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THE NVAP GLOBAL WATER VAPOR CLIMATE DATA RECORD: SCIENCE RESULTS AND PLANS FOR IMPROVEMENT AND CONTINUATION

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1. INTRODUCTION

The NASA Water Vapor Project (NVAP) began in the early 1990s as a NASA Pathfinder project to create a record of the distribution of Earth's water vapor on a daily basis using a variety of sensors. Since its inception, there have been several phases of NVAP, growing the dataset to include 14 years (1988-2001) of gridded total column and layered water vapor available over both land and ocean. The NVAP dataset is designed to be model-independent and relies mainly on satellite measurements; however historically, rawinsonde data has also been included. The early versions of NVAP included layered and total precipitable water (TPW) on a 1° x 1° grid combining water vapor measurements from radiosondes, the TIROS Operational Vertical Sounder (TOVS) and Special Sensor Microwave / Imager (SSM/I), while the "next generation" dataset, NVAP-NG (2000-2001) added data from the Advanced Microwave Sounding Unit (AMSU) and Special Sensor Microwave / Temperature-2 (SSM/T2). Additional differences between NVAP and NVAP-NG are shown in Table 1. Retrieved atmospheric water vapor values from each instrument were merged using a weighting scheme based on the perceived accuracy of each measurement (Figure 1). Gaps due to non-existent or bad data were filled using spatial and temporal averaging techniques.

The availability of NVAP data over both ocean and land makes it useful for a wide variety of research projects, from studies of global climate to studies of regional atmospheric features. As an example of one of the many uses of NVAP, Figure 2 displays a time series of anomalies of precipitation, NVAP TPW, and lower tropospheric temperature. NVAP data has also been used in the study of the Madden-Julian Oscillation (MJO; Maloney and Esbensen, 2003), as well as in the assessment of the NCEP-NCAR Reanalysis-2 project (Amenu and Kumar, 2005), and many more. The dataset for 1988-2001 can be found online via the NASA-Langley DAAC: http://eosweb.larc.nasa.gov/PRODOCS/nvap/table_nvap.html

Here, we discuss the current NVAP dataset and highlight some of its shortcomings. A new effort supported by the NASA Making Earth Science Data Records for Use in Research Environments (MEaSUREs) program is underway to improve and extend NVAP (NVAP-M)

2. NEED FOR REANALYSIS AND EXPANSION

Much of the initial stages of this project have been spent re-familiarizing ourselves with the existing NVAP dataset. By doing this, we were able to identify some of the improvements we would like to make in NVAP-M. Specifically, by creating global, ocean-only, and land-only Hövmoller diagrams of total and layered zonal water vapor anomalies, we were able to locate distinct discontinuities in the dataset. These discontinuities can be attributed to time-dependent biases, all due to some change in processing the input data. These discontinuities are highlighted in the Hövmoller diagram in Figure 3. The causes and potential solutions for them are outlined in Table 2.

In addition to correcting the biases in the existing dataset, expanding the period of coverage from 1987 through 2010 will increase the length of the dataset by 10 years. The increased temporal coverage and bias removal will result in a stable data record that can be used in weather and climate studies and for analyzing trends and variability.

In expanding the dataset, we also gain access to a wealth of new data sources that has become available since the mid-1990s. These include one additional SSM/I, improved infrared sounders, the instruments flying in the A-Train satellite constellation, quality controlled radiosonde data, and TPW information derived from GPS satellite information. Figure 4 shows the temporal coverage of the instruments used in previous versions of NVAP as well as many of the newer sensors that will be considered for use in NVAP-M.

3. UPDATES AND EXPANSION IN NVAP-M

3.1 User-focused datasets

In addition to the removal of time dependent biases in the NVAP dataset, one of the main improvements that we intend to make in NVAP-M will

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be the creation of several user-specific datasets. Currently, all users of NVAP have access to a single dataset regardless of their research needs. It is our goal to adopt a three-tiered approach that can meet the needs of different types of researchers. For example, users performing case studies of specific meteorological events would require as much spatial and temporal coverage as possible, and may not be as concerned about time dependent biases. The planned “synoptic” version of NVAP would include as many inputs as possible, reducing the potential for areas of non-coverage and potentially increasing temporal resolution over versions geared towards studies of variability and climate.

For those users interested in modeling and variability analysis, the planned “interannual” version of NVAP would rely on high quality retrievals and attempt to reduce year-to-year variability. A highly stable “decadal” version of the NVAP dataset would focus on keeping the most consistent and stable TPW inputs and retrieval methodology through time. While potentially sacrificing spatial coverage and temporal resolution, consistency through time is an important factor when using data for climate studies.

3.2 183 GHz Passive Microwave Measurements

In the original production of NVAP, 183 GHz measurements were used only after 2000; however, as can be seen in Figure 5, this channel has been available on DMSP satellites since the early 1990s. The available record, shown in the red, blue, and grey lines, indicates relatively stable observations between the sensors that track well through time. There is also the benefit of temporal overlap, with several spacecraft carrying this common channel simultaneously. Measurements from the 183 GHz channel are particularly attractive in that they are relatively insensitive to any clouds in the field of view.

There is great similarity in spectral coverage on the 183 GHz water vapor absorption line between each of the satellites shown in Fig. 5. At 183 ± 1 and 183 ± 3 GHz, all instruments shown have nearly identical spectral sampling and very low noise. The Advanced Technology Microwave Sounder (ATMS) instrument on the NPOESS Preparatory Project (NPP) satellite is very similar to heritage instruments, and may possibly become available late in the project.

3.3 Dataset Acquisition

The focus of work since NVAP-MEaSUREs project kickoff has been to acquire and understand datasets which will be used for both input and validation. Major progress has been made on climate quality radiosondes (Durre et al., 2006), TOVS retrievals, and GPS total precipitable water (Wang et al., 2007). Each of these datasets has distinct advantages for use within NVAP-M, and when used in concert, can account for some of the disadvantages of the others. The types of data being collected include sources that were useful in the previous NVAP datasets, as well as newly developed datasets that have come into existence in recent years. While much of this data is currently available in-house, some must be acquired from outside sources.

Since passive microwave measurements are most reliable over ocean, it is important to identify potential sources of TPW measurements over land. These include infrared soundings from the TOVS instrument package, as well as point measurements from both GPS and radiosonde. The TOVS package has been flying in some form for over 20 years, and has an added benefit of supplying information about the vertical structure of the atmospheric water vapor. We have acquired the entire available dataset of both the TOVS Path A and Path B retrievals via the DAAC at NASA-Goddard. Unfortunately, the Path A and B retrievals do not exist for the entire time period to be covered by NVAP-MEaSURES. For this reason, the International ATOVS Processing Package (IAPP; Li et al., 2000) is being explored for inclusion within NVAP

Point measurements from the Integrated Global Radiosonde Archive (IGRA) are available from the National Climatic Data Center (NCDC). The IGRA supersedes the Comprehensive Aerological Reference Dataset (CARDS, Eskridge et al. 1995) and employs rigorous quality control measures to ensure the best data possible. The creation of IGRA is good news for NVAP, in that the quality of the radiosonde water vapor record has increased since the initial NVAP efforts. Like the TOVS retrievals, vertical structure information can be obtained from the radiosonde dataset.

Surface-based Global Positioning System (GPS) TPW has never been used in NVAP, but this data has proven to be an accurate validation source of TPW in numerous studies (Wang and Zhang, 2008). Although there are slightly fewer available sites from this dataset than from the IGRA dataset, dense networks of ground-based GPS receivers in the United States, Europe, and Japan provide very good land coverage in these areas. Water vapor measurements from GPS are available currently from 1997 through 2007, and the producers of this data intend to continue updating the archive for the next few years (Junhong Wang, NCAR, personnel communication). Overland GPS measurements of PW have the benefit over measurements from infrared sounders in that they are valid regardless of the weather conditions, and are available with high temporal (2 hour) resolution; however they provide only measurements of the total column water vapor and have no information regarding the vertical structure.

3.4 Design Decisions to Be Made

As we continue to amass data in these first stages of NVAP-M, there are still several design considerations to be made regarding a variety of factors throughout the process. The current thinking for the spatial and temporal resolution of the final product is 1º x 1º, twice daily, however with the implementation of the three-tiered approach and use of new datasets, it may be possible to increase this resolution, particularly for "NVAP-synoptic". The NASA Modern Era Retrospective-analysis for Research and Applications (MERRA) project is produced at ½° x ⅔° resolution four times daily, so NVAP compatibility with this dataset is desirable.

Since the last processing of NVAP, there have been many developments improving physical retrievals of passive microwave radiometer data. While time-constraints of this project will prevent us from developing a new retrieval algorithm, we are currently researching these improved retrievals, and weighing them against the Greenwald et al. (1993) algorithm used for SSM /me in previous versions of NVAP. The choice of TOVS retrieval is currently focused on the IAPP.

Finally, although employing all of the available datasets would provide the highest spatial and temporal resolution in the final product, it is necessary to reserve some of these sources for independent intercomparison once the NVAP-M dataset is complete. Additionally, some measurements might add undesirable discontinuities to the dataset. For example, point data from radiosondes merged with larger scale data from satellites may result in "bull's-eyes" of anomalously high or low TPW values.

4. Conclusions

A reanalysis and extension of the NVAP dataset is underway under the NASA-MEaSUREs program. The resulting dataset will provide model-independent multi-sensor water vapor information over both ocean and land over the 24-year period from 1987 through 2010. This represents a 10 year increase in data coverage over the existing NVAP dataset, which can be acquired at http://eosweb.larc.nasa.gov/PRODOCS/nvap/table_nvap.html. While the existing dataset has been widely used in the science community, it contains time-dependent biases and represents a climactically short period of record. These factors, along with a growing number of available water vapor measurements, indicate a need and opportunity for this reanalysis and extension.

Current work is focusing on researching and compiling total column water vapor and water vapor profile datasets from 1987-present as well as investigating the ideal satellite retrieval algorithms and merging strategy to create the dataset. The resulting dataset will cater to multiple potential user needs, include a wider variety of sources, and will potentially increase the spatial and temporal resolution over previous versions.

5. Acknowledgements

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Table 1. Comparison of NVAP with NVAP – Next Generation

Description of NVAP By Processing Period	
NVAP (1988-1999)	NVAP-Next Generation (2000-2001)
• Global 1 degree grid • Daily • Total column water vapor • Cloud liquid water • 4 layers of water vapor • Inputs from SSM/I, TOVS, rawinsondes	• Global, ½ degree grid • Twice daily and daily • Total column water vapor • Cloud liquid water • 5 layers of water vapor • Data source and retrieval performance flags • Inputs from three SSM/I's, ATOVS, AMSU, SSM/T-2, TMI, and TOVS Pathfinder

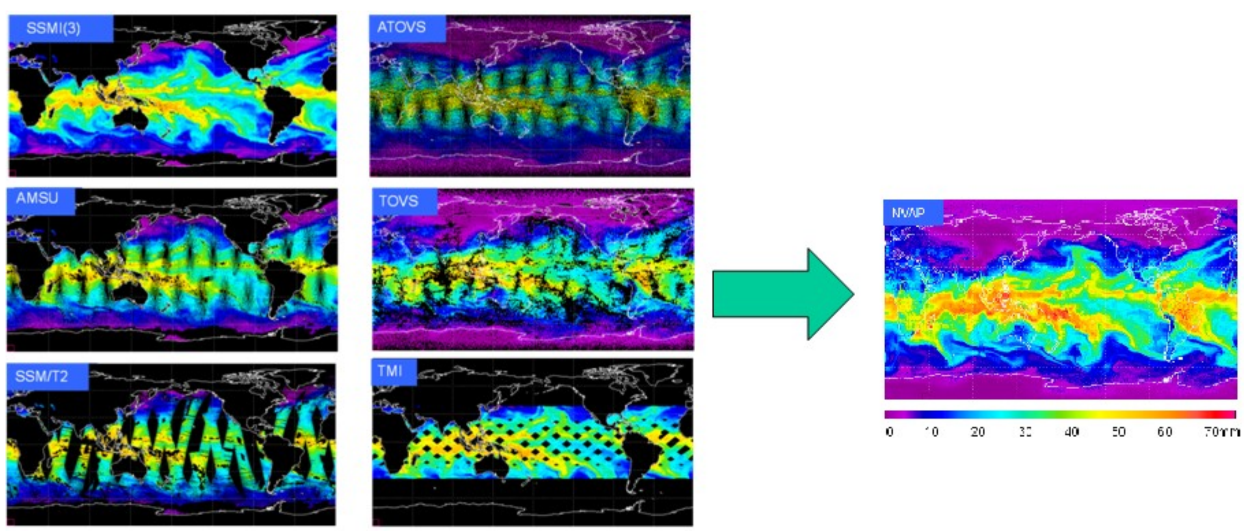

Figure 1. Illustration of multiple satellite datasets being merged together to create the NVAP global TPW product. TPW for January 1, 2000 is shown as an example.

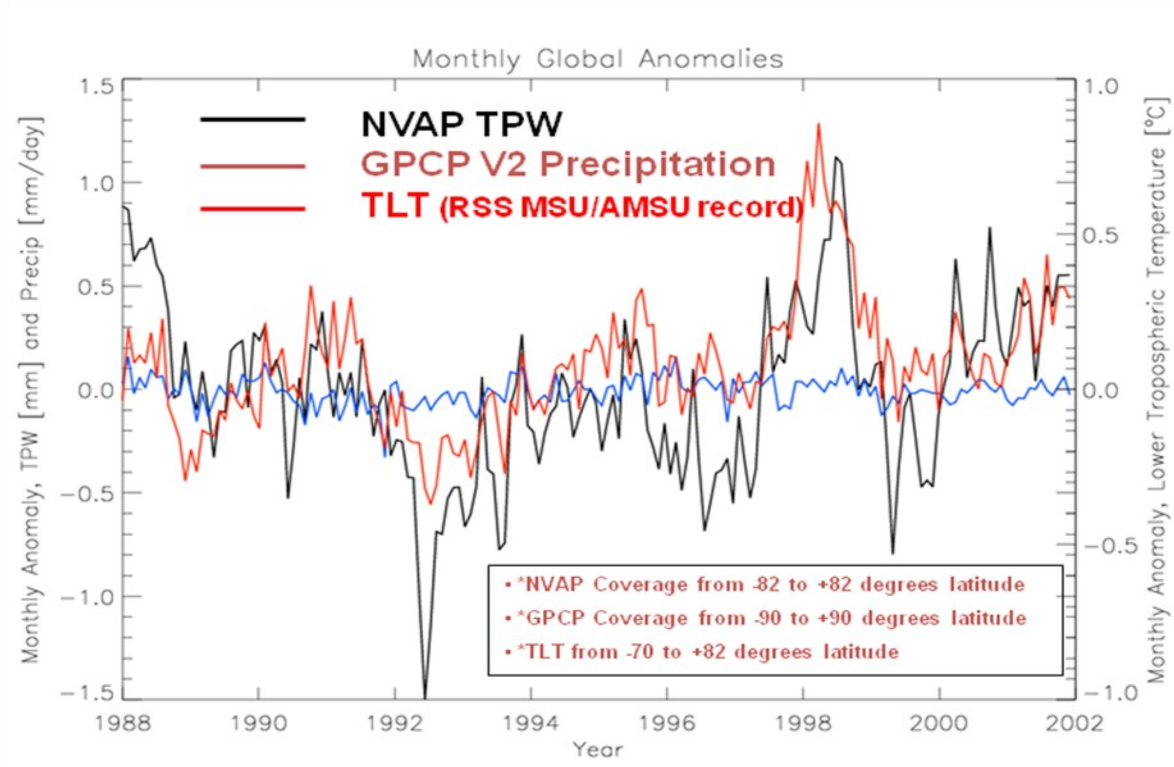

Figure 2. Anomaly time series of NVAP TPW, GPCP precipitation, and temperature of the lower troposphere.

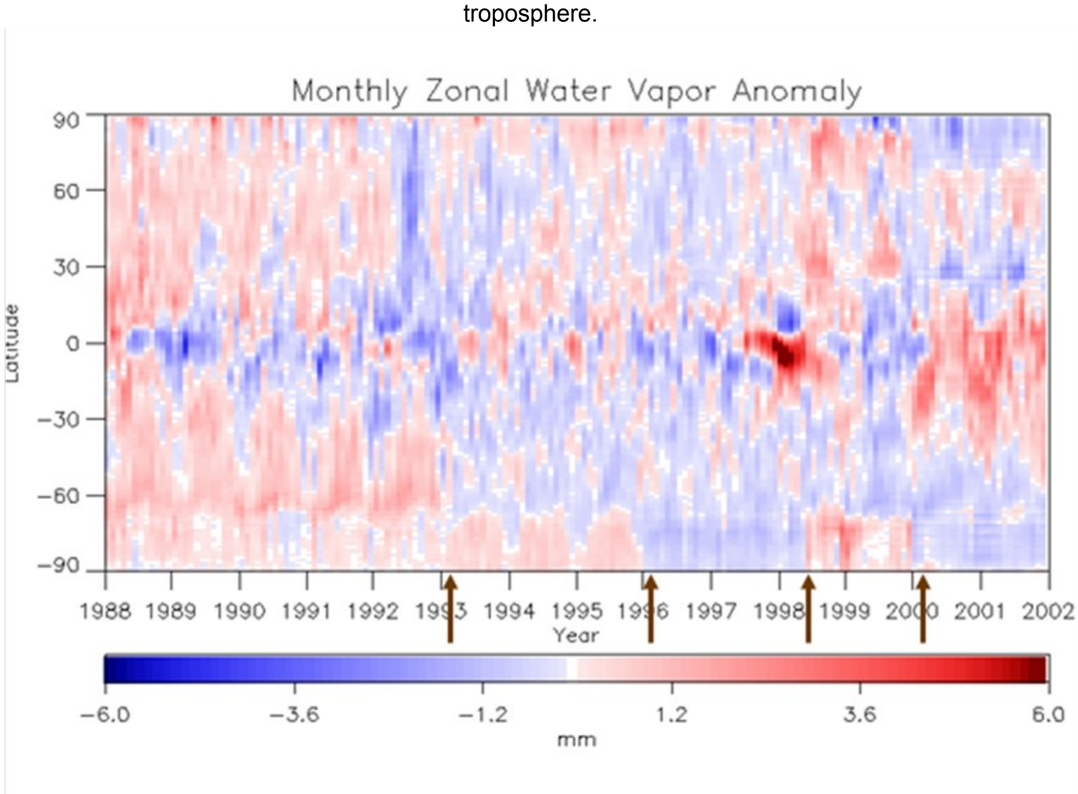

Figure 3. Zonal TPW anomaly from NVAP, with four time-dependent discontinuities highlighted. These discontinuities are due to differences in retrievals, processing algorithms, and input datasets used, and some are more apparent in the NVAP layered water vapor products.

Table 2. Outline of the major causes of time-dependent biases in the existing NVAP dataset, and potential solutions to remove them in NVAP-M.

Major NVAP Time-Dependent Biases (1988 – 2001)	
Time Dependent Bias	**Solution**
TOVS: 1. Changes in NOAA operational TOVS algorithm through time.	**Use a consistent climate-oriented retrieval such as NASA Pathfinder Path A (Susskind et al. 1997).** **AIRS Intercomparison**
SSM/I: 1. 22 GHz channel not used 1988-1992 2. Precipitation and sea ice detection methods vary 3. Need intercalibrated time series of Tb's using new instrument knowledge.	**Apply the same algorithm through time** **Chris Kummerow (CSU) working on SSM/I Tb time series**
Radiosonde: 1. Varying quality control methods 2. 2000 – 2001 did not use radiosonde	**Use new climate-oriented IGRA dataset (Durre et al. 2006)**
Miscellaneous: 1. Topography masking causes TPW too high over high terrain (1988 – 1992) 2. Coastline mask changed through time.	**Use single high resolution (< 10 km) global topography source such as GTOPO30**

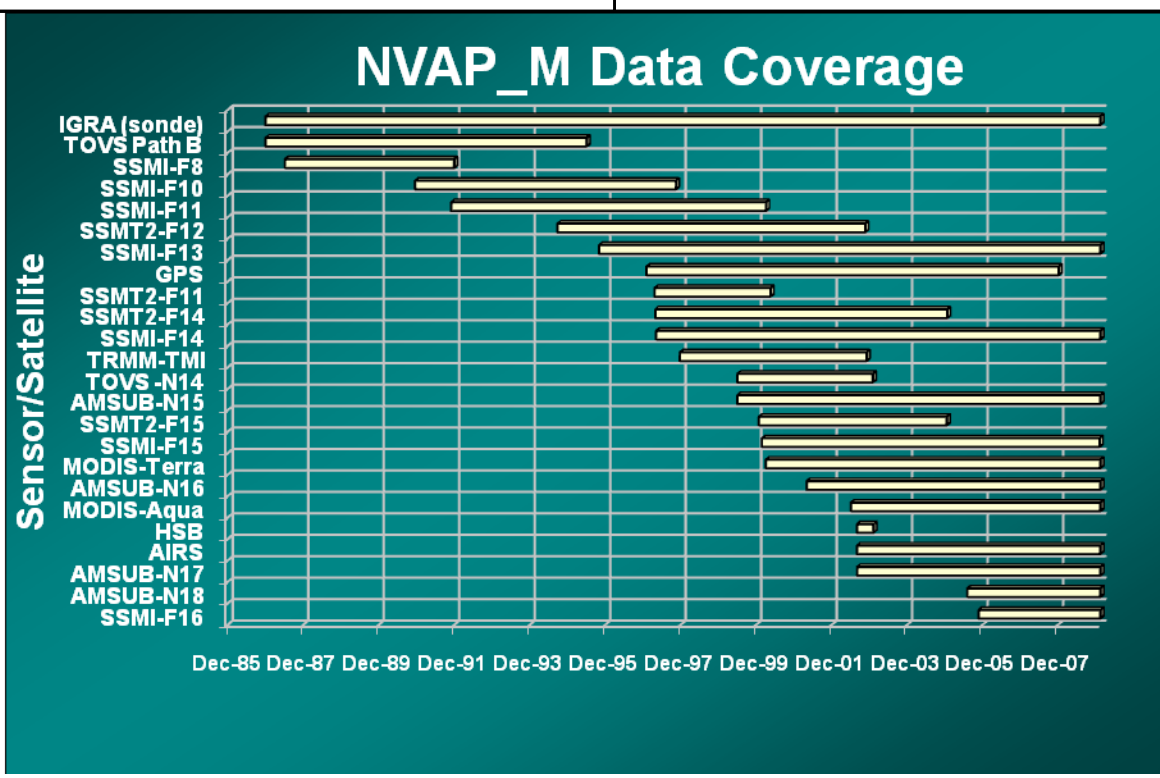

Figure 4. Summary of some of the datasets available for NVAP-M and their temporal coverage through 12/31/2008.

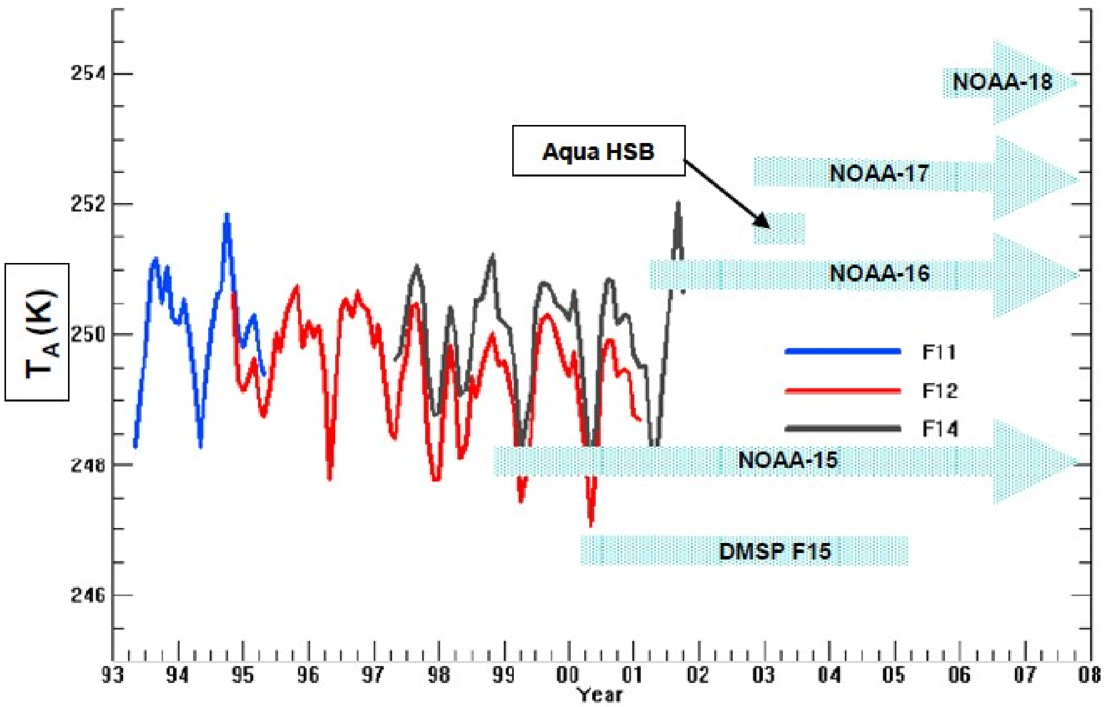

Figure 5. Time series of satellites with candidate 183 GHz measurements for upper tropospheric moisture. The monthly mean antenna temperature from 10º N to 10º S for the 183 ± 1 GHz channel on the SSM/T-2 instrument at near-nadir for the F11, F12 and F14 spacecraft is shown (blue, red, grey lines). Periods of coverage for the SSM/T-2 on F15 and the AMSU-B sensors, as well as the short-lived HSB instrument on Aqua are also shown.