



# Status of the AIRS on Aqua and the CubeSat Infrared Atmospheric Sounder (CIRAS)

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# AIRS Experiment Successfully Demonstrates Science and Technology

- Technology
  - AIRS Launched May 4, 2002 on Aqua Spacecraft
  - First demonstration of hyperspectral infrared grating spectrometer for atmospheric sounding
  - Successful demonstration IR spectrometer technologies including detectors, gratings and cryocoolers
- Science
  - Over 805 Peer Reviewed Publications To Date
  - Science Topics: weather related processes (transport, convection, extremes), climate science (ENSO, MJO, climate model validation), and Applications (drought, vector borne diseases, flu, air quality)
- Weather Forecasting
  - AIRS radiances assimilated into the operational forecast at NWP centers worldwide
  - AIRS and IASI have the highest impact of any single instrument to operational forecast improvement. Second highest overall next to microwave.

AIRS Instrument



First In-Flight use of Split Sterling Pulse Tube Cryocooler (NG)



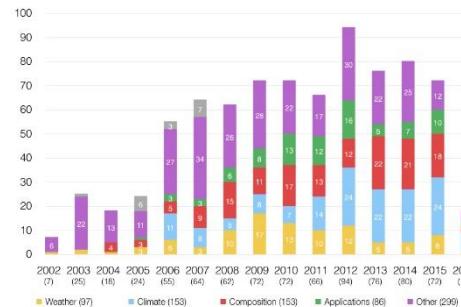
IR Grating Spectrometer 155K Operation



FPAs: PV HgCdTe to 13.7  $\mu\text{m}$ , PC HgCdTe to 15.4  $\mu\text{m}$

AIRS Peer Reviewed Publications

January 2002 to March 2016



Water Vapor % Difference 2007(Warmer)-2008(Cooler) (Dessler, 2008)

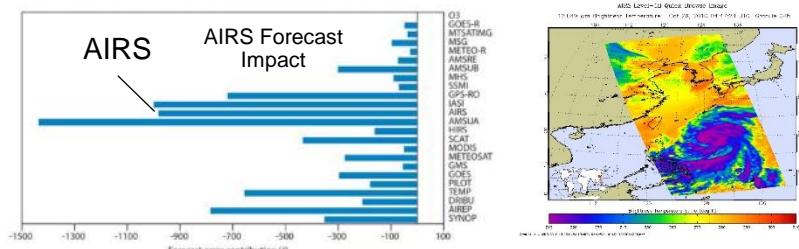
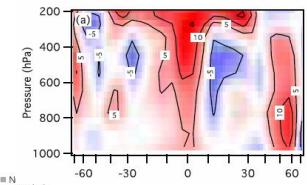
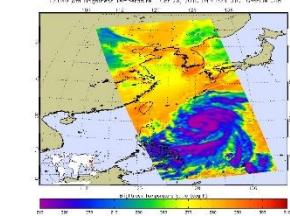


Figure 11. 24-hour forecast error contribution ( $\text{Joule} \cdot 10^4$ ) of the components (types) of the observing system during September, October, November and December 2008. Negative (positive) values correspond to a decrease (increase) in the energy norm of forecast error.

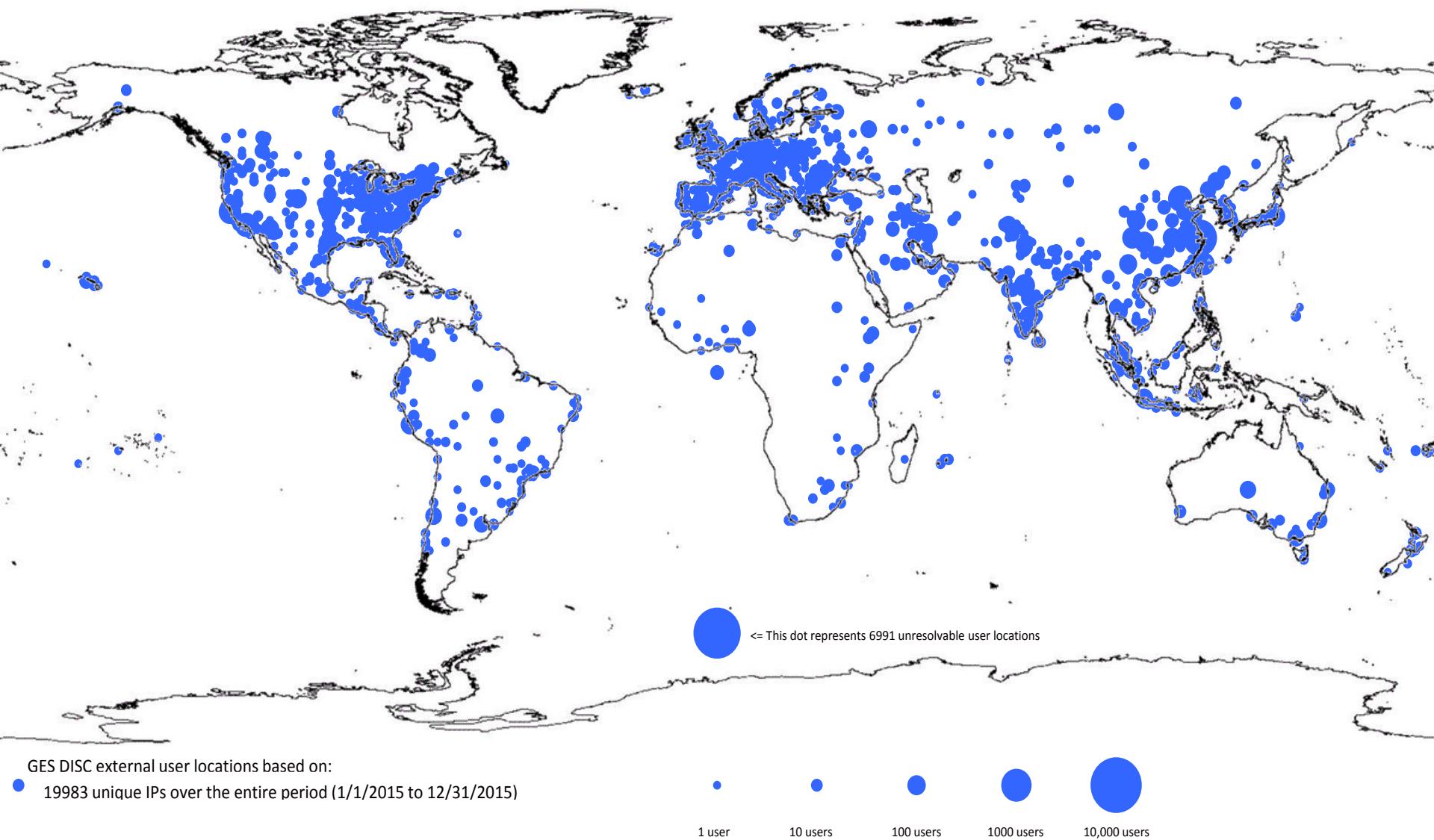
From Cardinali (ECMWF Tech. Memo. 599, 2009)

AIRS Imagery and Skew T Used in Near Real Time





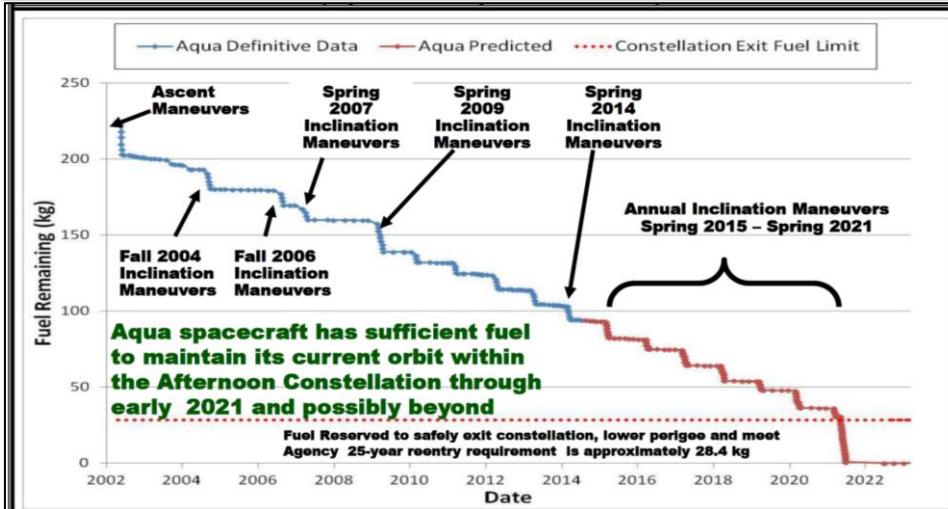
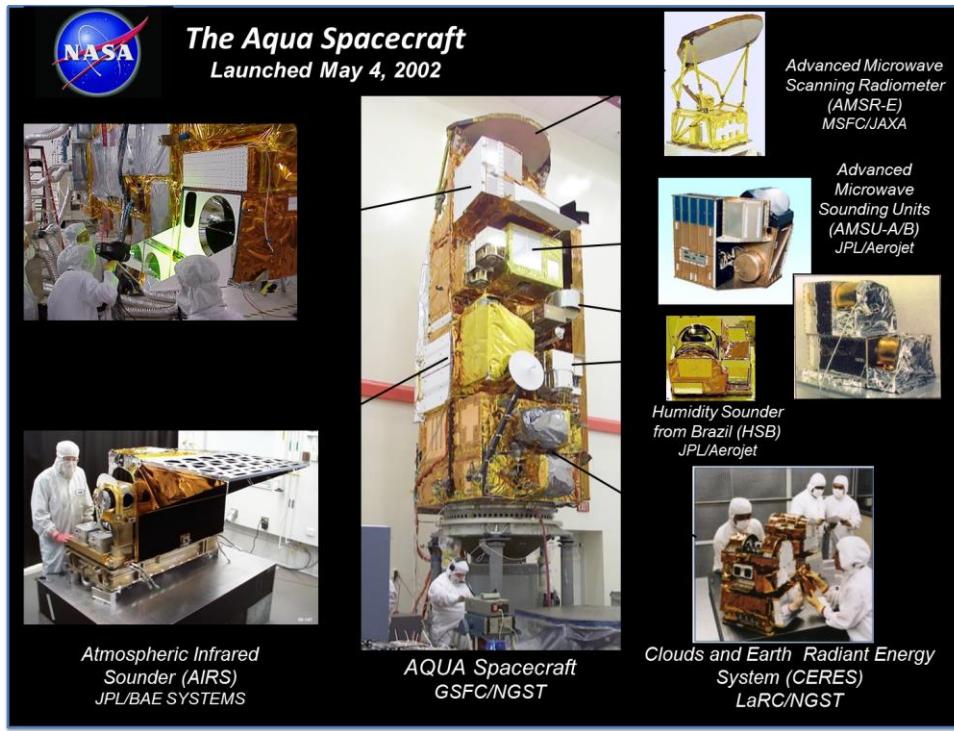
# Users Over the World Access AIRS Data in 2015



Feng Ding (GSFC)

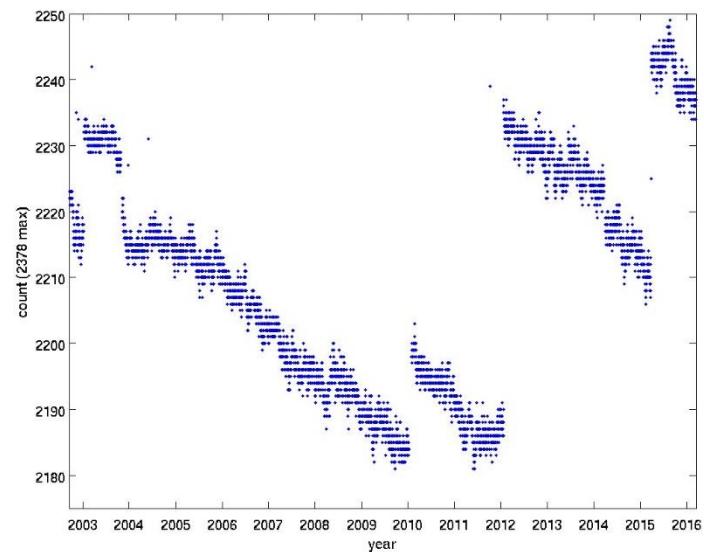


# AIRS operational for 14 years to date with more than 5 years to go!



- Aqua Spacecraft Healthy
- AMSR-E Instrument Failed
- HSB Instrument Failed
- MODIS Healthy
- AMSU Loss of several channels but still working
- AIRS Healthy. Lost channels recovered by switching to redundant detectors

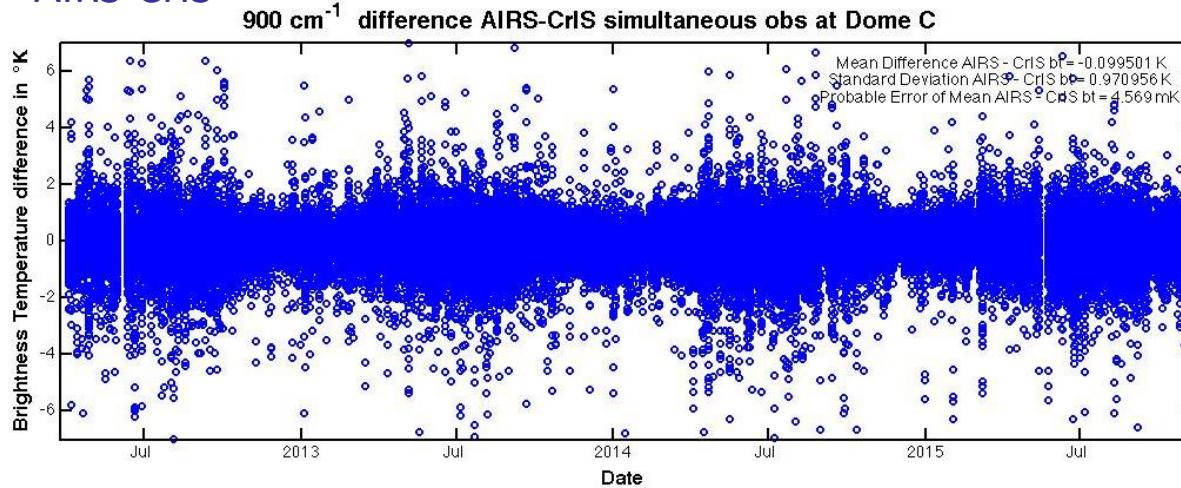
Channel count maintained



# IR Sounders AIRS, CrIS and IASI agree to better than 100 mK on average

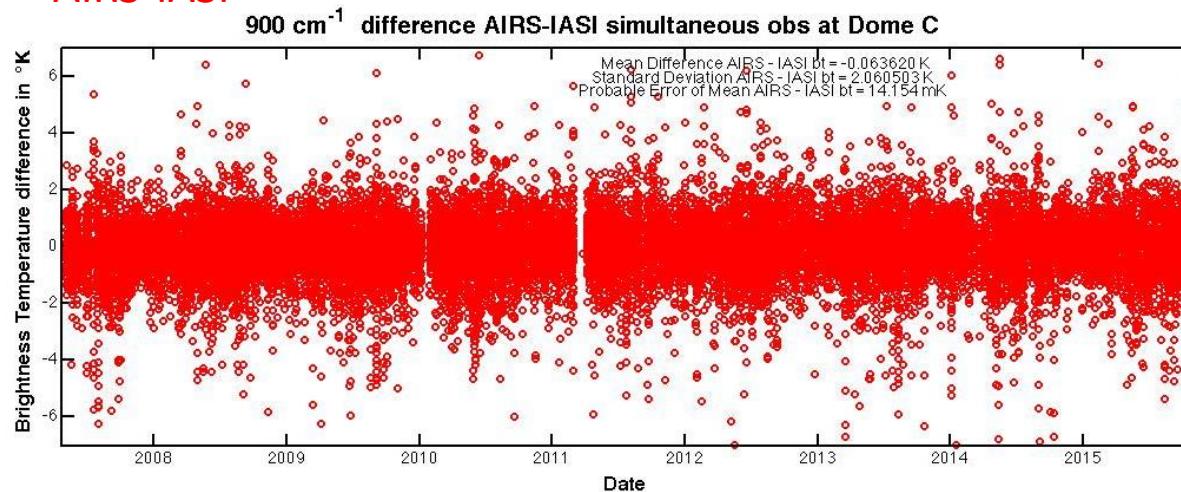
Averaged over all data AIRS is colder than CrIS by 100 mK with probable error 5 mK

AIRS-CrIS



AIRS is colder than IASI by 64 mK with probable error 14 mK

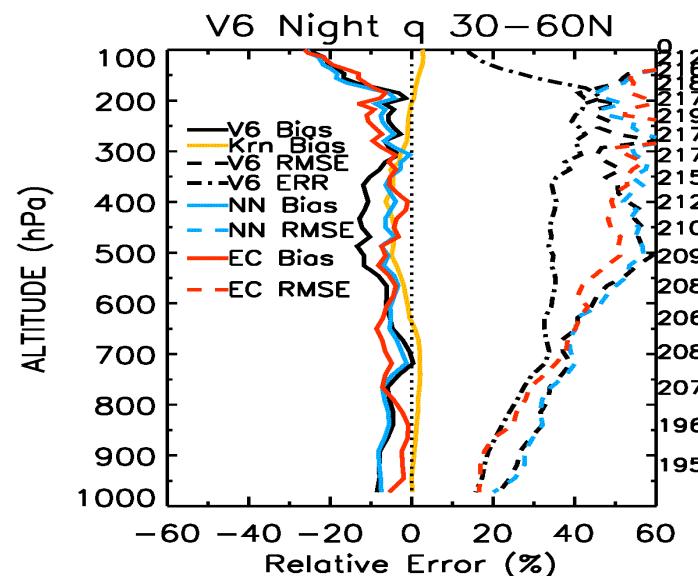
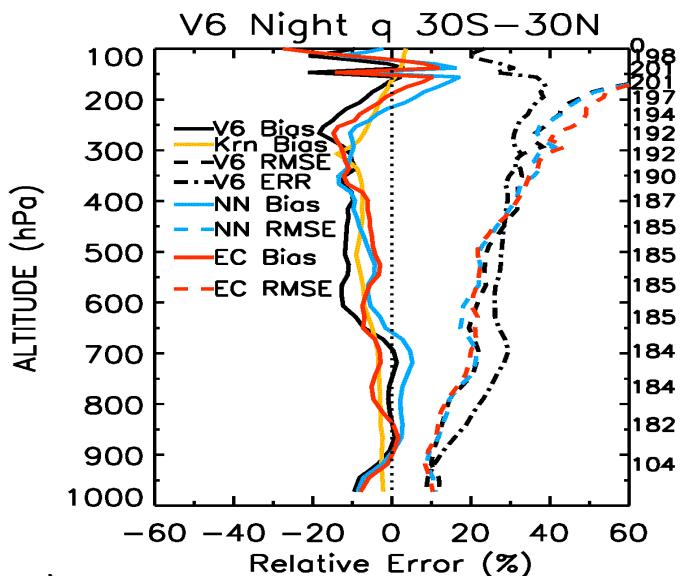
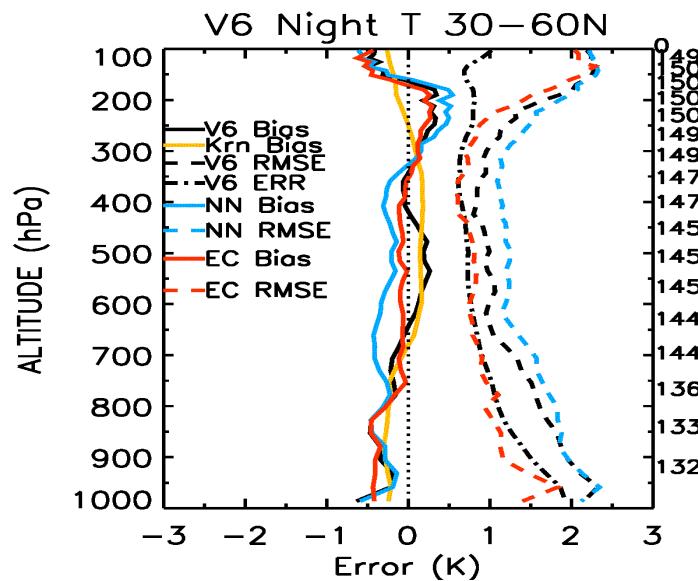
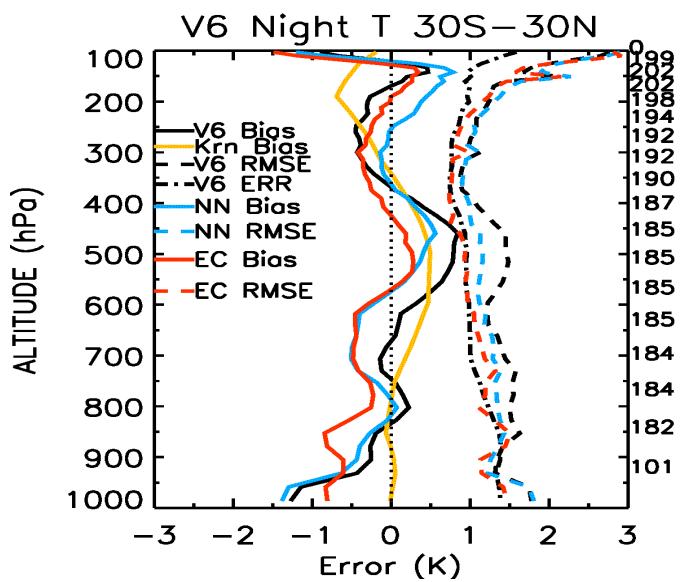
AIRS-IASI



The standard deviation of the differences is noticeably lower during Antarctic summer, especially for AIRS-CrIS

No significant trend with time was found

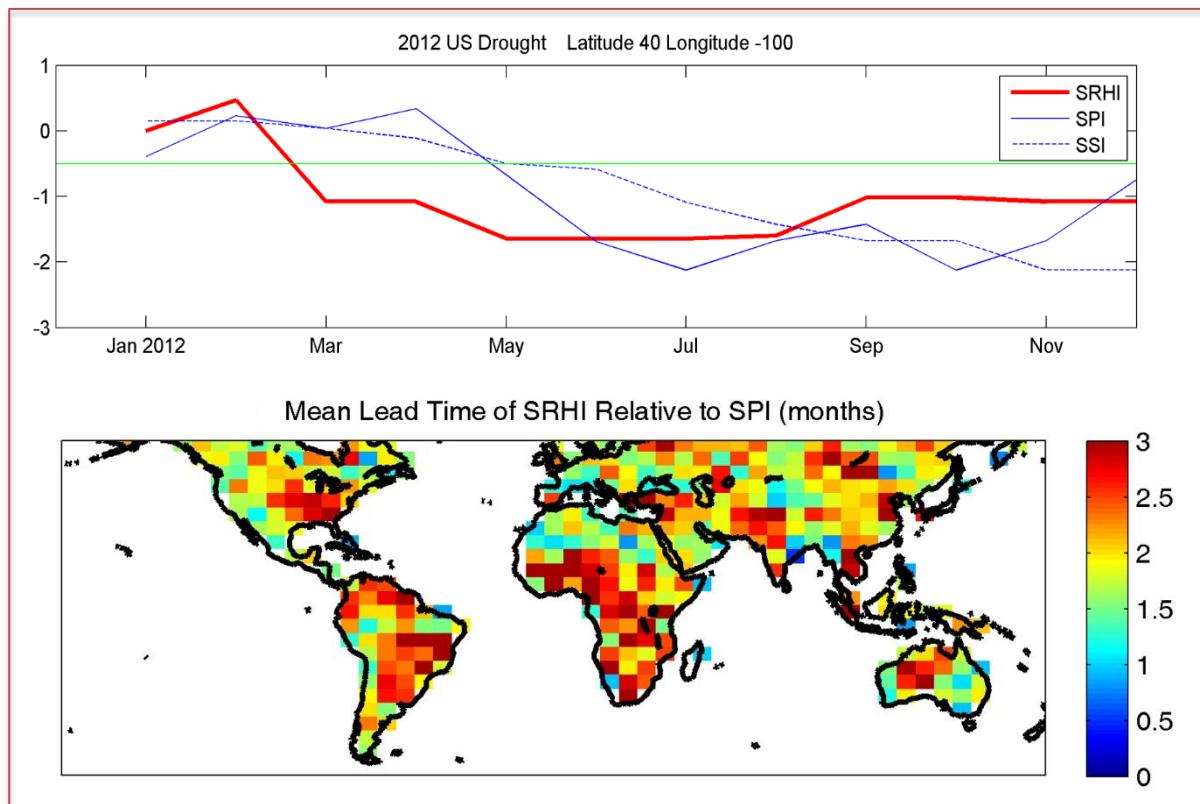
# V6 L2 Temperature and Water Vapor Bias and RMS Error Compare Well to Radiosondes





# AIRS Applications: AIRS Shows Skill in Early Drought Detection

Standardized Relative Humidity Index (SRHI) from AIRS near surface RH detects drought onset earlier than other indicators

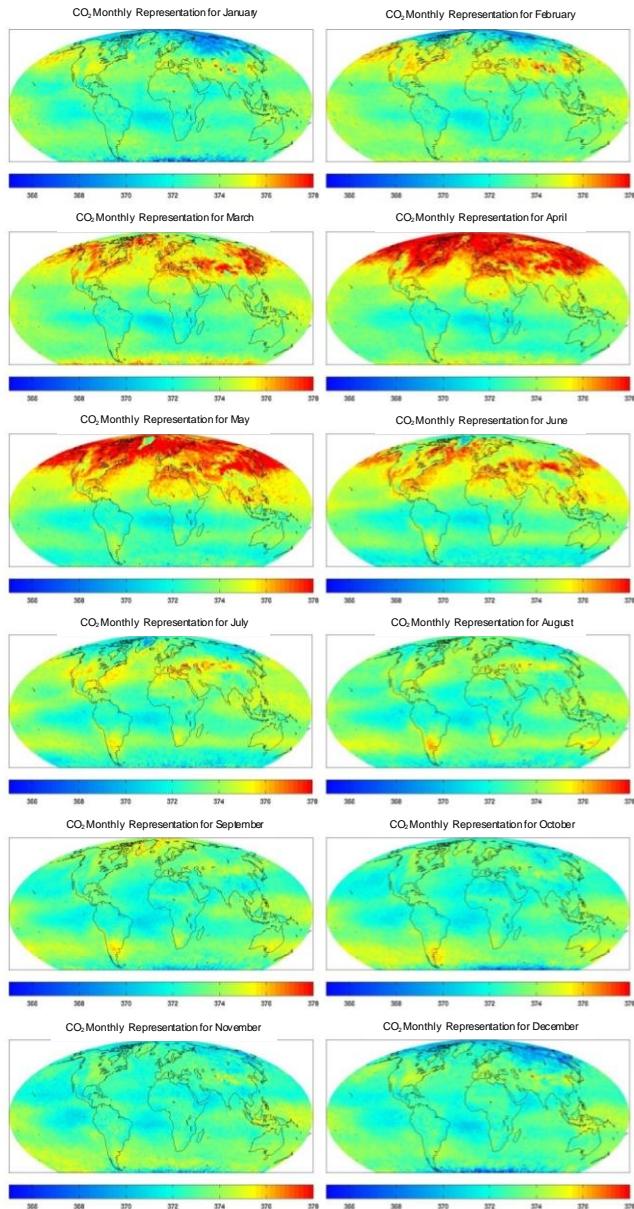


Mean global AIRS-based SRHI lead time: **1.9 month**

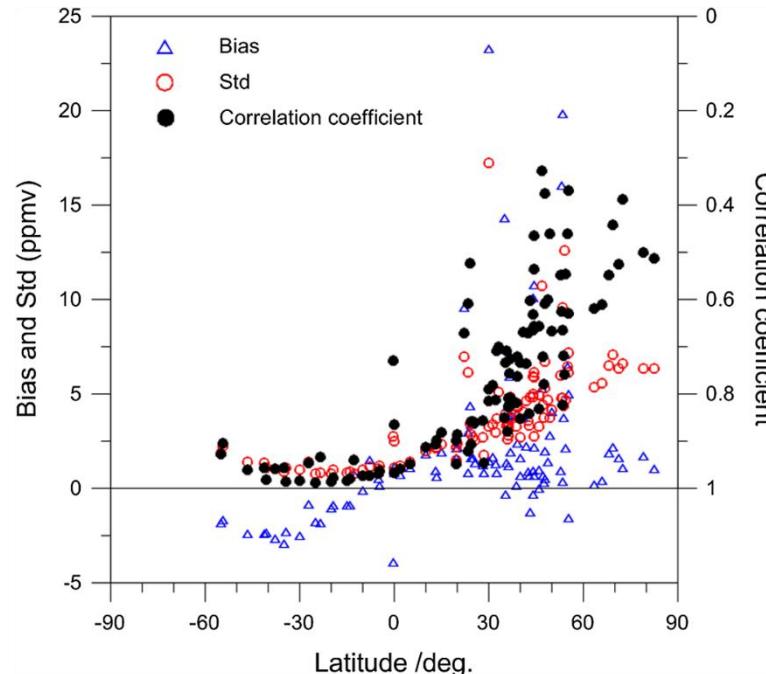
Farahmand et al, 2015, *A Vantage from Space Can Detect Earlier Drought Onset: An Approach Using Relative Humidity*, *Scientific Reports*, 5, 8553; doi: 10.1038/srep08553.



# AIRS Monthly L3 and Mid-Tropospheric CO<sub>2</sub> Version 5 Climatologies Now Online

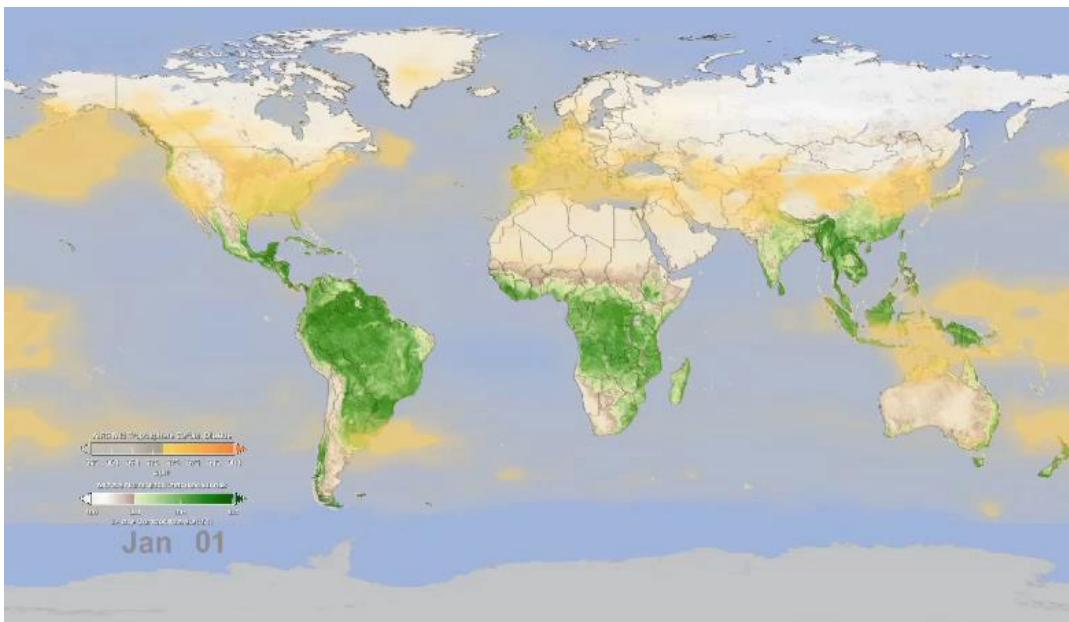


- AIRS CO<sub>2</sub> Climatology: Average of AIRS L3 Monthly CO<sub>2</sub> over years 2003-2014
  - co2.jpl.nasa.gov
  - AIRS L3 CO<sub>2</sub> Compared to Global Ground Network. AIRS Data from 2002-2011
  - Higher biases, lower correlation in northern lats

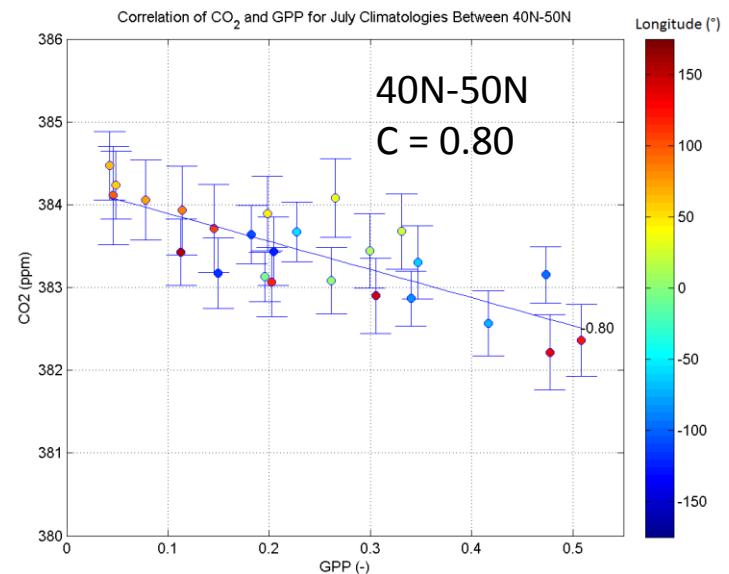


- Zhou, Mandi, Jiong Shu, Ci Song, and Wei Gao. "Sensitivity studies for atmospheric carbon dioxide retrieval from atmospheric infrared sounder observations." *Journal of Applied Remote Sensing* 8, no. 1 (2014): 083697-083697.
  - Pagano, T. S., Olsen, E. T., Chahine, M. T., Ruzmaikin, A., Nguyen, H., Jiang, X., "[Monthly representations of mid-tropospheric carbon dioxide from the Atmospheric Infrared Sounder](#)," Proc. SPIE 8158-11, San Diego, CA (2011).

# AIRS CO<sub>2</sub> Shows Influence of Surface in addition to Atmospheric Transport



High Correlation of CO<sub>2</sub> and GPP for July in NH Boreal Forests



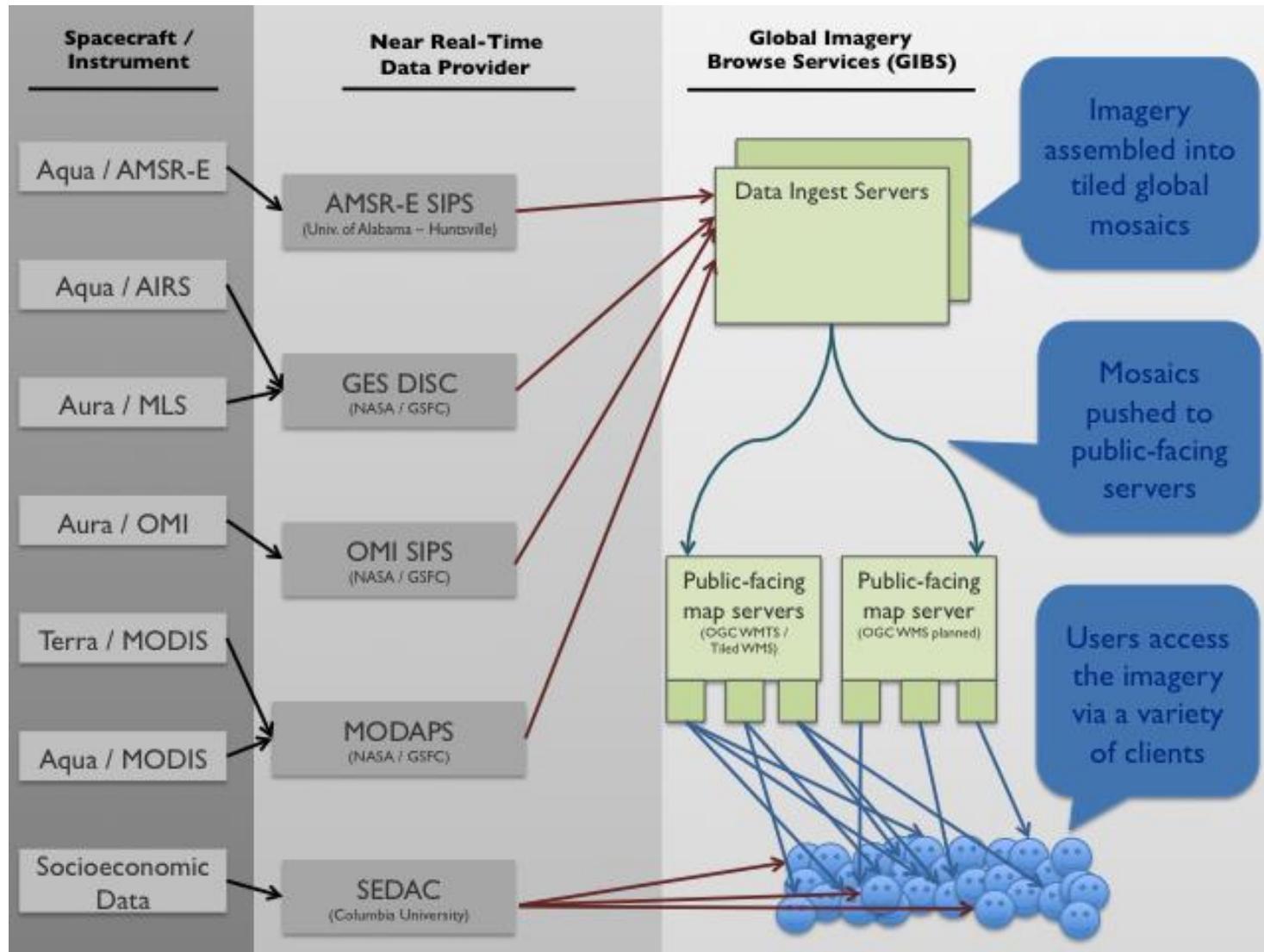
Animation: L. Perkins (GSFC/SVS)

## Mid-Trop CO<sub>2</sub> influenced by surface sources and sinks

- Strong seasonal cycle present in AIRS mid-trop CO<sub>2</sub>
- NH mid-trop CO<sub>2</sub> amplitude damped and phase delayed relative to the surface
- Spatial correlation of CO<sub>2</sub> distribution and GPP during period of strong seasonal drawdown



# AIRS Part of NASA Global Imagery Browse Services (GIBS)

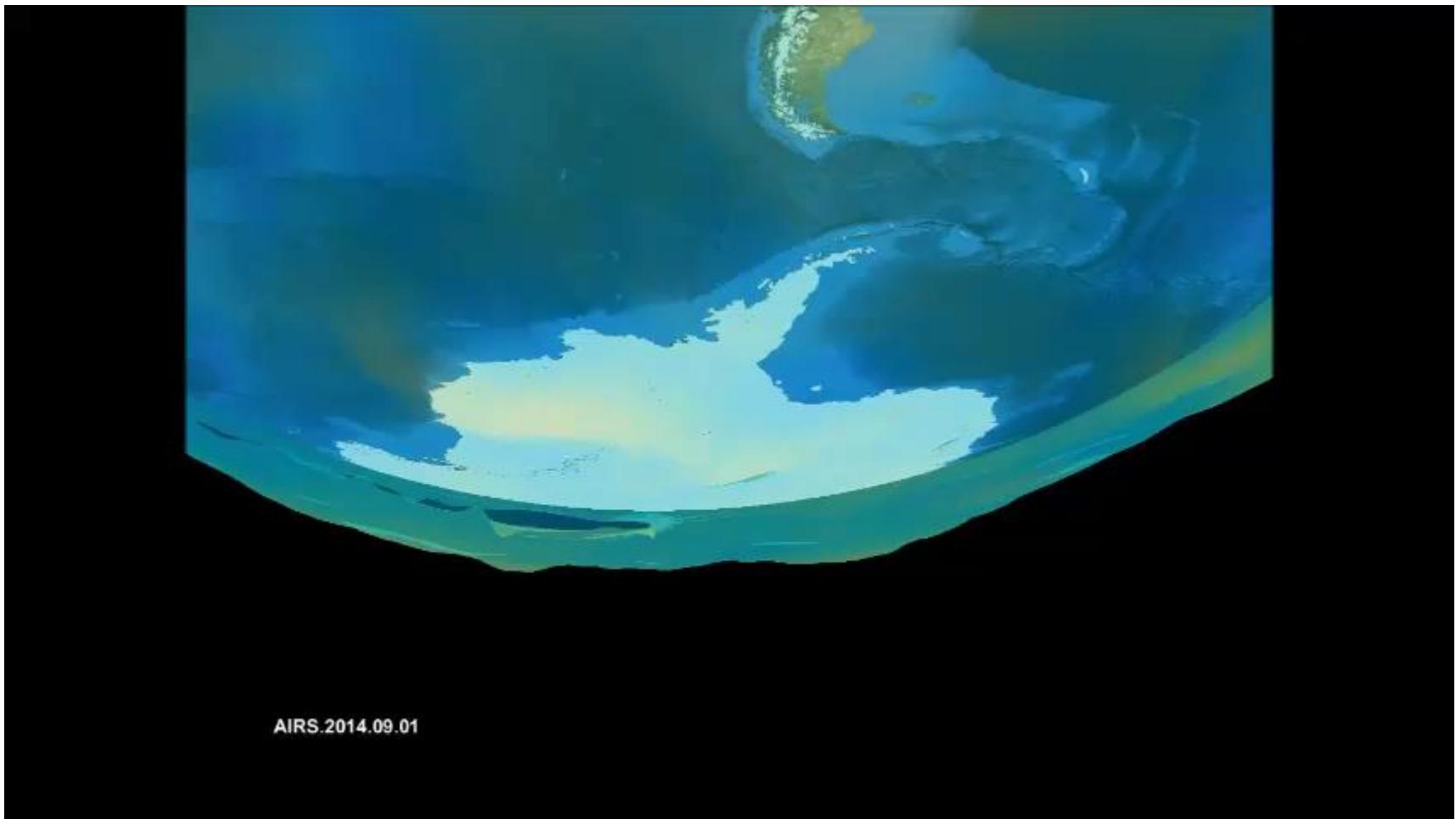


<https://earthdata.nasa.gov/about-eosdis/system-description/global-imagery-browse-services-gibs>



# IR sounders provide 3D view of atmospheric processes with multiple visits per day

AIRS O<sub>3</sub> Isosurface, Sept, 2014



AIRS.2014.09.01

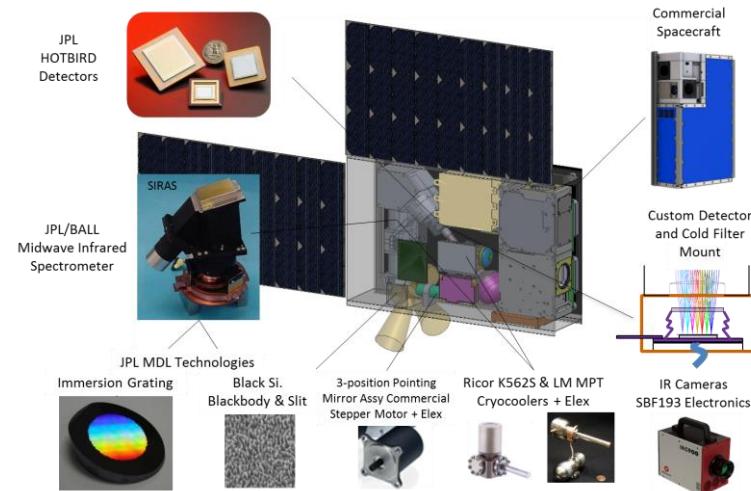
AIRS O<sub>3</sub>\_VMR, 2014. Isosurface at  $5 \times 10^{-7}$  ppmv. Altitude Scale: 100, Altitude Offset:  
10 km, Max Altitude (above which transparent): 18 km  
Animation: T. Pagano (NASA/JPL)

# The CubeSat Infrared Atmospheric Sounder (CIRAS) Objectives and Mission Summary

CIRAS is a ***technology demonstration*** mission to enable hyperspectral infrared atmospheric sounding on a low-cost, quick-turnaround platform.

- CIRAS Objectives
  - Selected by NASA ESTO InVEST in 2015
  - In-Space Technology demonstration of key infrared technologies: LM MPT Cryocooler, JPL HOT-BIRD IR Detectors, JPL Grism Spectrometer
  - Demonstration of Mid-wavelength Infrared (MWIR) temperature and water vapor sounding. Limited to mid to lower troposphere. Supports operational weather prediction and scientific research on the lower troposphere
- Implementation Summary
  - 6U CubeSat (approx. 30 x 20 x 10 cm, 9 kg)
  - Deployed into LEO Sun Synchronous Morning Orbit (400 km – 850km)
  - Minimum Mission Duration: 3 months
  - JPL Lead on Payload. Ball, IRCameras Sub
  - Commercial 6U spacecraft, I&T, & ATLO
  - Selected by NASA CubeSat Launch Initiative for Launch in 2018/2019 timeframe

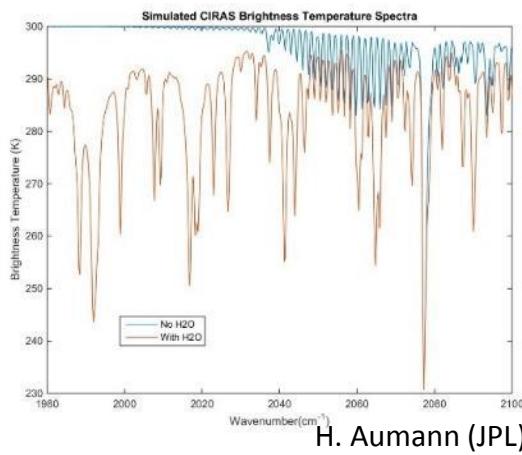
Parameter	Legacy (CrIS) Performance	CBE
Orbit	824 km	450 km
Vertical Range	1000-50mb	1000-300 mb
Temperature Profile	≤1.5 K/km	≤1.2 K/km
Humidity Accuracy	15%/2km	15%/2km
Spatial Res. (nadir)	13.5 km	13.5 km
Scan Range	2040 km	165 km
Spectral Range	3.9-15.4 μm	4.78-5.09 μm
Spectral Resolution	0.625 cm⁻¹	0.5 cm⁻¹
NEdT	<0.25 K	<0.25K



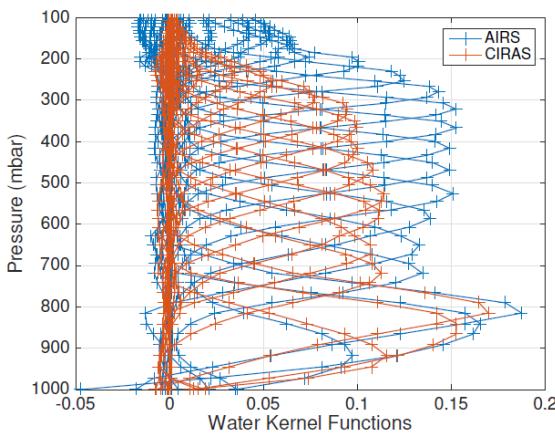


# MWIR Sounding Band Has Good Lower Tropospheric Water Vapor Sensitivity

CIRAS Temperature and Water Vapor Spectrum  
1965-2090 cm<sup>-1</sup>



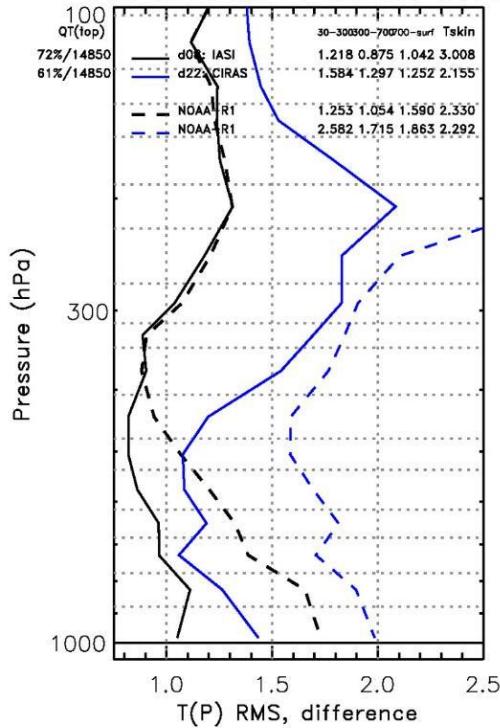
Sensitivity is Comparable to Legacy Sounders in Lower Troposphere



- MWIR-Only Sounding Gives Good Lower Trop Temperature and Water Vapor Sensitivity
- Proven Performance using IASI
- To be demonstrated again on the CubeSat Infrared Atmospheric Sounder (CIRAS) in 2018/2019

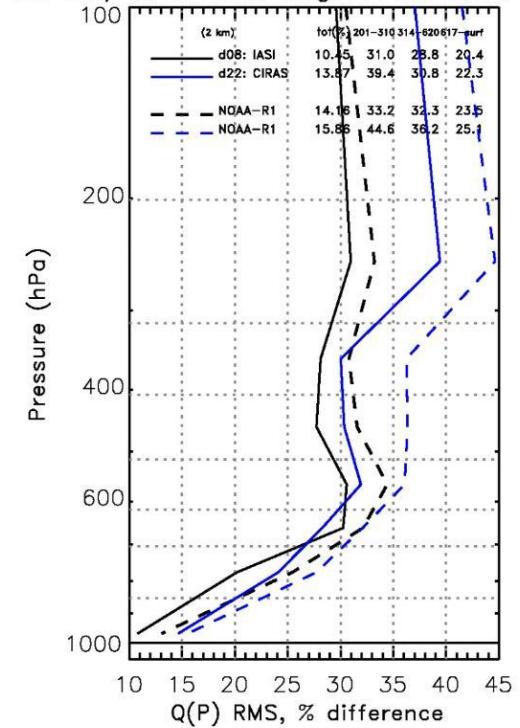
Temperature

IASI & CIRAS Feb. 17, 2015



Water Vapor

22 Day Granules, Regression First G



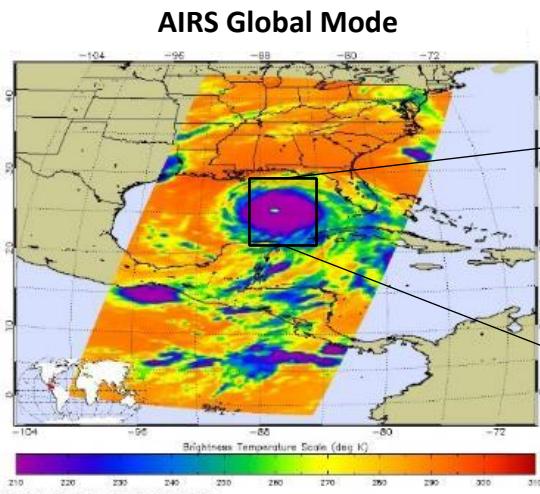
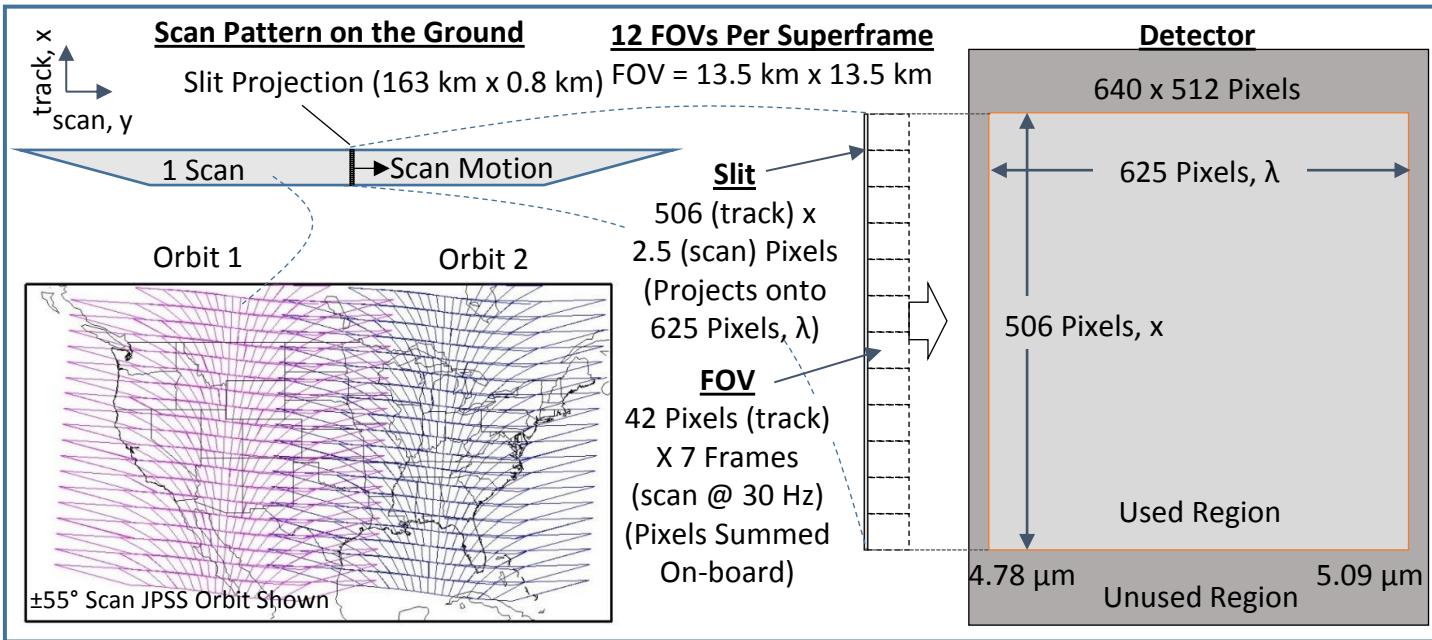
Relative to ECMWF

C. Barnet (STC)

# Zoom Mode and Global Mode Possible in CIRAS

- Programmable Pixel Binning and Scan Rate Allow Global and Zoom Modes

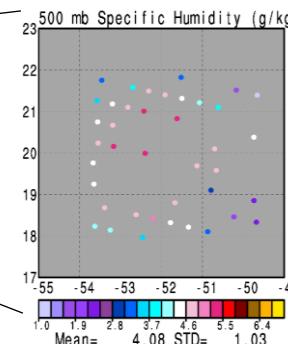
CIRAS  
Scan  
Pattern



Simulated Sounder Yield

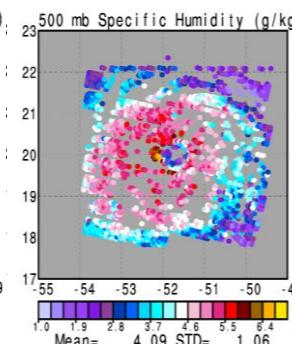
Global Mode

14 km GSD



Zoom Mode

3 km GSD

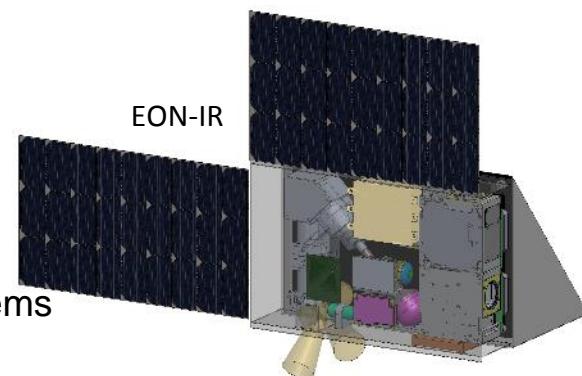


# CIRAS is EON-IR Technology Demo

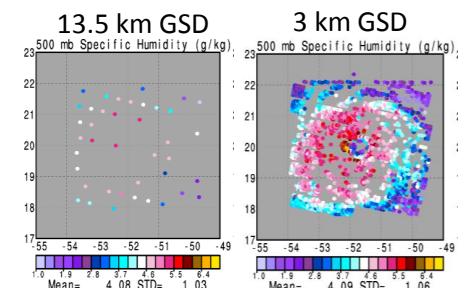
- CubeSat Infrared Atmospheric Sounder (CIRAS)
  - **Sponsor:** NASA InVEST Program (ESTO)
  - **Technology:** 6U CubeSat IR Sounder
  - **Project Start:** March 1, 2016. Launch in Late: 2018
  - **Orbit:** 400-800 km, Polar Sun Synch, 6am +- 3:30 hrs
  - **Spatial:** 3-13.5 km, Limited Field of View (+/- 7.7°, 165 km)
  - **Spectral:** 4.8-5.1  $\mu\text{m}$ , 625 Channels, 0.5  $\text{cm}^{-1}$  resolution.
  - **Radiometric:** NEdT of 0.25K
  - **Limited Data Download:** > 10 @ 165 km x 165 km granules per orbit
- Earth Observation Nano-satellite – IR (EON-IR)
  - **Sponsor:** First NOAA operational unit
  - **Mission:** Gap mitigation for CrIS, alternate orbit times possible
  - **Technology:** Same as CIRAS with gimballed panels and other new items
  - **Orbit:** Afternoon Orbit operation: 1:30 am/pm JPSS
  - **Spatial:** Same as CrIS: 13.5 km Spatial Resolution, Wide field scanning (+/- 57°, 2200 km Swath)  
Zoom Mode: 3km Spatial Resolution (+/- 7.7°, 165 km)
  - **Spectral:** Same as CIRAS, 625 Channels
  - **Radiometric:** Same as CIRAS NEdT of 0.25K
  - **Full Data Download:** On-board Binning, 350 channels, and 2X Data Compression



JPSS



Zoom Mode Improves Yield in Critical Areas



**TROPICS**



# Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats

**MIT Lincoln Laboratory** (proposing organization)

William J. Blackwell, Principal Investigator, Scott Braun (NASA GSFC), Project Scientist



## TROPICS

- PI: William J. Blackwell. MIT Lincoln Laboratory
- Sponsor: NASA Earth Science Directorate
- Program: Earth Venture-Instruments. 2016 Award
- Instruments: 3U CubeSat Microwave Sounders
- Orbits: 12 CubeSats, 4 in each of 3 orbital planes
- Measurement: Temperature, Moisture, Microwave Imaging
- Frequencies: 12 Channels at 90, 118, and 206 GHz
- Launch: 2019/2020

# Summary and Conclusions

- IR Sounders of high value to operational weather forecasting community and research scientists worldwide
- AIRS instrument still working well.
  - Instrument calibration is stable and compares well with CrIS and IASI
  - Numerous scientific papers published
  - AIRS used by international NWP centers worldwide
  - Spacecraft has enough fuel to last till >2022
- CubeSat Infrared Atmospheric Sounder (CIRAS) will demonstrate technologies for IR sounding in the MWIR
  - 6U CubeSat Hyperspectral Infrared Grating Spectrometer
  - MWIR Only Sounding (See H. Aumann s11-141)
  - Launch in 2018/2019 timeframe
  - Good lower tropospheric sensitivity
  - CIRAS is a NASA technology demonstration of future EON-IR for NOAA
  - A future constellation of CIRAS will enable increased timeliness of IR sounder measurements. Follow TROPICS for infrared/microwave sounding like AIRS/AMSU
- JPL Sounder SIPS is now prototyping products from CrIS/ATMS on the Suomi NPP satellite with AIRS-like retrieval system. Data continuity.
- AIRS, IASI, CrIS L1B, L2, L3 intercomparisons continue at JPL