# 6B.11 MIGRATION OF UPPER TROPOSPHERIC WATER VAPOR FROM SUBTROPICS TO THE US WEST COAST AS OBSERVED BY MICROWAVE LIMB SOUNDER

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## 1. INTRODUCTION

Despite its small quantity, the importance of upper tropospheric humidity (UTH) is its ability to trap the longwave radiation emitted from the Earth's surface, namely the greenhouse effect. Recently, preliminary measurements of UTH by the Microwave Limb Sounder (MLS) on the Upper Atmosphere Research Satellite (UARS) were made available (Read et al., 1995). Hu and Liu (1998) studied the impact of UTH on the distribution of midlatitude greenhouse warming using the MLS UTH data set. It was found that the UTH is enhanced over the storm tracks in the North Pacific and North Atlantic, collocating with an increase in the greenhouse warming. The mechanism of observed enhancement in UTH over the storm tracks seems to be associated with the increase in the amount of deep convective clouds, and thus the transportation of more water vapor upward to the tropopause.

Unlike the water vapor abundance near the ocean surface, which is correlated with local evaporation (Liu et al., 1994), water vapor in the upper troposphere is maintained by mesoscale and large-scale atmospheric flows. Using a general circulation model (GCM), Del Genio et al. (1994) studied different mechanisms controlling the seasonal variation of UTH and suggested that both mean meridional circulation and eddies may moisten the midlatitude upper troposphere. However, these GCM mechanisms need to be validated using UTH measurements. In this paper, we will present observations of UTH from MLS UARS. It is found that occasional warm advection from subtropics to the US West Coast can also bring much water vapor to the upper troposphere.

## 2. UTH OBSERVATIONS

The UARS MLS has taken direct measurements of water vapor content at pressure levels at 464 mb, 315 mb, 215 mb, and 146 mb since late September 1991 until present (with some interruptions). The advantages of MLS over other instruments are the ability to observe through thin cloud-like cirrus and a better vertical resolution of 3 km (Read et al. 1995). The best sensitivity of MLS instrument to water vapor is at ~12 km height at low latitudes and ~7 km height at high latitudes. Because the UARS satellite yawed 180 degrees every 36 days, so the mid and high latitude coverages alternate between Northern Hemisphere and Southern Hemisphere every 36 days.

Fig. 1 shows UTH from MLS at 215 mb on February 21, 1998 when the US West Coast was experiencing back-to-back winter storms travelling from central Pacific. The UTH map indicated a direct corridor of enhancements in UTH from the vicinity of the Hawaii islands (~ 160°W and ~ 20°N) to the US West Coast. Under normal conditions, the subtropical high-pressure system around 30°N latitude in Pacific will cause cold air descending, resulting in less UTH in this area. The anomalous increases in UTH shown in Fig. 1 are caused by the horizontal warm advection, the so called "Pineapple Express", bringing heat and moisture from subtropical ocean to the US West Coast.

The UTH observations are also compared with modeled products. Fig. 2 is the 300-mb UTH from reanalysis products provided by the National Center for Environment Prediction (NCEP). The main features associated with the migrating storms are in good agreement between the MLS measurements

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and the reanalysis product. Note, Hu and Liu (1998) reported that observed enhancements in MLS UTH over storm tracks in North Pacific and North Atlantic were not simulated in an atmospheric general model (GCM). It is possible that different mechanisms are responsible for the observed UTH enhancements in different regions. The enhancements reported here are resulted from horizontal warm advection, while those reported by Hu and Liu (1998) may be caused by vertical transport by eddies which may not be very well simulated in the GCM.

## 3. OTHER OBSERVATIONS

Fig. 3 is the total water vapor observed from Special Sensor Microwave Image (SSMI) on February 21, 1998. Since most water vapor in the atmosphere is constrained in the lower troposphere, the total water vapor can be considered approximately equal to the water content in the lower troposphere. Besides higher total water vapor in the Tropics, one also can see that much moisture was transported from the vicinity of the Hawaii islands to the US West Coast, a similar feature observed in the UTH measurements in Fig. 1. Again, this feature is different from the one reported

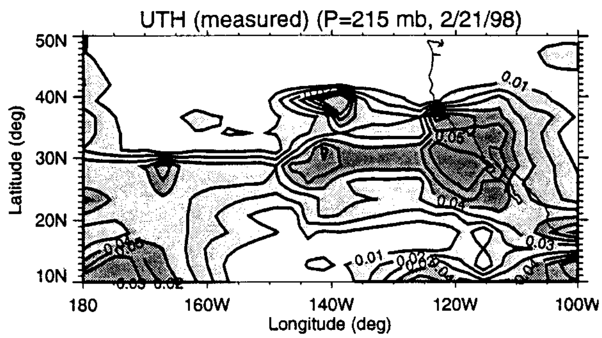


FIG. 1. The upper tropospheric specific humidity (at 215 mb) measured by MLS. Contour interval is 0.01 g/kg, values greater than 0.01 g/kg and 0.04 g/kg are denoted by light and dark shading, respectively. Data was collected on February 21, 1998.

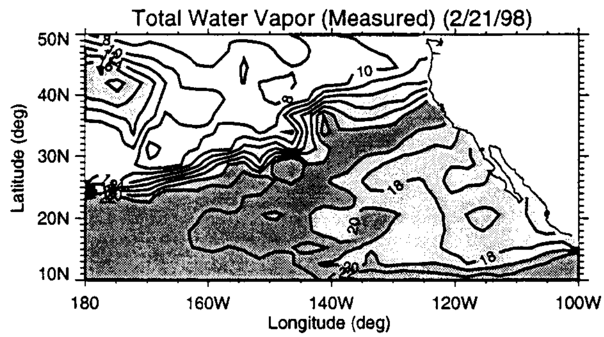


FIG. 3. The total water vapor measured by SSMI. Contour interval is 2 mm, values greater than 14 mm and 20 mm are denoted by light and dark shading, respectively. Data was collected on February 21, 1998.

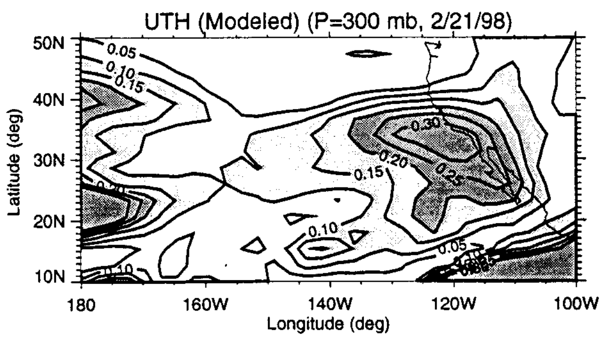


FIG. 2. The upper tropospheric specific humidity (at 300 mb) provided by the NCEP reanalysis product. Contour interval is 0.05 g/kg, values greater than 0.1 g/kg and 0.2 g/kg are denoted by light and dark shading, respectively. It is daily averages on February 21, 1998.

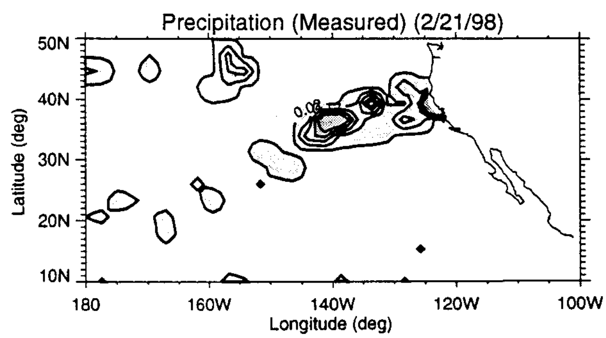


FIG. 4. The precipitation measured by SSMI. Contour interval is 0.1 mm/hr, values greater than 0.02 mm/hr are denoted by light shading. Data was collected on February 21, 1998.

by Hu and Liu (1998) in which total water vapor did not show significant increases over the midlatitude storm tracks. As the changes in total water vapor can approximately represent the changes in water vapor content in the lower troposphere, the similarities between Figures 1 and 3 confirm that the mechanism responsible for these features is the horizontal warm advection. The warm and moist atmospheric flows can develope into thunderstorms which dumped much water on California on February 21 1998. Fig. 4 is the precipitation observed from SSMI on that day. Although SSMI only makes observations over oceans, it clearly shows that back-to-back storms were migrating from the vicinity of the Hawaii islands to the US West Coast.

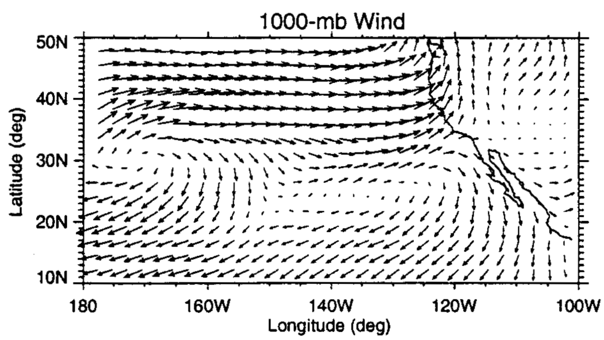


FIG. 5. The wind vectors at 1000 mb from NCEP reanalysis. They are daily averages on February 21, 1998.

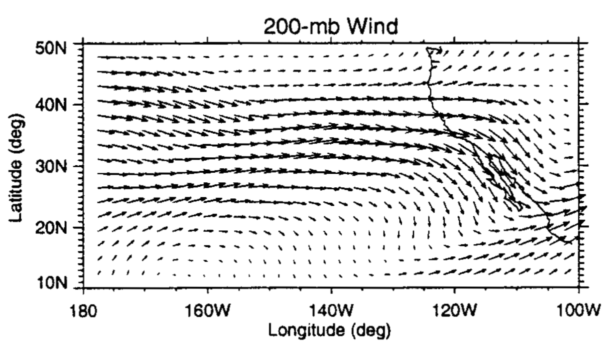


FIG. 6. The wind vectors at 200 mb from NCEP reanalysis. They are daily averages on February 21, 1998.

The mechanism of warm advection can be demonstrated in the wind fields from NCEP reanalysis products. Fig. 5 is the map of 1000-mb wind vectors on February 21, 1998. The anticyclonic flow (high pressure system), which under normal conditions is located off California coast with northerly winds along the shore, moved to south. It caused winds blowing toward the coastal inland and conducting the tropical moisture toward this area. This anomalous wind pattern was associated with the southern branch of the jetstream shown in Fig. 6, a map of 200-mb wind vectors. A strong sub-tropical jet out of Hawaii was tightly coupled to the east-west flow of the jet stream. Storms moving along this path carried warm and very moist subtropical air to the US West Coast and were associated with heavy precipitation. The position of the subtropical branch determines which portion of the coastal inland receives the heaviest precipitation. In this case, it was the California coast. The plumes of UTH and total water vapor, shown in Figures 1 and 3 respectively, delineated the subtropical branch of the jet stream.

## 4. SUMMARY

The extratropical influence of El Niño had been extensively demonstrated by the 1997/98 El Niño, the strongest and most persistent El Niño event ever recorded. For example, anomalous warm ocean temperatures off California in late spring 1997 may link to the El Niño event in the Tropics (Liu et al., 1998). While many efforts have contributed to the understanding of how midlatitude atmospheric dynamics and ocean state are influenced by El Niño, very little attention has been paid to the associated changes in upper tropospheric humidity. In this paper, it is reported that migration of subtropical storms can add much water vapor to the upper troposphere over the US West Coast. Although the subtropical storms are a normal feature of the US West Coast climate even in non-El Niño years, such storms tend to be more frequent and more vigorous in association with warm episode of ENSO events. During the warm phase, the unusually warm sea surface temperature pattern in the eastern tropical and subtropical Pacific create a southern branch of the jet stream, extending from the latitude of Hawaii (~ 20°N) to the US West Coast. The warm advection along the sub-tropical jet brings highly moist air along the path and can cause heavy precipitation (sometimes floods) in coastal inland. This study demonstrates the MLS ability to detect this synoptic-scale feature.

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## REFERENCES

Del Genio, A. D., W. Kovari, and M.-S. Yao, Climate implications of the seasonal variation of upper troposphere water vapor, *Geophys. Res. Lett.*, **21**, 2701-2704, 1994.

Hu, H. and W. T. Liu, The impact of upper tropospheric humidity from Microwave Limb Sounder on the midlatitude greenhouse effect, *Geophys. Res. Lett.*, **25**, 3151-3154, 1998.

Liu, W. T., A. Zhang, and J. K. B. Bishop, Evaporation and solar irradiance as regulators of sea surface temperature in annual and interannual changes, *J. Geophys. Res.*, **99**, 12,623-12,637, 1994.

Liu, W. T., W. Tang, and H. Hu, Spaceborne sensors observe El Nino's effect on ocean and atmosphere in North Pacific. *Eos Trans. of AGU*, **79**, 250 & 252, 1998.

Read, W. G., J. W. Waters, D. A. Flower, L. Froidevaus, R. F. Jarnot, D. L. Hartmann, R. S. Harwood, and R. G. Rood, Upper tropospheric water vapor from UARS MLS. *Bull. Am. Meteorol. Soc.*, **76**, 2381-2389, 1995.