Cloud and Precipitation Observations With the NPOESS Aircraft Sounder Testbed - Microwave (NAST-M) Spectrometer Suite at 54/118/183/425 GHz

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ABSTRACT

The National Polar-orbiting Operational Environmental Satellite System (NPOESS) Aircraft Sounder Testbed - Microwave, or NAST-M, has added two spectrometers to its original suite operating near the oxygen lines at 50-57 GHz and the oxygen line at 118.75 GHz. These new spectrometers are centered on the water vapor absorption line at 183.31 GHz and the oxygen absorption line at 424.76 GHz. This addition has increased the ability of NAST-M to retrieve humidity profiles and to sense smaller-diameter hydrometeors. The co-aligned NAST-M suite concurrently imaged clouds and convective cells during the Cirrus Regional Study of Tropical Anvils and Cirrus Layers-Florida Area Cirrus Experiment (CRYSTAL-FACE 2002) and the 2003 Pacific THOR*pex* (THe Observing-system Research and *p*redictability *ex*periment) Observing System Test (THOR*pex* 2003).

INTRODUCTION

The frequency-dependent backscattering of hydrometeors at millimeter wavelengths can reveal particle sizes [1], cell-top altitudes [2], and rain rates [3]. Atmospheric temperature and water vapor profiles can also be retrieved using such spectrometers. The National Polar-Orbiting Operational Environmental Satellite System (NPOESS) Aircraft Sounder Testbed-Microwave (NAST-M) has four passive microwave spectrometers, for these purposes, centered near 54, 118, 183 and 425 GHz [4, 5]. This paper discusses the utility of the NAST-M spectrometers for precipitation mapping and compares NAST-M, visible, infrared, and composite radar images.

The first flights of a 425-GHz temperature-sounding spectrometer occurred during the Cirrus Regional Study of Tropical Anvils and Cirrus Layers-Florida Area Cirrus Experiment (CRYSTAL-FACE 2002), and additional data was collected during the 2003 Pacific THOR*pex* (THe Observing-system Research and *p*redictability *ex*periment) Observing System Test (THOR*pex* 2003). Several overpasses of convective precipitation and possible stratiform precipitation were collected during these missions. They help demonstrate the potential utility of such systems for precipitation detection from geostationary orbit. Although the apparent area of each convective cell generally increased monotonically with frequency, it was generally smaller than in infrared images, which sense much smaller particles. A few small convective cells were observed that were at sufficiently low altitudes that they were obscured near 425 GHz by overlying water vapor, and this effect motivates the inclusion of additional longer-wavelength channels on future geostationary microwave precipitation observatories.

INSTRUMENT DESCRIPTION

Three of the NAST-M spectrometers observe oxygen absorption lines, and the other is centered at the 183.31 GHz water vapor line. One spectrometer amplifies and analyzes 50-57 GHz (54-GHz system), while the other three spectrometers are double-sideband superheterodyne systems with center frequencies at 118.75 GHz, 183.31 GHz, and 424.76 GHz. All of the receivers are total-power radiometers and measure a single linear polarization. The 24 oxygen temperature weighting functions have peaks ranging from the surface to the height of the aircraft. The six 183-GHz water vapor-burden weighting functions peak near 1.5, 0.7, 0.35, 0.2, 0.12, and 0.05 g/cm^2. The most transparent channels of the 118- and 425-GHz systems supplement these water vapor-burden peaks with peaks at 5 and 0.2 g/cm^2, respectively. All four of the spectrometers' horns are collocated, have 3-dB (full-width at half-max) points of $7.5°$, and are directed at a single scanning mirror, which produces a cross-track scan beneath the aircraft with a swath width of approximately 100 km. Aircraft carrying NAST-M cruise at altitudes of 17 to 20 km, yielding a nadir surface spatial resolution of ~ 2.6 km. Detailed specifications of the NAST-M instrument are available in [4] and [5].

CLOUD IMAGERY OVER NORTH PACIFIC OCEAN

On a transit flight during the 2003 Pacific THOR*pex* Observing System Test, the ER-2 flew over scattered thunderstorms, and the NAST-M instrument collected brightness-temperature imagery and video data of isolated clouds. Fig. 1 shows brightness-temperature perturbations for four clouds along with matching video of the clouds taken by the NAST-M video camera. A brightness-temperature baseline, using nearby clear-air data, was subtracted from the brightness-temperature image to create the perturbation images shown in the figure. One channel from each spectrometer was chosen by matching the brightness temperatures of the clear-air baselines. This assured that the channels were viewing approximately the same clear-air altitude within the lower atmosphere.

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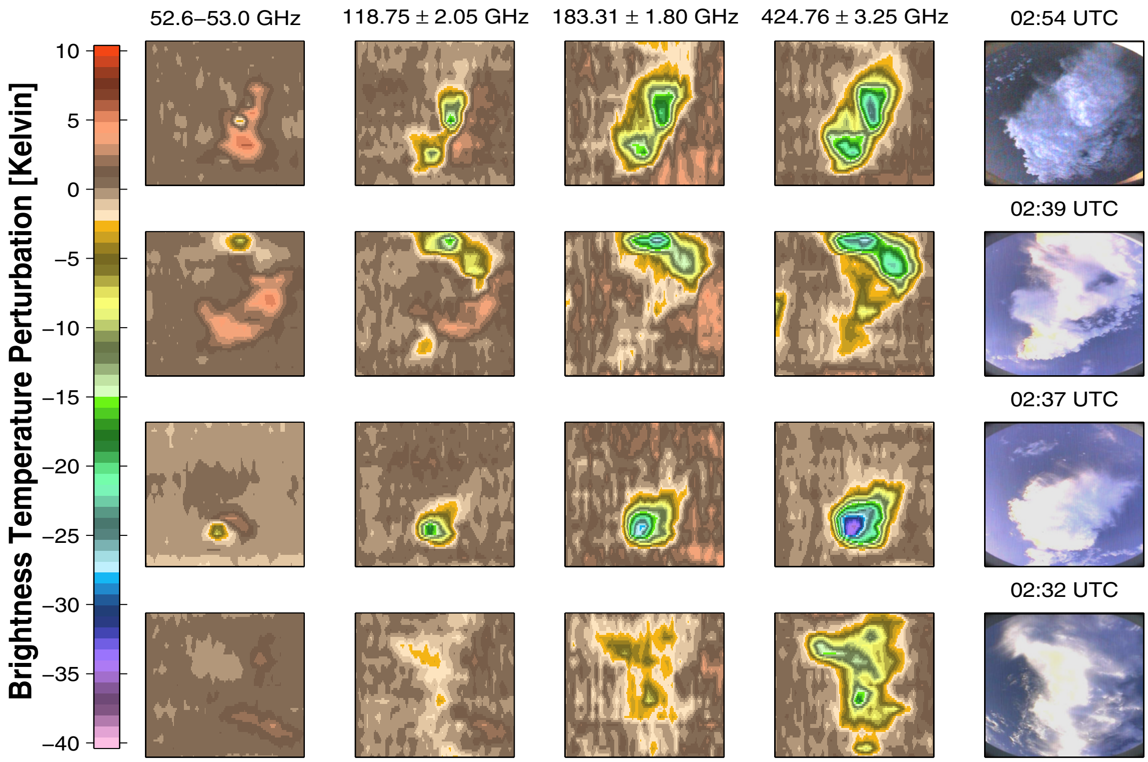

Figure 1: Cloud comparison with the NAST-M spectrometers between channels sharing similar temperature weighting functions (approximately 40 km per side). NAST-M video images of the clouds are also presented.

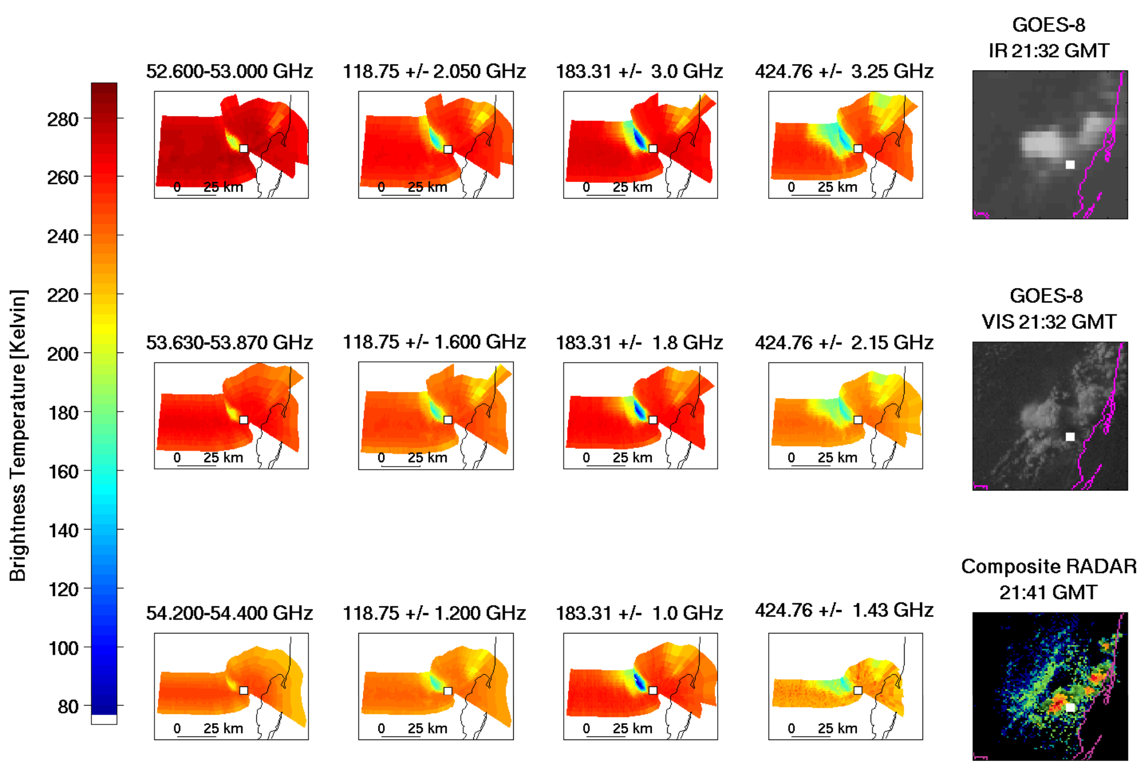

Figure 2: NAST-M brightness-temperature image of a convective cell over Miami, FL.

The clouds can perturb microwave brightness-temperature images by either backscattering or by absorption. The top two clouds of Fig. 1 illustrate the effect of the clouds on channels with similar temperature weighting functions, but at much different frequencies. The relatively long wavelength of the 54-GHz channel has almost no backscattering, but instead there is a warm perturbation from the cloud (warm compared to the cold background of the ocean) due to absorption and emission of the water within the cloud. As the sensitivity to backscattering increases with frequency, the cloud is no longer identified as a cold or warm perturbation from absorption, but instead by the reflection of the cosmic background radiation from hydrometeors. The third cloud is a classical convective cell with a vertical wind shear blowing toward the upper right-hand corner of the image. The vertical wind shear pushes the highest hydrometeors off of the updraft. The smallest hydrometeors travel the furthest, while the largest or heaviest hydrometeors generally fall just outside the updraft. Mie scattering explains the increasing sensitivity with frequency of the spectrometers to the hydrometeors. The fourth cloud is primarily high-altitude cirrus.

CONVECTION IMAGERY OVER MIAMI

During the CRYSTAL-FACE mission, the Proteus skimmed over a squall line on July 13, 2002. Fig. 2 presents brightness-temperature images from all four of NAST-M's spectrometers, GOES-8 visible and infrared sensors, and ground-based composite radar from Miami, FL during this overpass. It can be seen in Fig. 2 that the largest cell footprints are at 425 GHz and these footprints decrease in size as the frequency decreases. The largest brightness-temperature perturbations are with the 183-GHz channels, and the 425-GHz channels could have smaller perturbations because of the greater absorption. NAST-M crossed the convective cell at 21:42 UTC at an altitude of 17.5 km, and the Cloud Physics Lidar onboard the ER-2 has the cloud-top altitude at 15.5 km. The brightness temperatures were projected onto a Mercator-projection map by using the GPS position, aircraft altitude, angle of the scanning mirror, and the peak height of the respective channel's weighting function.

WINDOW CHANNEL CLOUD COMPARISON

Each spectrometer has a window channel, which is defined as the furthest channel from the respective absorption line. Due to the water vapor continuum, the 425-GHz system does not penetrate to the surface and its lowest-altitude temperature weighting function peaks near 5 km. In Fig. 3, an example is presented that illustrates the utility of longer wavelength spectrometers to penetrate to the lowest portion of the atmosphere. The figure includes the window channels of the 54-, 183-, and 425-GHz systems and a NAST-M video image of the clouds. Several of the clouds barely perturb the 425-GHz window channel, and therefore the 425-GHz system may not be as successful in attempts to cloud-clear infrared radiances or in attempting to map precipitation.

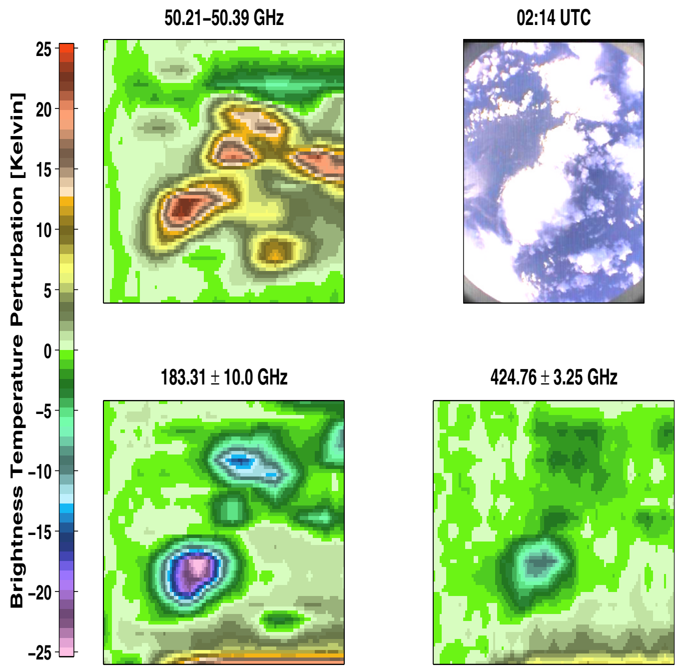

Figure 3: NAST-M brightness temperature and video of low-lying clouds.

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