THE HYPERSPECTRAL MICROWAVE PHOTONIC INSTRUMENT (HYMPI)

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ABSTRACT

We present an overview of the Hyperspectral Microwave Photonic Instrument (HyMPI), a NASA Instrument Incubation Proposal funded research project aimed at developing a hyperspectral microwave instrument intended for enhanced remote sensing of atmospheric temperature and water vapor from space.

This paper provides preliminary results on HyMPI's spectral and noise characteristics and a preliminary demonstration of its enhanced water vapor sensitivity and vertical resolution, with a particular focus on the Earth's Planetary Boundary Layer.

Index Terms— Hyperspectral, Photonic Integrated Circuits, Planetary Boundary Layer

1. INTRODUCTION

Hyperspectral (a few hundred to a few thousand channels) microwave sensors have been strongly advocated by numerous space and meteorological agencies worldwide, to augment Earth's sounding capability of temperature, water vapor and clouds from space. The NASA Planetary Boundary Layer (PBL) Incubation Study Team Report lists hyperspectral microwave sensors as an "*Essential Component*" of the future global PBL observing system, to provide accurate PBL and free tropospheric 3D temperature and water vapor structure context [1].

Liquid droplets and ice particles make most clouds completely opaque in the infrared region, but in the microwave they are partially transparent, enabling retrieval of vertical temperature and water vapor profiles under all sky conditions. However, operational passive microwave spaceborne sensors from the current Program of Record (POR), (e.g., the Advanced Technology Microwave Sounder (ATMS)), and even planned sensors have very limited and sparse spectral sampling, hindering vertical resolution and accuracy of the retrievable data and its applicability. The reason for stalled progress in hyperspectral microwave technology rests in the numerous technological challenges associated with simultaneously processing an ultra-wide bandwidth (20-200 GHz) at hyperspectral resolution (< 1 GHz), while maintaining a feasible instrument size, weight and power consumption, and cost (SWaP-C).

Traditional microwave radiometers are based on radio-frequency (RF) technology whose constraints limit the capabilities of current spectrometers. Recent advances in Photonic Integrated Circuits (PICs) technology have opened a new era of hyperspectral microwave instrument development. SWaP-C can be
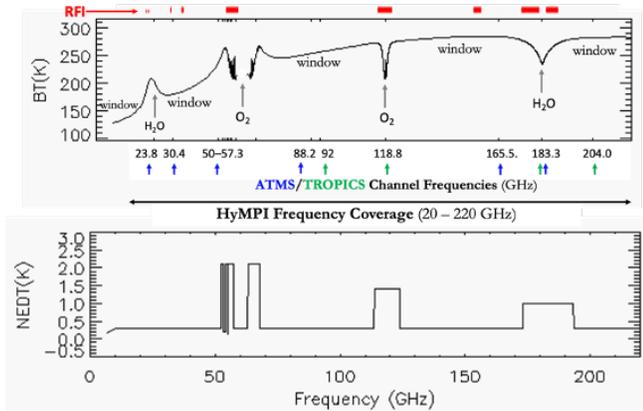
Figure 1. Top: An illustrative example of a HyMPI spectral coverage (black curve). Bottom part illustrates HyMPI's noise characteristics. To ensure continuity to the Program Of Record (POR), HyMPI includes all ATMS (blue arrows) and TROPICS channels (green arrows) at their native spectral resolution, a feature made possible by the PICASIC's unique modular design. This technology also enables to increase spectral resolution up to 500 KHz to detect and remove Radio Frequency Interference (RFI), whose spectral allocations are indicated by the red bars in the top figure.

improved by means of photonic signal processing techniques, enabled by up-conversion of a microwave signal to an optical carrier [2]. Our team at GSFC has been awarded the development of a Hyperspectral Microwave Photonic Instrument (HyMPI), which aims to solve the SWaP-C challenge of current RF technology by combining Photonic Integrated Circuits (PICs) and Application Specific Integrated Circuits (ASICs) into a "PICASIC" module [2]. The results will yield a low mass, low power, high spectral resolution and wide band instrument. The PICASIC modular approach enables full-spectrum (20 – 200 GHz) and contiguous spectral coverage with a tunable capability to measure the spectrum with higher resolution where higher structure in the signal is exhibited. The PICASIC forms the heart of HyMPI, configured to provide extended, high spectral resolution coverage in the

microwave domain of the Earth's thermal radiation.

This paper presents an overview of HyMPI's spectral and noise baseline specifications (section 2). Section 3 provides an overview of our preliminary water vapor sensitivity and vertical resolution studies. We conclude with a few summary notes on expected retrieval performance and applications beneficial to climate and numerical weather prediction.

2. THE HYPERSPECTRAL MICROWAVE PHOTONIC INSTRUMENT (HYMPI)

HyMPI's design leverages the results presented in [3] and [4] as an initial baseline, with some augmentation. This baseline design (illustrated in Figure 1) is characterized by continuous spectral coverage over the 20 - 200 GHz spectrum with a variable spectral resolution. The oxygen absorption lines in the 52.6-57.3 GHz, 63.3-67.9 GHz are sampled with a spectral resolution of 10 MHz. The oxygen line at 113.7-123.7 GHz is sampled with a spectral resolution of 20 MHz. Both are used to retrieve the vertical temperature profile. The water vapor absorption line centered in the 173.3-193.3 GHz band is sampled with a spectral resolution of 40 MHz. In addition to the conventional "window" regions in the POR (*e.g.*, the Advanced Technology Microwave Sounder), we studied the full interstitial window regions using contiguous sampling with a spectral resolution of 0.5 GHz. Window channels are used to retrieve key information about the surface (e.g., emissivity, temperature, classification) but are also important for their extended sensitivity to temperature and water vapor in the PBL. As highlighted in [5], hyperspectral coverage in the window region should not be underestimated, given their high sensitivity to different types of atmospheric hydrometeors (e.g., cloud ice/liquid water, all forms of precipitation). To ensure continuity to the POR, HyMPI includes all ATMS (blue arrows) and TROPICS (Time Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats) channels (green arrows) at their native spectral
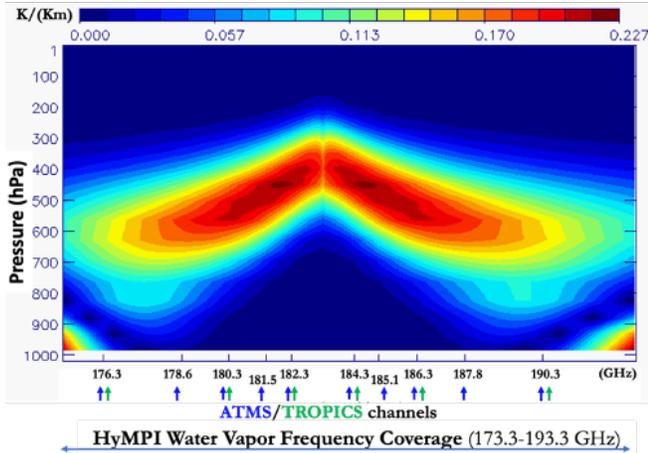
Figure 2. HyMPI's brightness temperature sensitivity to variations water vapor. 5% water vapor perturbations in each 1 km-pressure layer of the atmospheric profile have been applied to measure the response in brightness temperature at each frequency of HyMPI's water vapor bands. ATMS and TROPICS spectral channel frequencies are highlighted by blue and green arrows, respectively.

resolution, a feature made possible by the PICASIC's unique modular design. This technology also enables to increase spectral resolution up to 500 KHz to detect and remove Radio Frequency Interference (RFI), whose spectral allocations are indicated by the red bars in Figure 1.

3. PRELIMINARY SENSITIVITY RESULTS

We illustrate HyMPI's brightness temperature sensitivity to variations water vapor (Figure 2). Temperature is omitted for brevity and will be part of an extended future publication. In the figure, 5% water vapor perturbations in each 1 km-pressure layer of the atmospheric profile have been applied to measure the response in brightness temperature at each frequency of HyMPI's water vapor bands. For comparison purposes, ATMS and TROPICS spectral channel frequencies are highlighted by blue and green arrows, respectively. While in the infrared domain, trace gas interference often requires a
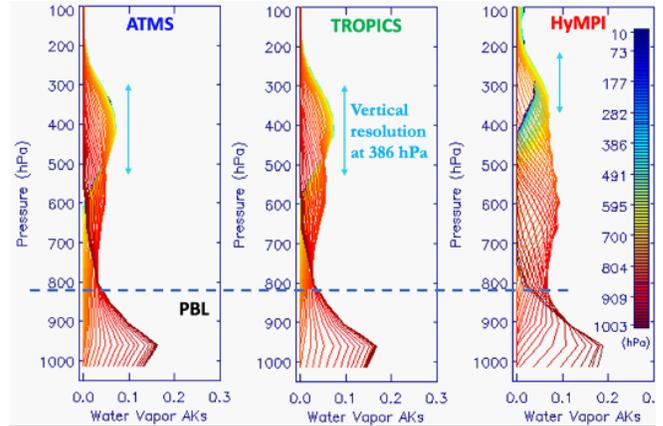

Figure 3. Water vapor AK row functions from ATMS, TROPICS and HyMPI. Each color indicates a retrieval vertical altitude (see color bar). The corresponding curve with that color describes the vertical resolution spread of the retrieval at that altitude, measured by the full width at half maximum of the peak along the y-axis (example at 386 hPa is shown in the figure). **Please note:** TROPICS AKs have been obtained using the same retrieval configuration as in ATMS and HyMPI and might not reflect its optimized operational configuration.

large amount of subsetting in the temperature and water vapor bands, the microwave domain is spectrally purer [6]. This feature makes the high redundancy in HyMPI's measurements fully exploitable. This feature is expected to provide high signal-to-noise to the retrieval process and to significantly benefit retrieval performance.

Figure 3 compares water vapor averaging kernel (AK) functions from ATMS, TROPICS and HyMPI. Each color indicates a retrieval vertical altitude (see color bar). The corresponding curve with that color describes the vertical resolution spread of the retrieval at that altitude, measured by the full width at half maximum of the peak along the y-axis (example at 386 hPa is shown in the figure). Our investigation demonstrates that HyMPI 1) fills the mid-troposphere - 800 hPa gap in the ATMS and TROPICS retrieval vertical resolution 2) nearly doubles the retrieval vertical resolution along the full extent of the mid/upper

tropospheric column, and 3) increases the vertical resolution and sensitivity in the PBL.

4. CONCLUDING REMARKS

Preliminary studies have demonstrated significant enhancements in the sensitivity and vertical resolution of the water vapor field obtained by HyMPI. These features are expected to enable enhanced thermodynamic retrieval vertical structure and accuracy with respect to program of record products that can be key to numerous climate and weather forecasting applications, particularly in the PBL. HyMPI's capability to reach a spectral resolution as high as 500-kHz will be key to Radio Frequency Interference detection, which has been shown detrimental for temperature and precipitation forecasting. Extended sensitivity and retrieval impact studies, including temperature and PBL height retrievals, are underway and will be the focus of the conference presentation.

11. REFERENCES

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