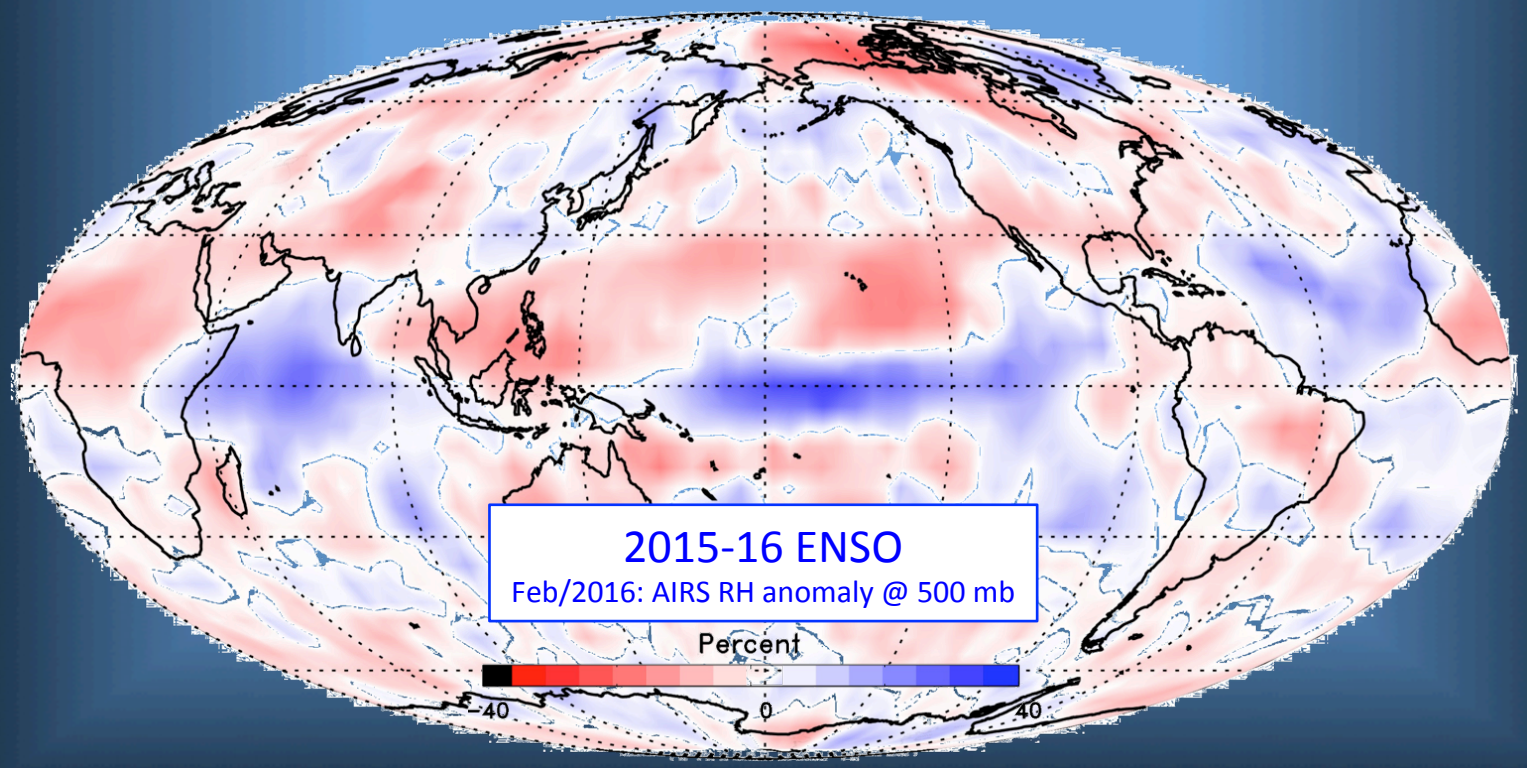
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Recent progress and future directions in atmospheric science enabled by the Atmospheric Infrared Sounder (AIRS)

Bjorn Lambrigtsen, Joao Teixeira, Tom Pagano, Eric Fetzer
Jet Propulsion Laboratory, California Institute of Technology



EUMETSAT Conference, Darmstadt, September 26-30 2016

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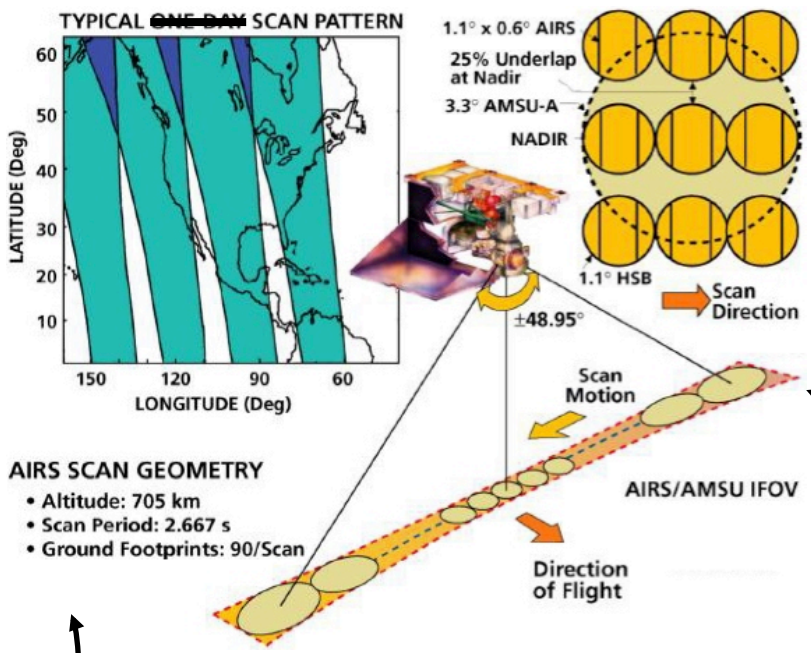
AIRS in brief

AIRS was launched in May 2002

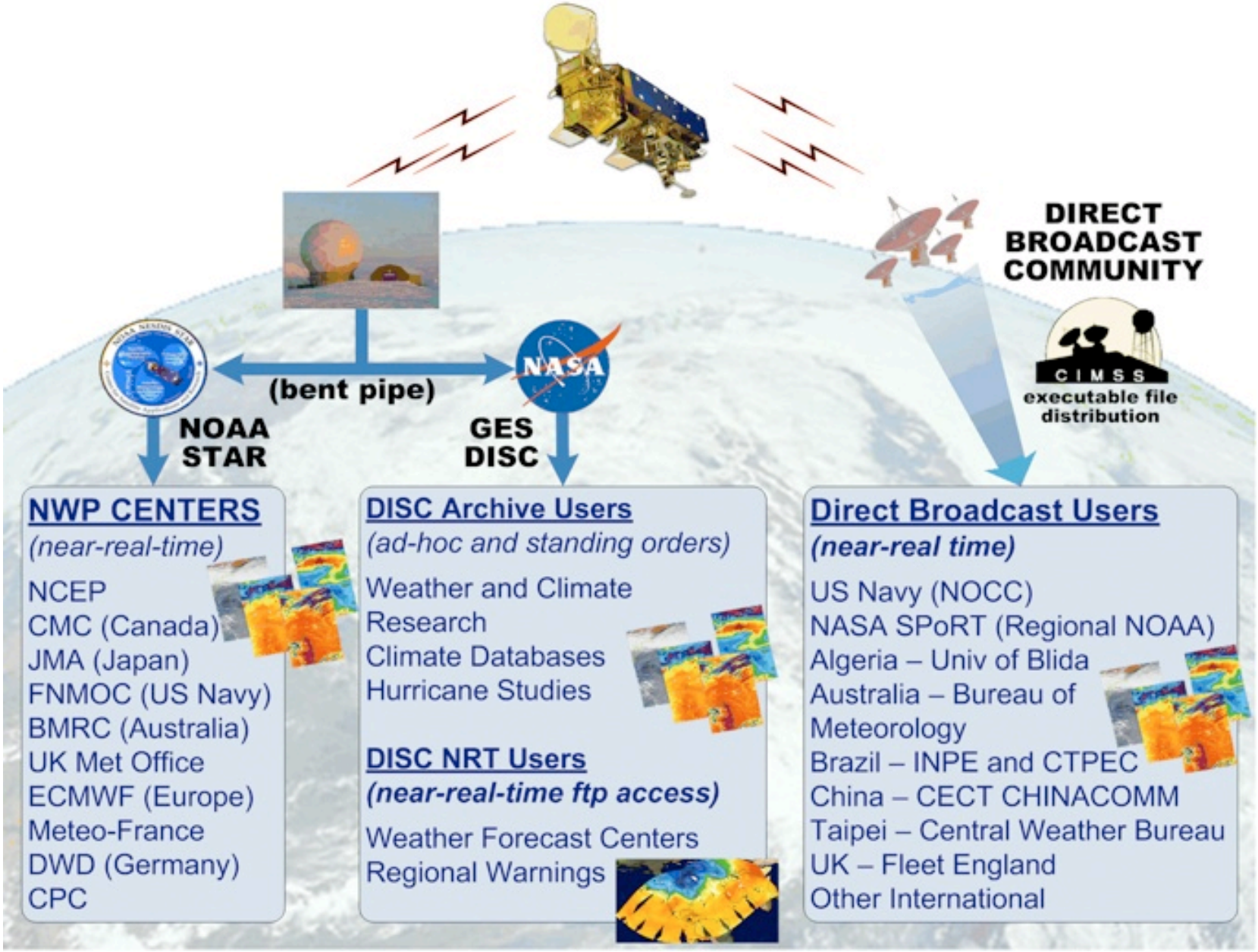
- Nearly 15 years of self-consistent data
- Weather: Significant forecast impact
- Climate: Can now study climate variability, can soon study trends
- Research: Widely used in process studies

Geometry and sampling:



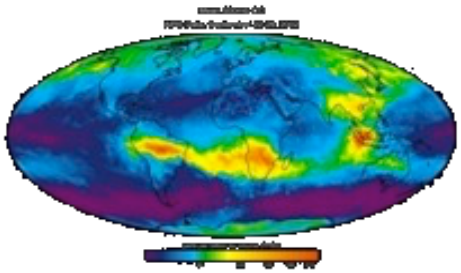
1. AMSU footprint, 45 km across at nadir, contains 9 AIRS spectra
   - THIS IS THE RETRIEVAL GRANULARITY.
2. Viewing swath 30 AMSU footprints or ~1650 km wide.
3. The result: 2,916,000 IR spectra and 324,000 retrievals per day

Three data paths



Key geophysical products

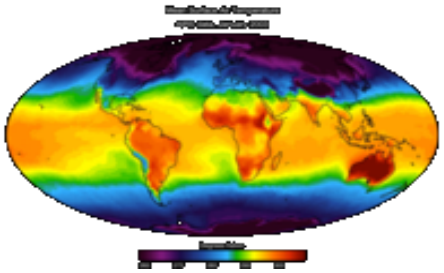
CO



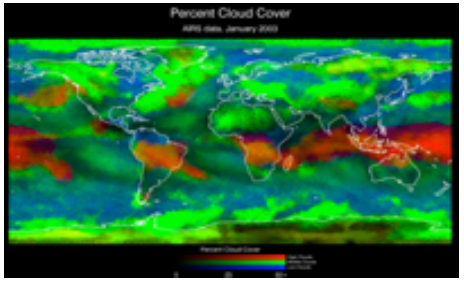
Greenhouse Gas Forcing

Clouds and Water Vapor Feedback

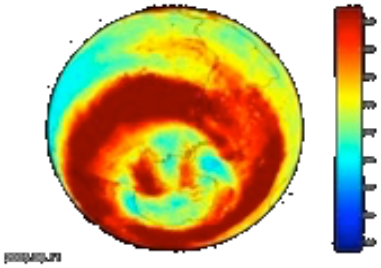
Atmospheric Temperature



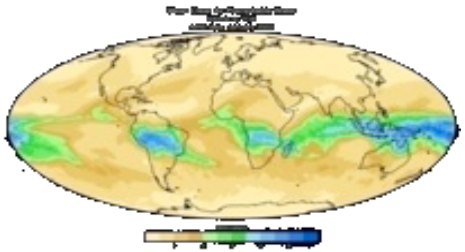
Cloud Properties



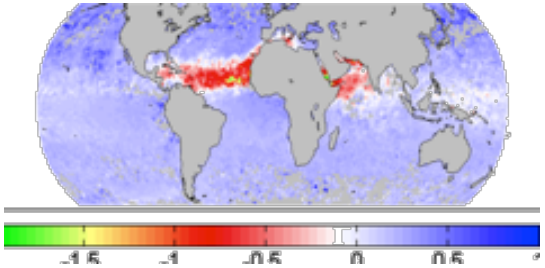
Ozone



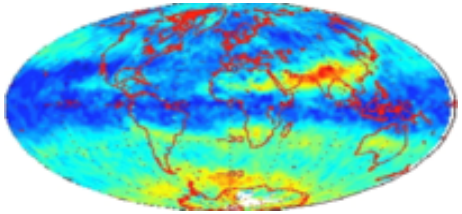
Atmospheric Water Vapor



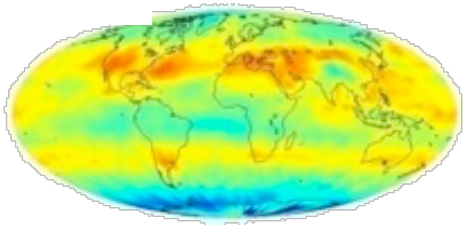
Dust & ash



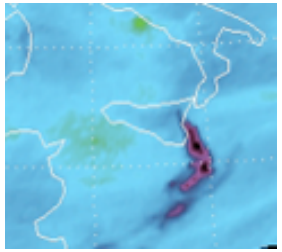
Methane



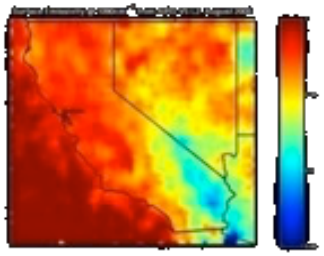
CO2



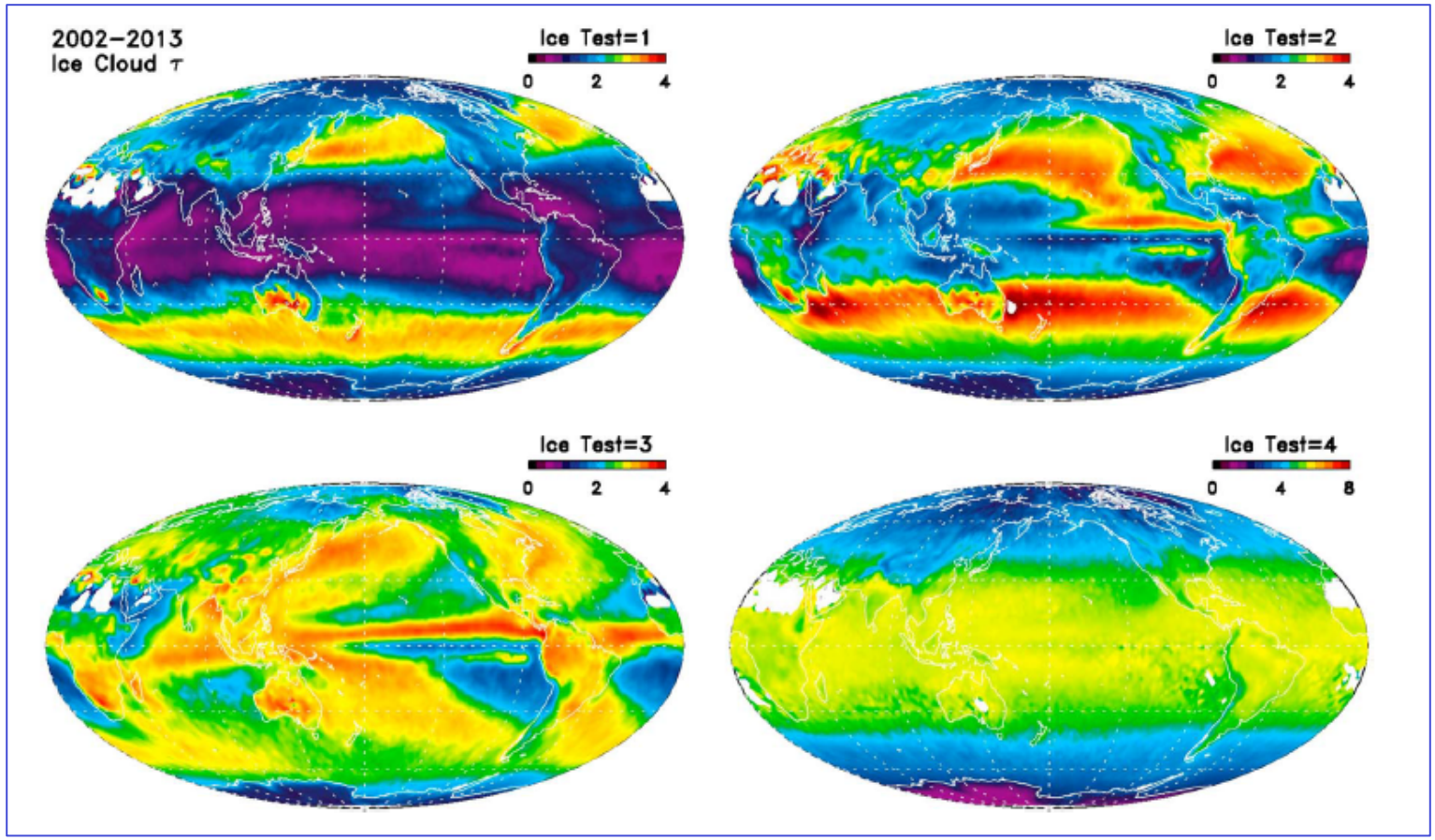
SO2



Emissivity



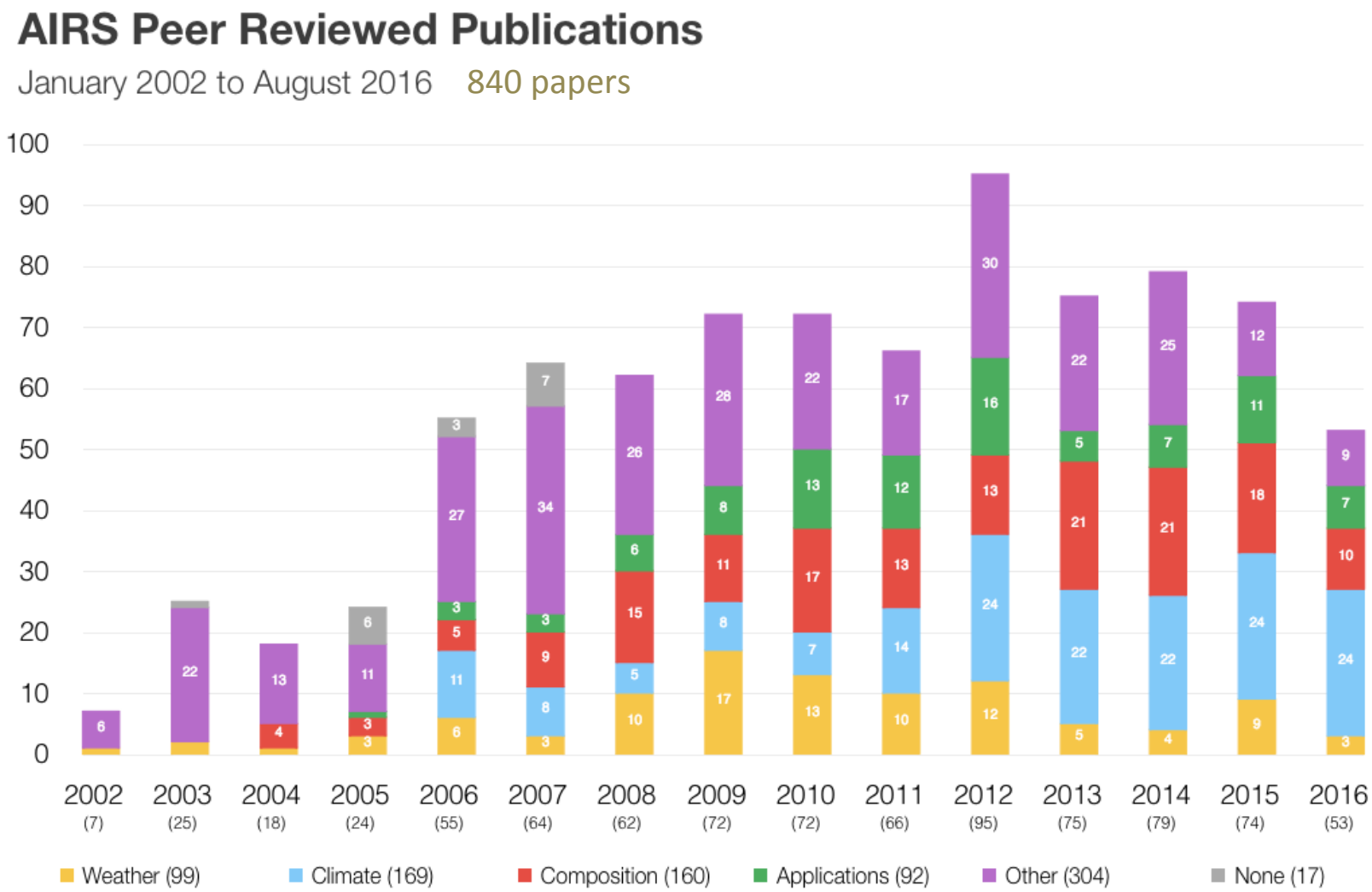
New product: Detection of ice clouds



Maps show increasingly robust cloud ice signatures.

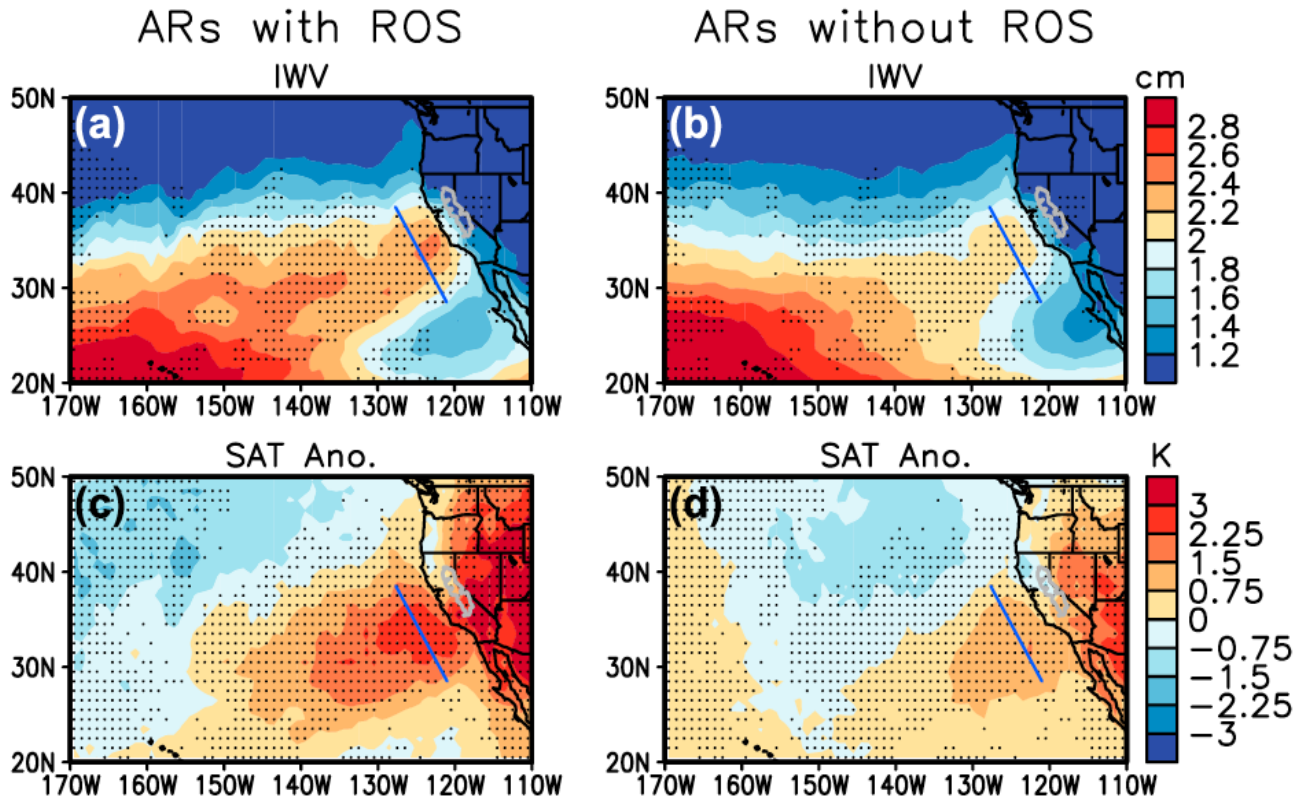
Kahn, B. H., M. M. Schreier, Q. Yue, E. J. Fetzer, F. W. Irion, S. Platnick, C. Wang, S. L. Nasiri, and T. S. L'Ecuyer (2015), Pixel-scale assessment and uncertainty analysis of AIRS and MODIS ice cloud optical thickness and effective radius, *JGR: Atmospheres, 120,* 11,669–11,689, http://dx.doi.org/10.1002/2015JD023950.

Steady stream of papers



Rain on Snow in Atmospheric Rivers

More water vapor and higher surface air temperature – both measured by AIRS – increase the likelihood of rain-on-snow events



Guan, B., D. E. Waliser, F. M. Ralph, E. J. Fetzer, and P. J. Neiman (2016), Hydrometeorological characteristics of rain-on-snow events associated with atmospheric rivers, *Geophys. Res. Lett., 43,* doi:10.1002/2016GL067978.

Weather: Ozone & anomalous events

Case study of high AIRS ozone and hurricane force winds as jet stream descends to surface.

Note: Qualitative relative information sufficient for some applications.

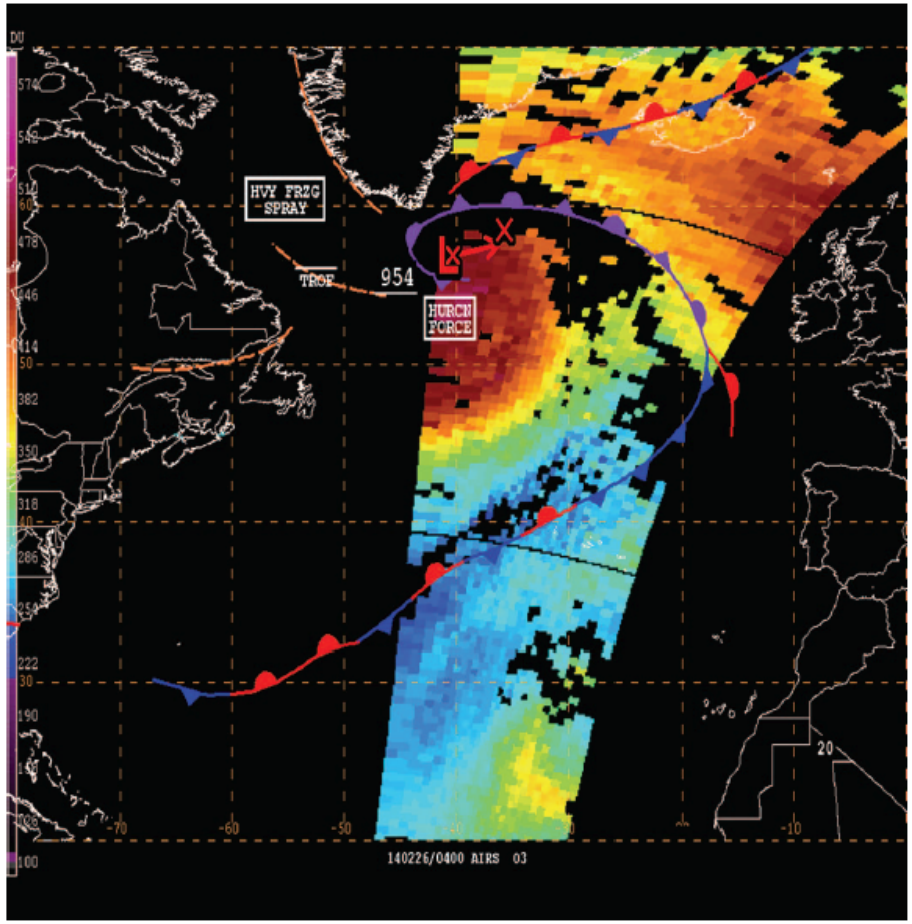
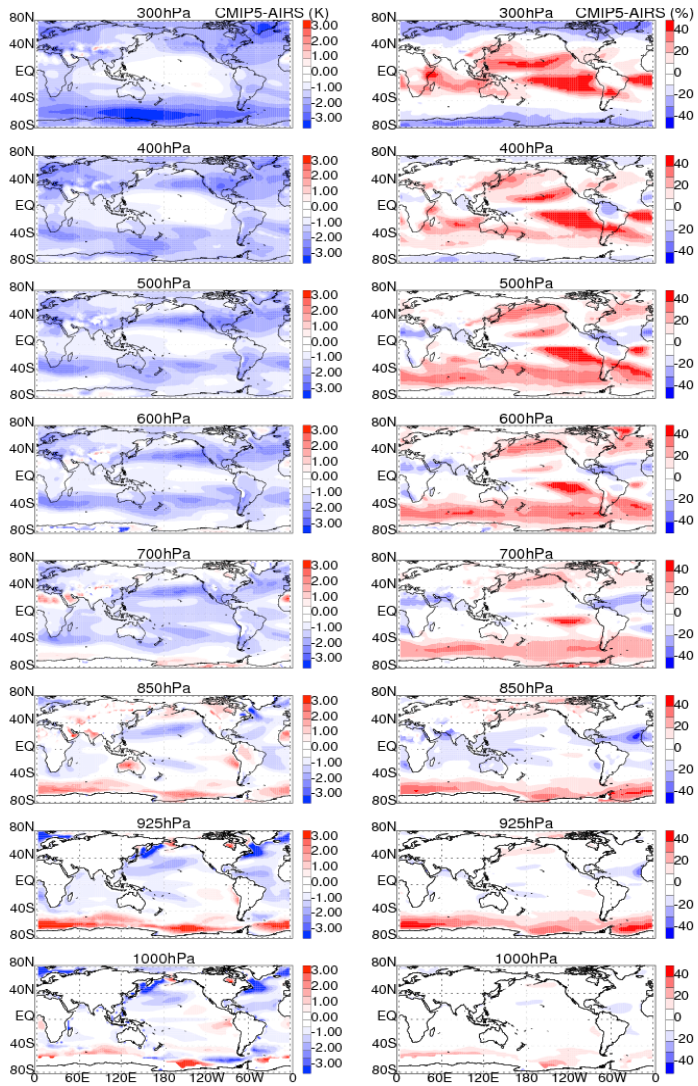


Fig. 9. 26 February 2014 1200 UTC OPC surface analysis overlaid on 0400 UTC AIRS total column ozone (DU).

Berndt, E. B., B. T. Zavodsky, and M. J. Folmer (2016), Development and Application of Atmospheric Infrared Sounder Ozone Retrieval Products for Operational Meteorology, *IEEE Transactions on Geoscience and Remote Sensing, 54(2),* 958-967, doi: http://dx.doi.org/10.1109/TGRS.2015.2471259.

Climate: Evaluating climate models

Evaluating CMIP5 models using AIRS tropospheric air temperature and specific humidity climatology



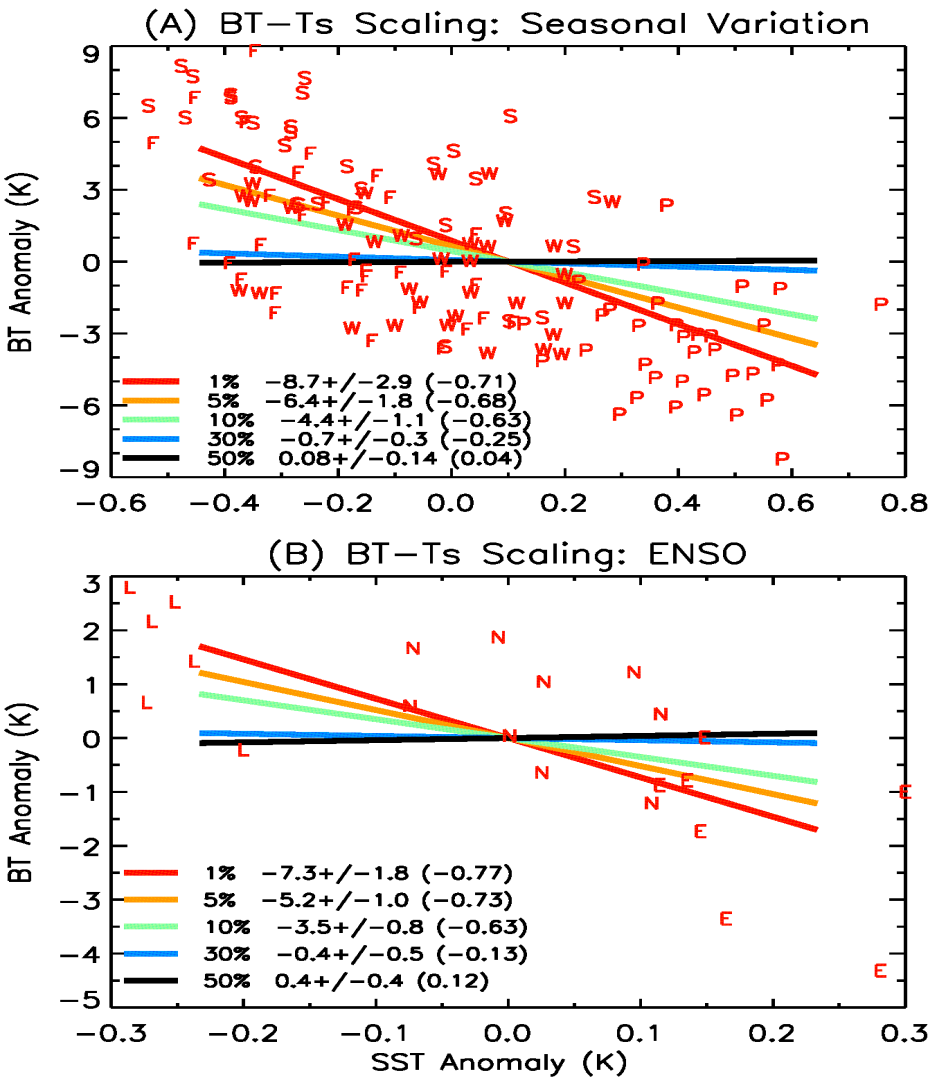
- **Problem:**
  The tropospheric air temperature and specific humidity simulations in CMIP5 climate models have not been well evaluated. Here, we compare the AIRS Obs4MIPs datasets and 16 CMIP5 climate model outputs to evaluate the tropospheric air temperature and specific humidity simulations in CMIP5 climate models.
- **Result:**
  Based on the AIRS Obs4MIPs datasets, we found two noticeable biases in CMIP5 climate models. The first is a tropospheric cold bias (~2 K) in most CMIP5 climate models (13 of 16). The second is the double-Intertropical Convergence Zone (ITCZ) bias in the troposphere in all CMIP5 climate models.
- **Significance:**
  This study demonstrates the strong values of the AIRS Obs4MIPs datasets for CMIP5 model evaluation and the significant biases of the state-of-the-art CMIP5 models.

Figure: Systematic biases of tropospheric air temperature (CMIP5−AIRS, K, left) and specific humidity ((CMIP5−AIRS)/AIRS, %, right) climatologies for 16 CMIP5 model ensemble mean.

Tian et al., 2013, J. Geophys. Res., 118, D50117, doi:10.1029/2012JD018607

Climate: Extremes

Extreme Convection and Tropical Climate Variability



How does extreme tropical convection change with sea surface temperature (SST)?

Finding:

Over the tropical ocean, as convection grows with SST, the more extreme convective events (measured by AIRS window channel brightness temperature) are more sensitive to SST changes, and the median events are insensitive.

Significance:

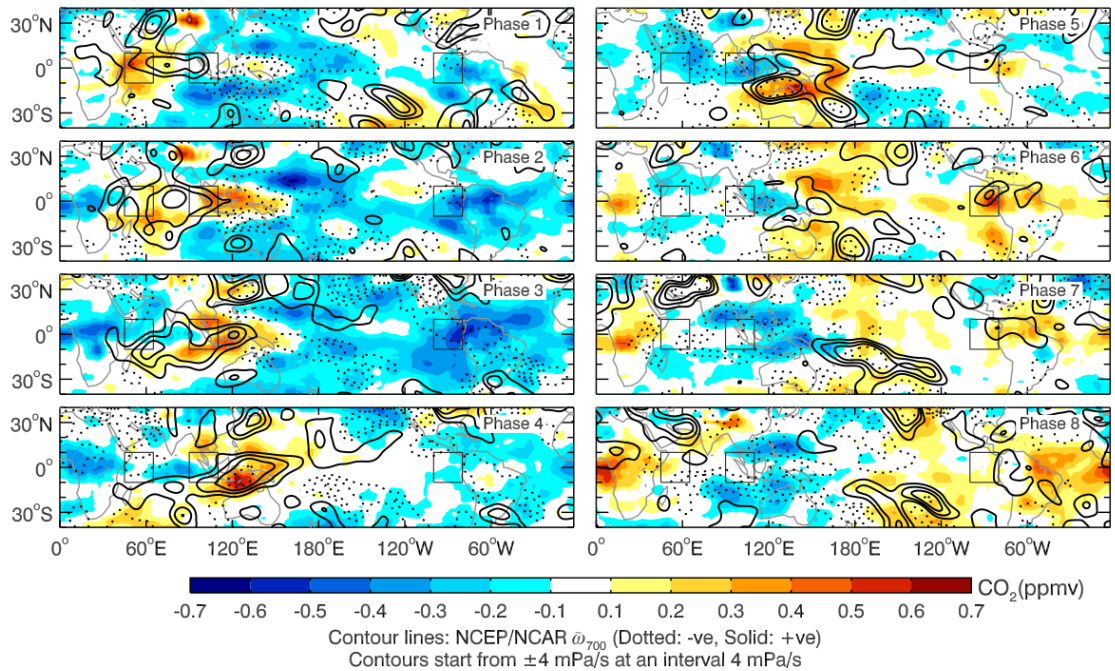
Extreme convective events may occur more frequently when SST warms up, in particular over regions where monsoon and tropical storms often occur.

Extreme (cold) Tbs, associated with intense storms, decrease faster with warmer ocean

Sun Wong and João Teixeira (2015): Extreme convection and tropical climate variability: Scaling of cold brightness temperatures to sea surface temperature, J. Climate, 29, 3893-3905, doi:10.1175/JCLI-D-15-0214.1.

Composition: Carbon dioxide

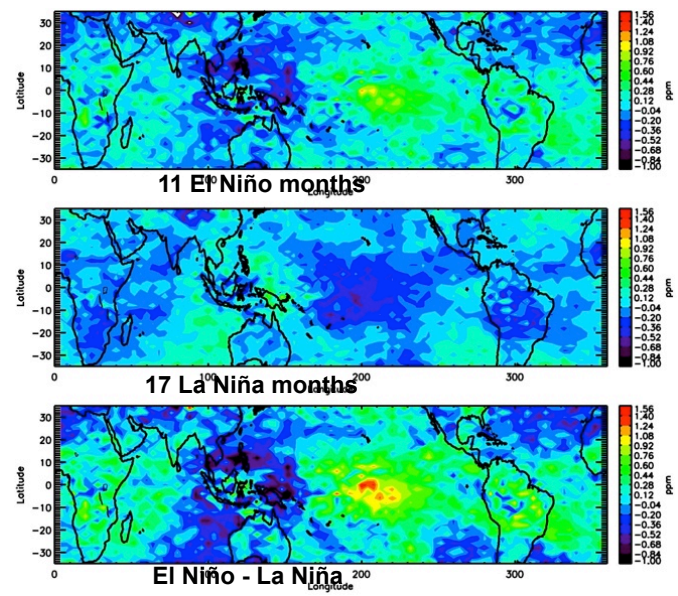
MJO Signal Visible in AIRS Retrieved CO_2



MJO related AIRS CO_2 anomalies (color) for 8 MJO 6-day phases. Data are for days with strong MJO activity, $(RMM_1)^2+(RMM_2)^2 \geq 1$,
for boreal winters in period from Nov 2002 through February 2010. Eastward propagation shown by solid/ dotted MJO-related rainfall anomaly outside of threshold ± 1 mm/dy.

Li et al. , (2010), "Tropical mid-tropospheric CO2 variability driven by the Madden–Julian oscillation." *Proceedings of the National Academy of Sciences* 107, no. 45, 19171-19175.

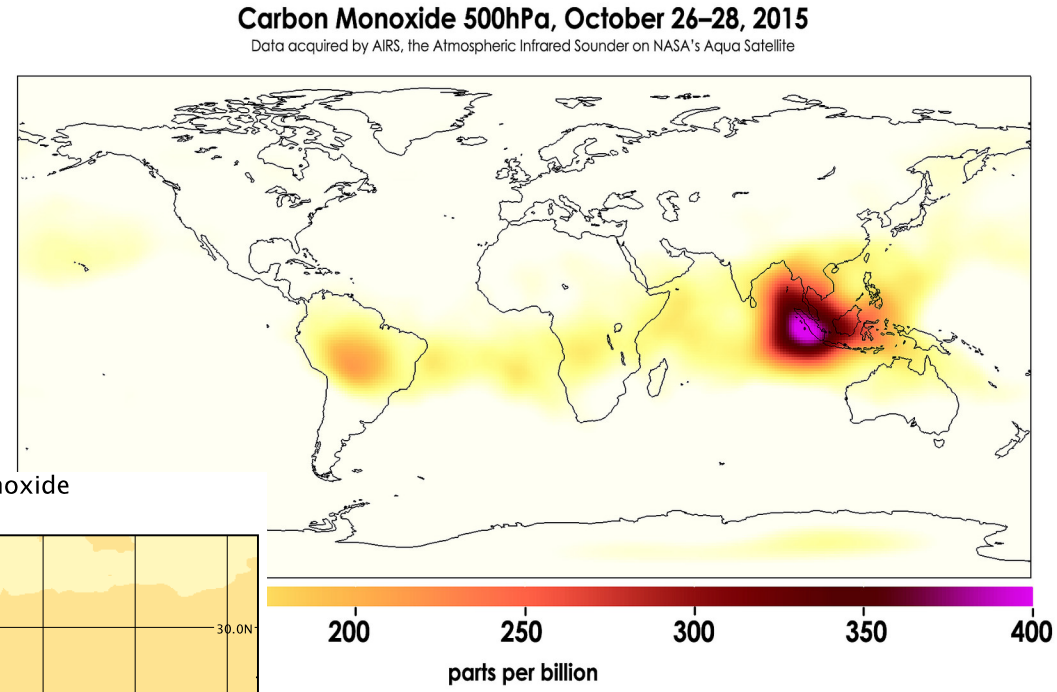
El Niño Signal Visible in AIRS Retrieved CO_2

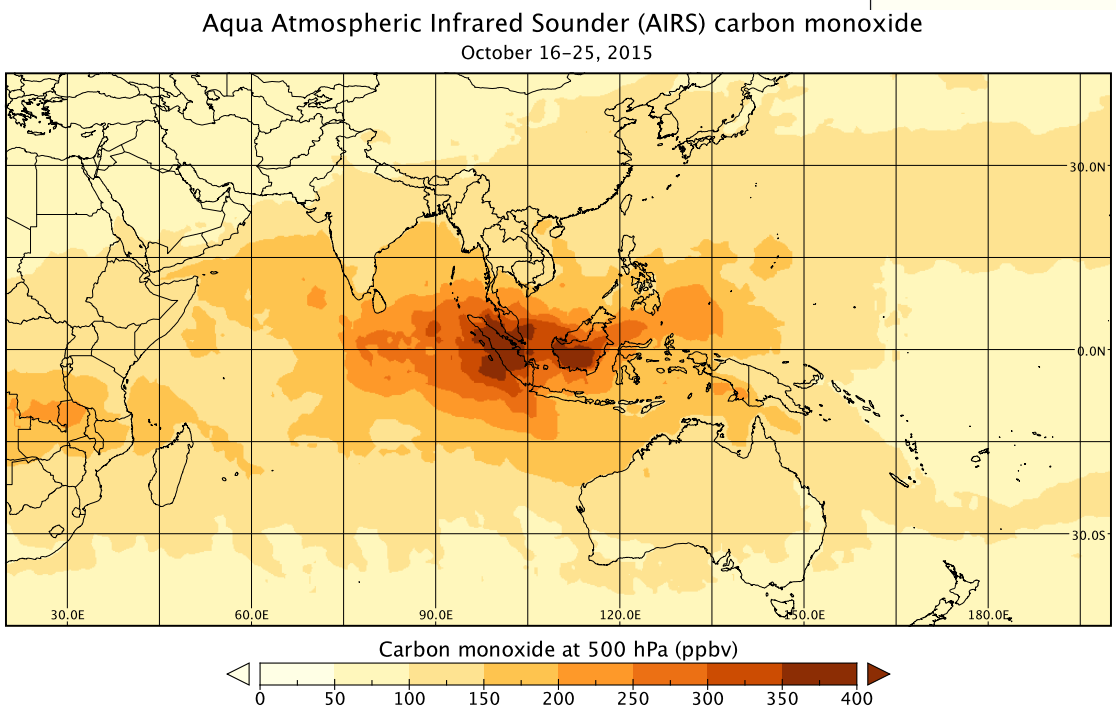


Jiang et al., (2012), "Influence of El Nino on mid-tropospheric CO2 from Atmospheric Infrared Sounder and model", JAS, doi:10.1175/JAS-D-11-0282.1

Composition: Carbon monoxide

Global daily tracking of large-scale lofting and advection, e.g., from fire biomass burning products
Captures short-term variability of CO emissions as well as seasonal variation



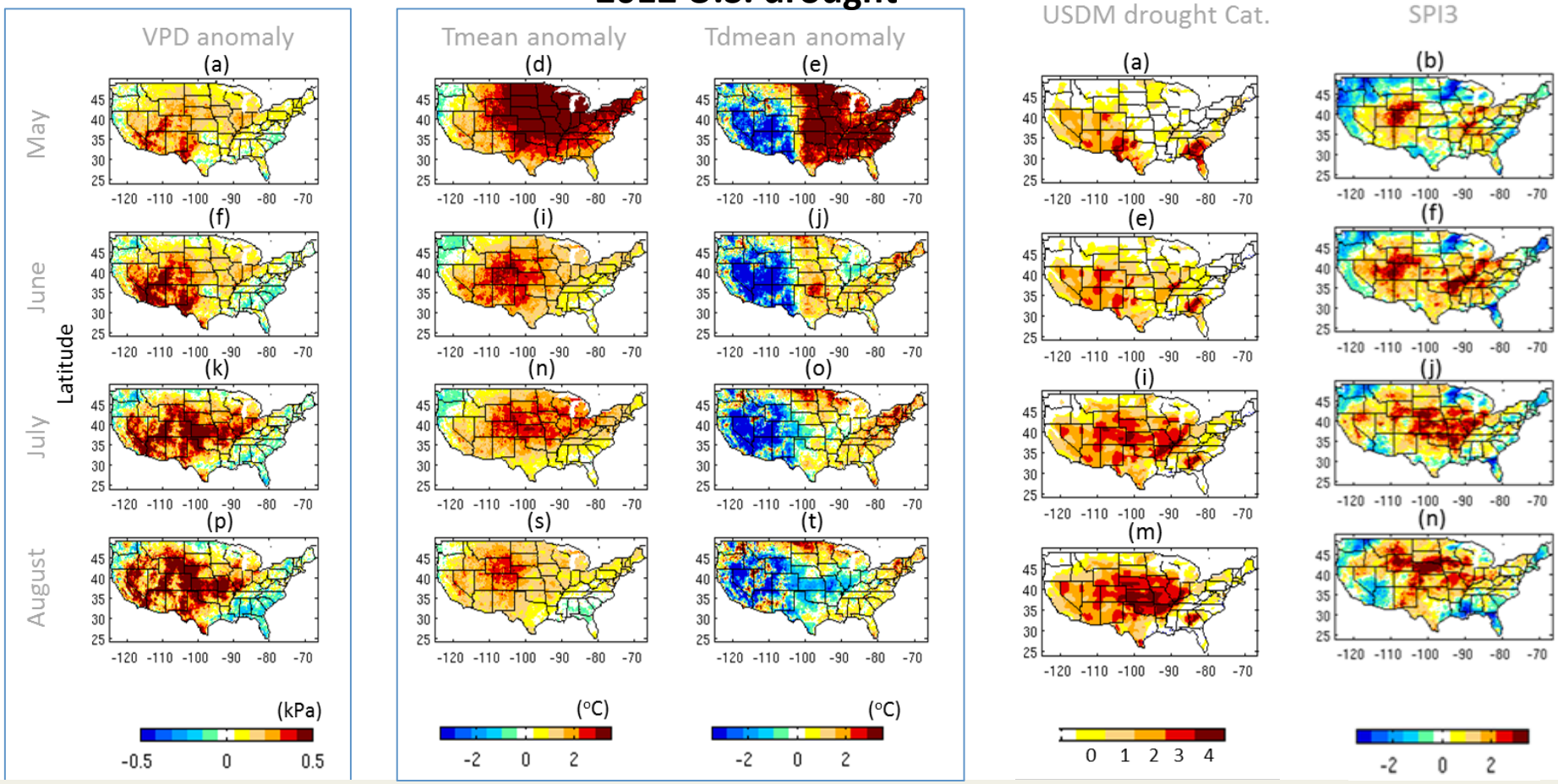


Field, R. D., et al. (2016), Indonesian fire activity and smoke pollution in 2015 show persistent nonlinear sensitivity to El Nino-induced drought, Proc. NAS, 113(33), 9204-9209.

Applications: Drought detection

AIRS helps understand drought development processes and can detect "metorological" drought onset earlier than several other indicators

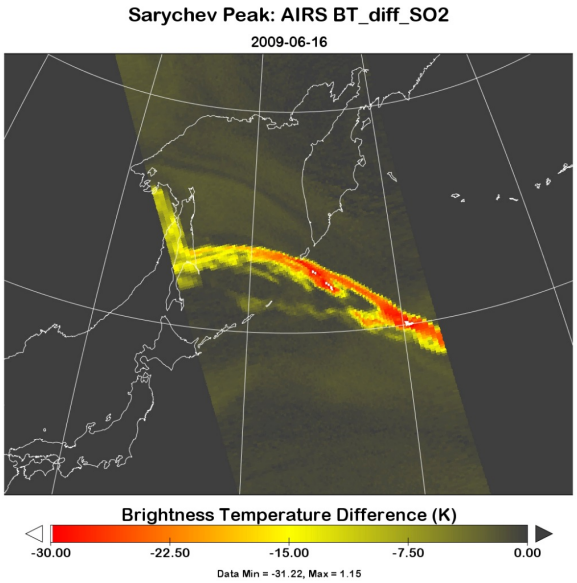
2012 U.S. drought

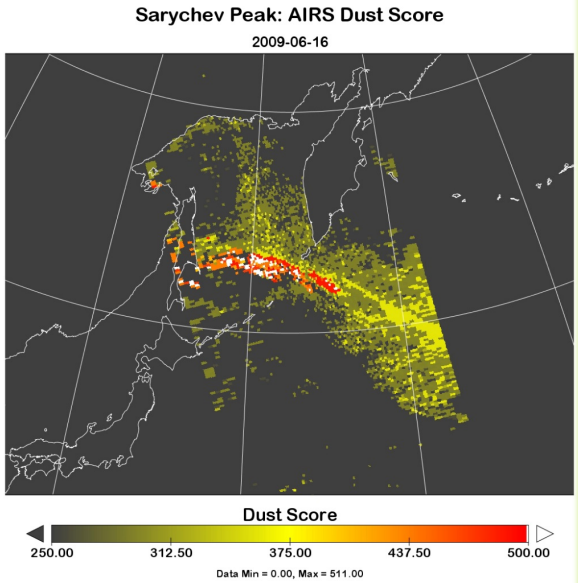


- **Behrangi, A.**, P. Loikith, E. Fetzer, H. Nguyen, and S. Granger, 2015: Utilizing Humidity and Temperature Data to Advance Monitoring and Prediction of Meteorological Drought. *Climate*, **3,** 999-1017.
- **Behrangi, A.,** E. J. Fetzer, and S. L. Granger, 2016: Early detection of drought onset using near surface temperature and humidity observed from space. *International Journal of Remote Sensing*, **37,** 3911-3923.

Applications: Volcanic eruptions

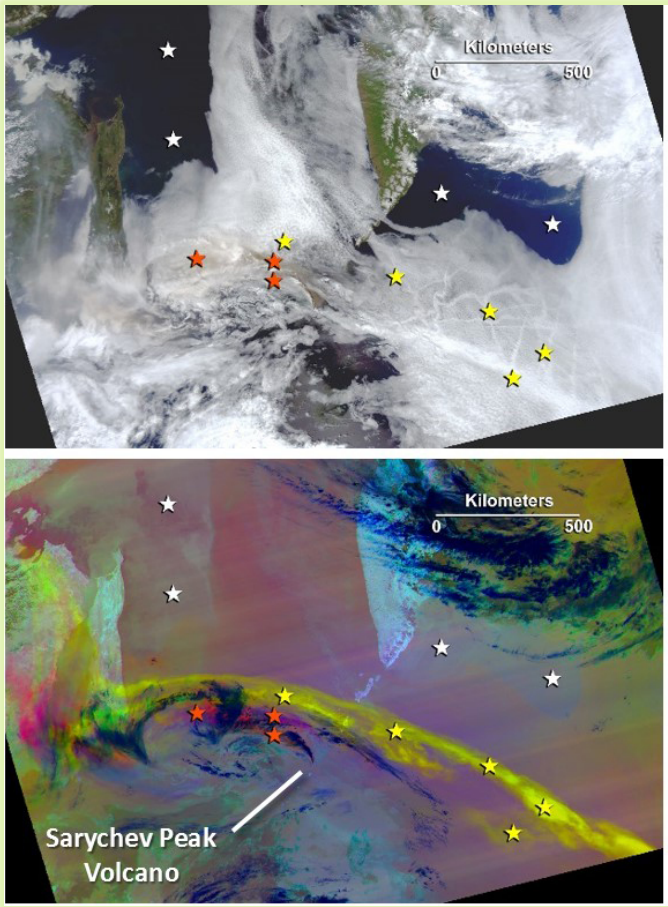
AIRS Standard Products Re-Purposed as Eruption Detection Tools





$\Delta T_b = T_b$ (1361.44 cm^{-1}) - T_b (1433.06 cm^{-1})
AIRS SO_2 Flag, $\Delta T_b < -6$ K, Does Not Show Distribution of SO_2 Within Plume

Dust Score is Sensitive to Volcanic Ash
Scores > 380 Indicate High Probability of (Silicate) Dust



MODIS RGB (top)
AIRS-MODIS TIR (bottom)

☆ Clear Path
★ SO_2 Plume
★ Ash Plume

- Define Thresholds for Volcanic SO_2 and Ash Detection Based on AIRS Archive (2002 – Present)
- Thresholds will be used to Trigger Retrievals of SO_2 Column and Ash Mass Concentration

Broad sounder expertise → Continued progress

AIRS Project and **SNPP-Sounder SIPS** provide mission anchor

- Staff has broad knowledge of AIRS/AMSU and CrIS/ATMS instruments
- Large infrastructure for algorithm development, integration & testing
- Large database supporting product testing & validation
- Supports seamless transition from Aqua to S-NPP to JPSS
- Can integrate past/current/future sounder data into long-term record

Atmospheric Physics and Weather group provides science anchor

- Broad knowledge and understanding of satellite data & their usage
- Understanding of science user needs from personal research experience

Partnerships provide invaluable expertise as well

- Science teams: Algorithm & product development
- NASA-NOAA-Universities: Instrument expertise, algorithms, mission context

JPL environment fosters exploration of future directions

- Specialized sounders: Address the boundary layer problem
- Geostationary sounders: Provide time resolution of storm environment
- Cubesats & Venture missions: Address cost & life-cycle challenges

Sounding science will continue after AIRS

Continuation of sounder time series
New ways to use the data
New sensors to solve new science problems

→ Future: Science questions

Boundary layer

- *What controls the characteristics of BL clouds as the climate warms?*
- *What is the climate forcing & feedback of BL clouds and other clouds?*
- *How can we improve the representation of BL clouds in climate models?*
- *What controls the BL temperature structure in polar regions, and what are the feedbacks?*

Weather & climate processes

- *How do frequency & intensity of extreme events (e.g., storms) change with climate?*
- *How do small-scale weather processes interact with the large-scale thermodynamic environment?*
- *What controls intensity, distribution, likelihood of convective storms; how can we use satellite observations to improve modeling and prediction of such events?*
- *What can a multi-decadal time series tell us about climate variability & trends?*

Climate models

- *How well do climate models compare to observations, and how can we use global satellite observations to improve the models?*

Observing systems

- *What phenomena relevant to our research themes are not adequately observed and require new observing strategies and systems to be developed?*

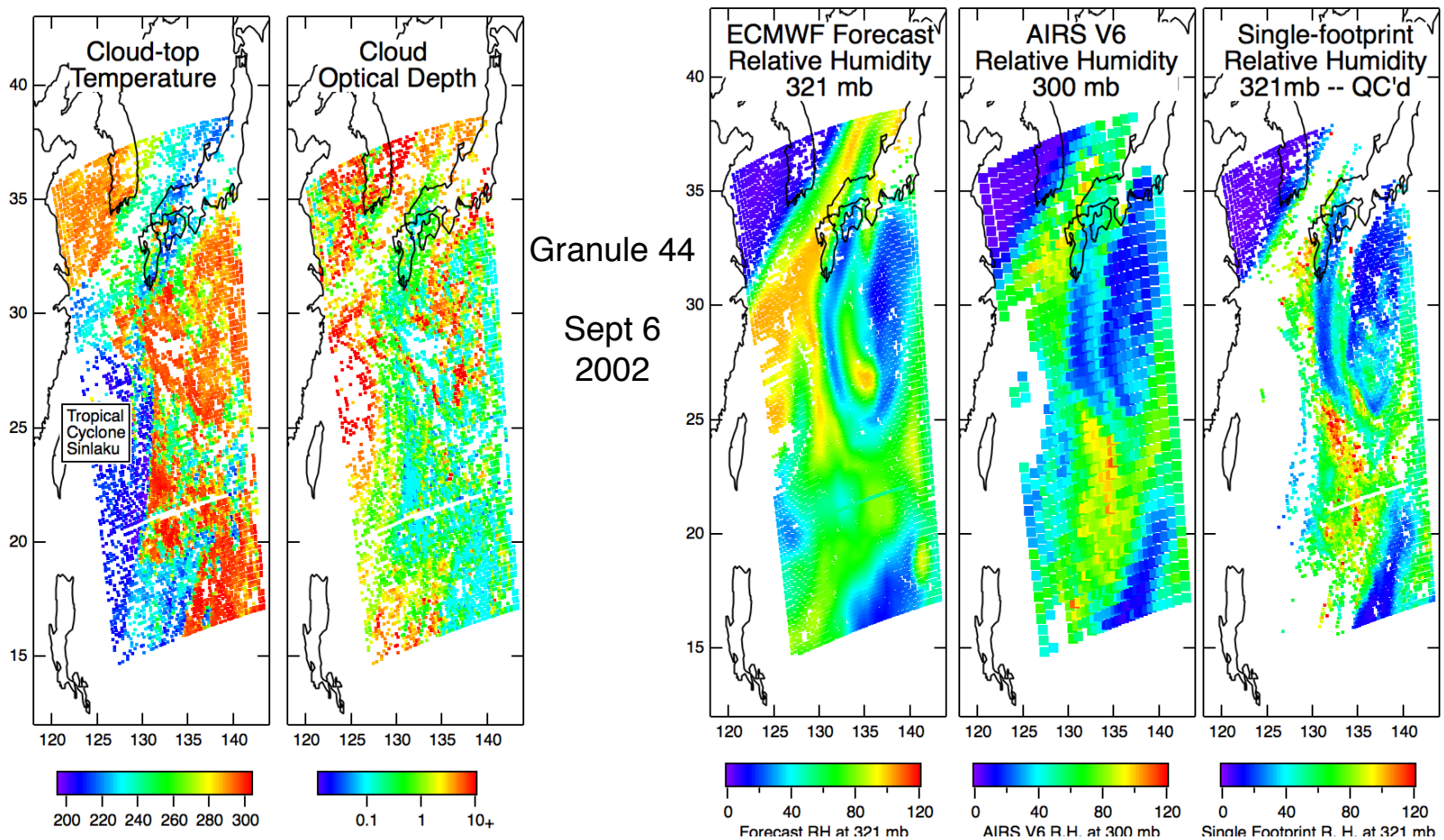
→ Future: High-res. cloudy retrievals

Single-footprint retrievals on cloudy pixels from AIRS (Bill Irion, PI)

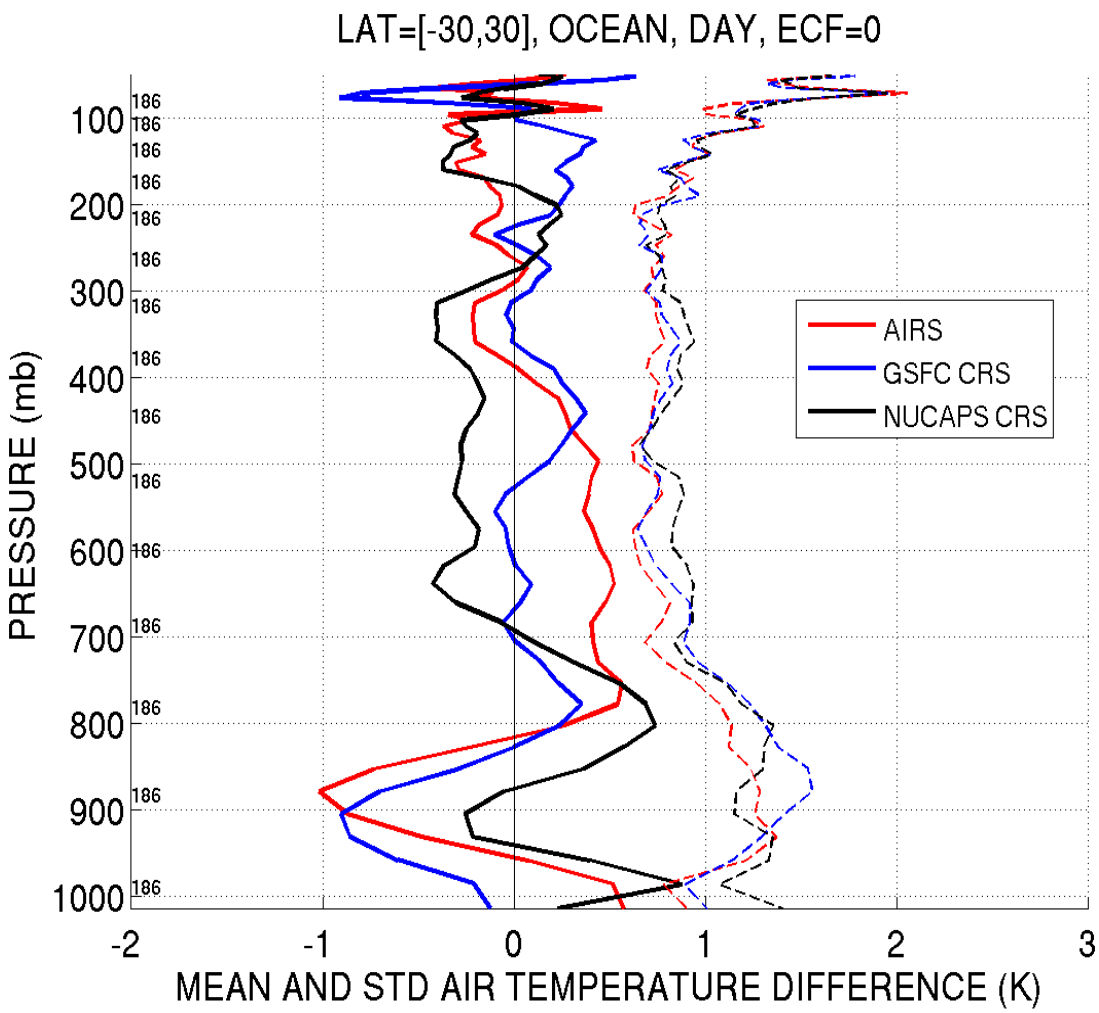
Optimal estimation retrieval using scattering forward model

MODIS cloud data
ECMWF forecast
AIRS L1b IR spectra
(No microwave)

- Cloud-top temperature
- Cloud optical depth
- Temperature profile
- Water vapor Profile
- Skin temperature



→ Future: Unified AIRS-CrIS retrievals



Unified retrieval algorithm for AIRS and CrIS (red & blue) shows comparable quality (NUCAPS is in black) in certain regimes

Can we add IASI to the mix through data fusion?

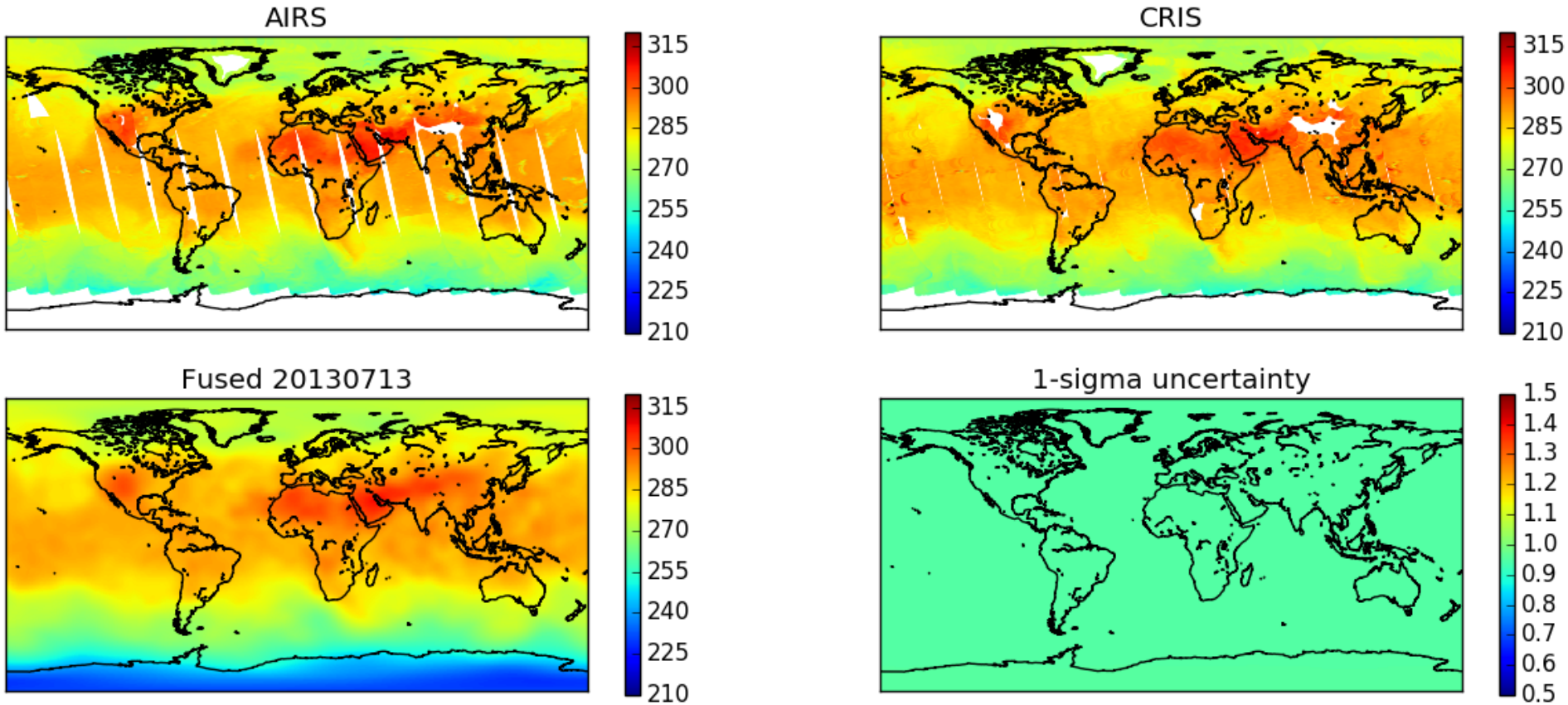
→ Future: Data fusion

Explore use of Spatial Statistical Data Fusion† to merge products (e.g. T, q profiles)

— currently developing with AIRS and CrIMSS; other data sets can be added later

— the challenge is robust estimation of bias and variance fields for input data sets

Proof-of-concept AIRS-CrIMSS fusion for T at 850 hPa, July 13 2013 (day) using input bias and variance estimated from a single region in NE Pacific:



†Nguyen, Cressie, and Braverman (2012), *Journal of the American Statistical Association*, 107

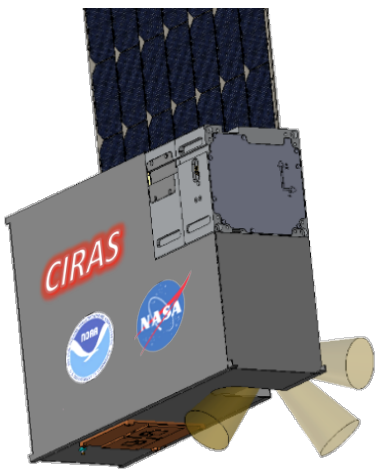
→ Future: Advanced sounders

Miniature infrared sounder: CIRAS

- Will be flown on a 6U CubeSat
- Demonstrate Key Technologies needed for Infrared Instruments on CubeSats
- Demonstrate ability of Hyperspectral Mid IR radiance measurements to retrieve Temperature and Water Vapor Profiles
- Fill Coverage Gaps and Improve Timeliness of Operational IR Sounders
- TRL in: 5-6, TRL out: 7
- Build: 2016, 2017. Launch 2018-2019

CIRAS Measurements

- Lower Tropospheric Temperature Profiles
- Lower Tropospheric Water Vapor Profiles
- Goal: Experimental Demonstration of 3D Winds

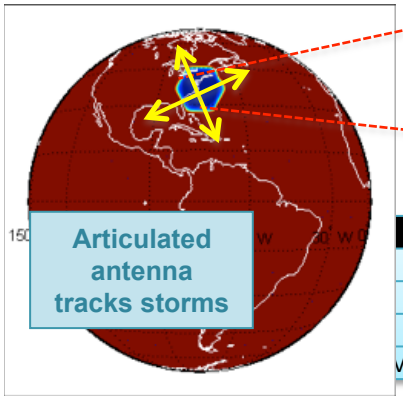


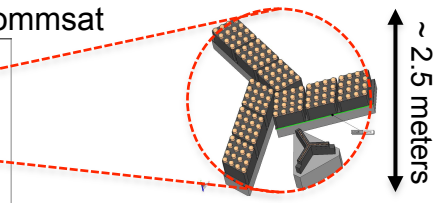
Parameter	CIRAS
Spatial	
Orbit Altitude	450-600 km
Pushbroom SW	>1000 km
Horizontal Res'n	13.5 km
Spectral	
Method	Grating
Band 1	4.08-5.13 µm
Spectral Resolution	1.2 cm^{-1} – 2.0 cm^{-1}
Total Channels	625
Radiometric	
NEdT (@250K)	<0.25 K
Resources	
Size	6U Cubesat
Mass	10
Power	40
Data Rate	2 Mbps

PI: T. Pagano

GEO microwave sounder: GeoSTAR

- Y-shaped steerable antenna, 2.5 m synthesized aperture
- Sensitivity: ~ 0.5 K
- Spatial resolution: < 35 km (T) and< 25 km (q)
- Can measure 3D wind (AMV from q(z, t))
- Technology Readiness Level: 6
- Can be hosted on a commsat





	CBE	CBE + Cont.
Mass	171 kg	222 kg
Power	199 W	259 W
Data Rate	< 100 kbps	< 150 kbps
Volume (m^3)	2.5 x 2.5 x 0.7	2.5 x 2.5 x 0.7

GeoSTAR Highlights	
Targeted Observations	Life-cycle storm tracking
Time-Continuous Coverage	Capture dynamic processes Diurnal cycle fully resolved
Simultaneous Measurements	Temperature, humidity, clouds, rain, & wind
All-Weather	Penetrates clouds & rain
3D Observations	Cylindrical volume 1000 km in diam. & 15 km in height
Wide Coverage	Full Earth disk from GEO

PI: B. Lambrigtsen

Collaborations?

- **Creating reference data sets**
- **Improving model physics**
- **Sharing analyses**
- **Exchanging personnel**
- **Participating in missions**

We invite and welcome collaborations!