

Spectral Fingerprinting of Hyperspectral Remote Sensing Data

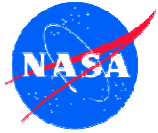
Xu Liu, W. Wu, Q. Yang, D. K. Zhou, A. M. Larar.

NASA Langley Research Center, Hampton, VA, USA

Xu.Liu-1@nasa.gov

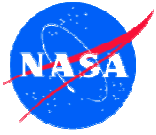
Acknowledgements

CRIS/ATMS data were provided by the NASA's Sounder SIPS at Jet Propulsion Laboratory. Thanks to the help with the SIP account by Ruth Monarrez, F. Griffin, T. Chung, & G. Wang. Resources supporting this work were provided by the NASA High-End Computing (HEC) Program through the NASA Advanced Supercomputing (NAS) Division at Ames Research Center. Thanks to the support from Tsengdar Lee and Nancy Carney

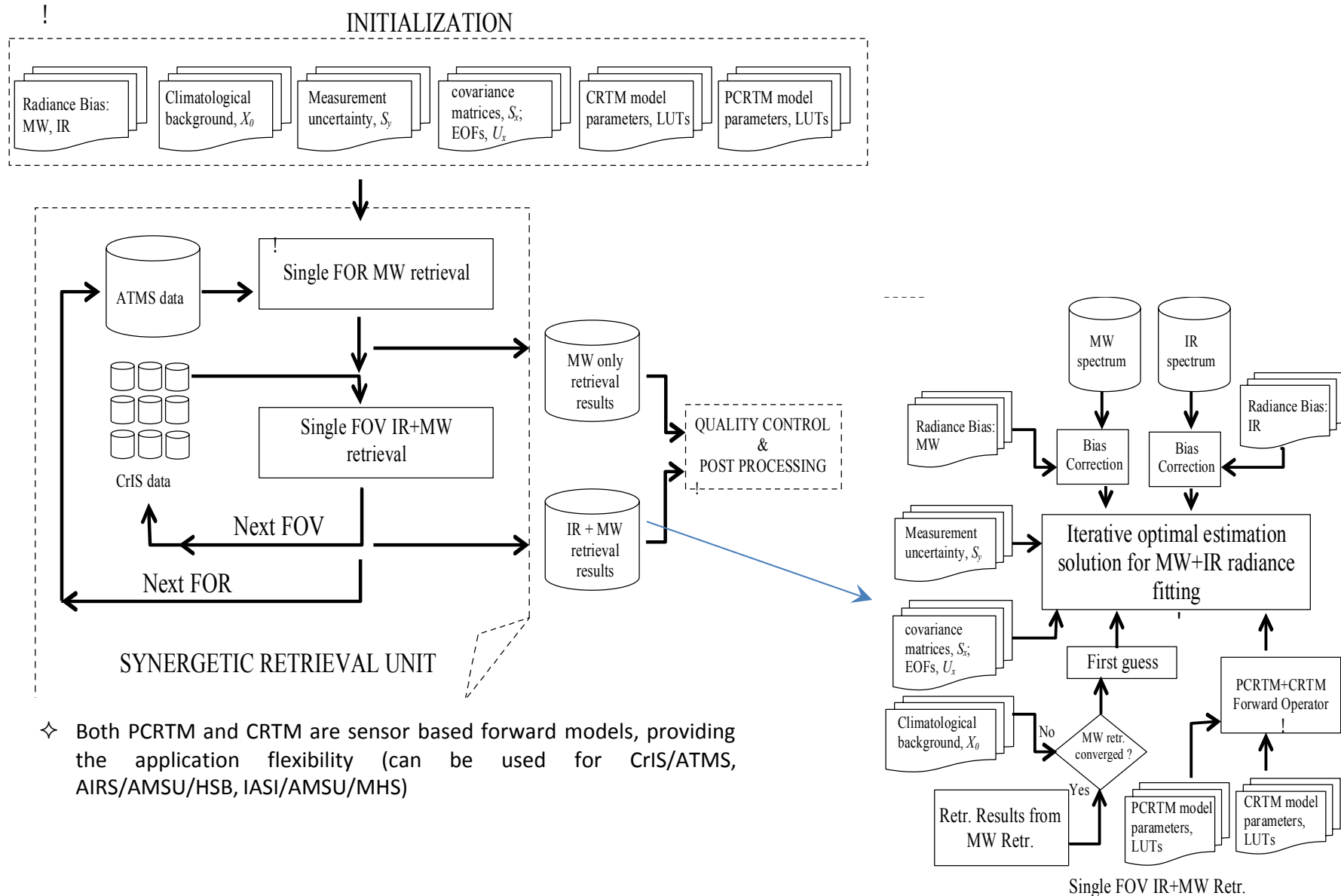


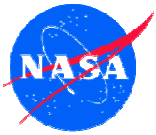
Objectives

- Perform Single FOV PCRTM retrieval of SNPP CrIS/ATMS data
 - Cloud clearing and hole-hunting are not optimal ways to use hyperspectral data
 - Needs a way to use the full spectral information instead of segments of them
 - Fast and accurate PCRTM model in cloudy atmosphere
 - Cloud and all other geophysical properties retrieved simultaneously
 - Radiative Transfer Kernel automatically generated by the retrievals
 - Unscramble temperature, clouds, and green-house atmospheric gases from the observed radiance spectral
 - Geophysical products can be gridded to perform anomalies and climate change studies
 - Geophysical products can be used to assess operational products and provides enhancements (such as high spatial resolution, more products)
- Perform gridded (5x5 degree) spectral fingerprinting using radiance anomaly spectra
 - Need radiometrically consistent radiative kernels (not from climate or NWP models)
 - Can be repeated if new instrument calibration or issue identified
 - Radiative kernels from PCRTM retrieval will not need to be recalculated
 - Spectral fingerprinting method quantifies contributions to the radiance anomalies from different geophysical parameters (T, H₂O, clouds, surface, trace gases ...)
- Compare results from spectral fingerprinting PCRTM single FOV retrievals
 - Both on the grid scale and time series

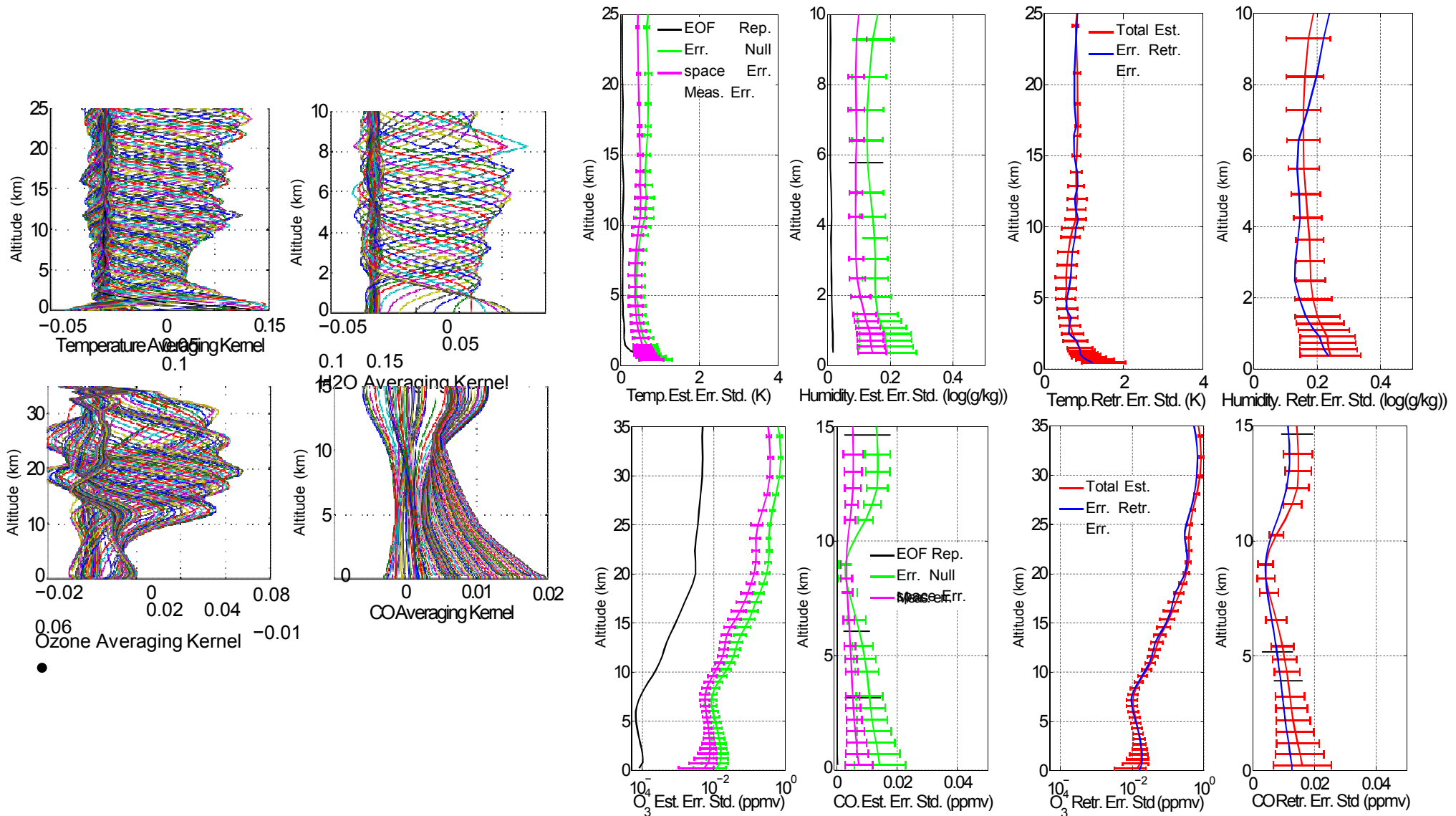


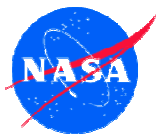
PCRTM Single FOV Physical Retrieval Algorithm





End-to-End Closure Experimental Study for IR only retrieval using Single FOV IASI spectra





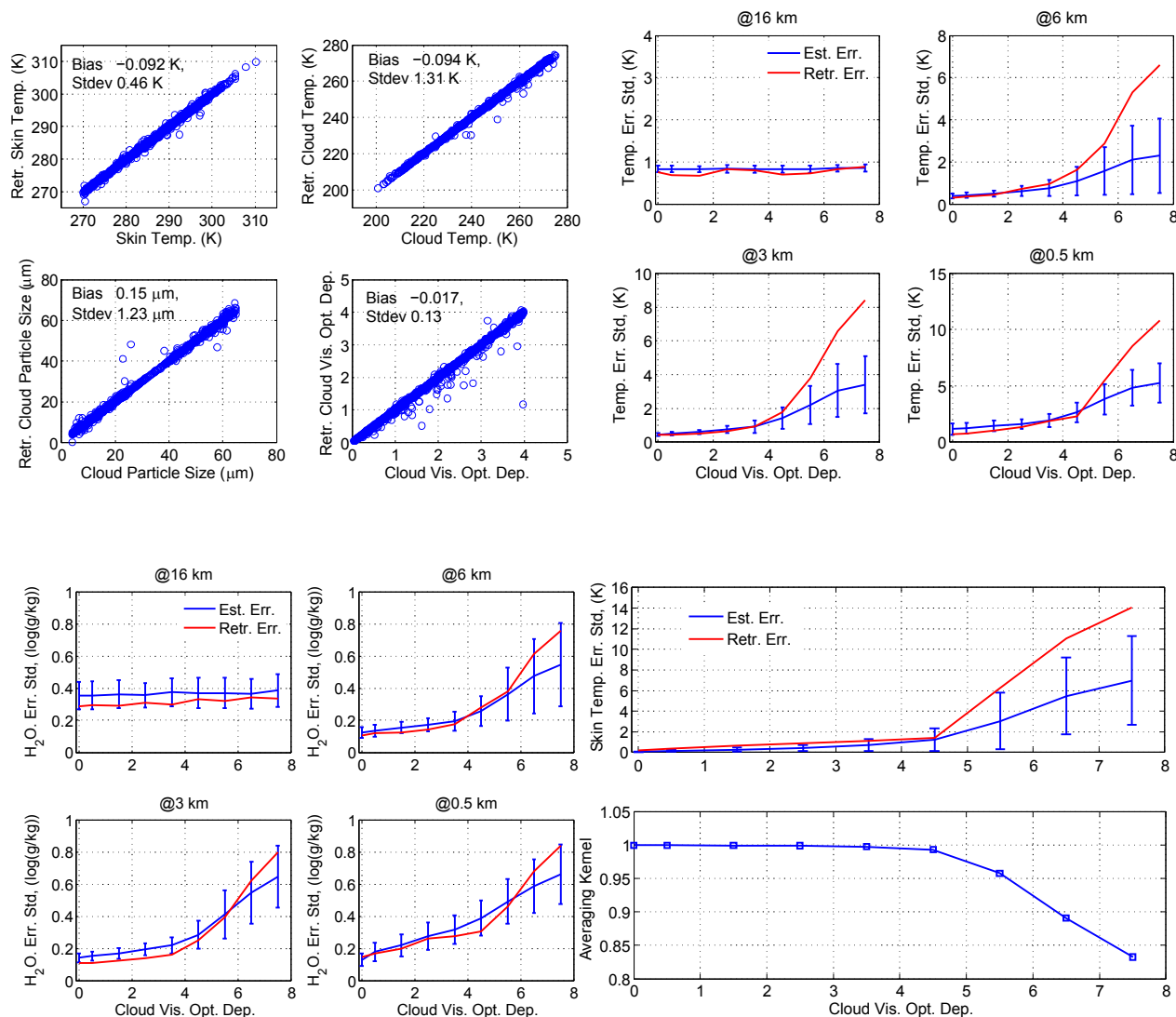
End-to-End simulation study – evaluation for IASI retrieval capability under all-sky condition

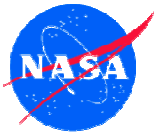
- The accuracy of the IR only retrieval below-clouds decreases as cloud optical depth increases, which can be compensated by using MW+IR combined retrieval.

Confusion Matrix for Cloud Phase Retrieval

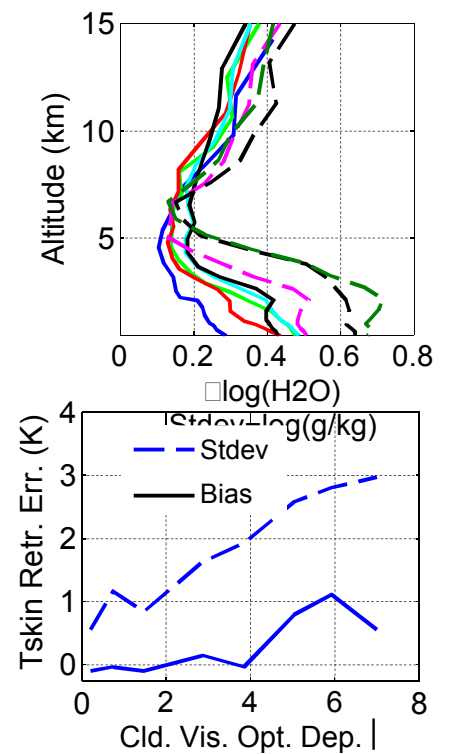
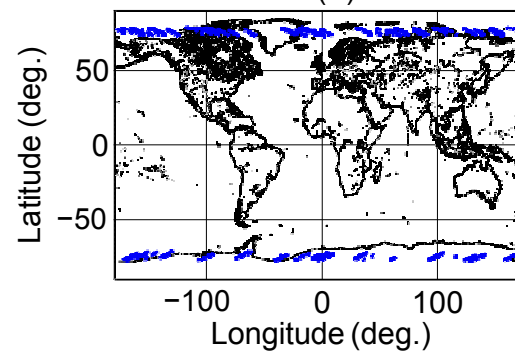
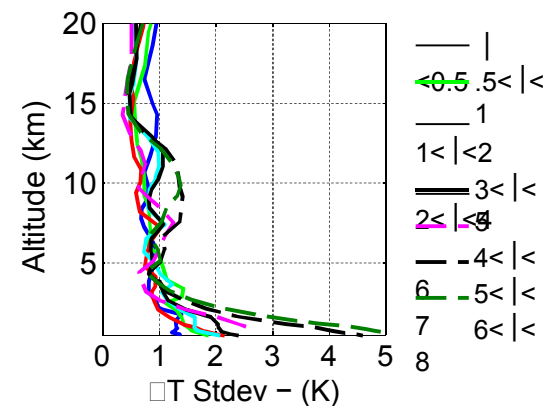
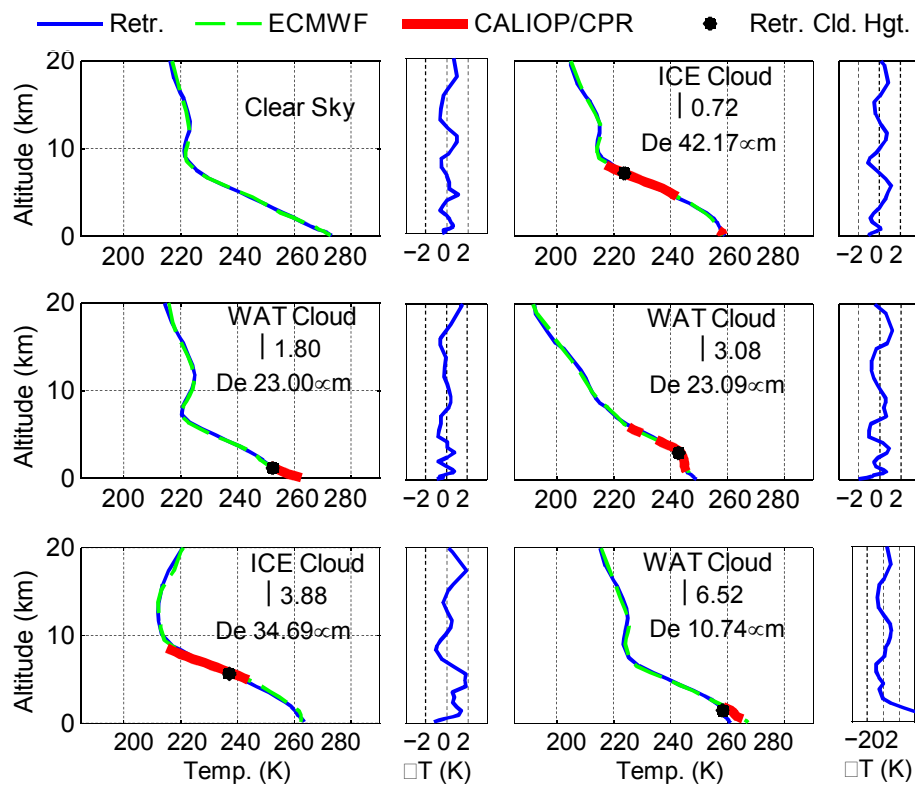
Output Class	Target Class		
	Ice Cloud	Water Cloud	
	47.98% ¹ 50.15% ² 47.18% A	0.58% ¹ 0.31% ² 0.68% B	
Output Class	Target Class		
	Ice Cloud	Water Cloud	
	0.91% ¹ 2.77% ² 0.23% D	50.53% ¹ 46.77% ² 51.91% E	
Output Class	Target Class		
	Ice Cloud	Water Cloud	
	Precision 98.15% ¹ 94.77% ² 99.51% G	Precision 98.87% ¹ 99.34% ² 98.71% H	
Output Class	Target Class		
	Ice Cloud	Water Cloud	
	Sensitivity 98.81% ¹ 99.39% ² 98.58% C	Sensitivity 98.24% ¹ 94.54% ² 99.56% F	
Output Class	Target Class		
	Ice Cloud	Water Cloud	
	Accuracy 98.52% ¹ 96.92% ² 99.09% I		

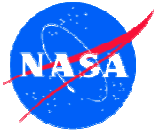
¹ over land, ² over ocean





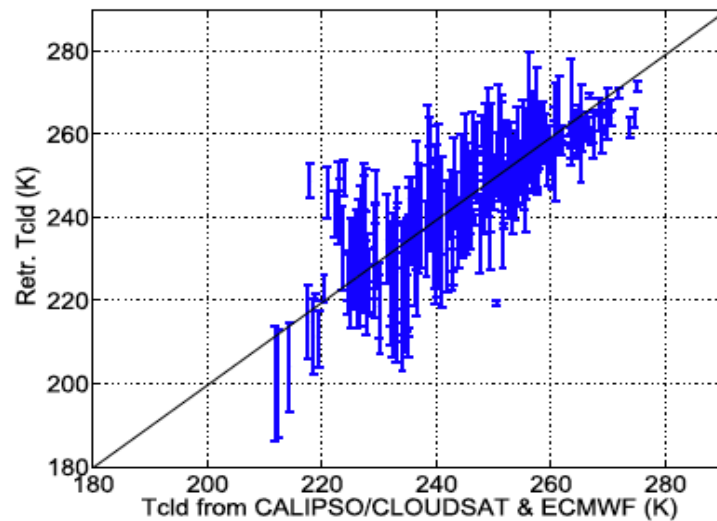
Validation using real satellite data



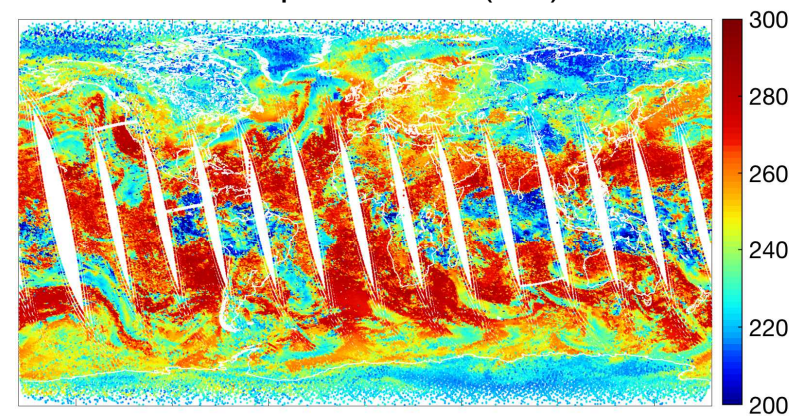


Cloud top Temp., particle size, optical depth

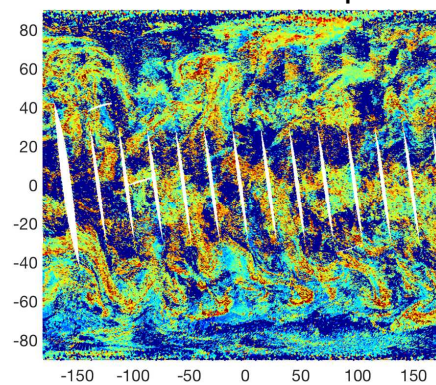
Cloud top Temp. retrieval validation using
IASI + CALIOP/CLOUDSAT/ECMWF



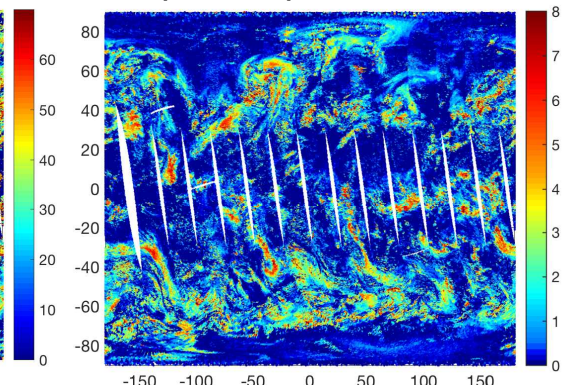
Cloud Top Pressure (mb)

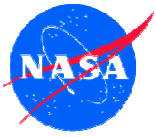


Cloud diameter μm



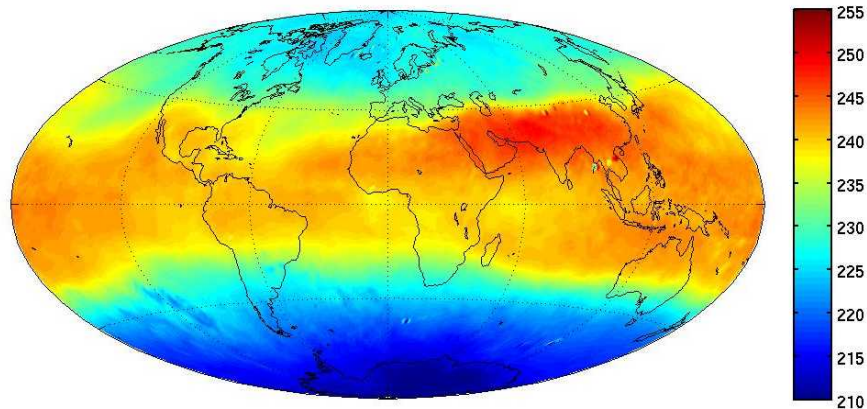
Optical Depth at 550nm



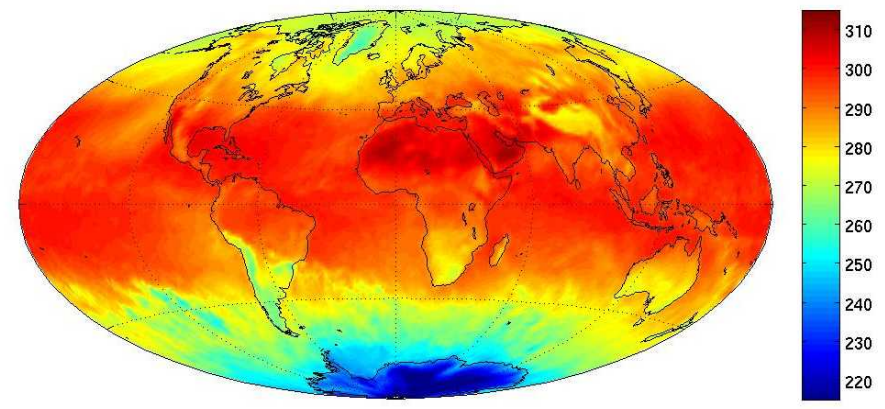


Example of retrieved global distribution of climate related properties retrieved using the PCRTM algorithm

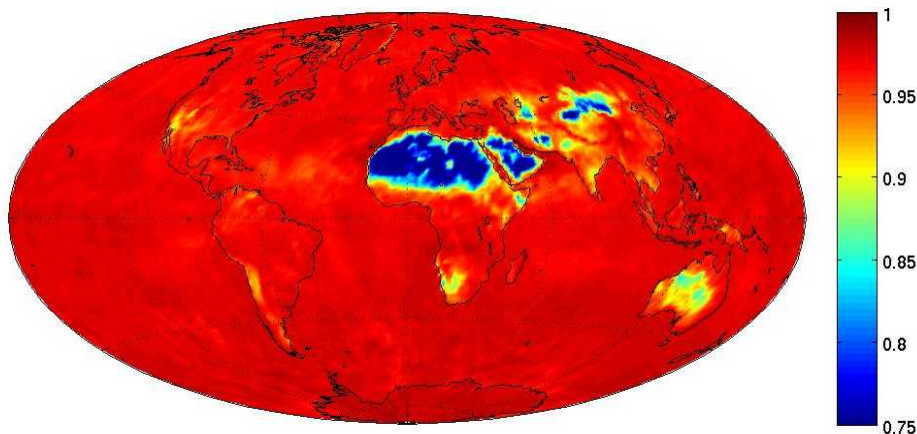
Atmospheric temperature at 9 km for July 2009



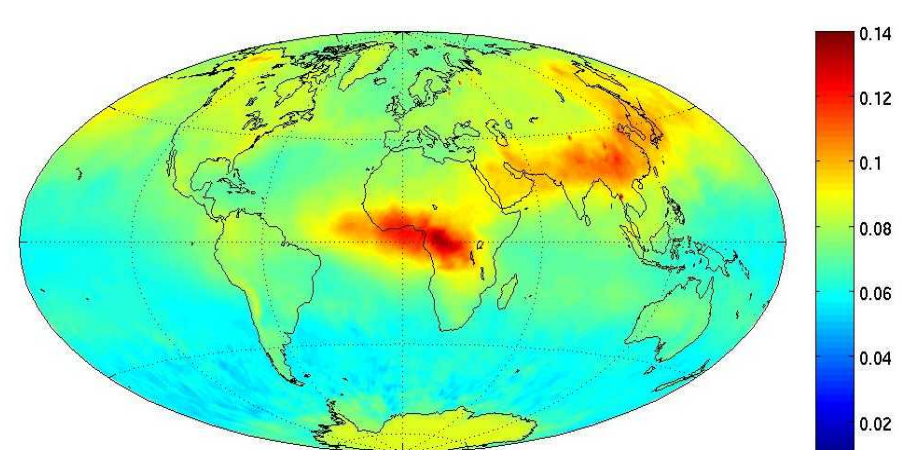
Surface skin temperature for July 2009

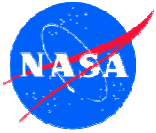


Surface emissivity for July 2009



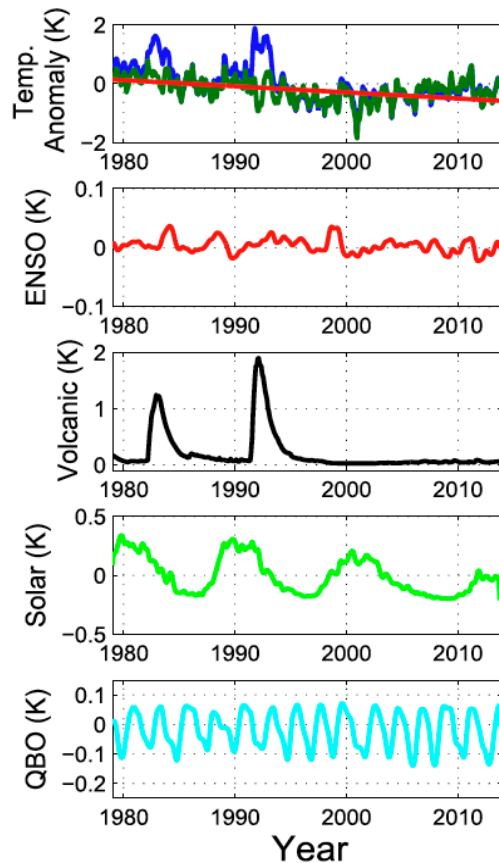
Atmospheric carbon monoxide mixing ratio for July 2009





Spectral Printing of Climate Trend

Anomaly



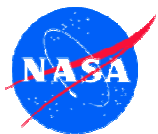
$$\Delta \bar{R} = \bar{S} \Delta \bar{\alpha} + \varepsilon$$

$\Delta \bar{R}$ - the radiance spectral fingerprints, $\bar{S}$ - radiative kernel,
 $\Delta \alpha$ - climate variable anomaly, ε - spectral fingerprints uncertainty
(non-linearity, spatial-temporal variability)

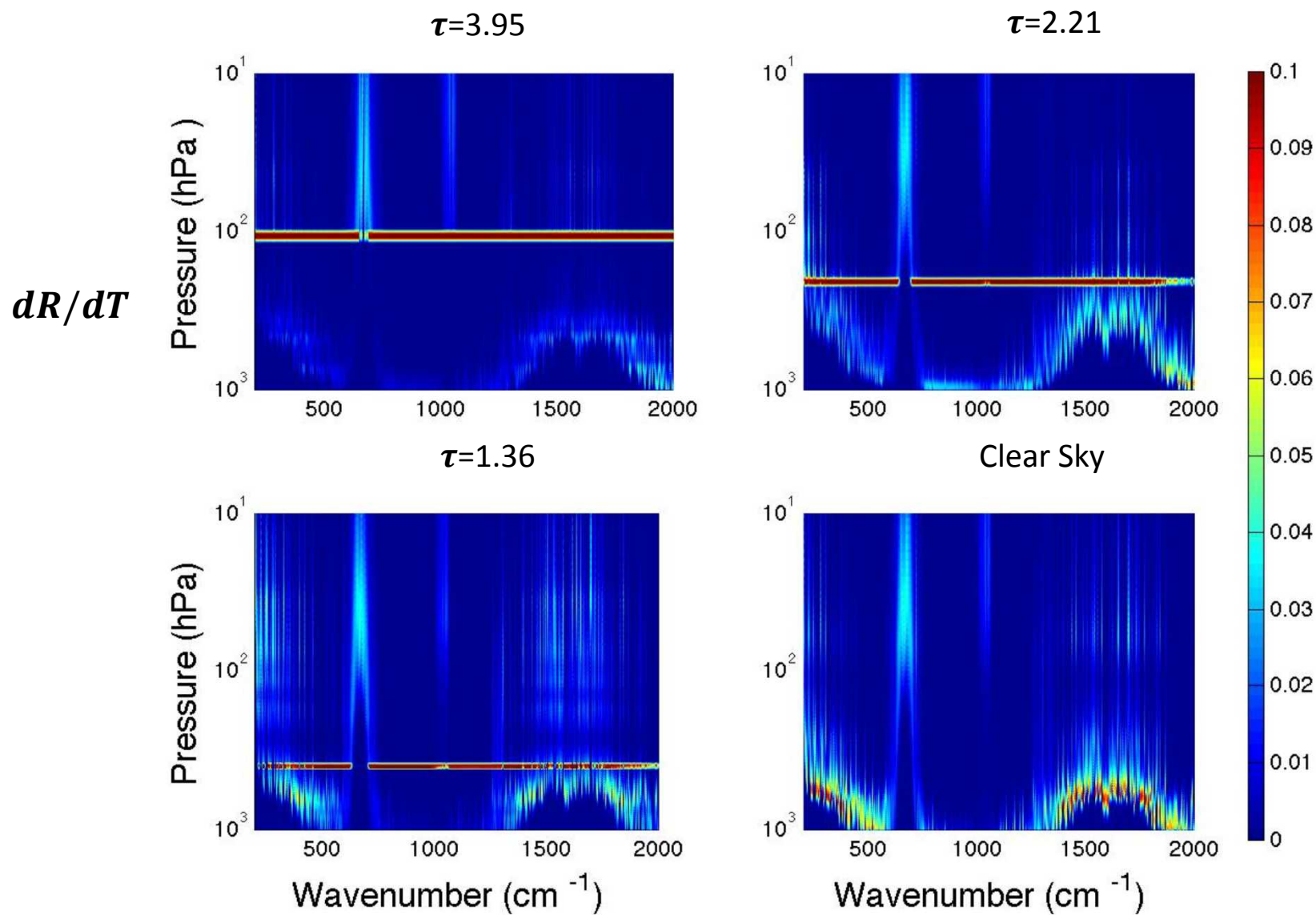
$$\bar{\alpha} = (S^T \Sigma^{-1} S + \lambda I)^{-1} S^T \Sigma^{-1} \Delta \bar{R}$$

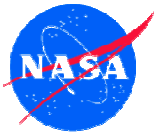
A radiometric consistent radiative kernel is an important factor in spectral fingerprinting

- Need consistent linearization points
- Need accurate radiative kernel *in the presence of clouds*
- PCRTM and PCRTM-RA is used to accurately calculate radiative kernels



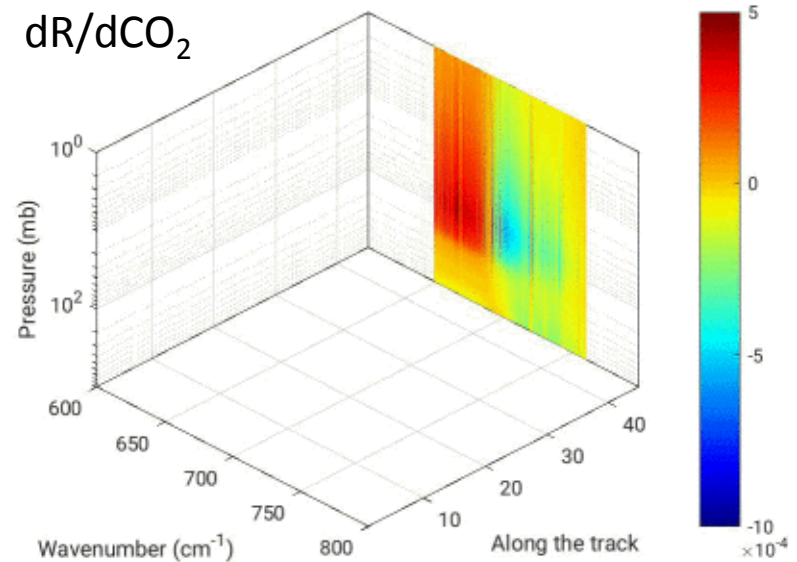
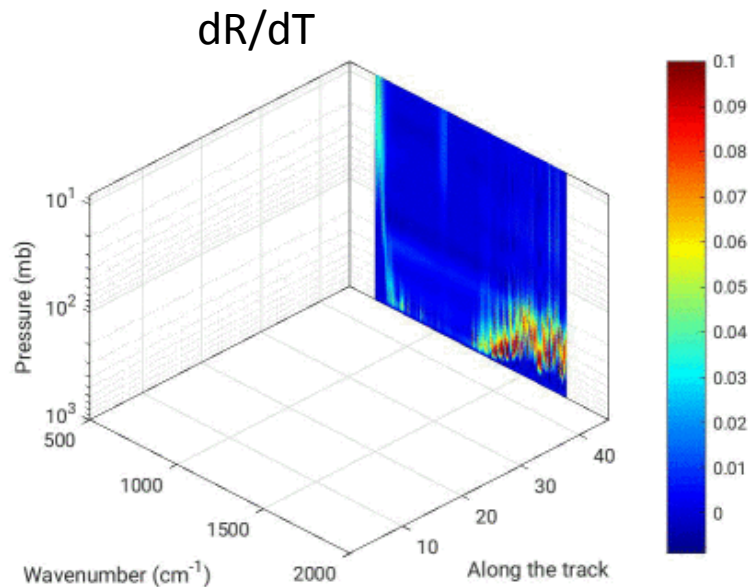
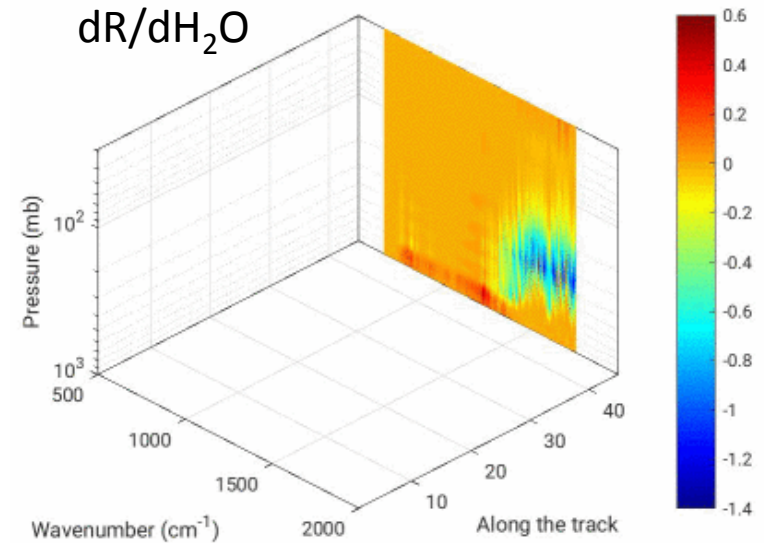
Temperature Jacobian in the presence of clouds

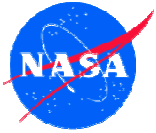




Spatial and Spectral Information of the Radiative Kernel

- Example PCRTM retrieved radiative kernel for CrIS along the scanline direction
- Retrieved parameters include
 - T, H₂O, CO₂, CO, CH₄, N₂O, O₃, cloud phase/temperature/optical depth/size, surface skin temperature and surface emissivity

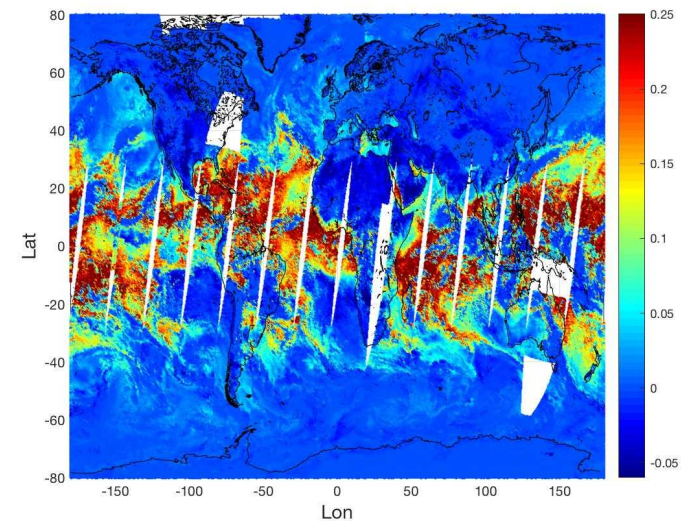




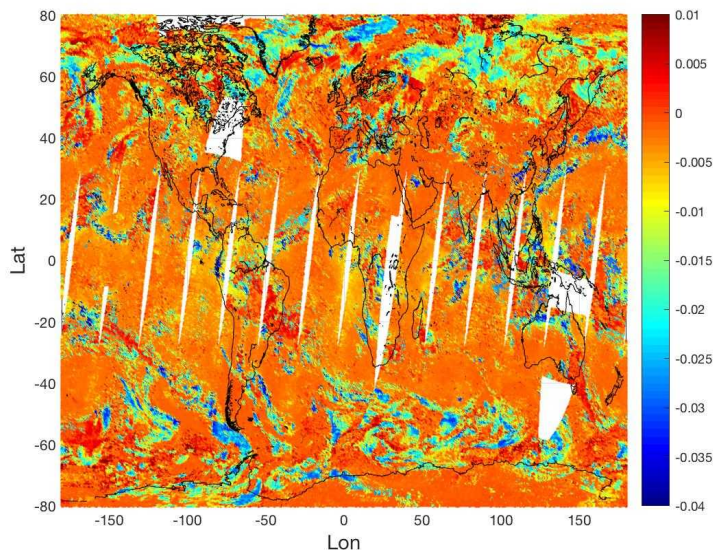
Global distribution of the Radiative Kernel

- Example PCRTM retrieved radiative kernel for CrIS at different altitudes
- Retrieved parameters include
 - T, H₂O, CO₂, CO, CH₄, N₂O, O₃, cloud phase/temperature/optical depth/size, surface skin temperature and surface emissivity

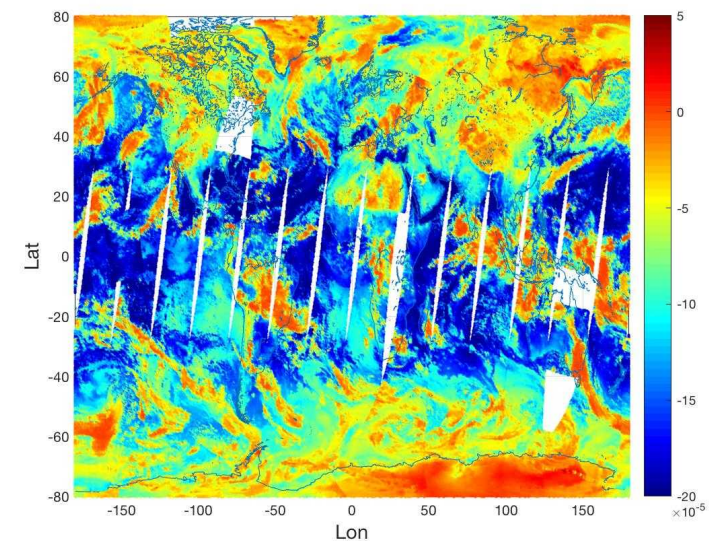
dR/dH_2O

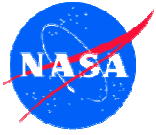


dR/dT



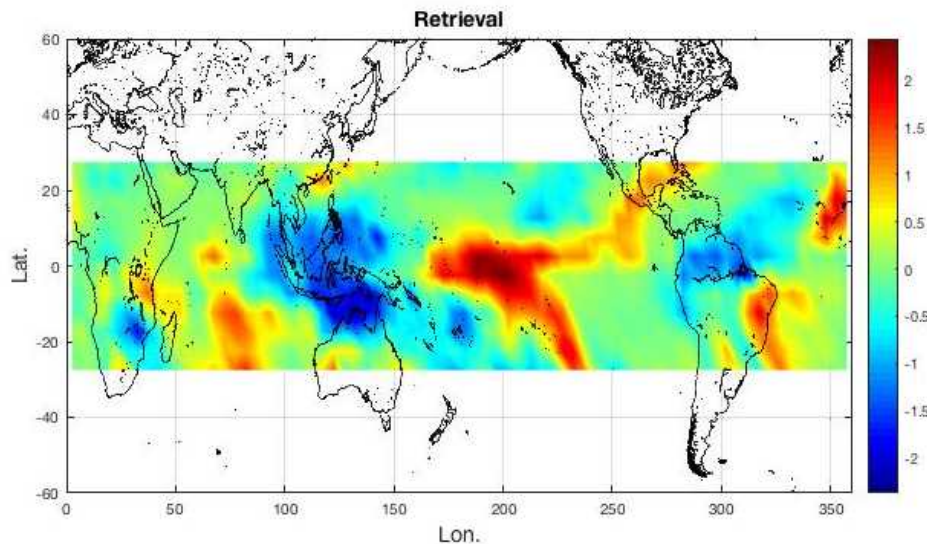
dPC/dCO_2



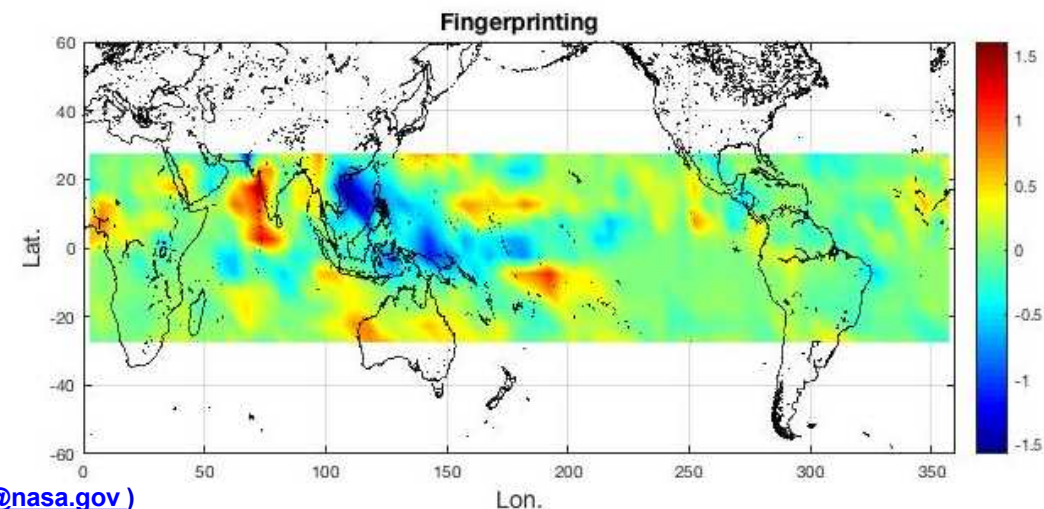
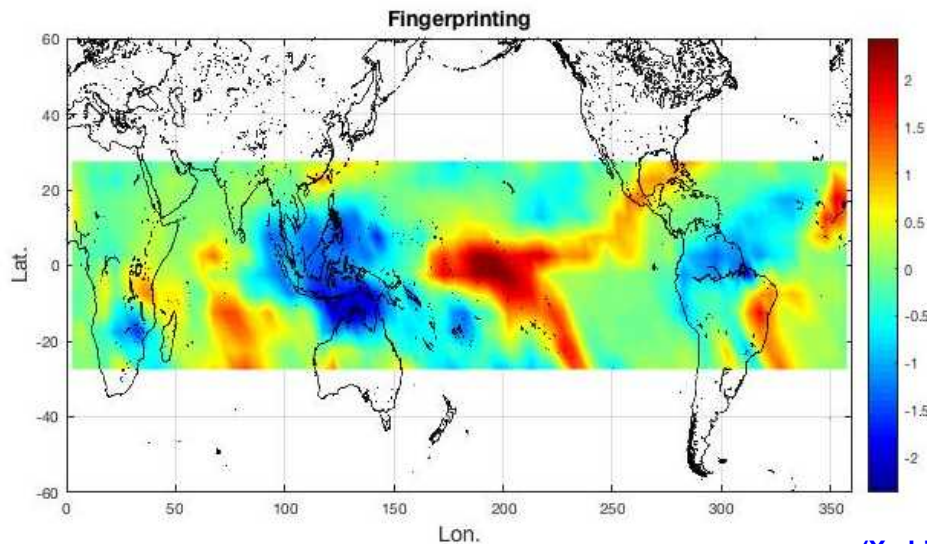
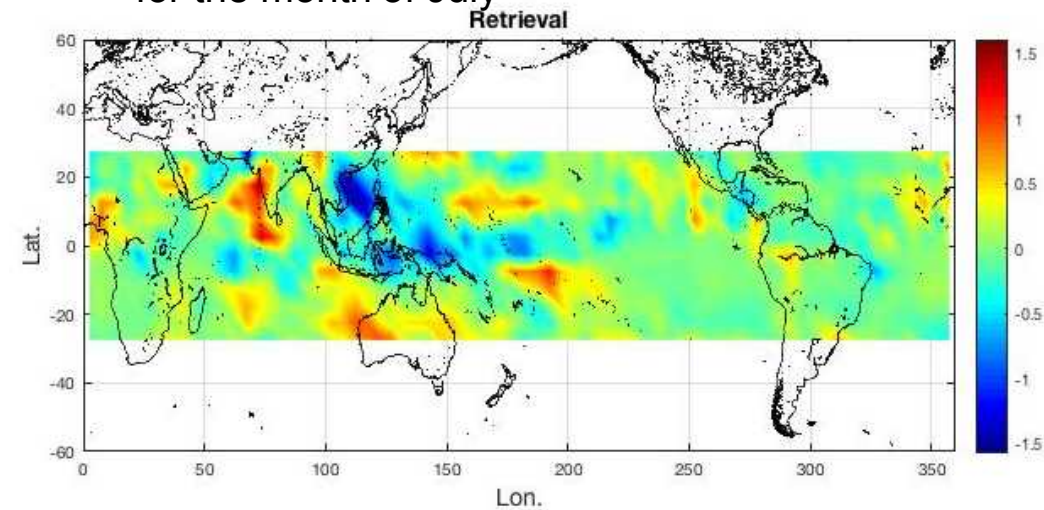


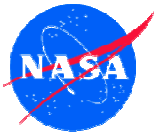
5x5 Degree Gridded Cloud Optical Changes (2016 minus 2017) using PCRTM Retrieval and Spectral Fingerprinting

Cloud Optical Depth Difference (2016-2017)
for the month of January



Cloud Optical Depth Difference (2016-2017)
for the month of July

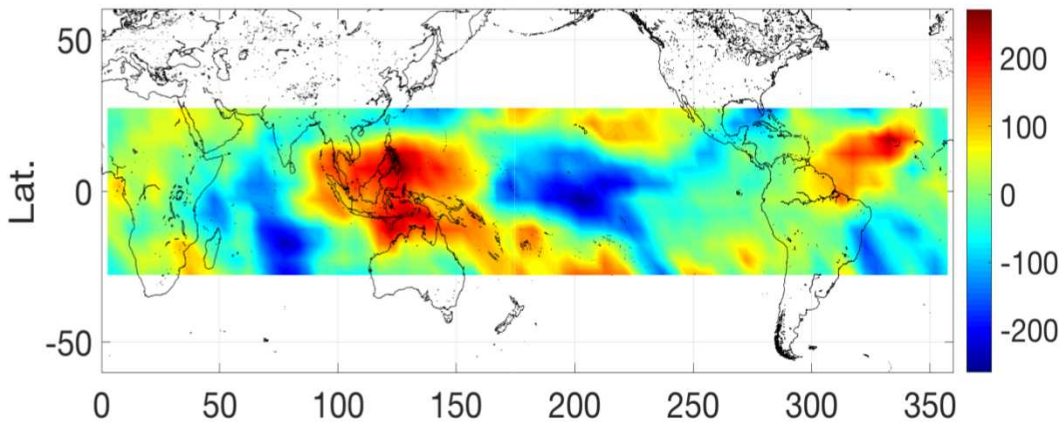




5x5 Degree Gridded Cloud Height Changes (2016 minus 2017) using PCRTM Retrieval and Spectral Fingerprinting

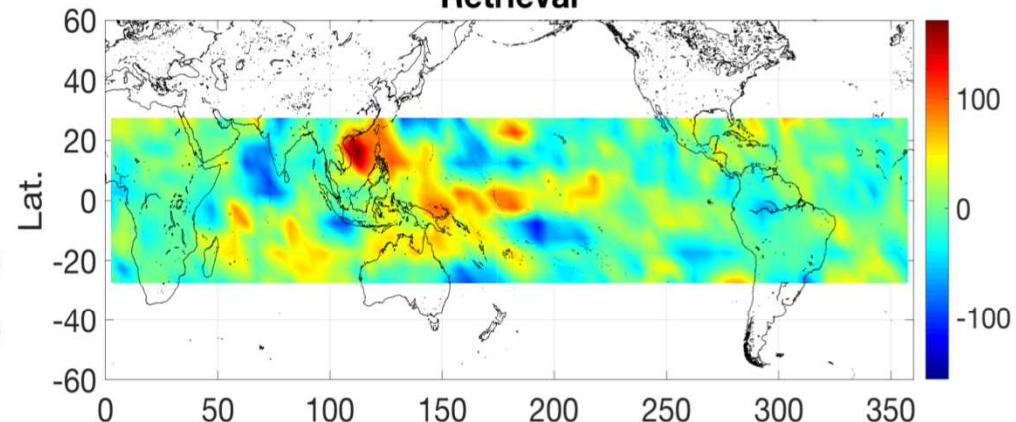
Cloud Effective Height Difference (2016-2017) for the month of January derived from CrIS/ATMS data

Retrieval

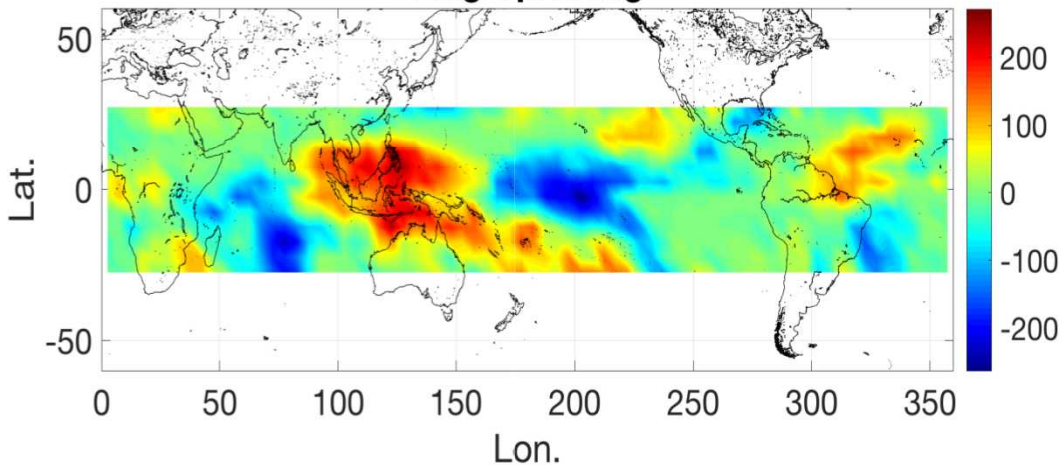


Cloud Effective Height Difference (2016-2017) for the month of July derived from CrIS/ATMS data

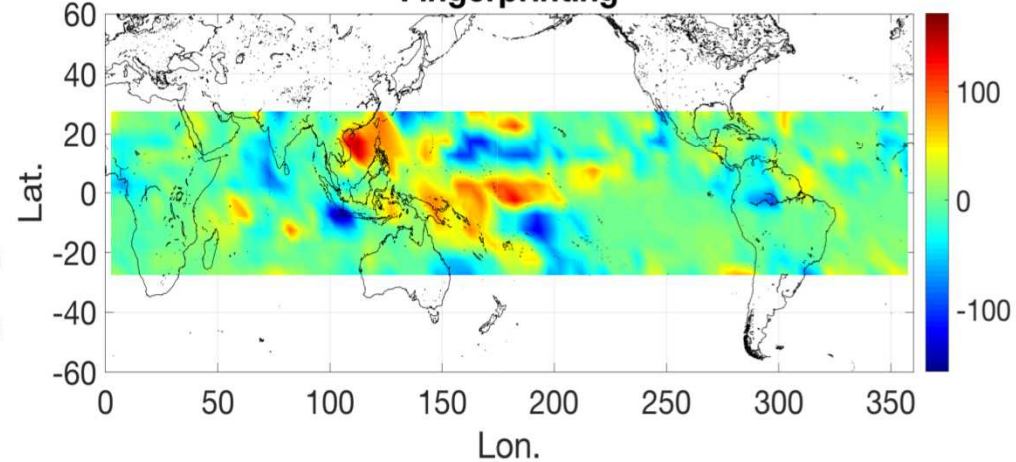
Retrieval

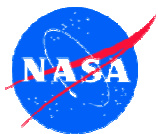


Fingerprinting

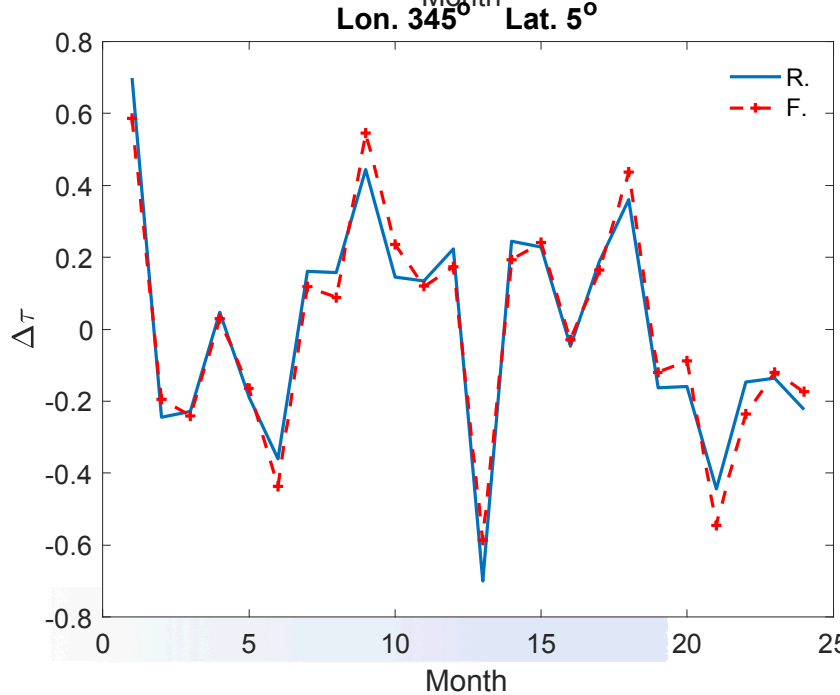
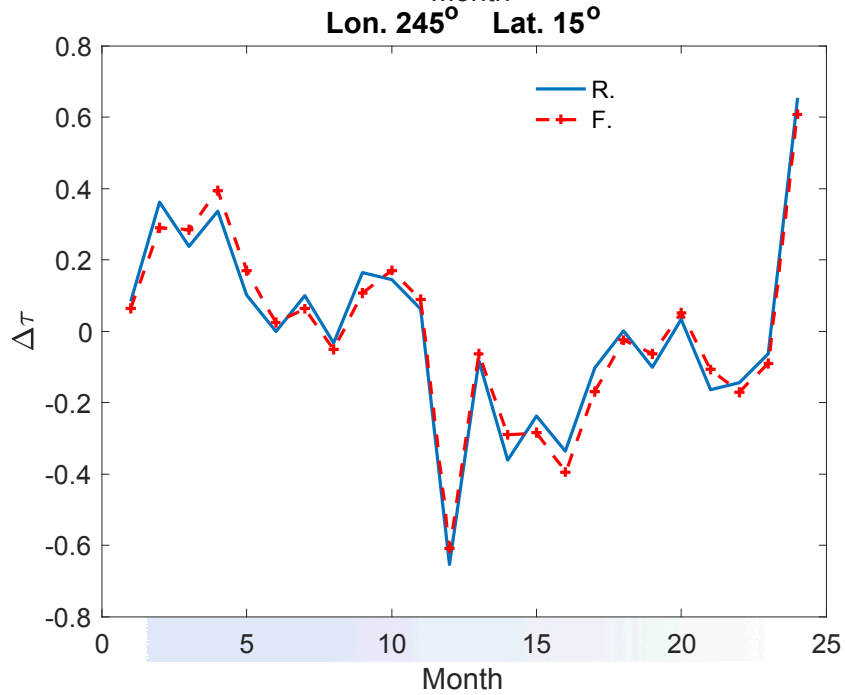
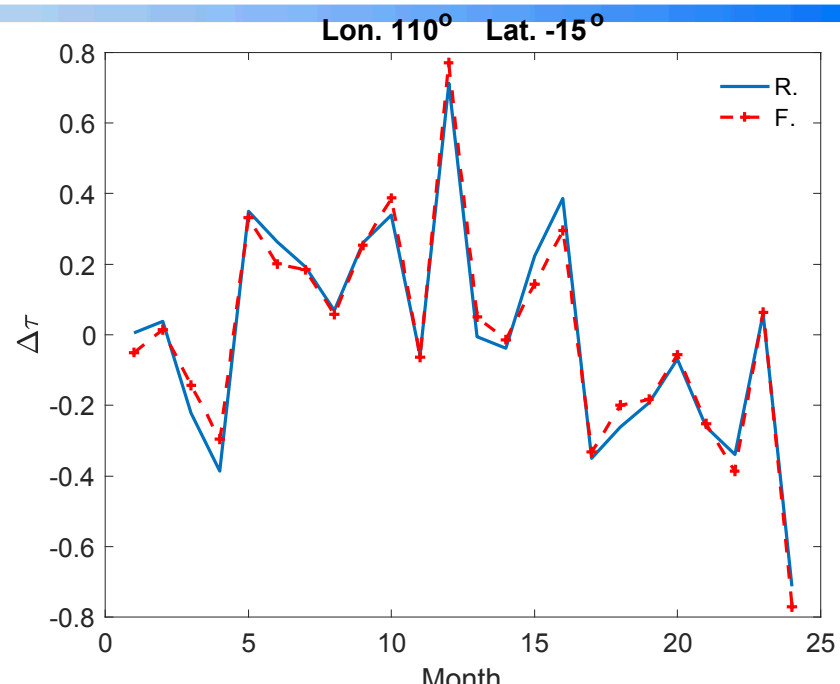
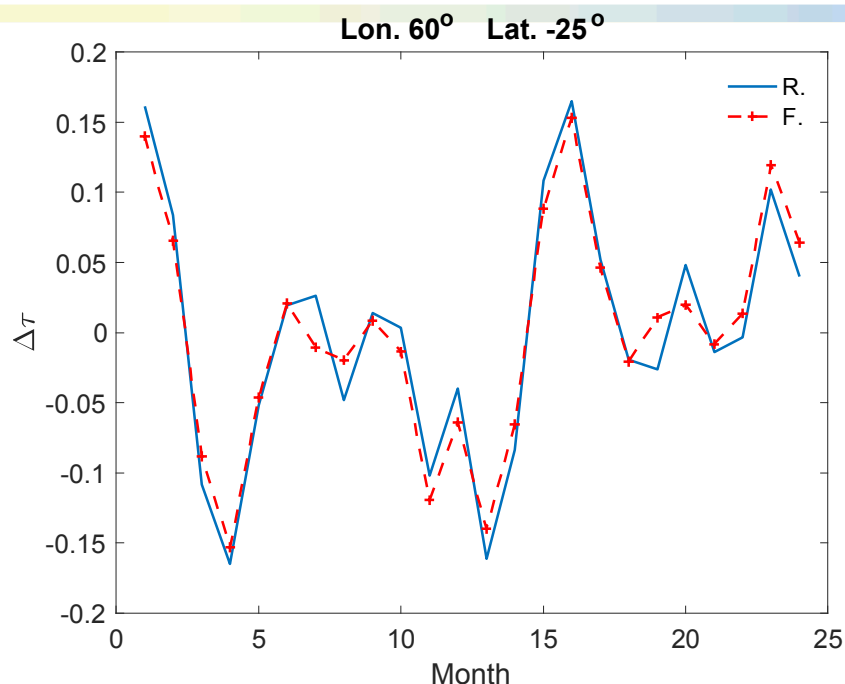


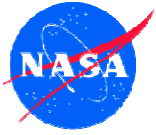
Fingerprinting



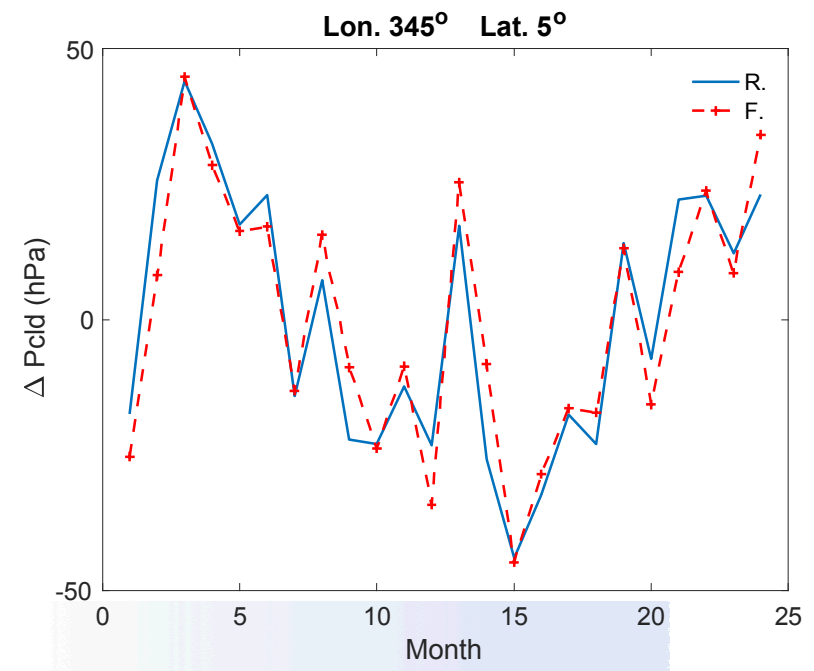
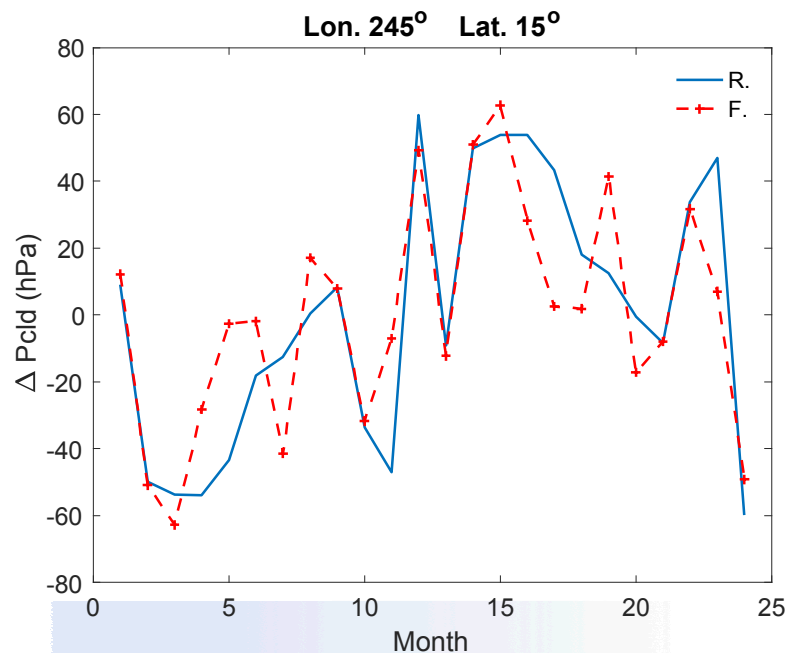
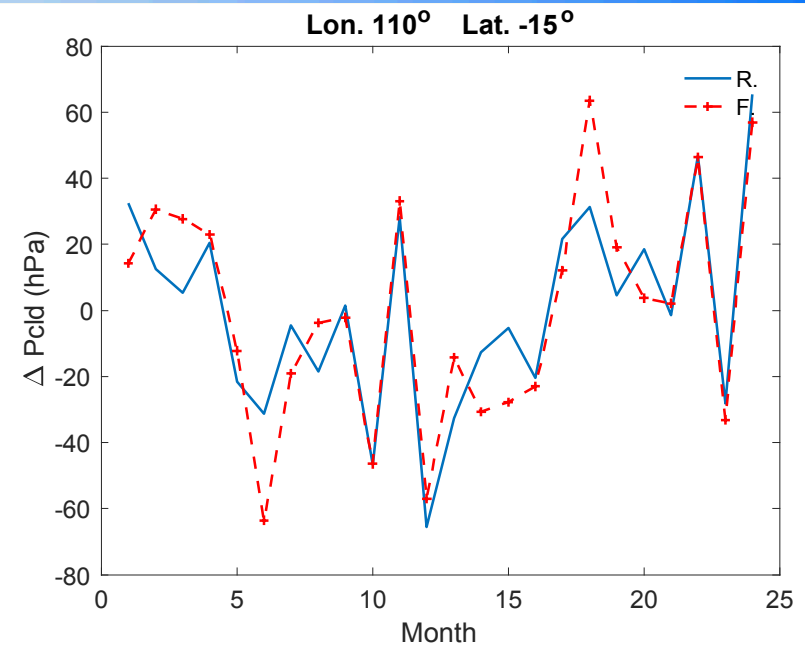
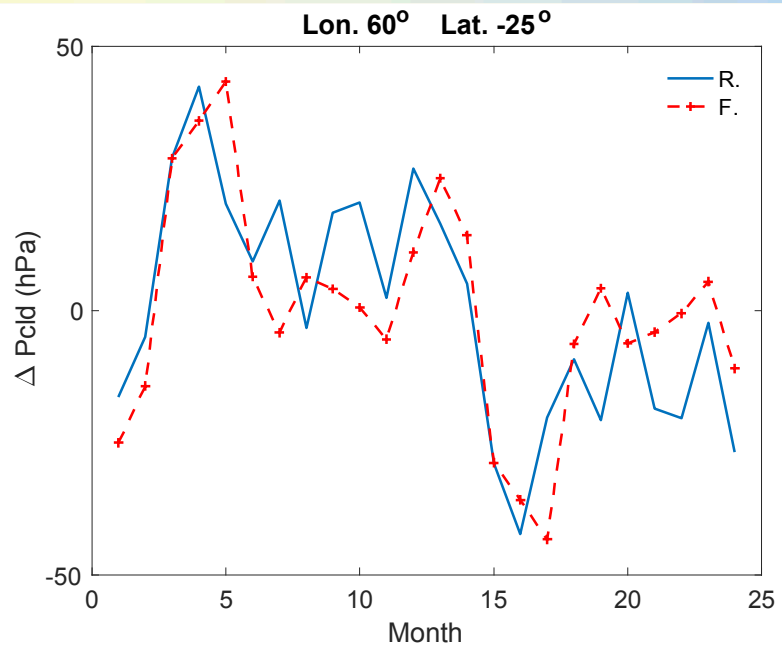


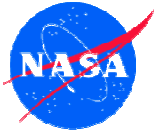
Cloud Optical Depth Anomaly (2016-2017) using PCRTM Single FOV Retrieval and Spectral Fingerprinting





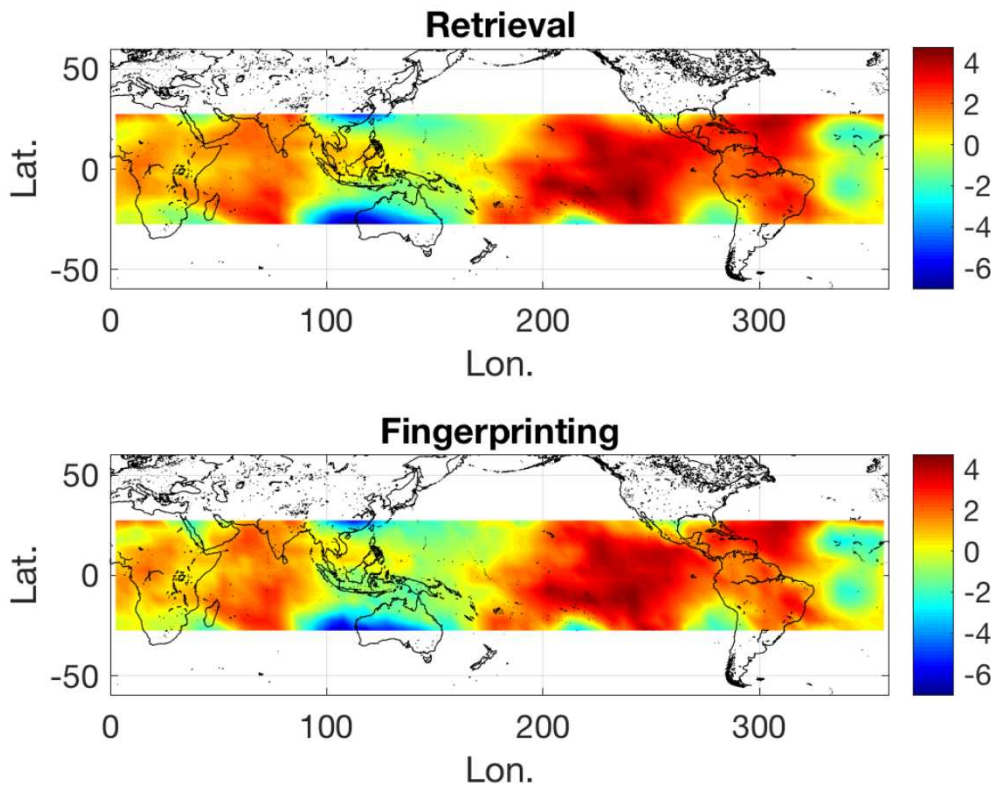
Cloud Height Anomaly (2016-2017) using PCRTM Single FOV Retrieval and Spectral Fingerprinting



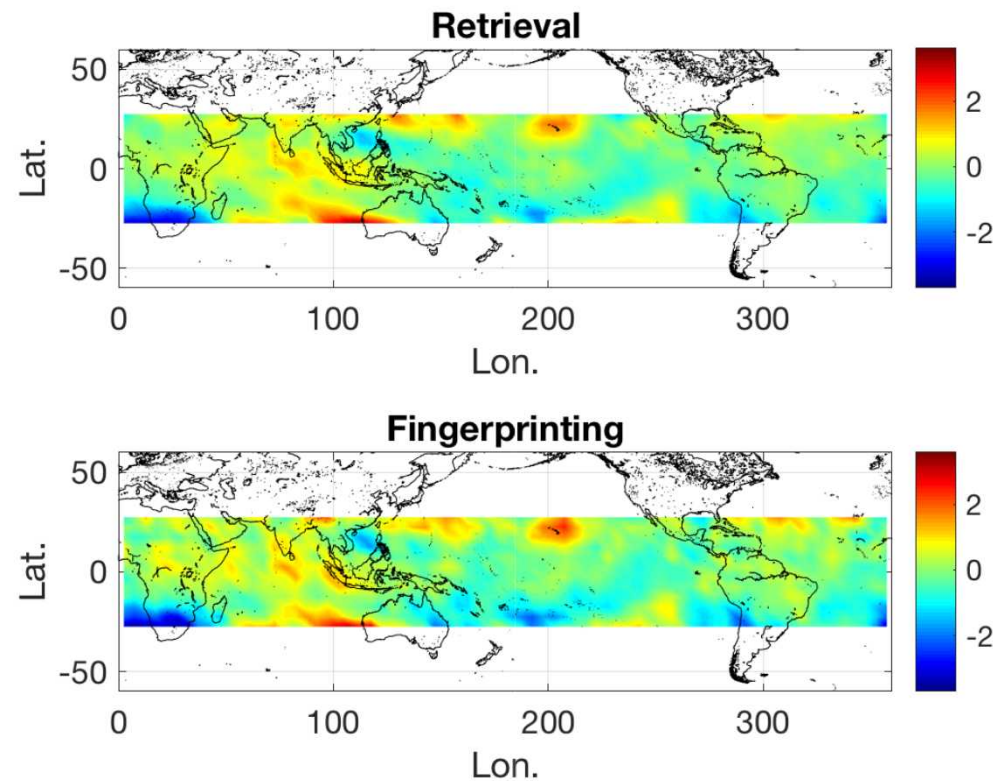


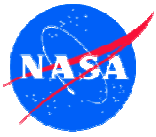
5x5 Degree Gridded Temp. Changes (2016 minus 2017) using PCRTM Retrieval and Spectral Fingerprinting

Δ Temp. @300 hPa (2016-2017) for the month of January derived from CrIS/ATMS data



Δ Temp. @300 hPa(2016-2017) for the month of July derived from CrIS/ATMS data



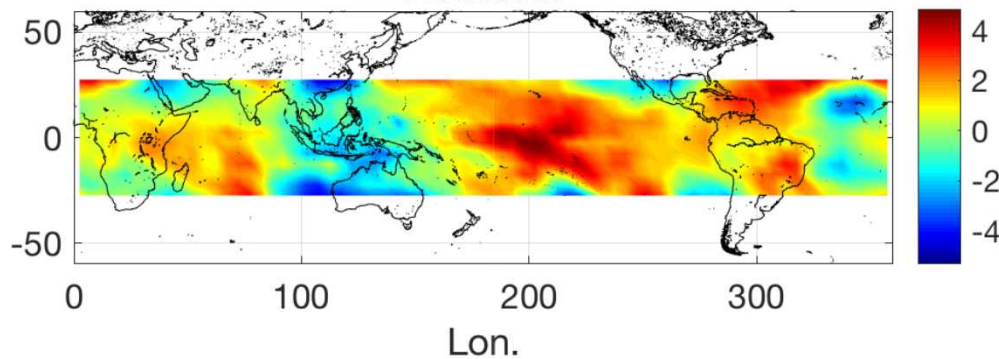


5x5 Degree Gridded Temp. Changes (2016 minus 2017) using PCRTM Retrieval and Spectral Fingerprinting

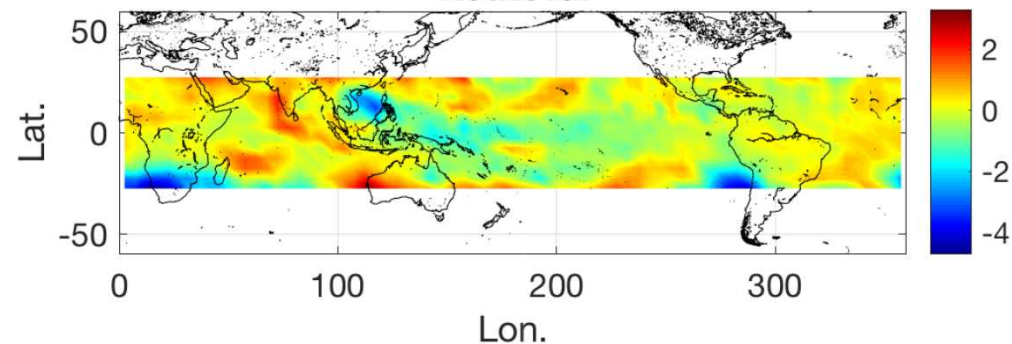
Δ Temp. @500 hPa (2016-2017) the month of January derived from CrIS/ATMS data

Δ Temp. @500 hPa ((2016-2017) for the month of July derived from CrIS/ATMS data

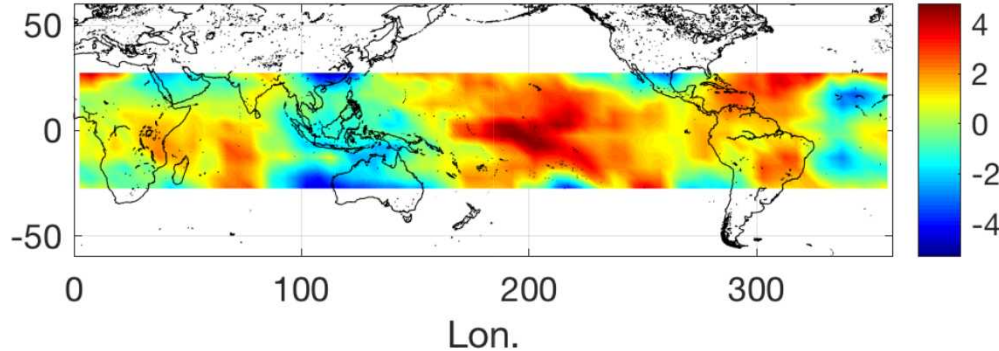
Retrieval



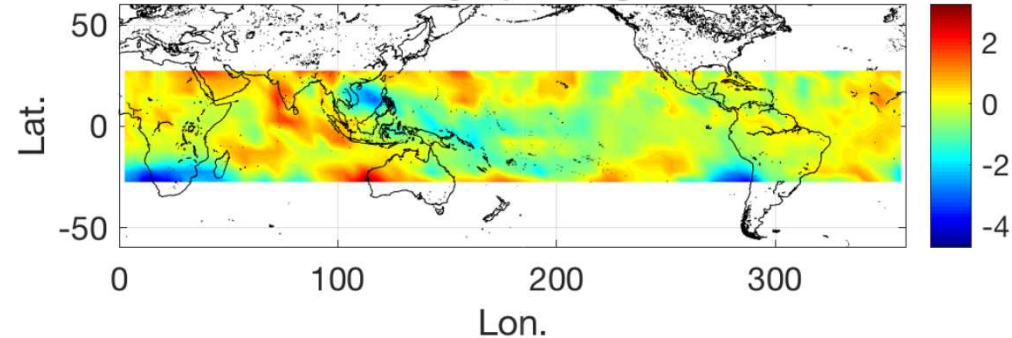
Retrieval

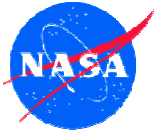


Fingerprinting



Fingerprinting



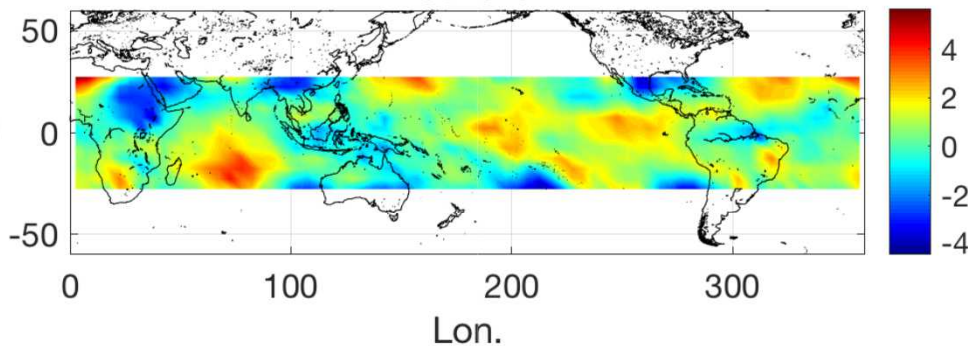


5x5 Degree Gridded Temp. Changes (2016 minus 2017) using PCRTM Retrieval and Spectral Fingerprinting

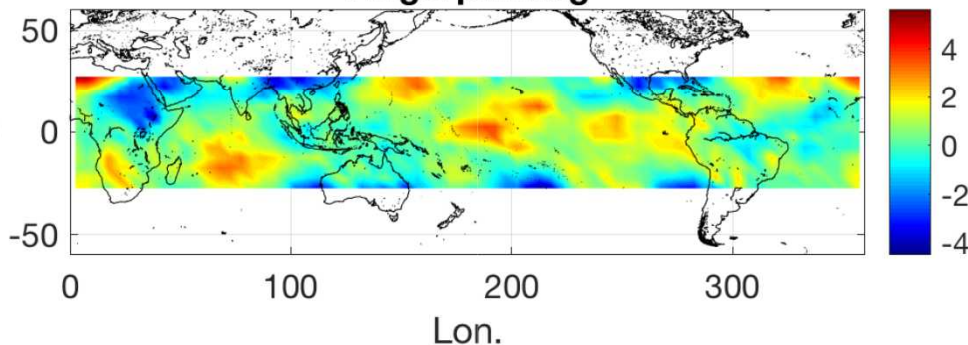
Δ Temp. @800 hPa (2016-2017) the month of January derived from CrIS/ATMS data

Δ Temp. @800 hPa ((2016-2017) for the month of July derived from CrIS/ATMS data

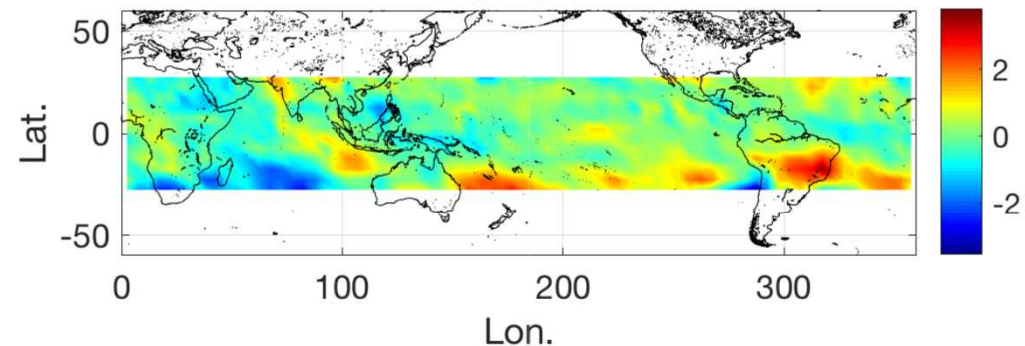
Retrieval



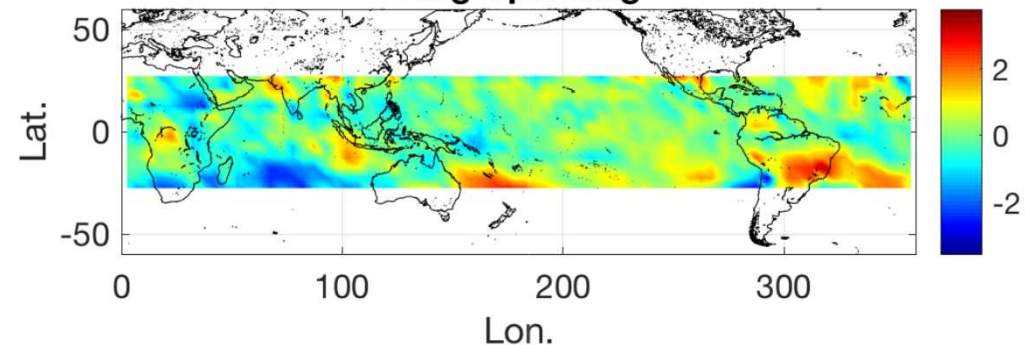
Fingerprinting

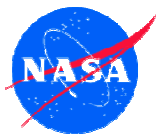


Retrieval

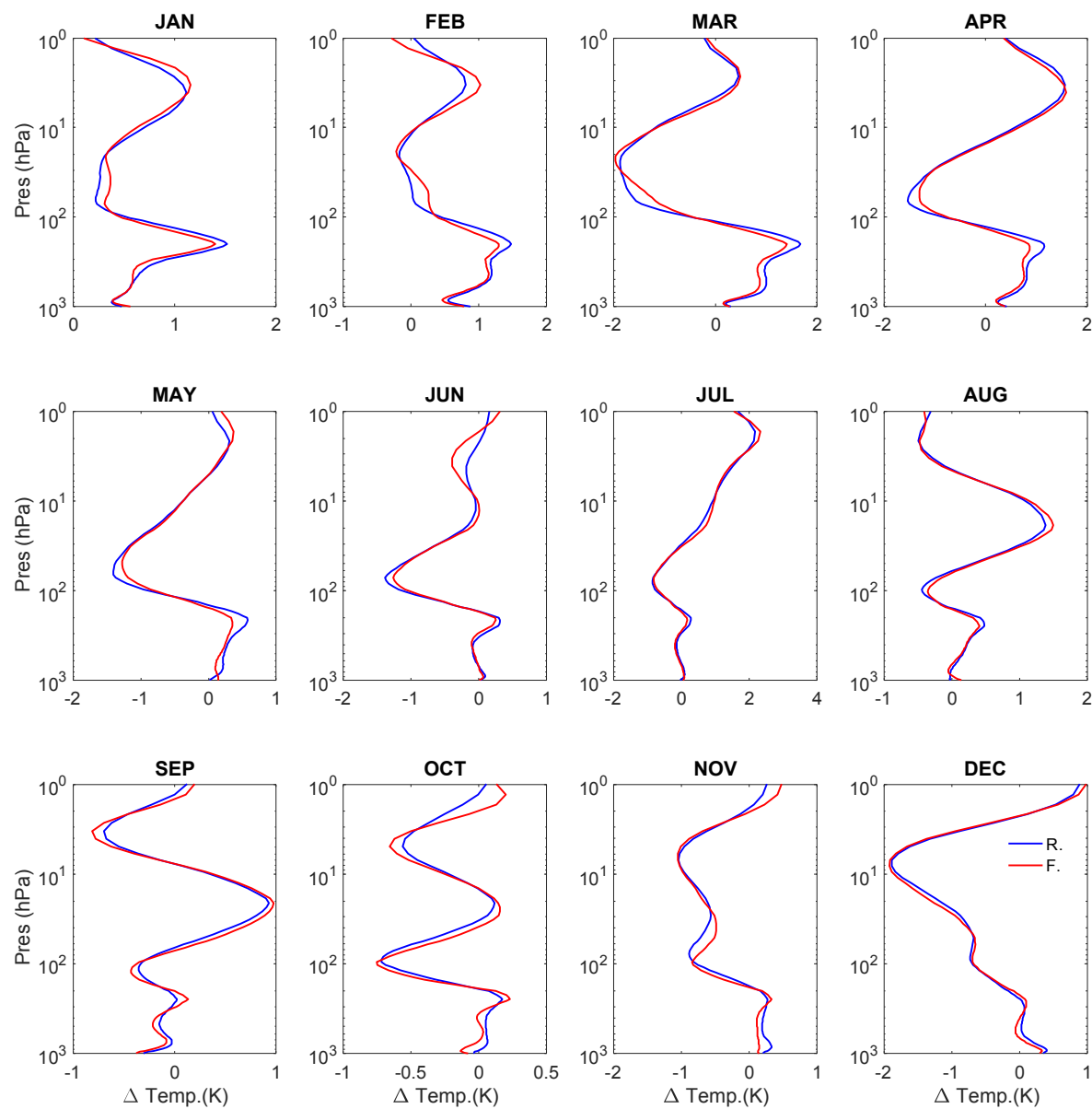


Fingerprinting



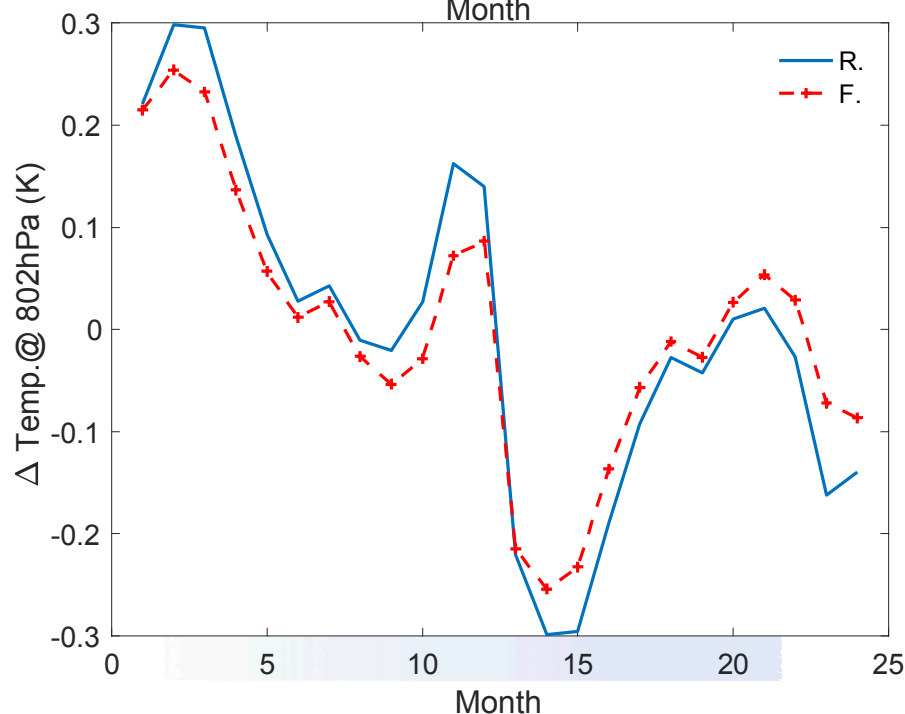
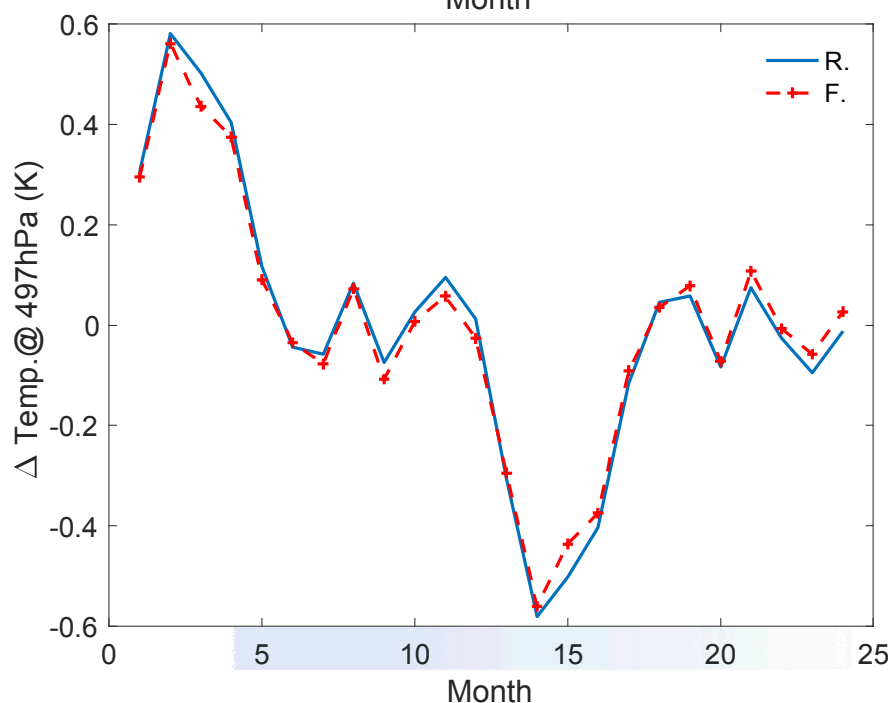
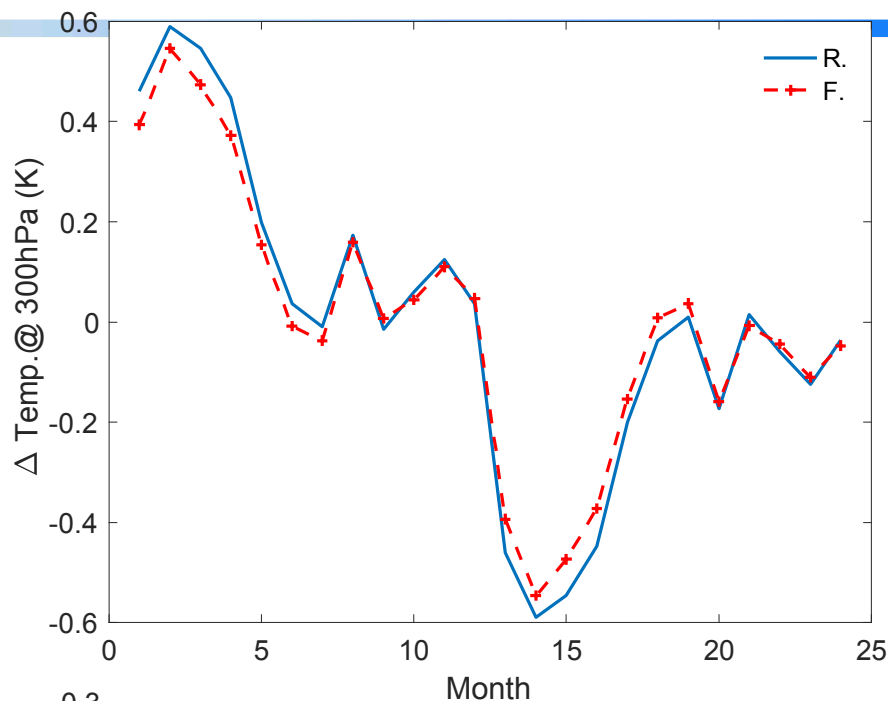
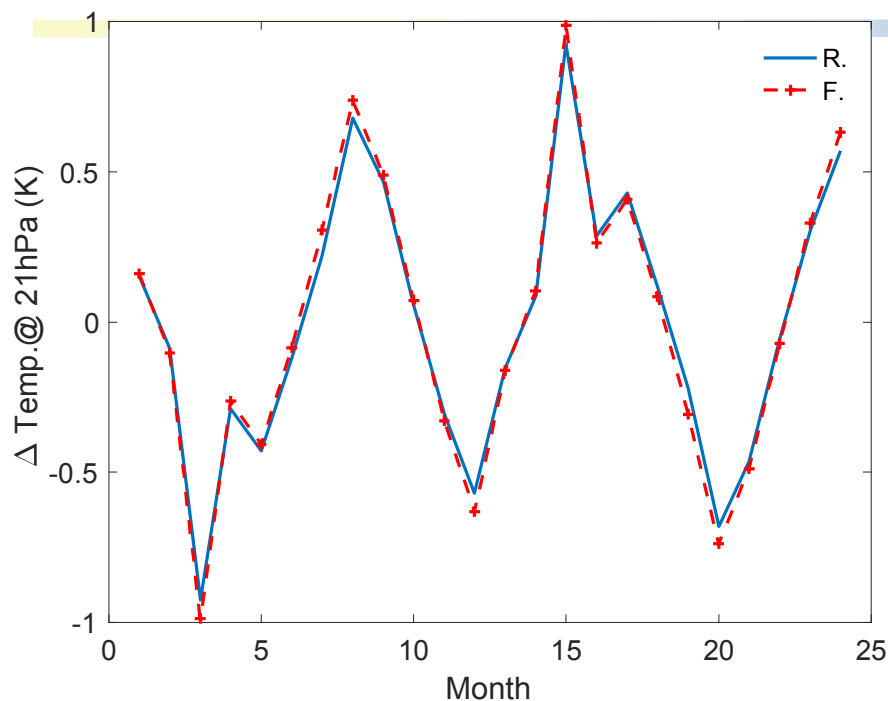


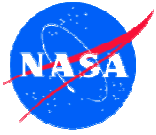
2016 minus 2017 Tropical Region Temp. Change (Zonal and Monthly averaged)





Tropical Region Temp. Anomaly 2016~2017 (zonally averaged after 5x5 degree grid binning)

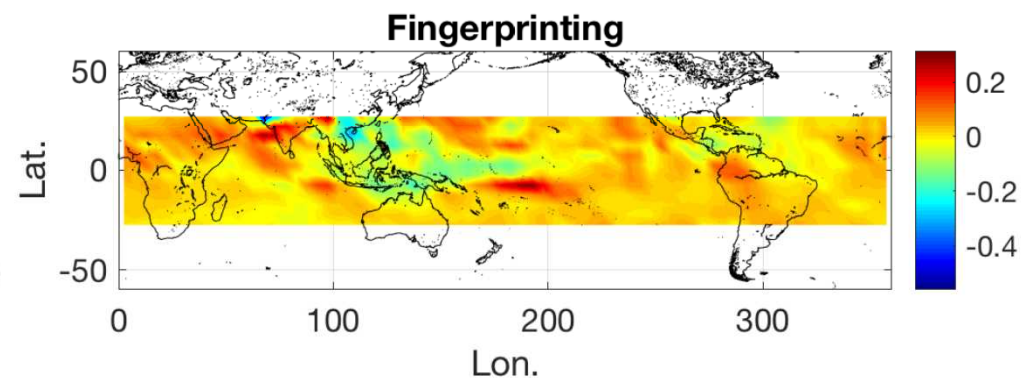
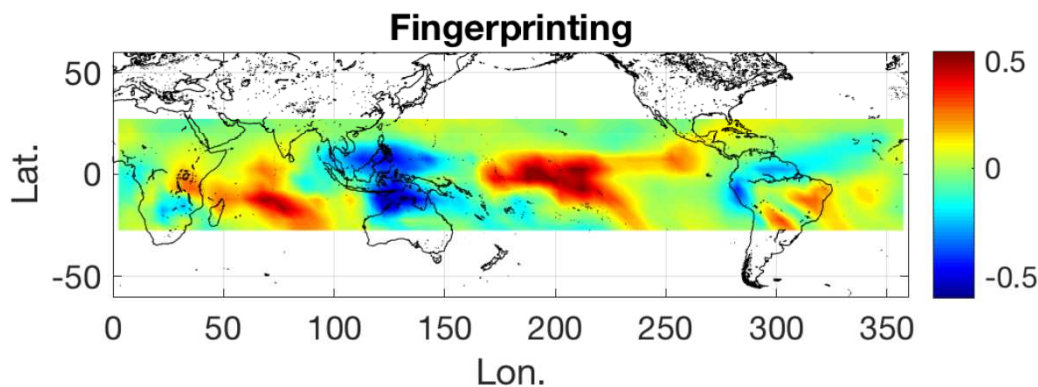
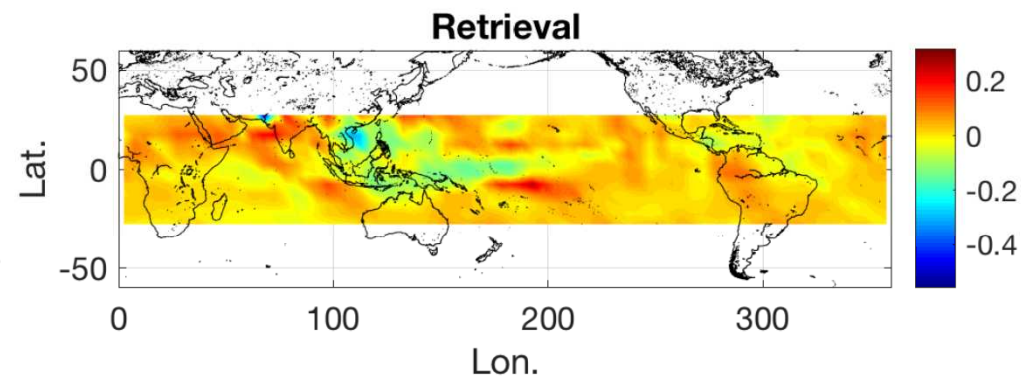
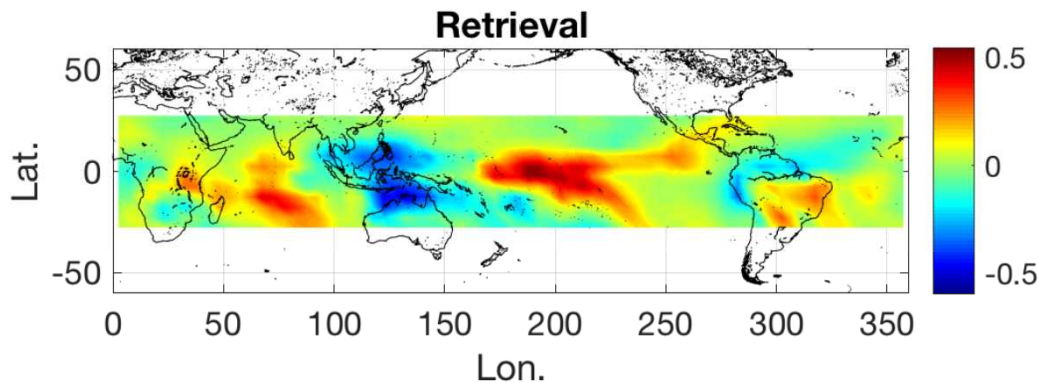


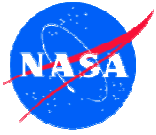


5x5 Degree Gridded H₂O Changes (2016 minus 2017) using PCRTM Retrieval and Spectral Fingerprinting

$\Delta\text{H}_2\text{O}$ (g/kg) @300 hPa (2016-2017) the month of January derived from CrIS/ATMS data

$\Delta\text{H}_2\text{O}$ (g/kg) @300 hPa ((2016-2017) for the month of July derived from CrIS/ATMS data



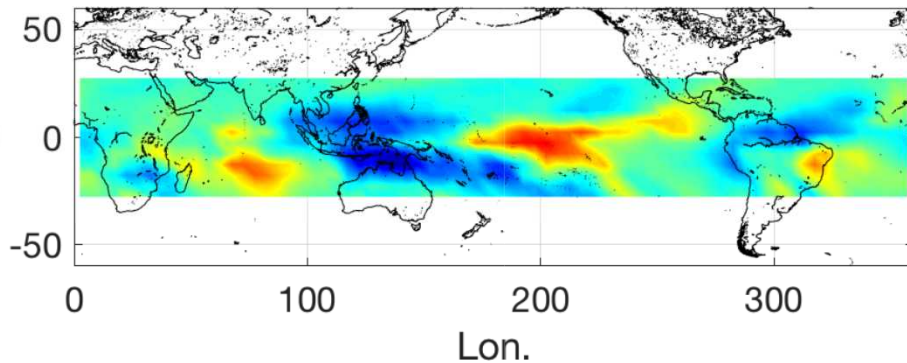


5x5 Degree Gridded H₂O Changes (2016 minus 2017) using PCRTM Retrieval and Spectral Fingerprinting

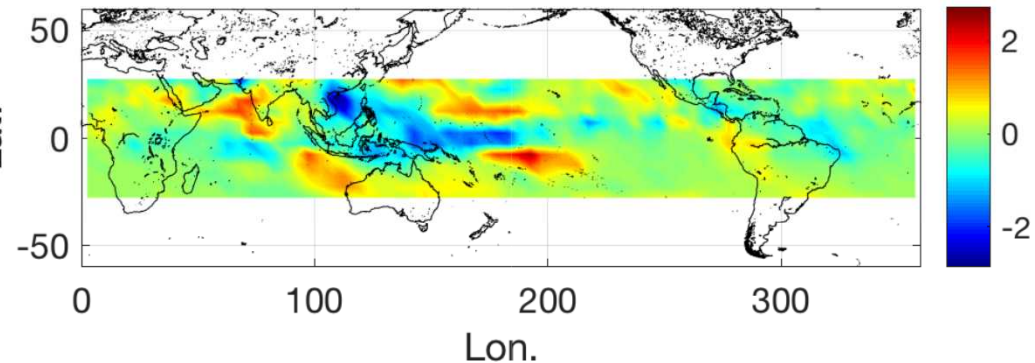
$\Delta\text{H}_2\text{O}$ (g/kg) @500 hPa (2016-2017) the month of January derived from CrIS/ATMS data

$\Delta\text{H}_2\text{O}$ (g/kg) @500 hPa ((2016-2017) for the month of July derived from CrIS/ATMS data

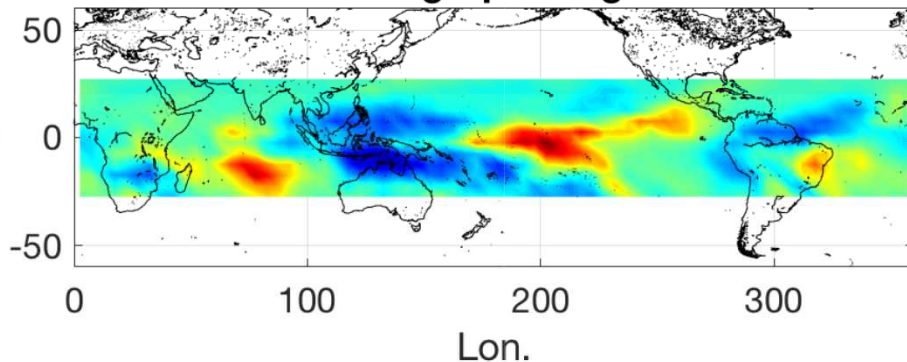
Retrieval



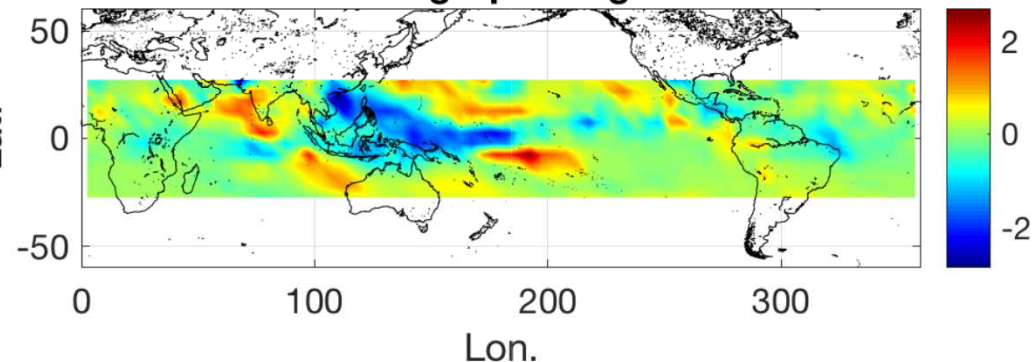
Retrieval

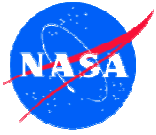


Fingerprinting



Fingerprinting

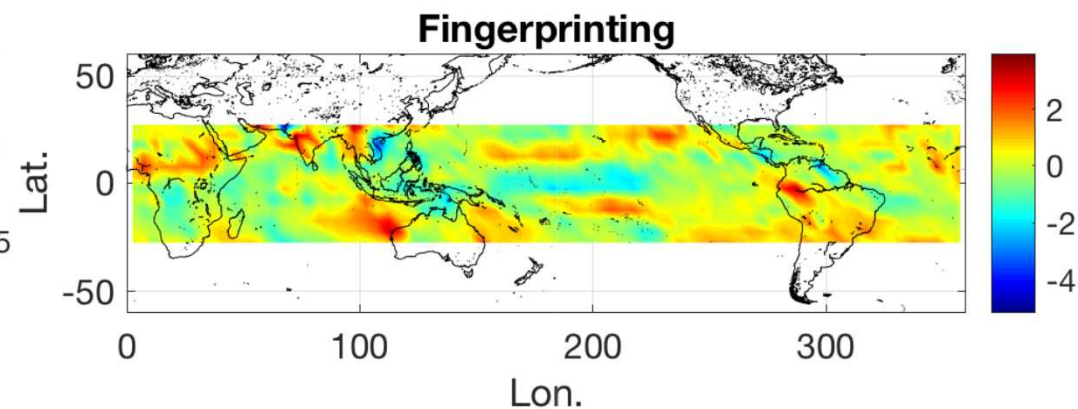
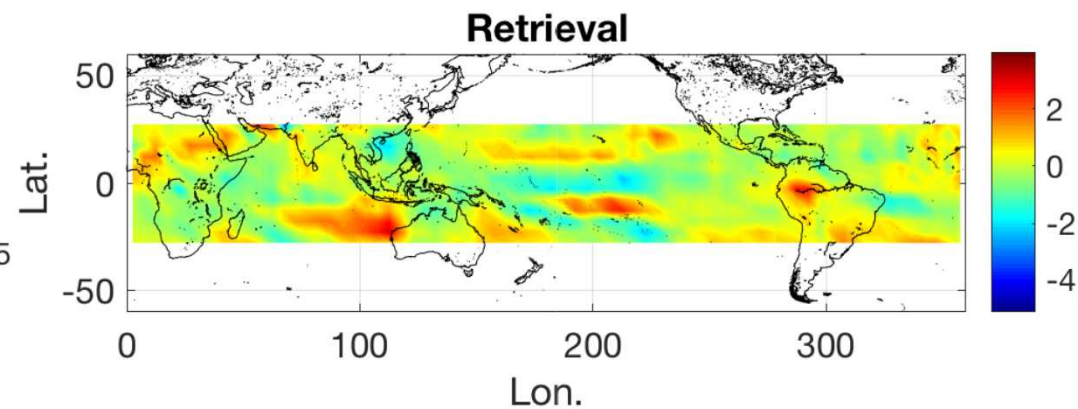
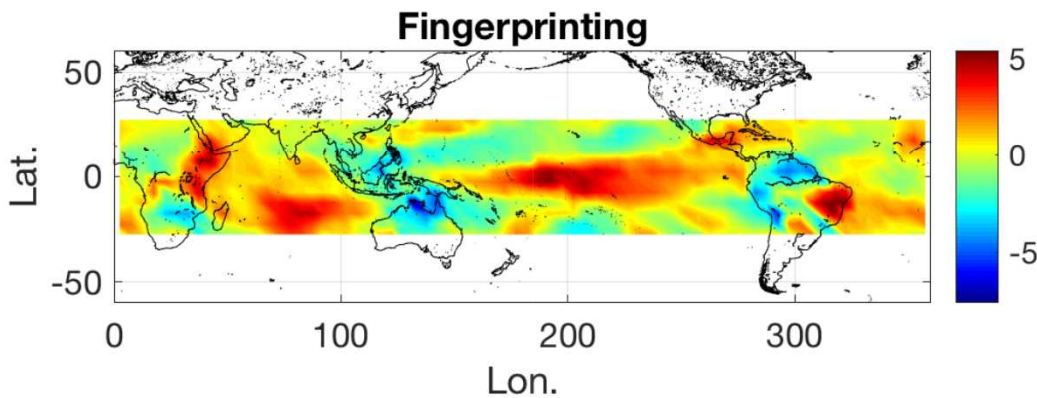
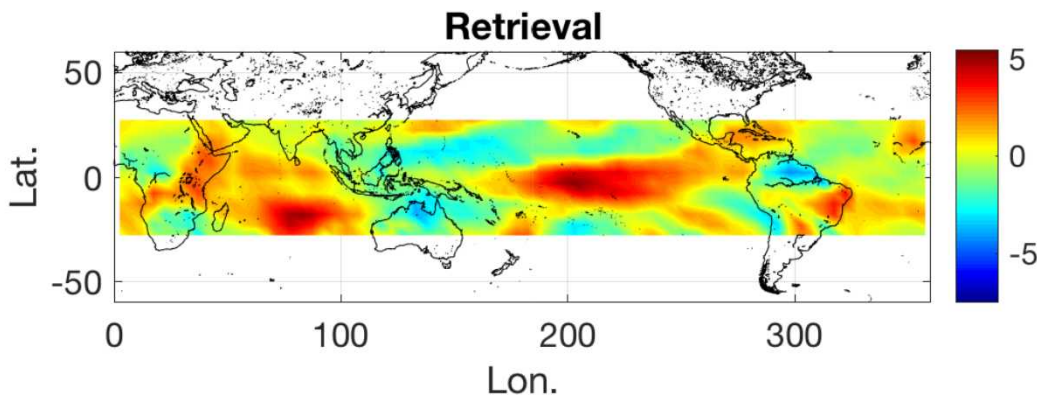


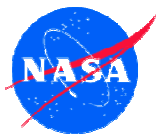


5x5 Degree Gridded H₂O Changes (2016 minus 2017) using PCRTM Retrieval and Spectral Fingerprinting

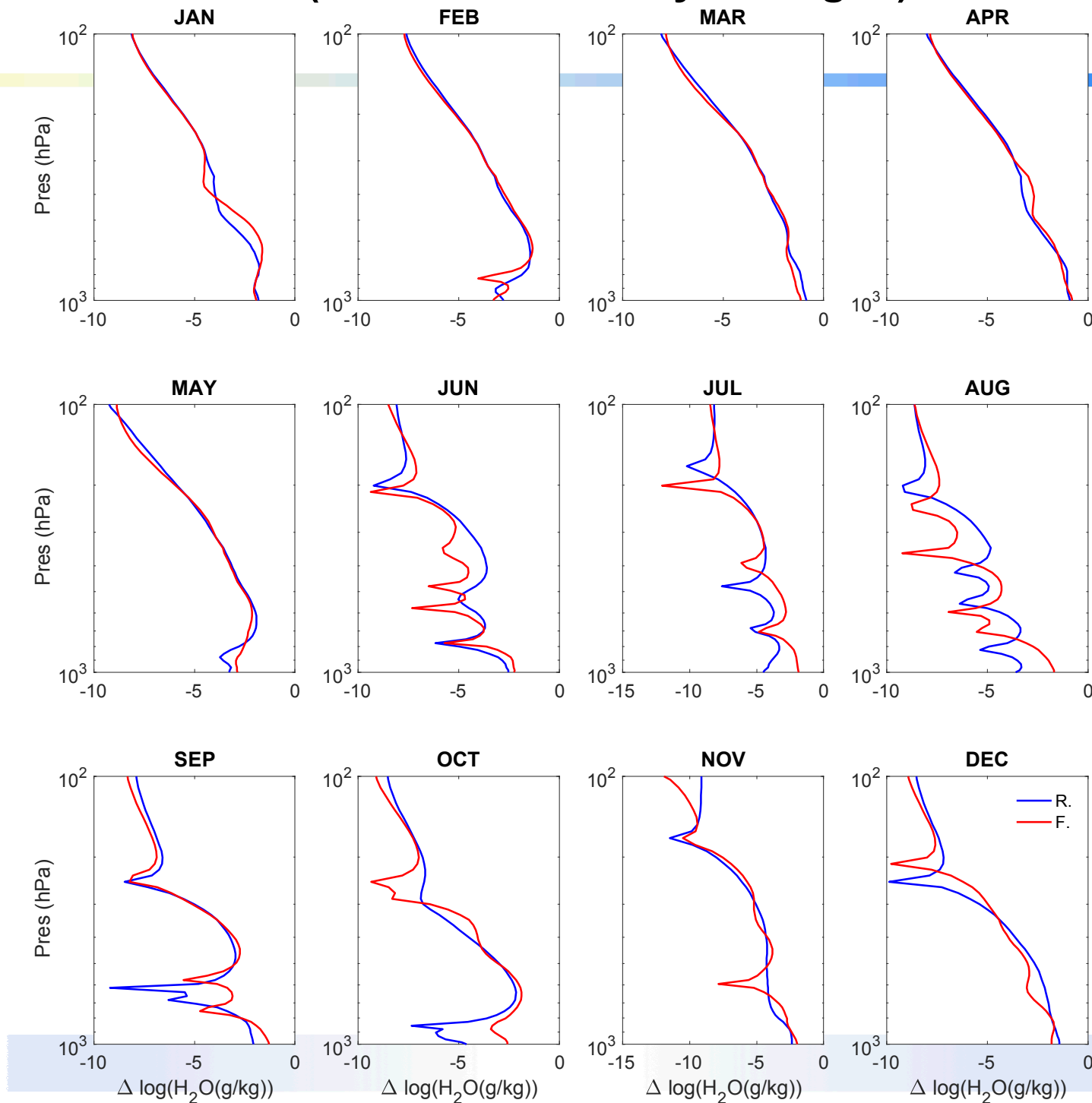
$\Delta\text{H}_2\text{O}$ (g/kg) @800 hPa (2016-2017) the month of January derived from CrIS/ATMS data

$\Delta\text{H}_2\text{O}$ (g/kg) @800 hPa ((2016-2017) for the month of July derived from CrIS/ATMS data



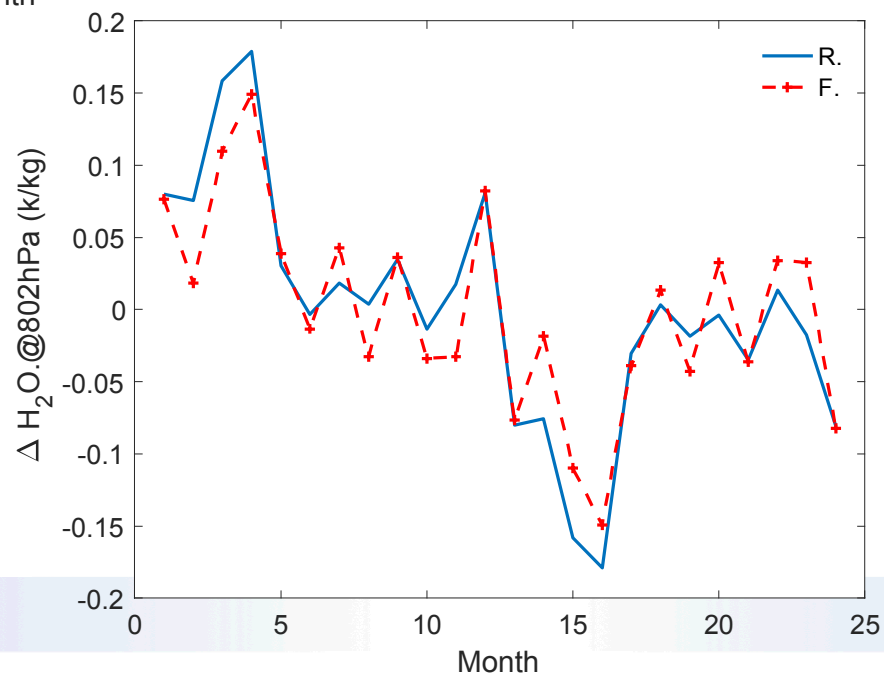
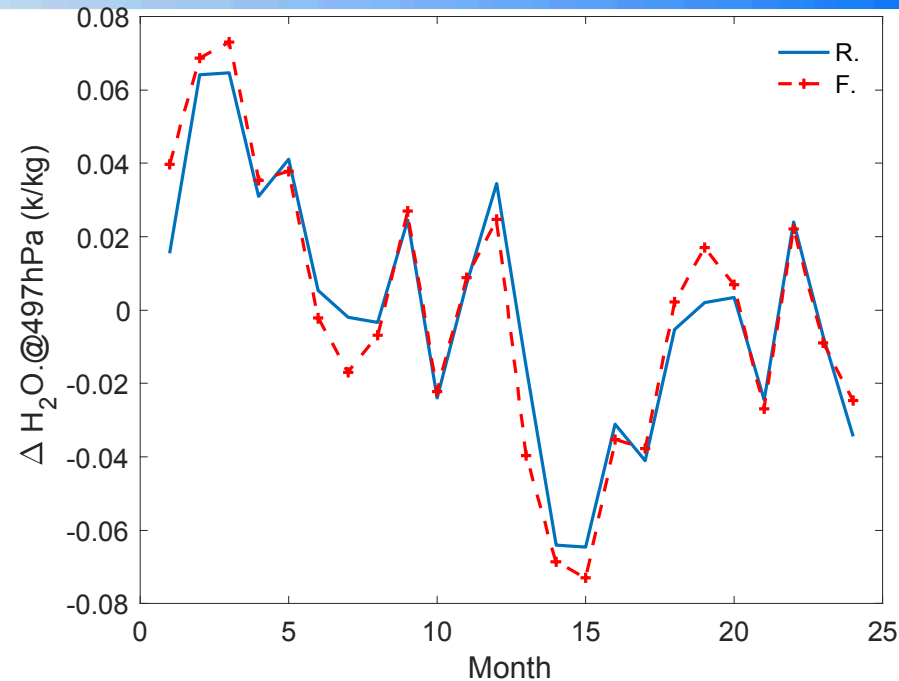
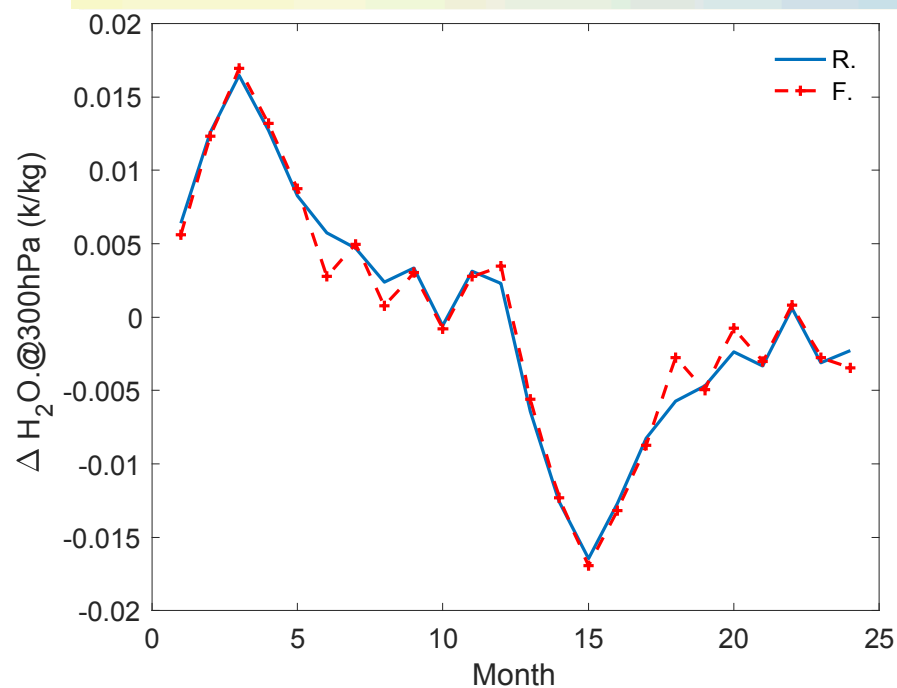


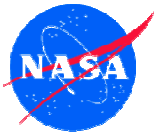
2016-2017 Tropical Region Water Vapor Change (Zonal and Monthly averaged)





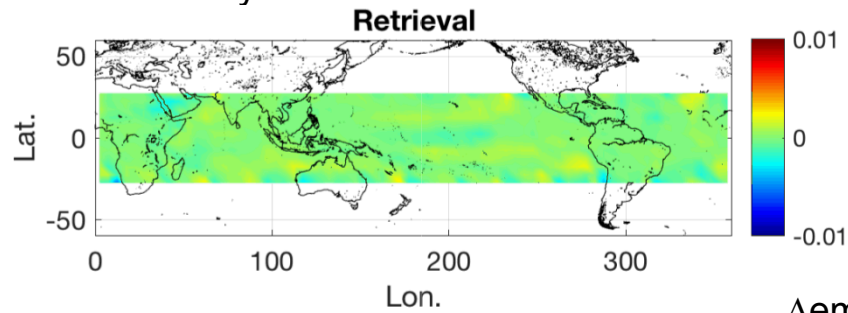
Tropical Region Water Vapor Anomaly at different altitudes 2016~2017



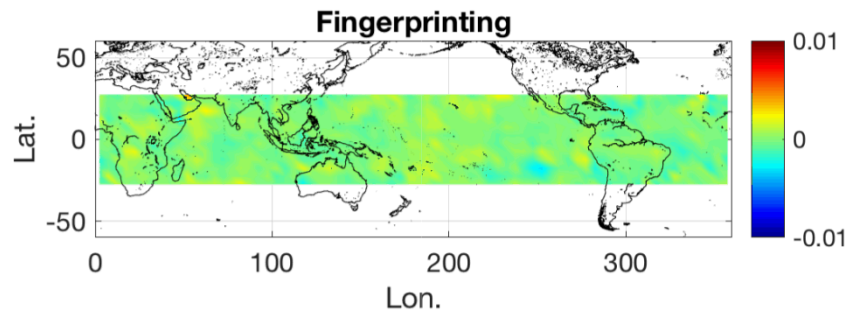


5x5 Degree Gridded Emissivity Changes (2016 minus 2017) using PCRTM Retrieval and Spectral Fingerprinting

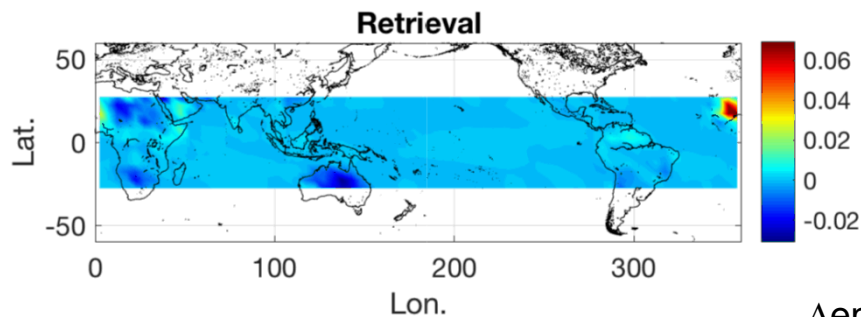
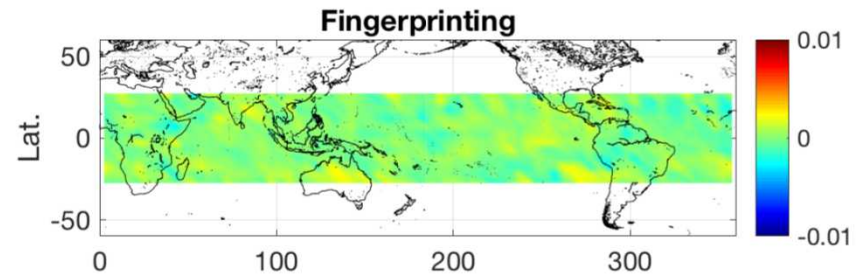
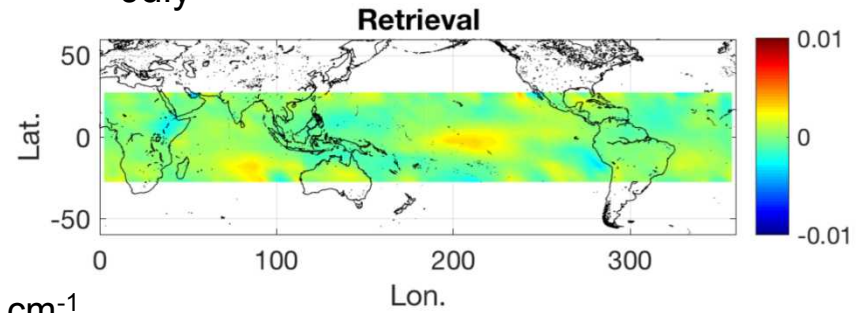
January



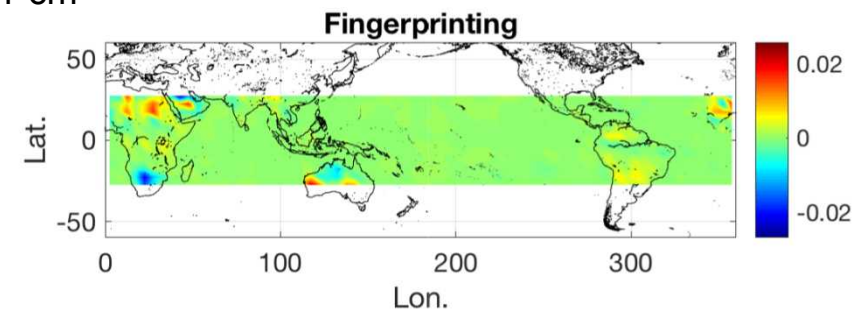
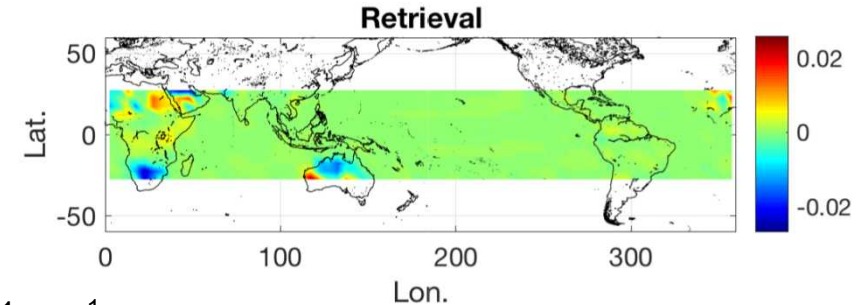
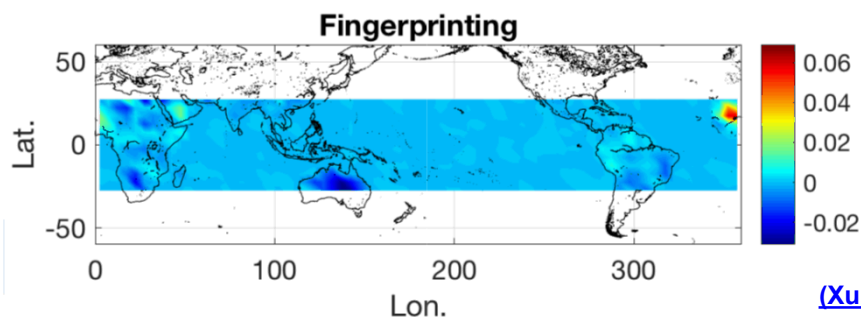
$\Delta\text{emis @721 cm}^{-1}$

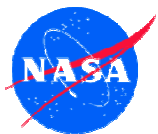


July

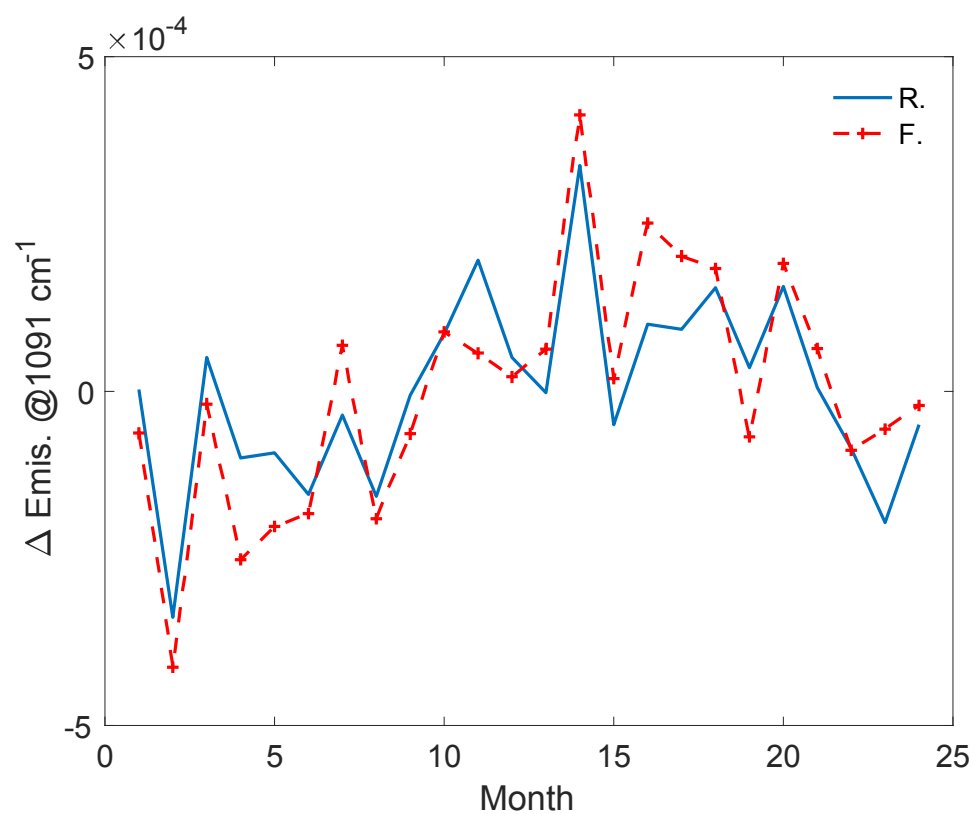
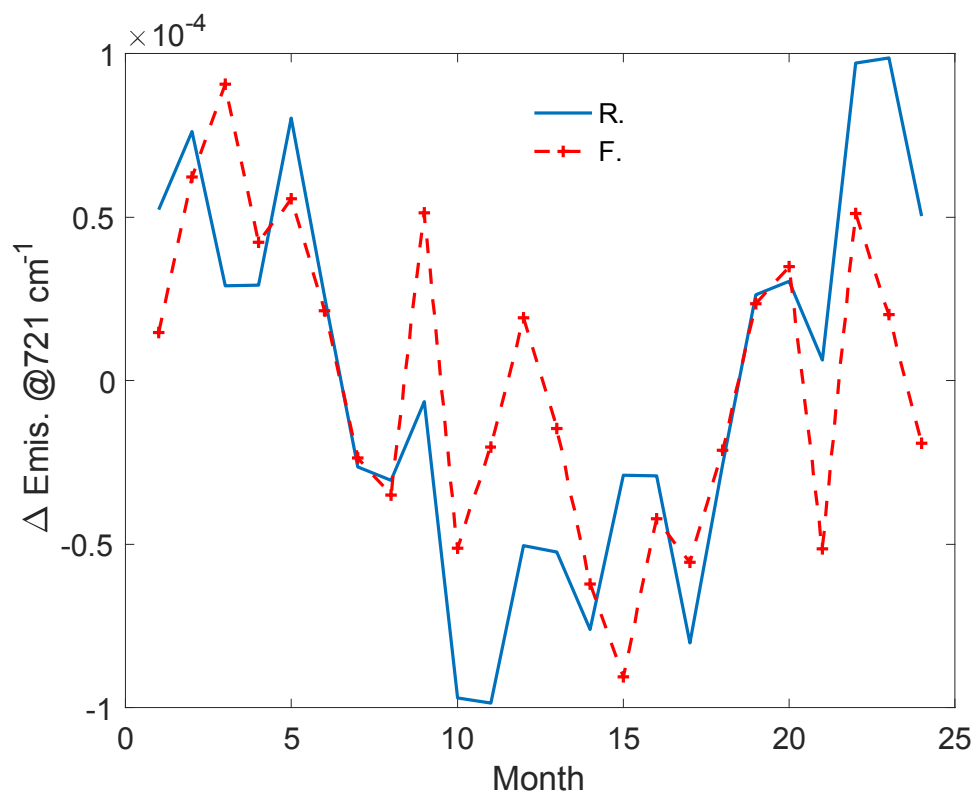


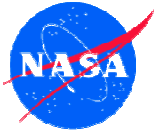
$\Delta\text{emis @1091 cm}^{-1}$





Tropical Region Surface Emissivity Anomaly 2016~2017





Summary and Future Work

- Single FOV PCRTM retrieval algorithm has been applied to CrIS/ATMS data
 - Processed tropical region for 2016-2017 and part of 2014
 - Atmospheric Temperature, Water, CO₂, CO, CH₄, O₃, and N₂O profiles
 - Cloud phase, height, temperature, size, optical depth
 - Surface emissivity spectrum and skin temperature
 - Anomaly studies done on averaged gridded data for all retrieved geophysical parameters
- Spectral fingerprinting done on gridded radiance anomaly data
 - Radiative kernel derived from CrIS/ATMS data using PCRTM
 - Consistent with radiance anomaly linearization point
- Spatial and temporal variability of derived temperature, water vapor, and cloud anomalies agree well between the PCRTM single FOV retrieval and spectral fingerprinting methods
 - Radiative kernels derived from CrIS/ATMS data using PCRTM are great
 - Consistent with radiance anomaly linearization point
- Future work
 - Continue to study the details of the results
 - Extend to all CrIS time series and other latitudes
 - Extend the method to AIRS/AMSU data