UMASS SIMULTANEOUS FREQUENCY MICROWAVE RADIOMETER (USFMR) INSTRUMENT DESCRIPTION, CURRENT AND FUTURE WORK

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ABSTRACT

The Stepped Frequency Microwave Radiometer (SFMR) is a key instrument in tropical cyclones and high-latitude winter storms research. Through the observed brightness temperature (Tb) over a range of C-band frequencies, the SFMR derives wind-speed and rain rate. However, the instrument requires 5 to 10 seconds of averaging to cycle through all the frequencies, so regions of strong wind gradients and/or narrow rain features may be overlooked. The University of Massachusetts Amherst Microwave Remote Sensing Laboratory (MIRSL) developed a specialized version of the SFMR, the UMass Simultaneous Frequency Microwave Radiometer (USFMR) that operates six frequency channels simultaneously, eliminating the averaging time.

In collaboration with NOAA/NESDIS/STAR we plan to use this instrument in studies of high latitude winter storms. We describe the instrument hardware, recent comparisons with operational SFMR measurements during hurricane flight in 2019, and current and planned investigation of retrieval inconsistencies in non-tropical cyclone environments.

Index Terms— Brightness temperature, microwave radiometer, ocean winds

1. INTRODUCTION

The Stepped Frequency Microwave Radiometer (SFMR) is a nadir-looking, C-Band radiometer that steps through six frequencies (4.74, 5.31, 5.57, 6.02, 6.69 and 7.1 GHz). Since the 1980s C-Band radiometers have been deployed on aircrafts to measure extreme ocean wind speeds.

The SFMR is used to retrieve both ocean surface wind speed and columnar rain rate in hurricane reconnaissance and research missions of tropical cyclones (TCs) and high-latitude winter storms on board of the NOAA WP-3D and AFRC WC-130J aircrafts. Fundamentally, the SFMR measures the upwelling C-Band emission generated by the sea surface driven by the wind and the atmosphere[1].

Using brightness temperature (Tb) measurements obtained over the six discrete frequencies in C-Band, the SFMR retrieval algorithm solves for both wind-speed and rain rate. However, this sequential nature of the SFMR can lead to inconsistencies in the measurements. The ocean surface roughness and whitecapping dominate the microwave signature of the ocean[2], at high-winds the environment changes rapidly, however, the SFMR measurements require 5 to 10 seconds of averaging to cycle through the frequency bands, corresponding to an averaging distance up to 1.5 km. Measurements through regions of strong wind gradients and/or narrow rain features can get corrupted or smear out fine-scale features in the precipitation environment or gust features on the sea surface. The University of Massachusetts Amherst Microwave Remote Sensing Laboratory (MIRSL) developed a specialized version of the instrument which measures all the frequencies in parallel, resulting in a 4-5 fold decrease in the averaging time. The UMass Simultaneous Frequency Microwave Radiometer, hereafter referred to as USFMR, eliminates the stepping sequence and provides measurements of all frequencies at the same time which gives more rapid updates.

The USFMR flew on board of the N43RF NOAA WP-3D aircraft during the 2019 hurricane season along with the ProSensing Inc. SFMR (from now on called operational SFMR) providing early data, collected in flights through Hurricane Lorenzo in September 28^{th} 2019, to assess the differences in sequential vs simultaneous sampling.

Aside from the inconsistencies that may be caused by the stepping nature of the SFMR, in measurements of extreme winds in extra-tropical cyclones, the SFMR wind speed retrievals and wind measurements from other ground-truth sources such as dropsondes are divergent[3]. The microwave emissivity model and retrieval algorithms have been developed for tropical cyclones and have been further improved by using data collected in such environments[4], below the freezing level. Whenever the algorithm is used outside of such situation, like high-latitude winter storms, where the atmospheric and ocean conditions are different, the algorithm is not as precise.

2. INSTRUMENT DESCRIPTION

The USFMR is a multichannel RF receiver operating at six different frequency bands (4.63, 5.50, 5.92, 6.34, 6.60 and 7.05 GHz), with 100MHz of bandwidth per channel. Two orthogonal linear polarizations are available from the antenna (only one polarization has been implemented to date). Table 1 shows the specifications of the instrument.

Parameter	Value
Frequency	4.63, 5.50, 5.92, 6.34, 6.60, 7.05 GHz
Polarization	dual linear
Antenna	diagonal horn w/OMT
Beamwidths	13, 15
Receiver Gain	90 dB
Channel Bandwidth	100MHz
System Noise Temperature	250-330 K
Dicke Clock Frequency	200 Hz
Integration time	1 s
Radiometric Precision (ΔT)	0.1 K

Table 1. USFMR specifications table.

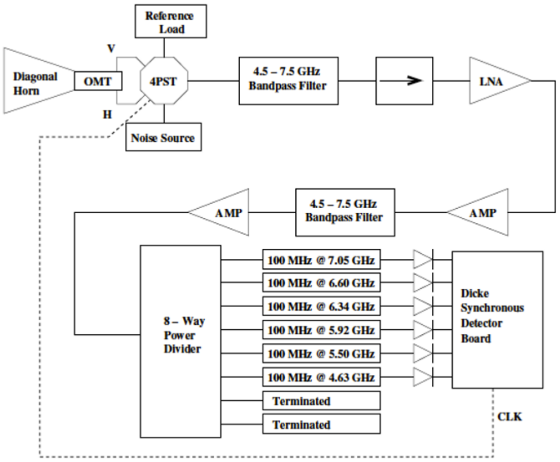
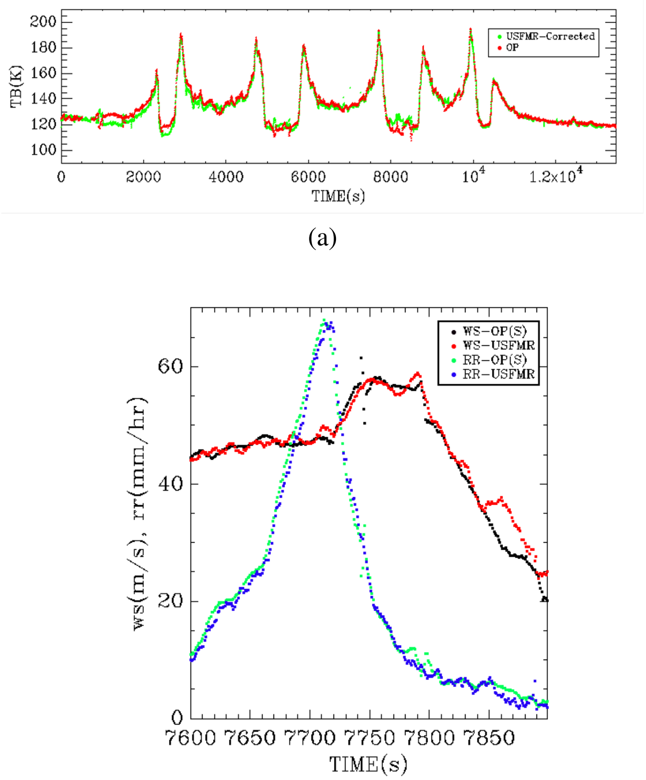


Fig. 1. Block diagram of the USFMR RF receiver.

As shown in figure 1, the USFMR follows the design of a Dicke radiometer circuit[5]. The design employs a four-port switch driven by a clock signal, commonly known as Dicke clock, that enables the radiometer to swap between two ports, the signal received by the antenna (both polarizations), an ambient temperature load and a calibrated noise source used as a hot reference source, resulting in a detected voltage proportional to the difference of the two chosen ports. The signal is divided into 8 ways by a power divider, then it goes through a bank of filters selecting each of the frequencies, afterwards each channel is downconverted to baseband by a diode detector and a synchronous detector circuit, also driven by the Dicke clock, yields a voltage proportional to the difference of the two selected signals. A multichannel A/D converts the signals and the raw data counts are stored on a Raspberry Pi 2, which stores the collected data and also generates the signals required to operate the radiometer, such as the Dicke clock.

Results obtained from the data collected on September 28^{th} 2019 by the USFMR and the operational SFMR, both flying on board the NOAA WP-3D during a mission into Hurricane Lorenzo, are shown in figure 2.



(a)

(b)

Fig. 2. (a) Brightness temperature (*Tb*) comparison of the USFMR channel 1 (*4.63GHz*), in green, vs operational SFMR channel 1 (*4.74 GHz*), in red, full hurricane flight. (b) Zoomed view of 3^{rd} inbound penetration of the eye wall, time relative to full hurricane flight (figure 2a) for both USFMR (red & blue) and operational SFMR (black & green) wind speed and rain rate, respectively.

Figure 2(a) shows a plot comparing the observed brightness temperatures in channel 1 of both the USFMR ($4.64GHz$), in green, and the operational SFMR ($4.74GHz$), in red. The eight peaks represent the inbound and outbound penetrations of the eye wall and the dips depict the flight time inside the eye of the hurricane. This plot shows USFMR data that has been corrected of uncompensated temperature trends caused by the change in ambient temperature within the instrument given by the rapid changes in altitude of the aircraft. Both observed brightness temperatures (Tb) coincide, as expected.

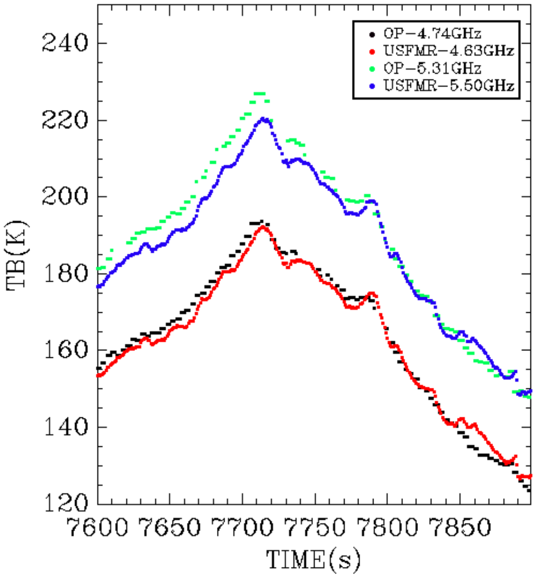


Fig. 3. Zoomed view of 3^{rd} inbound penetration of the eye wall for channels 1 & 2 (offset by 20K), time relative to full hurricane flight (figure 2a), for both USFMR (red & blue) and operational SFMR (black & green).

In order to assess further the differences between the two datasets, figure 2(b) and figure 3 show a zoomed view of the 3^{rd} inbound penetration of the eye wall. Figure 2(b) shows the wind speed and rain rate obtained with the retrieval algorithm for both instruments. The operational SFMR employs 10s smoothing to the data before applying the retrieval algorithm, to compensate for the stepping sequence of the instrument. As expected, the results are very similar but the USFMR data shows more attention detail. Figure 3 illustrates the brightness temperature for channels 1 & 2 of both instruments, with a 20K offset between channels for differentiating purposes. Looking at the operational SFMR data, it is easily noticed the sequential nature of the operational SFMR, as the inactive channels remain idle while others update, creating the "staircase" pattern, whereas the USFMR is constantly updating all the channels at once, giving further attention to detail over time. Following the trend of both datasets, even though they follow each other closely, it is discernible the areas with little dips and peaks which the operational SFMR smooths over while the USFMR presents observations with higher fidelity.

3. CURRENT AND FUTURE WORK

The inconsistencies that appear in the SFMR data in extratropical environments can be caused by many things. Among the issues causing this problem are the substantially lower air and ocean temperatures, together with the difference in temperature between air and water, the altitude of wet precipitation, if present, relative to the flight level and surface hydrodynamics.

NOAA/NESDIS/STAR has conducted research flights in high-latitude winter storms with the operational SFMR detecting that the observed data is often discrepant with other data sources. The hypothesis on the issue is that RTM model in the retrieval algorithm makes certain assumptions of the weather conditions, such as the freezing level, that are not valid for the current environment, causing the algorithm to fail. Therefore, it is proposed to further investigate the RTM model by comparing it with observed brightness temperatures from past extra-tropical storm flights, data made available by NOAA/NESDIS/STAR, to understand the implications of collecting data in colder conditions, study the effect of flying above the freezing level, the influence of the storm structure on the observed data and further characterize high-latitude winter storms in order to identify an error structure in the algorithm.

4. REFERENCES

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