Generating Essential Climate Variables from Multiple Satellite Hyperspectral Remote Sensors

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MASA Langley PCRTM Team and collaborators
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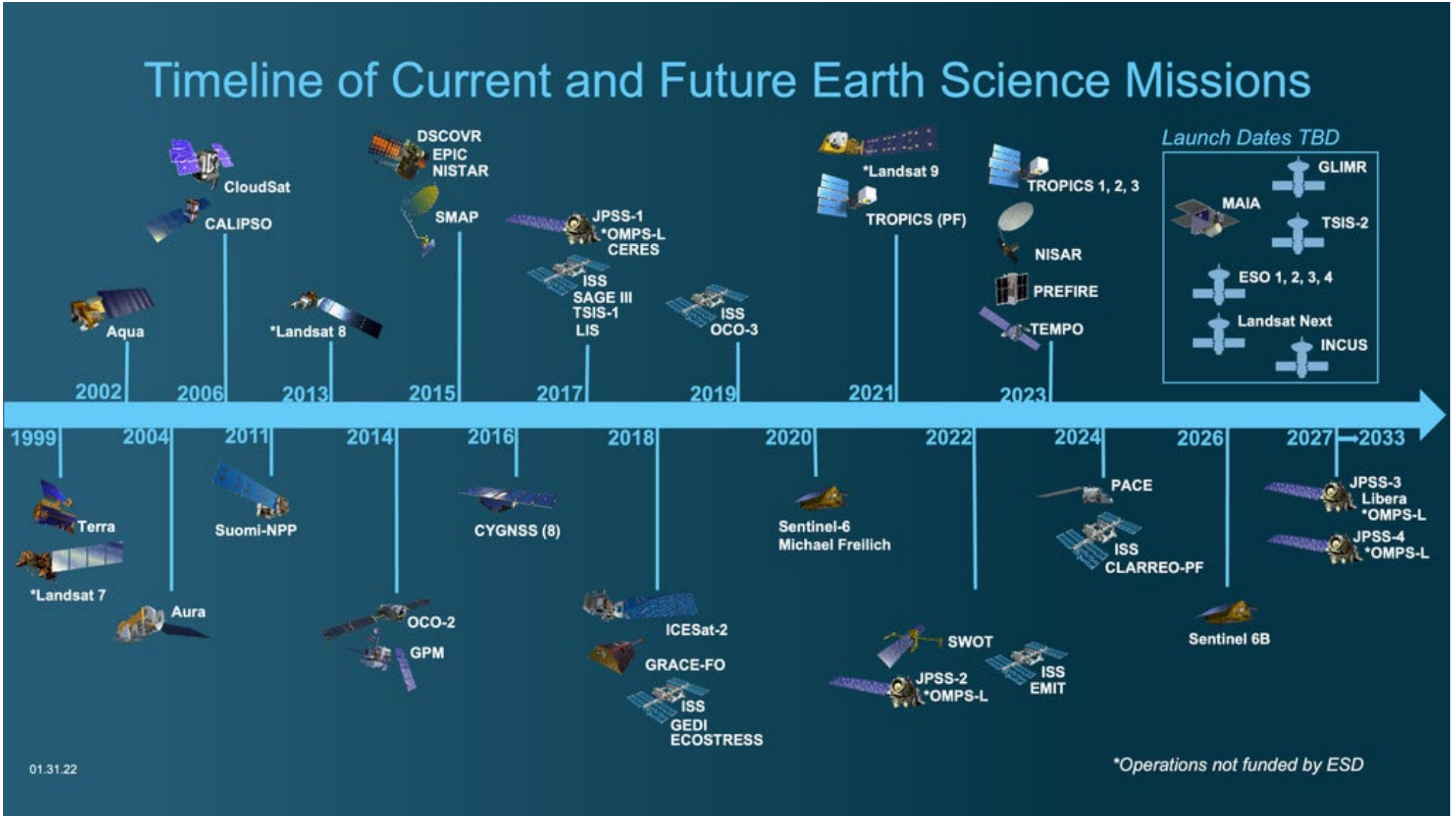
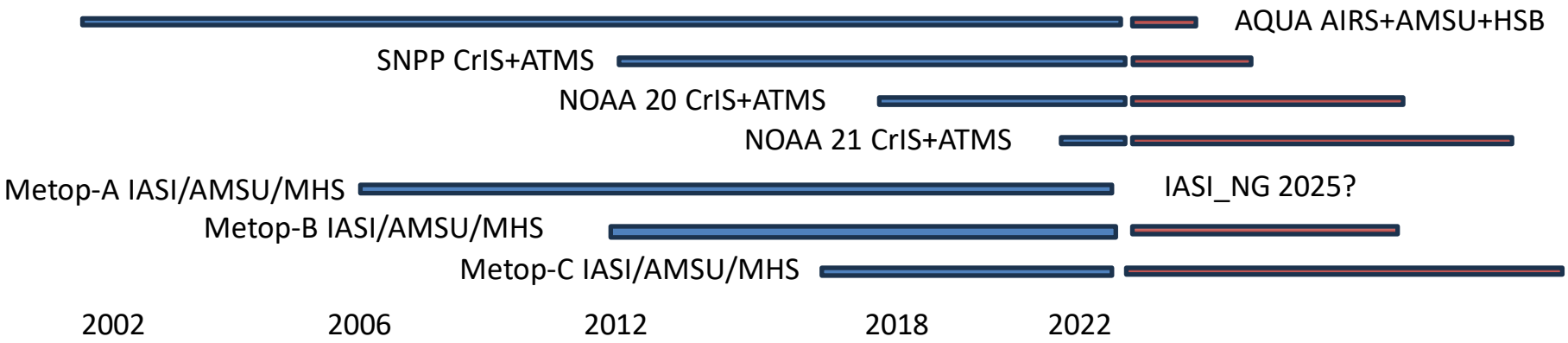

Timeline of Current and Future Earth Science Missions
Launch Dates TBD
GLIMR
MAIA
TSIS-2
ESO 1, 2, 3, 4
Landsat Next
INCUS
1999
Terra
*Landsat 7
2002
Aqua
2004
Aura
2006
CloudSat
CALIPSO
2011
Suomi-NPP
2013
*Landsat 8
2014
OCO-2
GPM
2015
DSCOVR
EPIC
NISTAR
SMAP
2016
CYGNSS (8)
2017
JPSS-1
*OMPS-L
CERES
ISS
SAGE III
TSIS-1
LIS
2018
ICESat-2
GRACE-FO
ISS
GEDI
ECOSTRESS
2019
ISS
OCO-3
2020
Sentinel-6
Michael Freilich
2021
*Landsat 9
TROPICS (PF)
2022
SWOT
JPSS-2
*OMPS-L
ISS
EMIT
2023
TROPICS 1, 2, 3
NISAR
PREFIRE
TEMPO
2024
PACE
ISS
CLARREO-PF
2026
Sentinel 6B
2027
2033
JPSS-3
Libera
*OMPS-L
JPSS-4
*OMPS-L
01.31.22
*Operations not funded by ESD

Introduction

- Hyperspectral IR sounders provide high quality observations on
  - Atmospheric temperature, water vapor and trace gas vertical profiles
  - Cloud and aerosol properties
  - Surface properties (temperature, emissivity, reflectivity …)



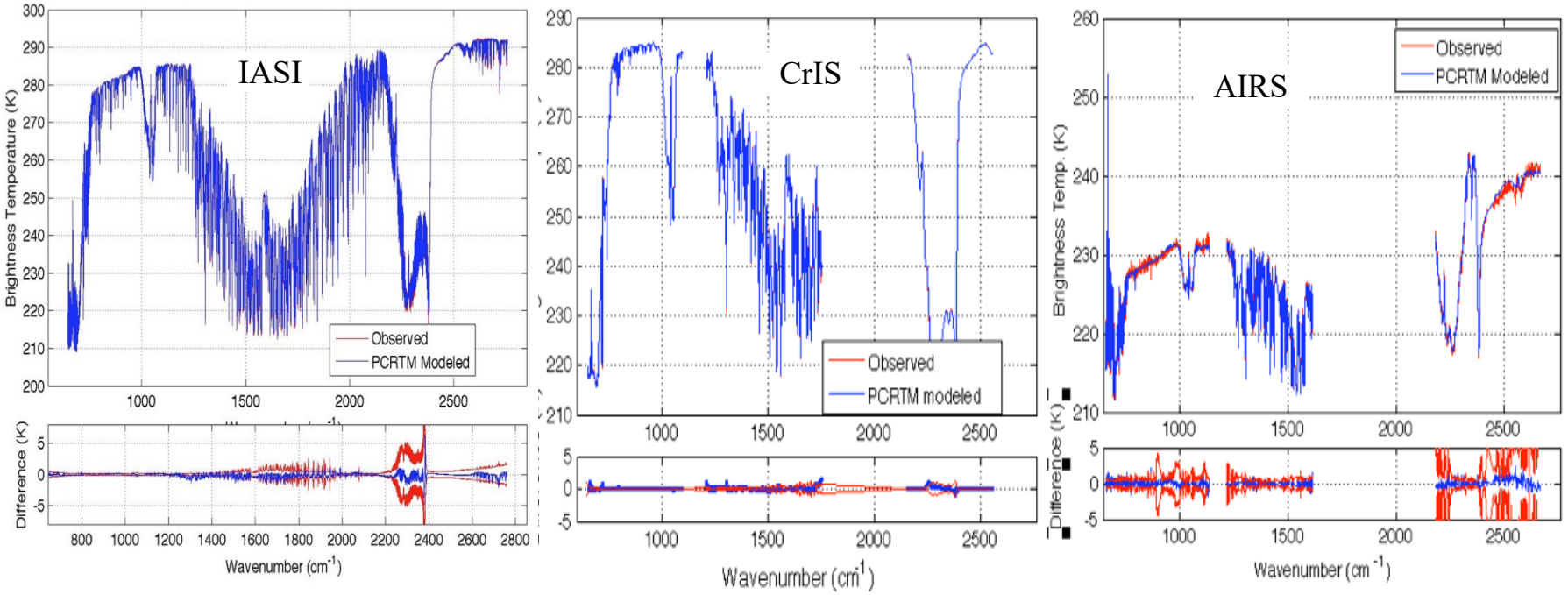
- Challenges in producing Climate Data Records (CDRs) from all these IR sounders
  - L2 algorithms may be different for these sounders which may introduce algorithm- related errors in deriving long-term trend or time series
  - Time consuming to process or re-process 20-years CDR from these IR sounders
- We developed a Climate Fingerprinting Sounder Product (ClimFiSP) at NASA Langley which is designed to address these challenges

Special Features of the ClimFiSP Algorithm

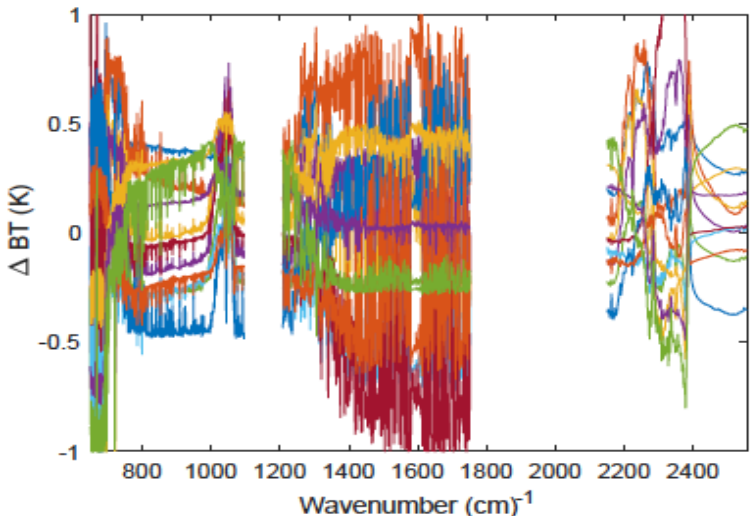
- ClimFiSP is a L3 algorithm which performs retrievals on gridded L1 data directly
  - 3-4 orders of magnitude faster than L1-L2-L3 approach
  - Uses consistent radiative kernels for all IR sounders
  - Fits all-sky cloudy radiance spectra directly to ensure radiometric closure
  - All sounder spectral channels (thousands) are used in ClimFiSP L3 algorithm
- Principal Component-based Radiative Transfer Model (PCRTM) is used to
  - Compress thousands of hyperspectral channels into less than 200 Principal Components (PCs)
  - Capture all information content of the hyperspectral sounders
- Retrieved atmospheric and surface properties are compressed into PC-domain
  - Reduce the ill-condition of the inversion
  - Efficiently keep error covariance and averaging kernels into smaller dimension
- Radiative Kernels derived from a Single Field-of-view Sounding Atmospheric Product (SiFSAP) (Liu et al. 2009, Wan et al. 2020, 2023, Xiong et al. 2022, 2023)
  - PCRTM-based all-sky retrievals (radiance closure)
  - Been delivered to NASA Goddard DAAC for public release
  - Dr. Wu will give a detailed description of the algorithm tomorrow

Radiometric Closure for SiFSAP and ClimFISP

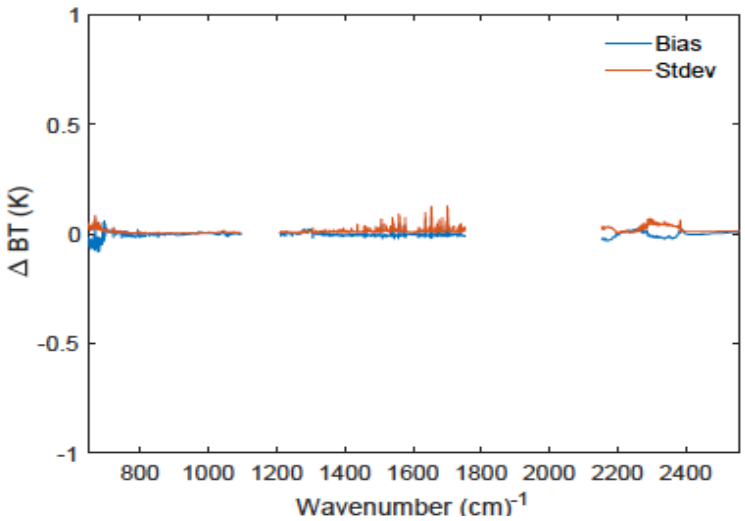
SiFSAP PCRTM modeled and observed spectra of three major hyperspectral sounders



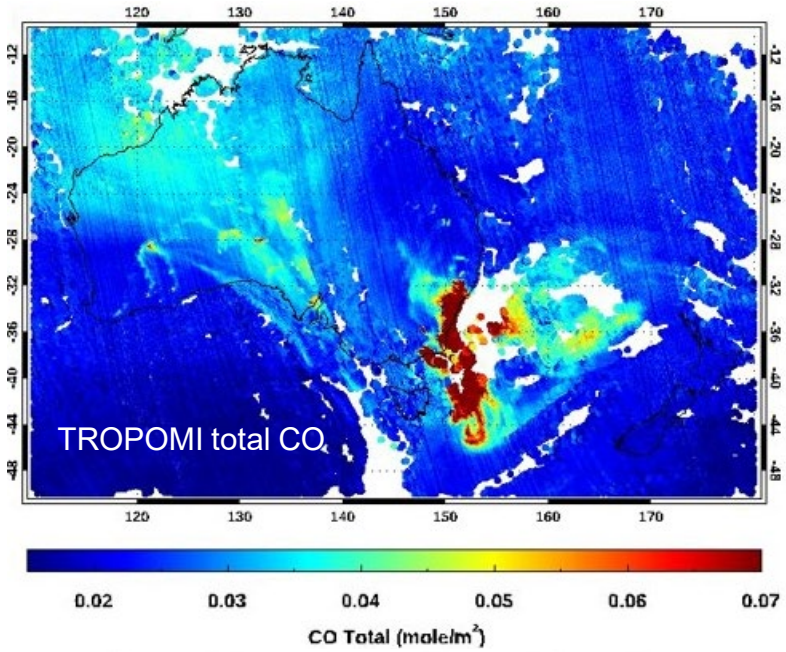
Examples of CrIS Spectral Anomaly (2016-2017)

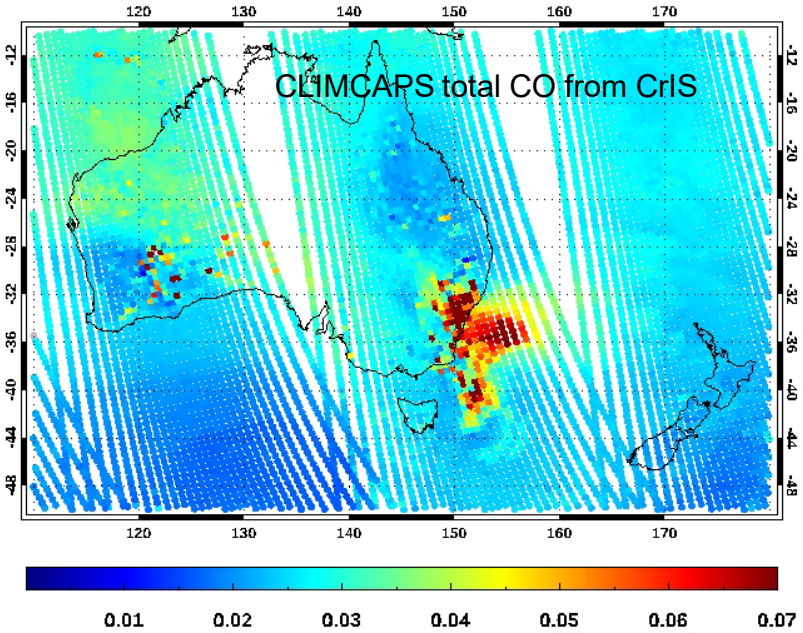


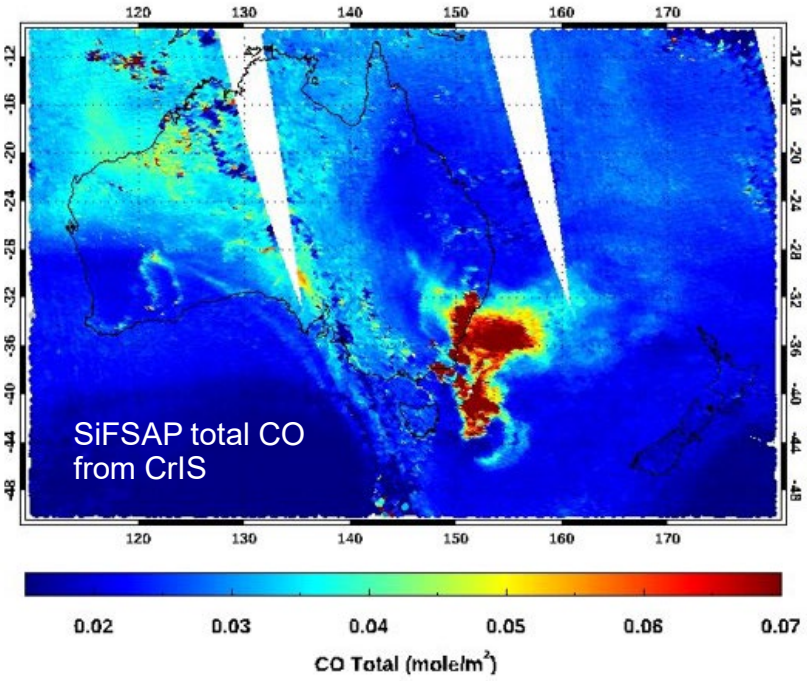
ClimFISP fiited CrIS residual spectra



High Spatial Resolution SiFSAP CO from CrIS and comparison with TROPOMI for Australia Fires on December 30, 2019







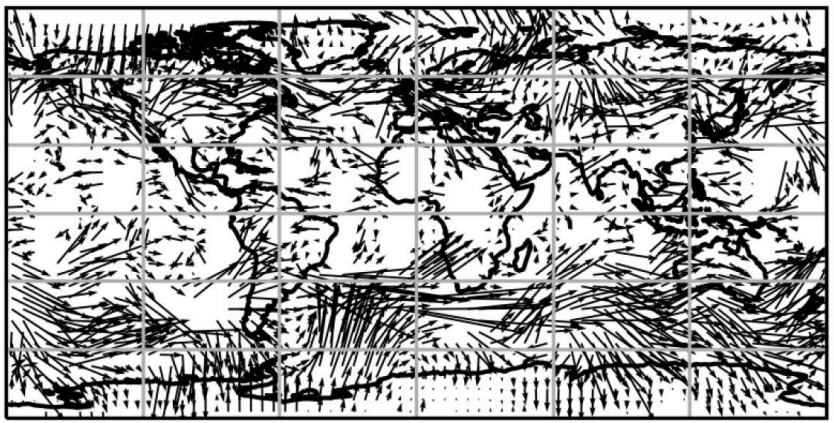
- Both TROPOMI (4 km resolution) and SiFSAP (14 km) capture fine CO plume spatial distributions
- CLIMCAPS cannot capture the fine CO features
  - Low resolution retrieval (45 km)
  - Less coherent CO due to errors in cloud clearing
- SiFSAP is less affected by the fire particular (dust) emission relative to TROPOMI
  - SiFSAP retrieves effective cloud optical depth to compensate for fire particular contributions
  - TROPOMI has many non-successful retrievals due to clouds and fire dust emissions

Example of 3-D Atmospheric Wind Vectors Derived from SNPP/CrIS and NOAA20/CrIS SiFSAP (Univ. Arizona)

SIFSAP (July 7, 2020)

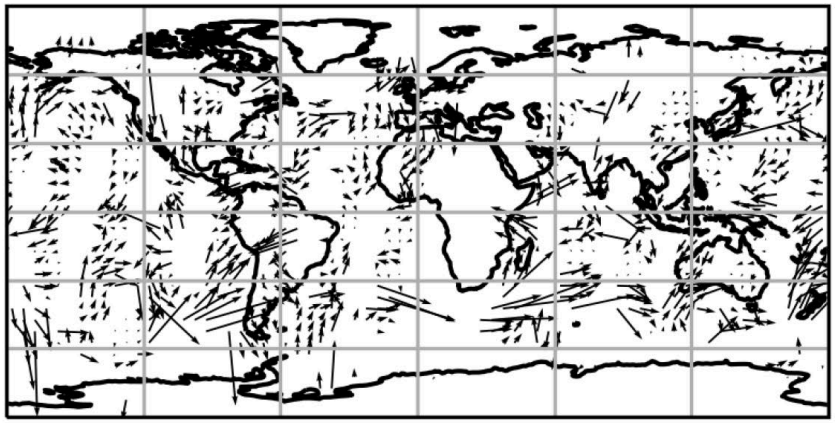
RMSVD = 6.1 m/s 850 hPa Δs = 0.77 m/s

RMSVD = 5.87 m/s 500 hPa Δs = -0.91 m/s



CLIMCAPS (July 7 2020)

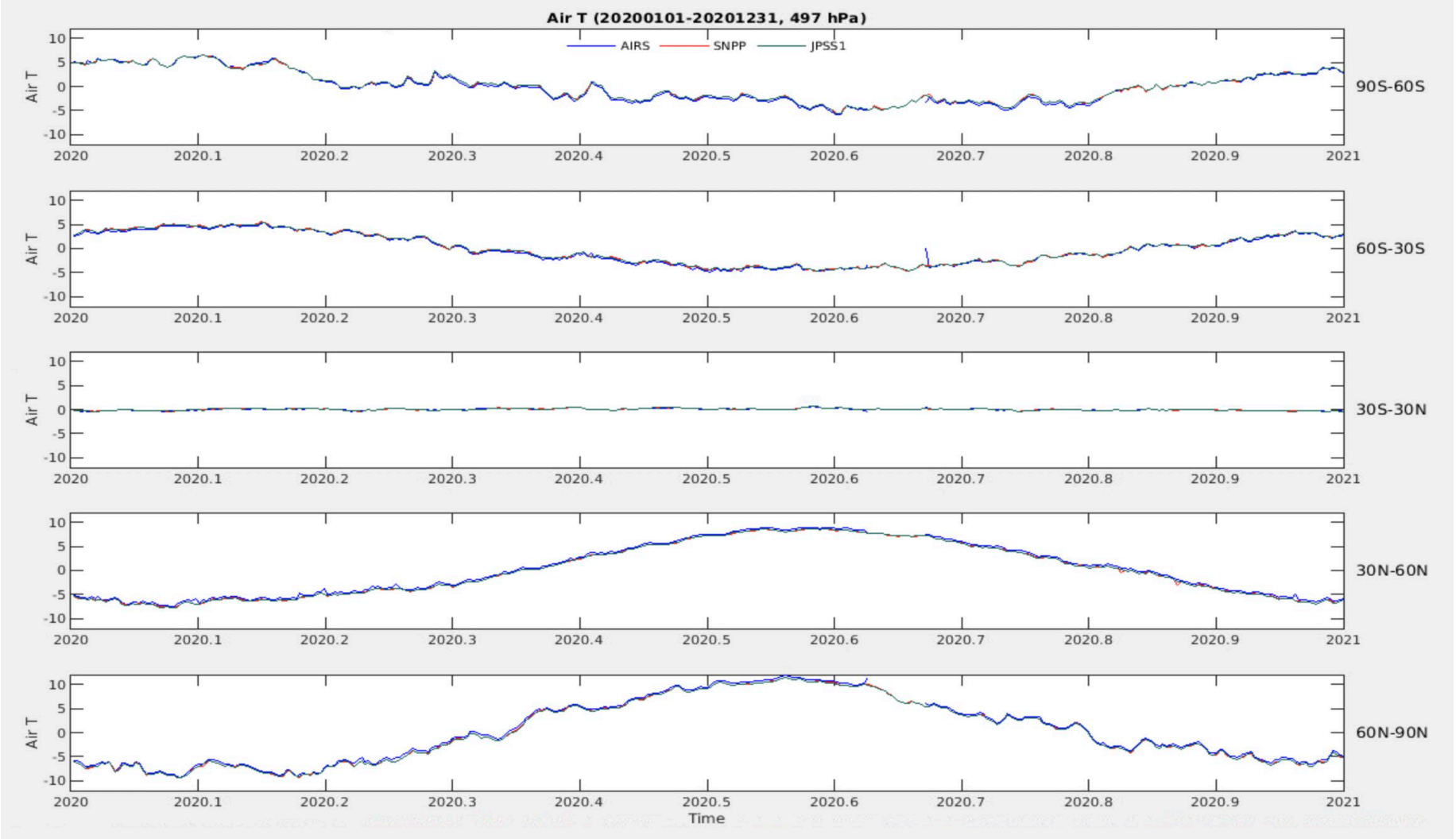
RMSVD = 5.72 m/s 850 hPa Δs = -2.18 m/s



RMSVD = 5.99 m/s 500 hPa Δs = -2.09 m/s

Consistent ClimFiSP Products from Aqua/AIRS, SNPP/CrIS, and NOAA20 CrIS (2020)

500 hPa Temperature from Aqua/AIRS (Blue) SNPP/CrIS (Red), and NOAA20/CrIS (Green)

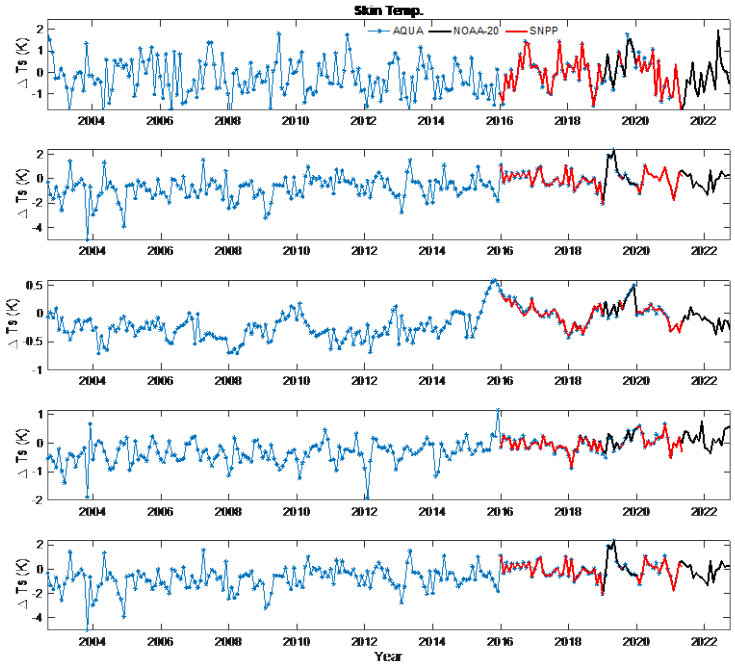


Applying the ClimFiSP Algorithm to CHIRP

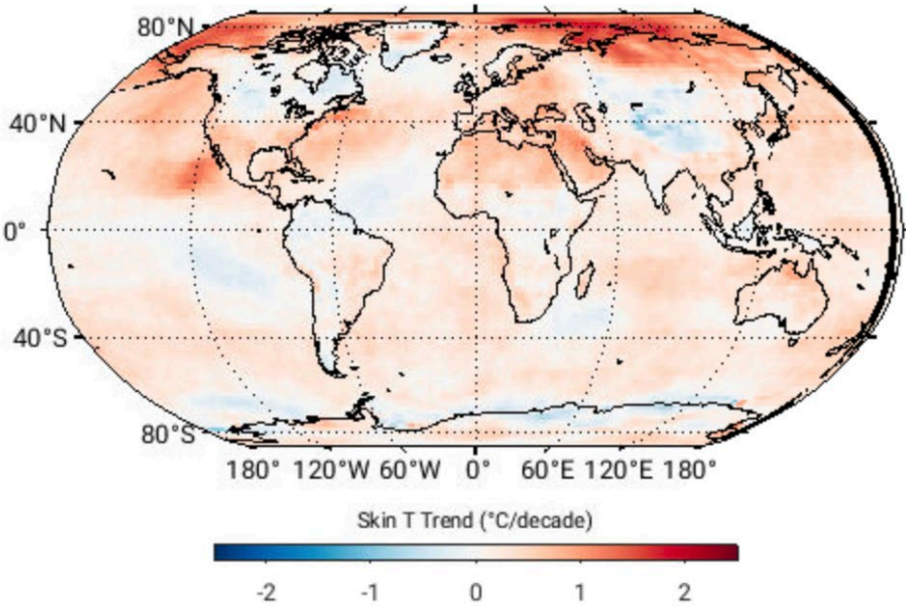
- CHIRP - Climate Hyperspectral Infrared Radiance Product
  - Bias-corrected radiance (L1) time series for Aqua/AIRS, SNPP/CrIS, and NOAA20/CrIS
  - Generated by Larrabee Strow et al (2021)
  - Available at NASA Sounder SIPS and DACC

- We have applied the ClimFiSP algorithm to CHIRP data from 2003-2022
  - 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 different latitude bins
Blue:Aqua/AIRS, Red: SNPP/CrIS, Black: NOAA20/CrIS

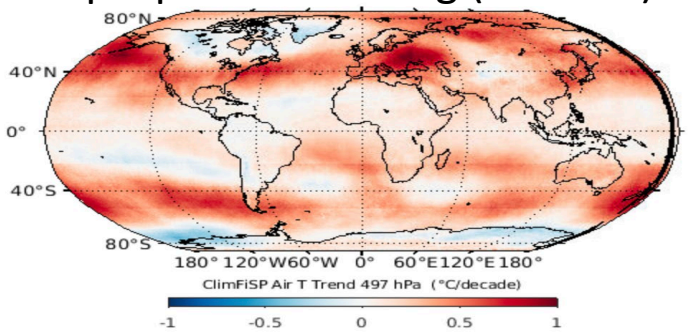


Example of ClimFiSP derived global surface temperature trend from 20 years of sounder data

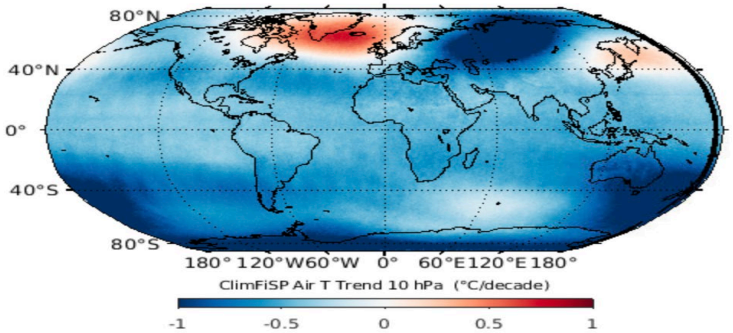


20-year Climate Trends from ClimFiSP

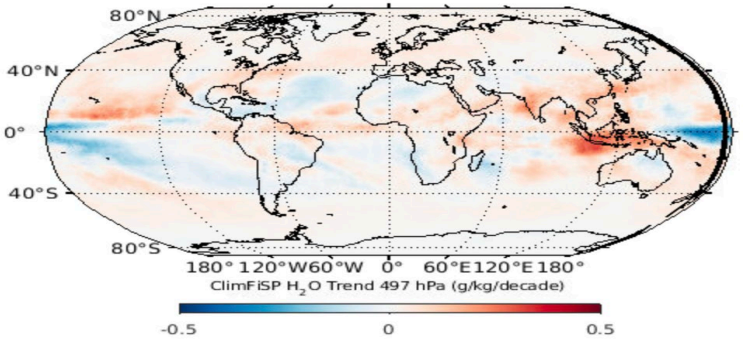
Tropospheric warming (500 hPa)



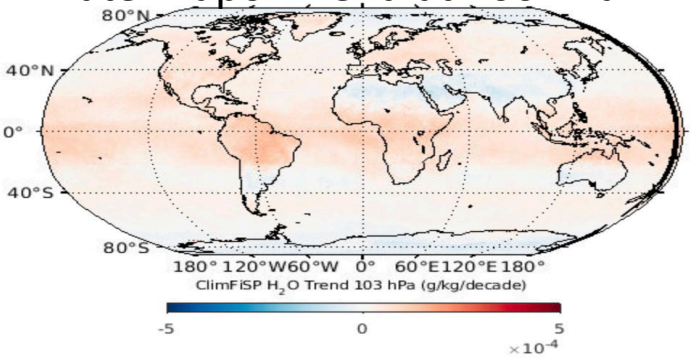
Stratospheric cooling (10 hPa)



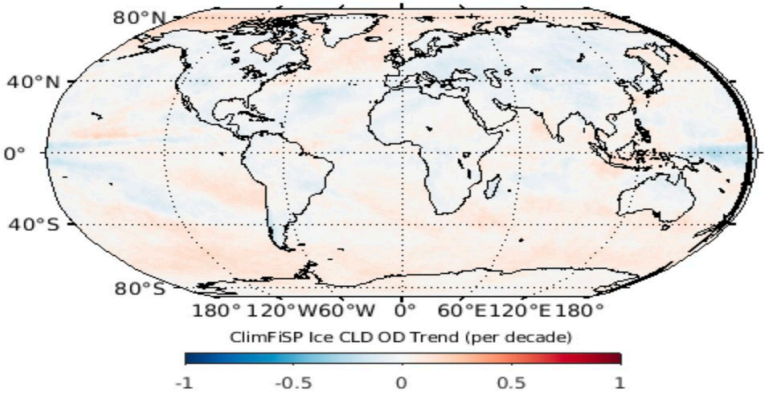
Water Vapor Trend at 500 hPa



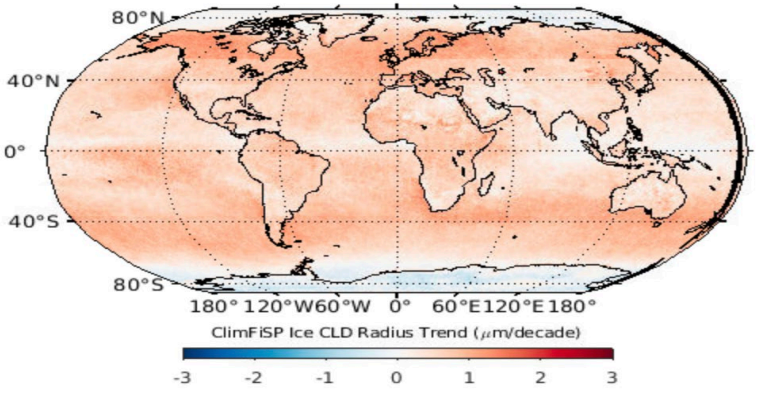
Water Vapor Trend at 100 hPa



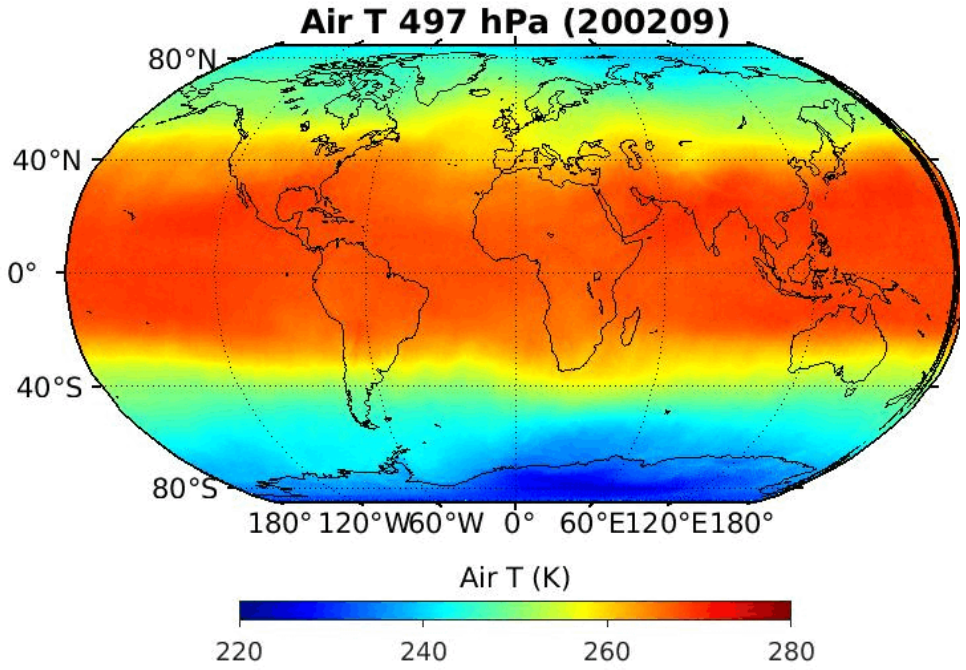
ClimFiSP Ice Cloud Optical Depth Trend

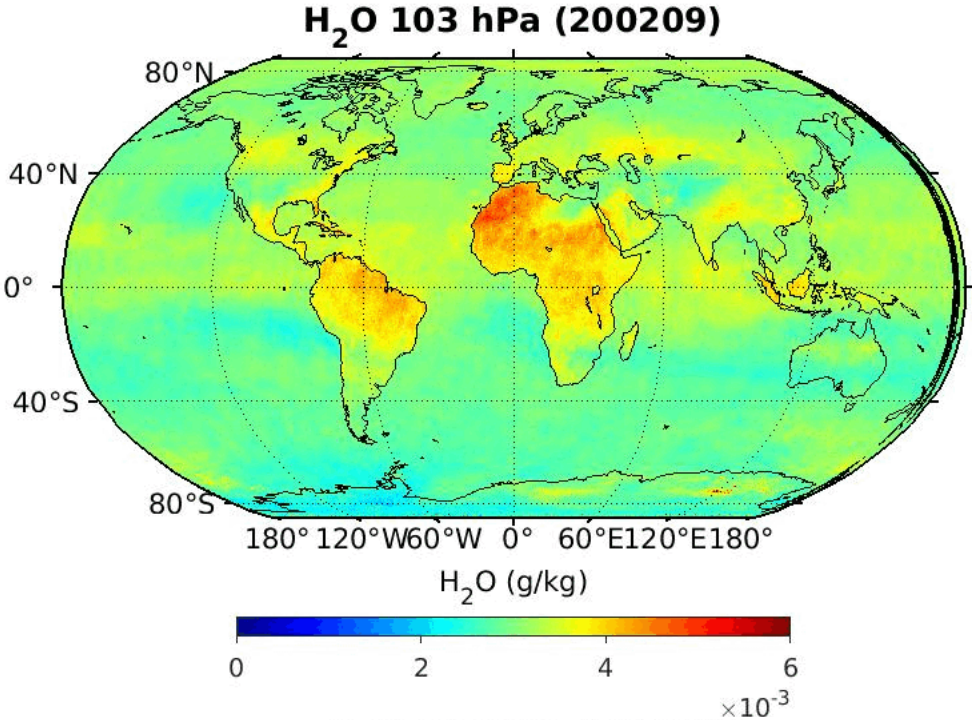


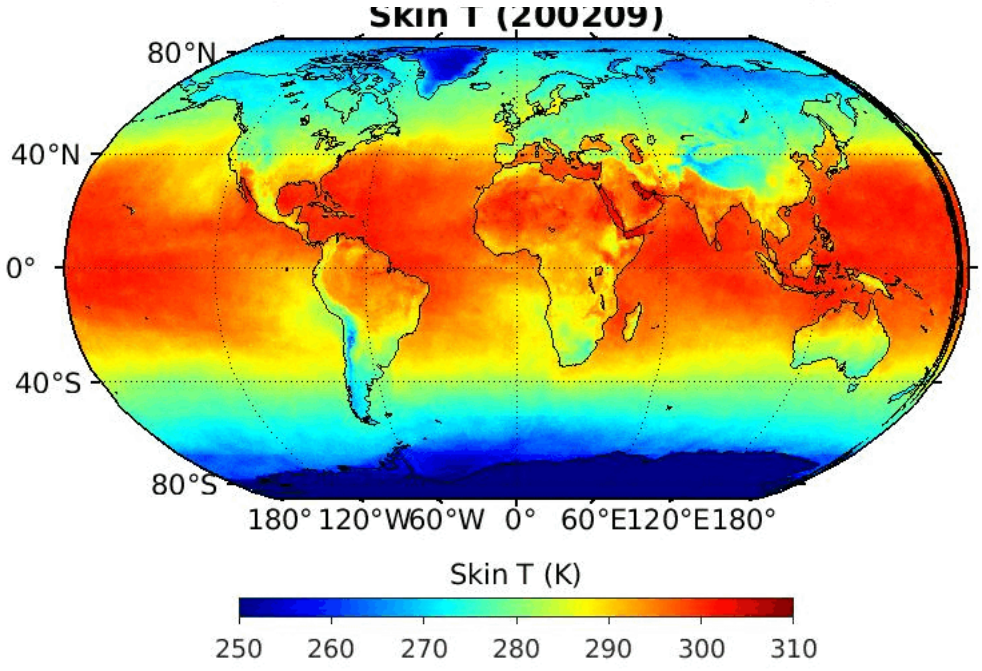
ClimFiSP Ice Cloud Effective Radius

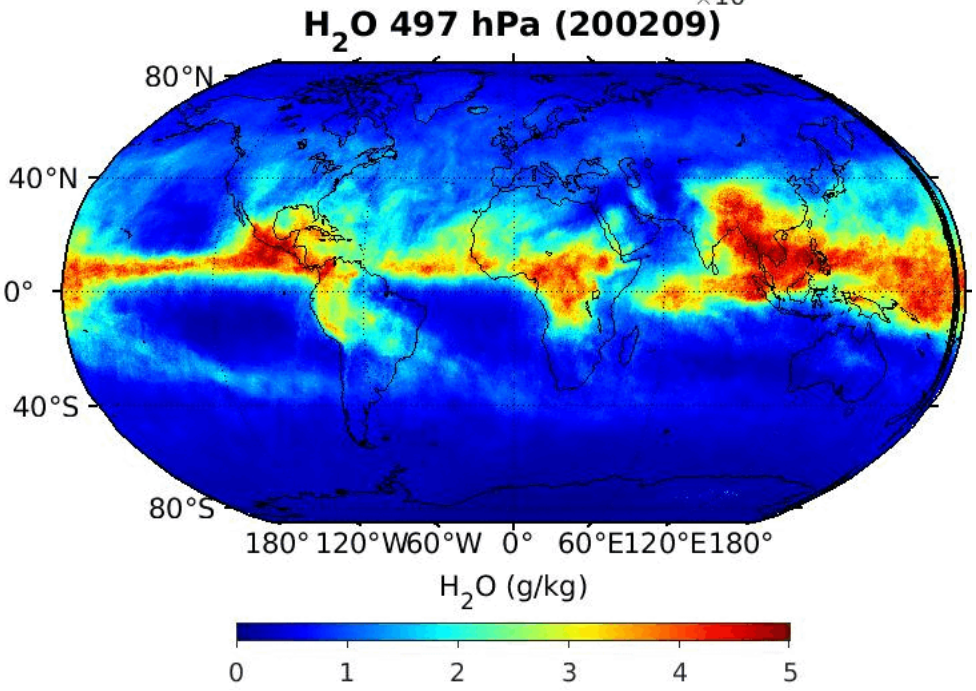


20-year of Daily and Monthly Mean Global Product from ClimFiSP









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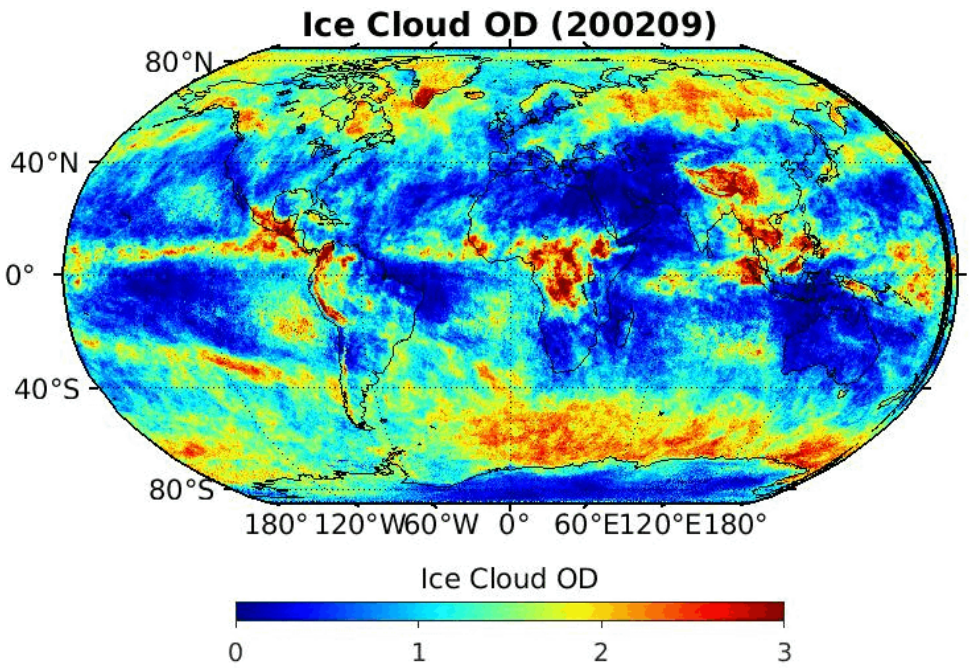

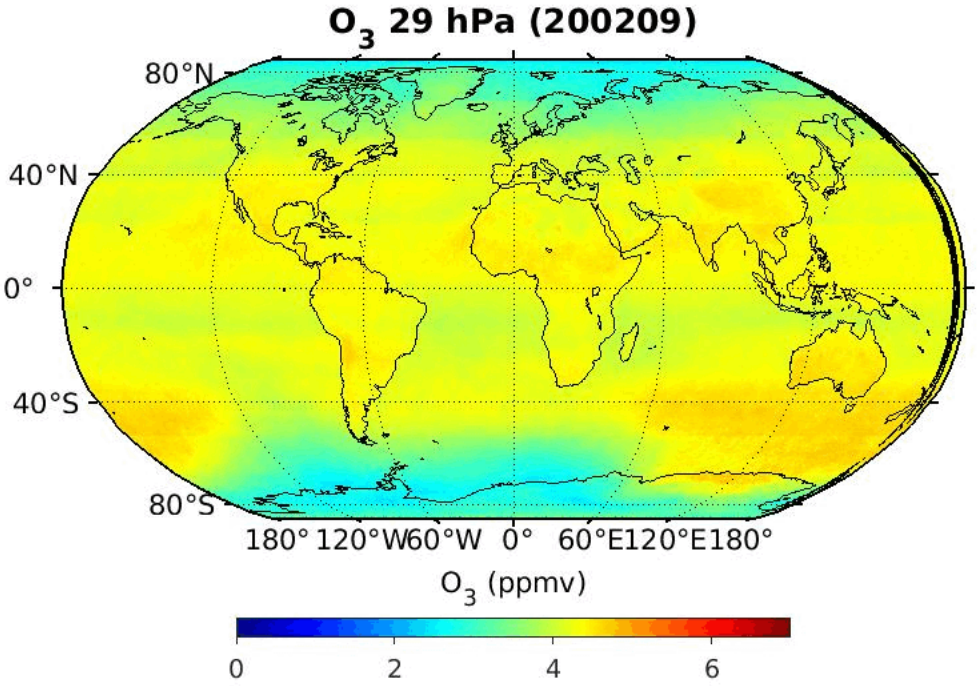

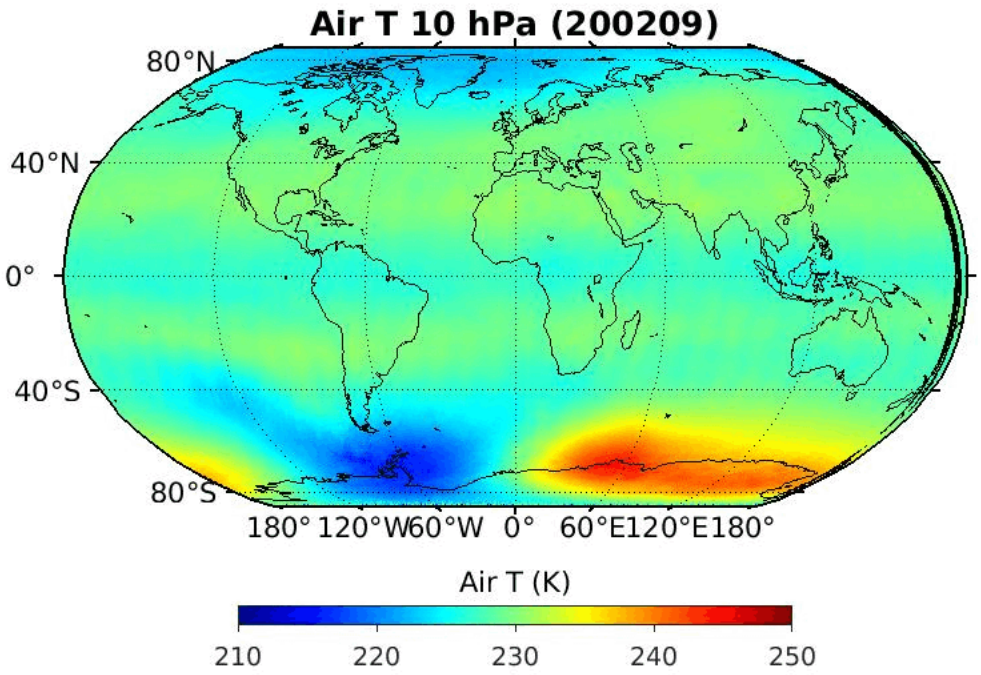

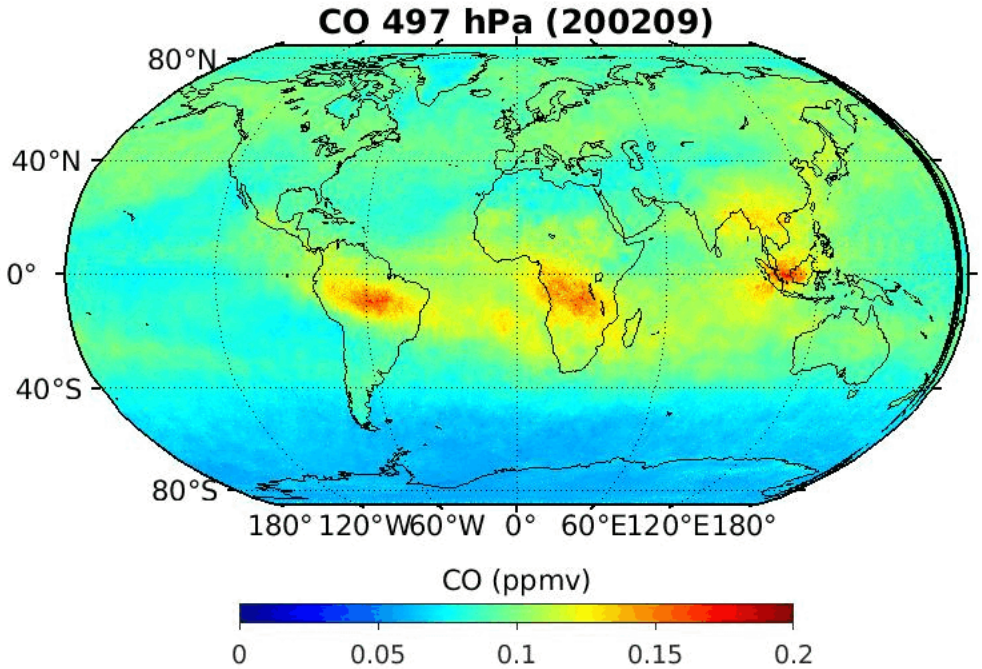

Summary and Conclusions

- Consistent CDRs from 20-years of IR hyperspectral Sounders has been derived using NASA Langley's ClimFiSP L1-L3 algorithm
  - Temperature, water vapor, and trace gas atmospheric profiles
  - Cloud temperature, pressure, optical depth, phase, and effective size
  - Surface skin temperature and surface emissivity spectra
- The advantages of ClimFiSP (L3) include
  - Observation-based radiative kernels derived from our SiFSAP L2 algorithm
  - 3-4 orders of magnitude faster than traditional L1-L2-L3 algorithms
  - Consistent CDRs using the same radiative kernels for all IR sounders
  - Radiance closure by fitting observed radiance spectra (all channels)directly
- SiFSAP (L2) products are being produced at NASA GES DICS
  - Available to public in NASA GES DISC since 2023
- ClimFiSP product will be available at GES DISC soon
  - Aqua AIRS, SNPP and NOAA-20 ClimFiSP will be available soon
  - Will continue to process NOAA-21 CrIS and future JPSS IR sounder data
  - ClimFiSP algorithm can also be applied to Metop IASI data