

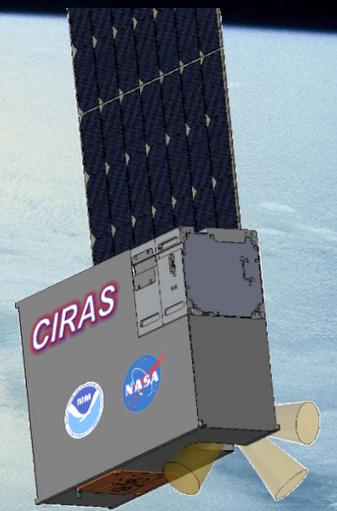
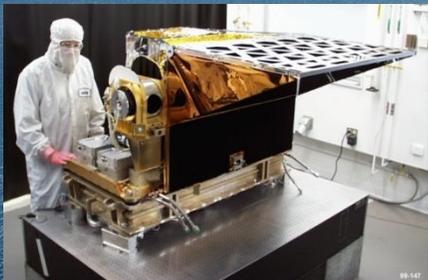


Hank Revercomb's Contribution to Hyperspectral IR Sounding From Space

A NASA AIRS Project Perspective

Monday, July 23, 2018

Madison, Wisconsin



Prepared by Thomas S. Pagano

Jet Propulsion Laboratory, California Institute of Technology

4800 Oak Grove Dr., Pasadena CA 91109; (818) 393-3917

thomas.s.pagano@jpl.nasa.gov

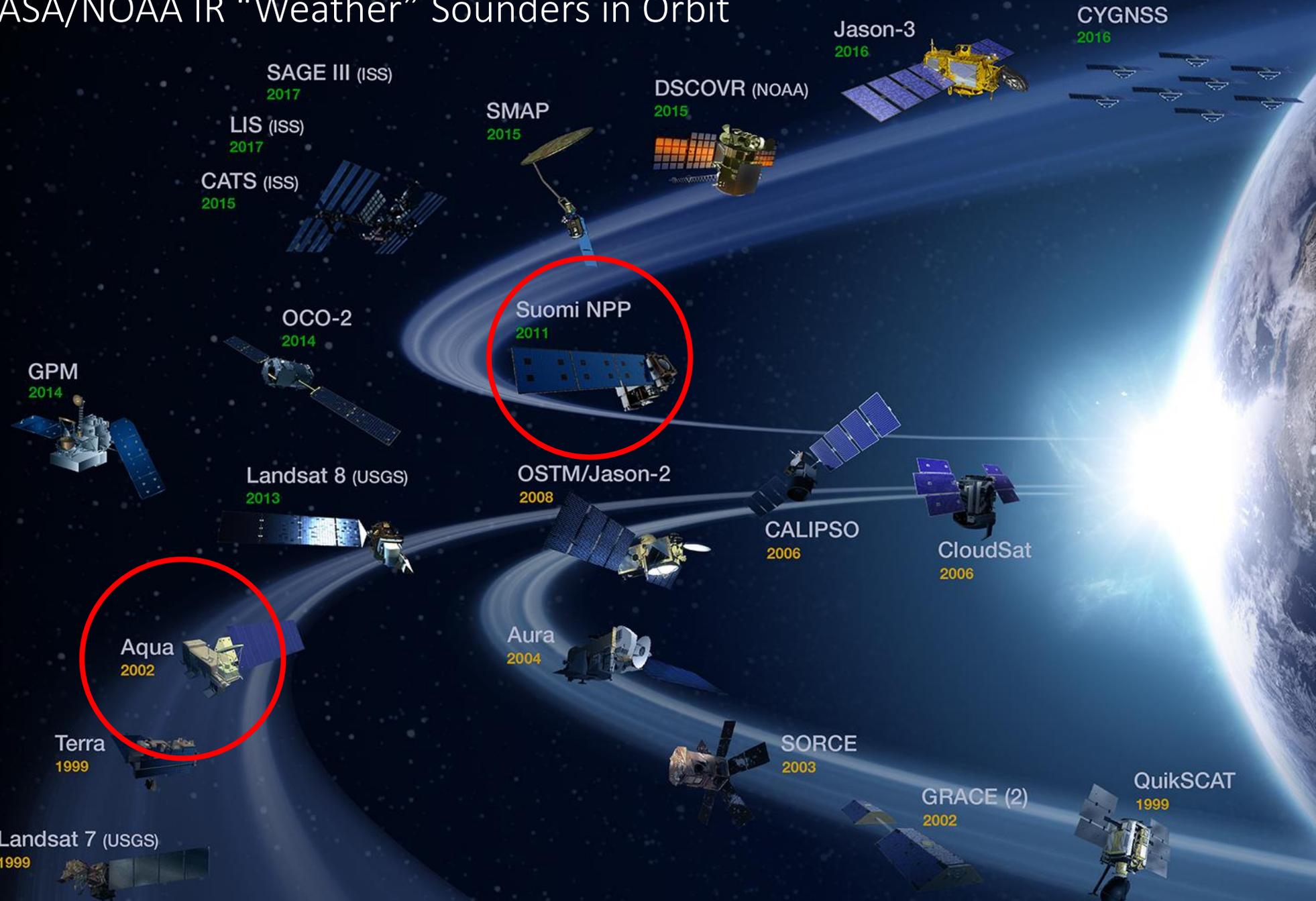
<http://airs.jpl.nasa.gov>

<https://www.jpl.nasa.gov/cubesat/missions/ciras.php>

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NASA/NOAA IR "Weather" Sounders in Orbit

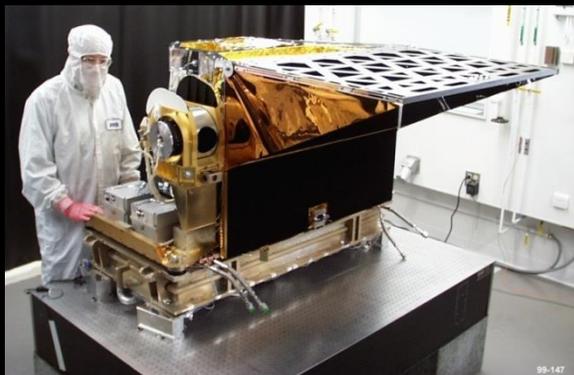




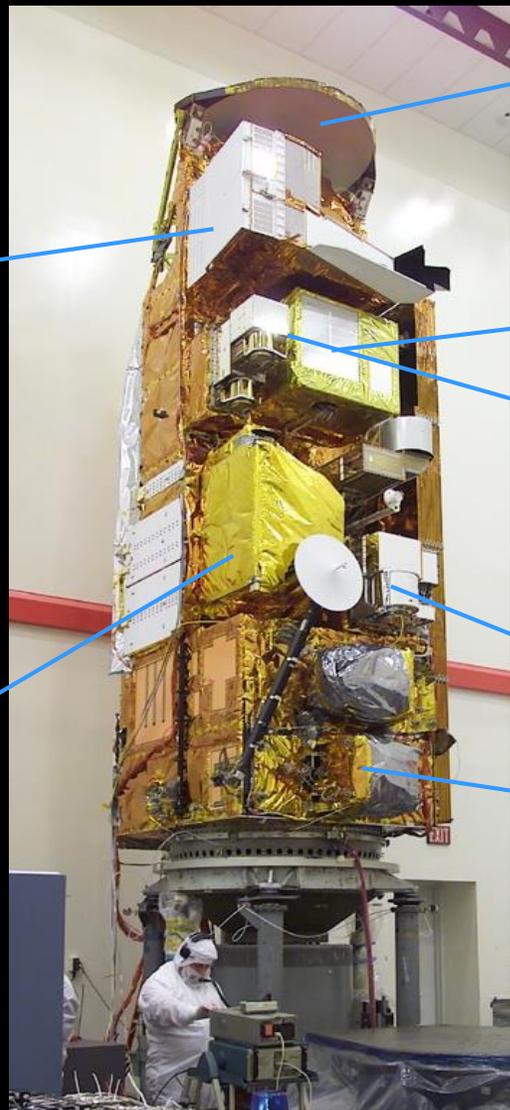
The Aqua Spacecraft and Instruments



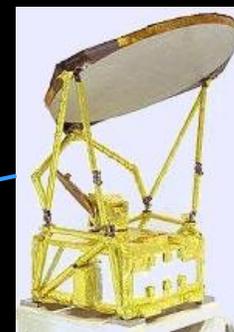
*Moderate Resolution Imaging Spectroradiometer (MODIS)
GSFC/Raytheon*



*Atmospheric Infrared Sounder (AIRS)
JPL/BAE SYSTEMS*



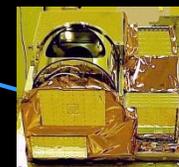
*AQUA Spacecraft
GSFC/NGST*



*Advanced Microwave Scanning Radiometer (AMSR-E)
MSFC/JAXA*



*Advanced Microwave Sounding Units (AMSU-A/B)
JPL/Aerojet*



*Humidity Sounder from Brazil (HSB)
JPL/Aerojet*



*Clouds and Earth Radiant Energy System (CERES)
LaRC/NGST₃*





Hank is one of the first members of the AIRS Science Team and has been active at NASA IR Sounder meetings even recently!



David Wark, Bill Smith, Phil Rosenkranz, Larrabee Strow, Catherine Gautier, Larry McMillin, Alain Chedin, Hank Revercomb, Roberto Calheiros, Joel Susskind, Moustafa Chahine, Mitch Goldberg, George Aumann



The Earth Observer

March - April 2018

Henry Revercomb [University of Wisconsin] described the calibration characteristics of CrIS. He noted that the CrIS performance is comparable to—and in some ways better than—AIRS. Revercomb also showed that radiance trends from AIRS, CrIS, and the two IASI instruments are very similar. This means that the hyper-spectral IR record begun with AIRS can be extended with the radiances from these other instruments—a basic requirement for a multidecadal record as noted during the AIRS STM.

evaporation point temp that while 1 annual mas dominant I at lowest el
Karen Cac analysis of megacities. other hype



Hank's Team among first to validate AIRS Radiances In Orbit



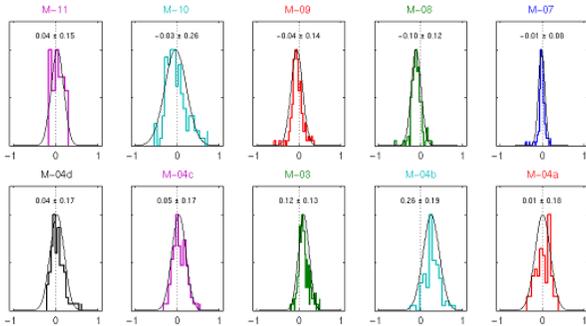
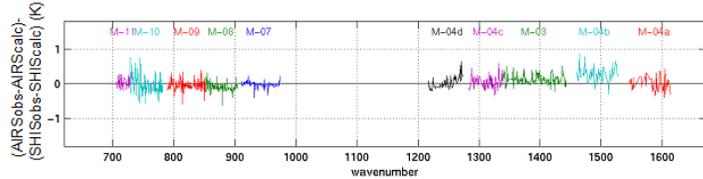
National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

AIRS Demonstrates High Radiometric and Spectral Accuracy/Stability

Radiometric Accuracy

Scanning HIS Validates Rad Accy to 0.2K – H. Revercomb (UW)

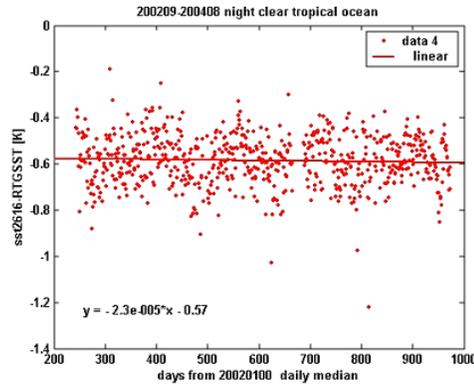
Final "Comparison 2" (21 November 2002)
Excluding channels strongly affected by atmosphere above ER2



Reference: JGR, VOL. 111, April 2006

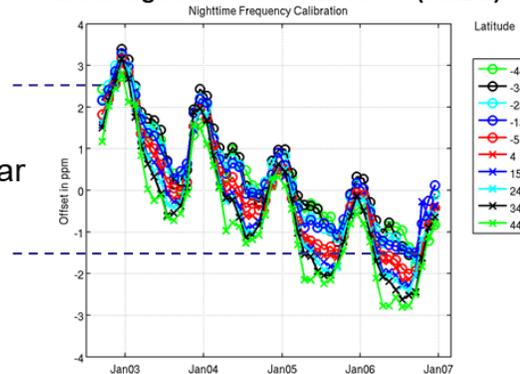
Radiometric Stability

Stable to <8mK/Y – H. Aumann (JPL)



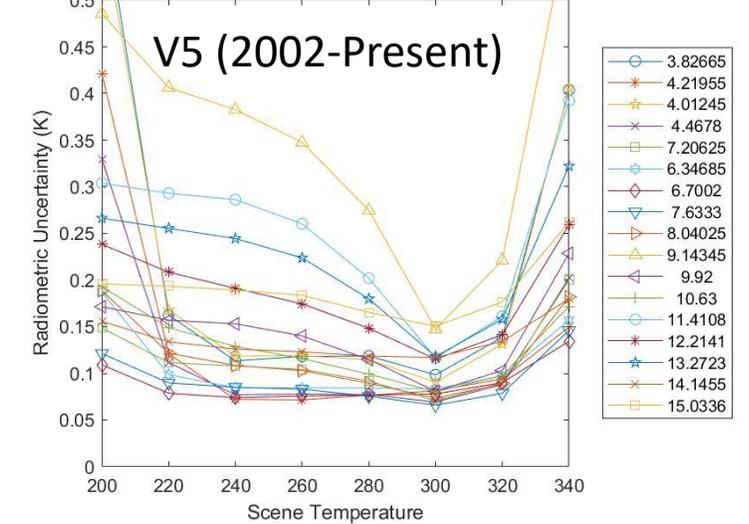
Spectral Accuracy/Stability

Knowledge to < 1 PPM - L. Strow (UMBC)

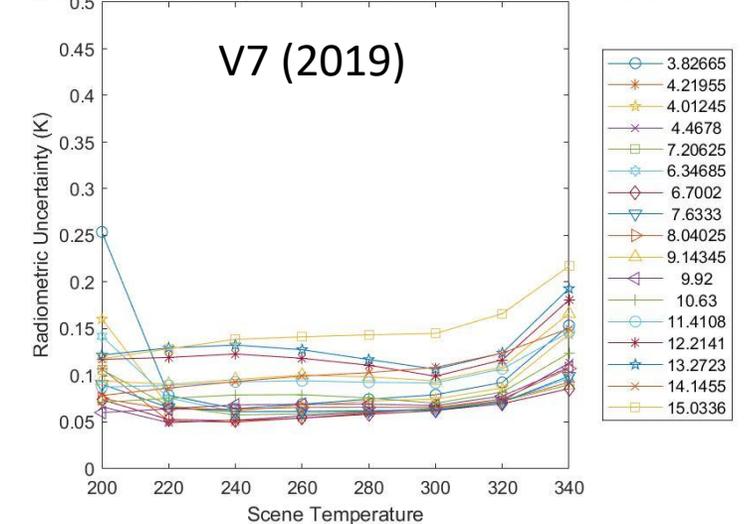


< 1 ppm/year

Radiometric Uncertainty vs Scene Temperature for AIRS by Module

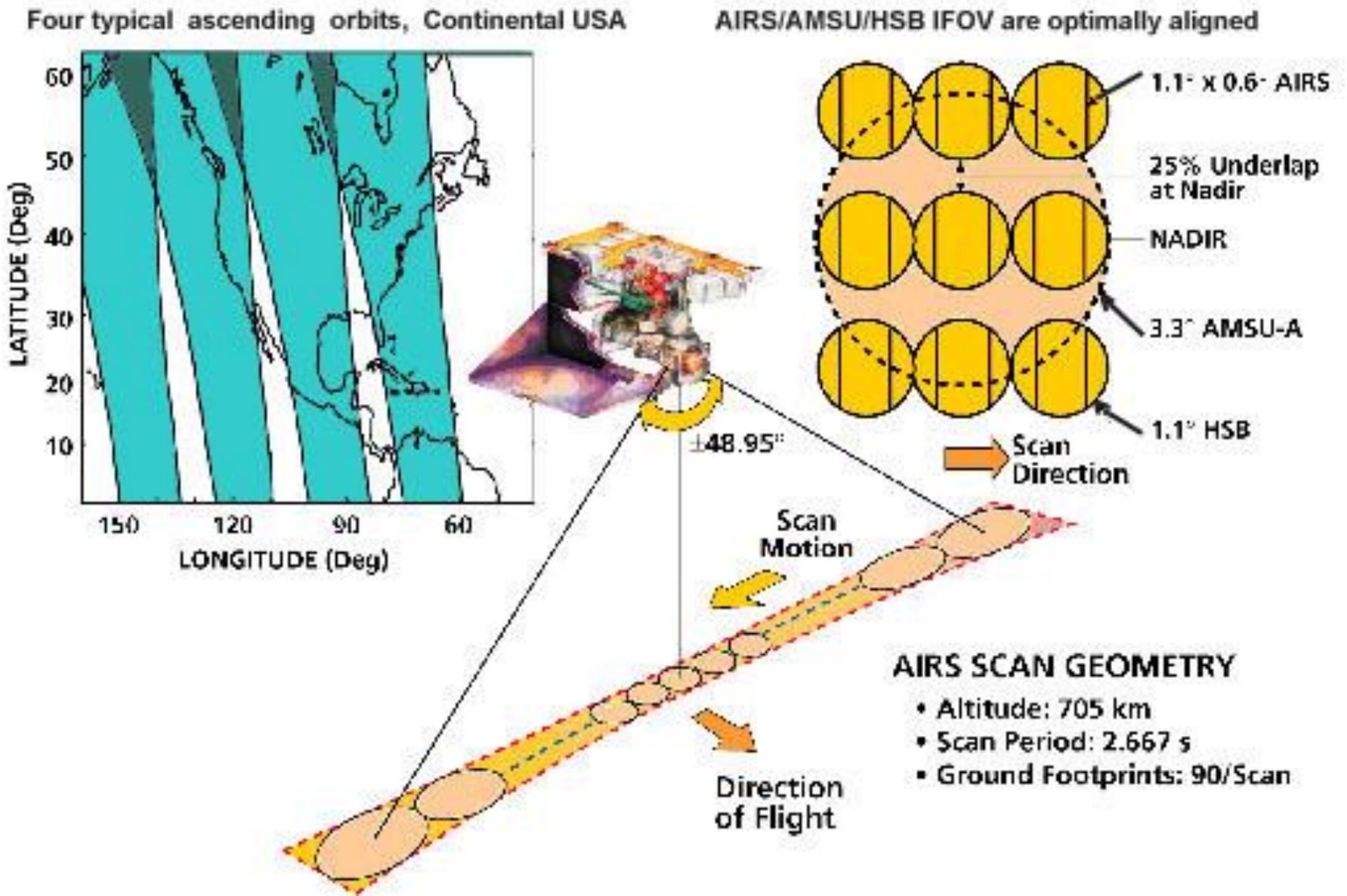


Radiometric Uncertainty vs Scene Temperature for AIRS by Module



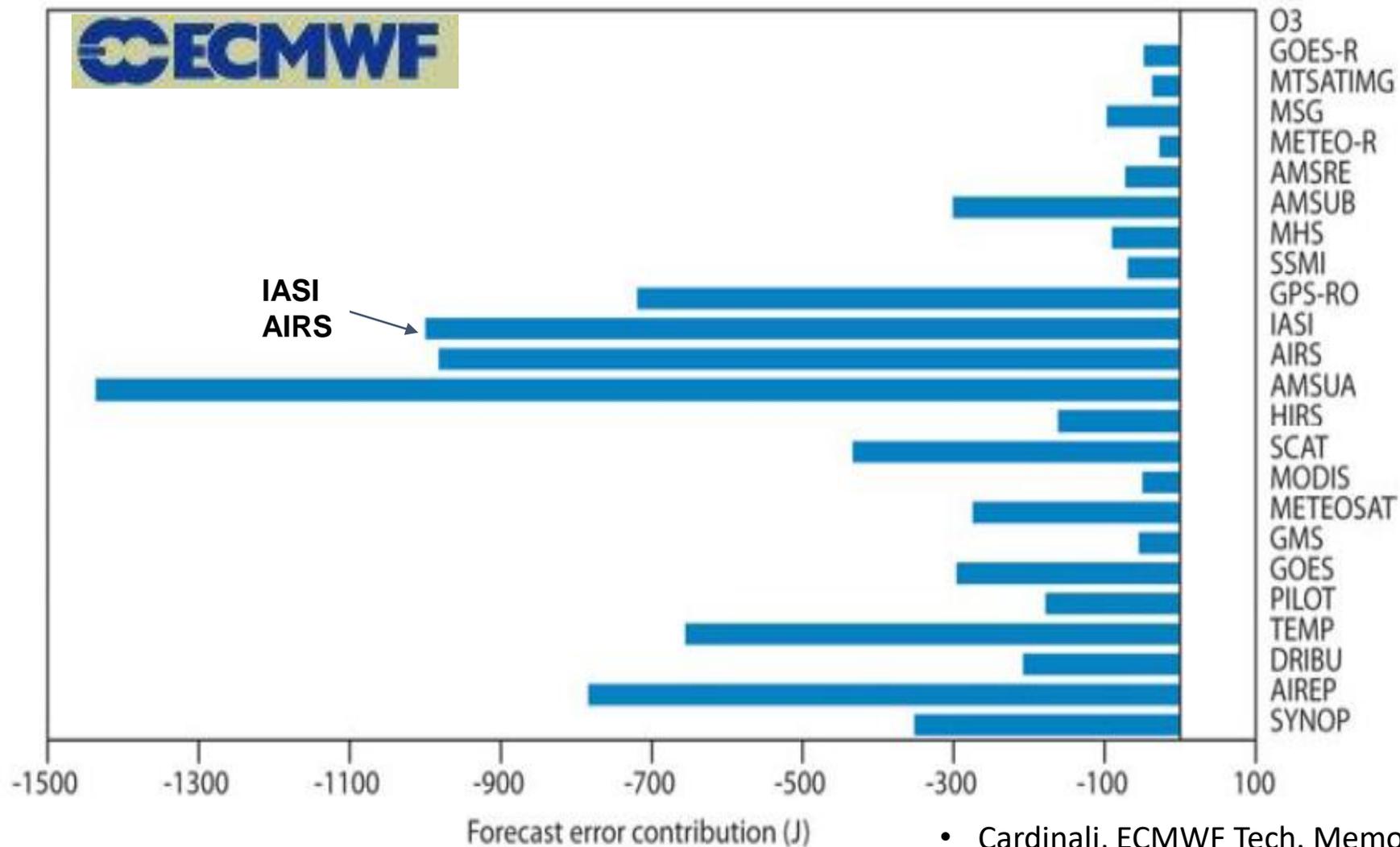


AIRS and CrIS Have a Wide Swath to Provide Global Daily Coverage





IR Sounders Improve Weather Forecasts



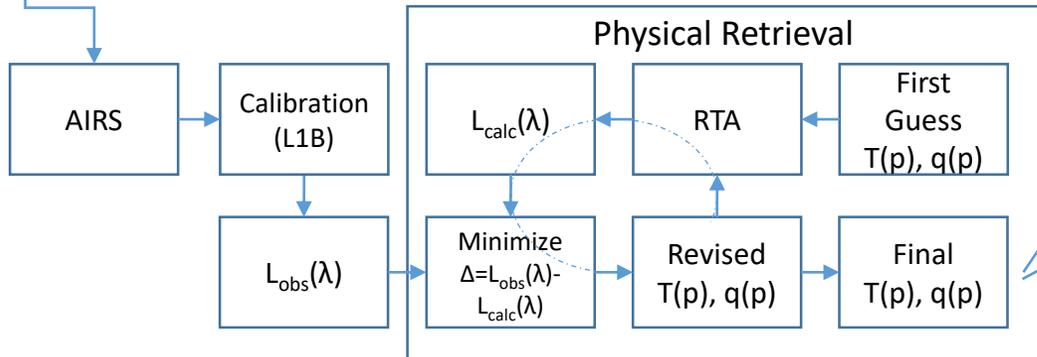
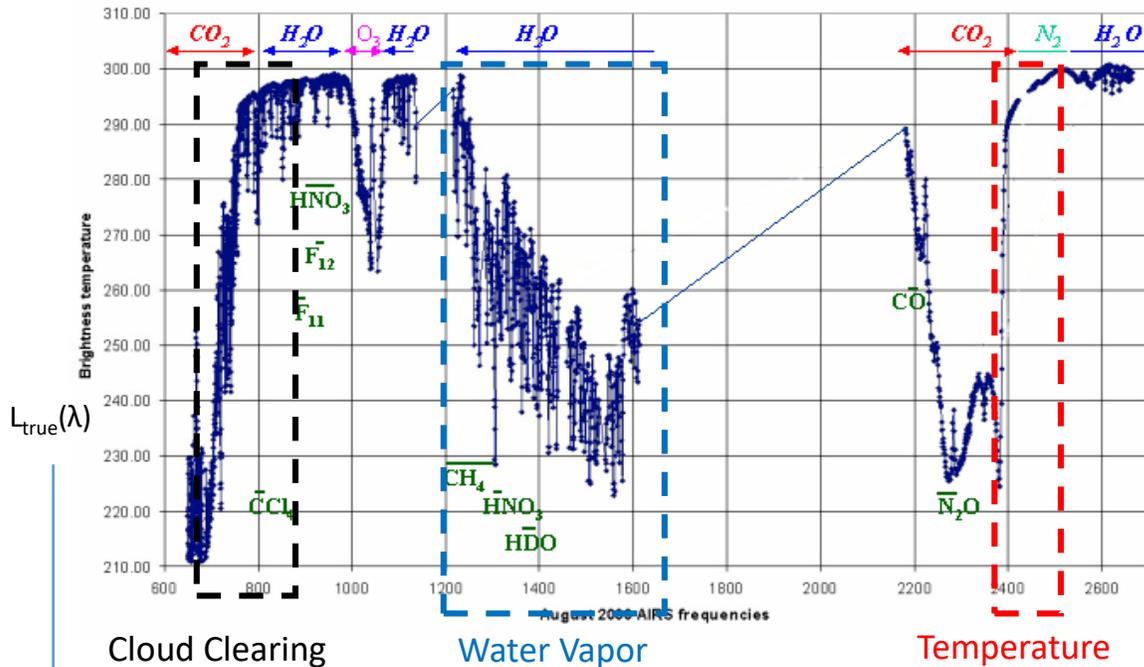
Old chart,
CrIS Impact
comparable to
AIRS and IASI

• Cardinali, ECMWF Tech. Memo. 599, 2009



IR Sounders Measure the Upwelling Earth Spectrum in the Infrared

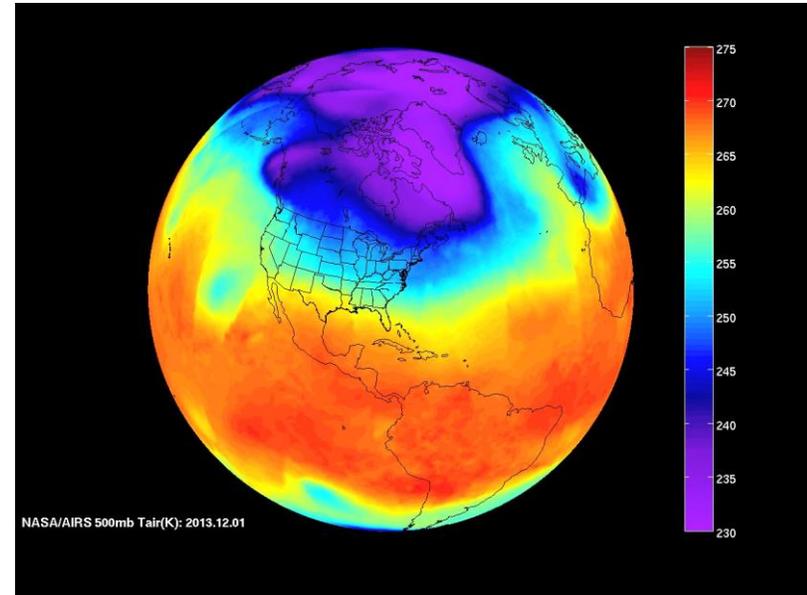
AIRS Channels for Tropical Atmosphere with $T_{surf} = 301K$ Full Spectrum



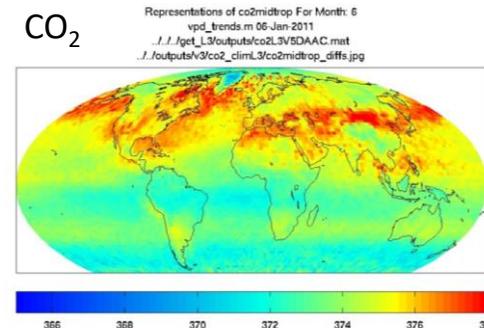
AIRS Temperature at 500mb

Dec 4, 2013: Denver weather: Temperature hits minus 13 — record low for the date
 Dec 24, 2013: Record Low Tied at Cedar Rapids This Morning | Iowa Weather Blog
 Jan 6, 2014: Chicago Record Low Temperature: City Hits -16 Mark To Kick Off ...
 Jan 29, 2014: Atlanta, Georgia, historic weather for the past week

H₂O



CO₂



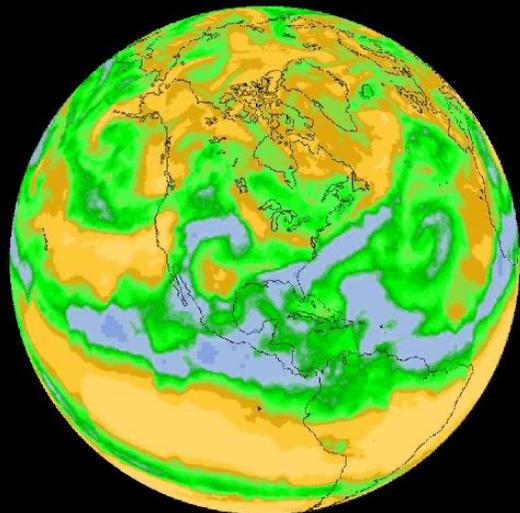
- Dr. Mous Chahine, 1935-2011
- AIRS Science Team Lead, 1991-2011
- Algorithms for Cloud Clearing, Temperature, Water Vapor and CO₂ Retrievals



National Aeronautics and Space Administration
 Jet Propulsion Laboratory
 California Institute of Technology
 Pasadena, California

H₂O

500 mb Water Vapor (g/kg dry air)

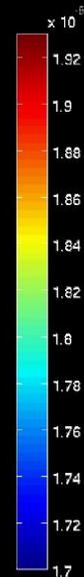
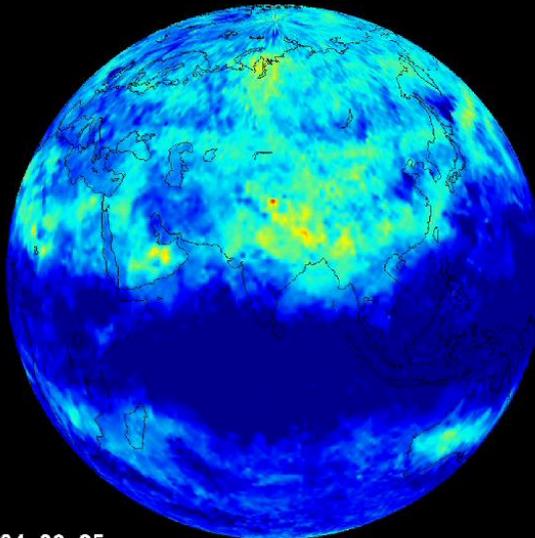


2005.08.01

AIRS Greenhouse Gases

CH₄

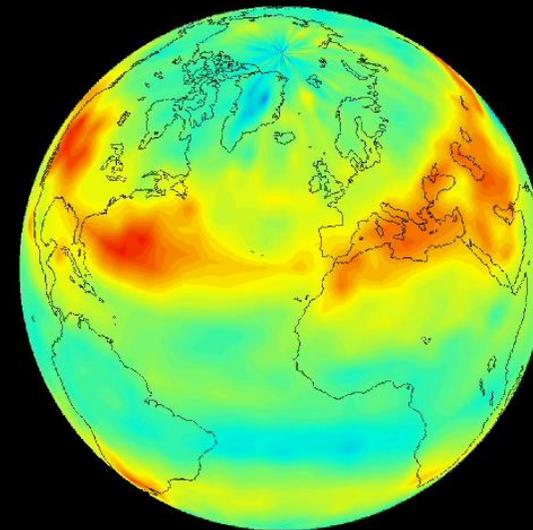
CH₄ VMR at 200 mb (ppm):



2004_09_25

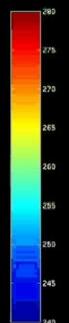
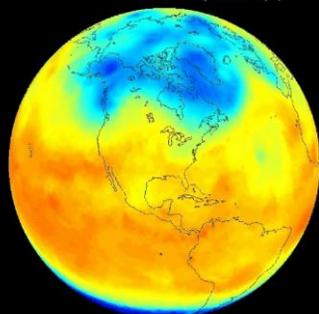
CO₂

Mid-Tropospheric CO₂ (ppm)



Other AIRS Atmospheric Climate Products

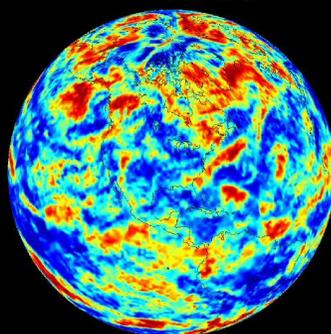
500 mb Temperature (K)



2005.08.01

Temperature

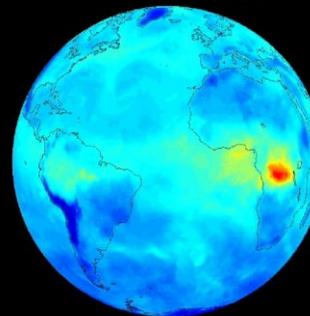
Cloud Fraction



2005.08.01

Clouds

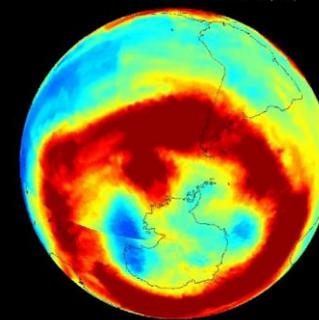
Total Column CO (molecules/cm²)



2005.08.01

CO

Total Column Ozone (DU)



2005.08.01

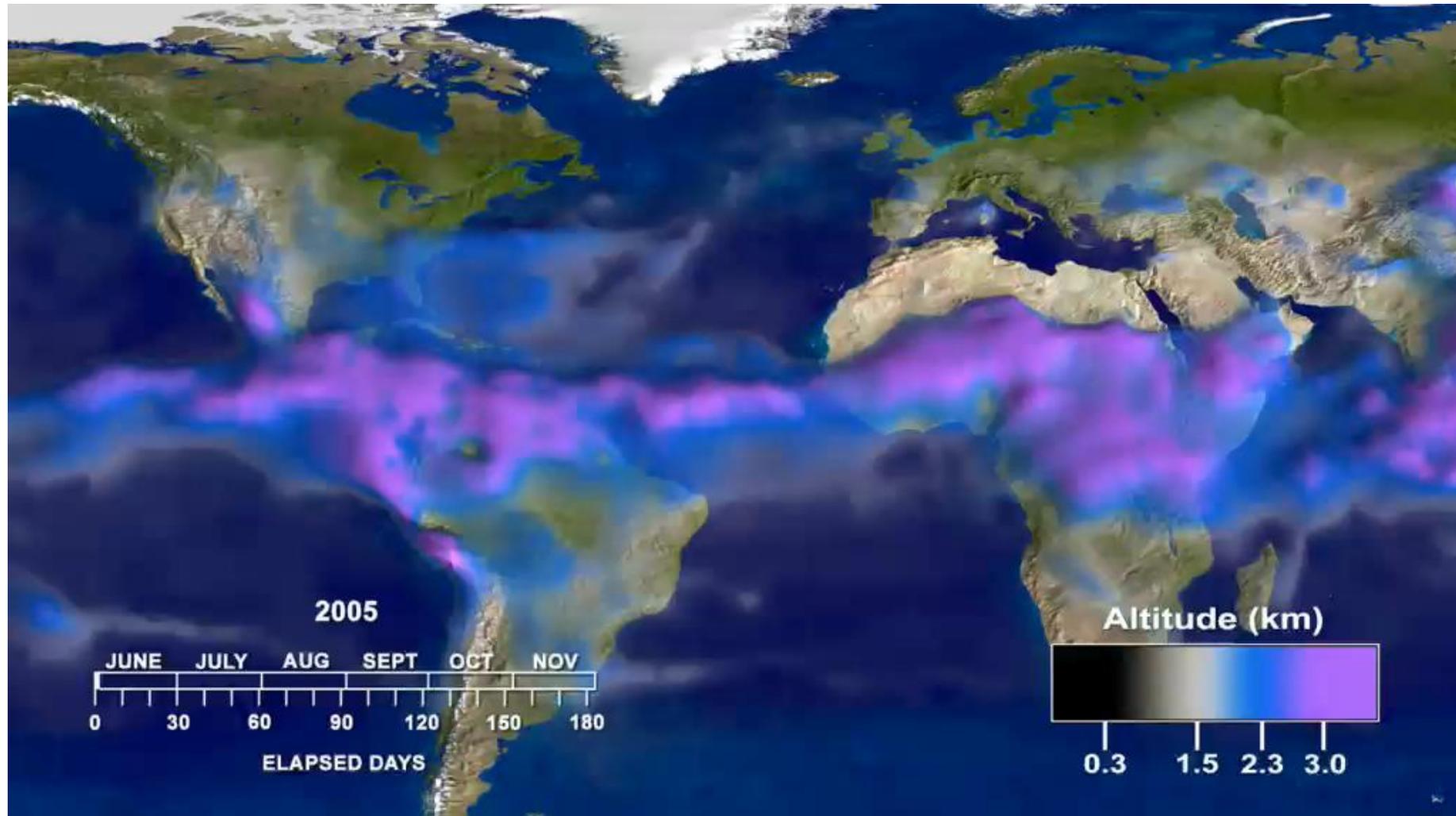
O₃

Pagano, JPL, 2009



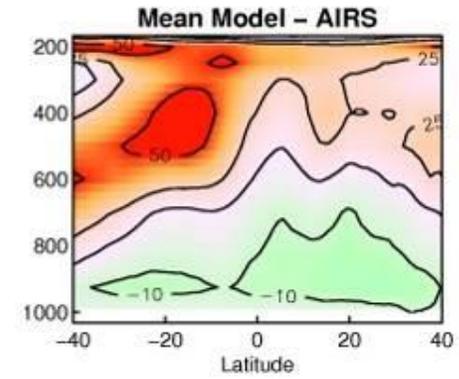
IR Sounder Data Support Climate Research and Model Validation

AIRS Water Vapor Transport

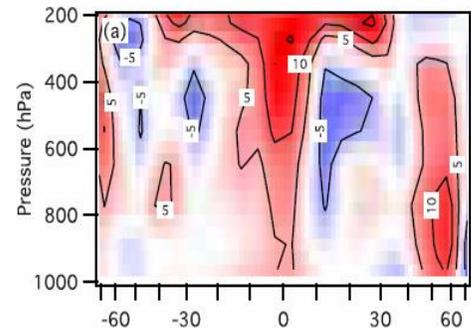


AIRS Water Vapor Isosurface (5kg H₂O /kg Dry Air)
 V. Realmuto, C. Thompson, T. Pagano, S. Ray NASA/JPL

Model Comparisons (Pierce, Scripps, 2006)



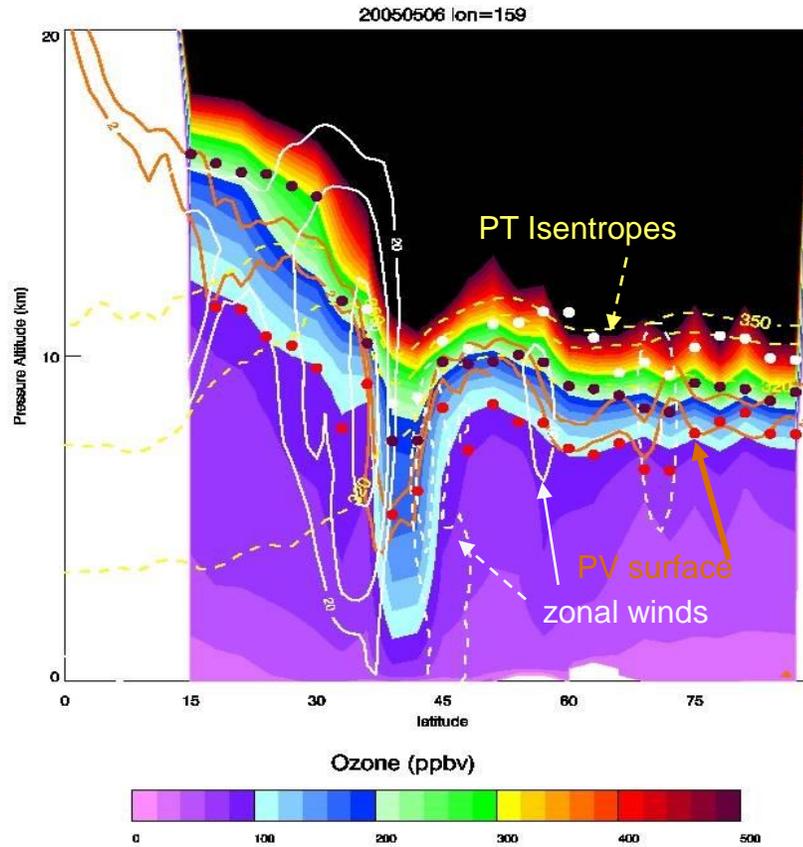
Water Vapor Feedback (Dessler, Texas A&M, 2008)



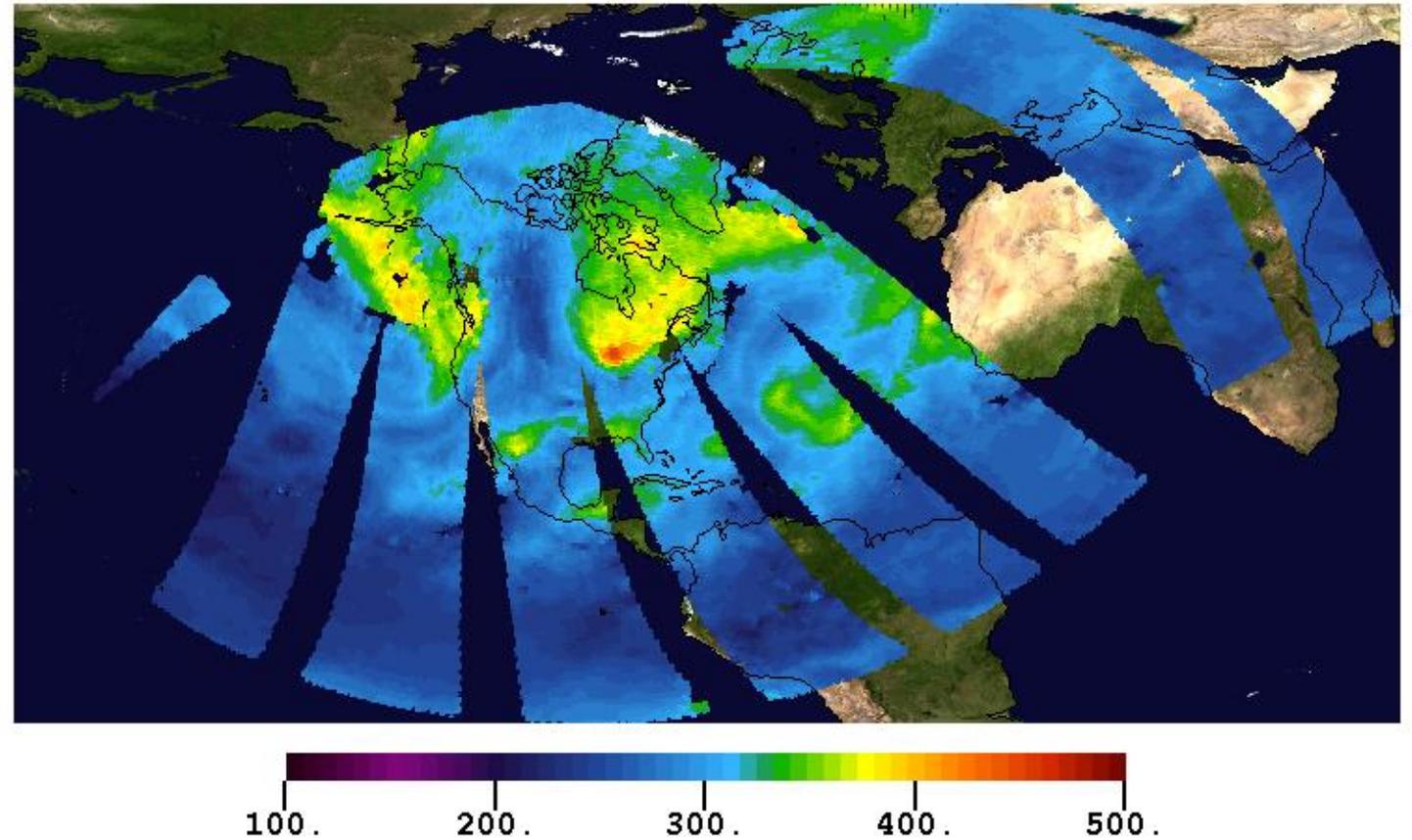


IR Sounders Measure Stratospheric Ozone Intrusions

AIRS Identifies Stratospheric Ozone Intrusion, May 6, 2005 (Wei, 2008)



AIRS Ozone Daily Global Imagery Enables Early Warning of Possible Poor Air Quality (7/19/07)

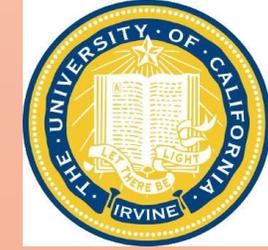
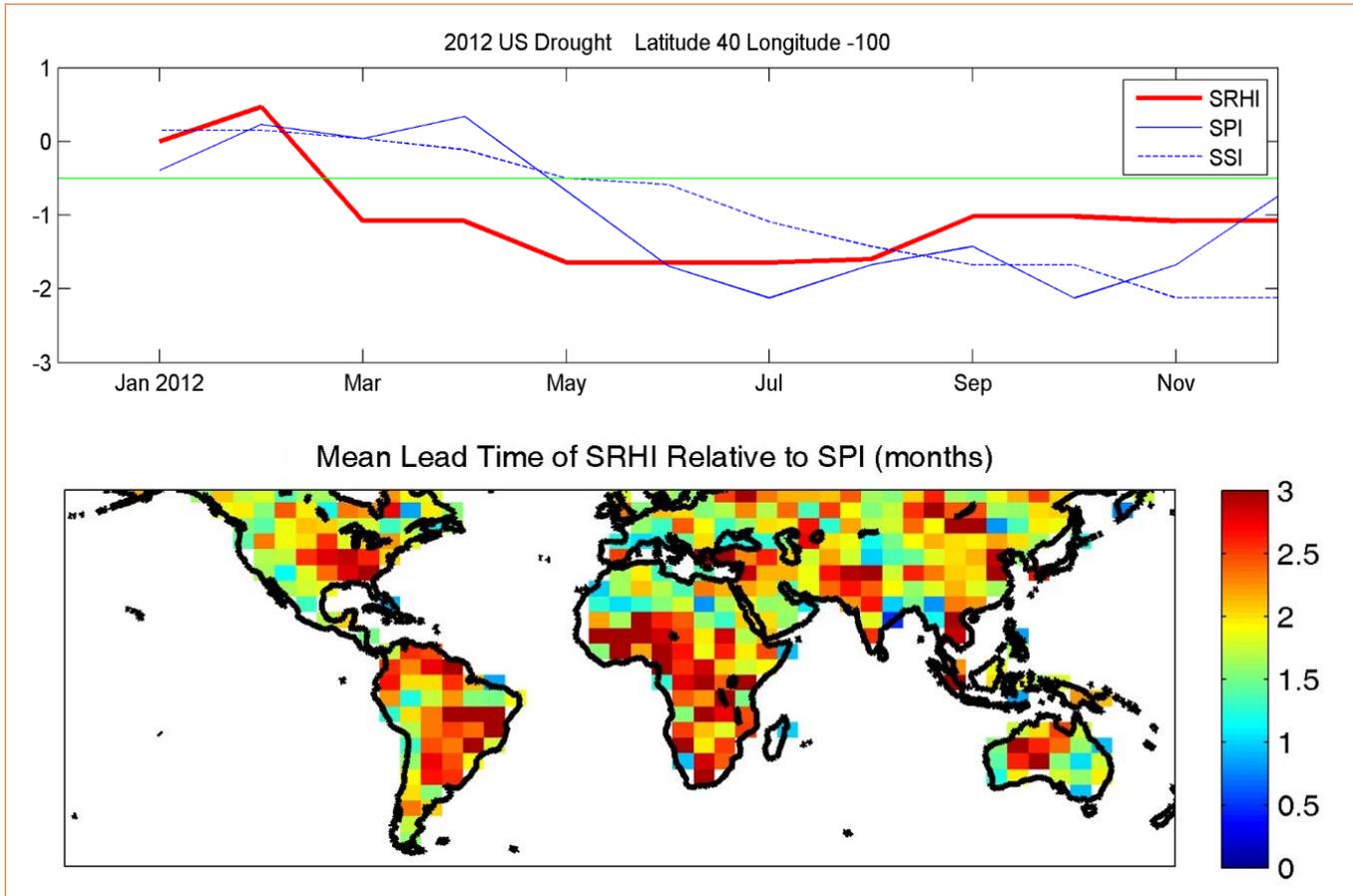


Pittman, J. V., L. L. Pan, J. C. Wei, F. W. Irion, X. Liu, E. S. Maddy, C. D. Barnet, K. Chance, and R.-S. Gao (2009), Evaluation of AIRS, IASI, and OMI ozone profile retrievals in the extratropical tropopause region using in situ aircraft measurements, *J. Geophys. Res.*, 114, D24109, doi:10.1029/2009JD012493



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**

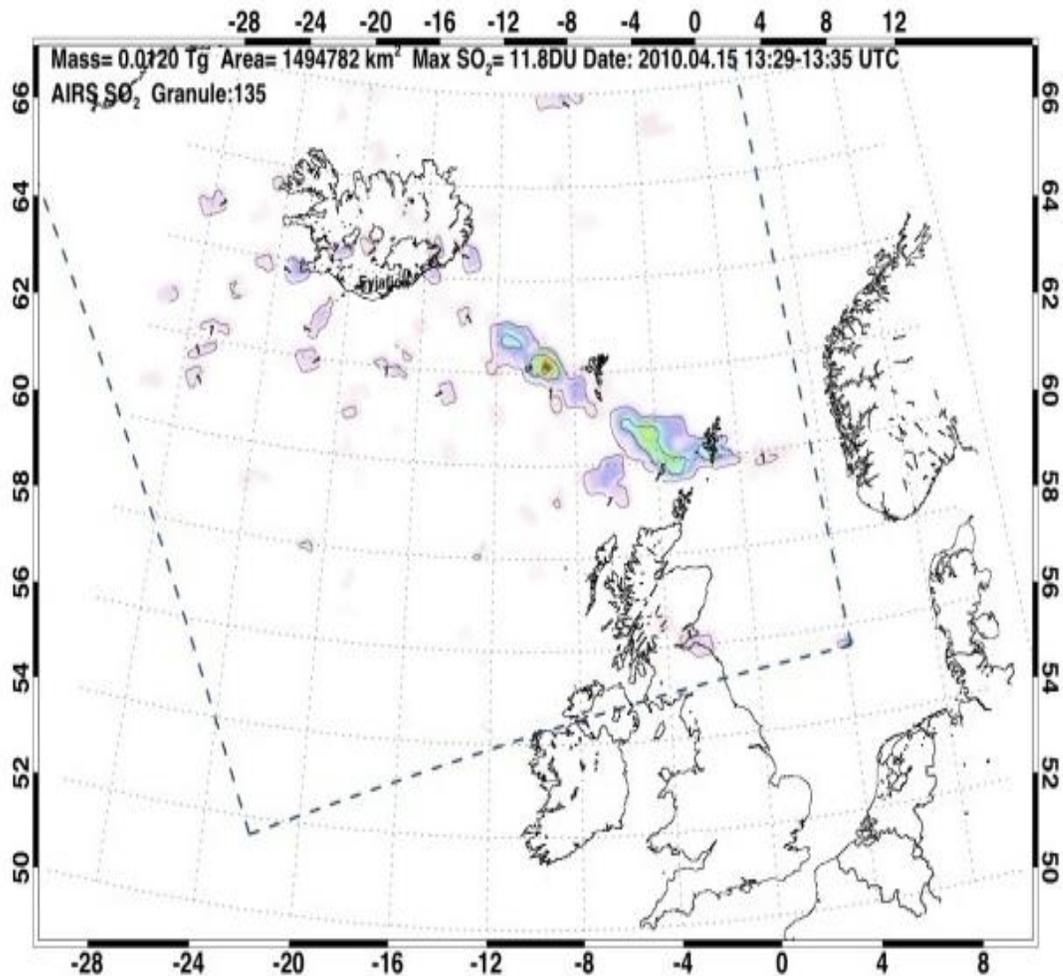
Farahmand et al, 2015, A Vantage from Space Can Detect Earlier Drought Onset: An Approach Using Relative Humidity, Scientific Reports, 5, 8553; doi: 10.1038/srep08553.



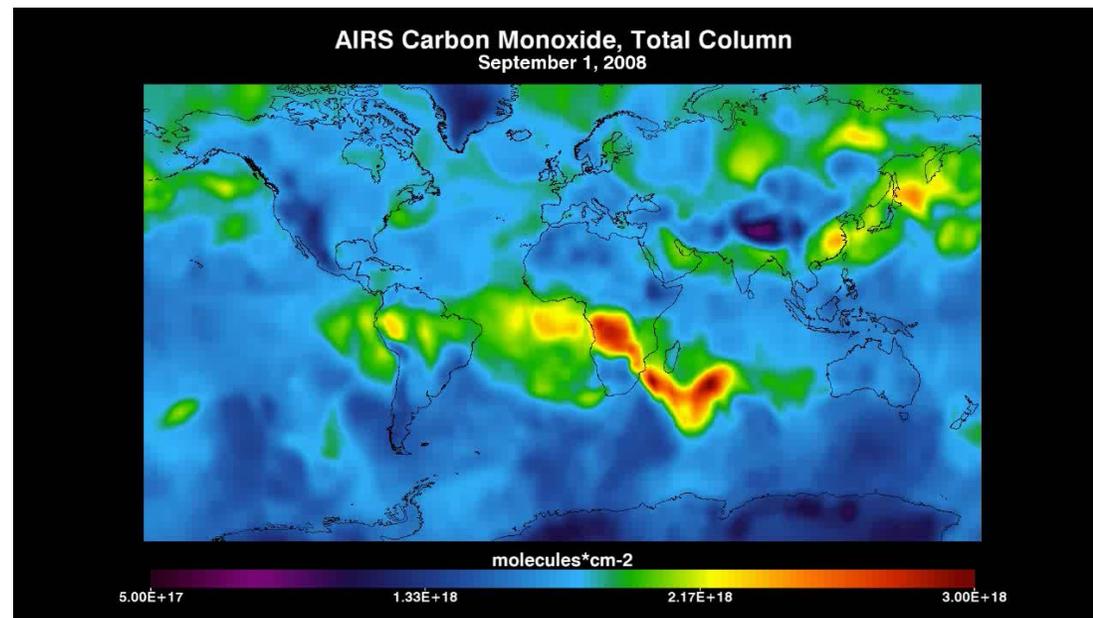
AIRS Composition Products Support Aviation Hazards and Air Quality

Sulfur Dioxide Alerts Aviation Warning

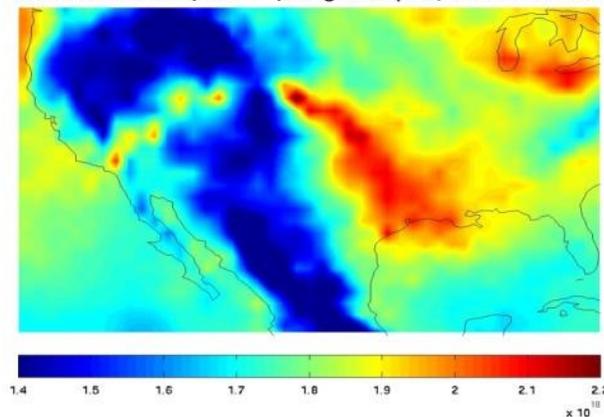
Ejyafyallajokul SO2
Fred Prata NIAR, Norway



Global Carbon Monoxide Transport (JPL, 2008)

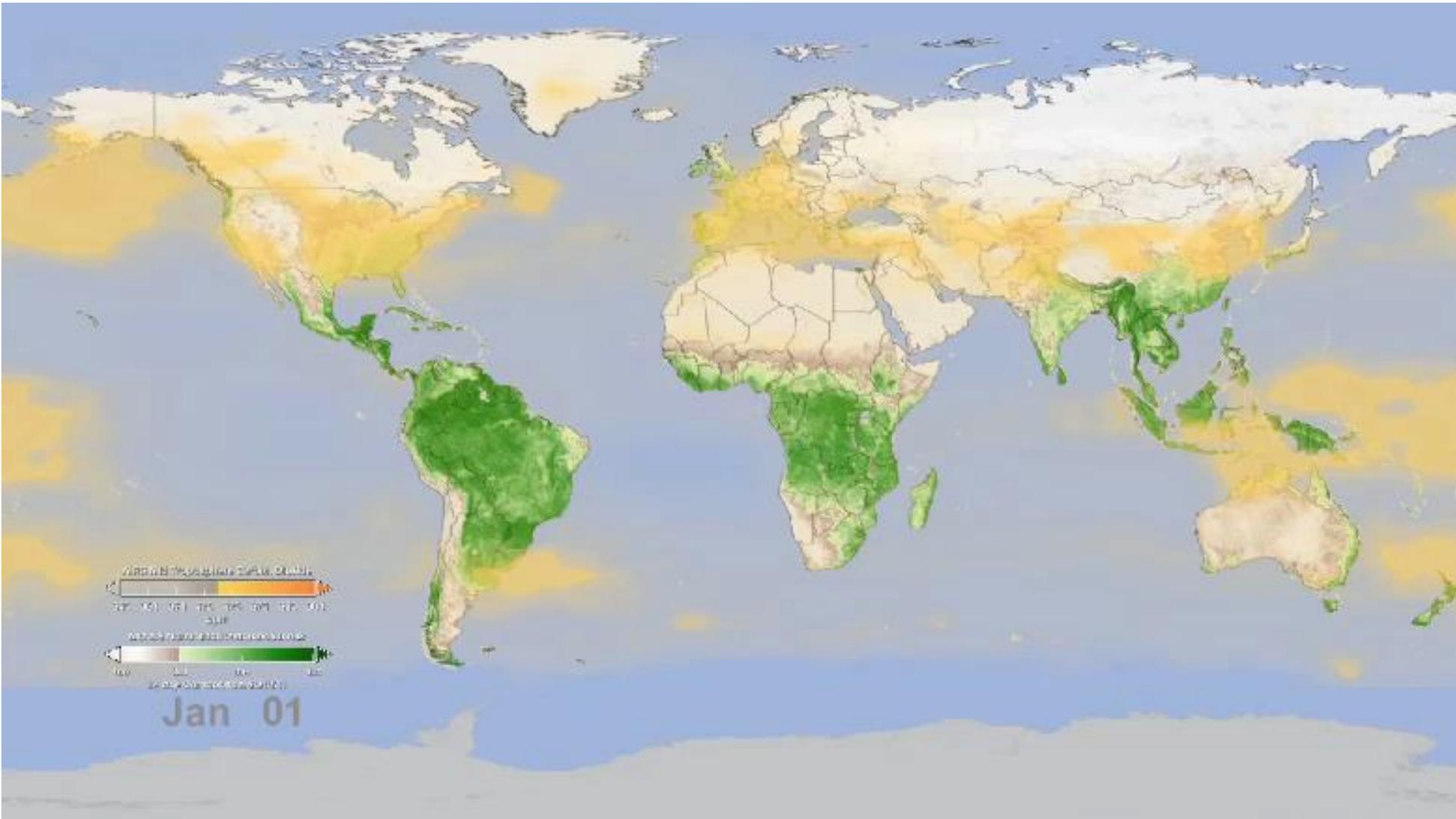


CO Total Column (mol/cm²): Aug 30-Sep 02, 2009 2009.09.02





AIRS Mid-Trop CO₂ Drawdown Follows Regional Vegetation Cycle

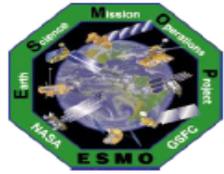


Lori Perkins (NASA/GSFC Science Visualization Studio)
T. Pagano, E. Olsen, S. Ray (JPL)

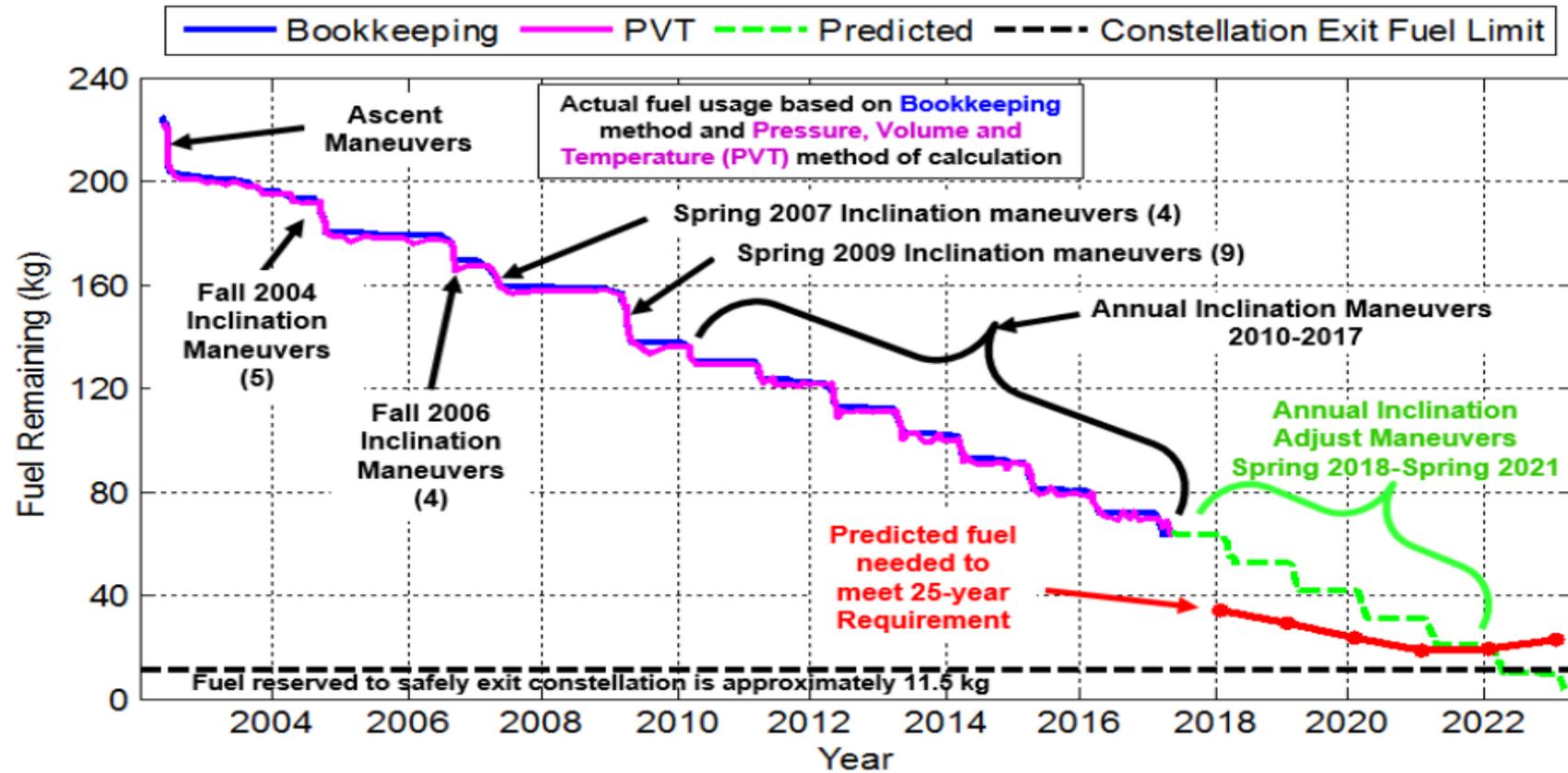
AIRS Mid-Trop CO₂ "Monthly Representation" + FRK
MODIS EVI Monthly L3



AIRS Expected to Operate For Life of Spacecraft through 2022



No Changes Fuel Usage: Actual & Predicted (November 2017)

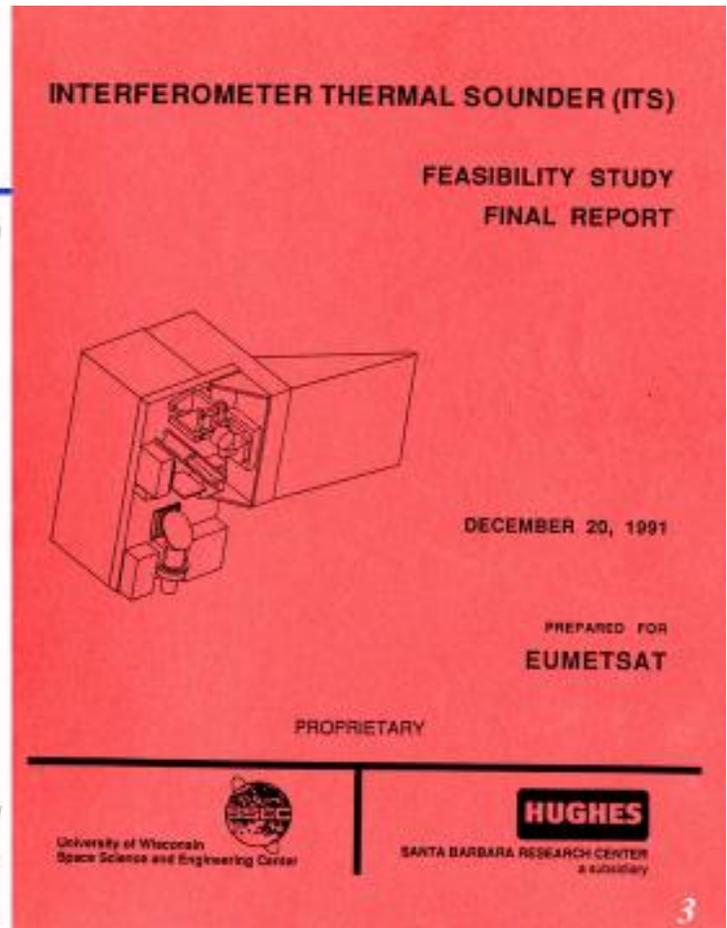
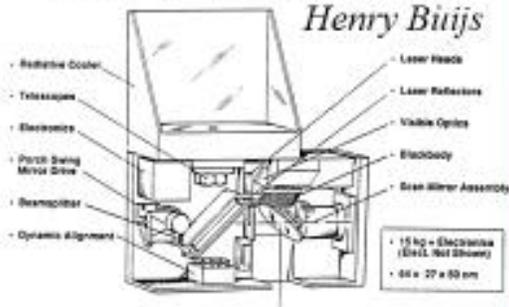




ITS Study with Hank as PI in 1990/91 Set the Stage for CrIS

CrIS: 1990/91 Historical Roots

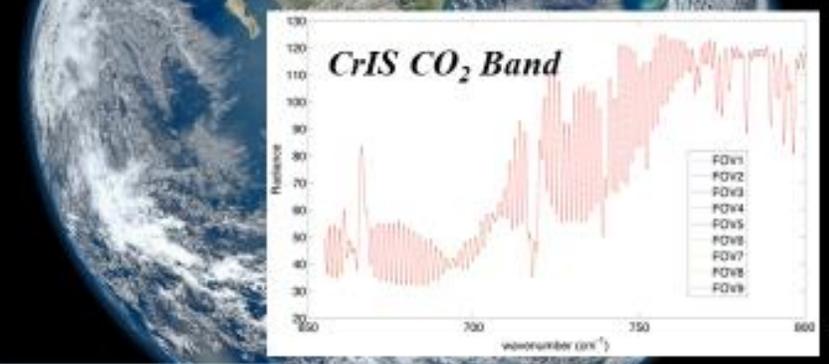
- *EUMETSAT (John Morgan) sponsorship*
- *Originated by Bill Smith, in residence at EUMETSAT*
- *UW-Madison/SSEC prime, Hank Revercomb, PI*
- *Detailed design by SBRC, Still Chase, Tom Pagano Bomem DA interferometer*



Weather Satellite renamed "Suomi NPP"

On 25 January 2012 NASA & NOAA renamed their newest Earth-observing satellite after UW-Madison space pioneer

And SSEC provided the 1st Light Products for the 2 Main Instruments!



& Phase A CrIS Sounder Design in 1991

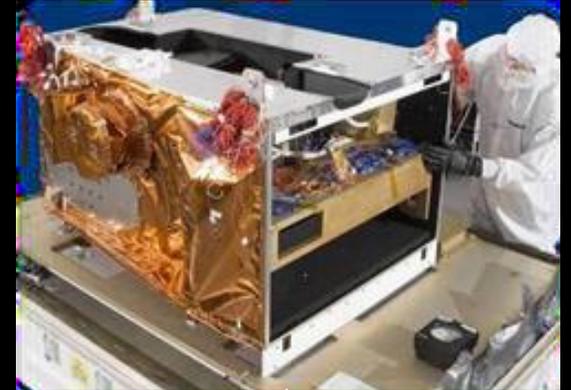
ATMS



CrIS



VIIRS



OMPS



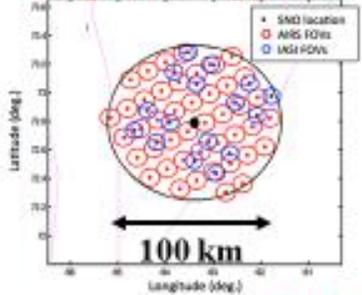
CERES



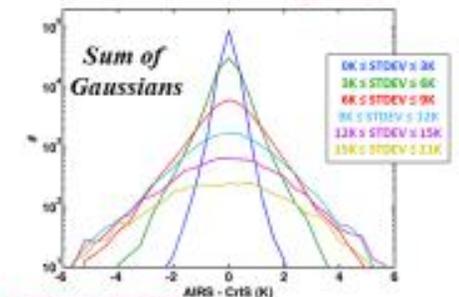
Simultaneous Overpass Comparisons: CrIS to AIRS & IASI

Example CrIS-IASI & CrIS-AIRS

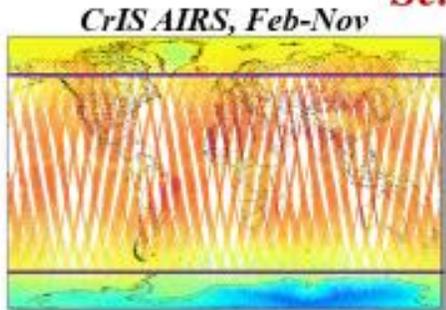
"Big Circle" Approach



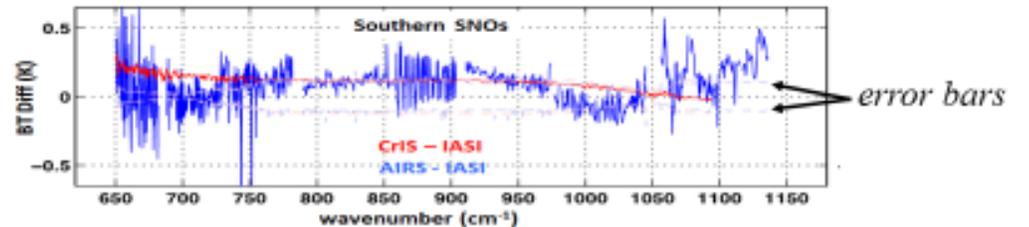
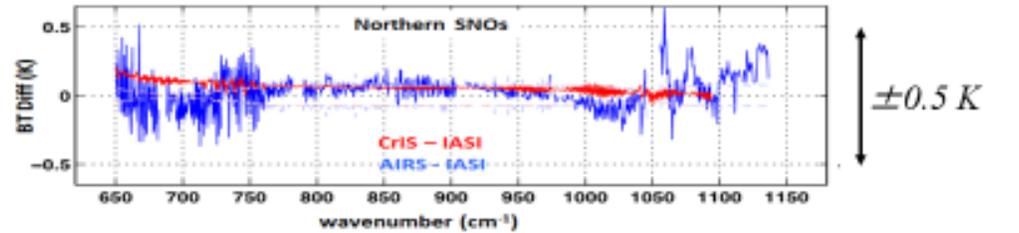
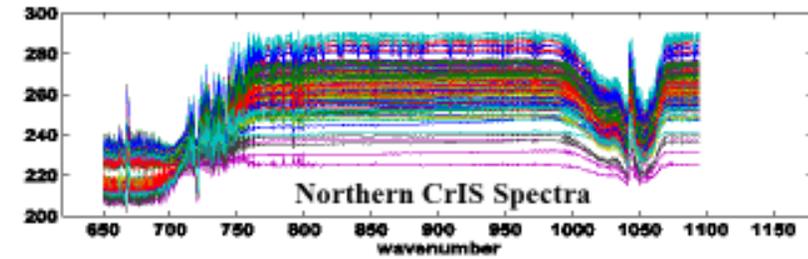
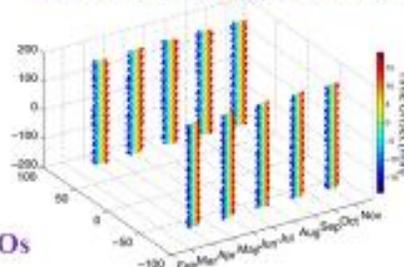
Well Understood Sampling Errors



Selected Overpasses



CrIS IASI SNOs, Feb-Nov

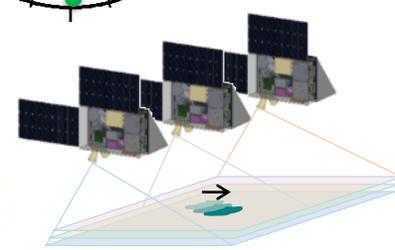
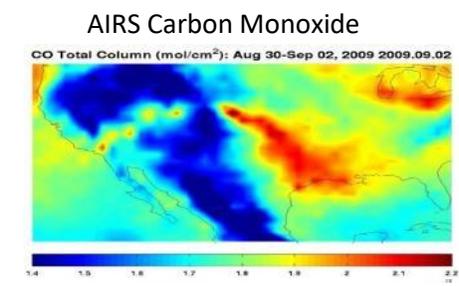
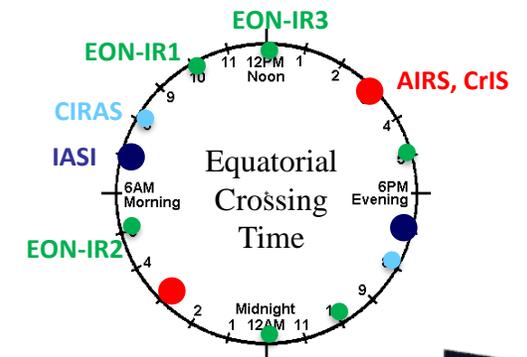
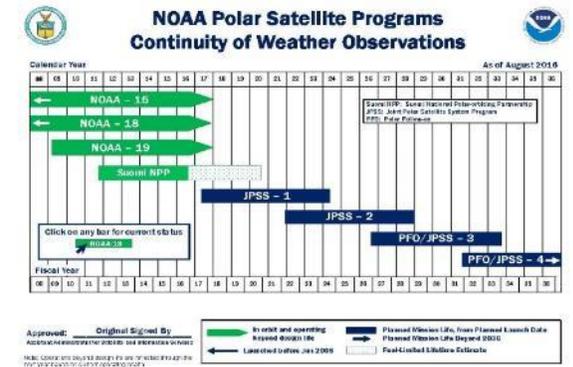


Revercomb, H. "Summary of UW-Madison SSEC Sounder Activities", presented at the NASA Sounder Science Team Meeting, September 30, 2014



NASA and NOAA Interested in CubeSat Sounders

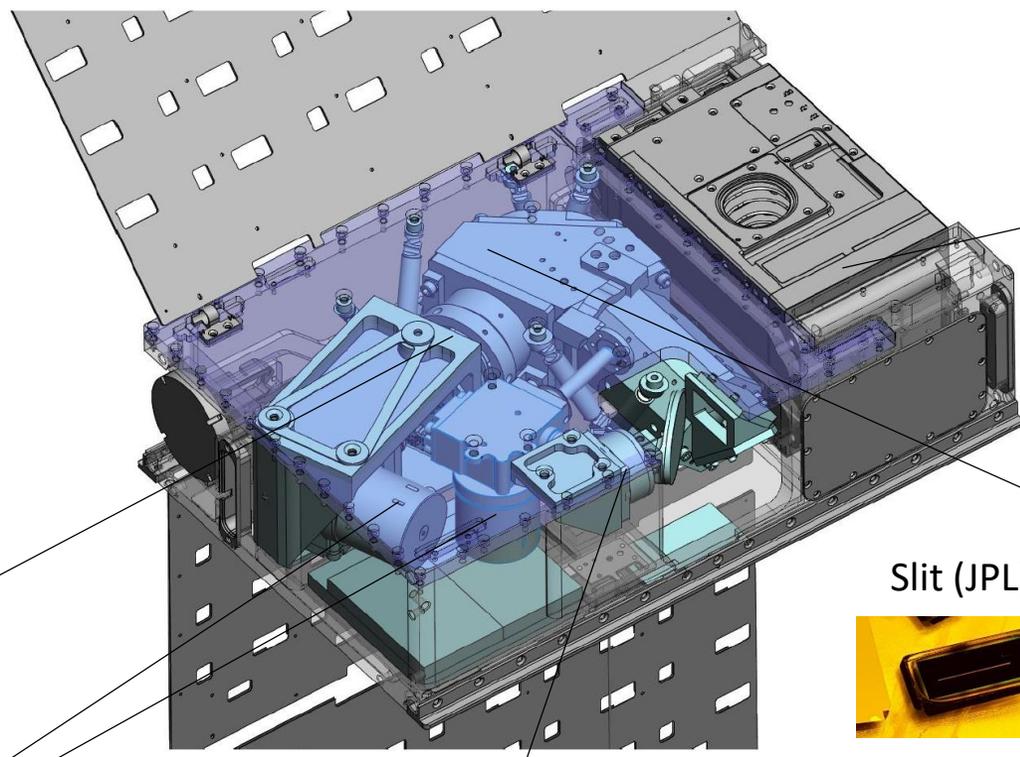
- Gap Mitigation
 - Support the NOAA Joint Polar Satellite System (JPSS) project as a gap mitigation of infrared sounding in the event of a loss of the Cross-track Infrared Sounder (CrIS) instrument
- Improved Timeliness
 - Low cost of IR Sounder CubeSats lends itself to placement in orbits to complement existing sounders and improve revisit time
- 3D AMV Winds
 - 2 or 3 instruments flown in formation and separated in time by 15 min – 1 hr would measure 3D Atmospheric Motion Vector (AMV) winds
- Atmospheric Turbulence
 - Trading a larger telescope for the scan capability enables hyperspectral imaging at high spatial resolutions enabling measurements of atmospheric turbulence
- Atmospheric Chemistry
 - The CubeSat IR Sounders can be tailored to see a variety of gases in addition to CO including N₂O and HDO with moderate to high spatial resolution.



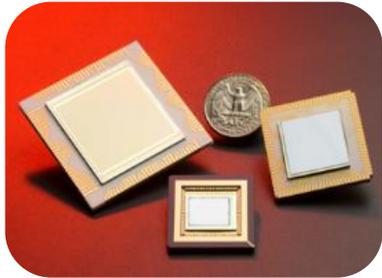


CubeSat Infrared Atmospheric Sounder (CIRAS)

Tech Demo Supports future IR Sounder CubeSats



FPA
HOTBIRD
(JPL)



Camera Electronics
(IR Cameras)



Dewar (IDCA)
(IR Cameras)



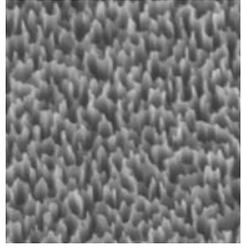
Payload
Electronics



Stepper Motor +
Mirror
(Lin Eng)



Blackbody
Assembly
Black Silicon



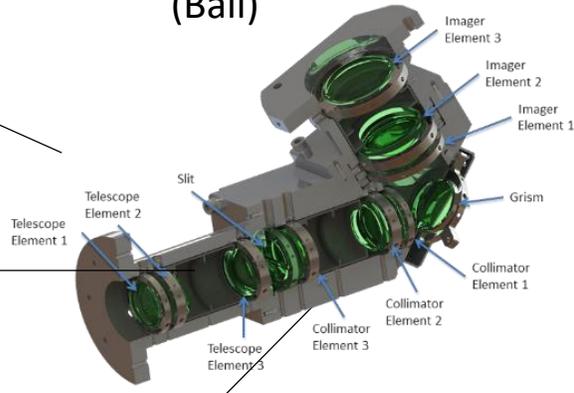
Slit (JPL)



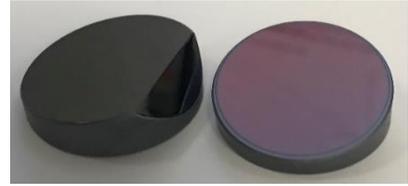
Spacecraft
(BCT)



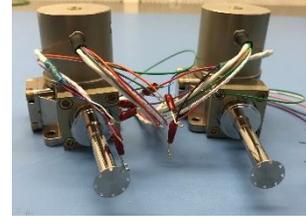
Optics Assembly
(Ball)



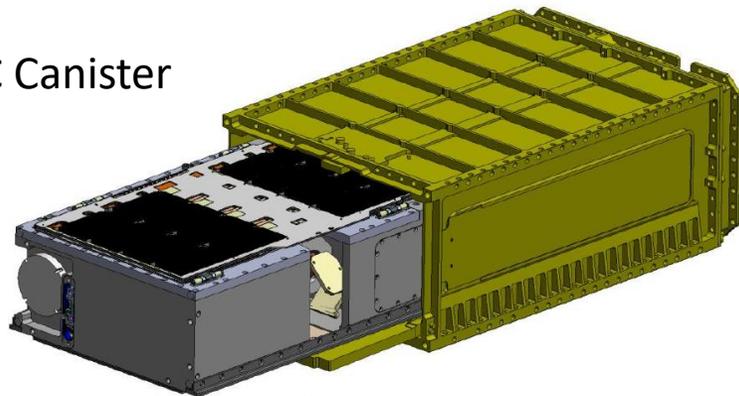
Immersion
Grating (JPL)



Cryocoolers +
Electronics
(Ricor K508N)



PSC Canister



Deployment Direction

Stowed



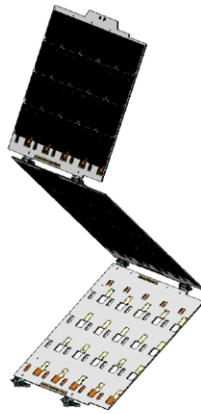
1st Panel Released



1st and 2nd Panel Released



All panels Released



Fully Deployed



CIRAS Spacecraft

Solar Arrays

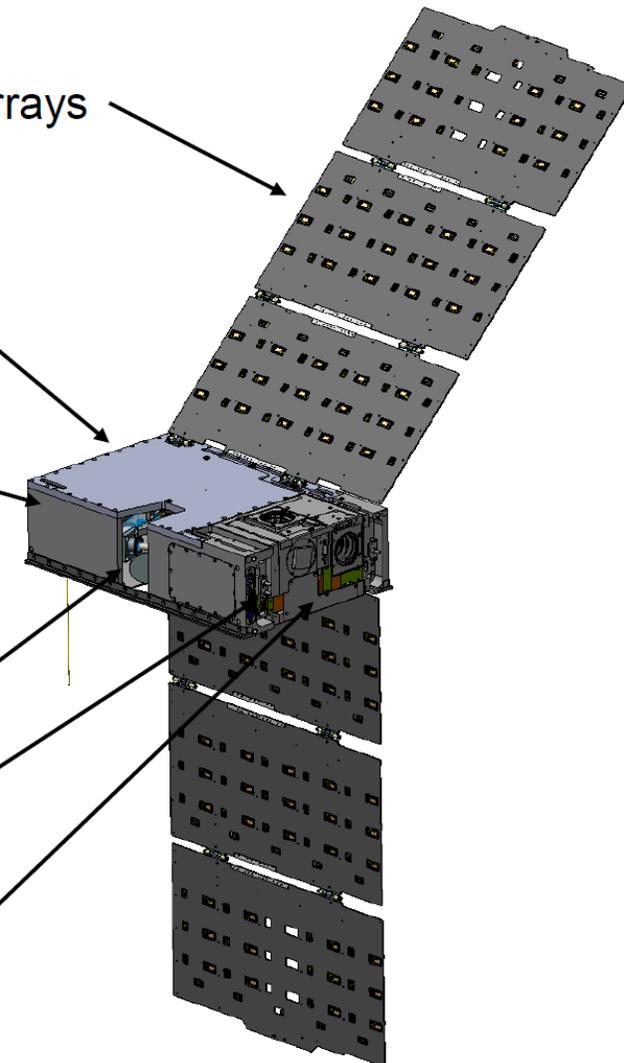
Instrument Panel

Main Chassis

Instrument Aperture

Sun Sensor

XB1 Avionics



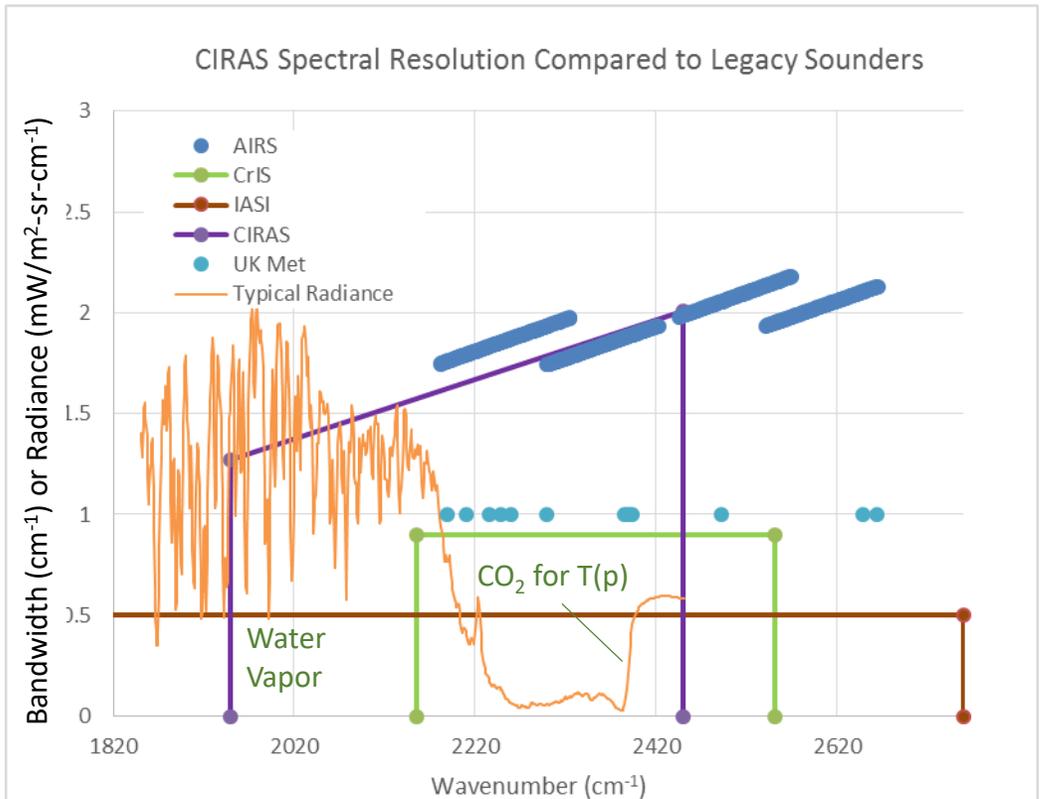


CIRAS uses MWIR Band for Low Cost and Good Lower Trop Sensitivity

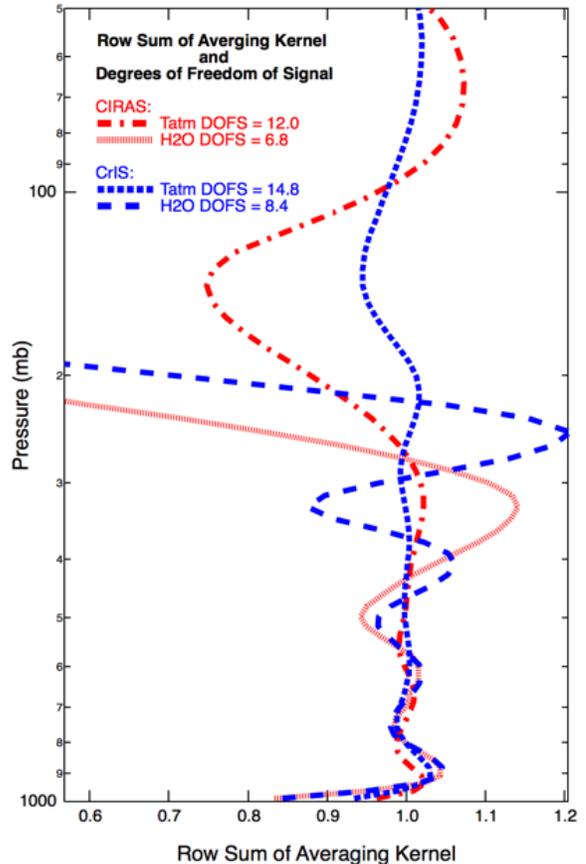
CIRAS Spectral like AIRS but Extends into the Water Band

1950 cm^{-1} – 2450 cm^{-1}

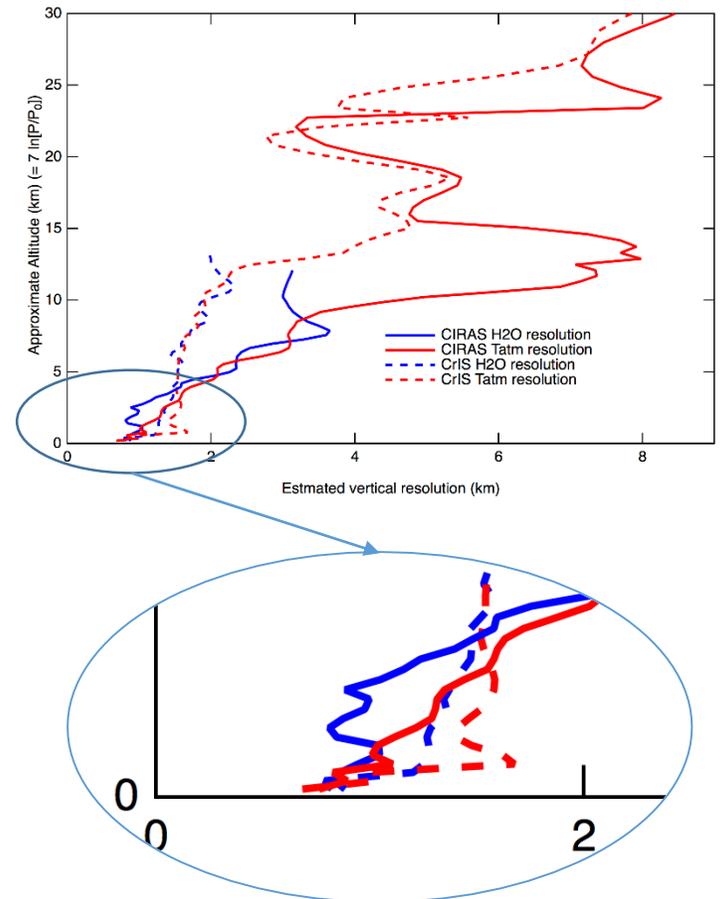
$\Delta\nu = 1.2\text{-}2.0 \text{ cm}^{-1}$, $N_{\text{ch}} = 625$



CIRAS Information Content Extends from the Surface to 300 mb

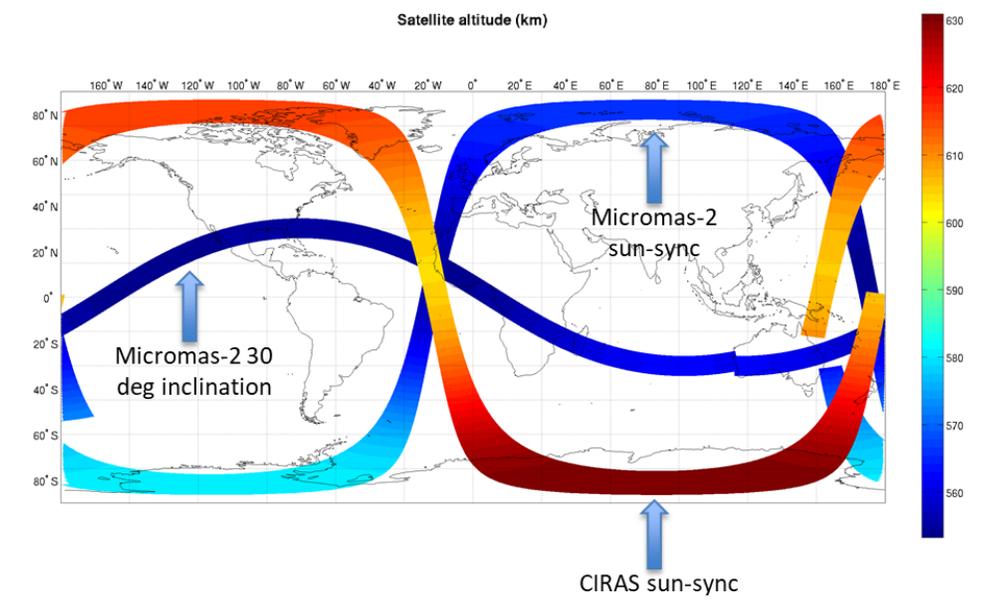
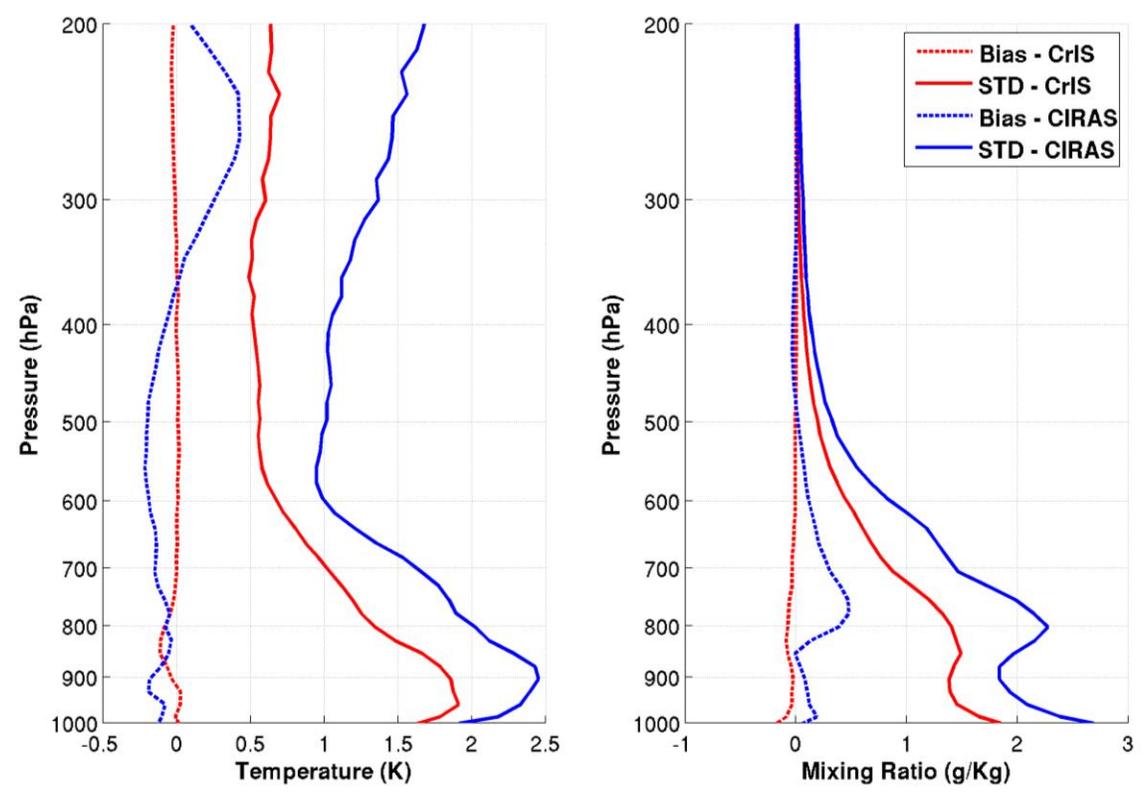


Vertical Resolution Comparable in Lower Troposphere



- Challenges using MWIR including Non-LTE, surface emissivity, solar reflected energy still need work.

CIRAS Spatial Resolution and Coverage Comparable to (but lower than) Legacy Sounders

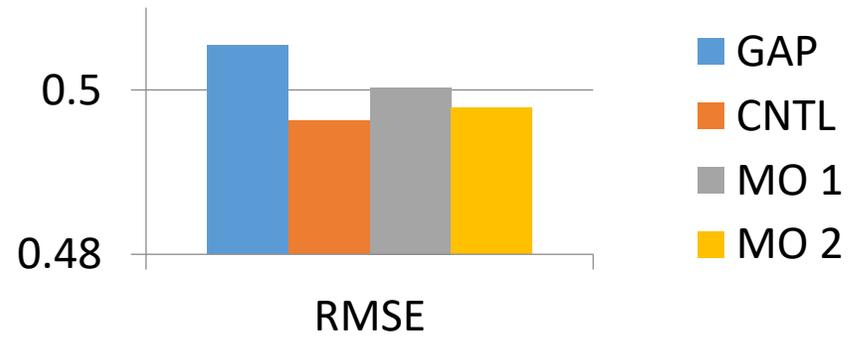


The alternative of CubeSat based advanced infrared and microwave sounders for high impact weather forecasting

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Draft Paper

OSSE Results





Summary and Conclusions

- NASA and NOAA Satellites Improve Weather Prediction and Support Earth Science
- Under Hank's direction, SSEC has been and continues to be a world leader in IR sounder development, calibration, applications and science.
- Infrared Sounders including AIRS, CrIS and IASI have among the highest impact of all satellite instruments for improving weather forecast and are used widely for climate science
 - Assimilated by NWP centers worldwide
 - Used to validate climate models
 - Used to explore and understand processes affecting weather and climate
 - Used to help us understand the composition and chemistry of the atmosphere (e.g. O₃, CO, CO₂)
 - Used for applications to help decision makers: (e.g. SO₂, Drought)
- Aqua expected to run out of fuel by 2022. The NASA/NOAA Joint Polar Satellite System (JPSS) will continue IR sounder measurements with CrIS into the late 2030's
- NASA and NOAA desire smaller satellites to save cost and complement existing satellites
- CubeSat technology now enables low-cost per satellite. Constellations are an alternative to GEO, provide global coverage of Temperature, Water Vapor, 3D Atmospheric Motion Vector Winds and Composition
- NASA JPL AIRS Project appreciates the work done by Hank and SSEC and is looking forward to continued collaboration in the near future.