A New, Efficient, and Consistent Method for Generating Climate Data Record from Operational Hyperspectral Sounder Instruments on AQUA, S-NPP and NOAA 20

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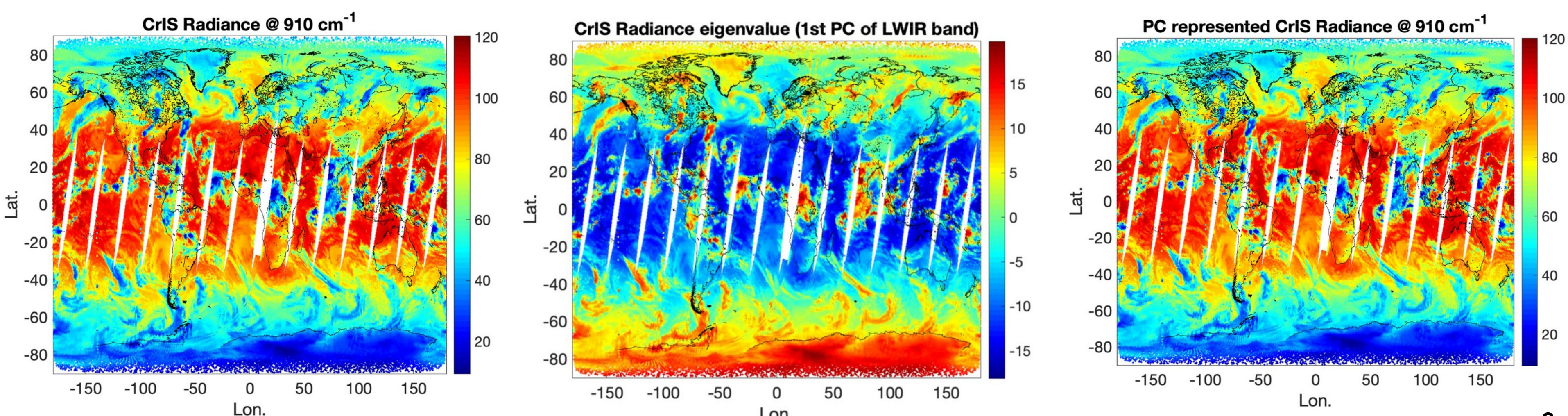
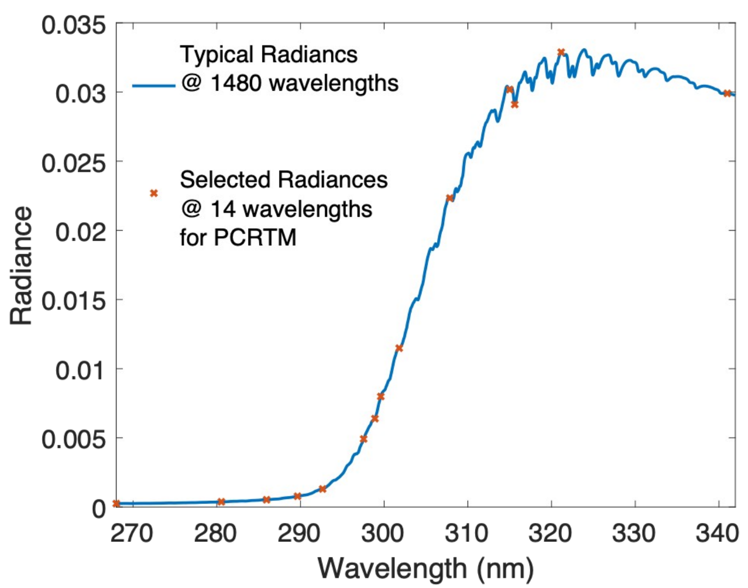
Introduction

- Modern hyperspectral satellite remote sensors provide wealth of information on
  - Atmospheric properties such as temperature, water vapor and trace gas vertical profiles
  - Cloud and aerosol properties
  - Surface properties (temperature, emissivity, reflectivity …)
- Fast and accurate forward models are needed to invert hyperspectral data
  - Hundreds to thousands of spectral channels with millions of observations each day
  - Line-by-line (LBL) radiative transfer model (RTM) is too slow (needs millions of LBL RT calculations to account for atmospheric gas spectral contributions)
  - Traditional channel-based forward models are also too slow (at least one RT calculations needed for each channel
- Principal Component Analysis (PCA) converts hyperspectral data into super-channels
  - Principal Components (PCs) capture the spectral correlations (remove redundant info)
  - Super channels capture the information content of the original channel spectrum
  - Super-channel number << than the original channel numbers



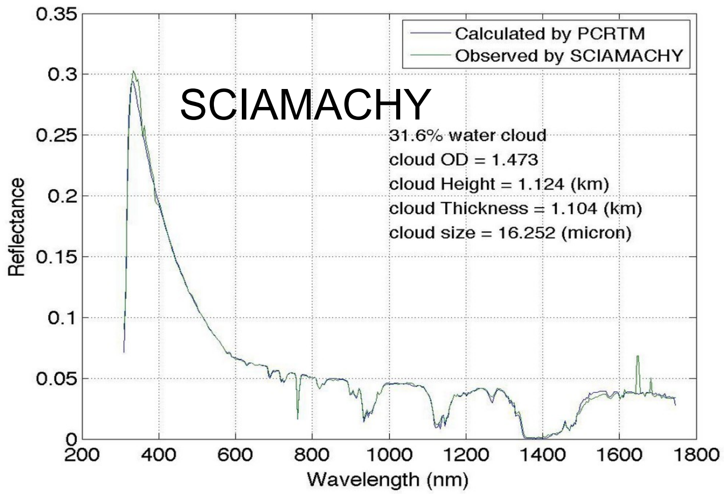
Principal Component Based Radiative Transfer Model (PCRTM)

- PCRTM was specifically for hyperspectral remote sensors
  - Number of RT calculations are << number of spectral channels
    - Orders of magnitude faster than LBL RTMs
  - RT calculations done monochromatically
    - Physical-based RTM and accurate relative to LBL RTMs
  - Provides analytical Jacobian needed for satellite data inversions

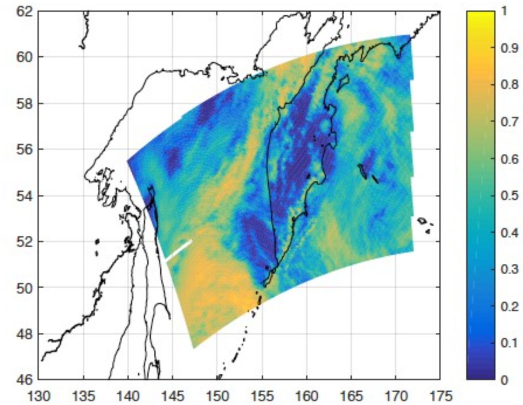


- Multiple scattering clouds and aerosols included
- Wide range of spectral coverage
  - Thermal: 50-3000 cm^{-1}
  - Solar: 200 nm – 2500 nm
  - Suitable for AIRS, CrIS, IASI, PREFIRE, IRS, IASI-NG, NAST-I, S-HIS, CLARREO, CPF, SBG, TEMPO, OMI, SCIAMACHY …
- Fast:
  - Milliseconds to fraction of seconds in IR
  - 3-4 orders of magnitude faster than LBL in solar
- Accurate relative to LBL:
  - Thermal: Bias error < 0.002 K RMS error < 0.03 K
  - Solar: bias error < 0.001%, RMS error ~0.05%

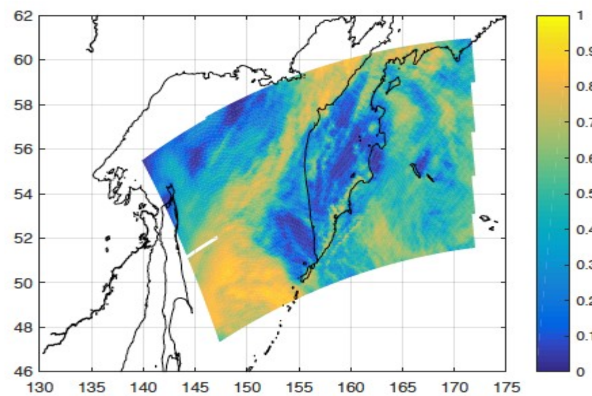
PCRTM Calculated Radiance Spectra Agree Well With Satellite Observations

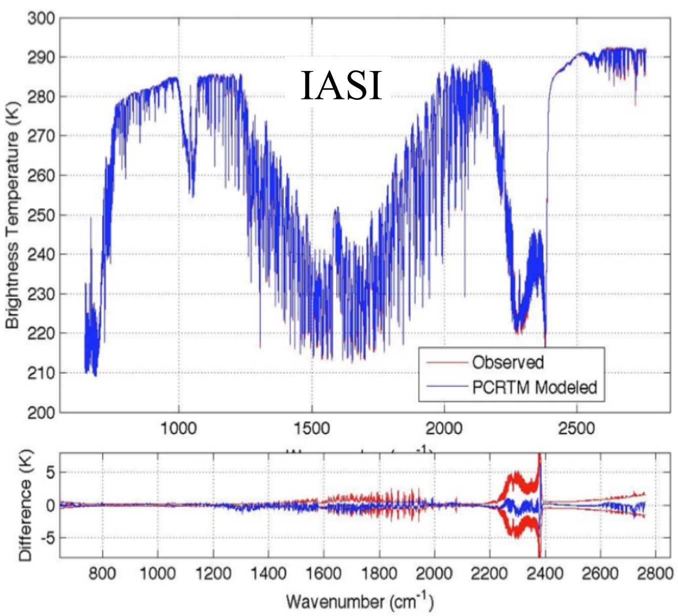


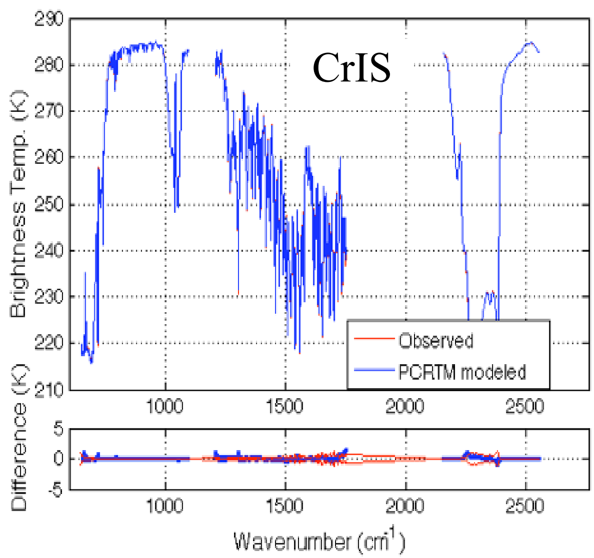
PCRTM Simulated Reflectance @646 nm using MODIS L2 data

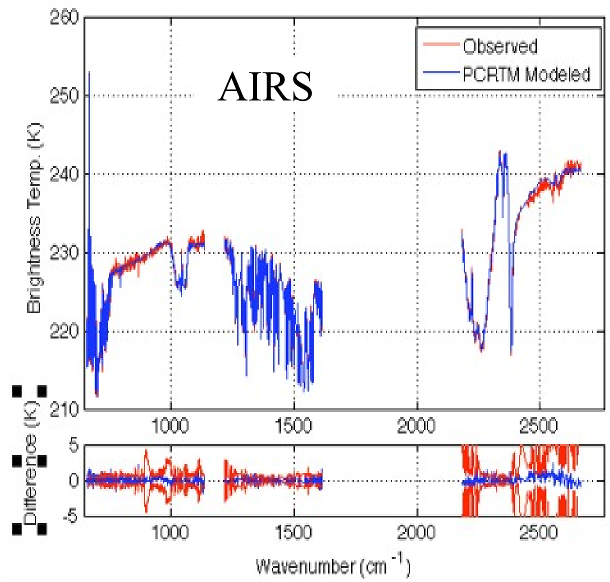


MODIS L1 Observed Reflectance @646 nm









Two PCRTM-based Inversion Algorithms

- L2 products: Single Field-of-view Sounder Atmospheric Product (SiFSAP)
  - 3-times higher spatial resolution
  - Uses all spectral channel
  - All sky algorithm-retrieves cloud explicitly
  - Retrieve temperature, clouds, trace gases, and surface properties simultaneously

  L3 Products: Climate Fingerprinting Sounder Products (ClimFiSP)

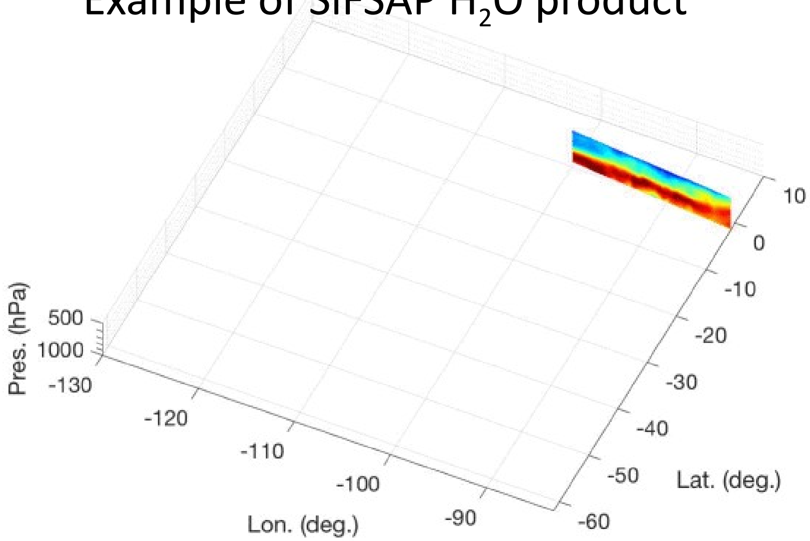
  Works on spatiotemporally averaged radiance spectra

  High quality climate product from multiple satellite data fusion

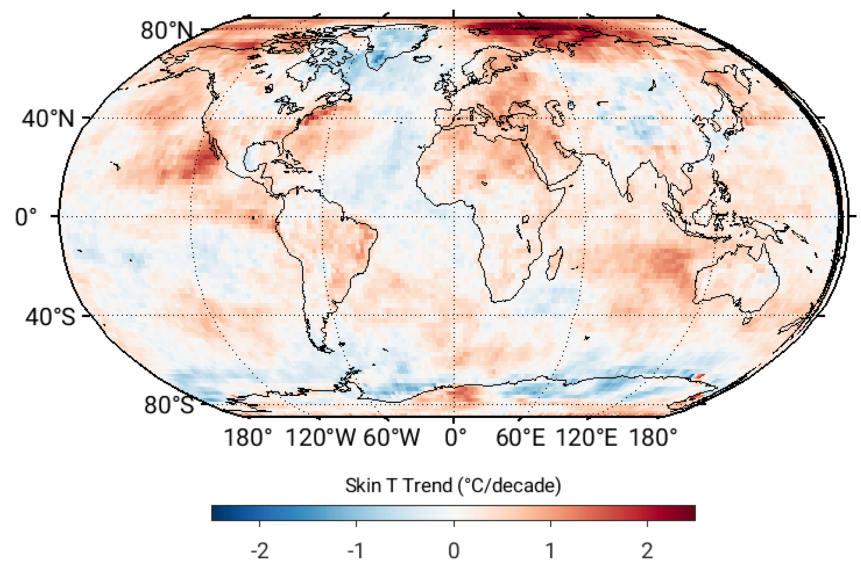
  Use consistent radiative kernels

  Ensure radiometric closures
- Both products will be available at NASA GES DISC for public access
- The PCRTM based algorithm can be easily extended to solar spectral region

Example of SiFSAP H_2O product



Example of ClimFiSP derived global surface temperature trend



Description of the ClimFiSP Algorithm

- Issues with traditional L1-L2-L3 climate products
  - L2 algorithm inconsistency for different satellite sensors
  - Lack of radiance closure (e.g cloud-clearing method)
  - L1-L2-L3 algorithm is computational demanding
- ClimFiSP is designed to address the above-mentioned deficiencies
  - Works on gridded L1 products directly using consistent radiative kernels
  - Provides radiometric closure
  - All parameters including clouds retrieved simultaneously
  - More than 5 orders of magnitude faster than traditional L1-L2-L3 method
  - Quick re-generation of climate products when instrument is re-calibrated or L1 algorithm is improved
  - Can be used to diagnose radiance differences due to different sensors
- Provide radiative kernels needed for climate studies
  - Climate model validations using satellite data
  - Climate model diagnosis/improvements

Radiometric Closure for ClimFiSP

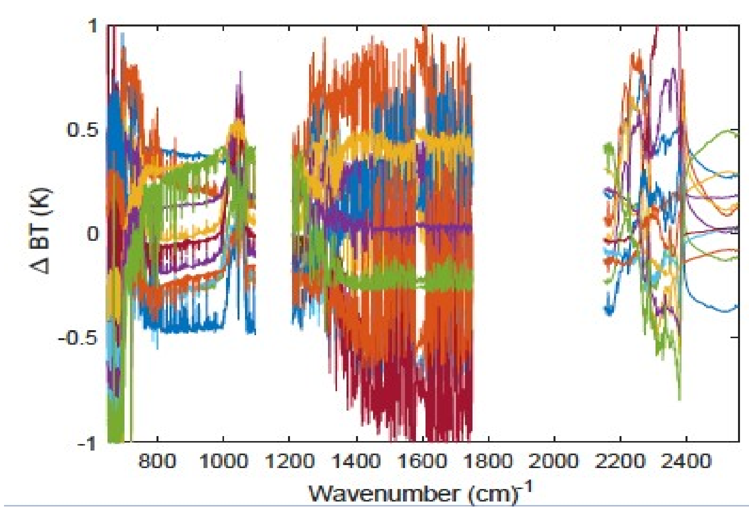
- Gridded AIRS and CrIS spectral anomaly derived from L1 directly
  - No assumptions when generating the anomaly spectra
  - All radiometrically significant geophysical variables are included in the radiative kernels
  - ClimFiSP include all geophysical variables including clouds
- Spectral fingerprinting errors are characterized

$$= (\boldsymbol{S}^{T}\boldsymbol{\Sigma}^{-1}\boldsymbol{S}+)^{-1}$$

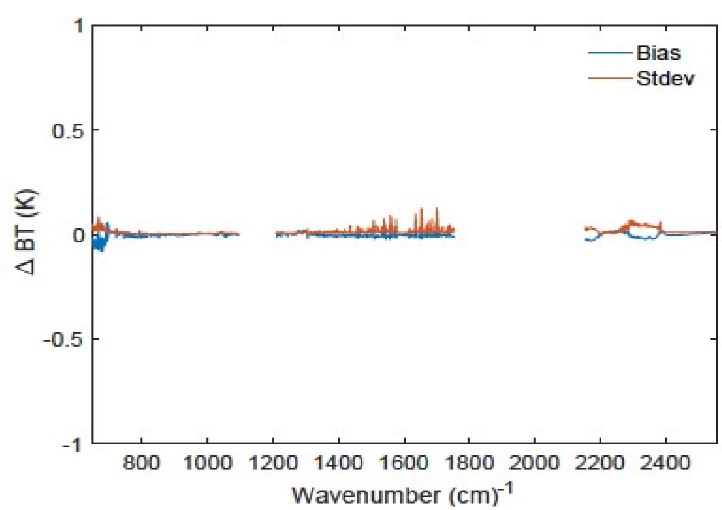
- Information content for each retrieved variable can be determined (diagonal elements of the averaging kernel)

$$= (\boldsymbol{S}^{T}\boldsymbol{\Sigma}^{-1}\boldsymbol{S}+)^{-1}\boldsymbol{S}^{T}\boldsymbol{\Sigma}^{-1}\boldsymbol{S}$$

Examples of CrIS Spectral Anomaly

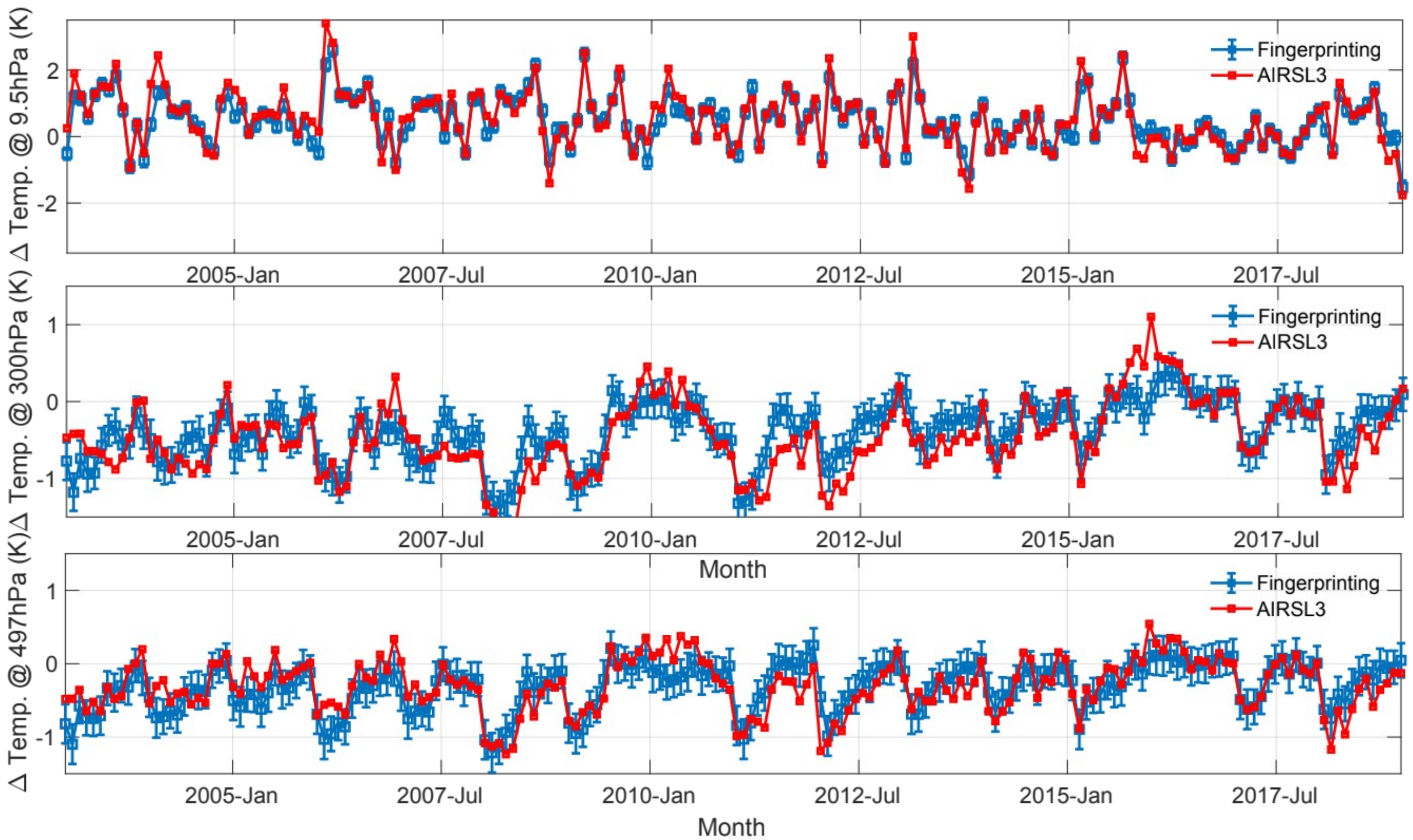


Closure for CrIS Gridded Spectral Anomaly



Example of AIRS and CrIS ClimFiSP product

- ClimFiSP enables of the fusion of AIRS and CrIS data into a consistent temperature anomalies at different atmospheric pressure levels
- ClimFiSP and AIRS L3 temperature anomalies from 2003 to 2018 show general agreement



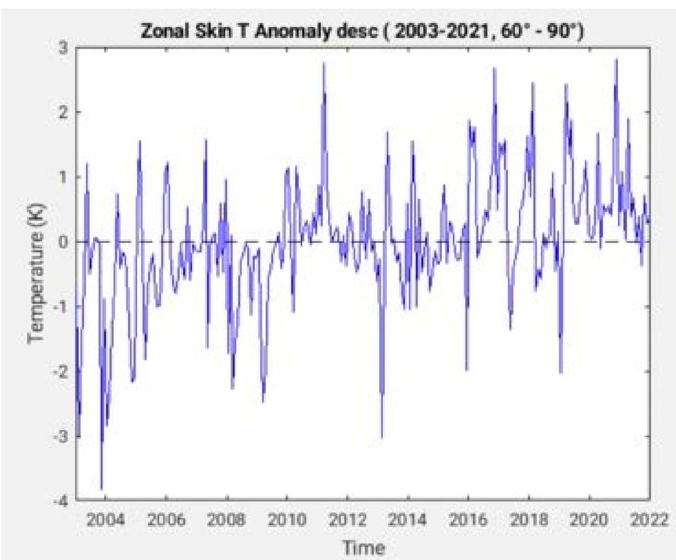
Wu et. al. (2020) "Radiometrically Consistent Climate Fingerprinting Using CrIS and AIRS Hyperspectral Observations" Remote Sensing. https://doi.org/10.3390/rs12081291

Applying the ClimFiSP Algorithm to CHIRP

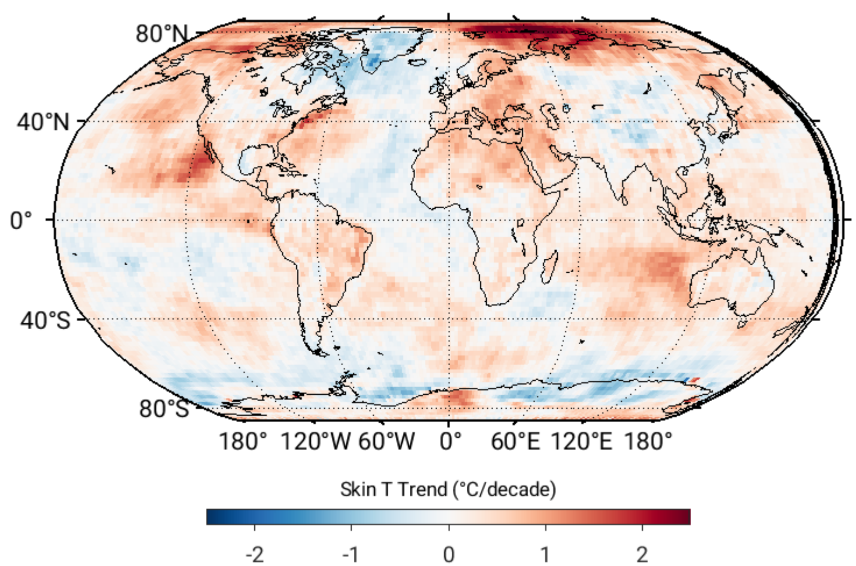
- CHIRP - Climate Hyperspectral Infrared Radiance Product
  - Bias-corrected radiance (L1) time series for Aqua/AIRS, SNPP/CrIS, and JPSS/CrIS
  - Generated by Larrabee Strow et al (2021)
  - Available at NASA Sounder SIPS and DACC

- We have applied the ClimFiSP algorithm to CHIRP data from 2003-2021
  - Obtained climate time series for:
    - atmospheric temperature, water vapor, O3, and other trace gas vertical profiles
    - cloud optical depth, cloud height, and cloud particle size
    - surface skin temperature, and surface emissivity

Example of ClimFiSP derived global surface temperature time series for 60-90° latitude



Example of ClimFiSP derived global surface temperature trend



Summary and Path Forward

- PCRTM is a fast and accurate RTM addressing hyperspectral data analysis challenges
  - Uses full hyperspectral information
  - Physically-based with a few hundred RT calculations
  - Includes multiple scattering clouds
  - PCRTM handles polarization in solar spectral region
- PCRTM-based ClimFiSP a new, efficient, and consistent method for generating climate data records from satellite IR sounders
  - Eliminates/minimizes the inconsistency due to L2 algorithm differences in traditional L1-L2-L3 approach
  - Radiometric closure (avoids CC errors, fits all parameters simultaneous including clouds)
  - Consistent long-term climate data records (T, Q, trace gases, cloud, surface T and emis) from multiple satellite IR hyperspectral sounders
  - Orders of magnitude faster than traditional approach (easy to reprocess once new improved L1 data are available)
- Both ClimFiSP and SiFSAP data products will be available at NASA DAAC soon