Tropical Cyclone Research: NASA's Activities

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Associate Director for Research
Earth Science Division
Science Mission Directorate

NASA Headquarters

March 5, 2013

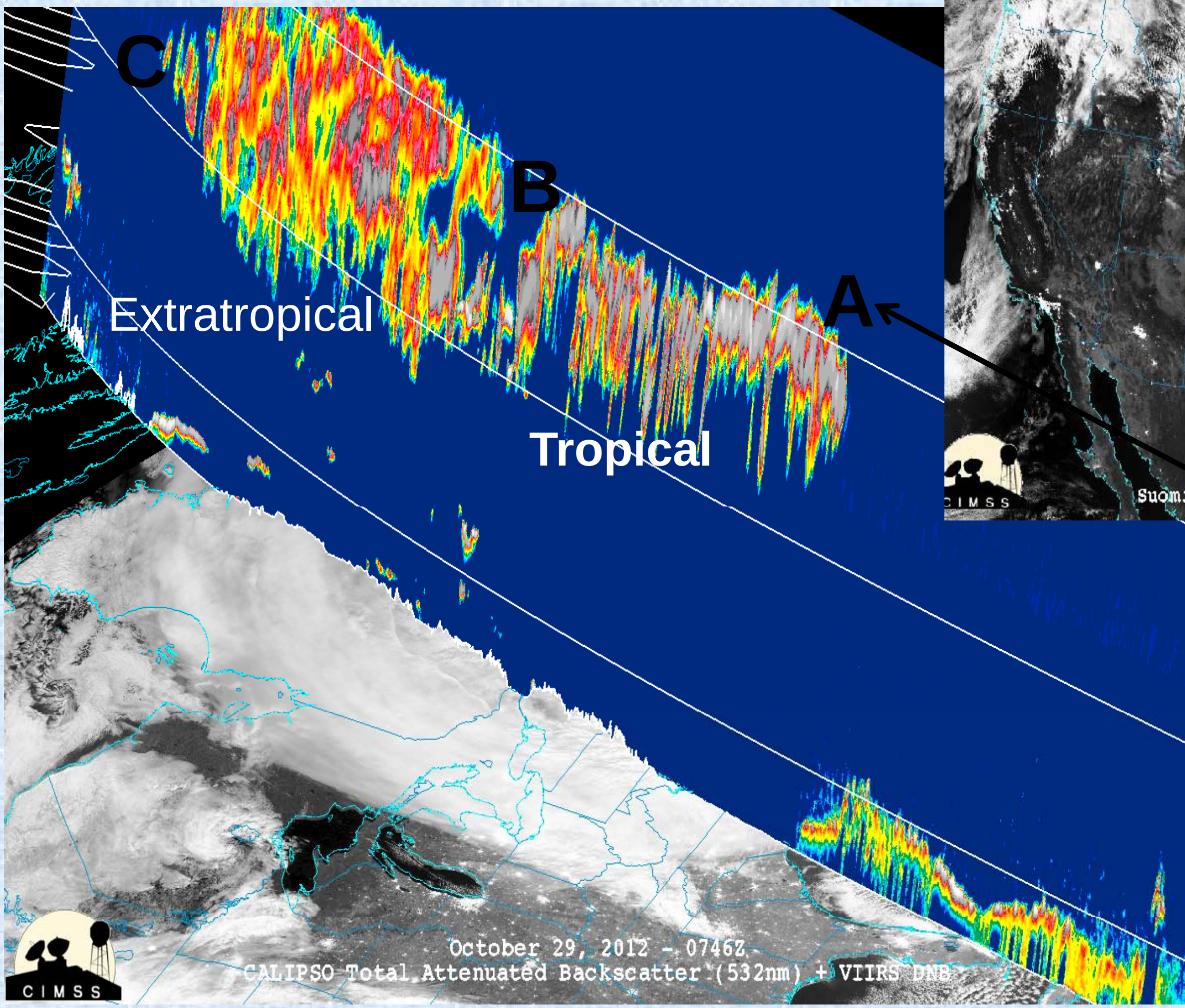
With inputs from multiple colleagues at NASA HQ and Field Centers!

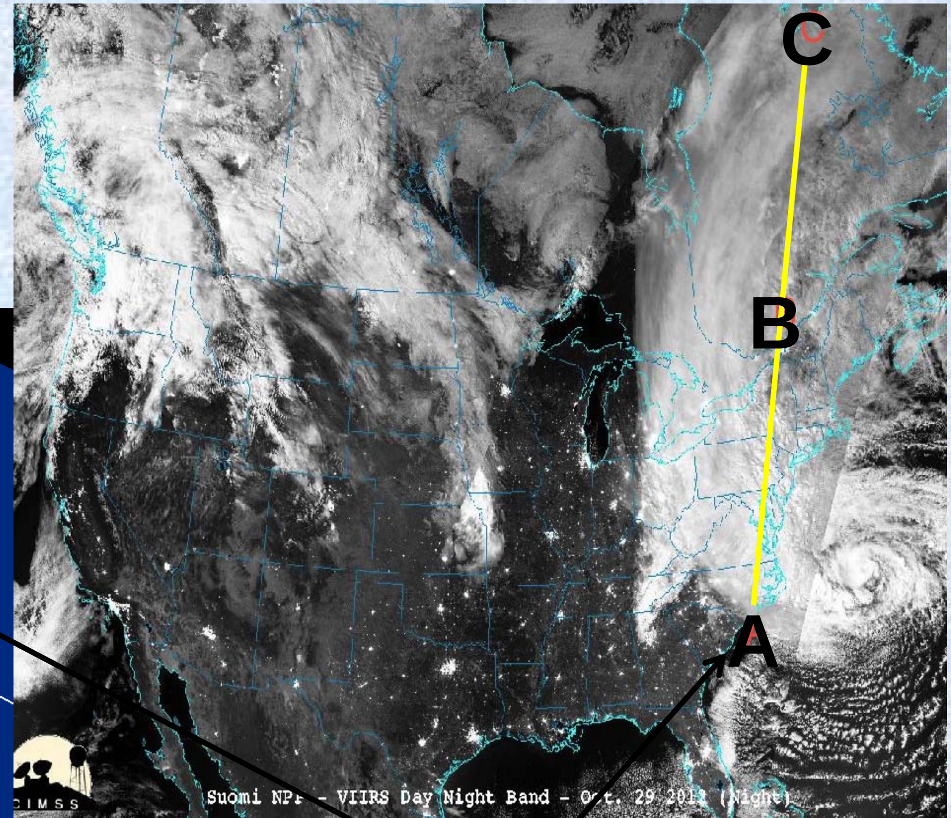
NASA Program Elements Contributing to Tropical Cyclone Research

- Satellites
  - Present
  - Future
- Airborne Observations
- Computational Modeling
- Technology Development and Evaluation
  - Instruments
  - Information Systems
  - Observing System Evaluation
- Applications of NASA Products


NASA Earth Observing
Satellite Fleet - 2012
Launch-CY2011
Launch-CY2012
Launch-CY2013
Aquarius
OSTM/Jason 2 (NOAA)
Jason
QuikSCAT*
TRMM
EO-1
Landsat-7 (USGS)
Aqua
ACRIMSAT
Terra
SORCE
LDCM
GRACE (2)
Aura
CALIPSO
CloudSat
Suomi-NPP

Hurricane Sandy Nighttime Overpass Oct. 29, 2012





VIIRS Day Night Band and CALIPSO Lidar images of Sandy

- **VIIRS image shows the massive extent of the storm.**
- **CALIOP attenuated backscatter shows the tropical vs. extra-tropical cloud morphology.**

Images credit: William Straka III, U. Wisconsin, CIMSS

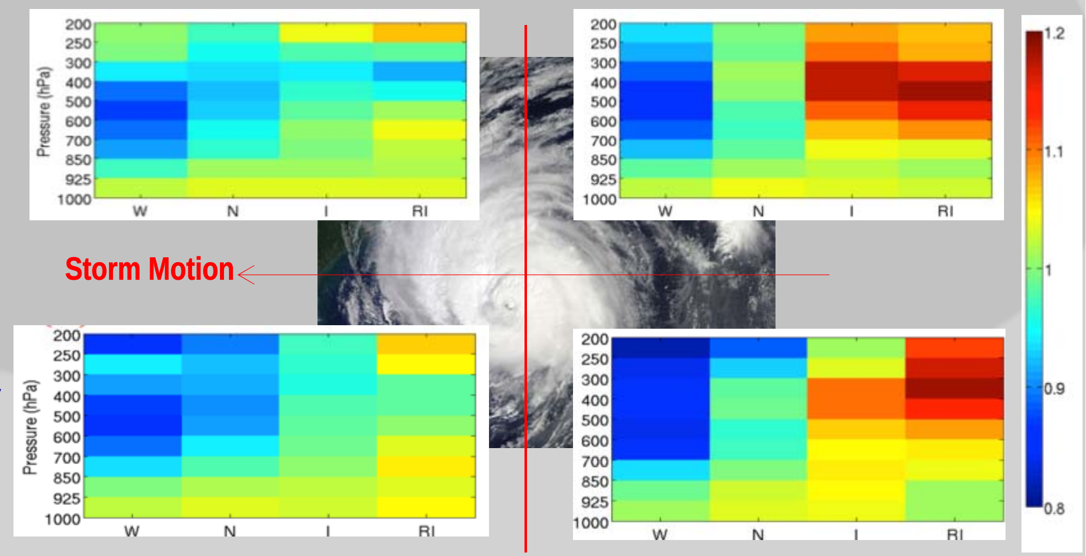
First Satellite Analysis to Quantify the Relationship Between Relative Humidity and Tropical Cyclone Intensification

Wu, L., H. Su, R.G. Fovell, B. Wang, J.T. Shen, B.H. Kahn, S.M. Hristova-Veleva, B.H. Lambrigtsen, E.J. Fetzer and J.H. Jiang (2012): Relationship of environmental relative humidity with North Atlantic tropical cyclone intensity and intensification rate, *Geophys. Res. Lett.* 39, 20809, 10.1029/2012GL053546

Nine years of NASA AIRS relative humidity (RH) profiles including 198 North Atlantic tropical cyclones (TCs) revealed that:

- Environmental RH increases with TC intensity and intensification rate.
- Substantial azimuthal asymmetry in RH exists.

Y-axis: Normalized RH profile in TC environment
400 - 600 km away from TC center in four quadrants



X-axis: TC intensification rate
W: Weakening; N: Neutral;
I: Intensifying; RI: Rapidly Intensifying

- **NASA Press Release:** http://www.nasa.gov/mission_pages/aqua/hurricane20121128.html
- **KABC News Coverage:** http://abclocal.go.com/kabc/video?id=8901861&pid=8901860

❖ **We acknowledge the funding support from NASA HSRP program.**

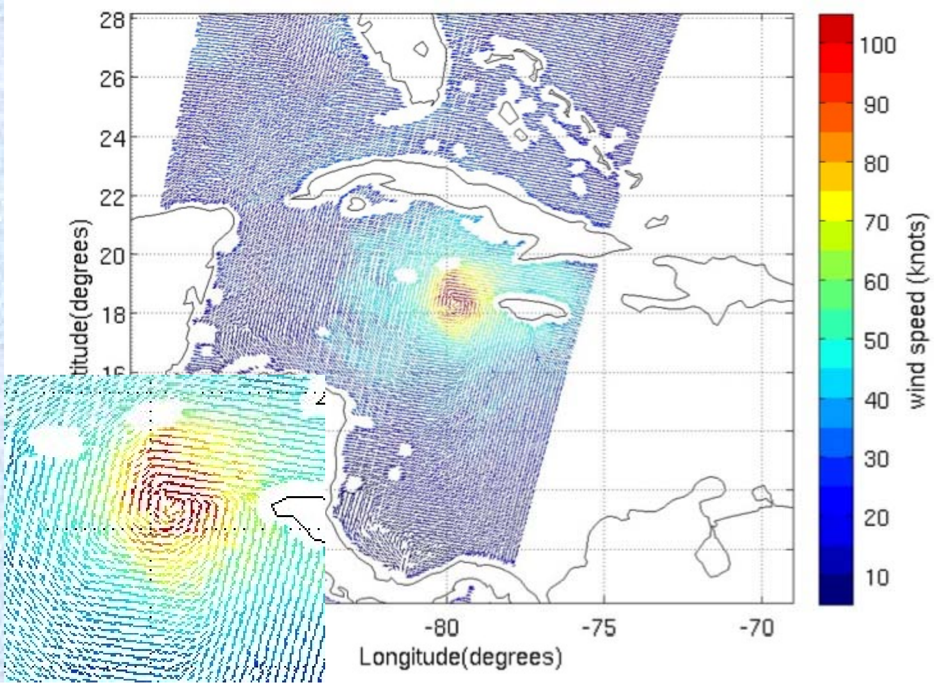
Global Impact of Tropical Cyclones on Ocean Climate

S. Hristova-Veleva & B. Stiles (JPL)

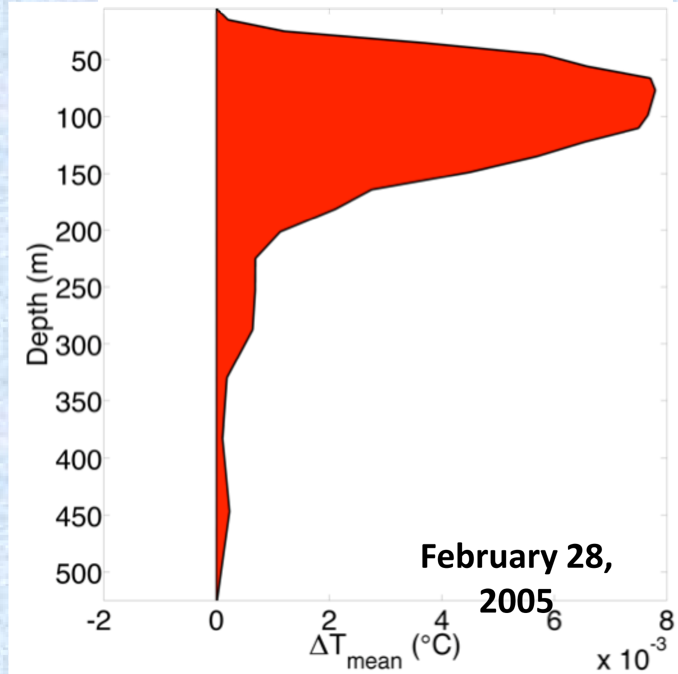
I. Ginis & M. Bueti (URI)

Using QuikSCAT tropical cyclone data in a high resolution global ocean model

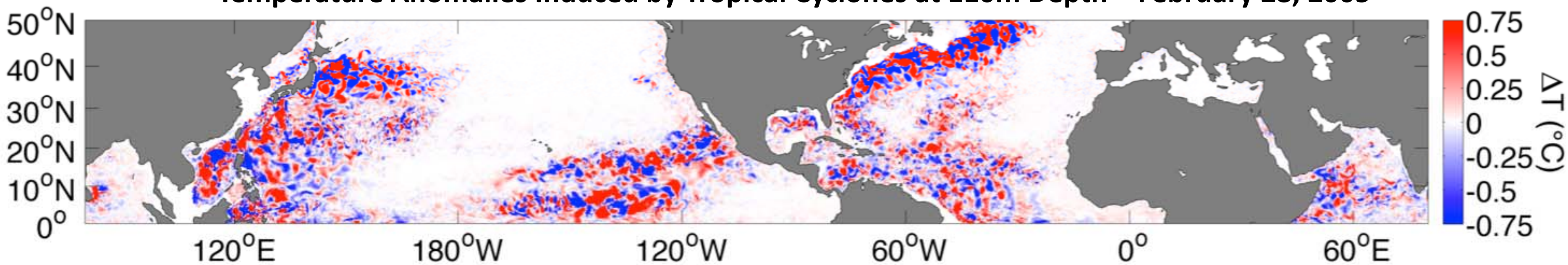
QuikSCAT Neural Net Winds: Hurricane Ivan 23:37 UTC 11 Sept. 2004



Global Temperature Anomalies Induced by Tropical Cyclones



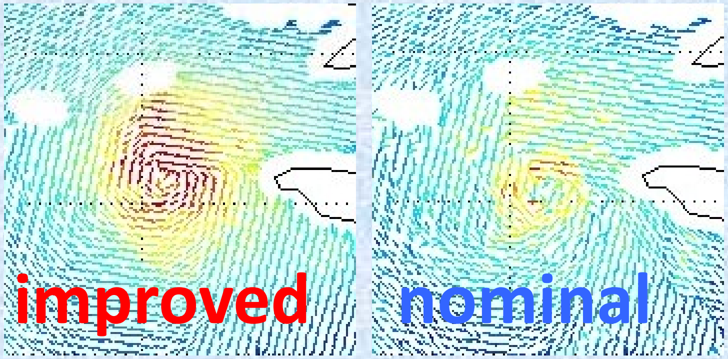
Temperature Anomalies Induced by Tropical Cyclones at 110m Depth – February 28, 2005

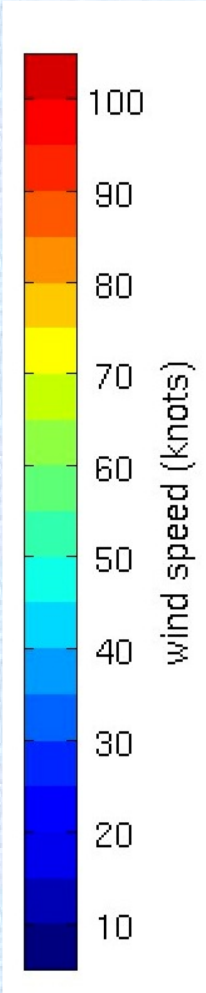


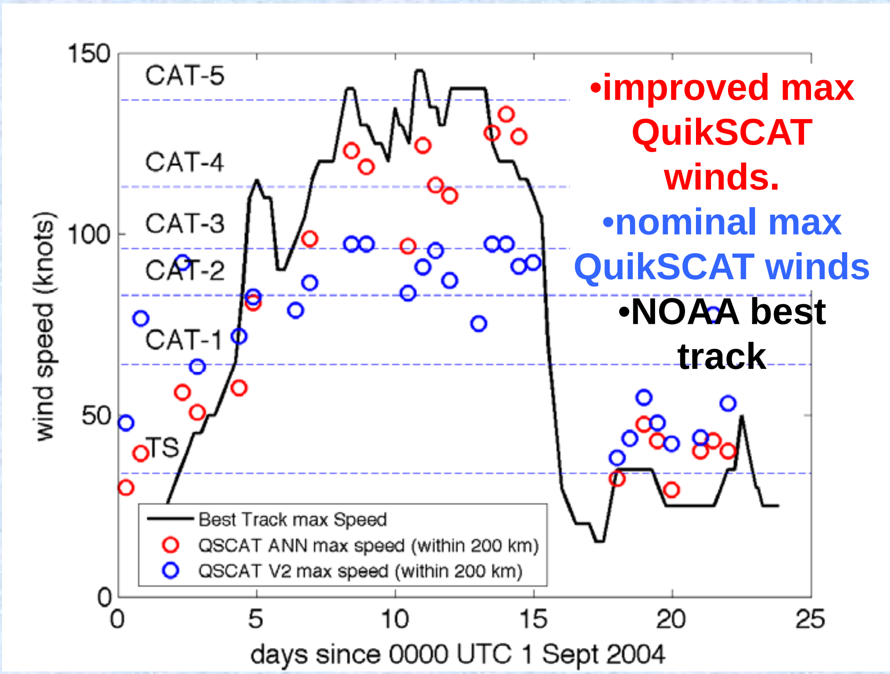
QuikSCAT Neural Network Tropical Cyclone Winds

Bryan Stiles (JPL)

Hurricane Ivan 23:37 UTC 11 Sept. 2004







Multi-Scatterometer Hurricane Winds

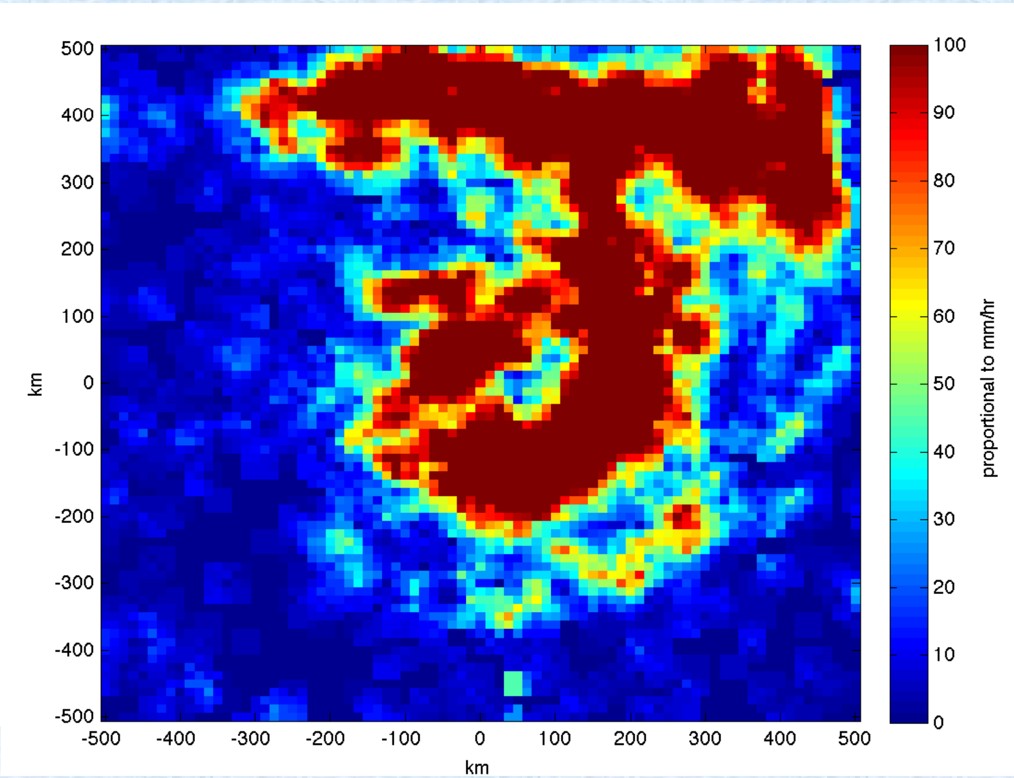
- Improved QuikSCAT tropical cyclone (TC) wind speed fields
  - –11,435 storm scenes over 10 years
  - –Validated vs. hurricane analysis fields and aircraft reconnaissance data.
- Problem: Scatterometer winds are corrupted by rain and use empirical retrievals not optimized for high winds.
- Solution: Neural network retrieval method trained specifically for TC winds.
- Developing similar datasets for OceanSAT-2 (ISRO) and ASCAT (ESA) scatterometers.

See http://tropicalcyclone.jpl.nasa.gov

Signature of Rapidly Intensifying Storms in QuikSCAT SRAD Rain Data

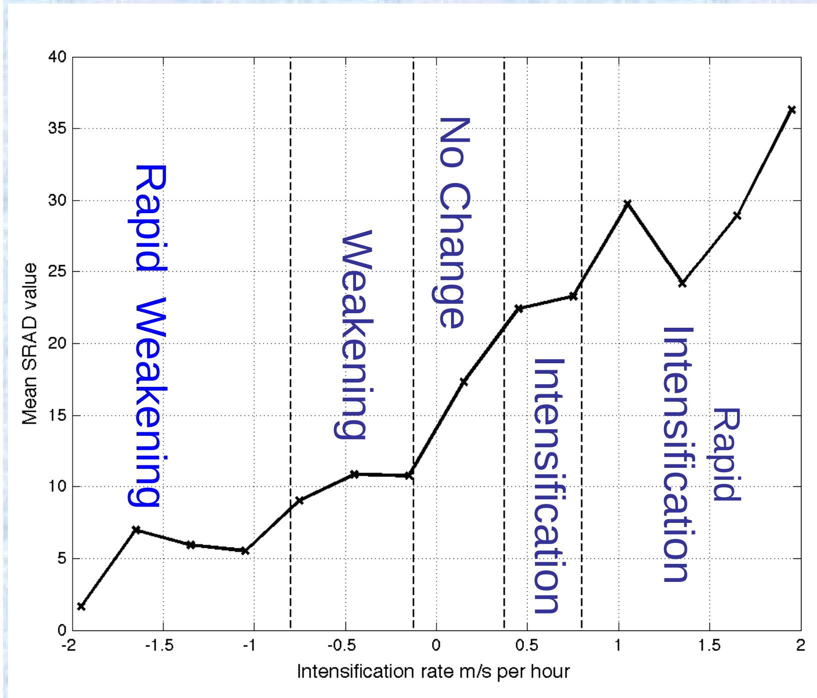
Bryan Stiles (JPL)

QuikSCAT SRAD (proxy for rain rate)

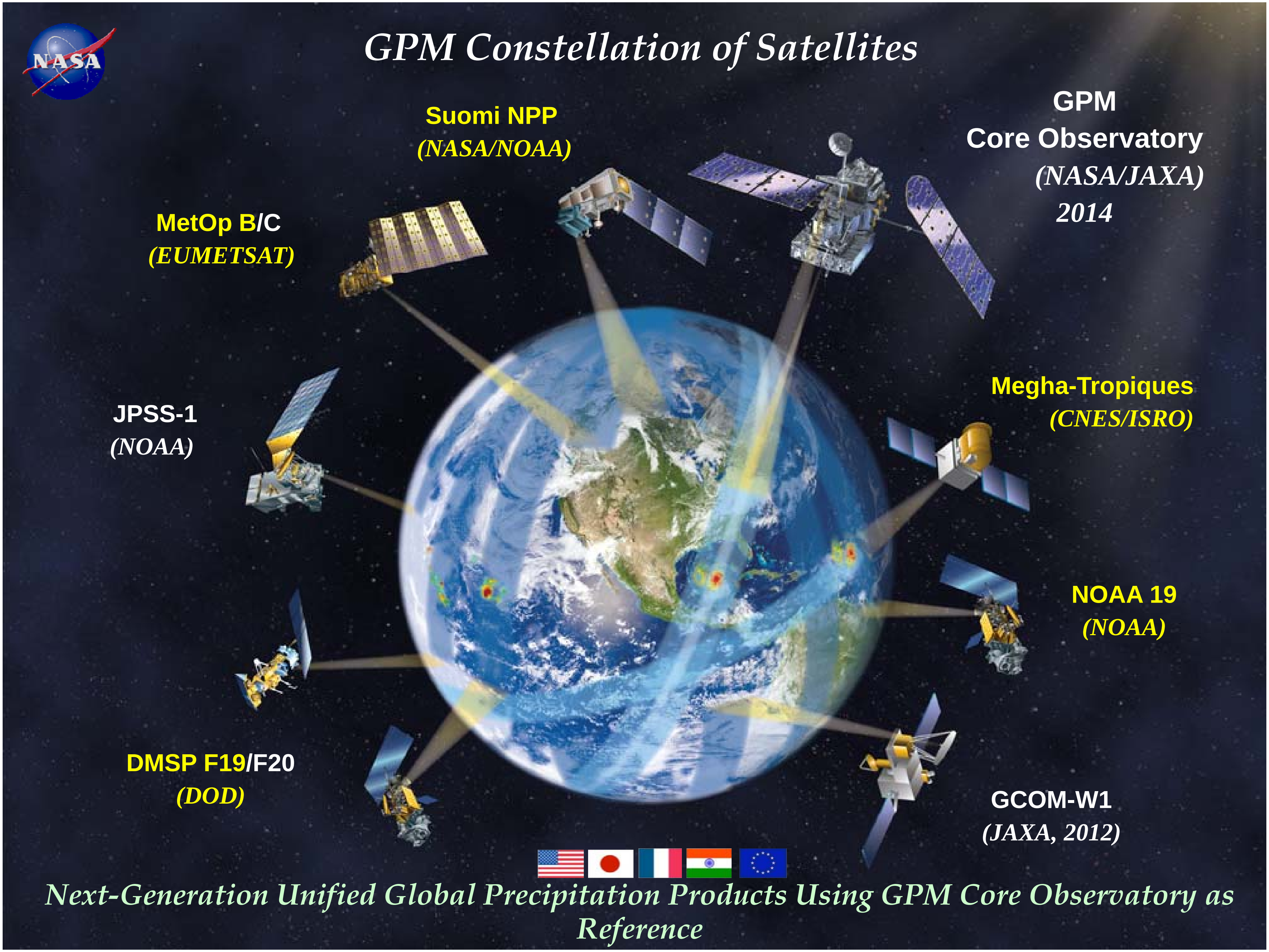


Example Storm: South Pacific Typhoon Zoe, 26 Dec 2002 UTC 18:54, JTWC maximum intensity increased by 15 m/s in 6 hours after the QuikSCAT observation from a tropical storm force to borderline CAT-2/CAT-3 hurricane force. Large values of SRAD around storm center indicate rapid intensification.

SRAD relationship to Rapid Intensification



Average SRAD (y-axis) within 200 km of storm center for all tropical storm force cyclones observed by QuikSCAT 1999-2009 vs. best track intensification rate (m/s per hour) during the 6 hours after the QuikSCAT observation.


GPM Constellation of Satellites
Suomi NPP
(NASA/NOAA)
GPM
Core Observatory
(NASA/JAXA)
2014
MetOp B/C
(EUMETSAT)
JPSS-1
(NOAA)
Megha-Tropiques
(CNES/ISRO)
NOAA 19
(NOAA)
DMSP F19/F20
(DOD)
GCOM-W1
(JAXA, 2012)
Next-Generation Unified Global Precipitation Products Using GPM Core Observatory as Reference

International Science Collaboration

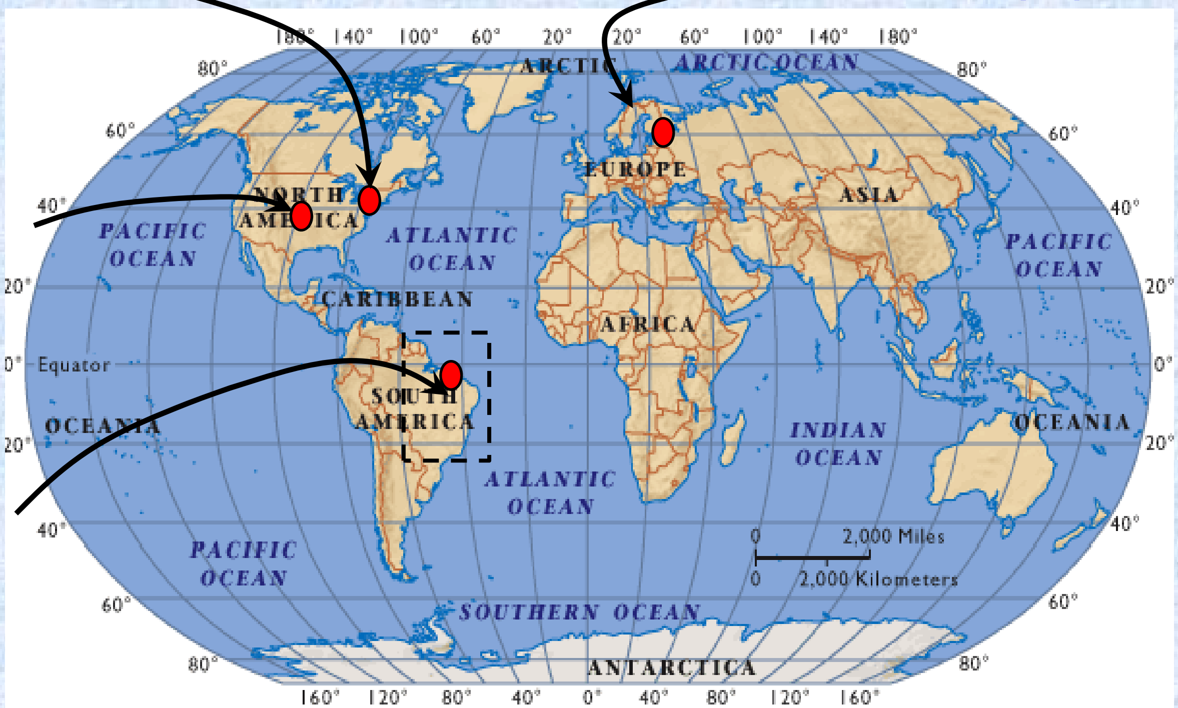
NASA has 21 active research projects with investigators from 19 countries to support satellite algorithm improvement and data evaluation including:

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)

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)

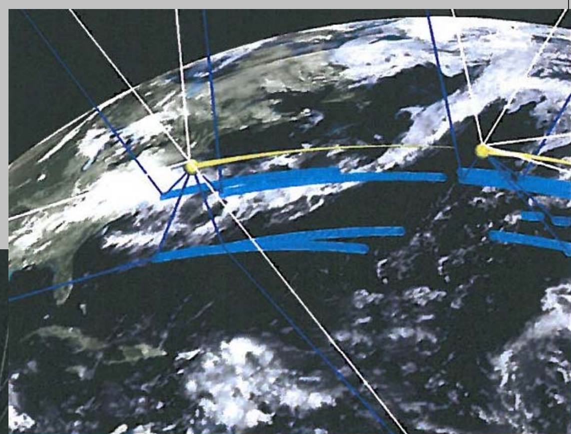


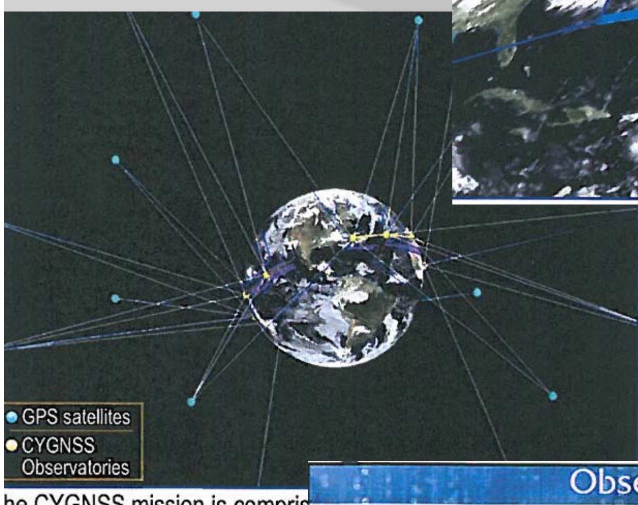
Earth Venture-2

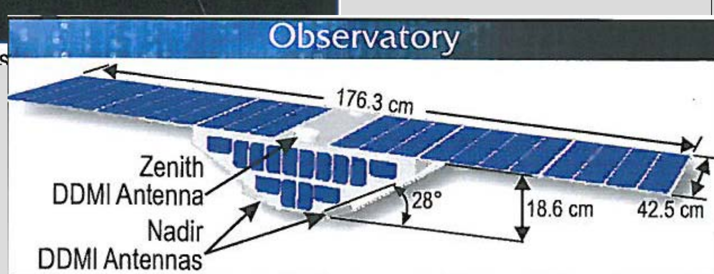
(CYGNSS) Cyclone Global Navigation Satellite System

Principal Investigator: Chris Ruf
University of Michigan, Ann Arbor, MI

Cost: NASA – $150M BY14, Contribution: $485K BY14







Summary

The impact of ocean winds in the genesis and intensification of tropical cyclones is not well understood.   The coupling of this data with other ocean parameters result in the Topical Cyclone (TC) inner core dynamics. CYGNSS will collect detailed measurements of the ocean surface wind speeds both external to the TC and within the eyewall, for all precipitation conditions.

Implementation

CYGNSS will use eight (8) three-axis stabilized satellites operating at 500km, 35 degree orbit. The instrument will be collecting signals directly from GPS satellites and the reflected GPS signal off the ocean surface.. The method of measuring wind speed is not affected by precipitation. The number of satellites and the orbit chosen will result in a full map of the area between the Tropic of Cancer and the Tropic of Capricorn every day (24 hour period). This data will also be used to information the national hurricane forecast community in support of further development and prediction of the TCs and the conditions that facilitate the genesis and speed of intensification.

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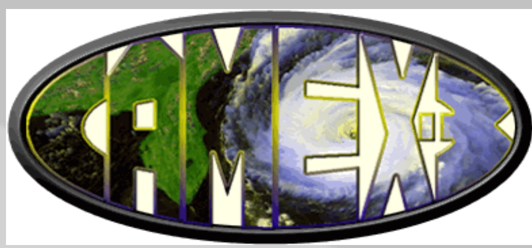
NASA Hurricane Field Experiments

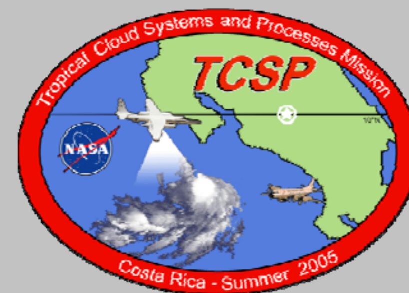
Field programs coordinated with other Federal Agencies

1998



2001

2005

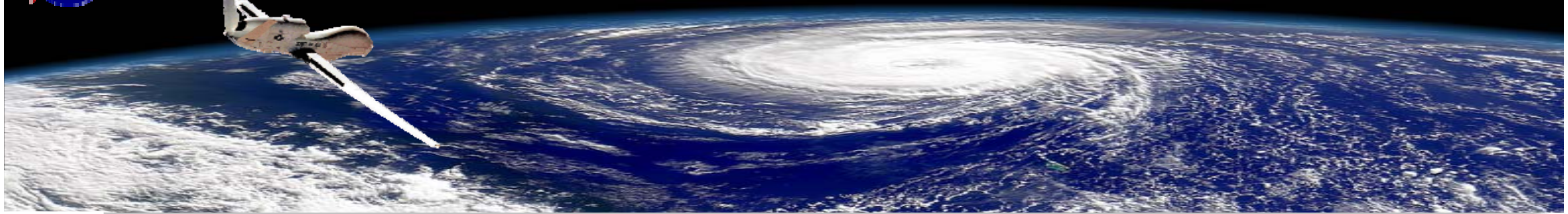


2006

2010 GRIP

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

Hurricane and Severe Storm Sentinel (HS3)



Science Goal: To understand hurricane genesis and intensification.

Key Science Questions:

- How do hurricanes form?
- What causes rapid intensity changes?
- What is the role of deep convective cores in intensification?
- What's the role of the Saharan Air Layer?

Deployment Details:

- Deployments in hurricane seasons of 2012-2014
- Based at NASA's Wallops Flight Facility in Virginia
- 275 science flight hours (~10-11 26-hour flights) per deployment

<u>**Two Global Hawk (GH) aircraft**</u>

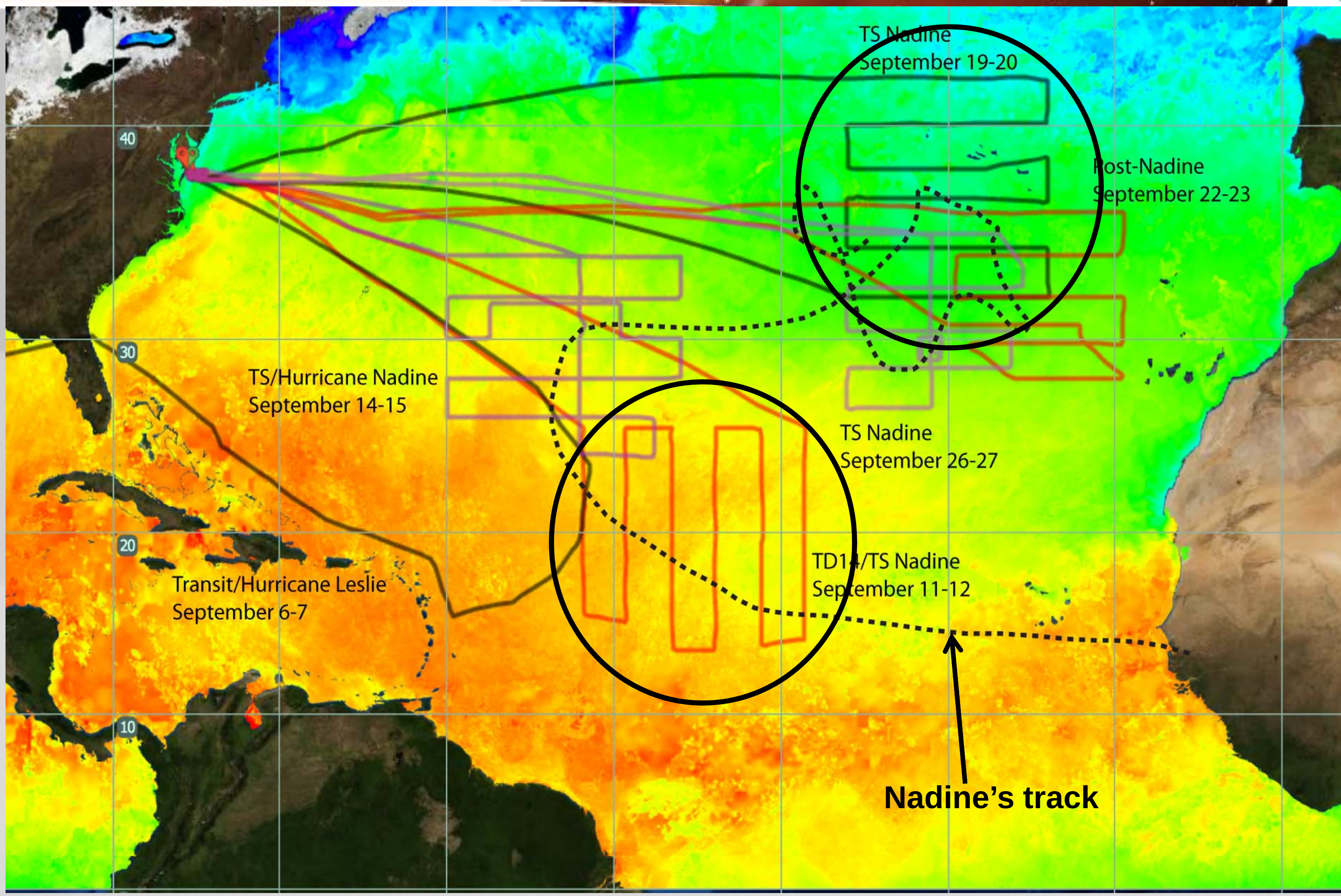
Environment GH instrumentation

- TWiLiTE (direct detection wind lidar)
- CPL (cloud & aerosol lidar)
- Scanning HIS (T, RH)
- Dropsondes (wind, T, RH)

Over-storm GH instrumentation

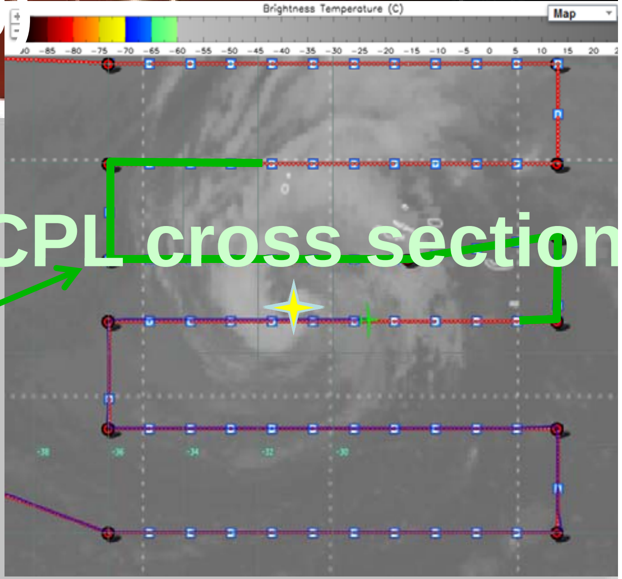
- HIWRAP (3-D preip. + 3D winds + sfc winds)
- HIRAD (sfc winds and rain)
- HAMSR (T, RH, hydrometeor profiles)

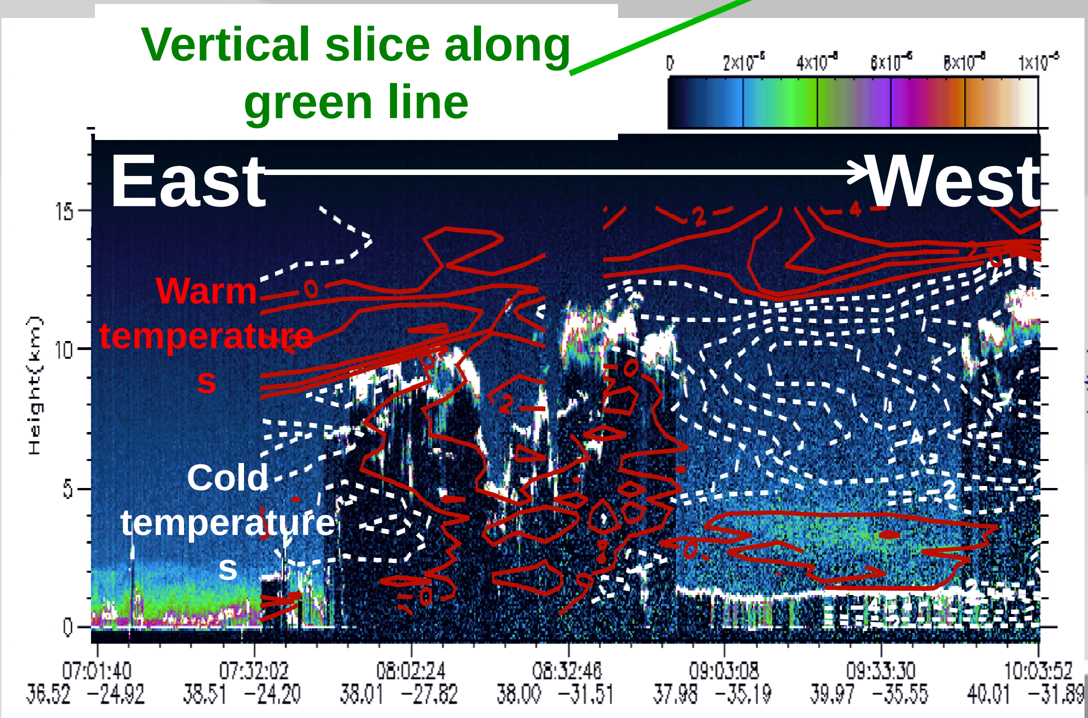
Hurricane and Severe Storm Sentinel (HS3) 2012 Deployment

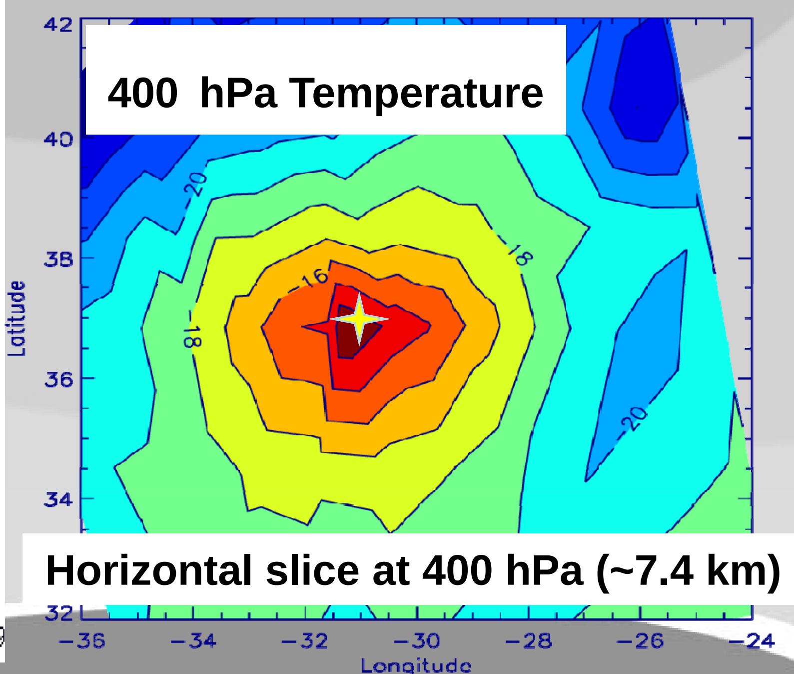


Nadine Survives Despite Adverse Conditions (Sept 19-20)

- Despite strong vertical shear, dry air and low SSTs (~24° C), Nadine survives
- Dropsondes reveal warm core structure near center through most of the troposphere
- NHC uses HS3 observations to maintain Nadine as a tropical storm







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GEOS-5 Forecasts of Hurricane Sandy

Global Modeling and Assimilation Office, NASA GSFC

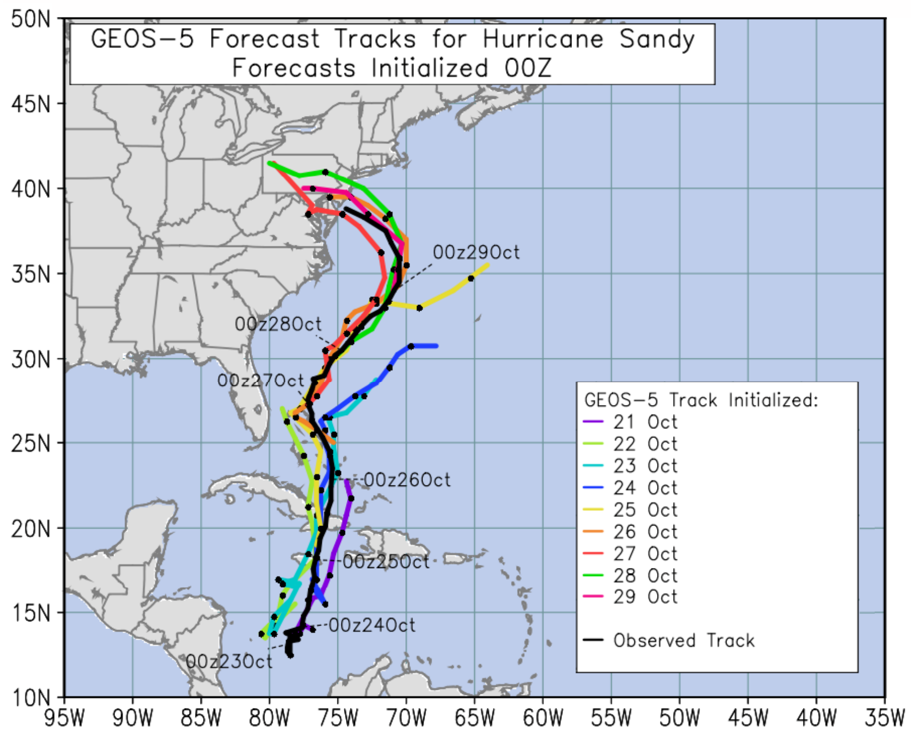


Figure 1: GEOS-5 forecasts for Sandy's track, initialized at 00Z (colored), and the observed track (black). Forecast storm locations are marked at 12 hour intervals.

Hurricane Sandy was an event unprecedented in both its impacts and its meteorology. When verifying the GEOS-5 forecasts for Hurricane Sandy, we found that GEOS-5:

- Forecast Sandy throughout its entire evolution from tropical depression to Category 1 hurricane.
- Successfully forecast Sandy's track and the general region of landfall.
- Successfully forecast Sandy's intensity (here, minimum central pressure) and key details of Sandy's storm structure.

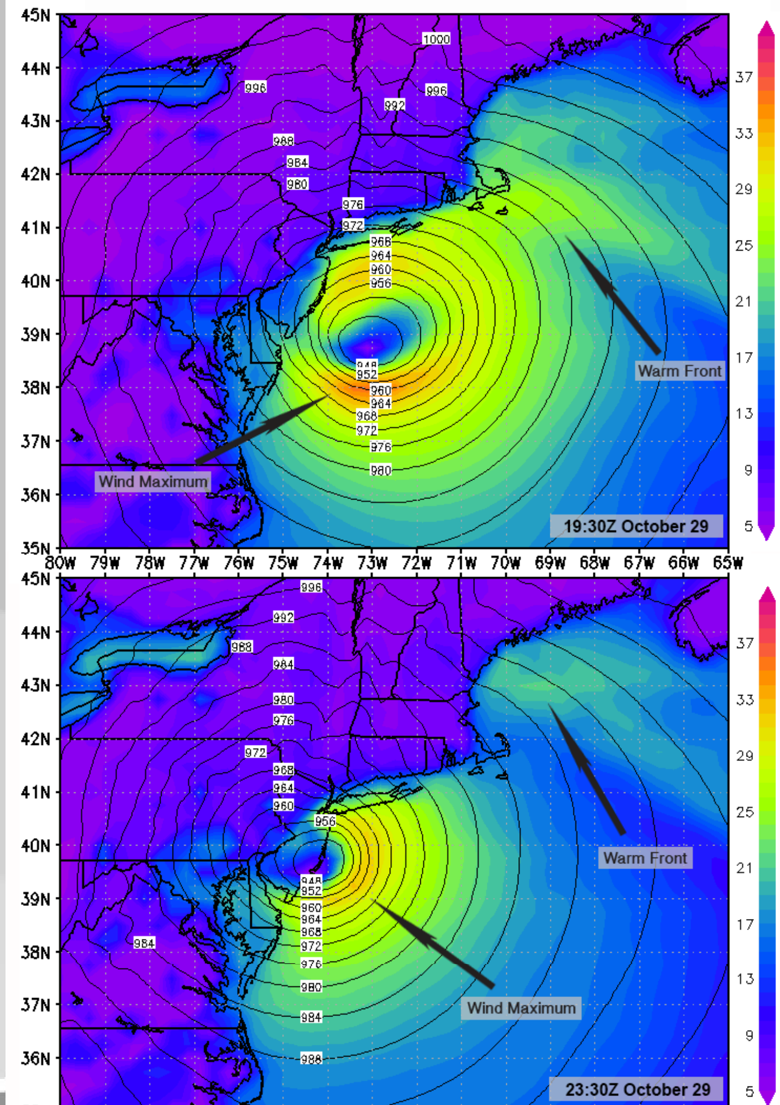
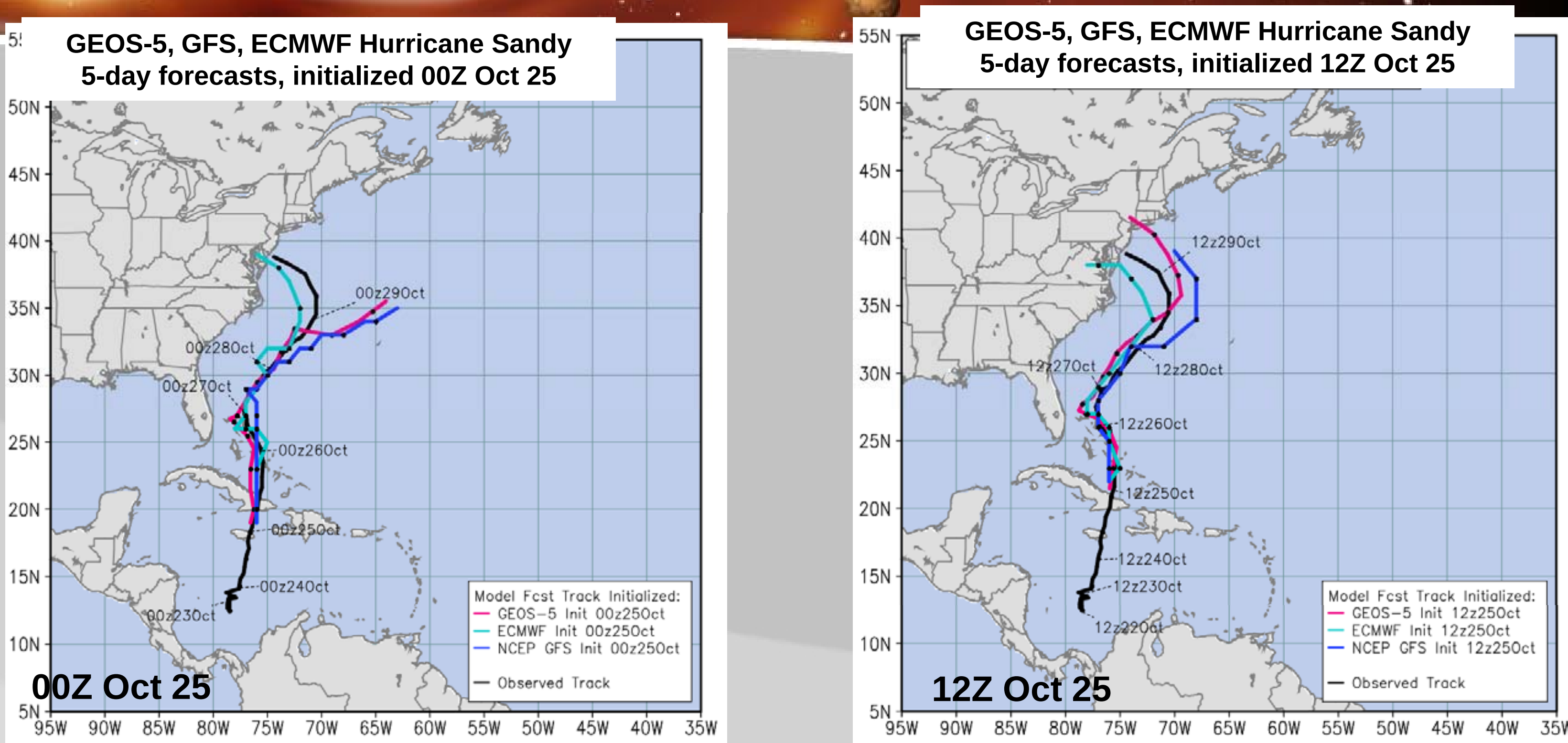


Figure 2: GEOS-5 forecast initialized 12Z October 26: Sea level pressure (hPa, contours) and 10m winds (m/s, color).

Hurricane Sandy Forecasts

Global Modeling and Assimilation Office, NASA GSFC



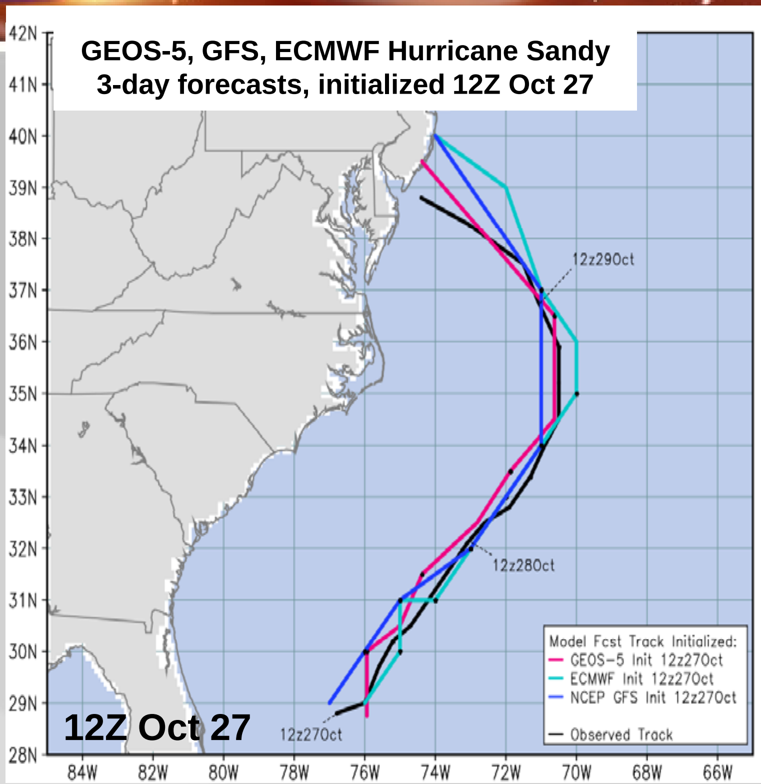
5-day forecasts for Hurricane Sandy's track from GEOS-5 (magenta), ECMWF (green) and NCEP (GFS, blue), with observed track (black). Forecasts were initialized at 00Z October 25 (left) and 12Z October 25 (right). Both GEOS-5 and the GFS forecast a turn in the 12Z October 25 forecast, whereas ECMWF forecast the turn 12 hours earlier.

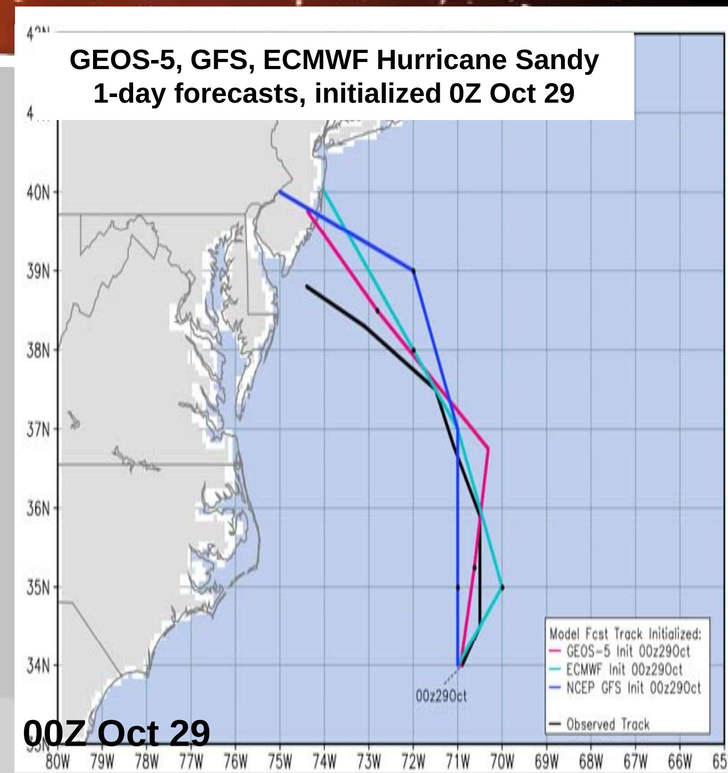
GEOS-5, which produces forecasts twice daily at a ¼ degree resolution with 72 vertical levels, predicted the track of Hurricane Sandy well:

- GEOS-5 (and NCEP GFS) initially forecast that an upper level trough would push Sandy away from the U.S.
- Starting 12Z Oct 25, 2012, GEOS-5 forecast that the upper level trough would acquire a negative (NW – SE) tilt, and cause Sandy to turn towards the Tri-State area. All forecasts after this followed a similar track.
- Sandy began making a turn towards the northeast coast on October 28, three days after being forecast by GEOS-5.
- ECMWF was able to forecast the turn 12 hours earlier than GEOS-5 and GFS.

Hurricane Sandy Forecasts

Global Modeling and Assimilation Office, NASA GSFC





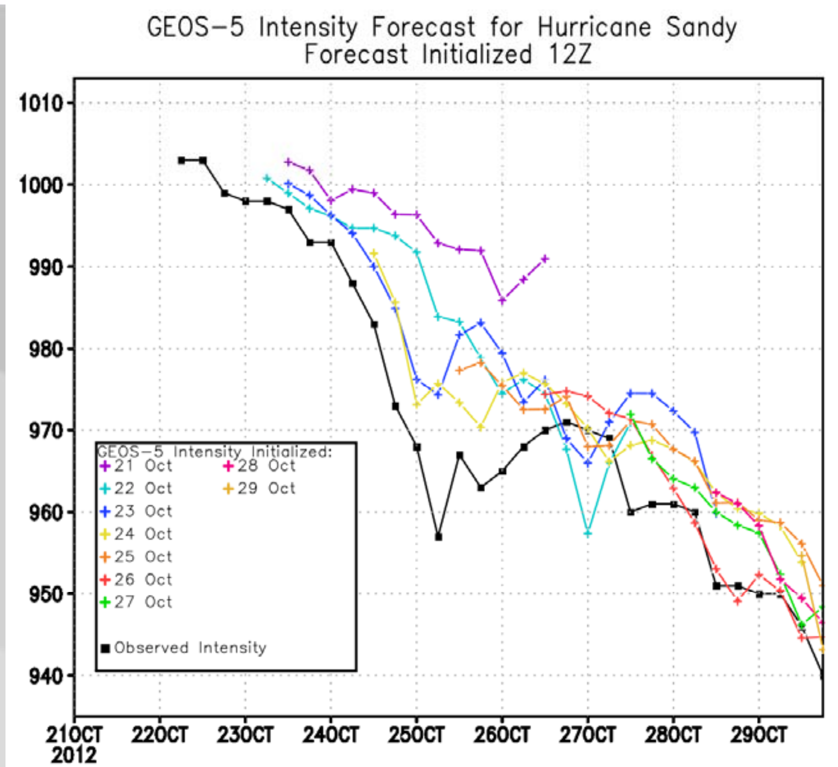
Short-range forecasts of Hurricane Sandy's landfall, initialized at 12Z on October 27 and 00Z on October 29. GEOS-5 predicts Sandy's track and location of landfall well in both of these short range forecasts.

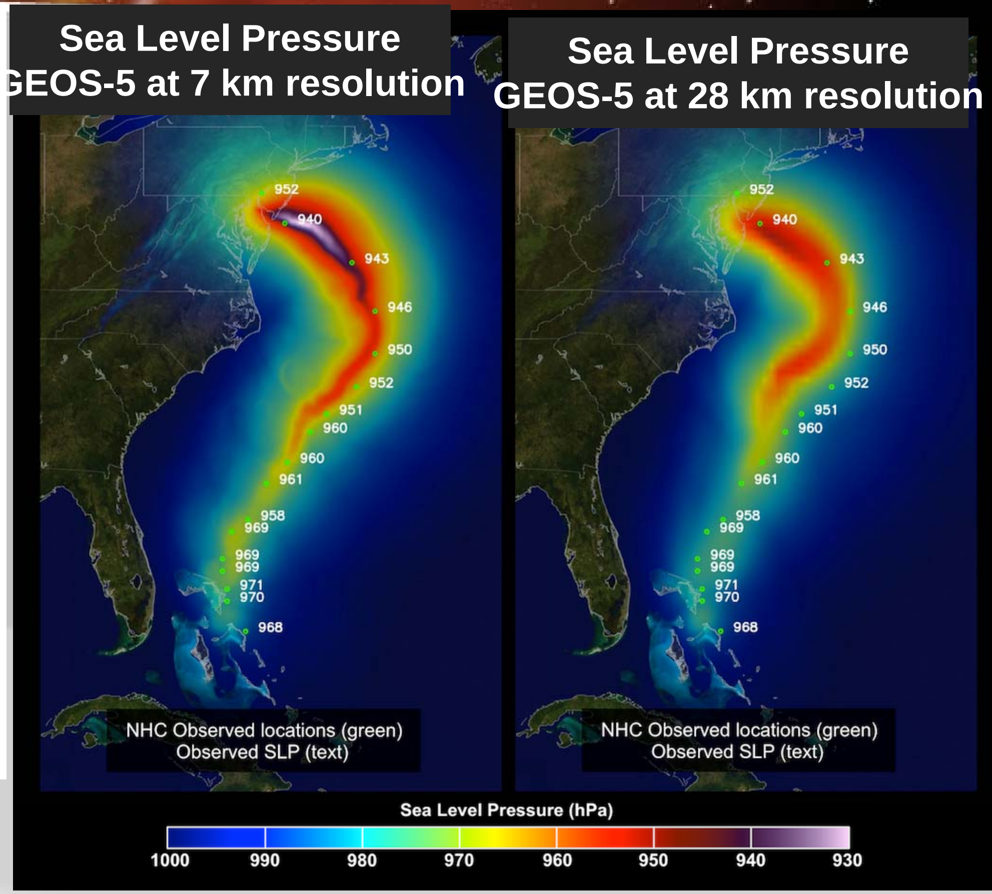
Hurricane Sandy made landfall in southern New Jersey with Category 1 winds on October 30, 2012. GEOS-5 forecast the location of landfall well:

- All GEOS-5 forecasts after October 25 predicted Sandy would make landfall between Delaware and central New Jersey, not far from where it actually occurred.
- GEOS-5 short term (one- to three-day) forecasts predicted Sandy's track prior to landfall with considerable accuracy, and predicted the location of Sandy's landfall very well.

Hurricane Sandy Forecasts

Global Modeling and Assimilation Office, NASA GSFC





- GEOS-5 predicted Sandy's intensity to within a few hectopascals over much of the life of the storm. The general pressure trends of the storm were also predicted relatively well.
- A comparison of GEOS-5 forecasts from 09Z 26 October 2012: The 7-km resolution run performed better at forecasting Sandy's track and its intensity than the typical 1/4-degree resolution configuration of GEOS-5.

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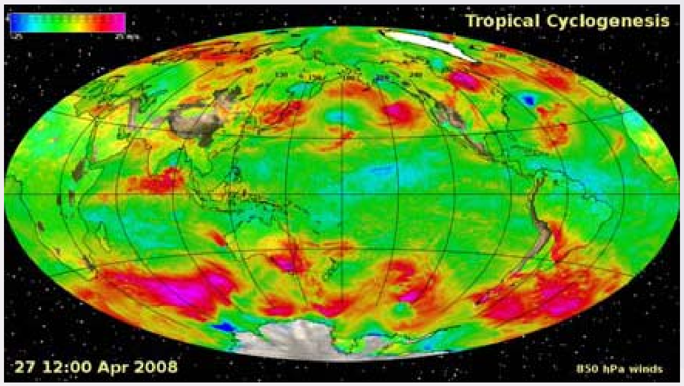
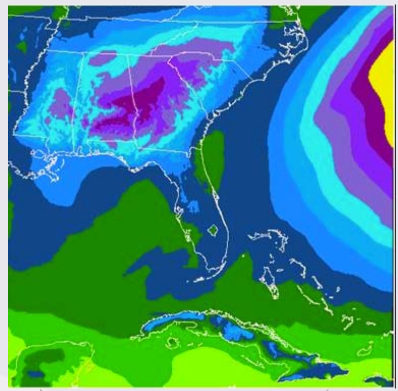
CAMVIS Tropical Cyclone Prediction Project

Bo-Wen Shen,
University of Maryland

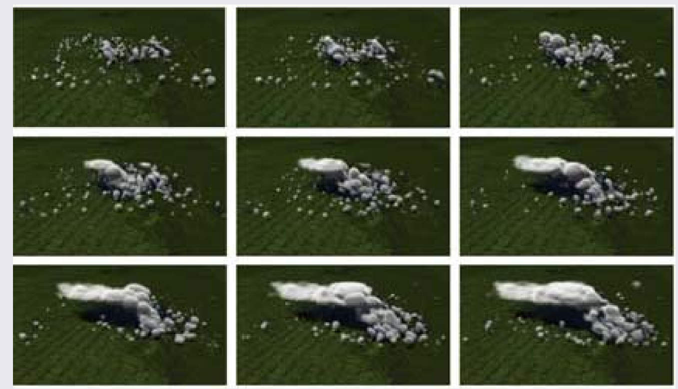
Global Model
Ex: Madden-Julian Oscillation, tropical waves



Regional Model
Ex: Vortex merger



Cloud Model
Ex: Precipitation and convection



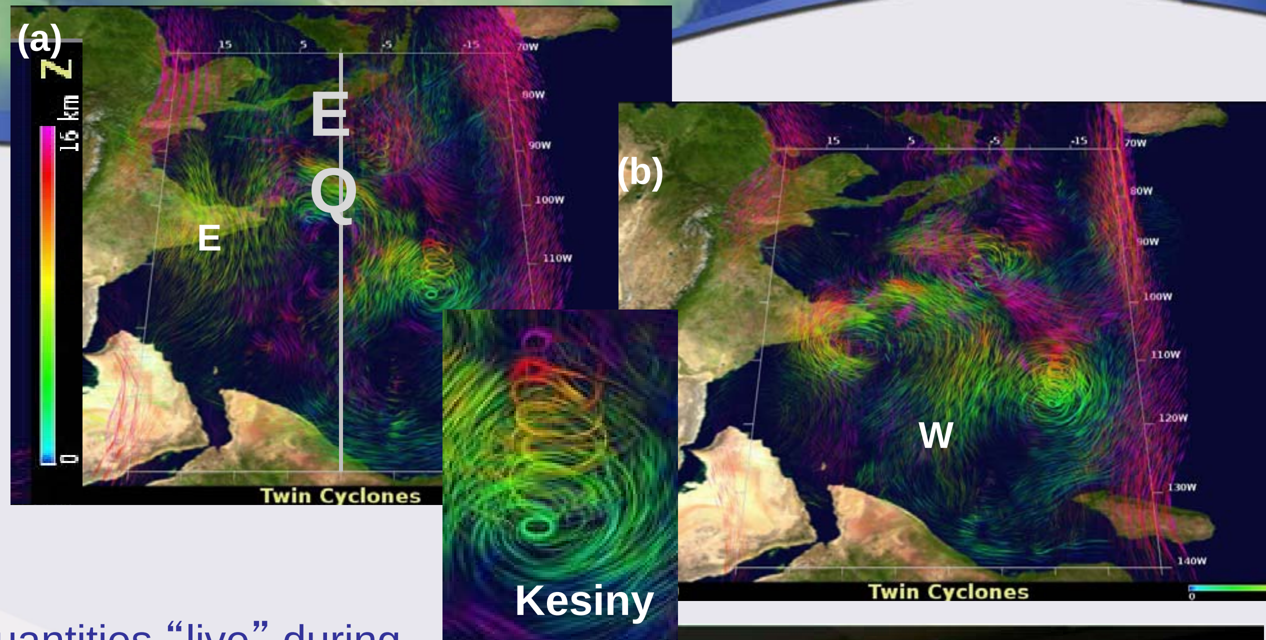
Downscaling → ← **Upscaling**

Super-parameterization
(multi-scale modeling framework, MMF)

Full simulation that accurately captures scale interactions: large-scale environment (deterministic), to mesoscale flows, down to convective-scale motions (stochastic).

Shen, Bo-Wen, B. Nelson, S. Cheung, W.-K. Tao, 2012d: Scalability Improvement of the NASA Multiscale Modeling Framework for Tropical Cyclone Climate Study. (<u>submitted</u> to CiSE in April, 2012)

CAMVIS Concurrent Visualizations



EXTRACT DATA from running simulations to graphics processors

AVOID SLOW DATA WRITES to disk (>100X improvement in performance)

VISUALIZE many different quantities "live" during the active simulation

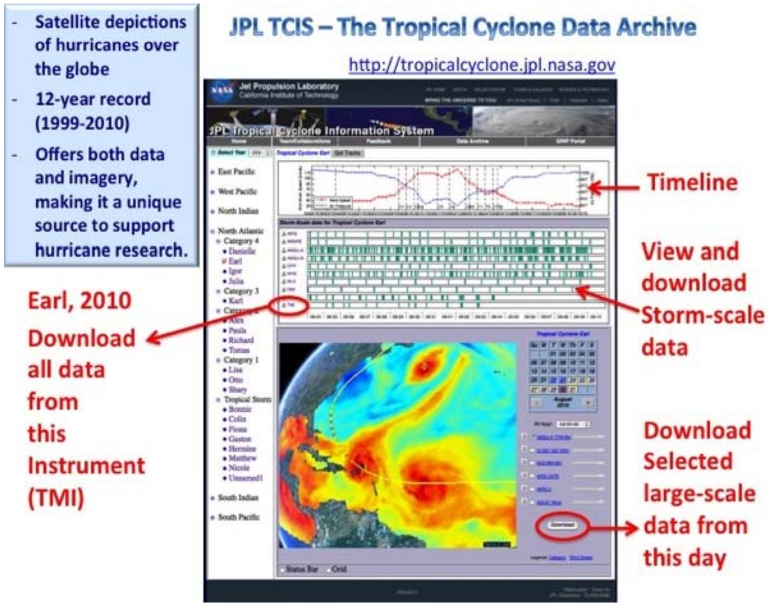
GENERATE MOVIES of the simulation that can later be played back

This method has a proven ability to discover features of interest that exist at very fine temporal scales

Green, B., C. Henze, B.-W. Shen, 2010: Development of a scalable concurrent visualization approach for high temporal- and spatial-resolution models. AGU 2010 Western Pacific Geophysics Meeting, Taipei, Taiwan, June 22-25, 2010.

The JPL Tropical Cyclone Information System (TCIS)

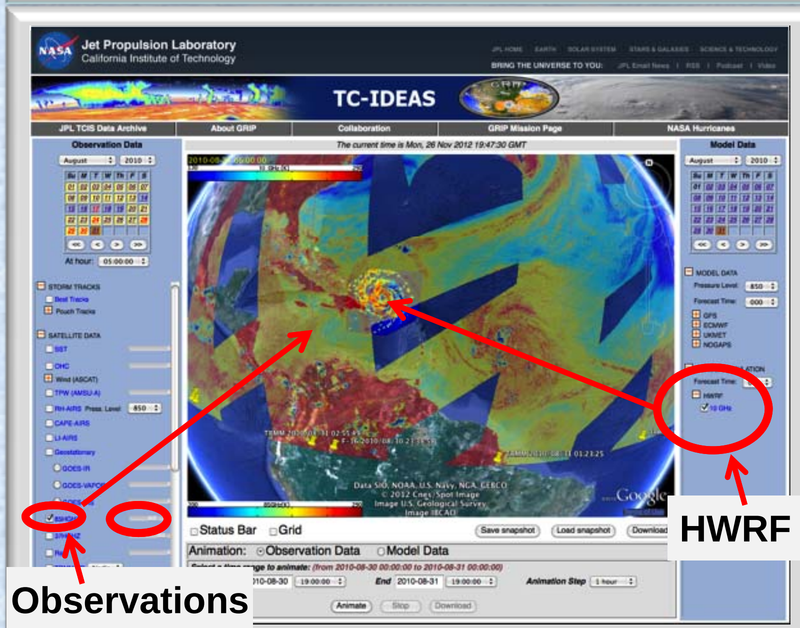
http://tropicalcyclone.jpl.nasa.gov - PI: S. Hristova-Veleva



Tropical Cyclone Data Archive

supported by NASA/HSRP-2008

- Satellite depictions of hurricanes over the globe
- Multi-instrument observations pertaining to: i) the storm structure; ii) the air-sea interactions; iii) the larger-scale environment
- 11-year record (2000-2010) First phase released 05/2012
- Offers both digital data and imagery
- A unique source to develop robust statistics for:
  - hurricane research
  - algorithm development



Fusion of Models and Observations

supported by NASA/ESTO/AIST-2011

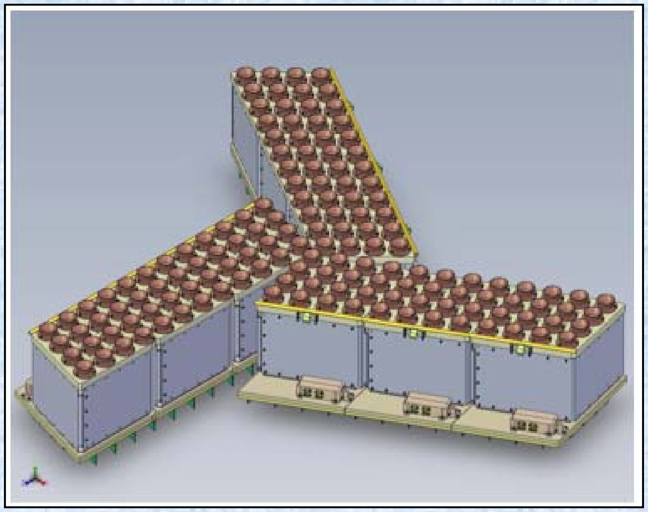
- Now: Integrating hurricane model forecasts with satellite and airborne observations from a variety of instruments and platforms
- Next: Analysis tools to allow interrogation of a large number of atmospheric and ocean variables
  - To evaluate and improve models
  - To better understand the large-scale and storm-scale processes and their interaction

New capabilities with GeoSTAR technology

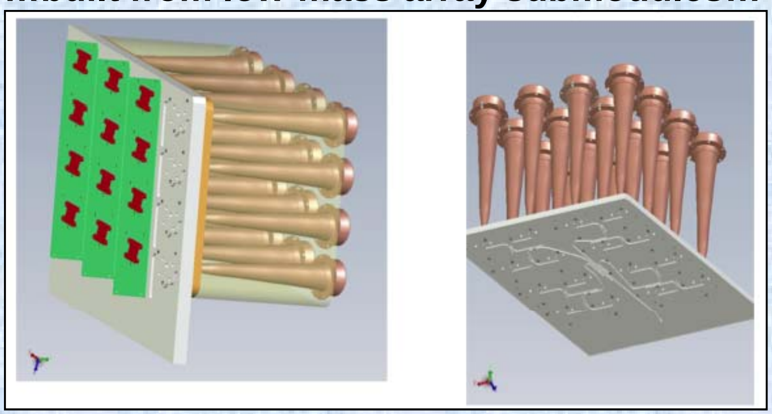
PI: Bjorn Lambrigtsen, JPL

New GeoSTAR antenna design enables targeted observations with microwave sounder from GEO

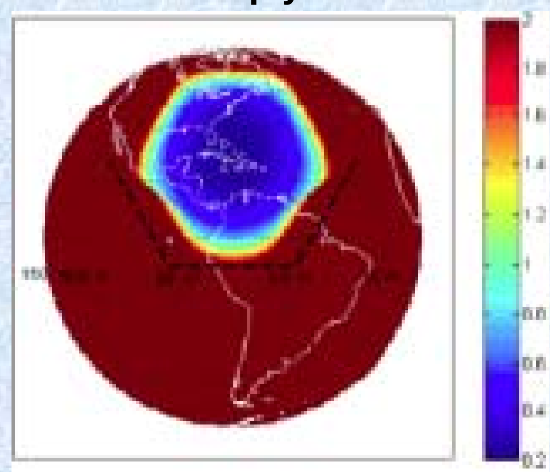
Multi-row receiver array…



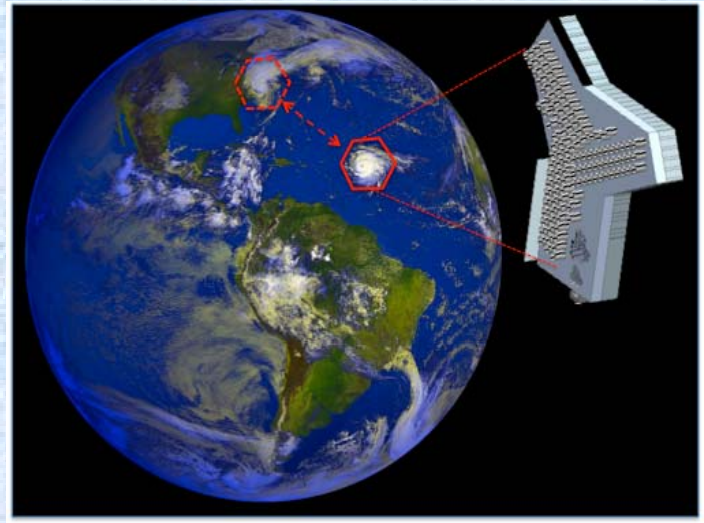
…built from low-mass array submodules…



…results in sharply bounded FOV…



…and enables continuous storm tracking



NASA is Preparing for the NRC Earth Science Decadal Survey-Recommended "3-D Winds" Mission

• Primary data product will be global vertical profiles of horizontal vector winds throughout the troposphere assimilated into Numerical Weather Prediction models

NASA Preparations:

• Measurement Requirements (with NOAA)
• Computer Simulation of Doppler Lidar Wind Measurement from Orbit
• Doppler Lidar Technology Development …
• OSSE Studies of Science Value of Predicted Wind Measurements (with NOAA)
• Instrument and Mission Design & Costing Studies (with NOAA)
• International Partnerships

Near-Term Contributions to Cyclone Research Possible With Airborne Wind Lidars

- Cyclone/hurricane research and forecasting will be advanced by both airborne and space-based pulsed Doppler wind profiling lidar systems
- NASA is developing several types of pulsed wind profiling lidar systems to progress from airborne to space-based platforms

Lidar Name	Type	Wind Tracer Target	Location	Airplane/Date First Flown	Airplane/Date First Flown
DAWN	Coherent	Aerosols	NASA Langley	DC-8 2010 (GRIP)	UC-12B 2012
TWiLiTE	Direct, Double-Edge	Molecules	NASA Goddard	ER-2 2011	Global Hawk planned
OAWL	Direct, ~ Mach-Zehnder	Aerosols	Ball Aerospace	WB-57 2011	
FIDDL	Fabry-Perot	Molecules	Ball Aerospace		

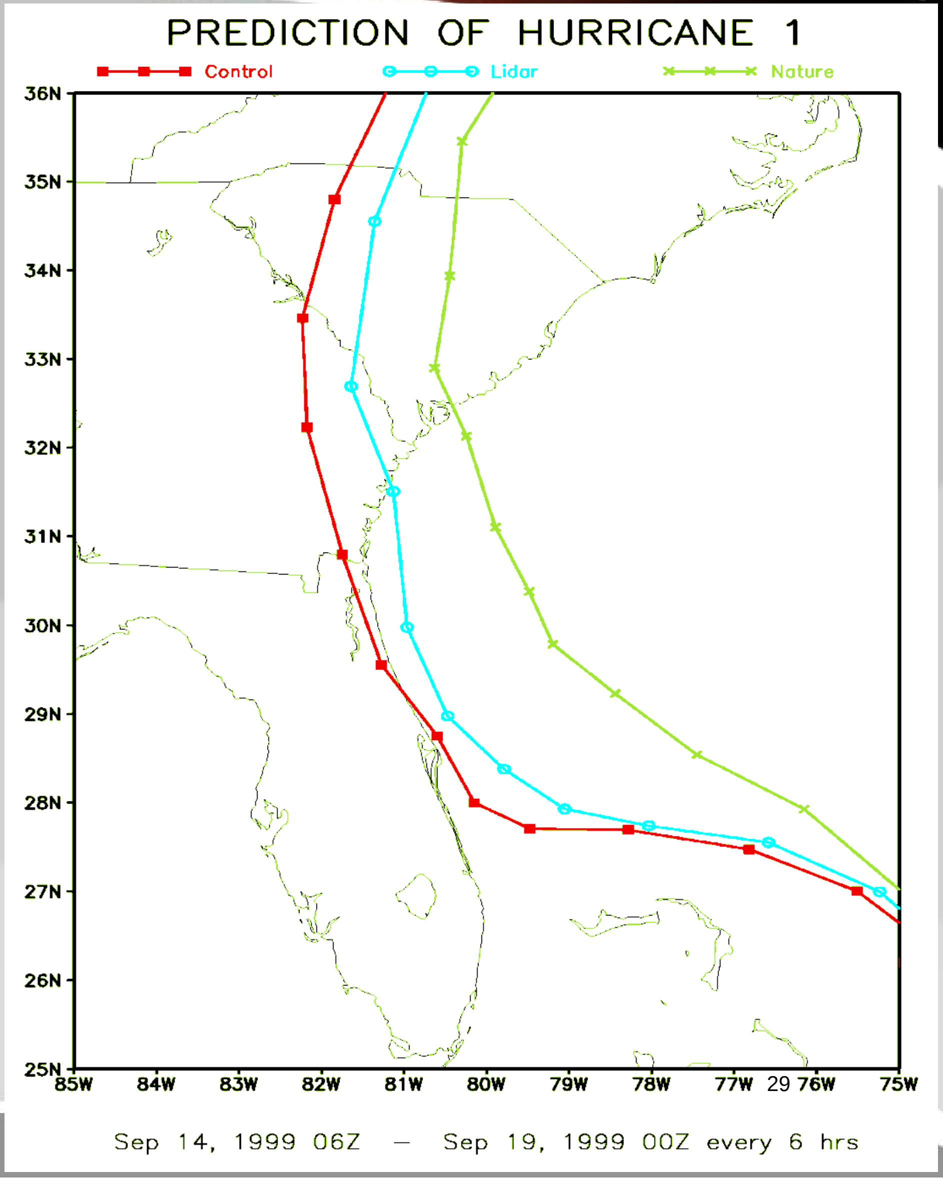
An Orbiting Tropospheric Wind Profiler Should Contribute to Improved Hurricane Intensity and Track Prediction

Green: Actual track
Red: Forecast beginning 63 h before landfall with current data
Blue: Improved forecast for same time period with simulated DWL data

Note: A significant positive impact was obtained for *both* land-falling hurricanes in the 1999 data; the average impact for 43 oceanic tropical cyclone verifications was also significantly positive

- **W. E Baker, R. Atlas, et al, "Lidar-Measured Wind Profiles – The Missing Link in the Global Observing System," Submitted to BAMS (2013)**
- **Atlas, R., and L.P. Riishojgaard, 2008: Application of OSSEs to observing system design. In Remote Sensing System Engineering, P.E. Ardanuy and J.J. Puschell (eds.). Proceedings, SPIE, 7087:708707, doi:10.1117/12.795344, 9 pp.**
- **Atlas, R., and G.D. Emmitt, 2008: Review of observing system simulation experiments to evaluate the potential impact of lidar winds on numerical weather prediction. ILRC24, Vol. 2 (ISBN 978-0-615-21489-4), 726-729.**

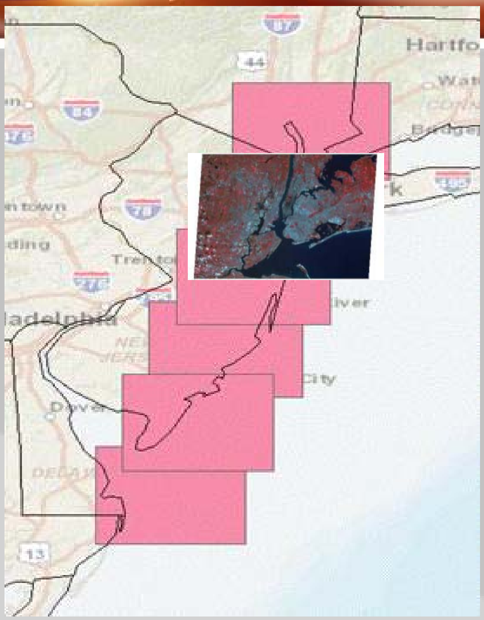
"… will provide winds from aerosols of the Saharan Air Layer, Arabian Dust and Asian Pollution. … expected to define the four dimensional winds from the Central Atlantic to the Central Pacific for improved prediction of the hurricane and the monsoon environment."
Prof. T. N. Krishnamurti, FSU (2013)



NASA Program Elements Contributing to Tropical Cyclone Research

- Satellites
  - Present
  - Future
- Airborne Observations
- Computational Modeling
- Technology Development and Evaluation
  - Instruments
  - Information Systems
  - Observing System Evaluation
- Applications of NASA Products

Examples of Daily Coordinated Support to FEMA



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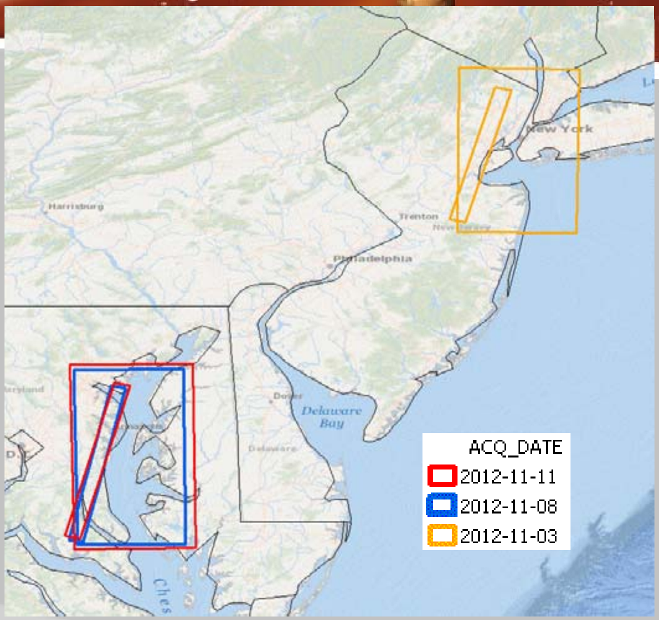
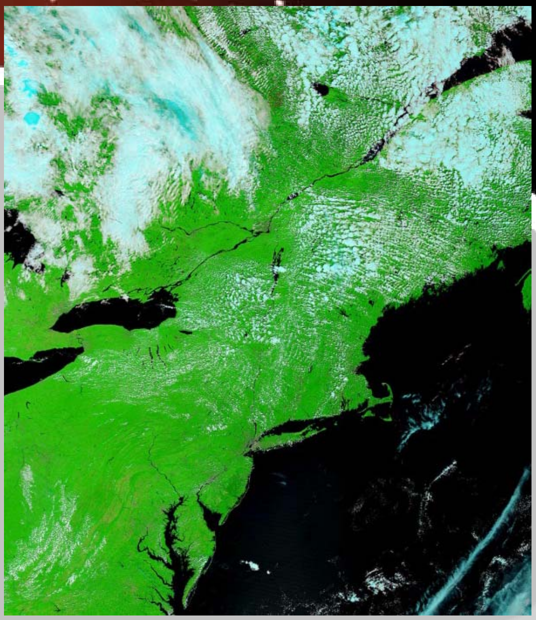
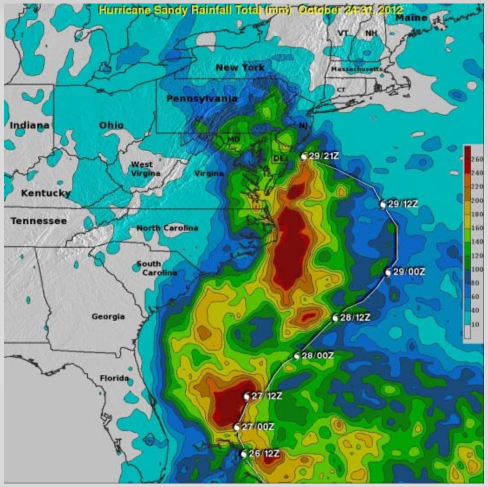


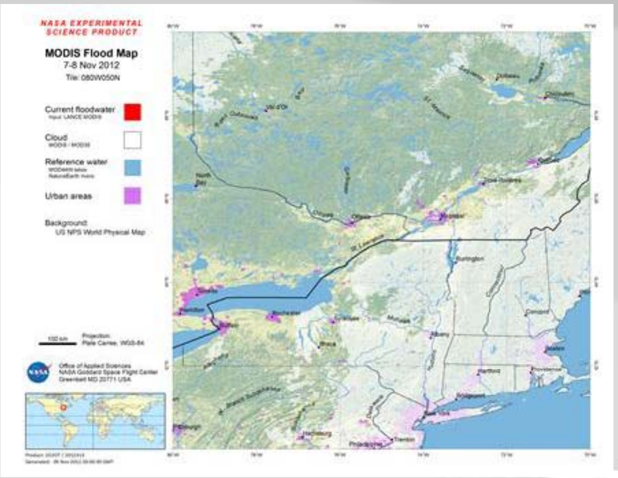
EO-1 3, 8, and 11 Nov 2012



Aqua and Terra MODIS, 23 August 2011, Clear Image



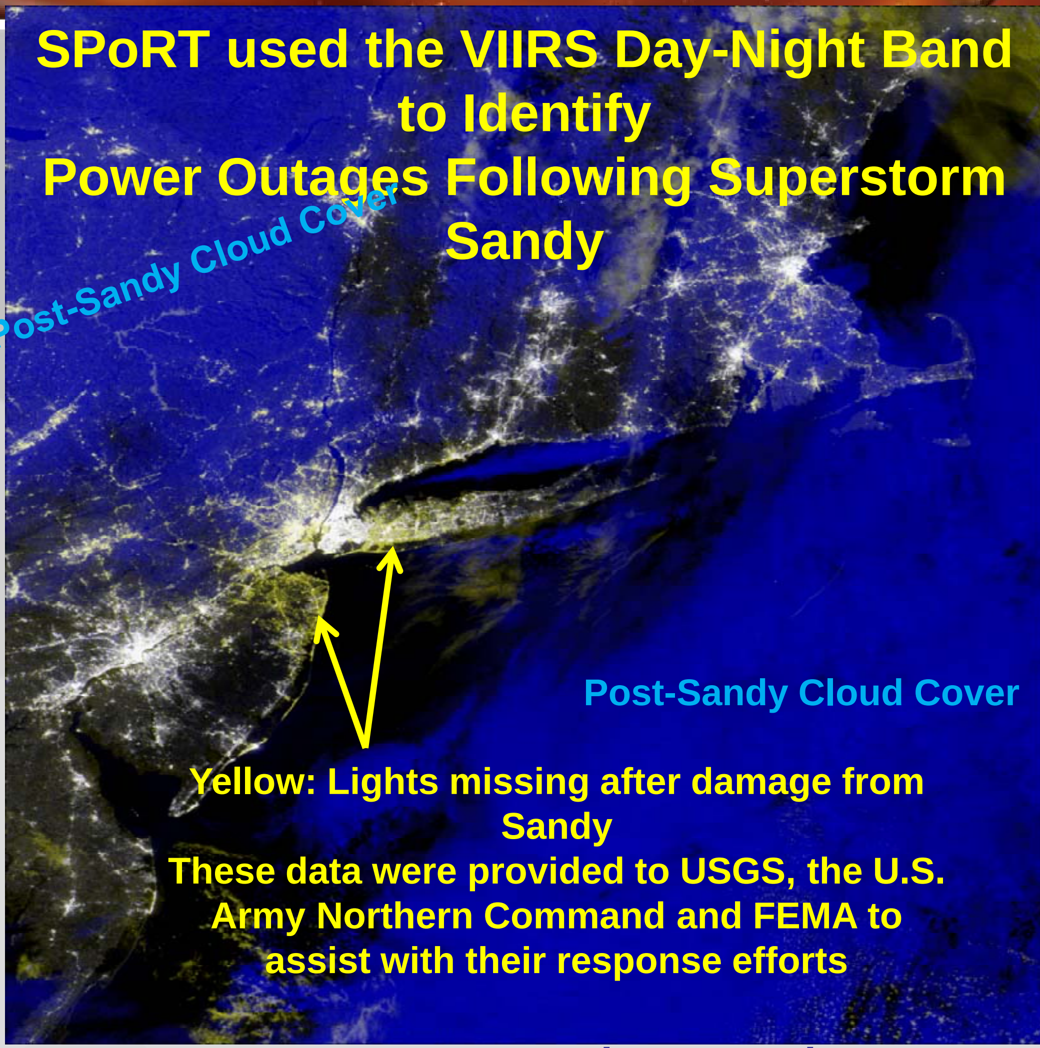
TRMM Rainfall Total Analysis 29 Nov 2012



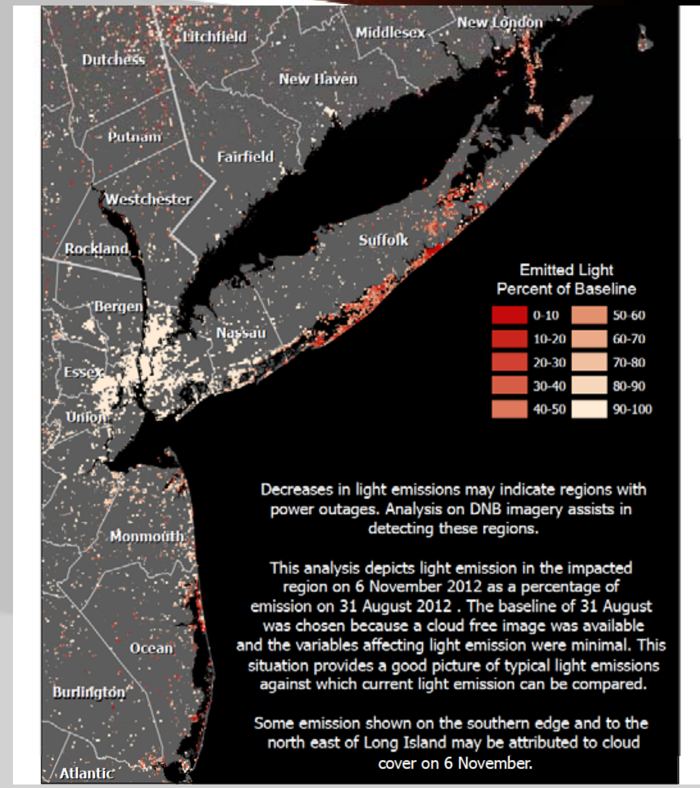
MODIS Flood Map, 7-8 Nov 2012

VIIRS 750 m Day Night Band, 31 October 2012

NASA's SPoRT Center Supports Disaster Response Following "Superstorm Sandy"

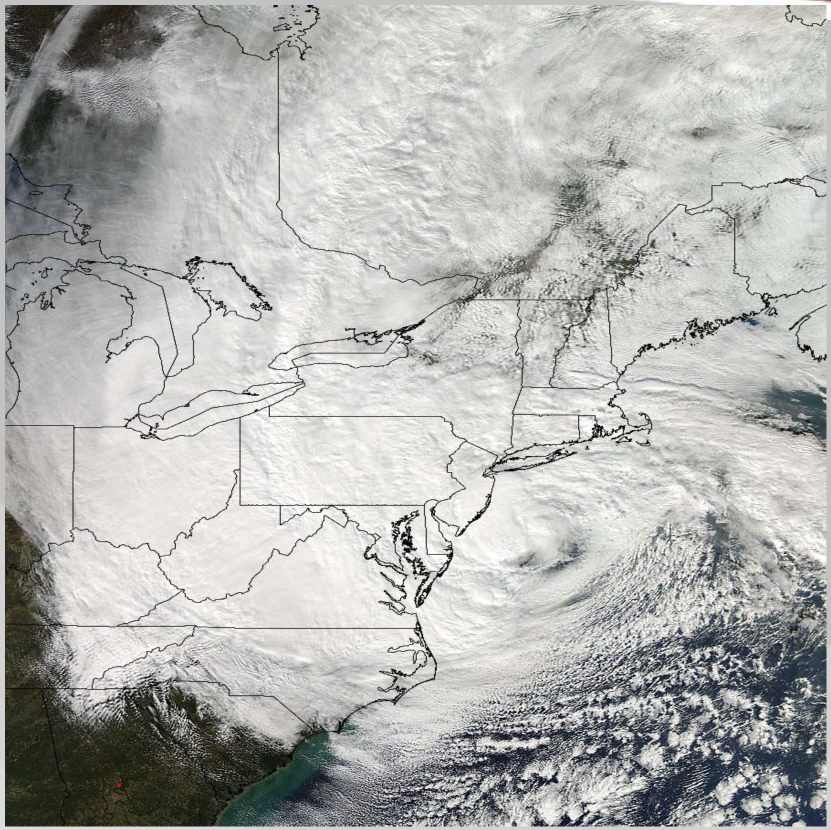


Post-Sandy: November 1, 2012



SPoRT provided VIIRS data to the Joint Task Force Civil Support (JTF-CS) and the Department of Defense Northern Command (NORTHCOM). With SPoRT's support, analysts adapted the VIIRS data into their own product to help gauge power restoration in support of recovery efforts.

NASA, Hurricane Sandy Archive



NASA's Aqua satellite captured a visible image Sandy's massive circulation on Oct. 29 at 18:20 UTC (2:20 p.m. EDT). Sandy covers 1.8 million square miles, from the Mid-Atlantic to the Ohio Valley, into Canada and New England. Credit: NASA Goddard MODIS Rapid Response Team

http://www.nasa.gov/mission_pages/hurricanes/archives/2012/h2012_Sandy.html

Summary

- Current and future satellites provide new ways of looking at tropical cyclones, informing a broad community of researchers
- 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
- 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