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WATER VAPOR TRENDS AND VARIABILITY FROM THE GLOBAL NVAP DATASET

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1. INTRODUCTION

Water vapor is Earth's most important variable greenhouse gas. The amount of water vapor the atmosphere may hold is closely coupled with temperature via the Clausius-Clapeyron equation. General circulation models predict an increase in the amount of Total Precipitable Water (TPW) in the atmosphere as Earth warms. Trend studies of TPW from radiosondes (Ross and Elliott, 2001) and the Special Sensor Microwave / Imager (SSM/I) (Wentz and Schabel, 2000) show upwards trends on regional to global scales. Can we detect any trends in other TPW datasets?

The NASA Water Vapor Project (NVAP) dataset is a widely-used, global, daily, 1-degree resolution blended product suitable for studies of water vapor in the climate system (Randel et al, 1996; Simpson et al, 2001). NVAP contains layered water vapor fields as well as TPW fields. In this paper, the years 1988 – 1999 are studied to examine any trends in NVAP TPW and their significance.

2. NVAP DATASET

While the NVAP dataset contains fields of cloud liquid water and vertical distribution of water vapor, the TPW field is the most reliable. This is due to the nature of the satellite retrievals used in creating NVAP. An example of the TPW field for July 1, 1998 is shown in Figure 1. NVAP is a climate dataset, but since it is based on daily data it captures weather as well, such as the Indian Monsoon apparent in Fig. 1.

NVAP was constructed by blending observations from radiosondes, satellite sounder instruments (NOAA TIROS Operational Vertical Sounder (TOVS)), and passive microwave radiometers (Special Sensor Microwave / Imager (SSM/I)). Retrievals are performed on each dataset, and the results are then blended together to create a global merged field. NVAP currently covers the time period 1988 – 2001. In this study, the years 2000 and 2001 are not used because they have just been recently released and a new methodology was used to create those years.

A key aspect of NVAP (or any satellite-based dataset) when used to study decadal or longer timescales is the changes through time of instrumentation and algorithms. For instance, the number of SSM/I instruments used in NVAP has ranged from one (1988 – 1992) to three. This provides varying amounts of global coverage. The number of TOVS soundings supplied by NOAA (NOAA Operational TOVS) has increased through time due to growth in computer power from 1988 – 1999. Any trends due to these artificial sources must always be ruled out when searching for a climate signal. In fact, the first look at a climate dataset for trends inevitably reveals time-dependent biases of the dataset. These biases can then be corrected and through a reanalysis process the focus of the dataset on real trends will sharpen. NVAP for 1988 – 1999 was not assembled in one large processing effort, but rather was built in a series of steps. There were some slight algorithm and methodology changes through time (Simpson et al, 2001). This should be kept in mind when interpreting the results presented here. Nevertheless, NVAP has fared well in comparison with other water vapor data sources. In the future, it is likely that the entire NVAP dataset will undergo a needed reanalysis to make it an even more powerful tool for long-term climate change detection.

The NVAP data and additional documentation is available at the NASA Langley DAAC at this URL: http://eosweb.larc.nasa.gov/PRODOCS/nvap/table_nvap.html.

3. METHODOLOGY

This study seeks to answer the question: "Are there any significant global or regional trends in the NVAP record of total precipitable water?" In order to approach

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this problem, the daily fields of NVAP for 1988 – 1999 were gathered and processed.

First, the 12 monthly mean fields are created from the twelve years of data. This allows the annual cycle (Figure 2) to be removed. Earth's mean water vapor during this time period is 24.5 mm. Table 1 shows the hemispheric and global NVAP TPW mean values.

Year	N. Hem.	S. Hem.	Global
1988	26.24	23.76	25.00
1989	25.64	23.37	24.50
1990	25.83	23.21	24.52
1991	25.82	23.18	24.50
1992	24.87	23.27	24.07
1993	25.37	22.95	24.16
1994	25.72	22.86	24.29
1995	25.61	23.02	24.32
1996	25.39	22.74	24.06
1997	25.79	22.93	24.36
1998	25.95	23.85	24.90
1999	25.45	22.78	24.12

Table 1. Mean global and hemispheric TPW (mm) from NVAP.

The annual cycle is on the order of 3 mm, or about 10 % of the total field. The monthly means are removed from the results to compute a TPW anomaly time series. The anomaly time series can either be global (weighted by the cosine of latitude), or at each NVAP grid box. Both types of time series are analyzed here.

A regression of the anomaly through time is then performed. The slope of the regression line is plotted. The lag-1 correlation is computed to reduce the degrees of freedom of the dataset, and the t-statistic and 95% and 99% confidence thresholds are calculated. The data is subdivided through time to test the robustness of the relationships.

4. RESULTS

Figure 3 shows the result for the trend of the global 12 year anomaly through time. By examining the 12 year record, a decrease of TPW at a rate of -0.29 mm / decade is observed. This relationship is significant at the 95 % but not at the 99 % level. A downward trend would be intriguing since there should be a positive slope if a global warming signal was present. However, by subdividing the data into two halves (1988-1993) and 1994-1999, trends with opposite signs are detected. Since the trend is not robust by subdividing the data, we conclude the global TPW has no significant trend from the NVAP dataset studied here.

A major purpose of this study was to examine the spatial distribution of trends from the NVAP data. A map of these is shown in Figure 4. This is the slope of the linear regression line for the 144 months at each grid box, with the annual cycle removed. There are some very interesting large-scale and small-scale features in Fig. 4. Regions of decreasing TPW are shaded in blue, while upward trends are shaded in red. The most striking feature is the upward trend in the Equatorial Pacific, very suggestive of El Nino influences, and the drying in the subtropical regions. The Southern Hemisphere midlatitude oceans in particular exhibit a drying trend. It is encouraging that the trends in general exhibit coherent spatial structure, indicating that they reflect large-scale atmospheric (or instrumental and algorithmic) behavior. There is a curious drying structure along the east coast of the U.S., approximately where the Gulf Stream is located. Has there been a change in the local climate in that region, or is there some effect such as more cloud liquid water which has manifested itself in the microwave retrievals?

Of as much interest as large-scale changes in water vapor amounts in Fig. 4 are the features which indicate artifacts of how NVAP was constructed. The trends in NVAP which Fig. 4 reveals can be used to guide construction of future datasets and in a reanalysis effort. NVAP was constructed by blending radiosondes (point measurements) with satellite retrievals. The position of some of the radiosonde stations is visible in Fig. 4, for instance over Australia and the West Pacific, over the Aleutian Islands, and over parts of southwest Asia. In some cases, the radiosondes indicate opposite trends from the adjacent (satellite-derived) fields. This is an interesting result and asks the question of whether point and satellite measurements can be successfully blended to detect long-term trends. Another artifact of NVAP processing is revealed by the decreasing trends around the coasts of Norway and Greenland. The sea ice mask analysis was changed in 1993 to be more restrictive, and the effect of that change is apparent here.

Where are the trends in Fig. 4 most statistically significant? To address that question, the t-test was applied to plot regions where the anomaly correlation through time was significant at the 99% level. In addition, the data was subdivided into 1988 – 1996 and 1988 – 1999. An exceptionally strong El Nino occurred during 1997 – 1998 and is the single most dominant natural event during the NVAP time period. How much of the trend was associated with El Nino? Figure 5 shows results where only significant regions are plotted for these two time periods. The major regions of agreement and disagreement are also shown. By removing 1997-1999, some large changes occur in the tropical Pacific, as would be expected, but many of the other regional trends show a similar spatial structure.

5. CONCLUSIONS

The global time series of NVAP TPW anomalies does not show a consistent trend from 1988 – 1999. The first half of the period is marked by a downward trend, while the second half is marked by an increase. The overall trend during this period is –0.29 mm / decade.

There are some significant regional trends in the twelve year TPW record examined here. The detection of discontinuities due to data blending methods (e.g. radiosonde with satellite) and ice edge masks is a valuable discovery. These effects can be mitigated in future production years of NVAP and in a future reanalysis.

The extent of drying at a global scale was surprising. A large area of the Southern Hemisphere shows a coherent drying trend. Is this a real climate signal, or something else, perhaps a drift in satellite calibration? Work in progress indicates that the NOAA TOVS retrievals may be responsible for much of this trend. Further study is needed on this point. What is that area of decreasing TPW over in the Western North Atlantic? Do other climate fields (e.g. clouds, tropospheric temperature) show anomalies in that region?

A journal paper on the variability seen in NVAP and including these results is in preparation for submission to the Journal of Climate.

6. REFERENCES

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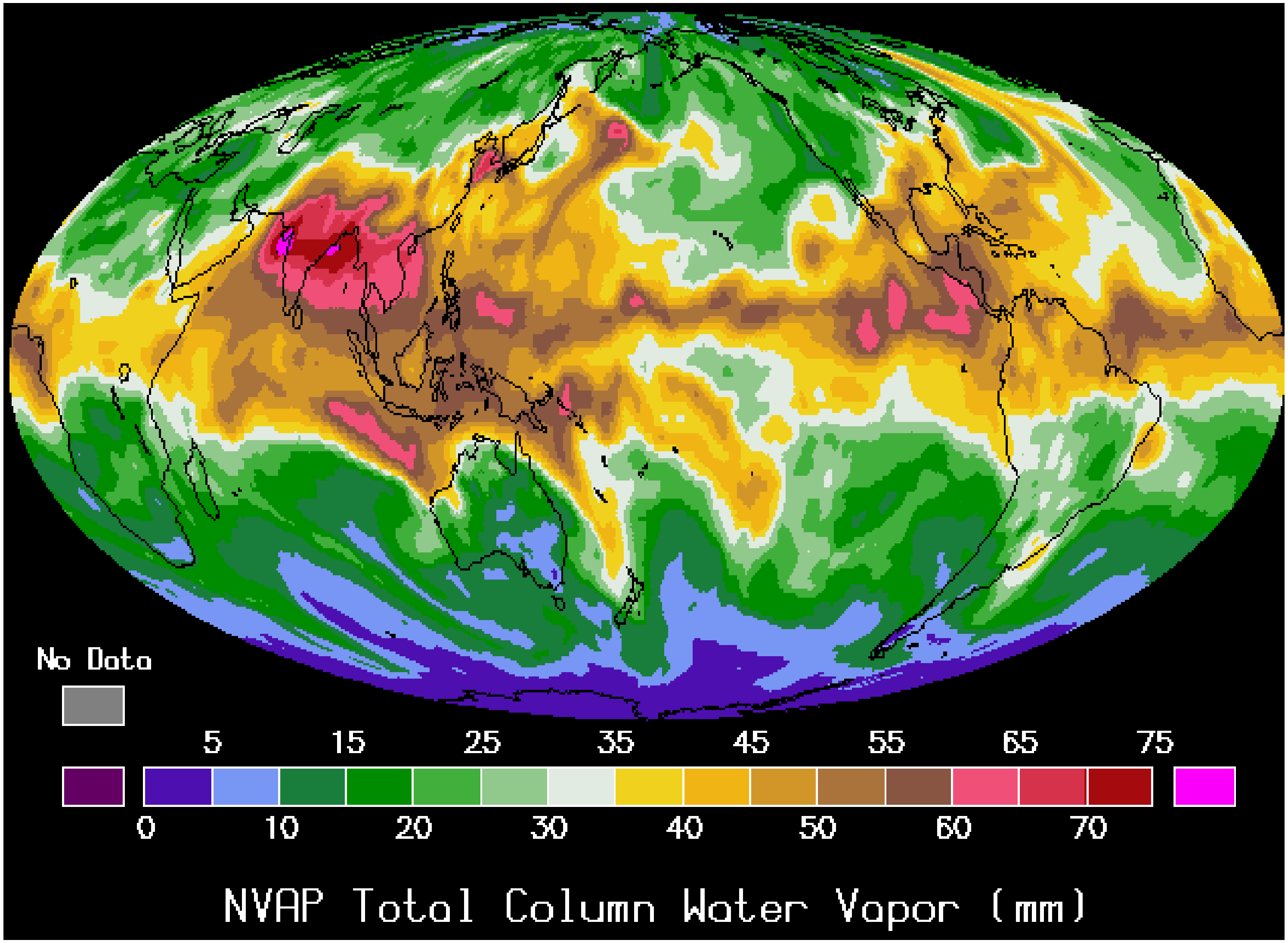


Figure 1: Example of NVAP Total Precipitable Water (mm): July 1, 1998

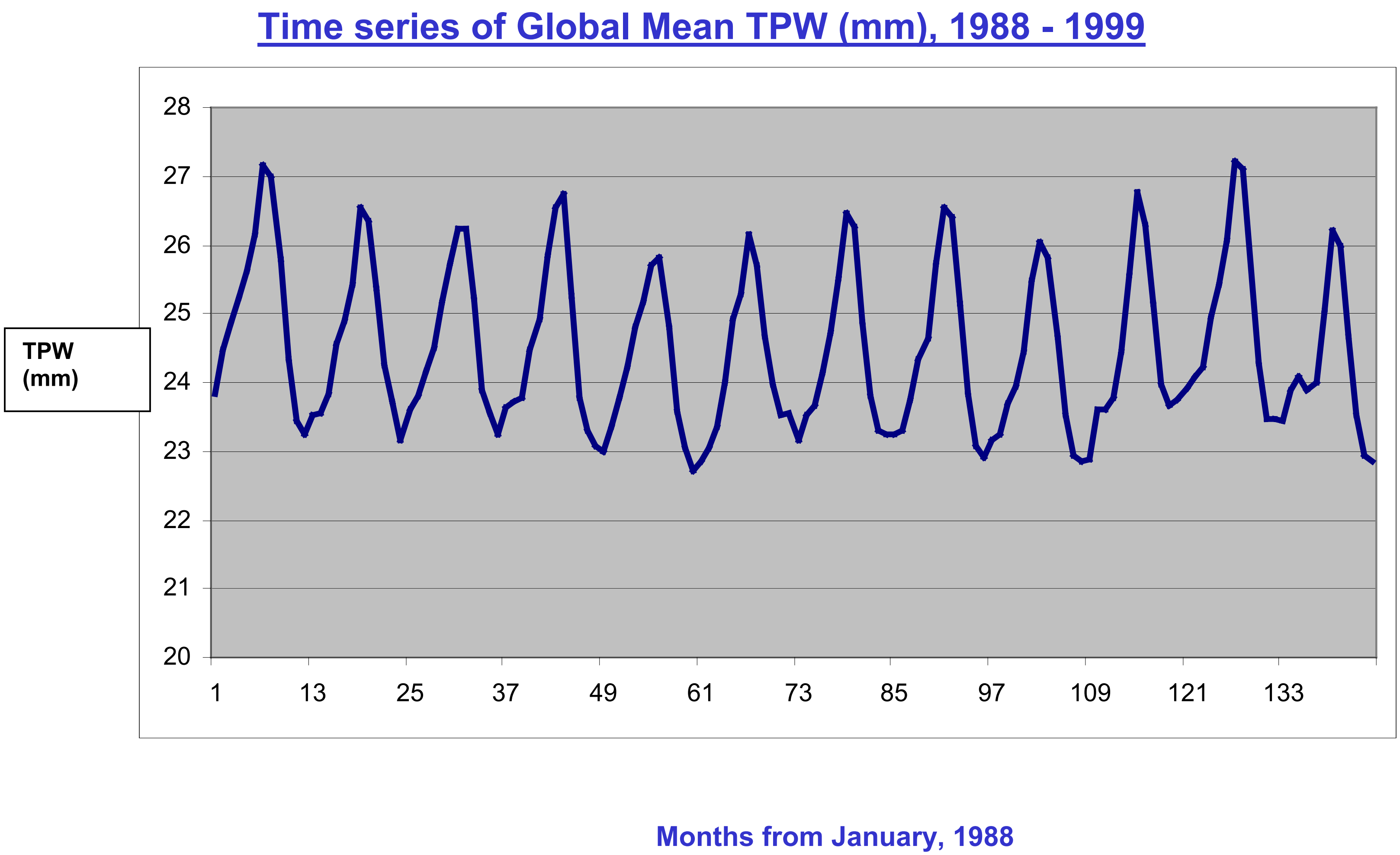
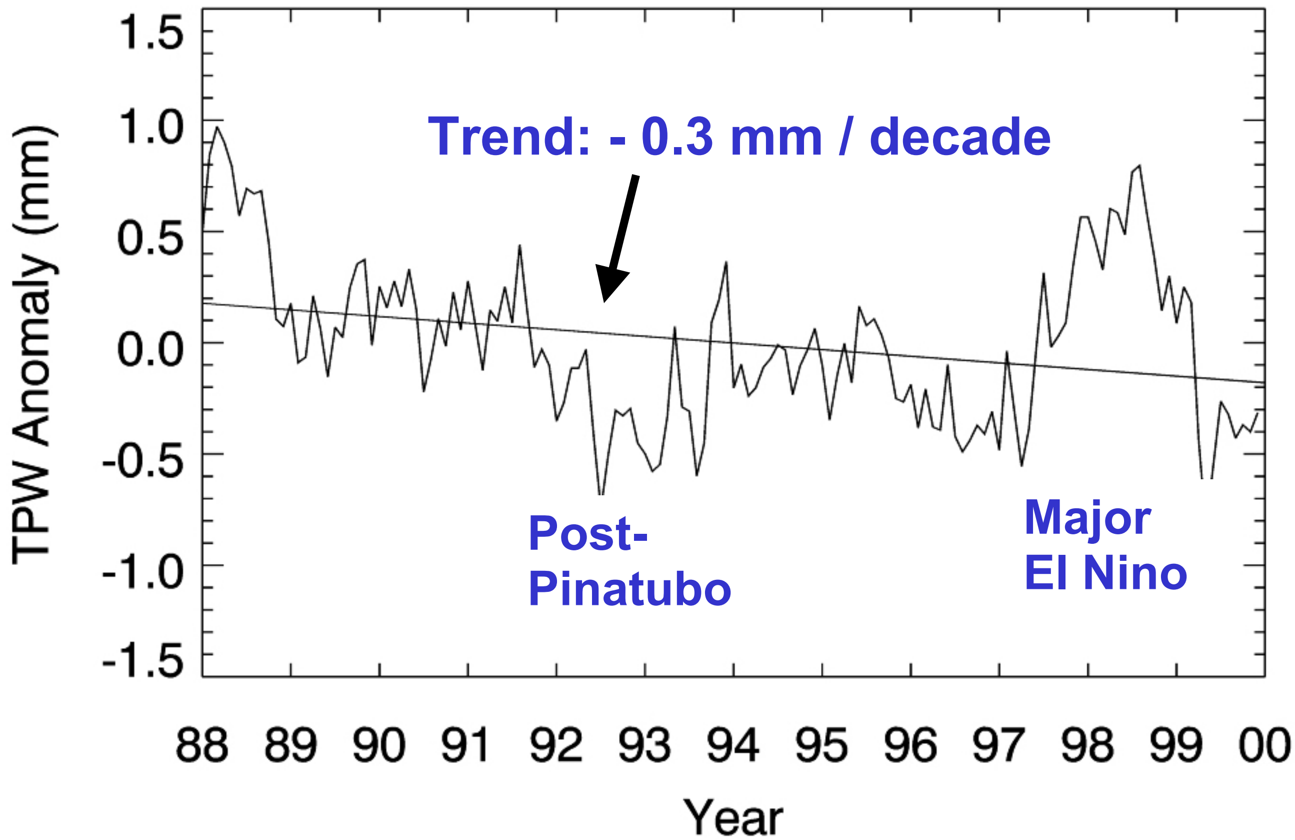


Figure 2: Annual cycle of TPW 1988 – 1999. This cycle was removed to create the anomaly time series.



1988 - 1993: Trend is -1.54 mm / decade
1994 - 1999: Trend is +0.33 mm / decade

Figure 3: Trend of the global TPW anomaly 1988 – 1999. The entire time series has a trend of -0.29 mm / decade, but 1988-1993 has a downward trend while 1994-1999 has an upward trend. The downward trend is significant at the 95 % but not at the 99% level.

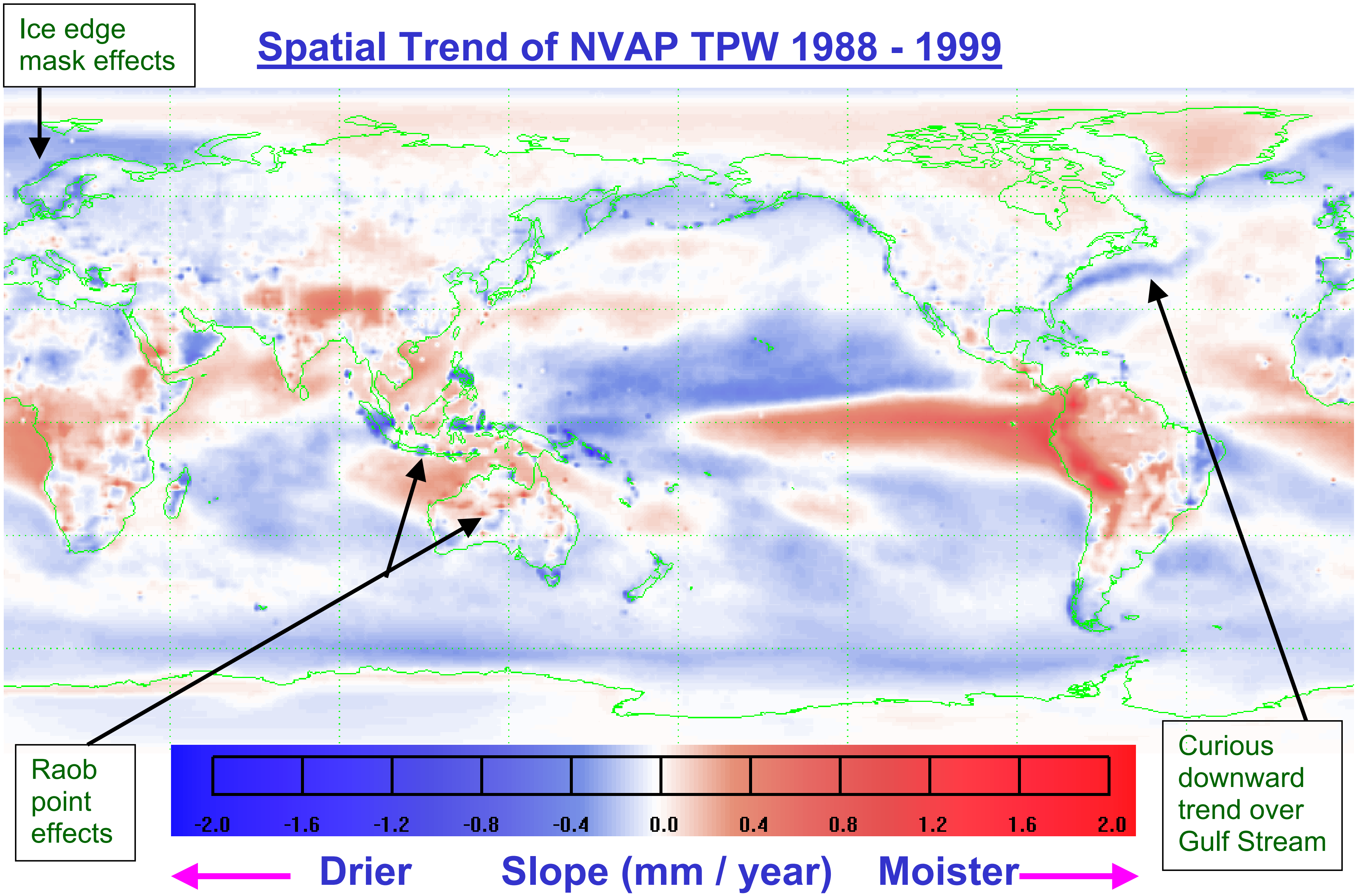


Figure 4: Slope of the TPW anomaly regression line for 1988 – 1999.

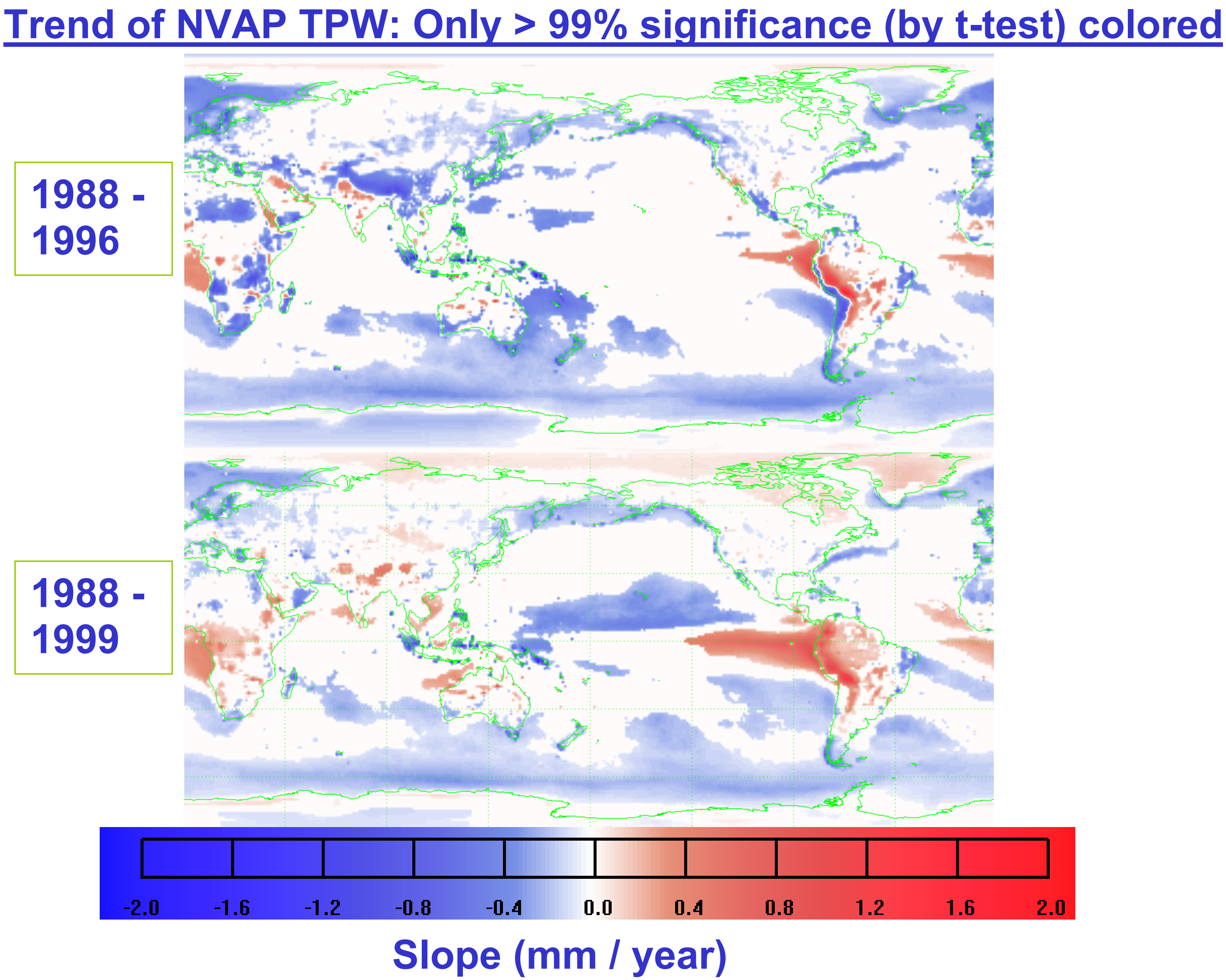


Figure 5: Significant trends in TPW for two time periods.