Water Vapor Variability in the Tropical Western Pacific from 20–year Radiosonde Data

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ABSTRACT

The 20–year (1976–1995) daily radiosonde data at 17 stations in the tropical western Pacific was analyzed. The analysis shows that the atmosphere is more humid in a warmer climate on seasonal, inter–annual and long–term (20–year) time scales, implying a positive water vapor feedback. The vertical structure of the long–term trends in relative humidity (RH) is distinct from that on short–term (seasonal and inter–annual) time scales, suggesting that observed water vapor changes on short time scales could not be considered as a surrogate of long–term climate change. The increasing trend of RH (3%–5% / decade) in the upper troposphere is stronger than that in the lower troposphere (1%–2% / decade). Such vertical structure would amplify positive water vapor feedback in comparison to the common assumption of constant RH changes vertically. The empirical orthogonal function (EOF) analysis of vertical structure of RH variations shows distinct features of the vertical structure of the first three EOFs. The first three EOFs are optimal for representation of water vapor profiles and provide some hints on physical mechanisms responsible for observed humidity variability.

Vaisala radiosondes were used at nine stations, and VIZ radiosondes used at other eight stations. The Vaisala data are corrected for temperature–dependence error using the correction scheme developed by NCAR / ATD and Vaisala. The comparison of Vaisala and VIZ data shows that the VIZ–measured RHs after October 1993 have a moist bias of ~ 10% at RHs < 20%. During 1976–1995, several changes including both instruments and reporting practice have been made at Vaisala stations and introduce errors to long–term RH variations.

Key words: Water vapor, Radiosonde

1. Introduction

Most General Circulation Models (GCMs) agree that water vapor feedback due to warming caused by increasing greenhouse gases is positive (Cess et al., 1990). However, Lindzen (1990) argued that GCMs might overestimate the water vapor feedback because increased convection in a warmer climate would actually dry the upper troposphere by subsidence. One of focal points of debates on water vapor feedback is the role of deep convection in regulating the vertical distribution of the tropospheric water vapor (Sun and Lindzen, 1993). The deep convection occurs most frequently in the tropical western Pacific. Therefore, a number of studies have been conducted to test whether the atmosphere is observed to be more humid in a warmer climate in the tropics. Gutzler (1992) show that both temperature and specific humidity in the tropical western Pacific have increased throughout the troposphere since the mid–1970's. Sun and Oort (1995) found that in both the lower and

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upper troposphere, tropical mean specific humidity increases with temperature on the interannual time scale. In order to complete the cycle of water vapor feedback, one has to know how surface temperatures (or earth radiation budget) respond to water vapor changes. Shine and Sinha (1991) found that the earth's radiation budget is most sensitive to lower tropospheric water vapor concentrations assuming equally relative perturbations of humidity vertically. Spencer and Braswell (1997) concluded that the sensitivity of outgoing longwave radiations (OLR) to tropical tropospheric relative humidity changes is much larger at very low humidities than at very high humidities, and is greater for changes in the free troposphere than for boundary layer humidity changes. Those studies suggest that it is important to know both vertical structure of water vapor variability (rather than total column value) and frequency distributions of humidity (rather than mean values).

In this study, we use a 20–year (1976–1995) record of daily radiosonde data at 17 stations in the tropical western Pacific to examine the vertical relative humidity (RH) variations on diurnal, seasonal, inter–annual, and decadal time scales. The tropical western Pacific is chosen because of frequent occurrence of deep convection described above and the availability of long–record and high quality of radiosonde data at a number of Island stations. VIZ radiosondes were used at 8 stations. Vaisala radiosondes were used at other 9 stations starting in 1987. The advantages of a 20–year daily radiosonde dataset are listed here. (1) The radiosonde data can provide information on the vertical structure of water vapor variability (rather than total column value). (2) The long–term water vapor variations can be studied because of its long record. (3) The availability of hourly data makes it possible to analyze water vapor variations on different time scales and to investigate their interactions, and analyze the frequent distributions of humidity (rather than mean values). (4) The long time record includes VIZ radiosonde data after October 1993, when VIZ data first started to include humidity reports at RH$<$20% and at temperatures lower than −40°C (Wade, 1994). (5) The combination of VIZ and Vaisala radiosonde data allows comparison to understand advantages and disadvantages of each instrument.

Both relative humidity and specific humidity are used in this study, but the paper emphasizes more on RH. The main reason is that RH is derived directly from measured capacitance (Vaisala) or resistance (VIZ) in radiosonde. So the measurement errors in temperature would not affect that in RH. RH depends on both the amount of water vapor in the atmosphere and the holding capacity of the air for moisture (e.g., temperature). This makes RH an attractive, dynamic parameter. The RH values can be related to dynamical processes (e.g., advection, convection, and subsidence) that bring about changes in temperature or to other forms of diabatic heating. Additionally, RH can be regarded as an indicator of the possibility of phase changes in the atmosphere (cloud formation, precipitation, etc.). Because of these facts, RH is frequently used by modelers as a basic moisture parameter in their studies. Therefore, in this study we try to document characteristics of RH vertical profiles and its variations on different time scales. Specific humidity can be regarded as an independent parameter for the moist atmosphere, and is more directly related to the radiative forcing. Therefore, long–term specific humidity variations are more relevant to the study of water vapor feedback and are given in Section 4 along with RH variations.

There are three goals in this paper. (1) To quantify characteristics of RH vertical profiles from lower to upper troposphere, we first analyze the VIZ data after October 1993 and the Vaisala data, which both provide measurements of RHs below 20% (Section 3).

(2) We next examine the vertical humidity variations on diurnal, seasonal, inter–annual and decadal time scales to assess the sign of the water vapor feedback in the tropics (Section 4). (3) Finally, in order to understand the RH variability, we make an EOF analysis of the vertical structure of humidity variations to decompose temporal and vertical variations (Section 5).

2. Data sources and errors

A 20–year (1976–1995) global daily radiosonde dataset has been created by collecting all available radiosonde data (Wang et al., 2000). In the tropical western Pacific (TWP: 20°S–20°N, 130°–180°E), there are eight U.S.–controlled stations (referred as VIZ stations hereafter), which use radiosondes manufactured by VIZ Inc. and follow U.S.–regulated observing and reporting practices (Gaffen, 1993), and nine stations currently using radiosondes made by Vaisala Inc. (referred as Vaisala stations hereafter) (Fig. 1). The data is available twice a day at 00 and 1200 GMT at eight VIZ stations, but only once a day at 0000 GMT at Vaisala stations for most of times. All VIZ stations are located in the Northern Hemisphere (N. H.), and all Vaisala stations except Tarawa are in the Southern Hemisphere (S. H.).

The VIZ radiosondes use the carbon hygristor as the humidity sensor. The electrical resistance of the carbon varies in response to relative humidity, producing a voltage that is converted to relative humidity. The VIZ carbon hygristor was used during 1976–1995 at VIZ stations. The only important change in data reporting practice at VIZ stations occurred in October 1993. Before October 1993, the humidity data were not reported for temperatures below –40°C, and the dew point depression was reported as 30°C when RH was below 20% (Elliott and Gaffen 1991). After October 1993, the humidity data were reported at all temperatures, but the 1b coefficients were used at RH < 20% in the data processing software to convert resistance ratio to RH, which introduces a moist bias to RH (Wade 1994; Elliott et al., 1998). In June 1997, the U.S. National Weather Service (NWS) began using the 1a coefficients at all RHs.

The Vaisala Humicap RH sensors are thin–film capacitive sensors whose temperature–

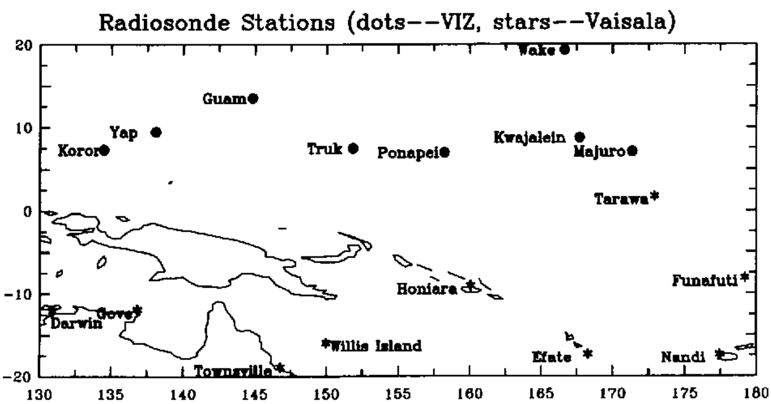

Fig. 1. Geographic distribution of 17 radiosonde stations. The dots represent VIZ stations, and the stars represent Vaisala stations.

compensated capacitance is proportional to the ambient water vapor concentration. The instrument and data reporting practice during 1976–1995 have changed frequently at Vaisala stations. Those changes are summarized in Table 1. Time series of 500 hPa RH anomalies from the 20–yr climatological monthly mean at Townsville, Australia in Fig. 2 show abrupt drop of RHs in August 1982 corresponding to the change of RH sensor from the lithium chloride to the carbon hygristor. The moist bias of the lithium chloride increases with altitudes. The lithium chlorides suffer from a very long lag, which increases with decreasing temperatures (cf. Elliott and Gaffen, 1991). Since RH tends to decrease with height, the lithium chloride would tend to indicate higher values than a faster–responding instrument. However, Fig. 2 does show some real temporal variations, such as dryer conditions during El Niño years (1977–1978, 1980, 1983, 1987–1988 and 1992) and the relative dryness in the 1990s associated with the long ENSO in 1991–1995 (Trenberth and Hoar, 1996; Zhang et al., 1997). Because of frequent changes of radiosonde types and resulted errors at Vaisala stations, we will focus on results derived from the VIZ data in the following discussions.

Table 1. List of known changes at Vaisala stations during 1976–1995

Date	**Changes in instrument and reporting practice**	**Humidity sensor**
1976	Introduced Astor Mark I radiosondes	Lithium chloride
1978–1979	Introduced Philips Mark II radiosondes	Lithium chloride
Before 1982	* RH reported missing at temperatures below–40° C	
1982	* RH reported missing at T< – 60° C or pressure below 100 hPa	
1982	Introduced Philips Mark II 1 / 2 radiosondes	VIZ carbon hygristor in housing
1983	Introduced Philips Mark III radiosondes	VIZ carbon hygristor in redesigned housing
1987	* RH reported missing at T< – 60° C or P< 200 hPa	
1987	Introduced Vaisala RS80–15 radiosondes	HUMICAP– capacitive thin film element

* Note: those changes are only applied to Australia stations including Darwin, Gove, Townsville and Willis Island.

NCAR / ATD has been collaborating with Vaisala to correct errors in humidity data from Vaisala RS80 radiosondes based on a series of laboratory tests (Wang et al., 2001). Errors include "chemical contamination error", "basic calibration model error", and "temperature–dependence error". Both contamination and temperature–dependence errors produce dry biases in humidity data. The contamination error is a result of contamination of the polymer used as the dielectric material in the capacitive RH sensor (humicap) and is a function of sonde age and RH. The temperature–dependence error results from an approximation of a linear function of temperature to the actual nonlinear temperature–dependence of the sensors and increases substantially with decreasing temperatures below about –30°C. We correct the temperature–dependence error in the Vaisala data in Section 3.

3. Characteristics of relative humidity

The frequency distributions of RH at 10 pressure levels from 1000 hPa to 100 hPa are presented in Fig. 3 at VIZ stations in both winter (DJF) and summer (JJA) using 94–95 data. Throughout most of this study, we do not present results for an individual station considering

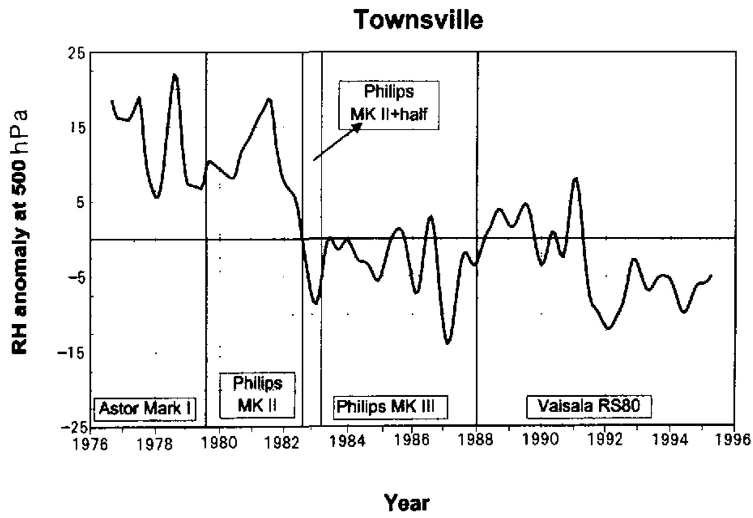

Fig. 2. Time series of RH anomaly at 500 hPa from the 20–yr climatological monthly mean at Townsville from 1976 to 1995. The vertical lines denote the time when the radiosonde type was changed. The radiosonde type in each period is labeled.

similarities in their characteristics. In TWP in N. H. winter, there is a very moist boundary layer (1000 and 850 hPa) (RH > 70%), overlain by very dry air (RH < 20%) within 700–250 hPa 30% of time, above which the atmosphere is often relatively humid (RH: 30%–50%) (Fig. 3a). This is similar to Fig. 3 in Spencer and Braswell (1997). In contrast to winter, the largest RH changes in summer occur within 700–400 hPa; at 700 hPa, the dominant peak shifts from around 15% in winter to 70% in summer, while at 500 hPa and 400 hPa, there are relatively uniform RH distributions from 10% to 100% (Fig. 3b).

In contrast, the data from nine Vaisala stations in 1994–1995 show RHs below 15% throughout the atmosphere above 700 hPa in winter, and ~ 10% dryer on the average than VIZ data in the boundary layer in both seasons (Fig. 4). The dry bias in Vaisala data from contamination and temperature–dependence errors (see Section 2) contributes at least in part to the difference between VIZ and Vaisala data. Because of lack of information on radiosonde ages and small magnitudes of contamination errors for those types of sondes, we did not apply the contamination correction to the data. After making the temperature–dependence correction, the data show a moist trend from the middle to higher troposphere as shown by VIZ data, but RHs above 250 hPa are still dryer than that from VIZ data (Fig. 5). The moist bias in the VIZ data due to using 1b coefficients instead of 1a at RHs < 20% contributes to the ~ 10% difference in RHs within 700–250 hPa(shifting of peaks from 15% in the VIZ data to 5% in the Vaisala data), which is consistent with that from the theoretical calculation (Wade, 1994; Elliott et al., 1998). However, the correction method to this moist bias still has some uncertainties (Elliott et al., 1998), so we choose not to correct VIZ data. The moist boundary layer shown by VIZ data than by Vaisala data is partly a result of the moist bias in the VIZ data in the boundary layer consistent with what Johnson and Ciesielski (2000) found during

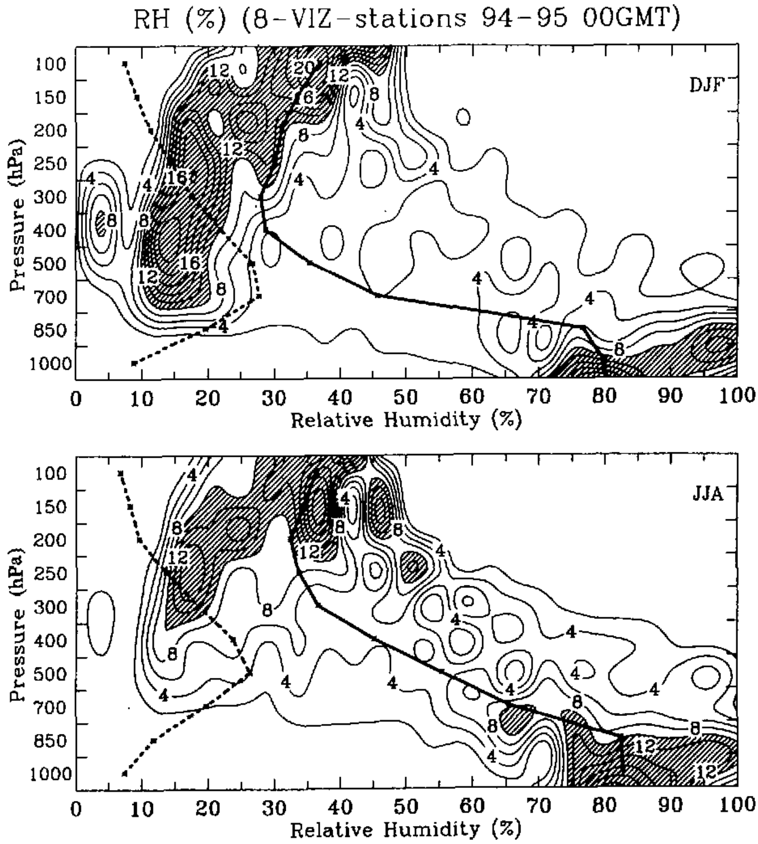

Fig. 3. Contoured frequency distribution of RHs at ten pressure levels in DJF and JJA derived from data at VIZ stations at 0000 GMT in 1994–1995. Isolines represent the frequency (percent) of total observations at a particular level, which have vales in a 4%–sized RH bin. The contours larger than 10% are hatched. The solid and dashed vertical curves with stars are vertical profiles of mean and standard deviation of RHs, respectively.

TOGA COARE (Wade and Schwartz, 1993). We found that the differences in geographic distributions of Vaisala and VIZ stations do not contribute the differences in RH distributions after some tests of limiting two datasets in a similar latitudinal zone.

4. RH Variations on different time scales

4.1 *Seasonal variations*

The relative humidity differences between warm and colder climates (summer v.s. winter, El Niño v.s. La Niña, and daytime (0000 GMT) v.s. night time (1200 GMT)) are derived from the VIZ data and are shown in Fig. 6a. The atmosphere is more humid in summer than in winter; the largest changes (> 30% of the mean) occur in the midtroposphere. The seasonal

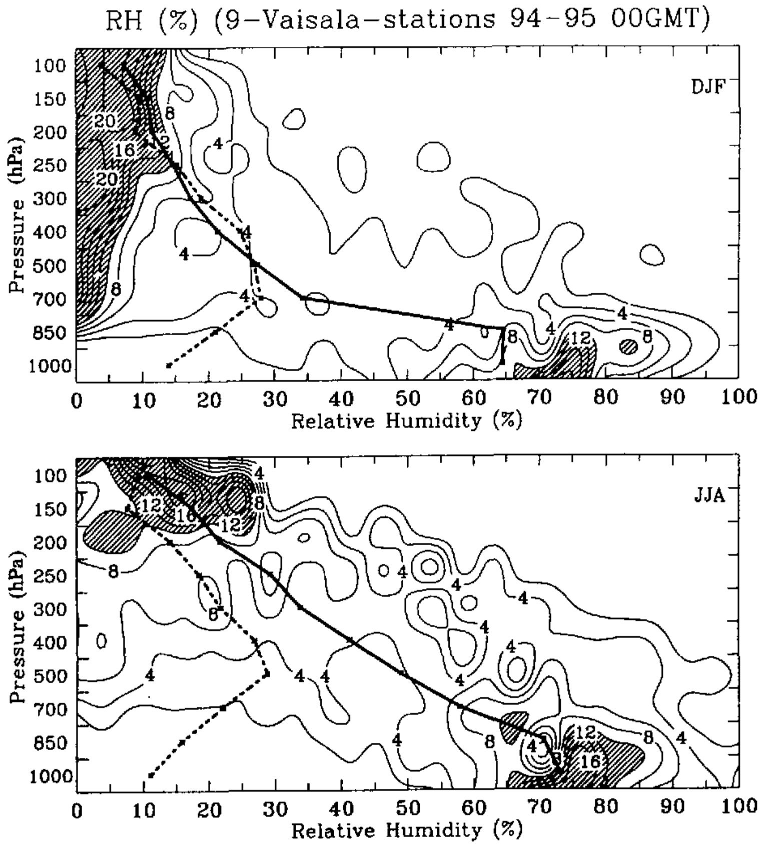

Fig. 4. The same as Fig. 3 except that derived from data at Vaisala stations at 0000 GMT in 1994–1995.

differences in RH agree very well (both sign and magnitude) with the GCM (Del Genio et al., 1994): 15–20% in the midtroposphere and 0–10% in the low and upper troposphere, and have the same sign as those from SAGE–II but larger magnitudes (Rind et al., 1991; Del Genio et al., 1994). The seasonal change of RHs derived from 1994–1995 Vaisala data shows the similar vertical structure to that of VIZ data except with large magnitudes (Fig. 6b).

4.2 *Inter–annual variations*

The inter–annual variations of water vapor in the tropics are primarily modulated by El Niño and La Niña events, so the contrast in RH between La Niña and El Niño events is used to represent humidity variations on the inter–annual time scale. We present the difference in RH between 1995 (La Niña) and 1994 (El Niño) from September to December in Fig. 6a. The data before 1993 are also employed to calculate mean RH profiles in DJF for La Niña (1976, 1985 and 89) and El Niño (1977, 1978, 1980, 1983, 1987, 1988 and 1992) years. The data both

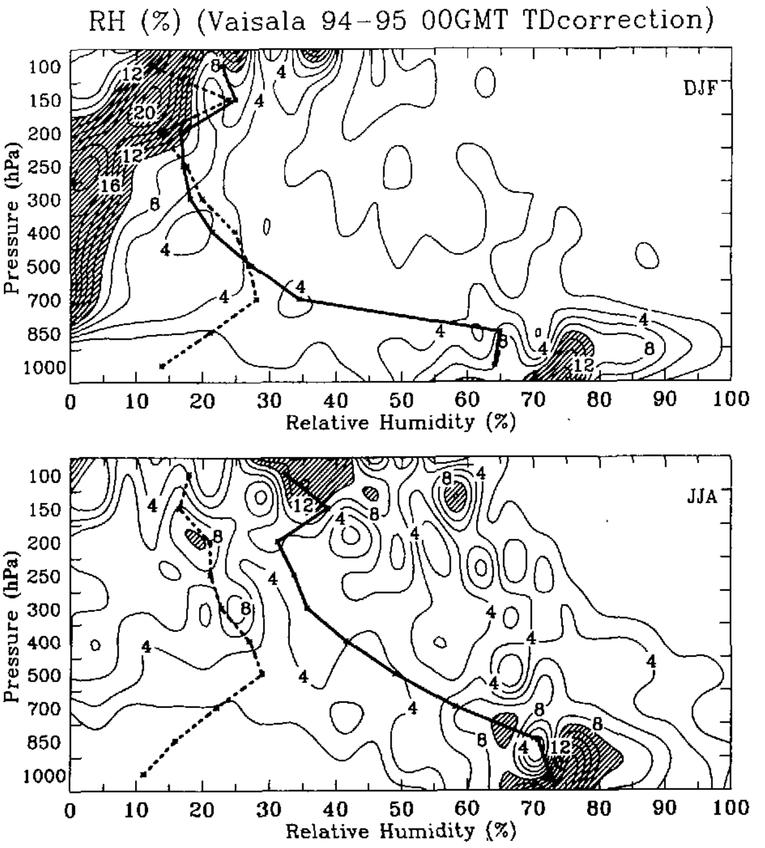

Fig. 5. The same as Fig. 4 except that corrected for temperature–dependence error.

before and after 1993 show that RHs are higher in La Niña years than in El Niño years, and the vertical structure exhibits peak amplitudes in the midtroposphere. The inter–annual variability of RHs has similar vertical structure to that of seasonal cycle, but smaller magnitudes.

4.3 *Diurnal variations*

On the diurnal time scale, the upper troposphere is drier during daytime (0000 GMT) than during nighttime (1200 GMT) (Fig. 6a). This is likely associated with more anvil and cirrus clouds during nighttime. From this data (not shown), we found that there are more frequent occurrence of RHs (with respect to water) around 60% at 250 hPa and 50% above 250 hPa, corresponding to RHs (with respect to ice) above 94%, indicating saturated air (e.g., clouds are formed). It suggests that the diurnal variability of RH is closely associated with local fluctuations of high clouds.

4.4 *Long–term trend*

The 20–year (1976–1995) and 13–year (1976–1988) long–term trends of temperature

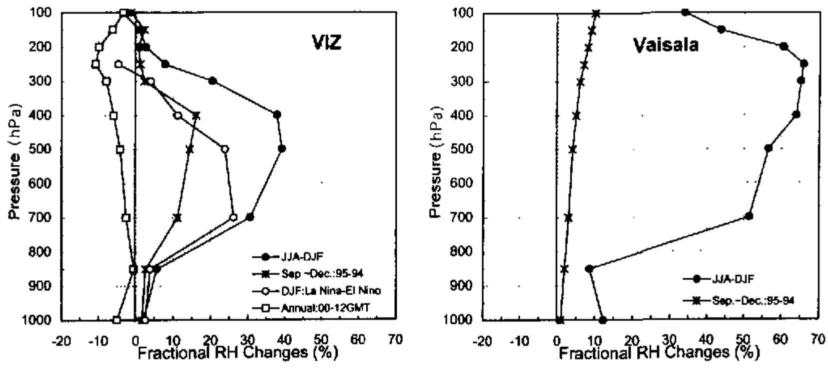

Fig. 6. Fractional changes (absolute changes normalized by mean values) in RH from VIZ data between JJA and DJF, 1995 and 1994 from September to December, La Niña and El Niño years in DJF, and 0000 and 1200 GMT. Fractional changes from Vaisala data between JJA and DJF, and 1995 and 1994 from September to December are also shown.

and humidity are calculated for both absolute and normalized monthly anomalies from the VIZ data (Fig. 2). The reason to study the 13–year trend is to compare our results with what Gutzler (1992) found about the 15–year (1974–1988) trend, and to investigate how the abnormal climate change in the 1990's affects the long–term trend. To avoid artificial trends due to changes in radiosonde practices after October 1993, RHs for 20–year data are calculated using the same practices: converting archived dew–point–depression, which is set to 30°C if measured RHs$\leqslant$ 20%, to RHs, and considering RHs at T<-40°C as missing. First of all, all cases show that the atmosphere throughout the troposphere becomes warmer and more humid since the mid–1970's. The specific humidity (Q) increase is large enough to produce the positive RH trends despite the warming trend. Secondly, the 13–year (1976–1988) trends are larger than the 20–year (1976–1995) trends for both temperature and humidity at all levels. This is attributed to relative coolness and dryness in the 1990s associated with the long ENSO in 1991–1995 (Trenberth and Hoar, 1996). Thirdly, the specific humidity trends decrease with height in absolute values but increase in relative values, which is not consistent with the assumption of equal relative perturbations of humidity vertically (Shine and Sinha, 1991). The RH trends in both absolute and relative values, however, generally increase with height. Such vertical structure would amplify positive water vapor feedback due to the greater sensitivity of outgoing longwave radiation (OLR) to lower RH and its variability in the free troposphere (Spencer and Braswell, 1997). The vertical structures of RH and Q long–term trends are distinct from those of seasonal and inter–annual RH variability that peak in the midtroposphere. As suggested by Gutzler (1992), the long–term humidity trend can be considered as a sensitive indicator of long–term climate change.

5. EOF analysis of vertical structure of RH variations

Based on the simulation in the Goddard Institute for Space Studies (GISS) GCM, Del Genio et al. (1994) concluded that four different mechanisms control the moisture budget in the tropics, the mean meridional circulation (MMC), moist convection, eddies, and stratiform cloud condensation and evaporation (see Fig. 2 in Del Genio et al., 1994). MMC produces moistening throughout the tropical troposphere because the tropics are located in its rising branches. The moist convection moistens the tropical upper troposphere by detrainment of water vapor near the tops of deep cumulus clouds (~ 300 hPa) and dries the atmosphere below 300 hPa via compensating environmental subsidence. Eddies dry the atmosphere below about 600 hPa (drying increases with pressures), but moisten it above with much smaller magnitudes. Stratiform phase changes moisten the atmosphere below 400 hPa because of the domination of evaporation over precipitation but dry it above. The above description of contributions of four physical processes to the tropical moisture budget is based on the simulation in the GISS GCM and has to be viewed with caution. However, no data are available to calculate those parameters. In addition, advection of air from the sub–tropics affects water vapor content (e.g., Sheu and Liu, 1995); melting of ice precipitation from high clouds can also lead to moistening below 0°C (Johnson et al., 1996); and detrainment of condensate from deep convections also occurs in other places rather than the top of deep convection and thus modulates RH vertical profiles.

In Sections 3 and 4, we have shown that the RH profiles have strong temporal and vertical variations. To understand which physical process (or a combination of several ones) is responsible for observed humidity variability, an empirical orthogonal function (EOF) analysis has been applied to the VIZ data. The advantages of EOF analysis are (1) to identify the most preferred modes (EOFs) of the variability, which explain the inherent variability with a minimum number of modes, and (2) to isolate the time scales that are associated with those modes. Moreover, the orthogonality of the EOFs implies that physical processes related to different EOF modes must be independent from each other. Therefore, the structure of the leading EOF modes and their corresponding time series can shed light on physical processes that cause the observed humidity structures. The first advantage has been widely taken by the remote sensing community to retrieve water vapor profiles (e.g., Smith and Woolf, 1976; Lipton et al., 1986; Lipton and Vonder Haar, 1987; Wagner et al., 1990).

The vertical structure of the first three EOFs and the time evolution of their principal components (PCs) at Majuro are derived from 1994–1995 data and shown in Fig. 8. EOFs represent the correlation coefficient between the normalized anomalies and the corresponding PCs at each level. The vertical structure of EOFs tells us the phase relationship of the variations at different levels. The first three EOFs explain 45%, 21% and 11% of the total variances, respectively, and are statistically significant (Fig. 8). The EOFs of the fourth and higher order are not considered here because they only explain less than 8% of total variances, and Lipton and Vonder Haar (1987) found that the first three EOFs are optimal for representation of water vapor profiles. The first EOF is positive throughout the whole atmosphere, increases with altitudes and reaches maximum in the upper troposphere. The correlation coefficients between time variations of the first PC and RH values in the upper troposphere can be as much as 0.9 (81% of the variance). The second EOF changes the sign around 300 hPa and shows negative correlations between the variations in the upper and lower troposphere. The third EOF indicates the out–of–phase relationship between variations in the middle and lower or upper troposphere. The vertical structure of the first three EOFs shown in Fig. 8 agrees well with previous studies (Lipton and Vonder Haar, 1987; Wagner et al., 1990). Similar patterns occur at other VIZ stations, for specific humidity profiles, and

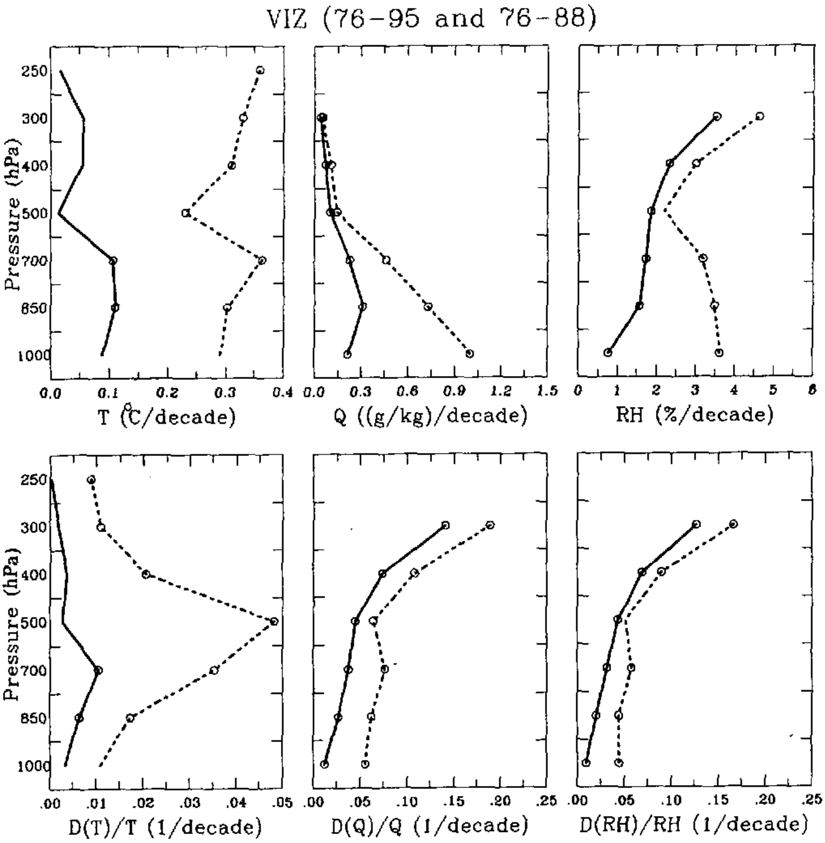

Fig. 7. Vertical profiles of linear trend coefficients for temperature (T), specific humidity (Q) and RH in both absolute (upper panel) and relative (lower panel) values for 20–yr (1976–1995) (solid lines) and 13–yr (1976–1988) (dotted lines) trends derived from VIZ data. The circles indicate that coefficients are statistically significant.

when the EOF analysis is conducted for any subset of data (such as 200–300 days at Majuro). It suggests that the vertical structure pattern shown in Fig. 8 is realistic, represents common features in TWP, and is related to physical processes governing humidity variations.

The positive correlations among humidities at all nine levels in the leading EOF mode (Fig. 8a) indicate that the first mode is likely associated with large–scale processes, which are capable of enhancing the communication between the free troposphere and the boundary layer and thus resulting in the same phases of variations at different levels through vertical mixing. The alternate occurrence of cloudy (wet) days and dry days due to large–scale subsidence produced by the circulations in TWP (e.g., MMC, Walker circulation, ISO, and quasi–2–day waves) is one of the candidates. However, it is not clear why the maximum correlations occur in the upper troposphere. Wagner et al. (1990) interpreted the first mode at mid–latitudes being related with warm and cold fronts due to a moistening of the whole atmosphere behind a

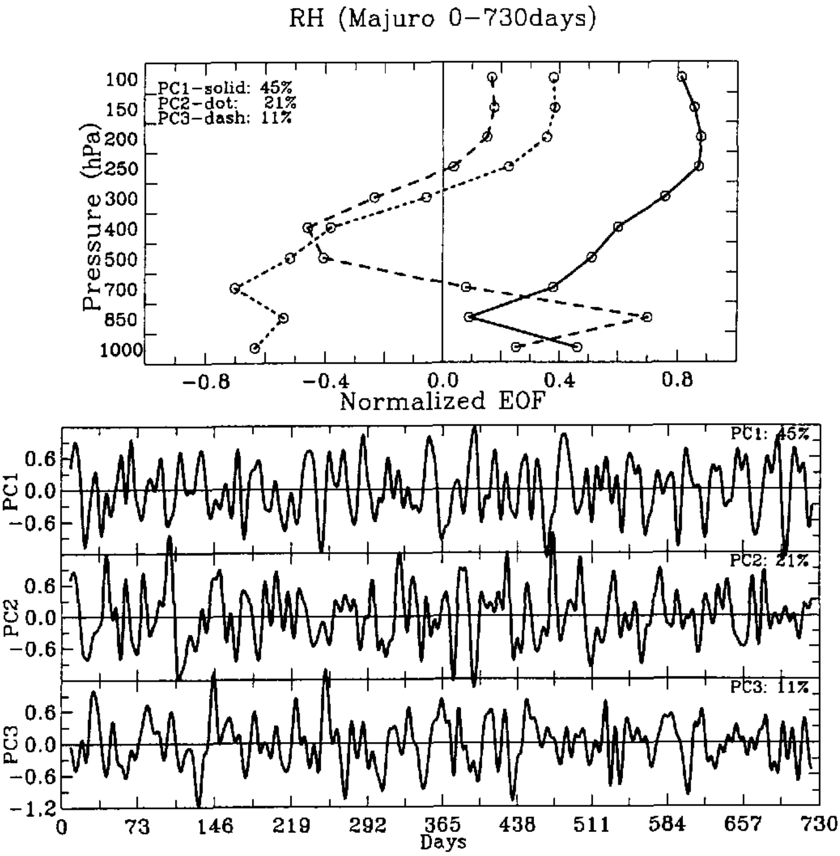

Fig. 8. The first three EOFs for the normalized RH variations at Majuro (upper panel) and corresponding time series of PCs (lower panel). The first three EOFs explain 45%, 21% and 11% of total variances, respectively. A 10–points smoothing scheme is used to smooth the time series of PCs, Day 1 corresponds to January 1, 1994, and Day 730 is December 31, 1995.

warm front or a drying in the rear of a cold front. The out–of–phase relationship between the variations in the upper and lower troposphere in the second EOF mode suggests that the second mode seems linked to moist convection since in the tropics, it moistens the upper troposphere by detrainment of water vapor near the tops of deep cumulus clouds (~ 300 hPa) but dries the atmosphere below it by compensating environmental subsidence (Del Genio et al., 1994). This needs to be validated by studying the relationship between the vertical velocity and the second PC. The third mode is likely the result of advection of dry air from the subtropics (Sheu and Liu, 1995; Yoneyama and Parsons, 1999). We need to evaluate this by utilizing the advection data in the future.

6. Summary and discussions

The upper tropospheric humidity (UTH) has been the focus of water vapor feedback issue because of the dependence of OLR on its magnitudes and the sensitivity of OLR to small absolute changes of UTH (Spencer and Braswell, 1997). However, the most fundamental observation of humidity—the radiosonde has a lot of uncertainties on measuring UTH. In this paper, we make use of the new VIZ radiosonde data after October 1993 in the tropical Pacific, which report RH from 0% to 100% at all temperatures, and compare it with the Vaisala data corrected for temperature–dependence errors. The comparison shows that the VIZ–measured RHs have a moist bias of $\sim 10\%$ at RHs $< 20\%$ as a result of using 1b instead of correct 1a coefficients. Such moist bias should be eliminated after NWS started to use 1a coefficient in June 1997. The 20–yr time series of RH anomaly at Vaisala stations illustrate spurious variations associated with instrument changes. Caution should be taken when those data are used to study long–term variations of water vapor.

The availability of a 20–year daily radiosonde data provides a unique opportunity to study the water vapor variability on different time scales. On short time scales (seasonal and inter–annual), the atmosphere is more humid in the warmer climate than in the colder climate; the largest variability occurs in the midtroposphere (700–400 hPa). On long time scale (20–year linear trend), the results also show that the atmosphere throughout the troposphere become warmer and humid from 1976 to 1995. All those results suggest that the atmosphere is more humid in a warmer climate, implying a positive water vapor feedback. The vertical structure of humidity long–term trends in relative values displays a monotonous increase with height, and thus amplifies the positive water vapor feedback magnitude. Such structure is distinct from those on short–term time scale that peaks in the midtroposphere, indicating that observed water vapor changes on short time scale can not be considered as a surrogate of long–term climate change.

An EOF analysis of vertical structure of RH variations is conducted in this study to understand which physical process (or combinations of several ones) is responsible for observed humidity variability. The data from different stations and different time series in TWP all show the common features of the first three EOFs. The first EOF is positive throughout the troposphere and increases with altitudes; the second one changes the sign from larger positive below 300 hPa to smaller negative above; and the third one shows the out–of–phase relationship between RH variations in the middle and lower / upper troposphere. Based on the vertical structure of the first three EOFs, we hypothesize that the first mode is likely associated with large–scale processes, the second mode seems linked to moist convection, and the third one is likely the result of advection of dry air from the subtropics. Those hypotheses need to be validated by studying the relationship between the PCs and other atmosphere parameters in the future.

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