Final Progress Report

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“Satellite Measurements of Upper Tropospheric Water Vapor: Development and Applications for the ARM Program”

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1.1 Product Development

Upper tropospheric humidity (UTH) measurements from the 6.7 micron channel on GOES (8, 9, 12) and GMS-5 satellites were employed to develop a near real-time UTH product that is now available from the ARM External Data Center (XDC). The UTH product is available in either gridded format (2.0x2.0 lat-lon resolution), full-disk pixel resolution, or individual pixel resolution for both the SGP and TWP sites. This product pro-

An example of the pixel resolution UTH product available from the ARM External Data Center. (sgpgoes8uthX.c1).

vides the basis for the instrument intercomparison and validation activities (Section 0.2), diurnal analysis and model evaluation (0.3), and cloud lifecycle studies (0.5); and is also an important component of the research proposed here. Full details regarding the retrieval algorithm for the ARM sites can be found in **Soden et al. (2004a)** and references therein.

1.2 Upper Tropospheric Water Vapor Assessment and Validation

Radiosonde and Raman lidar observations from four ARM/SGP water vapor IOPs (1996, 1997, 1999, 2000) were compared with co-located geostationary satellite radiances at 6.7 micron to assess our ability to measure the distribution and variation of upper tropospheric water vapor. During all four IOPs, we found excellent agreement between the satellite and Raman lidar observations of upper tropospheric humidity with systematic differences of <10% (see below). In contrast, radiosondes equipped with Vaisala RS-80H sensors were shown to be systematically drier in the upper troposphere by ~30% relative to both the lidar and satellite measurements.

We also assessed the performance of various correction strategies designed to rectify known deficiencies in the radiosonde measurements. It was shown that existing methods for correcting the radiosonde dry bias, while effective in the lower troposphere, offered little

A comparison of satellite and lidar upper tropospheric relative humidity from 4 ARM IOPs (Tian et al, 2004).

improvement in the upper troposphere. An alternative method based on variational assimilation of satellite radiances was developed and, when applied to the radiosonde measurements, was shown to significantly improve their agreement with coincident Raman lidar observations. It is suggested that a similar strategy could be used to improve the quality of radiosonde measurements of upper tropospheric humidity for the TWP.

Finally, the bimodality of water vapour was surveyed in satellite and in situ observations, as well as in global model re-analysis data and simulations. Probability distribution functions of tropospheric water vapour in the tropics were shown to be commonly bimodal which implies sharp gradients between dry and moist regimes in space and time and suggests that the radiative drying time after an injection of moisture by convection is short (1-2 days) compared to a homogenizing time, whether physical (mixing) or mathematical (averaging). It was shown that the local bimodality found in cloud-model simulations and in situ point measurements disappears with modest time averaging (18 h and 200 km), but then reappears on the global-scale, where dry and moist regions are separated so widely that synoptic- and large-scale mixing times exceed the drying time-scale. Large discrepancies exist in the ability to reproduce the global scale bimodality by global model re-analysis and simulations. Details regarding these results can be found in **Zhang et al. (2003)**, **Soden et al. (2004a)**, **Soden et al. (2004b)**, “An assessment of satellite and lidar observations of upper tropospheric water vapor from AFWEX”, in preparation).

1.3 Diurnal Analysis and Model Evaluation

Hourly observations of the 6.7 micron water vapor radiances from geostationary satellites were used to document the diurnal cycle in upper tropospheric water vapor and its relationship to cloud cover and convection. A fundamental difference in the diurnal relationships between deep convection and upper tropospheric moisture over tropical ocean versus tropical land regions was observed. Variations in upper tropospheric clouds and water vapor occur in phase with deep convection variations over land, but out of phase with those over ocean (see below). This difference was shown to be associated with a difference in the evolution of tropical oceanic convection.

A global high-resolution (3-hourly, 0.1×0.1 longitude-latitude pixel) water vapor radiance data set from multiple geostationary satellites was then constructed to: (i) document the diurnal cycle of upper tropospheric relative humidity (UTH) globally and its relationship to deep convection and high clouds, and (ii) evaluate the ability of the new

Diurnal cycle of deep convective cloud, cirrus cloud, and UTH from Soden (2000)

Geophysical Fluid Dynamics Laboratory (GFDL) global atmosphere model (AM2) to simulate these diurnal variations. These results have uncovered several important deficiencies in the model's convection and cloud parameterization schemes over both land and ocean. These deficiencies are believed to stem, in part, from a combination of inadequate boundary forcing and shortcomings in the model's ability to accurately simulate the lifecycle of tropical convective systems. Details of these results may be found in **Soden (2000)** and **Tian et al. (2004)**.

1.4 The Sensitivity of Water Vapor Feedback to Refinements in Continuum Absorption

Water vapor is the dominant greenhouse gas and provides the largest known feedback mechanism for amplifying global warming. All climate models predict a strong positive feedback from water vapor, arising from the exponential increase in saturation vapor pressure with temperature. In contrast to the simplicity of the thermodynamics, the radiative physics which underlies the feedback from water vapor is quite complex, consisting of thousands of spectral lines for water vapor alone.

Far from the line centers, the absorption from water vapor is parameterized in terms of a continuum whose formulation is uncertain and has been modified repeatedly for over a decade.

Because the impact of this absorption on top-of-atmosphere fluxes is comparable in strength to the forcing obtained from a doubling of CO₂, it is frequently argued that uncertainties in its parameterization are an important source of uncertainty in model estimates of climate sensitivity. In this study we performed GCM simulations to demonstrate that this is not the case. Indeed, the water vapor feedback predicted from the GCM was extremely insensitive to the representation or even the inclusion of continuum absorption. The results of this work are currently being prepared for publication **Soden and Schwarzkopf (2004**, “The sensitivity of water vapor feedback to refinements in continuum absorption”, in preparation).

Papers published or submitted under this grant:

- Soden, BJ, 2000: The diurnal cycle of convection, clouds and water vapor in the tropical upper troposphere, *Geophys. Res. Lett.*, **27**, 2173-2176.
- Soden, BJ, and co-authors, 2004a: An analysis of satellite, radiosonde and lidar observations of upper tropospheric water vapor from the ARM program, *J. Geophys. Res.*, **109**, D04105.
- Soden, BJ, AJ Broccoli, and RS Hemler, 2004c: On the use of cloud forcing to estimate cloud feedback, *J. Climate*, in press.
- Tian, B, BJ Soden, and X Wu, 2004: The diurnal cycle of convection, clouds and water vapor: A comparison of satellite observations and a model simulation, *J. Geophys. Res.*, in press.
- Zhang, C, BE Mapes, and BJ Soden, 2003: Bimodality in tropical water vapor, *Q. J. Roy. Meteor. Soc.*, **129**, 2847-2866.

Papers in preparation:

- Soden, BJ, and MD Schwarzkopf, 2004: The sensitivity of water vapor feedback to refinements in continuum absorption, in preparation.
- Soden, BJ and co-authors, 2004: An assessment of satellite and lidar observations of upper tropospheric water vapor from AFWEX”, in preparation.
- Tian, B, and co-authors, 2004: