Improved All-Weather Atmospheric Sounding Using Hyperspectral Microwave Observations[1]

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Abstract

We introduce a new hyperspectral microwave remote sensing modality for atmospheric sounding, driven by recent advances in microwave device technology that now permit receiver arrays that can multiplex multiple broad frequency bands into more than ~100 spectral channels, thus improving both the vertical and horizontal resolution of the retrieved atmospheric profile. Global simulation studies over ocean and land in clear and cloudy atmospheres using three different atmospheric profile databases are presented that assess the temperature, moisture, and precipitation sounding capability of several notional hyperspectral systems with channels sampled near the 50-60-GHz, 118.75-GHz, and 183.31-GHz absorption lines. These analyses demonstrate that hyperspectral microwave operation using frequency multiplexing techniques substantially improves temperature and moisture profiling accuracy, especially in atmospheres that challenge conventional non-hyperspectral microwave sounding systems because of high water vapor and cloud liquid water content. Retrieval performance studies are also included that compare hyperspectral microwave sounding performance to conventional microwave and hyperspectral infrared approaches, both in a geostationary and low-earth orbit context, and a path forward to a new generation of high-performance all-weather sounding is discussed.

Introduction

Remote measurements of the Earth's atmospheric state using microwave and infrared wavelengths have been carried out for many years [1, 2]. Physical considerations involving the use these spectral regions include the relatively high cloud penetrating capability at microwave wavelengths and the relatively sharp weighting functions at infrared wavelengths, particularly in the shortwave region near 4 micron where Planck nonlinearity further increases temperature sensitivity. Infrared spectrometer technology has advanced markedly over the last 15 years or so to allow the simultaneous spectral sampling of thousands of bands spaced along narrow atmospheric absorption features [3]. The Atmospheric InfraRed Sounder (AIRS), launched in May 2002, measures 2378 channels from 3.7 to 15.4 micron [4] and the Infrared

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Atmospheric Sounding Interferometer (IASI), launched in 2006, measures 8461 channels from 3.6 to 15.5 micron [5]. These sensors, and similar sensors to be launched as part of the NPOESS and Metosat Third Generation systems, substantially improve atmospheric sounding through the use of hyperspectral measurements, which yield greater vertical resolution throughout the atmosphere [6].

In this paper we explore the potential use of hyperspectral microwave observations and make three primary contributions. First, we propose a frequency multiplexing technique that can be used to realize hyperspectral microwave measurements with conventional receiver hardware. The approach is easily scalable and requires no new technology development. Second, we examine the relative merits of increased bandwidth versus increased channelization within an increased bandwidth and demonstrate that the optimal operating point depends on the available integration time. Third, we provide a set of comprehensive and global simulation analyses with state-of-the-art retrieval methods that illuminate many of the principal dimensions of the design and performance comparison trade space, including 60-GHz versus 118-GHz, hyperspectral microwave versus conventional microwave, and hyperspectral microwave versus hyperspectral infrared, and we also consider both geostationary and low-earth orbit configurations.

The Hyperspectral Microwave Concept

A spate of recent technology advances has significantly and profoundly changed the landscape of modern radiometry by enabling miniaturized, low-power, and low-noise radio-frequency receivers operating at frequencies up to 200 GHz. These advances enable the practical use of receiver arrays to multiplex multiple broad frequency bands into many spectral channels, and we explore the atmospheric sounding benefit of such systems in this paper. We use the term "hyperspectral microwave" to refer generically to microwave sounding systems with approximately 100 spectral channels or more. In the infrared wavelength range, the term "hyperspectral" is used to denote the resolution of individual, narrow absorption features that are abundant throughout the infrared spectrum. In the microwave and millimeter wavelength range, however, there are substantially fewer spectral features and the spectral widths are typically broad, and an alternate definition is therefore appropriate.

We begin by presenting a simple example of a multiplexed hyperspectral microwave system with eight instantaneous fields of view (IFOV's), four near 118~GHz and four near 183 GHz. Each IFOV is sampled by a single feedhorn measuring two orthogonal polarizations (vertical and horizontal, for example) that are each fed to a ten-channel spectrometer. The 183-GHz IFOV's each measure the same spectral channels. As the array is microscanned in two dimensions, each 50-km spot on the ground is eventually sampled by eighty channels near 118~GHz, and each 25-km spot on the ground is eventually sampled by 20 channels near 183~GHz for a total of 100 channels. Additional channels could be added by increasing the number of feeds and receiver banks, and hyperspectral microwave systems with hundreds of channels are therefore reasonable.

Simulation Methodology and Sample Results

All retrievals presented in this paper are carried out using neural networks [7-9] trained against cloud-resolving physical models. The neural network retrieval algorithms have been extensively validated on a global scale using AIRS/AMSU observations [10]. Global atmospheric profile databases are used to simulate several notional systems for comparison, including a Synthetic Thinned Aperture Radiometer (STAR) system similar to that proposed in [11], the Geostationary Microwave Array Spectrometer (GeoMAS), and the Hyperspectral Microwave Array Spectrometer (HyMAS). The sounding performance of these systems is also compared to the AIRS/AMSUA/HSB sounding suite. The temperature, moisture, and precipitation sounding performance of the hyperspectral microwave systems is competitive with state-of-the-art infrared+microwave systems. Examples for temperature profile retrieval performance [12] are shown in Figure 1.

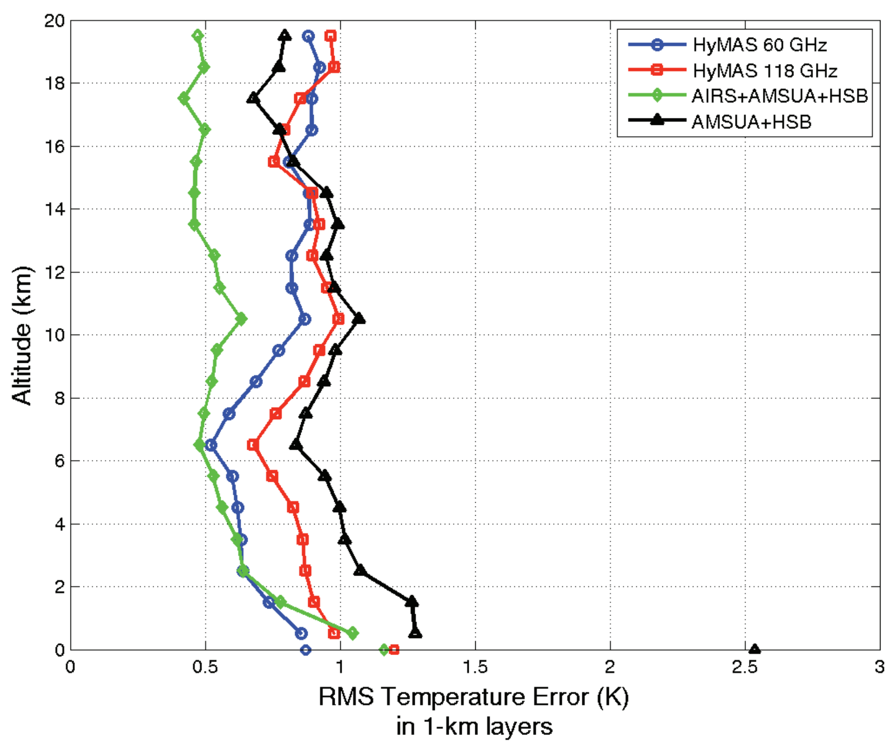

Figure 1. Comparison of $HyMAS_{60}$ (60/183-GHz), $HyMAS_{118}$ (118/183-GHz), AIRS/AMSUA/HSB, and AMSUA/HSB-only temperature retrieval performance over ocean at nadir incidence for seven focus days from 2002 to 2003

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