High-Altitude MMIC Sounding Radiometer - From the IIP to the Global Hawk

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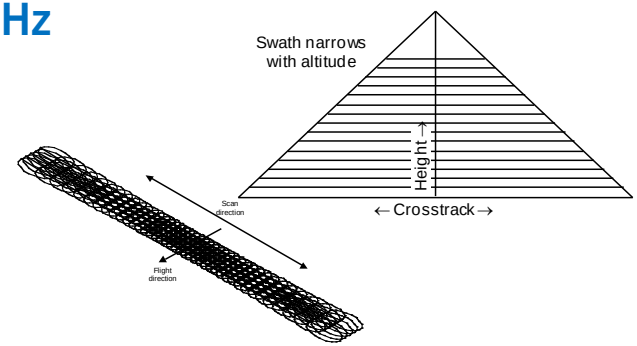
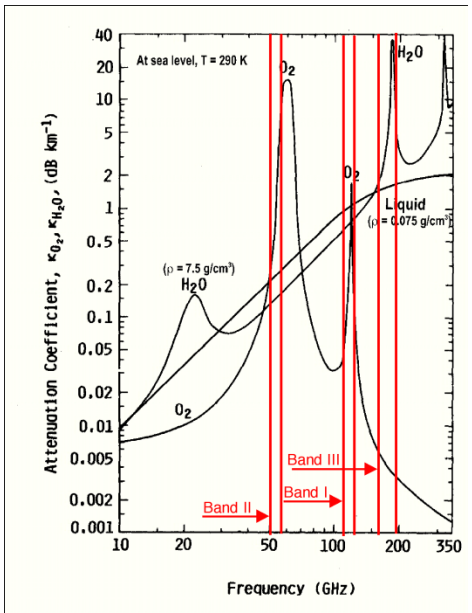
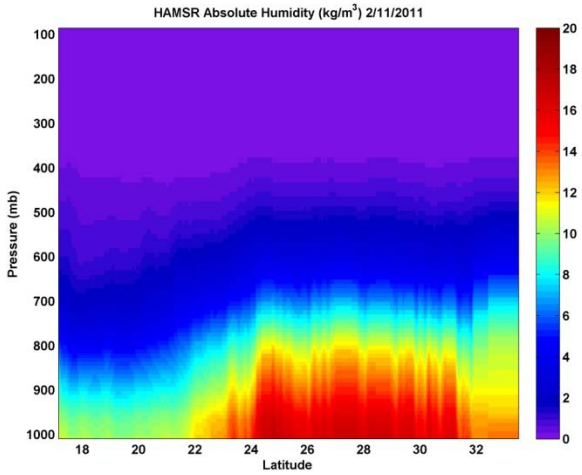
JPL High Altitude MMIC Sounding Radiometer (HAMSR)

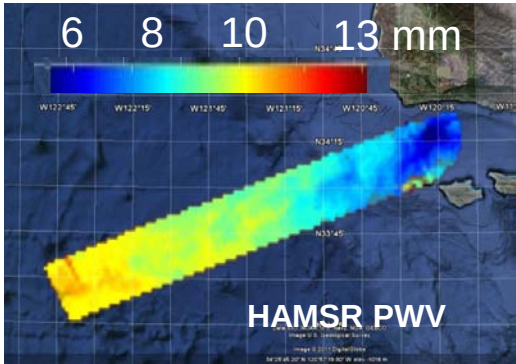
Jet Propulsion Laboratory
California Institute of Technology

- **JPL High Altitude MMIC Sounding Radiometer (HAMSR)**
  - Microwave radiometer for 3-D all-weather temperature and water vapor sounding, similar to AMSU on NOAA platform
  - 25 sounding channels in three bands:
    50-60 GHz, 118 GHz, 183 GHz
- **Cross track scanning**
  - ± 60° off nadir
  - 65 km swath
  - 1.9 km resolution









HAMSR Development Timeline

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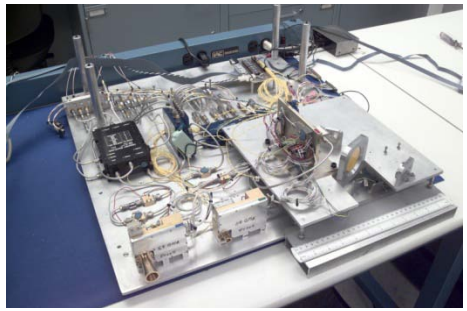
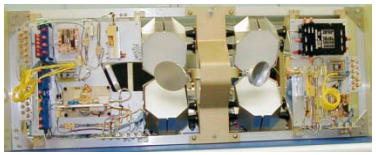
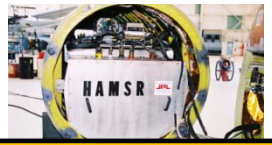
1998

IIP-98 "High Altitude MMIC Sounding Radiometer on a Remotely Piloted Aircraft" – Lambrigtsen (PI)





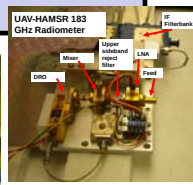
2001: CAMEX-4 on ER2



2005: TCSP on ER2

ACT-05 "Miniature MMIC Low Mass/power Radiometer Modules for the 180 GHz GeoSTAR Array" - Kangaslahti (PI)

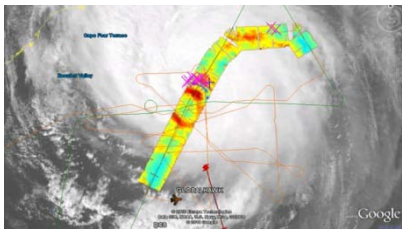
2006: NAMMA on DC-8



AITT-07 "Unmanned Aerial Vehicle - High Altitude MMIC Sounding Radiometer for Atmospheric State Reconnaissance" - Lambrigtsen (PI)

AIST-08 "Technology Infusion for the Real Time Mission Monitor - Goodman (PI)

2010: GRIP on Global Hawk



2011: WISPAR on Global Hawk

2012

2012-2014: HS-3 on Global Hawk

Upgrades for Global Hawk

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California Institute of Technology

- Recently completed extensive upgrades for HAMSR in preparation for Global Hawk deployment under NASA AITT program
- AITT objective was to make a state of the art operational instrument
  - State-of-the-art Low Noise Amplifier (LNA) added to 118 and 183 GHz receivers
  - Data system upgraded to provide real time data access and on-board science processing
  - Instrument re-packed into light-weight compact housing for deployment in forward bay of GH
  - Perform detailed instrument calibration and characterization

System Diagram

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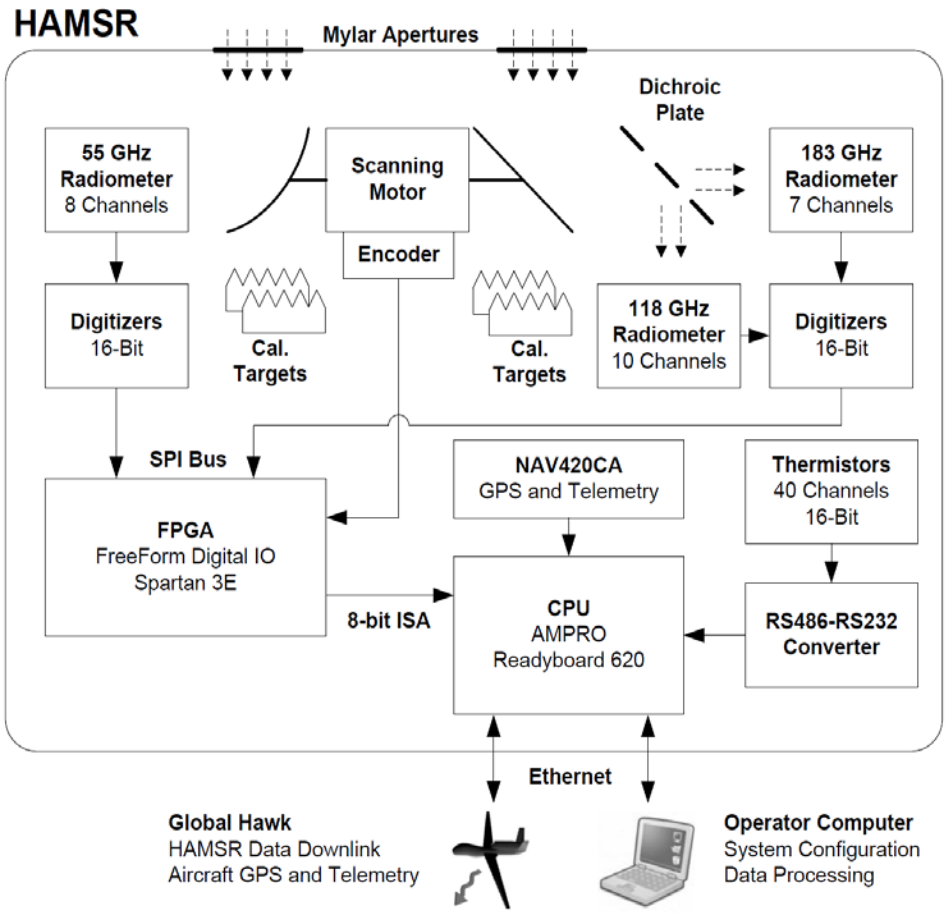
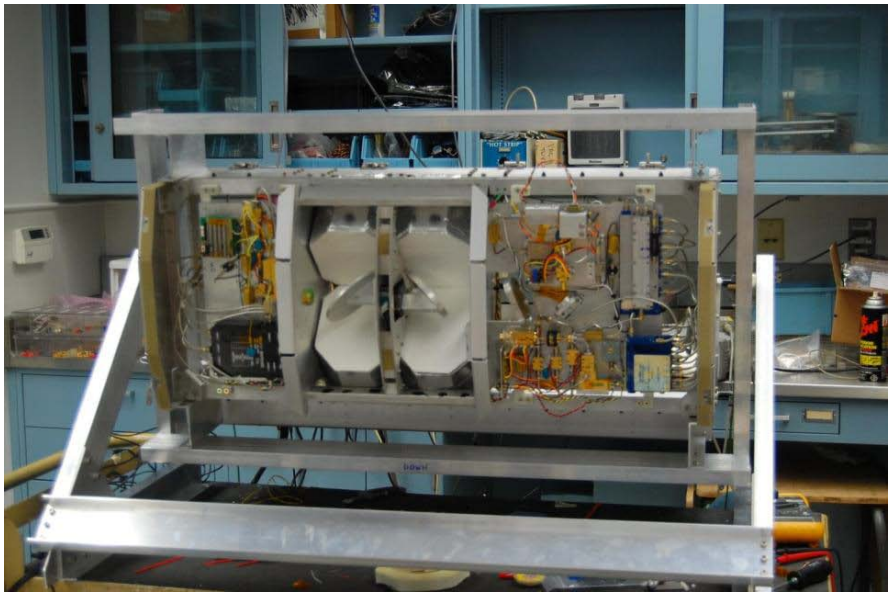
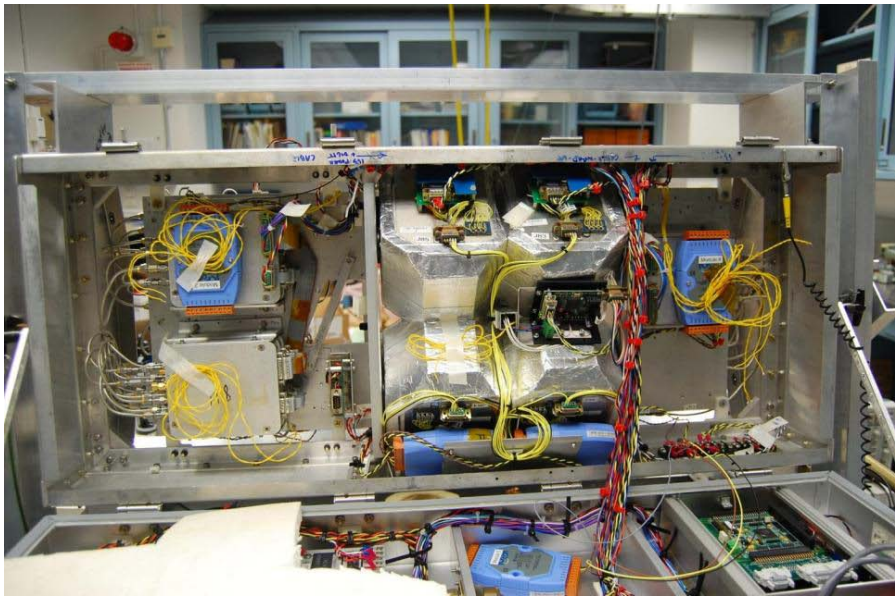
California Institute of Technology







New 183 GHz Receiver

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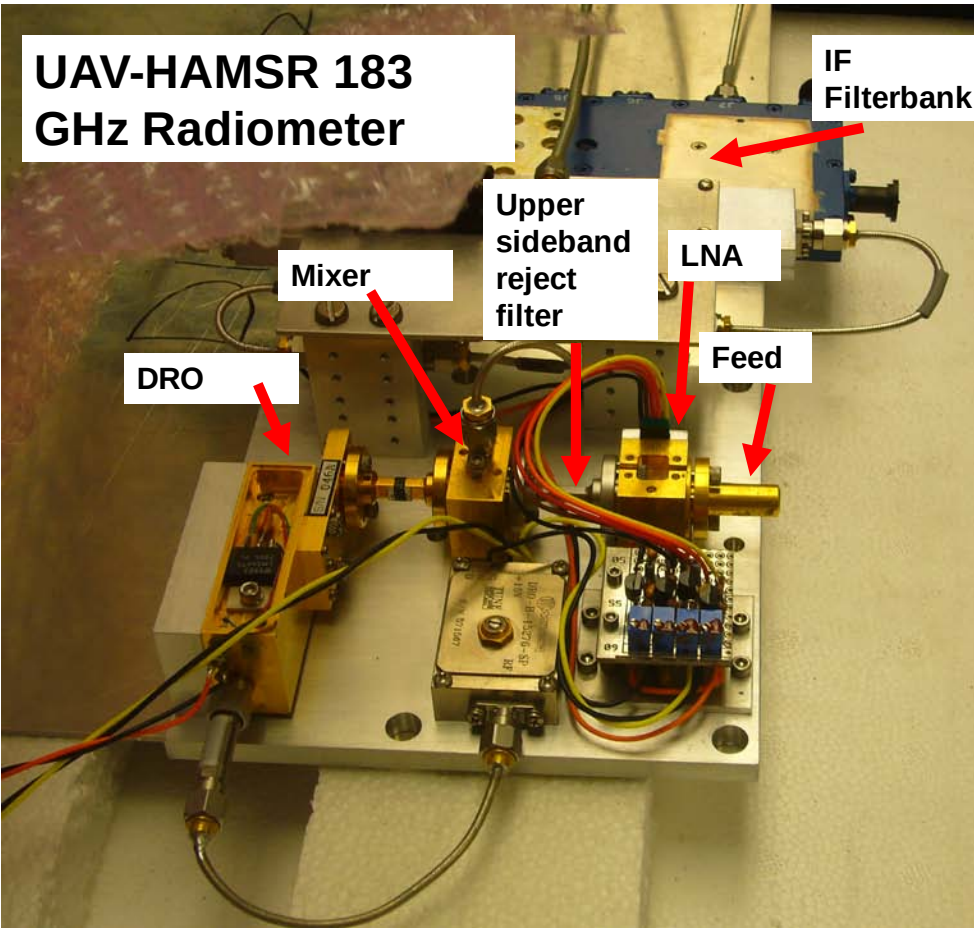
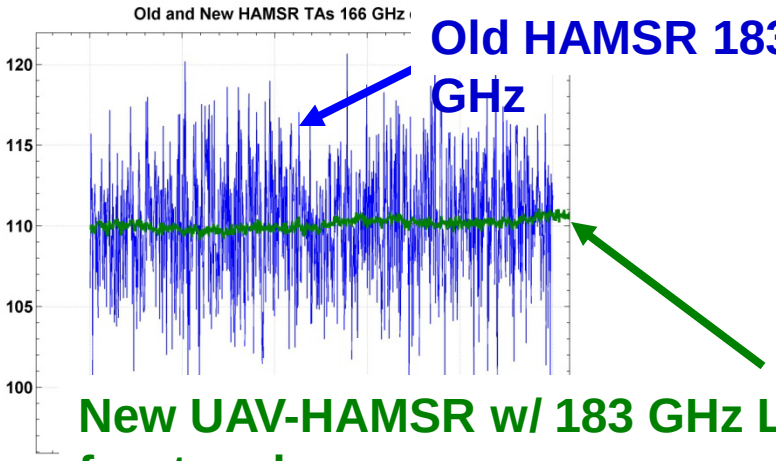
183 1	Old HAMSR	New HAMSR
Receiver Noise Temperature	9000 K	580 K
NEDT (7ms, 3 GHz BW channel)	2 K	0.2 K

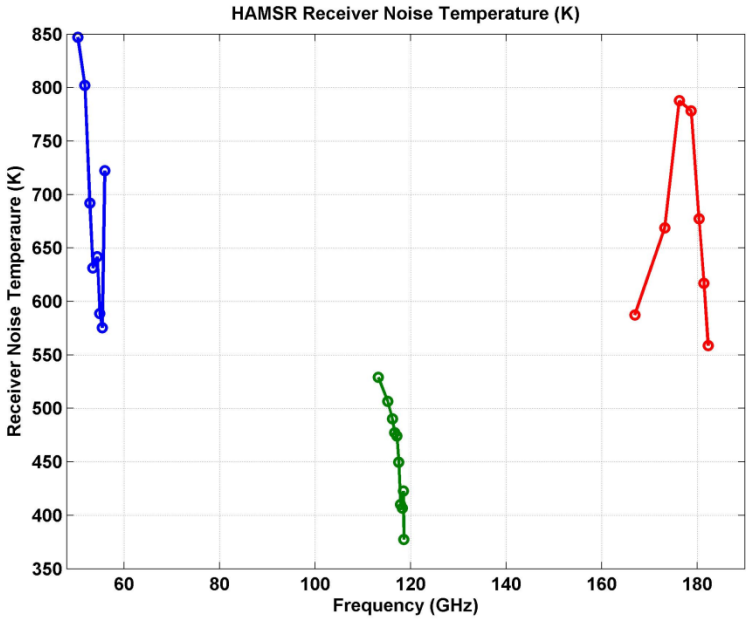


- Installed MIMRAM LNA developed by JPL under NASA ESTO ACT program into HAMSR 183 GHZ receivers
- Noise reduced by an order of magnitude
  - Noise at 0.1-0.2K level will improve observation of small scale water vapor features



Measured System Performance

- NEDT between 0.06-0.15 K for 118/183 GHz channels
- 0.16-0.3 K NEDT at 50 GHz – currently upgrading 50 GHz receiver front end to reduce noise temperature by a factor of 3



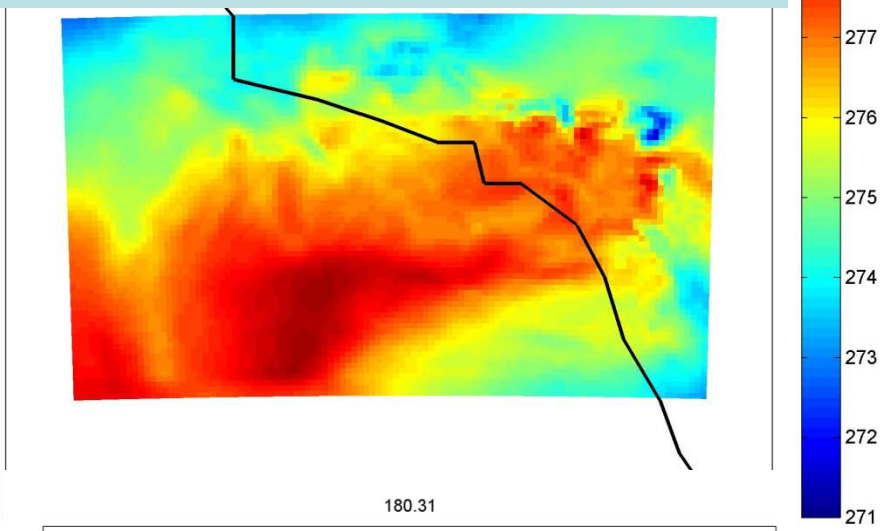
50 GHz Channel	NEDT [K]	118 GHz Channel	NEDT [K]	183 GHz Channel	NEDT [K]
1	0.29	**10**	0.12	**19**	0.06
2	0.22	**11**	0.10	**20**	0.07
3	0.18	**12**	0.14	**21**	0.09
4	0.19	**13**	0.13	**22**	0.09
5	0.17	**14**	0.14	**23**	0.10
6	0.16	**15**	0.13	**24**	0.10
7	0.16	**16**	0.10	**25**	0.10
8	0.19	**17**	0.10		
		18	0.15		

Impact of 183 NEDT Improvement

- km-scale water vapor features washed out with large NEDT
- Upgraded 183 GHz receiver will resolve water vapor structures at the scale of the observation (2km)

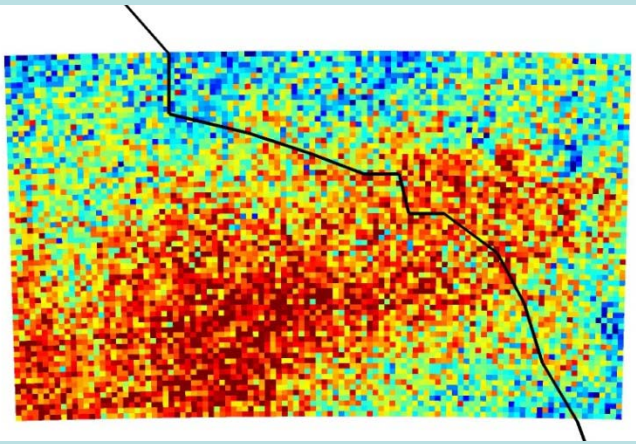
180.31

180.31 GHz TB simulated from 3km WRF model output – S. Calif. Coast



180.31

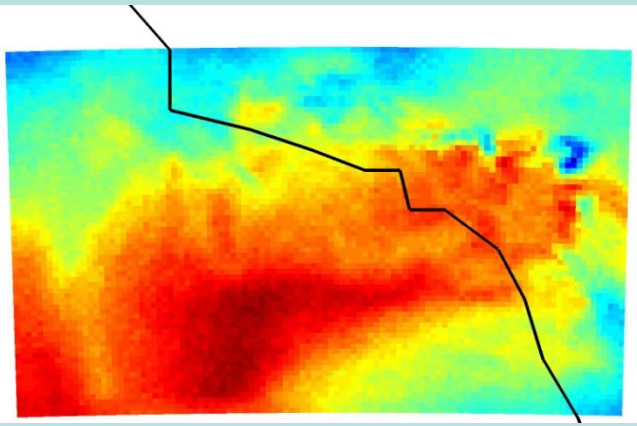
Old System: 1.2 K Noise



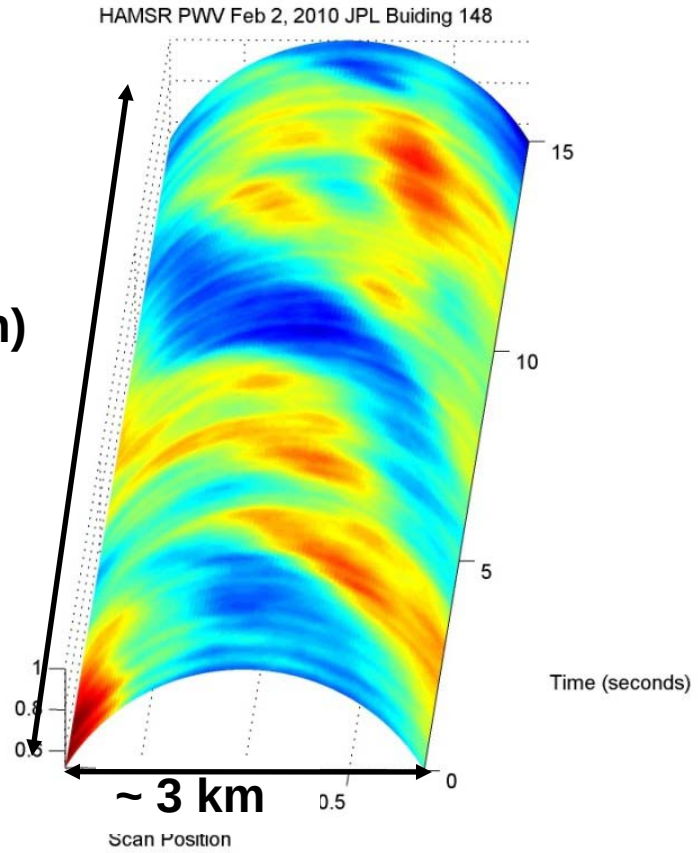
Small scale structure unresolved

180.31

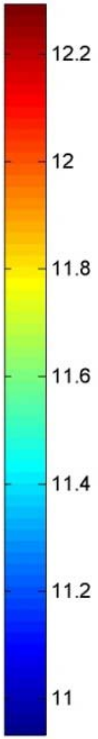
Upgraded HAMSR: 0.1 K Noise

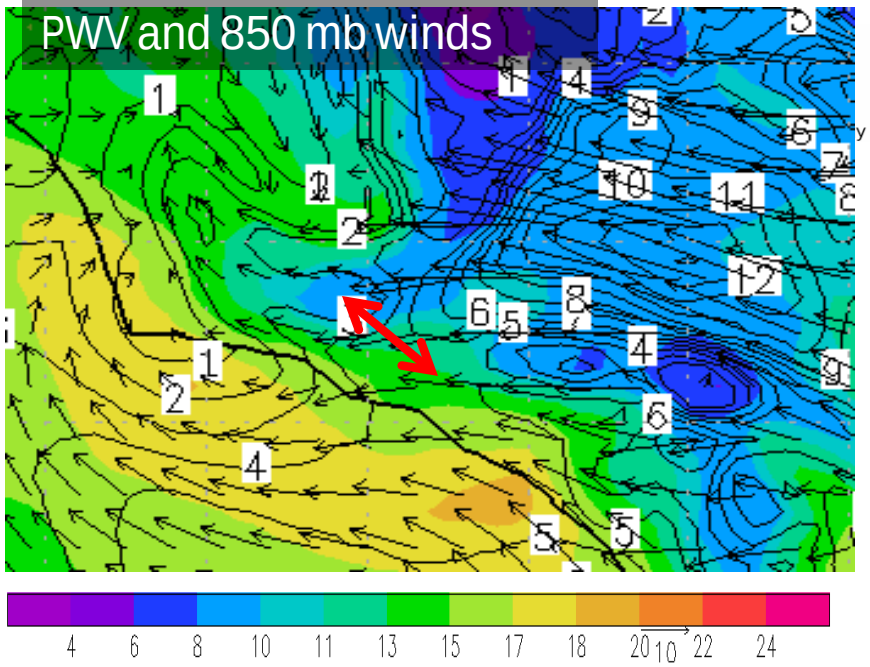


km-scale structure now resolved



Time (15 min)





Precipitable Water Vapor JPL 2/2/2010

- HAMSR operated in upward looking scan mode at JPL 2/2/2010
- Retrieved PWV time series along scan arc reveals small scale structure
  - 0.3 mm resolution

In Flight Illustration of 183 GHz Improvement

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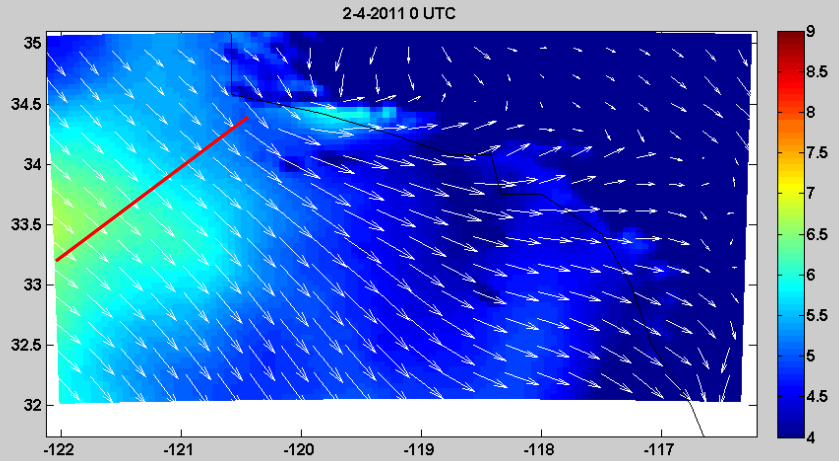
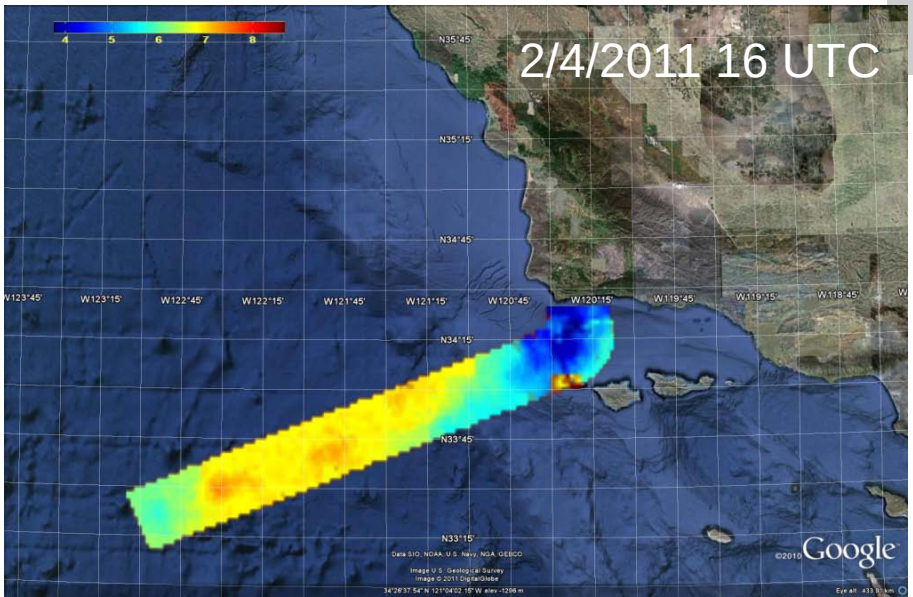
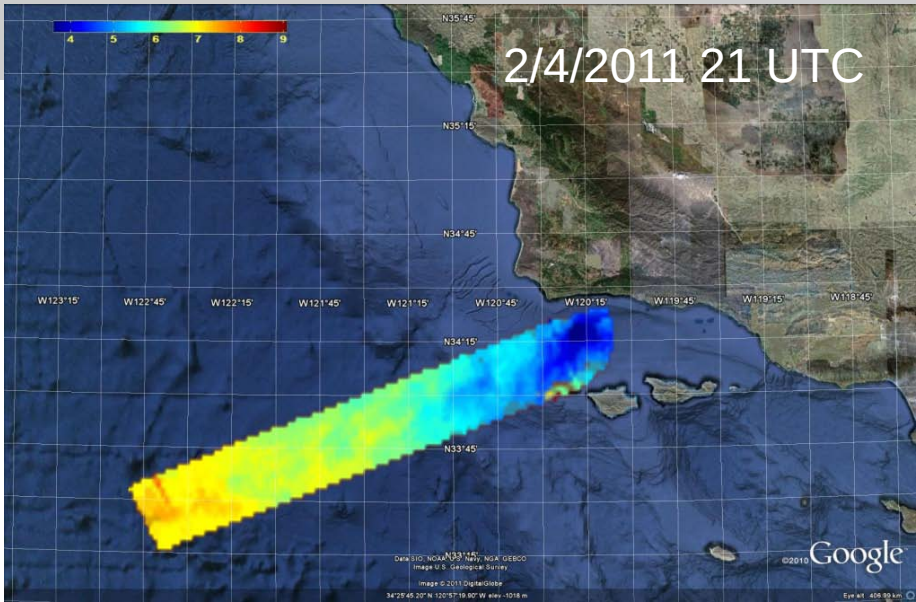
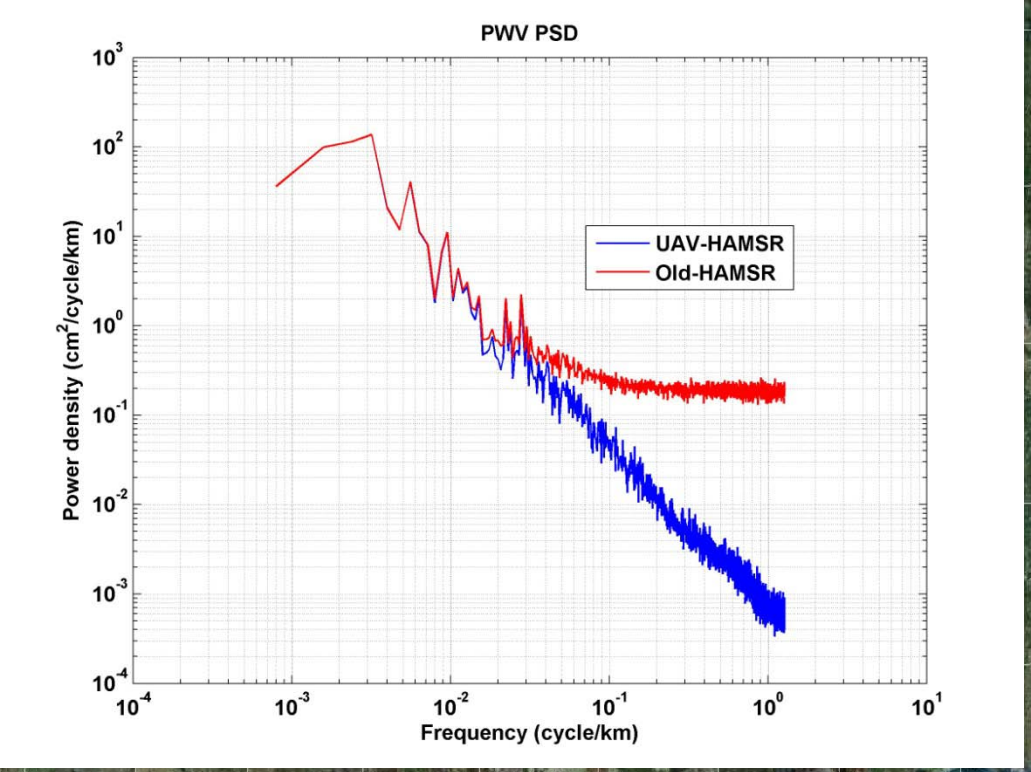
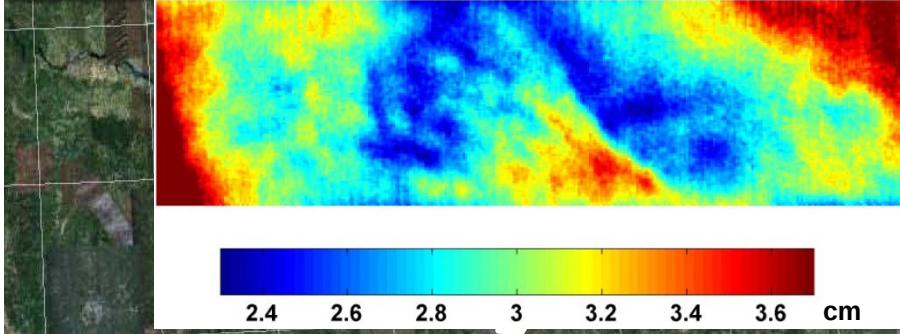
- HAMSR retrieved integrated water vapor compared to WRF model off Southern California coast
- Retrieval of small scale variability possible with new system








PWV PSD
Power density (cm²/cycle/km)
Frequency (cycle/km)
UAV-HAMSR
Old-HAMSR


2.4
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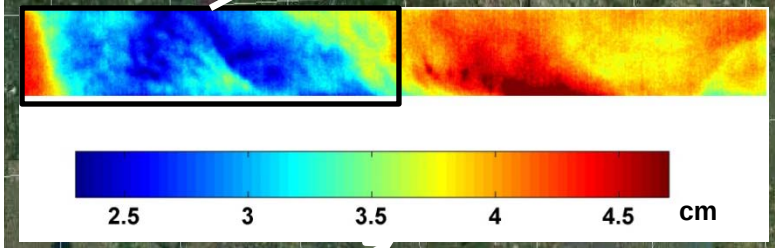
2.5
3
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4
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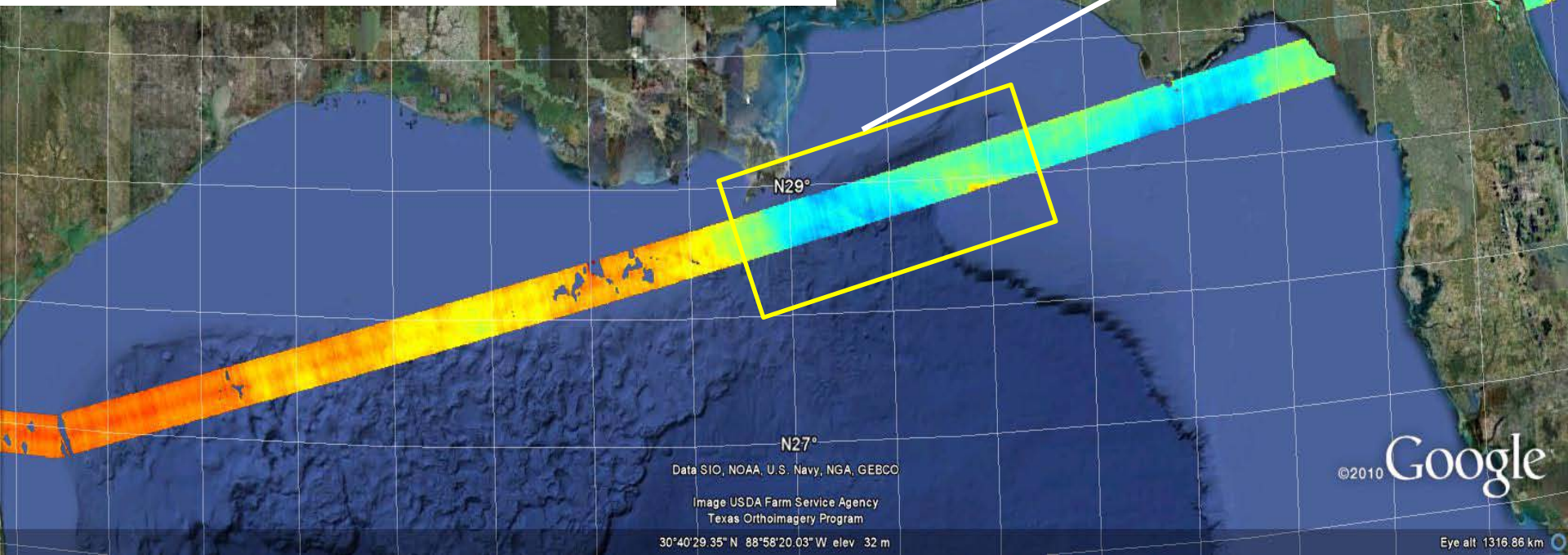
cm


N29°
N27°
W 81°
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image USDA Farm Service Agency
Texas Orthoimagery Program
©2010 Google
30°40'29.35" N 88°58'20.03" W elev 32 m
Eye alt 1316.86 km

Instrument Calibration/Characterization

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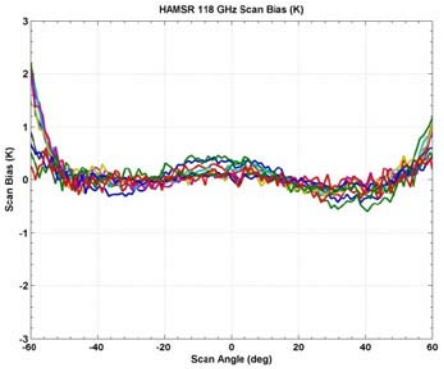
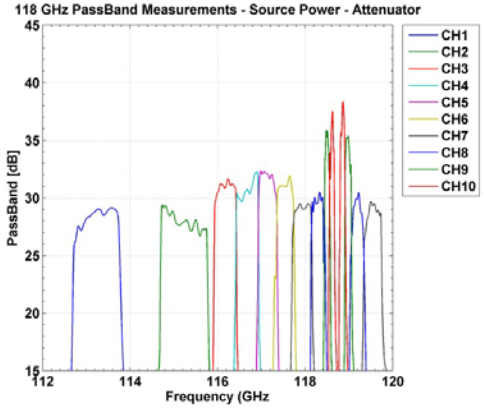
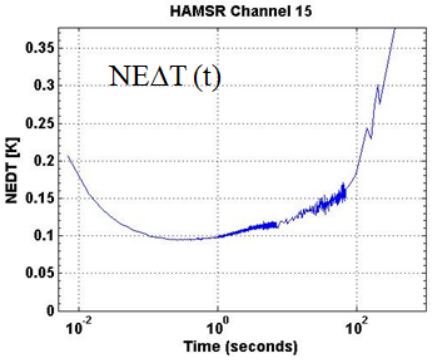
- Detailed instrument characterization performed
  - Passband measurements
  - Scan bias assessment
  - Scan rate/NEDT optimization
  - Linearity characterization
  - Absolute calibration

- Detailed instrument characteristic data available to users
  - e.g. direct radiance assimilation







Brown, S. T.; Lambrigtsen, B.; Denning, R. F.; Gaier, T.; Kangaslahti, P.; Lim, B. H.; Tanabe, J. M.; Tanner, A. B.; 2011, "The High-Altitude MMIC Sounding Radiometer for the Global Hawk Unmanned Aerial Vehicle: Instrument Description and Performance," *IEEE Trans. Geosci. and Rem. Sens., in press*

HAMSR In-Flight Calibration Assessment

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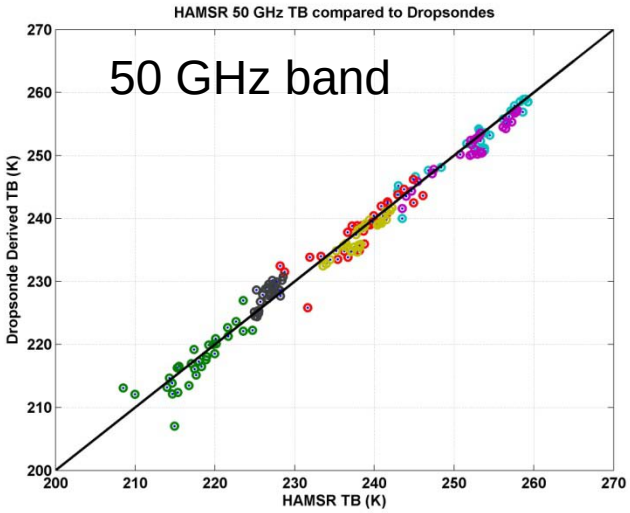
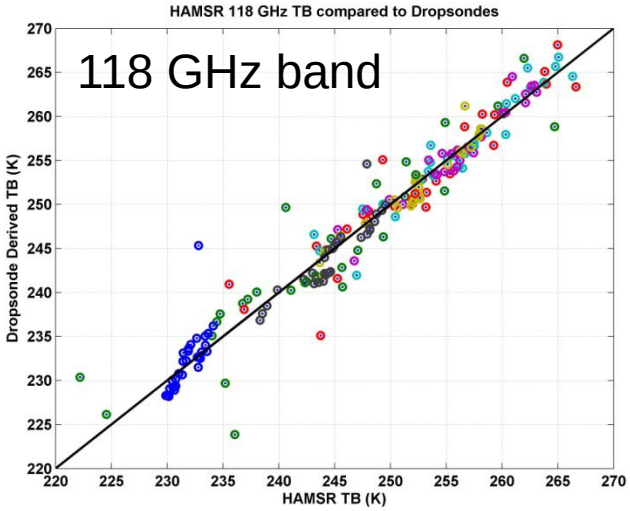
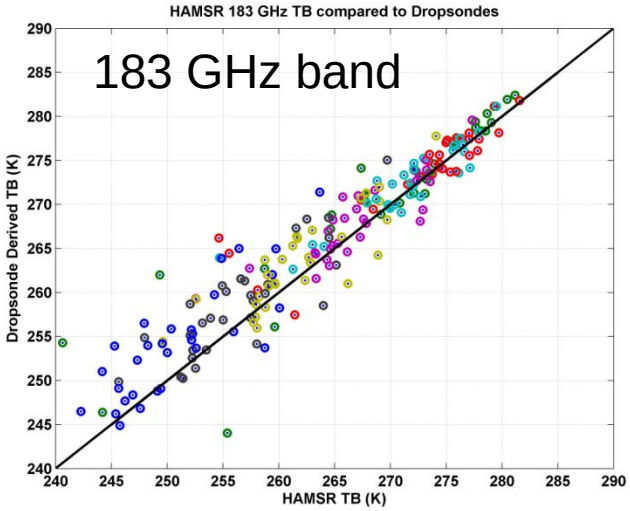
- HAMSR participated with dropsondes in NOAA WISPAR 2011 campaign
- Preliminary dropsonde profiles used to generate model TBs at aircraft altitude
  - Compared to HAMSR in each band for mostly cloud-free scenes (~30 profiles)
- Good agreement observed
  - More scatter at the higher frequencies mostly due to residual un-modeled clouds in scene
  - < 0.5K mean difference at 50/118 GHz
  - < 0.5K mean difference for upper 183 GHz channels
  - 1-2K difference for lower 183 GHz channels (model or calibration)







NASA GRIP Mission

- **Aug-Sep 2010; DC-8, Global Hawk, WB-57**
- **Improve understanding of tropical cyclone formation and intensification**
- **First ever over flight of a tropical cyclone with the Global Hawk**

NASA

Mission News

NASA Hurricane R
Hurricane Earl, cur
with maximum sus
continues to push
scientists, instrum
air and space. Thre
crossing Earl as pa
Processes missio
designed to help in
Earl form and inten

Among the instrum
Microwave Integrate
by NASA's Jet Propu
which flies aboard
the 3-D distribution
atmosphere.

The Global Hawk le
Calif., at 9 p.m. PDT
hours later to begin
day today flying over
as seen the mornin
Global Hawk is sho

HAMSR has been a
Figure 1 shows brig
half-hour sequence
Global Hawk was fly
approximately 1,125
eye is visible as the
surrounded by orang
instrument is seeing
instrument. The surr
cooler ocean surface
blue arch, which rep

redOrbit

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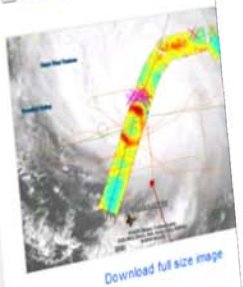

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aboard NASA's Global Hawk uninhabit
water in the atmosphere.

The Global Hawk left NASA's Dryden Fl
of Florida seven hours later to begin its
returning to Dryden tonight. An image o
is shown in Figure 3.

HAMSR has been able to make multipl
by HAMSR over a half-hour sequence o
about 19.2 kilometers (63,000 feet) app
blue-green circular area in the center of
instrument is seeing the ocean surface,
shield the cooler ocean surface from vie
convection (intense thunderstorms). Th
network. Ice particles and heavy precipit

This image illustrates many of the capa
sea surface and atmospheric temperatu
precipitation. For example, since there is
the ocean surface, scientists can determ
temperatures at different altitudes within
strength of convection in the core of the
condensation of water vapor that has be
strong convection. This is the engine tha
temperature data, in turn, can be used to
hurricane. NOAA's National Hurricane C
method to determine hurricane intensity

A second JPL instrument participating in
Airborne Precipitation Radar (APR-2), a
is taking 3-D images of precipitation abo
is being used to help scientists understa
hurricanes by looking at the vertical struc

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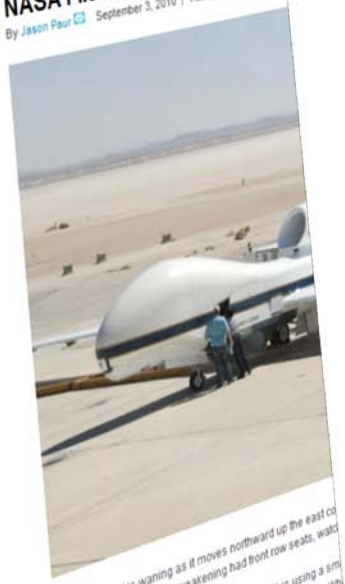


Hurricane Earl is waning as it moves northward up the east co
researchers to notice the weakening had front row seats, watc

In addition to the usual cadre of satellites, NASA is using a sm
around the hurricane as it tracks north from the Caribbean. Wh
the first hurricane that NASA has observed using their unmann

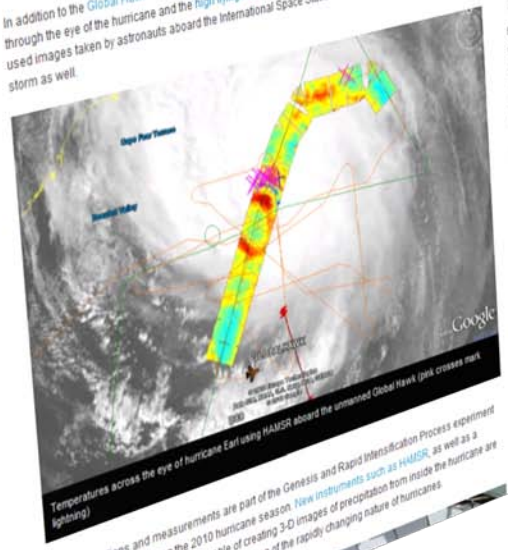
Hurricane Earl is waning as it moves northward up the east coast of the United States. Some of the first researchers to notice the weakening had front row seats, watching the eye of the hurricane via drone flights.

In addition to the usual cadre of satellites, NASA is using a small fleet of unmanned aircraft into, over and around the hurricane as it tracks north from the Caribbean. While flying into a hurricane is nothing new, Earl is the first hurricane that NASA has observed using their unmanned Global Hawk observation aircraft (pictured above).

The aircraft are giving researchers a 3-D view of the temperature, waver vapor and cloud liquid water in the hurricane. Using a High-Altitude Monolithic Microwave Integrated Circuit Sounding Radiometer, or HAMSR in official NASA acronymese, the Global Hawk is able to look down into the eye of the storm to the sea surface and compare different layers in relatively high resolution and in real time.

The unmanned aircraft left the Dryden Flight Research Center in California earlier in the week and spent all day Thursday flying over Earl at an altitude of about 63,000 feet. Along with HAMSR, the Global Hawk also carries an HD camera, giving hurricane scientists new capabilities to watch the storm strengthen or degrade in real time.

In addition to the Global Hawk which flew over the top of the hurricane, a NASA DC-8 is flying researchers through the eye of the hurricane and the high flying WB-57 is also participating in the research flights. NASA used images taken by astronauts aboard the International Space Station as their orbit took them over the storm as well.



Temperatures across the eye of hurricane Earl using HAMSR aboard the unmanned Global Hawk (pink crosses mark lightning)

The observations and measurements are part of the Genesis and Rapid Intensification Process experiment NASA is conducting during the 2010 hurricane season. New instruments such as HAMSR, as well as a weather radar aboard the DC-8 capable of creating 3-D images of precipitation from inside the hurricane are helping researchers gain a better understanding of the rapidly changing nature of hurricanes.

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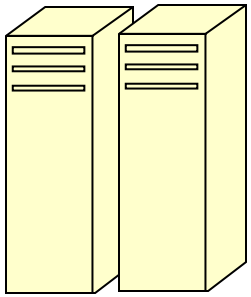
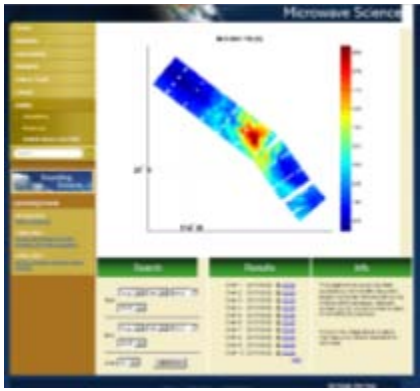


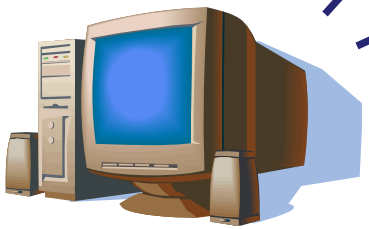
GHOC

netCDF L1B files

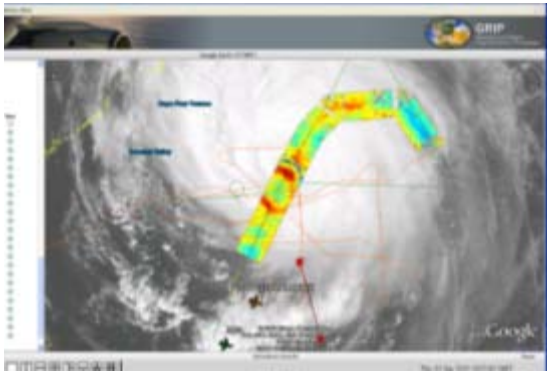
JPL Hurricane Portal

HAMSR website
quick look images





RTMM



HAMSR ground data processor

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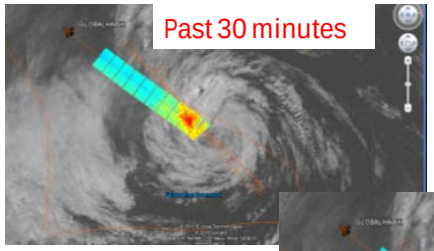
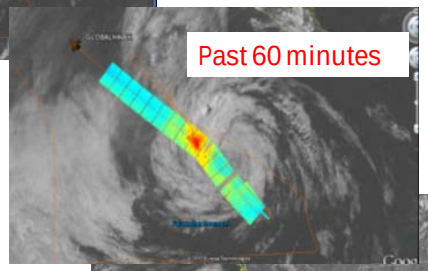
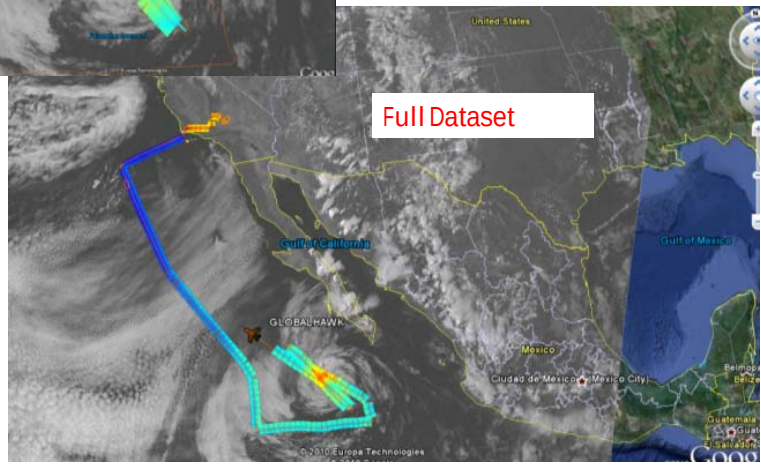
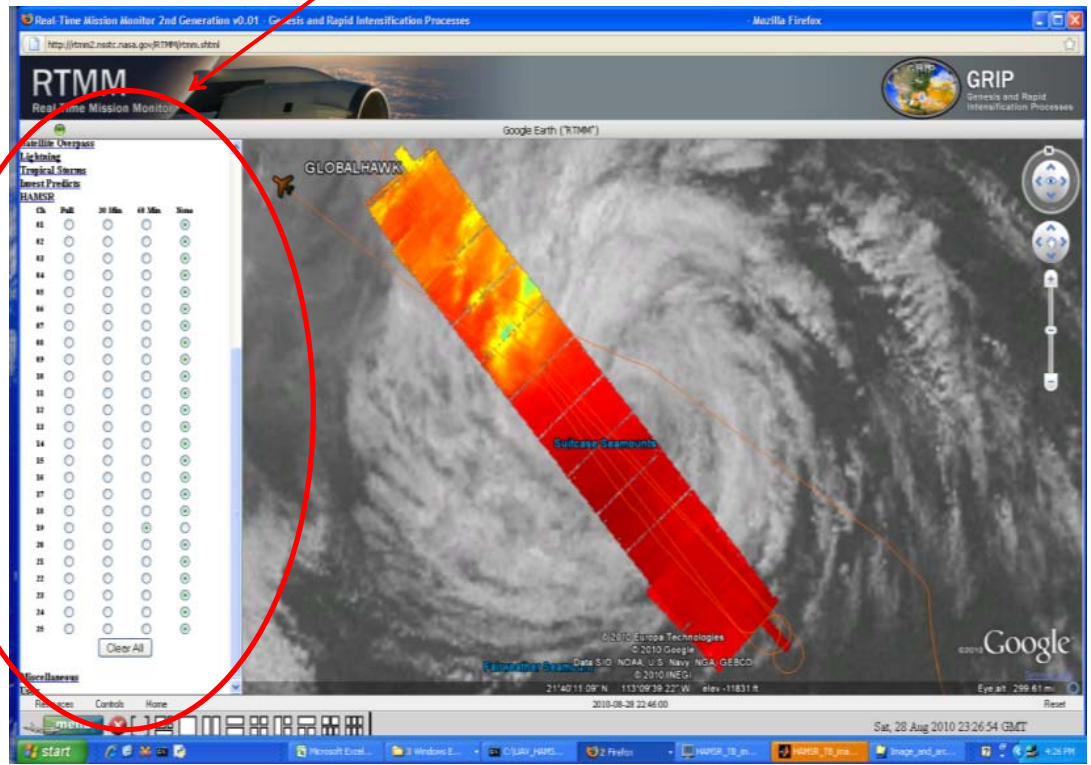
HAMSR RTMM Display for GRIP







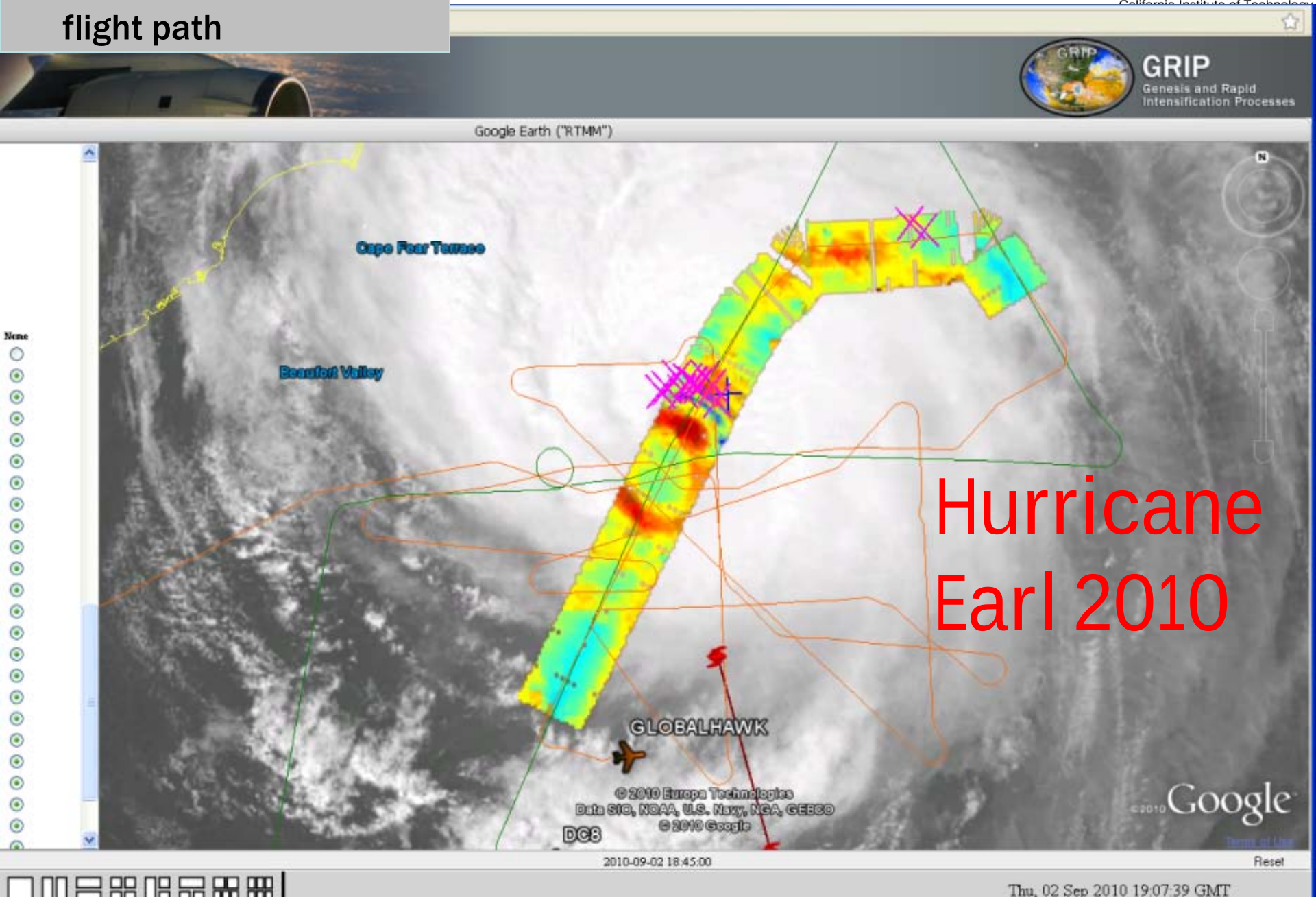
Select HAMSR channel – TB imagery
- Full data set, past 30 minutes or past 60 minutes



HAMSR software upgraded after GRIP to provide real-time imagery over Iridium

Successfully tested during 2011 WISPAR campaign

HAMSR data used in RTMM to determine flight path

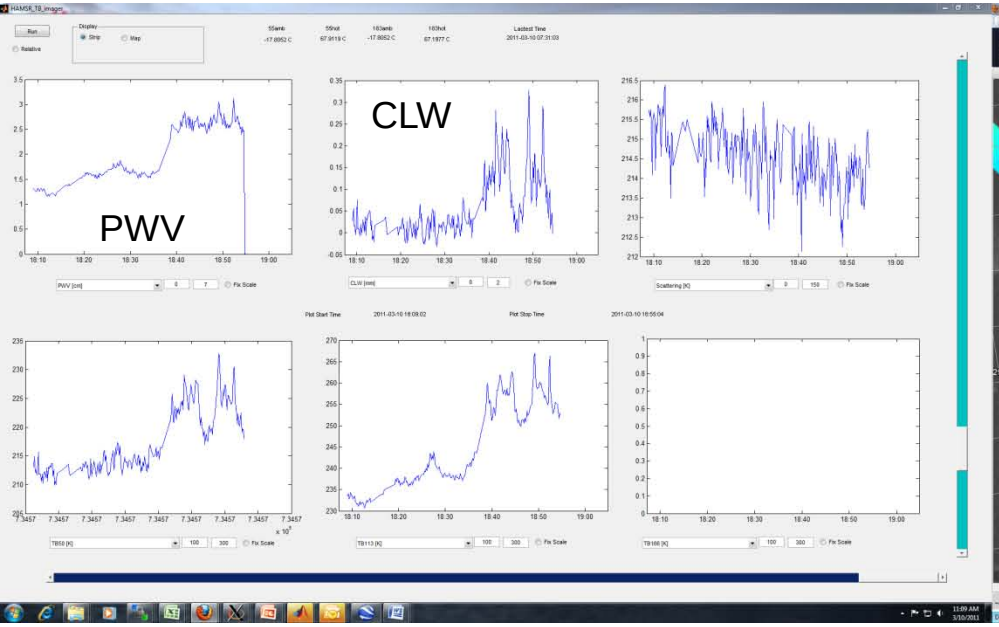


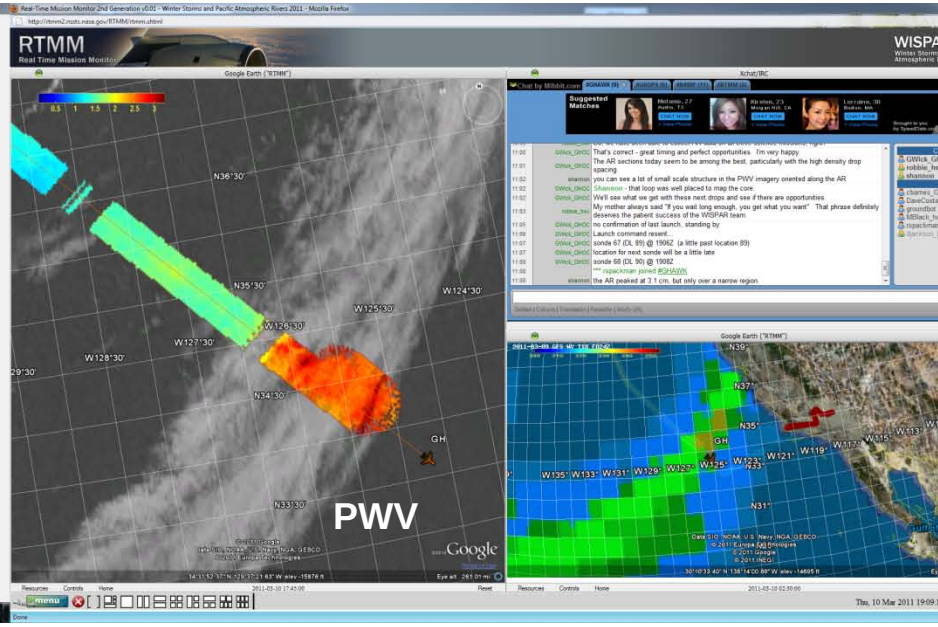
Hurricane Earl 2010

WISPAR Atmospheric Rivers Flights

Jet Propulsion Laboratory
California Institute of Technology

- HAMSR real-time PWV data used to time release of dropsondes near atmospheric rivers
- Data available within 10-30 seconds of acquisition



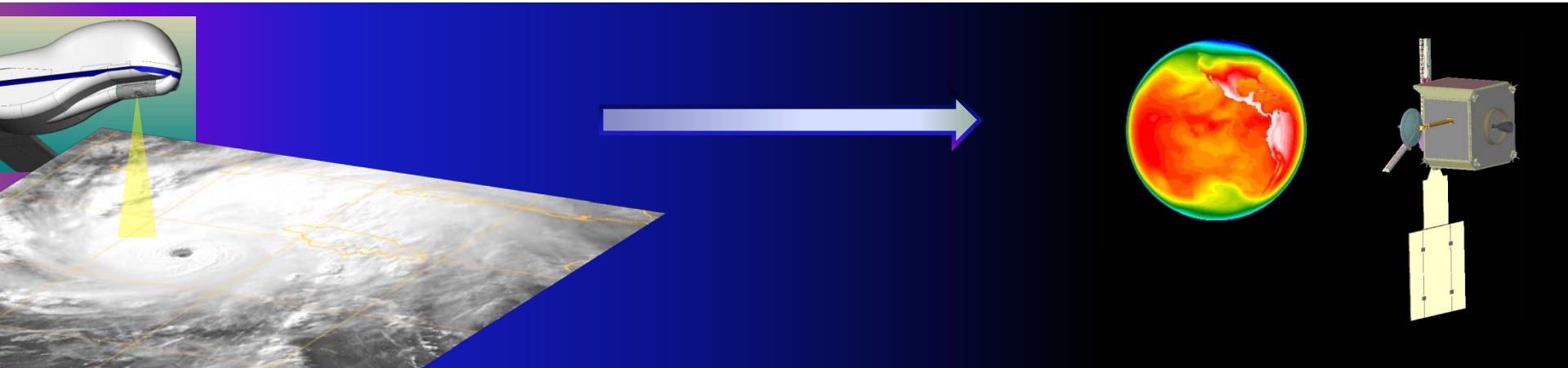


Tropical Cyclone Reconnaissance

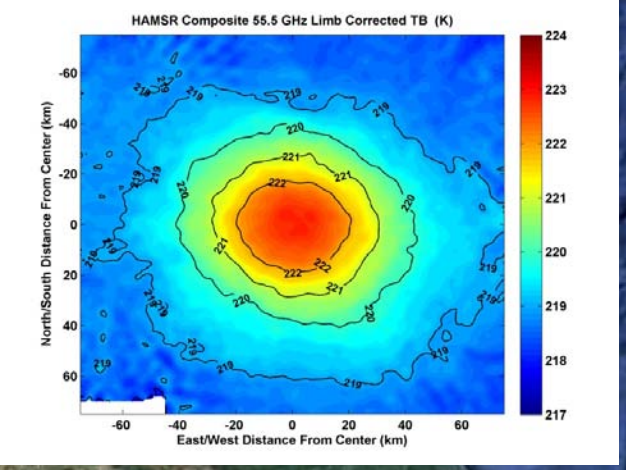
Jet Propulsion Laboratory
California Institute of Technology

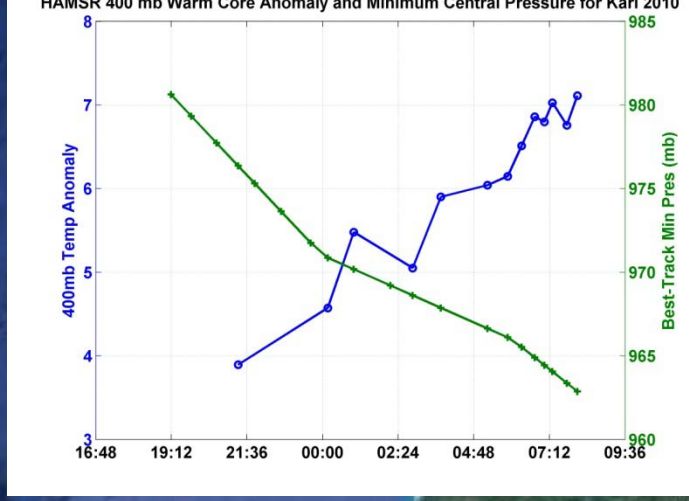
- HAMSR on the Global Hawk is a powerful tool for monitoring the thermodynamic evolution of tropical cyclones when loitering near eye of storm for periods up to 24 hours
  - Track intensity by observing warm core anomaly and 3-D precipitation structure
  - Useful for validating satellite retrievals

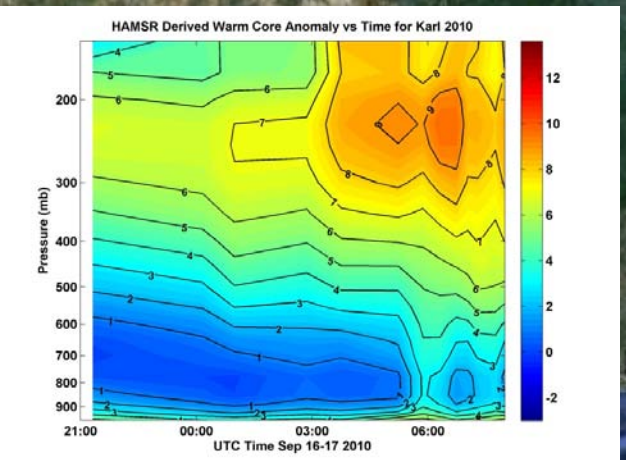
- Long duration data also key for demonstrating geostationary microwave sounding science -> PATH mission

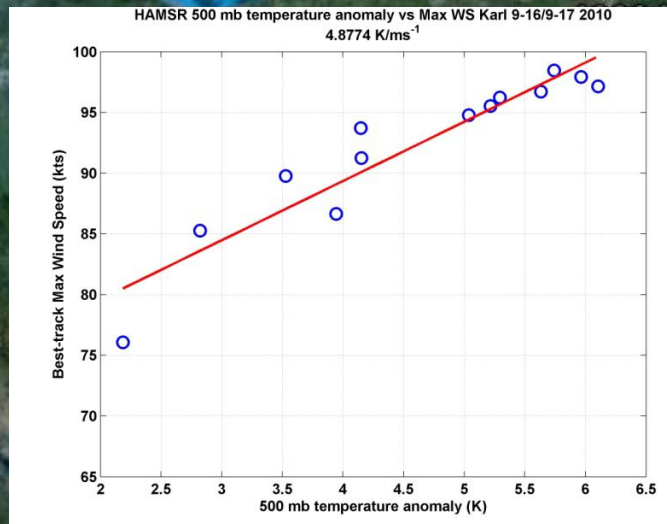


Hurricane Karl 2010



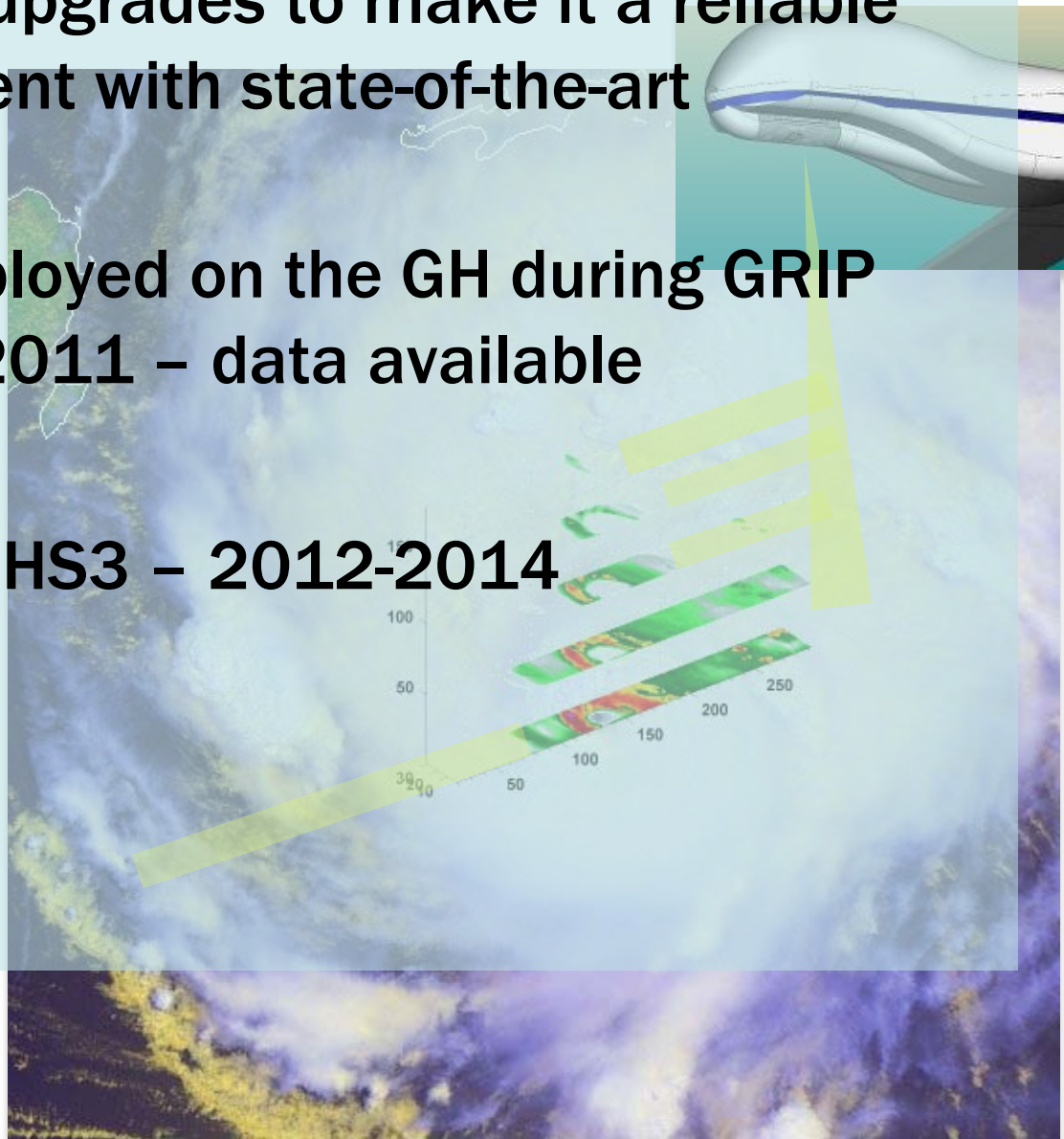






Summary

- Recent JPL HAMSR upgrades to make it a reliable operational instrument with state-of-the-art performance
- UAV-HAMSR has deployed on the GH during GRIP 2010 and WISPAR 2011 – data available
- Next mission will be HS3 – 2012-2014



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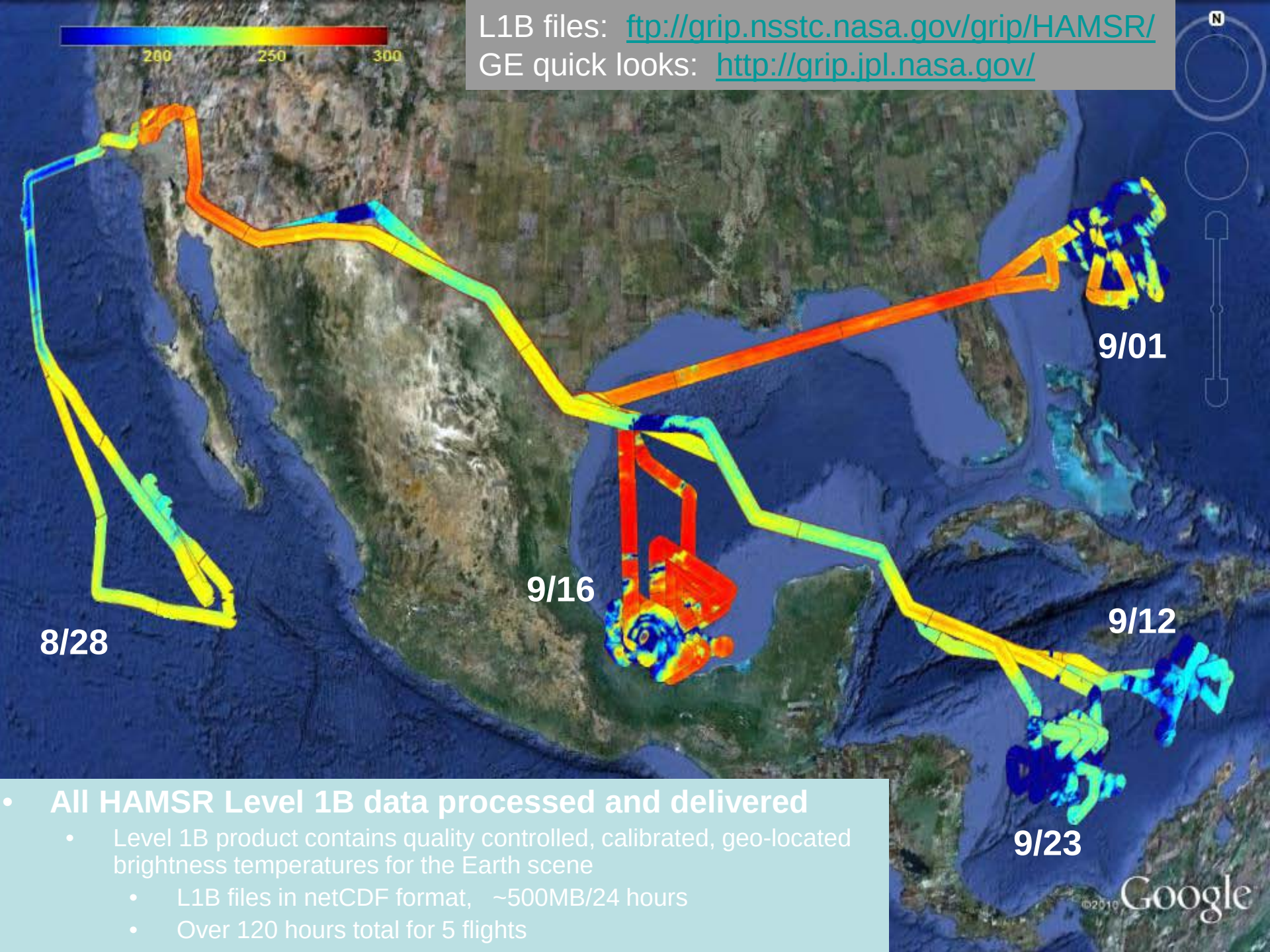

- **All HAMSR Level 1B data processed and delivered**
  - Level 1B product contains quality controlled, calibrated, geo-located brightness temperatures for the Earth scene
    - L1B files in netCDF format, ~500MB/24 hours
    - Over 120 hours total for 5 flights