Status of NASA's Atmospheric Infrared Sounder (AIRS) and CubeSat Infrared Atmospheric Sounder (CIRAS) Projects

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http://airs.jpl.nasa.gov
https://www.jpl.nasa.gov/cubesat/missions/ciras.php

Contributors:

- AIRS Project Team (JPL)
- AIRS Science Team (ROSES)
- AIRS DAAC, SVS (GSFC)
- CIRAS Project Team (JPL)
- BAE SYSTEMS (AIRS)
- Ball Aerospace
- IRCameras
- Blue Canyon Technologies

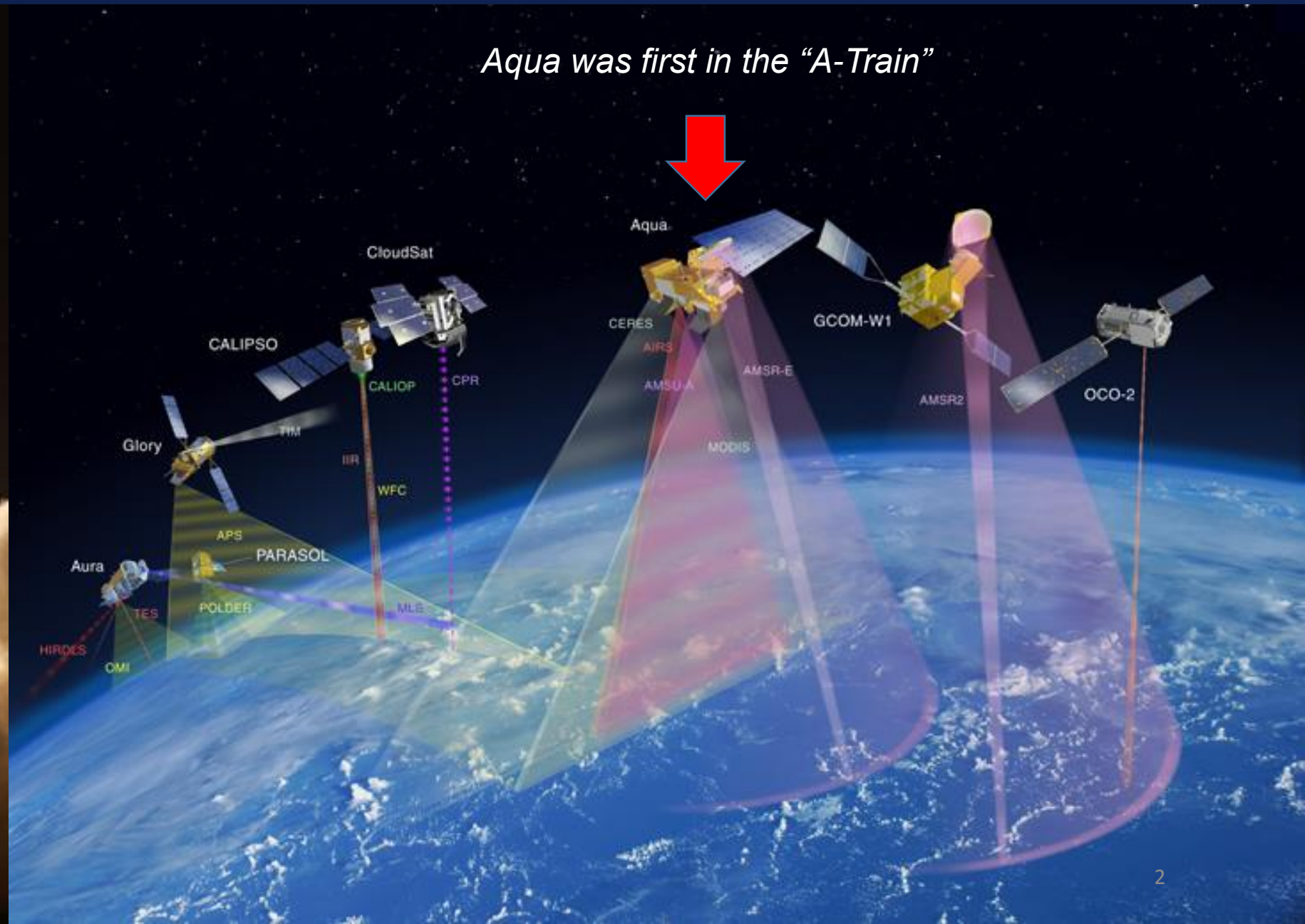
Sponsors

- NASA Science Mission Directorate, Earth Science Programs
- NASA Earth Science Technology Office (ESTO)
- NOAA NESDIS Office of Projects, Planning and Analysis (OPPA)

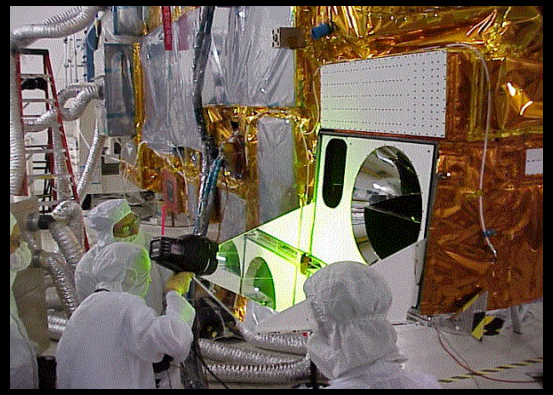
Aqua Launched May 4, 2002 from Vandenberg Air Force Base

Aqua Launched On a Delta 2

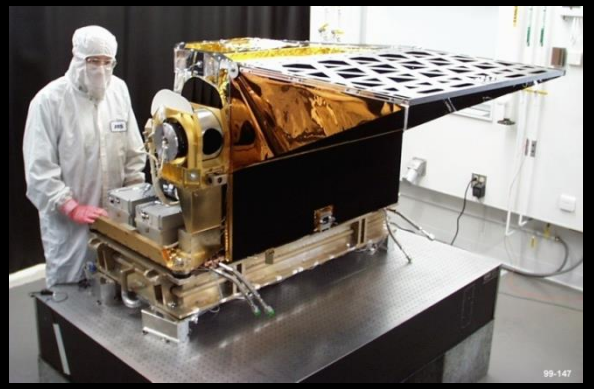
Aqua was first in the "A-Train"



The Aqua Spacecraft and Instruments



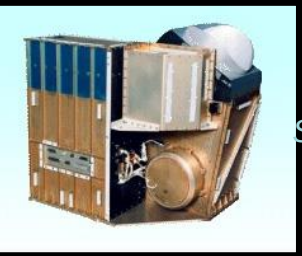
Moderate Resolution Imaging Spectroradiometer (MODIS)
GSFC/Raytheon



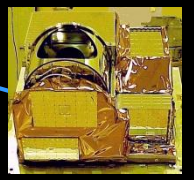
Atmospheric Infrared Sounder (AIRS)
JPL/BAE SYSTEMS

AQUA Spacecraft
GSFC/NGST

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



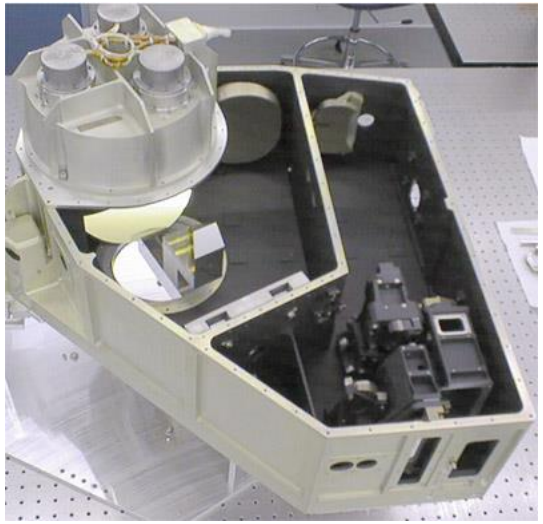
Advanced Microwave Sounding Units (AMSU-A/B)
JPL/Aerojet



Humidity Sounder from Brazil (HSB)
JPL/Aerojet

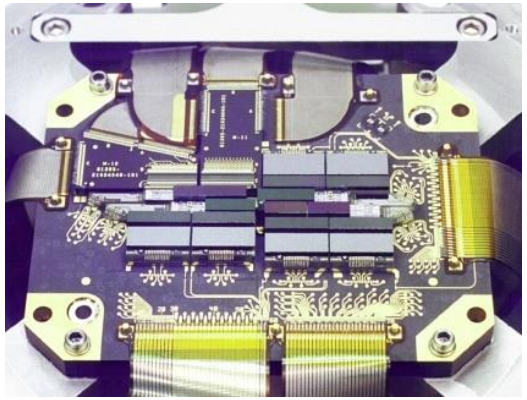
Clouds and Earth Radiant Energy System (CERES)
LaRC/NGST

AIRS Pioneered EO-IR Technology to Measure Earth's Spectrum

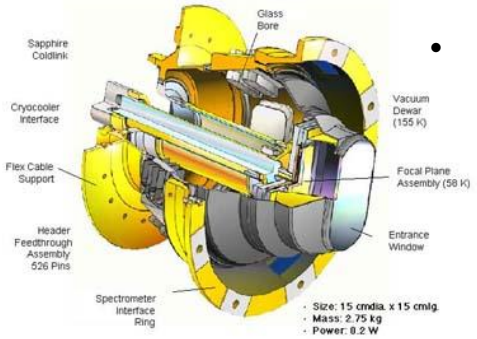


The Atmospheric Infrared Sounder (AIRS)

- **IR Spectrometer: Multi-Aperture Array Grating Spectrometer**
- **155K Operation**



- **FPAs: PV HgCdTe to 13.7 µm, PC HgCdTe to 15.4 µm**

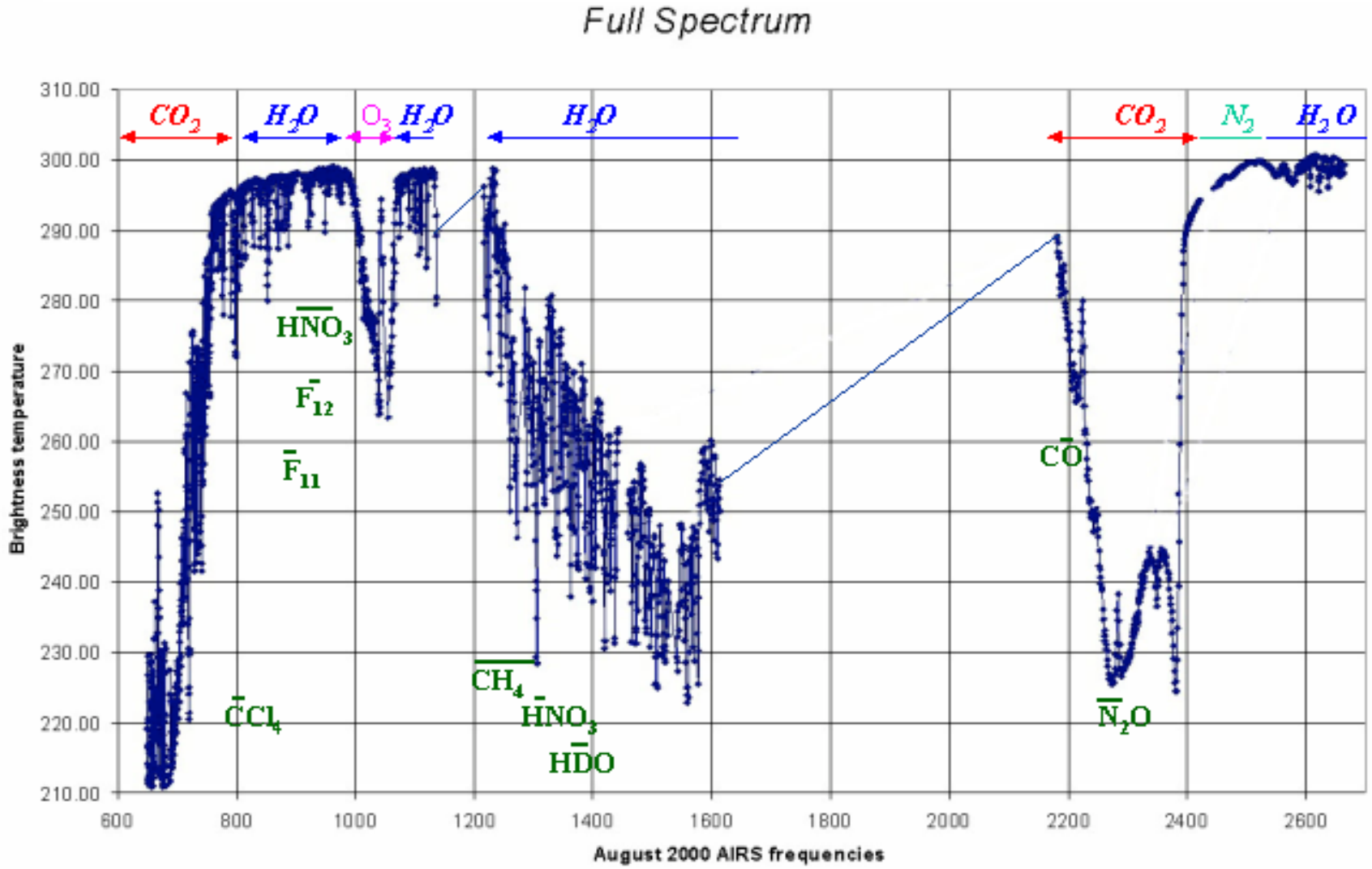


- **Evacuated Dewar with Cold Window**

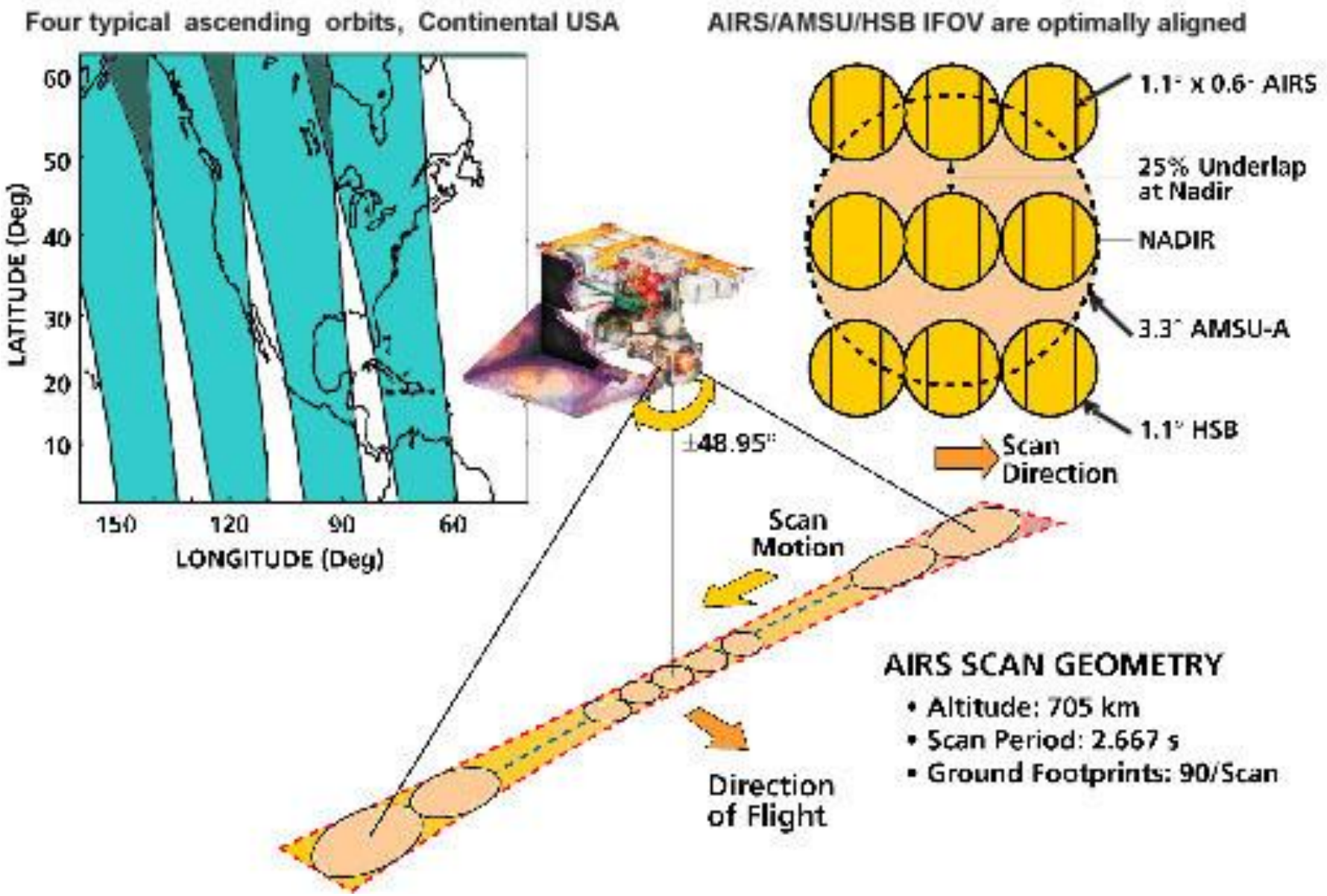
- **Focal Plane Cooling using Single Stage Stirling Pulse Tube, Redundant**

AIRS Measure the Upwelling Earth Spectrum in the Infrared

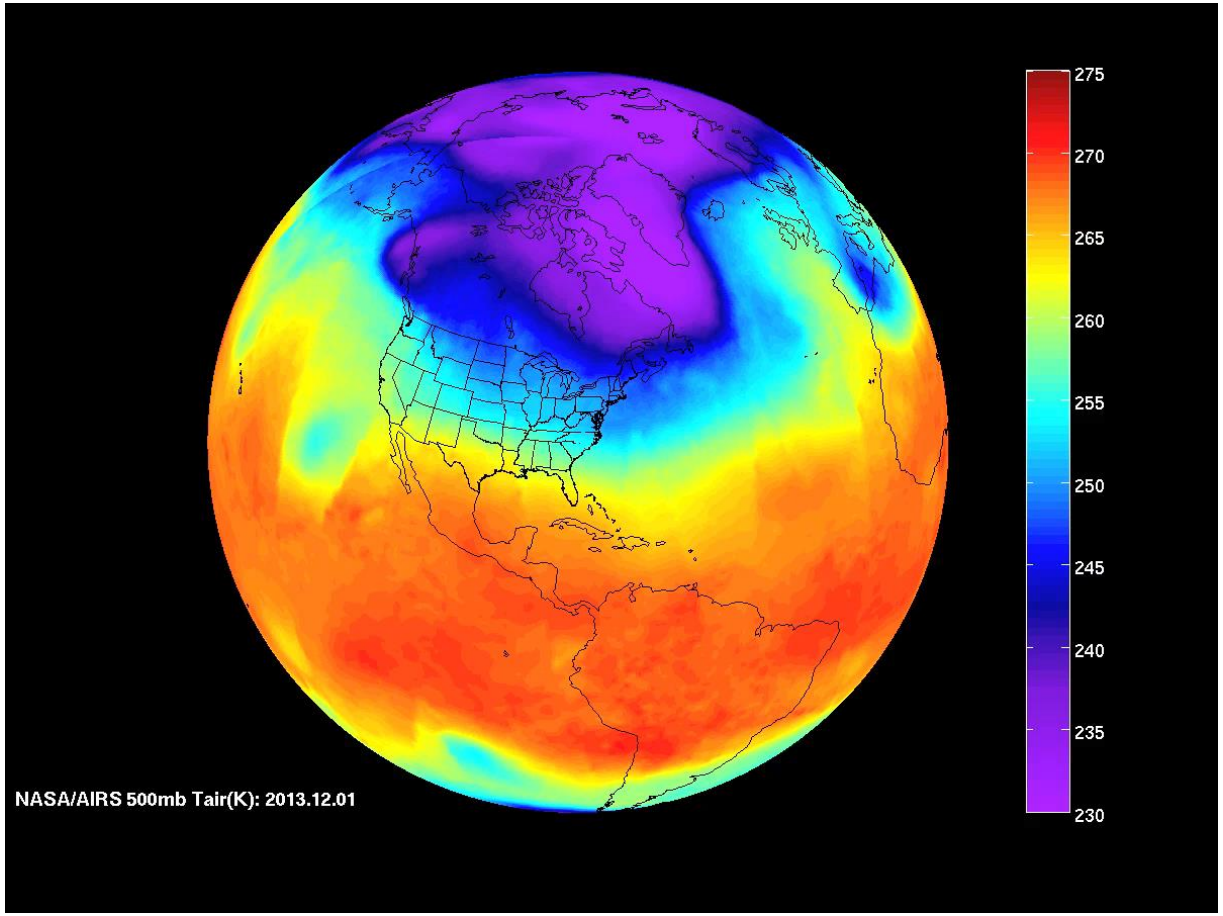
AIRS Channels for Tropical Atmosphere with T_surf = 301K

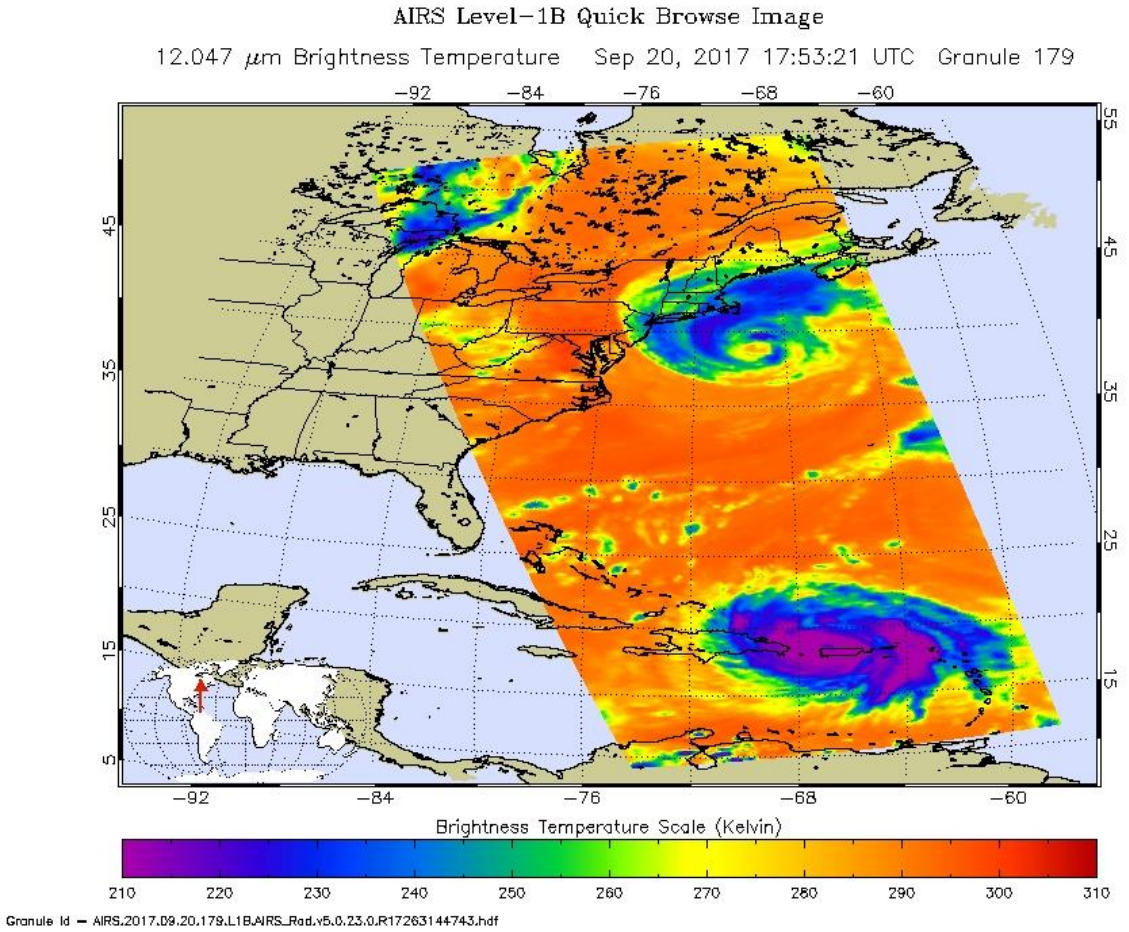


AIRS Wide Swath to Provides Global Daily Coverage

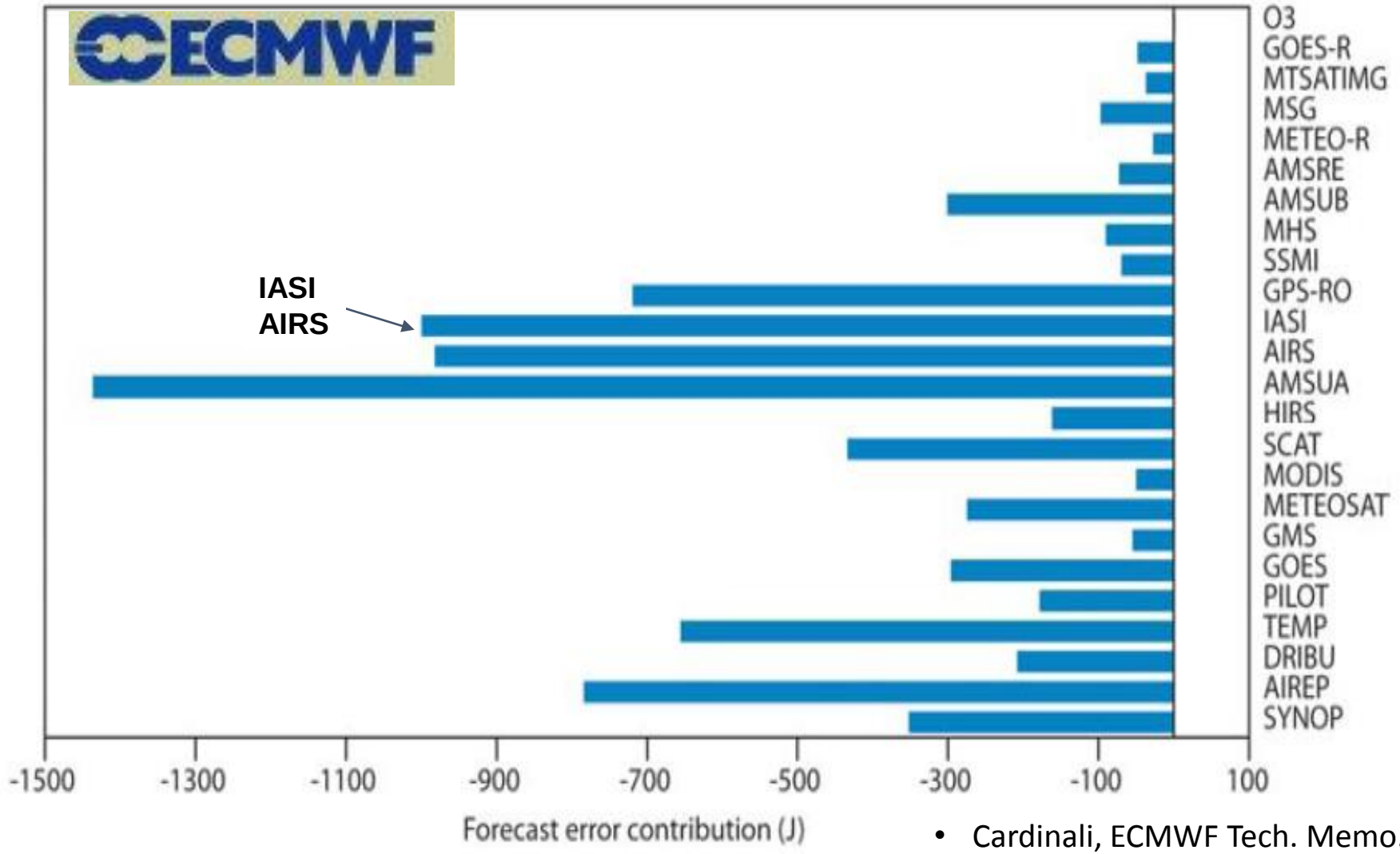


AIRS Wide Swath Captures Hurricanes Jose and Maria



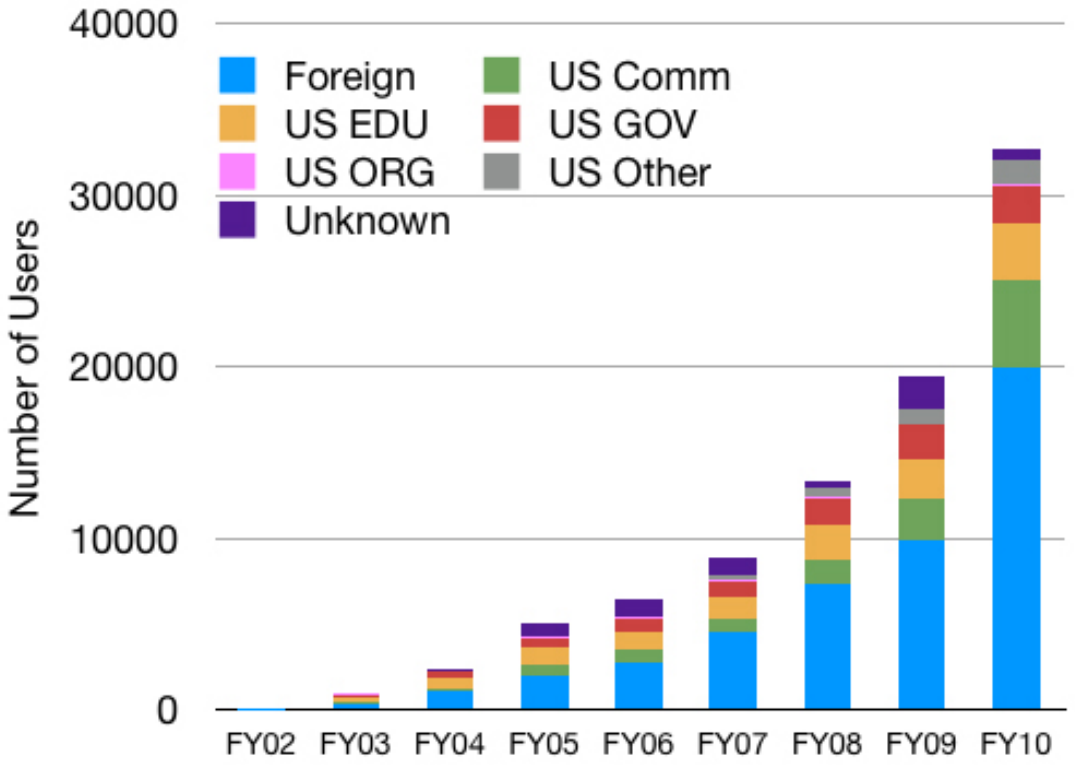


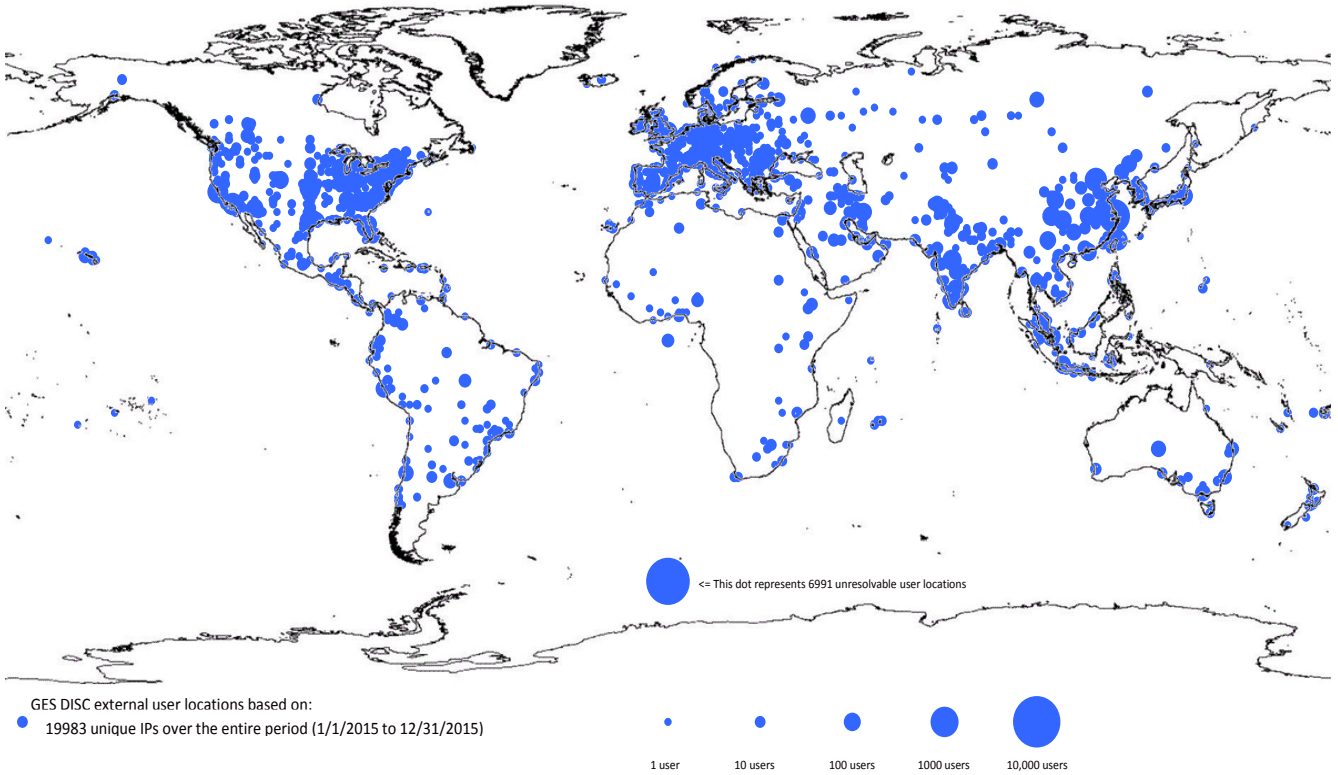
IR Sounders Improve Weather Forecasts



- Cardinali, ECMWF Tech. Memo. 599, 2009

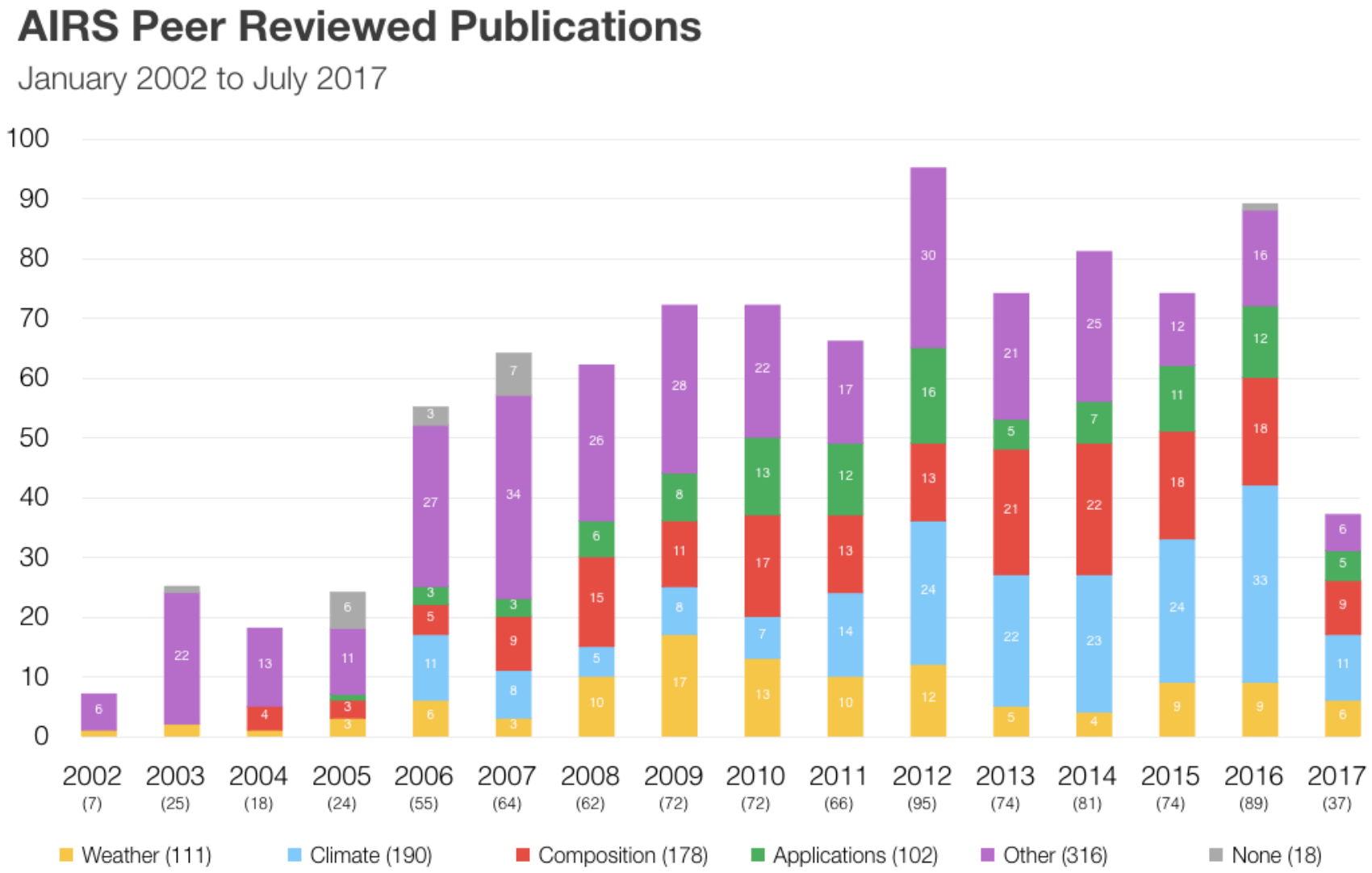
Users Over the World Access Aqua Data





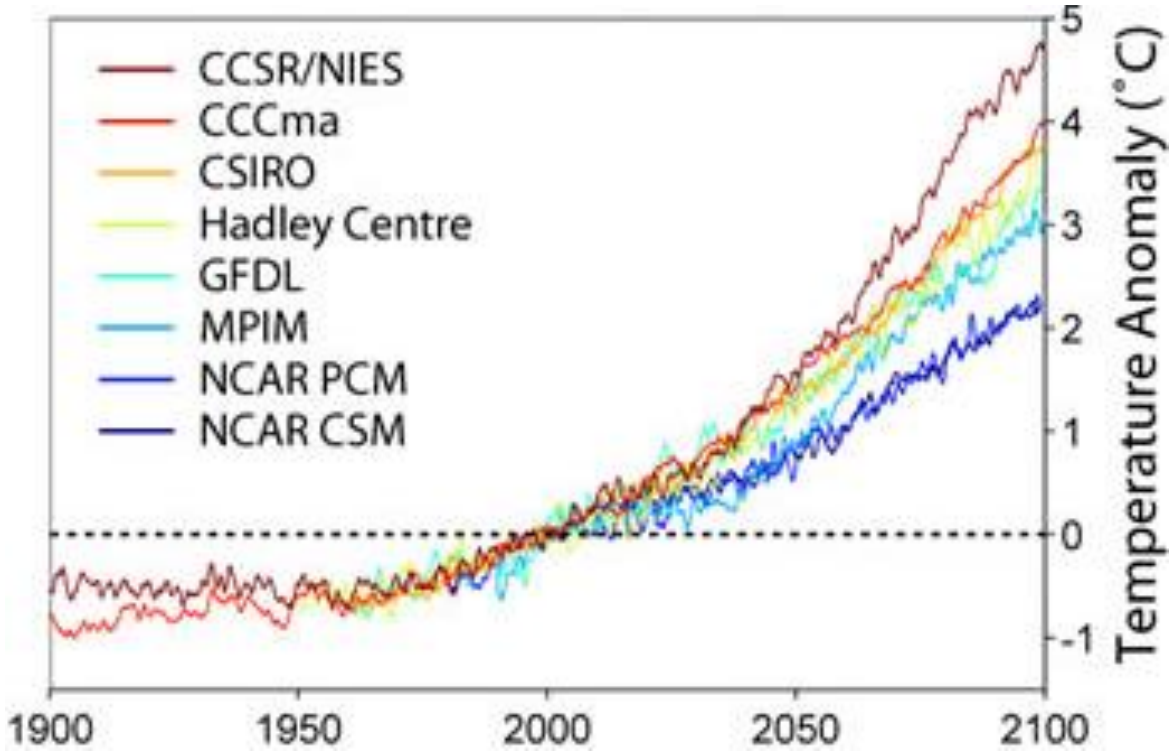
Feng Ding (GSFC)

AIRS Users Produce Dozens of Peer Reviewed Publications Annually



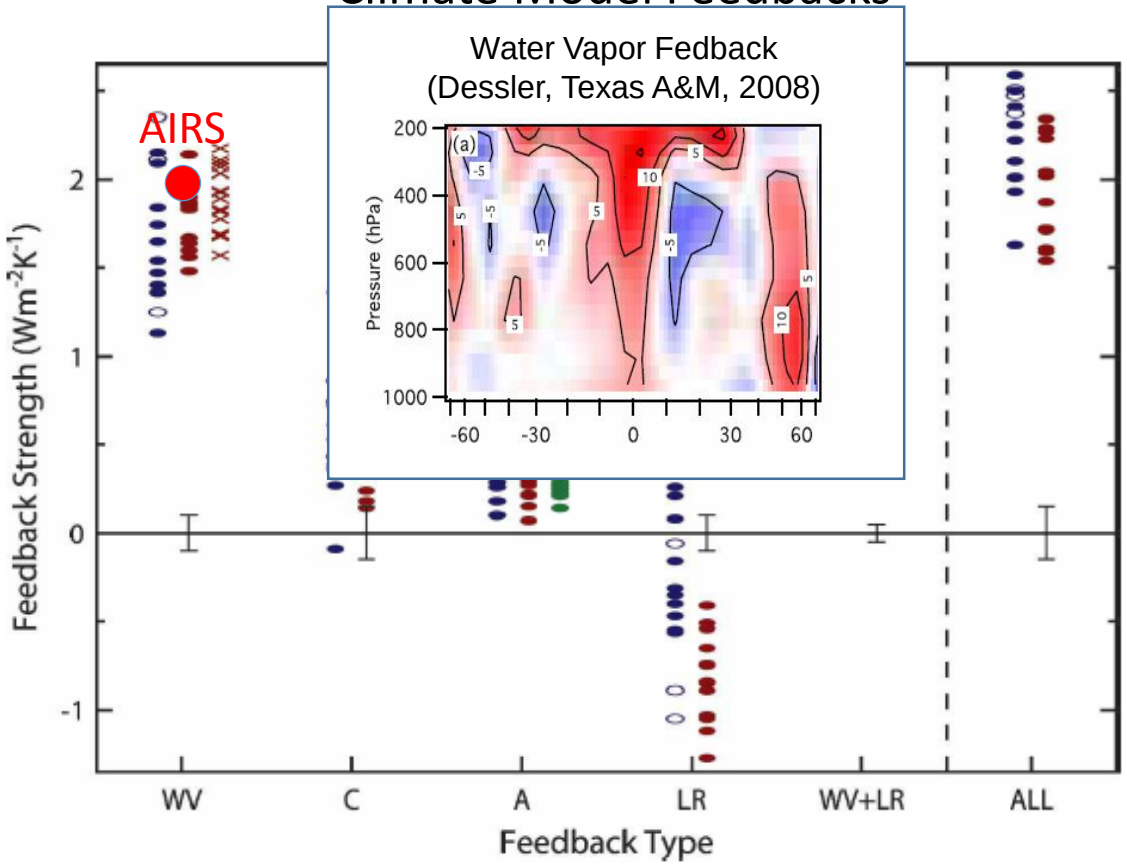
AIRS Data Used to Reduce Errors in Climate Models

Climate Warming Predictions



http://priweb.org/globalchange/climatechange/globalwarming/gw_05.html

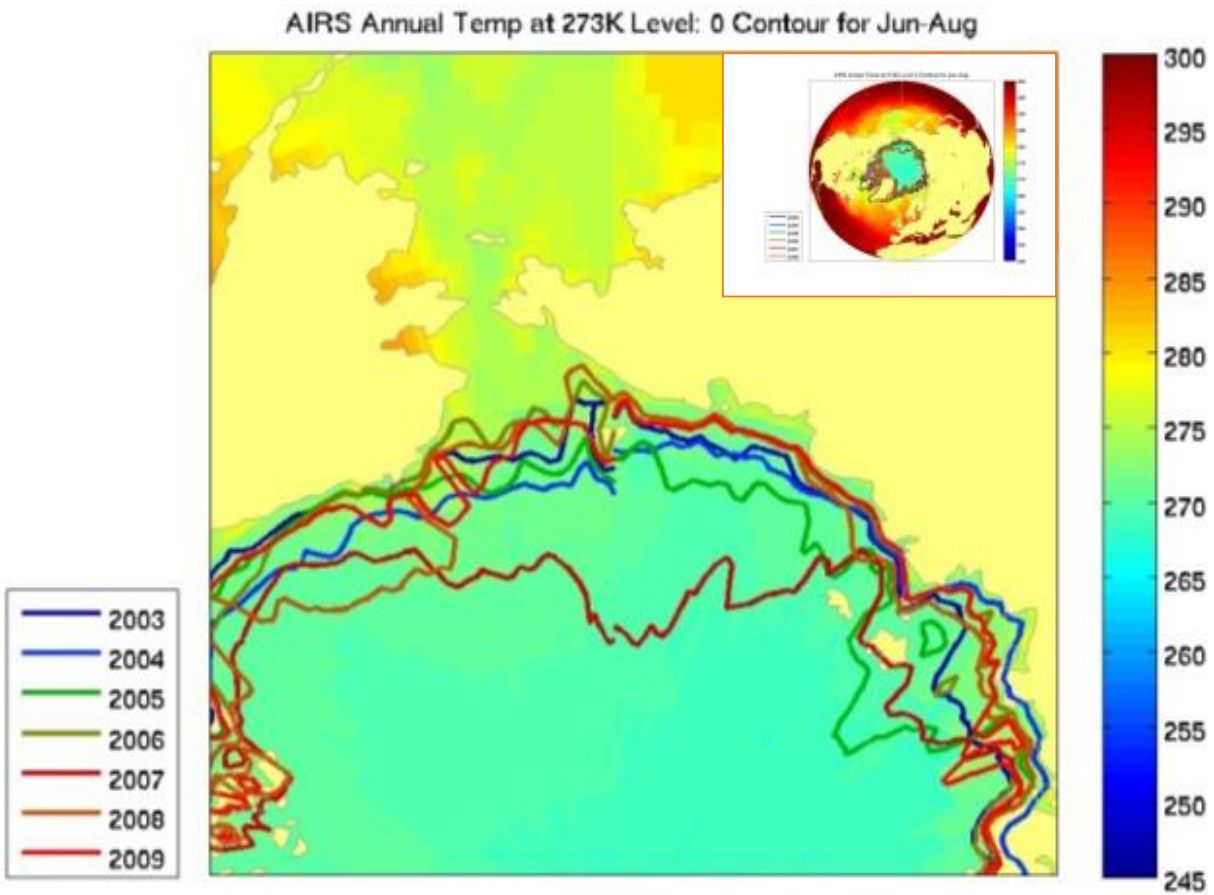
Climate Model Feedbacks



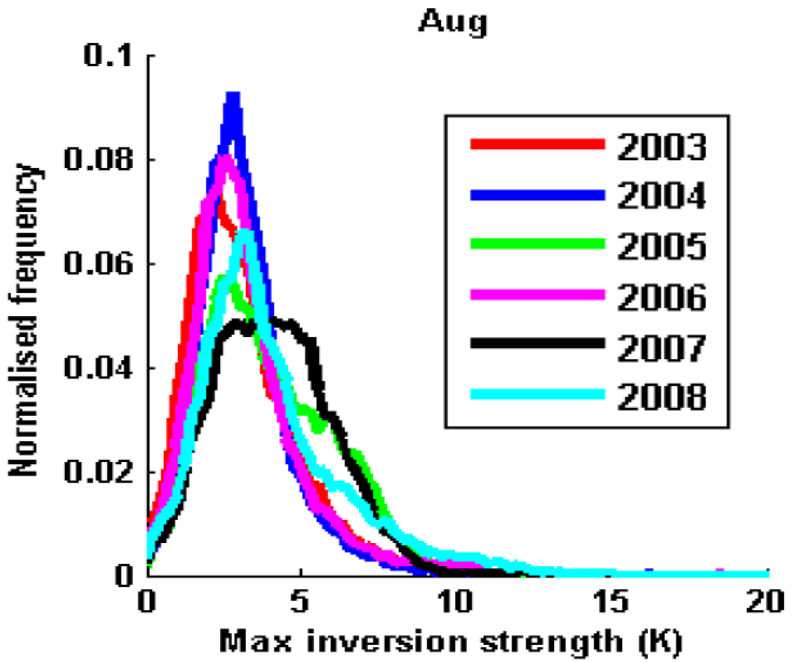
Bony, S., et al., "How Well Do We Understand and Evaluate Climate Change Feedback Processes?", Journal of Climate, Vol 19, p 3445-3482. + Dessler 2008

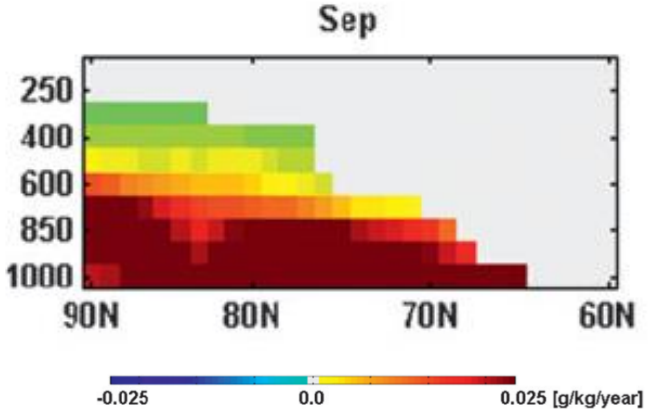
AIRS Data Used to Study Polar Warming Trends

AIRS Data Starting in 2003 Show Polar Warming Trends



Inversion Strength In Polar Regions Shown to Increase in Warmer Years





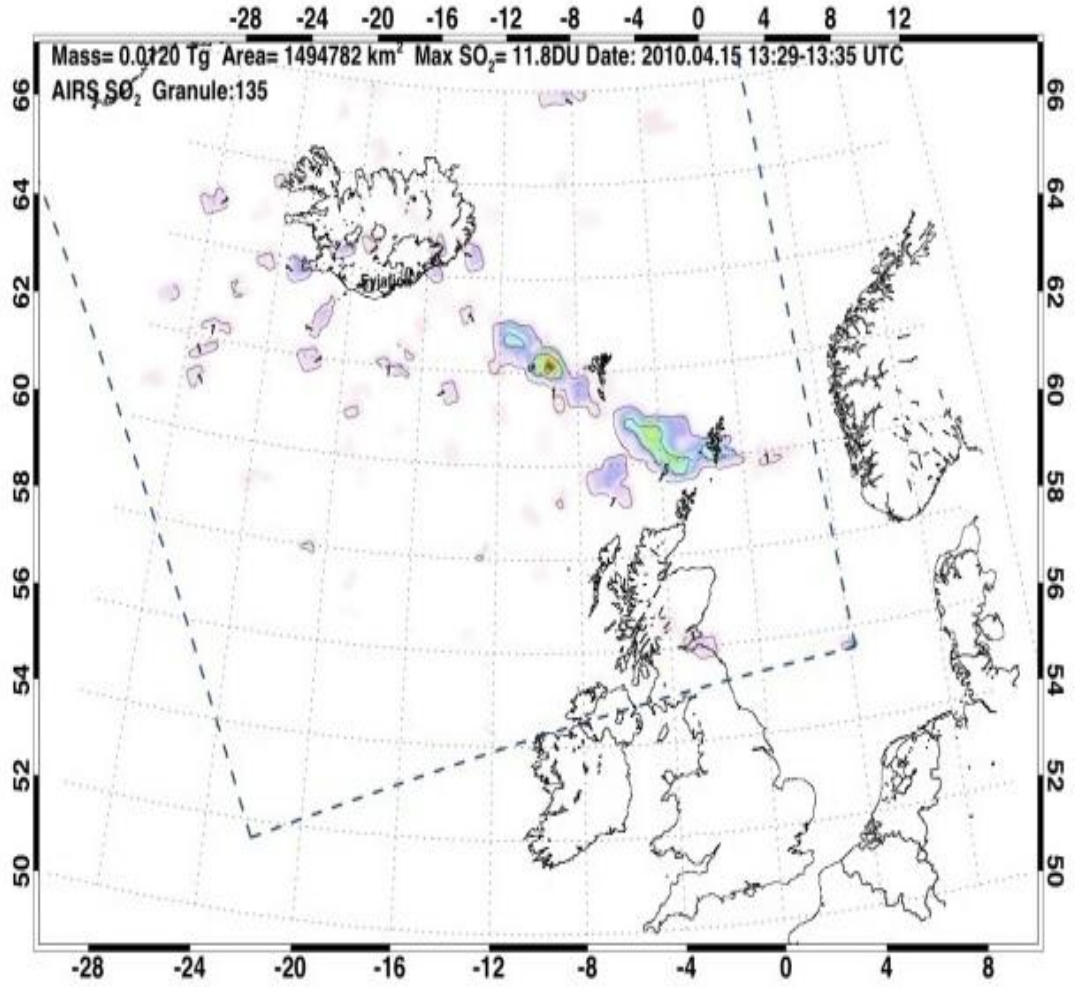
Decadal Trend In Water Vapor

A. Devasthale, 2010, 2016

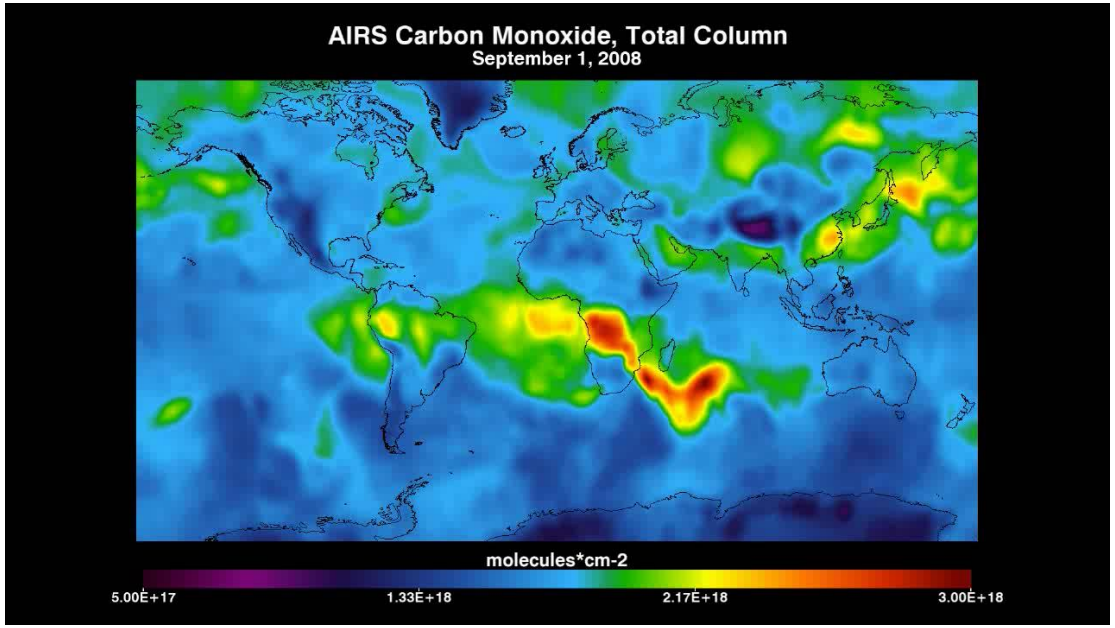
AIRS Composition Products Support Aviation Hazards and Air Quality

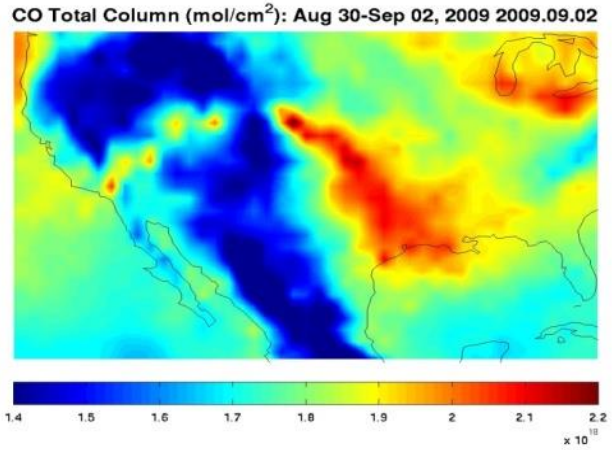
Sulfur Dioxide Alerts
Aviation Warning

Ejyafyallajokul SO2
Fred Prata NIAR, Norway

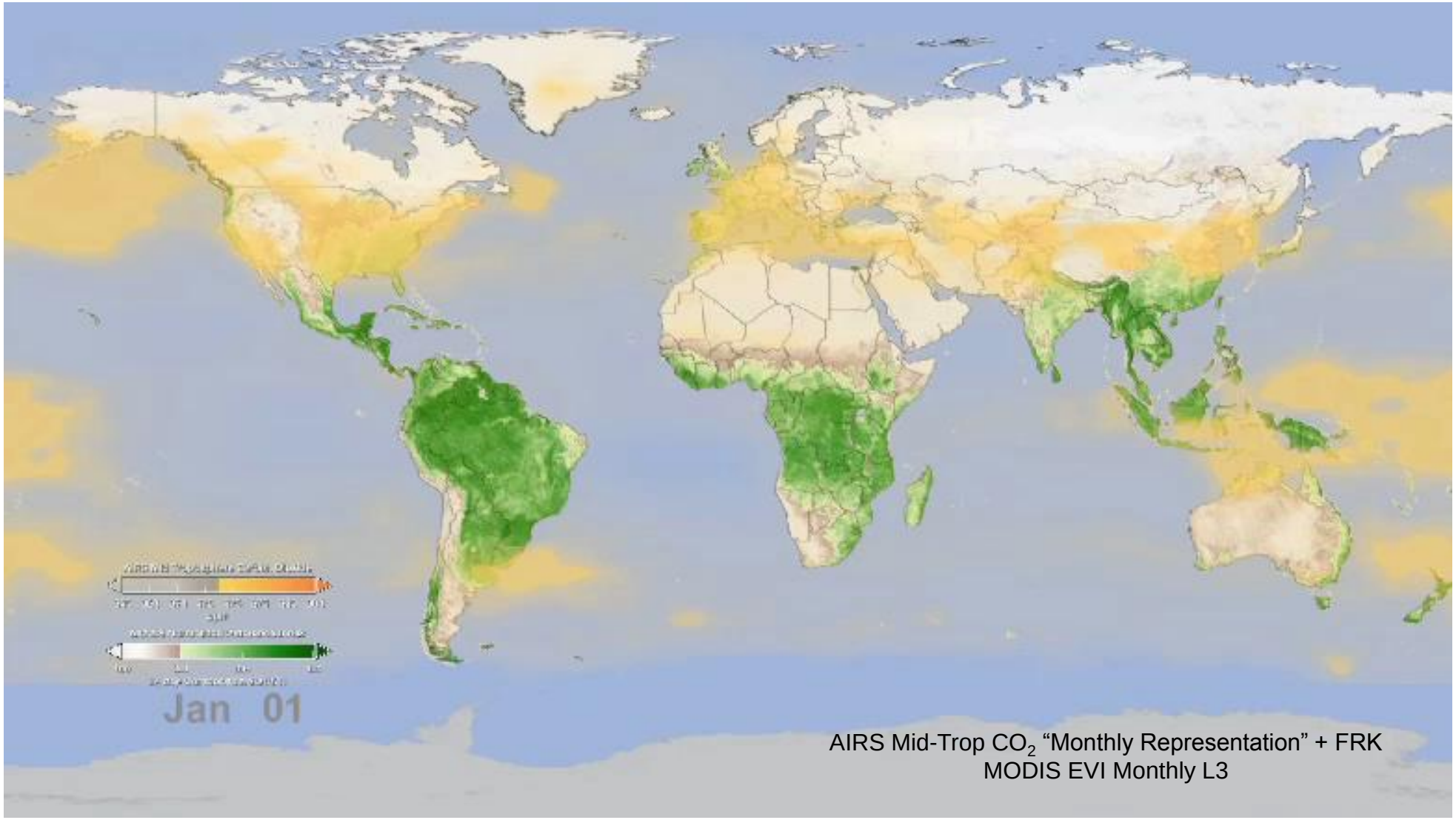


Global **Carbon Monoxide** Transport
(JPL, 2008)





AIRS Mid-Trop CO_2 Drawdown Follows Regional Vegetation Cycle



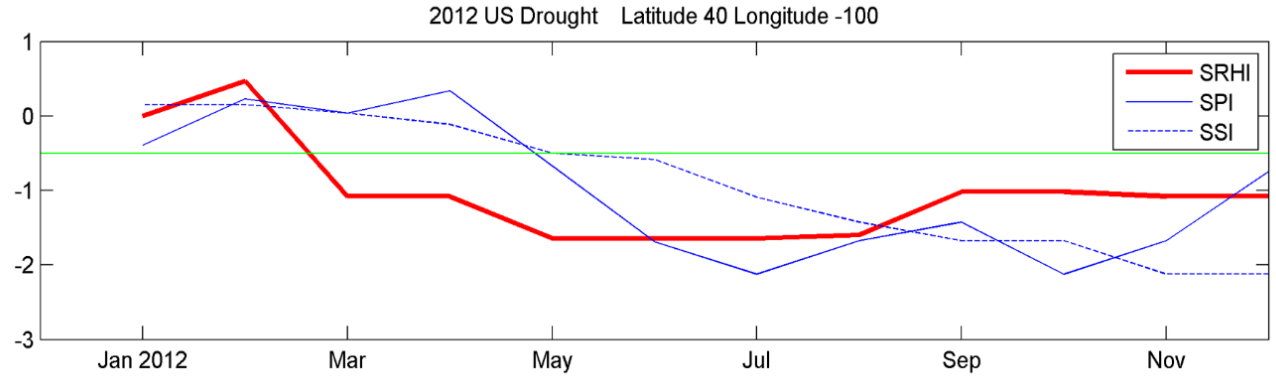
AIRS Mid-Trop CO_2 "Monthly Representation" + FRK
MODIS EVI Monthly L3

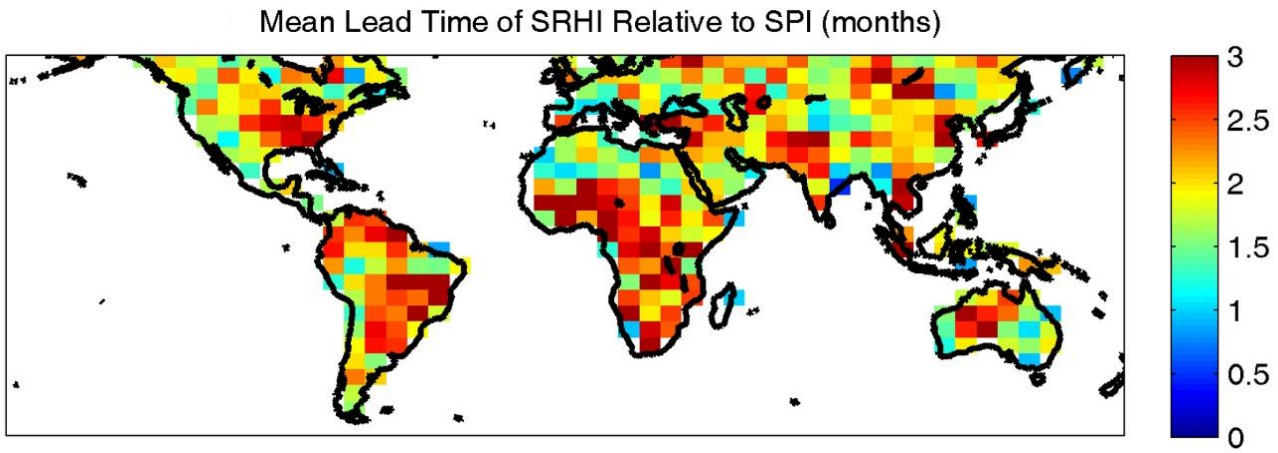
Lori Perkins (NASA/GSFC Science Visualization Studio)
T. Pagano, E. Olsen, S. Ray (JPL)

T.S. Pagano, E.T. Olsen, H. Nguyen et al.; "Global variability of midtropospheric carbon dioxide as measured by the Atmospheric Infrared Sounder," J. Appl. Remote Sens., 8(1), 084984 (2014). doi:10.1117/1.JRS.8.084984

AIRS Shows Skill in Early Drought Detection

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





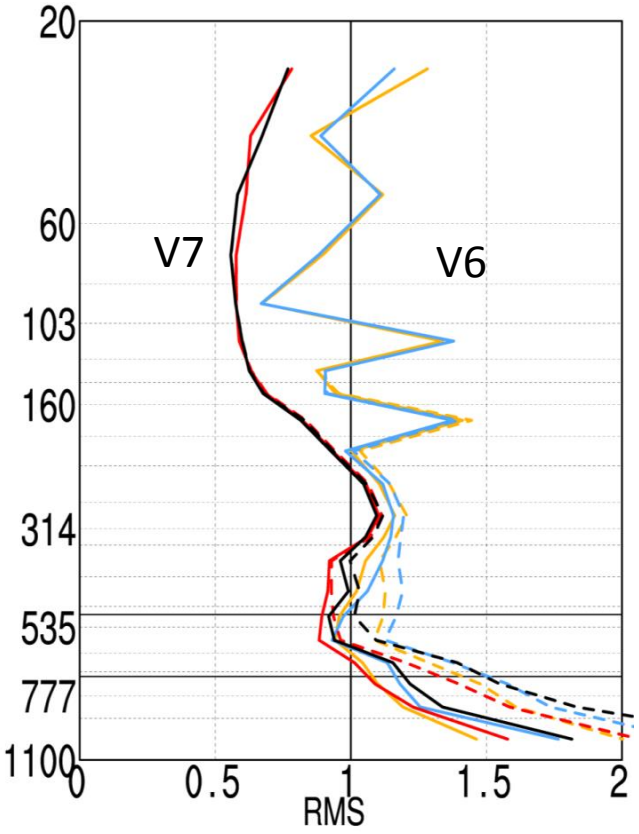
Mean global AIRS-based SRHI lead time: **1.9 month**

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 Team Working on Version 7 Release

- Corrected total precipitable water dry bias found during the day in V6, and also improved dry water vapor bias near 300 mb.
- Improved how the stratospheric water neural net guess adjusts smoothly to climatology at the top of the atmosphere, which corrected water vapor artifacts at 50 mb found in V6.
- Allowed additional structure in temperature and water vapor in the boundary layer.
- Made very large improvements in ozone retrieval methodology and QC methodology. AIRS total O_3 now matches OMPS extremely well, even under ozone hole conditions.
- Incorporated new 2016 ozone climatology which distinguishes between ozone hole and non ozone hole conditions, and significantly improved ability to produce accurate ozone retrievals in the region of the ozone hole.
- Improved internal noise covariance matrix methodology which resulted in improvements of *T(p)*, *q(p)*, and $O_3(p)$.
- Incorporated new neural net coefficients which significantly improved stratospheric temperature in polar night cases. This was a significant flaw in Version-6.28.
- Developed a new AIRS Only retrieval system that does not use AMSU A1/A2 in anyway and performs very well. This system makes use of GFS snow and ice flags to specify surface class.

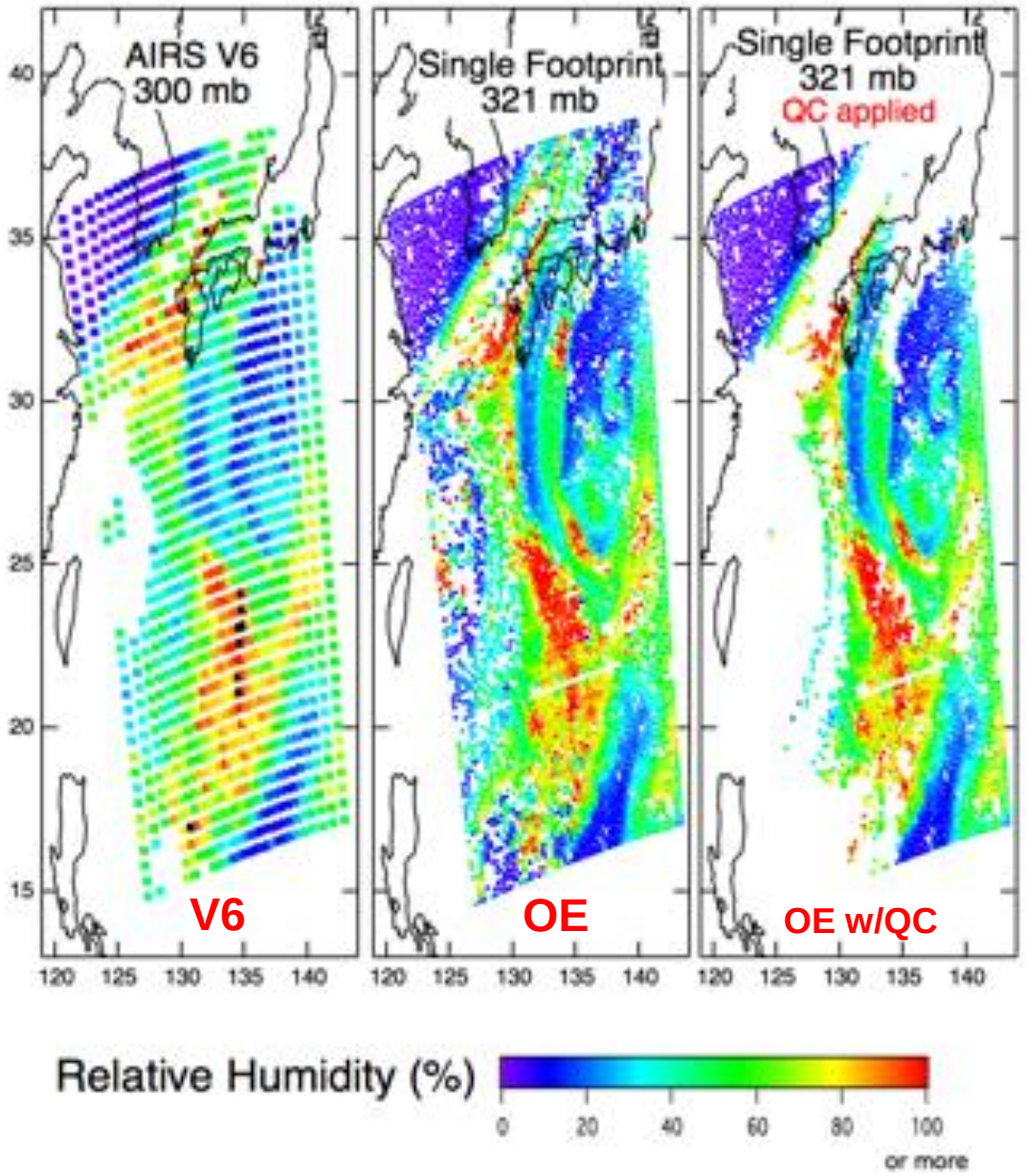
Polar Temperature Retrieval RMS Error Compared to ECMWF
V6 vs V7



J. Susskind (GSFC)

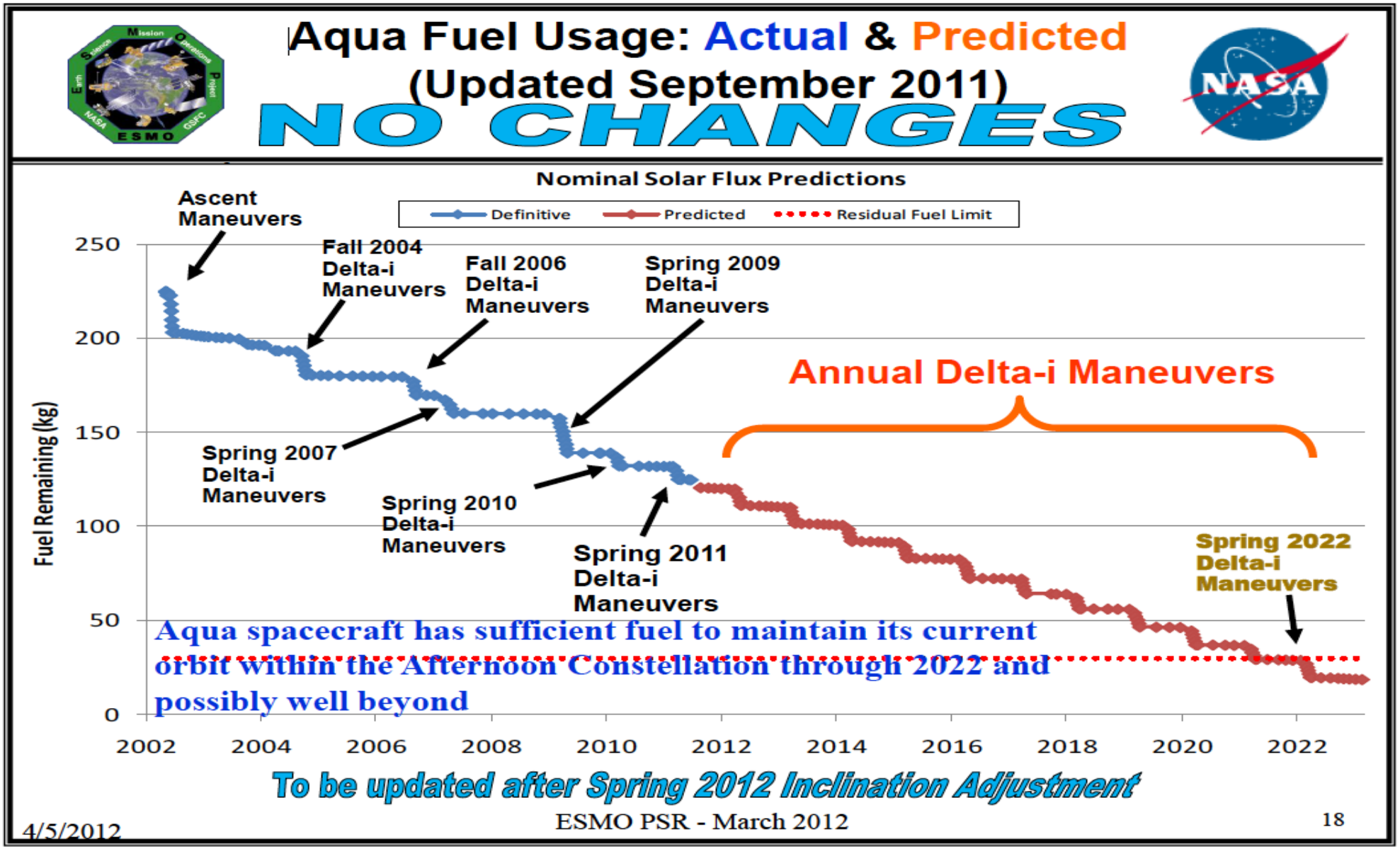
Single Footprint Retrievals from AIRS L1b Spectra Under Development

- Uses AIRS L1b directly – no microwave and no cloud-clearing
- 13.5 km horizontal resolution at nadir, but no retrieval below thick clouds
- SARTA forward model + Delta-4-Stream cloud calculation (Strow et al., 2003; Ou et al., 2013)
- Simultaneous optimal estimation retrieval of
  - surface temperature, cloud-top temperature, cloud optical depth and particle size, profiles of temperature, water vapor
- MODIS L2 cloud properties (averaged on AIRS footprint) used as cloud a priori
- ECMWF 6hr analyses used for surface, temperature and water vapor profile a priori



Irion, F. W., et al.: Single-footprint retrievals of temperature, water vapor and cloud properties from AIRS, Atmos. Meas. Tech. Discuss., in review, 2017.

AIRS Expected to Operate For Life of Spacecraft through 2022

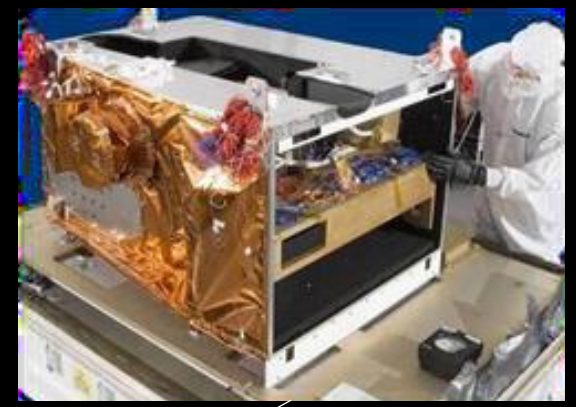


Suomi NPP / JPSS to Provide Continuity + Enhancements to Aqua

ATMS

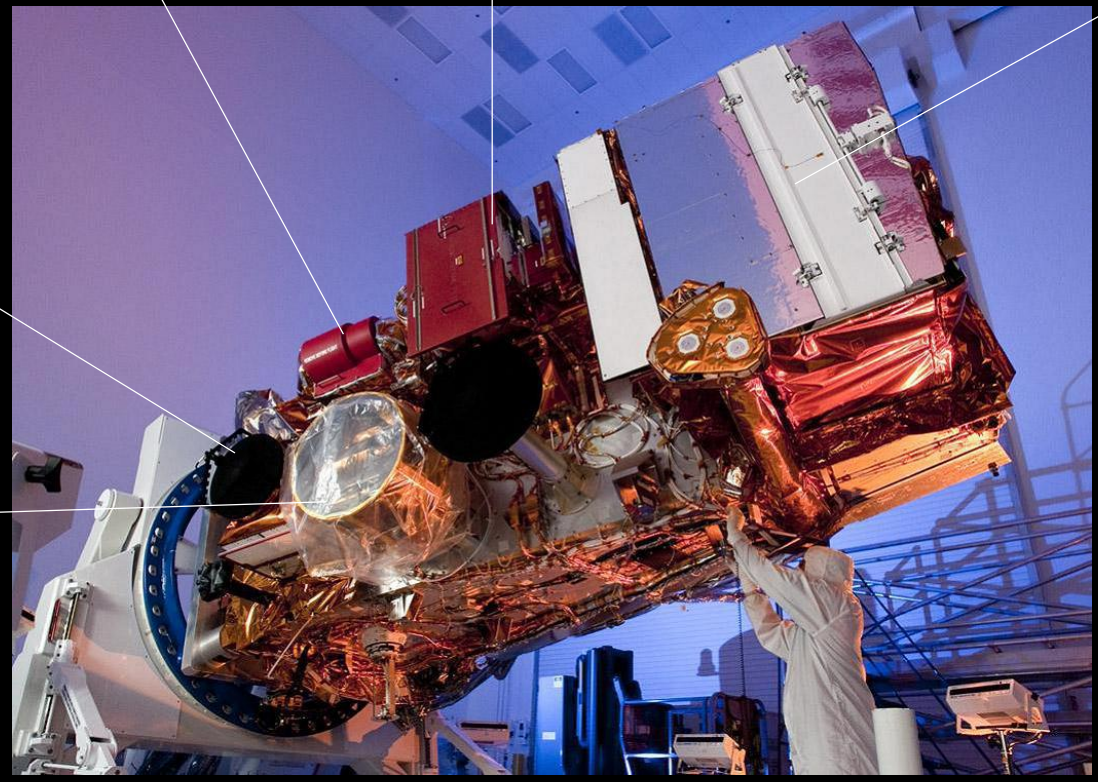
CrIS

VIIRS



OMPS

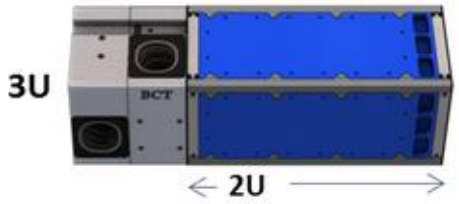
CERES



3U, 6U, 12U CubeSat Systems Now Available Commercially

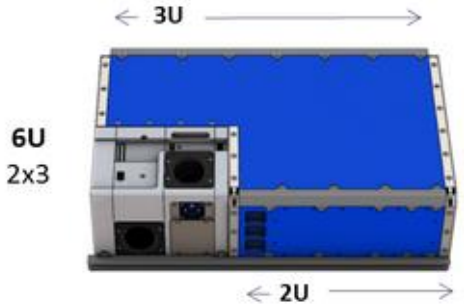
3U XB1 Spacecraft

2U Available Payload Volume



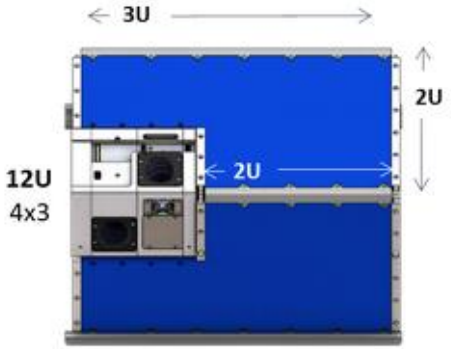
6U XB1 Spacecraft

5U Available Payload Volume



12U XB1 Spacecraft

11U Available Payload Volume

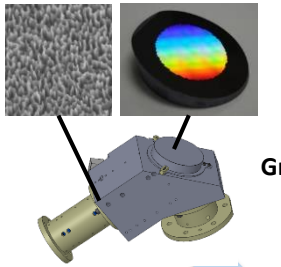
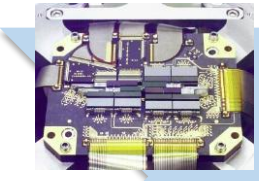
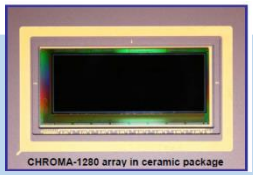
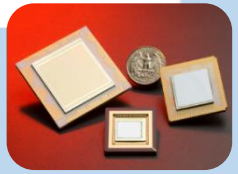
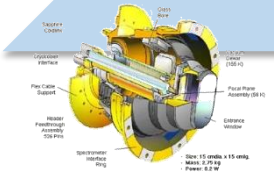
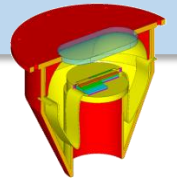
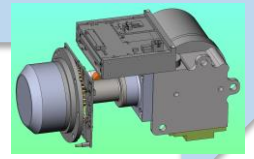


BLUE CANYON TECHNOLOGIES

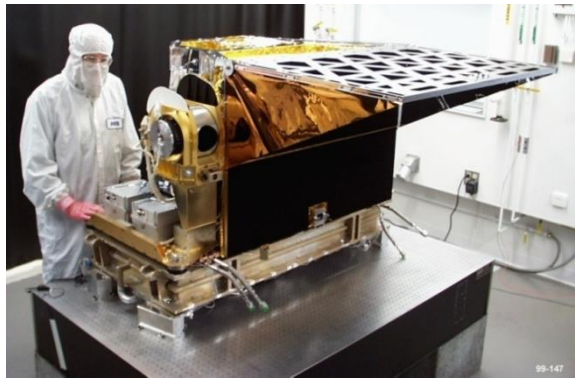
Micro-Sat XB1 Spacecraft

Leverages the XB1 Avionics and the FleXcore Attitude Control to maximize performance and available Payload Volume

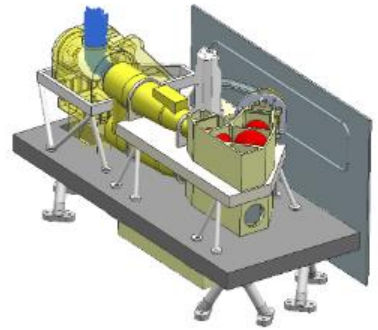
Infrared Grating Spectrometer Atmospheric Sounder Technology

	AIRS	MIRIS	CIRAS
Spectrometers	 AIRS BAE Systems Pupil-Imaging Grating Spectrometer FOV = 1.1° D = 2 mm	 SIRAS, SIRAS-G Ball Aerospace Imaging MWIR Grating Spectrometer FOV = 16° D = 25 mm	 CIRAS Ball Aerospace / JPL Imaging MWIR Immersion Grating Spectrometer FOV = 16° D = 15 mm
Detectors	 AIRS BAE Systems PV/PC HgCdTe 17 modules 2 x ~180 100 x 50 um	 CHROMA Teledyne PV HgCdTe 13.5 um Cutoff 480 x 1280 30 x 30 um	 HOTBIRD JPL 5.5 um Cutoff 640x512 24 x 24um
Dewars	 AIRS BAE Systems Cryo Dewar	 SIRAS Ball Aerospace Reflecting Warmshields	 CIRAS IR Cameras IDCA
Cryocoolers	 AIRS Northrop Grumman Pulse Tube Cryocoolers	 ABI / OCO-2 Northrop Grumman Smaller Pulse Tube Cryocoolers	 Ricor K508 Integral Sterling Cryocooler

AIRS 2002



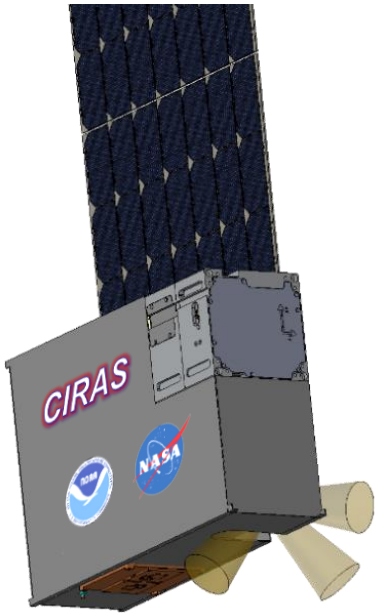
MIRIS 2010 (Concept)



CIRAS 2019

CubeSat Infrared Atmospheric Sounder (CIRAS) Mission Overview

- Mission Objectives
  - In-Space Technology demonstration for key infrared subsystems: HOT-BIRD IR Detectors, Immersion Grating Spectrometer, Black Silicon Blackbody
  - Demonstration of Mid-wavelength Infrared (MWIR) temperature and water vapor sounding. Comparable sensitivity to AIRS/CrIS in the lower troposphere.
  - All technologies will be advanced to TRL 7 at the end of experiment
- Implementation Summary
  - JPL Lead + HOTBIRD + Immersion Grating + Black Si, Ball Optics, IR Cameras Camera, Blue Canyon Technologies (BCT) Spacecraft
  - 6U CubeSat (approx. 30 x 20 x 10 cm, <14 kg)
  - LEO Sun Synchronous Morning Orbit (450 km – 600km)
  - Minimum Mission Duration: 3 months
- Programmatic Summary
  - Sponsored by NASA Earth Science Technology Office (ESTO) In-flight Validation of Earth Science Technologies (InVEST) Program, Awarded 2015
  - Design performed in collaboration with the EON-IR Study sponsored by the NOAA Office of Projects, Planning, and Analysis (OPPA)
  - Selected on 2/18/16 for a launch opportunity by the NASA CubeSat Launch Initiative .
  - Launch no earlier than January 2019

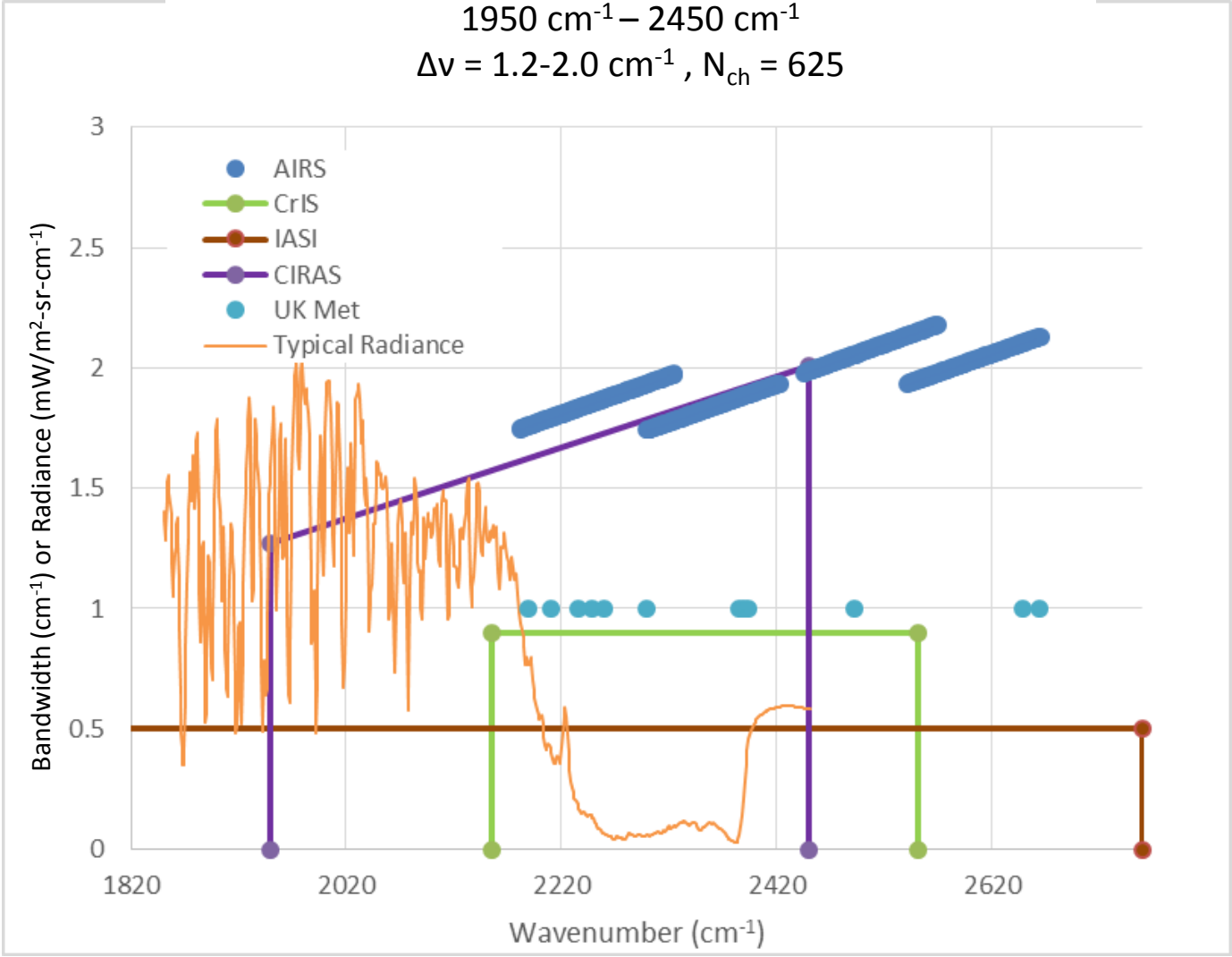


CIRAS spectral performance comparable to AIRS in the MWIR

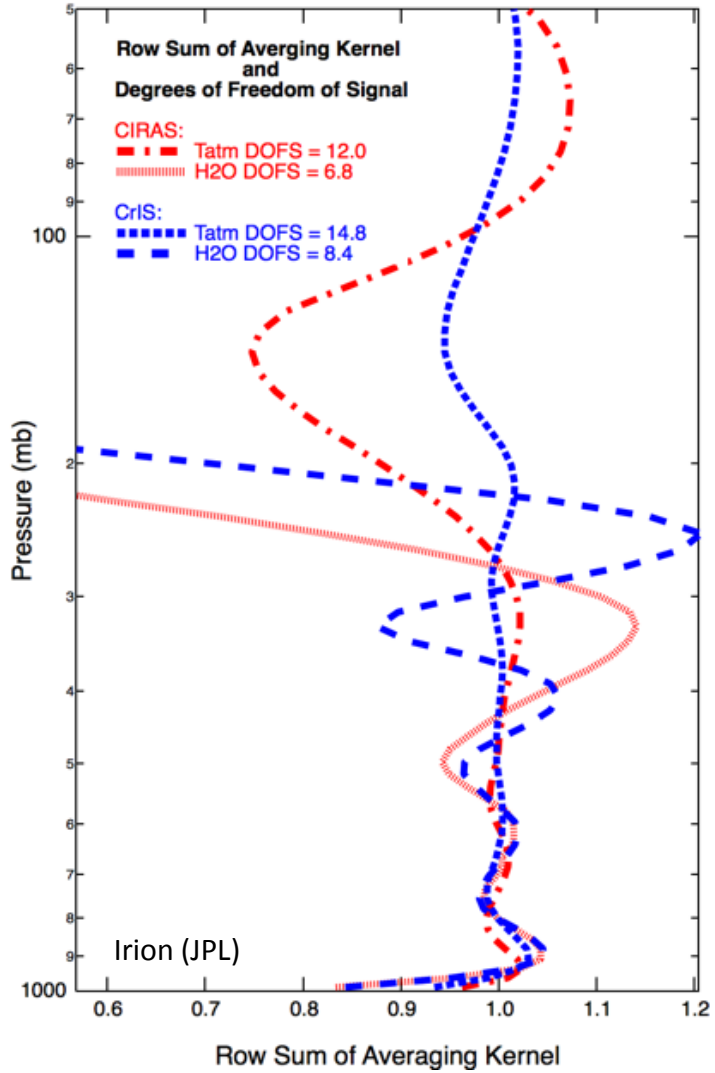
CIRAS Spectral like AIRS but Extends into the Water Band

1950 cm^{-1} – 2450 cm^{-1}

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

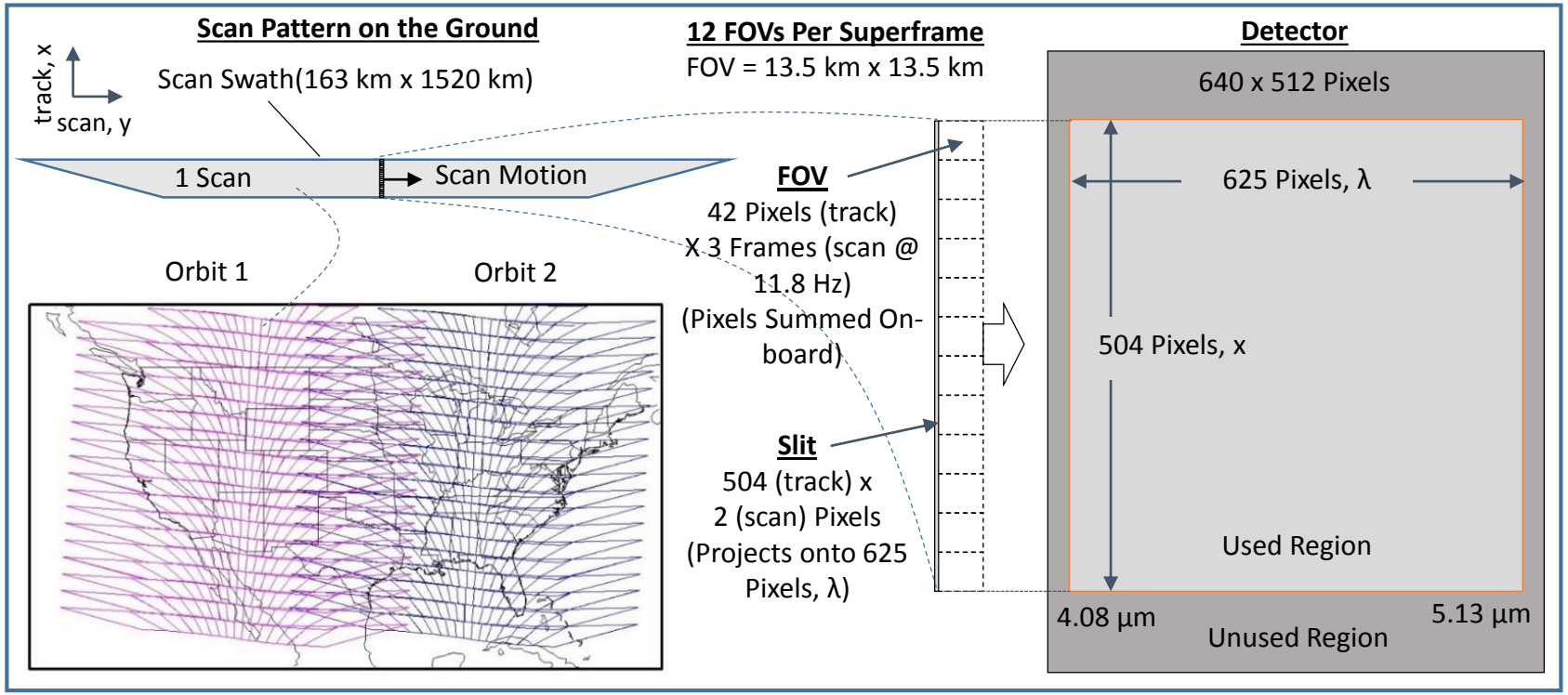


CIRAS Information Content Extends from the Surface to 300 mb

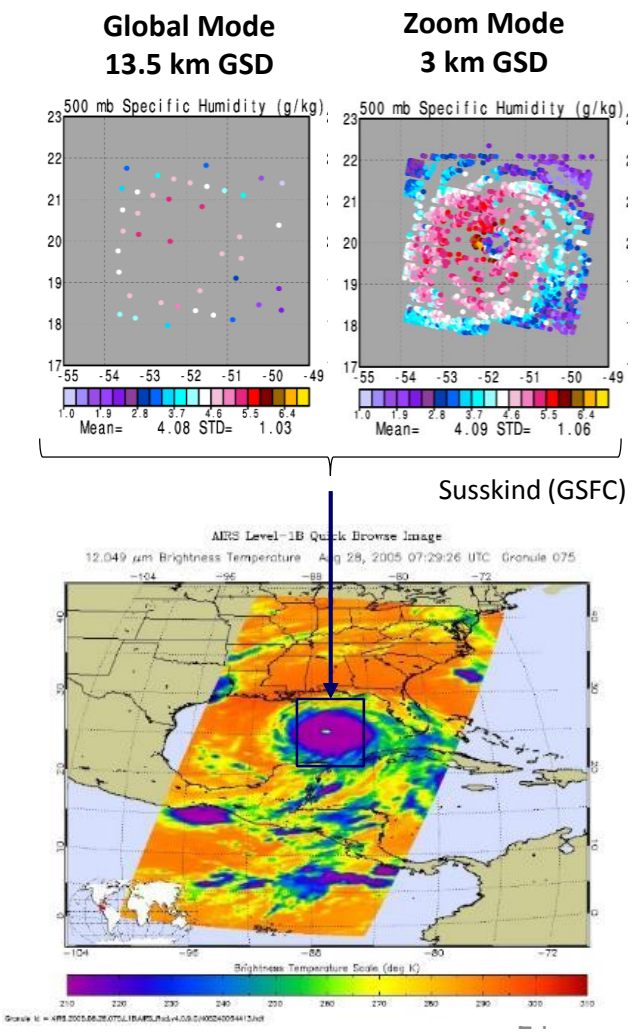


CIRAS spatial resolution comparable to AIRS, CrIS + Zoom

- **Programmable Pixel Binning and Scan Rate Allow Global and Zoom Modes**
- **CIRAS Binning Scheme (600 km Orbit):**

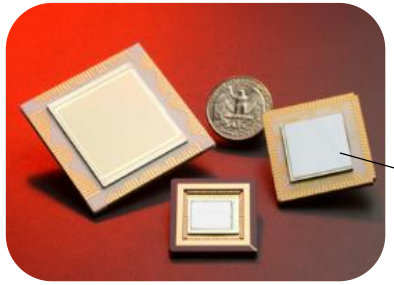


Zoom Mode Improves Yield

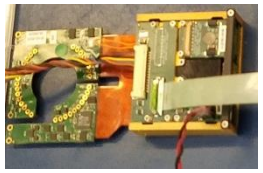


CubeSat Infrared Atmospheric Sounder (CIRAS)

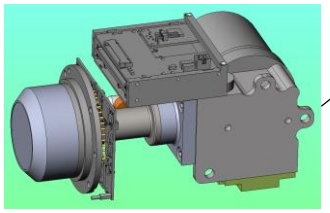
FPA
HOTBIRD
(JPL)



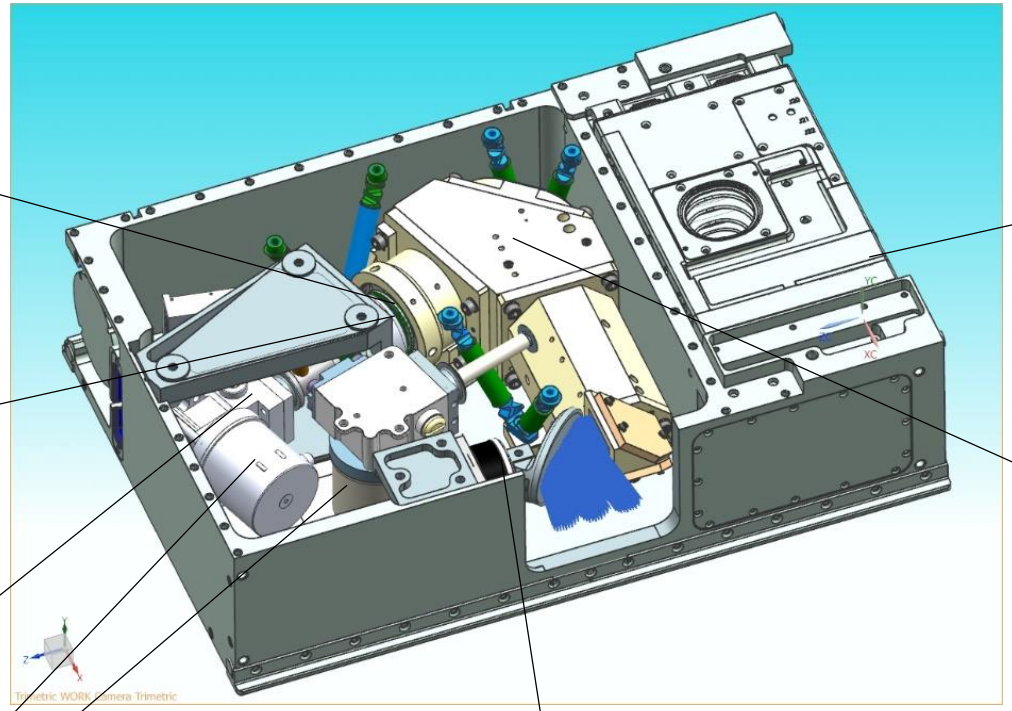
Camera Electronics
(IR Cameras)



Dewar (IDCA)
(IR Cameras)



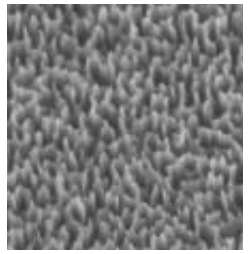
Cryocoolers +
Electronics



Payload
Electronics

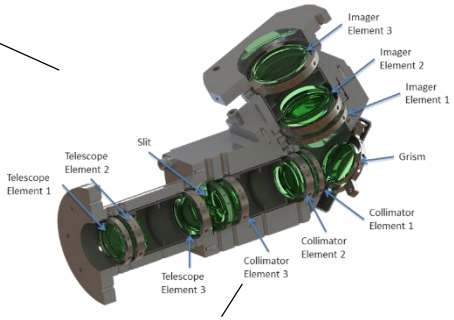
Stepper Motor +
Mirror
(Lin Eng)

Blackbody
Assembly
Black Silicon

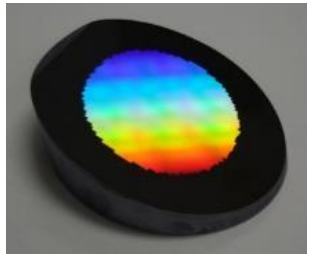


Spacecraft
(BCT)

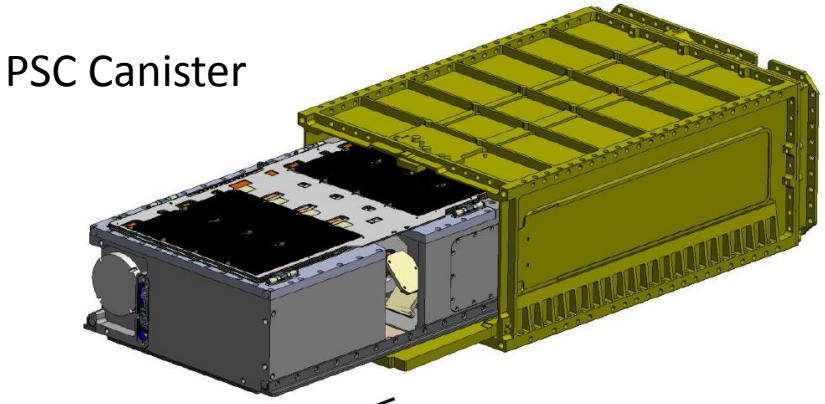
Optics Assembly
(Ball)

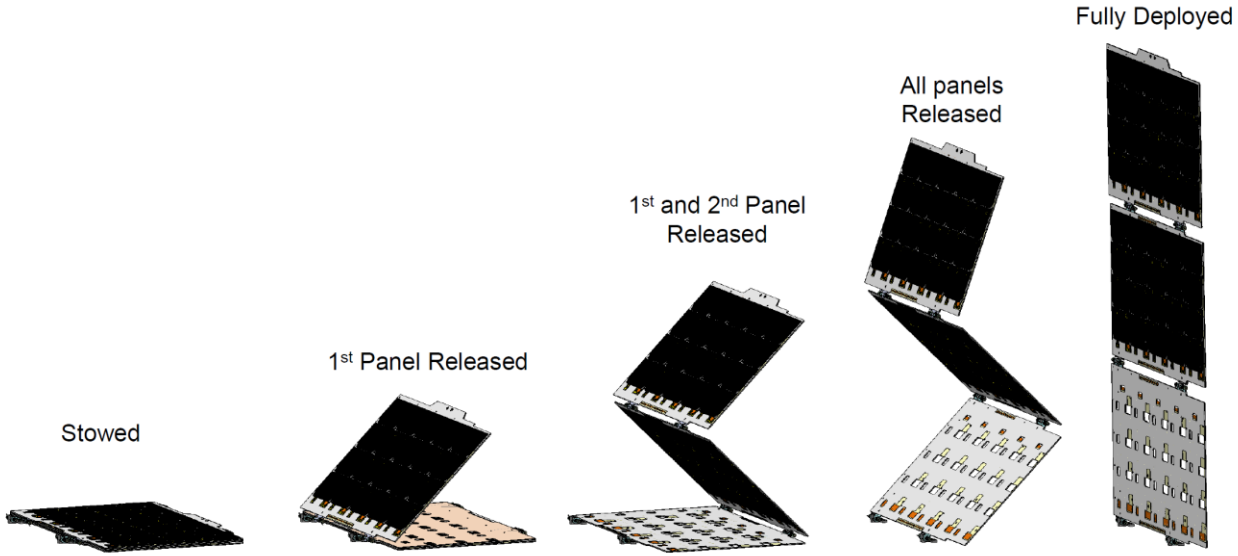


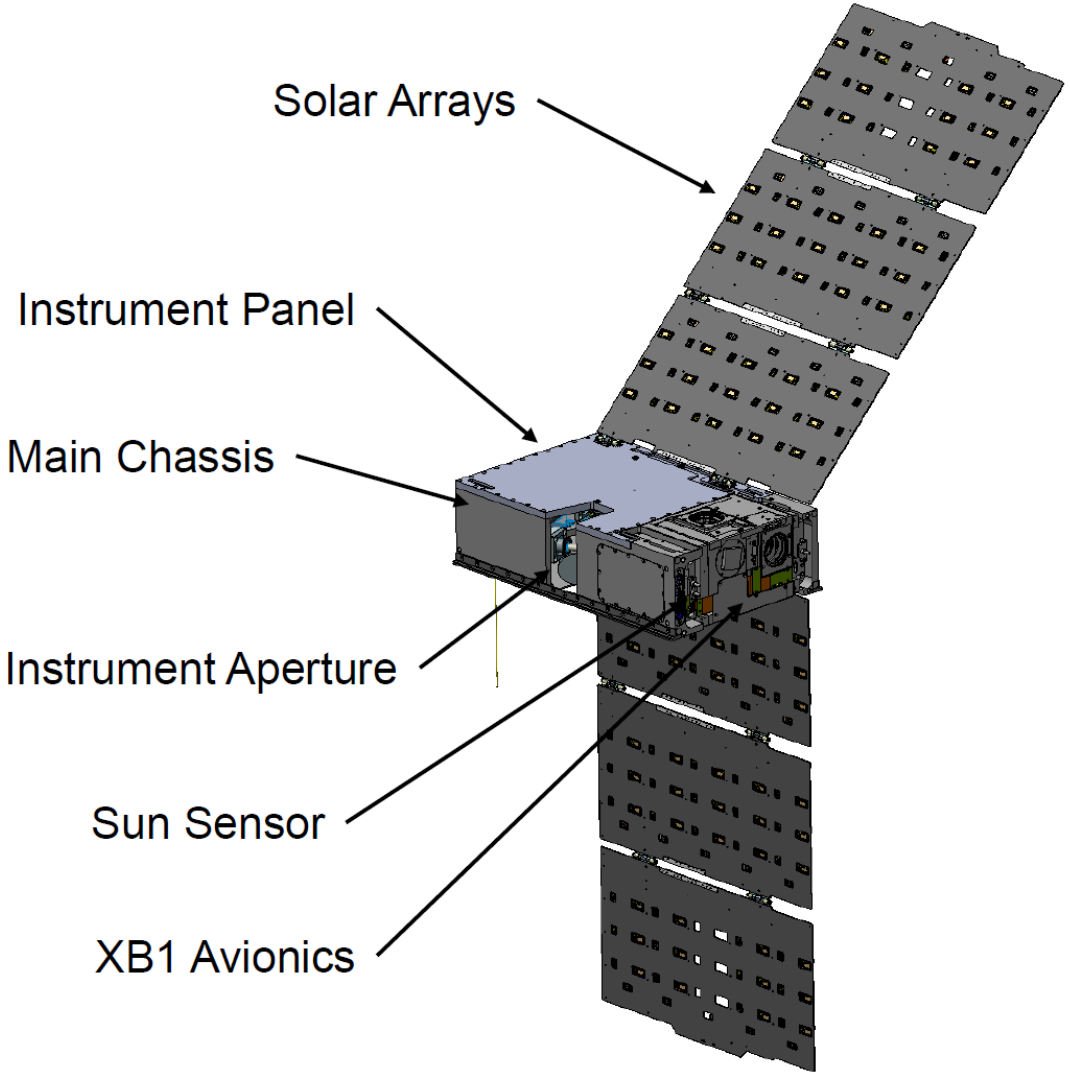
Immersion
Grating (JPL)



CIRAS Spacecraft and Deployment Approach

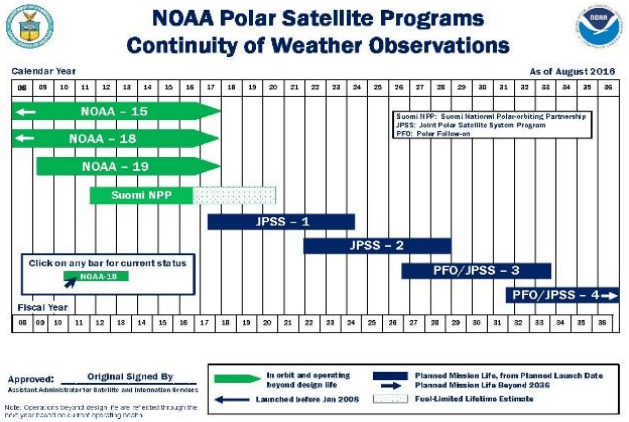


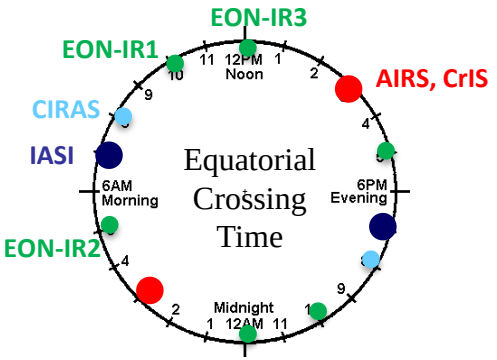


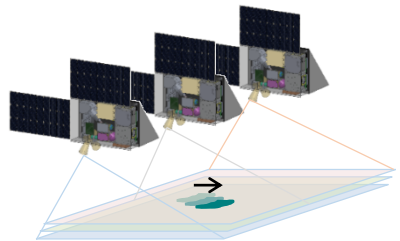


CIRAS Future Mission Concepts

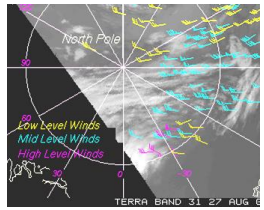
- **Gap Mitigation**:
  - Support the NOAA Joint Polar Satellite System (JPSS) project as a gap mitigation of infrared sounding in the event of a loss of the Cross-track Infrared Sounder (CrIS) instrument.
  - CIRAS is a technology pathfinder for EON-IR MWIR
  - EON-IR may require LWIR (most likely in a separate 12U CubeSat)
- **Improved Timeliness**:
  - Low cost of CIRAS lends itself to placement in orbits to complement existing sounders and improve revisit time
  - This application could be used to improve Numerical Weather Prediction worldwide, or to study the diurnal properties of hydro-thermodynamic processes in the lower troposphere.
  - Early studies show 3 EON-IR MWIR sounders in different orbits give comparable impact to CrIS
- **3D AMV Winds**:
  - Each CIRAS sounder provides imagery of water vapor in 3D since each horizontal pixel contains a vertical sounding profile.
  - 3 CIRAS instruments flown in formation and separated in time by 15 min – 1 hr would allow measurement of the data needed to produce 3D Atmospheric Motion Vector (AMV) winds
- **AIRS Pollution Studies**
  - The CIRAS band from 1950-2450 cm^{-1} can measure lower tropospheric Carbon Monoxide (CO)







MODIS AMV Winds



Summary and Conclusions

- The NASA AIRS Used to Improve Weather Prediction and Support Earth Science
- Infrared Sounders including AIRS, CrIS and IASI have among the highest impact of all satellite instruments for improving weather forecast second to the microwave
- AIRS highlights science processes and validates climate models. Users worldwide.
- CubeSat technology now enables low-cost per satellite. Constellations are an alternative to GEO and provide global coverage.
- The CubeSat Infrared Atmospheric Sounder (CIRAS) is a 6U CubeSat under development at JPL sponsored by the NASA ESTO In-Flight Validation of Earth Science Technologies (InVEST) Program in 2015. Launch in 2019+
- Several possible applications exist with this technology that complement the operational IR sounders including gap mitigation, improved timeliness, 3D IR AMV winds, and science investigations involving studies of the diurnal variation of the hydrological cycle
- Hope to see you at the NASA Sounder Science Team Meeting October 24-26, 2017 at the Greenbelt Marriot, MD