Continuation of the NVAP Global Water Vapor Data Sets for Pathfinder Science Analysis

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Continuation of the NVAP Global Water Vapor Data Sets for Pathfinder Science Analysis

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1. INTRODUCTION

This annual report covers August 2000 – August 2001 under NASA contract NASW-0032, entitled "Continuation of the NVAP Global Water Vapor Data Sets for Pathfinder Science Analysis". NASA has created a list of Earth Science Research Questions which are outlined by Asrar, *et al.* (2001). Particularly relevant to NVAP are the following questions:

(a) How are global precipitation, evaporation, and the cycling of waterchanging?

(b) What trends in atmospheric constituents and solar radiation are driving global climate?

(c) How well can long-term climatic trends be assessed or predicted?

Water vapor is a key greenhouse gas, and an understanding of its behavior is essential in global climate studies. Therefore, NVAP plays a key role in addressing the above climate questions by creating a long-term global water vapor dataset and by updating the dataset with recent advances in satellite instrumentation. The NVAP dataset produced from 1988–1998 has found wide use in the scientific community. Studies of interannual variability are particularly important. A recent paper by Simpson, *et al.* (2001) that examined the NVAP dataset in detail has shown that its relative accuracy is sufficient for the variability studies that contribute toward meeting NASA's goals. In the past year, we have made steady progress towards continuing production of this high-quality dataset as well as performing our own investigations of the data. Figure 1 shows a typical NVAP product of interest, i.e., the mean total column water vapor from 1988–1998.

This report summarizes the past year's work on production of the NVAP dataset and presents results of analyses we have performed in the past year. The term "NVAP" will be used to describe data produced before 1998, while "NVAP-NG" will be used to describe the next-generation dataset produced

from 1999 forward. NVAP and NVAP-NG both make a major contribution towards our understanding of the global energy and water cycles.

(mm)
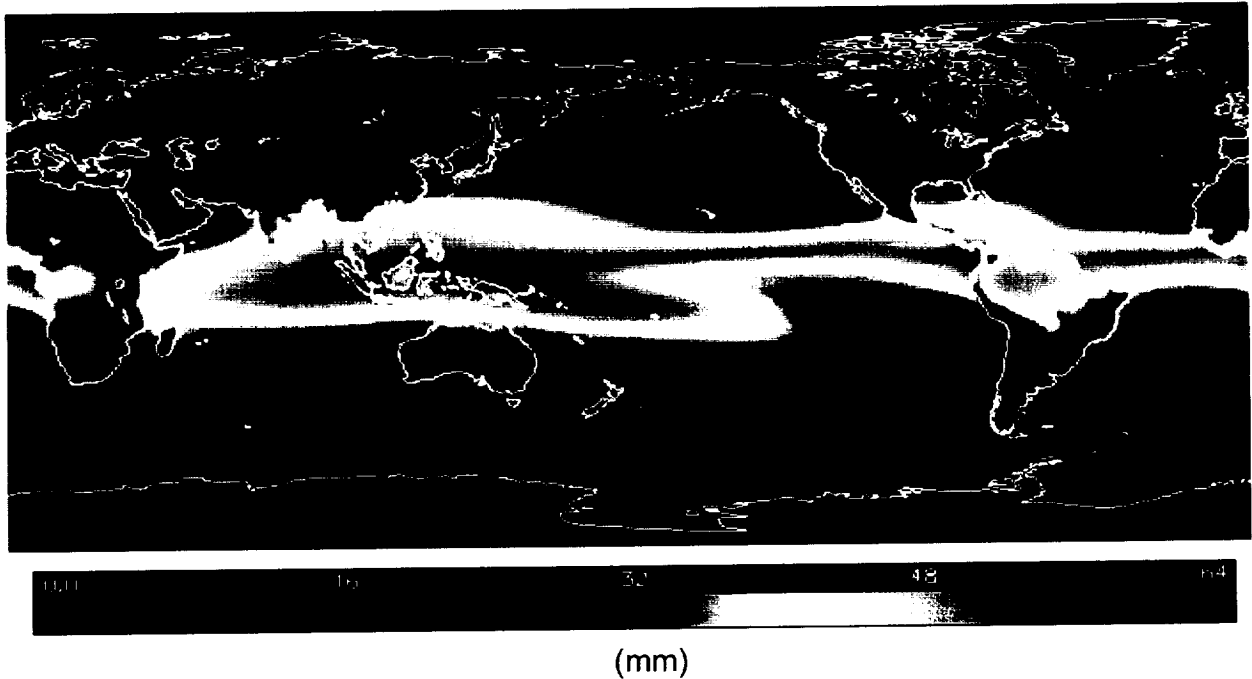
Figure 1. NVAP mean precipitable water vapor from 1988–1998.

Table 1 shows the project schedule for NVAP-NG. Progress is being made on all of the milestones.

Table 1. Project Schedule for the NVAP-NG Project, Starting January 1, 2000						
Milestones	6/00	1/01	6/01	1/02	6/02	1/03
Create 1999 NVAP data set	X	X				
Create 8 level specific humidity from NVAP data set	X	X				
Gather algorithms for next generation satellite data sets	X	X				
Identify interannual variability in the water vapor transports		X				
Apply published algorithms to NVAP-NG			X	X		
Process all satellite data sources			X	X		
Develop new scientific blending scheme			X	X		
Process last 6 months of 1999 with the new NVAP-NG blending scheme			X	X		
Process Year 2000 with new NVAP-NG			X	X	X	
Intercomparison of 1999 NVAP-NG with 1999 NVAP						
Process 2001 – first 6 months					X	X
Final Report / Documentation						X

2. PROGRESS: AUGUST 2000 – AUGUST 2001

During the past year, our tasks have involved data collection, product generation, algorithm development and implementation, and analysis of results. Our goal has been to create the Next-Generation of NVAP for 1999 onwards with the latest and most appropriate satellite sensors. In particular, the Advanced Microwave Sounding Unit (AMSU) on NOAA-15 and NOAA-16 will be a key sensor for water vapor profiles. AMSU was not available in previous production years of NVAP. In order to assess the impact of new sensors, we will create the 1999 NVAP dataset with the new sensors as well as by using the same techniques as in previous NVAP years. This "bridge" year will allow us to compare any differences.

Table 2 lists the candidate sensors we have been considering as a part in the Next-Generation NVAP dataset. Much of our work consists of obtaining the data and learning to work with it, then applying proven retrieval algorithms to the data. Developing a scheme to blend these data sources is an additional area of study. The AIRS and AMSR instruments on EOS-Aqua have not yet been launched,

nor has the SSM/IS instrument, but by planning for them now we create a pathway for their inclusion in future years of the NVAP dataset. Our philosophy is to use the best available instruments, retrievals and algorithms to create a high-quality water vapor dataset for climate studies.

Table 2. Candidate Satellite Sensors for NVAP-NG

	Frequencies	Products	Spatial resolution	Satellite platform
AMSR	6.925, 10.65, 18.7, 23.8, 36.5, and 89.0	Total precipitable water over ocean	23 km	EOS Aqua
AMSU-B	17, 89, 150, 183±1, 3, 5	Water vapor profile	16 km	NOAA KLM
SSM/I	9.35, 22.235, 37.0, and 85.5	Total precipitable water over ocean	15 – 50 km	DSMP
SSM/T-2	91.655, 150, 183±1, 3, 7	Water vapor profiles	48 km	DSMP
SSM/IS	Many microwave channels	Water vapor profiles		DSMP
HIRS/3	20 infrared channels	Water vapor profiles	20 km	NOAA KLM
AIRS	High-resolution infrared	Water vapor profiles	15 km	EOS Aqua

(a) Data Collection

We have been working on a wide array of datasets that are briefly listed below. Further details are found in the previous quarterly reports.

- TOVS Pathfinder Path A and Path B data from 1988–1999 through Brian Soden at NOAA GFDL. Processing software complete.

- SSM/I and SSM/T-2 data through 1999. Processing software complete.

- NCEP reanalysis winds from NCAR for 1988–1999. Ingest software complete. NCEP-II reanalysis winds, surface pressure, and sigma levels from NOAA/NESDIS for July, 1989 for a collaborative study.

- TOVS sounding product for January 1998 – December 1999 from Dr. Brian Soden.

- 1999 global radiosonde data.

(b) Algorithm Development

A significant accomplishment during the past year was the development of code to convert the NVAP precipitable water vapor layers into specific humidity at an arbitrary number of pressure or sigma levels. This was done to support the water vapor transport study component of NVAP-NG. The mathematical details were outlined as an appendix to our June 2001 progress report. Code to compute water vapor flux by blending the vertical profiles with wind vector data has also been developed and implemented.

We are exploring an optimal estimation-based water vapor profile retrieval from AMSU and SSM/T-2 data. The framework of this algorithm has been described in Engelen and Stephens (1999). Tests are underway on simulated data and we plan to have results from AMSU within a few months. The approach is described in McKague *et al.* (2001).

(c) Product Generation

An exciting product we have developed during the past year has been an 11-year dataset of precipitable water vapor from TOVS in the upper tropospheric 200–300 mb layer. Upper tropospheric moisture is particularly important because of its strong radiative impact and the difficulties encountered in measuring it. The upper tropospheric moisture content product was generated using the optimal estimation retrieval of Engelen and Stephens (1999). An example of the product is shown in Figure 2 for December 1995. In order to determine the amount of information being provided by the retrieval, we compared its results with the first guess. Figure 3 shows the percentage difference of the retrieved value from the initial guess for July, 1997. The retrieval differs significantly from the initial guess in the tropics and mid-latitudes but provides little additional information in the polar regions. This is due to the very low water vapor signal associated with the dry upper atmosphere in polar regions.

Animations of the NVAP upper troposphere moisture product for 1988–1997 produced by this research effort are available for viewing at *http://www.stcnet.com/projects/nvap.html*. We anticipate placing this data in the NASA DAAC after we perform a more extensive examination of its features.

We have created the standard NVAP products through April 1999. Recently, we received the TOVS sounding product for the remainder of 1999, so the balance of 1999 will be completed by this September. The year 1999 is important because it is the "bridge" year between NVAP and NVAP-NG.

0.0mm   1.0mm   2.0mm   3.0mm
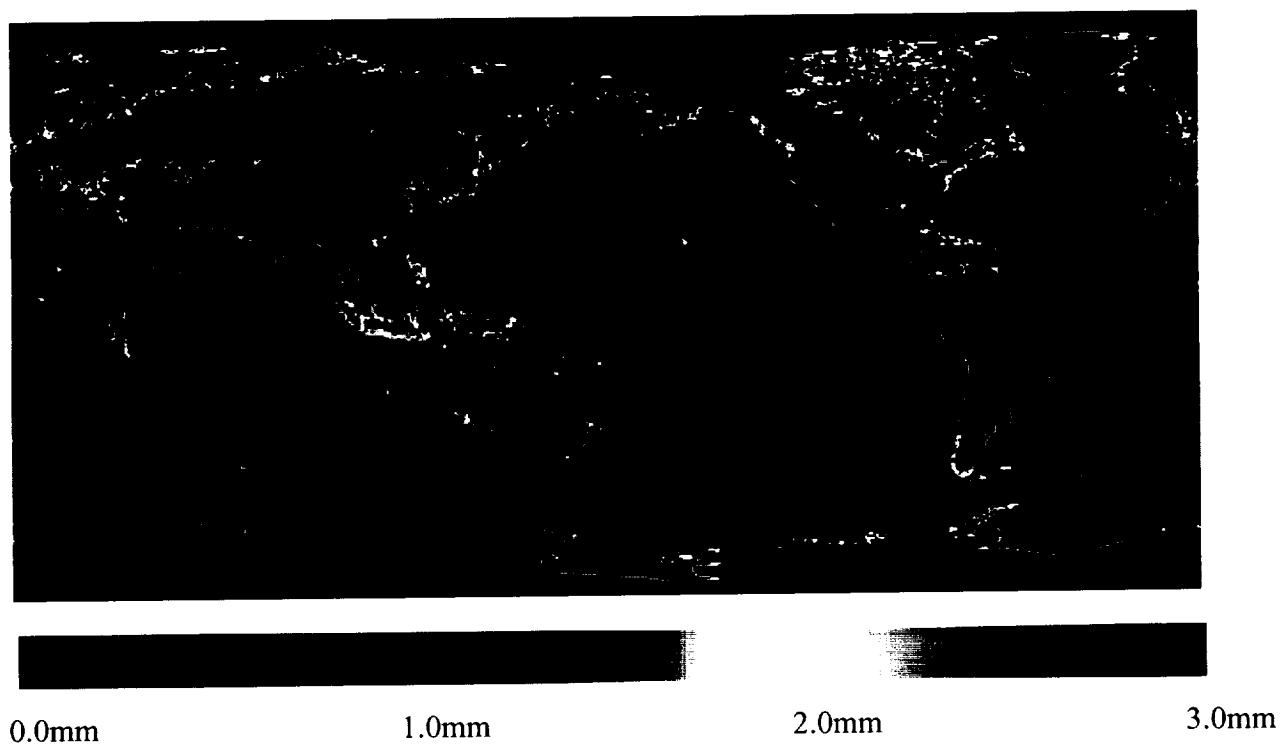
Figure 2. December, 1995 mean 200–300 mb precipitable water.
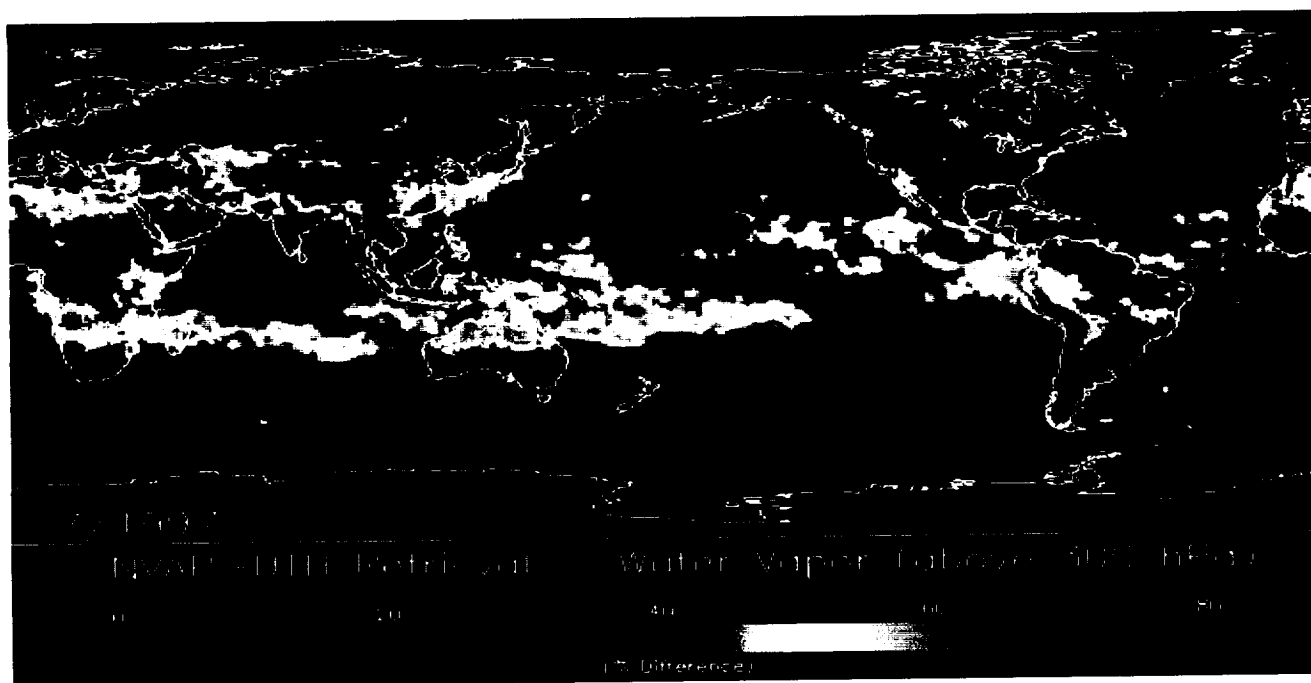
Figure 3. Percentage difference of TOVS 300–200 mb precipitable water vapor versus initial guess for July, 1997. Range of values indicates retrieval has information to modify initial guess, particularly in the tropics.

In order to explore the distribution and behavior of water vapor in the polar regions, STC-METSAT researchers have been experimenting with a polar stereographic projection of the data. Figure 4 shows examples of total precipitable water for the northern and southern hemispheres for August 1, 1998. This type of projection reduces the distortion in the polar regions present in our cylindrical equidistant projection, and should be a useful product for Global Water and Energy Cycle science questions focused on the polar regions.

We have performed our own calculations of water vapor transport, and compared them with those done at NESDIS. We have created the 8 mandatory layer-specific humidity datasets for 1988–1998. This supports our task to identify interannual variability in water vapor transport.

3. ANALYSIS OF KEY SCIENCE RESULTS

(a) Trends from NVAP

Dr. Thomas Vonder Haar presented the invited paper, "Search for Trends and Variability of the Global Water Vapor Cycle using Satellite Measurements", at the spring American Geophysical Union Meeting in 2001. Results from NVAP were featured prominently to address the question: "Is the Global Water Cycle Intensifying?"

No systematic increase in atmospheric water vapor was found in our short data set (thus far), in contrast to a climate model prediction with increased CO_2, as shown in Figure 5. This climate model—and 4 other major models—all show an expected increase of global water vapor of 2.5mm/100 yrs (or about 10%/100 yrs). Global and hemispheric statistics on total column water vapor for 1988–1998 are shown in Table 3.

Table 3. Annual Averages of Total Column Water Vapor from NVAP (mm)

YEAR	N. HEMISPHERE	S. HEMISPHERE	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
1994	25.61	23.02	23.32
1996	25.39	22.74	24.06
1997	25.79	22.93	24.36
1998	25.95	23.85	24.90

Northern Hemisphere   Southern Hemisphere

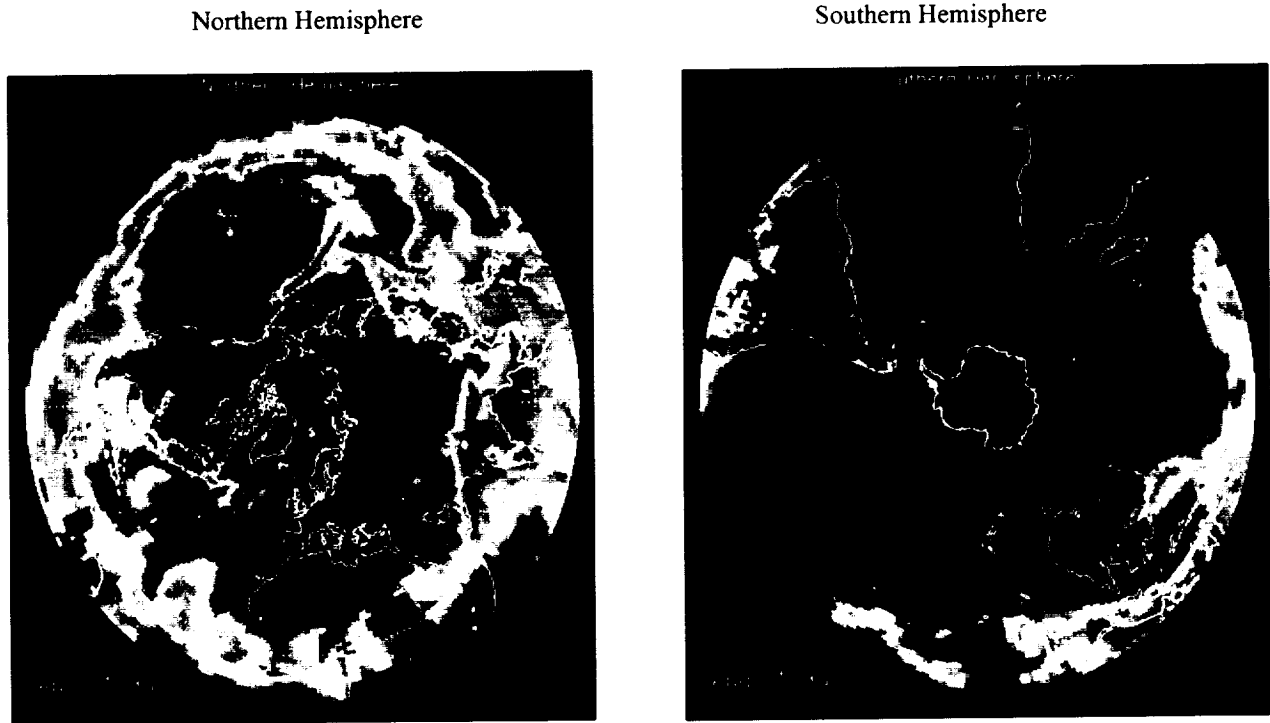Figure 4. Northern and Southern hemisphere views of total precipitable water for August 1, 1998.

**Global Total Atmospheric Water Vapor
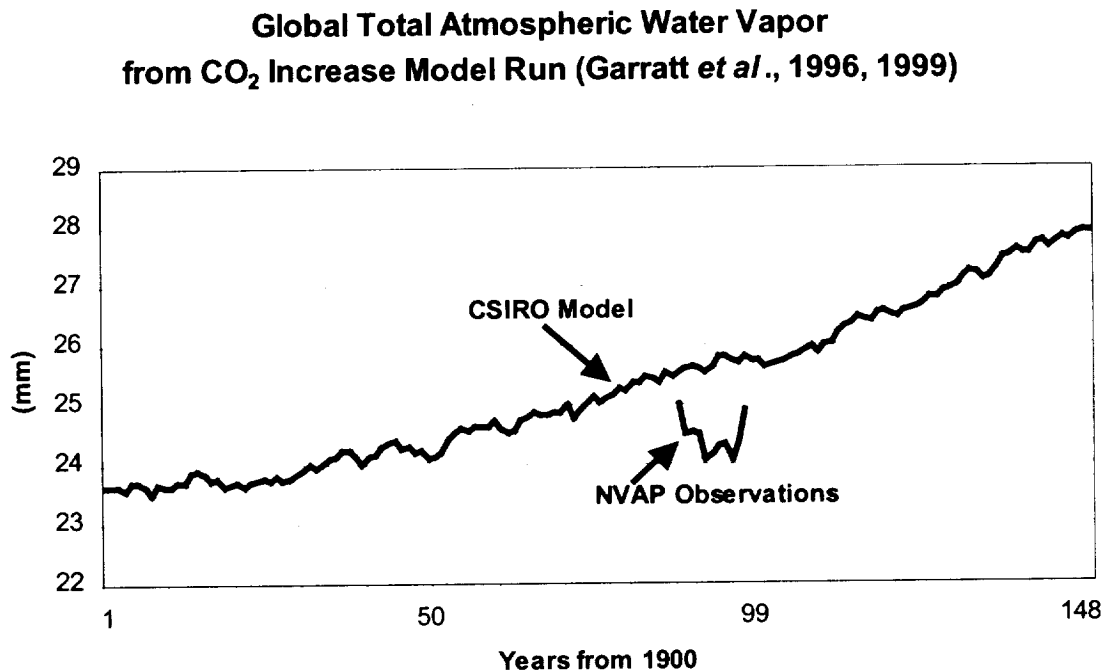from CO$_2$ Increase Model Run (Garratt *et al.*, 1996, 1999)**

Figure 5.   Comparison of NVAP total atmospheric water vapor with transient, increased, CO$_2$ model prediction.

Although there are no clear global trends, we do find significant interannual variability in atmospheric water vapor. Figure 6 shows that most of the interannual variability occurs in tropical regions. Figure 7 reveals significant variability of water vapor in the total column, lower troposphere, and upper troposphere values. Further scientific investigation is required to examine periods when the upper and lower tropospheric anomalies are uncorrelated, such as in late 1995 and early 1998.

Figure 8 compares water vapor anomalies from NVAP with the important Microwave Sounding Unit lower troposphere temperature anomaly. There appears to be a good degree of correlation. This suggests the intriguing possibility that the atmosphere maintains a nearly constant relative humidity of about 35 % below 700 hPa. Theoretical and modeling efforts within the scientific community should be evaluated in light of these findings. The aforementioned de-correlation of global temperature and water vapor in 1995 and 1998 emphasizes the sometimes over-riding effect of regional dynamics on the basic thermodynamic relationship.

(b) Water Vapor and Outgoing Radiation

We have begun a comparison of NVAP interannual variability with another independent observation of the planetary energy balance. Figure 9 shows a plot of the long-wave radiation anomaly for several instruments for 1985–1999. The region of study is from 20S to 20N. The period 1985–1989 is used as a baseline. NVAP water vapor anomalies for 20S–20N are shown in Figure 10, referenced to a 1988–1998 baseline since the NVAP data does not go back to 1985. The long-wave anomaly shows positive values after 1993, perhaps indicating fewer clouds or less water vapor, or a warmer surface. The NVAP data does not show any clear trend at any height level. There are positive water vapor anomalies in late 1997 through 1998, almost certainly associated with the El Nino event at that time. We should obtain the Outgoing Long-wave Radiation (OLR) anomaly values computed with a common baseline to further pursue this comparison.

The diagnostic study of the 20 S to 20 N region focuses on several interesting climate situations: (a) the Pinatubo event/recovery from mid-1991 to 1993, (b) the very strong El Nino for mid 1997–1998 and (c) the intervening period (mid-1994 to mid -997) where the OLR from ERBE showed an increase of 2-4 W/m^2 across the zone.
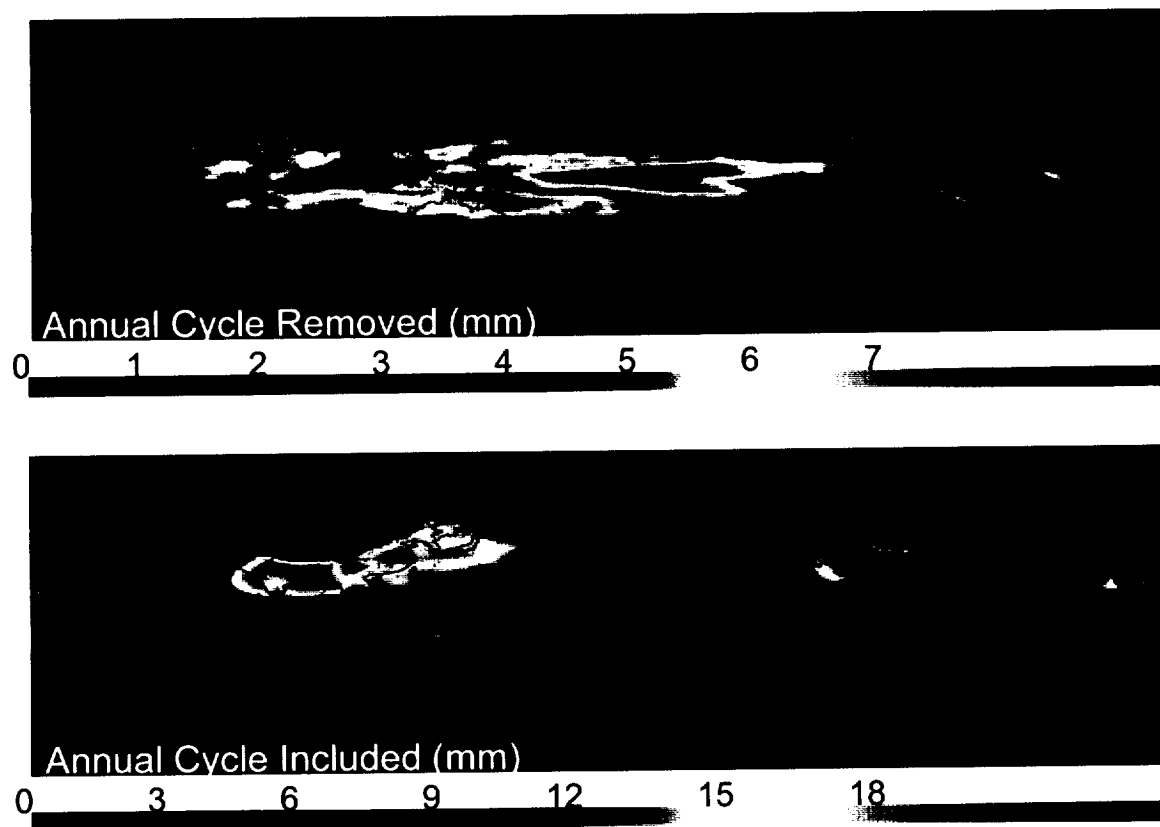
Figure 6. Interannual variability in the NVAP data 1988–1992. Standard Deviation from the mean is shown.

Comparison of the Total Column, Lower, and Upper Tropospheric
Water Vapor Anomalies - Global Means
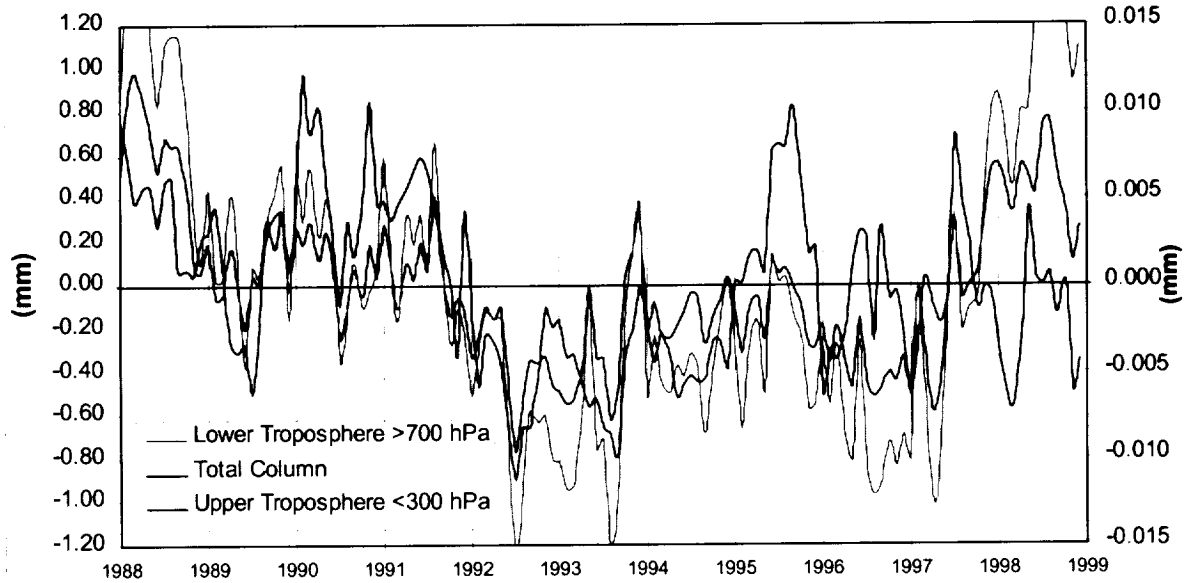
NVAP data from *STC*-METSAT via the NASA Pathfinder analysis program

Figure 7. Time series of NVAP layer precipitable water vapor anomalies.

Comparison of the Lower Tropospheric Temperature and Total Column Water Vapor Anomalies - Global Means
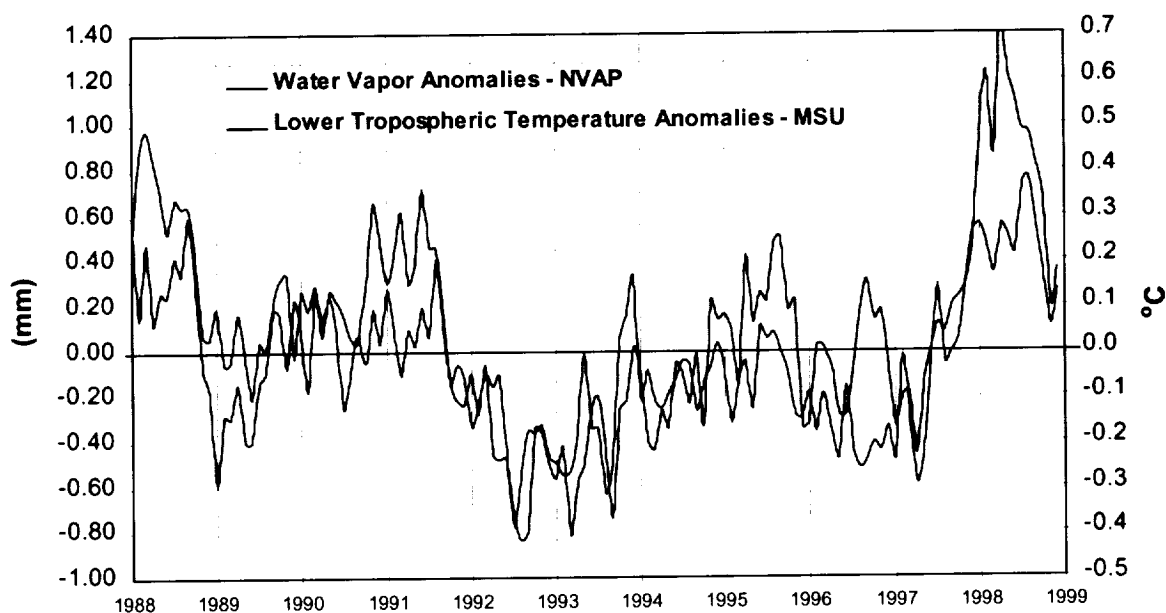
NVAP data from *STC*-METSAT via the NASA Pathfinder analysis program

Figure 8. Time series of MSU temperature anomalies versus NVAP precipitable water anomalies.
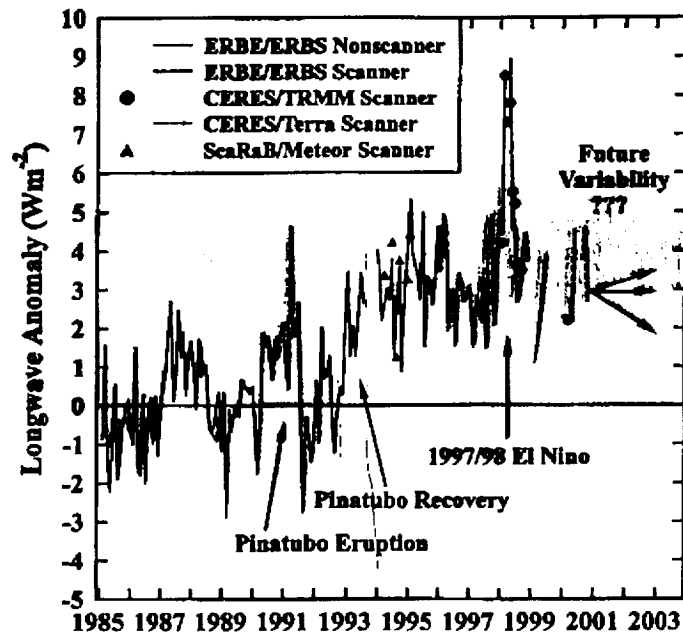
Figure 9. Time series of OLR anomaly from several radiation instruments (Wielicki, *et al* ., 2000).

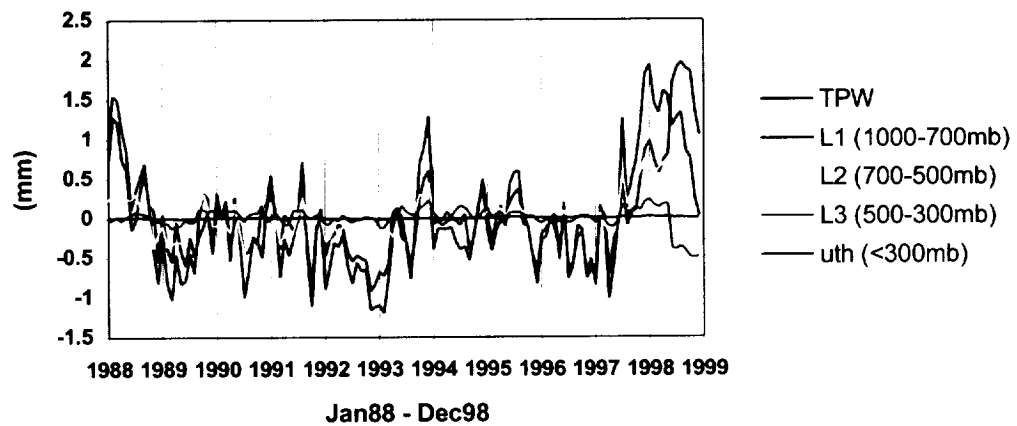### Monthly Water Vapor Anomalies (20N - 20S)

Figure 10. Time series of NVAP level water vapor anomalies for the tropical region.
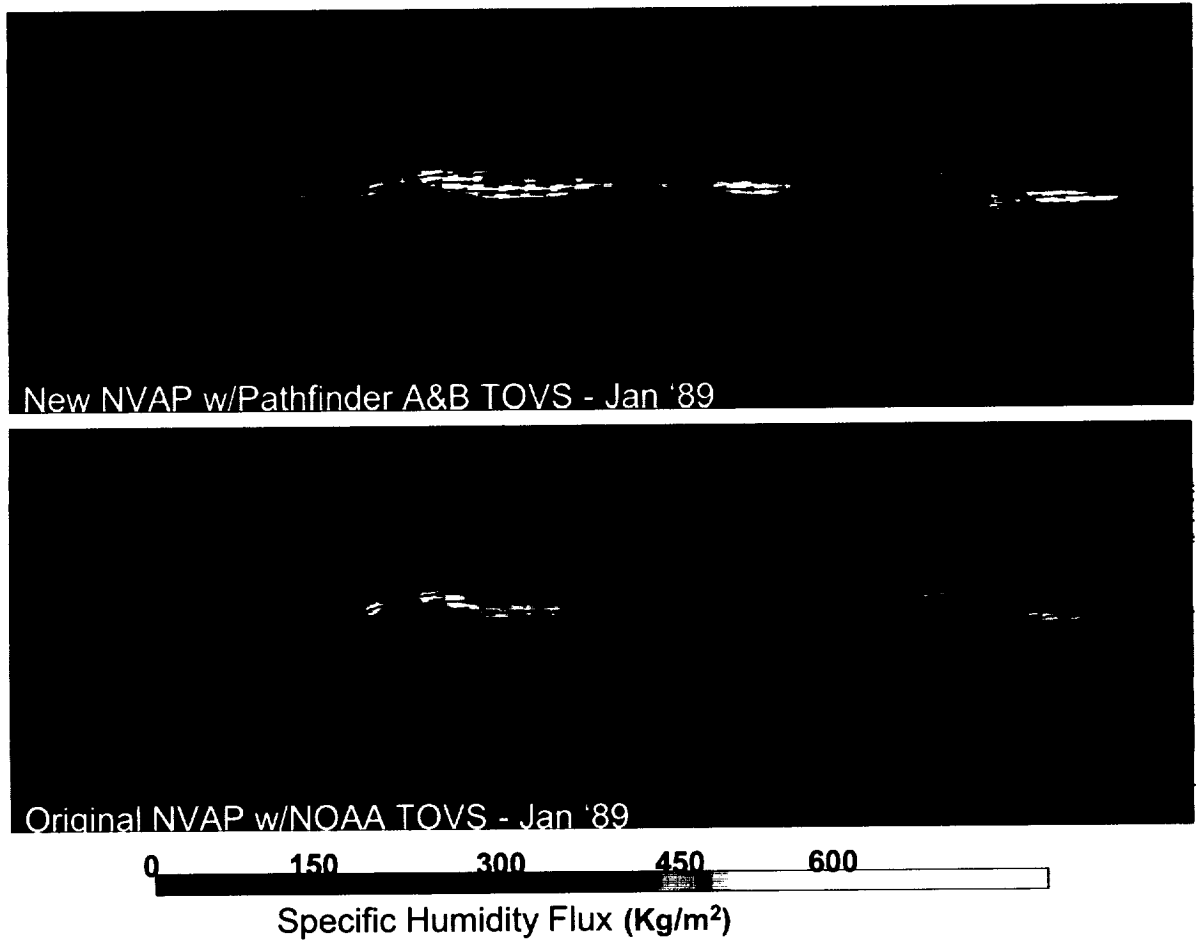
(c) Water Vapor Transport

Our collaboration with NESDIS scientists has already yielded productive results. We originally provided 8 levels of specific humidity data on mandatory pressure levels. In order to resolve the lower levels of the atmosphere better, we are now producing specific humidity on 29 sigma levels. Valuable global fields that support NASA's objectives for climate studies can be derived when the water vapor flux from NVAP and model analysis is combined with global precipitation data.

The NOAA TOVS retrievals have been used to calculate water vapor flux. We have also independently reanalyzed the NVAP data for January and July, 1989 by using the TOVS Pathfinder Path A and B retrievals. January and July flux fields are shown in Figures 11 and 12. While the results are very similar over most of the globe, there are key differences over some land regions. Recall that the TOVS data has a strong impact on the NVAP fields over land, since SSM/I data dominates the NVAP fields over ocean. Figure 13 shows a close up of South America for January. Note that the infusion of moisture from the Atlantic into the Amazon Basin is more subdued in the NOAA TOVS version as compared to the Pathfinder retrievals. The Pathfinder retrievals appear more realistic, since there is no orographic obstacle to moisture flux at the coastline. A similar comparison is shown over Africa in Figure 14. The Pathfinder flux has sharper gradients than the NOAA TOVS retrievals. Our work with the precipitation data had generated negative evaporation values over these areas when computed with NOAA TOVS. The fact that the Pathfinder retrievals show some differences in those regions is an encouraging sign. Further work will investigate the moisture flux computed from NVAP by using Pathfinder Path A and B results. These are vital measures of Earth's hydrologic cycle.

4. SUMMARY

The NVAP and NVAP-NG datasets play a vital role in NASA's mission to understand Earth's climate and how it is changing. During the next year, we expect to combine new algorithms and data sources to produce the initial NVAP-NG product, which will be a benchmark to be used by the scientific community. NVAP-NG will continue the successful legacy of the NVAP product. By August 2002, *STC*-METSAT will have several exciting new results and products which will help to understand the hydrologic component of Earth's climate.

New NVAP w/Pathfinder A&B TOVS - Jan '89

Original NVAP w/NOAA TOVS - Jan '89

| 0 | 150 | 300 | 450 | 600 | |

Specific Humidity Flux (Kg/m²)

Figure 11. Water vapor flux for January, 1989 from NVAP calculated with Pathfinder TOVS versus NOAA TOVS.

New NVAP w/Pathfinder A&B TOVS - July '89

Original NVAP w/NOAA TOVS - July '89

0 150 300 450 600

Specific Humidity Flux (Kg/m²)
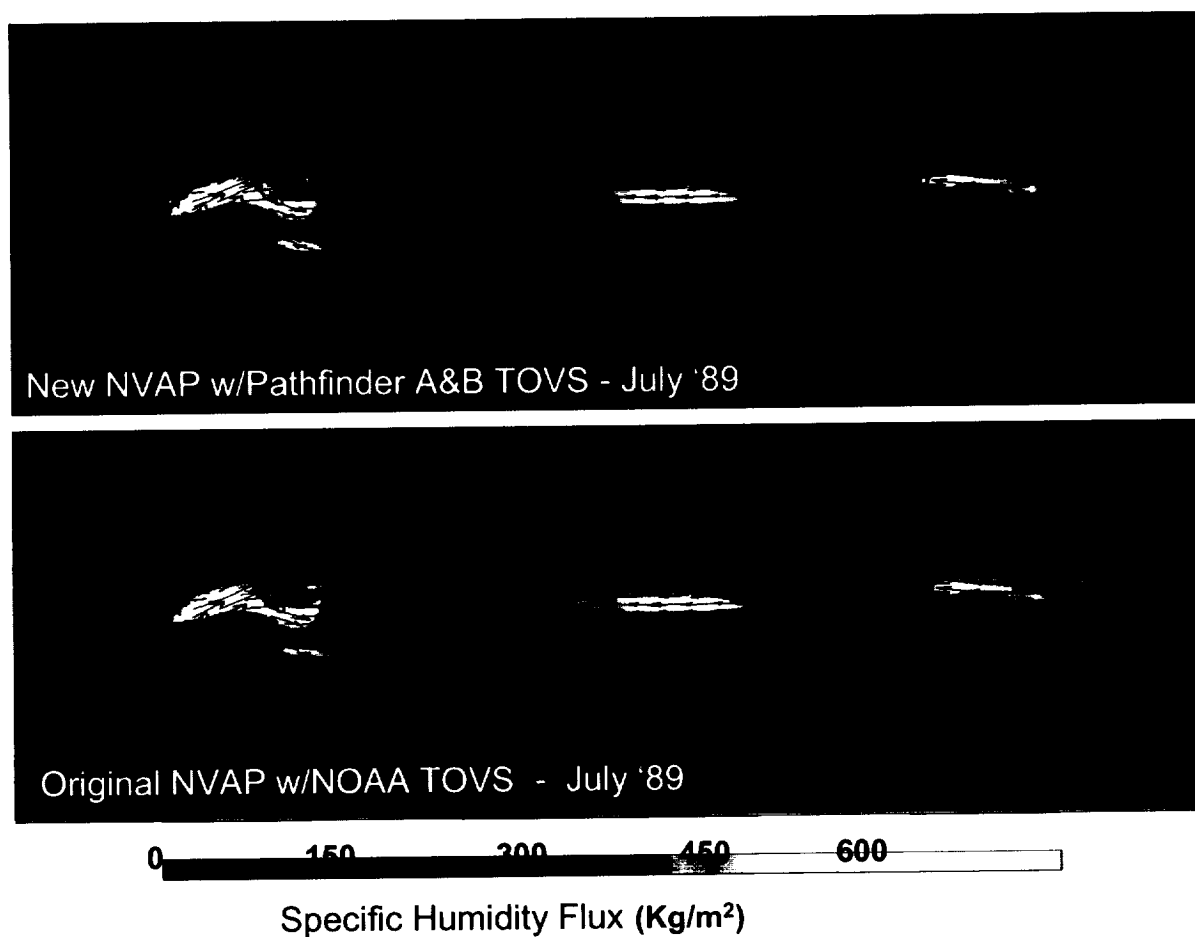
Figure 12. Water vapor flux for July, 1989 from NVAP calculated with Pathfinder TOVS versus NOAA TOVS.

New NVAP

w/Pathfinder A&B TOVS
January, 1989

Original NVAP

w/NOAA TOVS

January, 1989

0　　　　150　　　　300　　　　450　　　　600

Specific Humidity Flux (Kg/m²)
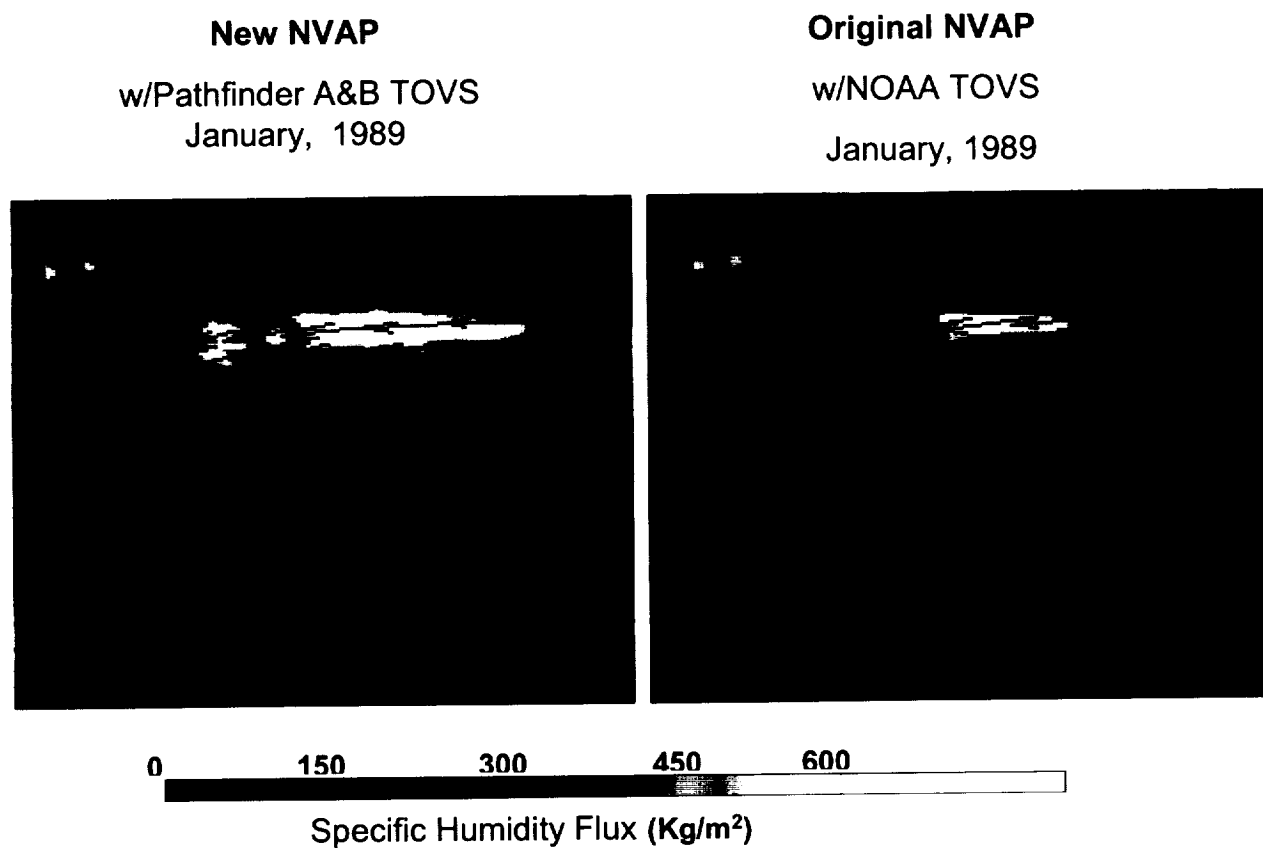
Figure 13. Comparison of specific humidity flux over South American region for January 1989.

New NVAP

w/Pathfinder A&B TOVS
July, 1989

Original NVAP

w/NOAA TOVS

July, 1989

Specific Humidity Flux (Kg/m²)
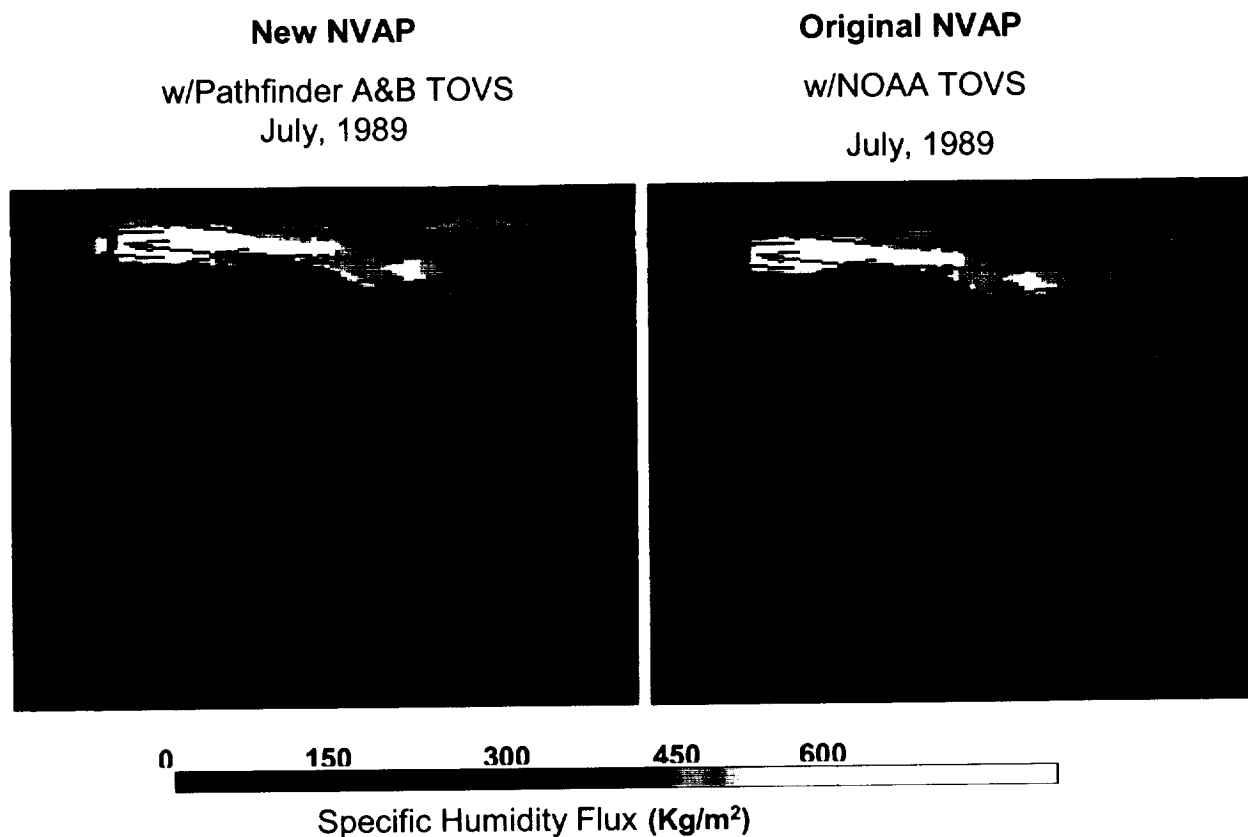
Figure 14. Comparison of specific humidity flux over South American region for July 1989.

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APPENDIX – SPECIAL REFERENCE

As noted in the report, the NASA Water Vapor Project data set from the Pathfinder Analysis Program is being used actively by hundreds of scientists around the world. This is documented by:

(1) The requests for NVAP data sets both to *STC*-METSAT and to the LaRC DAAC, and

(2) The publication of scientific papers using NVAP data sets. A special recent example is the paper by Simpson, *et al.* (2001), the abstract of which follows.

The NVAP global water vapor data set: independent cross-comparison and multiyear variability

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Abstract

Space-time variability in the global distribution of atmospheric total column water vapor (tcwp) greatly impacts the hydrologic cycle. NASA's Water Vapor Project (NVAP) produced a global $1° \times 1°$ tcwp data set for use as a tool to investigate, among other things, atmospheric variability. An independent cross-comparison of the NVAP tcwp product was performed using the TOPEX/POSEIDON (T/P) TOPEX microwave radiometer (TMR) data and the European Centre for Medium-Range Weather Forecasts (ECMWF)-based range delay data set produced by Météo-France (MF) and distributed with T/P data. When these T/P range delay data are converted to tcwp, they show that NVAP is biased dry and ECMWF/MF is biased wet relative to the independent TMR measurement. Although the absolute accuracy of the NVAP tcwp product is uncertain, results indicate its relative accuracy is sufficient for variability studies. Empirical orthogonal function (EOF) analysis and spectral analysis applied to this data set show that seasonal variability over the annual cycle accounts for about 20% of the variance (EOF1). An El Niño-southern oscillation (ENSO) signal is found in the annually demeaned data; the magnitude of the cross-correlation between the temporal amplitude (TA) of EOF1 and the Niño 3.4 (SST) time series is .9. Comparisons also were made between the NVAP patterns of variability in tcwp and independent reanalysis and interpretation of numerical model generated atmospheric fields. In general, there is good agreement between the NVAP data and the reanalysis fields. Finally, specific recommendations are made for: (1) improvement of the NVAP data set upon reanalysis and (2) use of the NVAP data, in place of ECMWF/MF-based range delay data, for T/P retrievals when TMR data are not available if and when T/P data are reanalyzed. This latter recommendation is especially important for regions of the tropical Indo-Pacific (e.g., Indonesia) where islands can interfere with valid TMR retrievals. © 2001 Elsevier Science Inc. All rights reserved.

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