Ultrafast High Accuracy PCRTM_SOLAR Model for Cloudy Atmosphere

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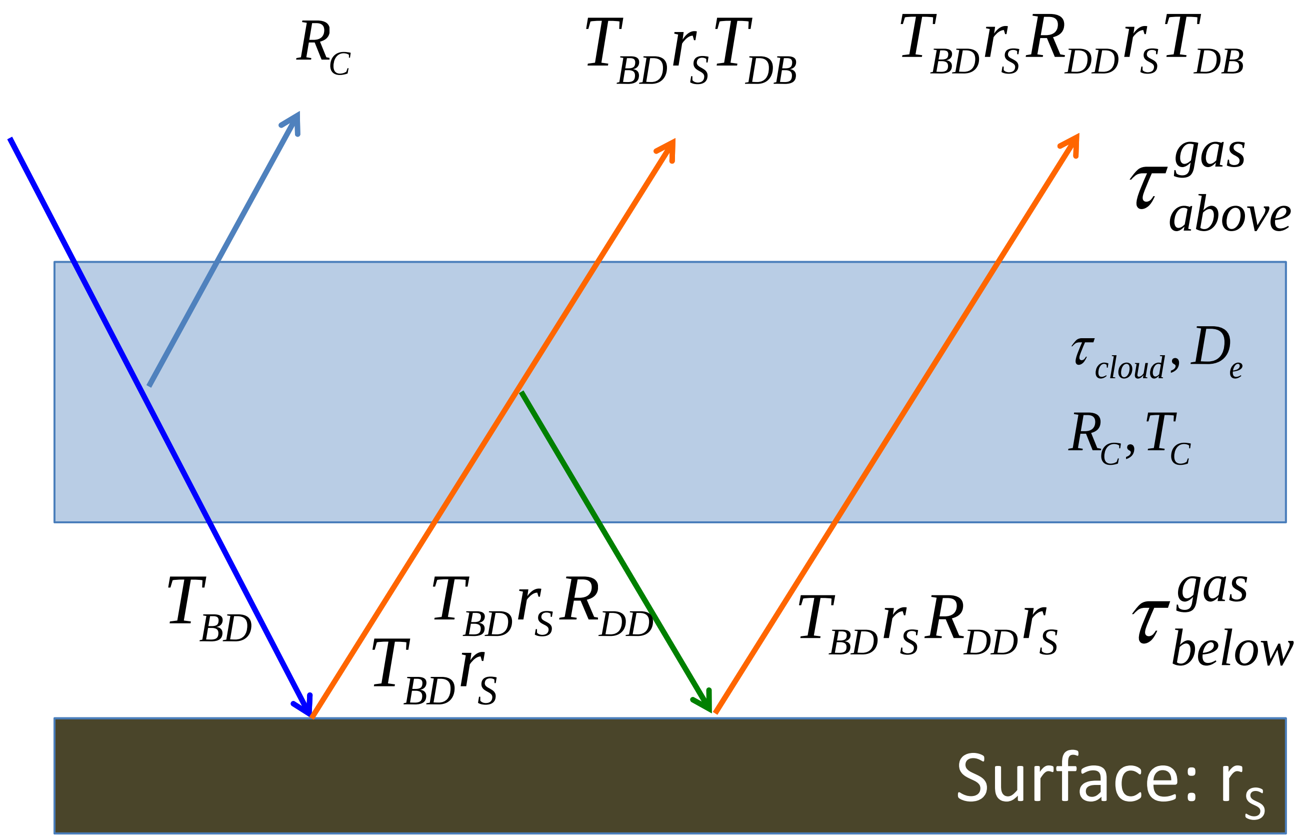
Motivation

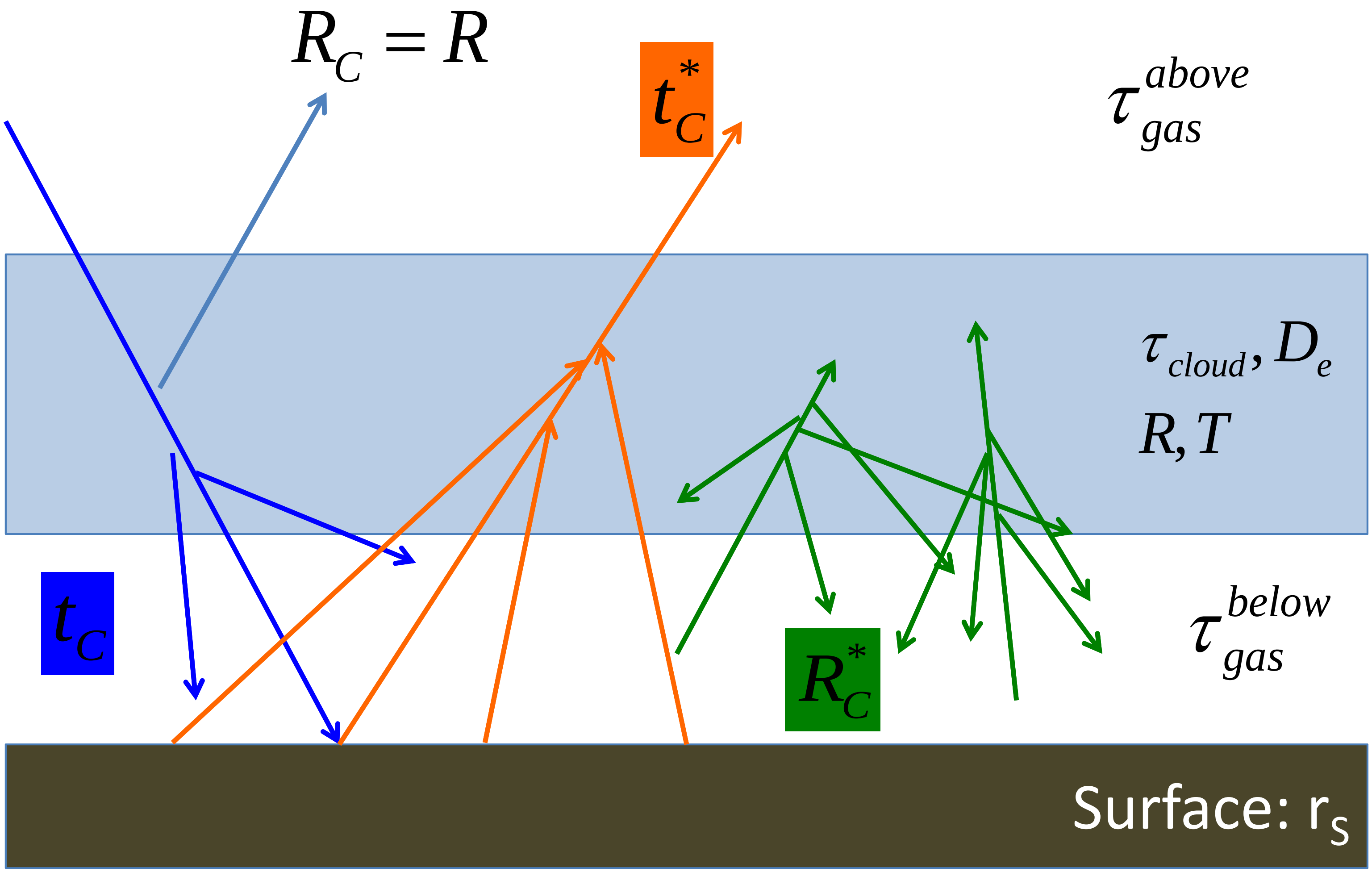
- Goal
  - Add reflected solar radiance simulation in the exist fast infrared PCRTM
  - Increase the computation speed of RS radiance simulation for cloudy atmospheres
- Radiative Transfer Models
  - Adding Doubling
  - DISORT
  - Our Way: Parameterization and LUTs, No Adding Doubling Calculation, 2-5 orders faster than DISORT.
- PCRTM - Principal Component-based Radiative Transfer Model
  - Uses PCA to compress information content
  - Reduce RT calculations by at least 3 orders of magnitude
- Expectation
  - over 4-5 orders faster than a reference radiative transfer model such as MODTRAN

Ultrafast High Accuracy PCRTM_SOLAR Model



$$R = \left(R_C + \frac{r_S t_C t_C^*}{1 - r_S R_C^*} \right) e^{-\frac{\tau_{gas}^{above}}{\mu_0} - \frac{\tau_{gas}^{above}}{\mu}}$$

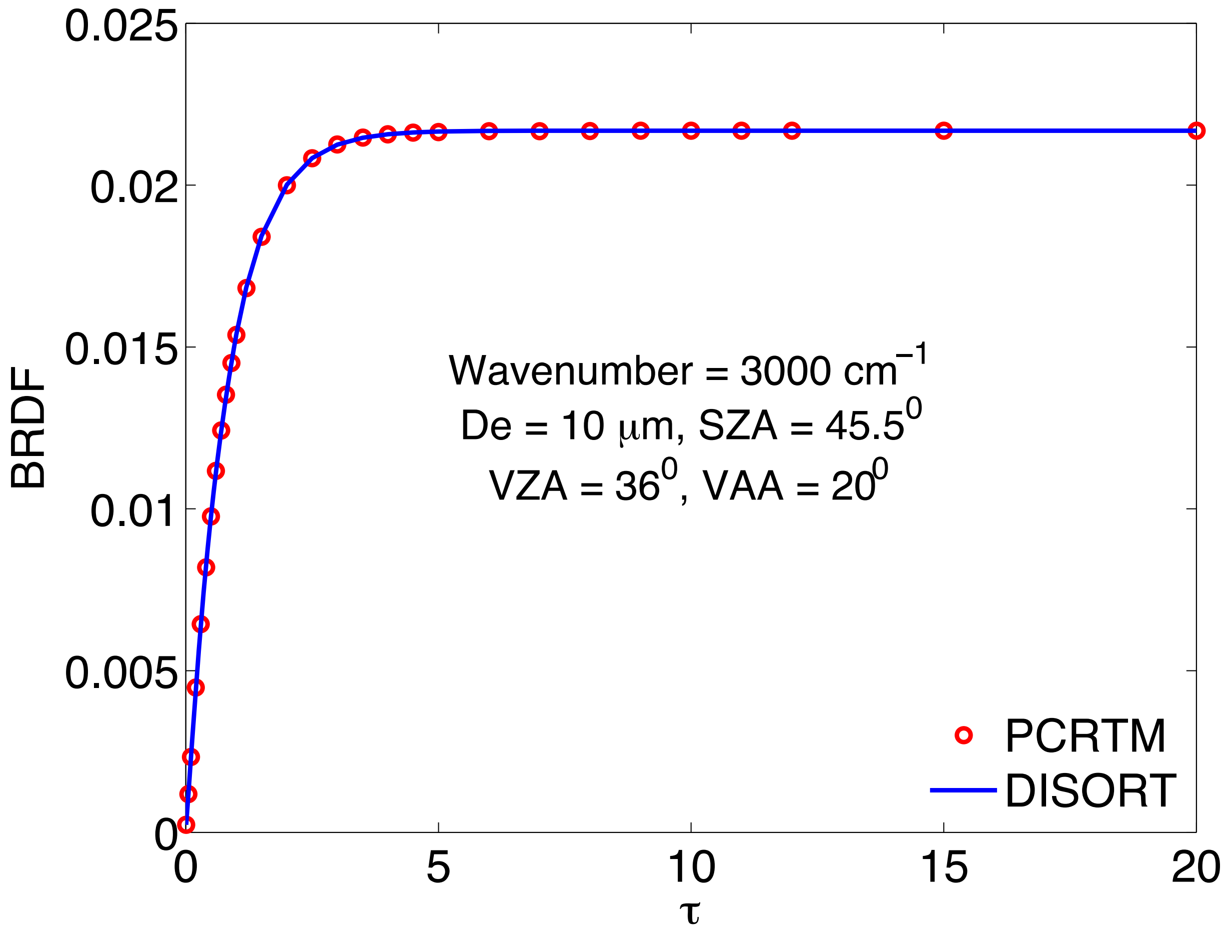
Multi-Scattering Processes



Downsize of LUTs

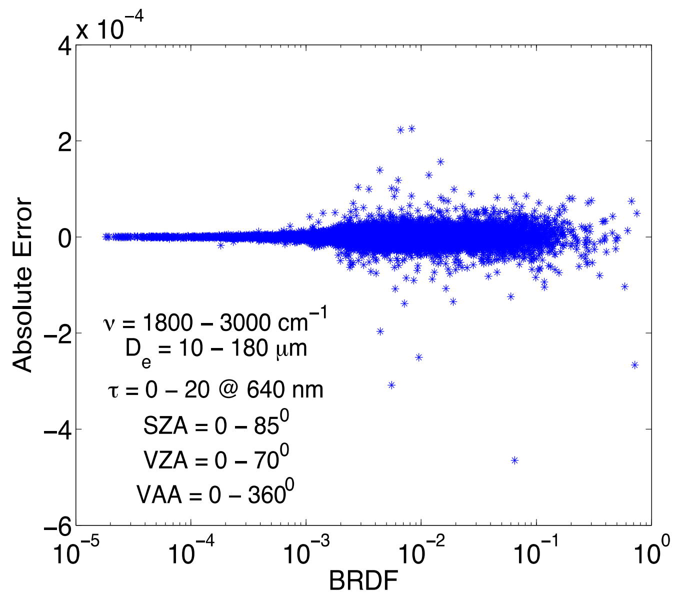
- BRDF: 3,300 MB to 23.68 MB
  - T_{BD}: 157 MB to 11.66 MB
  - T_{DB}: 157 MB to 11.66 MB
    - R_{DD}: 5.23 MB

Rebuilt of LUTs in PCRTM_SOLAR



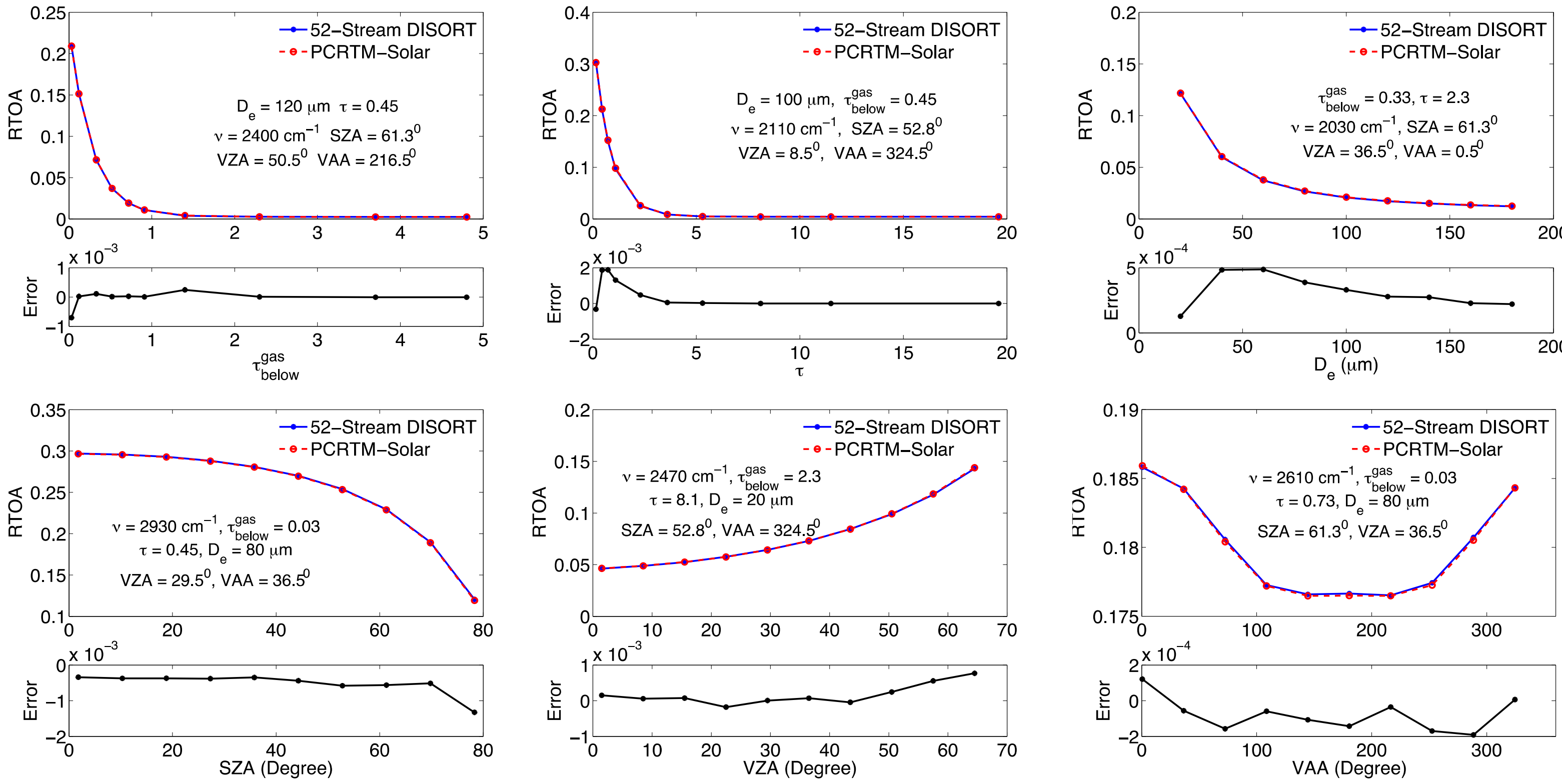
Accuracy of rebuilt multi-scattering properties of the cloud using PCRTM_SOLAR model

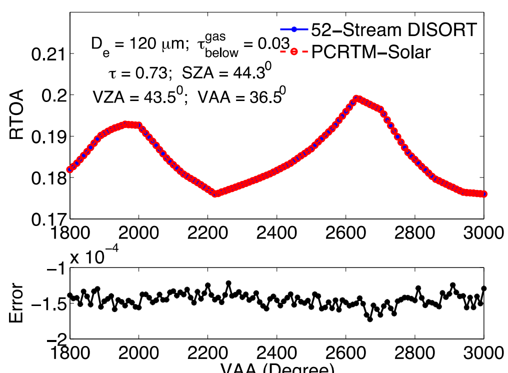
Accuracy of the Rebuilt BRDF LUTs (ice cloud) (compared to 52-stream DISORT)	
$\lvert\Delta BRDF\rvert < 10^{-4}$	99.75%
$10^{-4} < \lvert\Delta BRDF\rvert < 5x10^{-4}$	0.24%
$\lvert\Delta BRDF\rvert > 5x10^{-4}$	0.01%
$\lvert\Delta BRDF\rvert > 1x10^{-3}$	0.0%



Parameters Used	
Cloud Type	Ice
D_e: 10 – 180 μm	SZA: 0 - 85^0
τ_{cloud}: 0 – 20 @ 640 nm	VZA: 0 - 70^0
ν: 1800 – 3000 cm^{-1}	VAA: 0 - 360^0

TOA Reflectance Simulation: PCRTM_SOLAR v.s. DISORT





In the case of background scattering with VAA = 0^0 or front scattering with VAA = 180^0, max errors were obtained. This is due to the inaccurate simulation of DISORT at these specific directions (singularity issue in DISORT).

Accuracy in TOA Reflectance: PCRTM_SOLAR v.s. DISORT

Difference in Reflectance at TOA (PCRTM_SOLAR v.s. 52 Stream DISORT)	
$\|\Delta R\| < 10^{-3}$	93.30%
$10^{-3} < \|\Delta R\| < 10^{-2}$	6.65%
$\|\Delta R\| > 10^{-2}$	0.05%
Max ΔR	0.0337

Parameters Used	
Cloud Type	Ice
D_e: 10 – 180 μm	SZA: 0 - 85^0
τ_{cloud}: 0 – 20 @ 640 nm	VZA: 0 - 70^0
ν: 1800 – 3000 cm^{-1}	VAA: 0 - 360^0
τ_{below_cloud} = 0 - 5	

Reasons for the difference:

1. The stream-dependent errors in DISORT simulation (~ 0.36%).
2. The inaccuracy in front and back scattering directions in DISORT simulation (The percentage with $|\Delta R|$ larger than 10^{-3} reduced from 6.65% to 5% if these cases removed).
3. The interpolation errors in PCRTM_SOLAR.

COMPUTATION SPEED: PCRTM_SOLAR v.s. DISORT

Example Satellite Sensor: IASI 0.25 cm^{-1} Spectral Resolution Full Channel Set

– PCRTM_SOLAR: 0.52 ms/run

- 1000 runs with the following parameters:

  SZA = 10^0, VZA = 60^0, VAA = 72.5^0, υ changes with 439 different values, τ_{above} changes with wavenumber, τ_{below} constant, τ_{cloud} = 1.025, De = 48 μm, Rs = 0.02

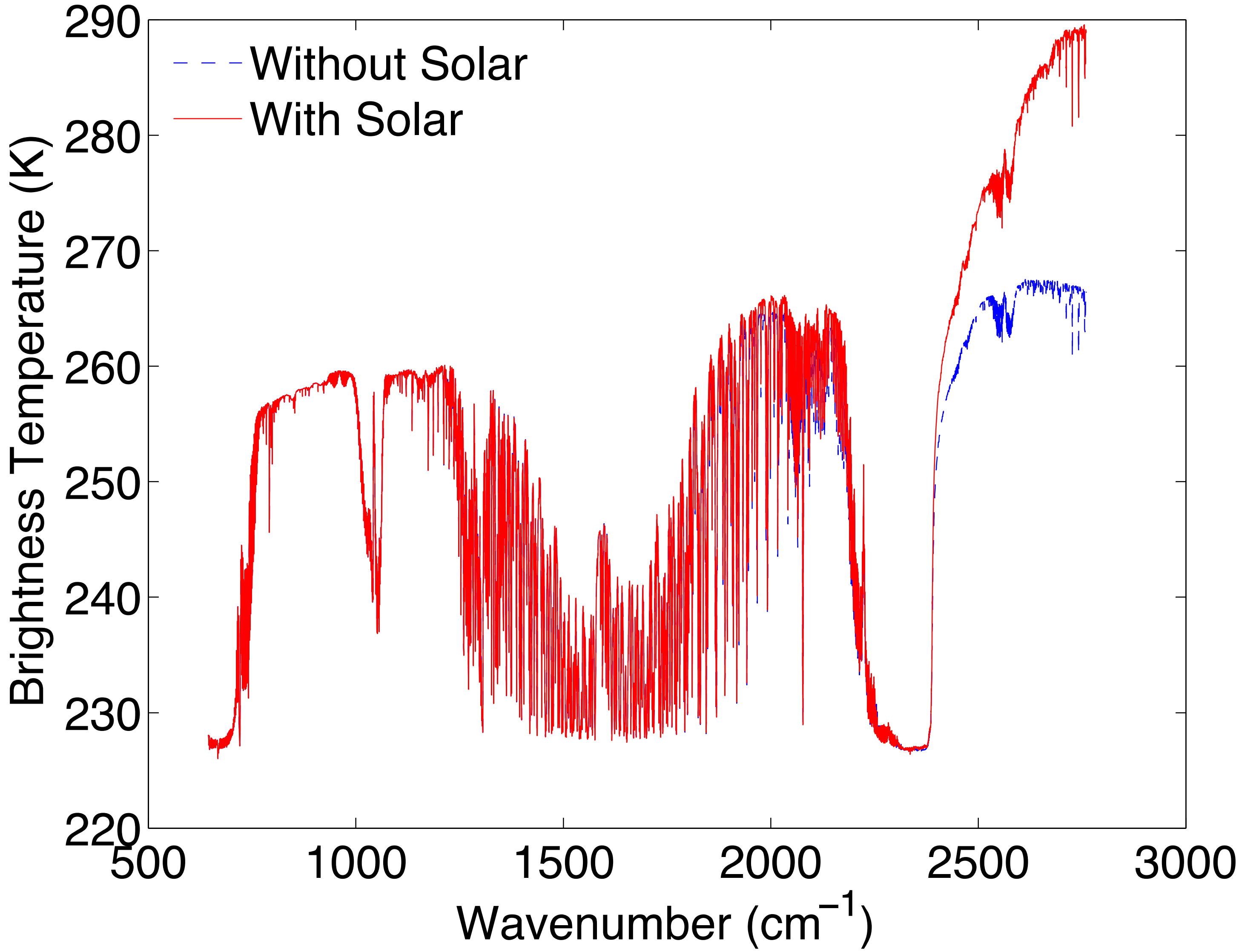
– DISORT (52-stream): 63.61 s/run

- 439 runs with the following parameters:

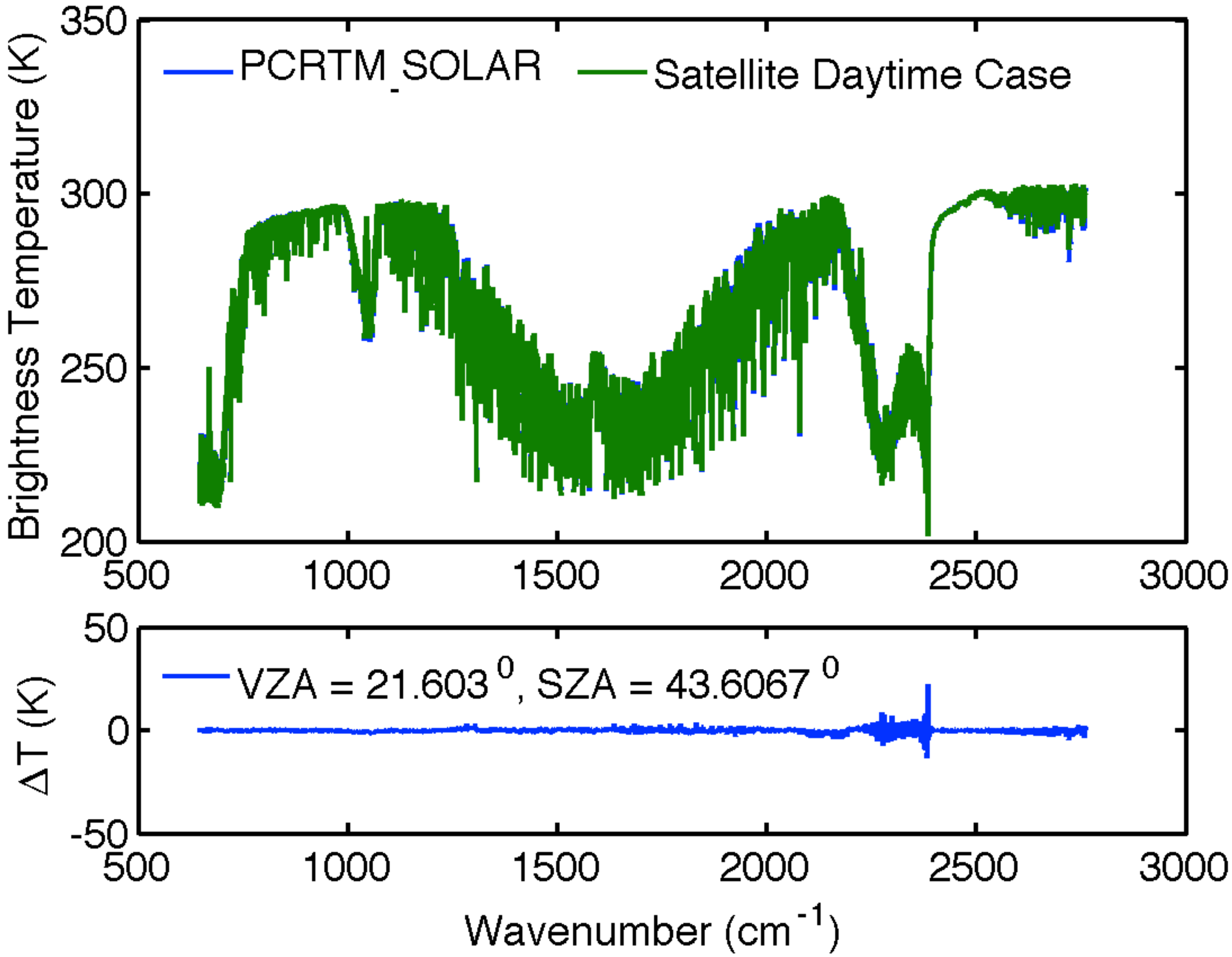
  SZA = 15^0, VZA = 50^0, VAA = 30^0, υ = 2500 cm^{-1}, τ_{above} = 0.3, τ_{below} = 4.8, τ_{cloud} = 1.5, De = 10 μm, Rs = 0.2

- PCRTM_SOLAR is 122,327 times (5 orders) faster than DISORT!!!

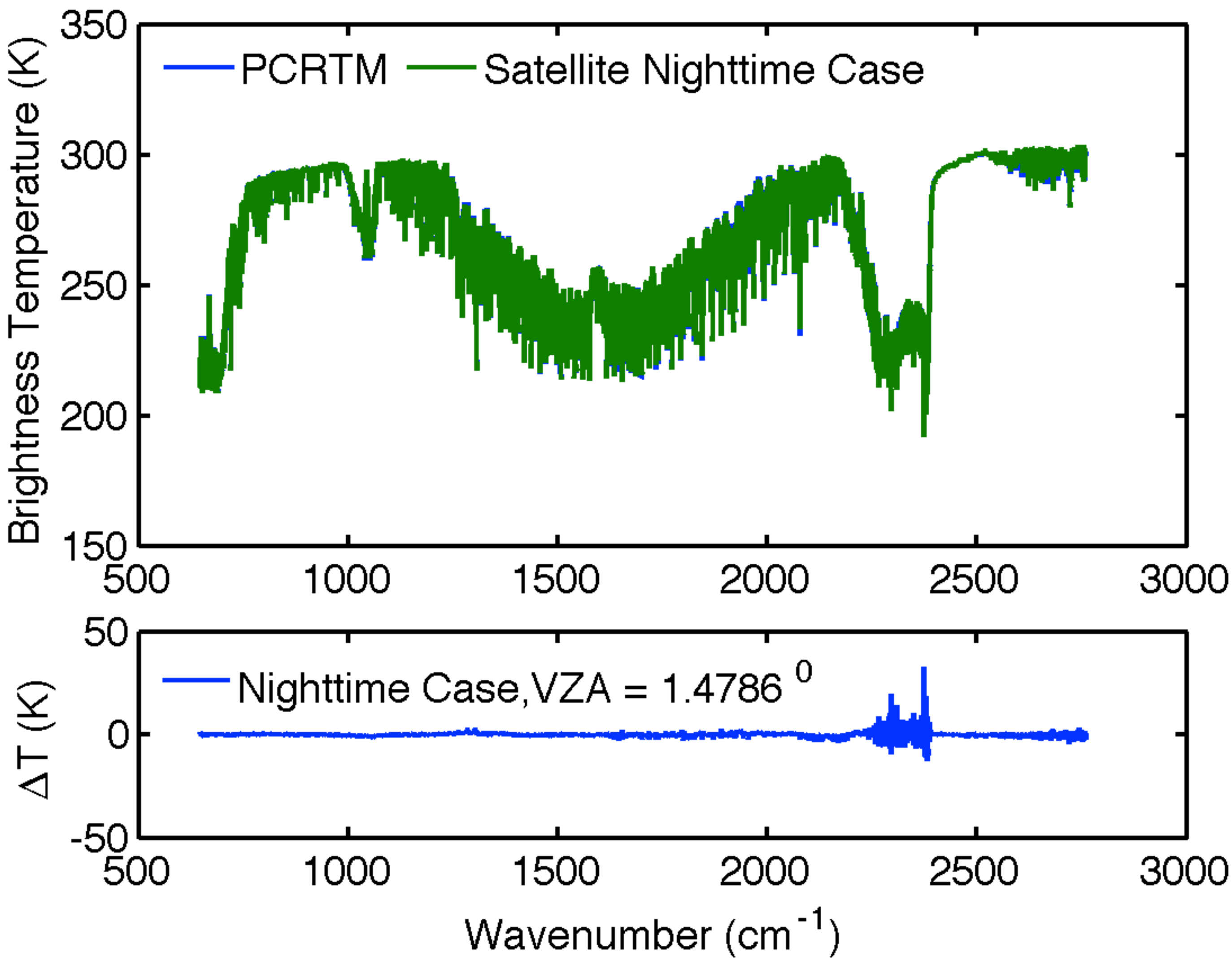
Ultrafast High Accuracy PCRTM_SOLAR Model



Ultrafast High Accuracy PCRTM_SOLAR Model



Ultrafast High Accuracy PCRTM_SOLAR Model



Fast and Ability to Simulate Clouds in the PCRTM Model is the Key Component to the Cloudy Single FOV OE algorithm

- Milliseconds to fraction of seconds for IR
- PCRTM available for nominal and full resolution CrIS, AIRS, IASI, NAST-I and S-HIS
- Spectral converage from 310 nm to 200000 nm

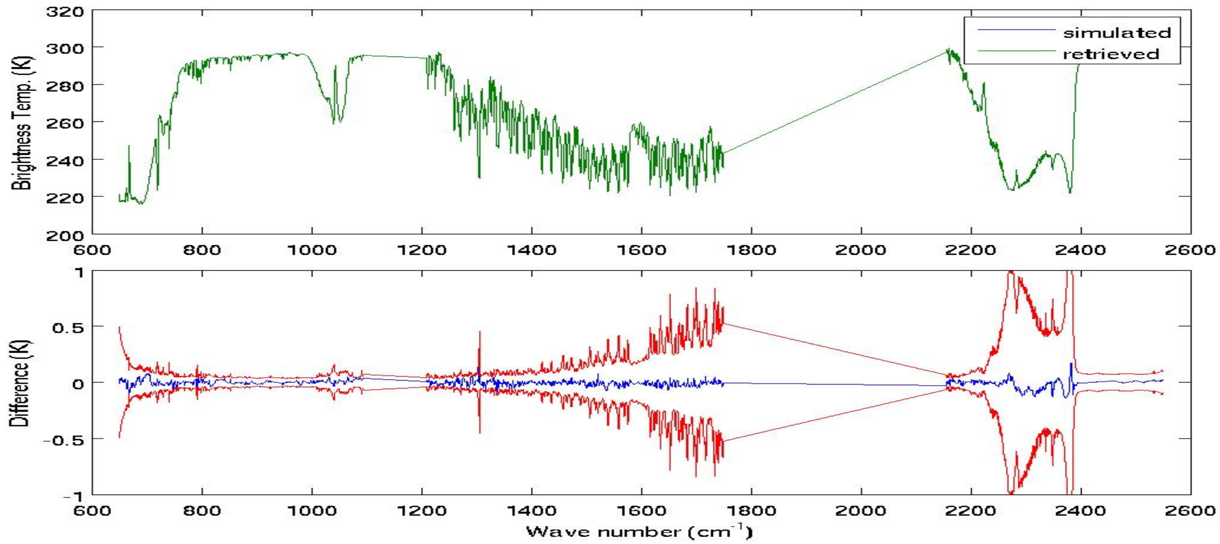
Computational speed For PCRTM in IR spectral region

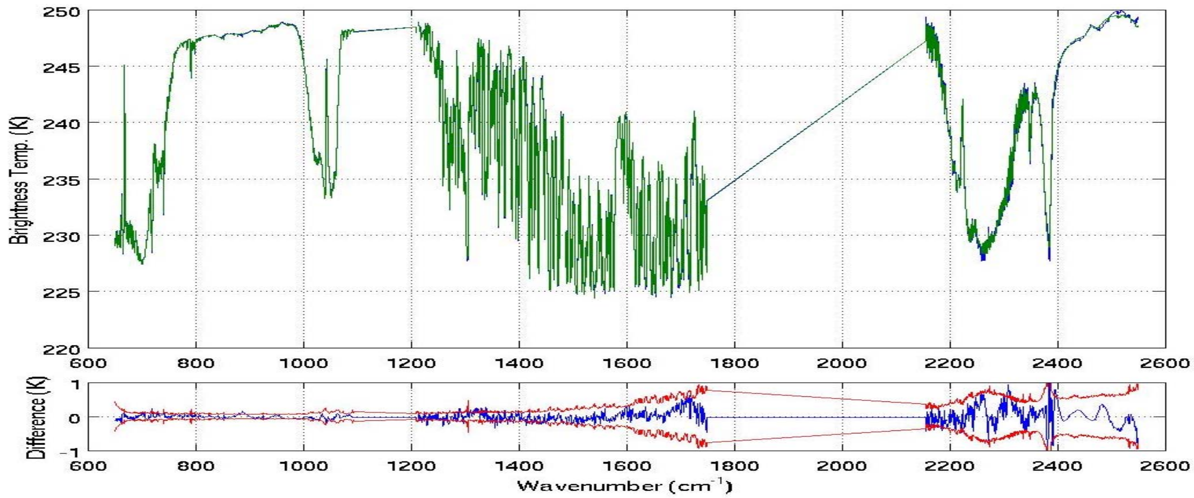
Sensor	Channel Number	PC score (seconds)	PC score + Channel radiance	PC score + PC Jacobian
IASI, 0.25 cm^{-1}	8461	0.011 s	0.012 s	0.044 s
AIRS, 0.5-2.5 cm^{-1}	2378	0.0060 s	0.0074 s	0.031 s
CrIS, Blackman, 0.625-2.5 cm^{-1}	1317	0.0050 s	0.0060 s	0.021 s
CrIS, Boxcar, 0.625-2.5 cm^{-1}	1317	0.0050 s	0.0060 s	0.022 s
CrIS, Hamming, 0.625-2.5 cm^{-1}	1317	0.0050 s	0.0058 s	0.022 s
NAST-I, 3 bands, 0.25 cm^{-1}	8632	0.010 s	0.013 s	0.045 s
S-HIS 0.5 cm^{-1}	4316	0.008 s	0.008 s	0.038 s
CrIS, Hamming Full resolution	2211	0.009 s	0.009 s	0.033 s

Computational speed gain relative to Modtran in Solar spectral region

	PCRTM RT	MODTRAN RT	speed up
Ocean 1cm^{-1}	956	259029	270
Land 1cm^{-1}	1339	259029	193
Ocean 4nm	279	259029	928
Land 4nm	354	259029	731

Spectral residues from simulated and real CrIS full-spectral Resolution Data





Conclusion

An ultrafast high accuracy PCRTM_SOLAR model is developed based on PCA compression and PCRTM method. This model make the simulation of the multi-scattering of the cloud very efficient. Together with the high speed PCRTM developed by Dr. Xu Liu, the new model is 5 orders faster than DISORT with very high accuracy for cloudy sky radiative transfer simulation. It will greatly help reduce the computing time for CLARREO-RS project.