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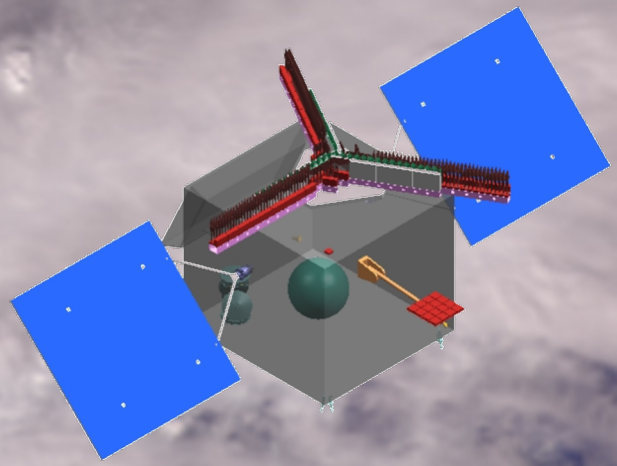
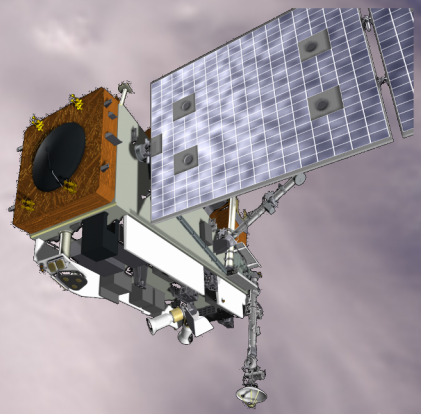


From aircraft to GEO: Using microwave sounders to observe the atmosphere



Bjorn Lambrigtsen, Mathias Schreier
(with contributions from many others)

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Briefing July 13, 2018

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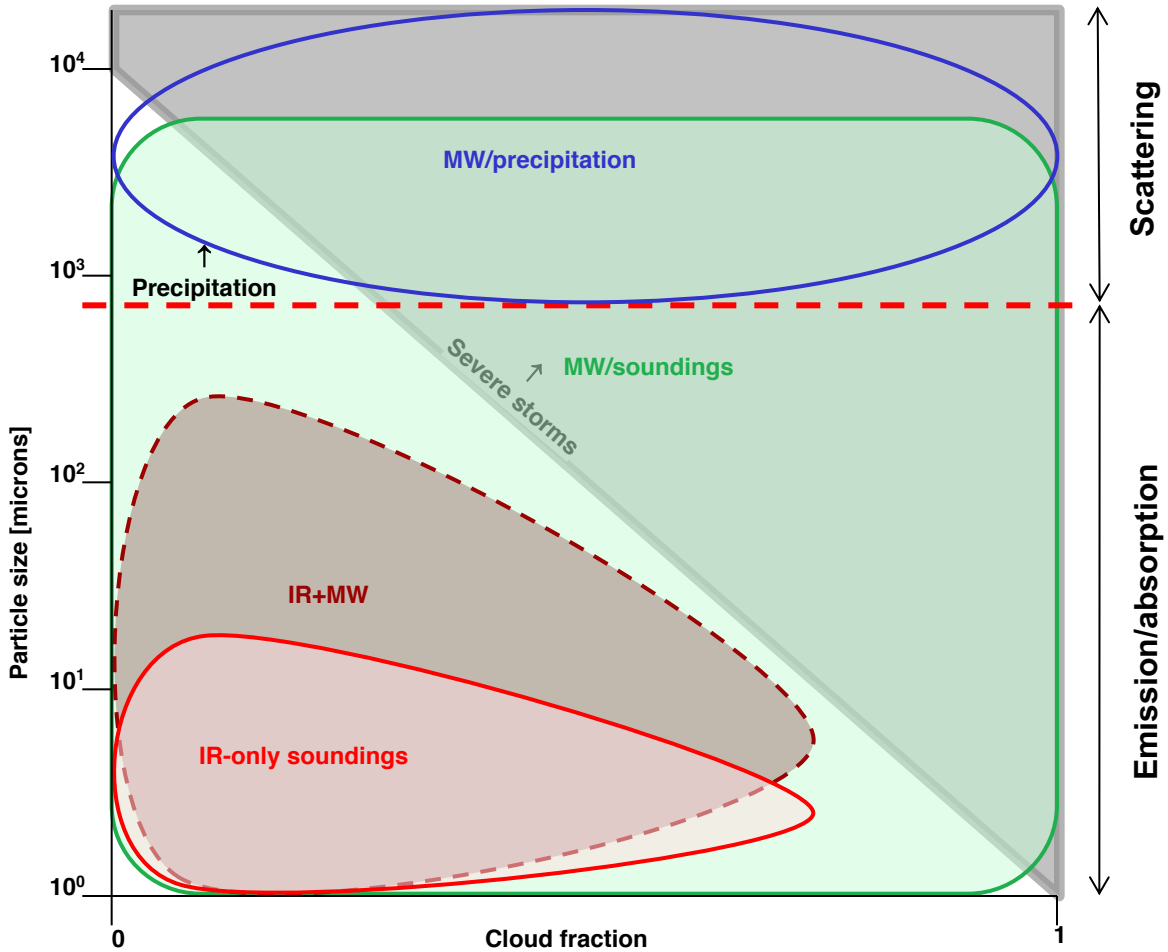
Why we need microwave sounders

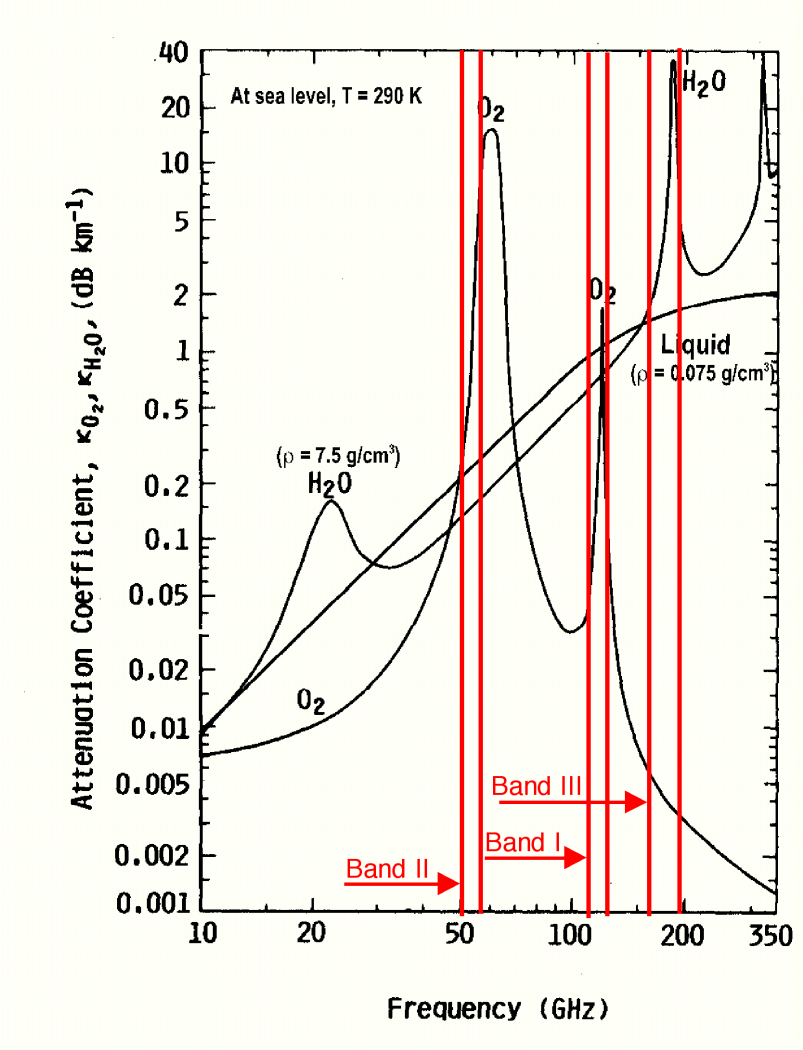
MW sounders measure all three phases of water: vapor, liquid (incl. rain), solid (incl. snow)
Ideally suited for the hydrologic cycle

MW sounders are "bad weather sensors"



Note: This is a 2-D view of a multidimensional world
Additional dimensions include spatial and temporal scales

Why we need microwave sounders



- Most MW-sounder applications focus on the O_2 band around 54GHz and the water vapor band around 183 GHz
- Another alternative is the O_2 118 GHz
- HAMSR provides channels in all 3 Bands, whereas systems like AMSU/HSB or ATMS provide only channels around 54GHz and 183 GHz
- In either case, these channels can provide very interesting information about the atmosphere
- It hereby matter, if the measurement is done from the ground, airplane, a polar orbiter or geostationary ….

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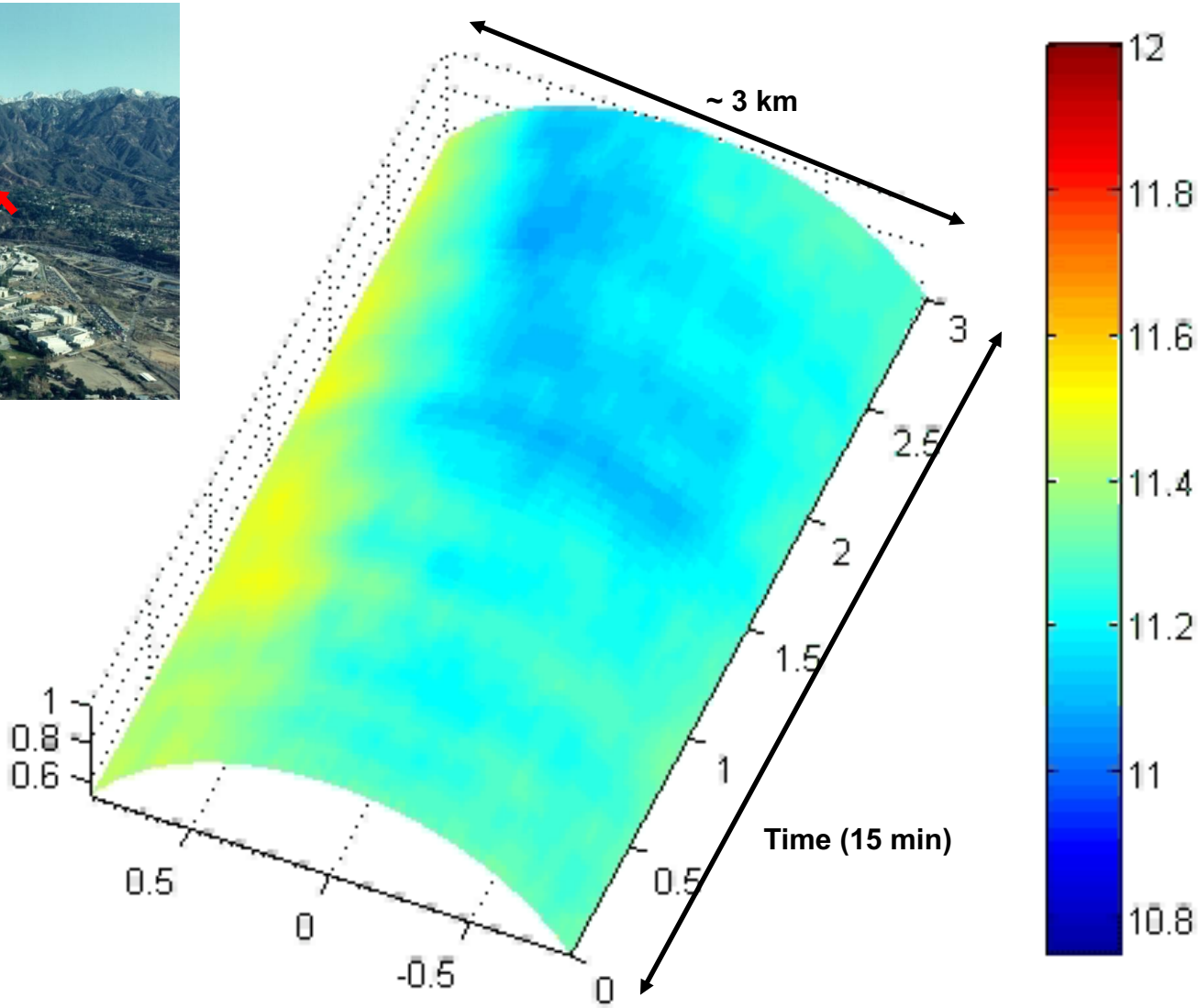
From the the ground: HAMSR



- 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

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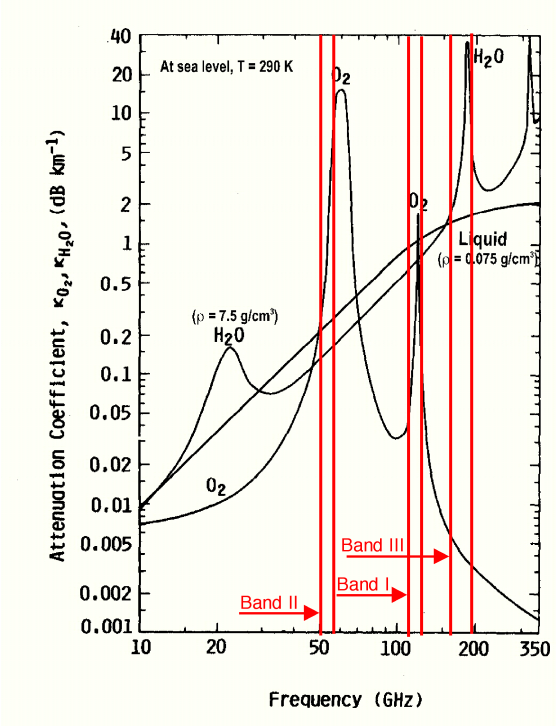
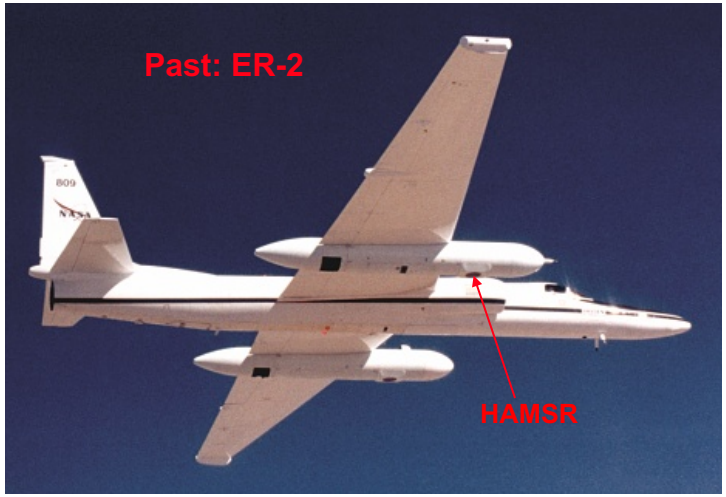
From the air: HAMSR

The High Altitude MMIC Sounding Radiometer

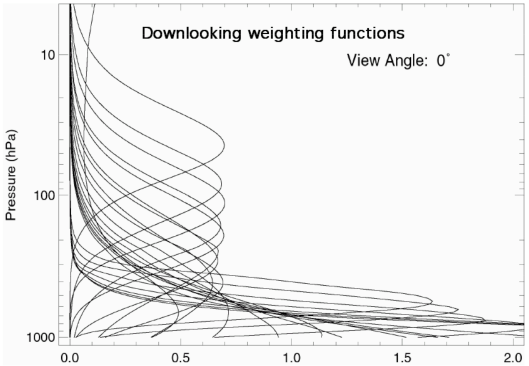


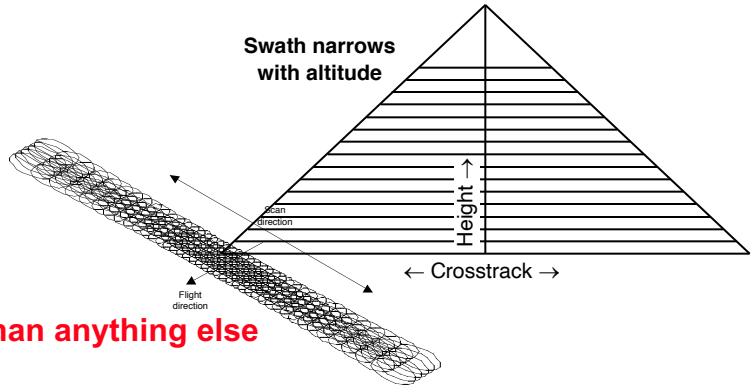
HAMSR



Chan #	Center freq. [GHz]	Offset [GHz]	Bandwidth [MHz]	Wt-func. Peak [mb or mm]
I-1	118.75	-5.500	1500	Sfc/[30 mm]
I-2	"	-3.500	1000	Surface
I-3	"	-2.550	500	Surface
I-4	"	-2.050	500	1000 mb
I-5	"	-1.600	400	750 mb
I-6	"	-1.200	400	400 mb
I-7	"	±0.800	2x400	250 mb
I-8	"	±0.450	2x300	150 mb
I-9	"	±0.235	2x130	80 mb
I-10	"	±0.120	2x100	40 mb
II-1	50.30	0	180	Sfc/[100 mm]
II-2	51.76	0	400	Surface
II-3	52.80	0	400	1000 mb
II-4	53.596	±0.115	2x170	750 mb
II-5	54.40	0	400	400 mb
II-6	54.94	0	400	250 mb
II-7	55.50	0	330	150 mb
II-8	56.02 56.67	0	270 330	90 mb
III-1	183.31	-17.0	4000	[11 mm]
III-2	"	±10.0	2x3000	[6.8 mm]
III-3	"	±7.0	2x2000	[4.2 mm]
III-4	"	±4.5	2x2000	[2.4 mm]
III-5	"	±3.0	2x1000	[1.2 mm]
III-6	"	±1.8	2x1000	[0.6 mm]
III-7	"	±1.0	2x500	[0.3 mm]

AMSU-equivalent channels circled in red



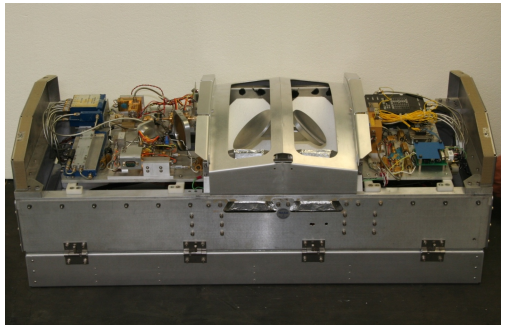


HAMSR sensitivity is 10x better than anything else

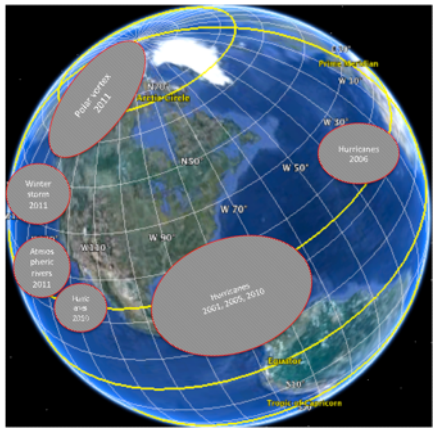
HAMSR Overview

High Altitude MMIC Sounding Radiometer

- Built under IIP-98 in 2001
  - Pre-ATMS prototype
- Currently most accurate/sensitive MW sounder
  - Upgraded under AITT in 2010
  - Flies on multiple platforms
    - Global Hawk
      - ER-2
      - DC-8
- Data transmitted from Global Hawk in R/T
  - Products displayed in R/T
  - V. useful for situational awareness



Global Hawk Setup



Flown in many regions

Measurements

- Observations under all weather conditions
  - Thermodynamic state of atmosphere
    - T(z), q(z), CLW
    - Precipitation
  - Convective structure
  - Reflectivity from hydrometeors
    - Applications:
      - Hurricanes
      - Atmospheric rivers
      - Storms

Past and current campaigns

- CAMEX-4/Florida: Hurricanes 2001
- TCSP/Costa Rica: Hurricanes 2005
- NAMMA/Cape Verde: Hurricanes 2006
- GRIP/California: Hurricanes 2010
- WISPAR/California: 2011
  - Atmospheric rivers
  - Pacific winter storms
  - Arctic science
- HS3/Virginia: Hurricanes 2011-2015
- CalWater2/California: Atmospheric rivers 2015
- SHOUT/CA, VA: Severe weather 2015-2016
- CPEX 2017
- EPOCH 2017

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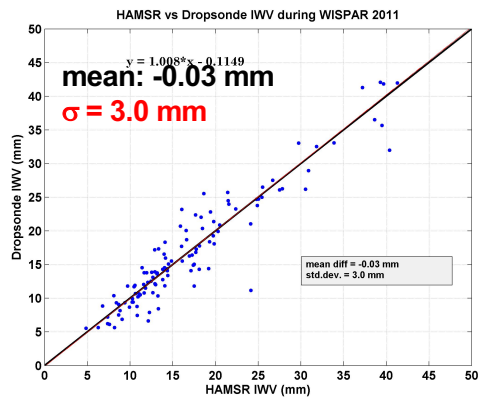
Accurate soundings

Sounders are normally used to determine thermodynamic structure:

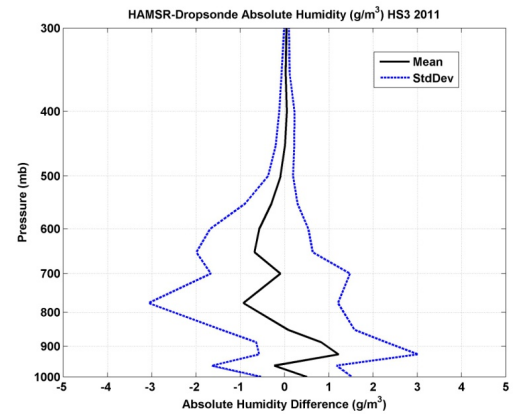
- Retrieval of 3-D atmospheric temperature, water vapor and cloud liquid water profiles using optimal estimation inversion approach
- Good agreement with dropsonde observations
- Vertical resolution (averaging kernels) is 2-3 km

- 50 dropsonde comparisons during HS3 over a wide variety of atmospheric conditions
- Dropsonde profiles smoothed vertically to match HAMSR vertical resolution
- HAMSR website contains validation reports for each flight
- Reports include comparison to MERRA and dropsondes T,q,RH

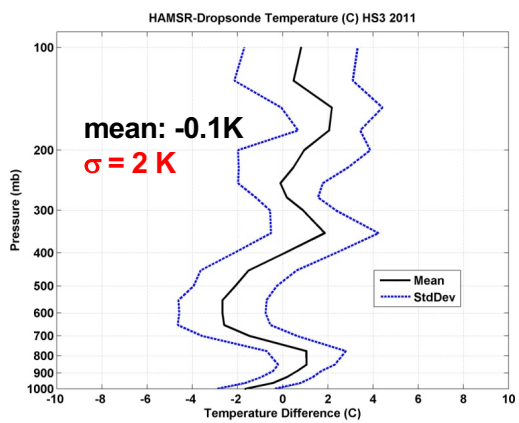
Precipitable Water Vapor (mm)



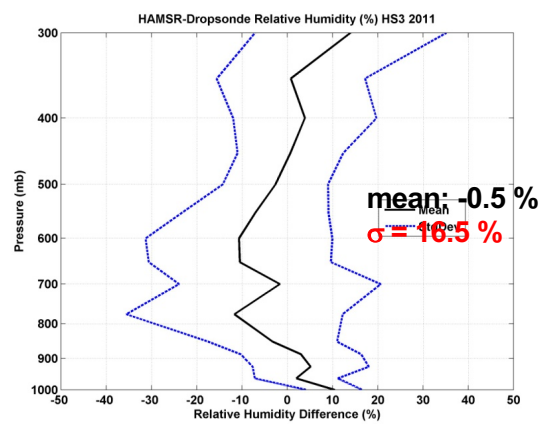
Absolute Humidity (g/m^3)



Temperature (K)



Relative Humidity (%)



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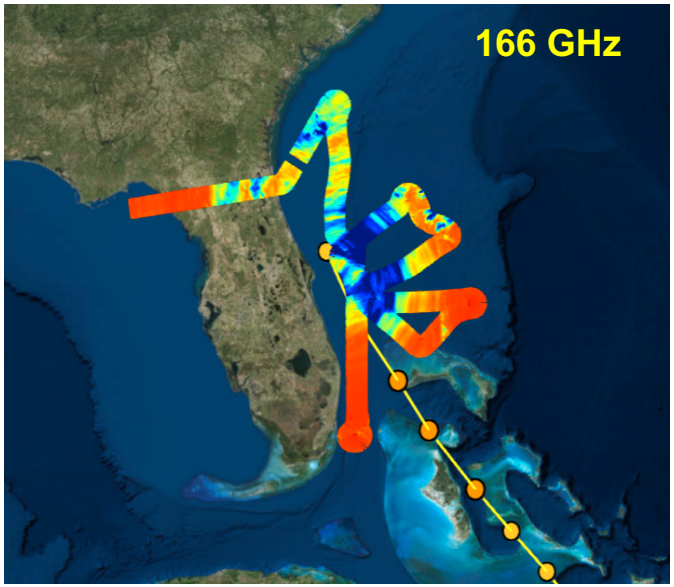
HAMSR in SHOUT Campaign

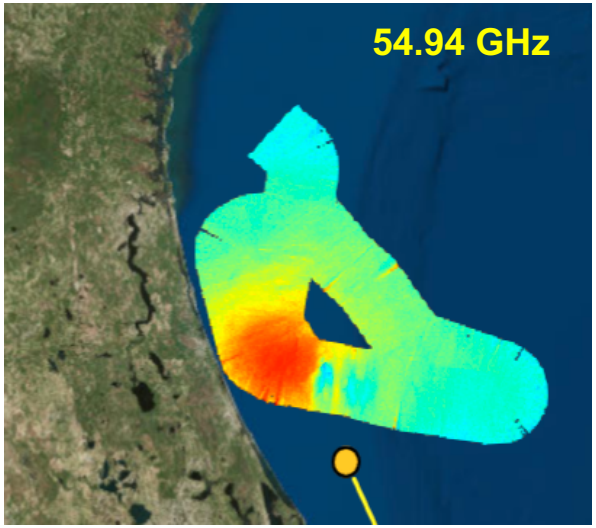
SHOUT

HAMSR was part of SHOUT (Sensing Hazards with Operational Unmanned Technology). The project is flying the Global Hawk from Armstrong and Wallops to make targeted observations of tropical meteorology and hurricanes. Goal is to demonstrate forecast impact from targeted observations, Campaign ended with H. Matthew October 9.

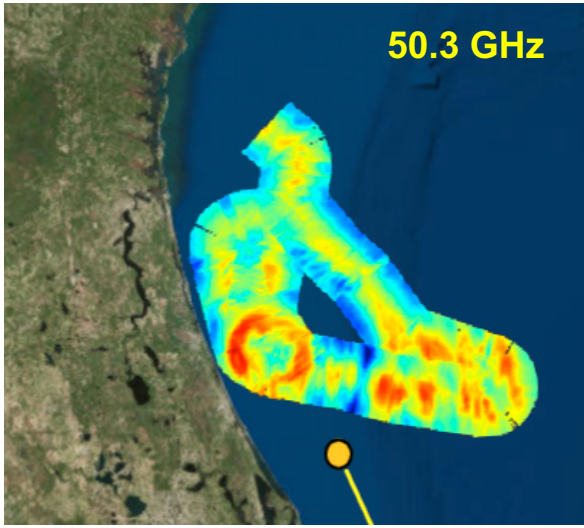
Gaston flight on 08/24 caused NHC to elevate Gaston from TS to hurricane, a first-ever case of forecast impact from targeted observations

HAMSR observations of Matthew, Oct 7, 2016





Warm core anomaly dome:
Air at 12 km is 6 K warmer than normal.
Anomaly is proportional to intensity



Near-surface structure:
Ring of shallow convection, often associated with rapid intensity changes

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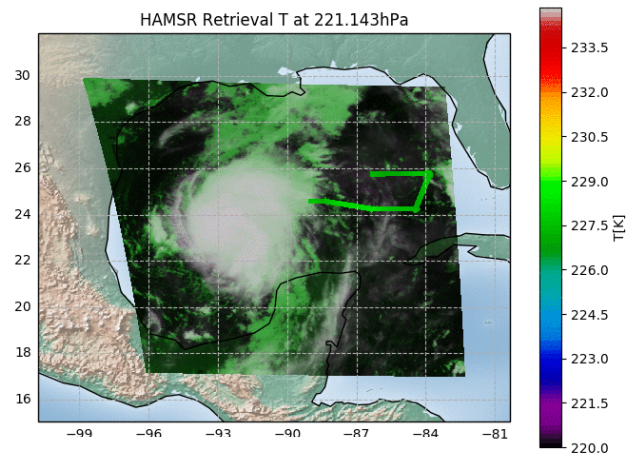
HAMSR in EPOCH: Harvey

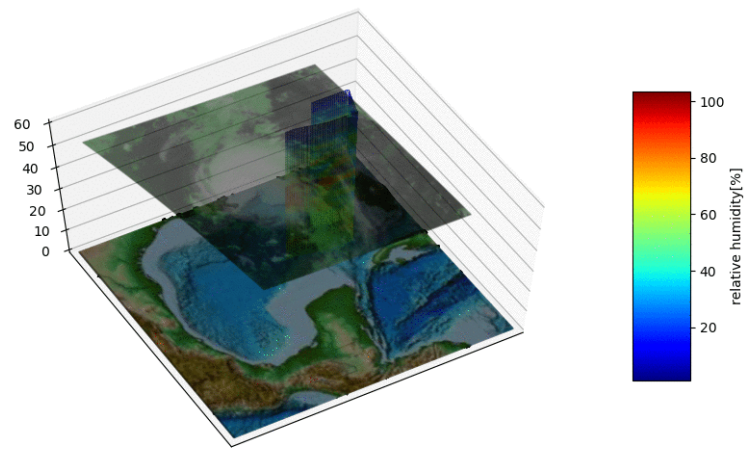
EPOCH

HAMSR was also part of EPOCH campaign (East Pacific Origin and Characteristics of Hurricanes) in 2017. Luckily, it was not restricted to the Pacific, so we got a chance to observe the intensification of Harvey before landfall on August 23rd/24th

- Upper animation shows the retrieved temperature at a level of ~200 hPa
  => Warm core is visible: Change from blue to green (2-5 K)
- Lower animation shows retrieved relative humidity at nadir

The retrieval here is an experimental system that includes scattering to allow continuous retrievals even under raining conditions





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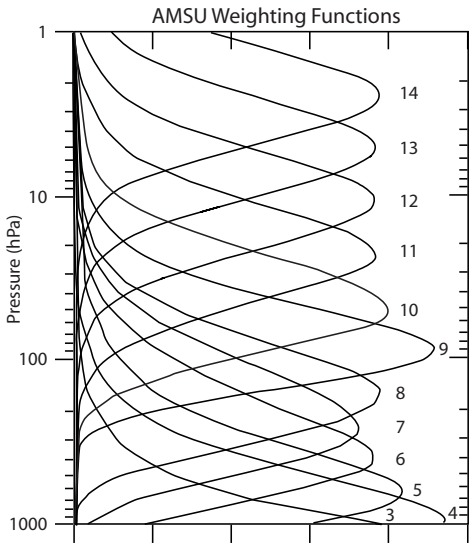
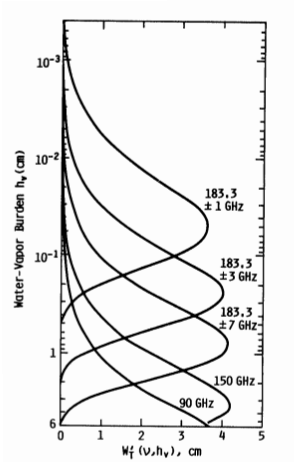
From the LEO satellites: ATMS etc.

AMSU-A (temperature sounder); spatial res ~ 50 km



AMSU-B/MHS (humidity sounder); spatial res ~ 15 km



AMSU/MHS			ATMS		
Ch	GHz	Pol	Ch	GHz	Pol
1	23.8	QV	1	23.8	QV
2	31.399	QV	2	31.4	QV
3	50.299	QV	3	50.3	QH
			4	51.76	QH
4	52.8	QV	5	52.8	QH
5	53.595 ± 0.115	QH	6	53.596 ± 0.115	QH
6	54.4	QH	7	54.4	QH
7	54.94	QV	8	54.94	QH
8	55.5	QH	9	55.5	QH
9	fo = 57.29	QH	10	fo = 57.29	QH
10	fo ± 0.217	QH	11	fo±0.3222±0.217	QH
11	fo±0.3222±0.048	QH	12	fo± 0.3222±0.048	QH
12	fo ±0.3222±0.022	QH	13	fo±0.3222±0.022	QH
13	fo± 0.3222±0.010	QH	14	fo±0.3222 ±0.010	QH
14	fo±0.3222±0.004 5	QH	15	fo± 0.3222±0.0045	QH
15	89.0	QV			
16	89.0	QV	16	88.2	QV
17	157.0	QV	17	165.5	QH
18	183.31 ± 1	QH	18	183.31 ± 7	QH
19	183.31 ± 3	QH	19	183.31 ± 4.5	QH
20	191.31	QV	20	183.31 ± 3	QH
			21	183.31 ± 1.8	QH
			22	183.31 ± 1	QH

AMSUs are flying on multiple satellites:

- NASA/Aqua
- NOAA-15
- NOAA-16
- NOAA-17
- NOAA-18
- NOAA-19
- Metop-A
- Metop-B

Producing > 2 million soundings per day!

ATMS successors

- S-NPP
- JPSS

ATMS ≈ AMSU, except

- 2x humidity channels
- 30 km res T-sounding

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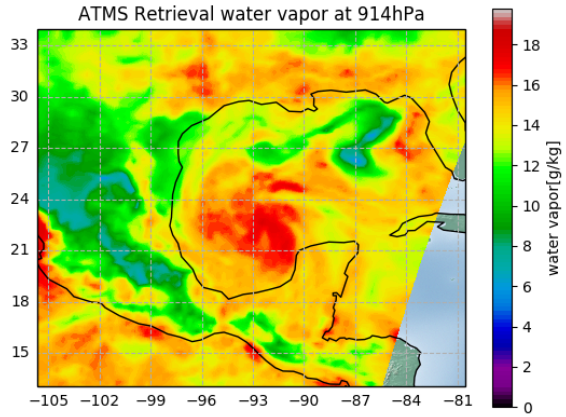
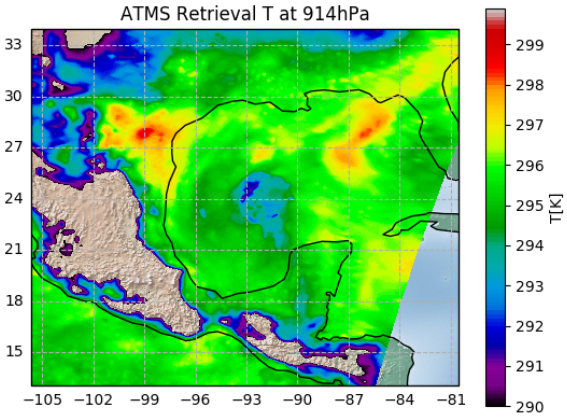
Scattering Retrieval Applied to ATMS

- The same MW-retrieval for HAMSR can also be applied to ATMS. The Figures below show Harvey observations from ATMS during the HAMSR flight.

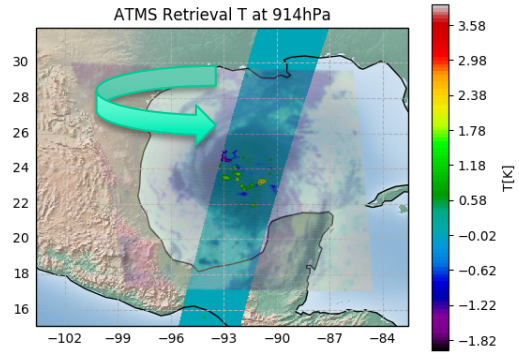


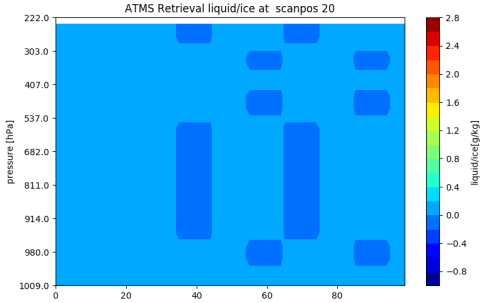


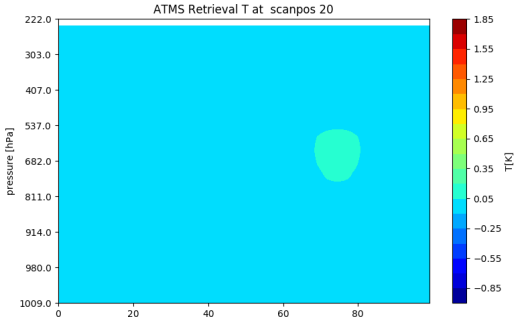
Synergy with other instruments:

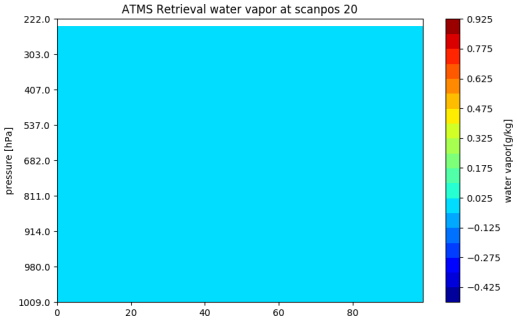
Under these strong scattering conditions, the retrieval is strongly dependent on accurate background information, like surface wind.

Additional observations, like CYGNSS, can hereby help. Below is a loop over the core that shows the impact of CYGNSS information on the retrieval









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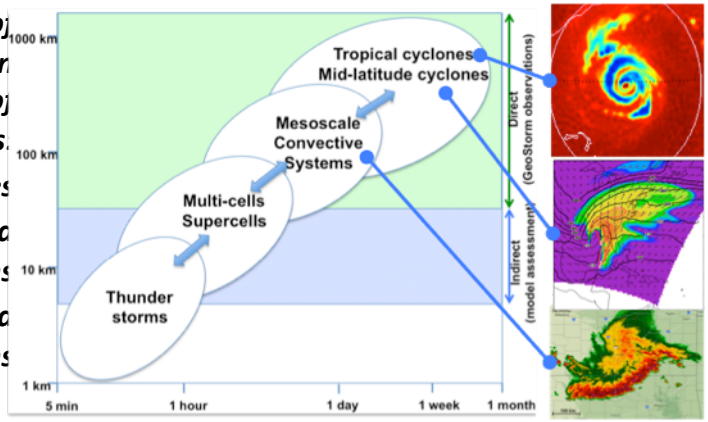
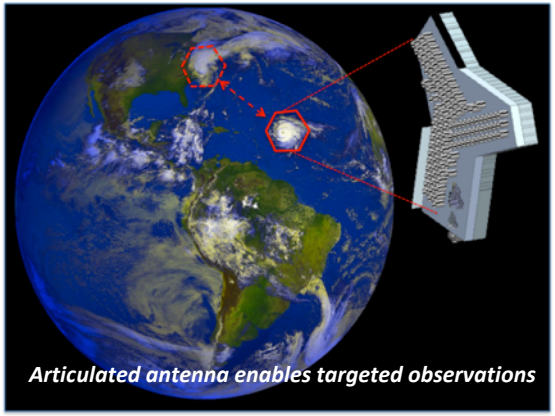
From GEO satellites: GeoSTAR

A GEOSTATIONARY MICROWAVE SOUNDER MISSION FOCUSED ON THE EVOLUTION OF SEVERE STORMS

Improve our understanding of sudden and unpredicted change in intensification and motion of destructive storms.

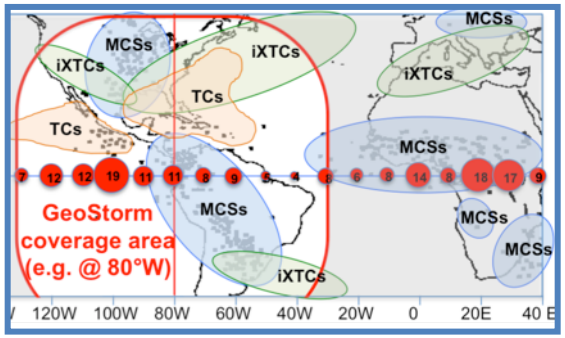
- *hurricanes*
- *severe thunderstorms and mesoscale convective systems*
- *mid-latitude cyclones and winter storms*





Low cost as a hosted payload

Many hosting opportunities in GEO:



There are more than 80 GEO comm-sats that provides a view of the Americas, being replaced at a rate of 5-6 per year

GeoStorm Highlights	
Targeted observations	Life cycle storm tracking
Time-continuous	Capture dynamic processes; diurnal cycle fully resolved
Multiple simultaneous key parameters	Temperature, humidity, precipitation, wind
All-weather	Cloud/rain-penetrating
3-D observations	1000 km dia x 15 km vert. (volume); 25 km dia x 3 km vert. (resolution)
Wide coverage	All storms visible from GEO

This mission concept was used as the basis for an OSSE study of 3D wind capabilities

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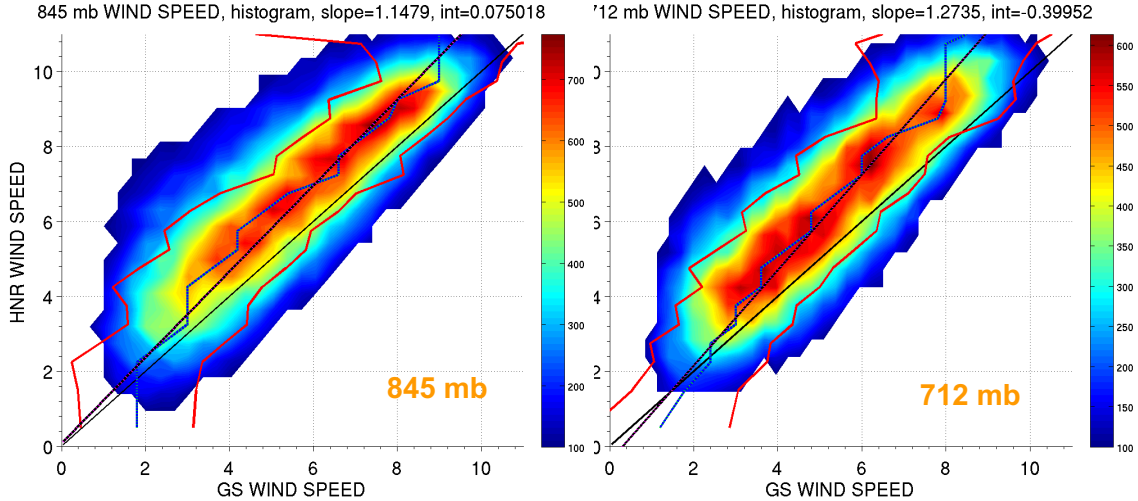
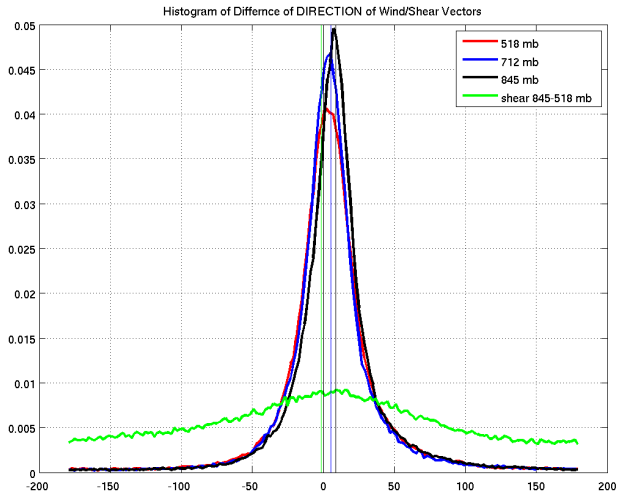
3D Wind from GEO MW Sounder

Shown for 2-3 pressure levels

Large sample size (> 5000); cases with rain rate < 1 mm/hr only



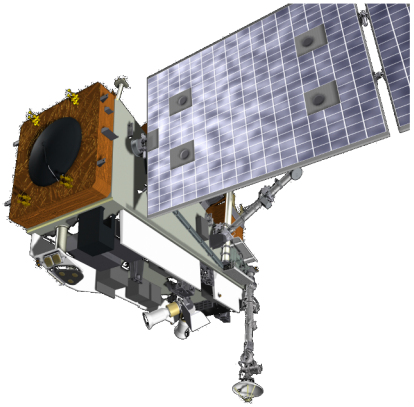
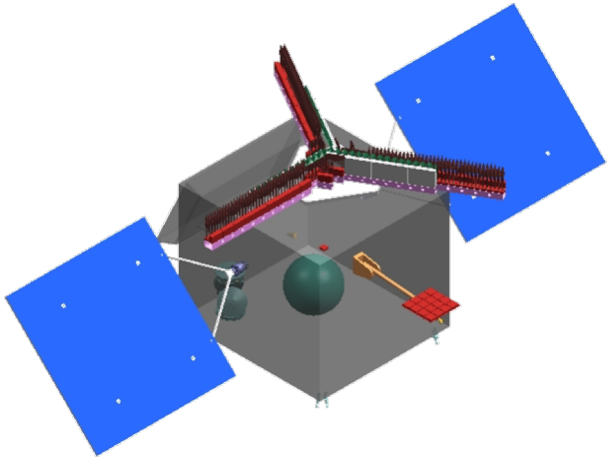
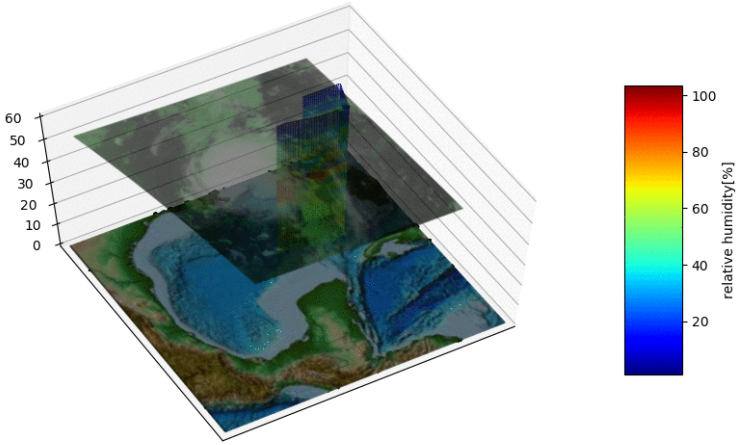


Red lines indicate 1-sigma levels. Black lines are best linear fits

Wind speed precision ≈ ± 2 m/s - This meets WMO requirements for wind

Wind direction precision ≈ ± 15°

Bias for both ≈ 0

Transfer function is nearly linear

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