A Radiometric Consistent Spectral Fingerprinting Algorithm for Continuity Products of Hyperspectral Sounders

Wan Wu[1], Xu Liu[2], Qiguang Yang[1], Hyun-Sung Jang[2], Daniel K. Zhou[2], Allen M. Larar[2]

[1] Science Systems and Applications, Inc, Hampton, VA, USA

[2] *NASA Langley Research Center, Hampton, VA, USA*

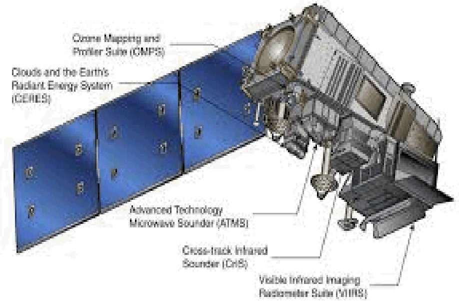
Outline

- Introduction of using multiple hyperspectral sounder measurements to derive Temp. and H_2O trend and anomaly continuity products
- Introduction of spectral fingerprinting methodology
- Demonstration of spectral fingerprinting using radiative kernels constructed from PCRTM physical retrieval results
- Validation of spectral fingerprinting results using individual retrieval results

Climate study using hyper-spectral sounder results

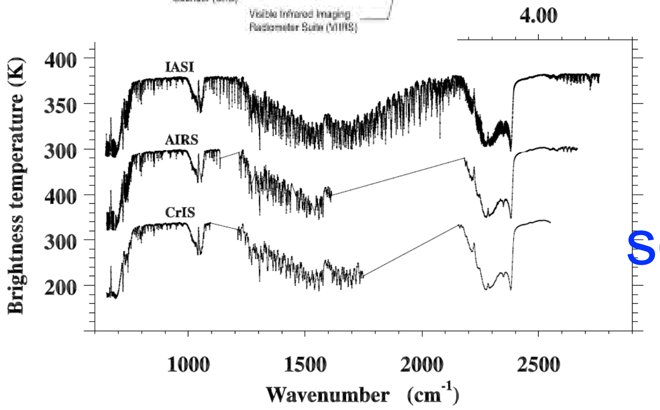
2002 -

2006 -

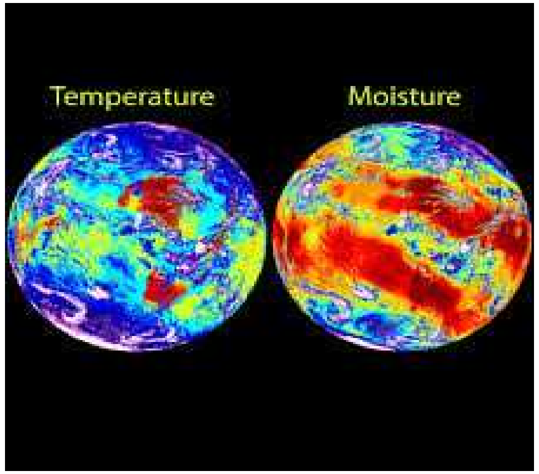


2012 -

- Spectral information of outgoing longwave radiation (OLR) can be utilized to discern the contributions of individual climate forcings to the total change of TOA radiation energy.
- Hyper-spectral sounders provide rich OLR spectral information. Existing missions have already achieved more than a decade long global scale observation. The continuity of those missions may eventually provide a data record long enough for climate trend study.
- Hyper-spectral sounders have been used for high vertical resolution sounding for temperature and moisture profiles, providing a means for better understanding the contribution of different atmosphere layer to climate change.



Growing need to assemble hyperspectral sounder data records for climate-scale studies



Retrieval-then-average vs Average-then-retrieval

Physical retrieval

Individual T OA radiances

Retrieval-then-average:

T and H_2O from individual retrieval

↓

Space and time avg. of T and H_2O

↓

Trends and anomalies of T and H_2O

- Individual retrieval algorithm for sounders have been developed
- Requires a lot of computational power and data storage space to process /reprocess the available data record.

Average-then-retrieval:

Space and time avg. of TOA radiances

↓

Trends and anomalies of radiances

↓

Spectral fingerprinting

Trends and anomalies of T and H_2O

- Requires minimal computational power and data storage space to process /reprocess the available data record.
- Fingerprinting algorithms for real sounder data application need to be developed

Spectral fingerprinting methodology

- Assumes a linear relationship between the change in climate variables and the introduced change in TOA spectral radiance within specified spatiotemporal scale

$$\boldsymbol{\Delta}\mathbb{R} = \boldsymbol{S\Delta\alpha} + \boldsymbol{\varepsilon}$$

$\boldsymbol{\Delta}\mathbb{R}$ - the radiance spectral fingerprints, $\boldsymbol{S}$ - radiative kernel,

$\boldsymbol{\Delta\alpha}$ - the change in climate variable, $\boldsymbol{\varepsilon}$ – nonlinearity residual.

- Attributes TOA spectral radiance change to the change in climate variable

$$\boldsymbol{\Delta\alpha} = (\boldsymbol{S}^{T}\boldsymbol{\Sigma}^{-1}\boldsymbol{S})\boldsymbol{S}^{T}\boldsymbol{\Sigma}^{-1}\boldsymbol{\Delta}\mathbb{R}$$

$\boldsymbol{\Sigma}$ - spectral fingerprints uncertainty, covariance of $\boldsymbol{\varepsilon}$

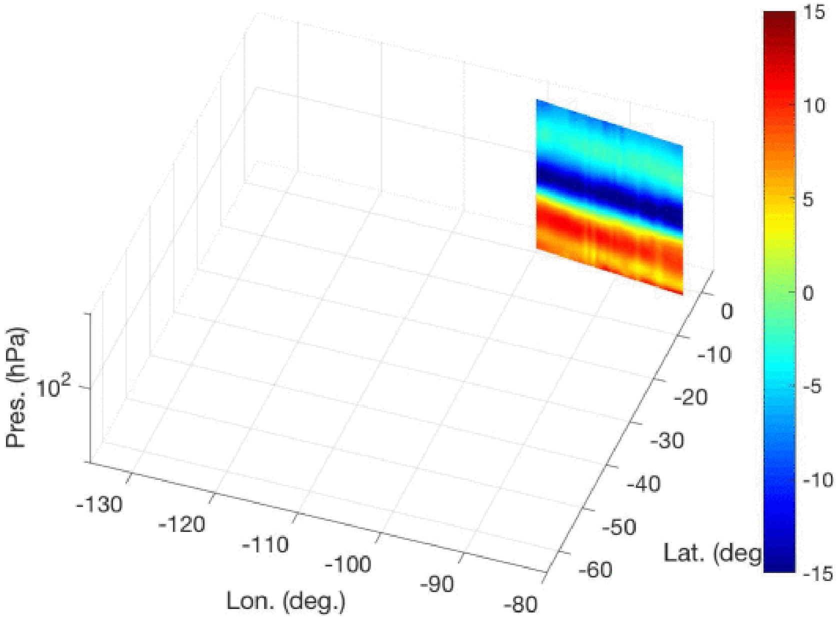
Spectral fingerprinting challenges

- Requires complicated radiative kernels $\boldsymbol{S}$ to account for contributions from major climate variables including temperature, water vapor, surface properties, trace gases, and clouds
- Need to ensure the 'radiance closure'

$\boldsymbol{S}$ is not readily available, The radiative kernel based on climate models may not match the real satellite observation (Pan et al. 2015)

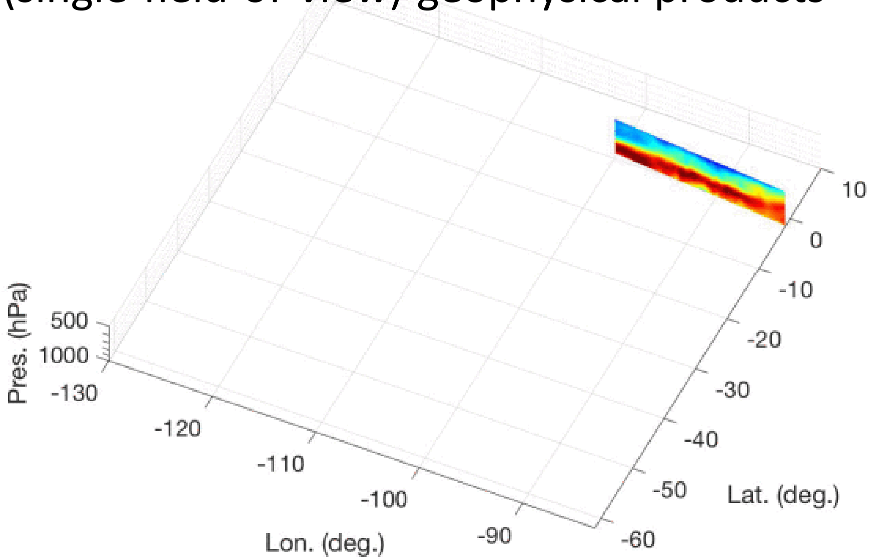
Pan, F., X. Huang, L.L. Strow, and H. Guo, 2015: Linear Trends and Closures of 10-yr Observations of AIRS Stratospheric Channels,. *J. Climate,* 28, 8939–8950

PCRTM based single FOV Physical retrieval algorithm



- Is based on principal component based radiative transfer model (PCRTM) that incorporates multiple scattering calculations into simulations under cloudy sky condition, uses optimally designed ‘super channels’ to reduce computational cost, outputs Jacobian along with hyper-spectral radiances
- Is a physical retrieval algorithm that retrieves atmospheric profiles, surface properties, and cloud height and microphysical properties simultaneously
- Fits spectral radiance of all channels directly without using the ‘cloud clearing‘
- Provides high spatial resolution(single-field-of-view) geophysical products

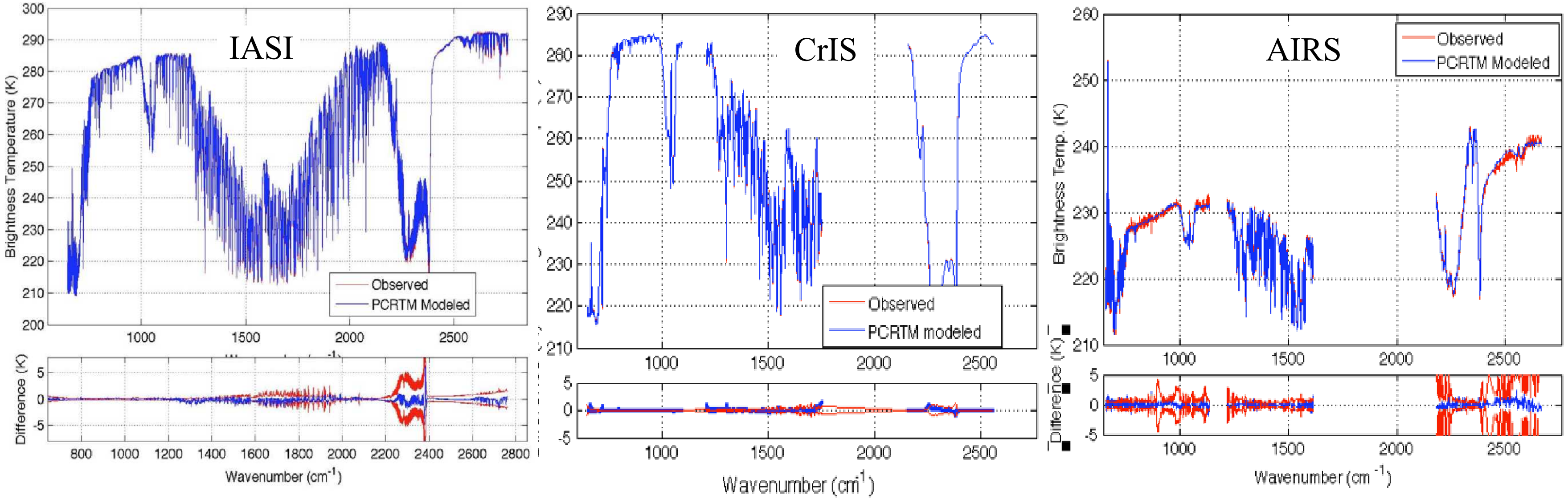
Retrieved Atmospheric Temp. and Relative Humidity from combined CrIS/ATMS(12/21/2015) observations using PCRTM algorithm



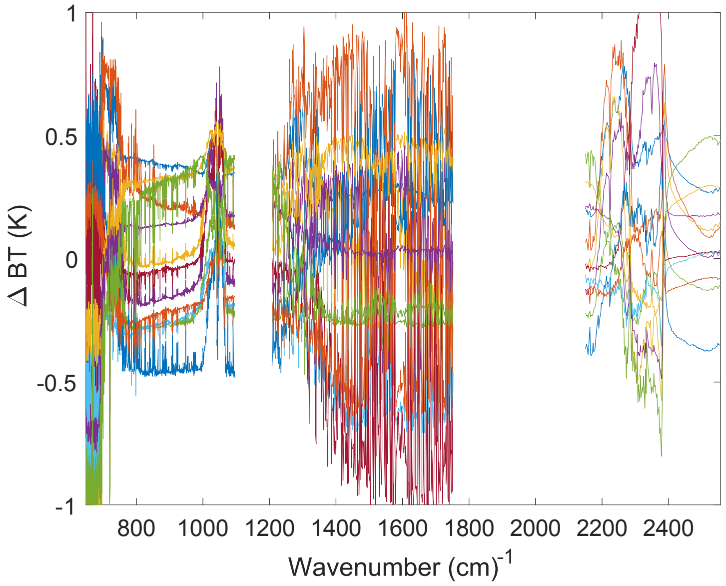
– Geophysical products can be gridded to obtain anomalies for climate change studies
– The application for different hyper-spectral sounders (AIRS, IASI, CrIS) share a common forward simulation module, facilitating the comparison of results from different sounder measurements

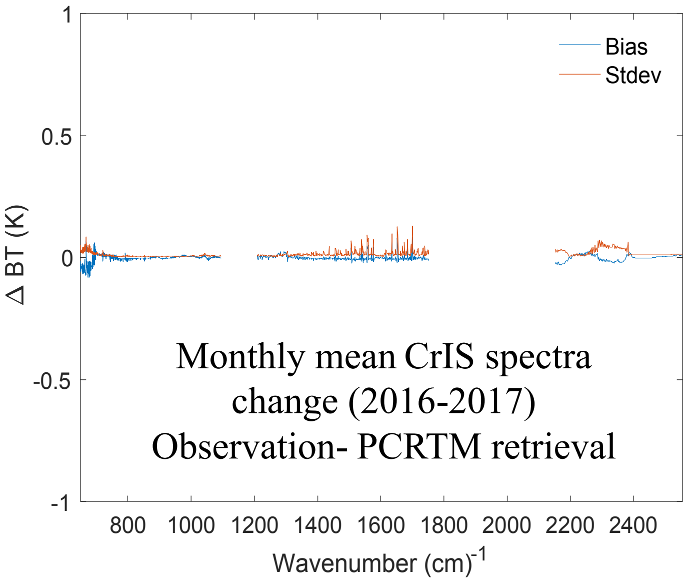
Radiometric consistency between Observation and PCRTM Retrieval

Comparison between observed and PCRTM modeled spectra of three major hyperspectral sounders



Monthly mean CrIS spectra change (2016-2017) Observation

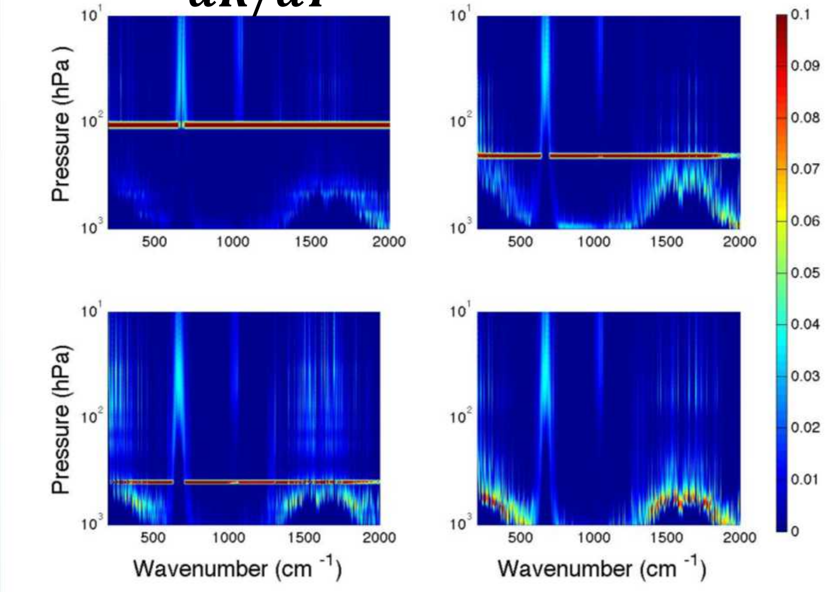




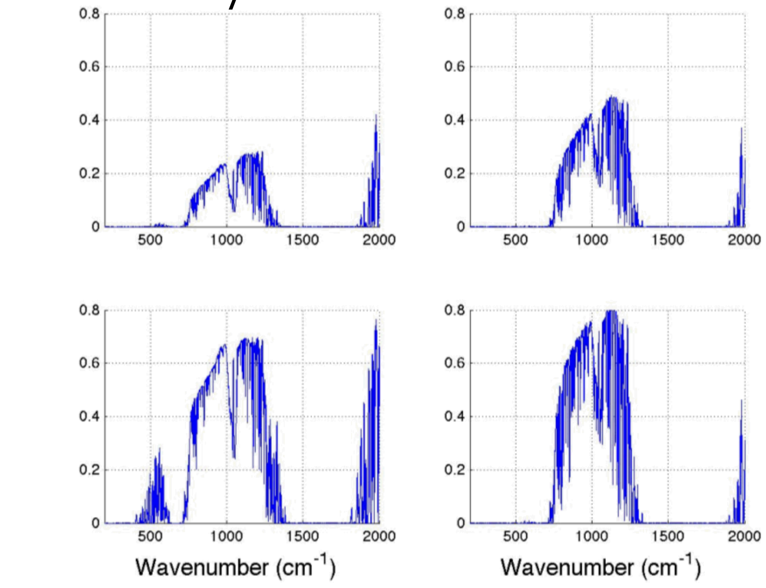
Jacobian calculated using PCRTM under all-sky conditions

***optical depth* @550nm**: τ=3.95, τ=2.21, τ=1.36, clear sky

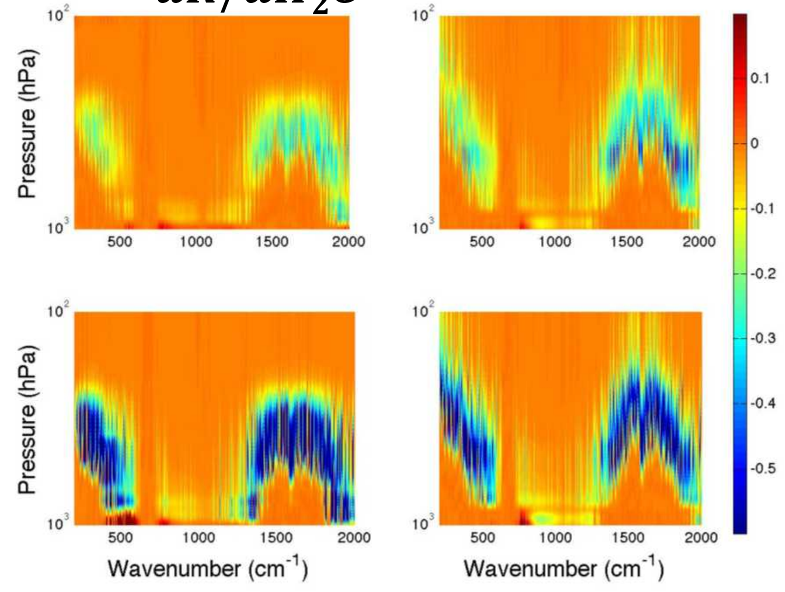
dR/dT



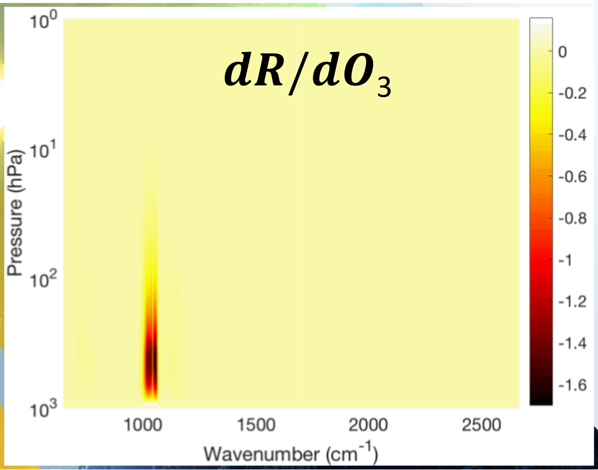
$dR/dTskn$



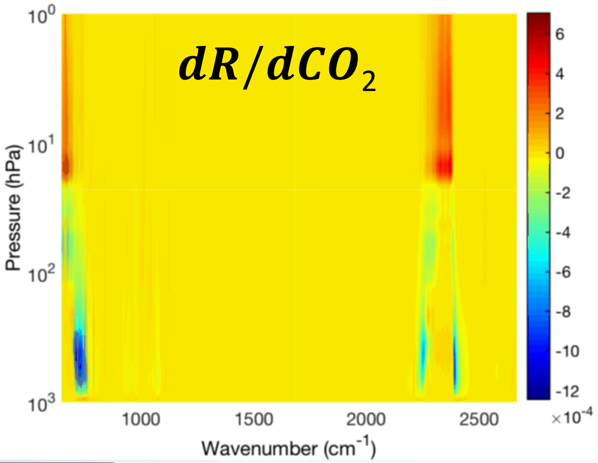
dR/dH_2O



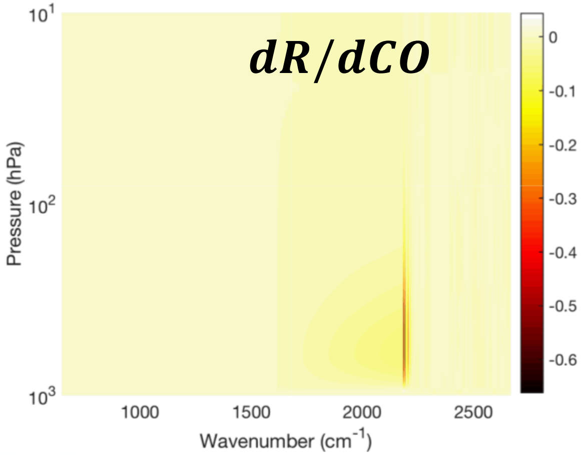
dR/dO_3



dR/dCO_2



dR/dCO

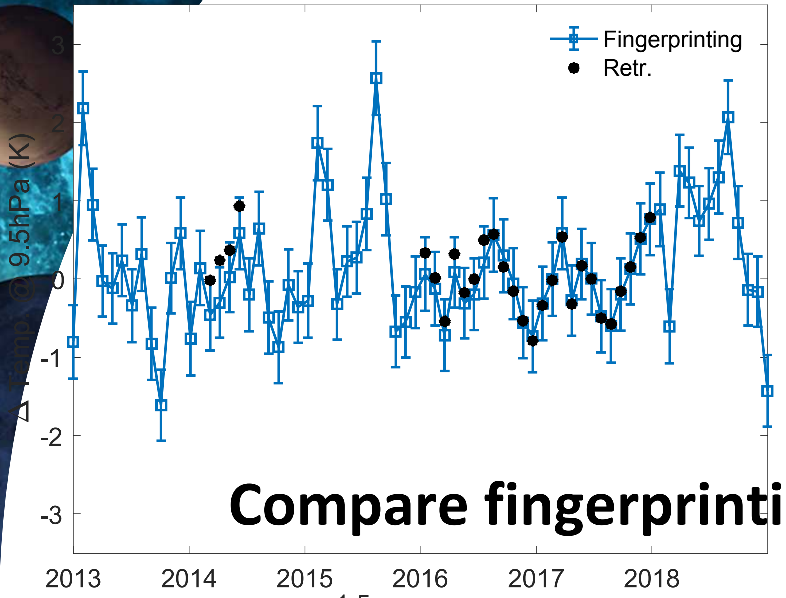


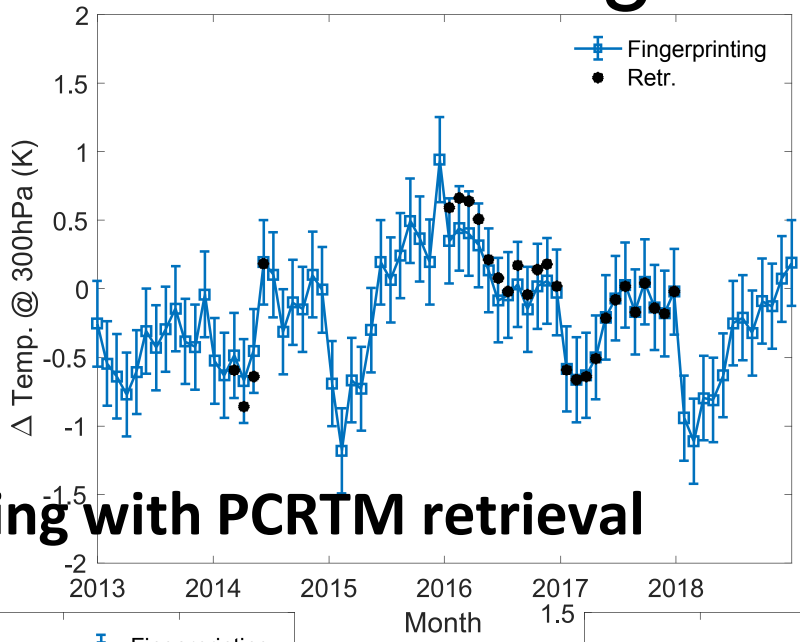
Construction of radiative kernels from individual PCRTM retrieval results

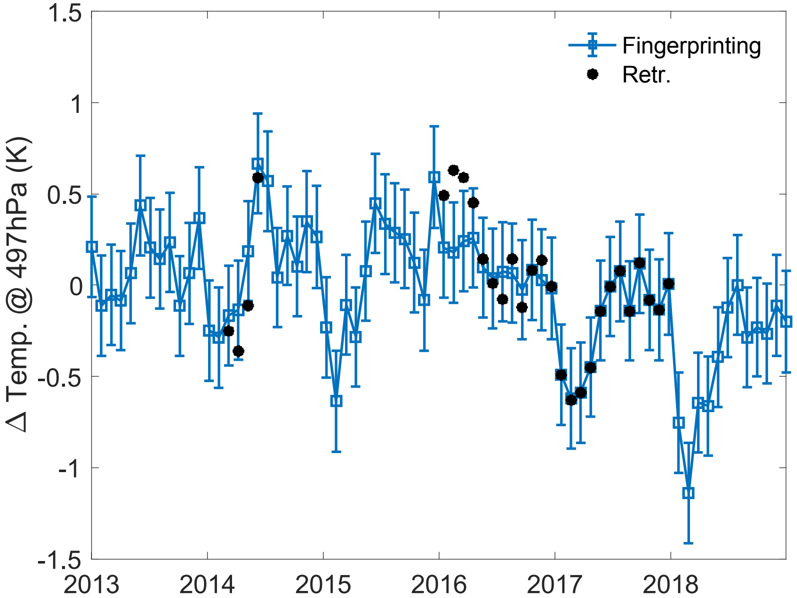
	Spectral Fingerprinting	Individual Retrieval	
Spectral Anomaly (Trend) / Indiv. Radiance	$\boldsymbol{\Delta}\mathbb{R}$	$\boldsymbol{R}$	$\boldsymbol{\Delta}\mathbb{R} = \overline{\boldsymbol{\Delta R}}$
Radiative Kernel / Jacobian	$\boldsymbol{S}$	$\boldsymbol{K}$	$\boldsymbol{S} = \overline{\boldsymbol{K}}$
Climate Anomaly (Trend) / geophysical Variable	$\boldsymbol{\Delta\alpha}$	$\boldsymbol{X}$	$\boldsymbol{\Delta}\mathbb{R} = \overline{\boldsymbol{\Delta X}}$
	$\boldsymbol{\Delta}\mathbb{R} = \boldsymbol{S\Delta\alpha} + \boldsymbol{\varepsilon}$	$\boldsymbol{R} = F(\boldsymbol{X})$ $\boldsymbol{\Delta R} = \boldsymbol{K\Delta X} + \boldsymbol{\delta}$	

- PCRTM retrieval provides radiative kernels and reference state information without using any additional information from either climate or NWP models
- The space and time scales for aggregation of individual retrieval results are flexible. Zonal temperature and water vapor anomalies over tropical ocean are the focus of this study.

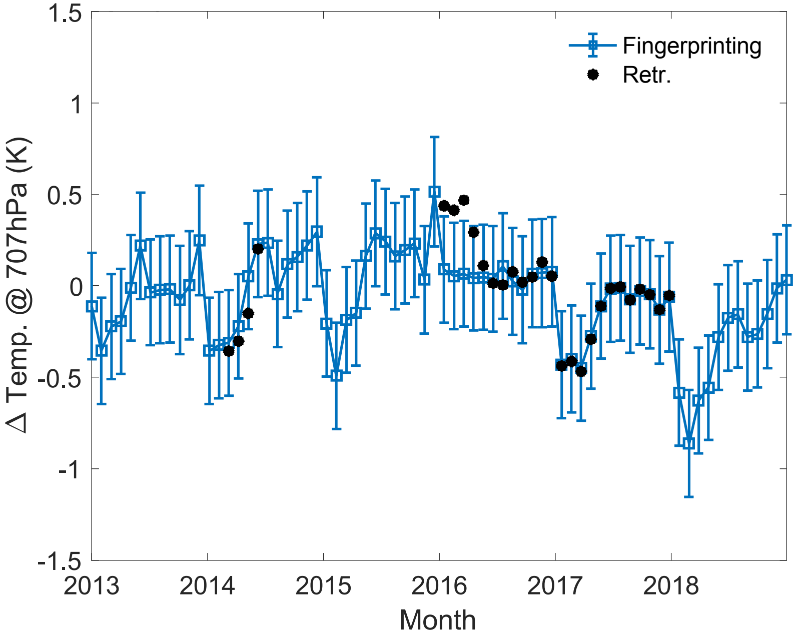
Monthly mean tropical ocean Temp. anomalies from CrIS Descending Observations

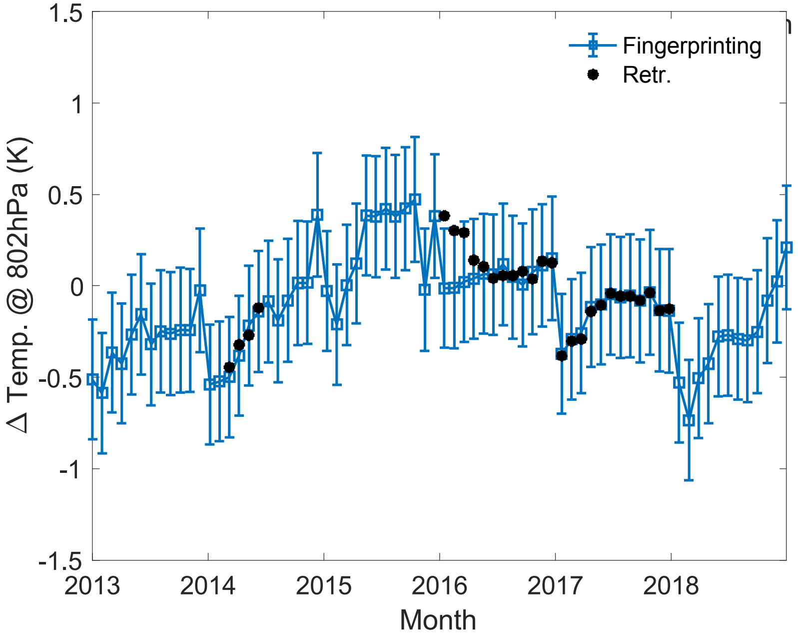




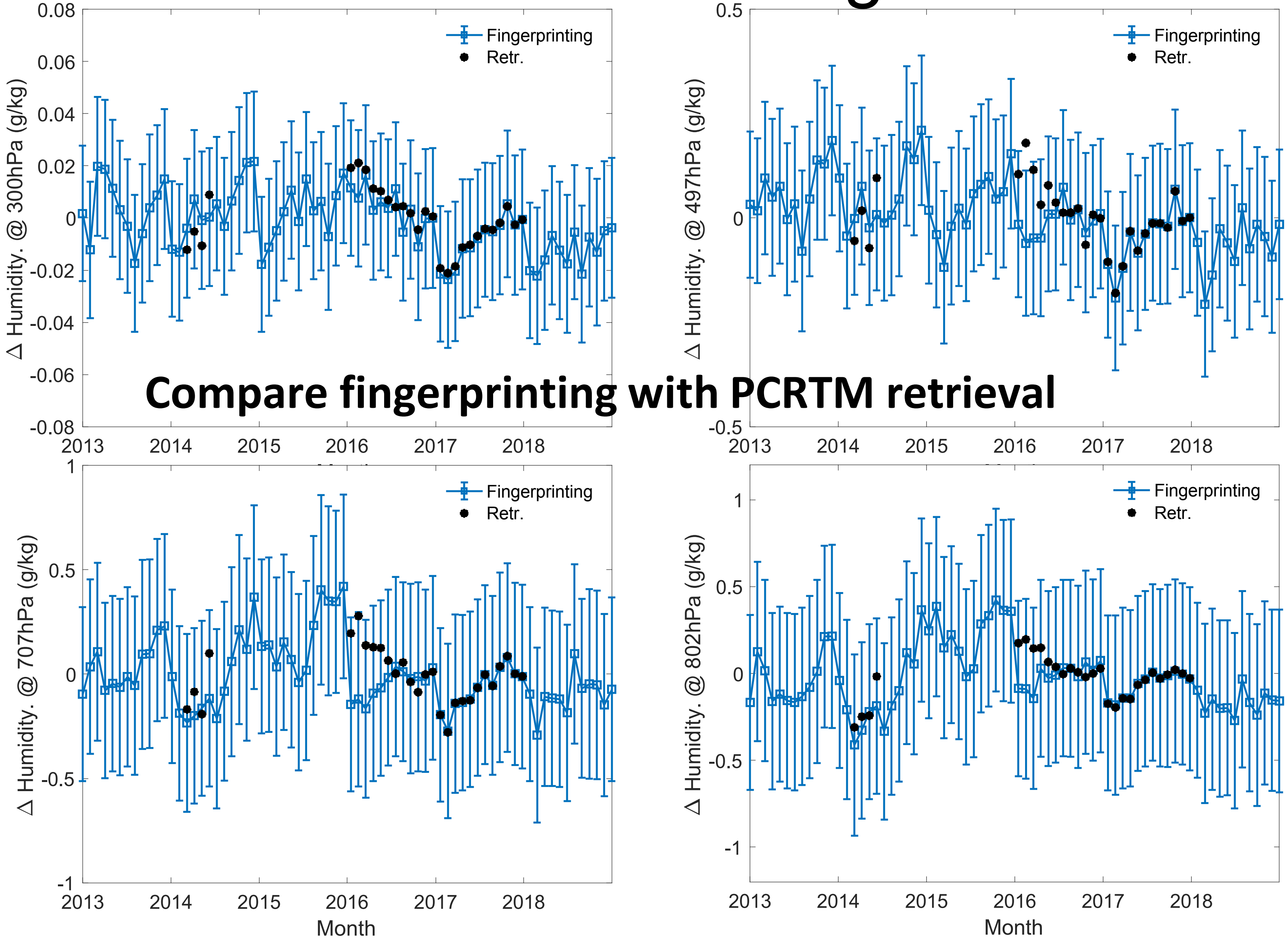


Compare fingerprinting with PCRTM retrieval





Monthly mean tropical ocean H_2O anomalies from CrIS Descending Observations

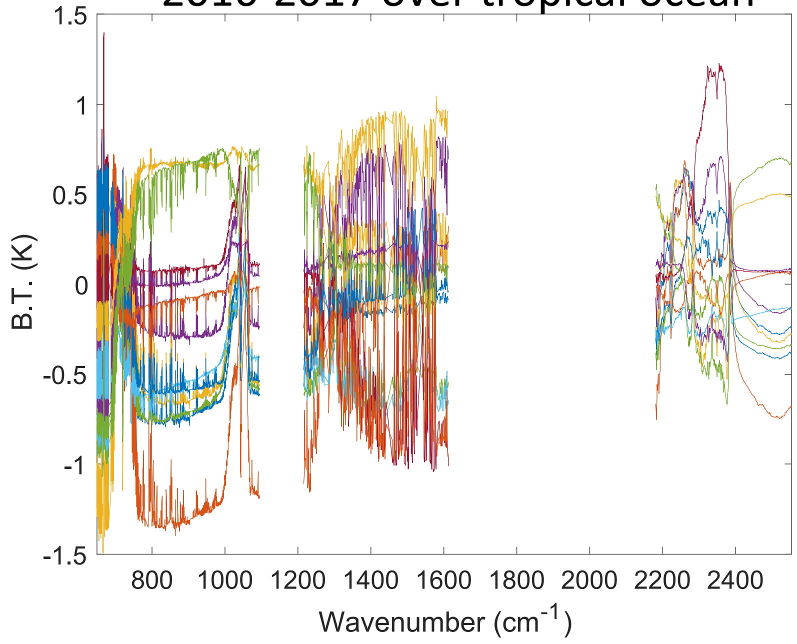


Compare fingerprinting with PCRTM retrieval

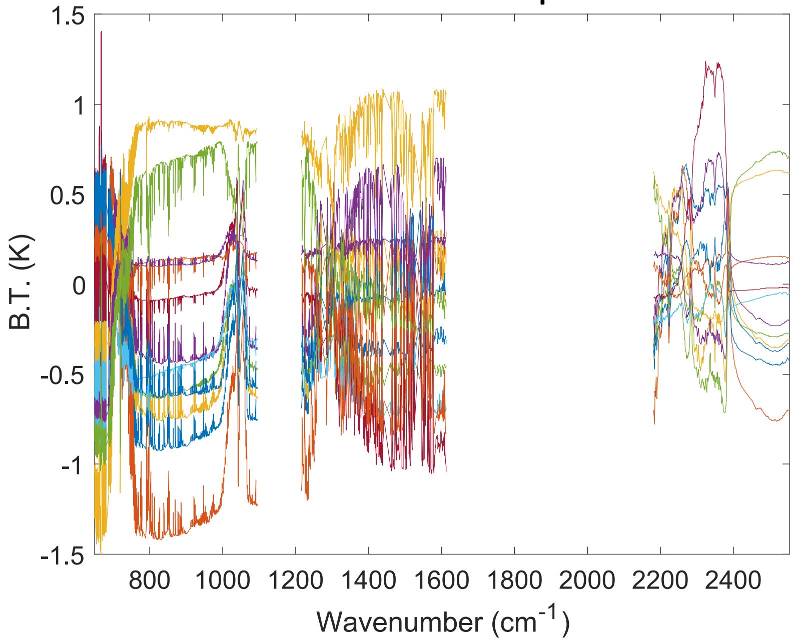
AIRS spectral fingerprinting using radiative kernels constructed from CrIS individual retrievals

- PCRTM simulated AIRS and CrIS spectra can be rigorously related via a regression relationship $\boldsymbol{R_{airs} = A\, R_{cris}}$
- Zonally average monthly mean AIRS and CrIS spectral anomalies during the overlapping observation years generally agree with each other
- Radiative kernels for AIRS can be derived from CrIS radiative kernels as $\boldsymbol{S_{airs} = A\, S_{cris}}$

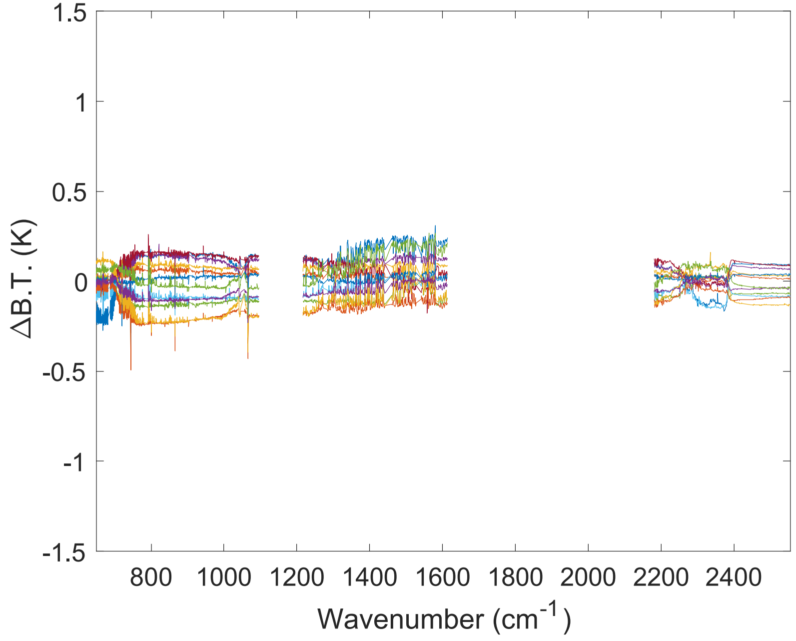
AIRS monthly mean anomaly 2016-2017 over tropical ocean



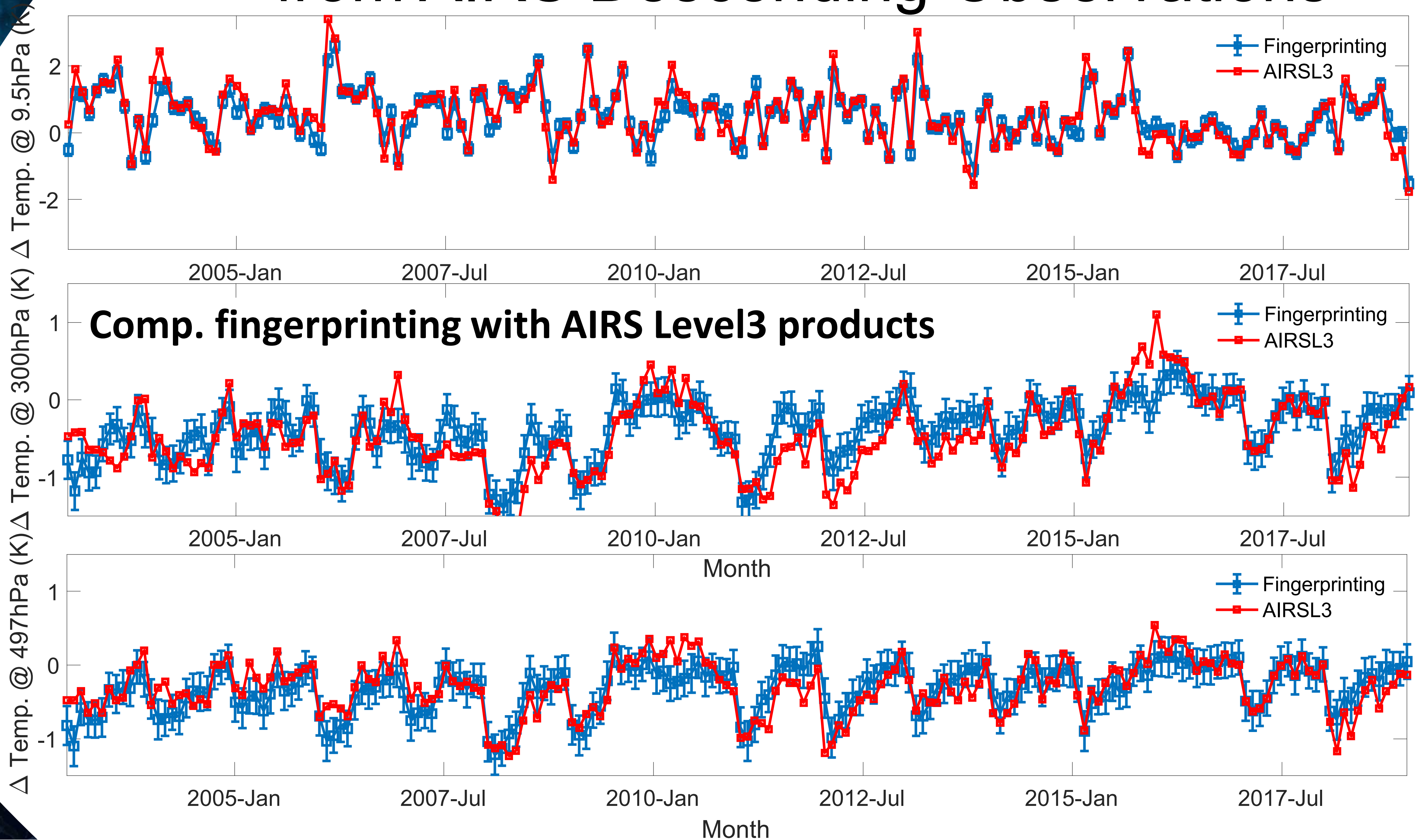
CrIS monthly mean anomaly 2016-2017 over tropical ocean



Diff. AIRS-CrIS

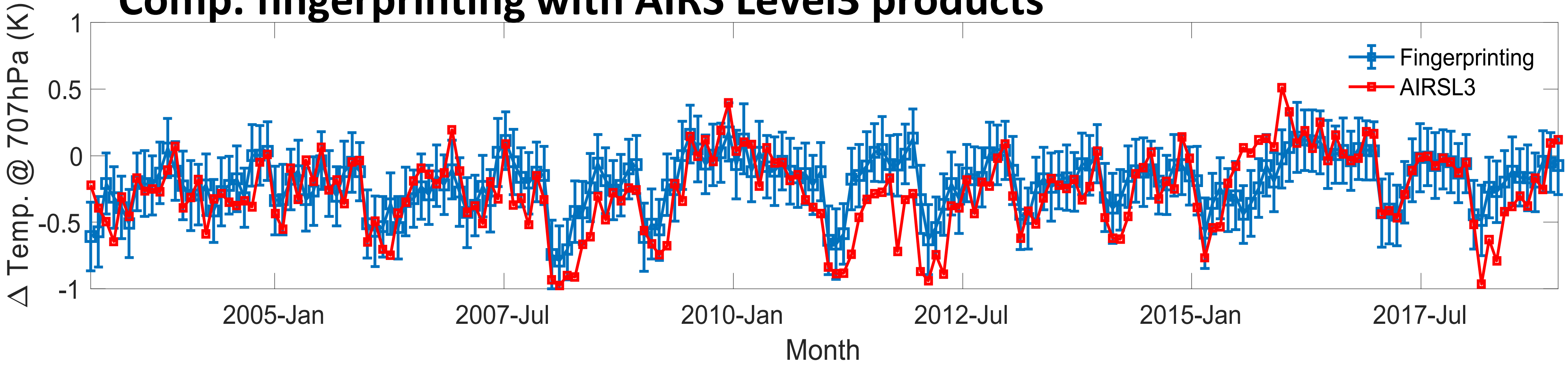


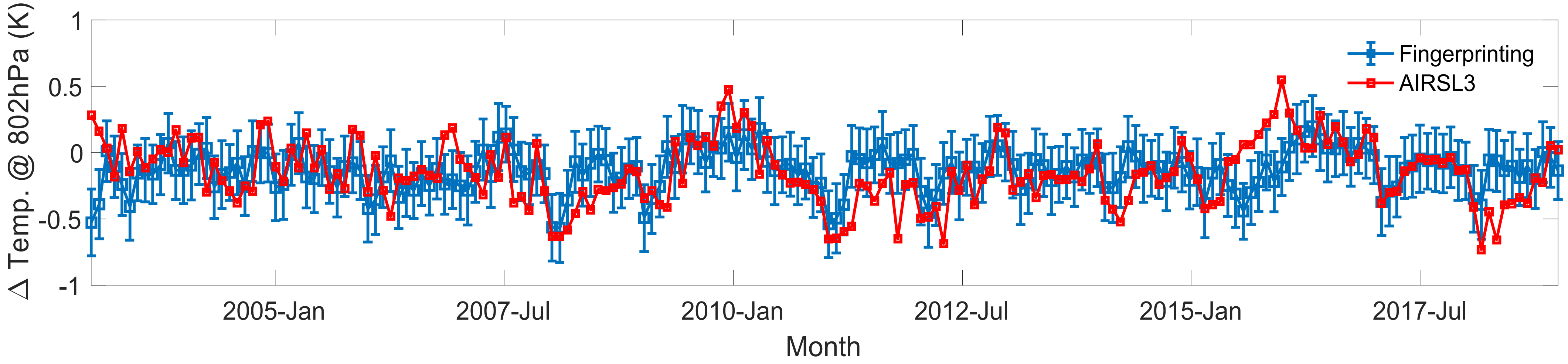
Monthly mean tropical ocean Temp. anomalies from AIRS Descending Observations



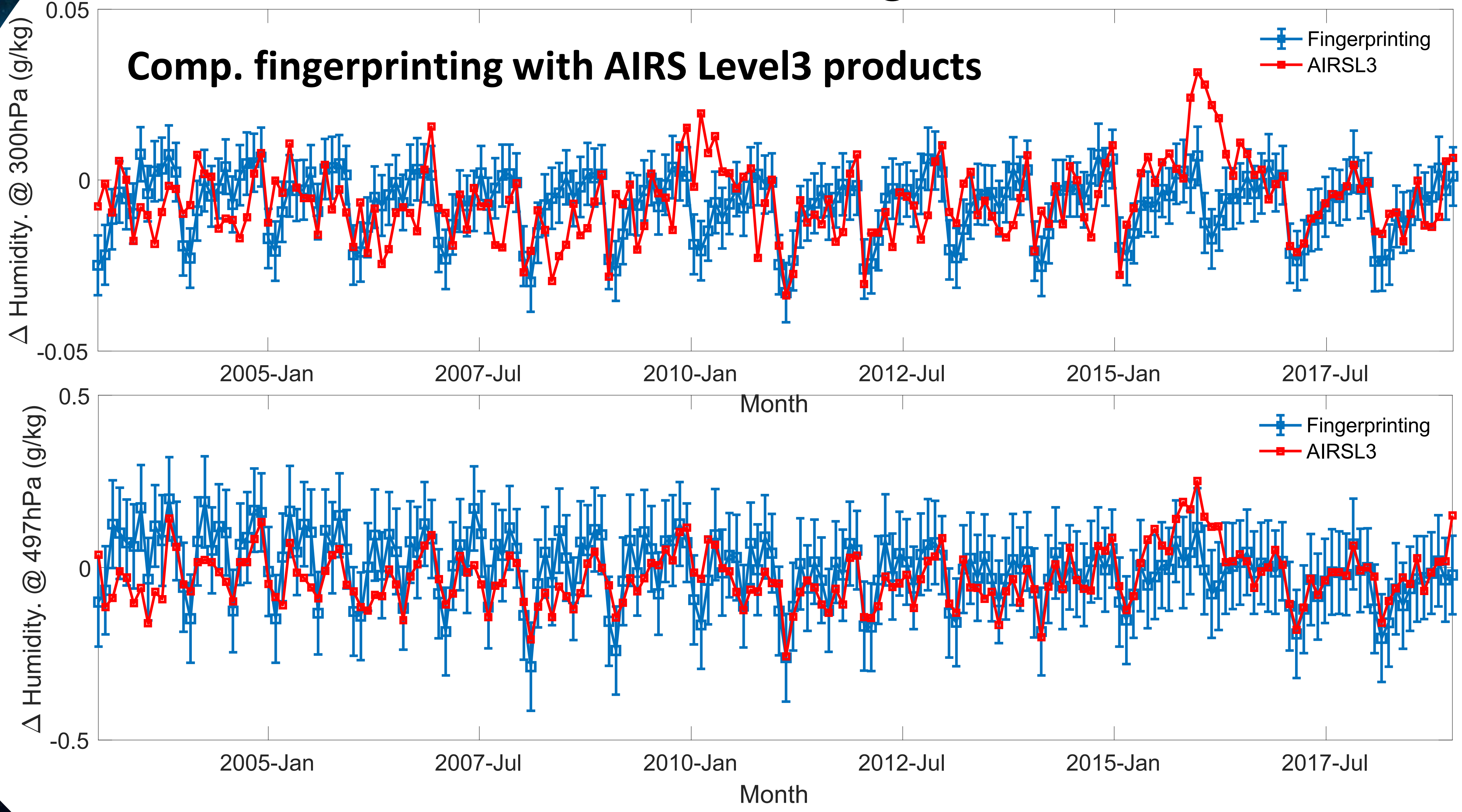
Monthly mean tropical ocean Temp. anomalies from AIRS Descending Observations

Comp. fingerprinting with AIRS Level3 products

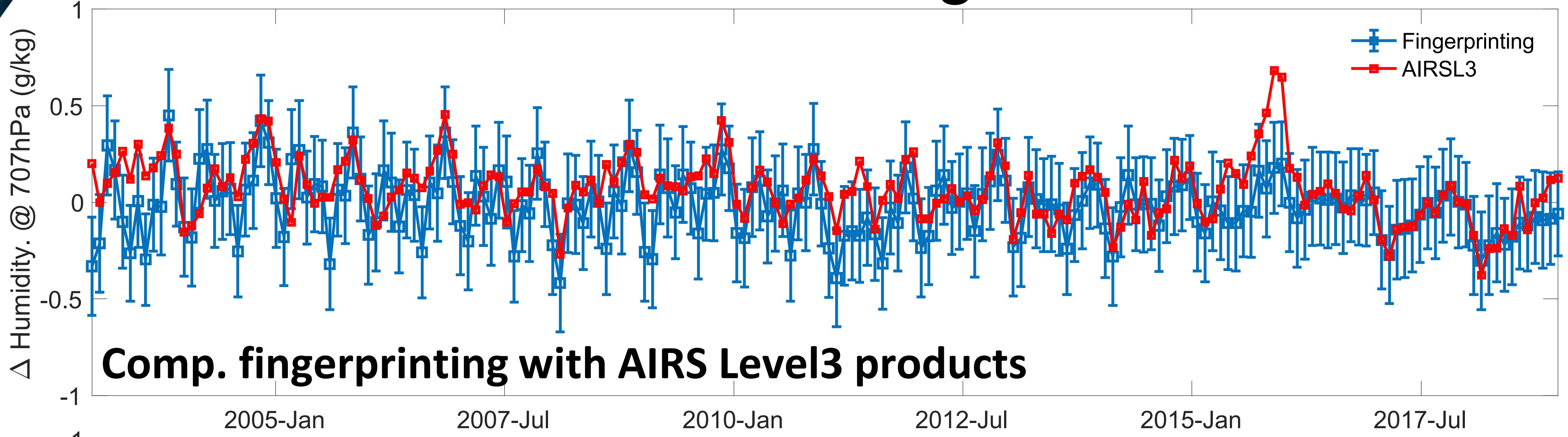


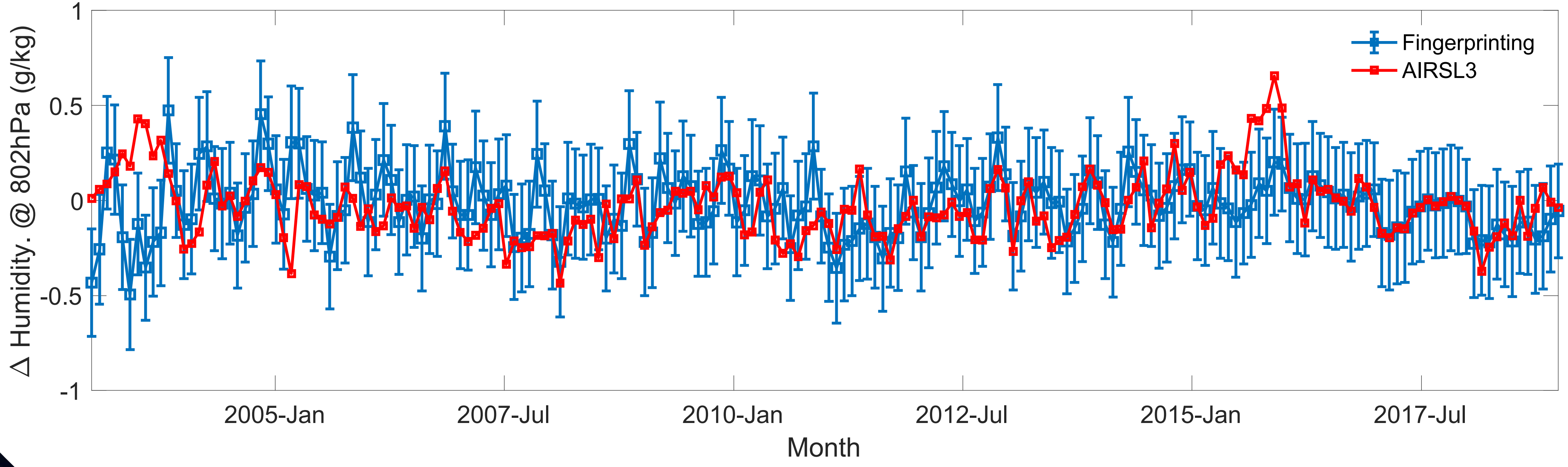


Monthly mean tropical ocean H_2O anomalies from AIRS Descending Observations



Monthly mean tropical ocean H_2O anomalies from AIRS Descending Observations





SUMMARY

- A radiometric consistent fingerprinting methodology that uses multiple hyper-spectral IR sounder observations for long term climate trend and anomaly studies has been developed.
- The use of the PCRTM based fingerprinting method to derive temperature and humidity anomalies from CrIS and AIRS data has been demonstrated.
- The spectral fingerprinting results have been shown to be consistent with retrieval-then-average results

FUTURE WORK

- To continue the application on global scale AIRS and CrIS data and provide AIRS/CrIS Continuity Products of temperature and humidity .
- Extend the application for long term trace gas anomaly studies

Thank you