Tropical Cyclone/Hurricane Research: NASA's Activities

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NASA Headquarters

March 4, 2014

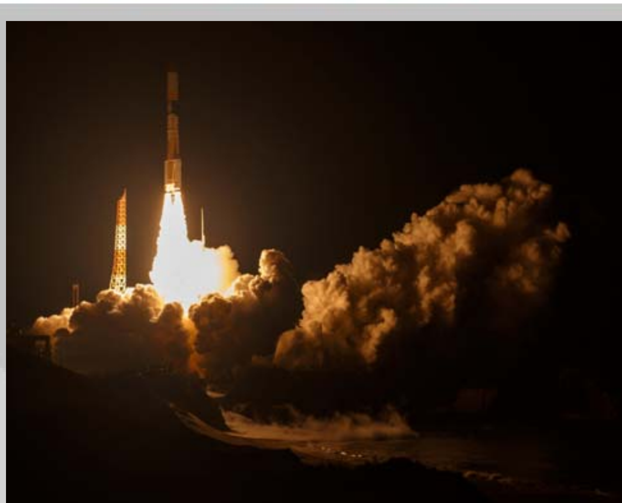
With inputs from multiple colleagues at NASA HQ and Field Centers!

NASA Program Elements Contributing to Tropical Cyclone Research

- Satellites
  - Present
  - Future
- Airborne Observations
- Associated Research
- Computational Modeling
- Technology Development and Evaluation
  - Instruments
  - Information Systems

NASA Earth Science Operating Missions 2014

GPM Launched 2/27/14!



GPM launching from Tanegashima, Japen – 2/28/14

GPM climbing to its altitude just over 400 km

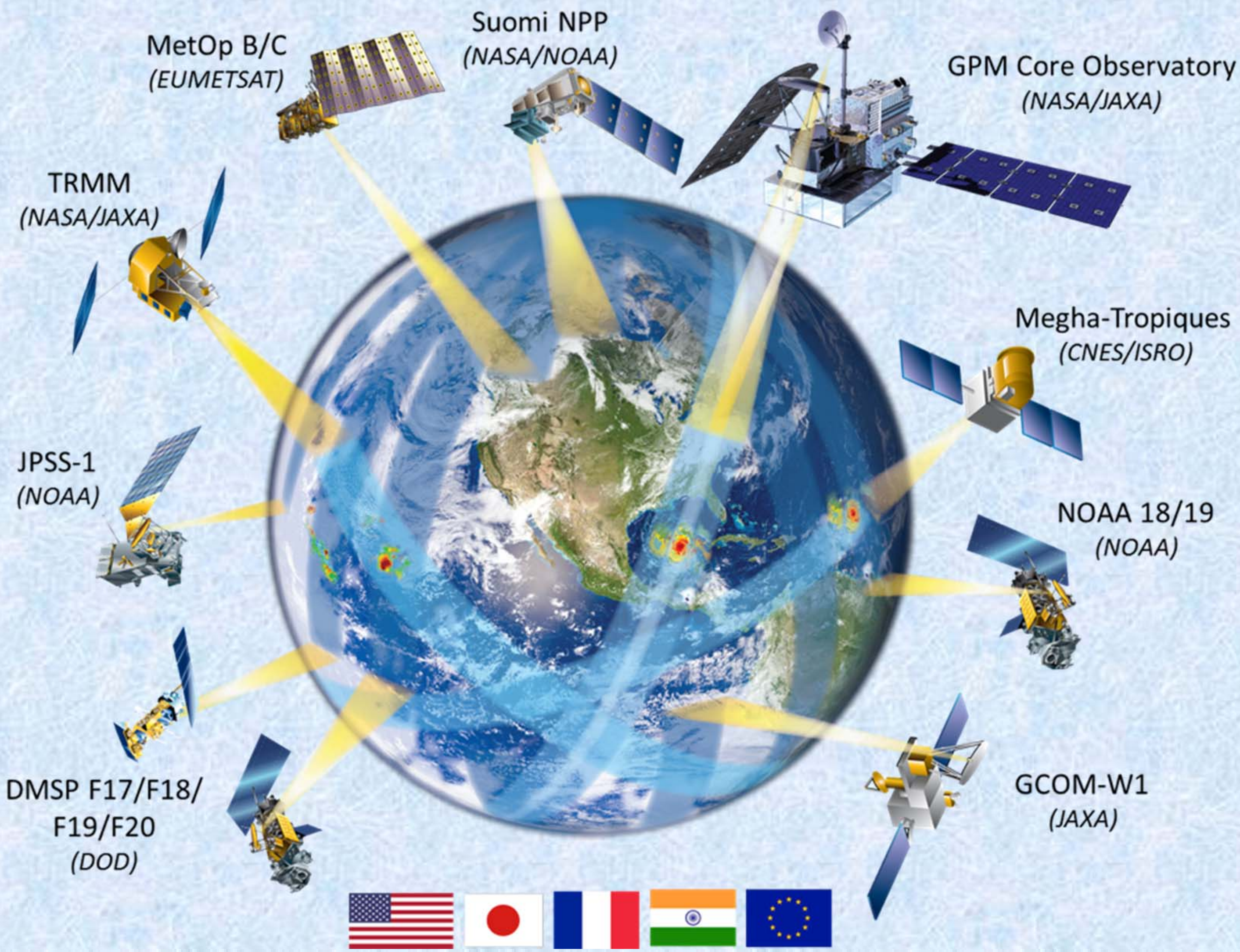
US Ambassador Caroline Kennedy speaking after launch

GPM Program Scientist Ramesh Kakar speaking in Japan

NASA TV Coverage of GPM launch with Daliia Kirschbaum (left) and Aries Keck (right)

“Launch party” for GPM at NASA Goddard Visitors’ Center

GPM's Global Scope



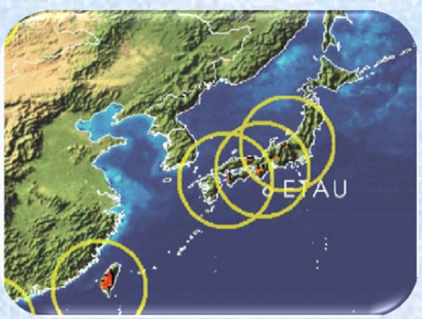
The GPM Core Observatory serves as an anchor to ensure that all constellation satellites produce uniform next-generation precipitation estimates everywhere in the world every three hours.

GPM: A science mission with integrated application goals

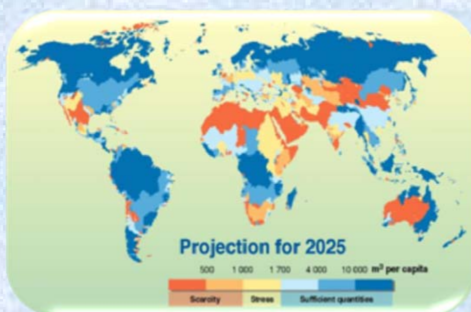
Science Objectives:

- **New reference standards for precipitation measurements from space**
  - **Active and passive microwave sensors**
- **Improved knowledge of water cycle variability and freshwater availability**
  - **Accurate description of space-time variability of global precipitation**
- **Improved numerical weather prediction skills**
  - **Better instantaneous precipitation information and error characterization**
- **Improved climate prediction capabilities**
  - **Better knowledge of latent heat, precipitation microphysics, and surface water fluxes**
- **Improved predictions for floods, landslides, & freshwater resources**
  - **Better hydrological modeling & high-resolution precipitation data via downscaling**

Floods and Landslides

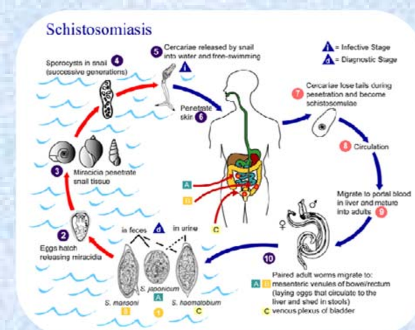


Freshwater Availability/ Agriculture/Famine



Extreme Events

World Health



GPM International Science Collaboration

NASA has 22 active science and ground validation research projects with investigators from 19 countries to support satellite algorithm improvement and data evaluation including:

Joint Warm season orographic rain field campaign in North Carolina with NOAA (May-June 2014)

Joint Cold season snowfall field campaign with Environment Canada (Jan-Feb 2012)

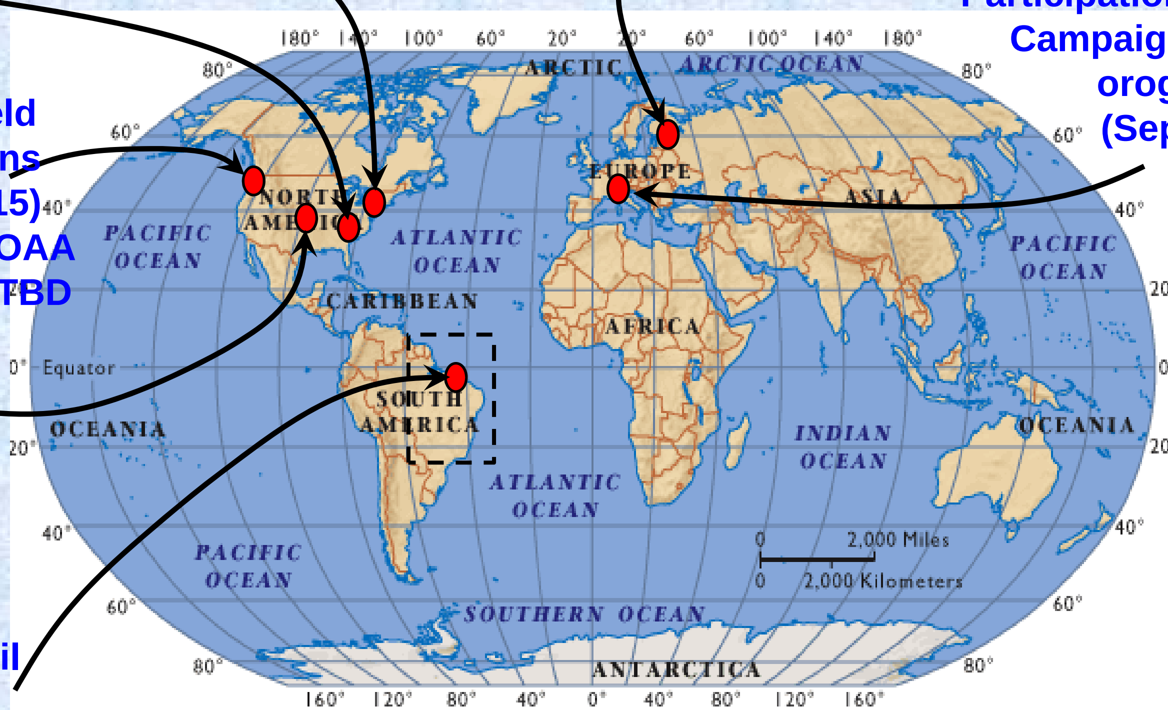
Joint campaign with Finland and NASA's CloudSat mission on light rain in Helsinki (Sep-Oct 2010)

Participation in EU-Led Campaign targeting orographic rain (Sep-Nov 2012)

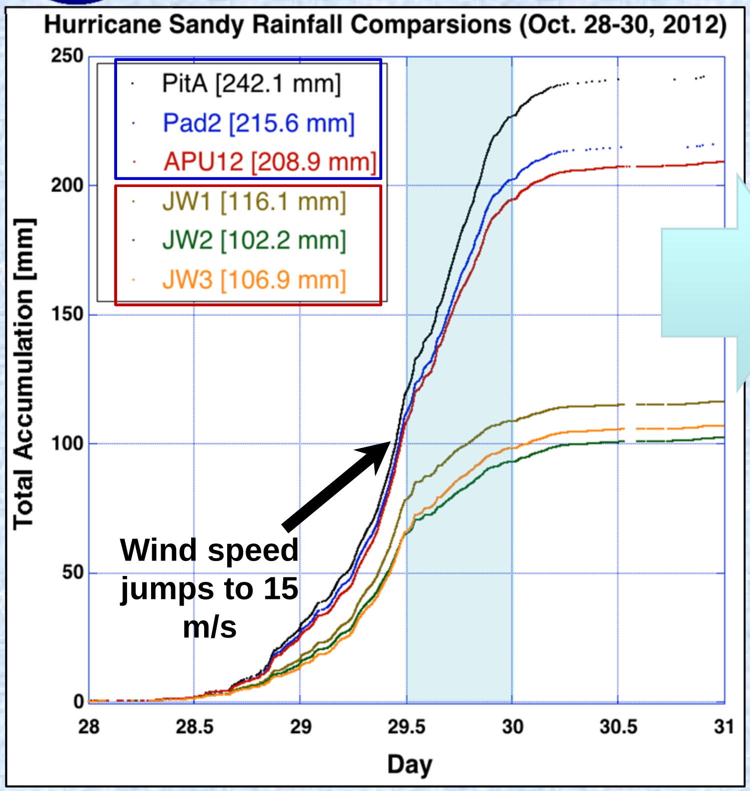
Cold season rain/snow field campaign, ocean/mountains Washington (Nov-Dec. 2015) Environment Canada and NOAA participation, other agency TBD

Joint campaign with U.S. Department of Energy on convective rain over land in Oklahoma, USA (Apr-Jun 2011)

Joint campaign with Brazil targeting warm rain in Alcântara, Brazil (Mar 2010) Participation in other rain campaigns (2012-2014)



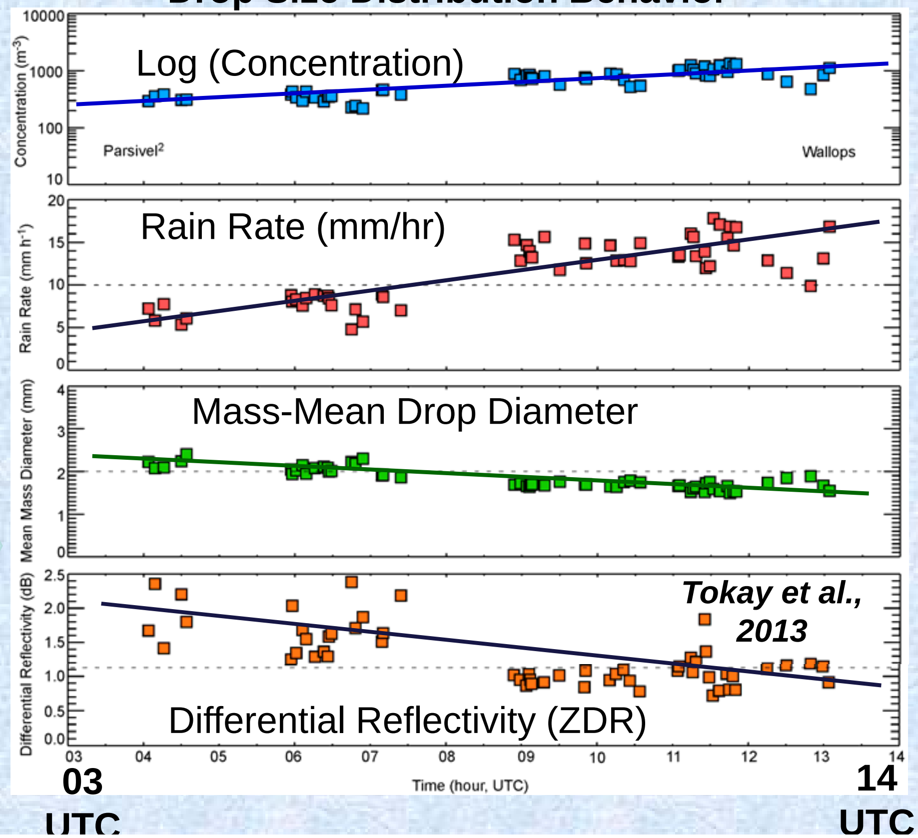
Measuring Rainfall Variability in H. Sandy at Landfall



Collocated Pit (reference) and Tipping Bucket (TB) gauges, optical and impact disdrometers

- Rain gauges and Parsivel disdrometer measure within 16% of the Pit Gauge rain accumulation
- Impact (Joss) disdrometers performed poorly
- Bias evolved as winds exceed 10-15 ms^{-1}

Drop Size Distribution Behavior



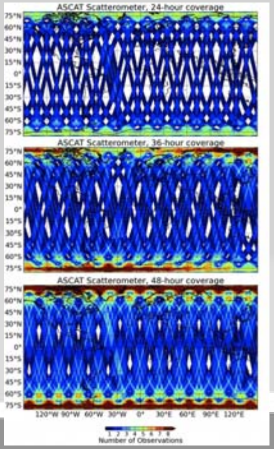
- Drop size distribution (DSD) evolves as Sandy bands move onshore
- Rain rates increase, drop concentrations increase, drop diameters decrease
- Pol. radar (ZDR) DSD trend consistent with disdrometer

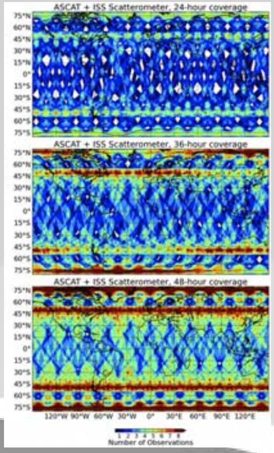
RapidScat Summary and Status

- RapidScat is a pencil beam scatterometer being built at JPL which uses engineering hardware from QuikSCAT
- RapidScat is expected to launch in summer 2014 and deploy in the International Space Station (ISS) for about 2 years
- RapidScat is currently in the final phases of testing at JPL
- The goals of RapidScat are:
  - Provide gap filler Ocean Vector Wind (OVW) data to improve the temporal coverage of the OVW constellation and improve weather forecasting
  - Cross-calibrate the OVW constellation to achieve a uniform unbiased climate data record
  - Use the ISS orbit to study diurnal and semi-diurnal wind variations
- The RapidScat project has as a goal providing near real time data to operational agencies

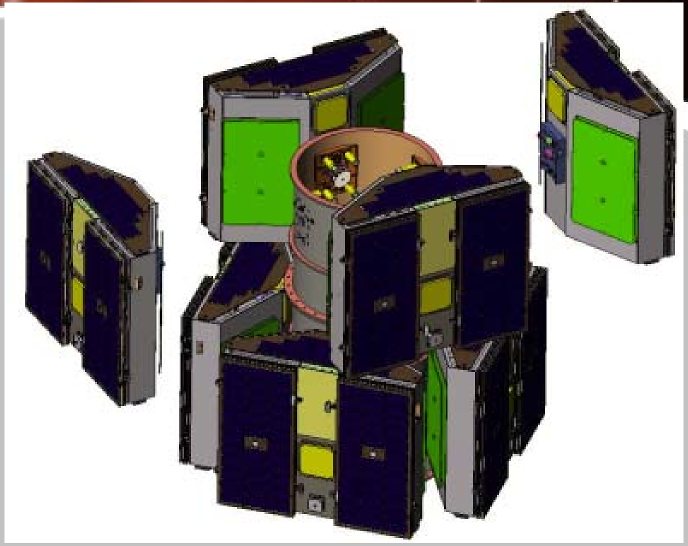
RapidScat & Tropical Cyclones

- RapidScat is expected to have approximately the same wind performance as QuikSCAT, which was a useful asset for tropical cyclone monitoring
- Due to the lower inclination of the ISS orbit, RapidScat will spend more time at tropical latitudes than polar satellites, improving its chances to observe tropical cyclones
- Due to the lower orbit height, RapidScat will only have a swath of about ~800 km (QuikSCAT: 1800 km), but its spatial resolution will be slightly better than QuikSCAT’s
- As an addition to the OVW constellation, RapidScat will provide significant improvements in temporal coverage when complementing EUMETSAT’s ASCAT





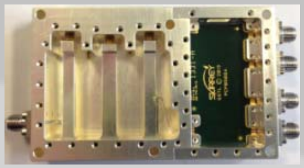
CYGNSS Overview



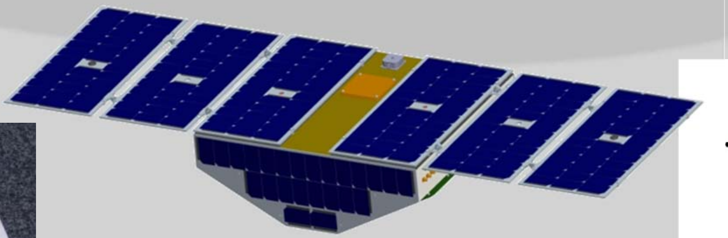
Key Mission Parameters

- Constellation: 8 LEO microsats
  - Single Launch
- Altitude: 500 km
- Inclination: 35^0

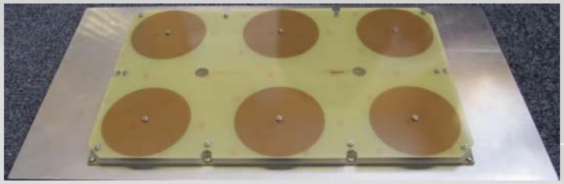
Delay Mapping Receiver



Low Noise Amplifier (1 of 3)



Zenith Antenna

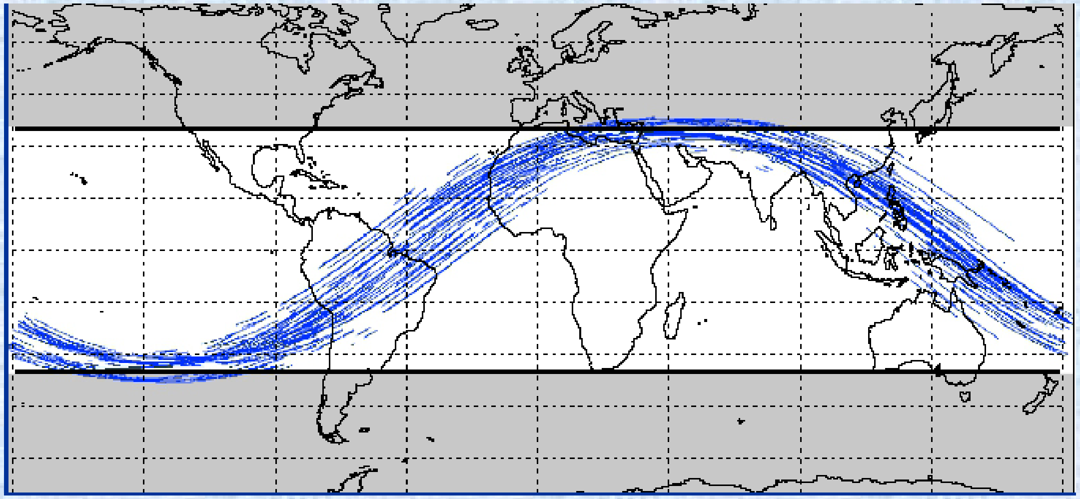


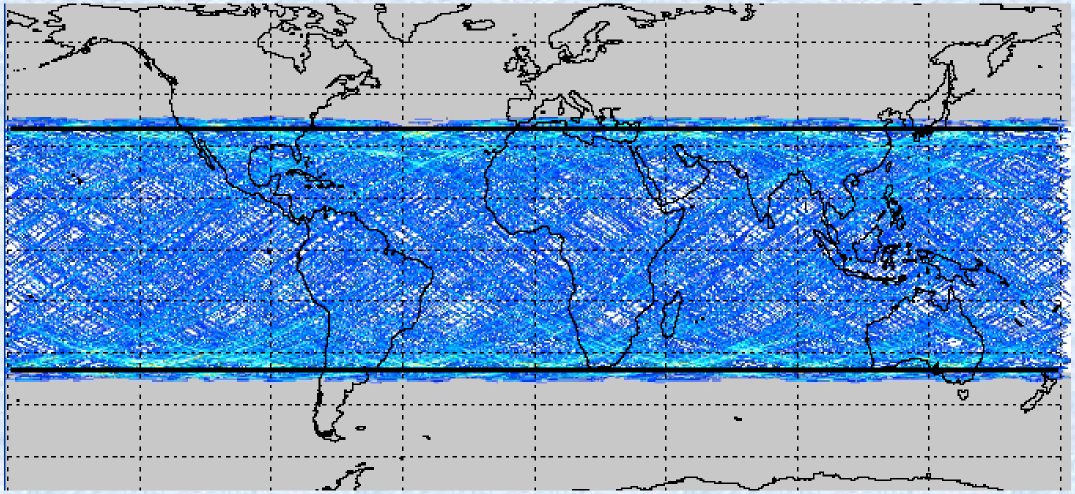
Nadir Antenna (1 of 2)

CYGNSS Temporal Sampling
(requirement is mean revisit time of 12 hr)

- Temporal sampling is not deterministic due to asynchronous CYGNSS and GPS orbits
- Model revisit time as a random variable with empirical pdf derived from Monte Carlo simulations
- (Top) 90 min (one orbit) coverage showing all specular reflection contacts by each of 8 s/c
- (Bottom) 24 hr coverage used to derive revisit pdf

- Median revisit time = 2.8 hr
- Mean revisit time = 5.9 hr





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  - Observing System Evaluation
- Applications of NASA Products

NASA Hurricane Field Experiments

Field programs coordinated with other Federal Agencies

1998 CAMEX

2001 CAMEX-4

2005 TCSP

2006 N-AMMA

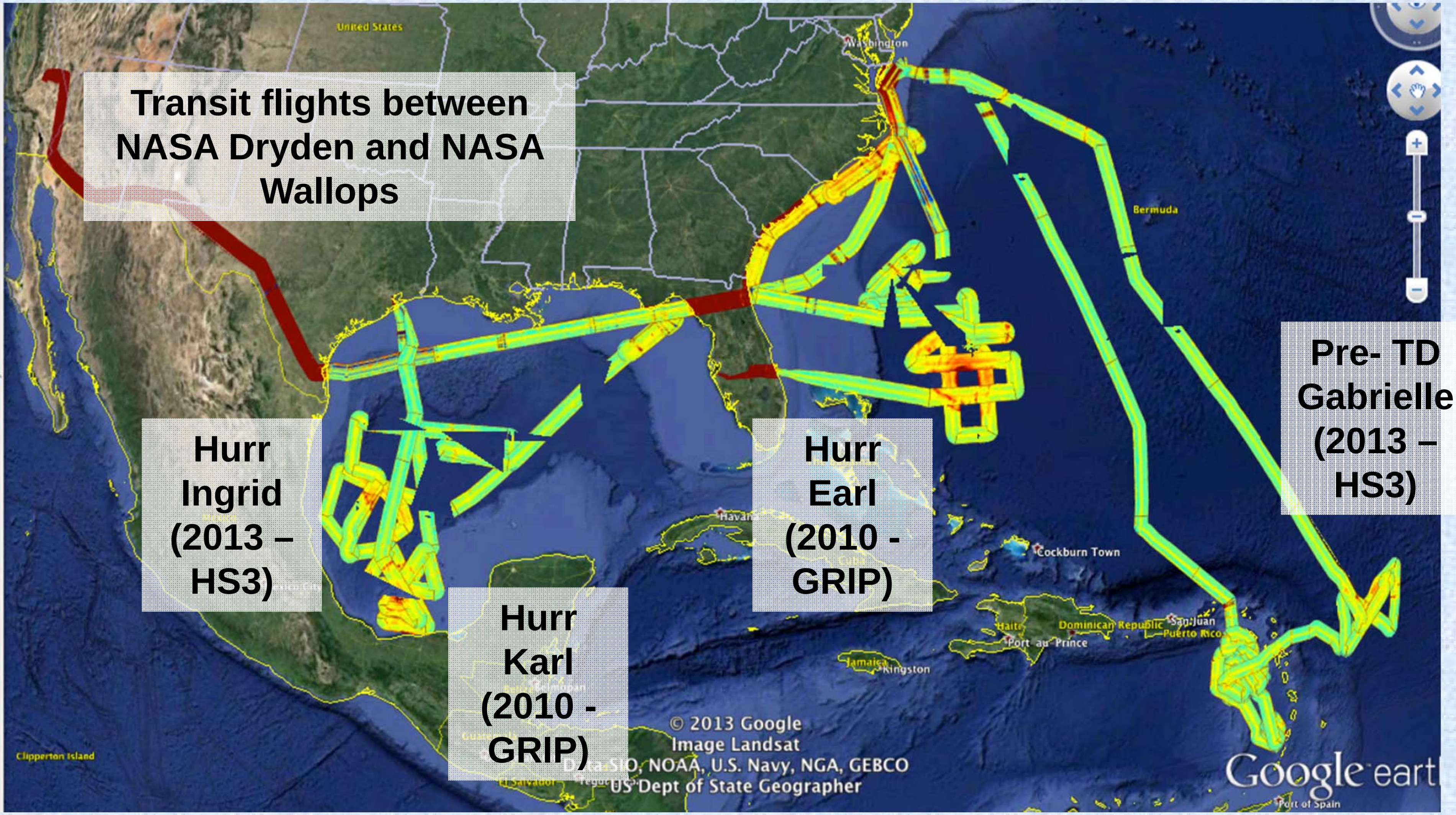
2010 GRIP

2012-2014* HS3

NASA sponsored field campaigns have helped us develop a better understanding of many hurricane properties including inner core dynamics, rapid intensification and genesis

* Years of field deployment only

Flights in 2010 & 2013 - HIRAD 6.6 GHz TB



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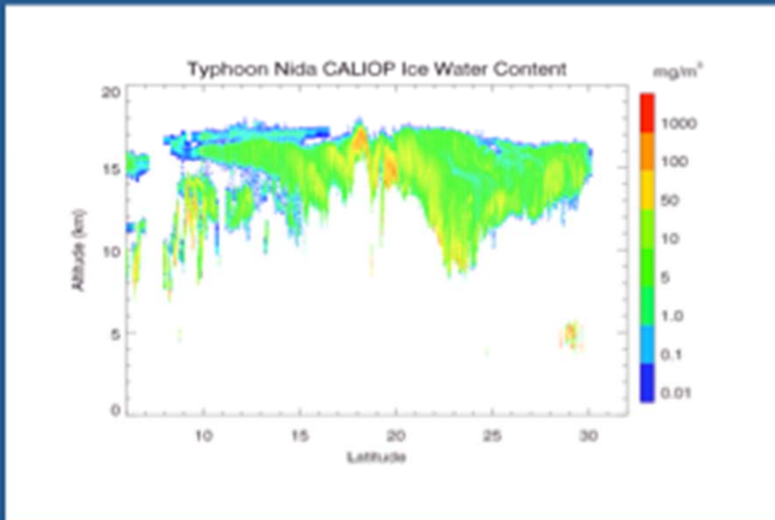
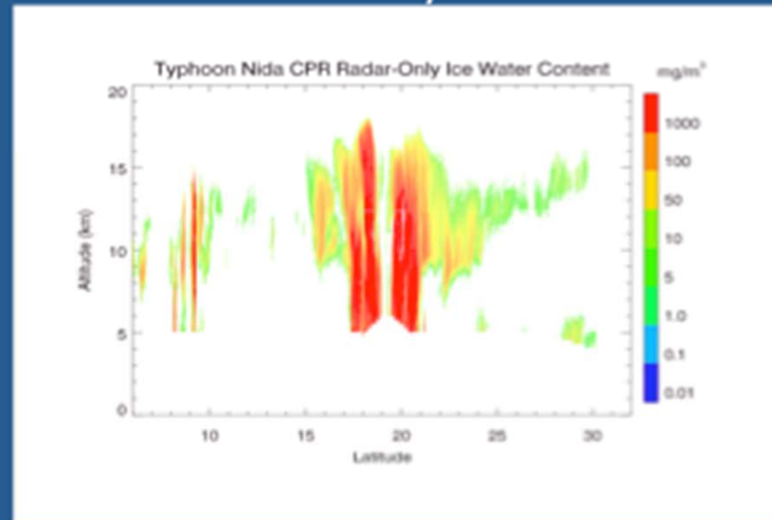
Typhoon Nida Active Sensor Ice Water Content Comparison

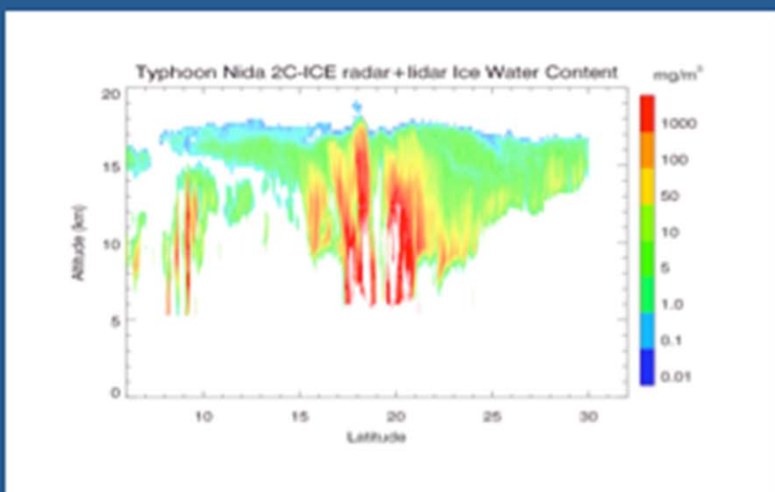
CALIOP – Lidar Only



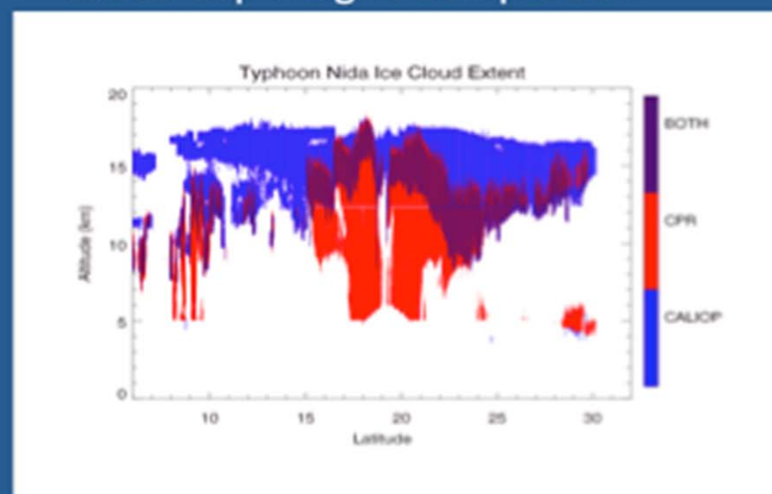
CPR – Radar Only



2C-ICE – Lidar + Radar



Cloud-top Height Comparison

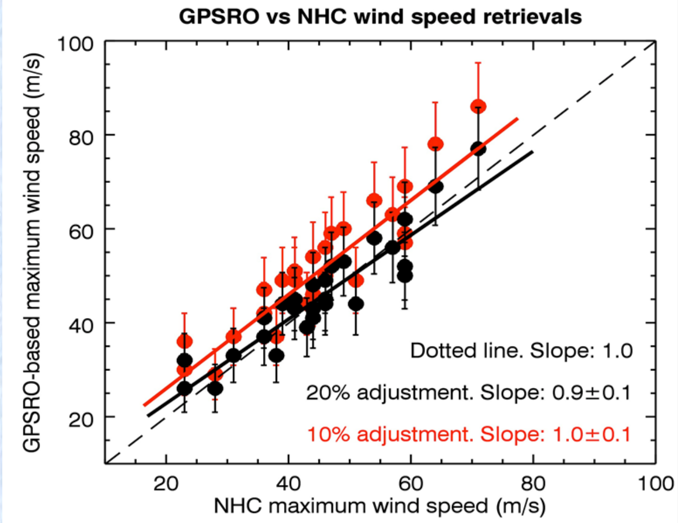


Hurricane intensity estimation: The GPS perspective

GPS-based vs National Hurricane Center intensity

First estimates of hurricane intensities (maximum wind speed) from GPS radio occultations (GPSRO) and the *Wong and Emanuel* [2007] hurricane model.

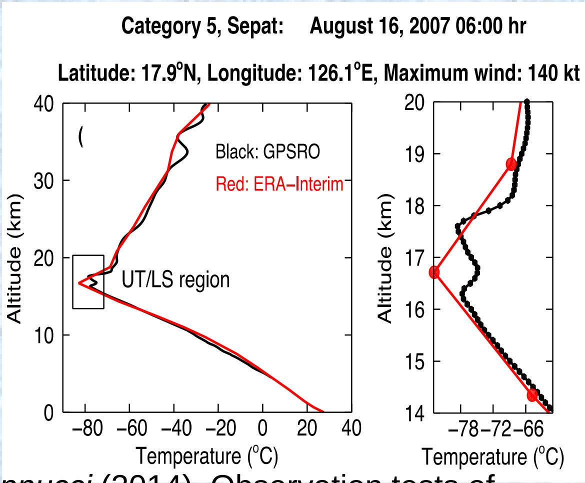
GPSRO-derived hurricane intensities show 0.9 linear correlation with respect to NHC intensities with a small bias. GPSRO shows great potential in augmenting current hurricane datasets, with possible applications to the initial vortex parameterization and intensity forecasting.

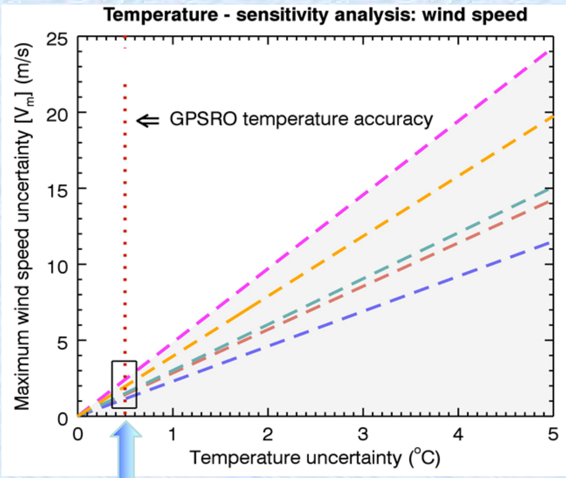


Accuracy of the GPSRO-retrieved hurricane intensities: Temperature sensitivity

Precise measurements of the eyewall temperature is the key to hurricane intensity estimation – **GPSRO observations penetrate clouds and heavy precipitation.**

Eyewall temperature at the tropopause height is a sensitive indicator of hurricane intensity. **GPSRO temperature accuracy is ~0.5 – 1.0 K (black rectangle). This translates to a 1–4 m/s hurricane intensity error.**

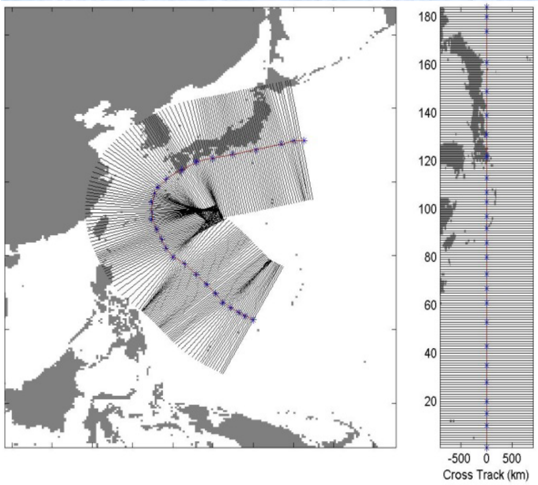




GPS temperature accuracy is ~0.5–1.0 K, suggesting that GPS can introduce only a 1– 4 m/s hurricane intensity error.

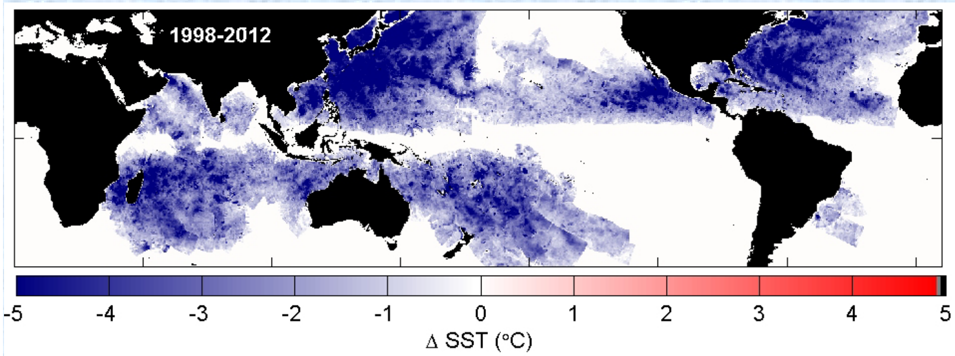
Vergados P., *Z. Luo, K. Emanuel, and A. J. Mannucci* (2014), Observation tests of hurricane intensity estimations using GPS radio occultations, *J. Geophys. Res. – Atmospheres.*, 13 p., doi:10.1002/2013JD020934

NASA Global TC database

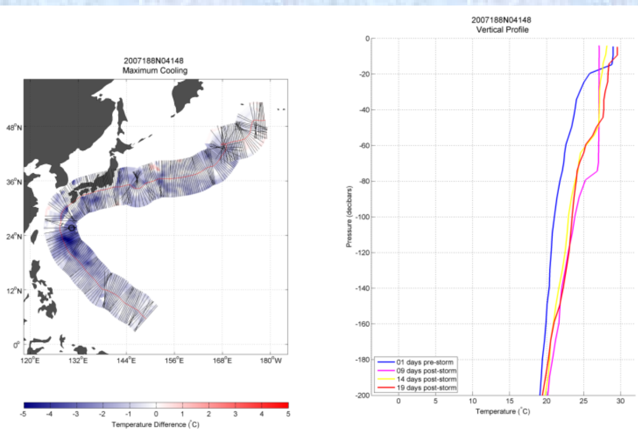


Uses the WMO's IBTrACS for storm info. Collocates over 65 satellite and in situ (profiles and surface) info into a storm centric database

Data is being used to investigate the impact of cyclone cold wakes on climate through the injection of warm water into the thermohaline circulation



Parameter	Type	Name	Spatial	Temporal
SST	product	NOAA AVHRR OI SST	0.25-deg	daily
	product	RSS MW OI SST	0.25-deg	daily
	product	RSS MW+IR OI SST	9 km	daily
	product	JPL MUR SST	1 km	daily
	observation	Terra MODIS	9 km	
	observation	Aqua MODIS	9 km	
	observation	TRMM TMI	0.25-deg	
	observation	Aqua AMSR-E	0.25-deg	
	observation	WindSAT	0.25-deg	
	observation	SEVIRI	4 km	30 min
	observation	GOES	4 km	60 min
	observation	moored buoys	point	
	observation	drifting buoys	point	
	observation	ship data	point	
	observation	ARGO profiling drifters	point	
Chlorophyll-a	product	merged	9 km	
wind speed & direction	observation	All PMW/Scat	0.25-deg	daily
	product	H*wind	25 km	daily
Atmospheric water vapor	observation	All PMW	0.25-deg	
Cloud	observation	All PMW	0.25-deg	
Rain Rate	observation	All PMW	0.25-deg	
Net Primary Production	product	OSU Ocean Productivity		monthly
Mixed layer depth climatology	product	NRL	111 km	monthly
Mixed layer depth	product	OSU Ocean Productivity	19 km	monthly
sea level anomaly	product	AVISO	25 km	weekly
geostrophic velocity anomaly	product	AVISO	37 km	weekly
Significant Wave Height	product	AVISO	111 km	daily
SSS	product	HYCOM		
	observation	Aquarius		
	product	SMOS		
currents	product	oscar	33 km	weekly



Collocated ARGO profiling drifters in cold wakes let us examine the mixed layer recovery mechanisms post-storm

For database info contact
support@remss.com

Supported by the NASA PO Program

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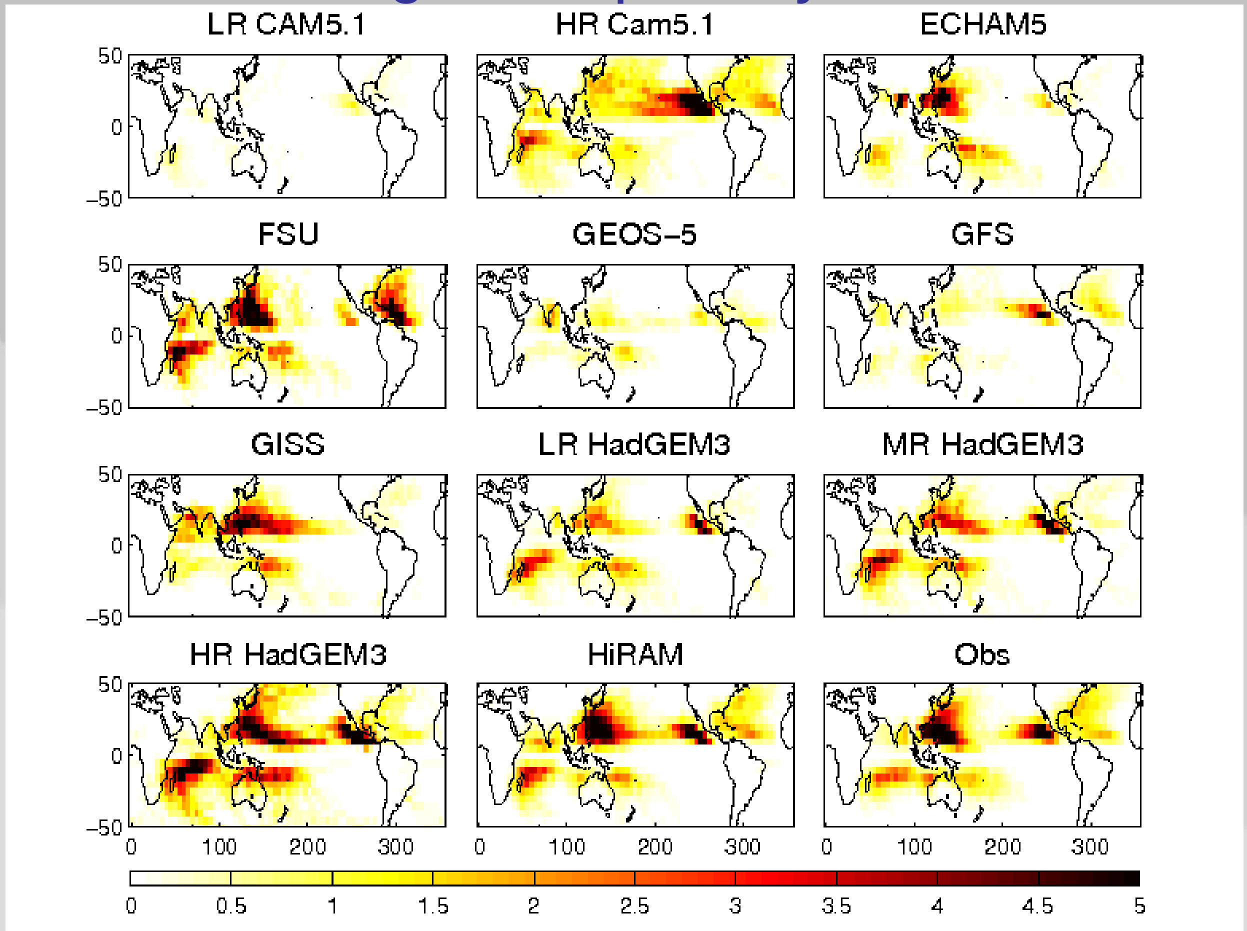
Tropical cyclones in the GISS 1x1 model

Annual climatological tropical cyclone track density

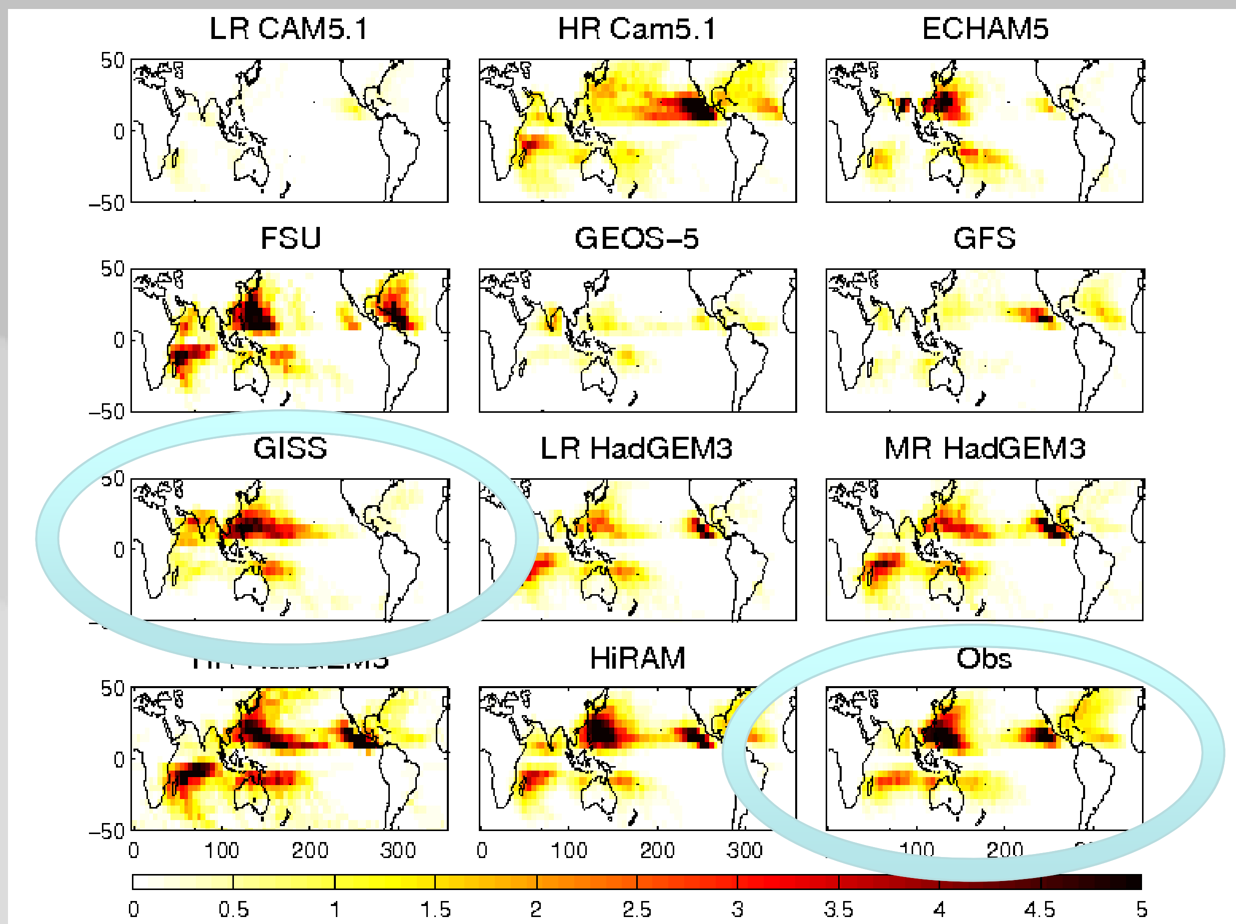


Simulations done for the US CLIVAR Working Group on Tropical Cyclones and Climate intercomparison study

From Shaevitz et al., “Characteristics of tropical cyclones in high-resolution models in the present climate”, submitted to *J. Climate*

Tropical cyclones in the GISS 1x1 model

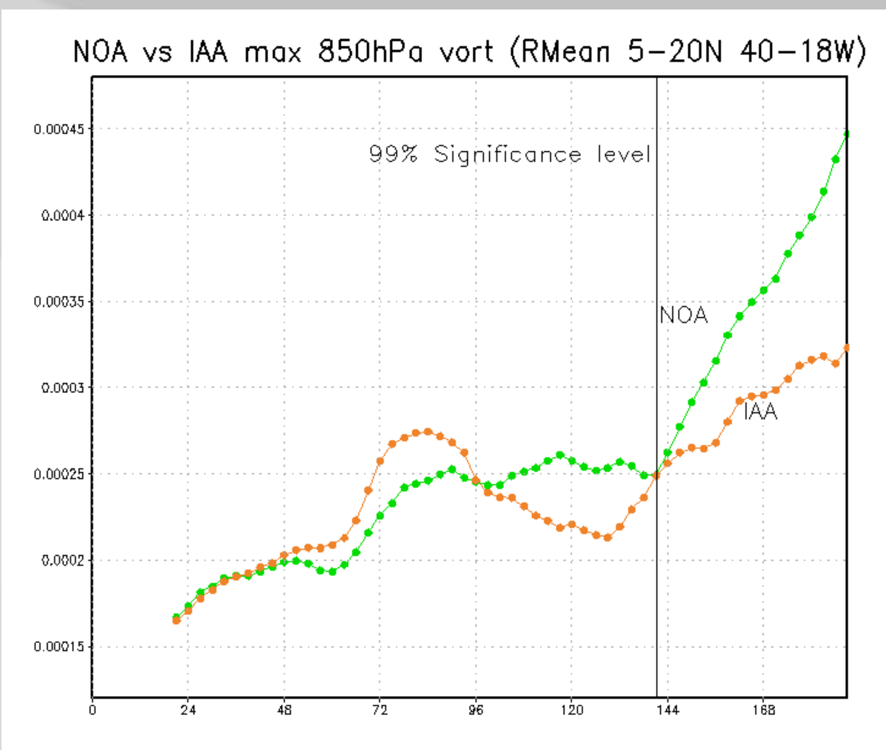
Annual climatological tropical cyclone track density



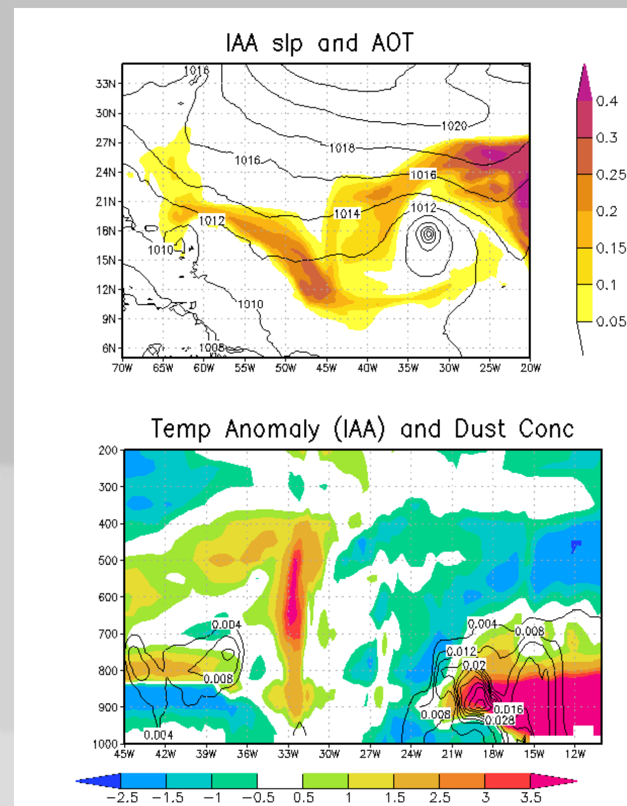
Impact of assimilated and interactive aerosols on tropical cyclogenesis

O. Reale, K.M. Lau, A. da Silva and T. Matsui

Average of eight 10-day forecasts for 850 hPa vorticity maxima detected over the south-eastern side of the Main Dev. Region, which is affected by dust at the time (Aug-Sep 2006). NOA – no aerosols; IAA Interactive aerosols. The forecasts are displayed up to day 8 (limit of skill). The 5-8 day range shows a significant impact on low-level maximum vorticity. TCs in which aerosols effects are included grow more slowly.



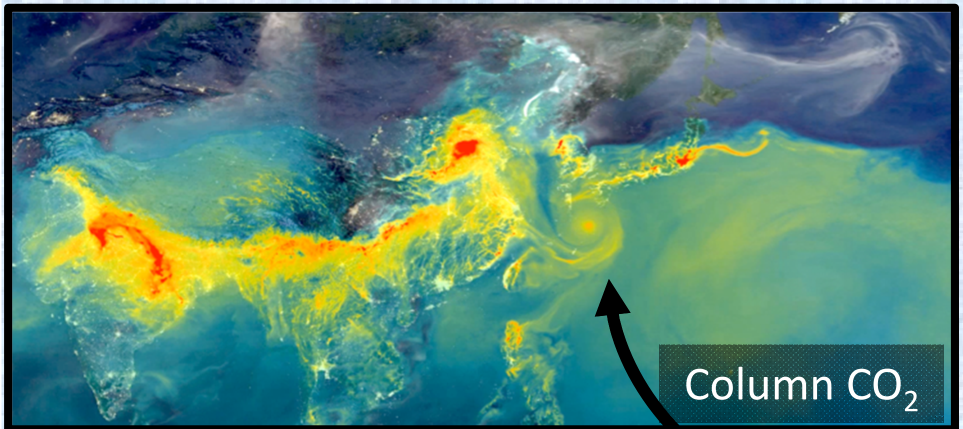
Example of one of the 8 forecasts, with TC interacting with dust

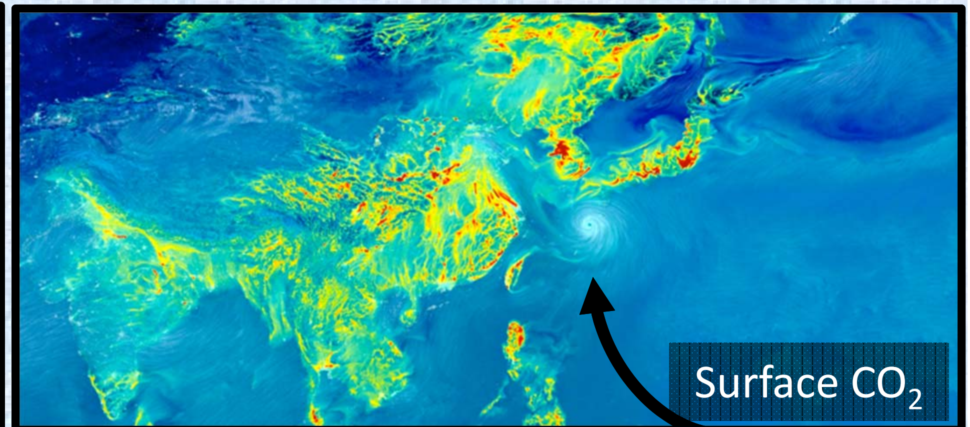


Vertical zonal cross-section across the TC center. Temperature anomalies (shaded) and dust concentration (solid)

CO_2 structures in 7-km GEOS-5 Nature Run

W. Putman, L. Ott





Nature Run Details

- 2-years : May 2005 - May 2007
- 7-km Global Resolution
- Non-Hydrostatic Dynamics
- 7-km Aerosol and Carbon Emissions
- Resolve meso-scale weather
- High-resolution constituent transport
- Executing at NASA GSFC/NCCS with a throughput of 15-days/day

High Resolution Emissions

- A typhoon impacts the CO_2 pattern, with low concentrations at the surface and relatively high column values.
- The surface concentration of CO_2 (above-right) highlights the fidelity of local emission centers
- The vertical transport at 7-km lifts these source emissions throughout the column (above-left)

North American tropical cyclone landfall and SST: a statistical model study

Timothy Hall and Emmi Yonekura, GISS, *J. Climate, 2013.*

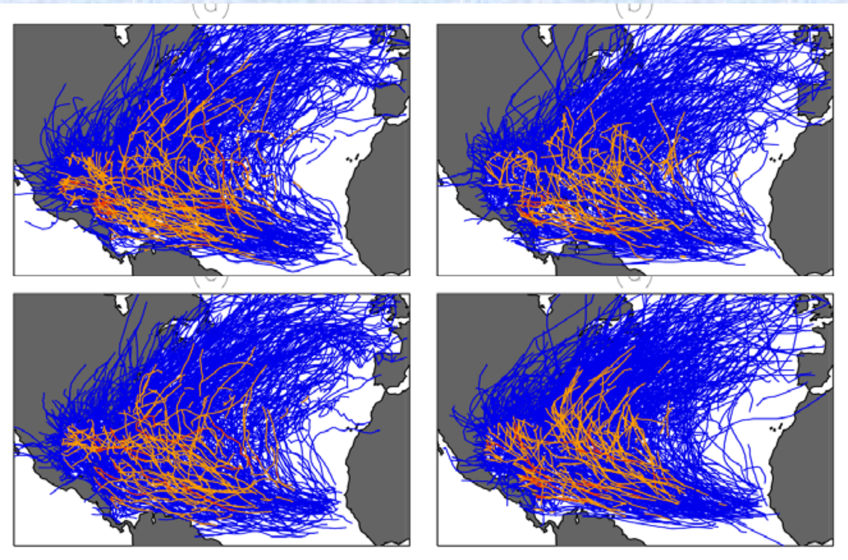


Fig 1: Three stochastic realizations of TCs 1950-2010 (a, b, c) and the historical TCs (d). Named TCs (blue), Cat 3+ (orange), Cat5+ (red)

A stochastic model of North Atlantic tropical cyclones (TCs) is used to examine the relationship between North Atlantic sea-surface temperature (SST) and TC landfall on North America. Millions of synthetic stochastic TCs are derived that have the same statistical properties and SST dependence as the historic TCs 1950-2010. The large synthetic set provides higher precision for regional landfall rates. TCs are generated in each of several fixed SST states, and landfall rate as a function of SST is obtained.

Warm North Atlantic relative to tropical mean linked to greater hurricane landfall on Caribbean and Gulf coasts. No effect on US east coast.

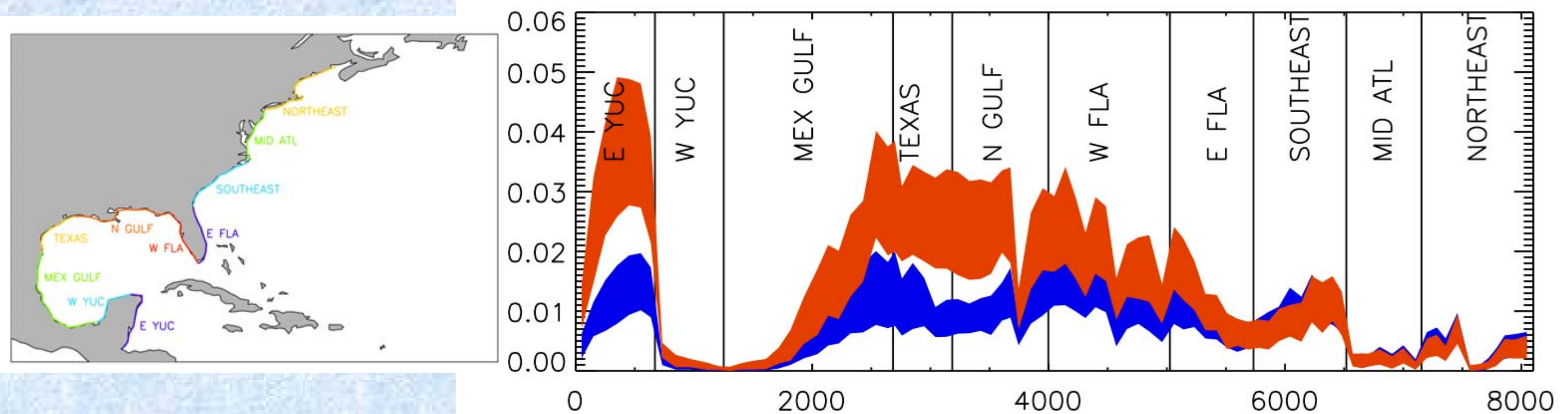


Fig 2: Left: Coastline to compute landfalls and regions as labeled. Right: Annual probability per 100km of a major (Cat 3+) landfall along the coast as labeled. Red high SST (+2σ), blue low STS (-2σ). The spread indicates 95% confidence.

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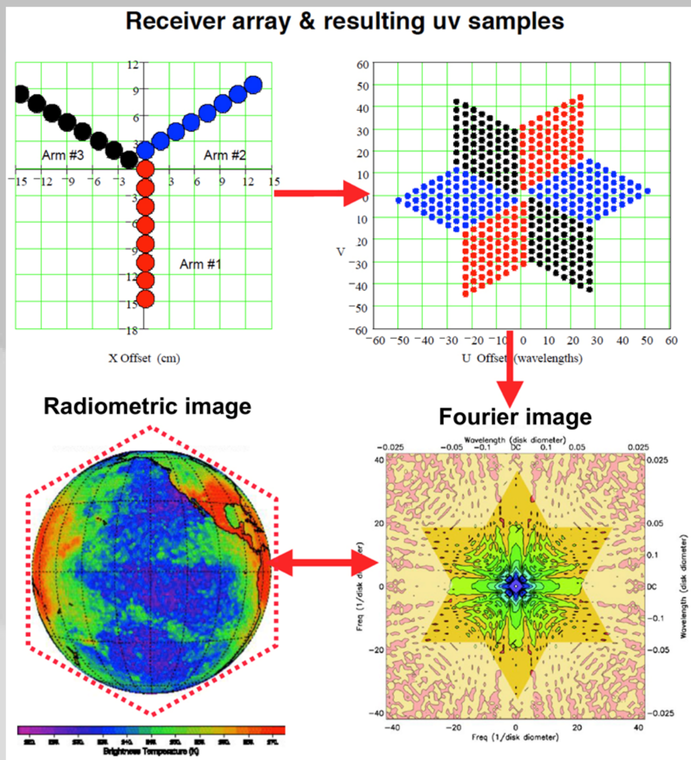
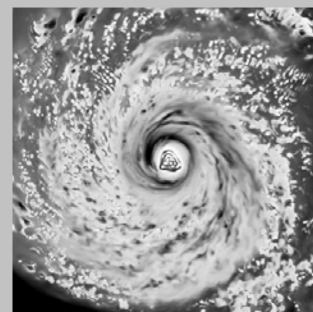
Resolution Enhancement of PATH Data Products using Sparse Optimization

Igor Yanovsky, Bjorn Lambrigtsen, NASA/JPL



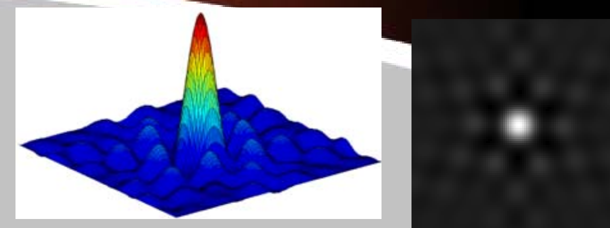
Sparse array (upper left) and u-v sampling pattern (upper right), as implemented in the GeoSTAR prototype. Typical visibility magnitudes in the uv-plane (lower-right) correspond to the radiometric image (lower-left).



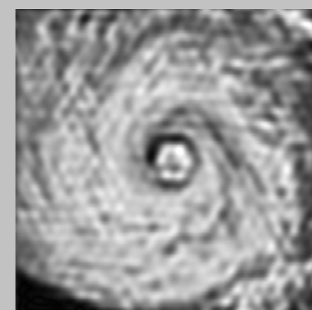
Original clean image

Successful sidelobe suppression

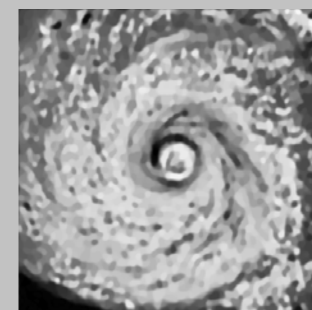
Improvement in spatial resolution by a factor of 3-4 over the conventional apodization method



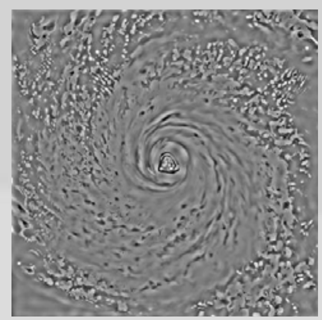
GeoSTAR point spread function



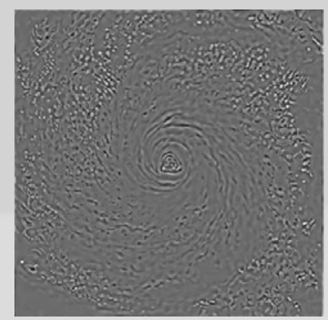
Original image is corrupted with GeoSTAR PSF and Gaussian noise



Reconstruction



Original error



Error after reconstruction

The new method can be used to significantly improve spatial resolution of existing and future microwave systems. The advantages of high spatial resolution is particularly important in the context of hurricanes, where spatial variability is very high.

NASA AIST Project CAMVis

PI: B.-W. Shen (UMCP/ESSIC)

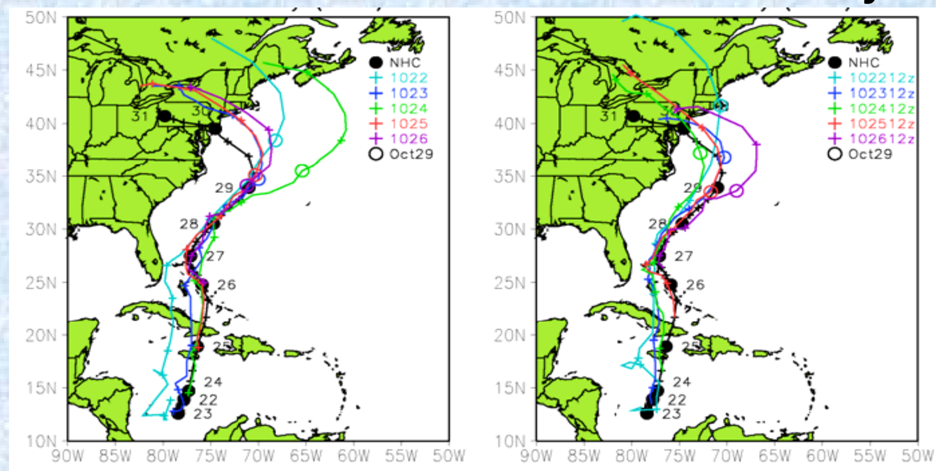
Objective

Develop and implement a scalable, multiscale analysis tool with the Coupled Advanced multiscale Modeling and Visualization system (CAMVis) to improve extended-range tropical cyclone (TC) prediction and consequently TC climate projection by enabling:

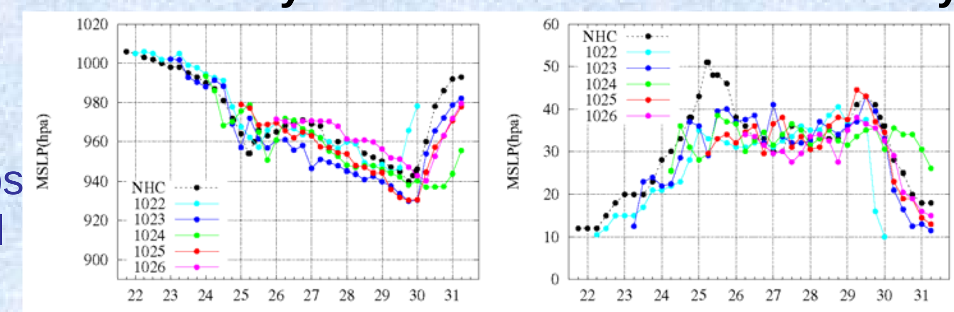
- Understanding of the TC genesis processes, accompanying multiscale processes (both downscaling by large-scale events and upscaling by small-scale events), and their subsequent non-linear interactions
- Discovery of hidden predictive relationships between meteorological and climatological events.

This project targets the ACE, PATH, SMAP, Next-generation scatterometer, and 3D-Winds missions.

Track Simulations of Hurricane Sandy



Intensity Simulations of Hurricane Sandy



Shen, DeMaria, Li and Cheung, 2013: Genesis of Hurricane Sandy (2012) simulated with a global mesoscale model, *Geophys. Res. Lett., 40,* 4944–4950, *doi:*10.1002/grl.50934.

Visualization of Sandy: http://goo.gl/hMkNd (*Credit: D. Ellsworth)*
Visualization of Vortex Interaction: http://goo.gl/kC7Jdm (*Credit: D. Ellsworth*)

Summary

- Current and future satellites provide new ways of looking at tropical cyclones and hurricanes
  - Recent GPM launch and upcoming RapidScat/ISS and CYGNSS launch will add capability
- Airborne missions enable focused observations of tropical cyclones, and can provide unique combinations of platforms, sensors, systems, and people
- Computational models can demonstrate how observations can better contribute to improved predictive capability and to understanding of role of Tropical Cyclones/Hurricanes in the Earth System
- New technology development in hardware and information systems can enable the discoveries and forecasting improvements of the future
- Partnerships are enabling the enhanced societal use of products from NASA research