OSDPD/ESPC-ATMO-BLTP-015-001-V1.1

Blended TPW Products

Algorithm Theoretical Basis Document (ATBD)

DRAFT—3 October 2008

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1 INTRODUCTION

The purpose of an Algorithm Theoretical Basis Document is to detail the algorithms used to construct a product. This document describes the algorithms used to construct the Blended TPW Products produced at NESDIS and at CIRA.

Section 2 of this document discusses the need for blending and the general approach to it. Two products are detailed in this ATBD: the Blended Total Precipitable Water (TPW) Product is detailed in Section 3; the Percent of Normal TPW Product is detailed in Section 4. Section 5 lays out the implementation of these products in the Data Processing and Error Analysis System (DPEAS). Finally, Section 6 contains the references.

2 THE NEED FOR BLENDED PRODUCTS

“Forecasters today are faced with many sources of data. What they need is meteorologically significant data fields blended from all available data sources, not many maps of observations from individual sources” (Kidder and Jones 2007, hereafter K&J). A good example of this is Total Precipitable Water (TPW, the integrated amount of water vapor in a column from the surface of the earth to space in kilograms per square meter or, equivalently, in millimeters of condensate). Many satellites which measure TPW have been launched, such as the Defense Meteorological Satellite Program (DMSP) satellites, with their Special Sensor Microwave Imager (SSM/I), and the NOAA satellites, with their Advanced Microwave Sounding Unit (AMSU). In addition, TPW can be retrieved in clear areas using infrared sounding instruments, such as the High-resolution Infrared Radiation Sounder (HIRS) on the NOAA satellites and the GOES Sounder. Finally, ground-based measurements of the transmissions of the Global Positioning System (GPS) satellites can yield TPW. Clearly, blending these measurements together to form a unified product is desirable, but how does one do that?

A first order solution is to map all of the orbits during a time period, such as 12 hours, on a single map, with newer observations replacing older ones. Figure 1 contains TPW estimates from three AMSU instruments and three SSM/I instruments. It is easy pick out the SSM/I swaths, which (being newer) are on top of the AMSU swaths. The reason the SSM/I swaths are easy to pick out is that SSM/I TPW retrievals are different than the AMSU TPW retrievals. They use different frequencies, different scan geometries, and different retrieval algorithms. It is inevitable that there will be some differences between AMSU and SSM/I. These differences are known as “artifacts,” and they can seriously degrade the quality of an analyzed field. The goal of blending is to remove these artifacts, which are unrelated to meteorology. This means, of course, that blending must be carefully done, because a blending algorithm can introduce its own artifacts.

Figure 2 shows the result when the data in Fig. 1 are processed by the blending algorithm described in Section 3.1. Artifacts are greatly reduced, and the meteorological features, such as the (double) intertropical convergence zone (ITCZ) are much easier to distinguish.

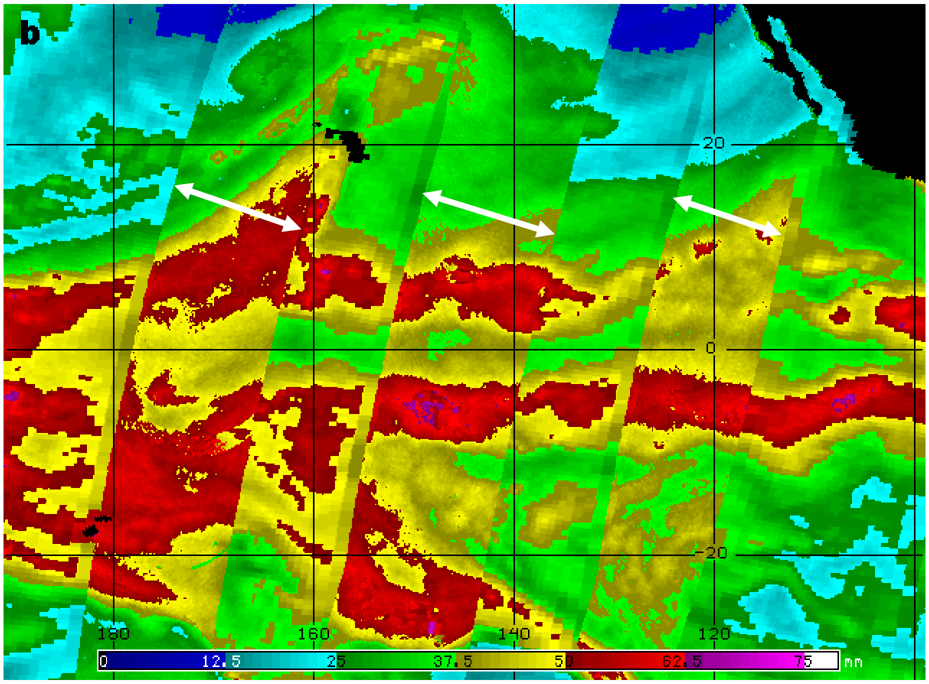


Figure 1. Composited AMSU and SSM/I TPW image (units: mm). Newer observations are overlaid on older observations. SSM/I swaths (marked with white arrows) are easily seen. The DMSP satellite which carried the SSM/I instrument which made these observations descended from NNE to SSW. [From K&J Fig. 8b.]

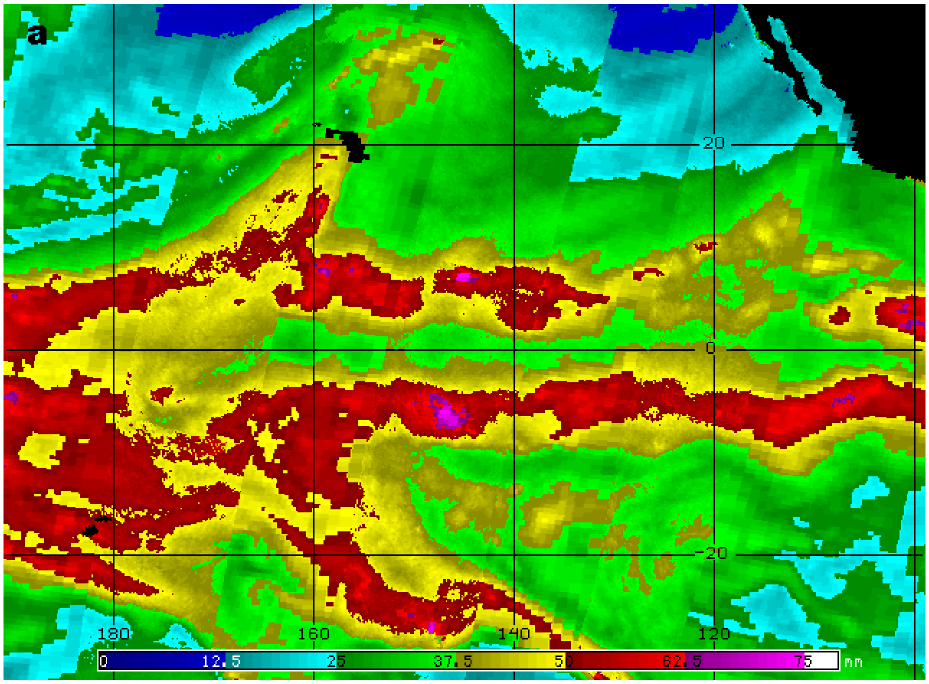


Figure 2. Blended AMSU and SSM/I TPW image (units: mm). Artifacts are considerably reduced. [From K&J Fig. 8a.]

Finally, a few things must be noted.

1. A blending algorithm is not a retrieval algorithm. Blending combines retrieved data from different instruments or different retrieval algorithms in a way that reduces artifacts.

2. The blending strategy must depend strongly on the data being blended. The same blending technique will not work with all data.

3. The difference between Fig. 1 and Fig. 2 is not the result of averaging or smoothing of the data. All points which appear in Fig. 1 also appear in Fig. 2, but they have been adjusted, as described in Section 3.1, so that they are all part of the same statistical distribution and thus appear to have been observed with the same instrument.

3 THE BLENDED TPW PRODUCT

Because TPW data over ocean and over land are currently blended differently, over-ocean and over-land blending techniques are discussed in two separate sections

3.1 Over-Ocean Blending

Two types of data are currently used to produce the TPW Product over ocean: AMSU data and SSM/I data.

The AMSU data come from the Microwave Surface and Precipitation Products System (MSPPS, http://www.osdpd.noaa.gov/PSB/IMAGES/MSPPS_day2.html). TPW is retrieved (only over water) from the 23.8 GHz and 31.4 GHz channels (Weng et al. 2003; Ferraro et al. 2005).

The SSM/I data come from the NOAA/Navy/Air Force Shared Processing Program (http://www.osdpd.noaa.gov/PSB/SHARED_PROCESSING/SHARED_PROCESSING.html). TPW is retrieved (only over water) from the 19, 22, and 37 GHz vertically polarized channels in an algorithm which is quite different from that used for AMSU (Ferraro et al. 1996).

Both AMSU and SSM/I data are acquired from the NESDIS Data Distribution Server (DDS). Both data sets are in HDF-EOS Swath format, and each file is approximately one orbit of data.

After the data are read, the blending algorithm (Section 3.1.1) is applied to each file and the "corrected" file is written out to disk. Next the corrected files are mapped onto a Mercator map grid, one orbital file in each map (Section 3.1.2). Then the corrected and mapped files are composited into the over-ocean Blended TPW Product (Section 3.1.3). Finally, the blended product is written to file in any (or all) of several formats, HDF-EOS Grid format, McIDAS format, or GIF format.

3.1.1 Blending Algorithm

As explained in K&J, when one thinks of making corrections to data, one usually thinks of removing biases and, perhaps, adjusting the standard deviations. This works well for data which are normally distributed and for which there is a standard, that is, for which “truth” is known. TPW data from different satellite instruments do not fit this description. First, a truth data set is not readily available; and, second, TPW retrievals from the two instruments differ in a statistically non-normal way from each other. To solve this problem, a technique was developed to make the probability distribution function (PDF) of the SSM/I TPW data look like the PDF of the AMSU TPW data. This is the heart of the over-ocean blending algorithm.

The first step in the blending algorithm is the construction of histograms of TPW values for a five-day period. A histogram is constructed for each satellite instrument at each scan position. The assumption is that in a five-day period, each scan position of each instrument will sample the global distribution of TPW. Both NOAA satellites and DMSP satellites are in sunsynchronous, near-polar orbits, which means that they observe the whole earth. Each satellite makes about 14 orbits per day sampling the moist tropics and dry extra-topics on each orbit. At each scan position, AMSU makes about 30,000 ocean observations, and SSM/I makes about 50,000 observations in five days. If n_{sat} is the number of satellites used in the composite, this step requires approximately $14 \times 5 \times n_{sat}$ files to be opened and processed. It can be performed once per day, or it can be done every time the Blended TPW Products script runs.

Let $n(i_{TPW}, i_{SCAN}, i_{SAT})$ be the five-day histogram, where i_{TPW} is the integral value of the retrieved TPW value in millimeters (range: 0-100), i_{SCAN} is the scan position (range: 1-30 for AMSU, 1-64 for SSM/I), and i_{SAT} is the index for the satellite (range: 1 to n_{sat}). The cumulative probability distribution function is defined as

$$PDF\left(i_{TPW}, i_{SCAN}, i_{SAT}\right) \equiv \frac{\sum_{j_{TPW}=0}^{i_{TPW}} n\left(j_{TPW}, i_{SCAN}, i_{SAT}\right)}{\sum_{j_{TPW}=0}^{100} n\left(j_{TPW}, i_{SCAN}, i_{SAT}\right)}, \tag{1}$$

where, of course, *PDF* ranges from zero to one.

The second step in the process is constructing a reference PDF. While the “true” TPW distribution is not known, one set of observations can be chosen to be the reference and an adjustment can be calculated. When the adjustment is applied to other observations it makes the distribution approximate the reference distribution. Currently the average TPW PDF (scan positions 6–25 only) of the AMSU instrument is used as the reference PDF. In the DPEAS script, the satellite for the reference is specified. The reference PDF (from the NOAA 17 AMSU) for the five day period ending at 2215 UTC on 29 March 2006 is shown in Fig. 3 as the red line.

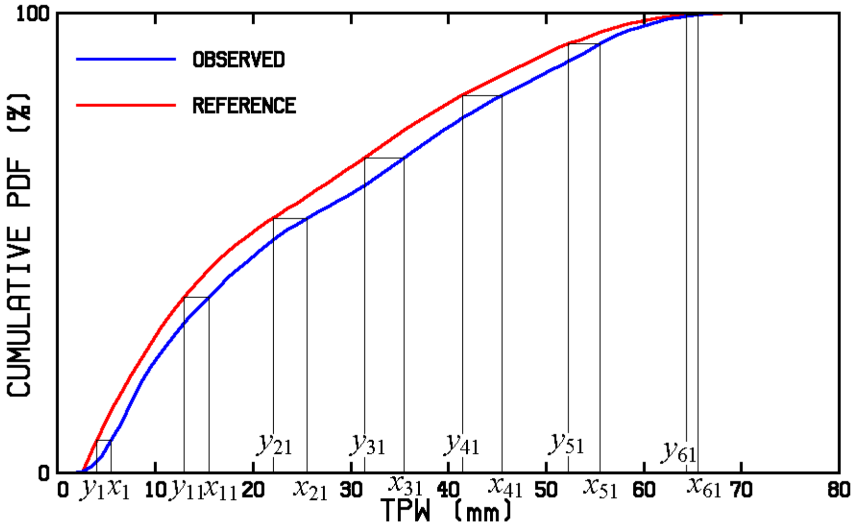


Figure 3. Illustration of the blending algorithm. [From K&J Fig. 1.]

The third step in the process is the construction of an adjustment for each scan position of each instrument (64 scan positions for SSM/I, 30 scan positions for AMSU). The blue line in Fig. 3 shows the cumulative PDF for scan position 32 on the *DMSP F14* SSM/I for the time period above. The TPW histograms are tabulated with 1-mm-width bins centered at 0.5 mm, 1.5 mm, etc. For each bin from 5.5 mm to 68.5 mm (the 64 x_i values) a y_i is interpolated such that the observed cumulative PDF has the same value as the cumulative reference PDF. This step is illustrated in Fig. 3 for a subset of the x_i and y_i values.

Note that the SSM/I TPW values are generally higher than the AMSU TPW values, so the SSM/I values need to be adjusted downward to match the AMSU reference However, the adjustment is not uniform. A larger correction is required in the middle range of TPW (where the “bars” in Fig. 3 are wider) than at either high or low TPW values. This adjustment cannot be accomplished accurately with a simple bias adjustment, which would simply shift the blue curve to the left, nor with a linear adjustment, which would shift the blue curve to the left and change its slope. A cubic polynomial fit to the (x_i, y_i) values was chosen for the correction.

Applying the adjustment is a simple process of selecting the coefficients (as a function of satellite and scan position), using the observed TPW as x, and calculating y:

$$\text{adjusted TPW} = a_0 + a_1\text{TPW} + a_2\text{TPW}^2 + a_3\text{TPW}^3 \qquad (2)$$

Figure 4 shows the adjusted cumulative PDF (dashed line) for the data shown in Fig. 3.

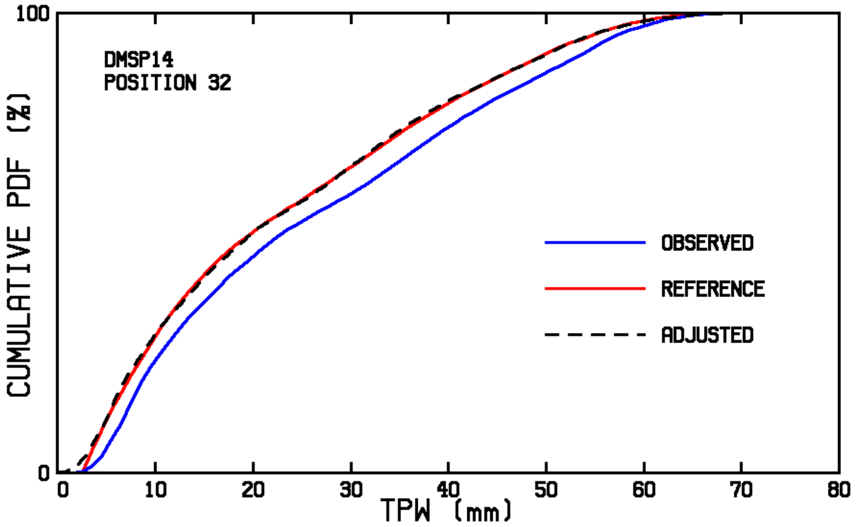


Figure 4. The dashed line shows the results of adjusting the observed TPW data with the blending algorithm. [From K&J Fig. 2.]

This blending algorithm is quite robust; it will work as long as the retrieved TPW values are monotonic with the true TPW values. It does not produce an absolutely calibrated value, but it does bring one set of observations into agreement with another set. In effect, it makes one set of observations (*NOAA 17* AMSU TPW retrievals, in this case) a reference with which other observations must agree. The advantage to the forecaster of doing this is illustrated in Figs. 1 and 2.

It must be noted that although the polynomial coefficients are calculated using TPW values between 5 mm and 69 mm, they are applied regardless of magnitude, and the results are clipped to be within the AMSU TPW range, 0–75 mm. The high and low values of TPW, therefore, are less accurate than the center values. This is a topic which deserves further study.

This blending algorithm is a dynamic algorithm. Suppose, for example, that the retrieval algorithm for one instrument is changed. In five days the blending algorithm will automatically adjust to the new reality.

Note again that this blending algorithm is fundamentally different than a retrieval algorithm. The duty of the retrieval algorithm is to produce the desired parameter (TPW in this case) as accurately as possible from the measured radiances. The job of the blending algorithm is to lessen the nearly inevitable differences between parameters retrieved with different algorithms from measurements made by different instruments. One would like the blending algorithm to combine the observations in a way which is closer to the truth. However, simply removing artifacts from the retrievals to aid the forecaster is useful even if increased accuracy cannot be claimed.

Since all of the satellites used in this study are sunsynchronous and, therefore, make observations at the same local time each day, the diurnal variation of TPW is possibly an issue. The diurnal variation is thought to be small, and the blending algorithm assumes that it is zero, that each satellite views that same distribution of TPW regardless of the time of observation. Clearly this deserves further study, as does the effect of varying field of view in the AMSU data on TPW.

Note that this blending algorithm is a type of histogram matching algorithm with roots in image processing (e.g., Richards and Jia 1999). Histogram matching has also been used to calibrate IR rainfall algorithms with passive microwave retrievals (Kidd et al. 2003) and to calibrate brightness temperatures between two different satellite instruments (Jones and Cecil 2006).

3.1.2 Mapping

Once the data have been "corrected," they need to be mapped for analysis. The base map was chosen to be compatible with a map used at SAB. It is a Mercator projection with 16 km resolution at the equator. The map is centered at the equator and 160° west. It has 1437 rows and 2500 columns. The upper left pixel is at 71°14'52" North, 20°20'38" East, and the lower right pixel is at 71°14'52" South, 19°35'3" East. The cut line is at 20° East, which was chosen to emphasize ocean areas. The map projection routines are part of the HDF-EOS libraries.

The TPW data are in files which represent approximately one orbit. Before mapping, the TPW value for each scan spot is adjusted with the blending algorithm described in Section 3.1.1. Then each scan spot is mapped by filling a quadrilateral that represents the scan spot. (Actually, the scan spots overlap somewhat, but the overlap is ignored.) The SSM/I quadrilaterals are 25 × 25 km, and the AMSU quadrilaterals are 48 × 48 km at nadir and approximately 79 × 148 km at the edges of the scan. The quadrilaterals are determined by interpolation and extrapolation from the latitudes and longitudes of the center points of the scan spots, which are contained in the input HDF-EOS files. The quadrilaterals are contiguous both along the scan lines and from scan line to scan line. Thus, the resulting map has no holes within the scanned area. (However, because the microwave swaths do not overlap near the equator, there are gaps between adjacent swaths. Also, there are holes in the map over land and where it is raining.) Figure 5 shows TPW values from a single orbit of *DMSP F14*.

In addition to mapping the TPW value, the time that the scan spot was observed and the satellite which observed it are also mapped. When the single orbits are composited (see next section) these additional mapped values are available to help interpret the data.

3.1.3 Compositing

Each orbit of data is adjusted and mapped once, then used without reprocessing in as many composites as desired. A 12-h composite is made each hour, which includes approximately $7 \times n_{sat}$ orbits, where n_{sat} is the number of satellites used in the composite. Approximately one "new" orbit for each satellite is found. The remaining $6 \times n_{sat}$ orbits (approximately) are accessed from disk files and composited again, which results in a considerable savings in computer processing.

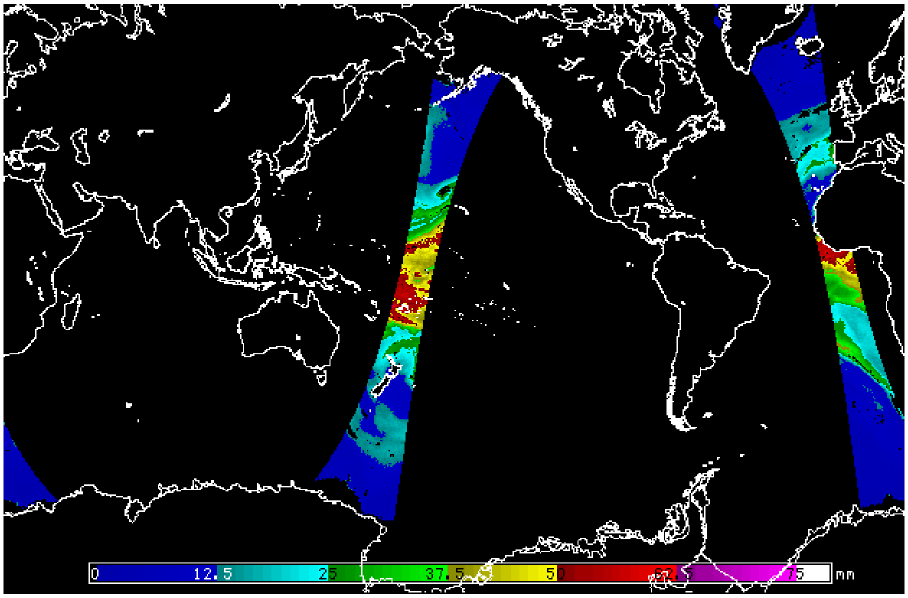


Figure 5. Adjusted and mapped TPW values during one orbit of DMSP F14. [From K&J Fig. 3.]

Satellite data may be composited or blended in a variety of ways depending on the intended use of the blended product. Perhaps the most common way to blend data is to average them over a specified time period. Figure 6 shows the TPW from three AMSU instruments and 3 SSM/I instruments averaged for a 12-h period ending at 1929 UTC on 29 March 2006. Because data from six satellites were used in the composite, there are few places which are unobserved, which is the goal of compositing—one wants to know the water vapor field for the entire globe, not simply the field as observed by a single satellite in one orbit, as in Fig. 5.

Another way to composite data is to overlay newer data on top of older data, such that only the newest data are displayed. This method of compositing is favored by forecasters because it is the most up-to-date image possible. Figure 7 shows an overlaid composite for the same time period as the averaged composite in Fig. 6. A disadvantage of the averaged composite, from the forecaster's point of view, is that averaging "retards" weather systems; that is, a moving weather system, if observed more than once in a 12-h period, will appear to be "behind" its position in the overlaid composite. An advantage of the averaged composite is that it is smoother than the overlaid composite. The Data Processing and Error Analysis System (DPEAS) software (see Section 5), which is used to construct these composites, is also capable of doing a weighted average of the observations, with older observations being weighted less than newer observations. This method is "between" the averaged product, which has uniform weights for every data point, and the overlaid product, which weights the newest observation one and all older observations zero.

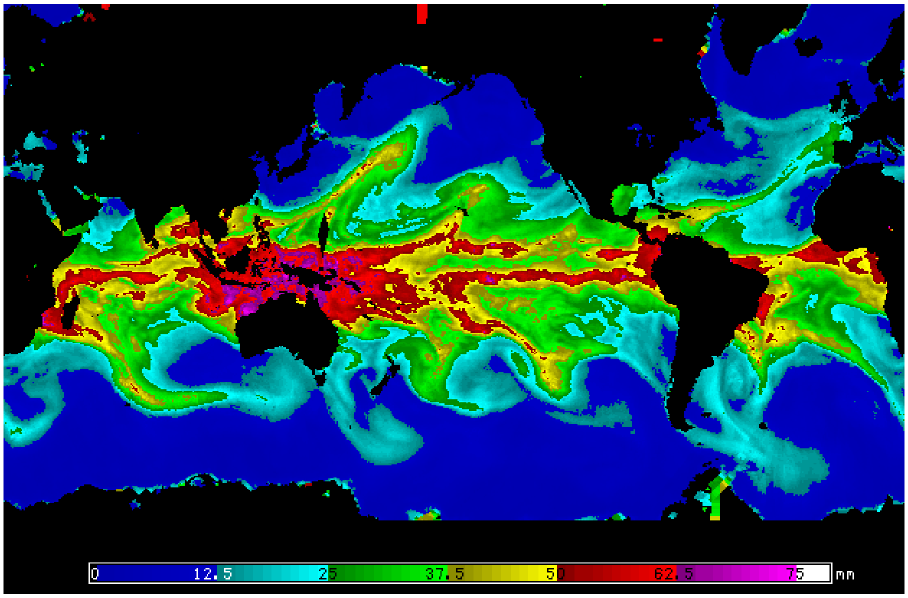


Figure 6. Average TPW for the 12-h period ending at 1929 UTC 29 March 2006. Approximately 30 orbits went into this composite. [From K&J Fig. 4.]

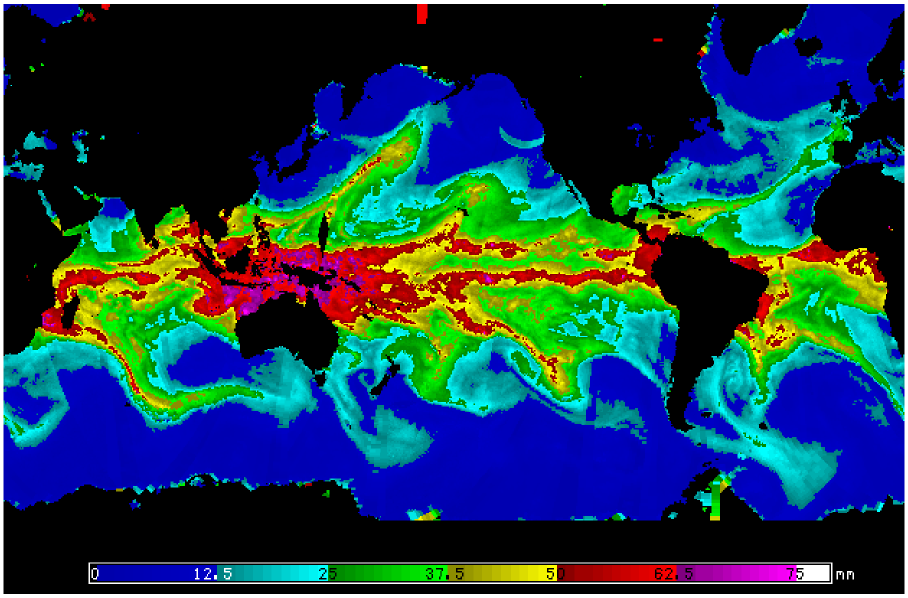


Figure 7. Overlaid TPW for the 12-h period ending at 1929 UTC 29 March 2006 (only the most recent datum at a point is shown). The same orbits were used in this composite as in Fig. 6. [From K&J Fig. 5.]

When the overlaid composite is constructed, one can optionally map the time of the most recent observation and the satellite which made it. These data are useful for analyzing the resultant TPW field.

3.2 Over-Land Blending

The blending process over land is different than over ocean because it relies on different data. The microwave data sources that are used over water do not have retrievals over land. (The Microwave Integrated Retrieval System, or MIRS, does provide over-land TPW retrievals, but they are not used yet). Two sources of data are currently used over land: (1) PW (layered and total) retrievals from the GOES Sounders on GOES-West and GOES-East, and (2) ground-based GPS TPW retrievals. These data sets are available only over the CONUS, with a few stations in Alaska, Hawaii, Puerto Rico, Mexico and Canada.

3.2.1 Land TPW Datasets

The GOES sounder data are obtained via anonymous FTP from satepsanone.nesdis.noaa.gov in the directory retcld/asciiTPW. Two files are obtained, one each from GOES East and West. The filenames contain the numbers of the current east/west GOES (12 and 11, respectively as of September 2008), so the filenames change as new GOES spacecraft take over the operational role. Total and layered PW is provided in the file, as well as time and earth location. The algorithm of Ma et al. (1999) is used for the PW retrievals and the retrieval performance is described further in Schmit et al. (2002). The GOES sounder does not retrieve TPW in cloudy conditions. Figure 8 shows an example of the GOES East and West TPW for September 26, 2008 at 00 UTC from http://cimss.ssec.wisc.edu/goes/rt/sounder-dpi.php. Notice how most of the east coast of the U.S., which is very cloudy, has no TPW retrievals. GOES Sounder TPW is produced hourly.

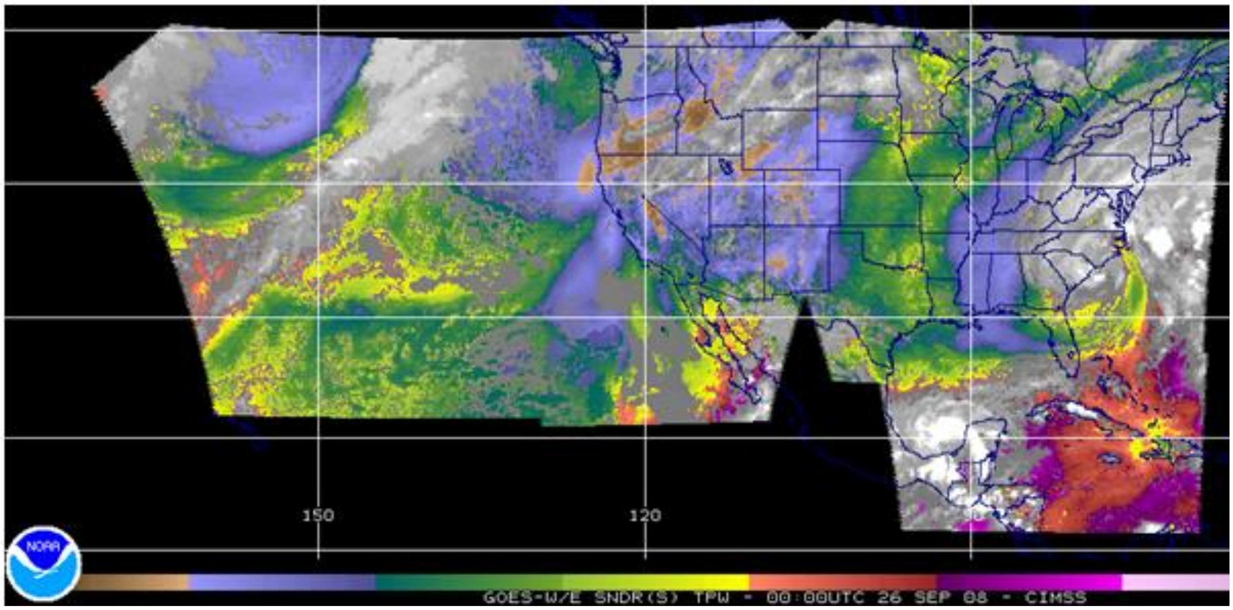


Figure 8. GOES East and West TPW only for 26 September 2008, 0000 UTC. Gray to white regions are cloudy with no TPW retrievals. [Image courtesy of CIMSS, University of Wisconsin].

The GPS total precipitable water is provided by the NOAA/GSD GPS-MET project (http://gpsmet.noaa.gov/jsp/index.jsp). The GPS TPW retrieval, which requires an accurate surface pressure measurement along with a surface GPS receiver, is described in Bevis et al. (1992). The NOAA GPS-MET network used in this work is further described in Rama Varja Raja et al. (2008). The GPS TPW in ASCII format is retrieved via anonymous FTP from gpsftp.fsl.noaa.gov. As of September 2008, TPW information is available for roughly 300 stations every half hour. The surface GPS meteorology network continues to expand. In September 2008, there were 515 possible stations available, including some new stations in Canada and Mexico. In April 2008, only 442 stations were candidates (Figure 9). TPW is not received routinely from every station in the candidate list. The relatively high spatial and temporal resolution of surface-based GPS TPW over CONUS makes these measurements very useful to include in the blended TPW product for forecasters.

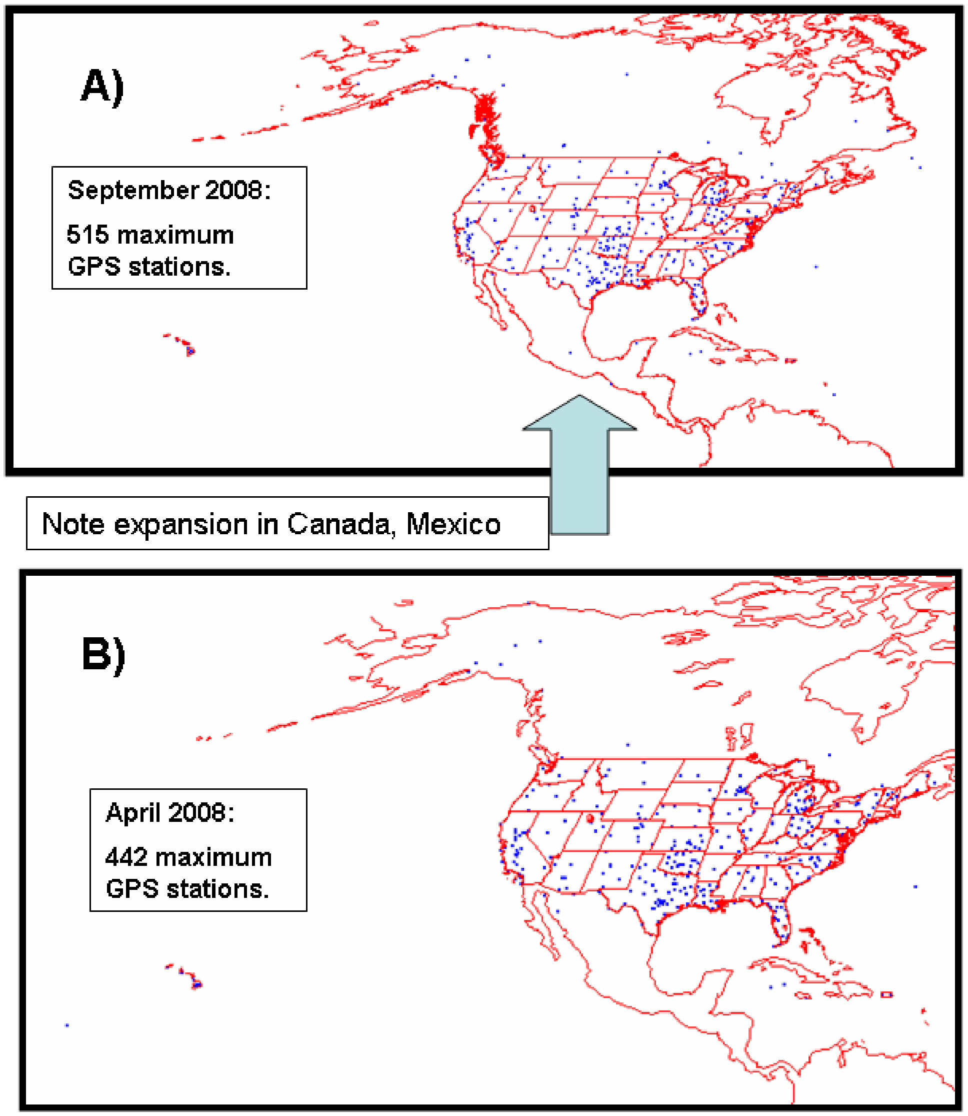


Figure 9. Map of all GPS stations available via NOAA GPS-MET project for (a) September 2008 and (b) April 2008. The network expanded from 442 to 515 stations in this time.

The spatial resolution of the GPS measurements is difficult to exactly specify, since it is a function of the geometry and number of GPS spacecraft relative to the surface receiver. A rough estimate (Rama Varja Raja et al., 2008) is that each measurement represents an 11 km radius inverted cone centered on the receiver. This resolution is more than sufficient to combine with passive microwave satellite sensors.

3.2.2 Merger of Land and Ocean TPW

The starting point for the over-land TPW is the TPW analysis produced in Section 3.1. (Figure 10 shows an example near CONUS). Note that there are no data over land. The basic plan for the Over-Land algorithm is to “fill the holes” in Fig. 10 using GPS data (first choice) or GOES PW data (second choice). GPS data are used in preference to the GOES PW data because GPS TPW values are unaffected by clouds, whereas GOES PW values can be retrieved only in cloud-free conditions. The GOES PW data provide a valuable backup in case the GPS data are not available.

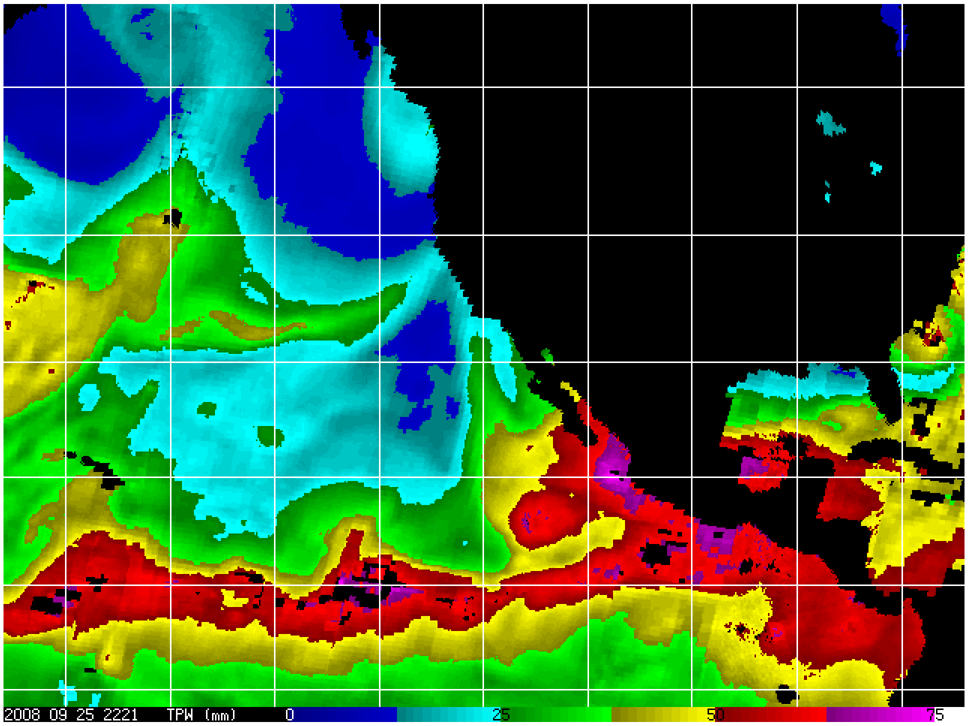


Figure 10. Ocean-only TPW for 25 September 2008, 2221 UTC.

For a subset of the entire map, which includes North America, a Barnes analysis (Barnes 1964, Koch et al. 1983) of the GPS data is performed. The Barnes analysis approach has several parameters which must be specified, relating to the spatial influence of the data. The values in this work were arrived at by visual inspection and interaction with NESDIS SAB forecasters. As the density of the GPS network increases, these parameters should be revisited. Table 1 lists the values used in the Barnes analysis of the GPS TPW data. The values chosen are rather liberal (e.g. allowing an analysis up to 300 km from the nearest station) and geared towards a smooth field and high spatial coverage over CONUS. These values could be modified in the future to emphasize for instance increased spatial structure at the expense of high coverage.

In regions with only a few stations in the Barnes analysis (e.g. Mexico, southern Canada), a circular feature can be produced in the analysis as only a few stations are available for interpolation and data points exceed the distance criteria in Table 1.

Table 1. Current Barnes analysis parameters for GPS data.

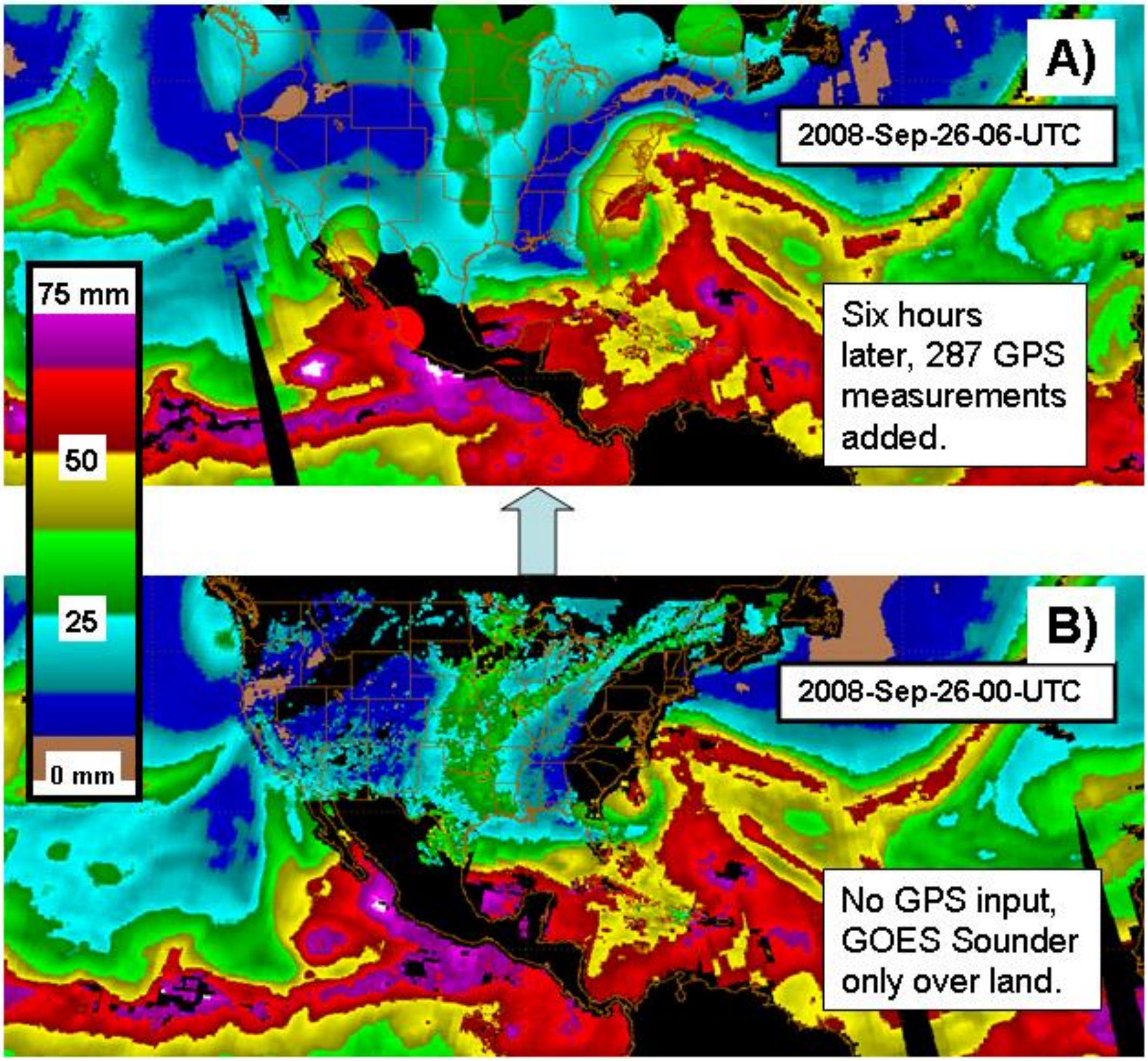
Barnes Analysis Parameter	Value
Minimum number of GPS data points within range for Barnes analysis to proceed	3
1/e decay length	250 km
Maximum number of stations in an analysis	100 stations
Maximum distance of closest station	300 km
Maximum distance of a station to consider (stations further than this not used)	600 km

In order to augment the ocean-only product, each point in the starting map (e.g., Fig. 10) which contains missing data after the addition of the microwave-derived TPW is examined. At each point, the TPW value is selected in the following order:

1. The TPW value from the starting map (if present – GPS or GOES does not replace existing TPW).
2. The GPS TPW from the Barnes analysis (if present).
3. The GOES TPW value (if present).

The search for a TPW value ends as soon as one is found, so that AMSU or SSM/I TPW values from the starting map are not replaced, and GPS data are selected preferentially over GOES PW values. No averaging or error-weighting of the data is currently performed, although such approaches are worthy of further study. Figure 11a shows the final result when GPS and GOES are both added on 26 September 2008, 06 UTC. Figure 11b shows the case six hours earlier when no GPS data was available, for instance due to a communications failure, and only GOES sounder is used to fill in the gaps in clear regions. The value of the GPS in detailing the structure of the tropical moisture plume affecting the eastern U.S. is apparent.

The GOES Sounder data are mapped directly into the Mercator projection, and then a 3 x 3 grid box expansion is performed, or up to roughly a 48 km^2 areal coverage. This is strictly to eliminate holes in the analysis from insufficient coverage of the gridded data. In the future, the GOES Sounder results could be remapped or averaged together to eliminate missing values.



2008-Sep-26-06-UTC

Six hours later, 287 GPS measurements added.

2008-Sep-26-00-UTC

No GPS input, GOES Sounder only over land.

Figure 11. (a) Fully blended TPW product with input from GPS and GOES Sounder. (b) Same product six hours earlier with no GPS input. Notice how the tropical flow of moisture into the eastern U.S. is not captured by GOES alone, due to clouds.

Essentially only points in North America are filled by this technique because that is the extent of both the GPS data (which is available to NESDIS) and the GOES PW product. But there is no inherent restriction of the technique to this region, if more GPS networks become available they can be included in other parts of the world.

MIRS retrieves TPW over both land and ocean. When this new data source is implemented, this portion of the blending algorithm will need to be modified.

4 THE PERCENT OF NORMAL TPW PRODUCT

To give forecasters an idea about how abnormally moist or dry the Blended TPW Product is, the TPW values from the blended product are divided by the weekly mean TPW values from the NVAP Dataset for 1988-1999 (Randel et al. 1996). NVAP is a daily, 1-degree resolution analysis which was created with TPW derived from SSM/I (ocean), NOAA TOVS (ocean and land), and radiosonde (land). This gives "percent of normal." There are 52 weekly mean fields used as normal from NVAP. No moving mean or 3-1-3 (three days before, the current day, and the next three days) calculation of the weekly mean is currently performed. The percent of normal product was developed at CIRA for research purposes but has proven useful for tracking atmospheric rivers, return flow of moisture from the Gulf of Mexico, and abnormally dry conditions associated with fire danger.

The color table which is usually used ranges from dark brown (0%) through white (100%) to cyan (199%). TPW values equal to or greater than 200% of normal are colored yellow. An example is shown in Fig. 12. Notice the values greater than 200% of normal over the mid-Atlantic states. This is the region of deep tropical moisture in Fig. 11a. From experience at CIRA, values greater than 200% are nearly always cloudy, while values less than 50 % are nearly always clear. The Percent of Normal product is especially robust in midlatitudes and shows a wide range. In the Tropics, even hurricanes do not generate values greater than 200% since the background state is already extremely moist.

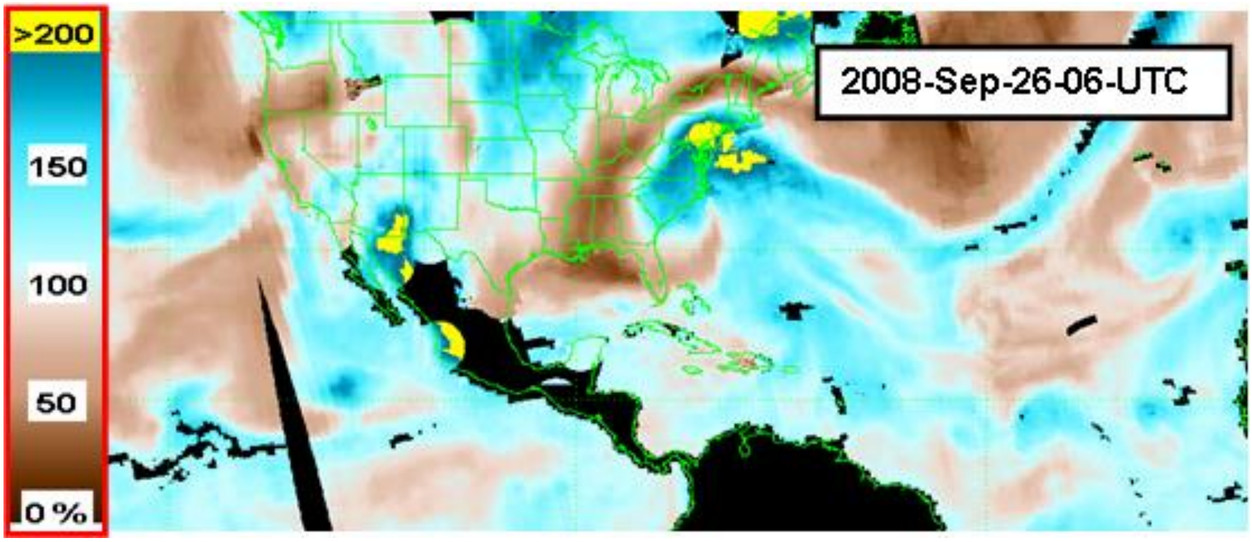


Figure 12. Example of the Percent of Normal product for 26 September 2008, 06 UTC.

5 IMPLEMENTATION ISSUES

The theory of the Blended TPW Products is discussed above. In this section, we practical issues: how does one actually implement the theory? The products are produced using the Data Processing and Error Analysis System (DPEAS, Jones and Vonder Haar 2002), which is documented elsewhere. [NOTE: the names of the documents should be inserted here.] In the following section, the names of the subroutines which implement the theory are listed to connect this ATBD with the Users' Manual, and other documents. In the second section, issues related to scheduling the subroutines are discussed.

5.1 DPEAS Subroutines

The scripting language for DPEAS is Fortran 90. The following table lists the DPEAS subroutines that are called to execute the algorithms above.

Table 2. DPEAS subroutines used to form the Blended TPW Products.

Subroutine Name	Algorithm Executed
create_tpw_correction	Forms the 5-day histogram of TPW observations discussed in Section 3.1.1
get_files	Gets a list of files to process.
read_hdfeos	Reads in an orbit of data.
apply_tpw_correction	Corrects the TPW data in the orbit by the cubic polynomials detailed in Section 3.1.1.
Remap	Maps the TPW values from one orbit to the Mercator map detailed in Section 3.1.2.
write_hdfeos	Writes the mapped TPW values for the orbit being processed to a file for use in the compositing routine.
composite	Composites a set of orbit maps (found using get_files) into a single map as discussed in Section 3.1.3. Arguments of the subroutine specify how the compositing is done.
write_mcidas	Writes out the composited file in McIDAS format.
write_gif	Writes out a GIF image of the composited file.
gps_tpw_interpolate	Reads and interpolates (via a Barnes analysis) the GPS TPW data and inserts them into the composited TPW map produced above as discussed in Section 3.2.2.
goes_sndr_tpw_merge	Reads the mapped GOES-PW data and inserts them into the composited TPW map produced above as discussed in Section 3.2.2. The result after this step is the Blended TPW Product
compute_tpw_percent	Produces the Percent of Normal TPW Product as discussed in Section 4.

5.2 Scheduling

The timing of the blended products and when to pull products and run blending jobs is important and interrelated. Figure 13 gives details on the time when the GPS and GOES sounder files are available, and also which sampling times are chosen at the run time.

The blended ocean TPW must be available first in order to know where to add the land inputs. This file (HDF-EOS) is typically available at 20 min past the hour and is produced hourly. The GPS data must be pulled from between 20 min and 50 min past the hour, before a new processing cycle begins. The current implementation is to pull the GPS data at 40 min past the hour. The file that is pulled represents the values at 15 min past the previous hour (HH-1) in Fig. 13. The GOES sounder TPW for HH-1 is available on the NESDIS server at about 15 min past the hour. Note that the GPS and GOES sounder products are retrievals and thus have latencies associated with them. Future instrument, algorithm, or hardware changes could affect the speed of the retrieval. The scheduling of these jobs should be checked periodically to ensure that datasets are not being missed.

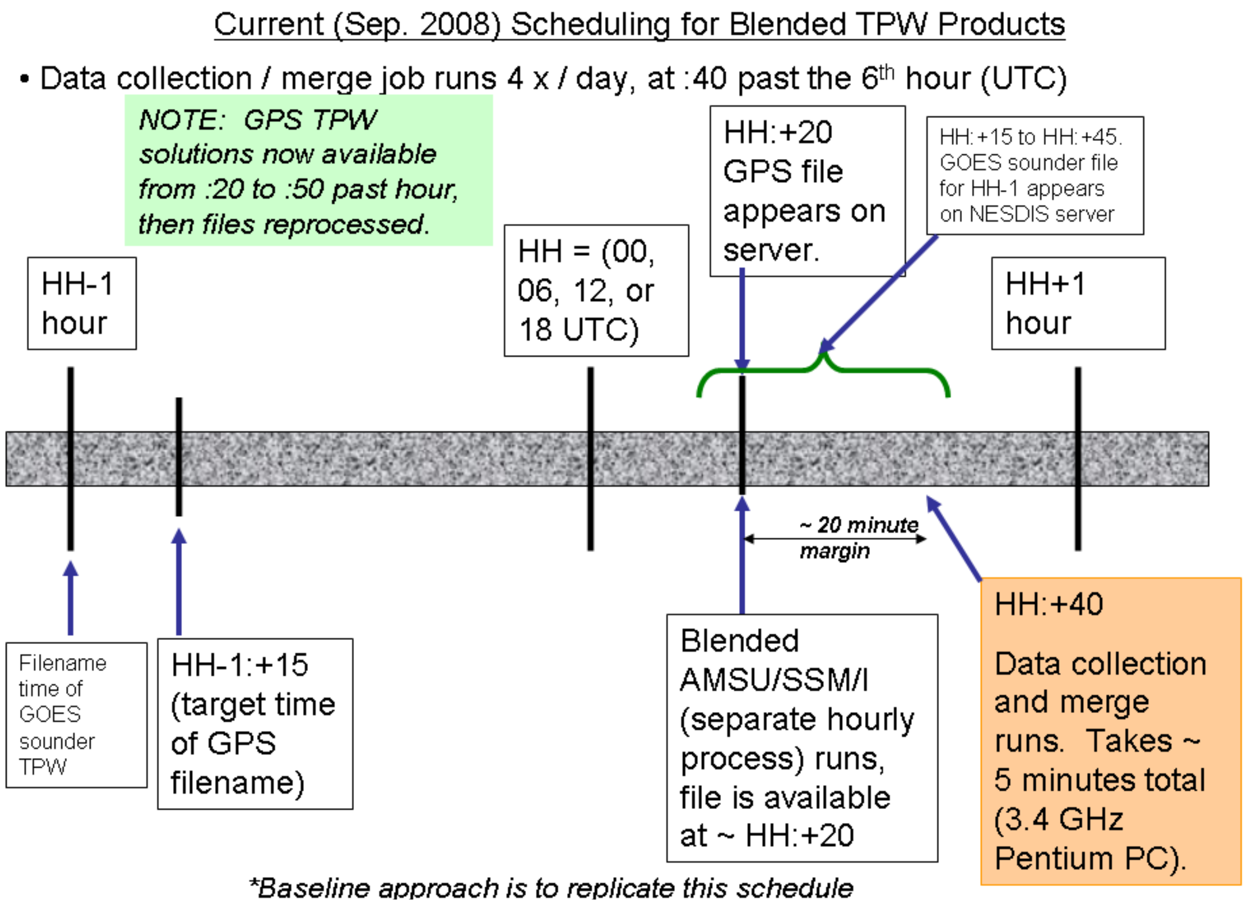


Figure 13. Schematic of timing of the ingest and production runs to create the blended TPW products. The jobs run at HH:+40 (e.g., 1240 UTC), while the filenames of the GPS and GOES would be at 1115 and 1100 hours, respectively.

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