UAS Applications for Hurricane Science

Hurricane and Severe Storm Sentinel (HS3)

Dr. Scott Braun, NASA Goddard Space Flight Center

UAS Commercialization Industry Conference, November 18, 2014

General Overview for Today's Talk

- NASA Global Hawk program, operations & challenges
- Improving science capabilities through UAS applications: Hurricane experiments
- Envisioning the future of high-altitude, long-duration Earth Science missions

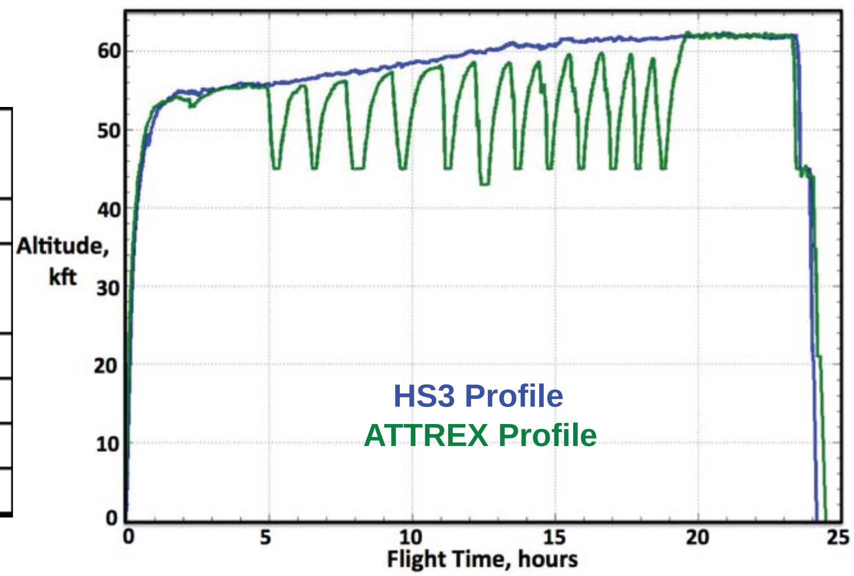
NASA's Airborne Science Program

- Responsible for providing aircraft systems that further science and advance the use of satellite data. Primary objectives:
    - Collect hi-res imagery for focused process studies
    - Test new sensor technologies in space-like environments
    - Calibrate/validate space-base measurements and retrieval algorithms
    - Demonstrate and exploit the capabilities of UAS for science investigations
- ASP supported aircraft include:
    – WB-57, ER-2, DC-8, G-III, P-3 Orion, C-130, Twin Otter, among other manned aircraft
    – Global Hawk, Ikhana, Sierra, Bat 4 UASs


NASA Global Hawk Capability

- NASA has been flying Global Hawk aircraft for airborne science research since 2010. Ten science campaigns have been completed.
- Operated from either NASA Armstrong Flight Research Center, NASA Wallops Flight Facility, or a portable Flight Control Station.
- A NASA/Northrop Grumman team is maintaining, modifying, and operating these 2 aircraft through a partnership that was established in 2008 and renewed in 2013.

Endurance	24-26 hours for Typical Missions 28.6 hours Demonstrated
Range	10,000 nmi
Service Ceiling	65,000 ft, < 50% available A/C payload power 62,500 ft, > 50% available A/C payload power
Airspeed (55,000+ ft)	335 KTAS
Payload	1,200 lb Demonstrated
Length	44 ft
Wingspan	116 ft



Typical Flight Profiles

NASA Global Hawk Asset Overview

Operational Aircraft

Spares Aircraft

Global Hawk Operations Center – East (WFF)

Global Hawk Operations Center (AFRC)

Portable Ground Systems

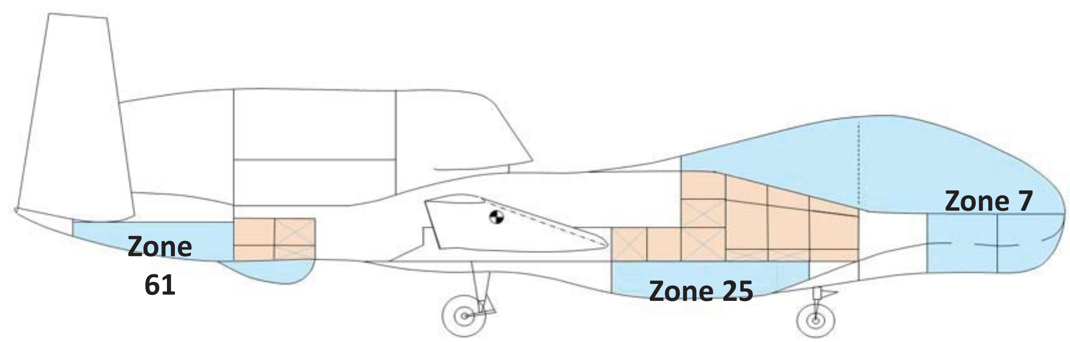
Challenges Along the Road to Hurricane Flights

Major modifications needed to make GH science operational

- Development of an Airborne Payload Command, Control, Communication (C3) System
- Development of instrument and data acquisition infrastructure
  - Data acquisition and transmission unit (NASDAT), Experimenter Interface Panels (EIPs), IT architecture
- Decoupling of aircraft and science instrument operations
  - Required separate pilot and payload portions of the Armstrong, Wallops and mobile operations centers
- Reinforcement of the fuselage to accommodate large sensors
  - More than 40 reinforcements to stiffen the fuselage
- Installation of hazard awareness equipment (low-light and HD cameras, Stormscope, accelerometers)

Challenges Along the Road to Hurricane Flights

- Instrument integration challenges
  - Cantilevered mount in tail zone, external mounts
  - Challenging aircraft for getting weight & balance correct
- Communications: Implementation of Ku, particularly joint use by pilots and instruments
- Turning the GH into a fast-turnaround and responsive science platform
- Working through the Certificate of Authorization (COA) process and getting approval for laser and dropsonde operations

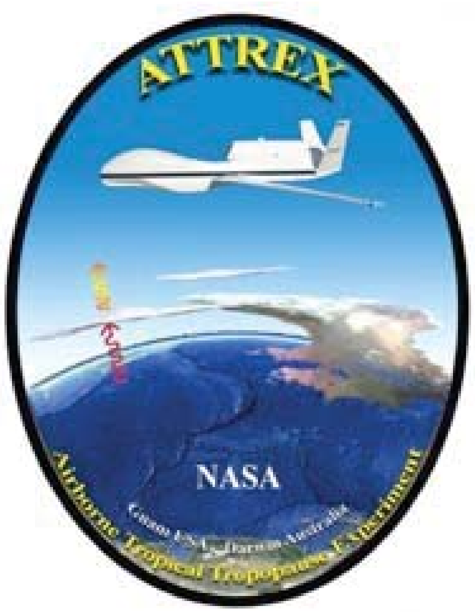


Completed Science Campaigns

2010

2010

2011

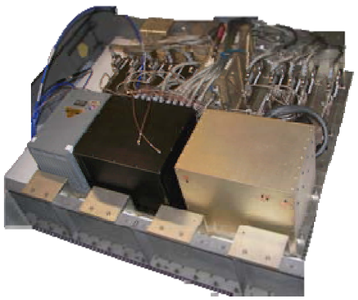


2011, 2013, 2014

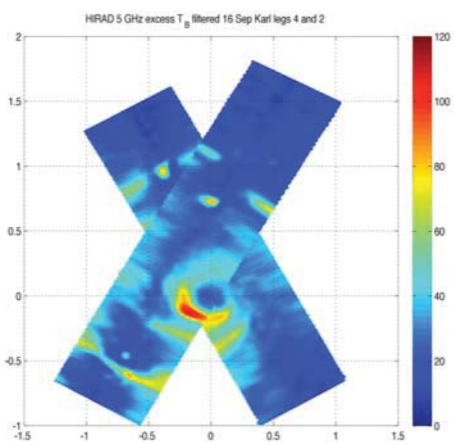
2011, 2012, 2013, 2014

Instruments For The GRIP Campaign

Hurricane Imaging Radiometer (HIRAD)

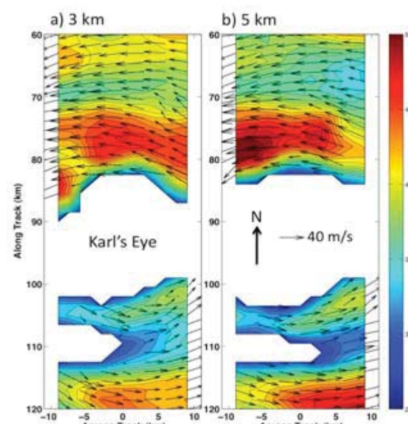


PI: Dr. Tim Miller
NASA MSFC
Measurements:
Surface wind speed, rain rate



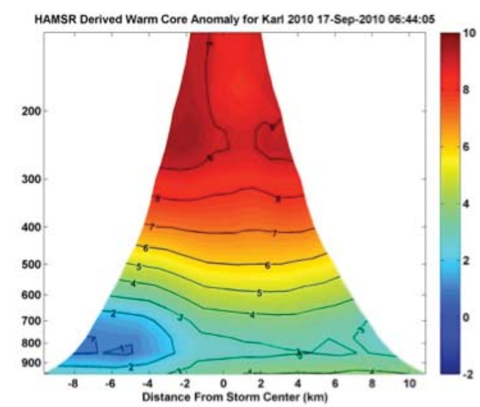
High Altitude Imaging Wind and Rain Airborne Profiler (HIWRAP)

PI: Dr. Gerry Heymsfield
NASA GSFC
Measurements: Radar reflectivity, wind profiles

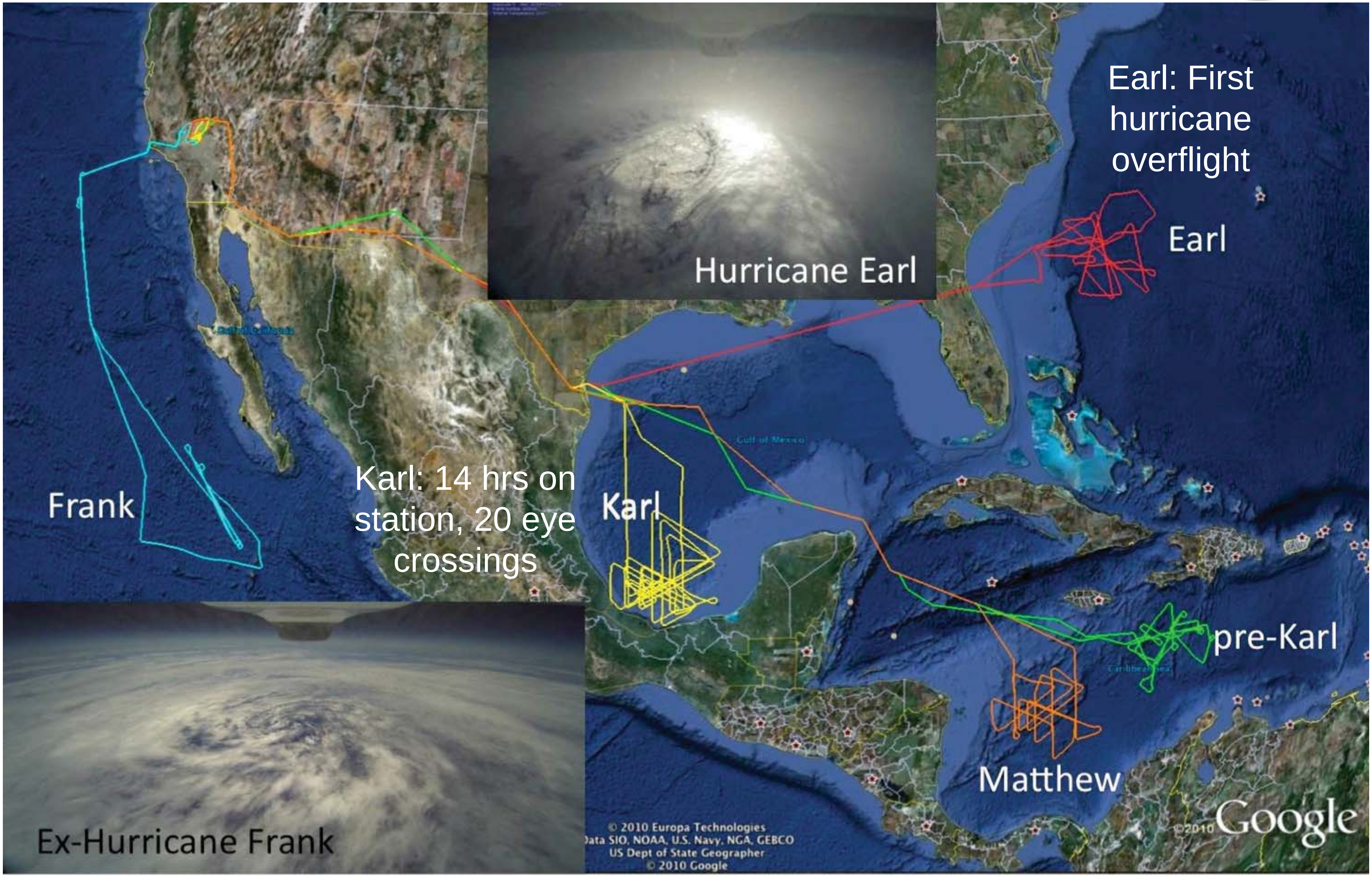


High Altitude Monolithic Microwave integrated Circuit Sounding Radiometer (HAMSR)

PI: Dr. Bjorn Lambrigtsen
Jet Propulsion Laboratory
Measurements: Temperature, water profiles, cloud liquid water

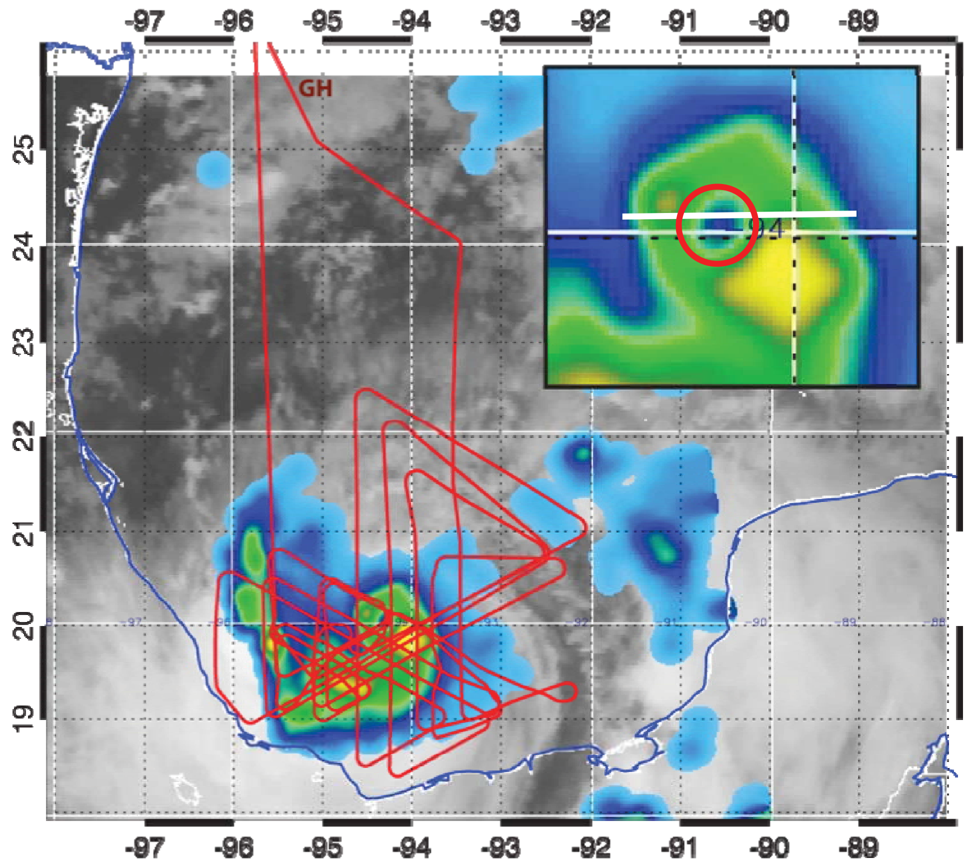


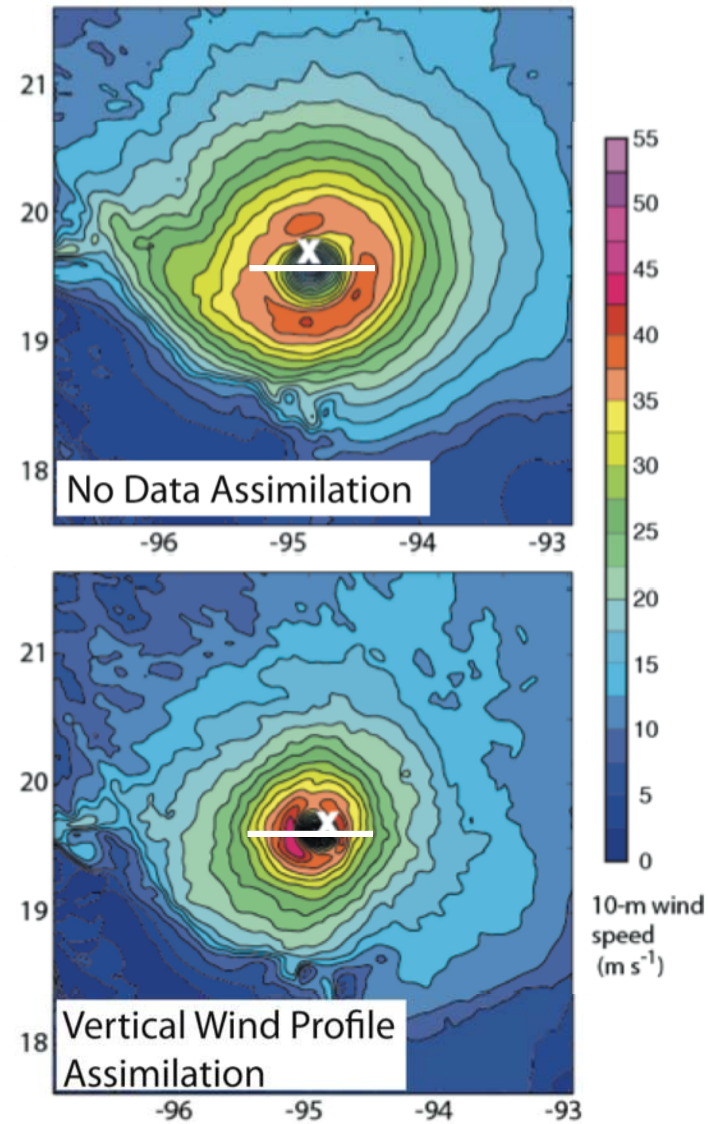
GRIP Accomplishments



Dramatic Improvement in Hindcasts of Hurricane Karl (2010)

Multi aircraft, multi instrument data assimilated into the Hurricane Weather Research and Forecasting model leads to significant improvements in track and intensity for Hurricane Karl





Hurricane and Severe Storm Sentinel (HS3)

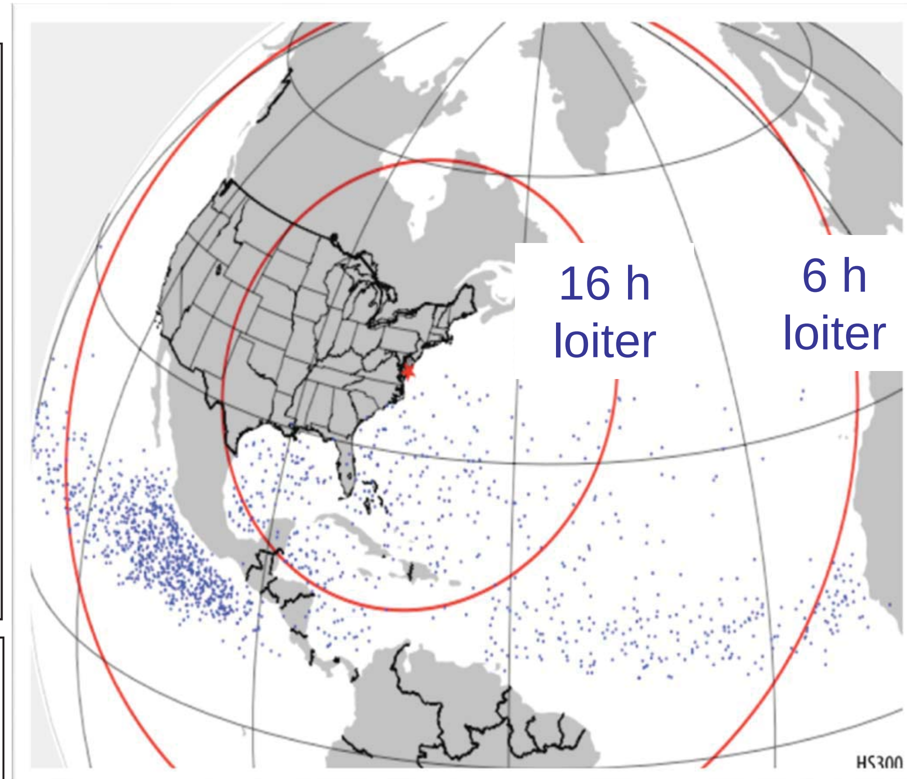
Science Goal: To understand hurricane genesis and intensification.

Key Science Questions:

- What is the impact of the large-scale environment, particularly the Saharan Air Layer?
- What is the role of storm internal processes such as deep convective towers?
- To what extent are these processes predictable?

Deployment Details:

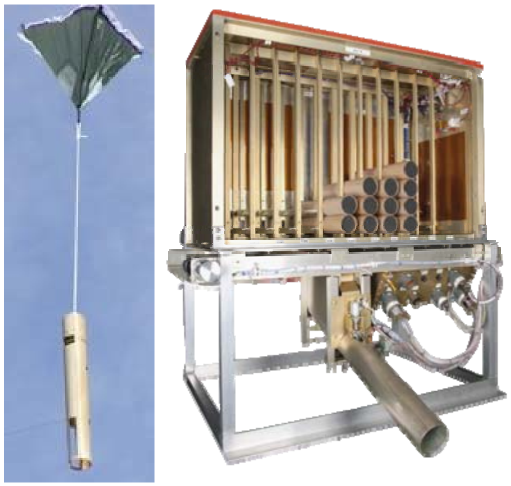
- Deployments in hurricane seasons of 2012-2014
- Based at NASA's Wallops Flight Facility in Virginia
- 275 science flight hours (~10-11 26-hour flights) per deployment



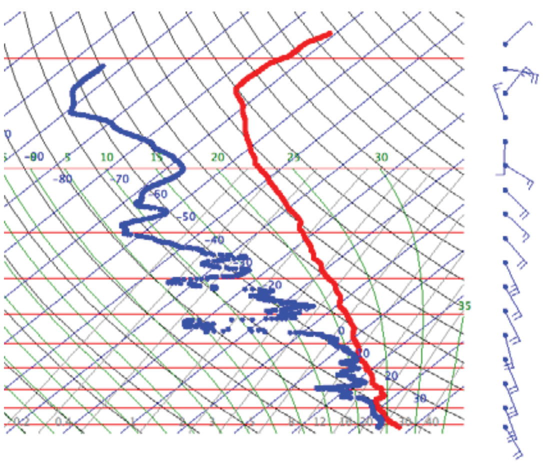
Blue dots show storm formation locations

Instruments on the Environmental Global Hawk

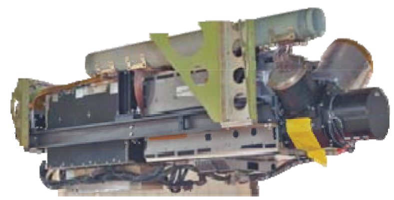
Airborne Vertical Atmospheric Profiling System (AVAPS)



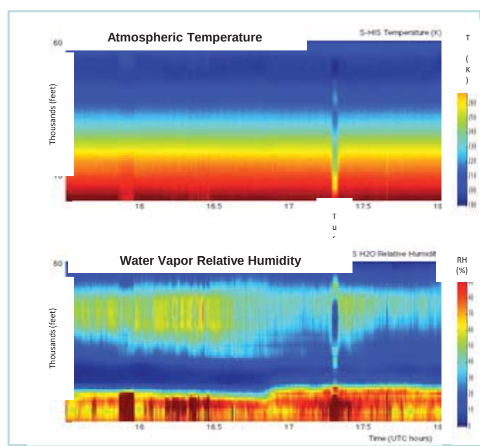
PI: Dr. Gary Wick, NOAA, NCAR
Measurements: Temperature, Pressure, wind, humidity vertical profiles; 88 sondes per flight



Scanning High Resolution Infrared Sounder (S-HIS)

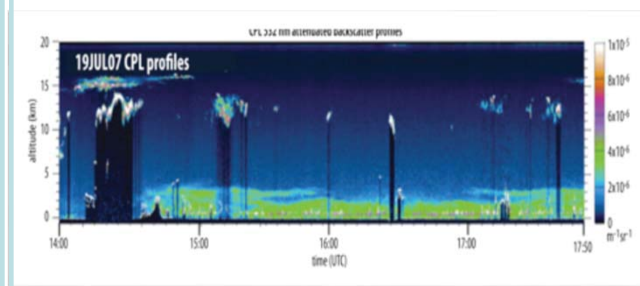


PI: Dr. Hank Revercomb
University of Wisconsin
Measurements: Upwelling thermal radiation at high spectral resolution between 3.3 and 18 microns, temperature, water vapor vertical profiles



Cloud Physics Lidar (CPL)

PI: Dr. Matt McGill
NASA Goddard Space Flight Center
Measurements: Cloud structure and depth



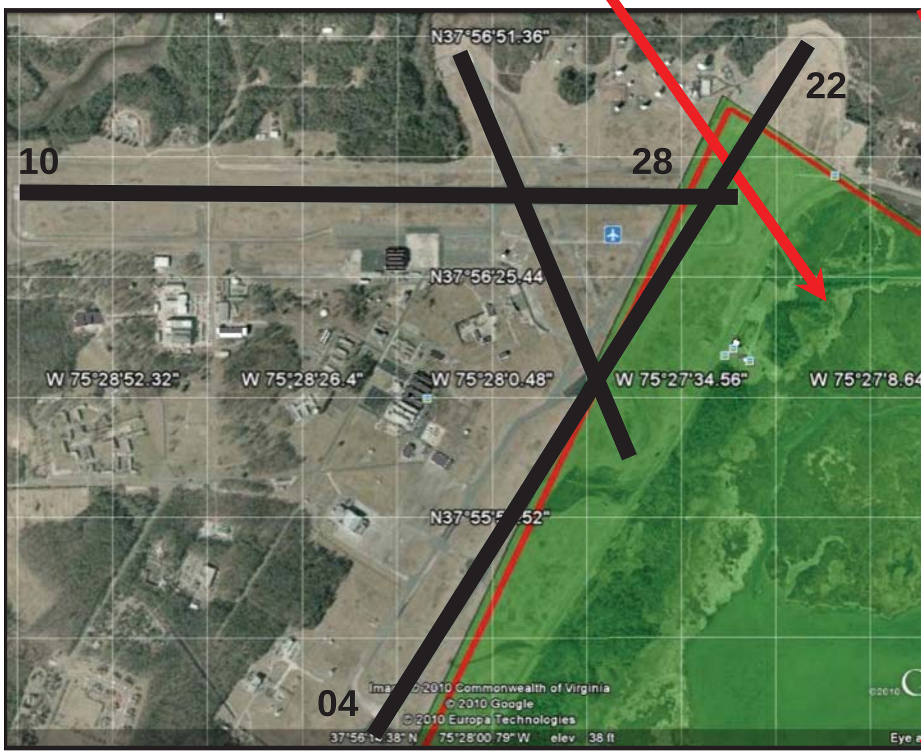
Unique Challenges to Operations At Wallops

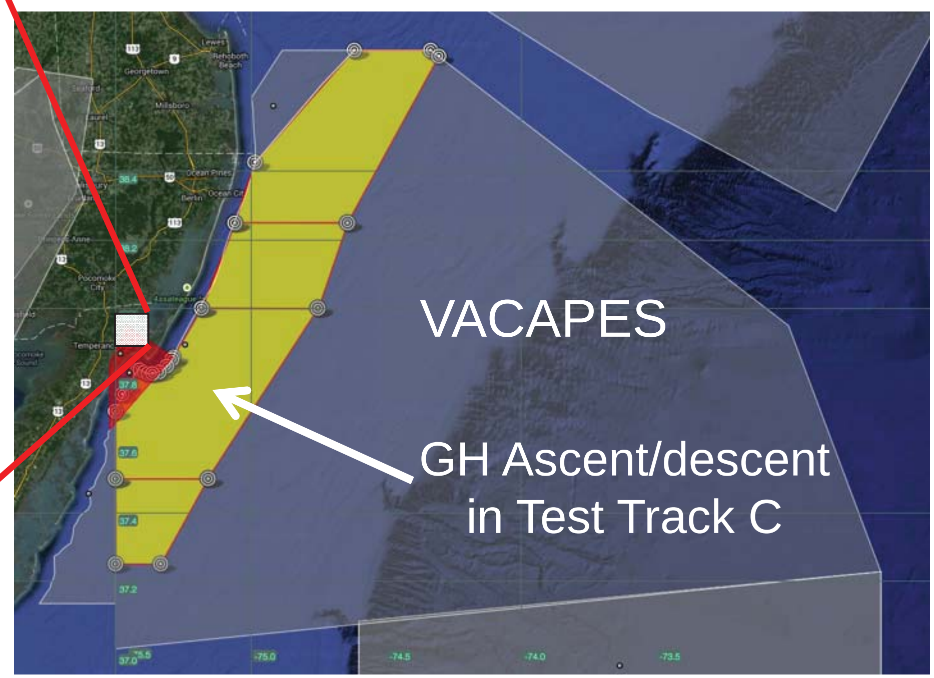
- *WFF Special Use Airspace: R-6604, VACAPES*

R-6604 only partially covers airspace over WFF

Chase aircraft used for all takeoffs and landings

Close coordination with VACAPES to get out into the Atlantic





HS3 Operated Under Many Constraints

1. ***Only one GH could fly at any one time.*** The second aircraft could take off 2 hours after the first lands.
2. A flight plan will be filed with the FAA for all flights per the COA ***2 business days*** in advance
3. Take off and landings had to be scheduled during ***daylight hours*** to allow chase.
4. GH flight durations were planned for ***no more than 26 hours***.
5. No more than 3-4 flights per 7-day period.
6. Instruments not interchangeable between aircraft so each flight plan had to specify which aircraft was used.
7. Take off and landing handled in Wallops GHOC. First/last crew shifts from WFF, middle shifts from AFRC GHOC.

Go-No Go and Mission Rules

Ground Weather Limitations

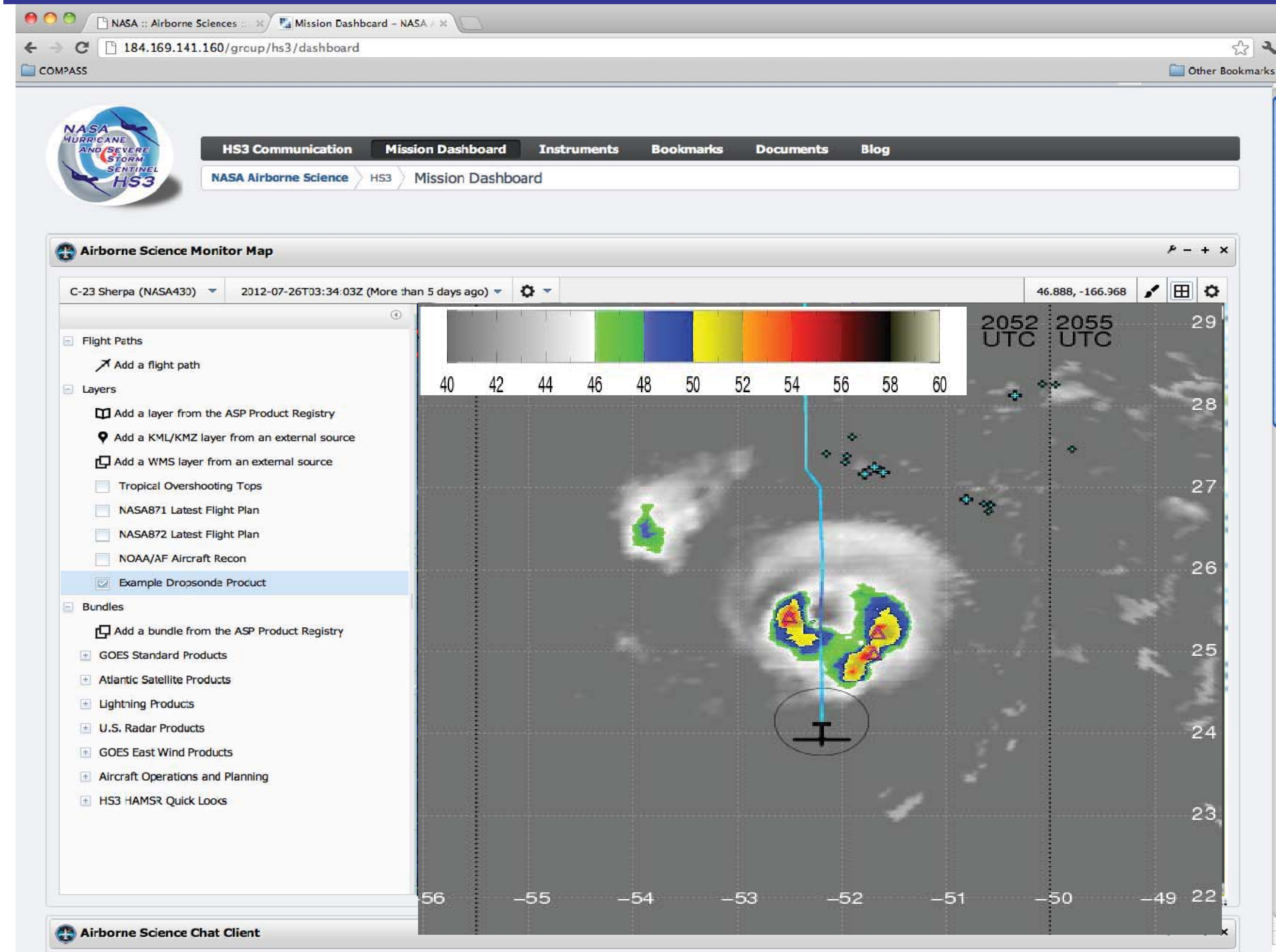
- Winds < 15kts (cross), 30kts (head), 25kts (tail)
- Min. runway visual range (RVR) – 1 mile
- No standing water reported on the runways
- No within 25nm of the projected takeoff or landing flight path
- Visual Flight Rules (VFR) conditions at WFF

In-Flight Weather Limitations

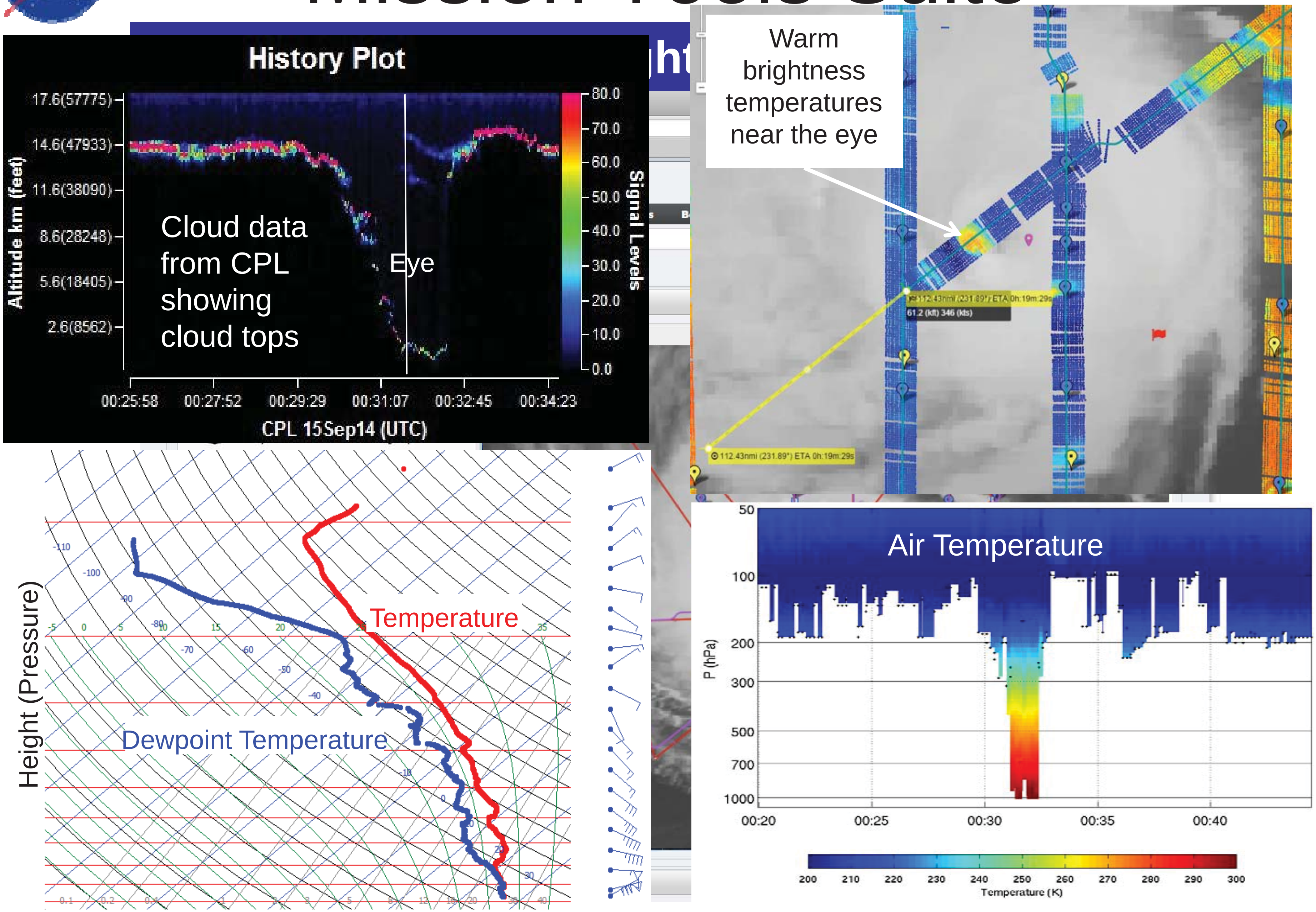
- Do not approach thunderstorms within 25 nm during flight below FL500
- No flights <u>into</u> significant weather clouds
- When significant convection with frequent lightning present
  - CTH>50 kft, maintain 25 nmi separation
  - CTH<50 kft, maintain 10 kft vertical separation
- When significant overshooting top without frequent lightning present
  - CTH>50 kft, maintain 5 kft vertical separation
- No flight into forecasted or reported icing conditions
- No flight into forecasted or reported moderate or severe turbulence

Mission Tools Suite

Hurricane Edouard Flight, September 14-15, 2014

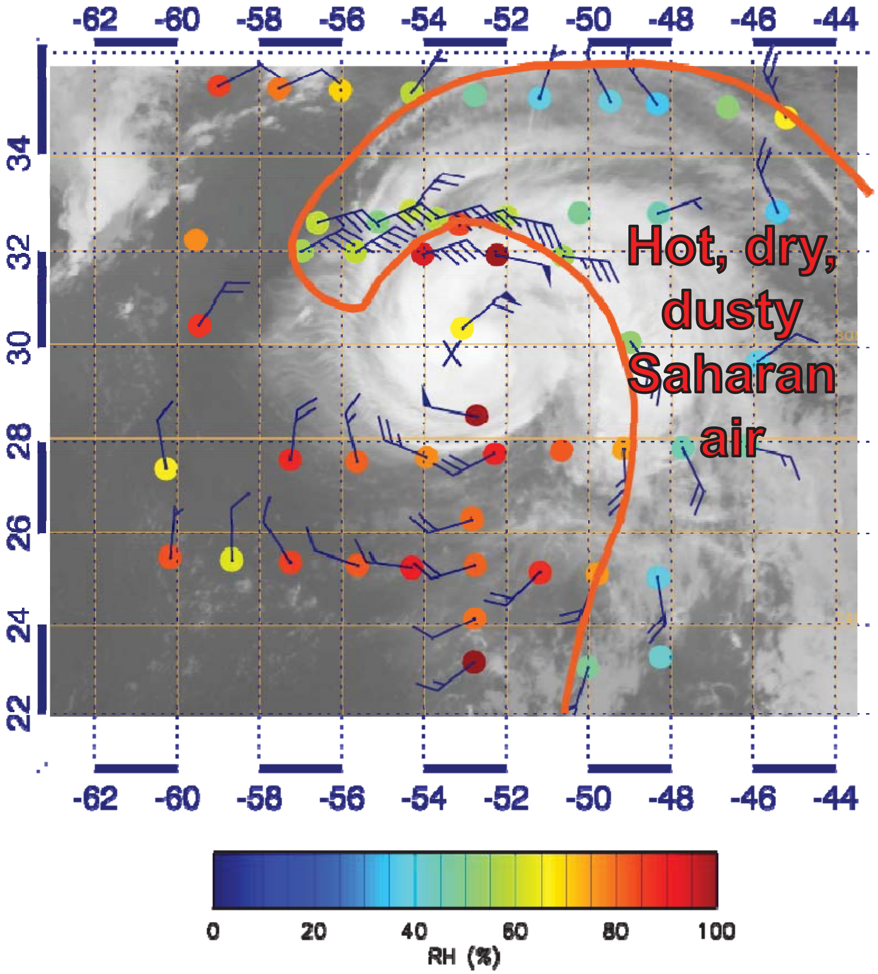


Mission Tools Suite

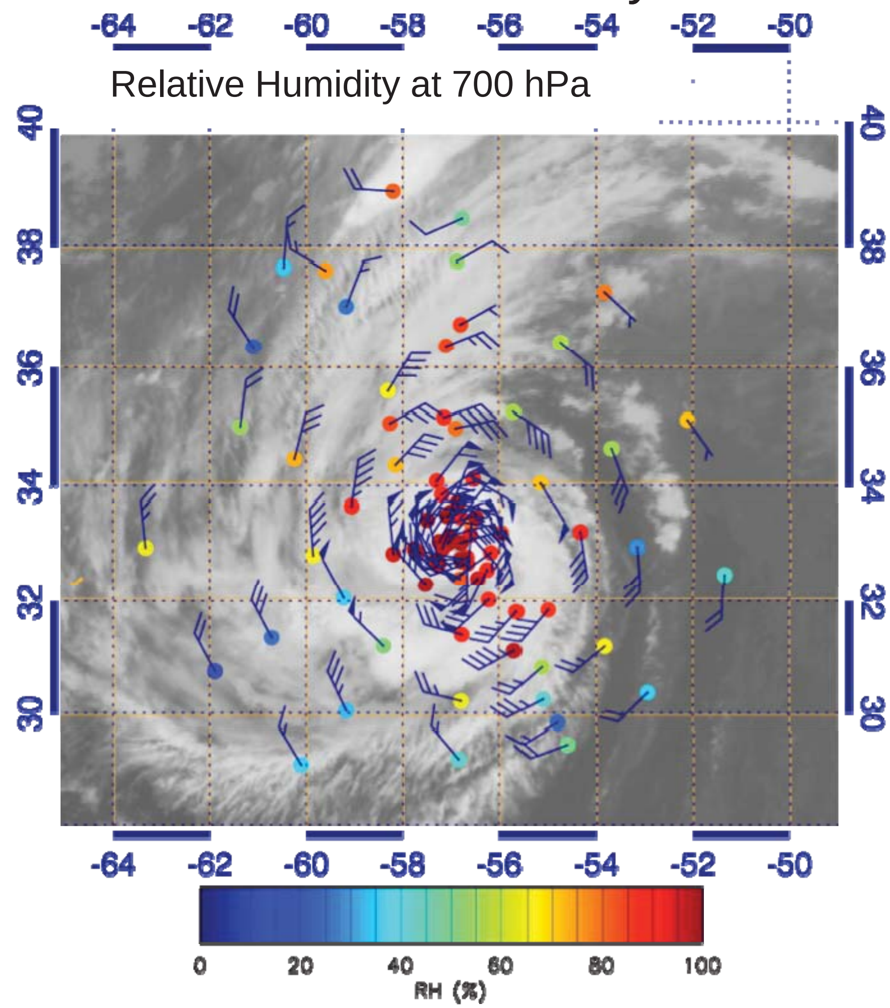


Measuring the Hurricane Environment and Structure

Hurricane Nadine (2012) and the Saharan Air Layer



Hurricane Edouard (2014) near maximum intensity



Impact of HS3 Dropsondes on COAMPS-TC Forecasts of Hurricane Nadine (2012)

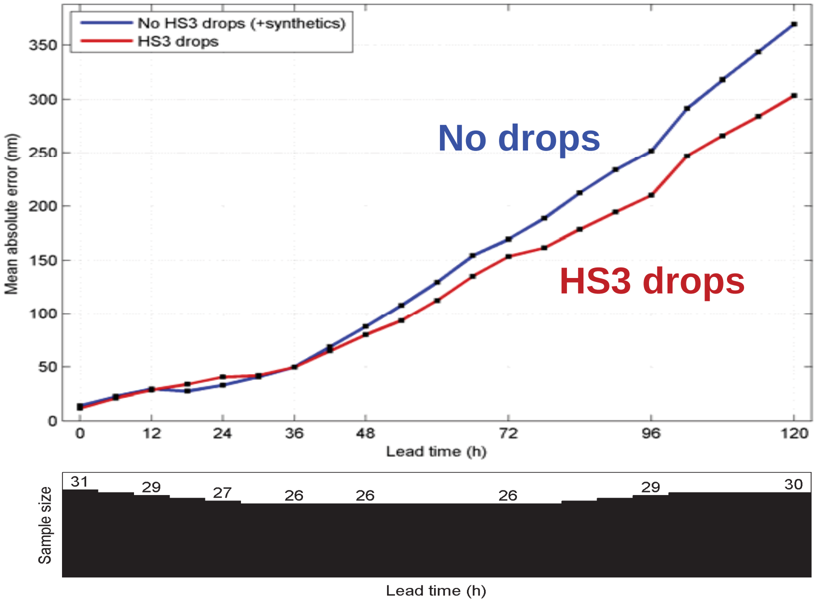
- Goal: To assess the impact of HS3 obs. on forecasts of Nadine

- Dropsonde impact experiments performed for 19-27 Sep. (3 flights)
    - -Red, with HS3 drops
    - -Blue, no drops with synthetics

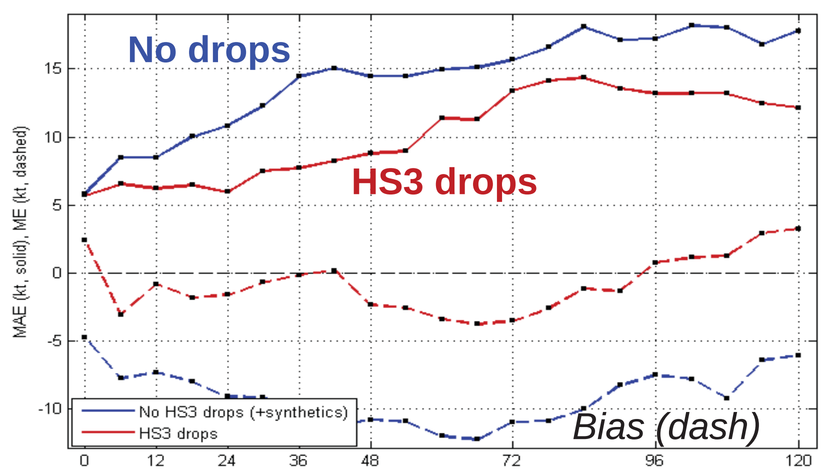
- COAMPS-TC Intensity and track skill are improved greatly through assimilation of HS3 dropsondes.

(From J. Doyle, NRL)

Track Error (nm)

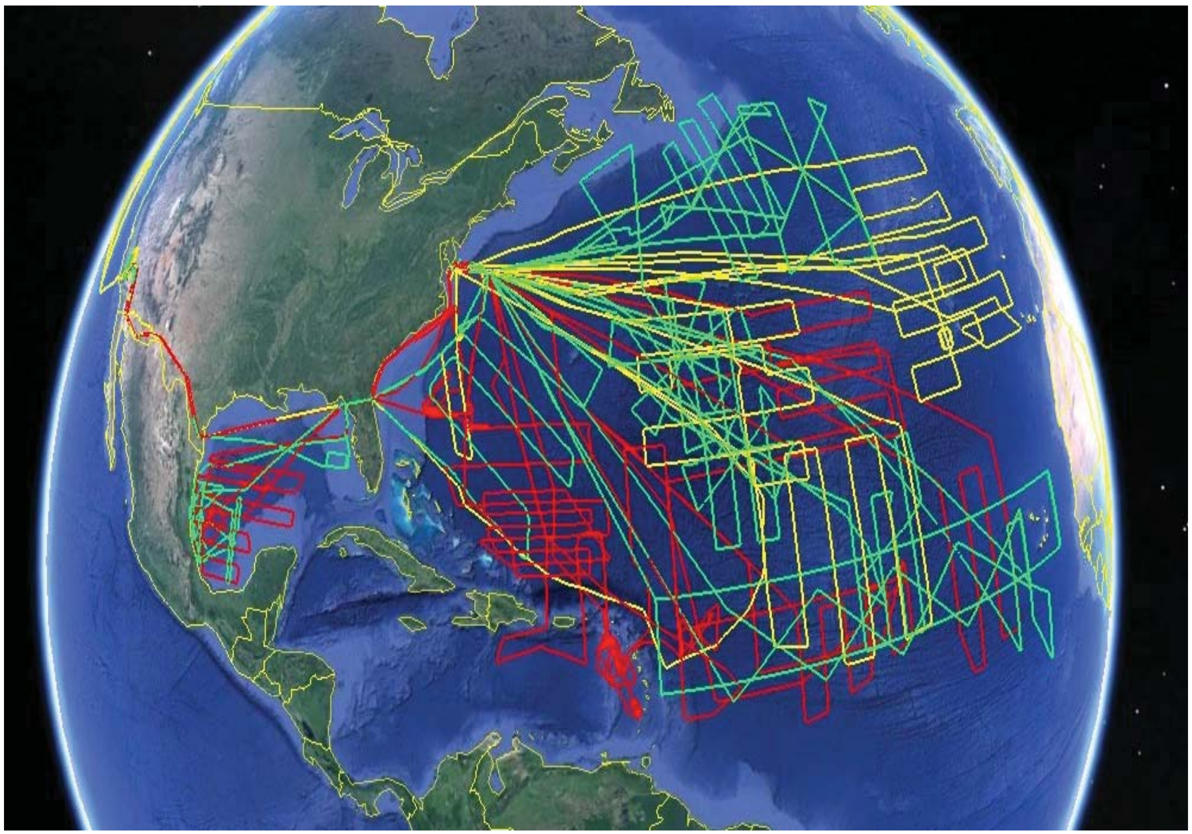


Intensity: Max. Wind Error (kts)



Three Years of HS3 Science

Year	Flights	Hours	Sondes	Named Storms
2012	8	174	343	2
2013	10	223	433	3
2014	13	252	649	4
Total	33	649	1425	9



Yellow=2012, Red=2013, Green=2014

2012

Leslie – 1 Flight
Nadine – 5 Flights

2013

Gabrielle – 4 Flights
Ingrid – 1 Flight
Humberto – 1 Flight
A95L (non-developer) – 1 Flight
Saharan Air Layer – 2 Flights

2014

Cristobal – 2 Flights
Dolly – 1 Flight
SAL, tropical wave —1 flight
Edouard – 4 Flights
Gonzalo – 3 WB-57 Flights

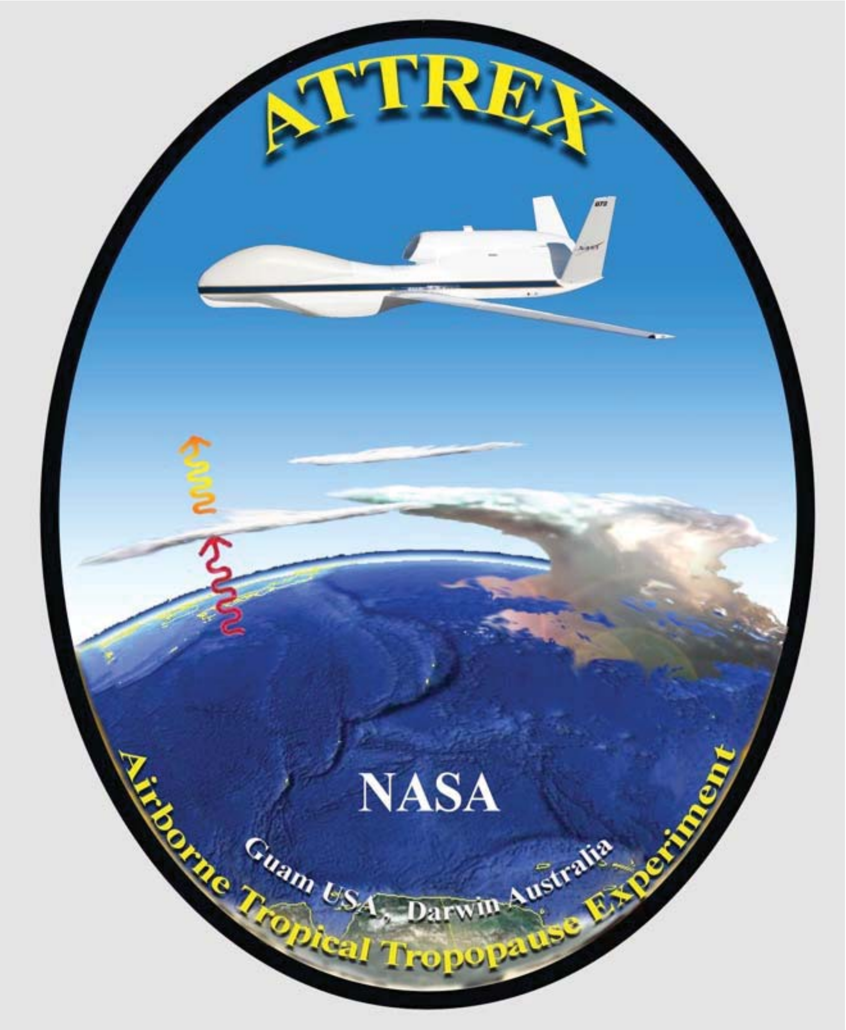
19 Flights Over 9 Named Storms

Stratospheric Water Vapor and Climate Change

The Airborne Tropical Tropopause Experiment (ATTREX)

Ongoing experiment to examine the processes that control water vapor in the Tropical Tropopause Layer and the stratosphere

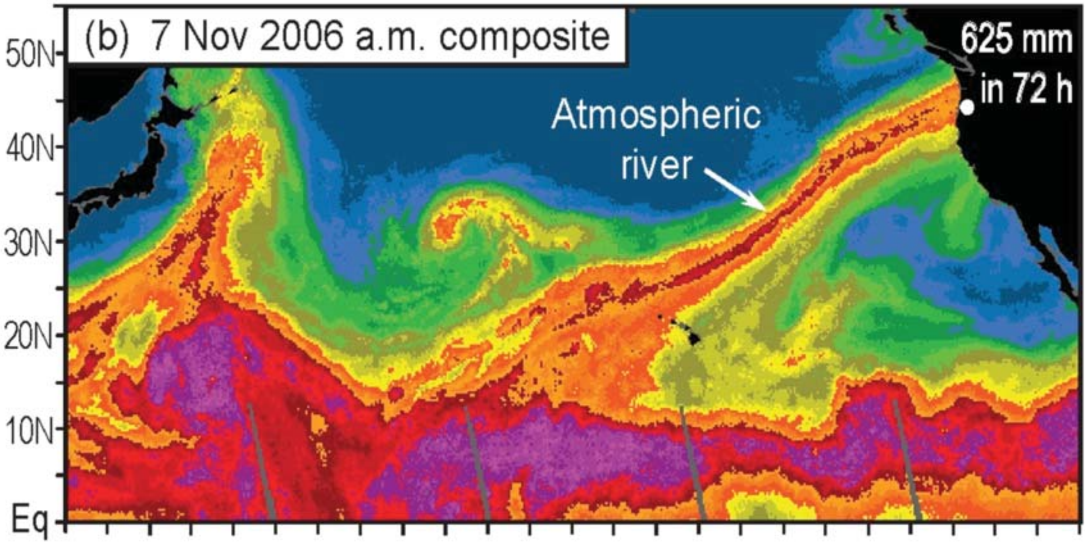
Like HS3, funded under NASA's EV-1 program



Winter Storms

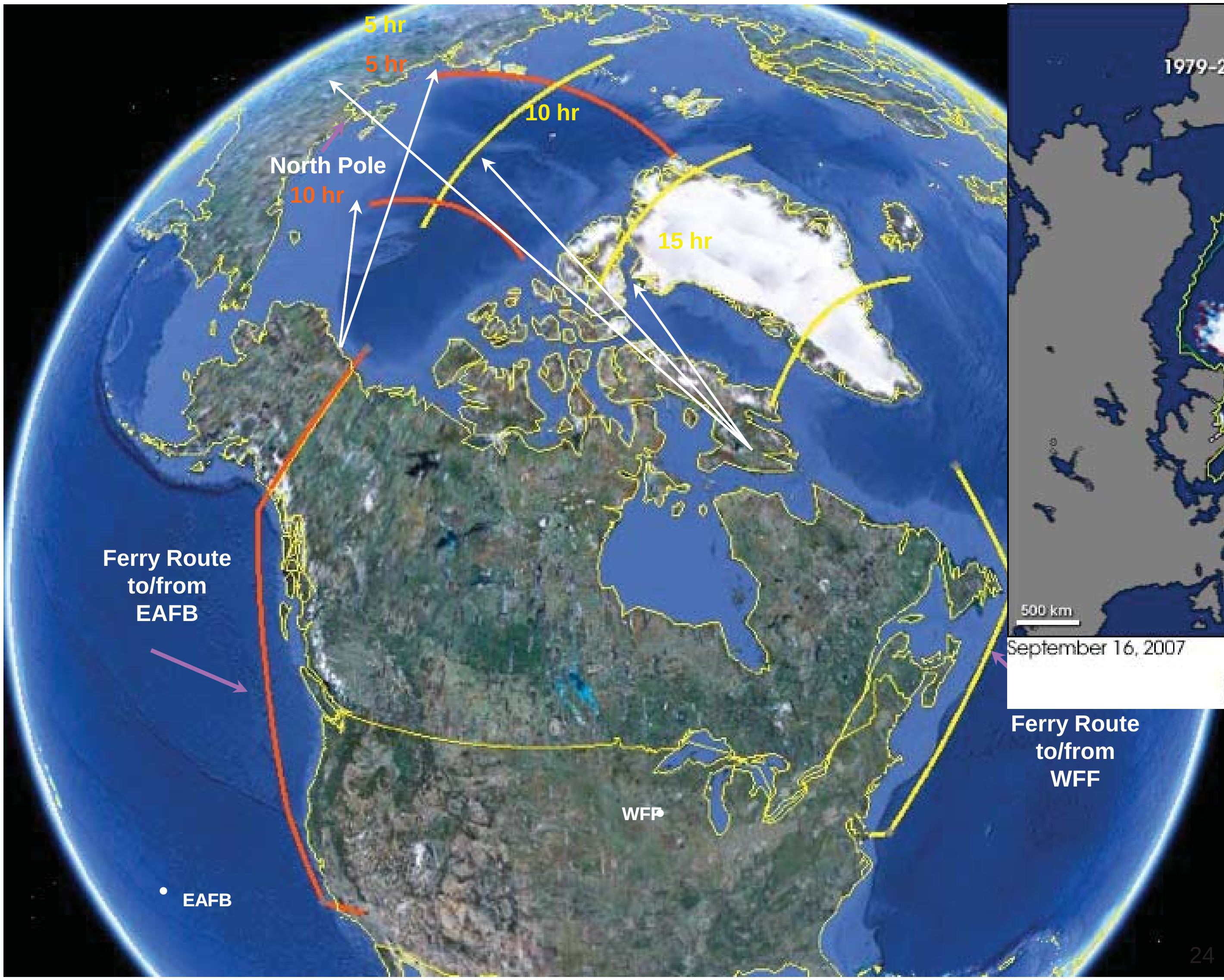
Heavy rain events along the U.S. West Coast associated with moisture streams over the Pacific

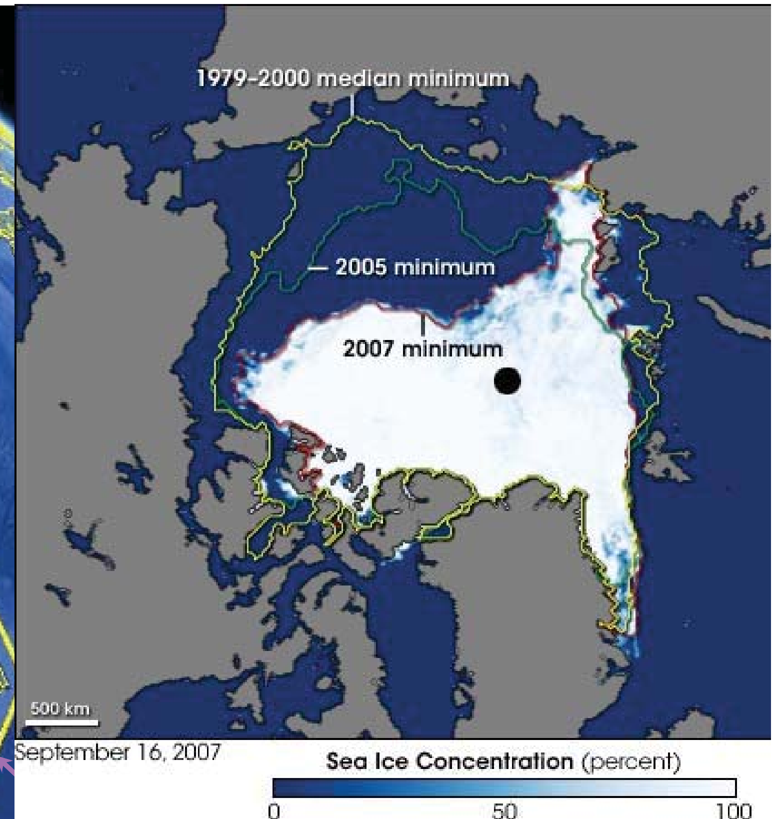
- Plumes of high moisture known as Atmospheric Rivers move over coastal mountains, dumping large amounts of rain
- Can better upstream measurements improve forecasting of these flood-producing events?



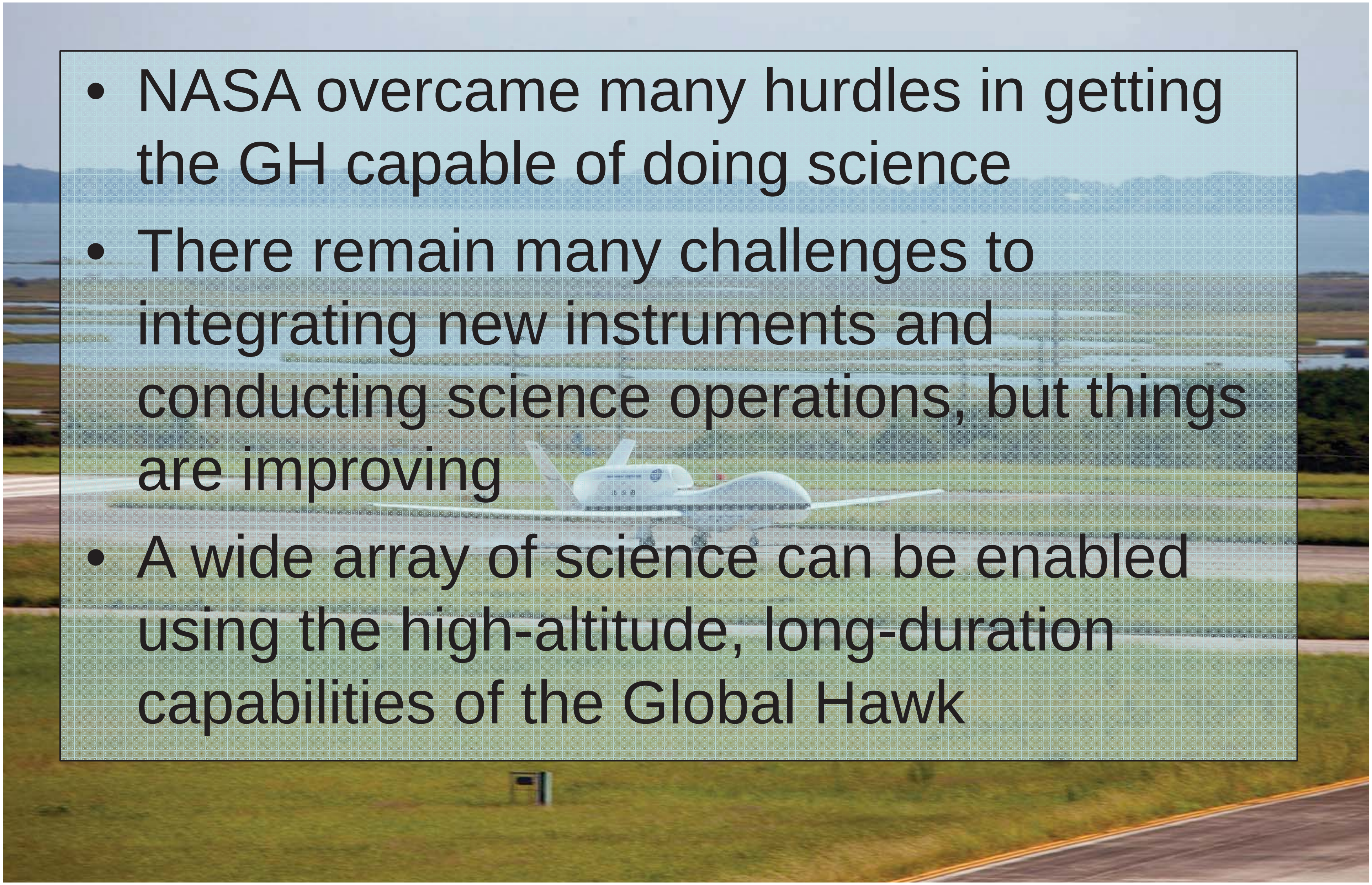
Polar Climate

GOAL: To examine changes in sea ice, ice sheets, and glaciers in polar regions





Summary



- NASA overcame many hurdles in getting the GH capable of doing science
- There remain many challenges to integrating new instruments and conducting science operations, but things are improving
- A wide array of science can be enabled using the high-altitude, long-duration capabilities of the Global Hawk