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SUBSEASONAL WATER VAPOR VARIABILITY IN THE TROPICAL TROPOPAUSE REGION

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1. INTRODUCTION

The tropical tropopause is a key region for dynamics, radiation, and chemistry of the stratosphere, owing to its role as primary entry point for air entering the stratosphere proper from the troposphere. At the tropopause, there are intricate linkages between temperature, clouds, water vapor on a range of timescales, from hourly (convective) to multi-decadal (long-term trends). There are still some key unanswered questions about how, when, and where air enters the stratosphere; water vapor provides some clues because it bears something of a saturation history of air (e.g., Mote et al., 1996).

The possibility that tropopause-level water vapor, temperature, and cloudiness might be influenced by subseasonal variations like Kelvin waves and the 40-50 day Madden-Julian Oscillation (MJO) was noted by Mote et al. (1998) and confirmed for Kelvin waves by Fujiwara et al. (1998) and Boehm and Verlinde (2000; see Figure 1) using ground-based data, and for the MJO by Mote et al. (2000). Canziani et al. (1994) and Mote et al. (2002) noted the presence of stratospheric Kelvin waves in satellite temperature measurements.

2. ANALYSIS

In this study, satellite measurements from the Microwave Limb Sounder (MLS) aboard the Upper Atmosphere Research Satellite (UARS) were used to investigate the possible role of Kelvin waves in influencing stratospheric water vapor. Equatorial temperature and water vapor data for July 1992-April 1993 were projected onto cos(longitude) and sin(longitude) to focus on wavenumber-one variations. Pressure-height variations were then analyzed using extended empirical orthogonal functions, or EEOFs (Mote et al., 2002). There were two periods of vigorous Kelvin wave activity, September 1992 and January-February 1993 (Figure 2a). These Kelvin waves have longer vertical wavelength than the ones in Figure 1, but they too should be capable of affecting the tropical tropopause layer.

Water vapor in the tropical stratosphere has a seasonally varying vertical profile owing to the seasonally varying tropopause-level water vapor, which is carried up by the mean circulation (Mote et al., 1996). To see how these Kelvin waves would influence water vapor, we multiply by q_z/T_z, where q_z is the lowpass-filtered zonal mean vertical gradient of water vapor and T_z is the time mean vertical gradient of temperature. This procedure nearly eliminates the Kelvin-wave variations in the second interval, though there are hints in the water vapor observations (Figure 2c) of the same sort of behavior. Note too that in the first interval, the signal is chopped up and it even looks as though the phase lines tilt the other way in the middle stratosphere. Peak-to-peak variations are only about 0.25 ppmv, making it a detection challenge. At the somewhat longer timescales characteristic of the MJO, water vapor variations at the tropopause are coherent with indicators of convection (Figure 3) in the sense that enhanced convection (lower OLR and velocity potential) generally coincides with reduced water vapor at 100 hPa. This suggests that the MJO also influences stratosphere-troposphere exchange.

To determine more systematically the role of Kelvin waves in stratosphere-troposphere exchange will require a combination of better lower-stratosphere measurements and more sensitive instruments. The next generation of satellite instruments (EOSMLS, HIRDLS) to be launched in 2004 should provide a better view.

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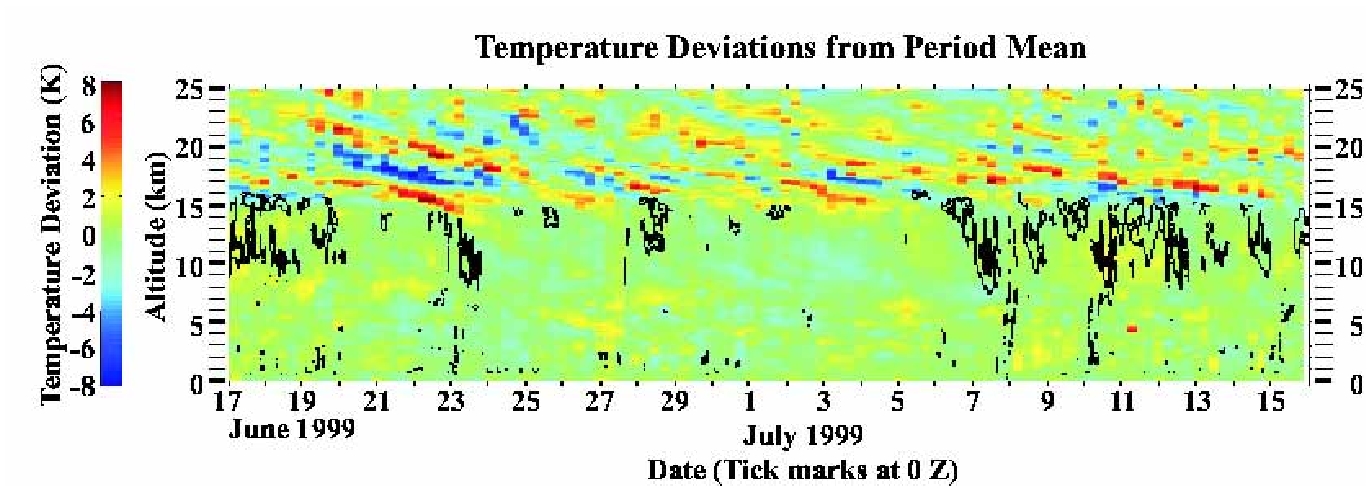

Figure 1. Sonde measurements at Nauru indicate the presence of regular variations in temperature, with a vertical wavelength of just a few km, and coincident cirrus cloud (dark splotches). Holton et al. (2001) have shown that these variations satisfy the dispersion relation for Kelvin waves. The large amplitude (order of 10K) implies that these waves could produce substantial dehydration in the tropical tropopause layer. Figure courtesy Matthew Boehm.

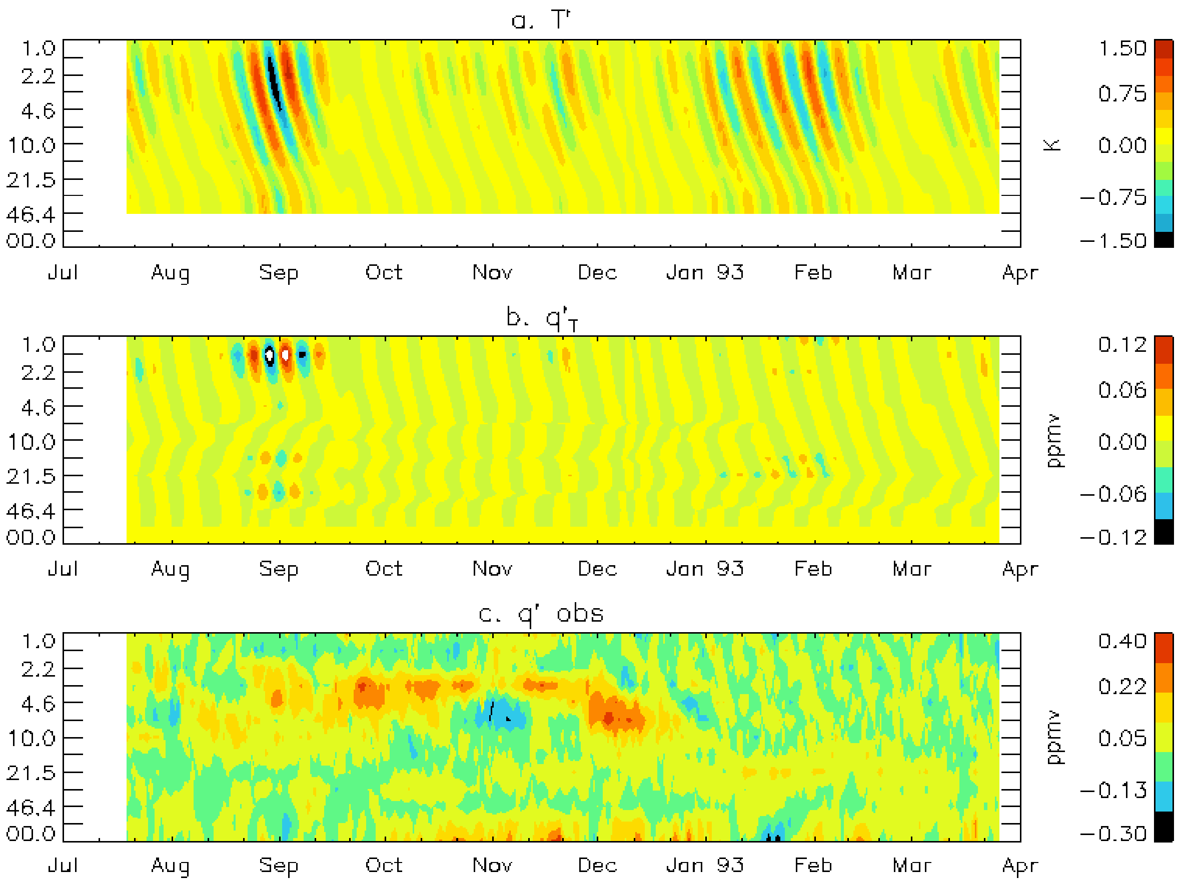

Figure 2. Equatorial MLS (satellite) data presented as time-pressure plots. (a) Reconstruction of Kelvin waves in temperature, (b) putative Kelvin-wave induced water vapor variations derived from (a), and (c) observed water vapor variations. See text for details.

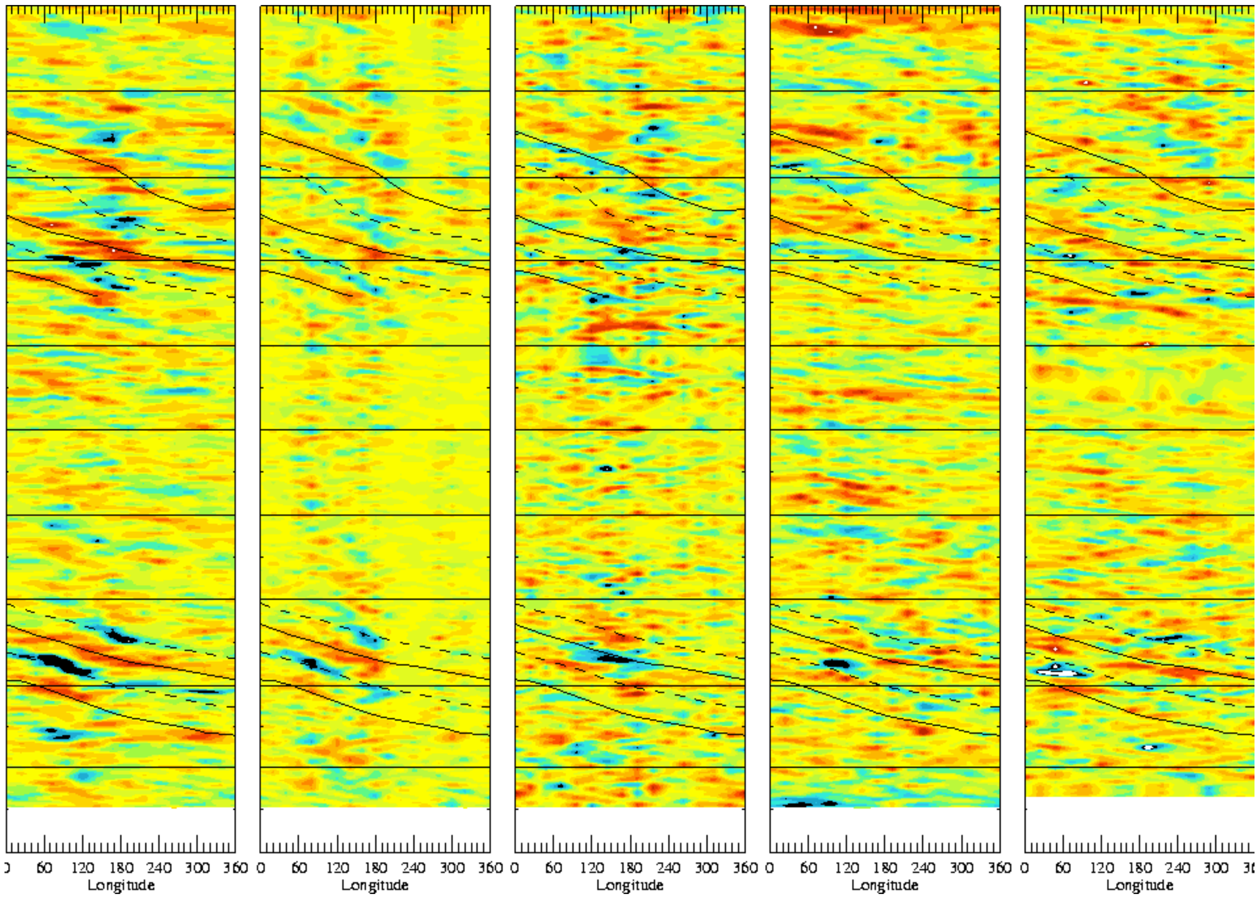

Figure 3. Hovmöller plots for (left to right) 200 hPa velocity potential, outgoing longwave radiation, 215 hPa water vapor, 100 hPa temperature, and 100 hPa water vapor. Low values are blue and high values are red. The range of values is about 160 Wm^{-2} for OLR, 120 ppmv for 215 hPa water vapor, 8K for temperature, and 1 ppmv for 100 hPa water vapor. The bold curves trace features in the velocity potential associated with the Madden-Julian Oscillation (MJO) with the convention that solid curves represent suppressed convection and dashed curves represent enhanced convection. Note that enhanced convection tends to moisten the upper troposphere and dry the tropopause.