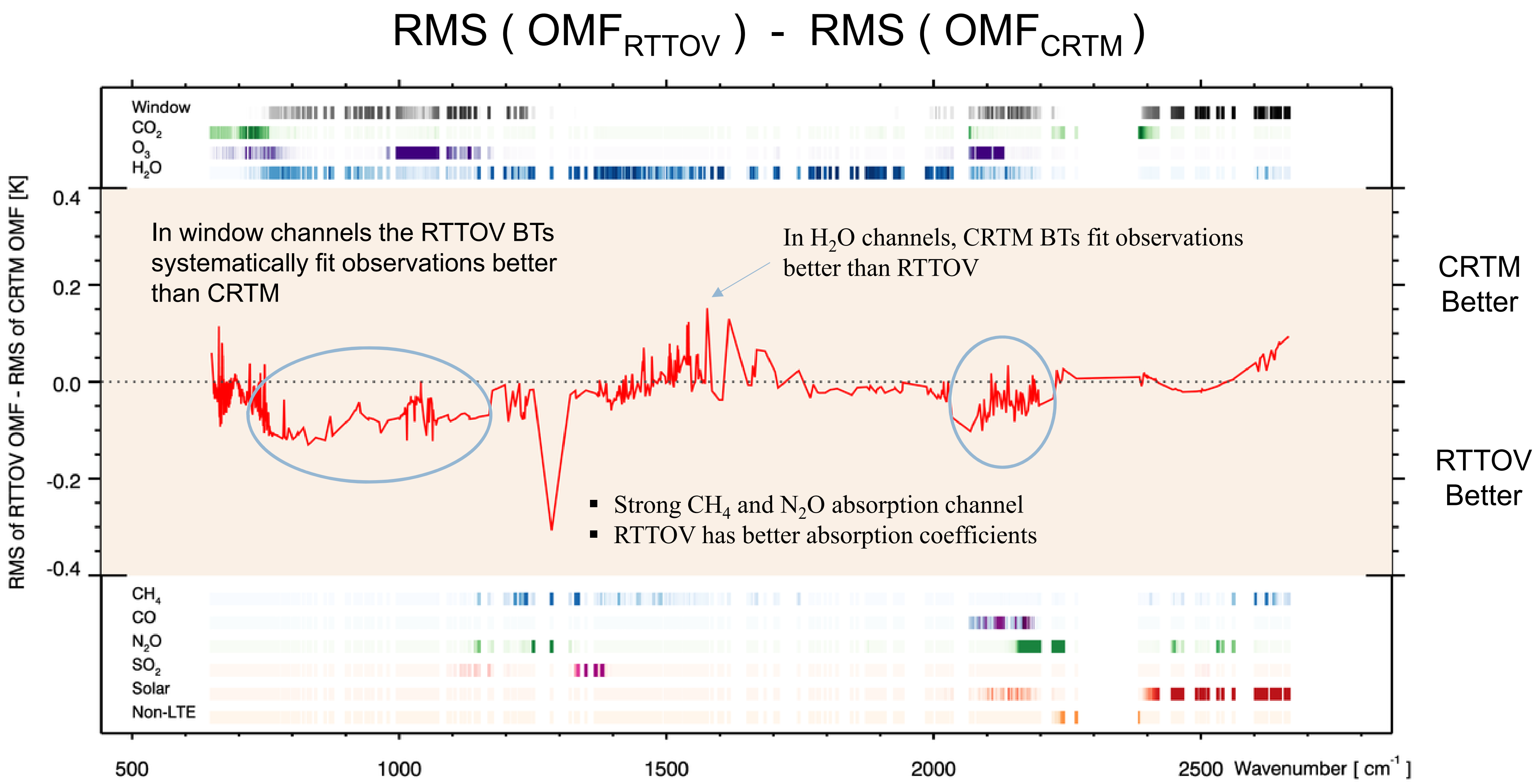
RMS (BT_{CRTM} – BT_{RTTOV})



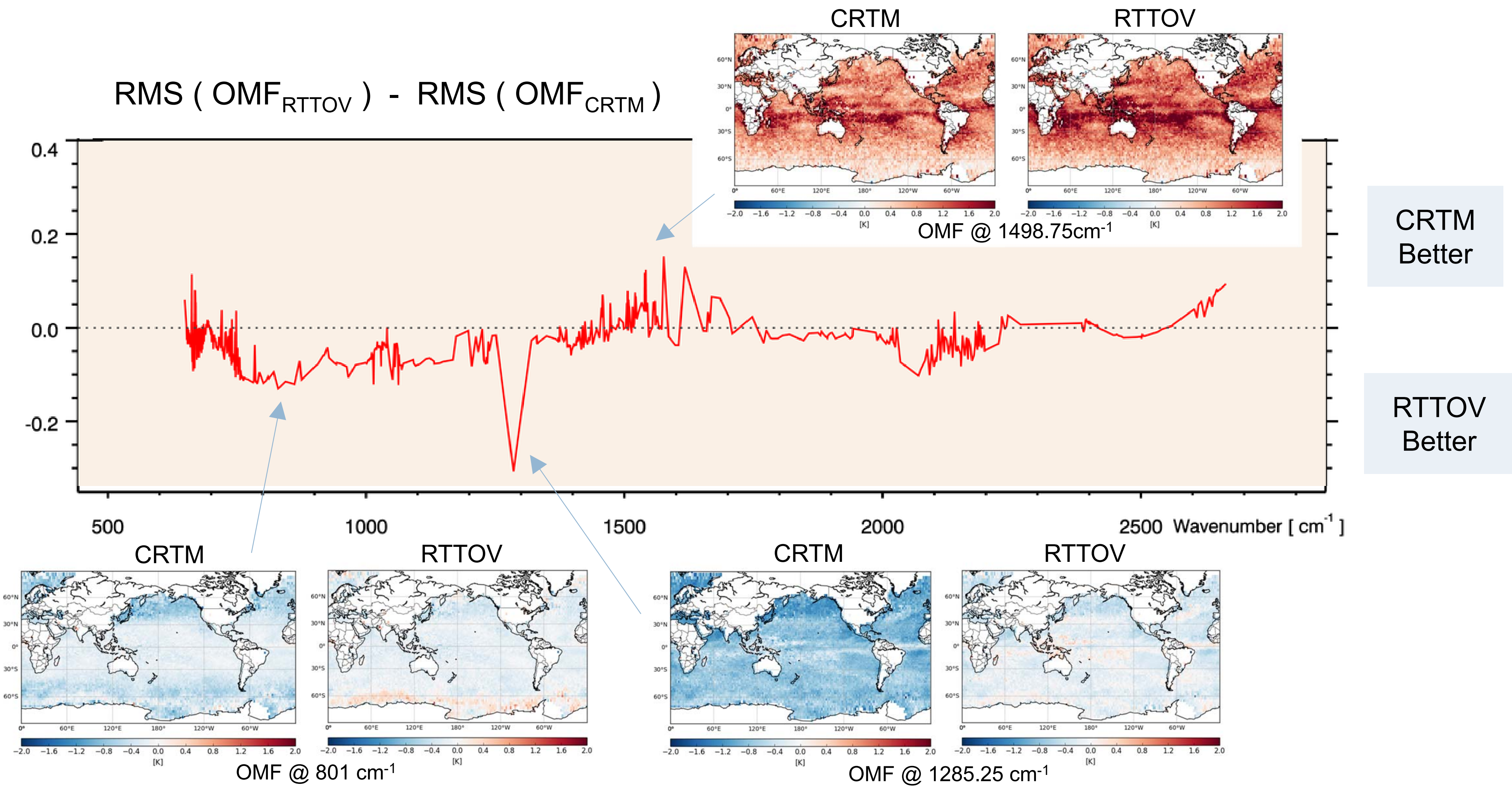
- Larger BT difference in solar affected channels
- Moderate BT difference in most window and moisture channels
- Channel 1285.25 cm^{-1} sensitive to CH_4 and N_2O as well as H_2O shows large BT difference

This is the NOAA 616 channel subset

Evaluate CRTM for Clear-sky IASI — Validation w/ Obs & RTTOV

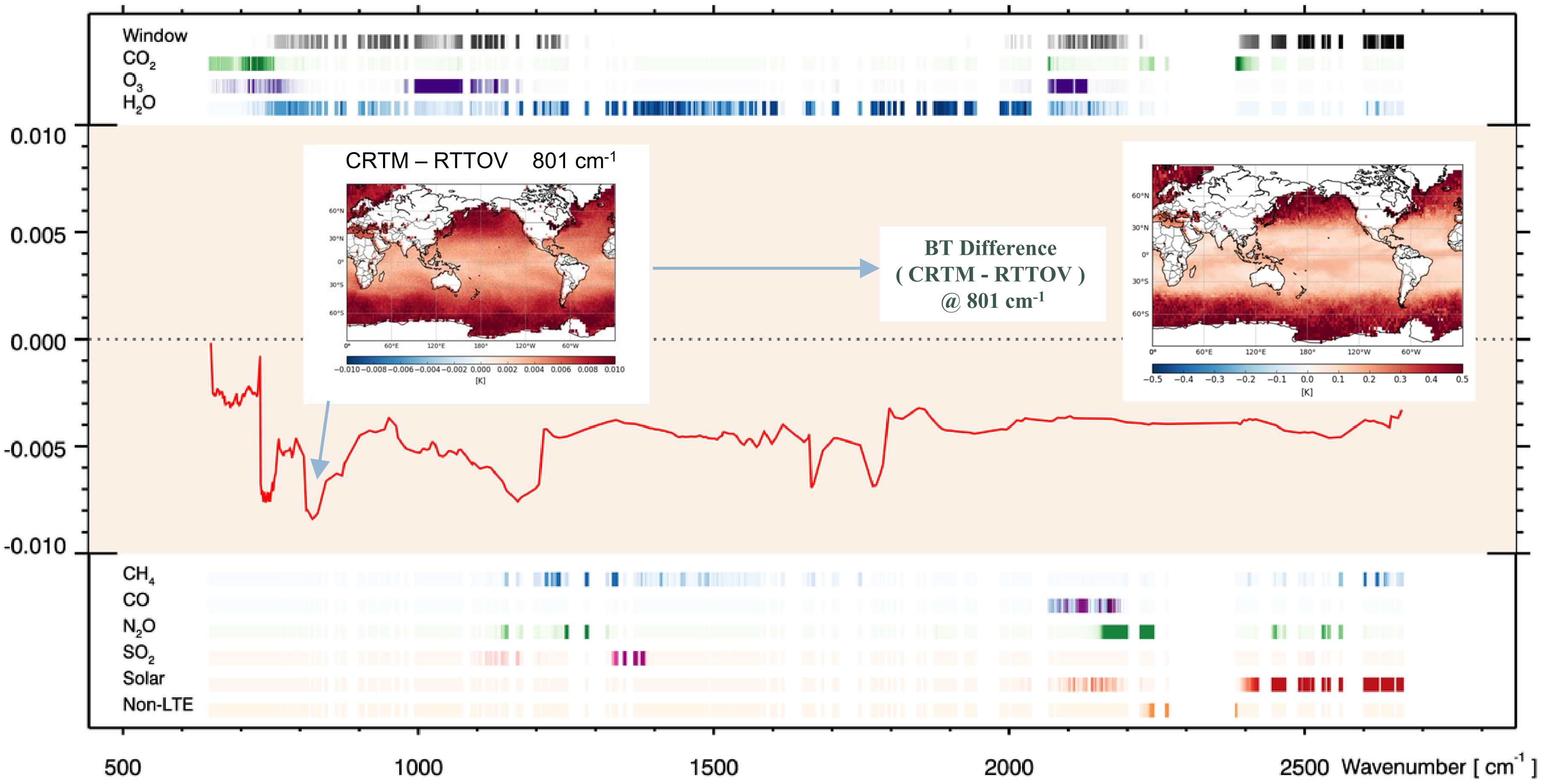


Evaluate CRTM for Clear-sky IASI   Validation w/ Obs & RTTOV



Evaluate CRTM for Clear-sky IASI   Compare w/ RTTOV

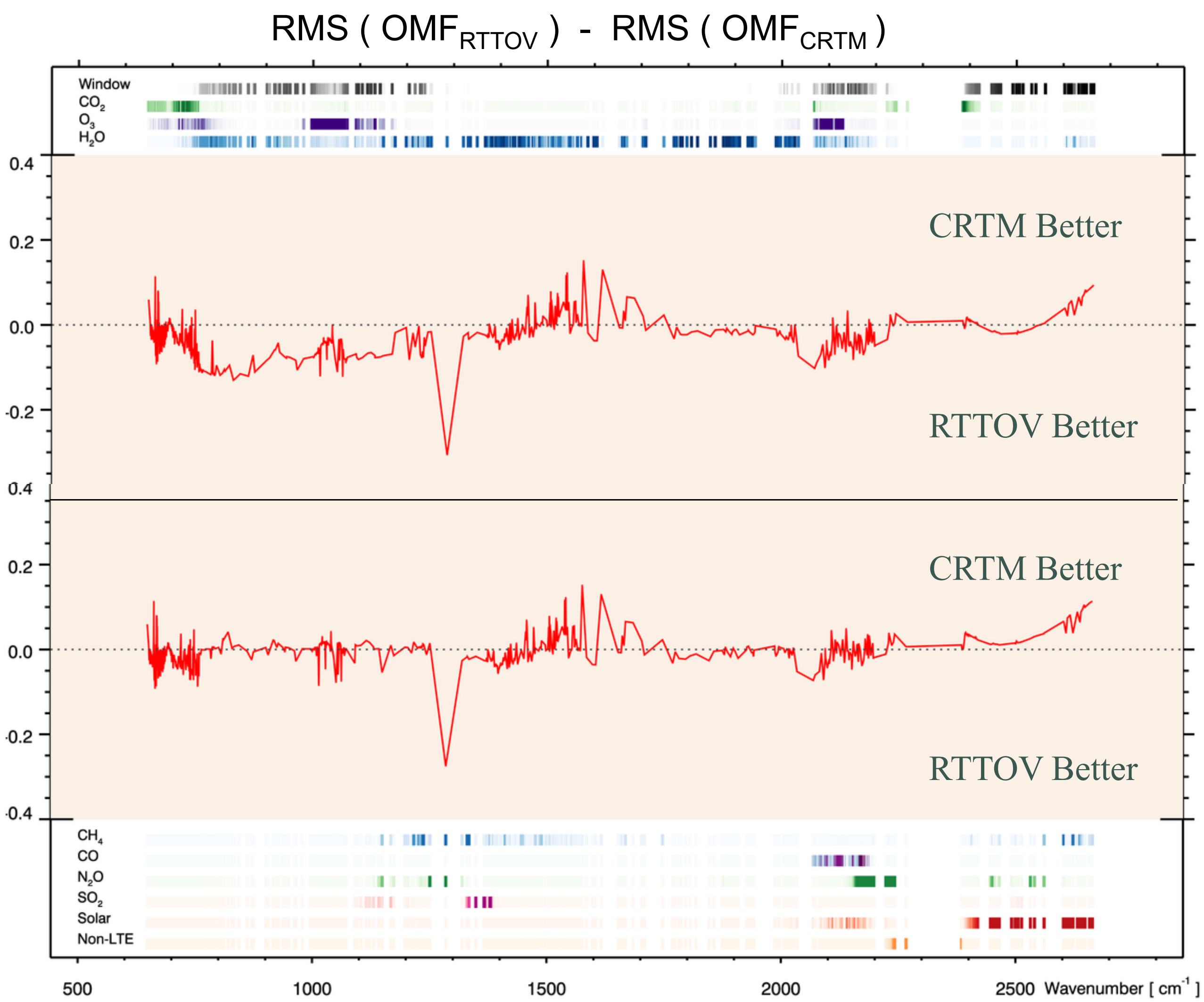
Surface Emissivity Difference (RTTOV - CRTM)



Evaluate CRTM for Clear-sky IASI Validation w/ Obs & RTTOV

CRTM using IRSSE (default)

CRTM using IREMIS from RTTOV



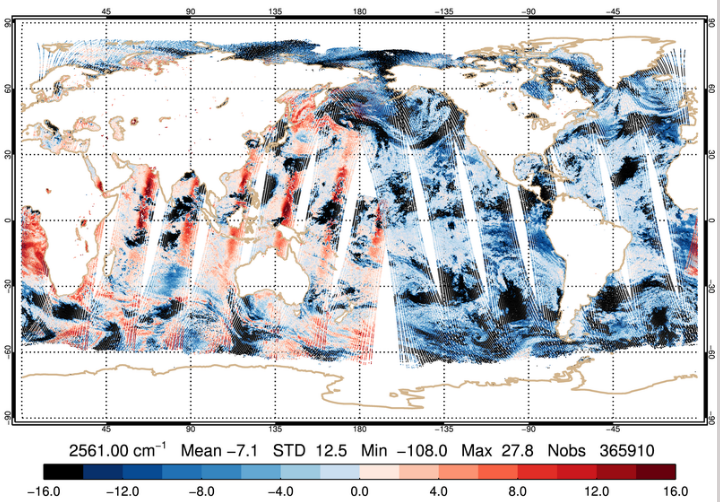
The OMF values show improvement not only in surface channels but in near surface channels as well

The IREMIS (RTTOV) model includes sea surface temperature in estimating sea surface emissivity (Newman 2005)

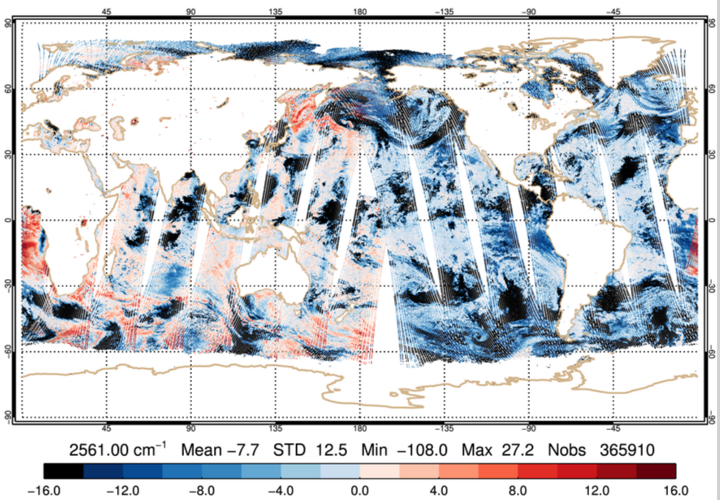
CRTM is working on including the sensitivity of sea surface temperature to its IR ocean emissivity model

Evaluate CRTM for Clear-sky IASI Solar-affected Channels

CRTM OMF

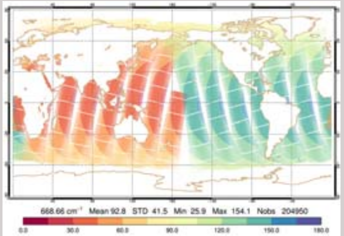


RTTOV OMF

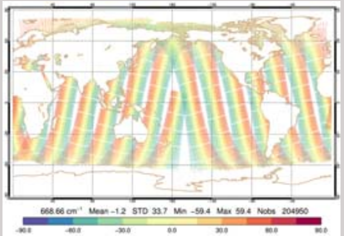


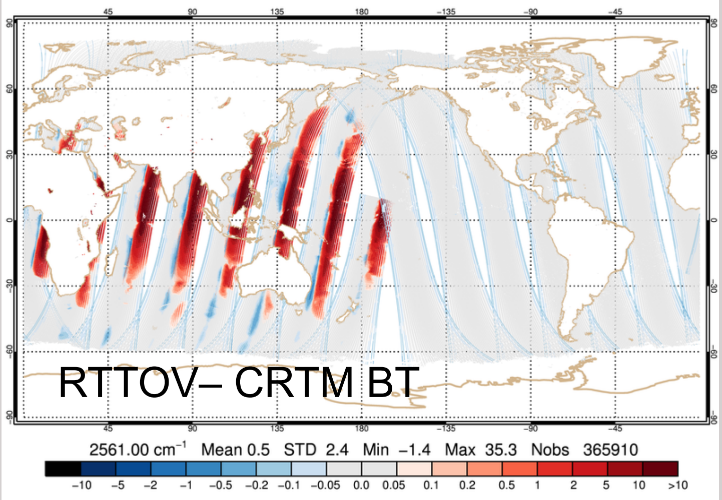
IASI Channel 600
2561 cm^{-1}

Solar Zenith Angle

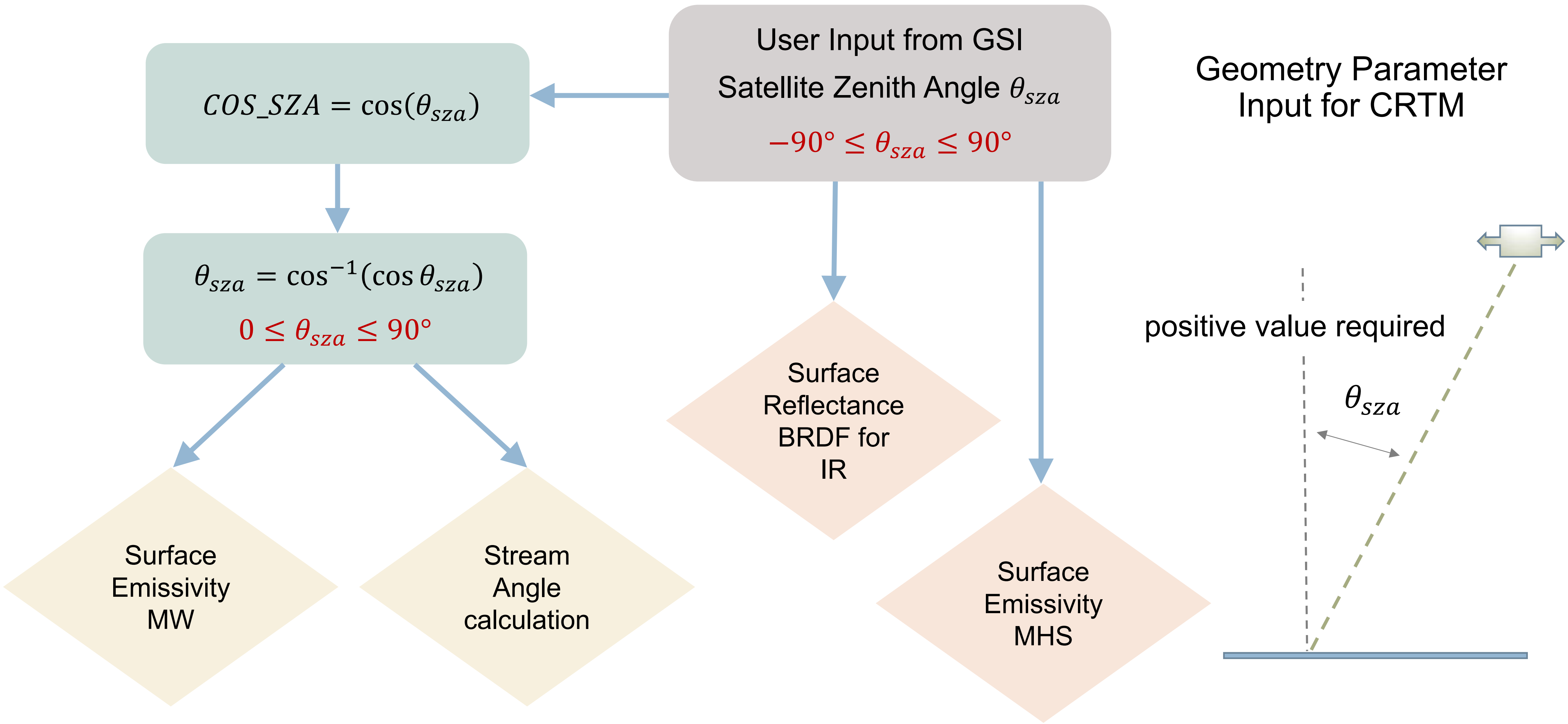


Sensor Zenith Angle





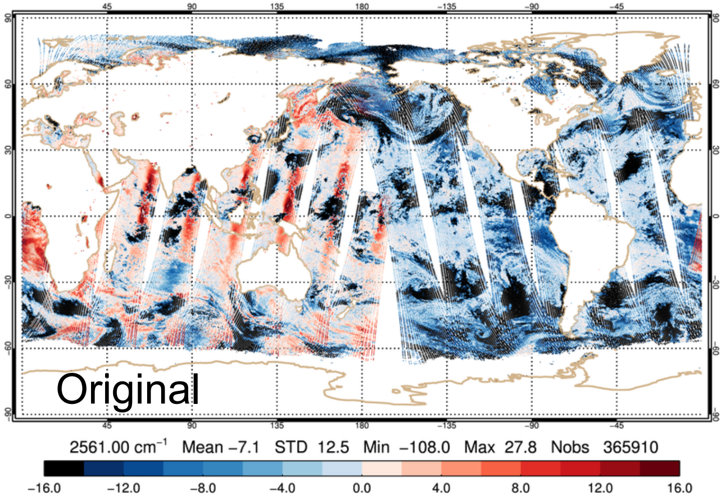
Evaluate CRTM for Clear-sky IASI Solar-affected Channels



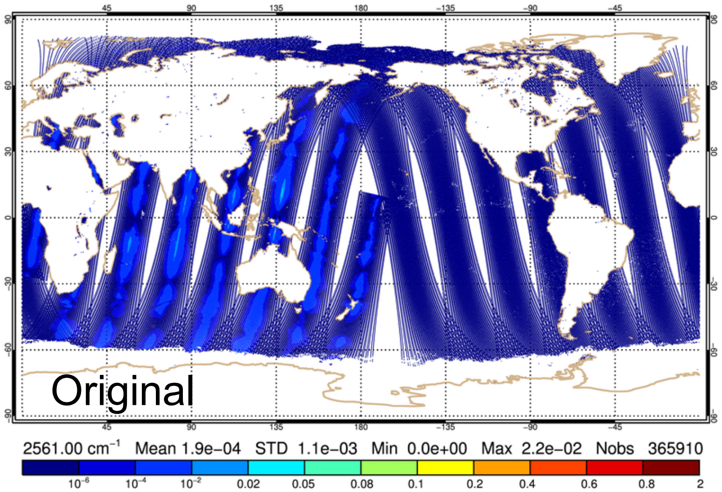
Evaluate CRTM for Clear-sky IASI Solar-affected Channels

IASI Channel 600
2561 cm^{-1}

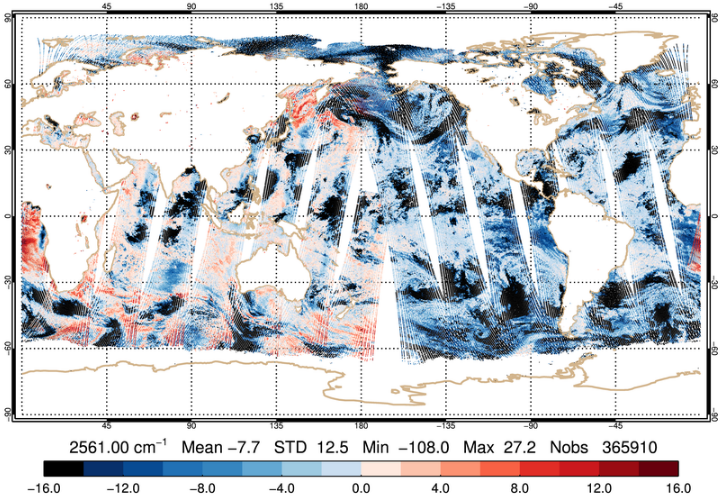
CRTM OMF

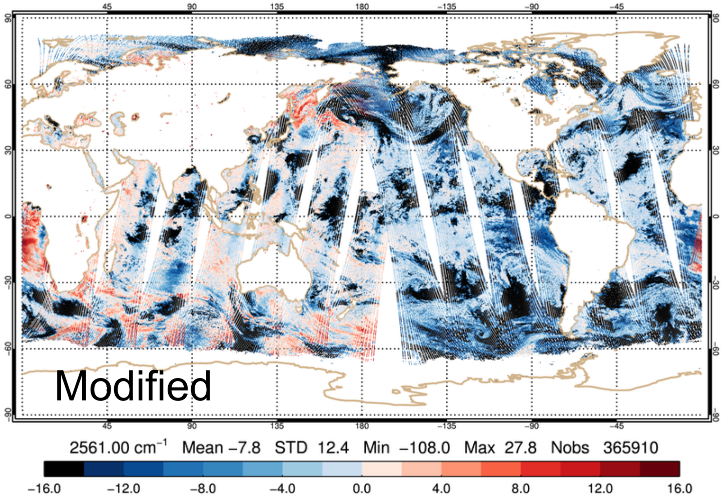


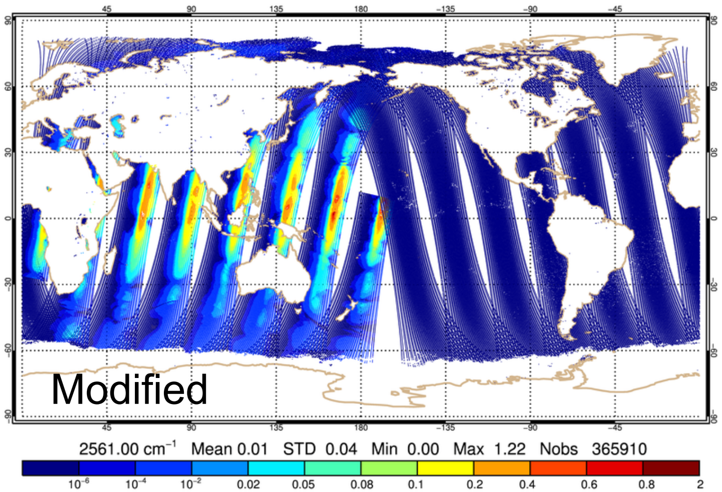
Direct Solar Reflectivity



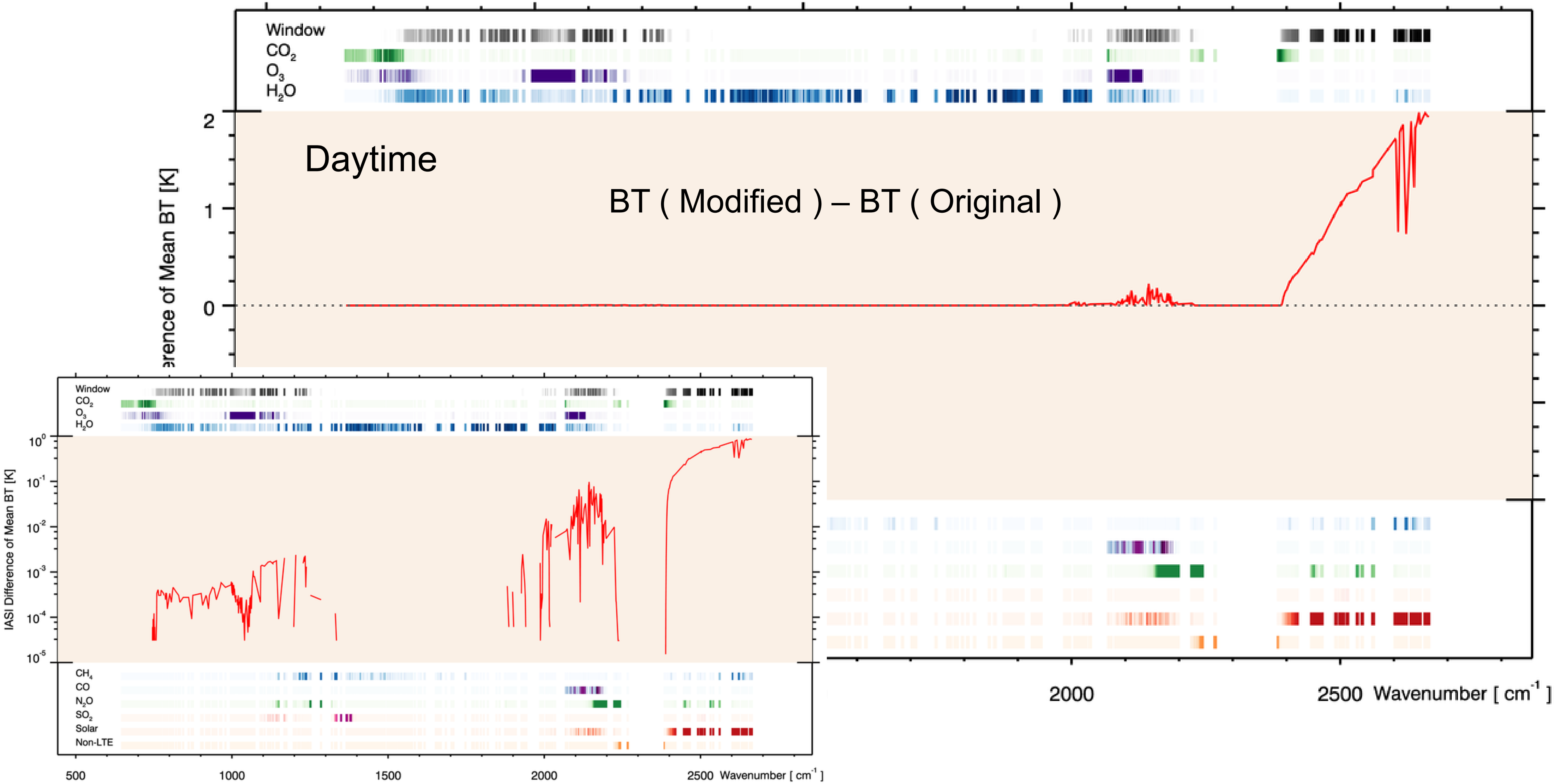
RTTOV OMF





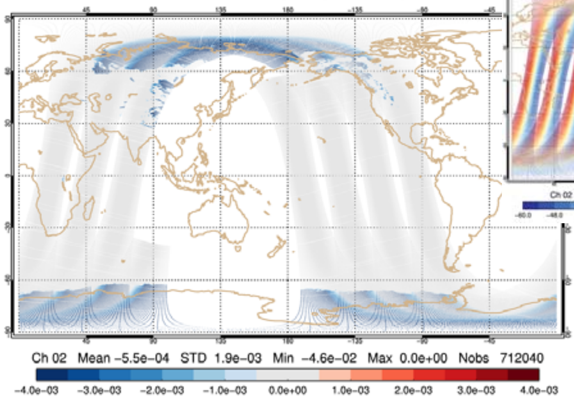


Evaluate CRTM for Clear-sky IASI   Solar-affected Channels

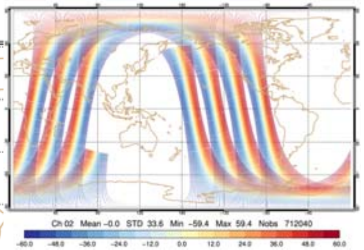


Evaluate CRTM for MHS Surface Emissivity — Impact of SZA Fix

Surface Emissivity
(Fixed – Original)

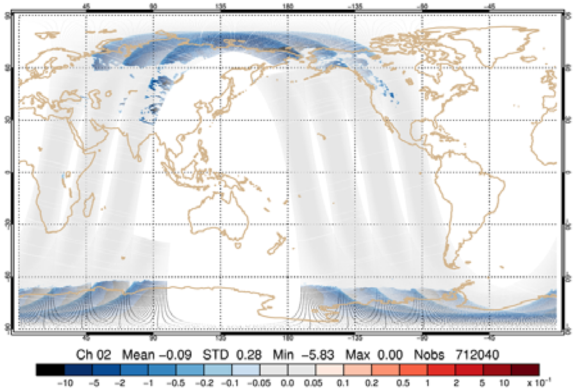


Sensor Zenith Angle

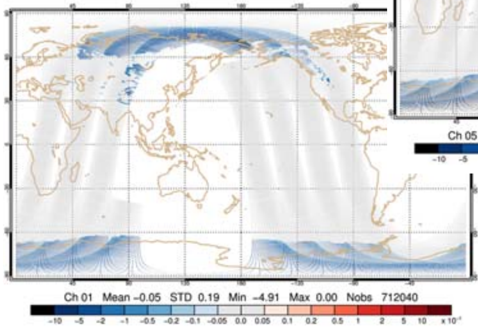


Impact found over snow, sea ice and mixed surface types

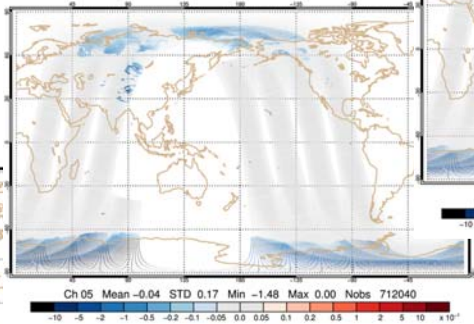
BT (Fixed – Original)



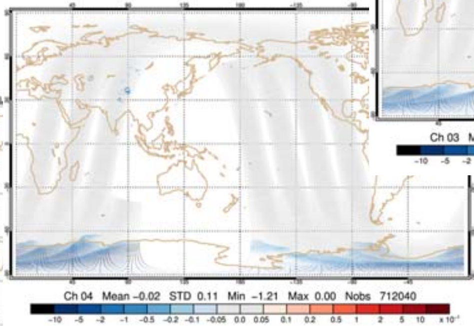
Near surface



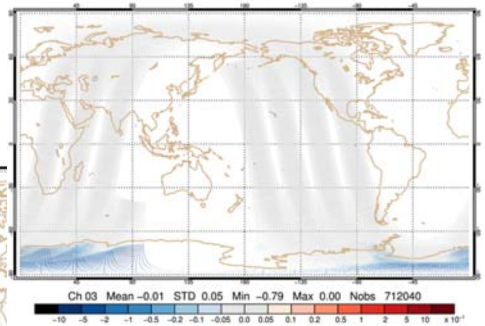
Mid Troposphere



Mid-upper Troposphere



Upper Troposphere



- Surface emissivity was under estimated and thus results in under-estimated brightness temperature
- Impact on BTs can be as large as 6 K
- Impact extends up to upper troposphere
- Need to run cycled experiment to assess impact

GOES-16 ABI

Clear Sky Radiances

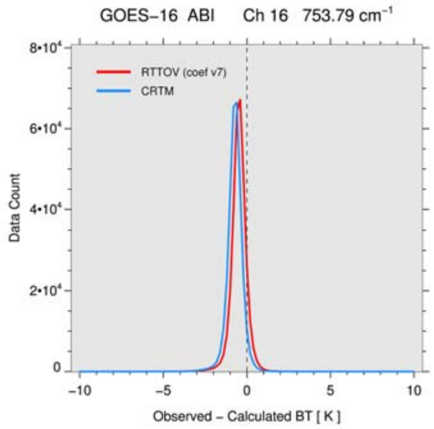
Comparison between CRTM & RTTOV

Table 1. Summary of the wavelengths, resolution, and sample use and heritage instrument(s) of the ABI bands. The minimum and maximum wavelength range represent the full width at half maximum (FWHM or 50%) points. [The Instantaneous Geometric Field Of View (IGFOV).]

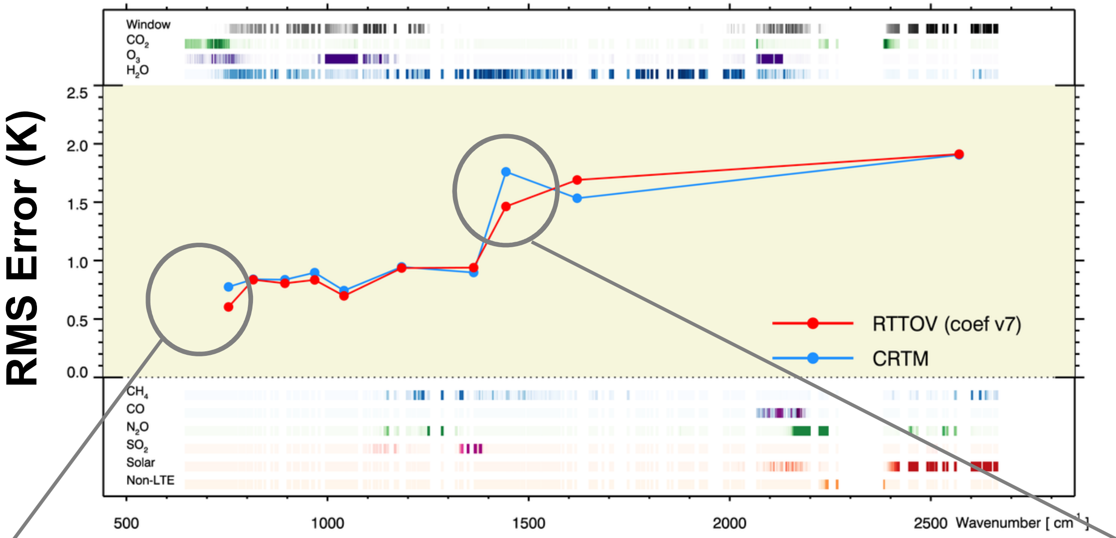
Future GOES imager (ABI) band	Wavelength range (µm)	Central wavelength (µm)	Nominal subsatellite IGFOV (km)	Sample use	Heritage instrument(s)
1	0.45–0.49	0.47	1	Daytime aerosol over land, coastal water mapping	MODIS
2	0.59–0.69	0.64	0.5	Daytime clouds fog, insolation, winds	Current GOES imager/sounder
3	0.846–0.885	0.865	1	Daytime vegetation/burn scar and aerosol over water, winds	VIIRS, spectrally modified AVHRR
4	1.371–1.386	1.378	2	Daytime cirrus cloud	VIIRS, MODIS
5	1.58–1.64	1.61	1	Daytime cloud-top phase and particle size, snow	VIIRS, spectrally modified AVHRR
6	2.225–2.275	2.25	2	Daytime land/cloud properties, particle size, vegetation, snow	VIIRS, similar to MODIS
7	3.80–4.00	3.90	2	Surface and cloud, fog at night, fire, winds	Current GOES imager
8	5.77–6.6	6.19	2	High-level atmospheric water vapor, winds, rainfall	Current GOES imager
9	6.75–7.15	6.95	2	Midlevel atmospheric water vapor, winds, rainfall	Current GOES sounder
10	7.24–7.44	7.34	2	Lower-level water vapor, winds, and SO_2	Spectrally modified current GOES sounder
11	8.3–8.7	8.5	2	Total water for stability, cloud phase, dust, SO_2 rainfall	MAS
12	9.42–9.8	9.61	2	Total ozone, turbulence, and winds	Spectrally modified current sounder
13	10.1–10.6	10.35	2	Surface and cloud	MAS
14	10.8–11.6	11.2	2	Imagery, SST, clouds, rainfall	Current GOES sounder
15	11.8–12.8	12.3	2	Total water, ash, and SST	Current GOES sounder
16	13.0–13.6	13.3	2	Air temperature, cloud heights and amounts	Current GOES sounder/ *GOES-12+* imager

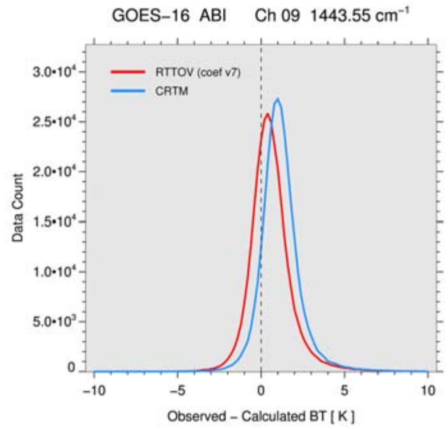
Source: Schmit, T.J., Gunshor, M.M., Menzel, W.P., Gurka, J.J., Li, J., Bachmeier, A.S., 2005, Introducing the Next-Generation Advanced Baseline Imager on GOES-R, Bulletin of the American Meteorological Society, v. 86, p. 1079-1096.

CRTM Simulation of ABI — Room for Improvement



States from 20 6-hour forecasts





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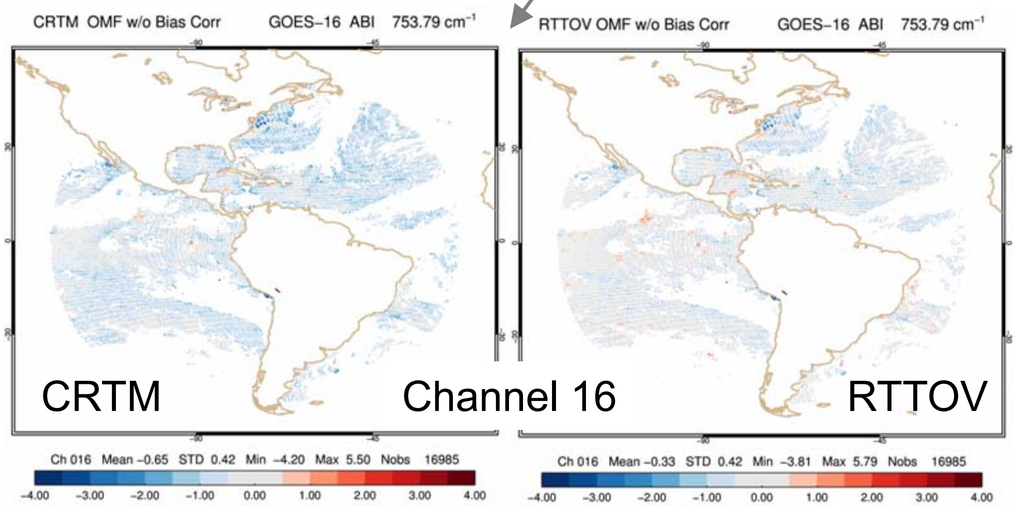

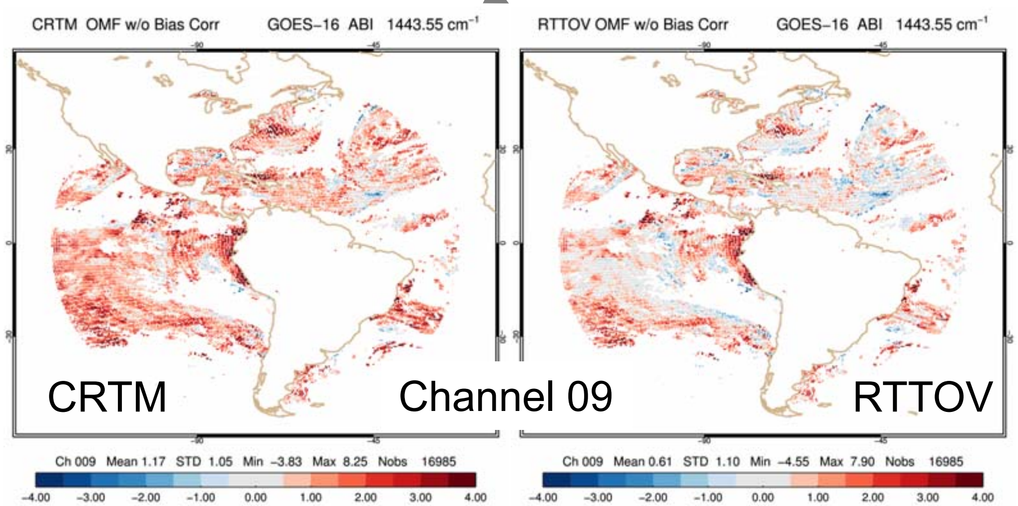

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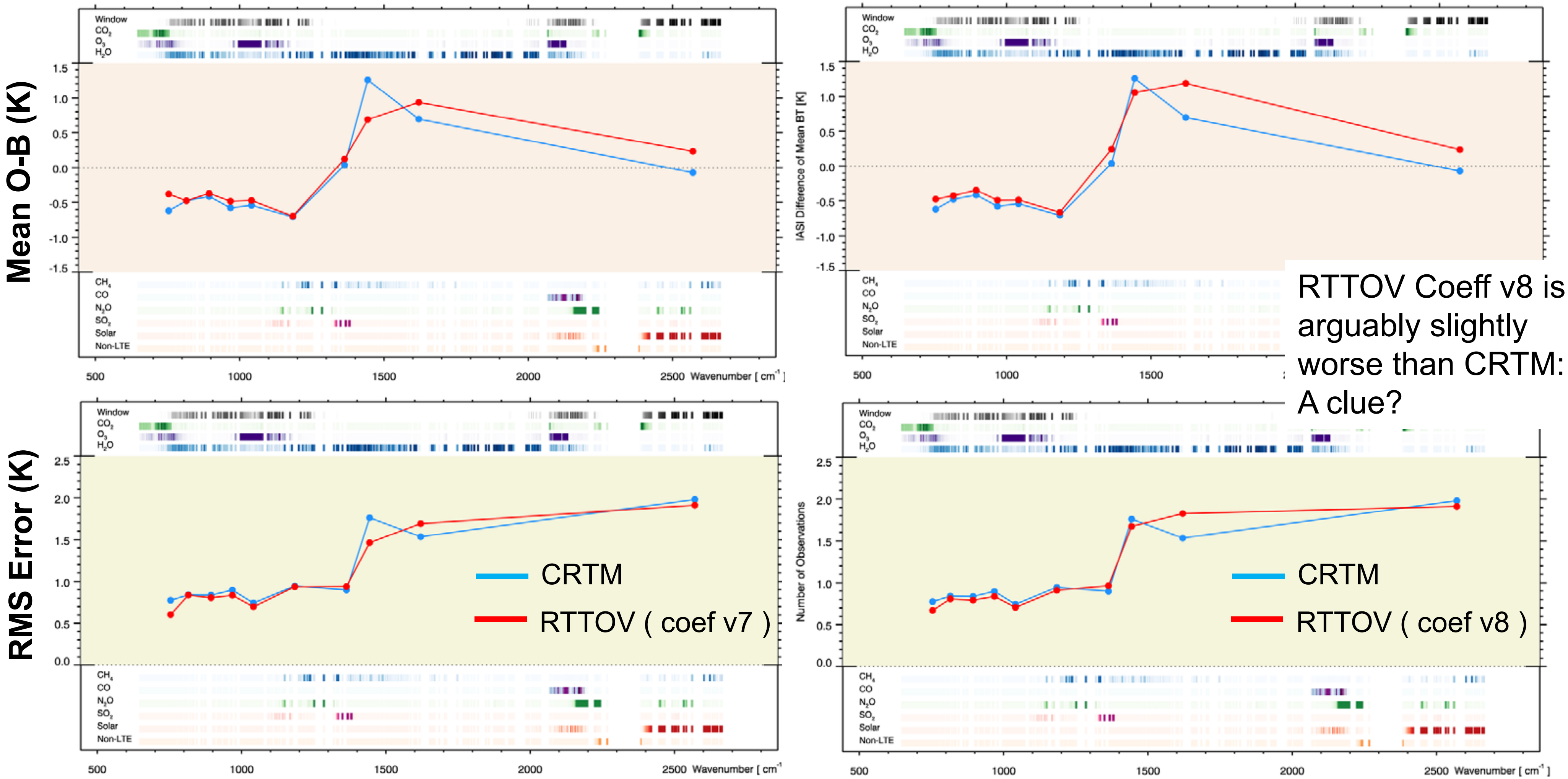
CRTM Simulation of ABI   Room for Improvement



RTTOV Coeff v8 is arguably slightly worse than CRTM: A clue?

The v8 predictor files allow variable CO_2 and has different treatment of H_2O

Outline

- Introduction and Motivation
- Overview of differences between CRTM and RTTOV
- Validation of CRTM under scattering conditions for MW sensors
  - Surface Reflectivity
  - Jacobians
- Validation of CRTM under clear-sky conditions for IR sensors
  - Surface Emissivity over Ocean
  - Input Profile Check
  - Simulation of ABI
- Summary

Summary

- Careful evaluation of radiative transfer capabilities is extremely important.
  - Having a large number of users evaluating the system will help catch possible errors sooner
  - Forward calculations and Jacobians (and TL/AD) should be considered.
- Intercomparison with other models can be an effective way to quickly find bugs and implementation errors
  - It can also point to possible areas where one or both models may potentially be improved.
- We will continue with these comparisons including extension into shortwave infrared and visible wavelengths and cloudy infrared.