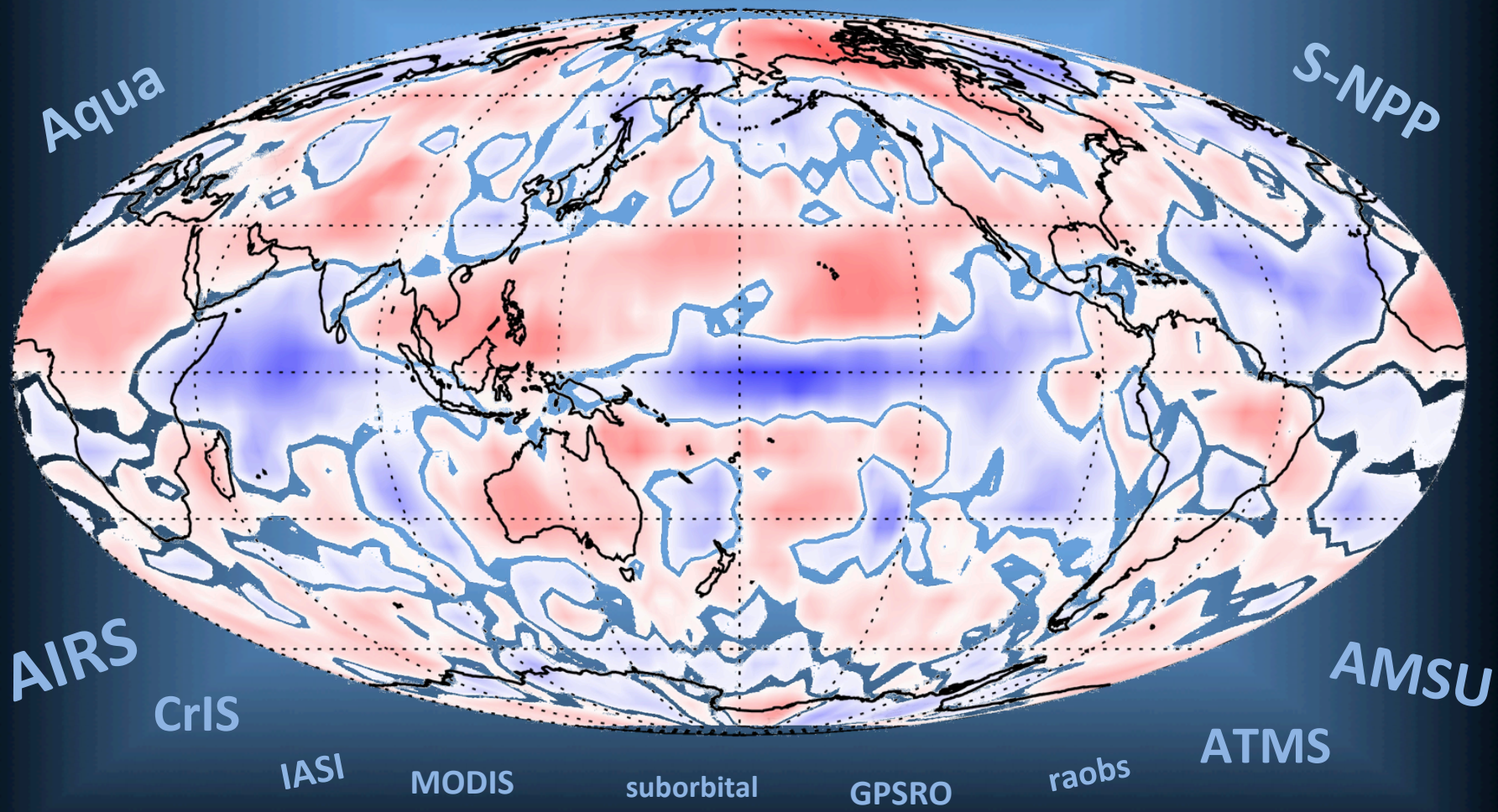
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Sounding Science at JPL

Bjorn Lambrigtsen, Jet Propulsion Laboratory, California Institute of Technology



NASA Sounder Science Team Meeting, Greenbelt, September 13-15, 2016

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What is "Sounding Science"?

Focus is on the troposphere

- "Moist thermodynamics": water vapor is the key variable
- Water cycle in the atmosphere: water vapor, clouds, precipitation
- Atmospheric processes controlling weather and climate; severe storms

Illuminated by tropospheric sounders & related sources

- IR sounders: AIRS, CrIS, IASI etc.; MW sounders: AMSU, ATMS etc.
- GPSRO, GPS-met, raobs, buoys, airborne

Science questions

- *How do small-scale weather processes interact with the large-scale thermodynamic environment?*
- *What controls the intensity, distribution and likelihood of convective storms, and how can we use satellite observations to improve modeling and prediction of important weather events?*
- *How well do climate models compare to observations, and how can we use global satellite observations to improve the models?*
- *What phenomena relevant to our research themes are not adequately observed and require new observing strategies and systems to be developed?*

Sounding Science Groups at JPL

"Atmospheric Physics and Weather" group: Focus on AIRS

- *Has provided most of AIRS science support since 1980's*
- Has developed into a significant sounding-science research group
- Funded from R&A, AIRS, NPP and other sources

Unique capabilities & expertise in Sounding Science

- *Complete range of expertise, from instruments to atmospheric research*
- Instruments & algorithms: AIRS, AMSU, CrIS, ATMS; L0→L3; climatology
- Data & data products: Thorough understanding; analysis & validation
- Research: Rich research program, high productivity re. papers

Related groups: Leverage and collaborations

- "Aerosols and Clouds" group: built around former MISR group
  - LES simulations; Cloud processes (Teixeira, Matheou, Kubar, Guan)
- "Tropospheric Composition" group: built around former TES group
  - Retrieval algorithms, radiative transfer models (Aumann, Fu)
- "Stratosphere and Upper Troposphere" group: former MLS group
  - Upper tropospheric moisture; WRF simulations (Read, Su)
- "Statistical Methods" group
  - Data fusion (Braverman, Nguyen, Kalmus)

NASA Sounder Legacy Capabilities

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
- GSFC, NOAA & CIMSS: Instrument expertise, algorithms, mission context

JPL environment fosters exploration of future directions

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

There can can be life after AIRS

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

Atmospheric Physics and Weather group

Demographics

- 15 employees; 1 contractor; 3 postdocs (→ 5)

Business mix and funding base

- 40%: AIRS and CrIMSS science support
- 50%: R&A
- 10%: Field campaigns, new developments, etc.

Expertise

- Satellite systems; sounders; data characteristics
- Atmospheric science & research
- Retrieval algorithms; radiative transfer models; spectroscopy
- Simulations; OSSEs
- Future instrument & mission development

Themes & topics

- Water vapor; clouds
- Precipitation
- Tropical cyclones & severe storms
- Water resources/hydrology, droughts, fires
- Climate
- Trace gases & composition; CO_2
- Sensor technology & design

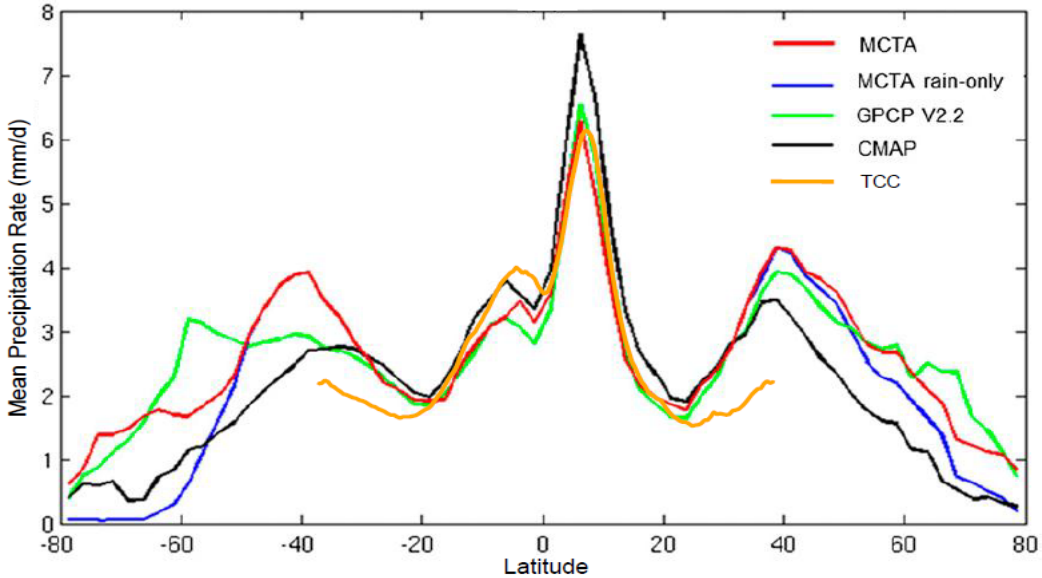
Principal-Investigator NASA R&A tasks

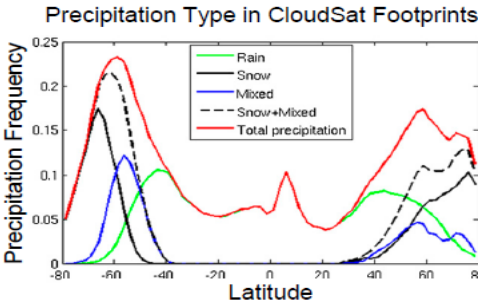
- Behrangi: Revising the global precipitation climatology in light of the most advanced observations from space (NEWS)
- Behrangi: Using GRACE to advance precipitation analysis in cold regions (GRACE)
- Behrangi: Multi-sensor Precipitation and Reflectivity Analysis and Retrievals for Precipitation and All-weather Temperature and Humidity (PATH) mission (Weather)
- Behrangi: Improving high latitude precipitation observation: A critical step towards evaluation of reanalysis and climate models (NIP)
- Behrangi: Radiative and Large-Scale Forcing of Tropical Clouds and Their Controls on High SST Environments Using Multi-Sensor Aqua and ECMWF-Reanalysis Datasets (Terra-Aqua)
- Fetzer: A Multi-Sensor Water Vapor, Temperature and Cloud Climate Data Record (MEaSUREs)
- Fetzer: A Merged Temperature and Water Vapor Record from Modern Sounders (SCIS)
- Irion: Single-footprint retrievals of cloud properties and water vapor from AIRS (Terra-Aqua)
- Kahn: Advancing ice cloud property retrievals from AIRS and the A-train (Terra-Aqua)
- Kahn: Environmental controls on preferred convective modes and potential for tornadogenesis (Weather)
- Lambrigtsen: Microwave sounder Earth System Data Records (SNPP)
- Olsen: Maintenance and Minor Refinement of AIRS CO_2 Product (Terra-Aqua Miantenance)
- Wong: Connecting precipitation to clouds and the large-scale circulation by atmospheric processes: water-budget oriented analyses (PMM)
- Wong: Cloud-dependent diagnostics of atmospheric water and energy budgets in MERRA and a GISS general circulation model (MAP)
- Yue: A comprehensive analysis on cloud radiative feedbacks by cloud type from A-Train using observation-based cloud radiative kernel method (CloudSat)

Research highlight: Ali Behrangi

An Update on the Oceanic Precipitation Rate and Its Zonal Distribution in Light of Advanced Observations from Space

Using ***combined TRMM/GPM and CloudSat*** to update the oceanic precipitation quantification and distribution



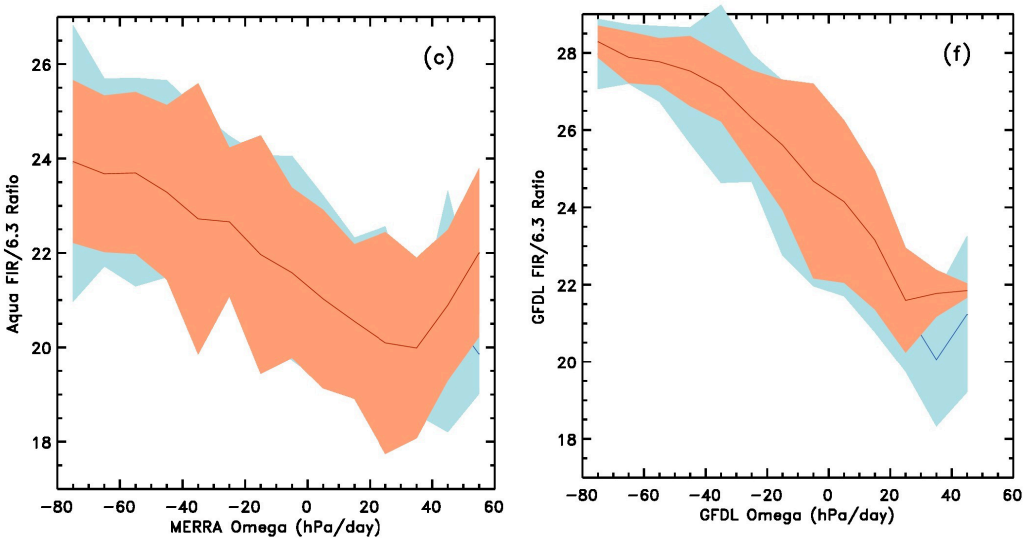


How much rain and snow fall over the oceans? In the tropics, two recent composite climatologies and a modern climate-scale product agree quite well, and generally agree with a second climate product. At higher latitudes, snow becomes important and the satellite estimates are less certain; the Southern Ocean (south of 40°S) has the largest discrepancies. GPM is starting to provide important new insights in this region.

Behrangi, A., G. Stephens, R. F. Adler, G. J. Huffman, B. Lambrigtsen, and M. Lebsock, 2014: An Update on the Oceanic Precipitation Rate and Its Zonal Distribution in Light of Advanced Observations from Space. *Journal of Climate*, **27,** 3957-3965.

Research highlight: Brian Kahn

ENSO regulation of far- and mid-infrared contributions to clear-sky OLR



***Left**: Ratio of far-infrared (FIR) and 6.3 μm band OLR for El Niño (orange) and La Niña (blue) calculated from a radiative transfer model, AIRS, and CERES observations versus MERRA 500 hPa vertical velocity. **Right**: Same as the left except calculated from the GFDL AM3 model.*

Problem: ENSO modulates the relationship between UT moistening (drying) and large-scale dynamical regimes, and in turn, the spectral characteristics of clear-sky OLR.

Finding: ENSO modulated variations in tropical-extratropical mixing are observed in far-IR and 6.3 μm emission bands.

Significance: The importance of making measurements in the far-IR spectral regions in the context of present-day moist tropical processes is argued. These diagnostics can be used to evaluate moist processes in the tropics within climate general circulation models.

Kahn, B. H., X. Huang, G. L. Stephens, W. D. Collins, D. R. Feldman, H. Su, S. Wong, and Q. Yue (2016), ENSO regulation of far- and mid-infrared contributions to clear-sky OLR, *Geophys. Res. Lett.*, doi:10.1002/2016GL070263 (in press).

Supported by the Strategic University Research Partnership (SURP) program with joint effort between JPL and U. Michigan

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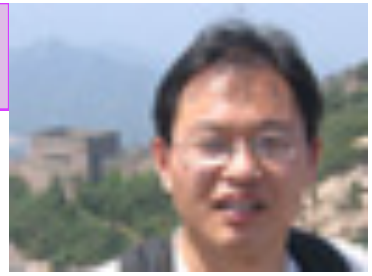
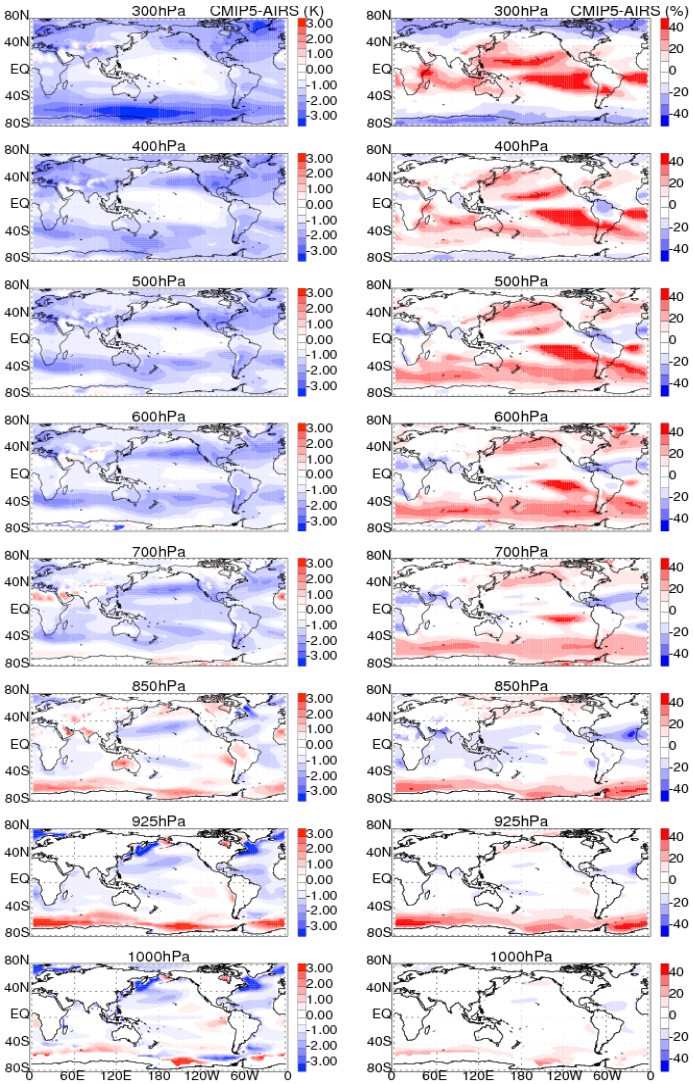
Research highlight: Baijun Tian



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



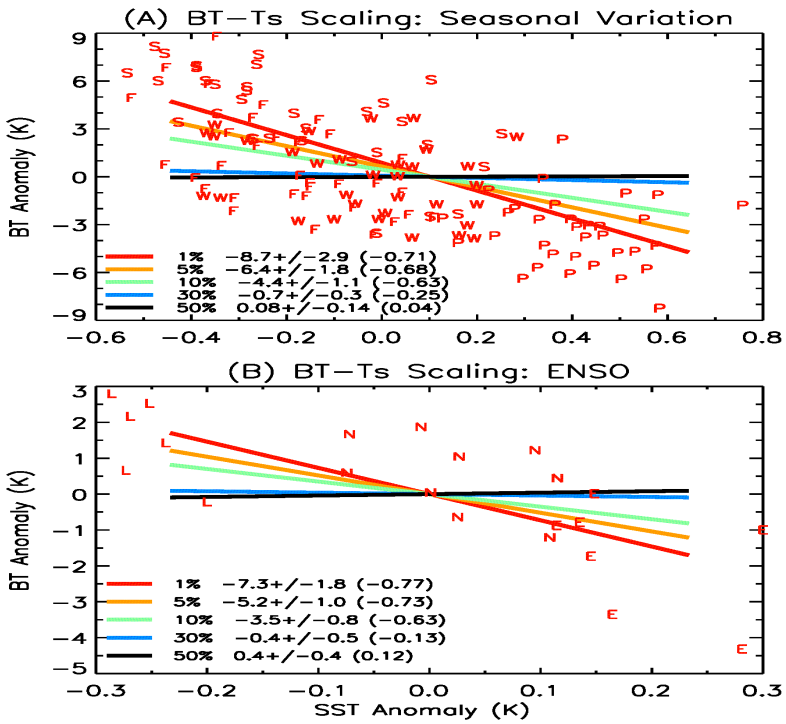
- **Problem:**
  The tropospheric air temperature and specific humidity simulations in CMIP5 climate models have not been well evaluated. Here, we compare the AIRS Obs4MIPs datasets and 16 CMIP5 climate model outputs to evaluate the tropospheric air temperature and specific humidity simulations in CMIP5 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

Research highlight: Sun Wong

Extreme Convection and Tropical Climate Variability



Sensitivity of tropical mean over-the-ocean AIRS brightness temperatures (BT) to tropical mean SST for (A) the seasonal variation and (B) the ENSO. Scatter plots are for the 1-st percentile anomalies and the corresponding fitted lines are the red solid lines. The sign of the dots in (A) indicate the Northern Hemispheric seasons with December-January-February as 'W', March-April-May as 'P', June-July-August as 'S', and September-October-December as 'F'. The colors of dots in (B) indicate the El Niño December-January as 'E', La Niña December-January as 'L', and the neutral December-January as 'N'.

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

Finding:

Over the tropical ocean, when 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.

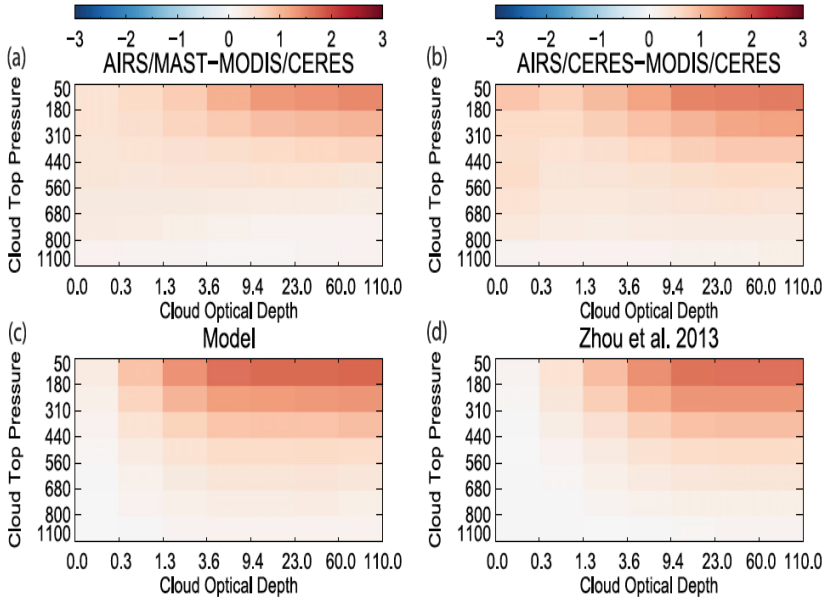
Significance:

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

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.
Funding source: AIRS Climate Data Record (PI: João Teixeira).

Research highlight: Qing Yue

Observation-based Longwave Cloud Radiative Kernels Derived from the A-Train



CRKs (W m^{-2} %$^{-1}$) obtained by different data and methods. (a) and (b): Obs.-CRKs using AIRS-MODIS-CERES data for different MODIS retrieval algorithms. (c) and (d): Fu-Liou model calculated CRKs based on satellite and model data as input, respectively.

Yue, Q., E. J. Fetzer, B. H. Kahn, M. Schreier, S. Wong, X. Huang, X. Chen, 2016, Observation-based Longwave Cloud Radiative Kernels Derived from the A-Train, J. Climate, 29(6), 2023–2040, doi: http://dx.doi.org/10.1175/JCLI-D-15-0257.1

Funding source: This work was supported by NASA MEaSUREs (PI: Eric Fetzer), CCST (PI: Qing Yue) and JPL SURP program (PI: Brian Kahn).

Problem: Observation-based longwave cloud radiative kernels derived from pixel-scale collocated A-Train and MERRA data to estimate cloud feedback by cloud regime.

Finding: The observation-based CRKs show the TOA radiative sensitivity of cloud types to unit cloud fraction change as observed by the A-Train. Observations show a larger TOA radiative sensitivity for optically thin clouds than models.

Significance: A combination of observation-based CRKs with cloud changes observed by A-Train provides an estimate of the short-term cloud feedback by maintaining consistency between CRKs and cloud responses to climate variability.

Not just satellites: Hurricane field campaigns

Lambrigtsen, Schreier

HAMSR

The High-Altitude MMIC Sounding Radiometer is an airborne microwave sounder

- 25 channels around 50, 118 and 183 GHz
- Provides information about temperature, water vapor and rain
- Cross scanning with a scan angle of + 60º
- Successfully flown in several campaigns (HS3, SHOUT, CalWater)
- PI: B. Lambrigtsen

SHOUT

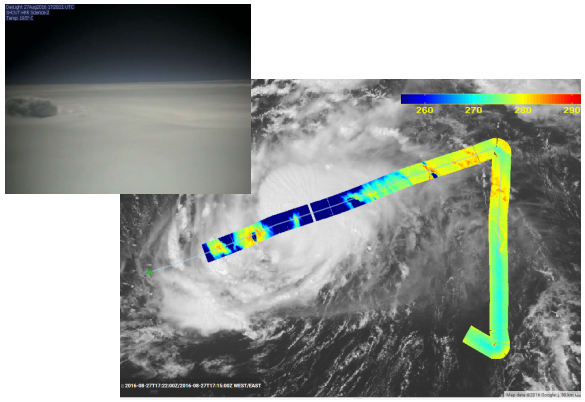
HAMSR is part of SHOUT (Sensing Hazards with Operational Unmanned Technology). The project is using the Global Hawk from Armstrong and Wallops to make targeted observations of tropical storms (TS) and hurricanes.

The Impact of SHOUT 2016

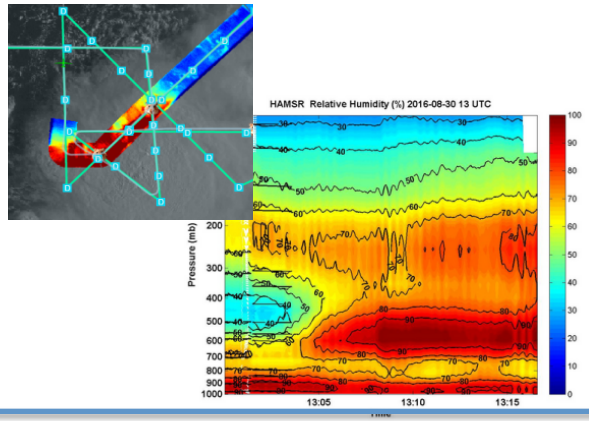
- From 08/24 - 09/02, SHOUT observed Gaston and Hermine, collecting valuable information during their transition from TS to hurricane
- The flight on 08/24 caused NHC to elevate Gaston from TS to hurricane, a first-ever case of forecast impact from targeted observations

HAMSR Observations during SHOUT 2016

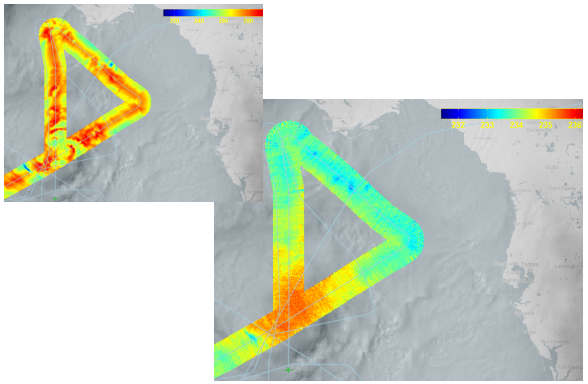
Hurricane Gaston, 27th August 2016
Passing the hurricane eye
GH-camera and HAMSR data at 50 Ghz



Tropical Storm Hermine, 29th August 2016
Flight over the core
real-time scattering index and retrieved RH



Tropical Storm Hermine, 31 August 2016
Observed surface and warm core anomaly
50 Ghz (surface) and 53.93 GHz (~250 mb)

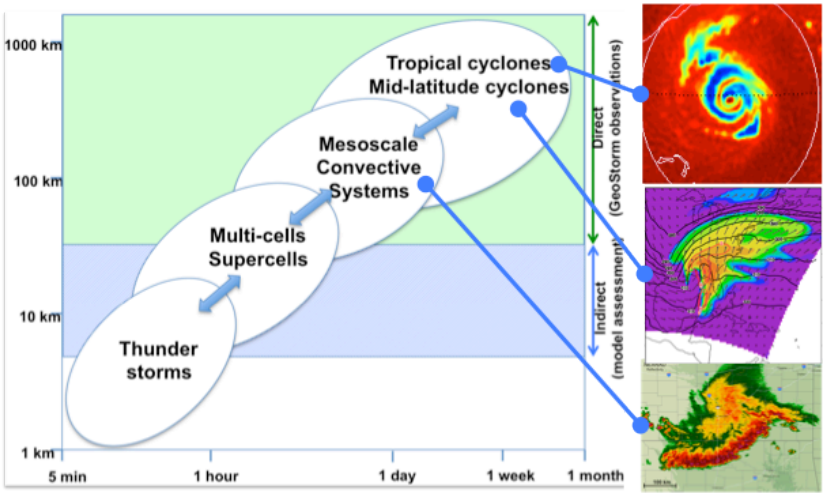


Future: A Geostationary Microwave Sounder?

GeoStorm (Venture EV-I concept)

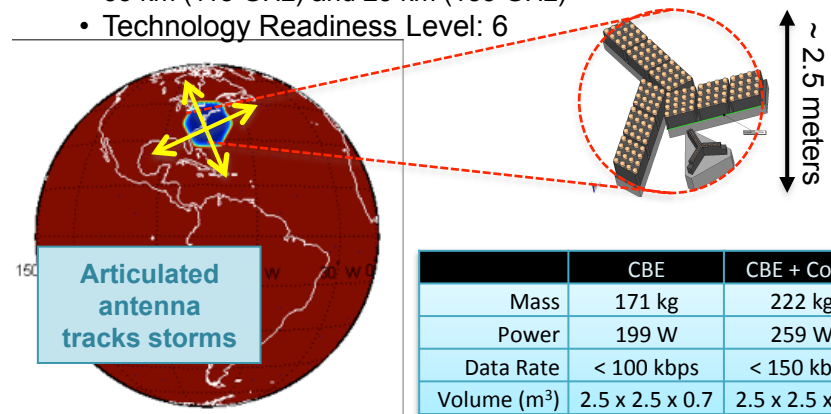
Lambrigtsen

Objectives: Hurricanes & Severe Storms

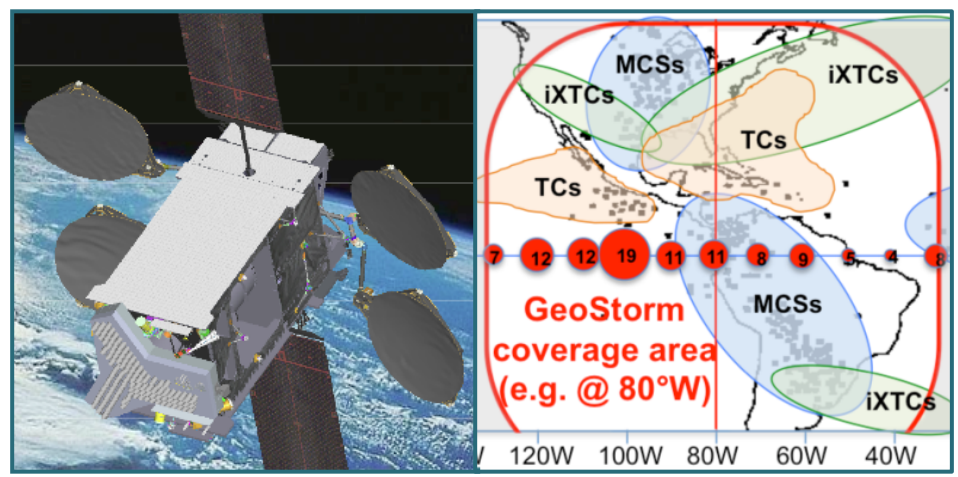


Instrument: GeoSTAR-lite

- *Microwave sounder; Y-shaped steerable antenna, 2.5 m synthesized aperture.* Sensitivity: ~ 0.5 K. Spatial resolution: 35 km (118 GHz) and 25 km (183 GHz)
- Technology Readiness Level: 6



	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

GeoStorm 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

Implementation: Hosted on GEO Comm-Sat