TOVS Observations of Water Vapour for Climate Monitoring

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The Earth's atmosphere is unique in that it possesses a full hydrological cycle including phase transitions between all state of water; gas, liquid, and solid. Within the atmosphere, water vapor is the most important greenhouse gas. Phase transitions of water vapor are governed by the Clausius-Clapeyron relationship (Webster, 1994). Observational data (Stephens, 1990; Stephens et al., 1994) show that the total column water vapor content for a given surface temperature follows the shape of the Clausius-Clapeyron vapor-liquid curve.This mechanism is present in all climate models and leads to a strong positive feedback (i.e., enhancing the warming) in climate simulations of anthropogenic greenhouse warming (eg., doubling CO2). Although the total column water vapor amount is largely determined by the water vapor in the boundary layer, the small amount of water vapor in the upper troposphere contributes as much to the radiative greenhouse effect as the total column water vapor. Thus, improving our understanding of the upper tropospheric water vapor balance is crucial to studies of climate and global change. The observations of upper tropospheric water vapor by TOVS (the HIRS12 channel at 6.7 microns) provide the best global data set for such studies.

We have developed a method for the intercalibration of the TOVS upper tropospheric water vapour band brightness temperature data and applied it to the NESDIS clear column radiance data from 1981-1994 (Bates and Wu, 1995; Wu et al., 1993). Particular attention is paid to the intercalibration of the eight different instruments used over this time period. Analysis of the adjusted anomaly time series show the location and strength of both the large-scale ascending and descending circulations in the tropics as well as water vapour anomalies. Comparison of these TOVS data with outgoing longwave radiation and sea surface temperature anomalies reveals that both convection and increased upper tropospheric moisture occur over anomalously warm water in the deep tropics. The development and movement of deep convection and increased upper tropospheric moisture can clearly be traced during El Nino/Southern Oscillation warm events. These TOVS data are also useful for monitoring upper tropospheric water vapour variability between the tropics and subtropics.

Seasonal variability of upper tropospheric water vapor brightness temperatures from the NOAA series satellites (HIRS12), and simulated HIRS12 and 300 mb omega from the GFDL GCM forced with observed SST from 1982-1993 is shown in Figure 1. In the tropics, high HIRS12 is related to low upper tropospheric water vapor amount and descending motion and low HIRS12 is related to high water vapor and ascending motion HIRS 12 is sensitive to both the centers of descent and ascent. Note that NOAA observations and simulations show similar patterns, but the dynamic range of GFDL simulations is much less by roughly a factor of two in the tropics. These results are similar to with comparisons of observed and modeled HIRS12 for a variety of climate models including the NCAR CCM1 (Soden and Bretherton, 1994) and the ECMWF model (Salathe and Chesters, 1995). This work suggest that HIRS12 data can be used as a strong constraint to improve simulation of the hydrological cycle in both general circulation models (GCMs) and numerical weather prediction (NWP) models. McNally and Vesperini (1995) report that the direct assimilation of HIRS water vapor channel data significantly improves the representation of many aspects of the hydrological cycle in the ECMWF model. These humidity adjustments produced by the assimilation of HIRS water vapor information are also shown to force significant changes in the model dynamics; doubling the intensity of the tropical Hadley circulation.

Figure 2 shows monthly mean/time longitude sections of HIRS12, OLR, and SST averaged from 10N-10S. ENSO warm events occurred in 1982-83, 1986-87, and 1991-1992; and cold events occurred during 1984-85 and 1988-89. OLR anomaly patterns are associated with shifts in deep convection from over the western Pacific-eastern Indian Ocean to the central and eastern Pacific Ocean. HIRS12 anomaly patterns are similar to OLR, but they show greater global continuity, suggesting they may be a better indicator of upper tropospheric teleconnections during ENSO than OLR.

This is particularly evident during the 1982-83 warm event where negative HIRS12 anomalies can be traced back to the eastern Indian Ocean during 1981. Both HIRS12 and OLR show the movement of deep convection and high upper tropospheric moisture into the central Pacific and the classic reverse Walker circulation by early 1983. By mid-1983, however, the HIRS12 maximum moist anomaly moves to 90W with a maximum dry anomaly to the east, not the west.

The leading EOF mode of time series variability for each data set shows global ENSO signals in the tropics (Figure 3). The spatial patterns of each, however, is quite different. The SST anomaly pattern shows the classic ENSO warm event pattern dominated by positive center in the central and eastern equatorial Pacific surrounded by a negative crescent-shaped area. The OLR anomaly leading mode is dominated by negative anomalies, indicating anomalous deep convection, in the central equatorial Pacific and positive anomalies over the western equatorial Pacific. Positive anomalies are also found in the southwest Pacific and over northeast Brazil. Thus, the OLR interannual variance is dominated by east-west shifts in deep convection between the western and central equatorial Pacific during ENSO warm events. The leading mode of HIRS12 interannual variance is dominated by a north-south pattern between the moist central and eastern equatorial Pacific and the dry region immediately north. HIRS12 moist anomalies continue east then bifurcate into north and south branches around South America. Anomalous moisture is also found over the Indian Ocean west of Australia.

As described above, most GCMs assume a simple water vapor profile throughout the troposphere based on a Clausius-Clapeyron versus SST equilibrium. During ENSO warm events, the zonally-averaged tropical troposphere warms. This has lead to the suggestion that ENSO warm events may be used as a surrogate to investigate the water vapor feedback mechanism within the present climate system.

The monthly mean HIRS12 tropical time series of observations shows no consistent relationship between ENSO warm events and upper tropospheric moisture (Figure 4). During the 1982-83 warm event, the HIRS12 anomaly is strongly positive indicating the response of the entire tropical troposphere was a net drying. Throughout the time series, the GFDL anomalies are substantially smaller than the HIRS12 observations and there is no significant correlation between them. In the 1986-87 warm event the HIRS12 anomaly hovers near -0.2K revealing that the tropical upper tropospheric moisture increased and continued high during the event. The 1991-92 event is characterized by a sharp negative spike suggesting an infusion of moisture into the upper troposphere during that event.

Sun and Lindzen (1993) suggest that the tropical upper tropospheric water vapor distribution is regulated by precipitation efficiency. If precipitation is more efficient, then the net effect of deep convection in the tropics will be to dry the upper troposphere and less efficient precipitation will lead to a more moist upper troposphere. This hypothesis is one possible explanation for the observed variability of upper tropospheric water vapor using HIRS12 observations. It would imply that precipitation efficiency during the 1982-83 event was quite high, but that precipitation efficiency was quite low during the 1991-92 ENSO.

HIRS12 upper tropospheric water vapor observations reveal there is a local increase in moisture above deep convection and the warmest water in the tropics. However, the global tropical response is complex and may be related to overall precipitation efficiency of the convection. This view is in contrast to current model simulations of the tropical hydrological cycle that require a constant relative humidity be maintained throughout the tropical troposphere.

References.

Bates, J. J., and X. Wu, 1995: Interannual variability of upper tropospheric water vapor brightness temperature. Accepted by J. Climate.

McNally, A. P., and M. Vesperini, 1995: Variational analysis of humidity information from TOVS radiances at ECMWF. Submitted to QJRMS.

Stephens, G. L. , 1990: On the relationship between water vapor over the oceans and sea surface temperature. *J. Climate*, , 634-645.

Stephens, G. L., D. L. Jackson, and J. J. Bates, 1994: A comparison of SSM/I and TOVS column water vapor data over the global oceans. *Meteor. Atmos. Phys.*, , 183-201.

Salathe Jr., E. P., and D. Chesters, 1995: Variability of moisture in the upper troposphere as inferred from TOVS satellite observations and the ECMWF model analysis in 1989. *J. Climate*, , 120-132.

Soden, B. J., and F. P. Bretherton, 1994: Evaluation of water vapor distribution in general circulation models using satellite observations. *J. Geophys. Res.*, , 1187-1210.

Sun, D-Z., and R. S. Lindzen, 1993: Distribution of tropical tropospheric water vapor. *J. Atmos. Sci.*, , 1643-1660.

Webster, P. J., 1994: The role of hydrological processes in ocean-atmosphere interactions. *Rev. Geophys.*, , 427-476.

Wu, X., J. Bates, and S. J. S. Khalsa, 1993: A climatology of water vapor band brightness temperatures from the NOAA operational satellites. *J. Climate*, , 1282-1300.

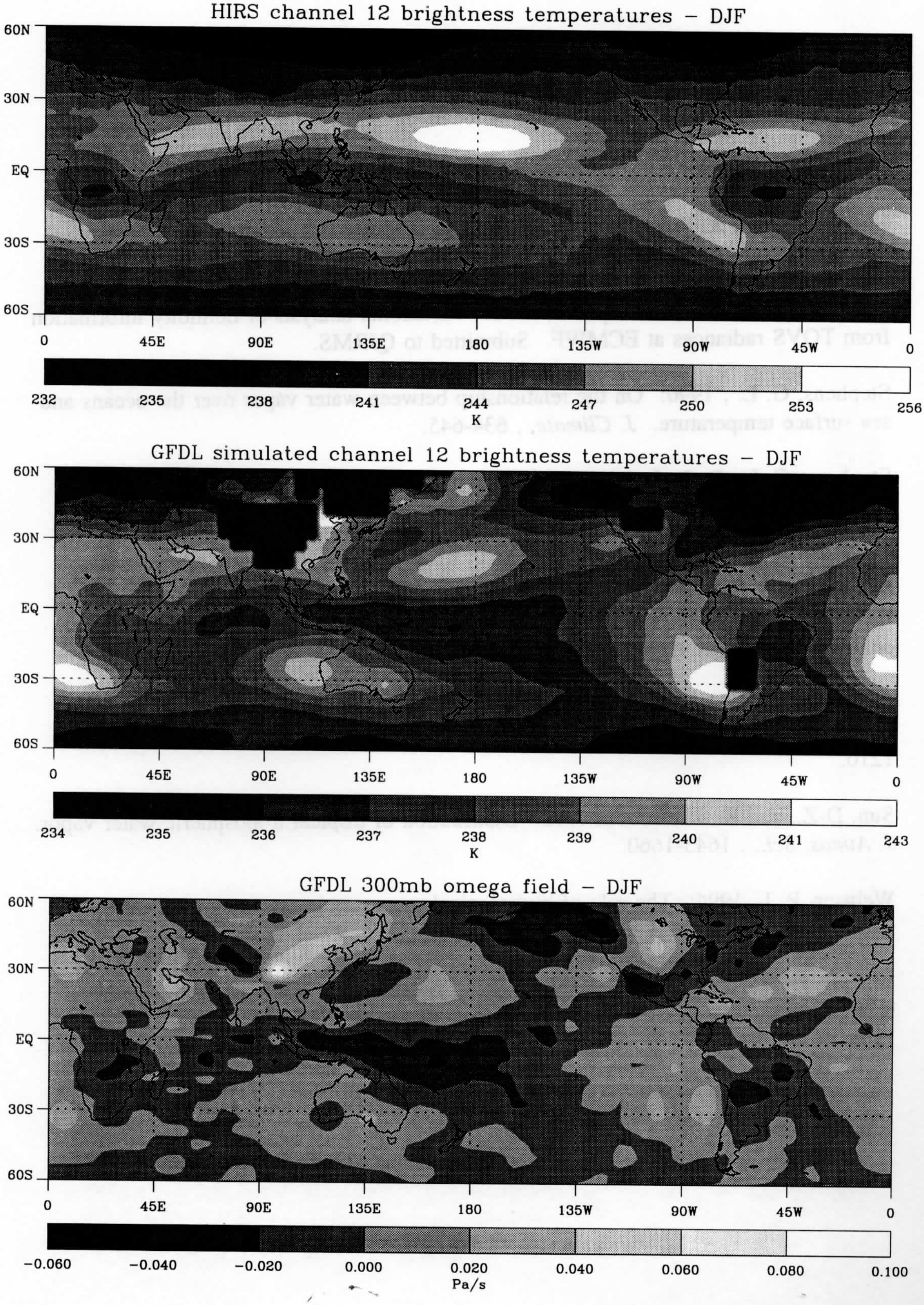

Figure 1a. Seasonal (dec-jan-feb) mean of HIRS12 1982-1993.

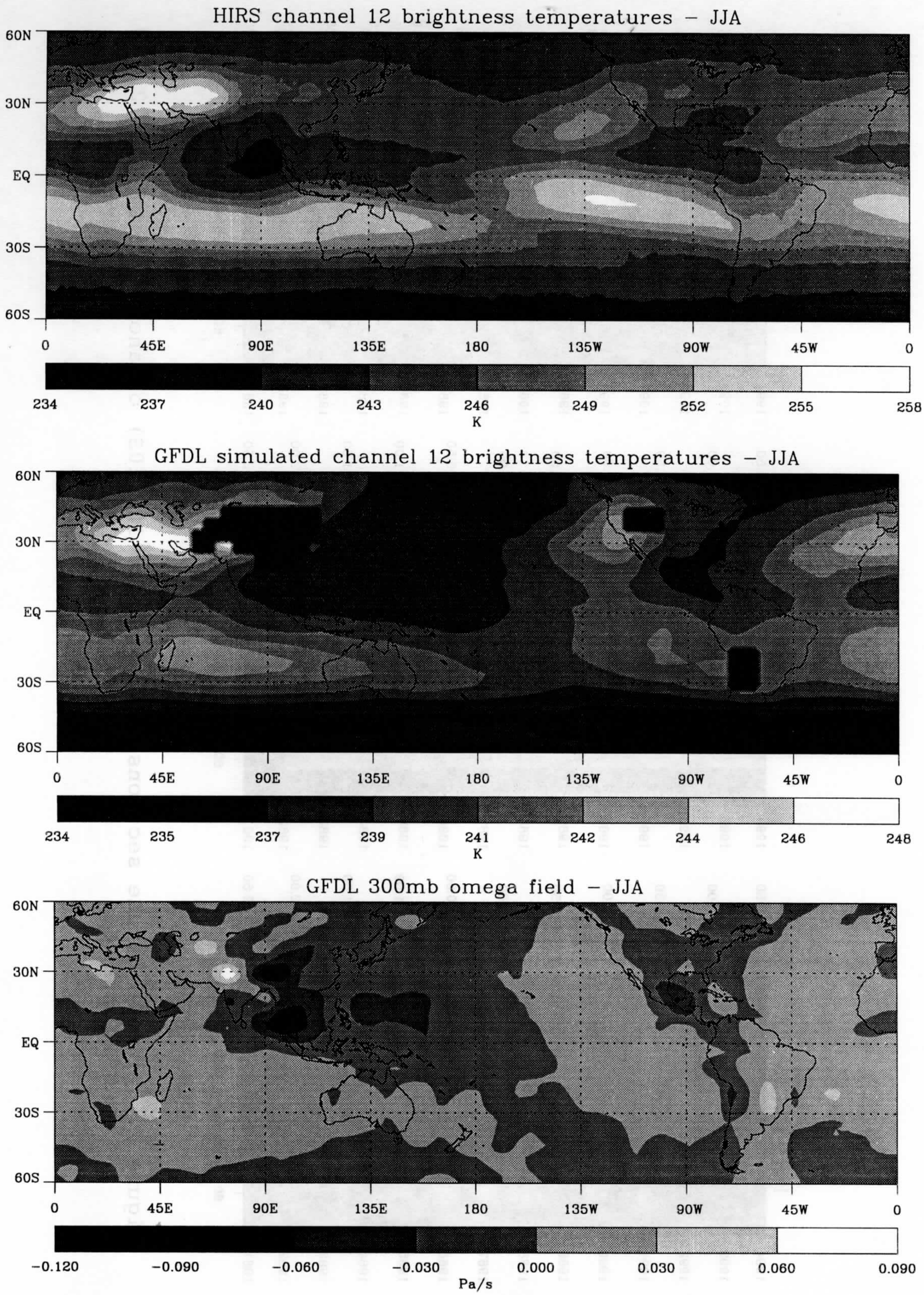

Figure 1b. Seasonal (jun-jul-aug) mean of HIRS12 1982-1993.

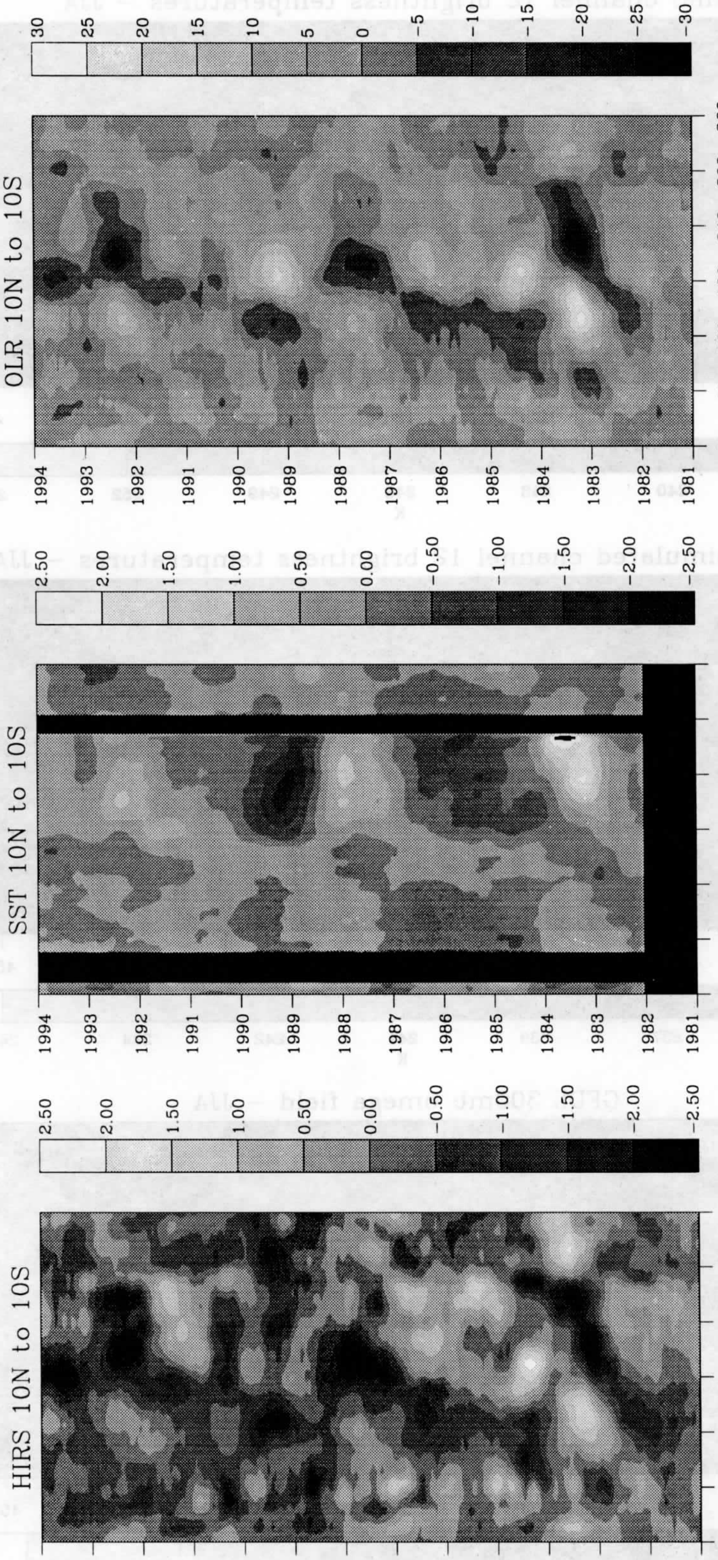

Figure 2. Time-longitude sections (ageraged for 10N-10S) of anomalies of HIRS12, SST, and OLR.

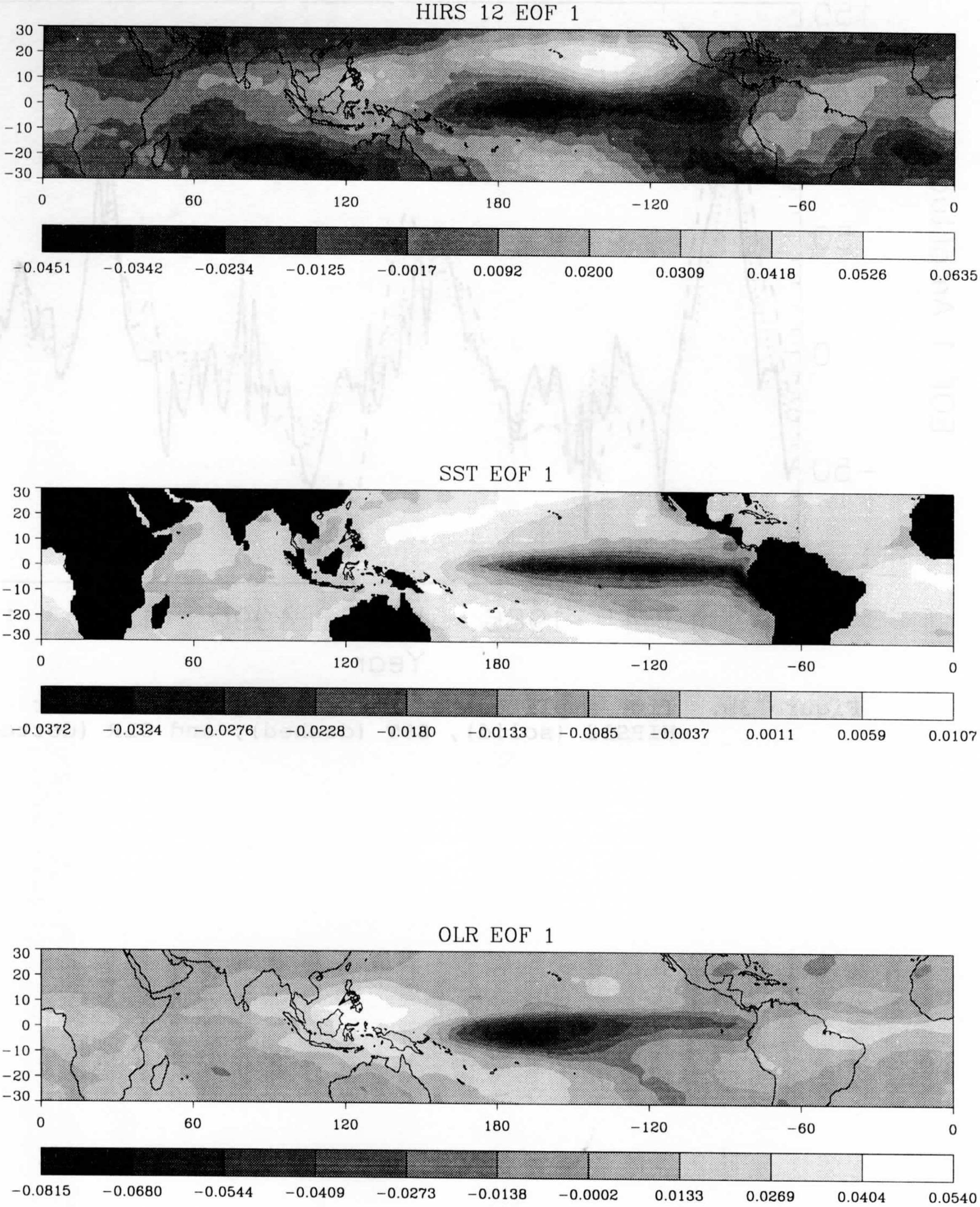

Figure 3d. Leading empirical orthogonal function (EOF) for anomalies of HIRS12, SST, and OLR from 1982-1993.

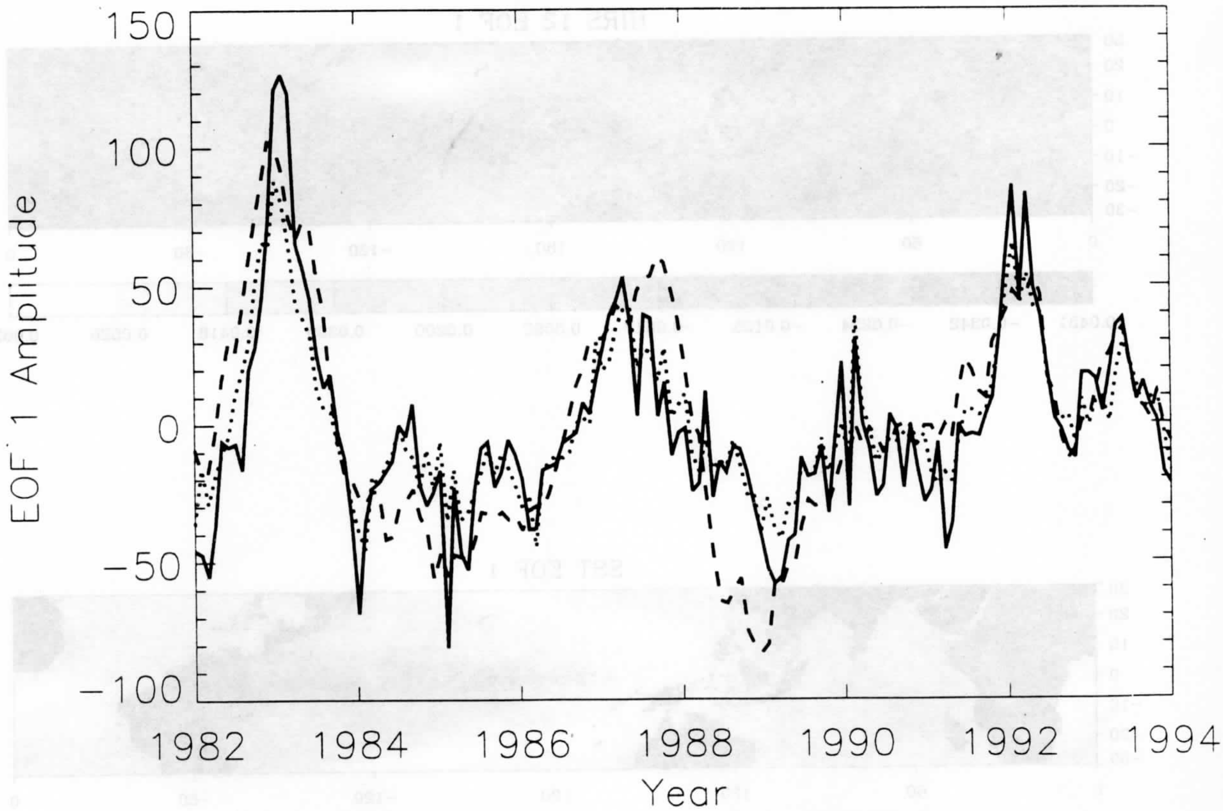

Figure 3b. Time amplitude of the leading EOF mode for HIRS12 (solid), SST (dashed), and OLR (dotted).

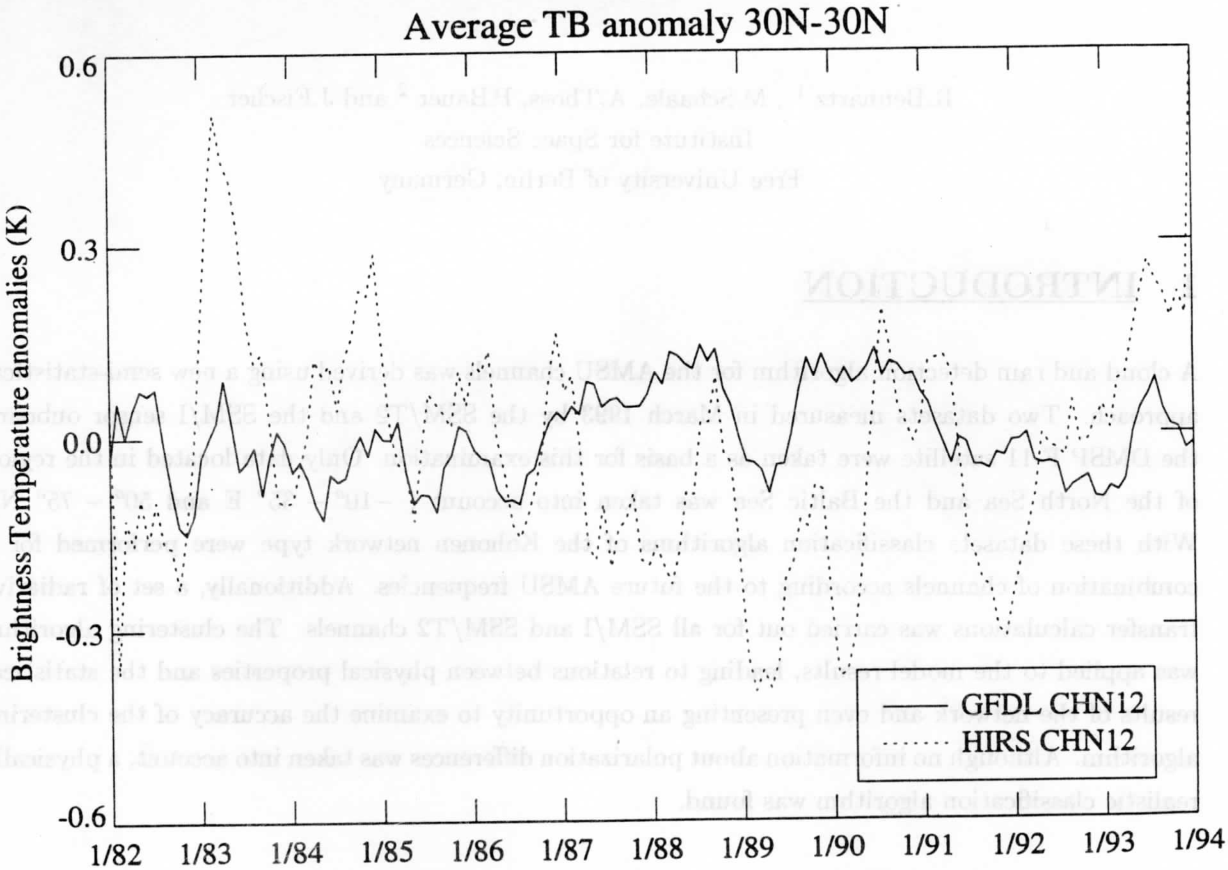

Figure 4. Observed (HIRS12) and Modeled (GFDL) average tropical anomalies of upper tropospheric moisture.

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