Observations of downwelling infrared spectral radiance at Mauna Loa, Hawaii during the 1997-1998 ENSO event

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Abstract. Measurements of downwelling infrared spectral radiance at Mauna Loa, Hawaii during April and May of 1998 indicate unusually high infrared atmospheric transmittance. This is linked to large-scale drying of the upper troposphere and stratosphere in the subtropical Pacific, which appears to be associated with the extreme El Niño-Southern Oscillation (ENSO) event of 1997-1998. During the driest periods, transmission windows opened in the wavenumber range of 500-600 cm^{-1}, a water vapor rotational band that normally has high opacity. These data demonstrate the potential value of long-term mountain-top measurements for monitoring upper tropospheric water vapor and for validating satellite measurements of upper-tropospheric water vapor.

1. Introduction

Water vapor is one of the most radiatively significant greenhouse gases and hence is a key component in the radiative balance of the Earth. In current thinking about anthropogenic climate change, however, the role of water vapor is paradoxical. Despite the radiative properties of water vapor being greater than all anthropogenic gases, the effect of water vapor is thought of as a feedback [*Harries,* 1997]. This is because, in climate change experiments, any imposed forcing may result in an increase or decrease of water vapor and thus further perturb the radiation balance. Since the radiative effects of water vapor are so significant, any small uncertainty in our knowledge of water vapor and its radiative properties will greatly affect climate change studies.

Two of the greatest sources of uncertainty about the role of water vapor in climate include our lack of understanding of its distribution in the tropical upper troposphere and our limited knowledge of the spectroscopic properties of the water vapor continuum. Although the consensus is that the upper troposphere will become more humid as a result of global warming [*Rind et al.,* 1991], this view has been challenged [*Lindzen,* 1990]. Comparisons of water vapor observations with model results have shown a large discrepancy between the two [*Bates and Jackson,* 1997]. Similarly, recent work on the spectroscopic properties of water vapor have emphasized the importance of better observing and modeling of the continuum absorption, which is attributed to the cumulative influence of the overlapping of the far wings of strong water vapor lines [*Clough et al.,* 1992; *Han et al.,* 1997].

During El Niño-Southern Oscillation (ENSO) warm events, enhanced precipitation and moistening of the upper troposphere occurs over the anomalously warm waters of the central and eastern equatorial Pacific Ocean and decreased precipitation and anomalous drying occurs in the subtropics at these longitudes [*Ropelewski and Halpert,* 1987]. The extreme ENSO event of 1997-98 produced an extended drought over much of the subtropical North Pacific, including Hawaii. Over Hawaii, rainfall for the period of January through early April of 1998 was the third lowest on record since record keeping began in 1874.

Figure 1 shows a time-latitude plot of anomalous brightness temperature for an upper tropospheric water vapor channel from the SSMT2 computed from the data set of Berg et al. [Berg, W. K., J. J. Bates, and D. L. Jackson, Analysis of upper tropospheric water vapor using SSM/T2, HIRS-12, and GMS VISSR data, in press *Journal of Applied Meteorology*, 1998] for the central Pacific. This channel measures water vapor emission from a thick layer of the upper troposphere. The figure indicates brightness temperature anomalies relative to climatology. Positive anomalies occur when the upper troposphere is unusually dry, allowing the sensor to see deeper into the warmer lower troposphere. Conversely, negative anomalies are associated with moist conditions when the sensor only sees the colder upper troposphere. Persistent negative brightness temperature anomalies, associated with anomalous deep convection and moistening of the equatorial upper troposphere, are observed for the entire six month period. Persistent positive anomalies, associated with drying of the upper troposphere, are observed in the northern subtropics from January through the end of April. The most intense drying occurs at the latitude of Hawaii during March and April (approximately 20N). Drying of this region is a normal feature of ENSO events, but extraordinary drying was observed in the large ENSO events of 1982-83 and 1997-98 [*Bates et al.,* 1996].

Mountaintop measurements of downwelling infrared spectral radiance near the end of this anomalously dry period show unusually high atmospheric transmittance in the 500-600 cm^{-1} water vapor rotational band. Additional measurements are needed to establish more fully how these measurements compare with those from a more typical annual moisture cycle. However, this initial measurement set demonstrates the potential value of this technique for monitoring the radiative effects of upper-tropospheric water vapor.

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Paper number 1999GL900362.
0094-8276/99/1999GL900362$05.00

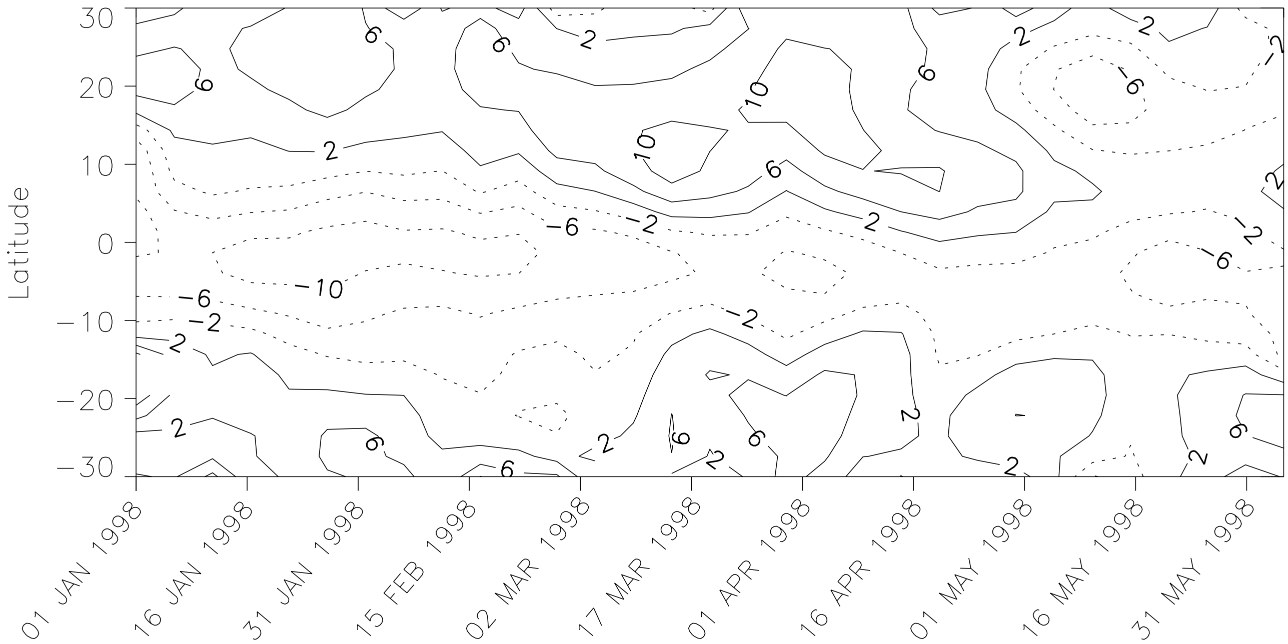

Figure 1. Time-latitude section from 150W-165W of anomalous brightness temperatures from the upper tropospheric water vapor channel of the SSMT2 instrument. As is typical in ENSO years, the tropical equatorial atmosphere is anomalously moist (negative brightness temperature anomaly), while the northern subtropical atmosphere is anomalously dry (positive brightness temperature anomaly).

2. Measurements of Infrared Spectral Radiance at Mauna Loa, Hawaii

We deployed a Fourier Transform InfraRed (FTIR) emission spectro-radiometer at the Mauna Loa Observatory on the island of Hawaii (19.539 N, 155.578 W, altitude 3397 m, HTTP://mloserv.mlo.hawaii.gov/). During much of this time the island of Hawaii was inside a dry air mass extending over a large area of the subtropical northern Pacific (see Figure 1). This instrument was developed for highly accurate radiometric measurements of atmospheric emission in rugged field environments, and has been deployed in locations ranging from the continental United States [*Shaw et al.,* 1995] to the tropical western Pacific [*Han et al.,* 1997]. The expected calibration uncertainty of 1% of terrestrial background radiance was verified in comparisons with the similar M-AERI (Marine-Atmospheric Emitted Radiance Interferometer) system from the University of Wisconsin during a 1996 cruise [*Shaw et al.,* 1997].

Figure 2 shows two spectra of downwelling emitted atmospheric spectral radiance measured with 15-min sky observation times during April 1998 at Mauna Loa. Measured spectra are shown during (Figure 2a) and after (Figure 2b) the extremely dry period. Both measurement periods had clear skies and nearly identical conditions, other than the amount of atmospheric water vapor. The integrated water vapor column above Mauna Loa, measured by Nedoluha's water vapor millimeter-wave spectrometer [*Nedoluha et al.,* 1995], was 0.25 mm for Figure 2a and 3.2 mm for Figure 2b. The extraordinarily dry air over the northern Pacific resulted in dramatically increased transmission through the water vapor continuum in the 500-600 cm^{-1} spectral region, indicated in Figure 2a by low emitted radiance. The usual transmission window in the 800-1200 cm^{-1} region of Figure 2a also exhibits remarkably low emitted radiance. During the more typical, but still very dry, conditions of Figure 2b the 800-1200 cm^{-1} window is still extremely clear, but the long-wave windows in the more highly absorbing region of 500-600 cm^{-1} have closed.

Spectra similar to these have been observed from sea level in the Arctic [*Tobin et al.,* 1999], and an important question to be addressed later is how well the Arctic sea-level data serve as proxy for the upper-troposphere data. In both the Arctic and subtropical atmospheres, these long-wave transmission windows, which open when the atmospheric water vapor content is sufficiently low, may produce a higher rate of heat loss from Earth to space [*Clough et al.,* 1992]. A unique value of this particular data set is the evidence it provides that such cooling may occur at altitudes as low as this 3397-m mountaintop height.

Extended measurements in this kind of mountaintop environment will promote better understanding of the role of these long-wave atmospheric transmission windows in regional and global climate. However, the small radiance values in such measurements challenge our ability to maintain accurate and precise instrument calibration under a wide variety of environmental conditions. Also, especially in the subtropics, care must be taken to identify cirrus clouds above the instrument because of the relatively large signal they can contribute relative to a dry upper troposphere. The existence of substantial cirrus is reasonably easy to recognize in the spectra alone, but subvisual cirrus may be much more subtle and difficult to recognize without additional, independent measurements with a cloud lidar or other technique.

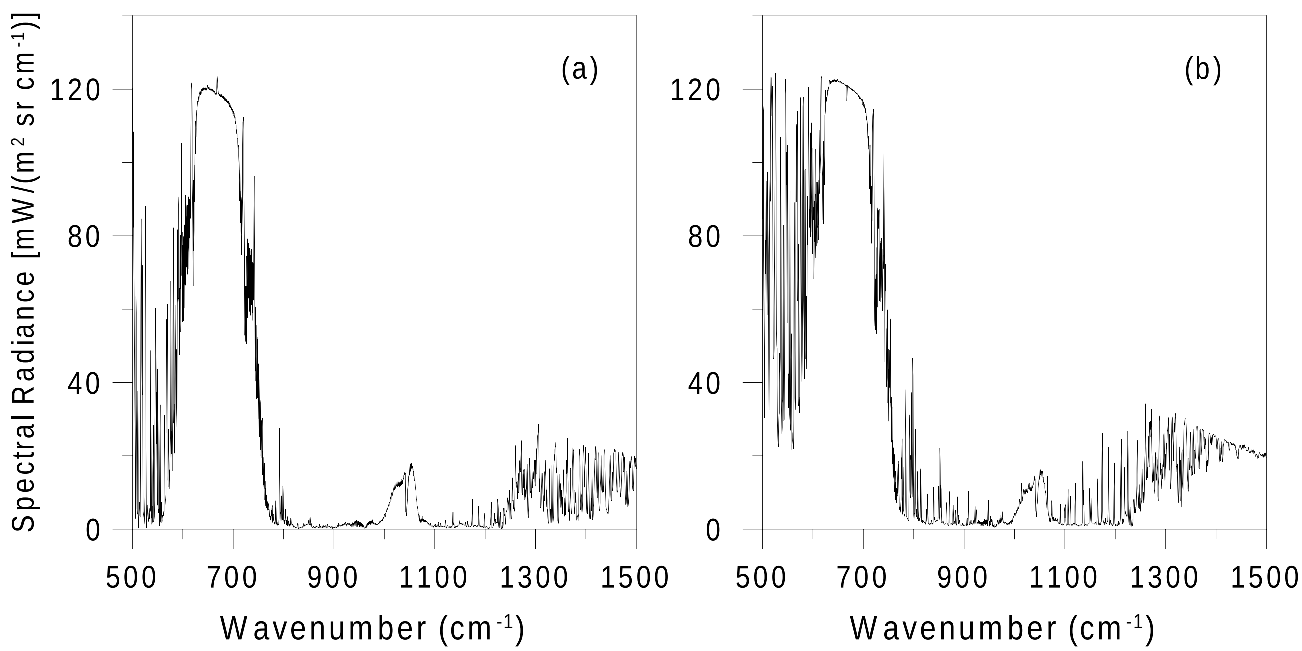

Figure 2. (a) Radiance spectrum measured during the dry period on April 11, 1998 at 4:27 GMT. The value for the integrated water vapor column was 0.25 mm. (b) Radiance spectrum measured after the dry period on April 24, 1998 at 6:13 GMT. The value for the integrated water vapor column was 3.2 mm.

3. Discussion

Because of the limited temporal coverage of the measurements shown here, we cannot absolutely relate them to the ENSO event of 1997-1998. However, it appears that the transmission window in the 500-600 cm^{-1} spectral region opens only when the overlying water vapor column drops to anomalously low levels. The satellite record of the last roughly 20 years shows clearly that such anomalously dry conditions occur over significant periods of time in the subtropical upper troposphere during ENSO events. We are developing instrumentation to make long-term infrared emission measurements at the Mauna Loa Observatory both for monitoring the interannual variation of upper tropospheric water vapor and for validating satellite measurements. Such upward-looking emission data from mountaintop locations will be particularly valuable because of the inadequacy of radiosonde water vapor measurements in the cold, dry upper troposphere.

The possibility of identifying the observed long-wave transmission window as a climate-cooling mechanism in response to a warming atmosphere is an intriguing, though at this point purely speculative, question that will require more analysis and observation to address. However, because of the scarcity of water vapor continuum measurements in this spectral region, especially in the upper troposphere, further analysis of these data will contribute to improved climate modeling capabilities and improved understanding of radiative transfer above the atmospheric boundary layer.

Acknowledgments. We thank the Mauna Loa Observatory staff for their support with the FTIR, and Dr. Gerald Nedoluha of the Naval Research Laboratory (nedoluha@wvms.nrl.navy.mil) for providing data from the water vapor millimeter-wave spectrometer.

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(Received November 11, 1998; revised February 10, 1999; accepted April 27, 1999.)