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EXTENDING THE 12-YEAR NVAP GLOBAL WATER VAPOR DATASET INTO THE 21ST CENTURY

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1. INTRODUCTION

The NASA Water Vapor Project (NVAP) is a NASA Pathfinder project designed to measure the distribution of Earth's water vapor from satellite on a daily basis. NVAP data now covers the period 1988 – 1999 (Vonder Haar et al 2003). NVAP from 1988 – 1999 blended radiosondes, Tiros Operational Vertical Sounder (TOVS), and Special Sensor Microwave / Imager (SSM/I) water vapor retrievals to create a global, daily, 4-layer, 1 degree resolution water vapor product (Randel et al. 1996). NVAP results have been referenced in more than 25 AMS refereed publications to date, and an equal number of non-AMS publications, and the consistency of the dataset has been independently verified by Simpson et al (2001).

In this paper, we describe the extension of the original NVAP dataset into the 21st century with the follow-on NVAP-Next Generation dataset (NVAP-NG). The Climate Data Records (CDR's) developed by NVAP-NG will employ up-to-date instruments and retrievals while maintaining consistency with previous twelve years of NVAP results. The CDR's generated from NVAP-NG will be archived within the NASA Distributed Active Archive Center (DAAC) system.

An important use of NVAP data is in general circulation model validation. A design philosophy of NVAP-NG is to make it independent of forecast model data. For instance, in NVAP-NG we create our own atmospheric temperature profile from available satellite data rather than using model temperature fields such as from the NCEP Reanalysis.

Consistency with the past is essential in order to monitor Earth's water vapor fluctuations on timescales greater than decades. With the plethora of satellite instruments becoming available by 2003, including the NASA AQUA platform, our ability to measure Earth's water vapor will continue to improve.

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2. HERITAGE OF NVAP-NG

NVAP-NG addresses several key NASA Earth science questions which have been posed by Asrar et al (2001). Figure 1 shows these questions to which NVAP-NG is particularly relevant. An example result from NVAP is shown in Figure 2, the global mean water vapor observed from 1988-1999.

NVAP-NG builds upon the successful foundation of NVAP. With any satellite-derived CDR, there exists the issue of seamlessly merging new sensors and algorithms to create a product which is consistent in time. Figure 3 shows a timeline of algorithm and data changes in the original NVAP. Removal of these algorithm changes is a reason to consider reanalysis of the entire NVAP dataset (Suggs et al 2001), but such work is beyond the scope of the NVAP-NG project.

With NVAP-NG, we have the concept of a "bridge" period, where we can compare the heritage NVAP products with the NVAP-NG products. Our bridge period is for the last few months of 1999 and first few months of 2000. The official production of NVAP-NG will cover 2000 and 2001 and will be delivered to the NASA DAAC in late summer, 2003.

3. SCOPE OF NVAP-NG

NVAP-NG will merge retrievals and products from low-earth orbiting satellite platforms and create a global, twice-daily, ½ degree resolution, multi-layer water vapor product for the years 2000 and 2001. NVAP-NG gridded products will contain water vapor mixing ratios at 1000, 850, 700, 500, and 300 hPa as well as mean precipitable water between these layers . The total column water vapor (TCWV) will also be determined at this resolution. In order to insure continuity with NVAP, products will be created on a once per day grid in order to fill in any blank spots missed in a 12 hour grid due to incomplete satellite coverage. Additional products of the processing such as cloud liquid water will be archived as well.

Figure 4 shows a list of available satellite platforms during the NVAP-NG timeframe. New instruments to be used in NVAP-NG, which weren't used for NVAP, are the Advanced Microwave Sounding Unit-B (AMSU-B) instrument on board the NOAA-15 and NOAA-16 satellites and the Special Sensor Microwave/Temperature-2 (SSM/T-2) instrument on board the Defense Satellite Meteorological Program (DMSP) F-12, F-14, and F-15 satellites. The presence of three SSM/I instruments should yield a product with few data gaps over the oceans. NVAP often had only one or two SSM/I instruments, while NVAP-NG will employ three SSM/I instruments throughout 2000 and 2001.

Certain satellite instruments will be withheld as inputs to the NVAP-NG product. The Tropical Rainfall Measuring Mission Microwave Imager (TMI), the TOPEX-Poseidon microwave radiometer, and the Moderate Resolution Imaging Spectrometer (MODIS) instruments will be withheld. This allows the possibility of using these instruments as outside sources of validation, as has previously been done with the TOPEX-Poseidon instrument for NVAP (Simpson et al 2001).

Retrieval products from the Advanced TOVS sounding product (ATOVS) from NOAA-15 and NOAA-16 will be used. TOVS Pathfinder Path A gridded results will be blended into NVAP-NG as well. The ATOVS and TOVS instruments have the key property that they provide soundings over land, whereas the microwave instruments are only performing retrievals over water at this time due to uncertainties about land surface emissivity.

Except for the TOVS and ATOVS components of NVAP-NG, the retrievals will be run in-house (AMSU-B, SSM/T-2, SSM/I). The SSM/I retrieval has been described in Randel (1996) and Greenwald (????), while AMSU-B and SSM/T-2 will use the optimal estimation (OE) scheme of McKague et al (2001) and Mckague et al (2003, Poster 4.14 this conference). The OE scheme is a physical retrieval that minimizes a cost function involving the measurements and climatology. An advantage to the OE scheme is it returns diagnostics reporting the relative weight of the input data and climatology in the solution.

The AMSU-B instrument on NOAA-15 has a well-known Radio Frequency Interference (RFI) problem (Atkinson, 2001) which occurs throughout 2000 and 2001. Fortunately, a transmitter reconfiguration after September 1999 and corrections ameliorate the problem considerably. We have obtained the raw level 1b data from NESDIS and have implemented the correction to reduce the noise of this instrument to below 2 K. The process of constructing NVAP-NG can be visualized as a series of shells, each containing a process. At the common center of the shells is the final merge which takes all of the results obtained beforehand and creates the NVAP-NG products which the science communities will use. Figure 5 is a graphic of the shell concept. The outermost shell is the input satellite data, whether products or raw radiances. The radiances are quality controlled, matched up with ancillary data, and brought into the next shell, where retrievals are run. Conditions where a retrieval is not possible, such as precipitation or sea ice, are detected at this stage. Each satellite is retrieved independently of other satellites. Then the files containing the retrieved fields for a 12-hour period are blended together. Statistics are kept to evaluate the error associated with the retrieval in each ½ degree grid box. A satellite identification flag at each grid box at each time will indicate which instruments were used. Note in Fig. 5 that quality control (QC) occurs at each of the shells. This can take the form of visual inspection of the input and output for artifacts like instrument noise. Physical consistency can also be used as tool to quality control, for instance making sure Earth's global average water vapor is within a few millimeters of the 25 mm global average value determined from NVAP.

A preliminary list of gridded fields to be produced from NVAP-NG is shown in Figure 6. All products are global at ½ degree, twice daily resolution. Some daily grids will be produced as well. All of the fields from the original NVAP are encompassed in the NVAP-NG family of products, this is one way to insure backwards-compatible datasets. Additional diagnostic fields may be added as we continue our production of NVAP-NG.

4. SAMPLE RESULTS

The NVAP-NG development team has made a considerable effort to employ the most current instrument calibration and algorithms. We are able to improve the quality of NVAP-NG by utilizing published results which were not available during the NVAP era. An example of this is shown in Figure 7. We have applied the conversion from antenna temperature to brightness temperature (antenna pattern correction or APC) as published in Colton and Poe (1999). This amounts to a fine tuning of the brightness temperatures of a couple of Kelvin, but normalizations like this are critical in long-term climate research, where the sought signal may be buried within instrument biases and noise. An increase of microwave brightness temperature by 1 K will make Earth appear to have suddenly become more moist. Figure 7, shows the result of improved calibration on the NVAP water vapor anomalies. Starting in mid-1995, new SSM/I calibration caused a water vapor anomaly adjustment of 0.3 – 0.8 mm based on applying the Colton and Poe (1999). If inter-satellite calibration is not been handled carefully, adding a new SSM/I (or conversely removing an old one) can cause what appears to be a jump in the climate record. In order to progress into the NVAP-NG timeframe with our SSM/I retrieval – which was developed before we had detailed knowledge of each SSM/I APC – we needed to be able to bring our past results forward in time so our retrieval was consistent.

Figure 8 shows a daily gridded field of 500 hPa mixing ratio retrieved from the SSM/T-2 F-14 instrument on July 1, 1999. This is from a full physical retrieval where the mixing ratio and temperature profiles are allowed to vary, as well as surface emissivity and cloud liquid water. In the case of SSM/T-2, we get an initial guess for cloud liquid water from the SSM/I and for AMSU-B we use the AMSU-A retrievals from the

Microwave Sounding and Precipitation Products System (MSPPS) of NESDIS.

5. CONCLUSIONS

The NVAP-Next Generation (NVAP-NG) water vapor dataset will be produced for the years 2000 and 2001. We will compare the NVAP-NG results with the heritage NVAP results for the end of 1999 and beginning of 2000 as a bridge into the future. NVAP-NG will use new instruments and methods to create a model-independent global water vapor product for use by the science community. Products from NVAP-NG will be available at a NASA DAAC in late summer 2003.

Originally it was hoped that the NASA AQUA platform would be available for use in NVAP-NG, but AQUA was not launched until May 2002. AQUA carries the Atmospheric Infrared Sounder and the Advanced Microwave Scanning Radiometer (AMSR). An AMSR is scheduled to be launched on the ADEOS-2 satellite in late 2002. The DMSP F-16 satellite, scheduled for launch in 2003, will carry the Special Sensor Microwave Image/Sounder (SSMIS), which combines the functionality of SSM/I and SSM/T-2. Once NVAP-NG is completed through 2000 and 2001, the next task will be to extend our global water vapor Climate Data Record to 2002, which will mark the fifteenth year of NVAP monitoring Earth's dynamic water vapor.

6. ACKNOWLEDGMENTS

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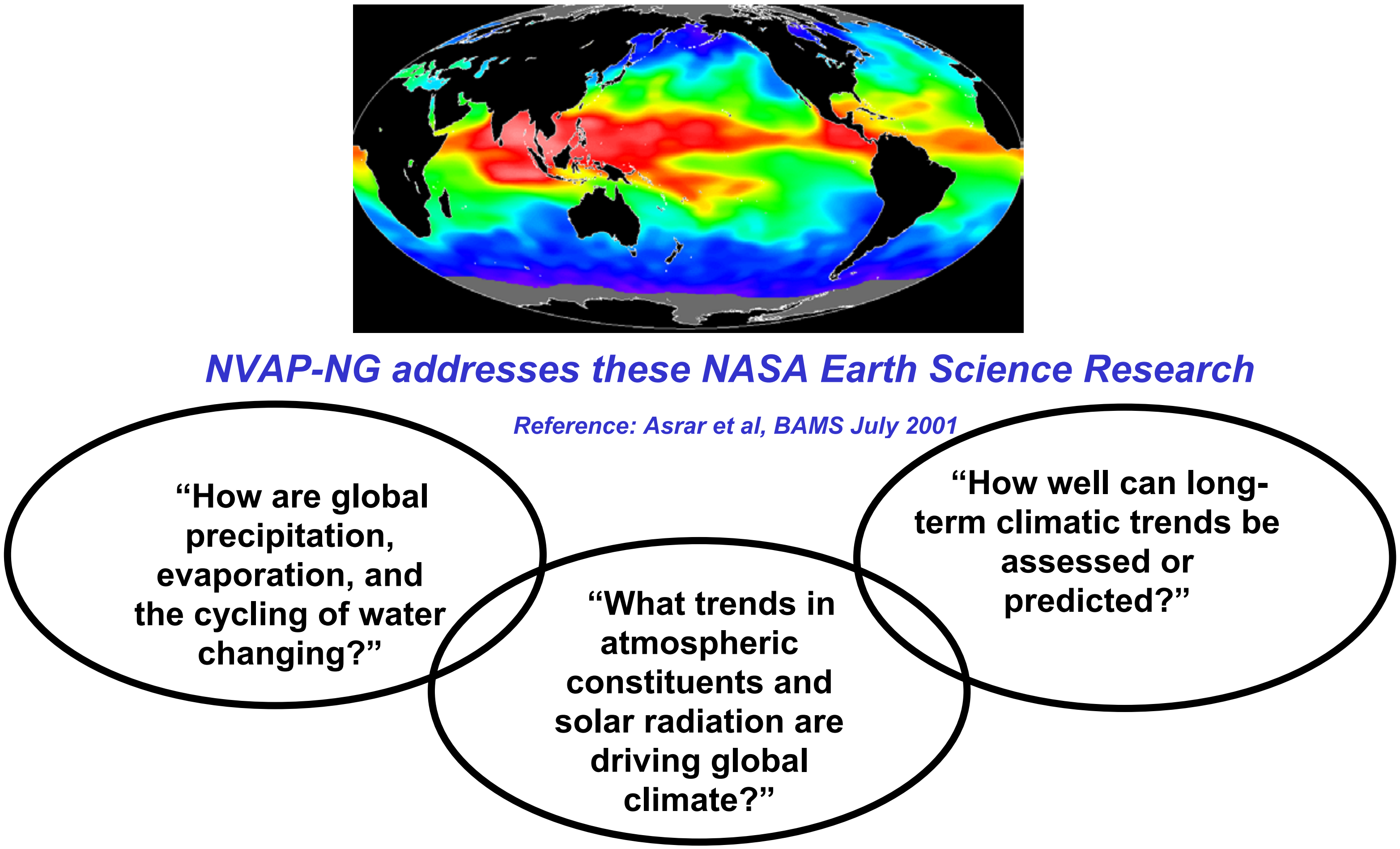


Figure 1: Key NASA earth science questions (Asrar et al 2001) addressed by NVAP.

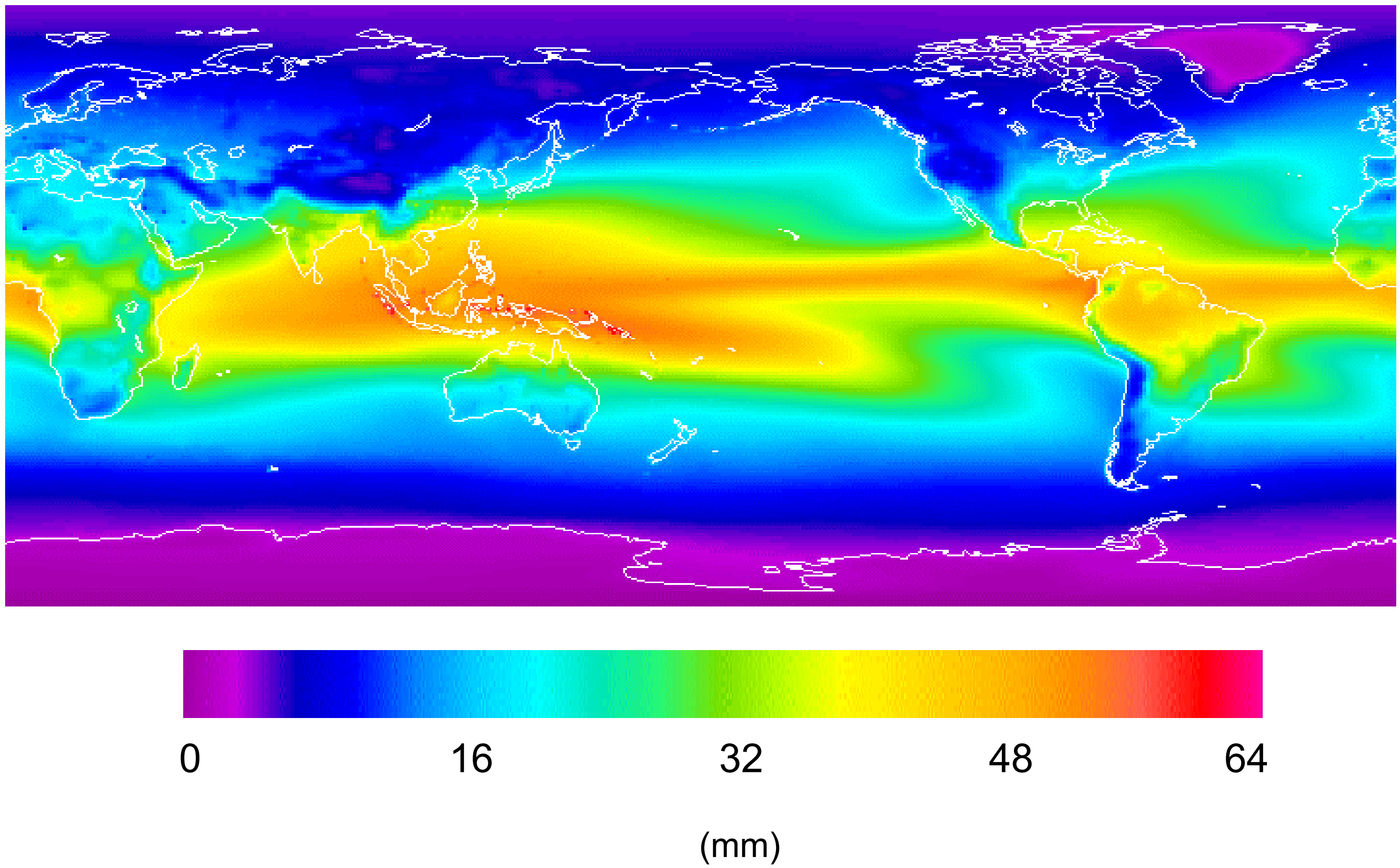
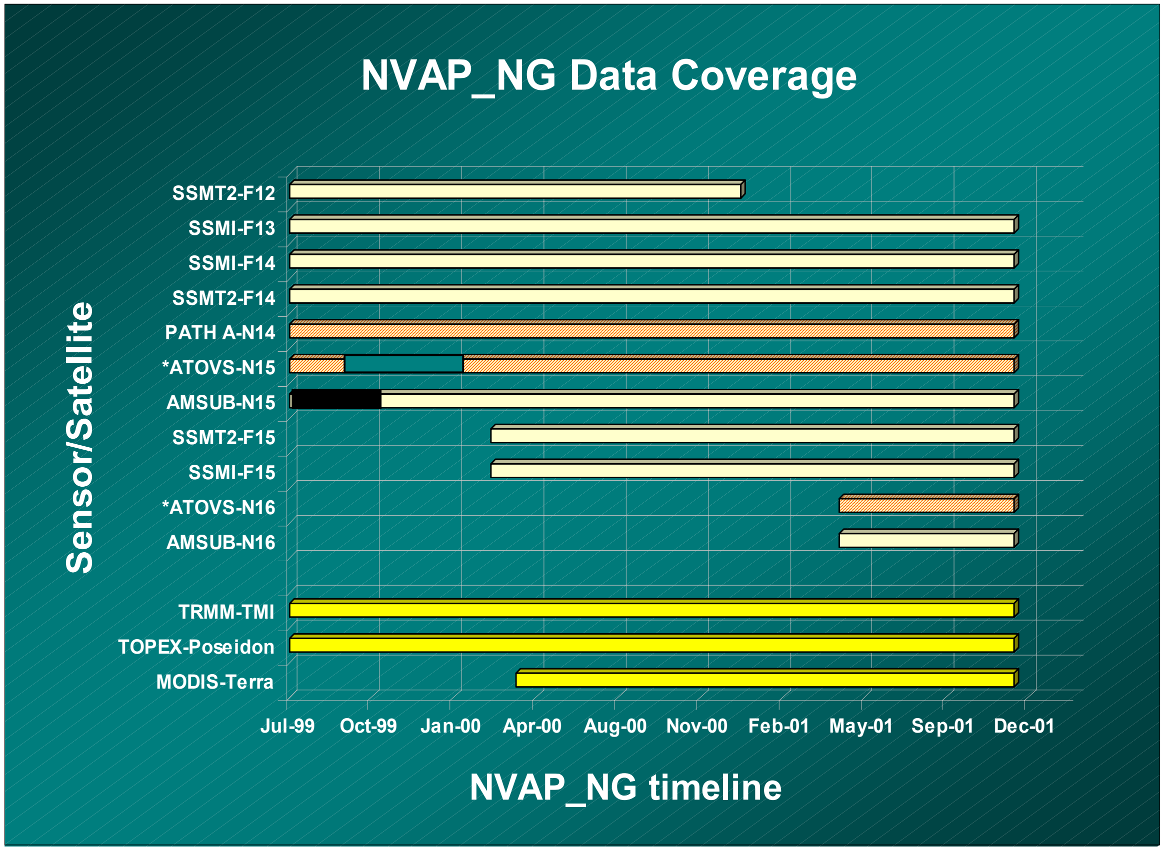


Figure 2: NVAP mean precipitable water vapor from 1988 – 1998

1988	1993	1995 - 1999	2000 - 2001
• Manual rawinsonde QC •No 22 GHz channel in SSM/I retrieval •Operational TOVS retrievals •Cloud liquid water threshold for precipitation	• Uses SSM/I 22 GHz channel •Explicit precipitation detection (Grody 1991 scheme) •Improved land mask •Improved sea ice detection •Automated rawinsonde QC using climatology	• • Added the 4th layer to NVAP product (water vapor above 300 mb) • 2-4 times more TOVS soundings	NVAP-Next Generation era • Consistent SSM/I antenna pattern correction • Optimal estimation retrieval with AMSU-B, SSM/T-2 • ATOVS and TOVS sounding products • 3 SSM/I instruments

Figure 3: History of NVAP processing.



Data used over both land and ocean.

Data used over ocean only.

Independent satellite-based TCWV for comparison.

NOAA-15 AMSU/B dataset contains RFI noise. Before Oct-99 the data is unusable, after Oct-99 the noise can be minimized to ~ 2K by applying bias correction.

* ATOVS Sounding

Figure 4: Low earth orbit satellite water vapor instruments and products employed in NVAP-NG.

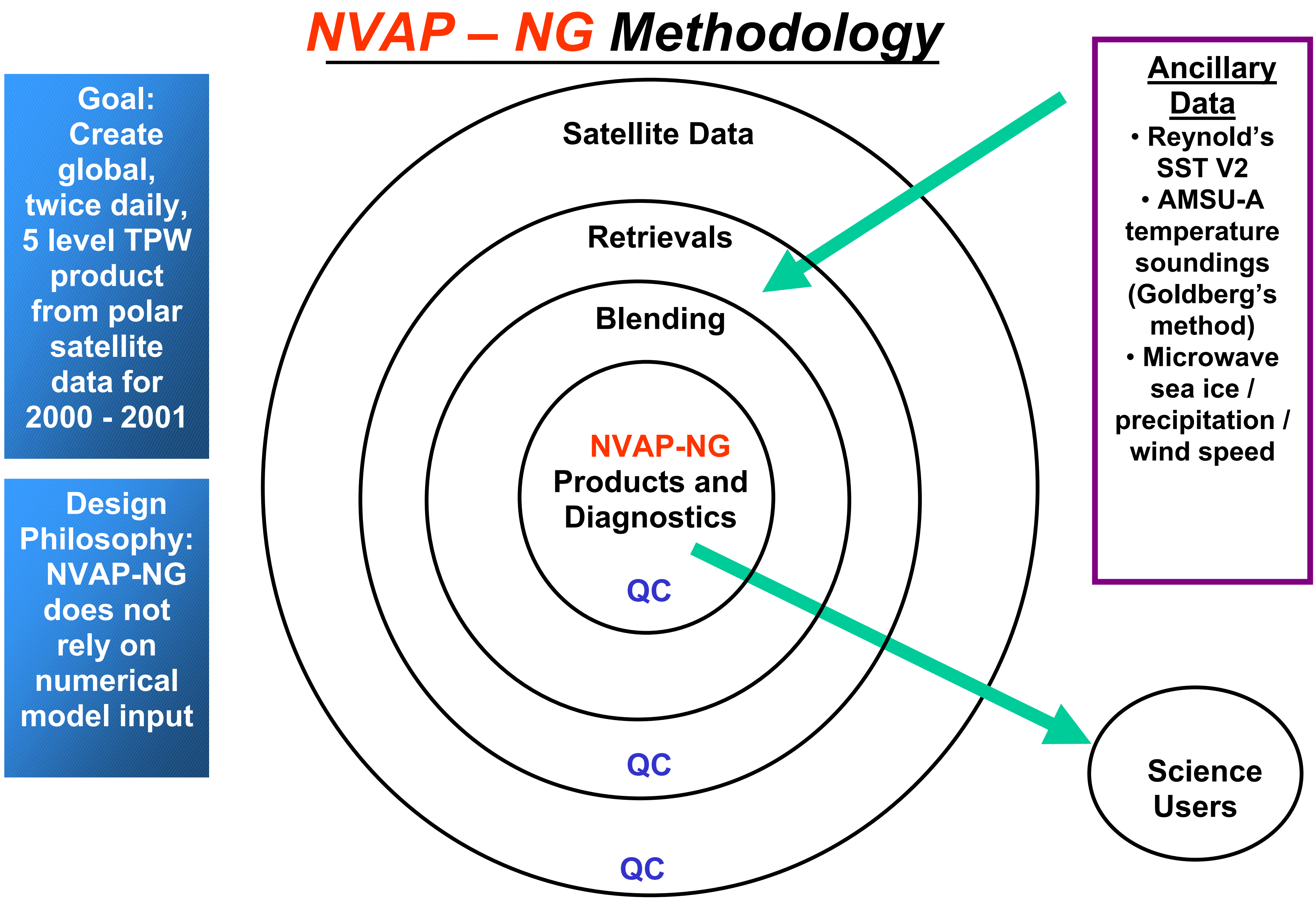


Figure 5: "Shell" concept of NVAP-NG. Raw and ancillary data is run through retrievals and blended with intermediate products to create the NVAP-NG fields. Quality control is performed at each level. The blended products then go to the science community.

Preliminary **NVAP_NG Gridded Products (25 grids total)**			
	q	% apriori	% model
1000	X	X	X
850	X	X	X
700	X	X	X
500	X	X	X
300	X	X	X
TCWV			
CLW			
Precip / sea ice			
"Problem" code (e.g. non-convergent, max iterations…)			
Clear or Cloudy	From IR or MW		
Number of obs used			
Std. Dev. of PWC / CLW	Not at levels, just total		
Data Source Code (Binary)			

Figure 6: Draft list of NVAP-NG products. Each product is a 360 x 720 two byte per pixel grid.

a)

b)

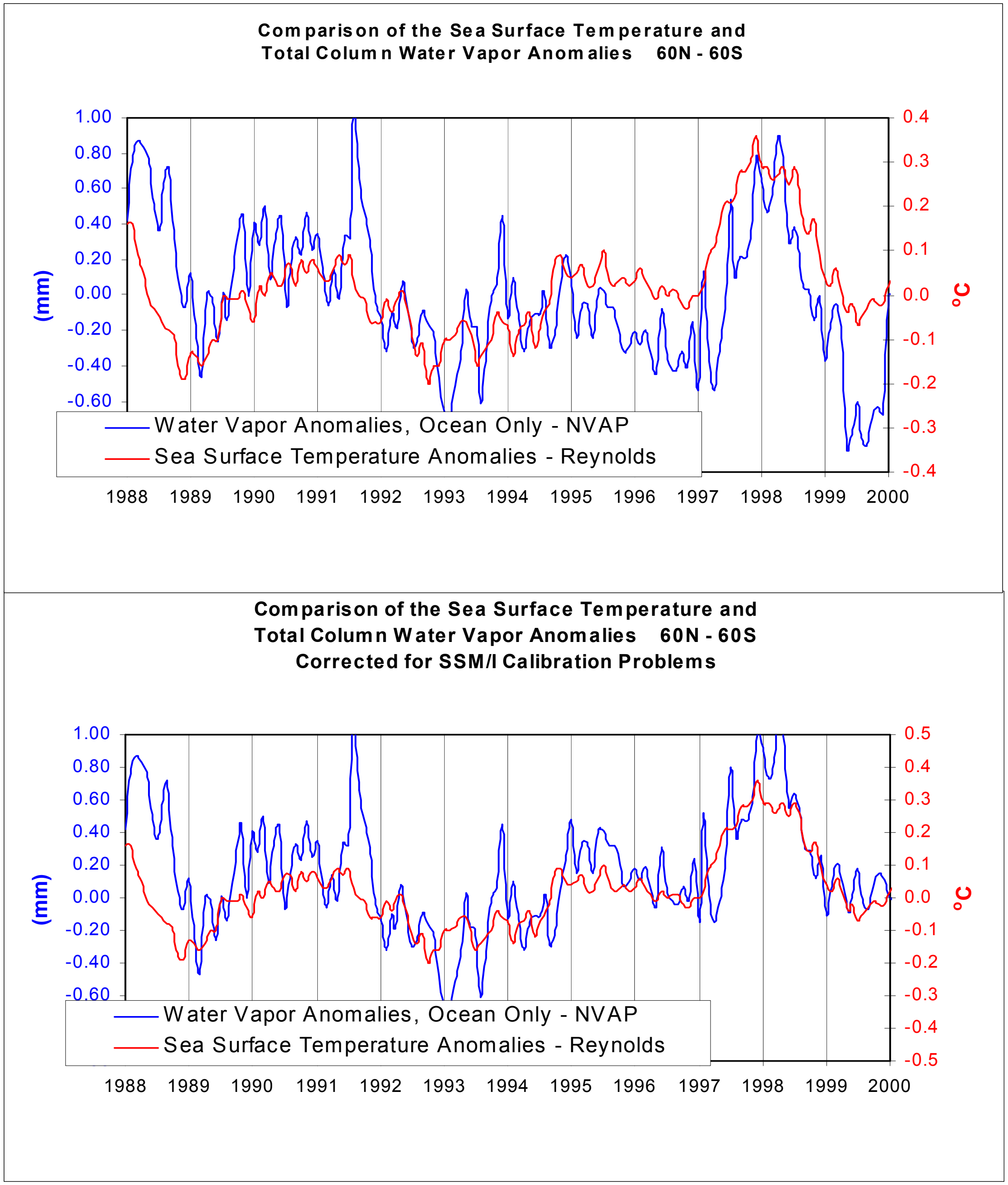


Figure 7: NVAP total column water vapor (TCWV) anomalies compared to sea surface temperature anomalies (Reynolds et al 2002) for 1988-1999. (a) Original NVAP TCWV anomaly for 1988-1999. In panel (b), the blue water vapor anomaly line is adjusted upwards after January, 1995 to include intersatellite calibration and implementation of the the SSM/I antenna pattern correction normalization of Poe and Colton (1999).

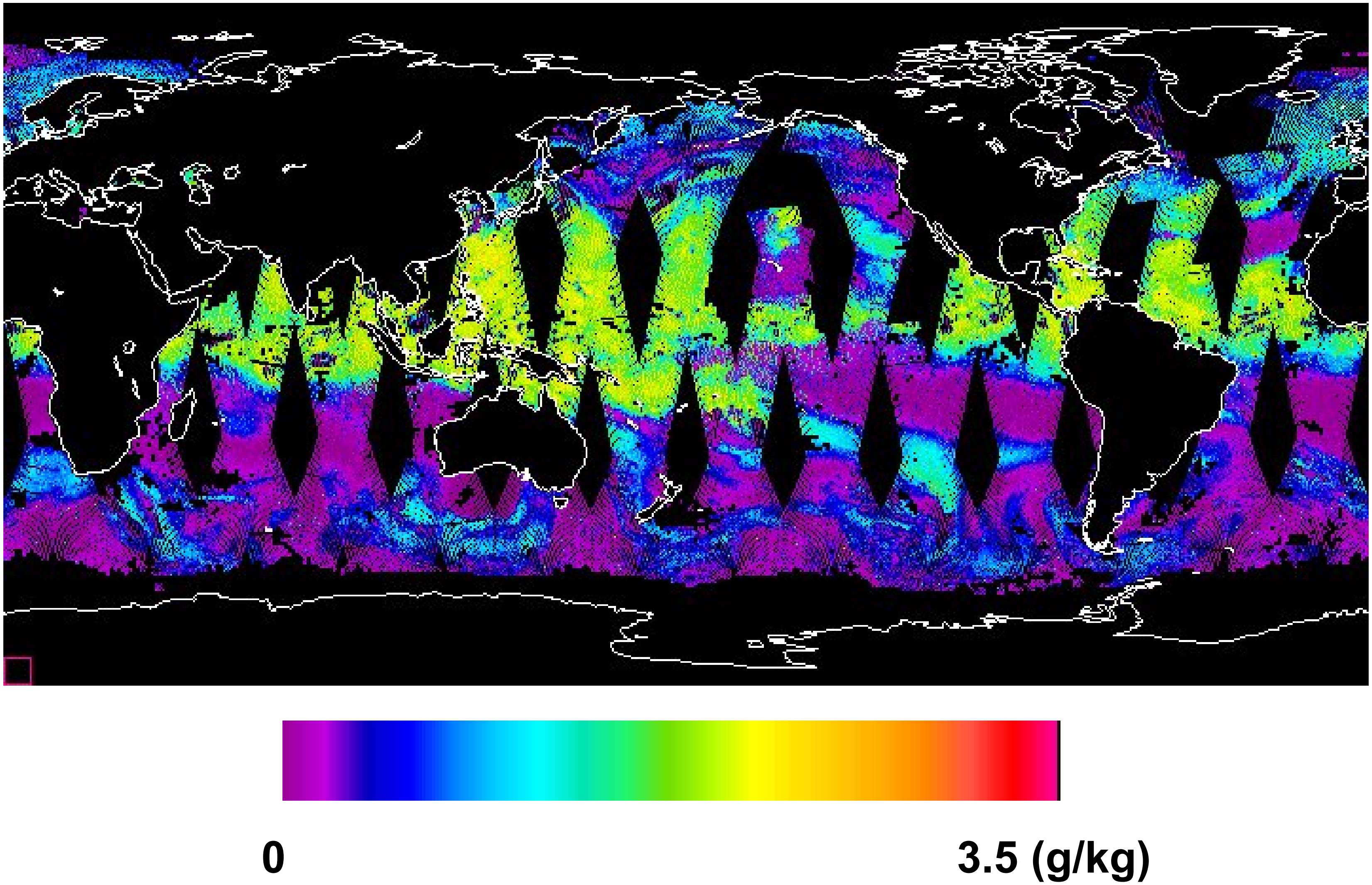


Figure 8: SSM/T-2 (F-12) retrieved 500 hPa mixing ratio for July 1, 1999. Some of the black areas are screened for precipitation.