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STC Technical Report 2927

Production of a Long-Term Global Water Vapor and Liquid Water Data Set Using Ultra-Fast Methods to Assimilate Multi-Satellite and Radiosonde Observations

Final Report

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Ian L. Wittmeyer
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Fort Collins, Colorado

Prepared for
Headquarters
National Aeronautics and Space Administration
Washington, D.C.
Under Contract NASW–4715
Technical Representative: Dr. James C. Dodge

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Science and Technology Corporation
101 Research Drive, Hampton, Virginia 23666–1340

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FOREWORD

Science and Technology Corp. (STC)-METSAT is pleased to submit this final report entitled "Production of a Long-Term Global Water Vapor and Liquid Water Data Set Using Ultra-Fast Methods to Assimilate Multi-Satellite and Radiosonde Observations," by Dr. Thomas H. Vonder Haar, Dr. David L. Randel, Mr. Donald L. Reinke, Dr. Graeme L. Stephens, Mr. Mark A. Ringerud, Ms. Cynthia L. Combs, Dr. Thomas J. Greenwald, and Mr. Ian L. Wittmeyer of the STC-METSAT office, Fort Collins, Colorado. The work was performed under NASA contract NASW–4715 of the same title. The period of performance covered by this report was July 1992 through July 1995.

The new global data sets have been very well received by the science community. In order to extend the initial 5-yr data set (1988—1992) to meet the Earth Observing System period, STC-METSAT has proposed an additional 5 yr (1993—1997) of processing and merging of DMSP, NOAA, and radiosonde data using the same methods developed under the current project.

STC-METSAT gratefully acknowledges the support and helpful discussions provided during the course of this work by Dr. James C. Dodge, NASA Technical Representative. Special thanks are extended to Mr. William Elliott, NOAA Air Resources Laboratory, and to Mr. John Bates, NOAA CIRES, for helpful discussions and access to their data sets.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYMS

AMIP	Atmospheric Model Intercomparison Project
AMS	American Meteorological Society
ARL	Air Resources Laboratory
AVHRR	Advanced Very High Resolution Radiometer
CD-ROM	Compact Disk-Read Only Memory
CIDOS	Cloud Impacts on DoD Operations and Systems
CIRA	Cooperative Institute for Research in the Atmosphere
CIRES	Cooperative Institute for Research in Environmental Science
CLW	cloud liquid water
CSU	Colorado State University
DAAC	Data Active Archive Center
DMSP	Defense Meteorological Satellite Program
DSC	Data Source Code
ECMWF	European Centre for Medium-Range Weather Forecasts
EOS	Earth Observing System
ERBE	Earth Radiation Budget Experiment
ETAC	Environmental Technical Applications Center (USAF)
GCIP	GEWEX Continental-Scale International Project
GCM	general circulation model
GEWEX	Global Energy and Water Cycle Experiment
GPS	global positioning system
GSFC	Global Space Flight Center (NASA)
GVaP	GEWEX Water Vapor Project
HDF	Hierarchical Data Format
IGY	International Geophysical Year

ACRONYMS

I/O	Input/Output
ITCZ	Inter-Tropical Convergence Zone
ISCCP	International Satellite Cloud Climatology Project
ISSSR	International Symposium on Spectral Sensing Research
JJA	June-July-August
LaRC	Langley Research Center (NASA)
LWP	liquid water path
MSFC	Marshall Space Flight Center (NASA)
NASA	National Aeronautics and Space Administration
NESDIS	National Environmental Satellite, Data, and Information Service
NH	Northern Hemisphere
NMC	National Meteorological Center
NOAA	National Oceanic and Atmospheric Administration
NVAP	NASA Water Vapor Project
PWC	precipitable water content
POT	percent-of-the-total
SH	Southern Hemisphere
SRB	Surface Radiation Budget
SSM/I	Special Sensor Microwave/Imager
STC	Science and Technology Corp.
TIROS	Television and Infrared Operational Satellite
TOVS	TIROS (Television and Infrared Operational Satellite) Operational Vertical Sounder
USAF	United States Air Force
WMO	World Meteorological Organization

1. INTRODUCTION

There is a well documented requirement for a comprehensive and accurate global moisture data set to assist many important atmospheric science studies (see Section 2). This need is emphasized by the U.S. Climate Research Program, the Global Energy and Water Cycle Experiment (GEWEX), and the GEWEX Continental-Scale International Project (GCIP). Currently, atmospheric water vapor measurements are made from a variety of sources including radiosondes, aircraft and surface observations, and in recent years, by various satellite instruments. Creating a global data set from a single measuring system produces results that are useful and accurate only in specific situations and/or areas. Therefore, an accurate global moisture data set must be derived from a combination of these measurement systems.

Under this NASA contract, STC-METSAT produced two 5-yr (1988—1992) global data sets. The first is the total column (integrated) water vapor data set and a global layered water vapor data set using a combination of radiosonde observations, Television and Infrared Observation Satellite (TIROS) Operational Vertical Sounder (TOVS), and Special Sensor Microwave/Imager (SSM/I) data sets. STC-METSAT also produced a companion, global, integrated liquid water data set. The complete data set (all three products) has been named NVAP, an acronym for NASA Water Vapor Project.

STC-METSAT has developed methods to process the data at a daily time scale and 1° x 1° spatial resolution. This work has become an internationally accepted contribution to the World Climate Research Programme. Preliminary results from this new NVAP data set have been used in numerous studies in the scientific community. They have shown significant interannual variability in regional water vapor values and have indicated the need for additional climate analysis and additional years of water vapor data.

2. THE NATURE OF THE PROBLEM

The majority of large scale water vapor climatological studies have, before this project was started in 1991, relied wholly upon analysis of radiosonde data (Bannon and Steele, 1960; Oort, 1983) or satellite observations from a single instrument. The development of a complete and accurate global water vapor data set is critical to the adequate understanding of the role of water vapor in the Earth's climate system. It will complement the growing global data sets on clouds, the Earth's radiation budget, precipitation, and other variables. Examples of climate research that are dependent on accurate water budget data include, but are not limited to, poleward energy transports, general circulation model (GCM) verification, climate model verification, regional climate studies, and global change baseline measurements. During the next decade, many programs and experiments under the GEWEX World Climate Research Programme (1990) will utilize present day and future data sets to improve scientific understanding of the role of moisture in climate, and its interaction with other variables such as clouds and radiation. The need for improved knowledge of the global water vapor distribution is well documented (e.g., international GEWEX reports, World Meteorological Organization, Geneva; AGU-Chapman Conference on Water Vapor in Climate). A comprehensive global water vapor data set is needed now for scientific studies. The STC-METSAT NVAP project addresses this need with a combination of ground-based radiosonde and satellite infrared and microwave retrievals. The project will provide the solid foundation from which investigators of future GEWEX-related and Earth Observing System (EOS) related work can learn and build upon.

Several research groups have recently developed algorithms to better define the global water vapor climatology from either infrared or microwave space-based retrievals. Satellite-based observations are critical inputs to this climatology effort because the data collected at each radiosonde site may not be representative of the surrounding atmospheric conditions. This lack of representativeness is due to significant gradients in precipitable water content (PWC) that exist between the limited spatial resolution of the stations. Analysis using only radiosonde data tends to smooth out mesoscale gradients that are important to the cloudiness, precipitation, and radiation balance fields. These fields are under special study by many scientists because of their central role in scale interactions in the climate system. Large data gaps over the oceans and even over some land areas limit the extent from which inferences may be made about the nature of the global water vapor distribution. The newer data sources, such as those from infrared and microwave satellite sensors, can greatly enhance the global coverage on a daily basis. Examples of currently available large-scale and global data sets include model-analyzed (operational) global humidity fields from the European Centre for Medium-Range Weather Forecasts (ECMWF) and the National Meteorological Center (NMC), which were reported by Trenberth and Olson (1988); satellite PWC retrievals from the Defense Meteorological Satellite Program (DMSP) SSM/I data over the ocean (Tjemkes and Stephens, 1991); TOVS infrared PWC retrievals in clear-to-partly-cloudy areas (Rossow and Kachmar, 1988; Wittmeyer and Vonder Haar, 1994), and a number of data sets using radiosonde measurements for research purposes on limited time and space scales.

Each of the above data sets individually has significant limitations. Radiosonde measurements are made primarily over land with limited spatial coverage; global humidity analysis fields from national forecast centers are highly model dependent; infrared satellite techniques only work in the absence of significant cloud cover; and microwave retrievals are currently feasible only over oceans. A comprehensive global data set (the goal of this project) must draw upon the strengths of each of these methods and utilize the advantages of each for all meteorological and geographical scenarios. The result is a combined effort far better than any one input data set. Improvements in the daily representation of the moisture field will be significant, and time means of one day or longer will exhibit increased accuracy. Use of such a data set in GCM and climate model studies will greatly improve scientific understanding of many of the most difficult phenomena to characterize, those relying heavily on the accurate description of the moisture field.

The development of a global cloud liquid water product is also important to the understanding of the Earth's climate system and is part of a growing number of scientific studies aimed at the improvement of climate models. For example, Stephens and Greenwald (1991) investigated the connection between cloud albedo and cloud liquid water, while Greenwald et al., (1995) examined the climatic characteristics of cloud liquid water and also the relationship between the Earth Radiation Budget and cloud liquid using collocated SSM/I and Earth Radiation Budget Experiment (ERBE) scanner measurements.

3. DATA PROCESSING

To satisfy the need for a complete and accurate global water vapor data set, including cloud liquid water over the oceans, STC-METSAT has produced for NASA, a comprehensive, 5-yr, 1° x 1° resolution, global PWC and liquid water path (LWP) data set. This consists of both daily composites and a multilayered PWC product at three layers (1000—700 mb, 700—500 mb, 500—300 mb). The SSM/I and TOVS, in addition to the radiosonde observations, have been used to derive the first 5 yr of the STC-METSAT NVAP global water vapor data set. The following sections describe the individual data sets used as input, the processing involved, and the products NVAP has produced.

3.1 INPUT DATA SOURCES

The SSM/I instrument provides data for microwave retrievals from space (Hollinger et al., 1987). Use of the 19.35 GHz channels at vertical and horizontal polarization allows for the determination of total column water vapor via the physical method employed by Tjemkes et al., (1991). Greenwald et al., (1993) extended and improved this physical method to include the retrieval of cloud liquid water. The SSM/I water vapor and cloud liquid water data sets produced by this method have been used in numerous published studies, including Stephens et al., (1994) and Webb et al., (1993). Determination of total column water vapor with the retrieval model of Greenwald et al., (1993) requires (1) the input of sea surface temperatures (Reynolds, 1988) and the SSM/I 19.35 GHz and 37 GHz brightness temperatures, among others, to an approximate radiative transfer model; and (2) the near surface wind speed to an empirical surface emissivity model. Using these data, total column water vapor is determined over oceans and gridded for use at a 1° x 1° resolution.

The TOVS instrument is flown on the National Oceanic and Atmospheric Administration (NOAA) series of operational sun-synchronous satellites. TOVS consists of 20 independent channels and includes wavelengths for retrieving temperature and moisture information. Three channels in water vapor absorption bands are located at 6.7, 7.3, and 8.3 μm with weighting functions peaking at 400, 600, and 900 mb, respectively. STC-METSAT used the operational TOVS sounding produced by NOAA/National Environmental Satellite, Data, and Information Service (NESDIS). These quality controlled radiance data were available on 8-mm tapes from other members of the water vapor science community (e.g., John Bates at NOAA/Cooperative Institute for Research in Environmental Science [CIRES]). These data are not gridded but include total and three-layer PWC for approximately 25,000 retrievals per day with geographical spacing of approximately 2°.

Historically, upper air balloon soundings have been the basis for statistics used throughout the scientific community (Oort, 1983). It is this data set the science community has the most confidence in thus far, so it is often considered "truth" versus the satellite data. A high quality radiosonde data set from (NOAA/Air Resources Laboratory [ARL]) was used. This set was produced to minimize documented problems with global radiosonde data (Elliott and Gaffen, 1991). These data were reformatted to specification and sent via Internet to STC-METSAT. Gridding and additional quality control were performed at STC-METSAT, and the data were included in the final total and layered products.

3.2 DATA QUALITY CONTROL

One of the more time-consuming steps in the processing was quality control. Experienced meteorologists viewed each individual input and output product to assure the quality of the final product. This task was divided into two parts. First. each individual daily input product of

SSM/I and radiosonde data was inspected. The SSM/I data were checked for sea ice contamination, land contamination in coastal areas, and for possible "bad" scan lines. Radiosonde sets were checked for individual points that were out of bounds both spatially and temporally. Any bad points were removed from the original data. In the second step, each daily merge product was checked for consistency with the other products. Any bad points located in this step were taken out of the original input data set and then remerged. This second step was also performed on each individual layered product.

3.3 PROJECT PRODUCTS

The total integrated water vapor product, or PWC, is a weighted merging of DMSP, SSM/I, and NOAA TOVS retrievals, and quality controlled radiosonde observations. These different data are weighted from daily mean, 1° x 1° gridbox averaged observations. Each of these measurement systems has limited data coverage. The radiosonde coverage is widely spaced and primarily over land, while TOVS retrievals are performed only in the absence of most clouds. The SSM/I retrievals are made only over the oceans. In both satellite data sets there are also missing orbital swaths. The final integrated PWC product is created by combining these three input data sets using a hierarchical weighting scheme. This algorithm uses radiosonde data when available as "truth" and then applies a weighting scheme to the TOVS and SSM/I retrievals. In the last step, simple linear and temporal interpolation routines are run to fill missing data points. Included as part of the PWC data set is a data source code (DSC) map that describes the origin of each point in the merged product. The DSCs are ordered by the estimated data error in the merged field. This ordering yields a quality-control index to be used by data users in their analyses. The DSC map (Fig. 2) contains values representing in order of lowest to highest confidence: missing data, temporally interpolated, spatially interpolated, TOVS only, SSM/I interpolated, SSM/I interpolated and TOVS combination, SSM/I only, SSM/I and TOVS combination, and radiosondes.

Included as a companion data set for analysis (since many GCMs are now beginning to include liquid water as an explicit variable), STC-METSAT has also processed the oceanic cloud liquid water path (LWP) on a daily 1° x 1° grid. The LWP product is the liquid water in any region, cloud or no cloud, and is built upon the physically based method of Greenwald et al. (1993), but at this time covers ocean areas only. Also produced are the monthly averages of cloud liquid water (CLW) content, which is the liquid water in cloudy only regions using a crude threshold of liquid water.

An important feature of the NVAP processing is the production of a layered water vapor product. In order to study the important energy transport processes, layered information, as well as the total integrated water, is needed. Two of the input data sources contain level information that can be used for multilayer water vapor processing. Operational TOVS retrievals are reported at three layers: surface–700 mb, 700–500 mb, and 500–300 mb. The radiosonde data PWC calculation is performed at these matching layers. For each day, three global grids are formed by the percent-of-the-total (POT) PWC in each of the three layers. Spatial and temporal interpolations are used to fill in missing data points. The assumption used in this method is that while the total and layered PWC can change rapidly, the POT in each layer is much more stable. The variability in the POT is a strong function of latitude and season and does not vary spatially as fast as the PWC. These POT fields are multiplied by the total PWC created in the SSM/I, TOVS, and radiosonde-merged process, and emerge as layered PWC global grids.

The "ultra fast" methods researched and produced from this project allowed processing of the data at a significantly decreased production time compared to the first year of the project. This research resulted in improved code efficiency and ultimately faster computer processors. The computer industry is continually upgrading to make faster processors. The main time constraint in processing the data is the input/output (I/O) of the data (from tape to computer to tape). Until computer companies develop the next generation of tape drive I/O, STC-METSAT is at maximum processing efficiency.

4. RESULTS

The NVAP products are intended for widespread usage in scientific fields requiring global moisture input. The NVAP products have been presented to the scientific community on numerous occasions since this project began. Various samples of the NVAP products have been distributed to scientists and researchers as well.

Section 4.1 contains some of the preliminary observations STC-METSAT has made about the data. Section 4.2 provides details relating to when and where NVAP products were presented. In Section 4.3 scientists and researchers who are currently using the NVAP data sets (June 1995) are listed.

4.1 DATA SET ANALYSIS

As discussed earlier three independent input data sets, Figs. 1a, 1b, and 1c, are used to produce the NVAP products. At this time, microwave retrievals using SSM/I are performed only over the oceans. The radiosonde data are made primarily over land, and the TOVS retrievals are performed only every 2° when there are no or relatively few clouds. Both the SSM/I and TOVS satellite retrievals have missing orbital swaths in the daily composite grids. Figure 2 illustrates the DSC grid used to identify the specific sources of each data point. The NVAP global water vapor merged product is shown in Fig. 3 for July 10, 1989. The values range from an average of 40 mm in the tropics to less than 1 mm near the poles. During July, the Indian monsoon is fully developed and the gradient in the PWC across the Himalayas is very dramatic. The three-layer PWC fields for July 10, 1989, are shown in Figs. 4a, 4b, and 4c. Note the scale change for each of the layered examples. The higher elevations contain maximum levels of PWC such as the Himalayas and the Andes. In Fig. 5 the LWP are shown for July 10, 1989 from SSM/I retrievals. For the same day, the cloud liquid water from SSM/I retrievals are shown in Fig. 6. The LWP in the Southern Hemisphere (SH) storm tracks and the Pacific Intertropical Convergence Zone (ITCZ) are the outstanding features. Figures 7a, 7b, and 7c illustrate the interannual variability

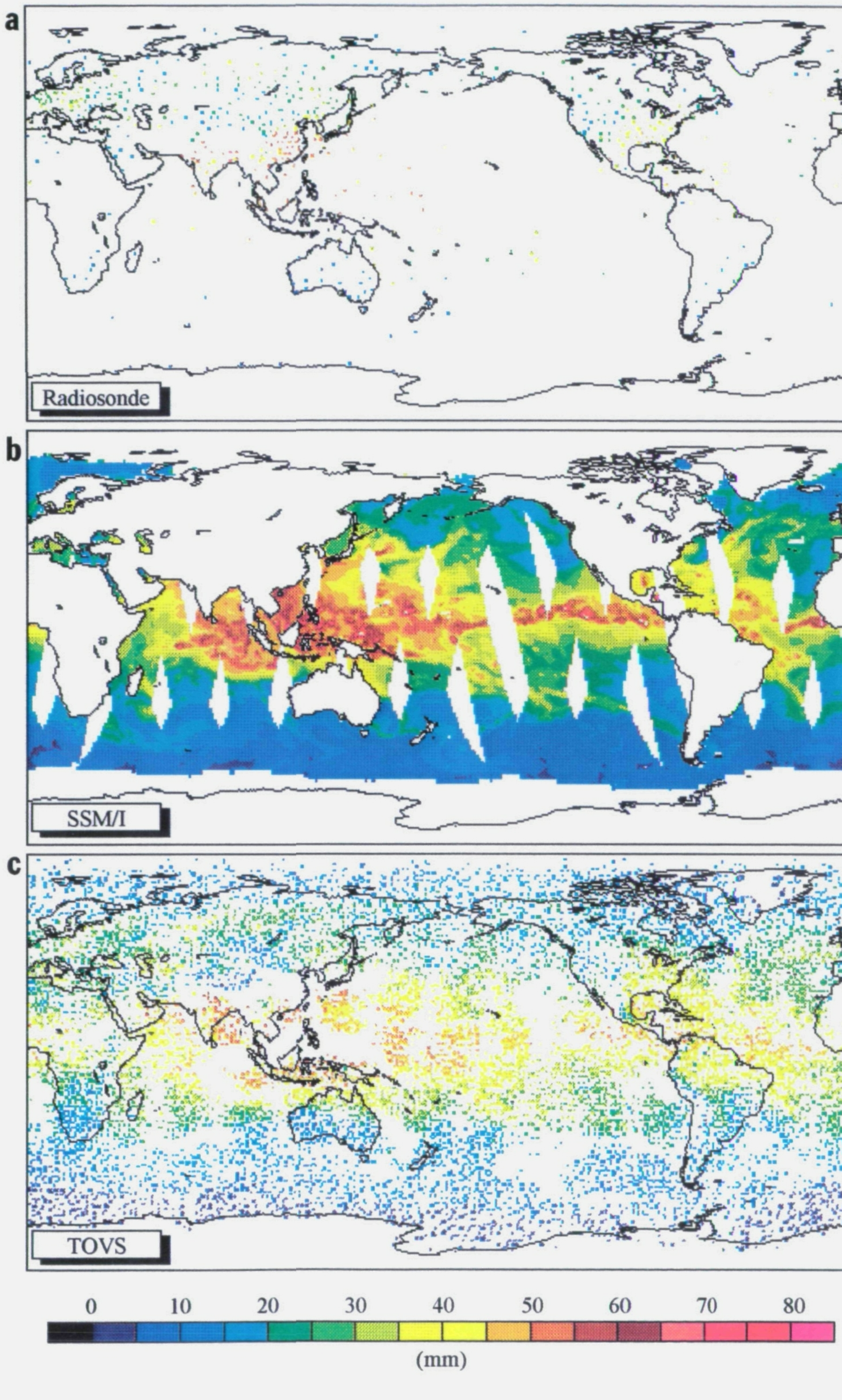

Figure 1. (a) Radiosonde, (b) SSM/I, and (c) TOVS PWC data for July 10, 1989.

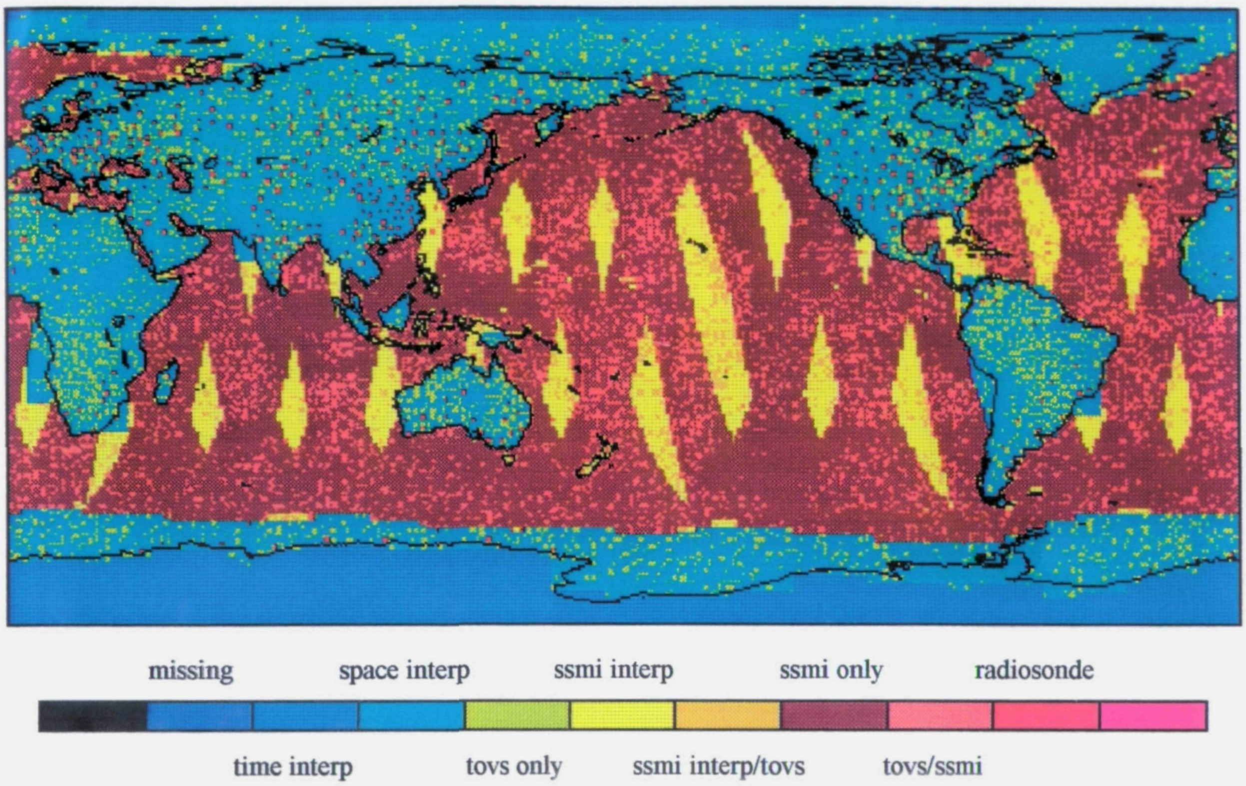

Figure 2. Data source codes for Total PWC for July 10, 1989.

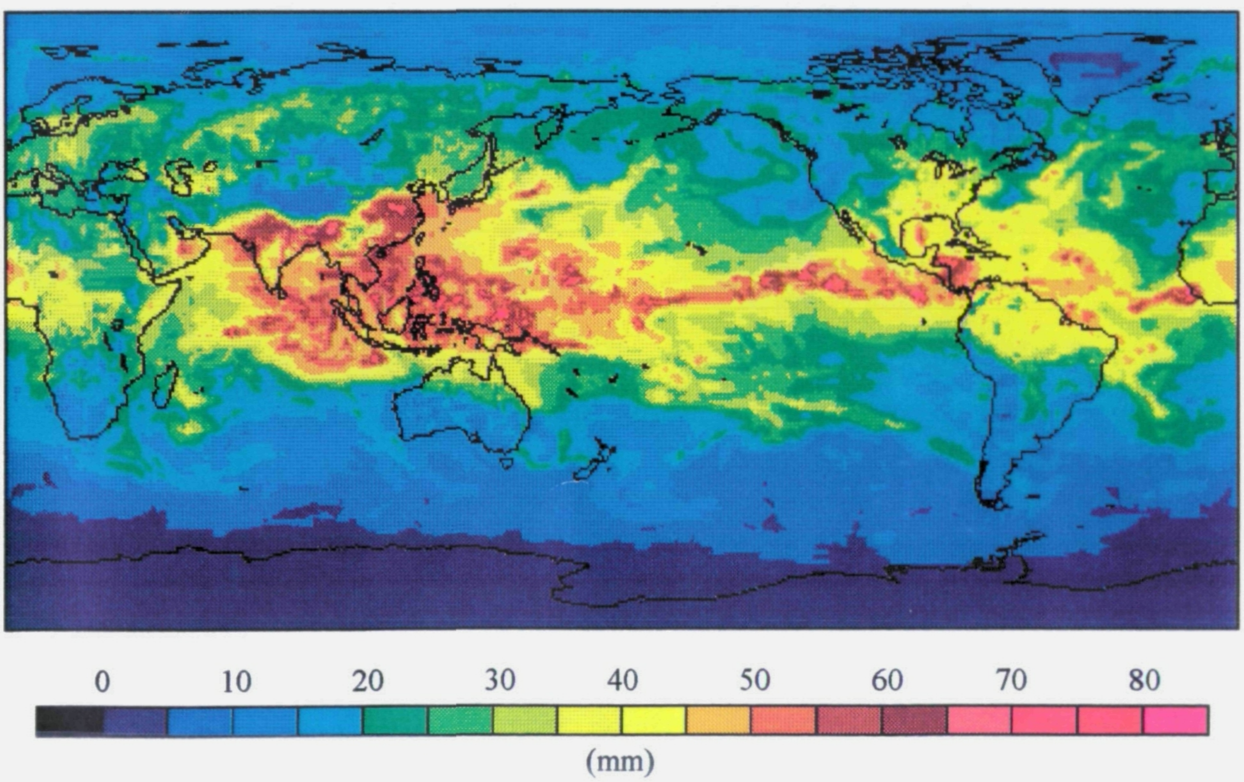

Figure 3. Merged total integrated PWC for July 10, 1989.

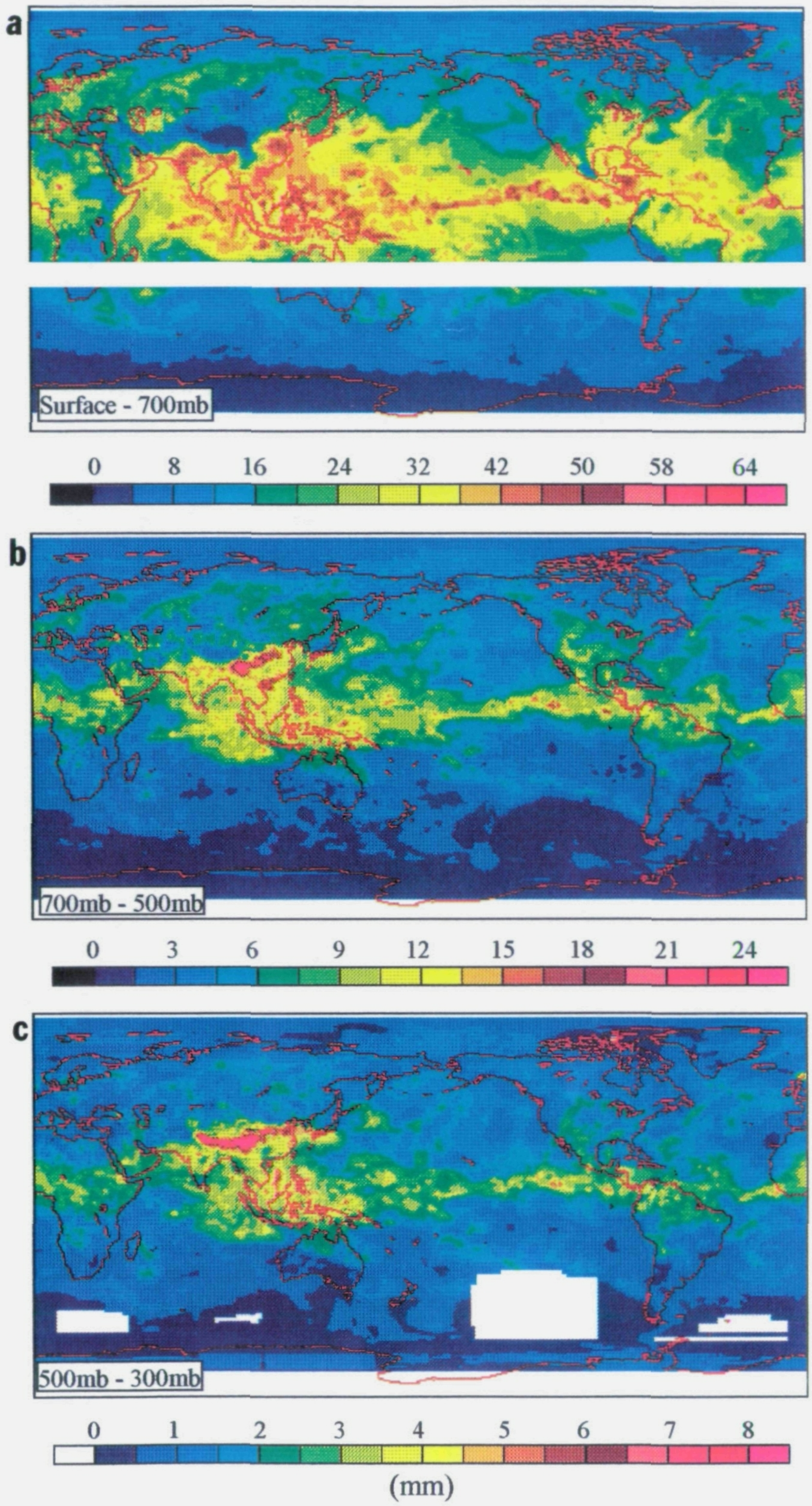

Figure 4. PWC (a) lowest (surface to 700 mb), (b) middle (700 mb to 500 mb), and (c) upper (500 mb to 300 mb) layer for July 10, 1989.

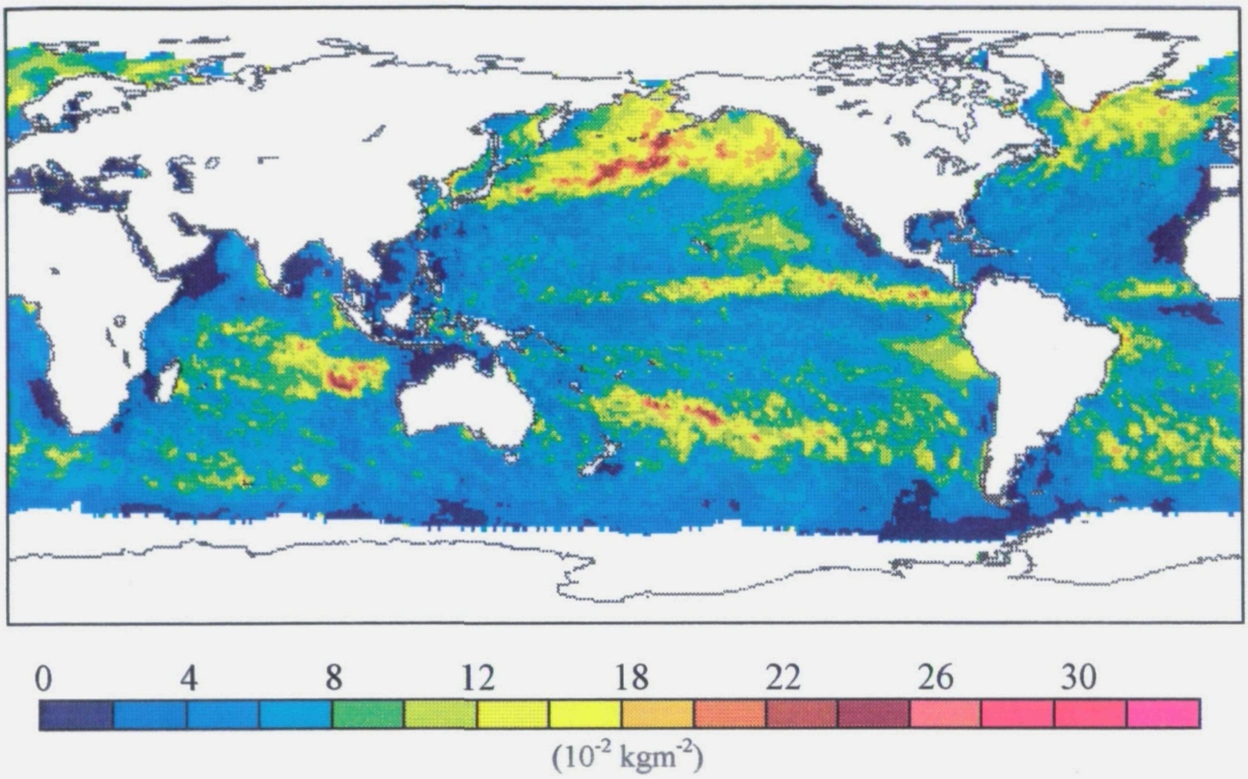

Figure 5. Total integrated liquid water path for July 10, 1989.

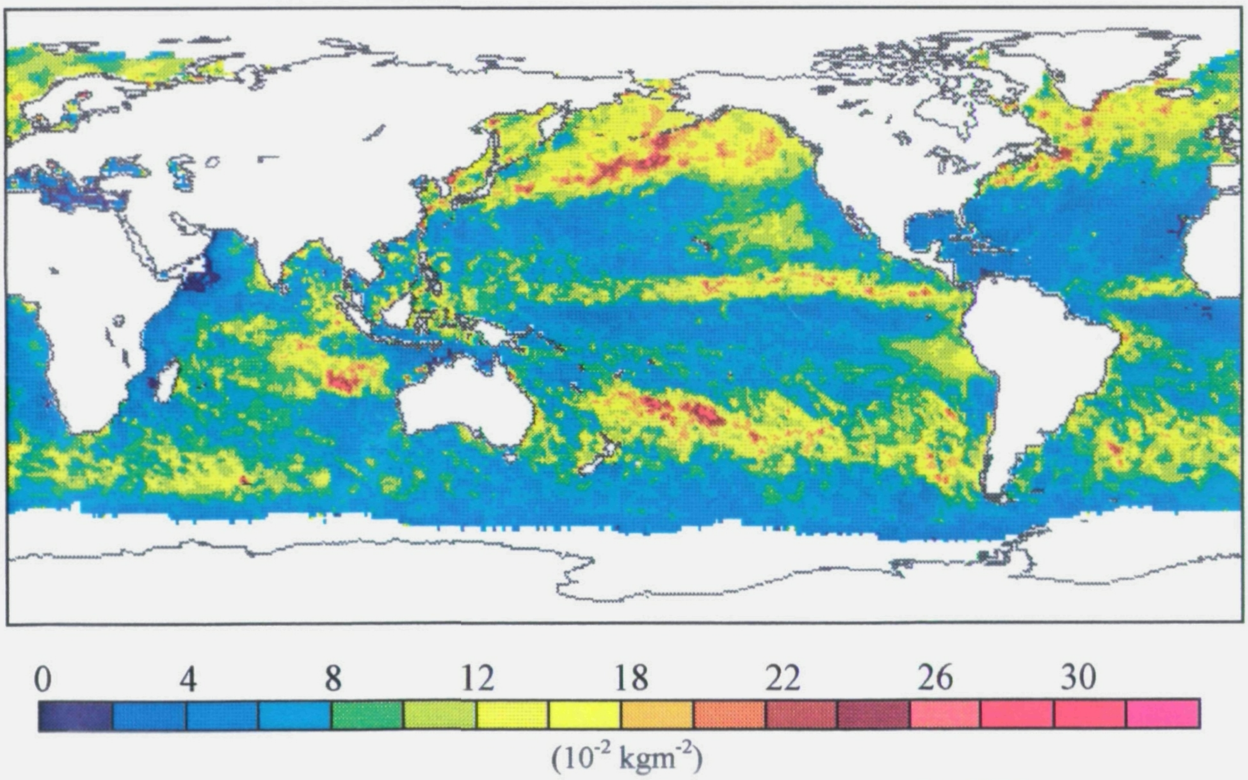

Figure 6. Total integrated cloud liquid water for July 10, 1989.

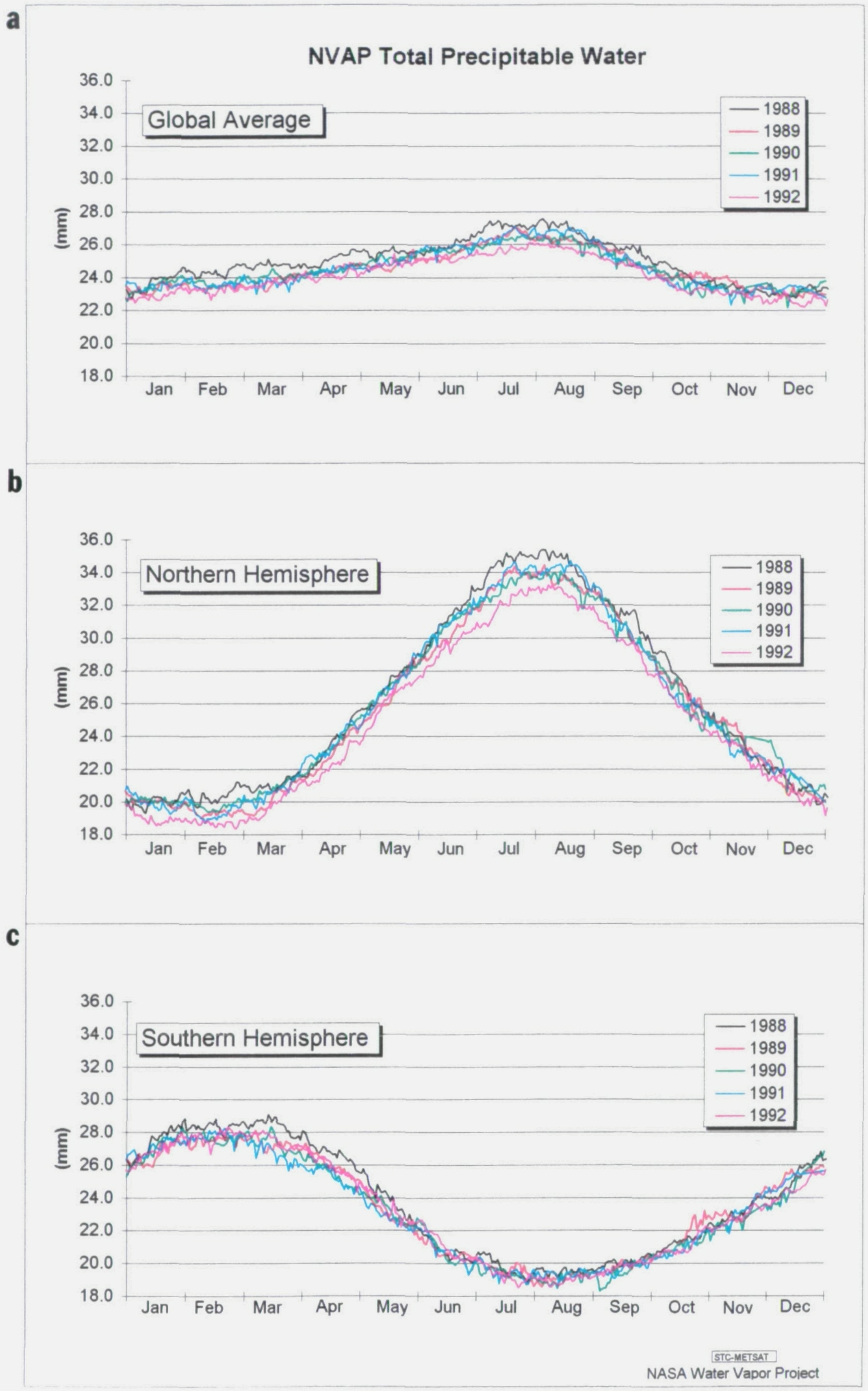

Figure 7. Total PWC annual cycle averages of the (a) global, (b) Northern Hemisphere, and (c) Southern Hemisphere, for 1988, 1989, 1990, 1991, and 1992.

of the total precipitable water global average for 1988, 1989, 1990, 1991, and 1992. The years match up quite well with each other except for the larger values in the first half of 1988.

In Fig. 8a the 1992 global average total PWC is combined with the three-layer global averages. Figure 8b depicts the total PWC plus the three level averages for the Northern Hemisphere (NH), and Fig. 8c contains the corresponding information for the SH. The plots show that more than 75 percent of the total PWC is below 700 mb and more than 90 percent is below 500 mb. The highest level exhibits more seasonal variability in the NH than in the SH, as does the midlevel. Again, this would be largely due to NH and SH differences. The seasonal variation of the global water vapor and some of the hemispheric differences are evident in Fig. 8a. One can see from a comparison of the three panels of Fig. 8 that the annual cycle is not symmetrical and the NH summer dominates. These variations were first reported by Wittmeyer and Vonder Haar (1994) using only the TOVS data.

It is seen that the time series of global PWC averages are sinusoidal in shape and have a maximum during June-July-August (JJA). The NH values have a maximum during the summer months (JJA) and a minimum in the winter. The differences between the NH and the SH are significant. The average temperature range of the NH is twice that of the SH, the summer maximum being much greater for the NH. This variation is due mainly to land and ocean differences (the NH contains most of the Earth's land area). The large NH land areas produce a greater seasonal temperature range than the oceans. The amount of water vapor in the air is related to the temperature through the Clausius-Clapeyron equation and, in combination with the strong summer convective maximum, results in the larger NH seasonal range. Other factors include the severe summer monsoon season in India (NH) and the lower water vapor concentrations in the SH contributed by the cold and elevated Antarctic Continent.

The estimates of global and hemispheric averaged PWC (in mm) from previous studies are listed in Table 1. The present study includes data for 1988—1992 and is in agreement with

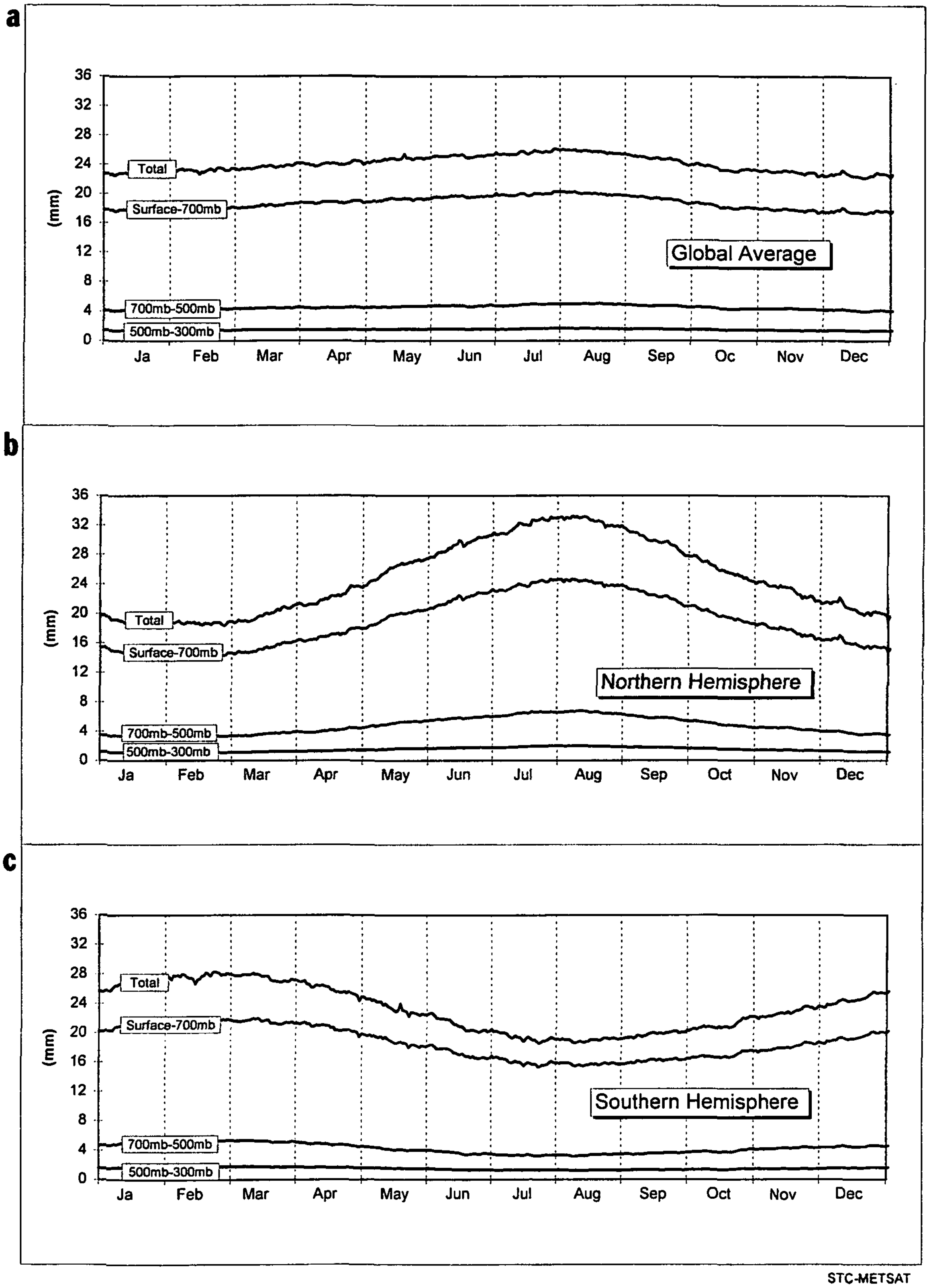

Figure 8. Total and layered PWC annual cycle averages of the (a) global, (b) Northern Hemisphere, and (c) Southern Hemisphere, for 1992.

previously published TOVS results. It is generally accepted that including the ECMWF the PWC results in excessively high values (Wittmeyer and Vonder Haar, 1994).

Table 1. Historic Estimates of Global and Hemispheric Averaged PWC (mm)

Investigator	Data	Time Period	NH	SH	GL
Present Study	3 sources	1988–1992	25.7	23.3	24.5
Wittmeyer and Vonder Haar (1994)	TOVS	1983–1989	24.3	22.5	23.4
Wittmeyer (1990)	ECMWF	1983–1988	28.7	26.1	27.4
Rosen et al. (1979)	MIT	1958–63, 1968	25.7		
Starr et al. (1969)	IGY	1957–1958			26.0
Trenberth (1981)	6 sources	1957–1978			25.3
Trenberth (1987)	ECMWF	1978–1985			28.6

In Table 2 the global and hemispheric averages are listed for the NVAP products from the layered and total column PWC (for the time period 1988–1992). As shown in the table, the expected larger PWC values occur in the NH versus the SH and the PWC values decrease with height.

Table 2. The NVAP Layered and Total Column PWC, Global and Hemispheric Averages (mm) for 1988–1992

NVAP 1988–1992	Northern Hemisphere	Southern Hemisphere	Global
500 mb–300 mb	1.52	1.39	1.46
700 mb–500 mb	4.96	4.23	4.59
Surface–700 mb	19.41	18.42	18.92
Total	25.68	23.35	24.52

The interannual variability of the annual averaged PWC, expressed as a standard deviation, is shown in Fig. 9. The use of annual averages removes the annual cycle of PWC. The most striking high variability areas are due to changes in the tropical circulation patterns caused by the El Nino - Southern Oscillation events during the time period. The low variability areas over the persistent strato-cumulus areas and also over the U.S. Pacific Northwest are easily observable. The variability of the PWC including the annual cycle is shown in Fig. 10. The most striking seasonal changes occur because of the strong Asian monsoon over India and China, the position of the Pacific and Atlantic ITCZs, and the severe drought in the Southeastern United States in 1988.

4.2 PAPERS AND PRESENTATIONS

During the 3-yr project effort, many presentations on the results of this work have been made. In November 1992, Dr. David Randel presented a paper at the International Symposium on Spectral Sensing Research (ISSSR) entitled "Combining Multi-Satellite Measurements with Different Spatial and Temporal Resolutions into a New High Resolution Water Vapor Data Product." This paper describes the production of the version 1 product.

In January 1993, Dr. Thomas H. Vonder Haar presented a paper "A New High-Resolution Water Vapor Data Product for Global Climate Studies" at the 1993 American Meteorological Society (AMS) Conference on Climate and Global Change. At that meeting, copies of the significant new results were provided to Dr. James C. Dodge of NASA. In early February 1993, the early NVAP results and methods were also presented by Dr. Vonder Haar to the GEWEX Science Steering Group and the Joint Scientific Committee for the World Climate Research Programme. A separate presentation of these results was made by Dr. Graeme Stephens to the Climate Research Committee of the U.S. National Academy of Sciences. On each occasion the early water vapor data set results were well received.

In August 1993, Dr. Vonder Haar presented a paper "A Pilot Study Blended Column Vapor Product for GEWEX" at the GVaP Meeting in Breckenridge, Colorado. In November 1993, Dr. Vonder Haar presented a paper entitled "Global Water Vapor and Cloud Liquid Water Analyses" at the Cloud Impacts on DoD Operations and Systems 1993 (CIDOS, 1993) Conference. This paper describes the background for the project, the production, and some of the first-year results. Dr. Randel gave a similar presentation at the Surface Radiation Budget

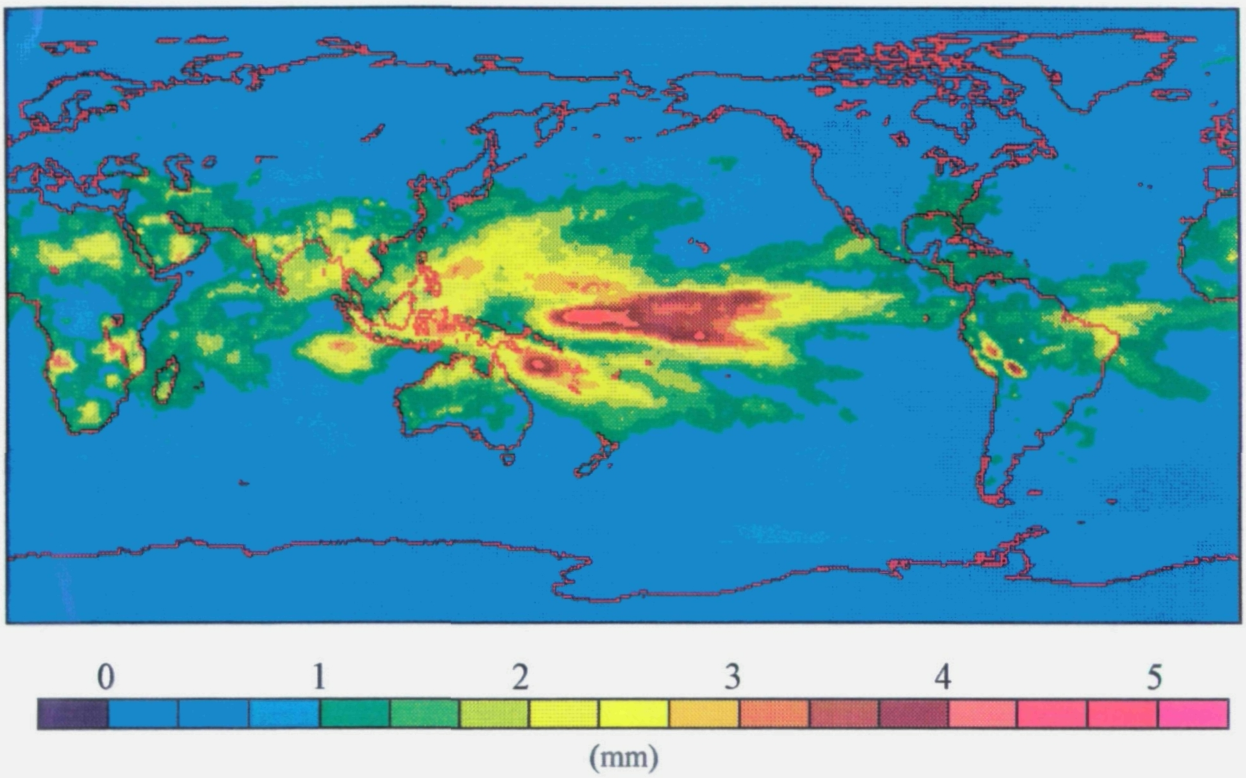

Figure 9. Interannual variability (standard deviation) of precipitable water from 1988–1992 from NVAP annual averages (annual cycle of PWC is removed).

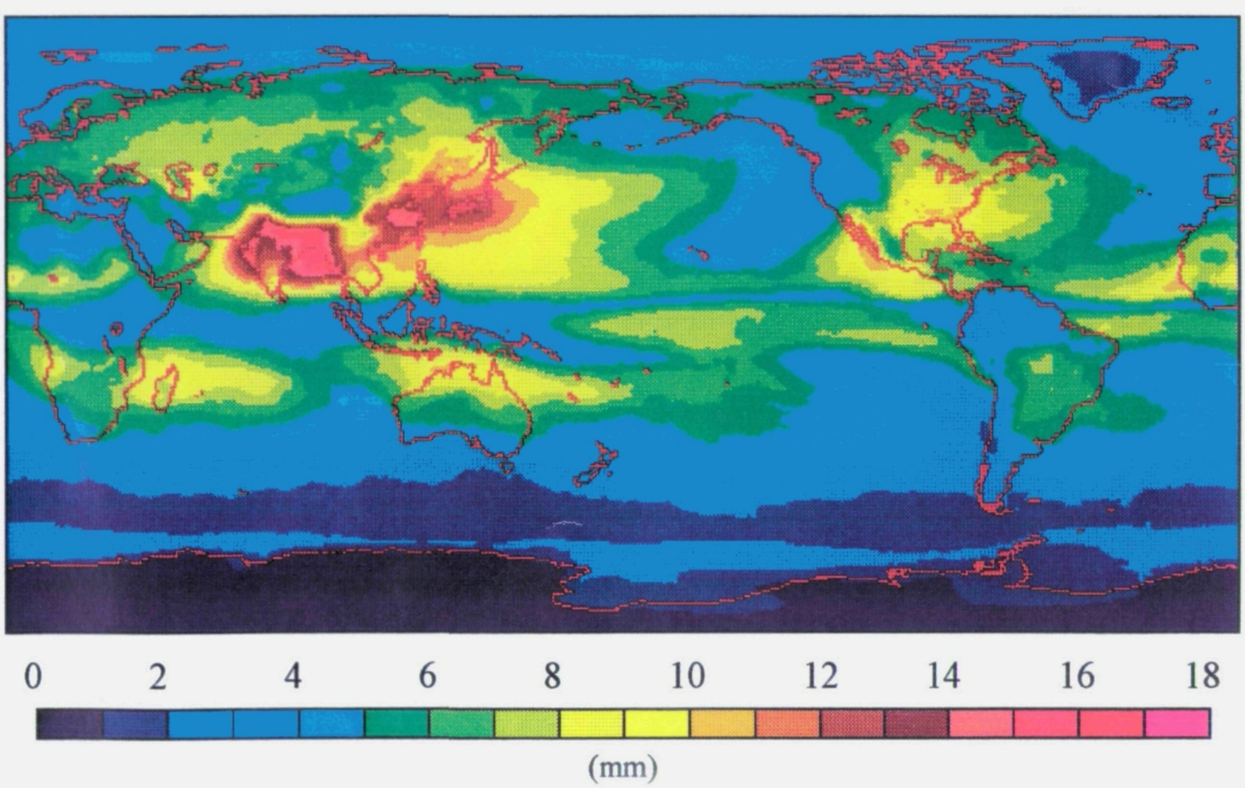

Figure 10. Interannual variability (standard deviation) of precipitable water from 1988–1992 from NVAP monthly averages (annual cycle of PWC is included).

Workshop in Williamsburg, Virginia, in November 1993, which led to the workshop recommendation to use the NVAP data set for future SRB modeling.

In January 1994, Mr. J. Ganse, Dr. Randel, and Dr. Vonder Haar gave a poster presentation entitled "Observational Investigation of the Water Vapor Distribution and the Water Vapor Forcing Effect" at the AMS Radiation Conference in Nashville, Tennessee. This presentation included results from a preliminary version of the merged PWC data for 1988 over the Continental United States.

In February 1994 and March 1994, Dr. Vonder Haar presented a paper entitled "Progress in Global Water Vapor and Cloud Liquid Water Data Sets" with some of the early year 2 results (layered products) at the Science Steering Group of GEWEX and at the Fifteenth Session of the Joint Scientific Committee for the World Climate Research Programme in Geneva, Switzerland. Mr. Mark Ringerud presented a paper in June 1994 at the AMS Seventh Conference on Satellite Meteorology and Oceanography in Monterey, California, entitled "Total and Layered Global Water Vapor Data Set," which describes the multilayer merged PWC production and results.

In October 1994, Dr. Vonder Haar gave a presentation entitled "New Water Vapor Data Sets and Analyses for Climate Studies" at the AGU-Chapman Conference on Water Vapor in the Climate System. Dr. Graeme Stephens made a presentation entitled "GVaP: The GEWEX Water Vapor Project" at the Global Ocean Atmosphere Land Surface (GOALS) and Tropical Ocean—Global Atmosphere (TOGA) Program panel meetings in October 1994. A paper entitled "A New Total and Layered Global Water Vapor Data Set" by Dr. Vonder Haar, Dr. Randel, Mr. Ringerud, and Dr. Stephens was published in the August 1994 GEWEX newsletter, with the figure for the total precipitable water for July 10, 1989, printed on the cover.

A video tape of the global water vapor maps was presented by Dr. Vonder Haar at the Annual AMS meeting in Dallas, Texas, in January 1995, containing the first year (1988) NVAP data set. The video was well received by the conference participants.

Dr. Vonder Haar presented the NVAP material at the National Academy of Sciences, GEWEX Conference in Tucson, Arizona, in February 1995. He also gave a presentation and displayed the video at the Joint Science Committee for the World Climate Research Programme in Pasadena, California, in March 1995. Dr. Randel will present a poster of NVAP products at the American Geophysical Union conference in June 1995.

4.3 SCIENTISTS AND RESEARCHERS CURRENTLY USING THE DATA SET

In order to introduce the new water vapor set to the scientific community, samples of this data set have been distributed to scientists and researchers who requested it. Table 3 is a listing of the scientists and researchers currently examining test data sets from the NVAP products and the nature of their scientific studies.

5. CONCLUSIONS

An extensive data set of global water vapor has been produced from three independent data sources. These products include total column integrated values and vertical layered values at three levels. Each of the individual input data sets has significant limitations: microwave retrievals are presently feasible only over oceans; infrared satellite techniques only work in the absence of significant cloud cover; and radiosonde measurements are made primarily over land and are widely spaced, not showing small scale water vapor variations. A comprehensive global data set must draw upon the strengths of each of these methods and utilize their advantages for all meteorological and geographical scenarios. The result is a combined product far better than any single input data set. In addition, a method has been derived using the layered PWC from radiosondes and TOVS retrievals to create a three-layer global PWC data set. By using this information along with the SSM/I PWC retrievals over ocean areas, the NVAP project has produced an extensive global three-layer data set. The complete 5-yr data set along with documentation and a users manual, will be available electronically through the Marshall Data Active Archive Center (DAAC) and the Fort Collins, Colorado STC-METSAT office, at the conclusion of this project (July 1995).

Table 3. Scientific Uses of NVAP Data Sets

Contact	Organization	Science
Wayne Darnell Nancy Ritchy	Langley DAAC	TOVS pathfinder
Jim Knowles	NASA Ames	CD-ROM data set
Teng-Kui Lim	GSFC	TOVS pathfinder
Rachel Pinker	Univ. Maryland	SRB model input
Stephen Tjemkes	Europe	ISCCP Compare
Jack Ganse	CIRA/CSU	GCIP area climatology
Tom Charlock Tim Alberta	LaRC	SRB model input
Paul Beaudoin	GSFC	TOVS pathfinder
Jean-Jacques Morcrette	ECMWF	ECMWF compare
Chris Lietzke Garrett Campbell	CIRA/CSU	Water vapor transports
Anthony Guillory	MSFC	Intercomparison
Er-Woon Chiou	LaRC	Upper tropospheric PWC
Ross Mitchell	NOAA/NESDIS	Correction to AVHRR vegetation index
Tonie VanDam	CIRES	GPS PWC verification
Jean Philippe Duvel	Lab de Met. Dynam.	Clear-sky greenhouse AMIP GCM intercomparison
Tak Wong Ed Harrison	LaRC	Radiation budget studies
Chris Lietzke	CIRA/CSU	Interannual PWC variability
Garrett Campbell	CIRA/CSU	ERBE studies
David Randel	CIRA/CSU	Water vapor radiative forcing
B.J. Sohn	Seoul Nat. Univ.	Interannual Indian Monsoon

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Thomas H. Vonder Haar, David L. Randel, Donald L. Reinke, Graeme L. Stephens, Mark A. Ringerud, Cynthia L. Combs, Thomas J. Greenwald, and Ian L. Wittmeyer

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Science and Technology Corporation
101 Research Drive
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Dr. James Dodge
NASA Headquarters, Code SED
300 E Street, S.W.
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13. ABSTRACT *(Maximum 200 words)*

There is a well-documented requirement for a comprehensive and accurate global moisture data set to assist many important studies in atmospheric science. Currently, atmospheric water vapor measurements are made from a variety of sources including radiosondes, aircraft and surface observations, and in recent years, by various satellite instruments. Creating a global data set from a single measuring system produces results that are useful and accurate only in specific situations and/or areas. Therefore, an accurate global moisture data set has been derived from a combination of these measurement systems.

Under a NASA peer-reviewed contract, STC-METSAT produced two 5-yr (1988–1992) global data sets. One is the total column (integrated) water vapor data set and the other, a global layered water vapor data set using a combination of radiosonde observations, Television and Infrared Observation Satellite (TIROS) Operational Satellite (TOVS), and Special Sensor Microwave/Imager (SSM/I) data sets. STC-METSAT also produced a companion, global, integrated liquid water data set. The complete data set (all three products) has been named NVAP, an acronym for NASA Water Vapor Project. STC-METSAT developed methods to process the data at a daily time scale and 1 x 1° spatial resolution.

14. SUBJECT TERMS
global moisture, NVAP, water vapor, precipitable water, cloud liquid water, SSM/I, TOVS, radiosonde, layered water vapor

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