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

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ABSTRACT

The HAMSR instrument is a 25 channel cross-track microwave sounder developed by the Jet Propulsion Laboratory under the IIP-98 program. The instrument was recently upgraded under the NASA AITT program in 2008 to deploy on the Global Hawk UAV. The instrument now has state-of-the-art radiometric performance and the capability to process and display both brightness temperature imagery and derived products in real time. The improved performance of the instrument is demonstrated through retrievals of temperature and water vapor.

1. INTRODUCTION

This paper describes the JPL High Altitude MMIC Sounding Radiometer (HAMSR) and presents the instrument performance through two recent field campaigns on the Global Hawk UAV. HAMSR is a 25 channel cross-track scanning microwave sounder with channels near the 60 and 118 GHz oxygen lines and the 183 GHz water vapor line. HAMSR owes its current state-of-the art performance to three ESTO programs, the IIP, ACT and AITT. HAMSR was originally designed and built at the Jet Propulsion Laboratory through the first NASA Instrument Incubator call in 1998 [1]. Subsequent to this, HAMSR participated in three NASA hurricane field campaigns, CAMEX-4, TCSP and NAMMA. Beginning in 2008, HAMSR was extensively upgraded under the first NASA Airborne Instrument Technology Transfer (AITT) program to deploy on the NASA Global Hawk (GH) platform and serve as an asset to the NASA sub-orbital program. One of the major upgrades was the addition of a front-end LNA, developed by JPL through the MIMRAM Advanced Component Technology (ACT) project, to the 183 GHz channel which reduces the noise in this channel to less than 0.1K at the sensor resolution (~2km) and enabling HAMSR to observe much smaller scale water vapor features. The 118 GHz receiver was also upgraded using the state-of-the-art ACT developed LNA, lowering the noise figure of this receiver significantly. Another major upgrade was an enhanced data system that provides on-board science processing capability and real-time data access. During the 2010 GRIP hurricane field campaign, this capability was exploited with HAMSR image products displayed within 5 minutes of acquisition in the Google Earth based Real Time Mission Monitor (RTMM) system operated by NASA Marshall. HAMSR data were used in real time by the Global Hawk platform scientists to identify the tropical cyclone circulation center and made adjustments the flight path in real time. Because of this, the Global Hawk was able to pass directly over the eye of Hurricane Karl an unprecedented 20 times as it transitioned from a tropical cyclone to a strong category 3 hurricane.

2. INSTRUMENT DESCRIPTION

A complete description of the HAMSR instrument is found in [2] and is summarized here. HAMSR scans cross track below the airplane and has a ± 60° field of view. The scan system consists of two reflectors mechanically connected to a common scanning mechanism with both beams pointing along the same boresight direction. One reflector is a flat mirror for 118 and 183 GHz and the other is a parabolic mirror for 55 GHz. The size of the beam at each band is 5.7° (HPFW), and the sidelobes for all beams are well below 30 dB with a beam efficiency of >95%, providing minimal footprint contamination. The polarization of the beams rotates as the reflectors scan, with pure V-pol at nadir. A table of the HAMSR passband characteristics including center frequency, bandwidth and side-band weighting ratios are shown in Table 1.

Each reflector scans across two calibration targets during each scan. One target is at the ambient air temperature (about -10C at altitude) and the other is heated to about 70°C. The reflectivity of the targets has been designed to be less than -50 dB. The temperature of each target is measured with four temperature sensors. The targets are constructed of heavy aluminum and are insulated to keep gradients across them to less that 0.25 K. The integration time on each target is about 10 times the integration time for the atmospheric measurements. The

Channel	f_c – LSB [GHz]	BW – LSB [MHz]	W_1	f_c – USB [GHz]	BW – USB [MHz]	W_2
1	50.30	185.34	-	-	-	-
2	51.81	456.26	-	-	-	-
3	52.82	444.60	-	-	-	-
4	53.46	151.29	0.58	53.69	155.73	0.42
5	54.41	446.50	-	-	-	-
6	54.94	442.91	-	-	-	-
7	55.46	374.80	-	-	-	-
8	55.99	279.05	0.90	56.61	235.84	0.10
9	113.27	1062.11	-	-	-	-
10	115.19	1060.03	-	-	-	-
11	116.18	506.09	-	-	-	-
12	116.70	504.33	-	-	-	-
13	117.13	432.13	-	-	-	-
14	117.54	418.95	-	-	-	-
15	117.93	459.60	0.54	119.56	424.56	0.46
16	118.30	319.84	0.54	119.19	302.38	0.46
17	118.50	117.19	0.47	118.98	140.74	0.53
18	118.61	100.86	0.42	118.86	105.95	0.58
19	166.95	3812.82	-	-	-	-
20	173.22	3298.97	0.54	192.88	2926.96	0.46
21	176.26	2409.16	0.34	190.23	2472.45	0.66
22	178.74	2133.24	0.23	187.95	2162.90	0.77
23	180.39	1093.10	0.29	186.32	1119.17	0.71
24	181.44	1157.75	0.36	185.09	1109.80	0.64
25	182.30	536.28	0.27	184.31	539.22	0.73

Table 1. HAMSR passband characteristics.

absolute accuracy of the HAMSR TBs has been demonstrated in flight to be better than 1.5 K using dropsonde and radiosonde comparisons.

The HAMSR instrument was originally developed through the first IIP in 1998. Subsequent to the completion of the instrument under the IIP, HAMSR was prepared to participate in the CAMEX-4 field campaign in 2001 on the ER-2. It was then later flown in the TCSP campaign in 2005 again on the ER-2 and in the NAMMA campaign in 2006 on the DC-8. Because the instrument was originally developed as a technology demonstration instrument, it lacked the robustness that is needed for an operational airborne instrument. Starting in 2008, HAMSR was extensively upgraded under the ESTO AITT program with the

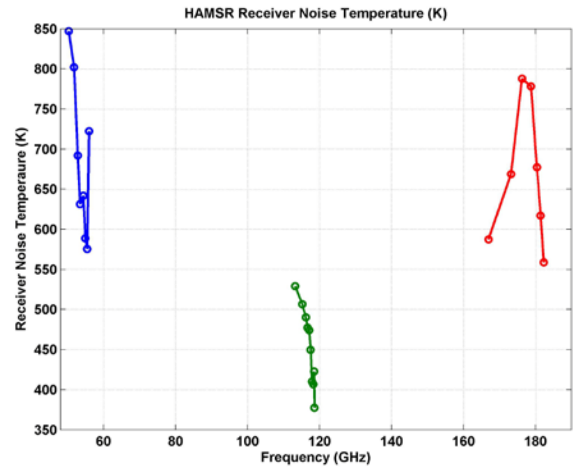

Figure 1. Measured receiver noise temperature as a function of frequency for the HAMSR channels.

objectives to bring the instrument to the current state-of-the-art and improve the reliability of the system so that it may serve as an operational asset to the NASA sub-orbital science program.

The major upgrades under the AITT program include the addition of a state-of-the-art low noise amplifier (LNA) to the 183 GHz receiver, an upgrade to the 118 GHz LNA, an upgraded data system capable of on-board science processing and a re-designed instrument packaging concept to consolidate the power, data, thermal and receiver sub-systems into one compact housing for deployment on the NASA Global Hawk Unmanned Aerial System (UAS).

3. RECIEVER SYSTEM UPGRADES

The HAMSR 183 GHz receiver sub-system takes advantage of the state-of-the-art high frequency LNA development projects at JPL. The 130-220 GHz LNAs developed under the NASA ESTO MIMRAM program have demonstrated excellent performance both in terms of low noise figure and high gain [3]. The old HAMSR 183 GHz channel had a mixer front end and a very high receiver noise temperature, on the order of 6000K. The MIMRAM LNA was added to the system just after the feed horn. A side band reject filter was added between the LNA and the mixer to reject the upper-side band. Adequately rejecting the upper sideband image is most important for the 166 GHz window channel and matters less for the channels closer to the line center. The upper sideband rejection ratio is greater than 20dB for the image of the 166 GHz channel.

The 118 GHz receiver system was also upgraded with a current generation LNA developed under the same MIMRAM program, reducing the LNA noise temperature in this receiver to approximately 350K, from greater than 1000K. A plot of the HAMSR end-to-end receiver noise temperatures as a function of frequency is shown in Figure 1. The measured HAMSR NEDTs at 300K are between 0.16-0.3 K at 50 GHz, 0.1-0.15 K at 118 GHz and 0.06-0.14 K at 183 GHz for a 2km pixel at the Global Hawk cruising altitude.

4. DATA SYSTEM UPGRADES

Because the HAMSR instrument was originally built as a laboratory demonstration instrument, the data system was not optimized for an operational scenario. The data system was upgraded to accommodate real time data transfer to the GH platform as well as to have the ability to perform on-board processing. Because the main advantage of the GH is its long duration, it is essential that data can be transmitted to the ground during the flight. The data system consists of an FPGA that is used to read the digitized radiometer counts from the analog-to-digital converters and receive the reflector position from the scan motor encoder, which are then sent to a microprocessor and packed into data files. The microprocessor additionally reads telemetry data from 40 on-board housekeeping channels (containing instrument temperatures) and receives packets from an on-board navigation unit, which provides GPS time and position, as well as independent attitude information (e.g. heading, roll, pitch and yaw). The raw data files are accessed through an Ethernet port and are stored on-board the instrument using a removable flash memory card. The HAMSR full data rate is relatively low, at 75 kbps, allowing for real time access over the Global Hawk high data rate downlink. The instrument also broadcasts a low data rate stream providing swath imagery over the iridium data link to the GH, which is limited to 2 kbps. The main difference between the high and low data rate steams is that the full data steam is over sampled by a factor of 12 and the low data rate stream only includes one observation per beamwidth and does not include the 118 GHz channels.

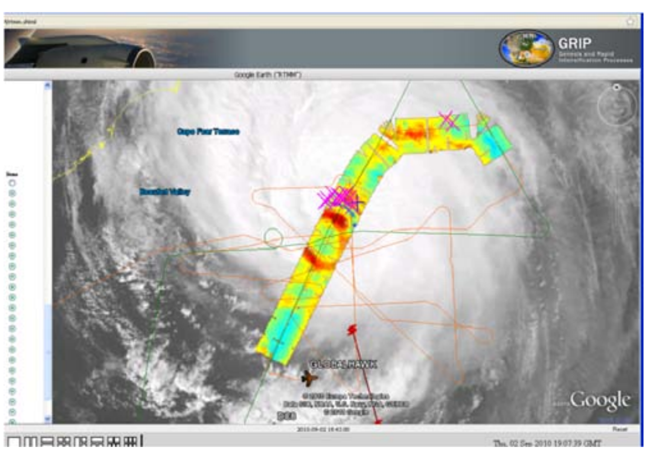

Figure 3. Example of the HAMSR TB imagery available in real time during GH flights. The "x" markers show observed lighting which is correlated with deep convection evident as TBs depressed due to scattering.

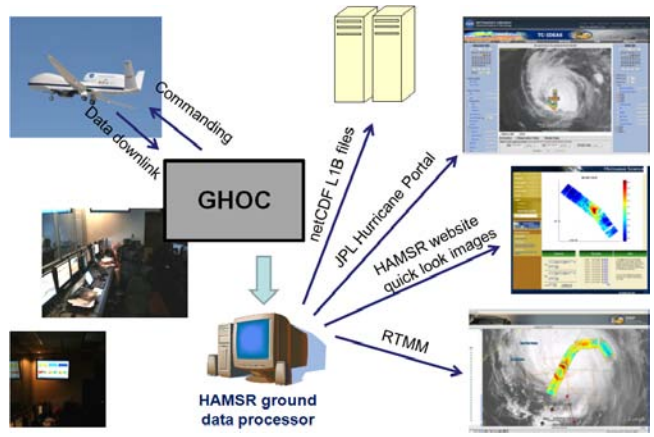

Figure 2. HAMSR ground data system on the Global Hawk.

Once on the ground, the raw data are unpacked and processed though two levels of processing. The Level 1B product contains geo-located, time stamped, calibrated brightness temperatures for the Earth scan. During deployment on the GH, these data are processed into swath imagery and placed into Google Earth kml format. The HAMSR ground data system is illustrated in Figure 2. The kml files are hosted on a server and made available to the NASA Real Time Mission Monitor and the JPL Hurricane Portal. Image files are also posted in real time on the HAMSR website. The swath products include brightness temperature imagery as well as derived products such as precpitable water vapor and integrated cloud liquid water. Off-line, these data are then input to a 1-D variational retrieval algorithm to produce temperature, water vapor and cloud liquid water profiles, as well as several derived products, such as potential temperature and relative humidity. These data are included in the Level 2 product.

An example of the RTMM display showing the HAMSR 50.3 GHz imagery over an eye overpass of Hurricane Earl in 2010 is shown in Figure 3. This example shows a clearly defined eye wall with significant convection indicated by a scattering depression of the TBs. The markers shown in the image indicate observed lighting strikes. The HAMSR data were used in real time to make adjustments to the flight path to enable sub-sequent eye overpasses.

A second example of the real time data products is shown in Figure 4. This image was taken during the NOAA

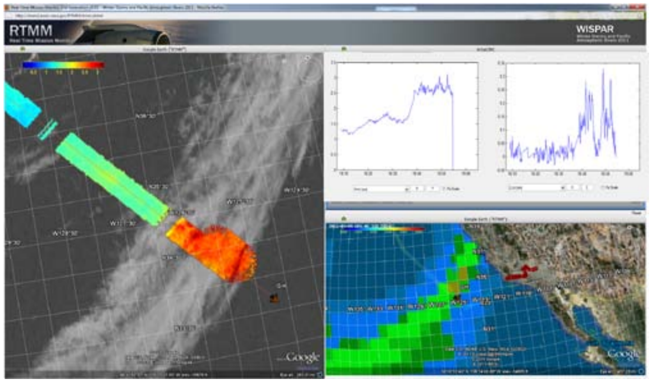

Figure 4. Image of the Real Time Mission Monitor display showing an atmospheric river transect during WISPAR. The image on the right shows HAMSR derived PWV over the transect. The strip chart in the upper right shows the nadir trace of PWV and CLW. The bottom right image shows the aircraft track and AMSU PWV imagery. These data were transmitted over the low-bandwidth iridium link.

Winter Storms and Atmospheric Rivers Campaign (WISPAR). An objective of this campaign was to study atmospheric water vapor rivers. HAMSR precipitable water vapor data were used in real time during this campaign to locate the boundaries of the atmospheric river to time the release of dropsondes, which were the main payload on this mission.

5. HAMSR OBSERVATIONS ENABLED BY THE NEW TECHNOLOGY

5.1. Upward looking water vapor retrievals

Several observations were conducted to demonstrate the measurements enabled by the new receiver technology. The first was a roof-top upward looking sky scan measurement. A simple statistical linear regression algorithm was used to derive precipitable water vapor from the HAMSR TBs. Windowing this data in time reveal very small scale water vapor structures passing over the instrument field of view. Figure 5 shows an image of 15 minutes of sky scans revealing PWV structures on the order of a few tenths of a mm over spatial scales of less than 1km. A power spectrum of the PWV time series is shown in Figure 6, demonstrating that the new system is able to resolve water vapor variability on time scales of seconds. The equivalent noise for the old system was added to the data to illustrate the improvement offered by the new LNAs. This is also shown in Figure 6, showing that the old system was not capable of resolving variability on time scales less than about 5 minutes.

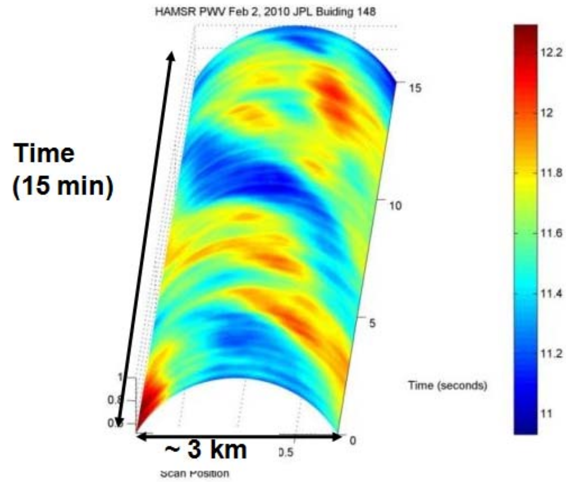

Figure 5. Image of PWV in mm over JPL in Pasadena CA in February 2010. The data show small scale structures in PWV passing over the instrument.

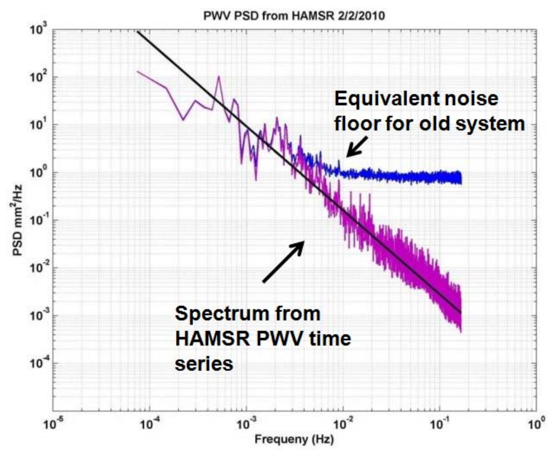

Figure 6. Power spectrum of the HAMSR derived PWV demonstrating that the new system is capable of resolving water vapor variability on time scales of seconds.

5.2. Temperature and Water Vapor Profiles from the Global Hawk

In February and March 2011, HAMSR participated in the WISPAR campaign on the Global Hawk to study winter storms and atmospheric rivers in the Pacific Ocean. The improved system performance enabled high quality retrievals of vertical temperature and water vapor profiles using the retrieval algorithm described in [4]. An example of the retrievals for an atmospheric river transect are shown in Figure 7. The atmospheric river is characterized by a marked increase in water vapor through the lower

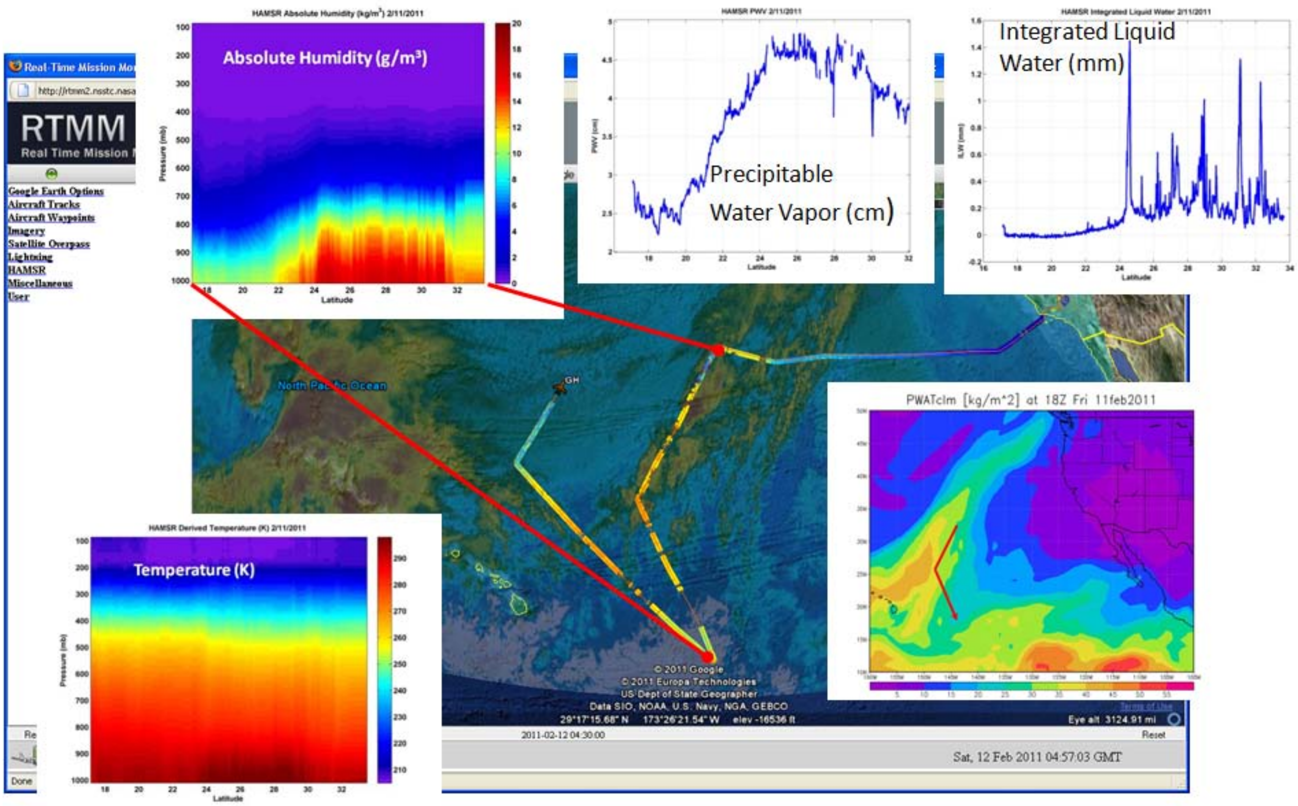

Figure 7. This image shows HAMSR retrievals of precipitable water vapor, integrated cloud liquid water, vertical temperature profile and vertical moisture profile during an atmospheric river transect. The image on the bottom right shows the PWV from NCEP.

troposphere as well as a local temperature increase below about 900 mb.

6. CONCLUSIONS

The HAMSR instrument, originally developed through the first IIP program and upgraded under the AITT program is now considered an operational and reliable instrument for the airborne science. During GRIP, the instrument was operational 100% of the time with only one channel having data unavailability for 5 hours out of over 100 hours of flight time. A minor system modification was completed after GRIP to address the channel drop out and during WISPAR, the instrument worked flawlessly. The injection of state-of-the-art technology developed by JPL under NASA ESTO funded ACT programs has dramatically improved the performance of the instrument. This was demonstrated through retrievals of temperature in water vapor both on the ground and in the Global Hawk.

The HAMSR instrument will be participating in the NASA Venture Hurricane and Severe Storm Sentinel (HS3) program to study hurricanes through 2015.

11. REFERENCES

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