"High Spectral Resolution Sounding: Latest Results from Aircraft and their Implications for Future Satellite Systems"

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Abstract:

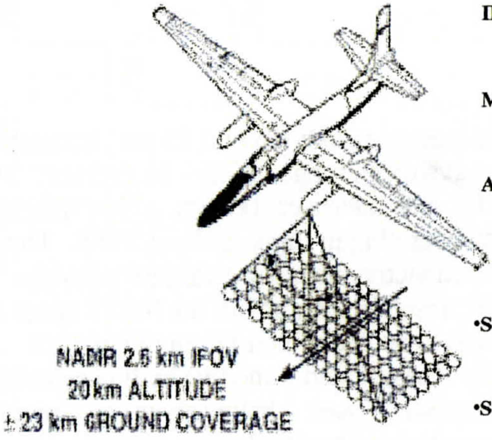
A new high spectral resolution (0.25cm-1) and high spatial resolution (2 Km) scanning (45 Km swath) interferometer sounding system has been built for flight on NASA high altitude (20 Km) ER-2 aircraft. The instrument, called the NPOESS Aircraft Sounding Testbed-Interferometer (NAST-I) has been flown to provide experimental observations needed to finalize the specifications and to test proposed designs for future satellite instruments, particularly the Cross-track scanning Infrared Sounder (CrIS) to fly on the National Polar orbiting Operational Satellite System (NPOESS). NAST-I has been flown during several field campaigns. The data have been utilized to analyze spectral and spatial resolution requirements for future sounding systems. Also, the NAST-I has provided new and exciting observations of the mesoscale structure of the atmosphere, including the fine scale thermodynamic characteristics of Hurricanes. Remote sensing results obtained from the NAST-I aircraft data are presented. Implications for future satellite sounding system designs are discussed.

Introduction:

The National Polar orbiting Operational Environmental Satellite System is being developed jointly by an Integrated Program Office (IPO), consisting of the Air Force, NOAA, and NASA, as the next generation US contribution to the world weather watch. The NPOESS will carry advanced imaging and sounding instruments to improve global and regional weather prediction capabilities. A most important instrument is called the Cross-track Infrared Sounder (CrIS) which will be a high spectral resolution interferometer designed to provide atmospheric profiles with 1 to 2 km vertical resolution with 1K and 10% accuracy for temperature and water vapor, respectively. The first of the NPOESS satellites is not scheduled for launch until the year 2008. However many of its sensors, including the CrIS, will be put into operational use aboard NASA's NPOESS Pathfinder Project (NPP) satellite to be orbited in 2005. NPP will provide a bridge of observations between NASA's EOS-PM satellite, which carries the Advanced Infrared Radiation Sounder (AIRS), and the NPOESS, which carries the CrIS.

In order to optimize the design of the CrIS instrument and its data processing algorithms, the IPO supported the development of the NPOESS Aircraft Sounding Testbed (NAST). NAST is comprised of a passive infrared (IR) Michelson interferometer and Microwave (MW) multi-channel radiometer sensing system that scans the Earth and atmosphere from a pod beneath the wing of the high-altitude NASA ER-2 research airplane (figure 1). The microwave instrument, (NAST-M) was developed at the Massachusetts Institute of Technology (MIT) while the infrared instrument (NAST-I) was developed at MIT's Lincoln Laboratory (MIT-LL) using important technology contributions from the University of Wisconsin-Madison, and BOMEM Inc. of Quebec Canada. NASA's Langley Research Center and MIT are responsible for the field deployment of NAST and the subsequent scientific analysis of the data with the support of scientists from the University of Wisconsin - Madison.

The NAST-I measures thermal radiation in more than 10,000 spectral regions which can be



Instruments

IR Interferometer (NAST-I)
Spectral Range: 3.5 - 16 Microns
Spectral Resolution: > 2000 (0.25cm^{-1})

Microwave Radiometers (NAST-M)
Spectral Regions: 50 - 60 GHz
113 - 119 GHz

Ancillary Instruments
MIR: 183 GHz
MAS: 50 Ch. Vis. - IR Multi-Spectral Imager

Objectives

•Support NPOESS Sounding Instrument Hardware and Software Development

•Serve as an EOS Validation Tool

•Provide Mesoscale Earth Science Observations

Figure 1: The NAST Measurement Characteristics

used to measure the temperature of the earth's surface and clouds as well as the vertical distribution of temperature and water vapor in the atmosphere. The concentrations of ozone, carbon monoxide, methane, nitrous oxide, and other radiatively active trace gases can also be measured. Precipitation cells are also produced to delineate areas of intense rainfall. Since NAST spatially scans the earth beneath the aircraft, three-dimensional images of atmospheric temperature, water vapor, and other emitting constituents are achieved (figure 2).

NAST is the first instrument suite capable of imaging atmospheric temperature and moisture

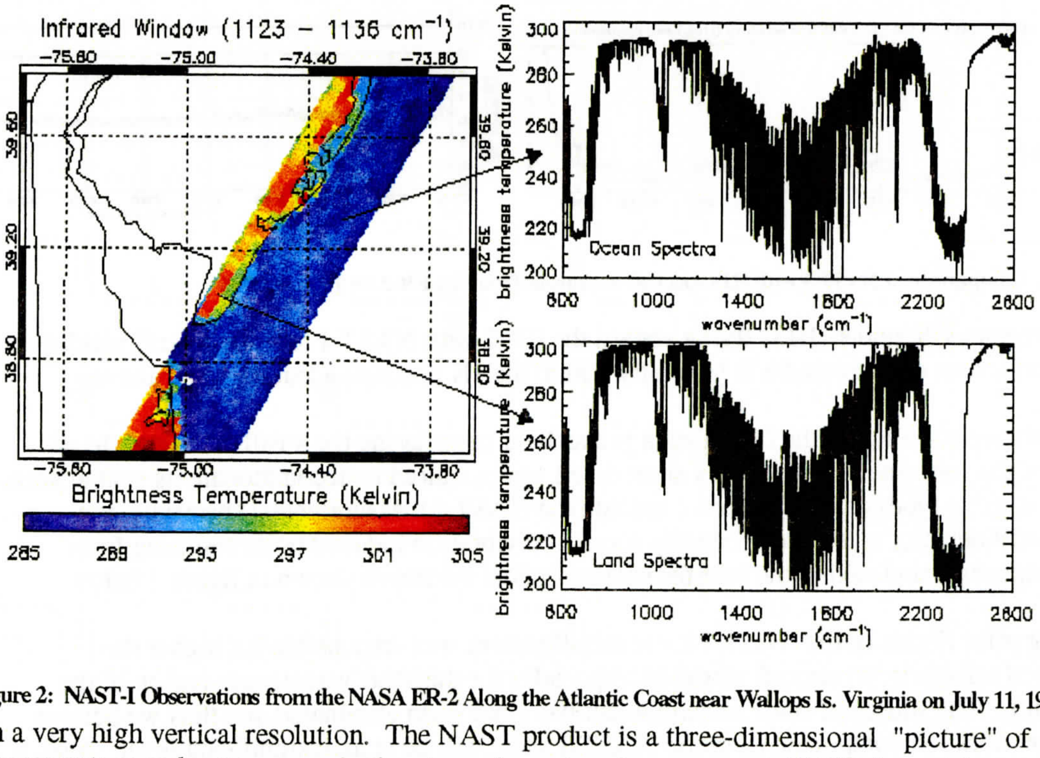


Figure 2: NAST-I Observations from the NASA ER-2 Along the Atlantic Coast near Wallops Is. Virginia on July 11, 1998

with a very high vertical resolution. The NAST product is a three-dimensional "picture" of the temperature and water vapor in the atmosphere at a given moment. NAST-I provides a vertical resolution of 1 – 2 kilometers, which means that 20, or more, distinct layers are observed. As the ER-2 aircraft passes over the Earth, NAST scans an area of approximately 45 kilometers wide, at the earth's surface, collecting data on the properties of the Earth's surface and atmosphere beneath the aircraft. These data are used in a variety of ways to help scientists examine characteristics of the atmosphere that play a significant role in weather, climate, and pollution episodes.

NAST-I Data Accuracy

The NAST-I observes spectral radiance with a spectral resolution of 0.25 cm^{-1} in three overlapping spectral bands covering the total wavelength range of 3.5 – 16 microns. The instrument utilizes two on-board blackbodies for radiometric calibration, a "hot" blackbody operating at 330K and an "ambient" blackbody operating in flight at about 255K. The data are corrected for the non-linearity of its photo conductive mercury cadmium telluride detectors as part of the calibration process. The absolute accuracy of the NAST spectral brightness temperature measurements is believed to be better than 1K on the basis of comparisons with independent spectral radiance measurements and line by line calculations of spectral radiance based on radiosonde measurements. Figure 3 below shows a comparison of long-wave NAST-I spectral radiance with those obtained by the High resolution

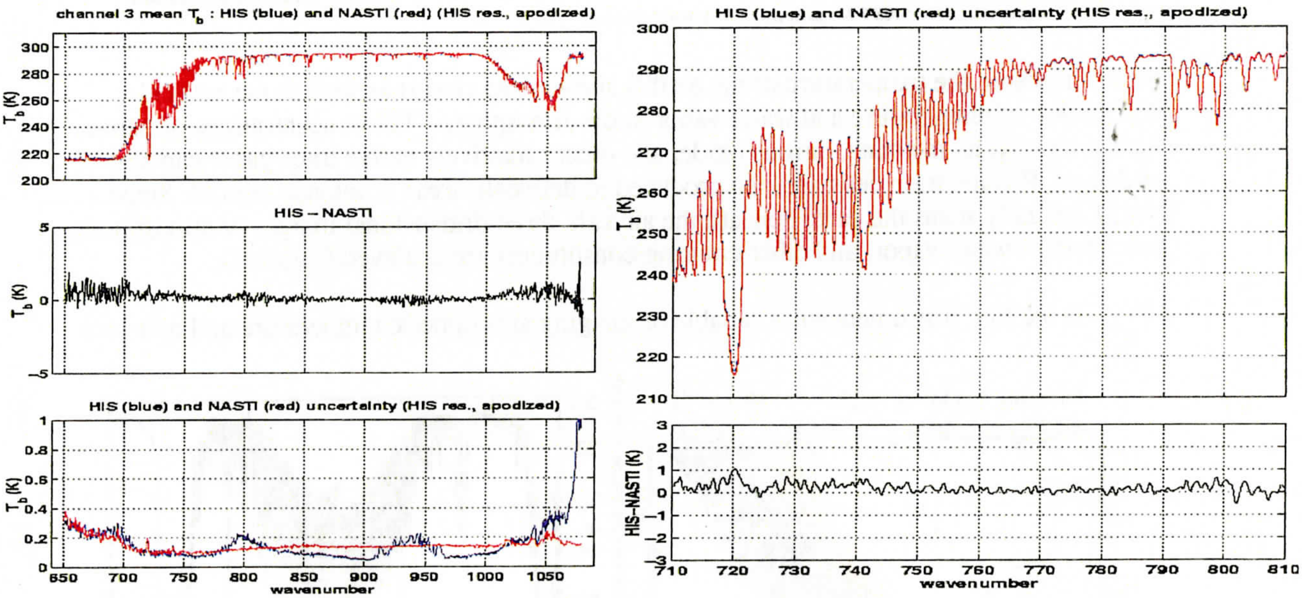


Figure 3: Comparison of NAST-I with HIS spectral Radiances from the ER-2 on July 11, 1998

Interferometer Sounder (HIS) flying aboard the ER-2 with NAST-I for radiometric validation. As can be seen the agreement is generally within the 1K absolute accuracy cited above.

The relative accuracy of the NAST data is excellent considering the small 2.5 Km field of view of the instrument and the very short dwell time required to accommodate its spatial scan. There are two types of noise which dominate the NAST-I measurements: spectrally non-correlated detector noise and spectrally correlated vibration induced noise resulting from static misalignment within the interferometers optical system as shown in figure 4 below.

During prior flights of the NAST-I static misalignment was responsible for higher than expected sensitivity to aircraft vibration, especially for the short wavelength region of the spectrum. The source of static misalignment has since been eliminated and thus we believe that the vibration component of future NAST-I noise will be at an insignificant level. Also, it

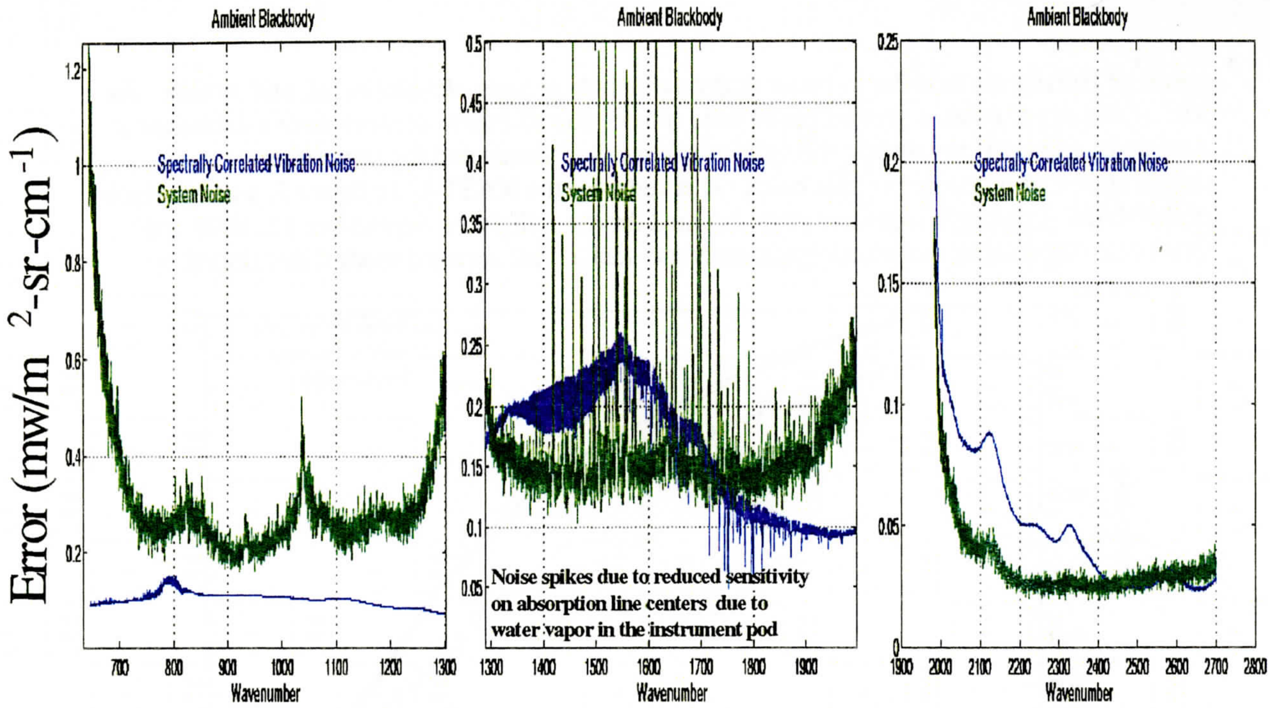
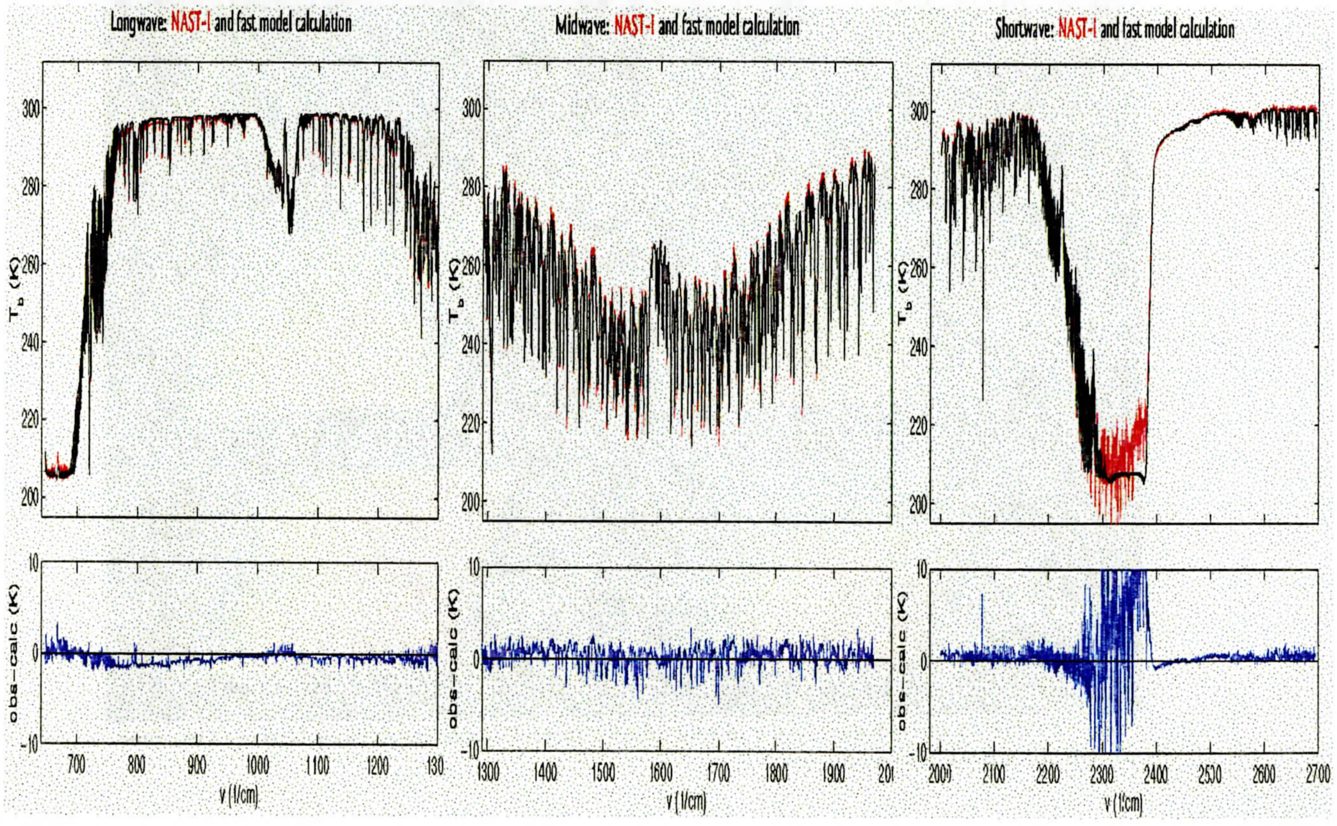


Figure 4: (a) Vibration Induced Spectrally Correlated Noise (Blue Curve) due to static misalignment between the main IR interferometer beam and the metrology Helium-Neon (HeNe) beams used to control mirror alignment. (b) System Noise (Detector, Amplifier, Quantization, etc.) (Green Curve)

is important to note that because the vibration noise is proportional to the square of the observation frequency, it can be alleviated greatly in the application of the data. Complete details of the NAST-I error characteristics and procedures on how to alleviate the vibration induced noise in the data application can be found on the NAST web site http://danspc.larc.nasa.gov/NAST/.

Comparison with Calculations

During August and September, the NAST-I flew aboard the ER-2 during the third Convection and Moisture Experiment (CAMEX-3). The mission was to sample the environment and



center of Hurricanes in order to better understand their genesis, development, and motion. As part of this experiment, a ground based suite of remote and in-situ sensors were established at Andros Is. Bahamas to validate the radiometric measurements and the atmospheric temperature and moisture profiles being observed with the NAST-I. In figure 5, a comparison of the NAST-I radiance measurements obtained during a flight on September 13, 1998 and those calculated using radiosonde measurements and a "fast forward model" developed by

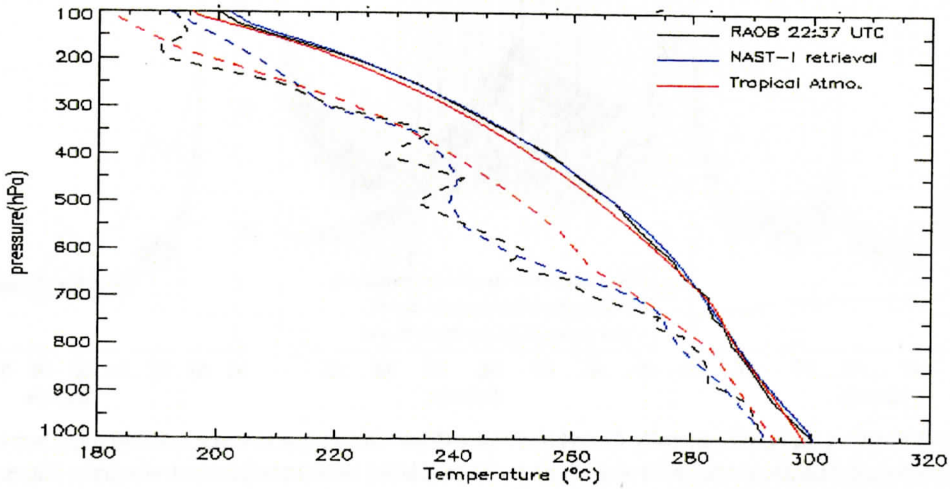


Figure 6: Comparison between a radiosonde and a NAST-I physical retrieval. A tropical standard atmosphere is also shown for comparison.

Prof. L. Strow, at the UMBC, based on line by line atmospheric transmittance calculations. The results for the three NAST-I bands are shown. As can be seen the agreement is remarkably good with the **largest differences being generally less than two degrees.**

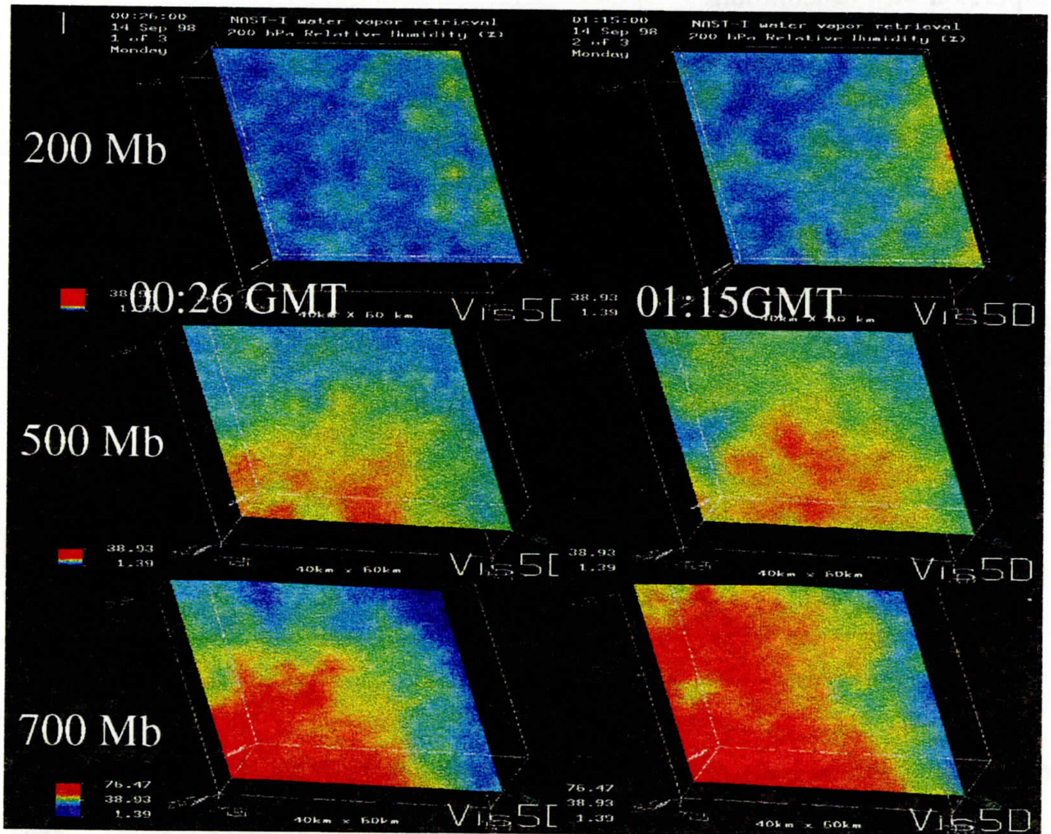


Figure 7: NAST-I derived water vapor mixing ratio for three different atmospheric levels and two time periods about forty five minutes apart.

Retrieval Studies

The NAST-I has also been used to produce fields of temperature and moisture retrievals. A comparison of a temperature and moisture retrieval with the Andros Is. Bahamas radiosonde for September 13, 1999 is shown in Figure 6 below. As you can see, the NAST-I is capable of retrieving relatively fine scale vertical structure in the atmospheric temperature and moisture profile. Finally, figure 7 shows the water vapor mixing ratio fields retrieved for a common area near Andros Is. Bahamas. The red colors refer to moist areas while the blue colors refer to dry regions. As can be seen the movement of water vapor features at different atmospheric levels can be observed. At 700 mb (about 3 Km altitude) the movement of water vapor is from southwest to northeast. At 500 mb (approximately 6Km altitude) the water vapor seems to be moving from south to north while at the 200 mb (about the 10Km level) the water vapor is moving from east to west. Thus, it is readily seen from this example that the vertical wind profile might be inferred from the observed movement of the water vapor at different atmospheric levels. This result has great implications for the ability to sound the atmosphere's structure using high spectral resolution radiance observations from a geostationary satellite made with high temporal frequency.

Conclusions:

The NAST-I is providing an exciting new remote sensing capability from the NASA ER-2 aircraft. The radiometric measurements have been validated to have an absolute accuracy within about 1 K in terms of radiometric brightness temperature. The very high relative accuracy of the data enables accurate retrievals of atmospheric temperature and moisture profiles to be retrieved from the radiometric data. The spatial scan of the instrument enables the mesoscale features of the three dimensional temperature and moisture structure to be resolved. Time sequences of the three-dimensional moisture structure have been used to resolve water vapor tracer wind profiles. These results have great implications for the potential of a high spectral resolution-sounding instrument on a geostationary satellite to observe the three dimensional wind velocity structure of the atmosphere.

The NAST-I data will be used to refine the specifications for the CrIS advanced atmospheric sounder to fly on the future NPOESS series of operational weather satellites. Initial results indicate that these data will be invaluable for optimizing the instrument as well as for validating radiometric models used to retrieve surface and atmospheric variables from the NPOESS sensors as well as those soon to be orbited on NASA's AM and PM Earth Observing Satellites (EOS).

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