Exploring the Benefits of Satellite Hyperspectral Microwave Observations: Toward the New Generation of Microwave Sounders

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Motivation

Satellite microwave sounder measurements have been highly beneficial to Numerical Weather Prediction (NWP), improving forecasts by as much as 18% (Cardinali 2009). The launch of the Advanced Technology Microwave Sounder (ATMS) in October 2011 (Weng et al. 2012) was a big step in improving NWP accuracy.

This is where a new, experimental sounder, the Hyperspectral Microwave Sounder (HyMS) has gained attention. This sounder has increased spectral resolution compared to the ATMS, which would provide more accurate atmospheric profiling (Maddy, Iturbide-Sanchez, and Boukabara 2024).

Goal:
Demonstrate the improvements of HyMS over the ATMS.

Data

The cases used in this study were two hurricanes that both occurred in 2021:

- Hurricane Felicia:
  - Max intensity was category 4
  - Did not make landfall
  - 14 - 20 July

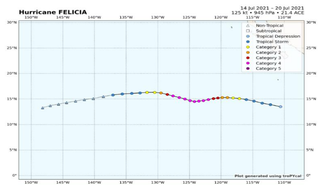


Figure 1 - Track and intensities of hurricane Felicia made in Python with data pulled from the National Hurricane Center (NHC)

- Hurricane Larry:
  - Max intensity was category 3
  - Struck Newfoundland, Canada
  - 31 August - 11 September

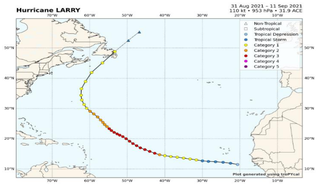


Figure 2 - Track and intensities of hurricane Larry made in Python with data pulled from the National Hurricane Center (NHC)

The data was simulated within the Community Radiative Transfer Model (CRTM) with the base environment set as the Global Forecasting System (GFS) output. The GFS serves as the reference data for a comparison of HyMS and ATMS accuracy.

Important Data Characteristics:

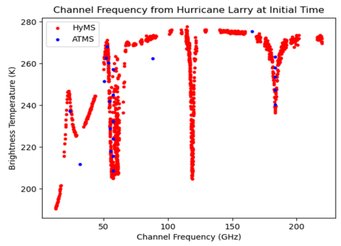
- Water vapor expressed on a log-scale with height
- 32 pressure levels from 972 hPa to 1 hPa
- Each pressure level is composed of 9118 data points
- Water vapor is near zero above 100 hPa, that level is omitted from future plots
- The cases have 7 different time steps, each about 12 hours apart

Machine Learning Algorithm

The Multi-Instrument Inversion and Data Assimilation Preprocessing System-Artificial Intelligence (MIIDAPS-AI) was used to process the data (Maddy, Iturbide-Sanchez, and Boukabara 2024, Maddy and Boukabara 2021). This algorithm can process data in a timely manner, this is needed because the HyMS datasets are approximately 5x larger than ATMS datasets.

This algorithm takes the CRTM output (which is in brightness temperature) and calculates the geophysical parameters such as water vapor, temperature, and cloud water.

Spectrum Comparison



- HyMS has 1266 channels
- ATMS has 22 channels
- Absorption and window regions

Figure 3 - The spectrum of HyMS (red) and ATMS (blue). Brightness temperature is on the y-axis expressed in Kelvin, and the channel frequency is on the x-axis in GHz.

Vertical Profiles

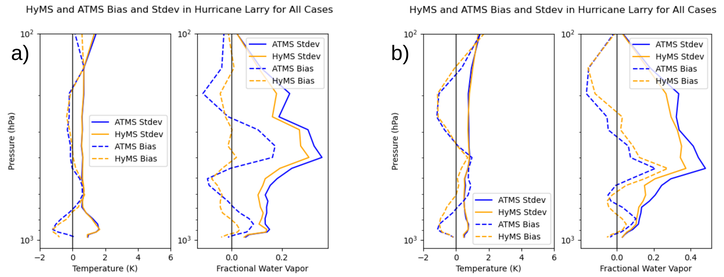


Figure 4 - Vertical cross sections of hurricane Larry of standard deviation (solid) and average bias (dashed) for HyMS (orange) and ATMS (blue) at 0hr (a) and 48hr (b)

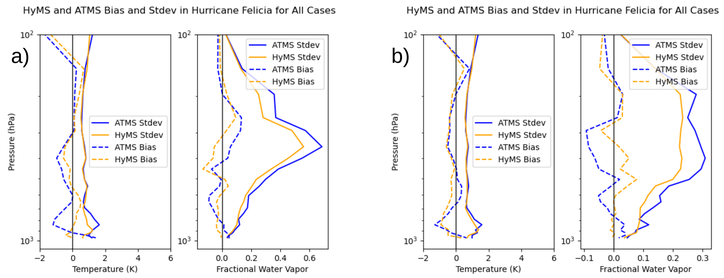


Figure 5 - Vertical cross sections of hurricane Felicia of standard deviation (solid) and average bias (dashed) for HyMS (orange) and ATMS (blue) at 24hr (a) and 48hr (b)

- Water vapor is calculated as a fraction, the x-axis for the water vapor profile is a percent difference.
- Clear improvements shown by HyMS over ATMS

Horizontal Cross-Sections: Temperature

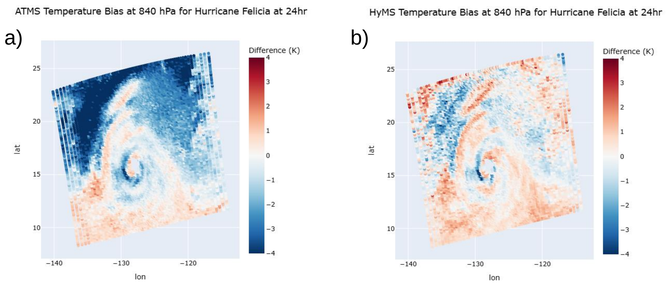


Figure 6 - Horizontal cross-sections at 840 hPa of hurricane Felicia at 24hr. Both figures (**a** and **b**) are the bias calculations of ATMS and HyMS, respectively, from the GFS output. Blue represents a cold bias, and red represents a heat bias.

Horizontal Cross-Sections: Water Vapor

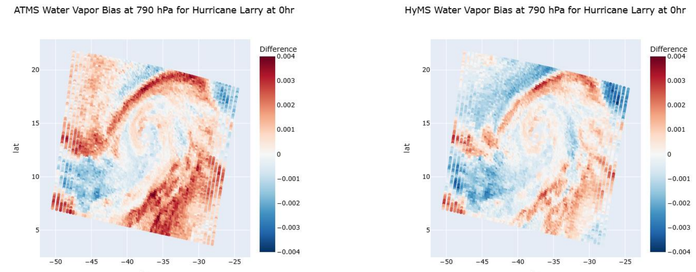


Figure 7 - Horizontal cross-sections at 790 hPa of hurricane Larry at 0hr. Both figures (**a** and **b**) are the bias calculations of ATMS and HyMS, respectively, from the GFS output. Blue represents a cold bias, and red represents a heat bias.

Average Bias Heatmaps

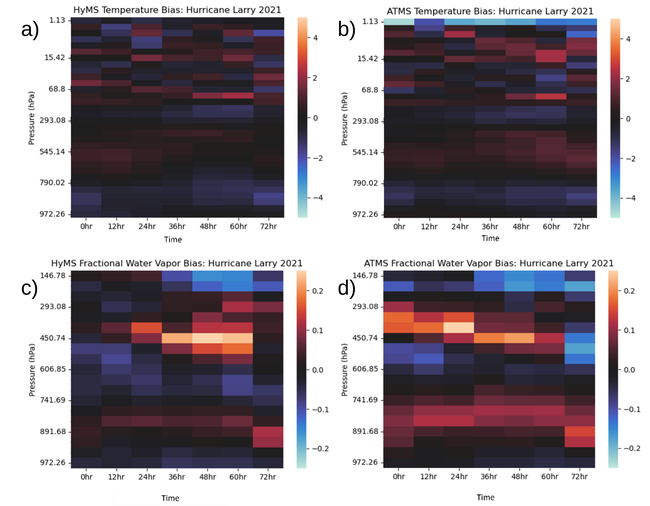


Figure 8 - Average bias heatmaps of temperature (**a** and **b**) and water vapor (**c** and **d**) between HyMS (left) and ATMS (right). The x-axis represents each timestamp in the hurricane, the y-axis is each pressure level in the system, and each individual box is the average bias of each layer. Red shows a hot bias, blue shows a cold bias, and black is a zero bias.

Conclusions

1. Improved tropospheric water vapor sounding as shown in figure 8d
2. Water vapor sounding improved by about 5-15%
3. Temperature sounding improved by about 0.2-2 K
4. MIIDAPS-AI can process large amounts of data quickly and effectively

References

C. Cardinali, 2009: Forecast sensitivity to observation as a diagnostic tool. *ECMWF Technical Memorandum No. 599*, 28 pg.

E. S. Maddy, F. Iturbide-Sanchez, and S. A. Boukabara, 2024: Next generation of microwave sounders of a low-earth orbit hyperspectral microwave instrument in all-weather conditions. *Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, **17**, 4235-4246.

E. S. Maddy and S. A. Boukabara, 2021: MIIDAPS-AI: An explainable machine-learning algorithm for microwave remote sensing and data assimilation preprocessing - application to LEO and GEO sensors, *IEEE Journal of Selected Topics*, **14**, pp. 8566-8576.

F. Weng, X. Zou, X. Wang and M. D. Goldberg, 2012: Introduction to Suomi national polar-orbiting partnership advanced technology microwave sounder for numerical weather prediction and tropical cyclone applications, *J. Geophys. Res.: Atmospheres*, **117**.

Acknowledgments

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