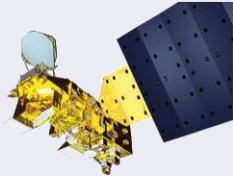

IR remote sensing for weather and climate

Tom Pagano
NASA Jet Propulsion Laboratory
Pasadena, CA 91109

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December 9, 2016

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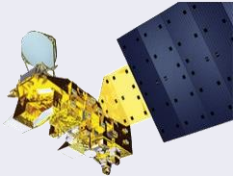
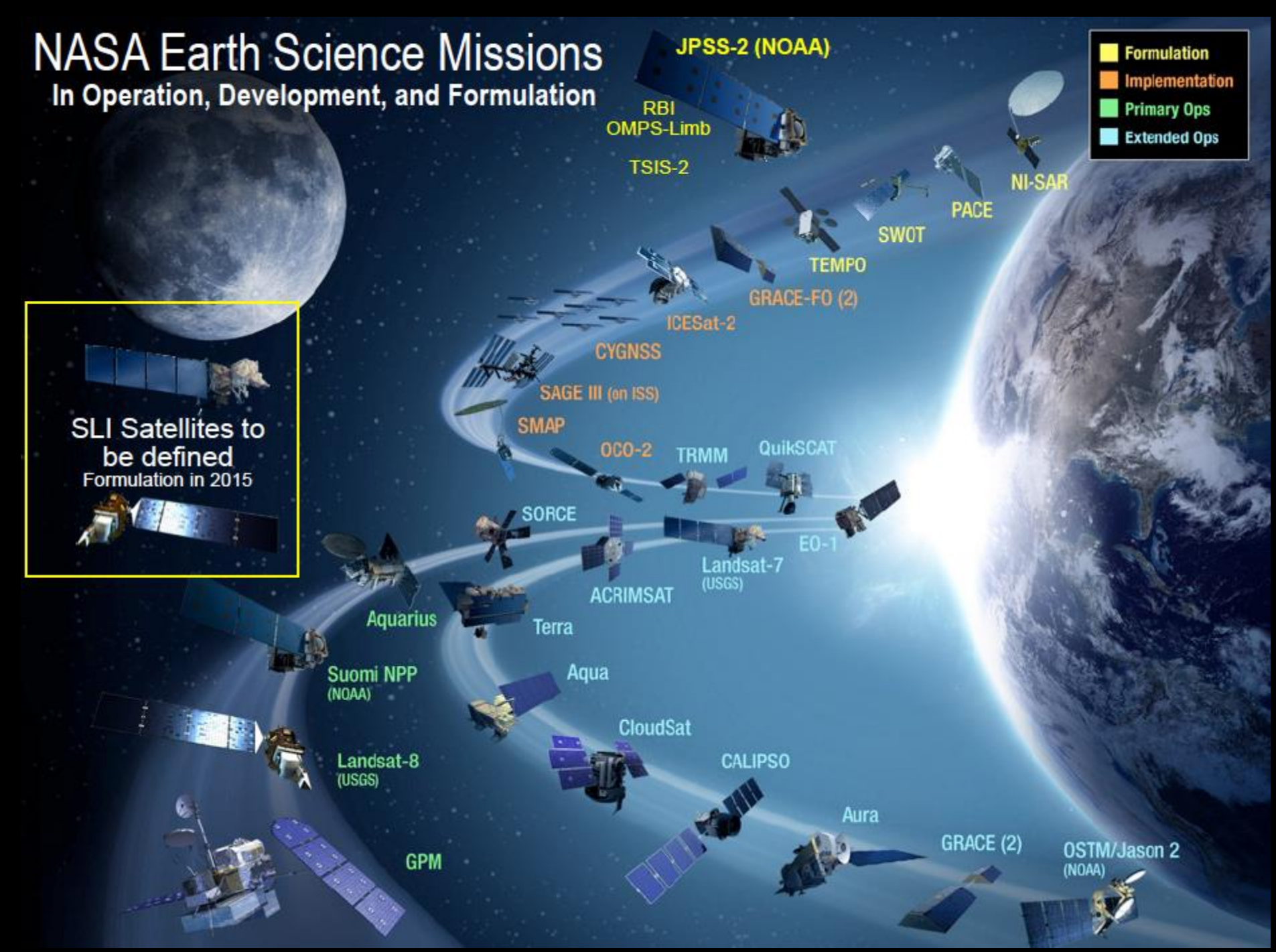
Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not constitute or imply its endorsement by the United States Government or the Jet Propulsion Laboratory, California Institute of Technology

Agenda



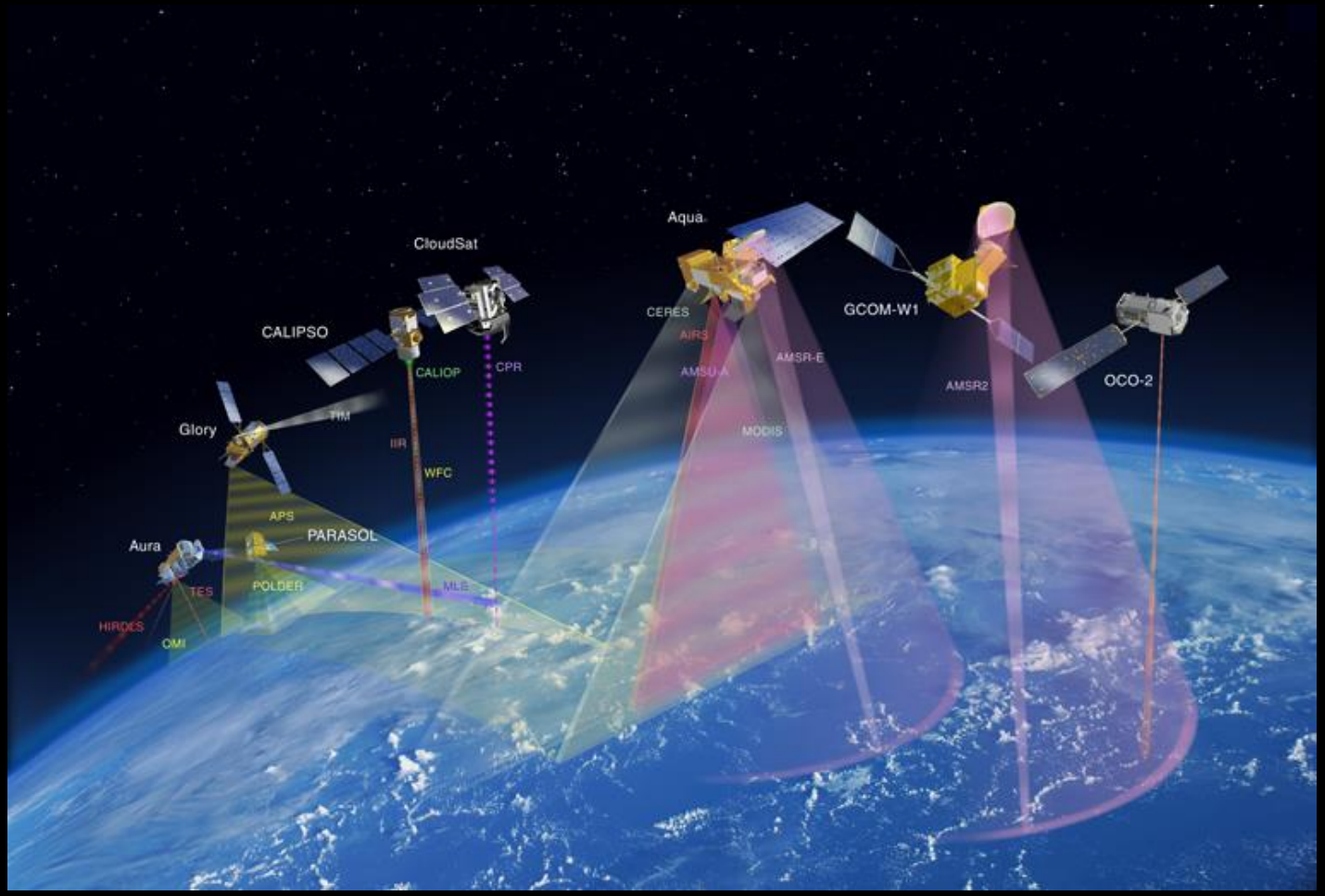
- NASA Earth Observing Satellites, The A-Train
- Infrared remote sensors on the Aqua spacecraft. Highlight two instruments:
  - Imager: Moderate Resolution Imaging Spectroradiometer (MODIS)
  - 0.25-1.0 km Spatial Resolution, Low Spectral Resolution:
  - Sounder: Atmospheric Infrared Sounder (AIRS)
    13.5 km Spatial Resolution, High Spectral Resolution:
- What we observe with infrared sensors. Radiance Spectrum
- Products we derive in the Land, Ocean, and Atmosphere
- Applications and Operational uses of the data
- Numerous users worldwide
- Smaller satellites for the future.


NASA Earth Science Missions
In Operation, Development, and Formulation
Formulation
Implementation
Primary Ops
Extended Ops
JPSS-2 (NOAA)
RBI
OMPS-Limb
TSIS-2
NI-SAR
PACE
SWOT
TEMPO
GRACE-FO (2)
ICESat-2
CYGNSS
SAGE III (on ISS)
SMAP
OCO-2
TRMM
QuikSCAT
SORCE
EO-1
Landsat-7
(USGS)
ACRIMSAT
Aquarius
Terra
Suomi NPP
(NOAA)
Aqua
CloudSat
Landsat-8
(USGS)
CALIPSO
Aura
GRACE (2)
OSTM/Jason 2
(NOAA)
GPM
SLI Satellites to
be defined
Formulation in 2015

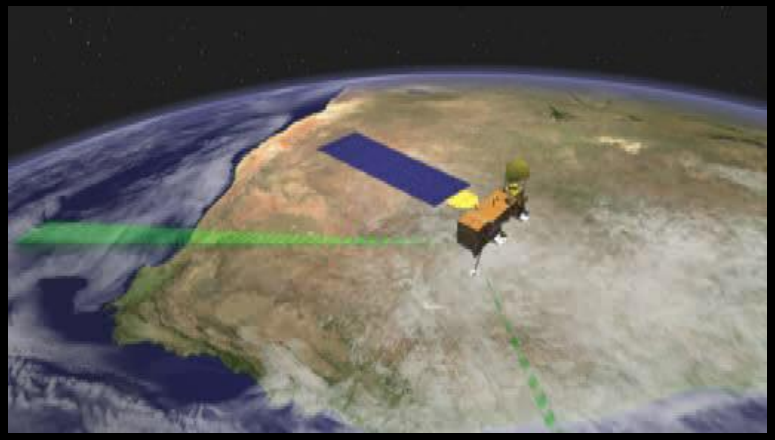
Aqua Launched May 4, 2002 from Vandenberg Air Force Base

Aqua was first in the "A-Train"

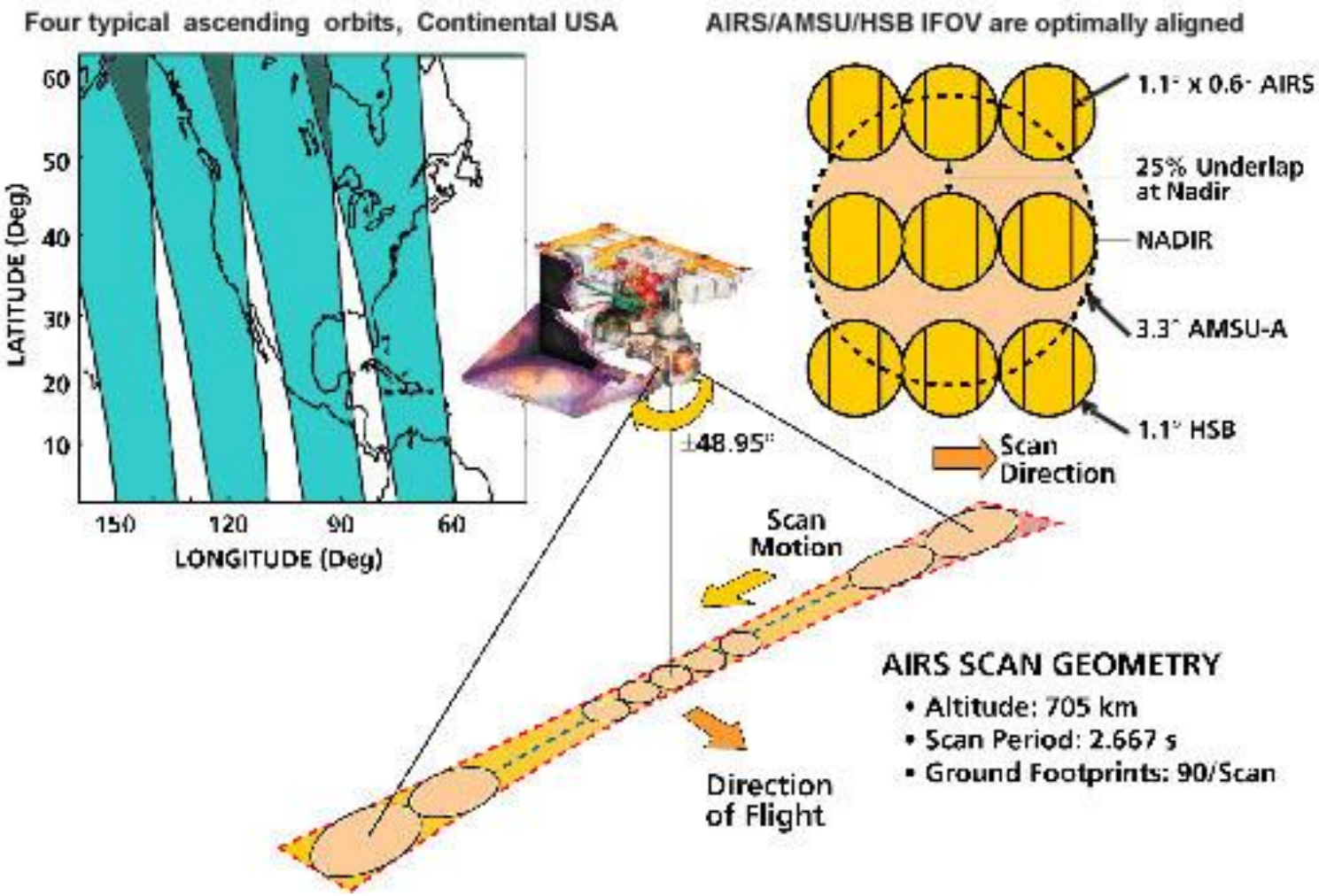
Aqua Launched On a Delta 2



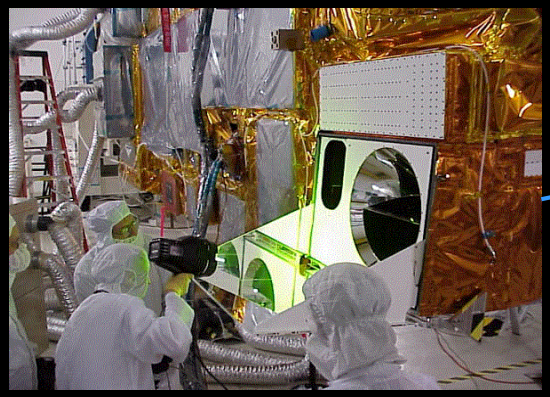
Aqua Instruments Scan the Earth as the Aqua Satellite Moves Along Its Orbit Track



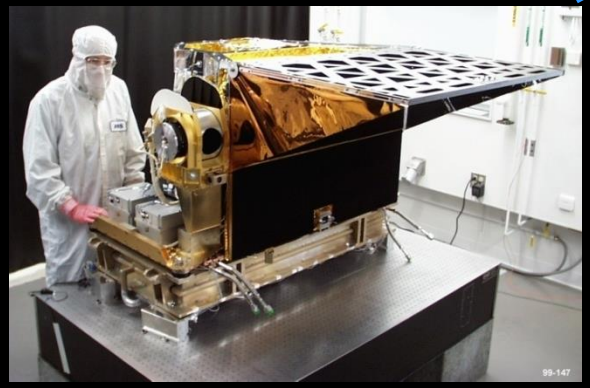
AIRS and MODIS Have a Wide Swath to Provide Global Daily Coverage



The EOS Aqua Spacecraft



Moderate Resolution Imaging Spectroradiometer (MODIS)
GSFC/Raytheon

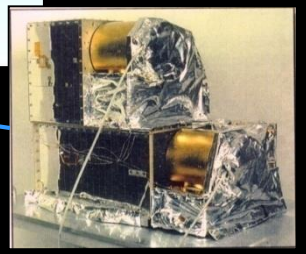


Atmospheric Infrared Sounder (AIRS)
JPL/BAE SYSTEMS

AQUA Spacecraft
GSFC/NGST

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

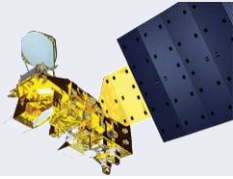
Advanced Microwave Sounding Units (AMSU-A/B)
JPL/Aerojet



Humidity Sounder from Brazil (HSB)
JPL/Aerojet

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

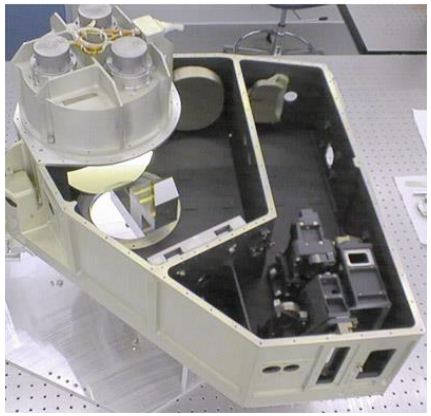
AIRS Demonstrated Advancement in Hyperspectral IR Technology



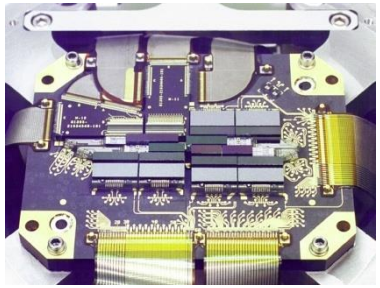
- **JPL's Role on AIRS**
- **Science Requirements Flowdown**
- **Systems Design**
- **Contract Technical Management**
- **Spacecraft Integration**
- **Instrument Operations**
- **Instrument Calibration**
- **Science Algorithm Integration**
- **Data System Development**
- **Product Validation**
- **Leadership and Management**

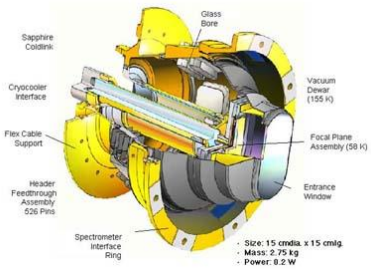
The Atmospheric Infrared Sounder (AIRS)

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

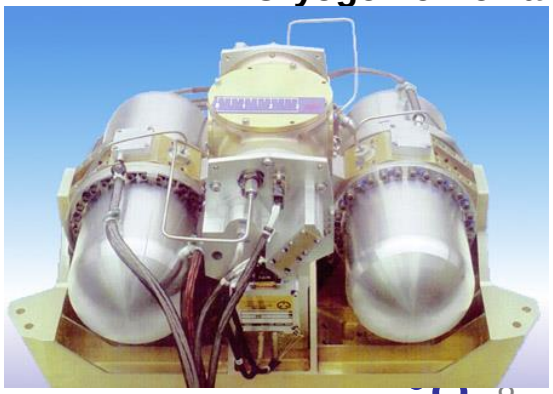


- **FPAs: PV HgCdTe to 13.7 µm, PC HgCdTe to 15.4 µm**

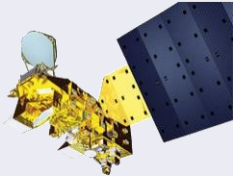




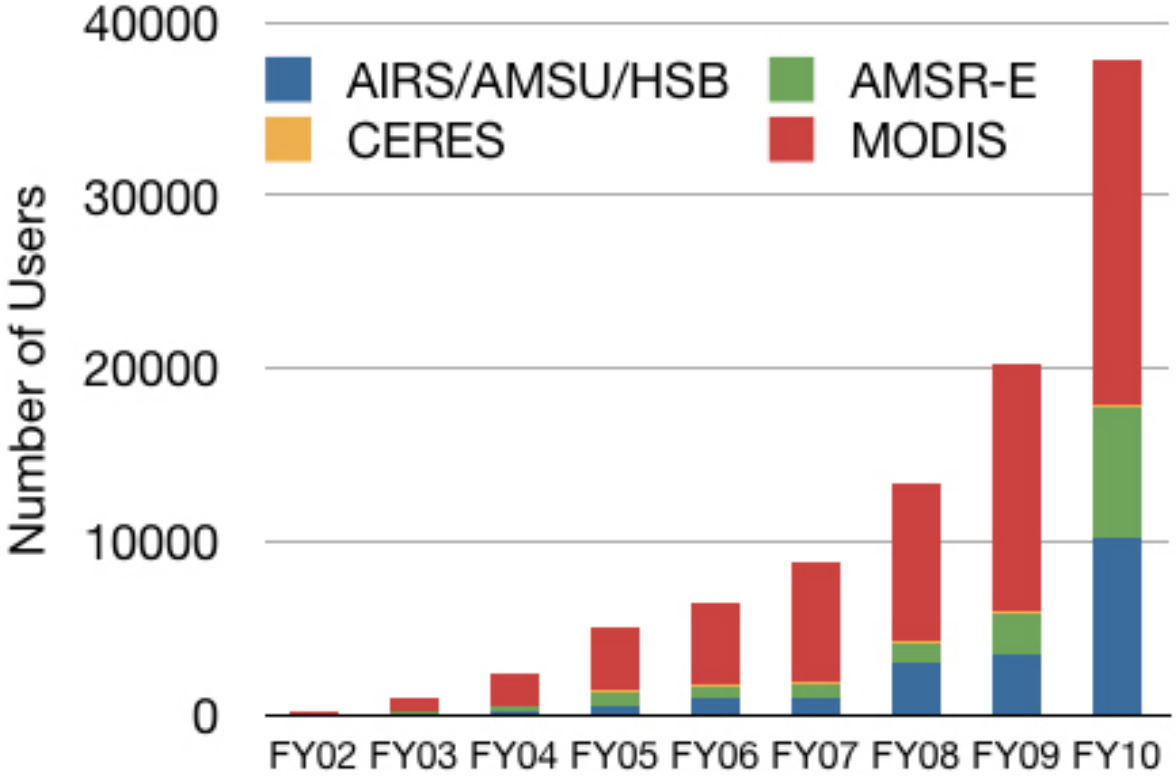
- **Focal Plane Cooling using Single Stage Stirling Pulse Tube, Redundant**
- **Cryogenic Dewar**



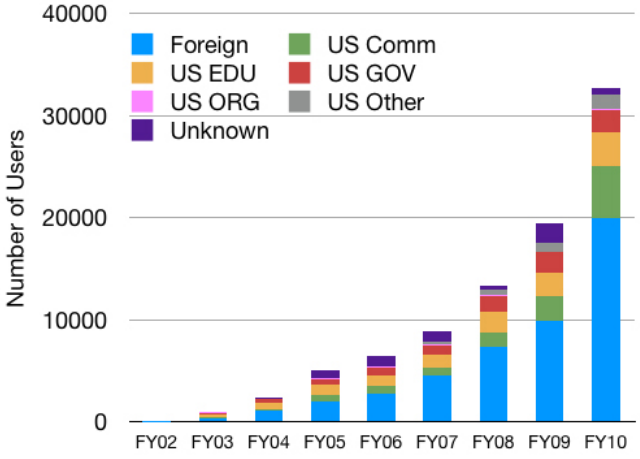
Over 30,000 Users of Aqua Data



MODIS and AIRS have Most Users



Most Users Foreign

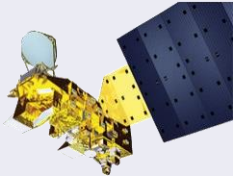


Imagers and Sounders are Essential to Earth Science Investigations and Must be Continued

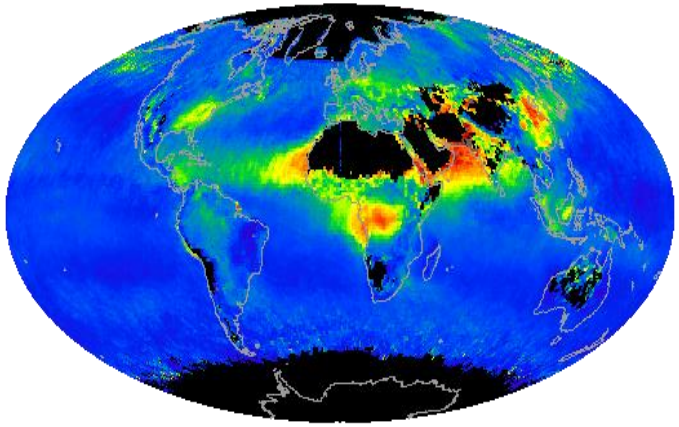
Courtesy of GES/DISC

NASA NRC DS Assigned to NOAA

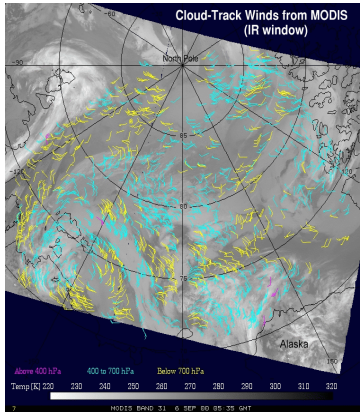
MODIS has over 40 products including…



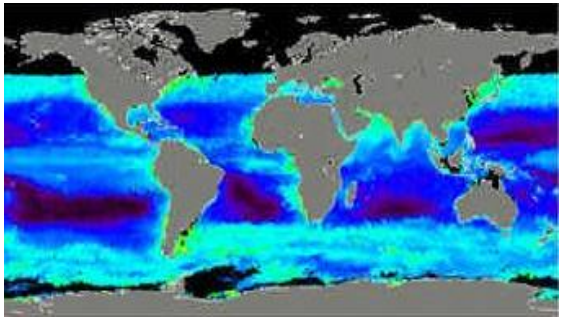
Aerosols



Polar Winds

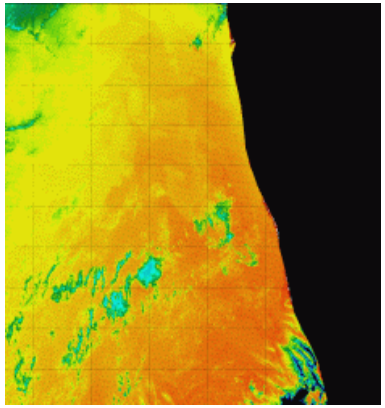


Ocean Chlorophyll

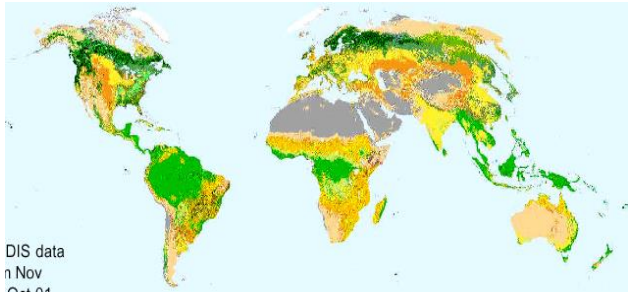


Fires

SST

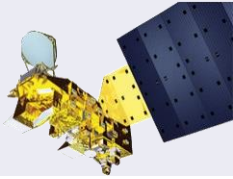


NDVI

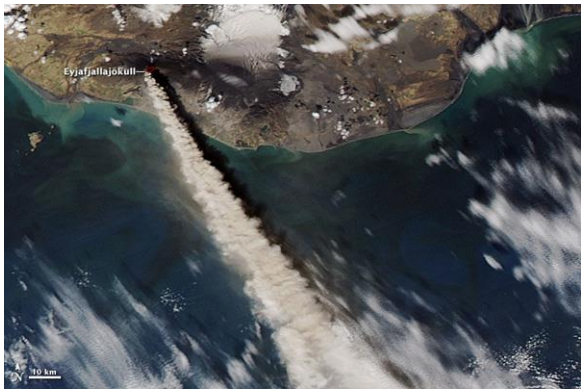


Vince Salomonson, IAC Earth Observation Symposium, 2002

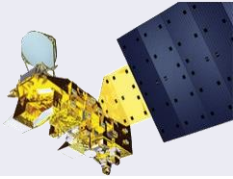
MODIS Widely Used for Government and Civil Applications



- Water Vapor Winds assimilated operationally at numerous NWP Centers
- 40 NWS Centers Regularly Use MODIS IMAPP Data
- Forecast Support for Johnson Spaceflight Center Meteorology Group
- Snow/ice/cloud discrimination
- Fog detection
- Lake Temperature Detection
- Aerosol data used for air quality estimates by EPA
- Disaster Monitoring: Volcanos, Oil Spills, Fires, Hurricanes, Floods
- Agriculture, Commercial Fishing
- Military Operations

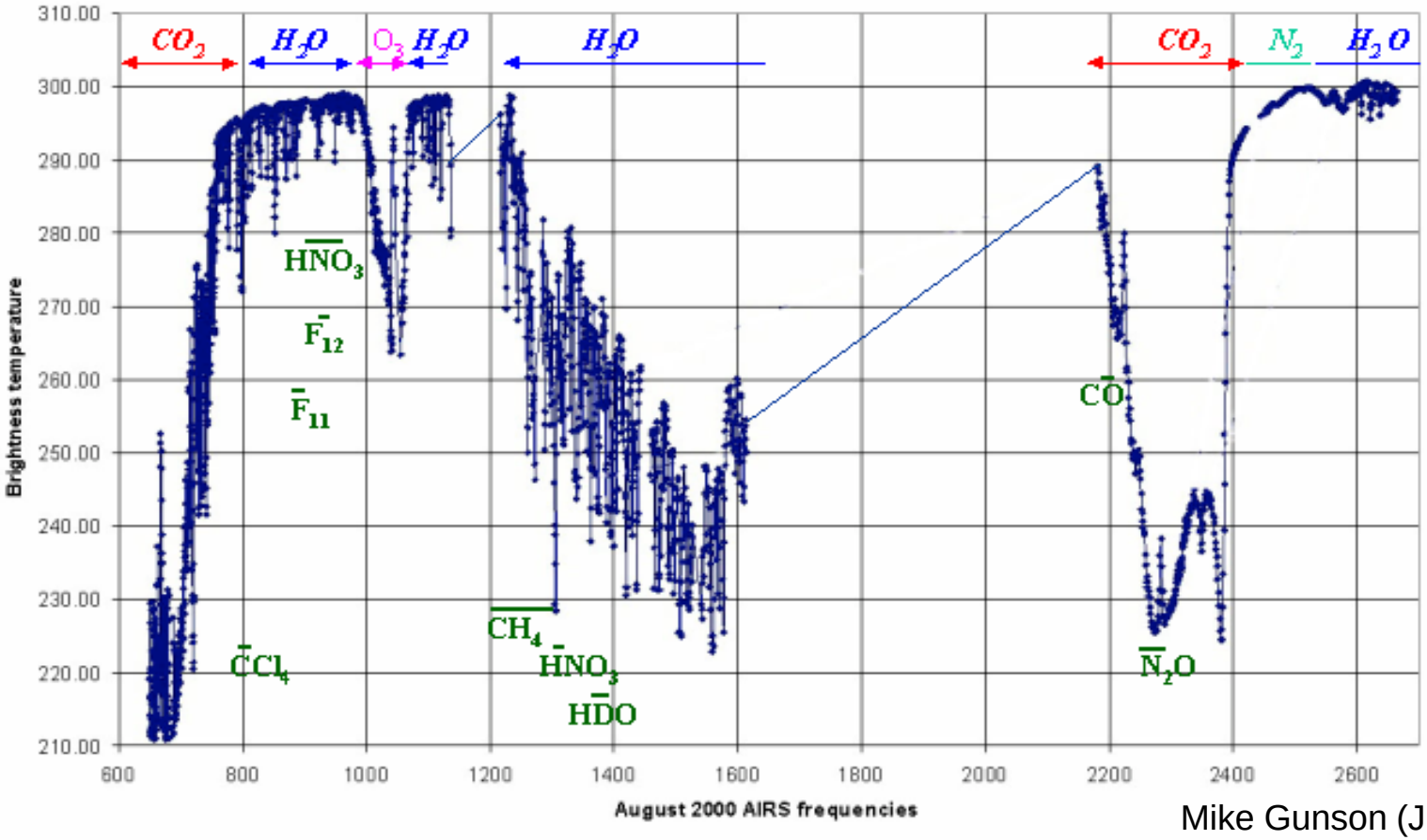


AIRS Measures the Upwelling Earth Spectrum in the Infrared



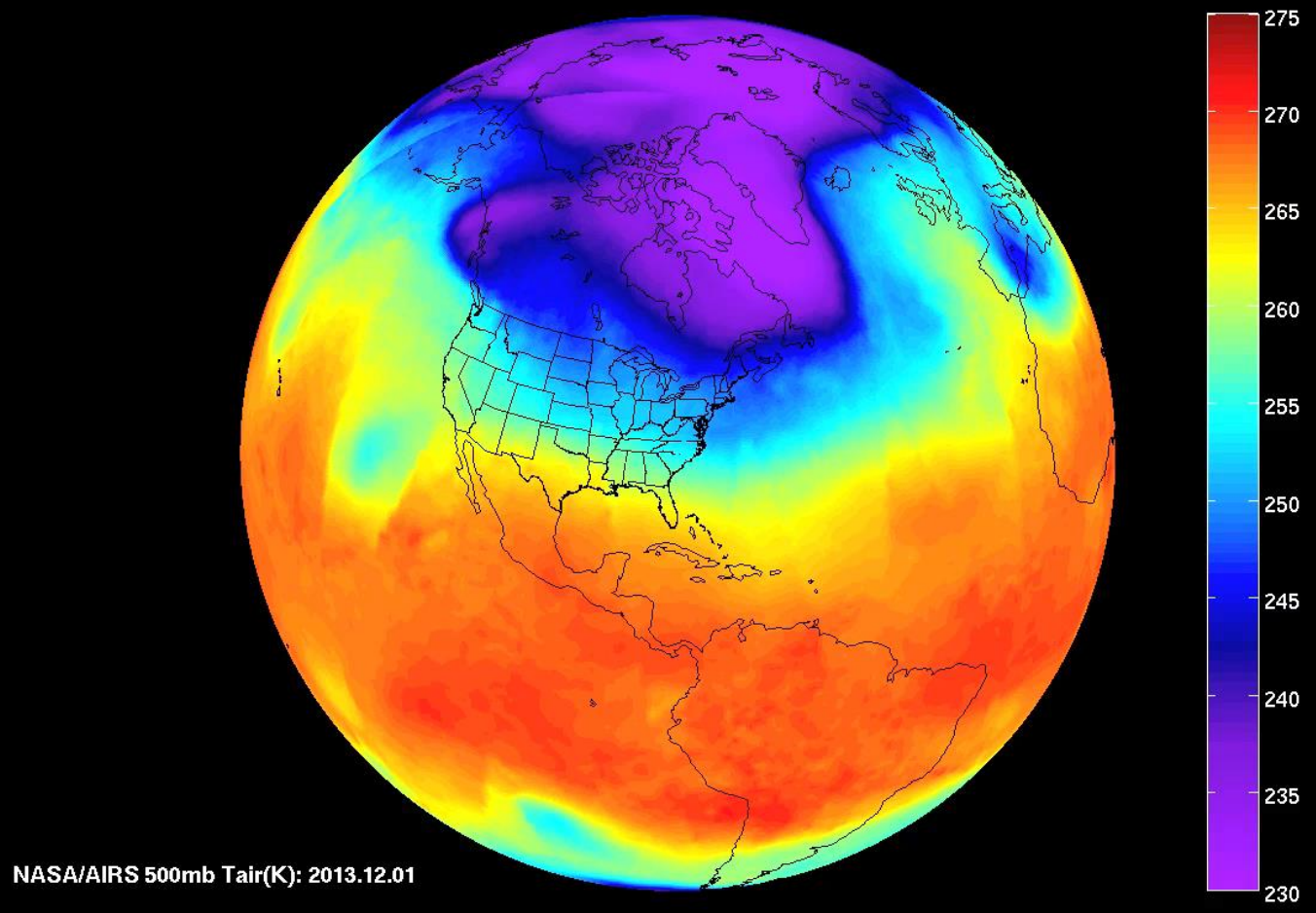
AIRS Channels for Tropical Atmosphere with T_surf = 301K

Full Spectrum



Mike Gunson (JPL)

IR Sounders Capture Severe Weather Events (Polar Vortex of 2013/2014)



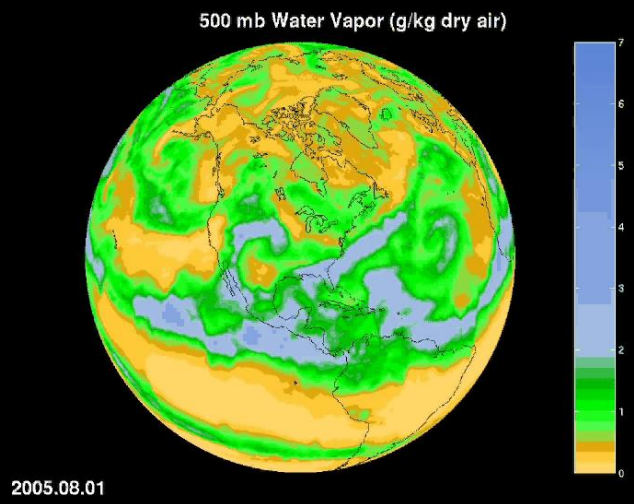
Dec 4, 2013: Denver weather: Temperature hits minus 13 — record low for the date
Dec 24, 2013: Record Low Tied at Cedar Rapids This Morning | Iowa Weather Blog
Jan 6, 2014: Chicago Record Low Temperature: City Hits -16 Mark To Kick Off ...
Jan 29, 2014: Atlanta, Georgia, historic weather for the past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

National Aeronautics and
Space Administration

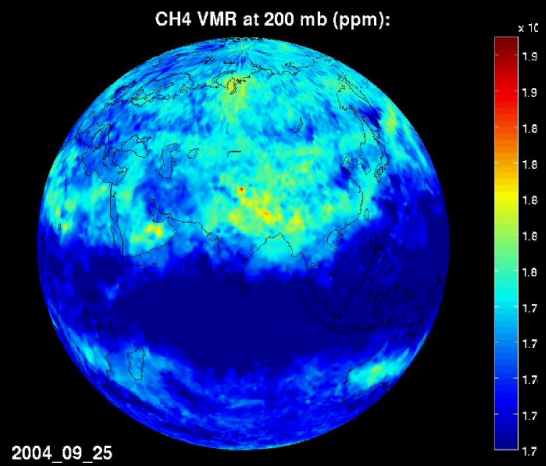
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

AIRS Greenhouse Gases

H_2O

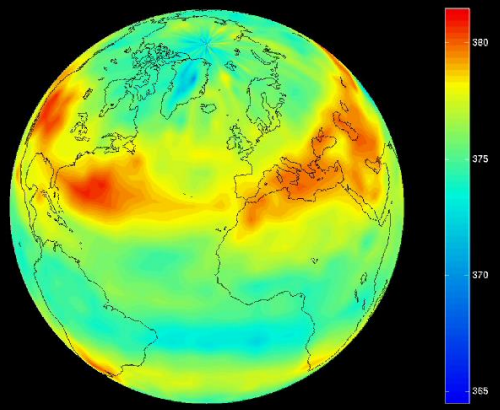


CH_4



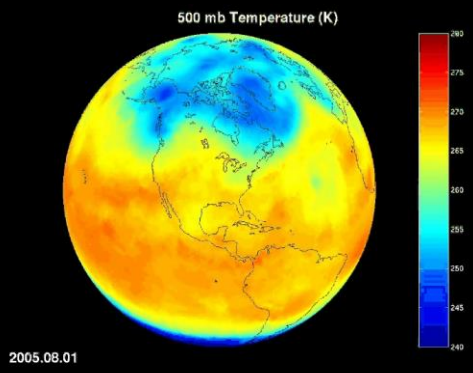
CO_2

Mid-Tropospheric CO_2 (ppm)

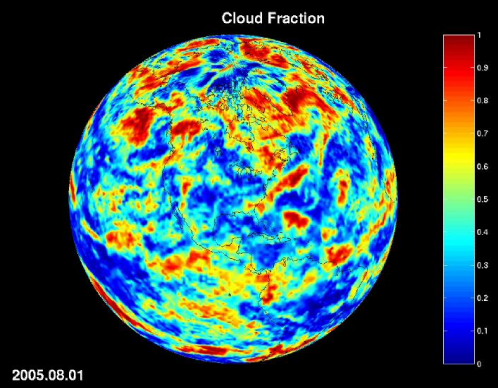


Pagano, JPL, 2009

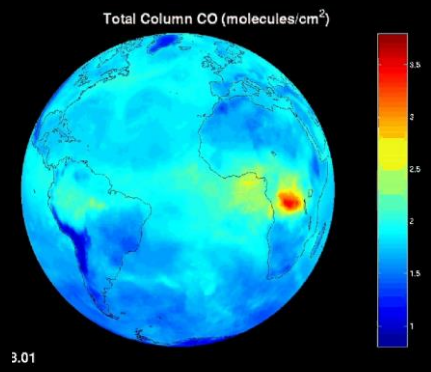
Other AIRS Atmospheric Climate Products



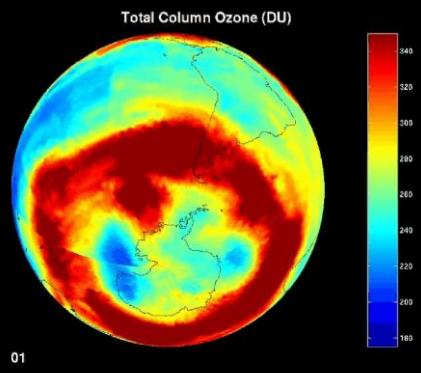
Temperature



Clouds



CO



O_3

Infrared Sounders Measure the 3D Distribution of Temperature and Water Vapor

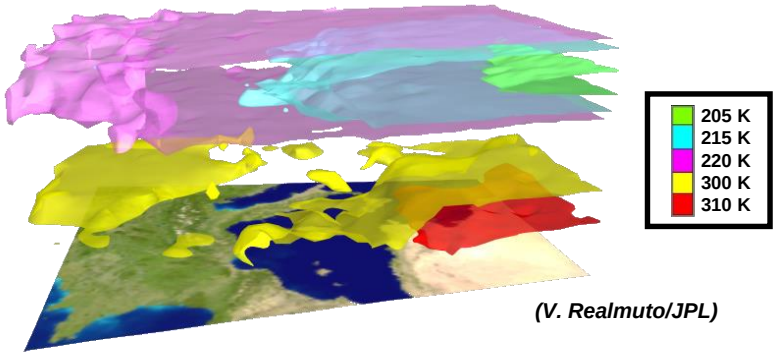
Jet Propulsion Laboratory
California Institute of Technology

Imagers measure the 2D Distribution
Of Radiance with Global Daily Coverage

VIIRS on JPSS

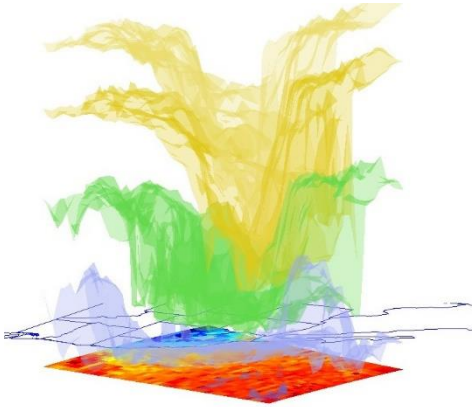
Sounders measure the 3D Distribution

AIRS Temperature Isosurface



(V. Realmuto/JPL)

AIRS Water Vapor Isosurface

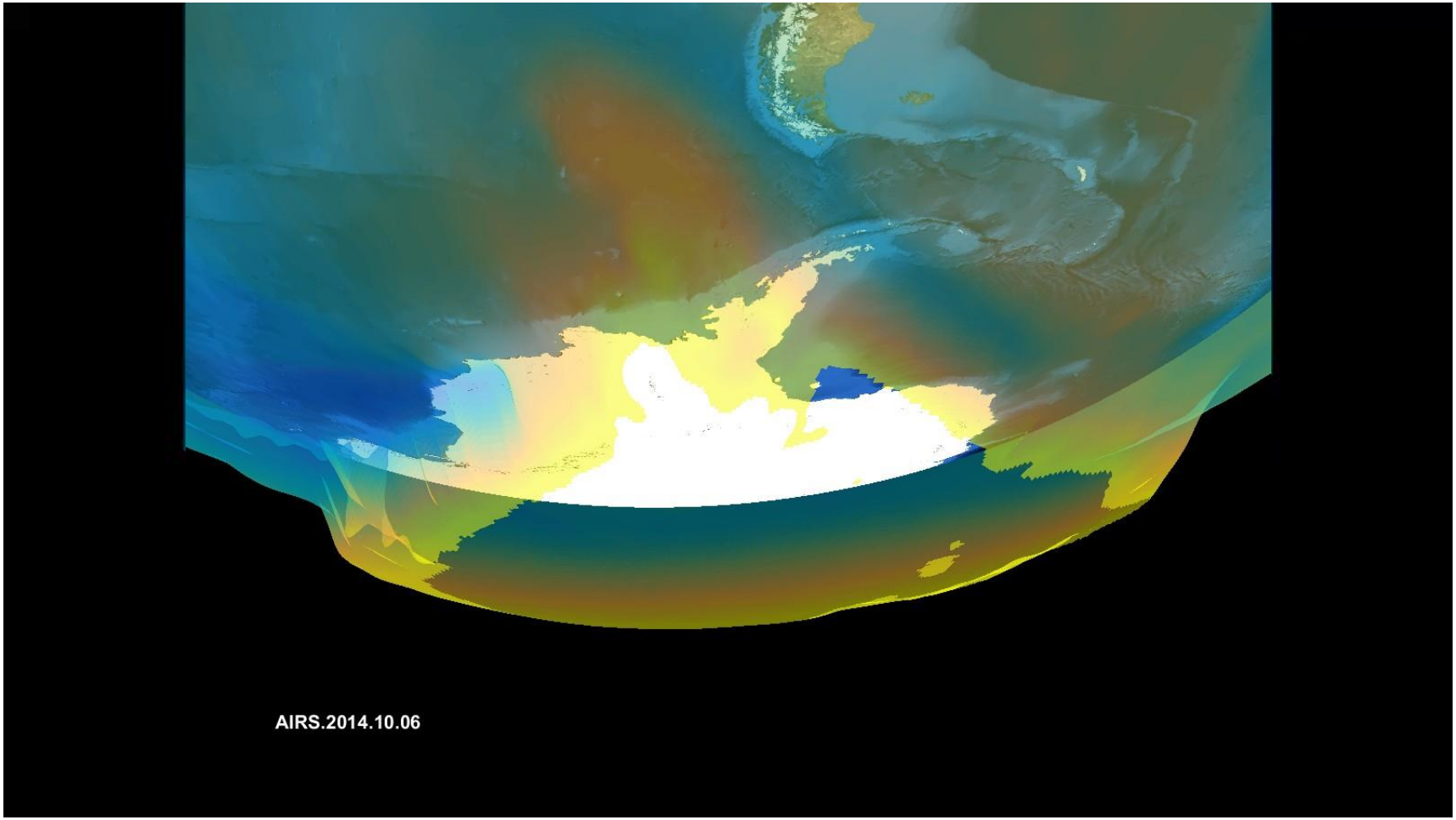


(T. Pagano/JPL)

15

Jet Propulsion Laboratory
California Institute of Technology

2014 Ozone Hole Formation
Isosurface from AIRS O_3 VMR 12 hr Profile

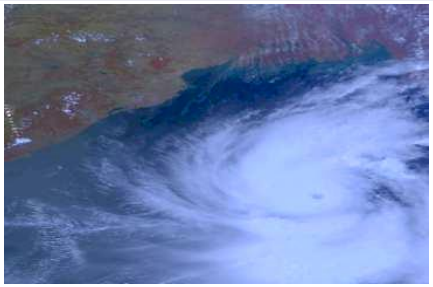


AIRS O3_VMR, 2014. Isosurface at 5 x 10^{-7} ppmv. Altitude Scale: 100, Altitude Offset: 10 km, Max Altitude (above which transparent): 18 km

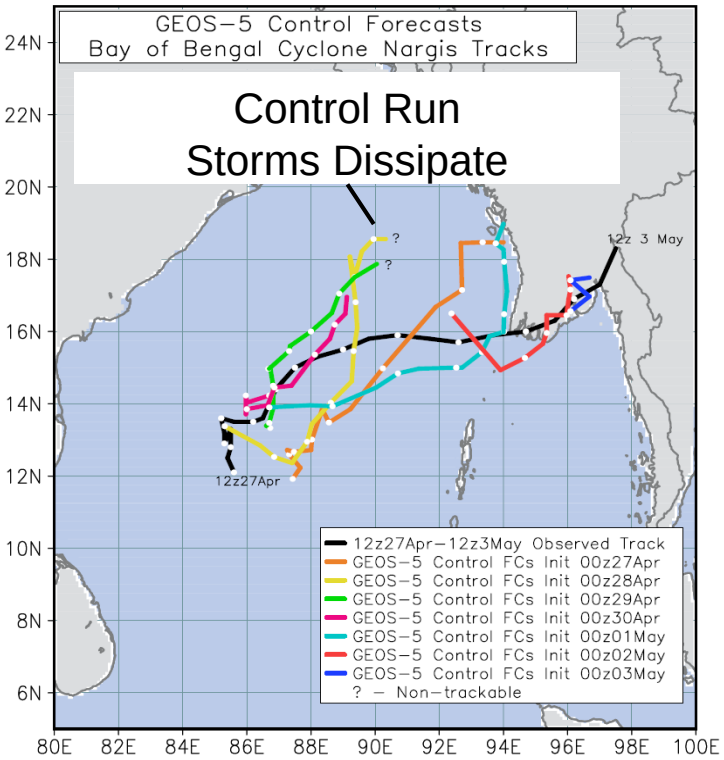
16

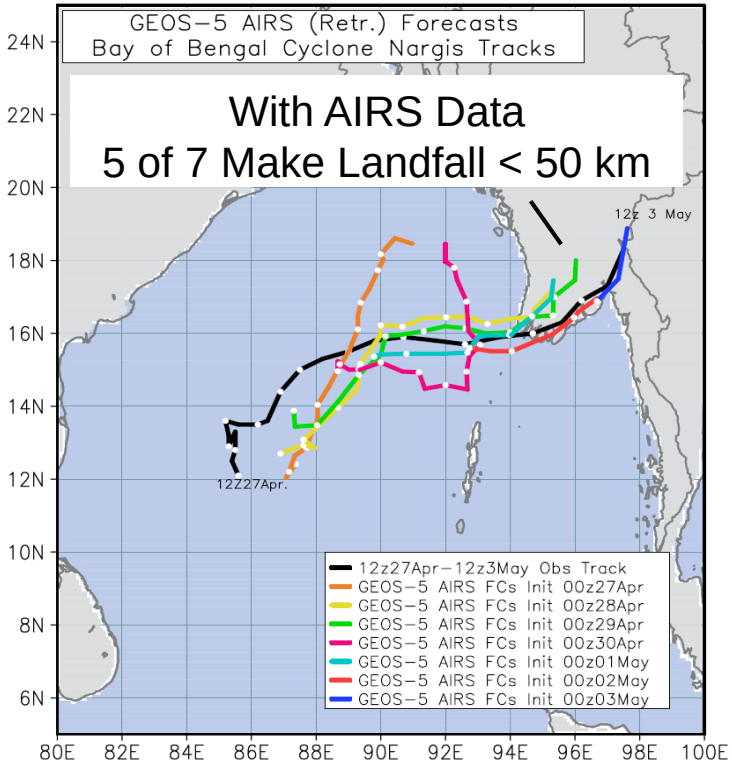
Jet Propulsion Laboratory
California Institute of Technology

AIRS Data Improves Prediction of Hurricanes



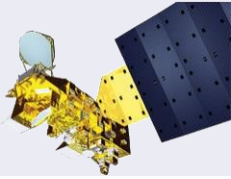
- Tropical Cyclone Nargis
- Killed over 140,000 People
- Worst Natural Disaster in history of Burma`
- O. Reale, GSFC, 2008





Reale, O., W. K. Lau, J. Susskind, E. Brin, E. Liu, L. P. Riishojgaard, M. Fuentes, and R. Rosenberg (2009), AIRS impact on the analysis and forecast track of tropical cyclone Nargis in a global data assimilation and forecasting system, Geophys. Res. Lett., 36, L06812, doi:10.1029/2008GL037122. http://www.agu.org/journals/gl/gl0906/2008GL037122/

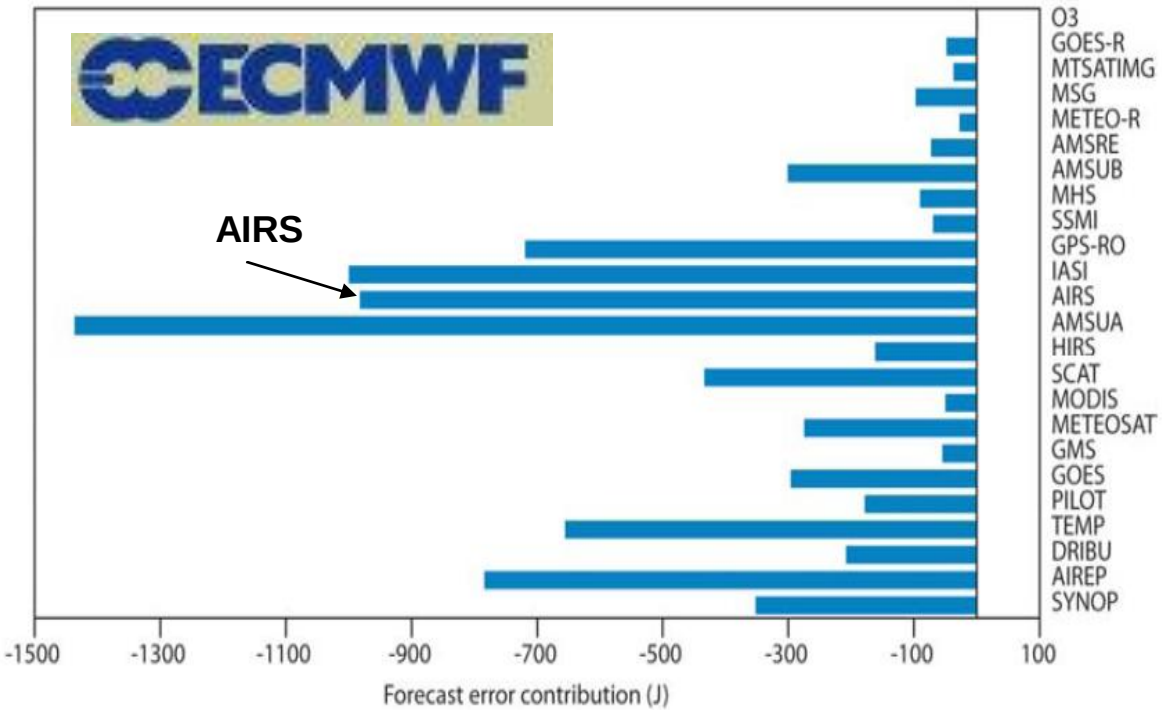
AIRS Improves Weather Forecasts

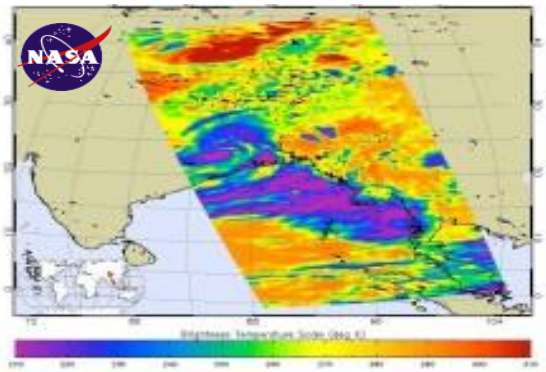


JPL/ GSFC

NOAA NESDIS/NCEP

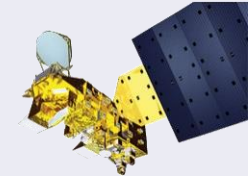
JCSDA



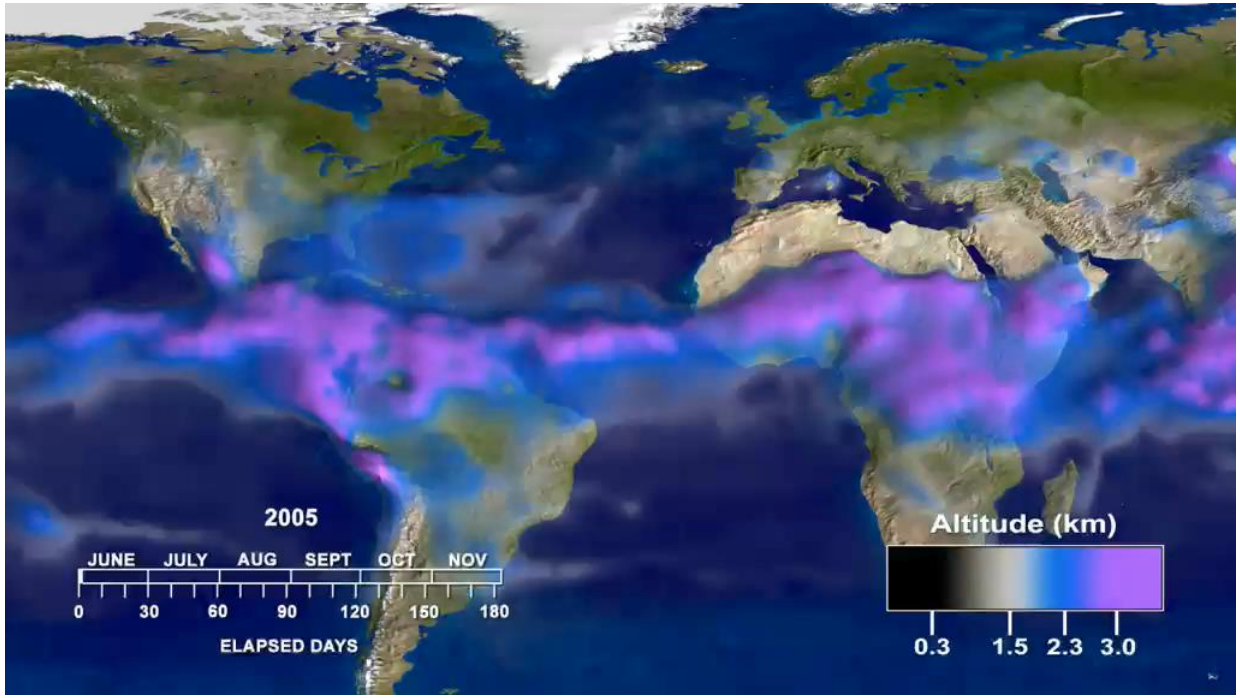


- Third Highest Impact to Forecasts
  - AMSU has 4 Instruments
  - IASI is also an IR Sounder
  - (Cardinali, ECMWF Tech. Memo. 599, 2009)

AIRS Data Support
Climate Research and Model Validation

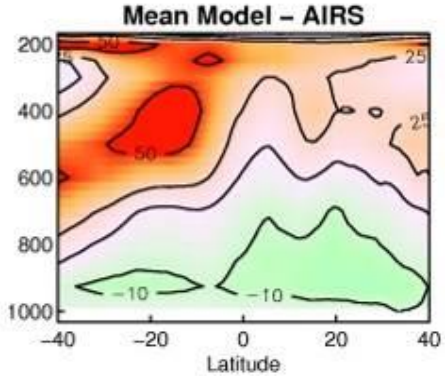


AIRS Used to Validate Water Vapor Transport
(Dessler, Texas A&M, 2007)

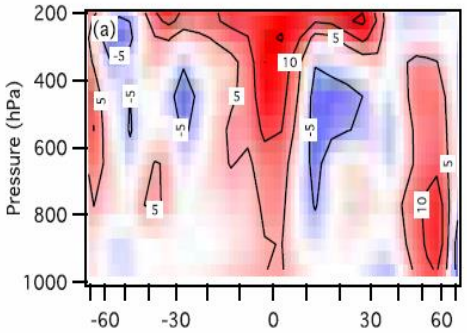


AIRS Water Vapor Isosurface (5kg H2O /kg Dry Air)
V. Realmuto, C. Thompson, T. Pagano, S. Ray NASA/JPL

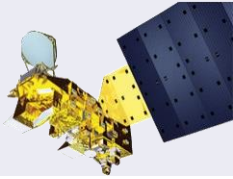
Water Vapor Climatology
(Pierce, Scripps, 2006)



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

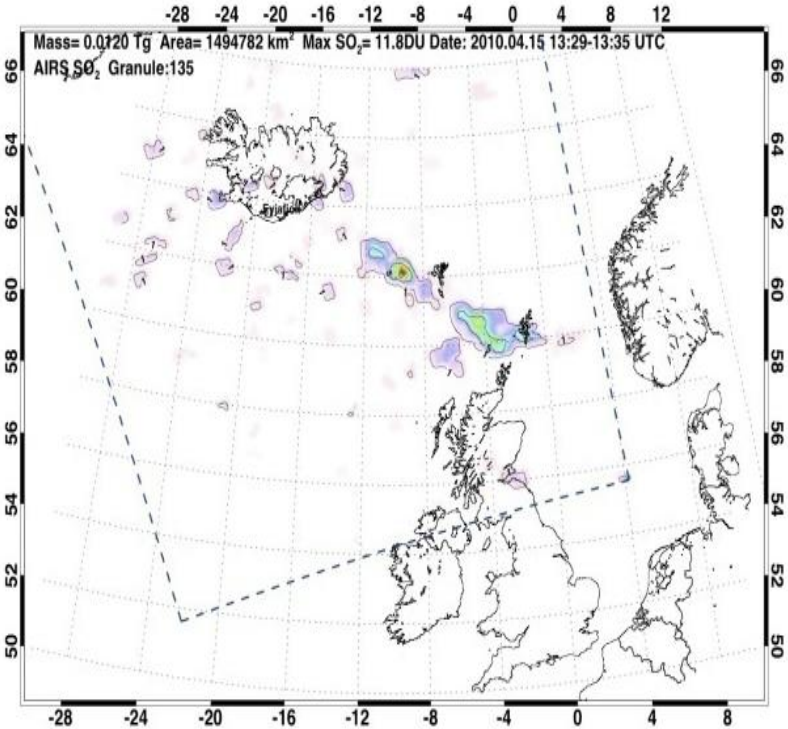


AIRS Composition Products Support Research and Operations

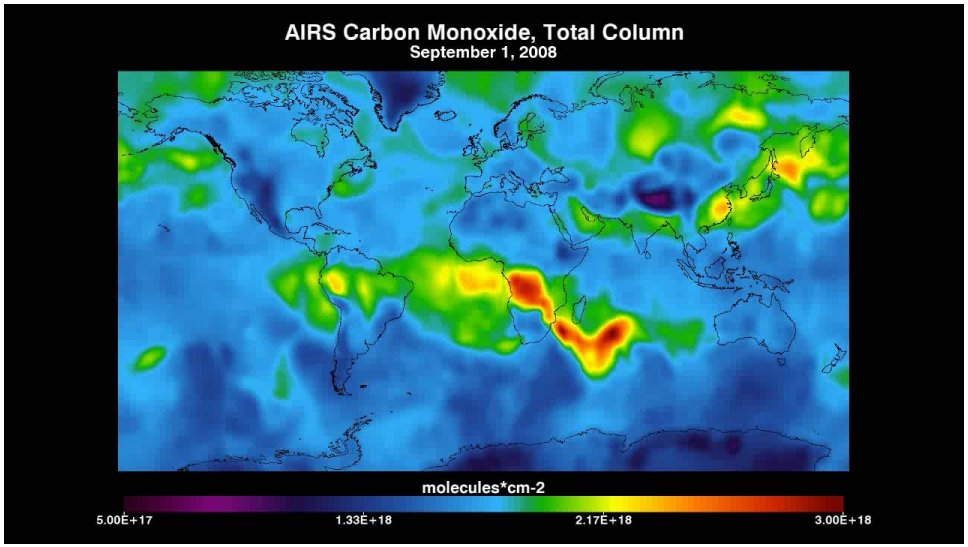


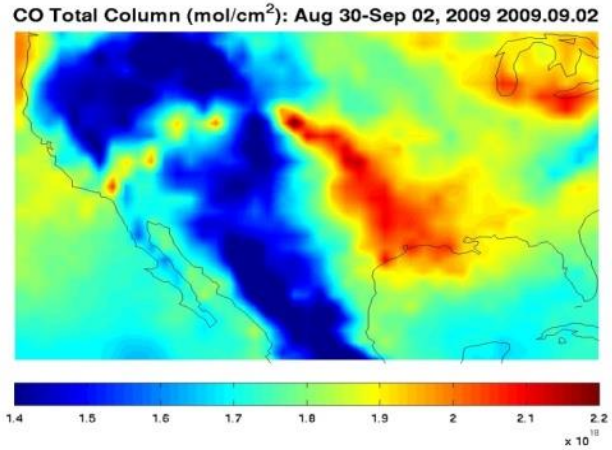
Sulfur Dioxide Alerts
Aviation Warning

Ejyafyallajokul SO2
Fred Prata NIAR, Norway

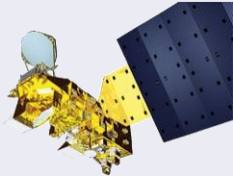


Global **Carbon Monoxide** Transport
(JPL, 2008)

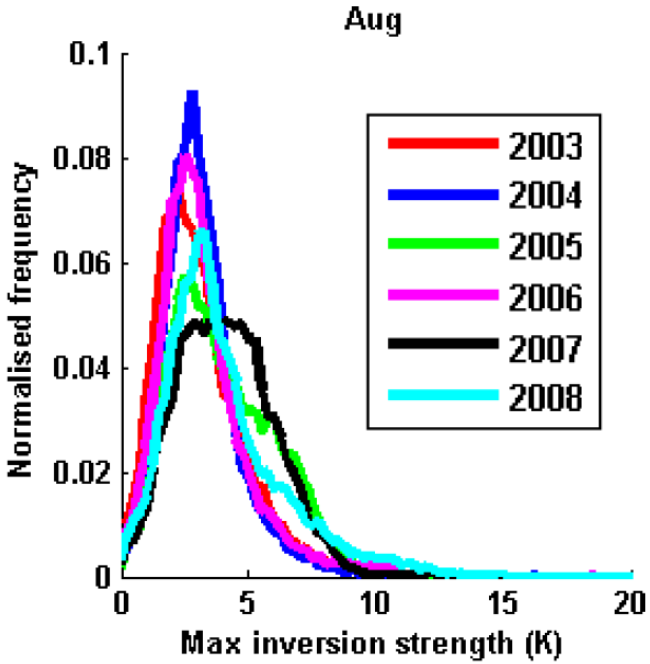




Swedish Study uses AIRS data to Study Temperature Inversions in Arctic Region



- Arctic Region warming at twice the rate of the rest of the world
- Temperature inversions play a crucial role in mass and moisture flux
- AIRS data used to study frequency and strength of inversions
- Inversions of 2007 stronger than other years. Warming seen to 400mb



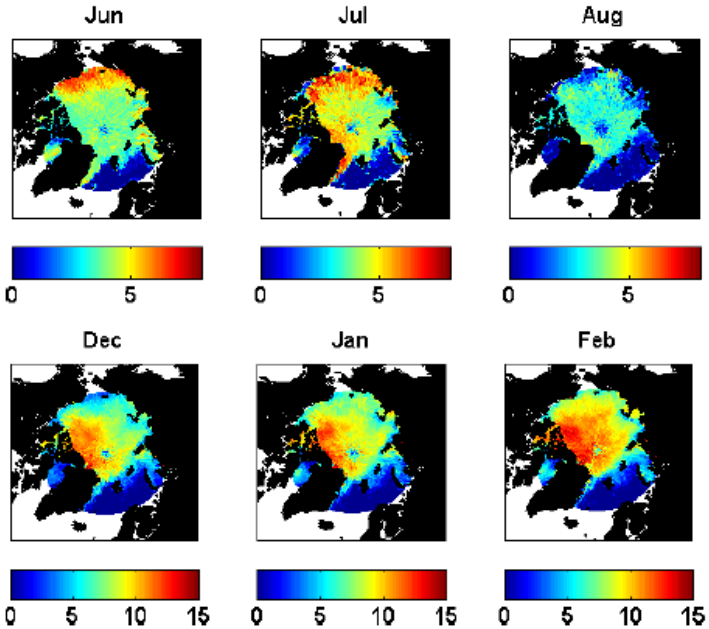
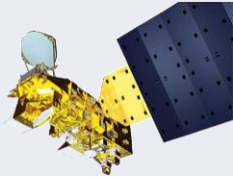


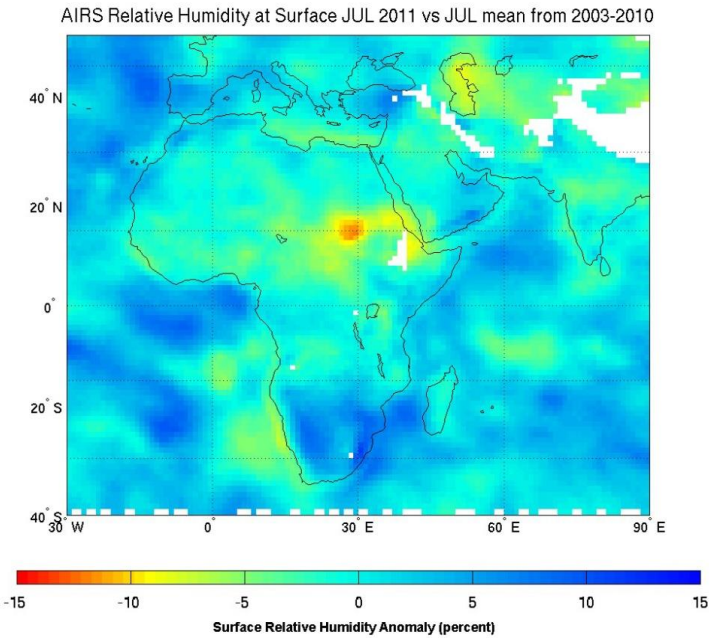
Fig. 5. The spatial pattern of inversion strength (in K) averaged over 2003–2008 for summer (top row) and winter (bottom row) months from the ascending passes. Note that the scale for the winter months is doubled.

A. Devasthale, U. Will´en, K.-G. Karlsson, C. G. Jones, "Quantifying the clear-sky temperature inversion frequency and strength over the Arctic Ocean during summer and winter seasons from AIRS profiles". Atmos. Chem. Phys., 10, 5565–5572, 2010

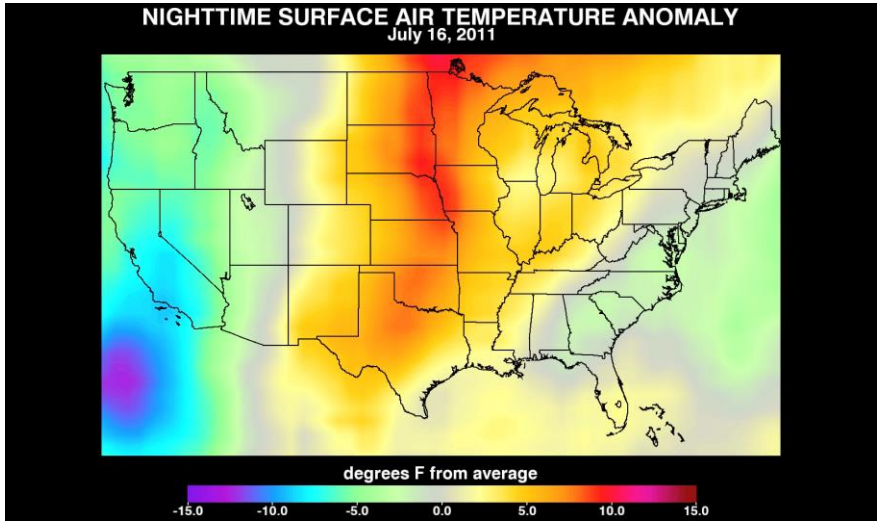
AIRS Project Developing New Products for Applications



Relative Humidity Anomaly Somalia Drought of July 2011



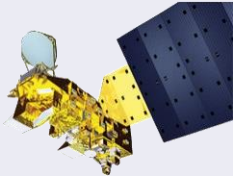
Surface Skin Temperature Anomaly Heat Wave of July 2011



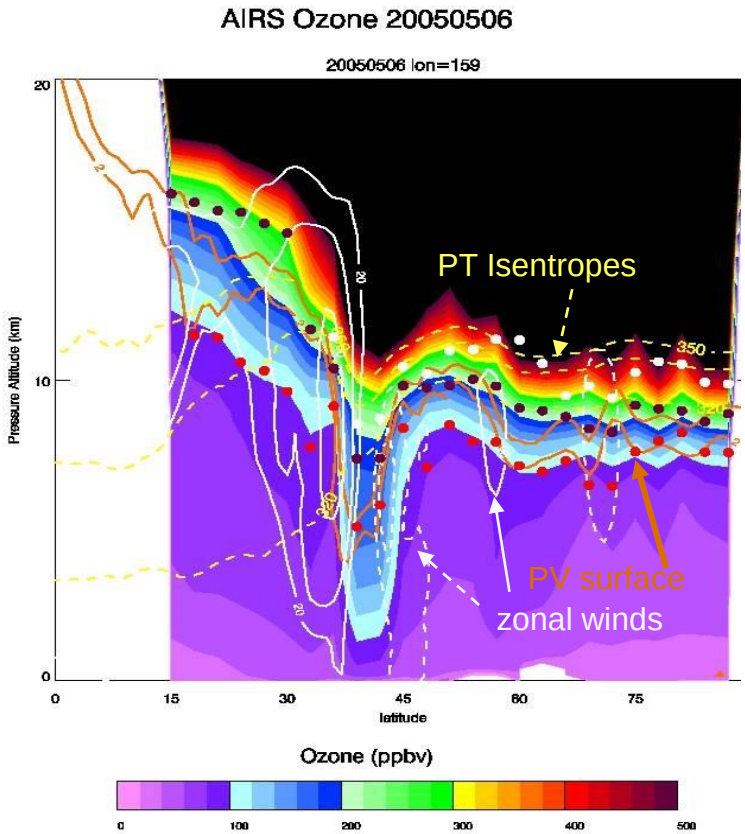
Additional Products Under Development:

- Mosquito Habitat Identification
- Temperature Inversion Identification (for Air Quality)

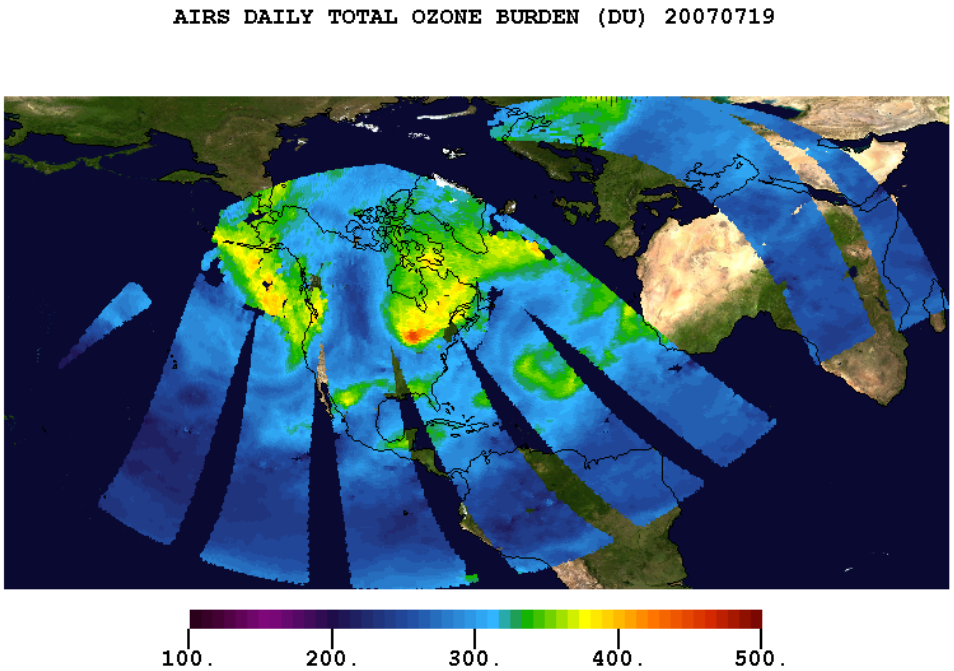
AIRS Monitors Upper/Tropospheric-Stratospheric Ozone

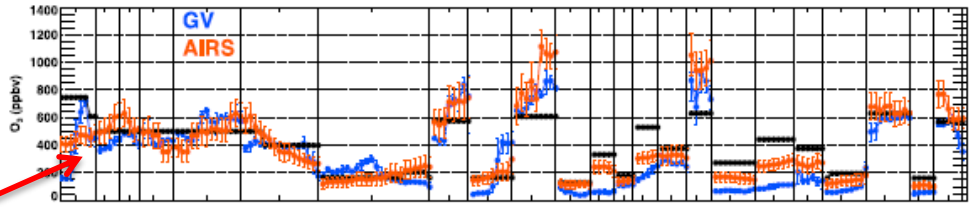


AIRS Identifies Stratospheric Ozone Intrusion, May 6, 2005 (Wei, 2008)



AIRS Ozone Daily Global Imagery Enables Early Warning of Possible Poor Air Quality





AIRS data compare well with ground and aircraft based ozone measurements

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

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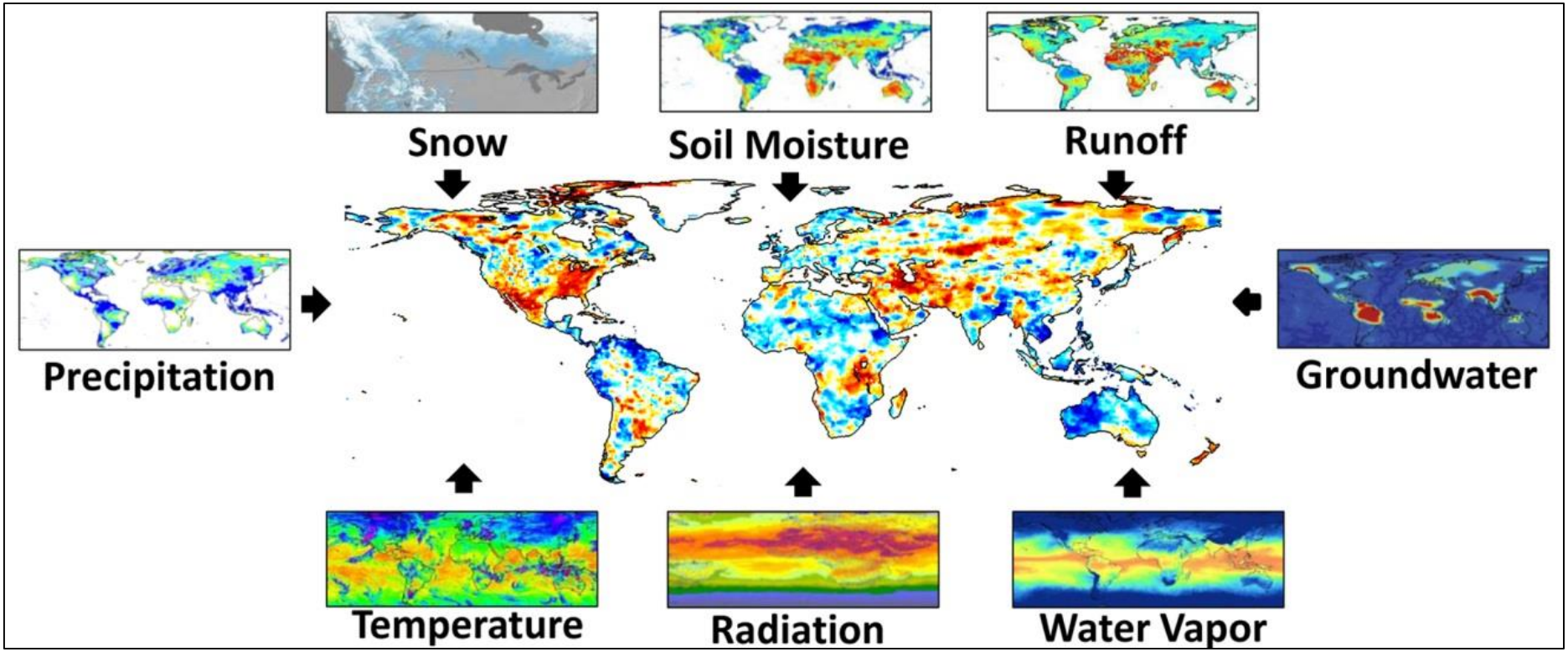
Remote Sensing of Drought

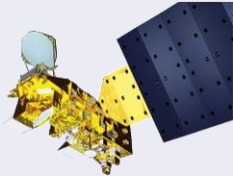


Data records are not consistent (often exhibit different distributions).

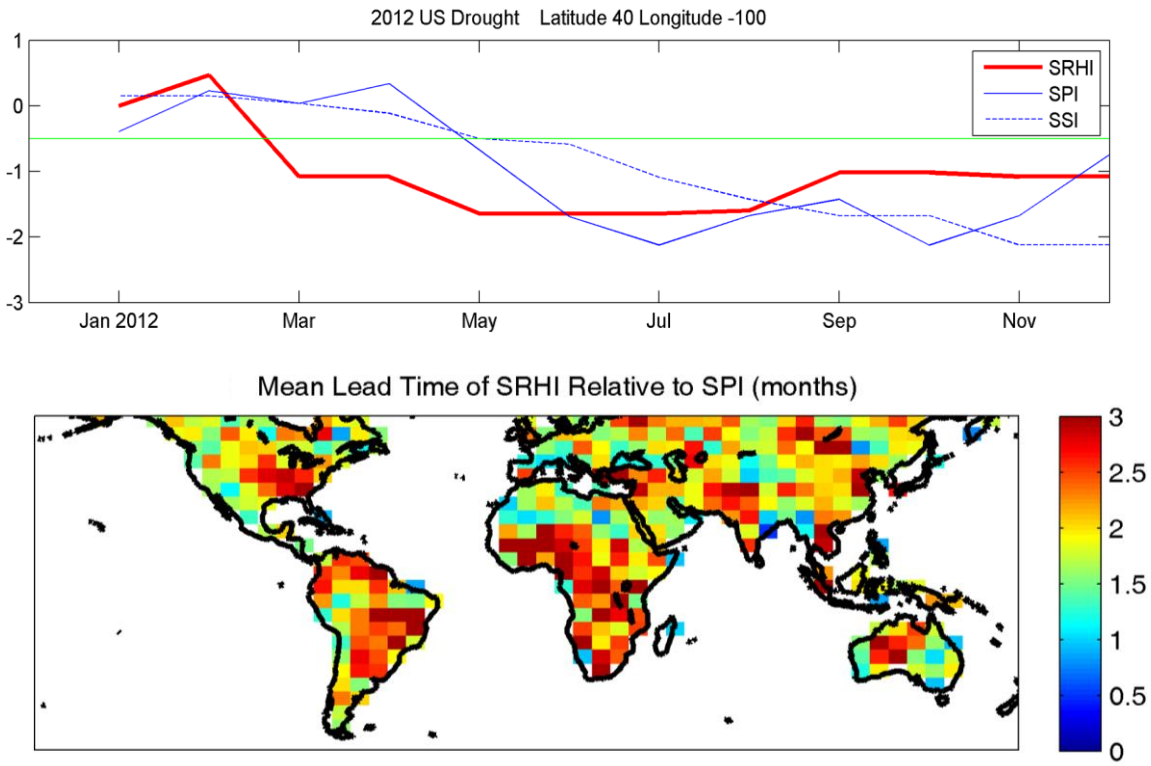
Lack of theoretical frameworks for linking different variables for multi-index drought assessment.

Amir AghaKouchak

AIRS Shows Skill in Early Drought Detection



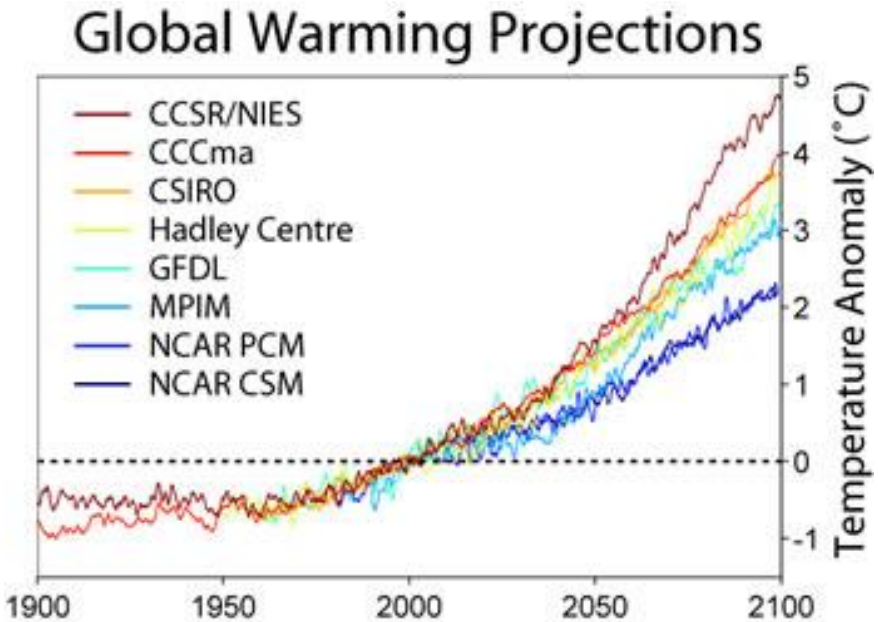
Standardized Relative Humidity Index (SRHI) from AIRS near surface RH detects drought onset earlier than other indicators



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

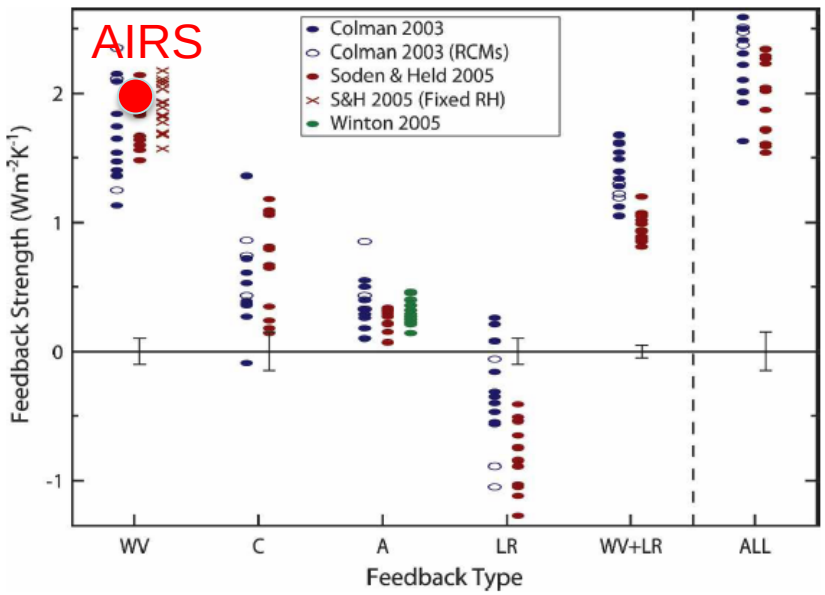
Farahmand et al, 2015, A Vantage from Space Can Detect Earlier Drought Onset: An Approach Using Relative Humidity, Scientific Reports, 5, 8553; doi: 10.1038/srep08553.

AIRS Data Used to Reduce Errors in Climate Models



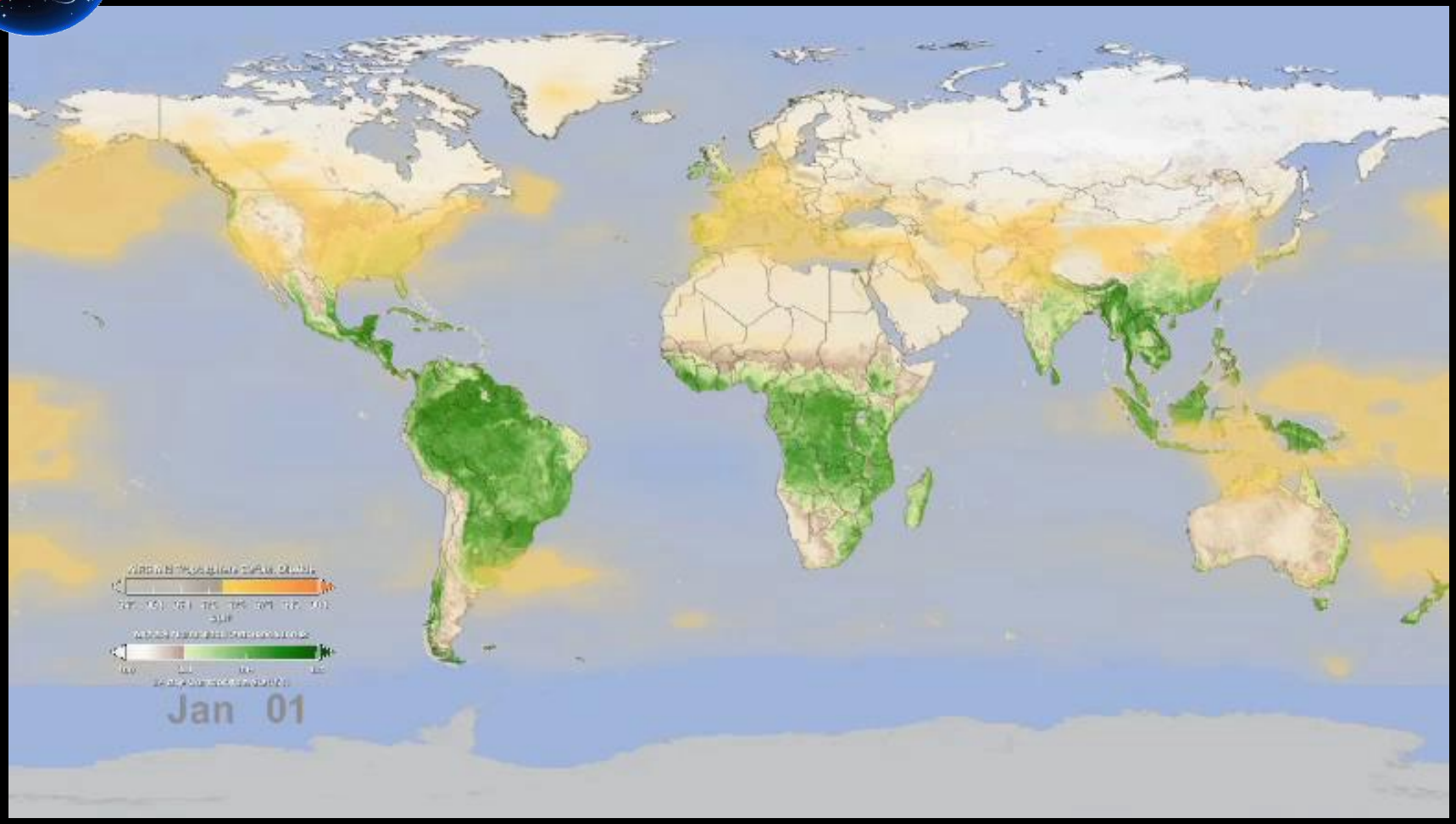
http://priweb.org/globalchange/climatechange/globalwarming/gw_05.html

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

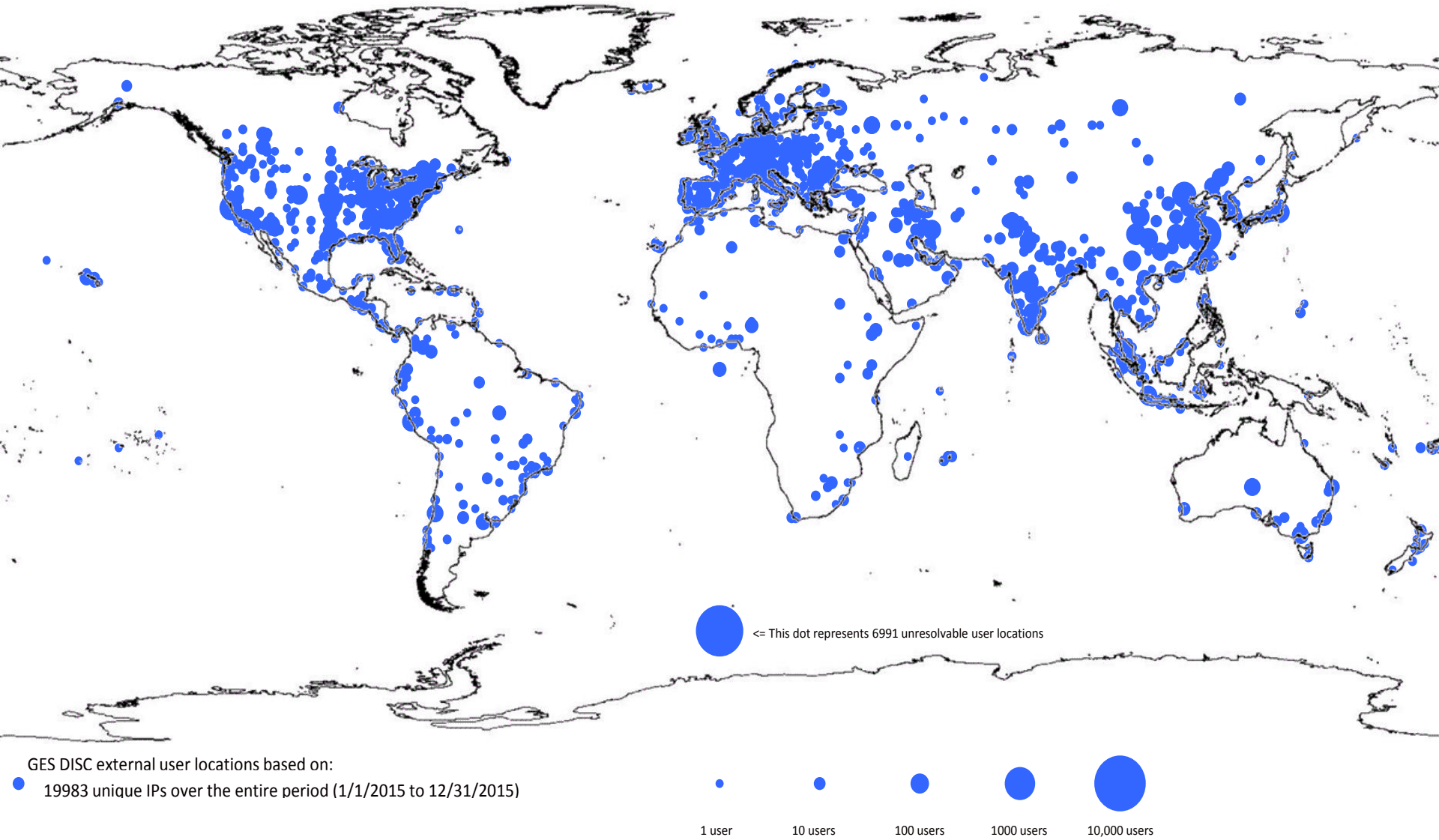
AIRS Mid-Trop CO_2 Drawdown Follows Regional Vegetation Cycle



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

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

Users Over the World Access Aqua Data in 2015

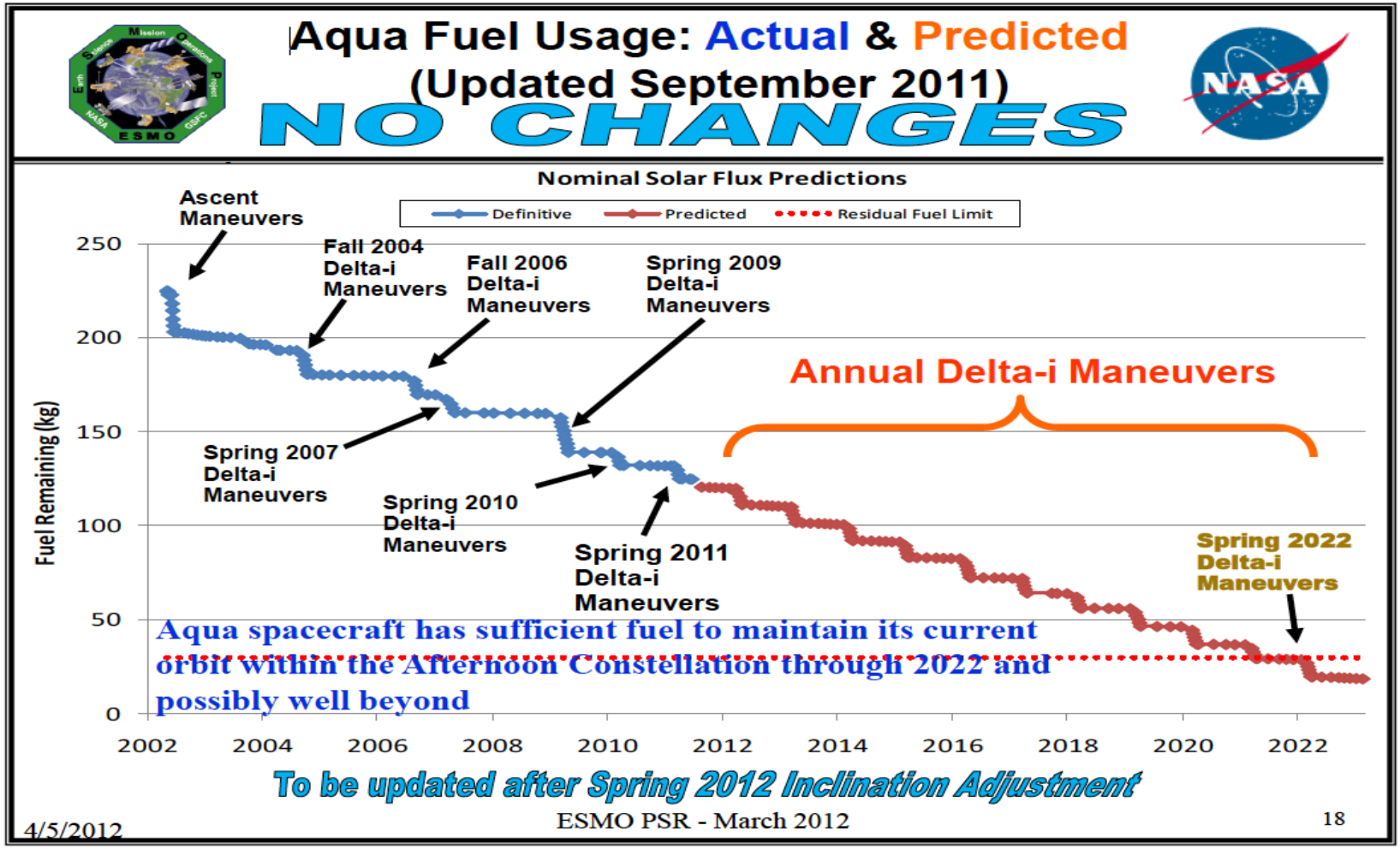


GES DISC external user locations based on:

- 19983 unique IPs over the entire period (1/1/2015 to 12/31/2015)

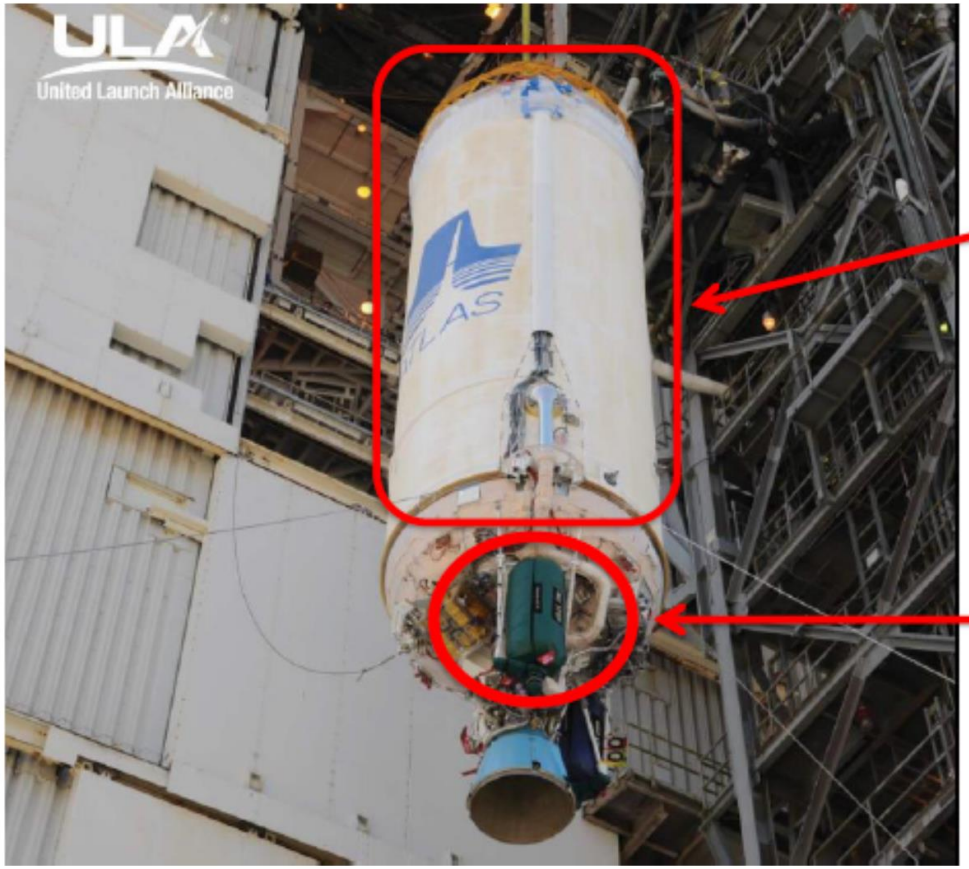
Feng Ding (GSFC)

AIRS Expected to Operate For Life of Spacecraft through 2022



CubeSat Launch Costs Low as Secondary Payload

Launch Canister on Atlas



Main payload

$200M

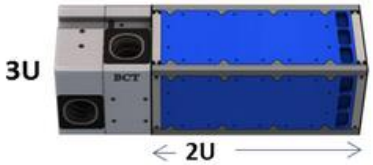
Cubesats
$250K

The cost information contained in this document is of a budgetary and planning nature and is intended for informational purposes only. It does not constitute a commitment on the part of JPL and/or Caltech.

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

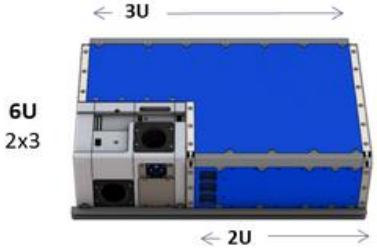
3U XB1 Spacecraft

2U Available Payload Volume



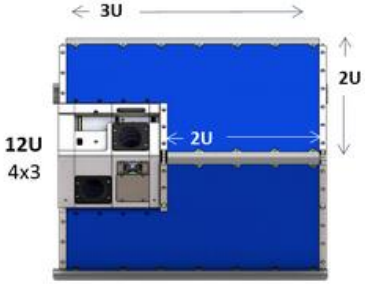
6U XB1 Spacecraft

5U Available Payload Volume



12U XB1 Spacecraft

11U Available Payload Volume



Micro-Sat XB1 Spacecraft

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

BLUE CANYON TECHNOLOGIES

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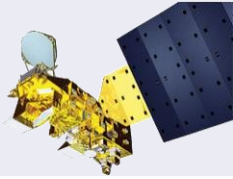
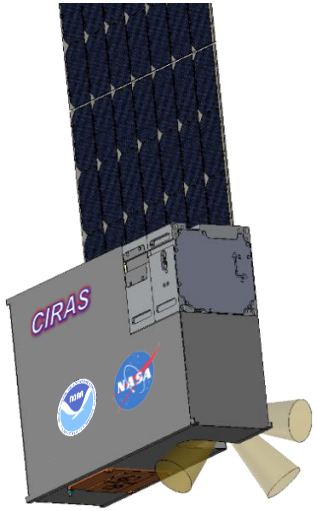
CIRAS Mission Overview



CIRAS is a ***technology demonstration*** mission to enable hyperspectral infrared atmospheric sounding on a CubeSat

- **Mission Objectives**
  - In-Space Technology demonstration for key infrared subsystems: JPL HOT-BIRD IR Detectors, JPL Grism Spectrometer, Black Silicon Blackbody
  - Demonstration of Mid-wavelength Infrared (MWIR) temperature and water vapor sounding. Limited to mid to lower troposphere.
  - All technologies will be advanced to TRL 7 at the end of experiment
- **Implementation Summary**
  - 6U CubeSat (approx. 30 x 20 x 10 cm, <14 kg)
  - LEO Sun Synchronous Morning Orbit (400 km – 850km)
  - Minimum Mission Duration: 3 months
  - JPL Payload Development, Ball Optics, Commercial Spacecraft
  - CubeSat Launch Initiative for Launch Services
  - 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 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 June 2018.



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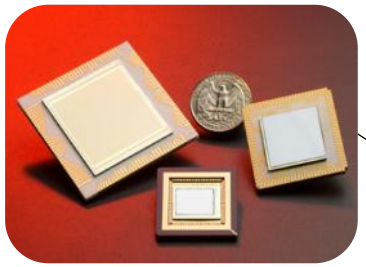
CIRAS Instrument Uses Latest HSIR Technologies

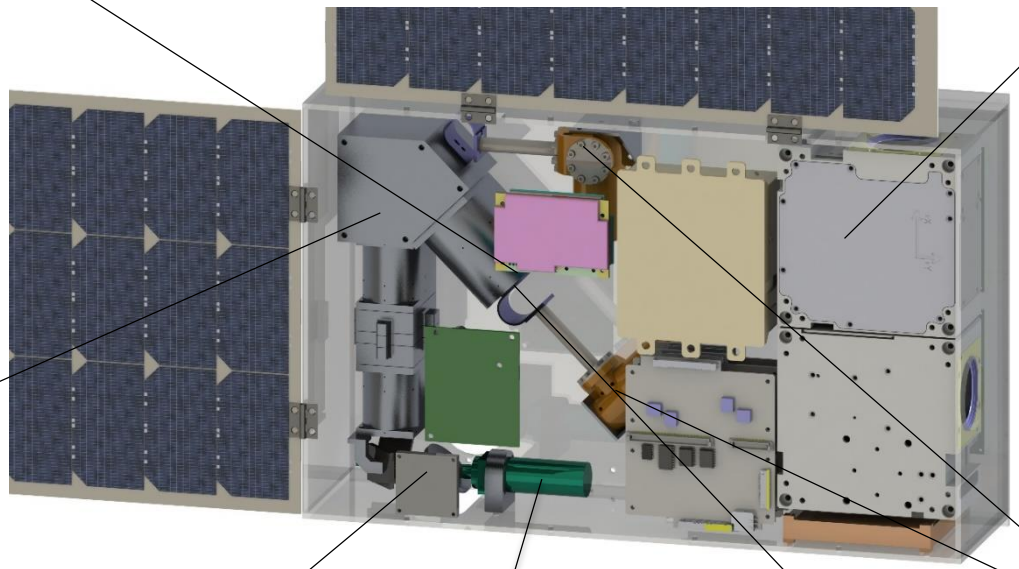


JPL
HOTBIRD
Detectors

Size	*6U Cubesat*
Mass	*8.5 kg*
Power	*37.5W*
Data Rate	*2 Mbps*

Commercial
Spacecraft

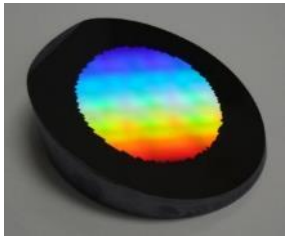
JPL/BALL
Midwave Infrared
Spectrometer



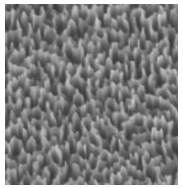
IR Cameras
SBF193 Electronics

JPL MDL Technologies

Immersion Grating

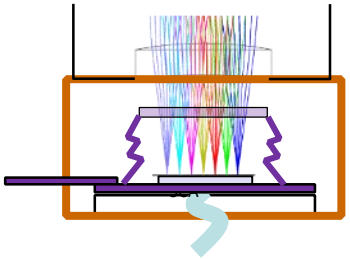


Black Si.
Blackbody & Slit



Scan Mirror Assy
Commercial Stepper
Motor + Elex

Custom Detector
and Cold Filter
Mount



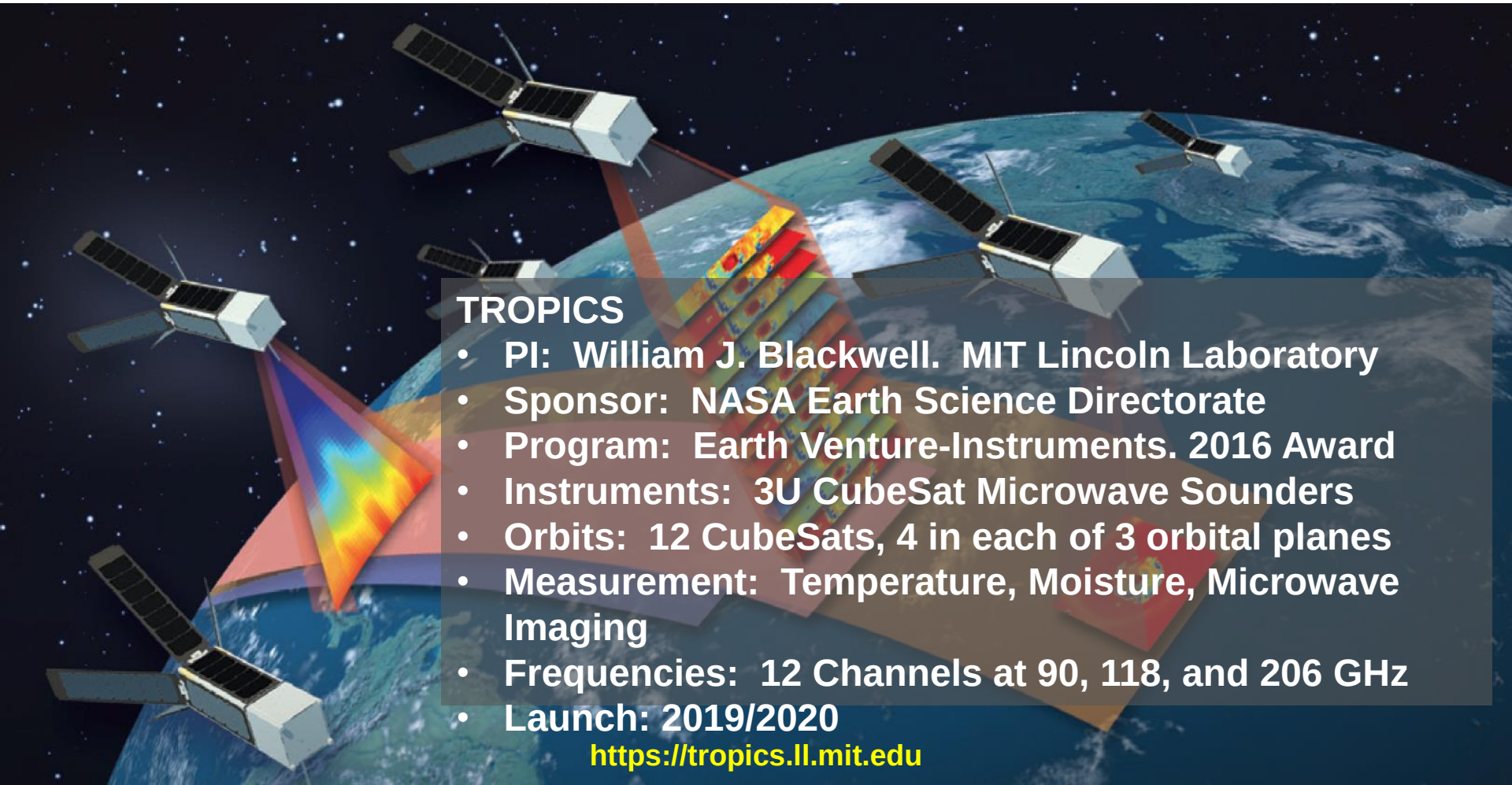
Ricor K562S
Cryocoolers + Elex

33

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

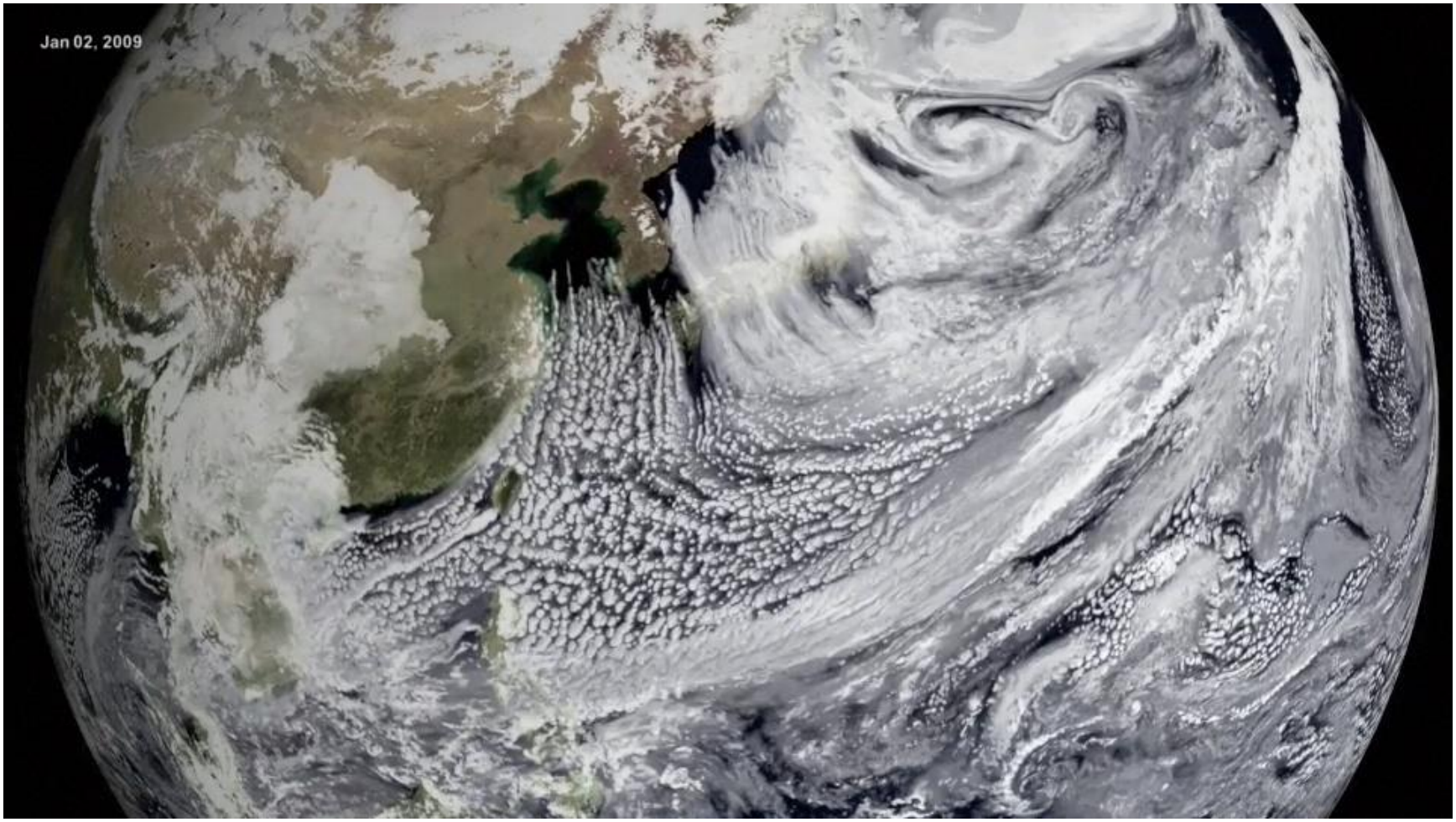


TROPICS

- 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

https://tropics.ll.mit.edu

Improved Timeliness Important for Storm Development: Model Clouds Shown Below



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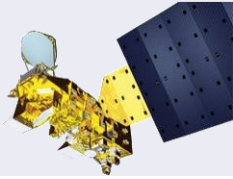
Summary



- Satellite Earth remote sensing instruments operating in the infrared measure the surface temperature, atmospheric temperature and water vapor profiles, and trace gases species in the atmosphere.
- The data are used by operational meteorological agencies, weather and climate forecasters (e.g. drought), agriculture, disaster response (fires, floods, hurricanes) worldwide
- The technology is developed under NASA and commercial programs in government and industry.
- Future systems underway to reduce cost and increase timeliness using constellations of small satellites