Improving PBL Temperature and Water Vapor Information by Combining Hyperspectral MW and IR Sounders with Active Lidar Measurements

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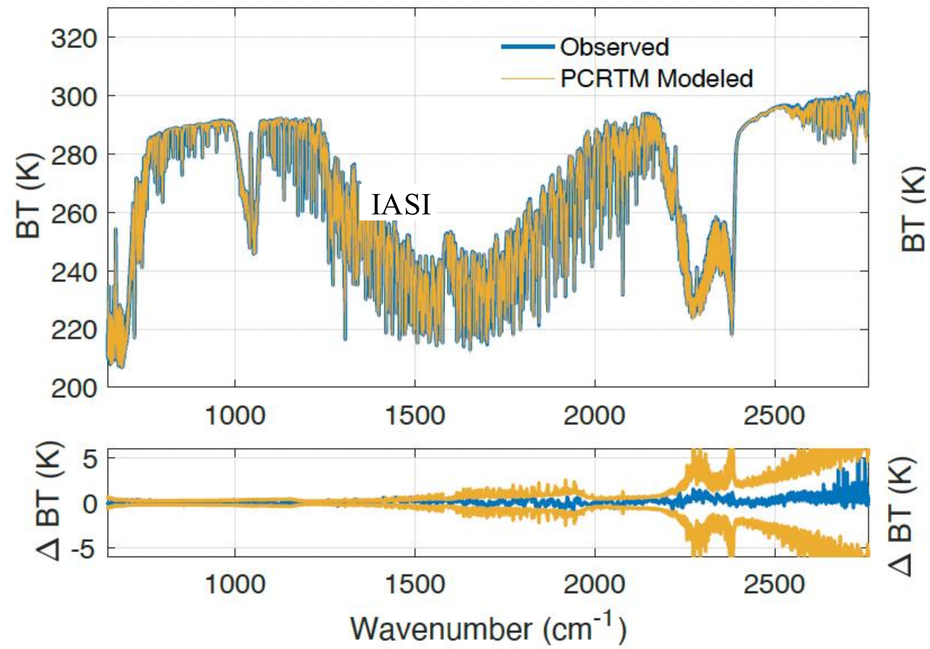
Outline of the Presentation

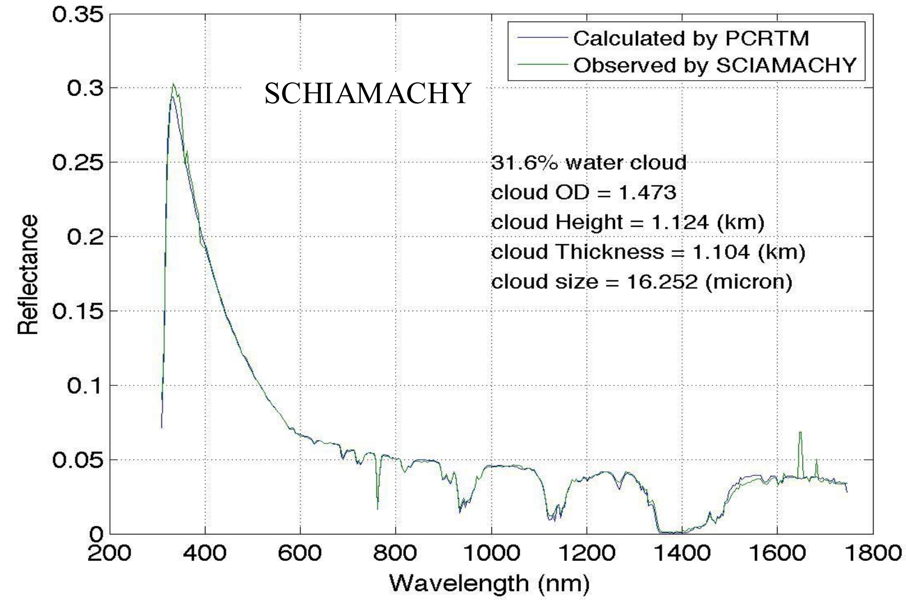
- Objectives of our PBL studies
- Progress of Developing PCRTM for COSMIR-H and ATMS
- Progress in designing the trade studies to improve PBL retrievals
- Summary

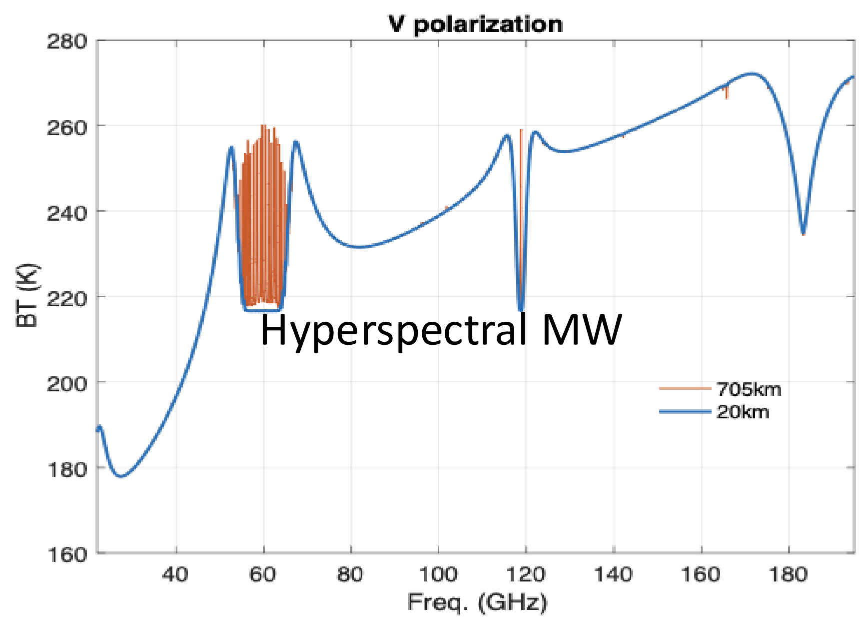
Description of PCRTM

- PCRTM is a physical-based RTM
  - RT is done monochromatically
- PCRTM is fast
  - Orders of magnitude faster than Line-by-Line (LBL) models (reduces RT calculations from millions to hundreds)
- PCRTM is accurate
  - 0.03 K Brightness Temperature RMS errors relative to LBL for thermal IR
  - Less than 0.05% relative to LBL in solar spectral region
- PCRTM was developed in 2004 and has been extensively used by many projects
  - AIRS, IASI, CrIS, NAST-I, S-HIS, CLARREO, CPF, EMIT, SCHIAMACHY, OMI ..
  - Covers far-IR, mid-IR, Near-IR, Visible, UV-Vis spectral regions
  - Handles cloud and aerosols
  - Handle polarization due to gas, clouds, aerosols, and surface (in solar spectral region)
- PCRTM has been used for many applications
  - Forward model for a physical retrieval algorithm
  - High fidelity satellite radiance/reflectance spectral simulator for new satellite sensors
  - Observing System Simulation Experiments (OSSEs)
  - Training data for AI algorithms
  - Spectral matching and angular matching error corrections for inter-satellite sensor calibrations
  - Instrument spectral characterization and new sensor performance studies

PCRTM Covers Far-IR, IR, Visible, and UV (soon MW)





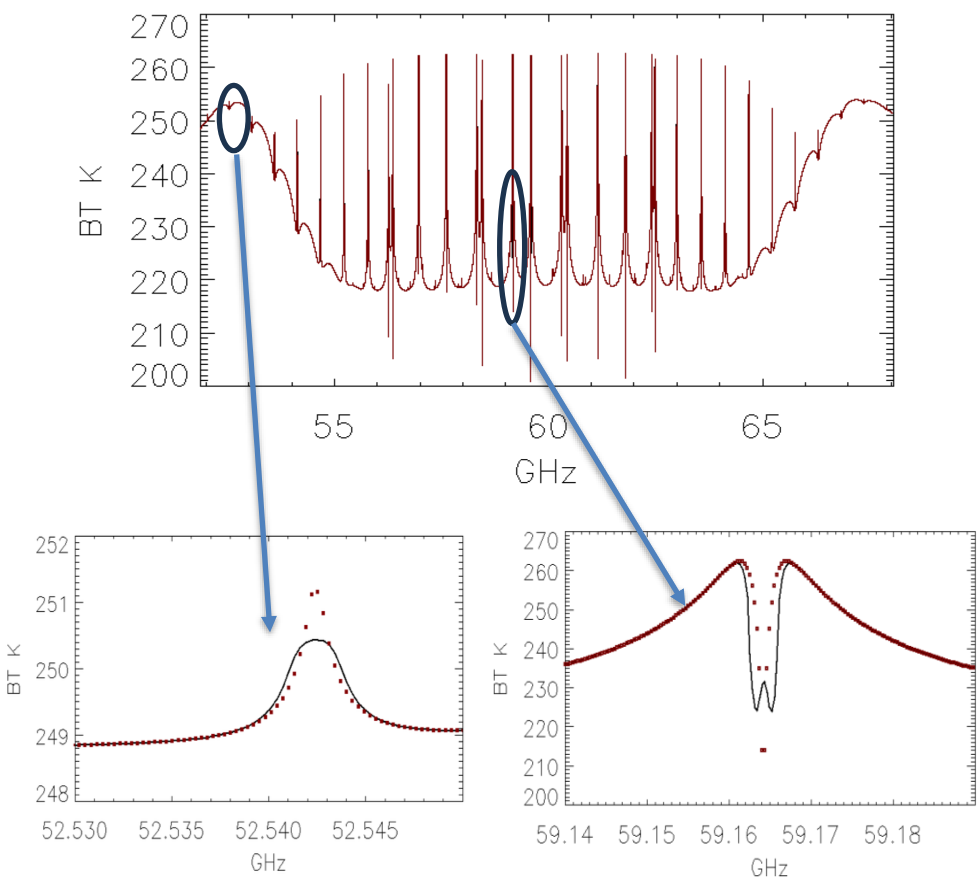


Sensor	Channel Number	PC score (seconds)
CLARREO, 0.1 cm^{-1}	19901	0.014 s
CLARREO, 0.5 cm^{-1}	5421	0.011 s
CLARREO, 1.0 cm^{-1}	2711	0.0096 s
IASI, 0.25 cm^{-1}	8461	0.011 s
AIRS, 0.5-2.5 cm^{-1}	2378	0.0060 s
CrIS,0.625-2.5 cm^{-1}	1317	0.0050 s
NAST-I, 0.25 cm^{-1}	8632	0.010 s
S-HIS, 0.5 cm^{-1}	4316	0.008 s
CrIS, 0.625 cm^{-1}	2211	0.009 s

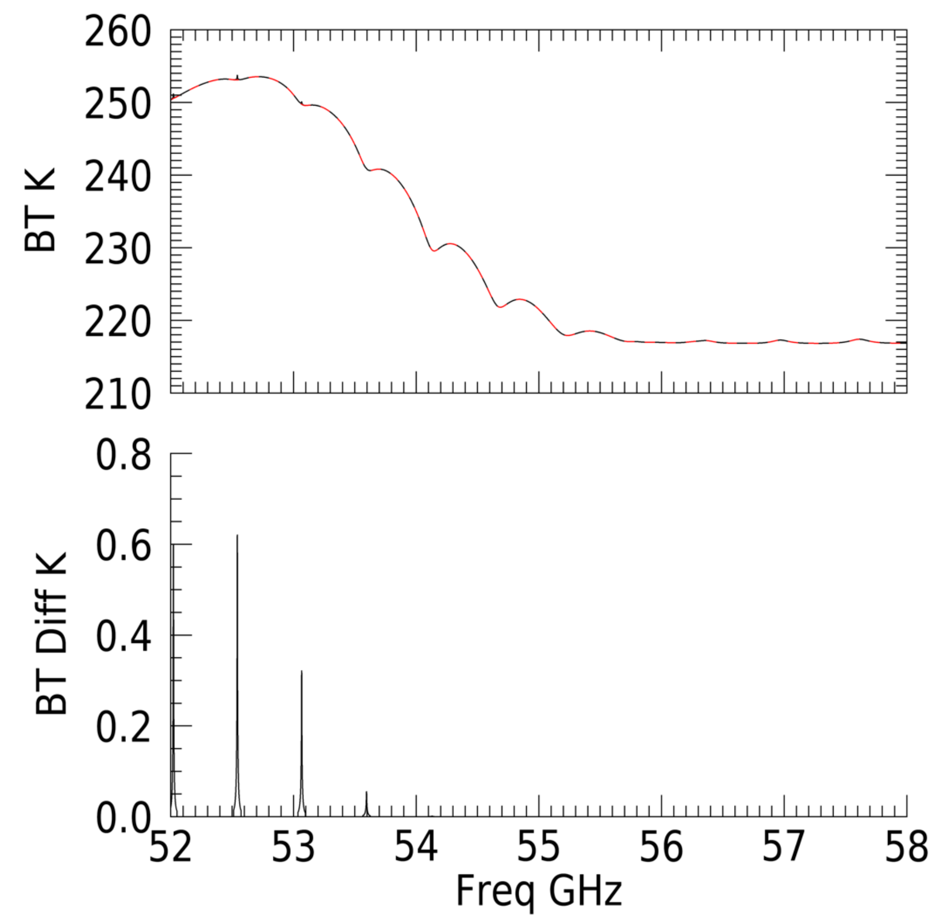
Impact of Ignoring Zeeman Effect in Radiative Transfer Calculations

Comparing TOA BT at 60 GHz O2 band

-resolution: 0.3MHz   -Red dot without Zeeman

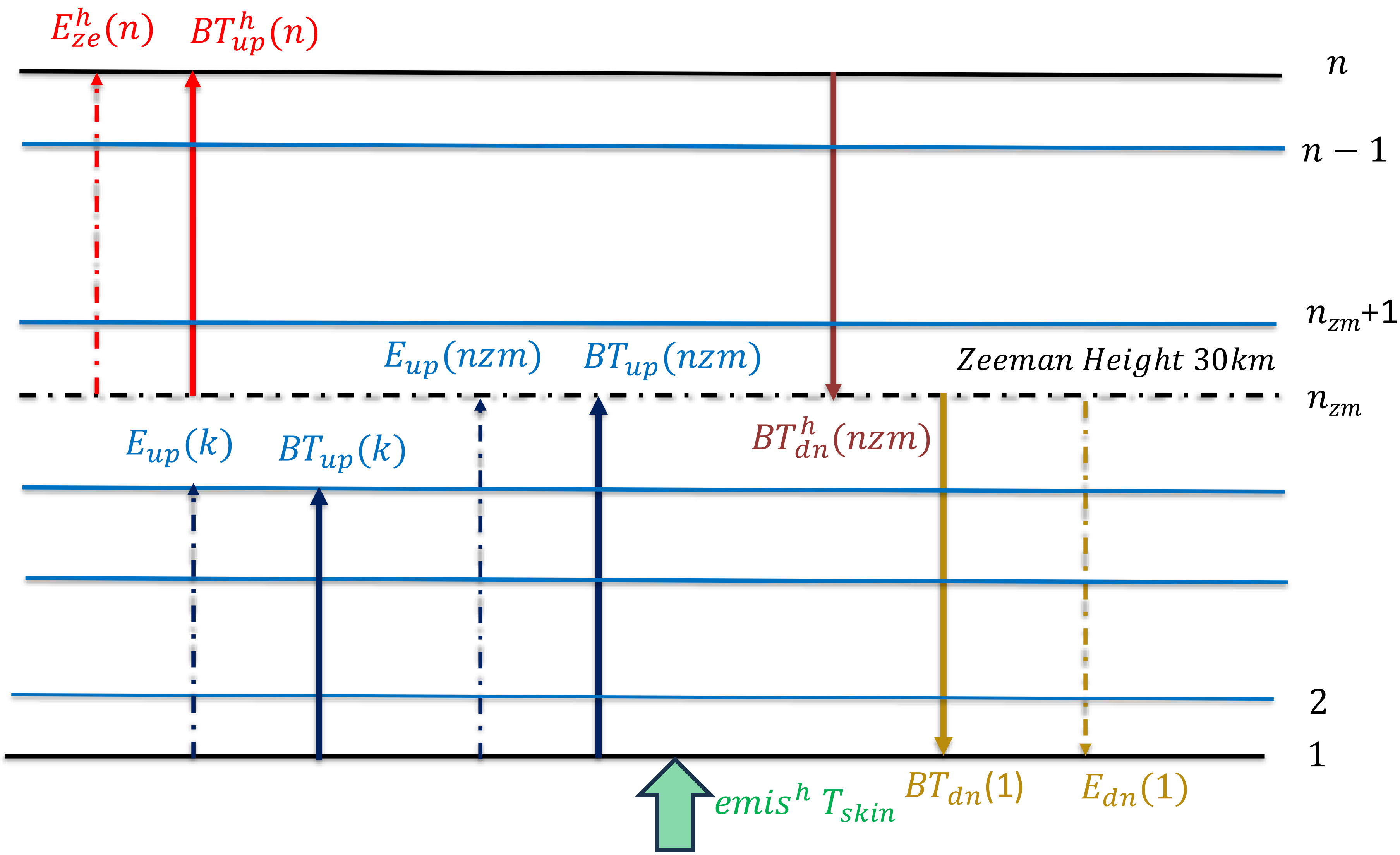


BT at 20km averaged at 4 MHz (COSMIR-H)



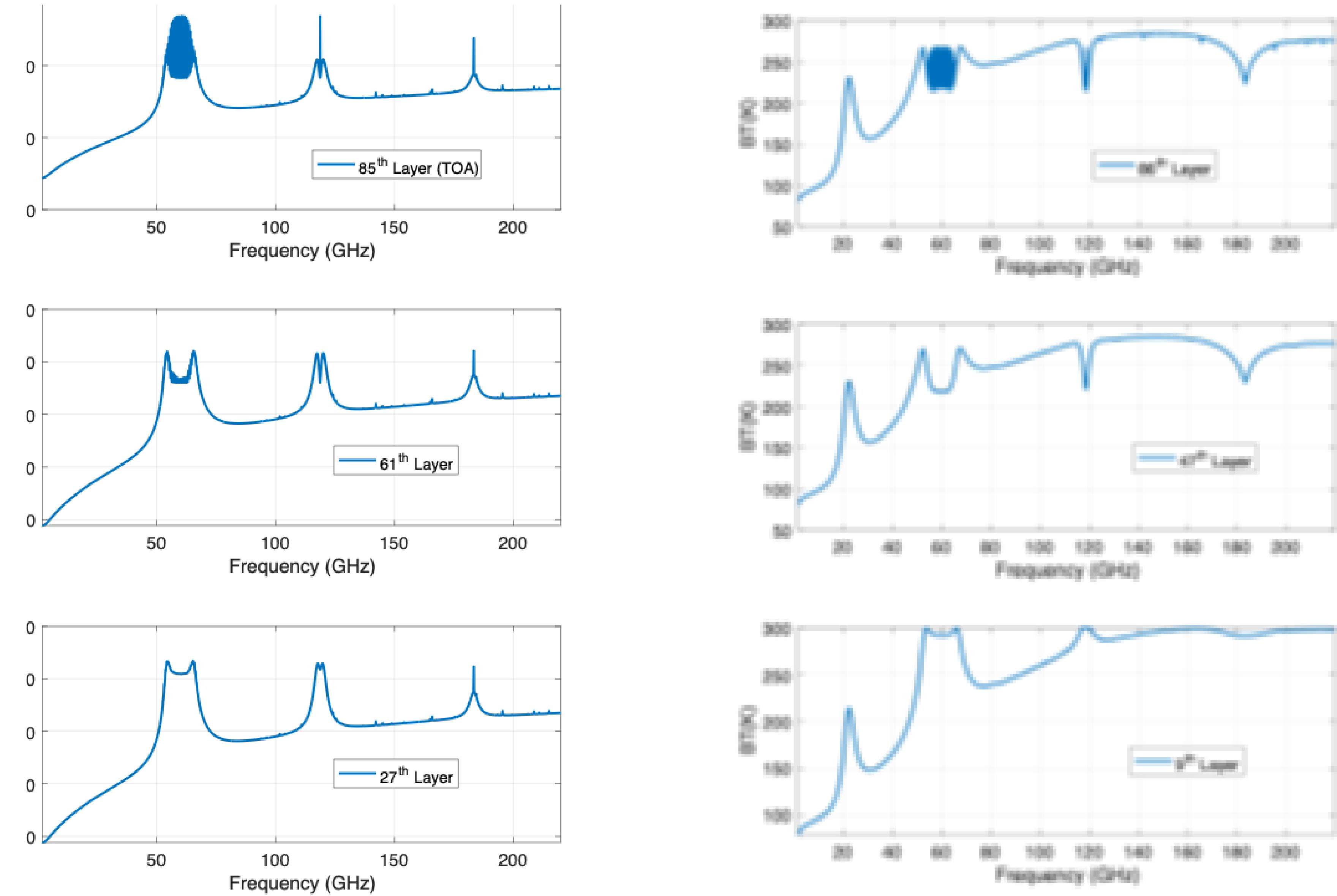
Radiative Transfer Equations for Space and Airborne MW remote sensors

$$\boldsymbol{Satellite\ BT^{h}} = BT^{h}_{up}(n) + E^{h}_{ze}(n)\, BT_{up}(n_{zm}) + E^{h}_{ze}(n)\, E_{up}(n_{zm}) \{R^{h}_{sfc}\ [BT_{dn}(1) + BT^{h}_{dn}(n_{zm}) E_{dn}(1)] + emis^{h}\, T_{skin}\}$$



$$\boldsymbol{Airborne\ BT^{h}} = BT_{up}(k) + E_{up}(k) \{R^{h}_{sfc}\ [BT_{dn}(1) + BT^{h}_{dn}(n_{zm}) E_{dn}(1)] + emis^{h}\, T_{skin}\}$$

Examples of Brightness Temperature at Different Observation Heights (1 km to 900 km)

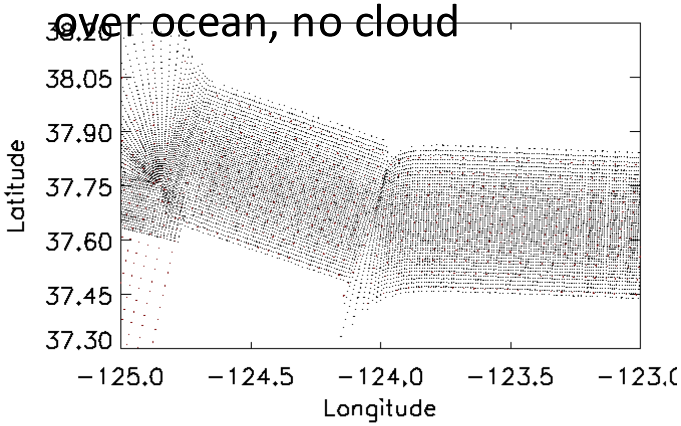


PCRTM Model Developed for COSMIR-H Airborne Instrument

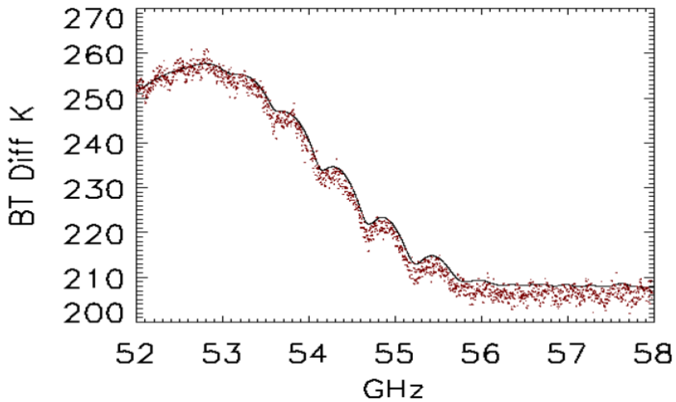
Frequency Range (GHz)	Number of Channels	Number of Simulations in LBL	Number of Simulations in PCRTM	Speed Up to LBL	Speed Up to Channel	Bias (K)	RMSE (K)
50-58	2048 (H)	22622	40	566	51	-0.00005	0.061
175.31-191.31	4096 (V)	6463	21	308	195	-0.000055	0.035
89.0 $\pm$ 1.25	4 (H/V)	152	2	76	2	0.003	0.025
165.3 $\pm$ 1.25	4 (H/V)	152	3	51	1.3	-0.001	0.067
Total	6152	29389	66	445	93	0.0005	0.047

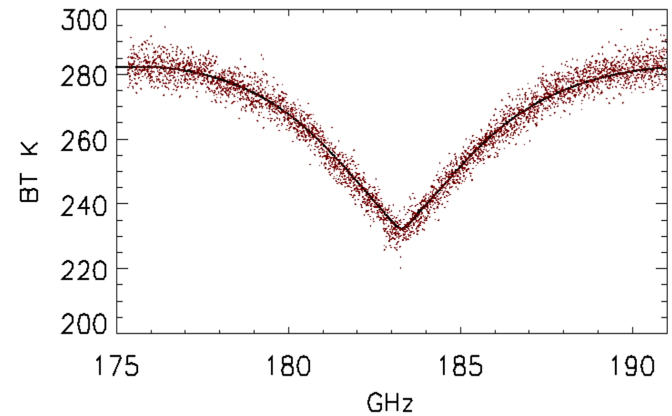
Validating of PCRTM Using COSMIR-H Data from WHyMSIE

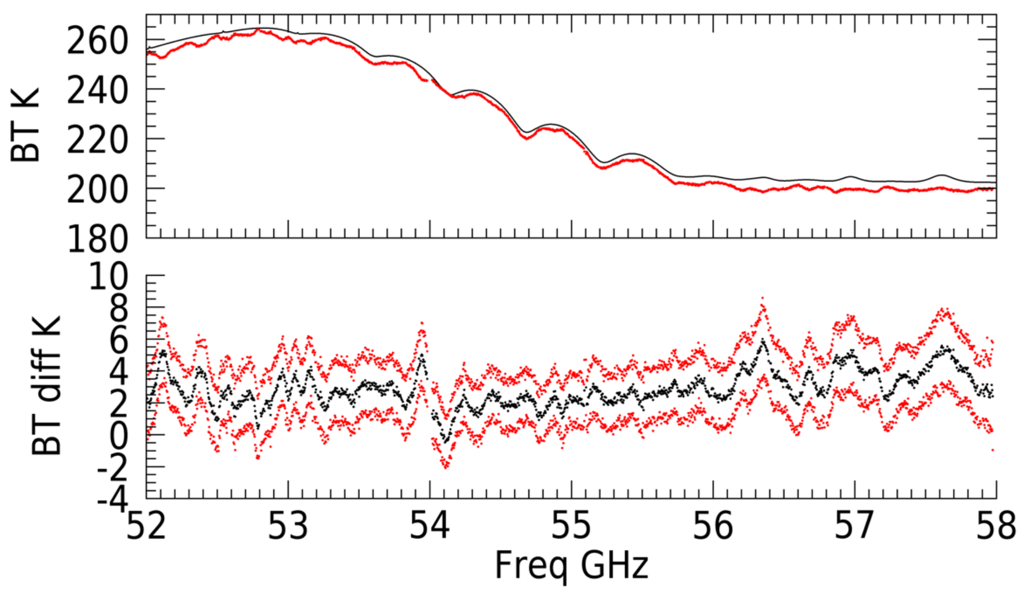
Fingerprint match: COSMIR-H and NASTI
co-located: lat and lon <0.005 degree (1km)
over ocean, no cloud

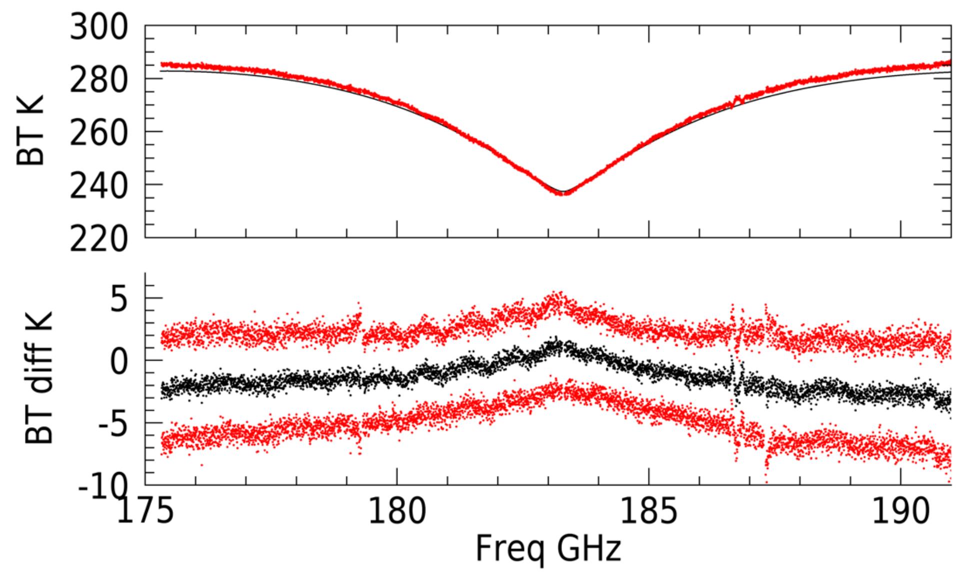


Comparison of PCRTM simulated BT with COSMIR-H observations





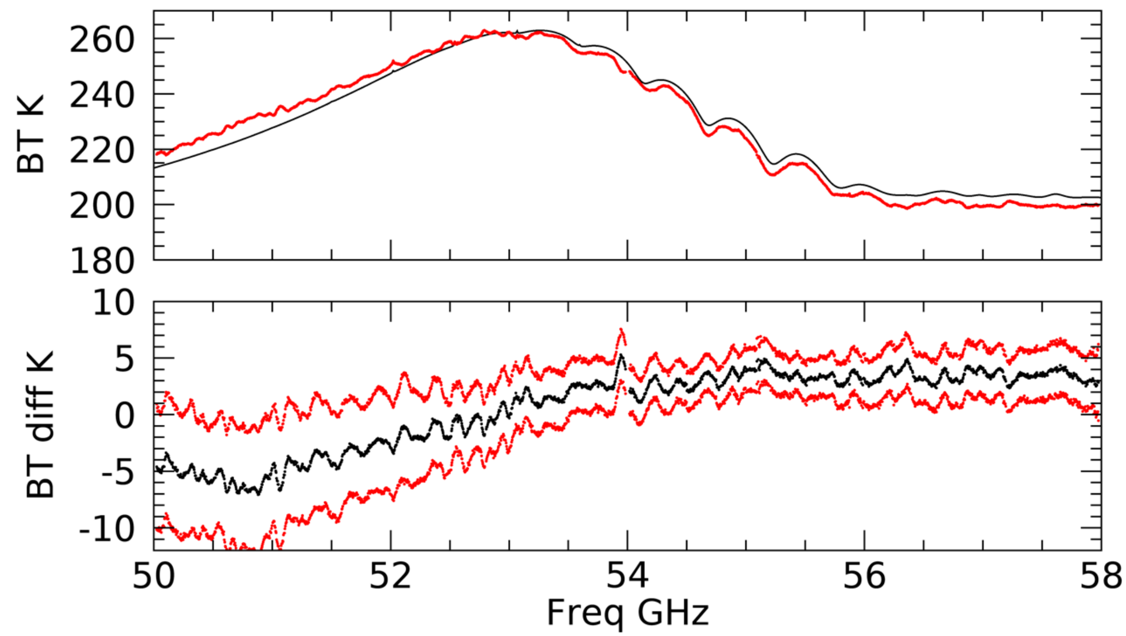




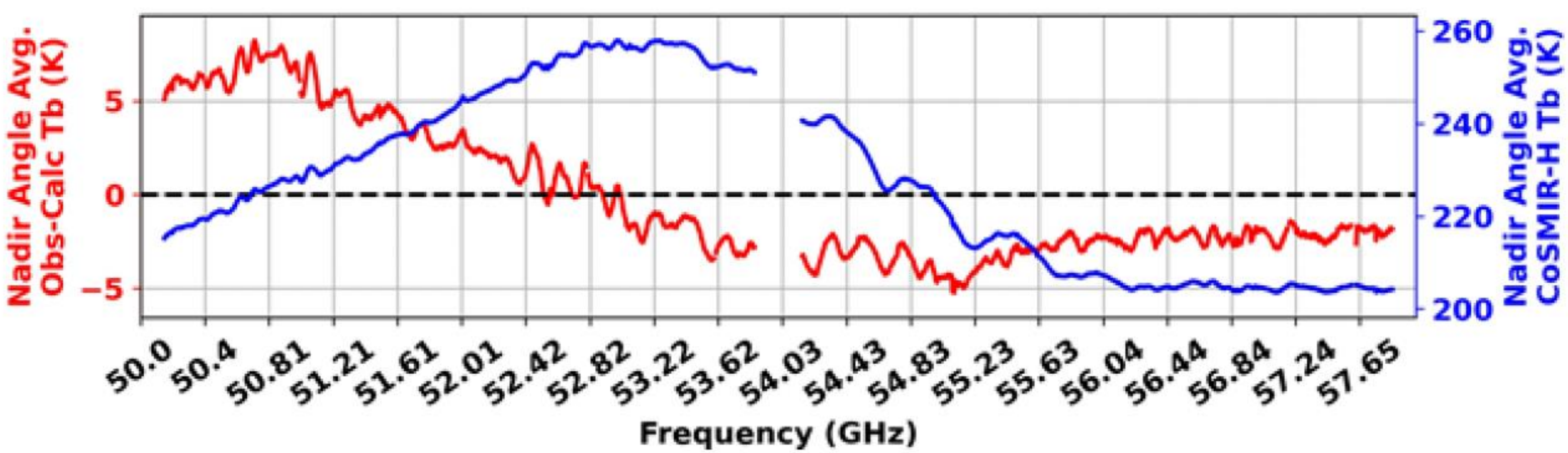
Validating of PCRTM Using COSMIR-H Data from WHyMSIE

Red: COSMIR-H BT
Black: PCRTM Simulated BT

Red: STD of the BT diff
Black: Mean difference

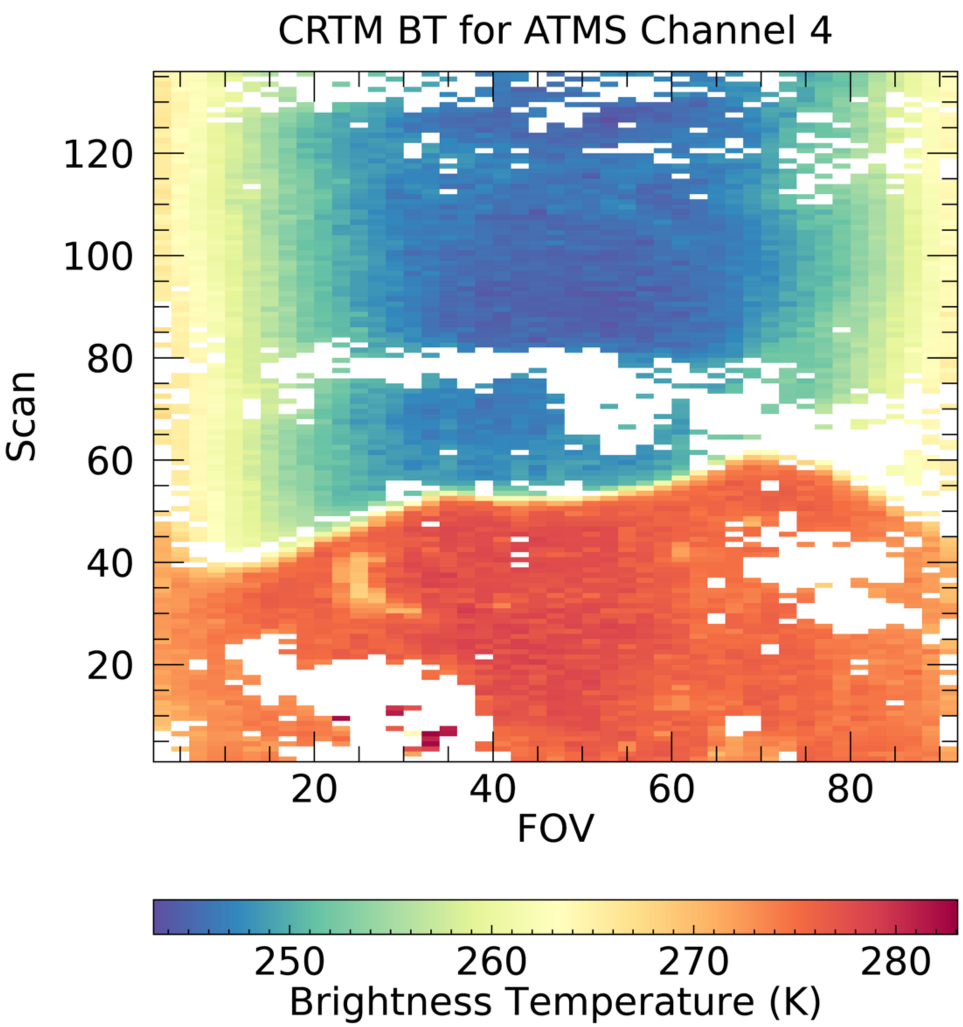


Plot below: Results from COSMIR-H team:

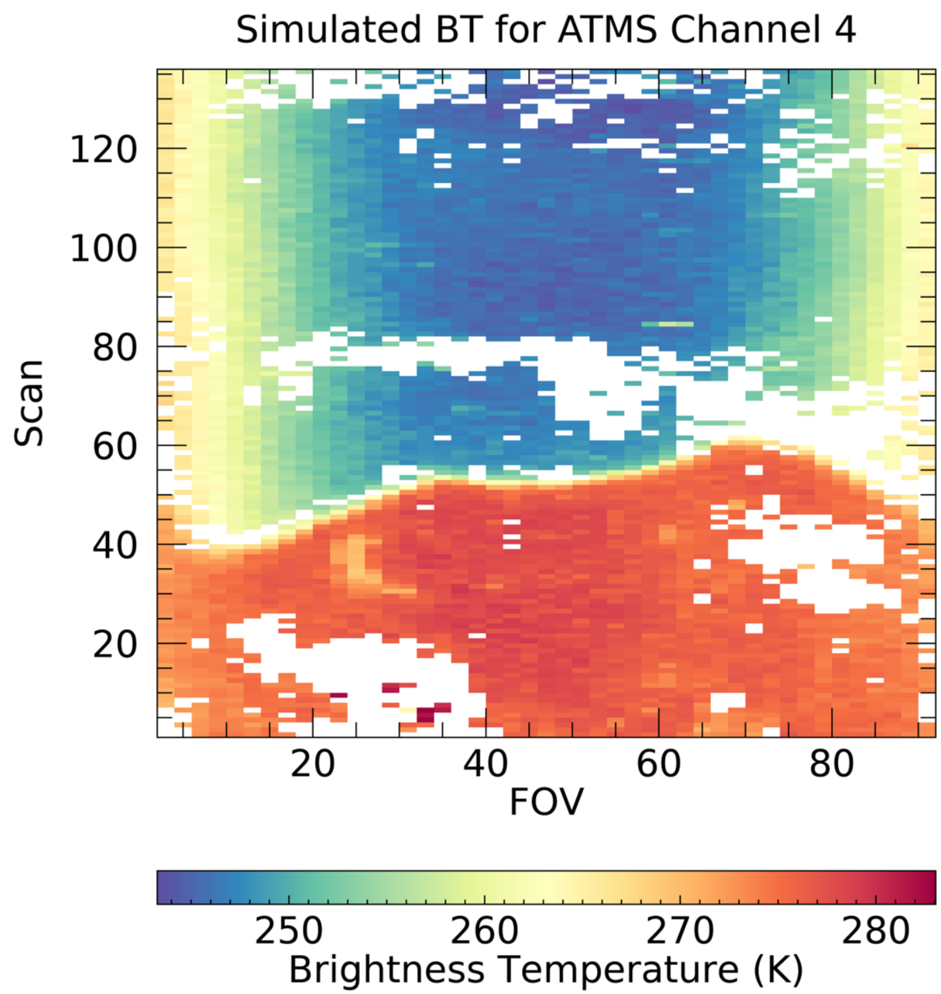


Comparison of PCRTM ATMS Brightness Temperatures (BTs) with CRTM BTs

CRTM calculated ATMS BT at 51.76 GHz

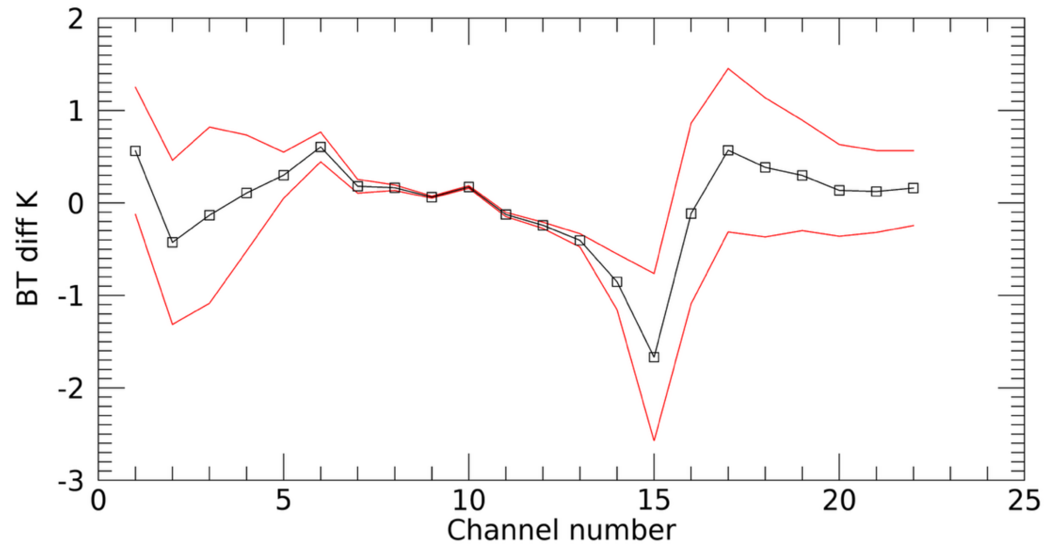


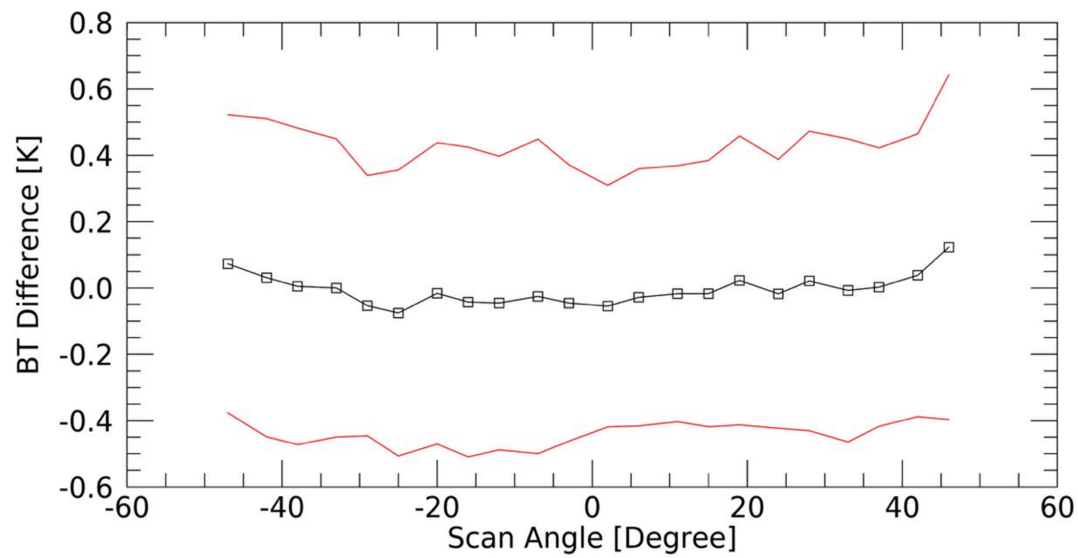
PCRTM calculated ATMS BT at 51.76 GHz



Brightness Temperature Differences (bias & RMS) between PCRTM and CRTM

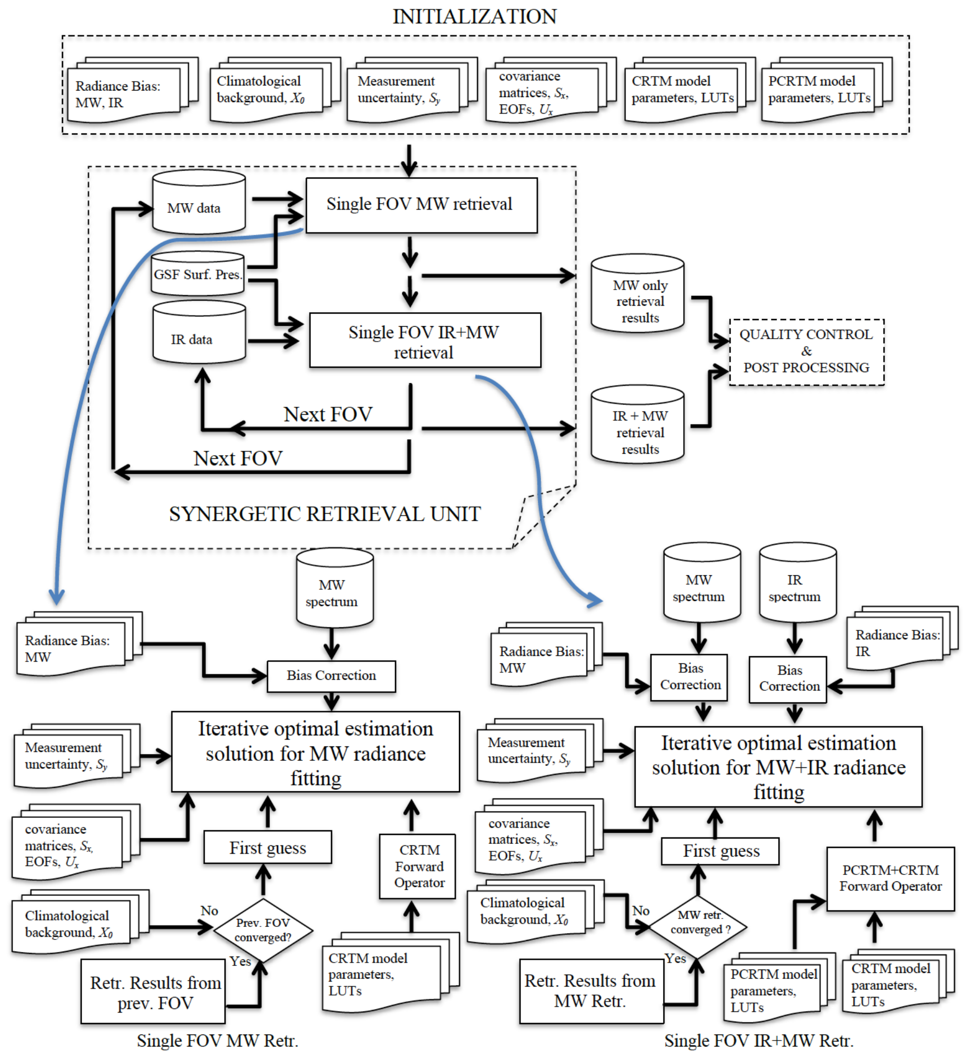
- Zeeman Effect turned off
    - CRTM does not handle it for ATMS
    - PCRTM considers Zeeman but turned to be consistent with CRTM
- CRTM trained with Rozenkranz line-by-line radiative transfer model
    - Uses Lorentz line-shape for O2 lines
    - Uses switch between doppler and Lorentz line shape for H2O lines
- PCRTM trained with monoRTM which uses Voigt line shape
    - Needed for the strong O2 lines with weighting function peak at upper atmosphere
- The difference is frequency dependent with different angular differences
    - PCRTM does not have scan angle dependency when compared with LBL
- We prefer to use Voigt line shape for the MW PCRTM
    - Can be trained with Rozenkranz LBL



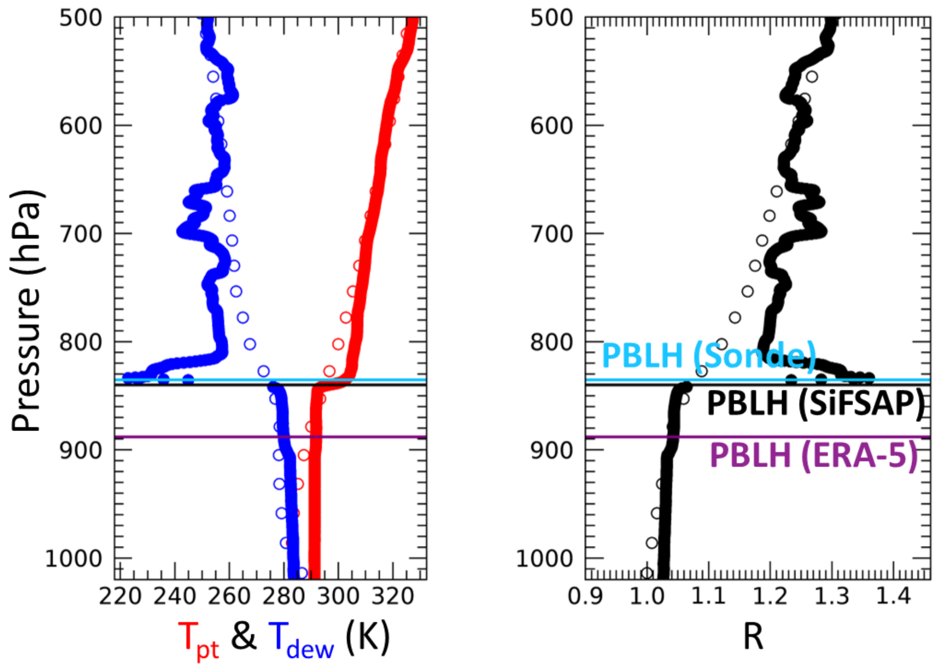


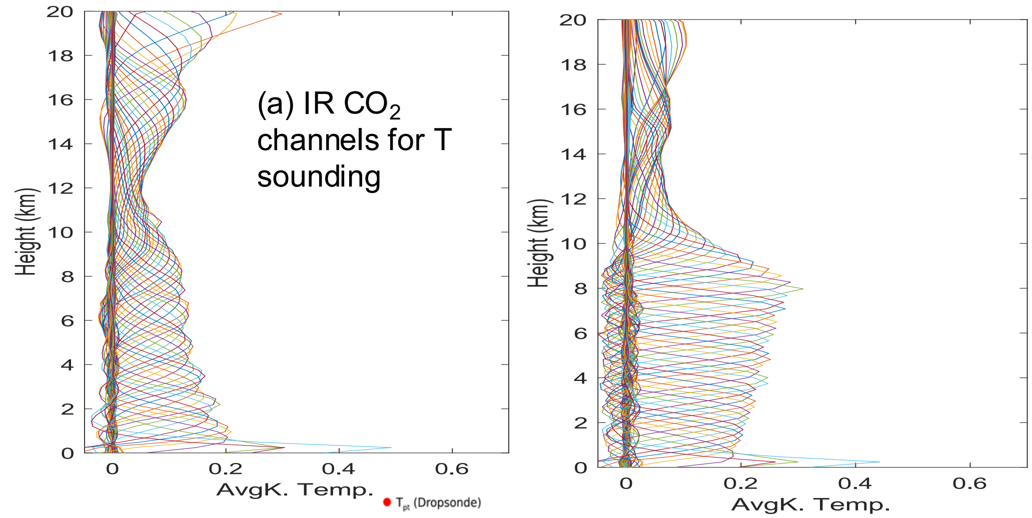
Single Field-of-view Sounder Atmospheric Product (SiFSAP) Retrieval Algorithm

- SiFSAP is a physical-based OE retrieval algorithm
  - ➢ 3-modes: MW-only, IR-only, IR+MW-joint retrievals
  - ➢ Modular design and very fast
  - ➢ PCRTM enables use of all spectral information
  - ➢ Simultaneous retrieval of all atmospheric and surface properties
  - ➢ 9-times higher spatial resolution relative to cloud-clearing algorithm
  - ➢ Provides averaging kernel and error estimates on the retrieved products
- SiFSAP uses EOF (PC) to represent state vectors
  - ➢ Reduces dimensions
  - ➢ Can change PCs No. according to instrument information content
- SiFSAP uses only climatology a priori information
  - ➢ Independent of NWP models
- SiFSAP fits observed radiance spectrum directly
  - ➢ Radiometrically consistent is the key to quality products
- The SiFSAP products for CrIS/ATMS are available at NASA GES DISC since 2023



PBL Height from Dewpoint & Potential Temperature



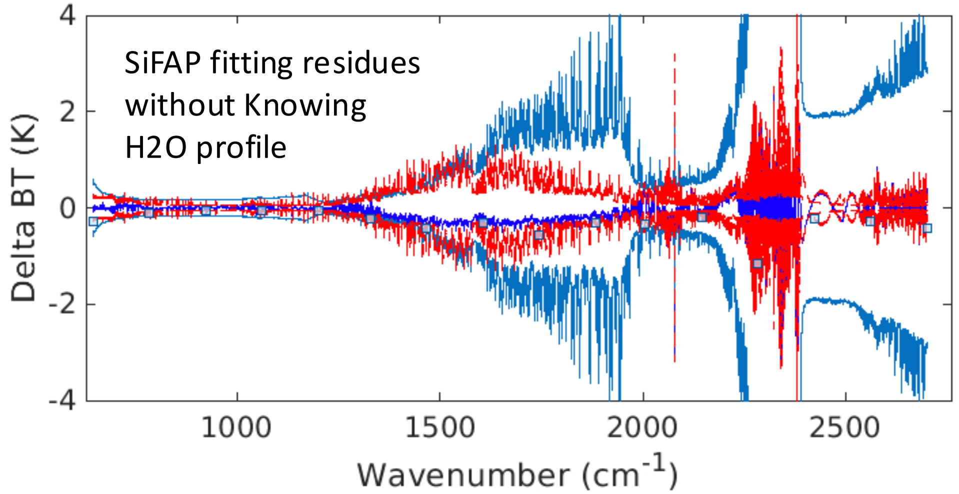


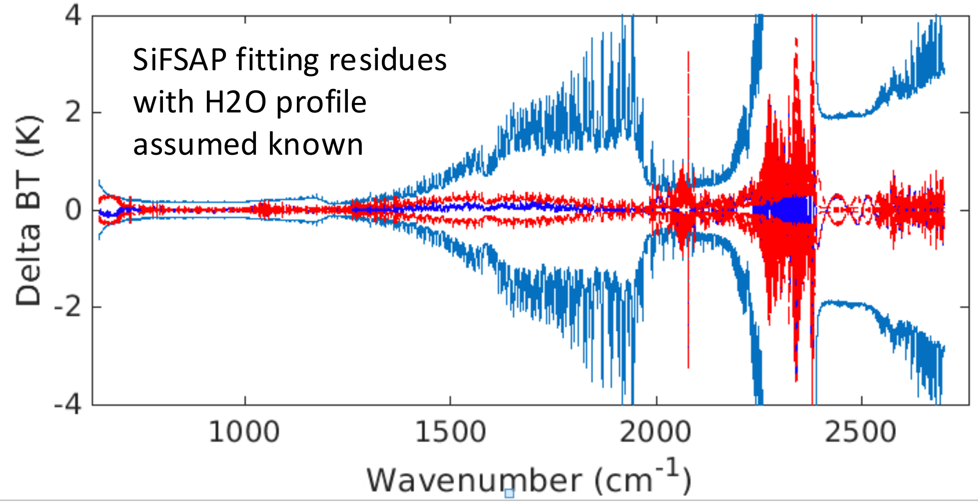
Averaging kernels for the temperature retrieval using (a) the long-wave band, (b) the mid-wave band of the NAST-I

- Reanalysis PBL height may not be right for various reasons
- A good temperature and water vapor profiles can provide PBL height information independent of NWP models
- Jang et al. published a paper describing a method of using dewpoint and potential temperatures retrieved from SiFSAP NAST-I product
- Water vapor spectral lines from both IR and MW hyperspectral sounders have high information content
  - ➢ Better water vapor a priori or measurements such as those from HALO Dial water vapor lidar will improve sounder retrieval performance

Improving Temperature SiFSAP Retrievals with Known Water Profiles (Simulated retrieval studies)

- Simulation retrieval study performed using HRRR model T/H2O which matches the NAST-I flight observation geometry and footprint size
  - NAST-I simulated radiance spectral calculated using PCRTM with HRRR model T/H2O as input, random noise added Experiment 1: SiFSAP retrieval performed to retrieve T/H2O profiles simultaneously
  - Experiment 2: SiFSAP retrieval performed with H2O profile fix the that of the HRRR

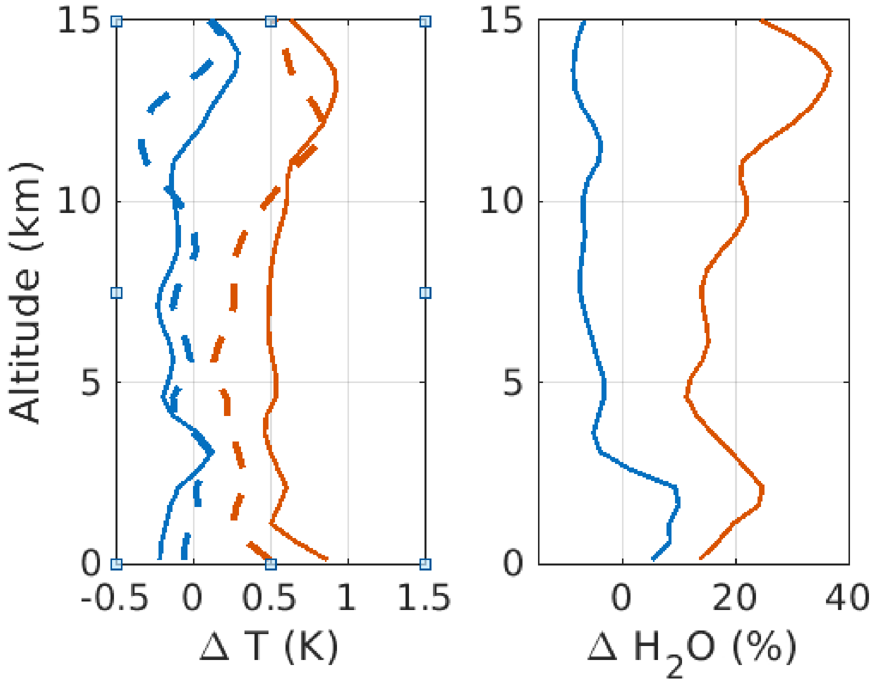


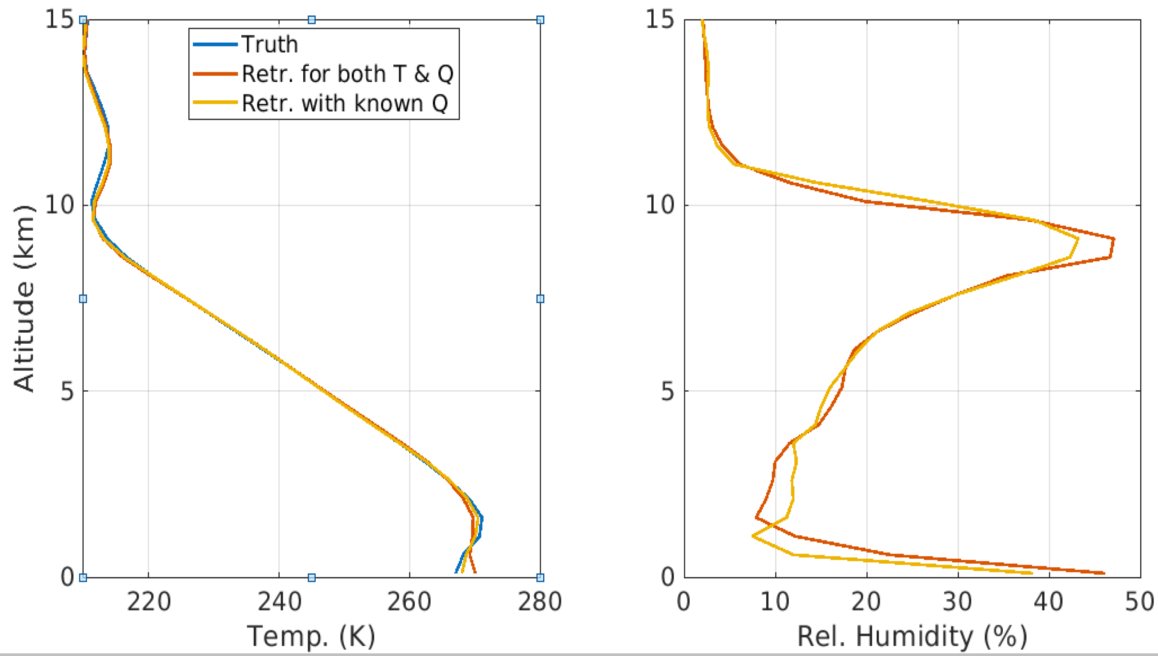


Improving Temperature SiFSAP Retrievals with Known Water Profiles (Simulated retrieval studies continued)

- Solid red line is RMS error when both T/H2O are retrieved in SiFSAP
- Solid blue line is bias error when both T/H2O are retrieved in SiFSAP
- Dashed red line is RMS error when H2O is fixed to the truth
- Dashed blue line is the bias error when H2O is fixed to the truth

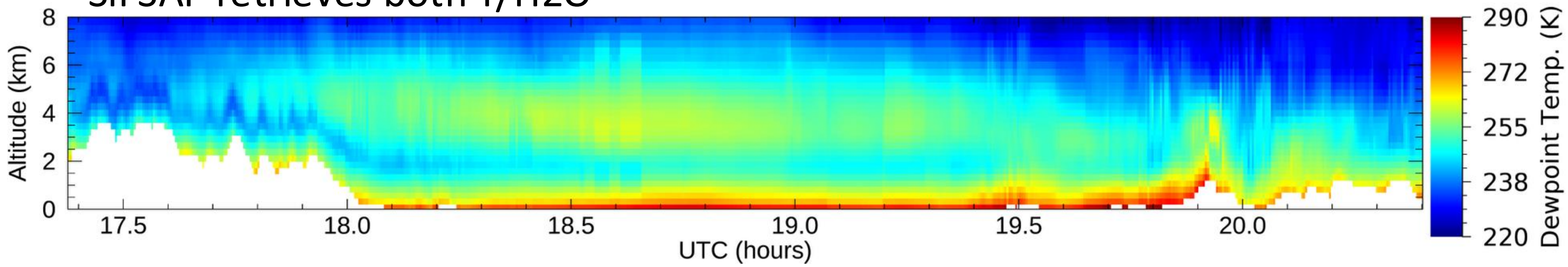
Example of improved PBL retrievals when H2O profile is known



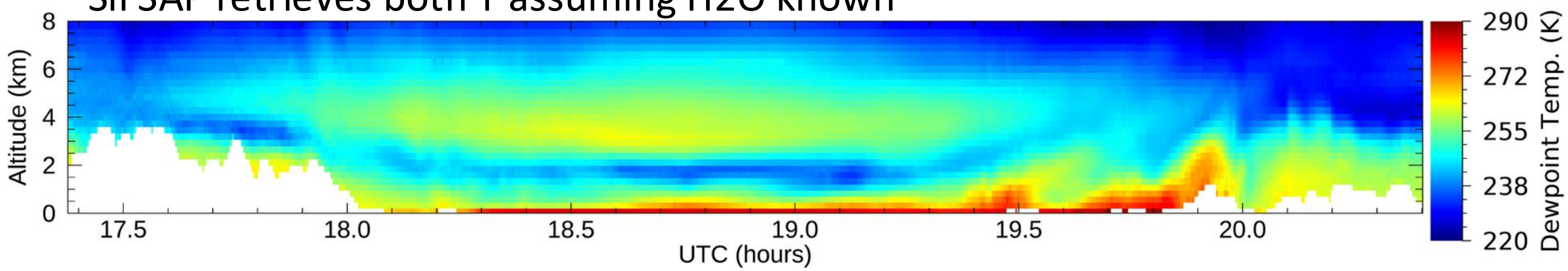


Improving Temperature SiFSAP Retrievals with Known Water Profiles (Simulated retrieval studies continued)

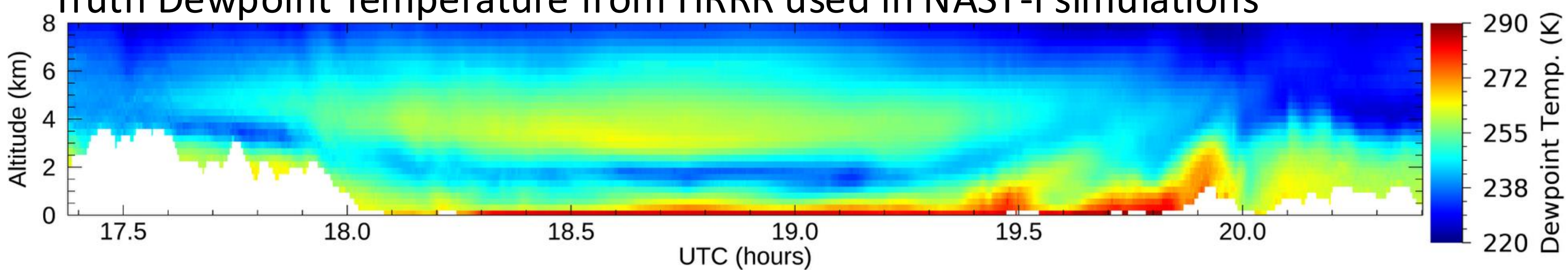
SiFSAP retrieves both T/H2O



SiFSAP retrieves both T assuming H2O known

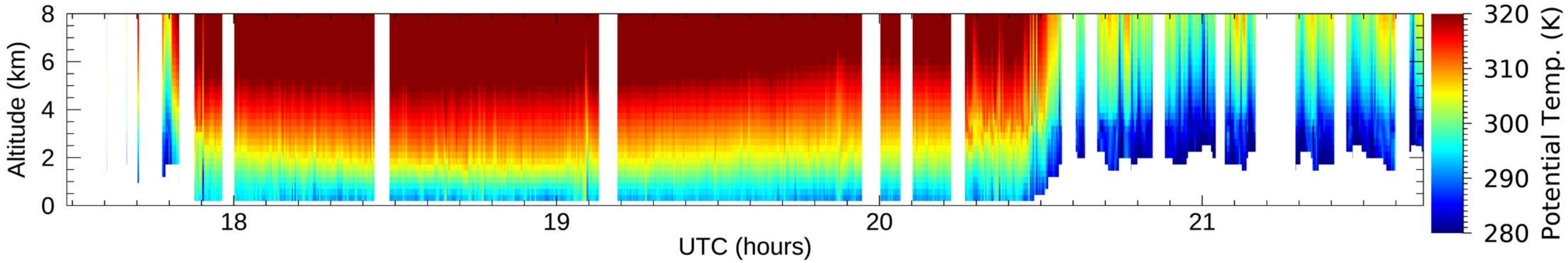


Truth Dewpoint Temperature from HRRR used in NAST-I simulations

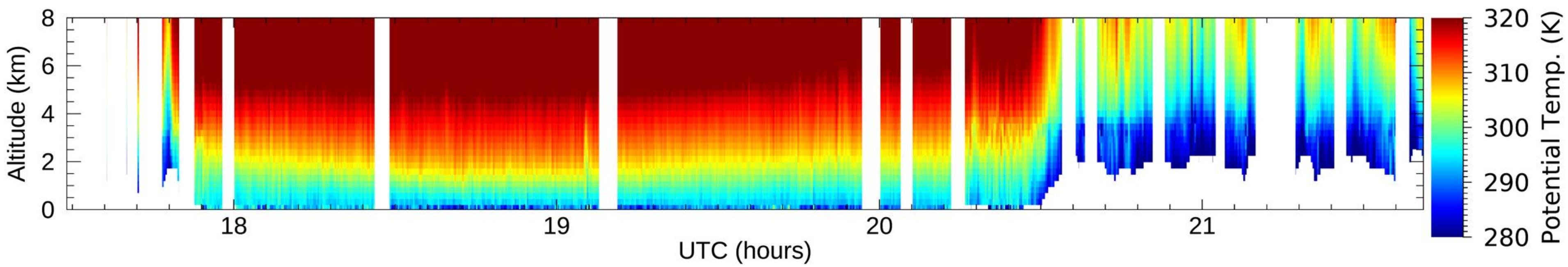


Improving Temperature SiFSAP Retrievals with Known Water Profiles (Real NAST-I data from WHyMSIE)

SiFSAP retrieves both T/H2O

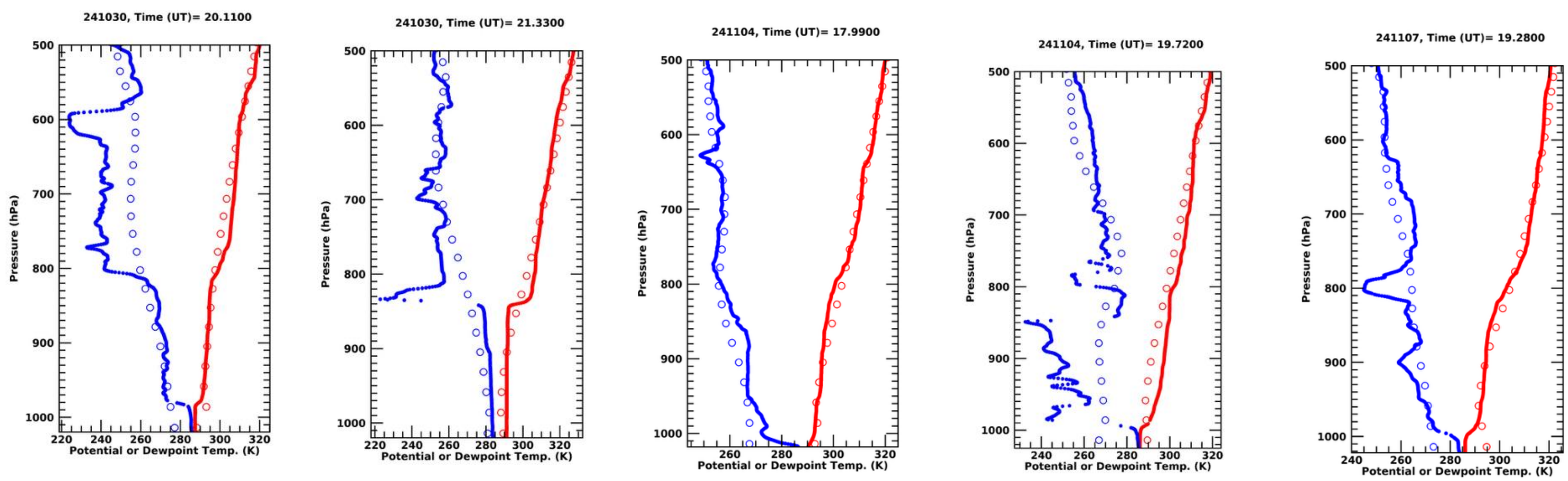


SiFSAP retrieves both T using HRRR H2O profile

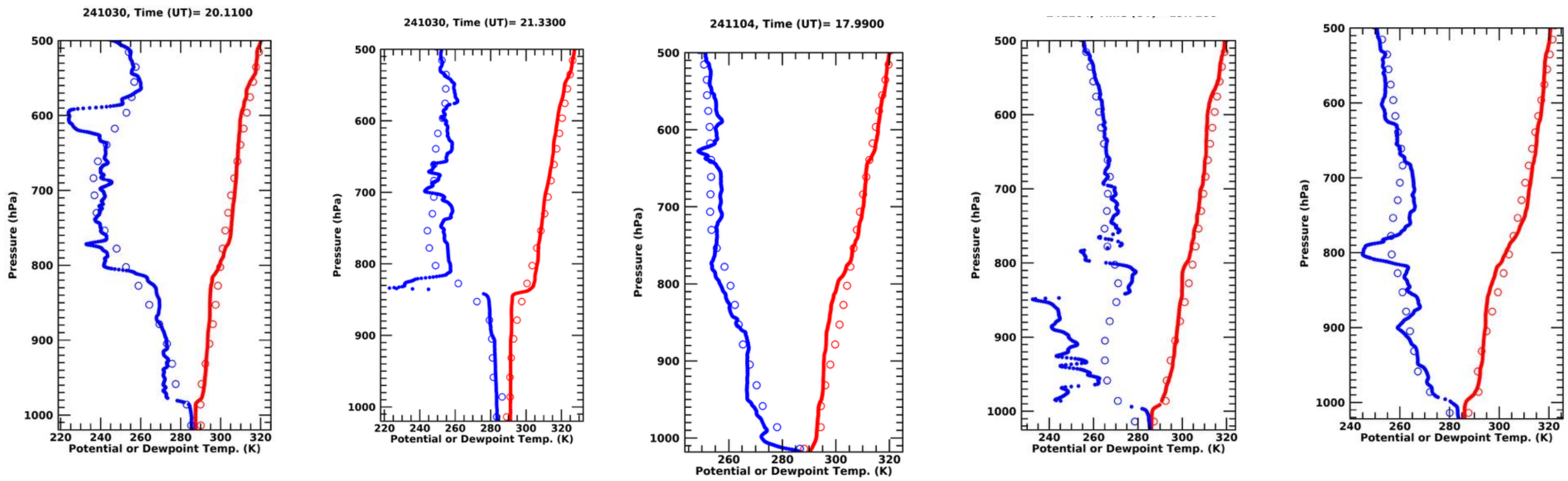


Improving Temperature SiFSAP Retrievals with Known Water Profiles (Real NAST-I data from WHyMSIE continued)

Dewpoint and potential temperatures retrieved fromNAST-I WHyMSIE data using SiFSAP (T/H2O retrieved Simultaneously)



Improved retrievals when H2O is fixed to that of HRRR



Summary and Conclusions

- COSMIR-H and ATMS PCRTM fast model developed
- SiFSAP has been modified to retrieve temperature profiles using both water vapor and CO_2 spectral lines (tested using both synthetic data and real NAST-I data)
- Better H_2O a priori will provide improved PBL retrievals.