Passive Microwave ESIP Project Status Report for the Period July– December 1999

The Passive Microwave ESIP continues to develop new Earth science products, extend the time period for existing products, expand our web site offerings and, and integrate new and improved information science capabilities into our data center operations. The following narrative briefly describes milestone progress and achievements between July-December 1999, discusses plans for 2000.

TMI Products

Completion of the Version 1 TMI ocean algorithm.

In January 1999, the TMI ocean algorithm was completed. This was a major milestone. The extensive testing, calibration and validation, which was discussed in our previous progress report, lead to a finalized algorithm that provides accurate estimates of sea-surface temperature (SST), wind speed, water vapor, cloud water, and rain rate. The algorithm is based on a physical retrieval method that matches the TMI brightness temperatures T_B to a simplified radiative transfer model. To reduce the retrieval error due to wind direction variability (particularly with respect to SST), we download NCEP wind directions every 6 hours. These directions are used by the algorithm to help specify the direction of the wind relative to the TMI look direction. As discussed in our previous progress report, it appears that the TMI antenna is slightly emissive, and hence the T_B measurement contains a 3 to 4% component proportional to the temperature of the antenna. A rather elaborate procedure is used to estimate and remove this error component. The January 1999 algorithm is called Version 1 and will be used to process the 1998-1999 TMI data. Towards the end of 1999, an extensive calibration/validation activity will be done to determine the performance of the Version 1 algorithm. If warranted, a Version 2 algorithm will be developed early in 2000, and all data will be reprocessed.

Science with TMI Ocean Products

The early results for the TMI SST retrievals are quite impressive and are already leading to improved analyses in a number of important scientific areas, including tropical instability waves (TIWs) and tropical storms (*Wentz et al*., 1999; *Chelton et al.*, 1999). The image in Figure 1 shows the global SST field (40°S to 40°N) for August 25-27, 1998. Except for a few small areas of persistent rain (indicated by white), the TMI provides nearly global coverage. The most striking feature in the figure is the tropical instability waves (TIW) in the Equatorial Pacific, which are unusually strong during this La Niña period. The figure also shows cold water wakes for two active cyclones: Hurricane Bonnie in the West Atlantic and Cyclone Howard in the East Pacific. The strong winds cause upwelling of cold water, leaving a cold track just to the right of the cyclone path (*Monaldo et al.*, 1997). Strong monsoonal upwelling off the coast of Arabia and Somalia is visible.

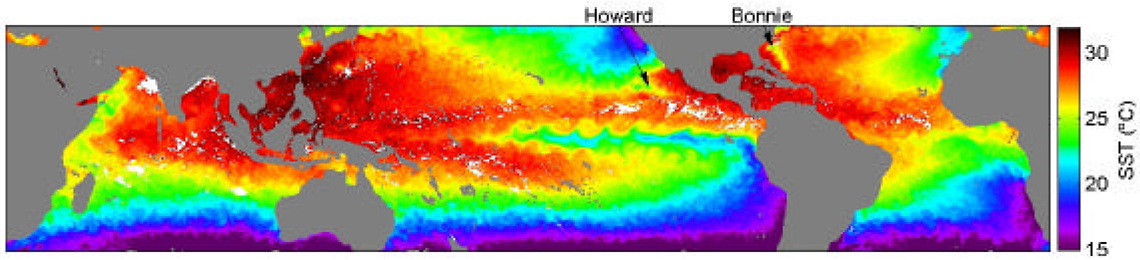

Fig. 1. The SST field for August 25-27, 1998 as seen by TMI from 40°S to 40°N. Areas of persistent rain are indicated by white.

Tropical Instability Waves

Satellite microwave measurements of sea-surface temperature (SST) reveal previously unreported features of tropical instability waves (TIW) seen in both Fig. 1 and 2. In the Pacific, TIW-related variability is observed from the eastern boundary to at least 160 º E. Cusp-shaped distortions of SST fronts and associated trains of anticyclonic vortices propagate eastward both north and south of the equator with approximately 50% larger displacements in the north. In the Atlantic, TIWs and associated anticyclonic vortices are clearly observed only on the north side of the equator where they propagate from the eastern boundary to the western boundary.

Tropical Air-Sea Interface

Microwave observations are an ideal way to observe the interaction between SST and wind since both variables can be simultaneously retrieved. TMI SST and wind fields (Fig. 2) reveal how highly correlated SST-wind couplings are on a much finer temporal-spatial scale (weekly, 50 km) than previously reported. The space-time structures of the TIWs are reproduced with remarkable detail in the surface wind stress field. The linear correlation between the weekly SST and surface wind at a 50-km resolution is 0.78, and the observed relationship between SST and wind is consistent with a relatively simple boundary layer model. This close coupling between SST and wind stress supports the Wallace et al. (1989) hypothesis that surface winds vary in response to SST modification of atmospheric boundary layer stability.

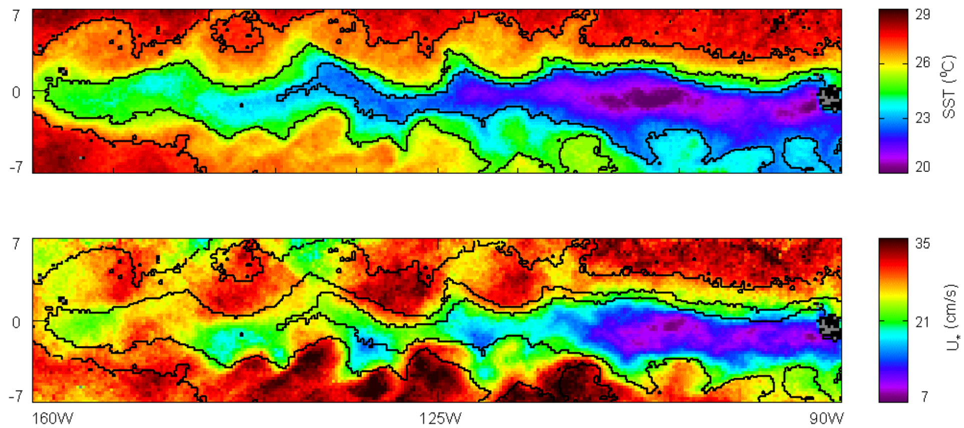

Fig. 2. SST and surface wind in the vicinity of the Eastern Pacific equatorial cold tongue during the first week in October 1998. The surface wind is given in terms of the friction velocity U_*. The black contour lines show the isotherms for 23°C, 25°C, and 27°C derived from the SST image. These contour lines are superimposed on the U_* image to highlight its correlation with SST. Both SST and wind clearly delineate the tropical instability waves to the north and south of the cold tongue.

Hurricane Intensity

Cold wakes from storms and hurricanes have been studied in the past using the infrared SST observations (*Monaldo et al., 1997; Black et al., 1995; Nelson et al., 1998*) but the analysis has been limited by the extensive cloud cover associated with these storms. Fig. 3 compares the TMI SST field with infrared SST imagery (*Vazquez et al., 1996*) of Hurricane Bonnie on August 24-26, 1998. The microwave imagery provides nearly complete coverage, whereas much of the infrared imagery is blocked by clouds. Fig. 3 also illustrates another possible problem for the infrared retrievals. The Gulf Stream east of Cape Hatteras, which is clearly resolved in the microwave imagery, is barely visible in the infrared imagery. We attribute this to either undetected clouds or a relatively high amount of water vapor obscuring the ocean surface.

Storm track prediction skill has steadily improved along with better numerical models and observations, but intensity prediction skill falls short of expectations (*Emanuel, 1999*). Several studies (*Emanuel, 1999; Saunders et al., 1997*) have shown that after initial development, the intensity of severe storms is strongly influenced by the thermodynamic structure of the upper ocean, and an accurate prediction of the storms future intensity requires measurements of the ocean's thermal structure ahead of the storm. Extensive cloud cover around storms often prevents infrared satellite SST measurements. Microwave SST retrievals clearly have the potential to improve skill in these important forecasts, as was shown in 1998 hurricane season. In late August, Hurricane Danielle closely followed Hurricane Bonnie. Danielle’s intensity dropped significantly as it passed over a region of cold water caused by Bonnie (Fig 3A). Due to the cloud problem for infrared SST retrievals, the National Hurricane Center (NHC) uses a low-resolution (weekly, 100 km) SST field (*Reynolds et al., 1994*) from the previous week (Fig. 3C) in their intensity models (*DeMaria et al., 1994*). For the Danielle prediction, this weekly SST product was missing Bonnie's cold wake, which may explain why most official forecasts overestimated Danielle's intensity by 30 to 40 knots (*Pasch et al., 1999*). TMI SST images of hurricanes (1998 and 1999) are available from the TMI web page as animations.

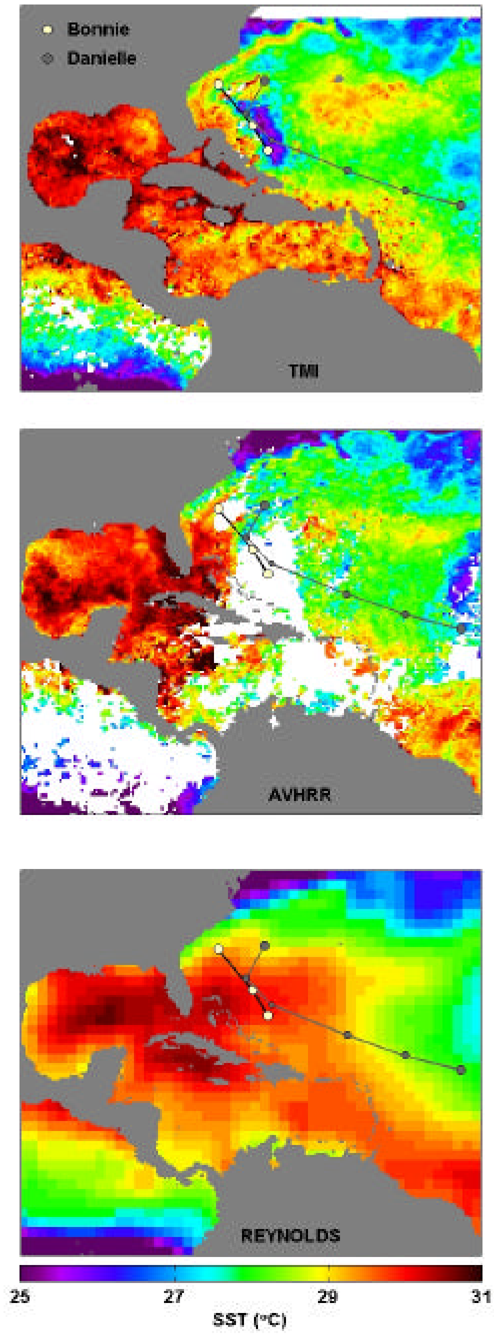

Fig. 3. (A) The cold wake produced by Hurricane Bonnie for August 24-26, 1998, as seen by TMI. The small white patches are areas of persistent rain over the 3-day period. The white dots show Hurricane Bonnie's daily position as it moved northwest from August 24 through 26. The gray dots

show the later passage of Hurricane Danielle as it moved northwest from August 27 through September 1. Maximum hurricane wind reported by the NHC is indicated by dot diameter. Danielle crosses Bonnie's cold wake on August 29, and its intensity drops.

(B) The August 24-26, 1998, Pathfinder AVHRR SST product derived from infrared observations (*Liu et al., 1979*). Extensive cloud cover (white areas) associated with Hurricane Bonnie hides the cold wake. Also, the Gulf Stream east of Cape Hatteras, which is clearly resolved in microwave imagery (A), is barely visible in the infrared imagery, possibly due to interference from undetected clouds.

(C) The weekly SST map used by the National Hurricane Center (NHC) in their intensity models to predict Danielle.

TMI Web Site Redesign and Dynamic Data Selection

The web site provides access to TMI daily maps (separated into ascending and descending orbit segments), weekly mean and monthly mean maps and binary data files. The data are available from December 1997 to the present. All images cover a global region extending from 40S to 40N at a pixel resolution of 0.25 deg (25 km). The actual data are available via FTP as byte arrays.

The TMI data browse section was redesigned in September '99 to give the user the ability to select between options of viewing the data in **dynamic** (as discussed in the next section) or **static** modes. Viewing of static data (Data pre-stored as images) is a faster option but provides no capability of further interaction with the data. Dynamic viewing is slower, but gives the user several options to further visualize the data.

Dynamic Image Display Capability Added

The TMI website was extended in September 1999 to dynamically generate images and to allow the user to manipulate data on demand. Research Systems Inc.'s IDL/ION (IDL – Interactive Data Language/ ION – IDL on the Net) was used as the programming system. The IDL/ION (IDL on the Net) interfaces Java and Internet technology with in-house IDL libraries to deliver data analysis and visualization capabilities of IDL directly to the net for the display, sharing, and interactive control of data.

The interface design allows selection of data to create images on demand. The selection interface offers regional subsetting by interactive specification of a latitude/longitude bounding box using a clickable Java map, as shown below in Fig 4. It also includes selections for desired zoom level, and for the geophysical parameter to display.

The selection graphical user interface is shown in the next figure:

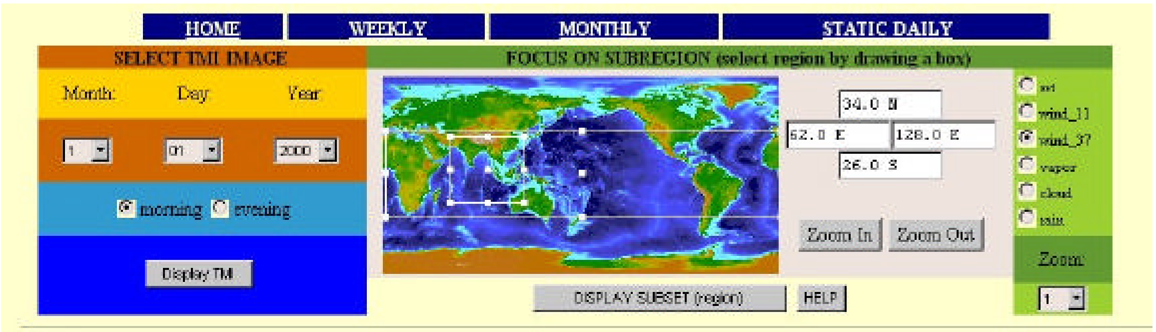

Fig. 4. TMI data selection interface demonstrating 'dynamic' data selection including geographical subsetting and zoom factor selections.

A new web page displays a subset of the data extracted in latitude/longitude and additionally, a histogram and statistical information about the region selected, such as minimum, maximum and mean values of the data. The user can reselect zoom factor and geophysical parameter from this page and redisplay the selected region. An example of a 'subsetted' image with accompanying statistics and histogram display is shown below:

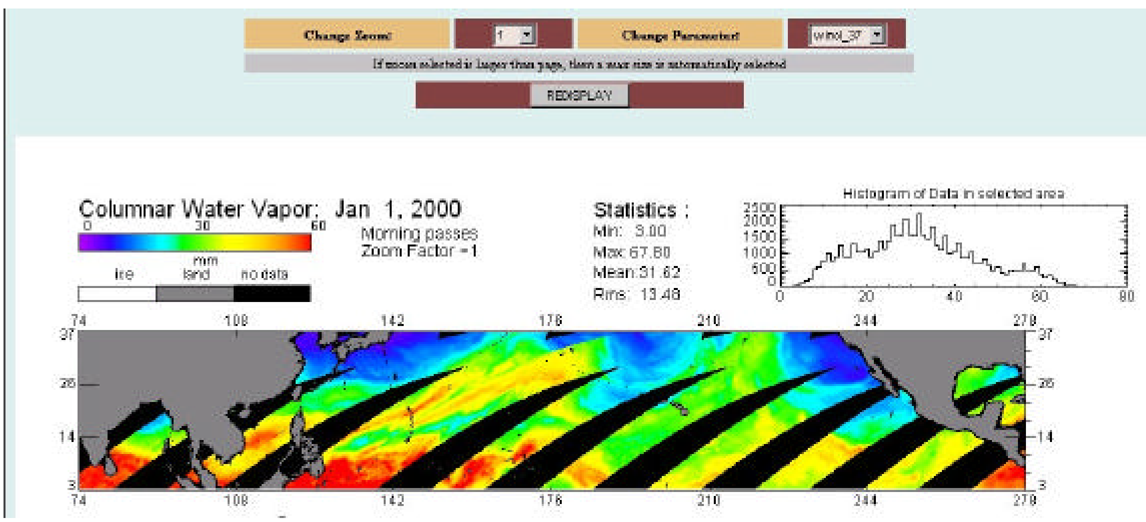

Fig. 5 TMI geographically subsetted and zoomed image with summary statistics.

TMI Usage Metrics

An analysis of www logs for the July –Dec '99 period was performed. These statistics show a significant increase in the number of requests compared to the previous 6 month period (Jan – June '99).

The web statistics were calculated from the daily logs after filtering out local accesses. The total number of visits to the TMI sections of the web site showed a significant increase from 895 in the previous six month period to 1507 in the current six month period. During the current period, 741 unique visitors accessed the web site. The total number of requests (number of times the web server was accessed) was 3357.

AMSU-A Limb Corrected Brightness Temperatures

The AMSU-A limb corrected brightness temperatures are produced daily and are the basic input data set for the computation of tropical cyclone maximum sustained wind speed, the extension of MSU data set into a AMSU/MSU merged period of record, and the Daily Earth Temperature web site. The various input AMSU-A raw data channels are corrected for varying limb viewing path lengths. These daily data sets are in operational production. This task is in a maintenance and operations mode with no new major milestones projected.

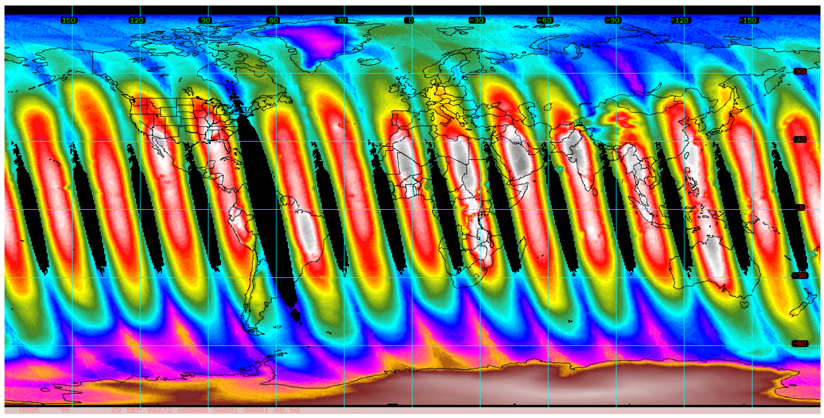

Figure 6a. Raw AMSU-A data set

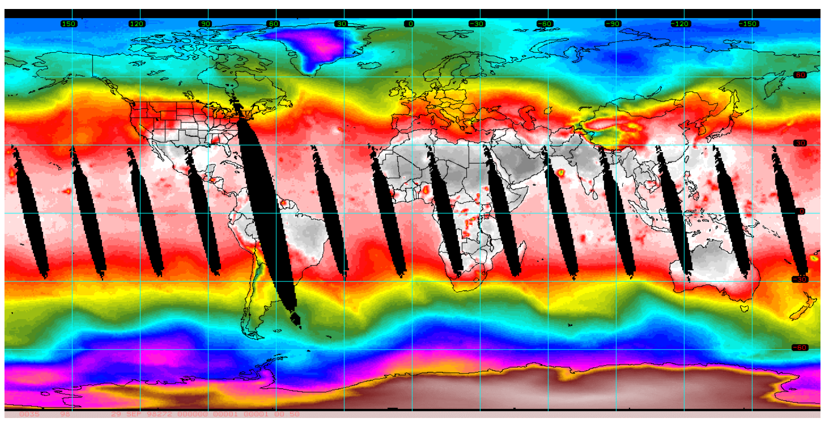

Figure 6b. Limb corrected brightness temperatures corrected for different limb viewing path lengths

AMSU-A Pitch & Role Errors

In the process of analyzing the AMSU-A data sets for our global atmospheric temperature tasks, we have discovered pointing errors in the AMSU-A1 and -A2 units. These were discovered by differencing ascending and descending pass imagery of the surface sensitive channels. The position of landforms was seen to change in these comparisons between ascending and descending data. By introducing roll and pitch changes, we were able to remove these effects and thereby quantify the roll and pitch errors in the data. As an example, we found a 1.2 degree roll error and 0.3 degree pitch error in the A1-unit. It is not known whether these errors are directly attributable the AMSU-A instrument, or to the mounting of the instrument on the spacecraft. Dr. Tsan Mo / NOAA/NESDIS has been informed of the errors and has been tasked by NESDIS to prepare a TIROS Operational Anomaly Report (TOAR) which formerly notifies the science user community of these errors.

Tropical Cyclone Maximum Sustained Wind Diagnosis

The strong surface winds in tropical cyclones are directly related to the warm middle- and upper-atmosphere temperatures which exist around the cyclone center. The AMSU-A instrument flying on the NOAA-15 satellite measures this warmth at several frequencies near 55 gigahertz (GHz). We have developed a method for converting the satellite measurements into an estimate of maximum sustained wind speed (Vmax) in the cyclone. The basic concept is not new, and has been previously explored by *Kidder* et al. (1978), *Kidder* et al. (1980), *Grody* et al. (1979), and *Velden and Smith* (1983) with earlier generations of satellite temperature sounders (SCAMS and MSU).

Our AMSU-A Vmax is the radially averaged limb-corrected brightness temperature gradient in the 50 km to 100 km distance range from the warm core, where the brightness temperature is a weighted multi-channel average of AMSU-A channels 5 through 9. The AMSU-A Vmax method has been calibrated using aircraft reconnaissance measurements in tropical depressions, tropical storms, and hurricanes from the 1998 Atlantic hurricane season. Only those systems with diagnosed winds of at least 40 knots are classified as tropical cyclones. .

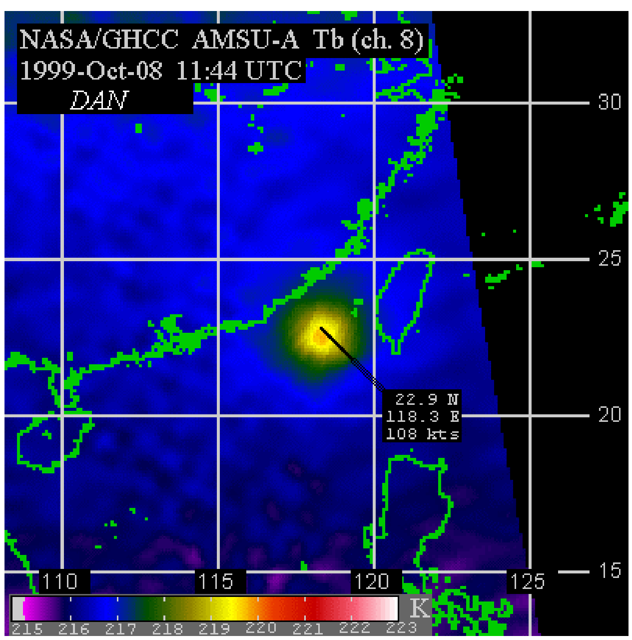

Figure 7. Typhoon Dan near China and Taiwan with 108 kt. AMSUA Vmax wind speed

The tropical cyclone maximum sustained wind diagnosis algorithm was integrated into the UAH Algorithm Development and Mining System (ADaM) data miner. The algorithm ingests the AMSU-A limb corrected brightness temperatures, computes the Laplacian of the brightness temperatures, applies latitudinal filters, screens for false alarms and then computes the maximum sustained wind speed. The algorithm does not compute a wind field, but a single maximum wind speed. The Vmax wind speed is of interest to both the National Hurricane Center (NHC)and the Joint Typhoon Warning Center (JTWC). Spencer and Braswell submitted a paper to Monthly Weather Review for publication. Reviewers suggested that the algorithm should be further tuned with data from this past (1999) hurricane season. The algorithm is being re-calibrated and the paper will be re-submitted this year.

A web site (pm-esip.msfc.nasa.gov/cyclone) was developed that dynamically displays the latest algorithm findings and has the capability to e-mail new storm locations and wind speeds to forecasters at NHC and JTWC. The algorithm and associated web site were placed into operational mode during the 1999 Atlantic hurricane season. The web site ingests the hurricane and typhoon warnings, and automatically displays the storm name, date, time, location (i.e., latitude, longitude, and ocean basin name), Vmax wind speed, and storm motion, and compares them to the official wind speed estimate as identified by either the NHC or JTWC. Additionally, browse images of the storm are included on the web site to aid in storm identification and tracking. The wind speed estimates and browse images are kept online for two weeks.

Daily Earth Temperature Web Site

As a follow-on to the landmark MSU temperature studies conducted by Spencer and Christy, the AMSU-A atmospheric layer temperatures are being computed for eleven layers extending from 900 mb up to 2.5 mb. The temperatures have been processed back to July 1998 and continue to the present. In order to make the results of this work more widely available, we are in the final stages of creating a publicly available web site (pm-esip.msfc.nasa.gov/amsutemps) that will interactively allow the user to select and display multiple annual temperature graphs for each of the eleven atmospheric layers (Fig. 8). The web site is automatically updated four times a day to incorporate the most recent AMSU-A measurements.

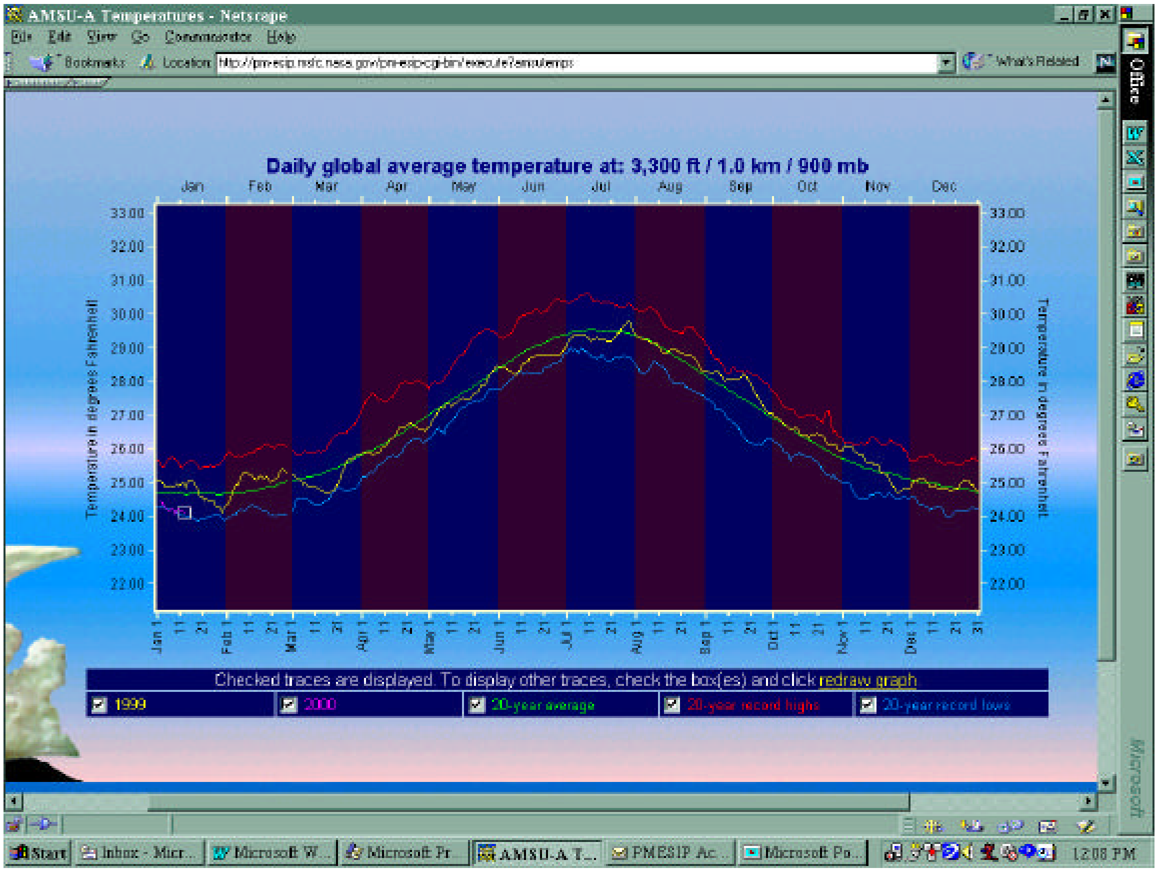

Figure 8. Daily atmospheric temperature traces display the current global temperature, the annual cycle, and 20-year highs and lows.

Tropical Upper Tropospheric Humidity from SSM/T-2

Partly in response to a request from Dick Lindzen (MIT), we will bring our SSM/T-2 Upper Tropospheric Humidity (UTH) product up to date. This product, originally described in a June, 1997 Bulletin of the AMS article (*Spencer and Braswell*, 1997) should prove useful for climate diagnostics, model intercomparison, and water vapor feedback studies. The data sets were initially produced, but never put into operational production. The data can be reprocessed and the period of record brought up to the present.

SSM/T-2 Limb Corrected Brightness Temperature Grids

Daily grids of limb corrected Tb for the 183 GHz channels of the SSMT-2 have been produced approximately every month, and will continue to be processed. We not yet transferred these products to the operational data server. These daily grids will be incorporated into the PM-ESIP data server and will be made available for public distribution from the PM-ESIP web site and from the Global Hydrology Resource Center web site.

Clear Sky Outgoing Longwave Radiation

Data sets of clear-sky Outgoing Longwave Radiation (OLR) computed from SSM/T-2 water vapor channels, the SSM/I total integrated water vapor, MSU deep-layer temperatures, and Reynolds SST have not received much interest. Unless this interest picks up again, we do not intend to continue producing this data set.

Integrated On-Demand Search, Order & Processing

During this last reporting period, the Information Technology effort on the PM-ESIP has been involved with adding value to the AMSU-A data sets, as well as, continuing developing of an overall next-generation information system prototype to provide data and product ordering, services, and visualization for the various PM-ESIP related data sets.

As before the PM-ESIP team has continued the effort of making information available through a public web site (http://pm-esip.msfc.nasa.gov/). This site has continued to evolve as our system has grown and improved.

An initial prototype system for our next generation product-on-demand information system was completed during the last reporting period and early investigation into a next evolution of the system was underway. During this period the design and development of this system has continued and is resulting in good progress for the creation of a functional system. The biggest effort during this past period has been work towards a close integration of the UAH VisAnalysis Systems Technology group's Space Time Toolkit (STT) technology with the UAH Information Technology & Systems Center's data mining, data ordering and catalog technology. Progress to date has resulted in an integration allowing for the visualization of the PM-ESIP data sets through the STT remote client interface, using the Algorithm Development and Data Mining system as the server-side data analysis component. This integration is opening many possibilities into methodologies that will be employed for the distributed processing and visualization of data products based on user's demands. This technology and integration is based on commonly used HTTP communications protocols as well as some of the latest Java servlet and object serialization technology. A demonstration of this integration effort will be available at the January ESIP Federation meeting in Houston, Texas.

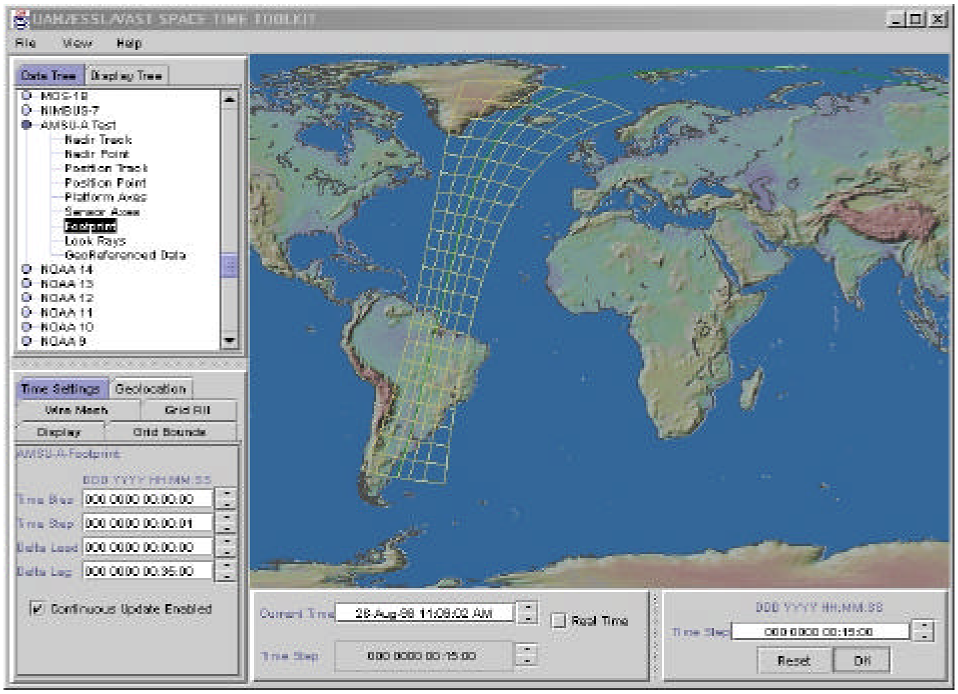

Figure 9a. Space Time Toolkit display showing AMSU-A footprint wire mesh grid track over a 35-minute time period on 28 August 1998.

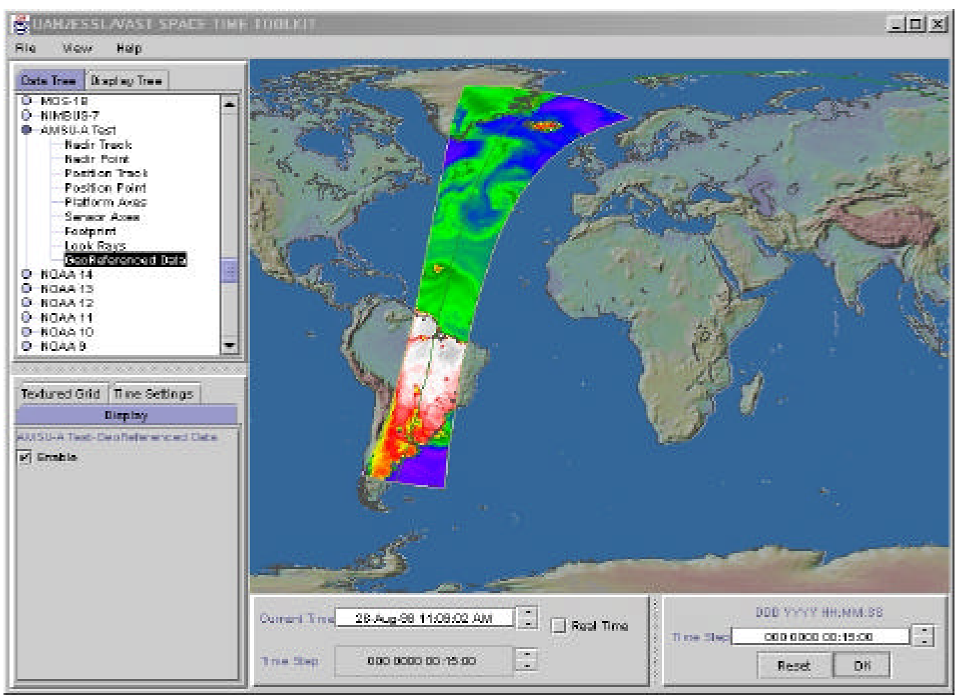

Figure 9b. Same as in 9a, but with the results of a remote internet on-demand request to subset and display of AMSU Channel 1 data using with the ADaM data miner and a catalog / database from a distributed data server.

The next PM-ESIP milestones include the continued integration and evolution of the STT-ADaM connections. Work is underway and will be formalized to build new interface capabilities into the STT graphical interface to allow users to directly select PM-ESIP related data sets and products. Initial test versions of this technology should become available during the next six-months. Additional database connectivity will be implemented within this environment during this period, allowing users to access geospatial and temporal data using some of the latest database technologies. Planned developments on the server side of this technology will allow for the interactive generation of data products, through interactions between the user interface components, a product knowledge base and the ability to submit processing tasks to multiple distributed processing engines providing different functional components. For instance Hew (an HDF-EOS independent tool) could be used for subsetting and ADaM for other data analysis operations.

Future Work For Year 2000

1. In 2000, we will reconfigure the TMI processing system to produce near real-time products (within 6 hours of observations time.) We have obtained approval from NASA Headquarters to obtain the near real-time Level 1 data from Goddard. A significant amount of work will be required to reconfigure the software to produce these more timely products. Two major modifications are 1) we will need to obtain forecast wind directions rather than analysis wind direction from NCEP, and 2) we will need to modify the emissive antenna correction so that it will just require the previous day's observations rather than looking ahead at the next day.

2. We will begin a collaboration with the National Hurricane Center (NHC) to explore the possibility of using the TMI "through-clouds" SST retrievals in their prediction models at some future date. The microwave SSTs are able to clearly resolve the cold upwelled water hurricane wakes, which can affect the intensity of subsequent hurricanes. Infrared retrievals, which are currently being used by NHC, usually do not see these wakes because of cloud interference.

3. We will continue to improve the Tropical Cyclone Maximum Sustained Wind Speed algorithm (Vmax) by re-calibrating the algorithm with both 1998 and 1999 hurricane data. We will explore integrating the work of TMI SST retrievals and the Vmax algorithm.

4. We will be developing improved TMI retrievals algorithms using a new 2-stage regression technique.

5. We will continue our research into TIWs. Some questions we hope to resolve are how SST and sea surface height (SSH) are related north and south of the equator; what the trans-equatorial phase structure is in TIWs in SST data and to what height are boundary layer winds modified by SST?

6. Populate PM-ESIP data base with SSM/T2 Limb Corrected Brightness Temperatures the SSM/T2 Tropical Upper Tropospheric Humidity, and AMSU/MSU monthly grid

7. UAH information technology teams and Remote Sensing Systems intend to remain at the forefront of modern Internet-based data visualization and distribution technologies, and are committed to continued improvements in data accessibility and utility. Further intended extensions to the website include:
    - Web interface to integrated STT and distributed processing engines (e.g., AdaM)
    - Exploring ways to increase the speed of display for dynamic image generation.
    - The capacity to generate spatially-resolved time series of observations on demand.
    - Dynamic selection of regions of interest (example: Equator, Gulf of Mexico, Indian Ocean), and creation of animations for a desired time range for that region.
    - Inclusion of the Remote Sensing Systems domain and appropriate keywords in search engines and linking it to other relevant sites to increase visibility.

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