A CLIMATOLOGY OF THE WATER VAPOR BAND BRIGHTNESS TEMPERATURES FROM THE TOVS

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1. INTRODUCTION

The variations of water vapor in the atmosphere play key roles in our environment. Our knowledge about these variations, however, is disproportionately inadequate. This is largely due to a lack of observations to stimulate and to verify theoretical and modeling efforts.

Atmospheric water vapor has been measured by various techniques, each has its own advantages and difficulties. In this study we present a climatology of the brightness temperatures of the HIRS water vapor band channels. A series of HIRS instruments have flown aboard the NOAA operational polar-orbiting satellites since 1979. Compared with other techniques, the HIRS has a number of advantages for climate studies: data have been continuously archived using the same type of instrument; the entire earth has been monitored by two satellites at most times; measurements are made every 12 hours for most parts of the world; and three of the channels [HIRS channels 10, 11, and 12, their measurements are denoted hereafter as $T_b(10)$, $T_b(11)$, and $T_b(12)$] are dedicated to the observations of water vapor, respectively, in the lower, middle, and upper troposphere. A careful examination of these data should complement other observations of atmospheric water vapor.

2. CONSTRUCTION AND ERROR ANALYSIS OF THE T_b CLIMATOLOGY

NOAA/NESDIS operational data of clear radiance (both clear and cloud-cleared) from 1981 through 1988 were used in this study. The T_b climatology was compiled by sorting the satellite measurements into bins of 2.5° latitude by 2.5° longitude by 5 days. Simple mean of the bin was used as bin average.

Error analysis showed that the random error of the bin average is about 1 K for all channels, chiefly due to uncertainty in cloud conditions. The random error of Figs.2-4 should be much smaller, for they are monthly or zonal/global means.

Systematic errors (biases) may also be present. The largest systematic error, perhaps, is that the clear radiance is biased toward the clear part of a region. Because of such selective sampling, the derived results probably will have some "dry bias," assuming the air under clouds is on average more moist than that without clouds. Another bias arises from the inconsistency between the six satellites that were in operation at different times from 1981 to 1988. The details of this bias are currently under study. The magnitude of this bias for global monthly averages is less than 0.2 K for most cases, but could be as large as 0.5 K for certain cases. This bias should cause little concern with our study of mean climatology, where the signal level is at least 5 K.

3. INTERPRETATION OF THE T_b MEASUREMENTS

Figure 1 plots the average profiles of temperature *T* and specific humidity *q* in the tropics. The other three curves are weighting functions for the HIRS Channel 12 using the temperature profile *T* but different specific humidity profiles. To compute WF(12), the specific humidity profile *q* was used. To compute WF(+), the specific humidity *q* was doubled or increased by 0.2 $g{\bullet}kg^{-1}$, whichever is smaller. To compute WF(-), the specific humidity *q* was reduced by 90% or 0.2 $g{\bullet}kg^{-1}$, whichever is smaller. These three weighting functions reveal that T_b(12) is the average temperature of certain atmospheric layer that is determined by the water vapor content in the upper troposphere. Similar relationship was found between T_b(11) and H_2O content in the middle troposphere, and, to a less extent, between T_b(10) and H_2O content in the lower troposphere.

The relationship revealed by Fig.1 suggests that the water vapor band brightness temperatures can be used as an index of water vapor content under certain conditions. First of all, temperature must change monotonically with height. For example, if temperature always decreases with height, which usually is the case in tropical middle and upper troposphere, a drier atmosphere will produce a higher value of T_b, and vice versa.

It is also necessary that the variation of the T_b due to water vapor be much larger than those due to any other factors. Otherwise the observed T_b variations could not be related with certainty to water vapor variations. Measurements of T_b(10-12) are determined by the vertical distributions of temperature and water vapor. Statistics of the global atmosphere show that a minimum of temperature variation coincides with a maximum of moisture variation, both horizontally and temporally, in the tropical region (about 30°S-30°N). In this region, T_b(12) variation due to moisture variation is three times that due to temperature variation.

4. SOME RESULTS OF THE T_b CLIMATOLOGY

Figure 2 is the global 8-year average of T_b(10-12), weighted by the cosine of latitude. The curve for T_b(10) (dash) is unimodal, peaking at the end of June. This must relate to the fact that T_b(10) is very much affected by the temperature at the surface.

The curves for $T_b(11)$ (dot) and $T_b(12)$ (solid) are similar, so what is said about $T_b(12)$ applies to $T_b(11)$ as well. These curves are bimodal with a smaller peak at end of January and a larger peak at the end of July. To understand this temporal variation, it is necessary to realize the differential response of $T_b(12)$ to subsidence and convection. Subsidence makes the air warmer and drier, both of these lead to a higher value of $T_b(12)$. In contrast, the response of $T_b(12)$ to convection is weaker for a number of reasons: (1) Convection usually results in a slightly warmer and more moist upper troposphere. These have opposite effects on $T_b(12)$, although the effect of added moisture usually prevails and the $T_b(12)$ measurements are cooler. (2) Convection tends to be under-sampled because of the associated clouds. Even if clouds are extensive at one level, clear radiance will not be available for any HIRS channel. (3) Strong convection sometimes injects water vapor into lower stratosphere, where temperature is higher than in the tropopause.

Because convection must always be balanced by subsidence for the global average, and because $T_b(12)$ shows a stronger positive response to subsidence and a weaker negative response to convection, the net effect is that the global average of $T_b(12)$ responds positively to the global average of meridional circulation (Fig.2). Furthermore, the peak of curve for $T_b(12)$ is higher during boreal summer than during austral summer, which agrees with the seasonal variation of the mean meridional circulation. The overall magnitude of the annual variation for $T_b(12)$ is much smaller than that for $T_b(10)$, and the phase is further delayed from the solstices.

Figure 3 is the zonal average of $T_b(12)$ for the 8-year period. In low latitudes (30°N-30°S), maxima appear regularly in the winter subtropics, where zonally averaged temperature is cooler. These maxima mark the dry middle and upper troposphere caused by subsidence. Again, these local maxima are found to be more extensive during austral winters, when the mean meridional circulation is intensified.

Minima are observed in Fig. 3 during July-August at about 10°-15°N and, with lower intensity, during January-February at about 5°-10°S. These are signatures of moist upper and middle troposphere associated with the convections in the summer hemisphere (the zonally averaged atmospheric temperature is higher during those seasons). The convective zones move steadily from their austral summer position of 5°-10°S to their boreal summer position of 10°-15°N, but the return to the austral winter position is often interrupted by a pause in convective activity, during November-December, until convection appears again south of the equator. Such asymmetry of the annual migration of the convective zones has been reported in other studies.

Figure 4 is the 8-year monthly averages of T_b(12) for January and July. One feature that stands out immediately is the maxima in T_b(12), which are about 10 K warmer than the global average of 245 K (Fig. 2). Most of these maxima are best developed in the winter subtropics and associated with strong zonal gradient. The observed temperature variation can neither produce T_b(12) variation of this magnitude nor of such spatial and temporal distribution. Therefore these maxima must indicate areas of dry upper and middle troposphere.

These maxima manifest a unique advantage of this data set in identifying dry regions. Previously, the location and intensity of convection have been inferred from spaceborne estimates of OLR and cloud. Location of dry atmosphere and, in particular, the degree of dryness have been difficult to quantify, for observations of the OLR and cloud cannot tell whether one cloud-free area is drier than another cloud-free area. Additionally, the OLR data in clear areas may reflect surface temperature variations, which could be misleading if interpreted as "less convective" or "drier". These drawbacks are eliminated from the T_b(12) measurements.

The latitudinal locations and seasonal variations of the T_b(12) maxima further suggest that the drier upper and middle troposphere is the result of the descending branch of the Hadley cell. The maxima on the east side of ocean basins in summer may reflect a well-documented longitudinal preference, for example the subsidence within subtropical highs and the regularity of the trade wind.. However, it is unclear whether the drier upper and middle troposphere is produced by local subsidence or by the horizontal advection of dry air.

The minima of T_b(12) in the tropics (Fig. 4) indicate moist regions in middle and upper troposphere caused by convection. These minima are about 5 K cooler than the average of 245 K. The location, strength, and seasonal march of the three minima along the equator broadly confirm known characteristics of the three convection centers in the west Pacific and Indian Ocean, South and Central America, and west Africa.

5. <u>SUMMARY</u>

Measurements of brightness temperatures from the water vapor band channels of the HIRS from 1981 through 1988 are analyzed. Clear (including cloud-cleared) radiances from the operational sounding product are used to produce averages for bins of 2.5° latitude by 2.5° longitude and 5 days. The standard deviations of random errors for these bin averages are about 1 K. A unique feature of this data set is its ability to identify the dry regions in the middle and upper troposphere with unprecedented detail. Results agree with the known climatology in the tropics. More detail should appear in the July (1993) issue of *Journal of Climate*.

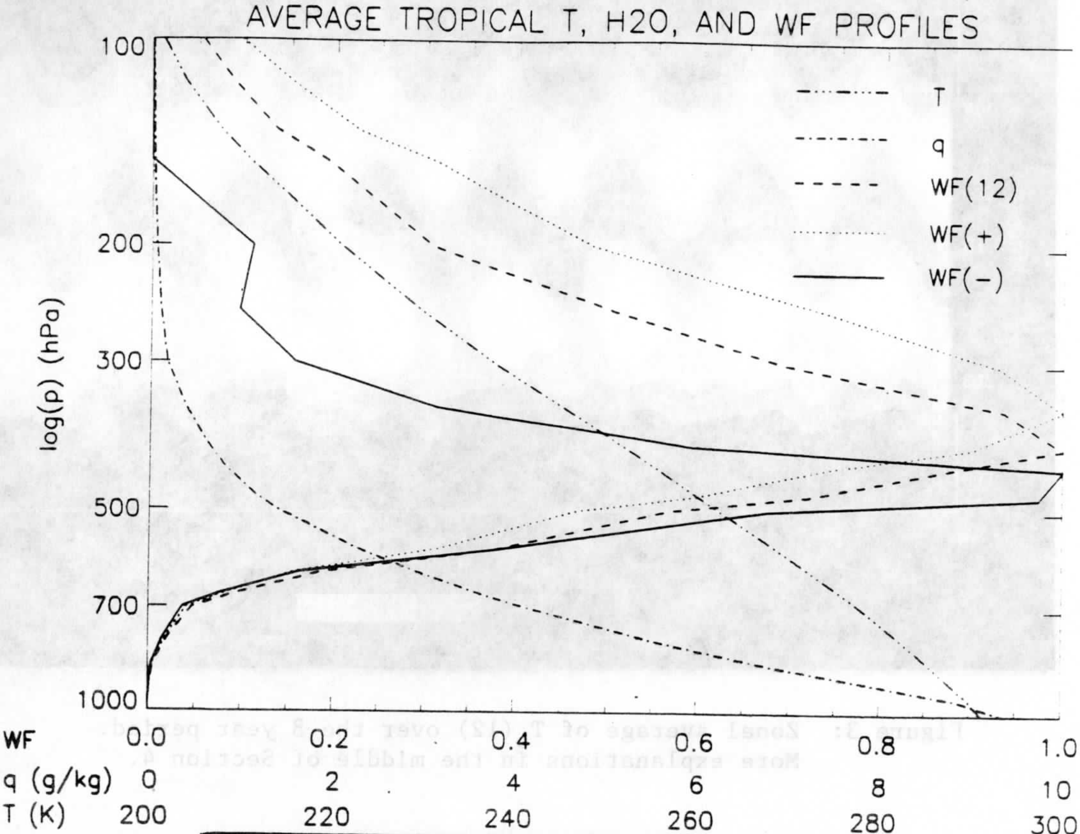


Figure 1 (explained in Section 3)

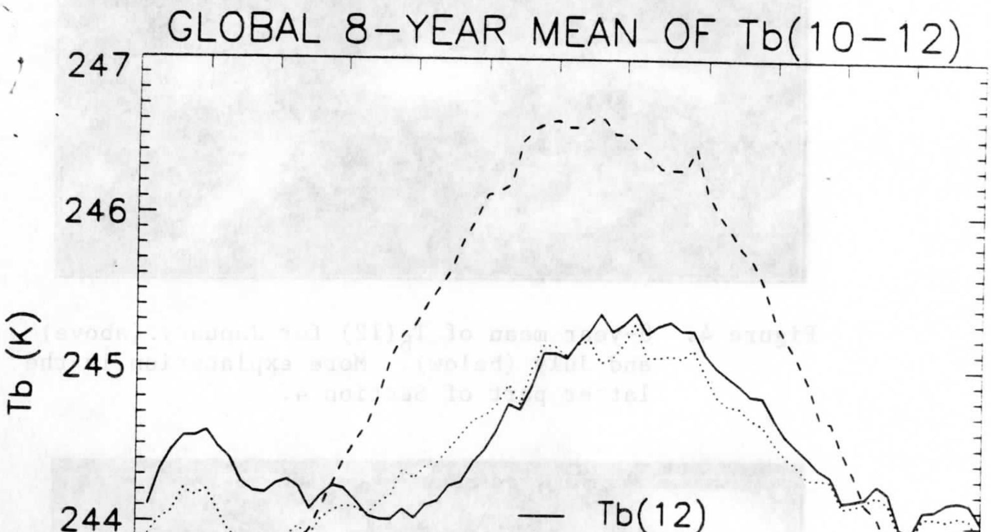


Figure 2 (explained at the beginning of Section 4)

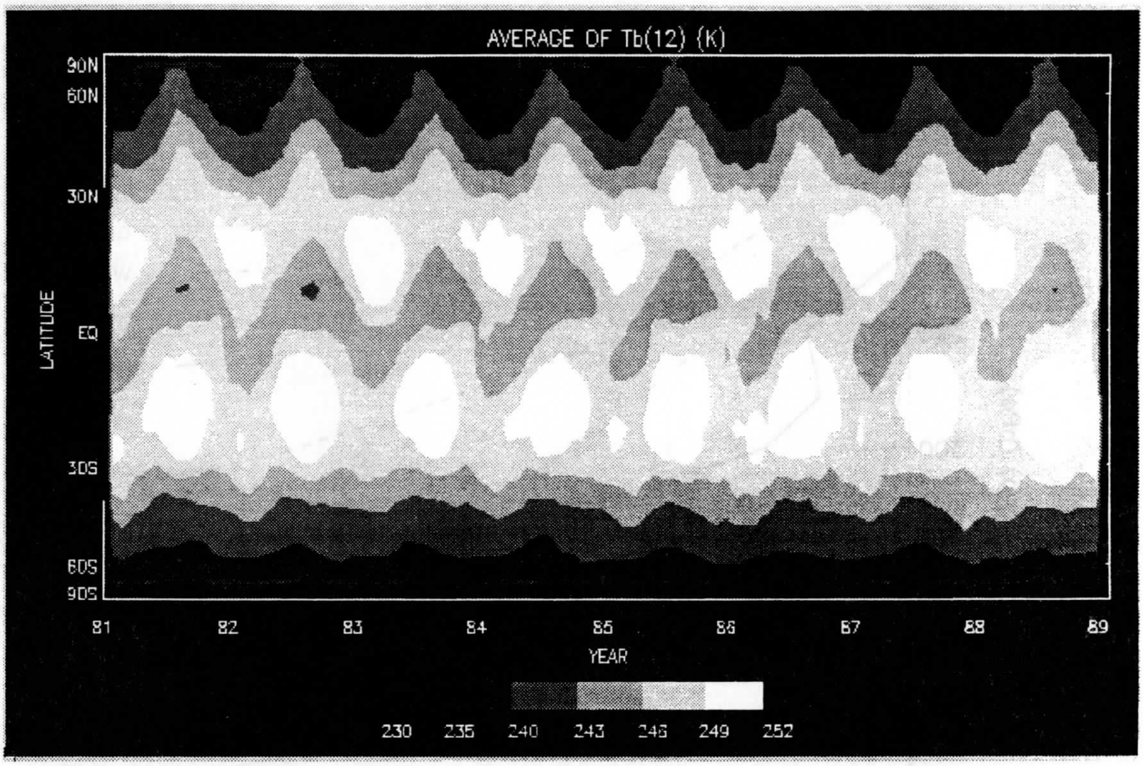


Figure 3: Zonal average of T_b(12) over the 8 year period. More explanations in the middle of Section 4.

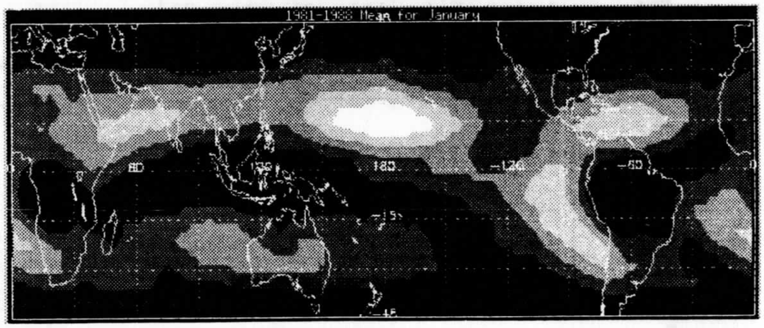
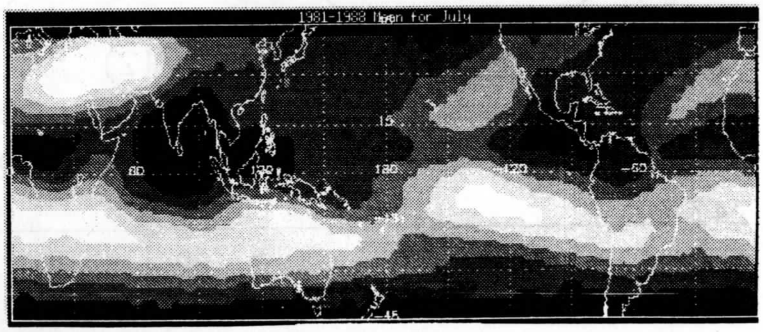


Figure 4: 8-year mean of T_b(12) for January (above) and July (below). More explanation in the latter part of Section 4.



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