RSS One-Degree Monthly

Microwave Ocean Surface Wind Speed

1. Intent of This Document and Point of Contact (POC)

1a) This document is intended for users who wish to compare satellite derived observations with climate model output in the context of the CMIP/IPCC historical experiments. Users are not expected to be experts in satellite derived Earth system observational data. This document summarizes essential information needed for comparing this dataset to climate model output. References are provided at the end of this document to additional information.

This NASA dataset is provided as part of an experimental activity to increase the usability of NASA satellite observational data for the modeling and model analysis communities. This is not a standard NASA satellite instrument product, but does represent an effort on behalf of data experts to identify a product that is appropriate for routine model evaluation. The data may have been reprocessed, reformatted, or created solely for comparisons with climate model output. Community feedback to improve and validate the dataset for modeling usage is appreciated. Email comments to HQ-CLIMATE-OBS@mail.nasa.gov.

Dataset File Name (as it appears on the ESGF):

sfcWind_SSMI_L4_RSSv07r00_198801-201512.nc

sfcWind_SSMI_L4_RSSv07r00_198801-201512-CLIM.nc

1b) Technical point of contact for this dataset:

Carl Mears, mears@remss.com

also email: support@remss.com

2. Data Field Description

CF variable name, units:	wind speed, m/s
Spatial resolution:	1.0 x 1.0 degrees latitude/longitude
Temporal resolution and extent:	monthly averages, Jan 1988 - Dec 2014 in one file, (increases yearly)
Coverage:	global oceans

3. Data Origin

The One-Degree Monthly Microwave Ocean Surface Wind Speed data set is constructed by merging together carefully intercalibrated microwave wind speed values derived from a series of satellite microwave radiometer instruments (see Section 6). This wind data product is provided as two files. One with monthly maps of mean wind speed over the ocean regions covering the time period of Jan 1988 to December 2014, and the other a monthly climatology for the 1988-2007 reference period. The data product described here is also available at RSS and is referred to there as the Merged Wind Speed 1-deg Monthly Climate Product (http://www.remss.com/measurements/wind/wspd-1-deg-product).

The satellite microwave radiometer data used in creating this product are from 6 SSM/I on DMSP satellites (F08, F10, F11, F13, F14 and F15), 2 SSMIS on DMSP satellites (F16 and F17), and the WindSat polarimetric radiometer on the NPP Coriolis satellite (all sensors are further described in Section 6 below with full names for each acronym). Each of these polar-orbiting sensors measures the Earth radiance at multiple frequencies and polarizations in the microwave spectrum. RSS obtains homogenous brightness temperatures using careful intercalibration and a consistently applied data processing scheme [*Wentz*, 2013]. On-orbit calibration is accomplished with observation of cold (cosmic background radiation) and hot (on-board warm source) targets. These measurements are needed to maintain consistency of values over time.

The transformation of satellite measured brightness temperatures to geophysical measurements is accomplished by using a consistent algorithm and a well-developed and tested radiative transfer model to simulate satellite measured brightness temperatures and derive a regression algorithm [*Meissner and Wentz*, 2004; 2009; 2012; *Wentz and Spencer*, 1998]. The currently used algorithm at RSS is referred to as Version-7 and is consistently applied to each of the microwave radiometers. Uniformity of process and intercalibration between sensors on the brightness temperature level ensures the variables coming from each platform can be successfully merged to produce a high-quality climatological product.

The satellite-measured ocean surface wind speed values represent the speed of air movement at a height of 10 meters above the ocean surface. The CF-compliant unit for this measurement is m/s. Wind speed values range from 0 to 50 m/s. The wind speed is retrieved by noting the microwave radiance measured by the satellite. The radiance is a combination of surface emission and atmospheric emission, part of which is scattered by the ocean surface. Wind-induced roughening of the ocean surface causes changes in emission and scattering at the ocean surface. By analyzing measurements made at different frequencies, the contribution to changes in brightness temperature caused by atmospheric emission, scattering and attenuation can be accurately removed. The resulting roughening is a measure of wind stress, which is converted to a 10m neutral density wind speed for this product. This only works for the ocean surface, and thus measurements are available only over the world's oceans. Wind speed retrieval is prevented in regions with rain, radio frequency interference, and near land or sea ice. The near-polar orbiting satellite microwave sensors provide daily coverage consisting of approximately 15 orbits per day which we plot as ascending and descending swaths on a gridded map. For each sensor, the swaths and resulting gaps between swaths vary in width. When averaged over a month, the swath gaps can result in geographically varying data sampling. With the exception of areas bordering land and sea ice, the global oceans are well represented throughout the month. In Figure 1 we show a map of the descending measurements of wind speed made by WindSat.

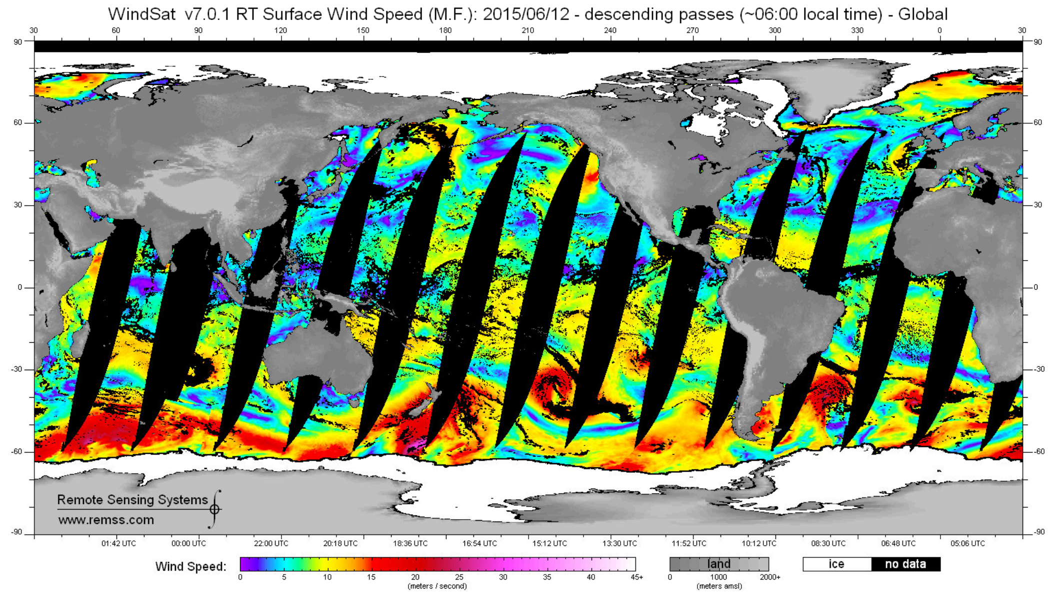

Figure 1: Color-coded map of WindSat descending pass observations of surface wind speed for a typical day (June 12. 2015). Land in shown as various shades of gray, ice is shown as white, and missing data is shown as black.

The Version-7 ocean wind speed values from the individual SSM/I, SSMIS, and WindSat sensors that are used to create this product are available from RSS and are freely available at ftp.remss.com. Further documentation on the RSS microwave radiometer products is available from www.remss.com/missions.

This merged ocean wind speed product is made using a two-step construction process. First, we make monthly 1-deg maps from individual satellite wind speed values, keeping track of the number of observations per grid cell, the number of ice observations, and the mean day of month. We re-grid using cosine latitude weights to reduce the spatial resolution from 0.25 deg (RSS daily satellite products) to the 1-deg grid used here. In the second stage of processing, we apply quality control measures, and apply small bias adjustments (<0.1 m/s) to each satellite. The values of these adjustments were found by comparing the retrievals from each satellite to measurements made by the Tropical Rainfall Measuring Mission (TRMM) Microwave Radiometer, which has been in continuous operation from 1997 to early 2015. This part of the process is described in more detail in Section 5.5 below. We then combine wind speed values from all sensors using simple averaging. The resulting merged wind speed product is constructed using the following requirements: We only calculate a wind speed value for a specific 1-deg grid cell if the cell contains more than 160 observations during the month, if ice is present for less than 30 of the observations in that cell, and if the calculated mean day of the month (derived by averaging the time of the data falling within the cell) is within 6 days of the center day of the month.

We then compute the monthly gridded climatology by averaging together spatially-smoothed gridded maps for each month of the year over the 20 year period, 1988-2007. Each monthly map for each satellite is smoothed using a 3 degree by 3 degree boxcar smooth prior to computing the climatology. This serves to fill in small regions with missing data, and reduce sampling noise in the climatology.

This Obs4MIPS product is updated yearly and will continue for as long as microwave satellite radiometers are in operation.

4. Validation and Uncertainty Estimate

Wind Speeds are typically validated by comparison with values measured by moored ocean buoys and with winds from global circulation models. At RSS, we have completed extensive intercomparisons between winds from all microwave sensors including those from scatterometers. The mean differences of satellite minus buoy wind speeds for closely collocated measurements (within 50 km and 30 minutes) were calculated using data from 1988 through to present. The typical stats found for any individual radiometer is on the order of ~1.0 m/s root-mean-square error. This decreases for buoys in tropical regions such as those in the TAO/TRITON, RAMA and PIRATA arrays for which the RMS error is closer to 0.7 m/s for most radiometers.

Two papers summarize the results for the series of SSM/I as compared directly to buoy winds [*Mears et al.*, 2001] and model winds [*Meissner et al.*, 2001]. For this merged product, the contribution of measurement noise, important for a single retrieval, is greatly reduced by averaging large numbers of measurements into a monthly grid point.

Comparisons of this merged product with other data are underway.

5. Considerations for Model-Observation Comparisons

5.1 Temporal sampling bias

There are two types of temporal sampling biases to take into consideration:

1) Ocean wind speed has significant diurnal variability in certain ocean regions. The sun synchronous orbit of any polar-orbiting sensor yields retrievals at specific local times. Figure 2 shows the ascending node time for each sensor and the change in this value over time, which demonstrates that the ocean wind speed is well measured from only 2 points in the diurnal cycle, a morning and an evening time window of roughly 6-10 am/pm represented by the microwave radiometers used in this product. Due to the size of ocean wind variability, we exclude measurements from AMSR-E and AMSR2 (both were used in our TPW product of similar construction). The AMSR-E and AMSR2 measure at 1:30 AM and 1:30 PM (local time), significantly different from the other.

2) In creating this merged product, there were 3 satellite-months that did not meet our data production requirements (as stated at the end of Section 3). We require that the average time of the calculated monthly mean fall within 6 days of the center of the month. This was not the case for: F08 in Jan 1988, F08 in Oct 1990 and F10 in Dec 1991 when the sensors operating at that time had data outages. In each case, the month values were needed for consistency of the time series so an exception is made and the data are included despite the poor sampling. These exceptions are early within the time-series and one can avoid any bias that may result by starting analysis in 1992.

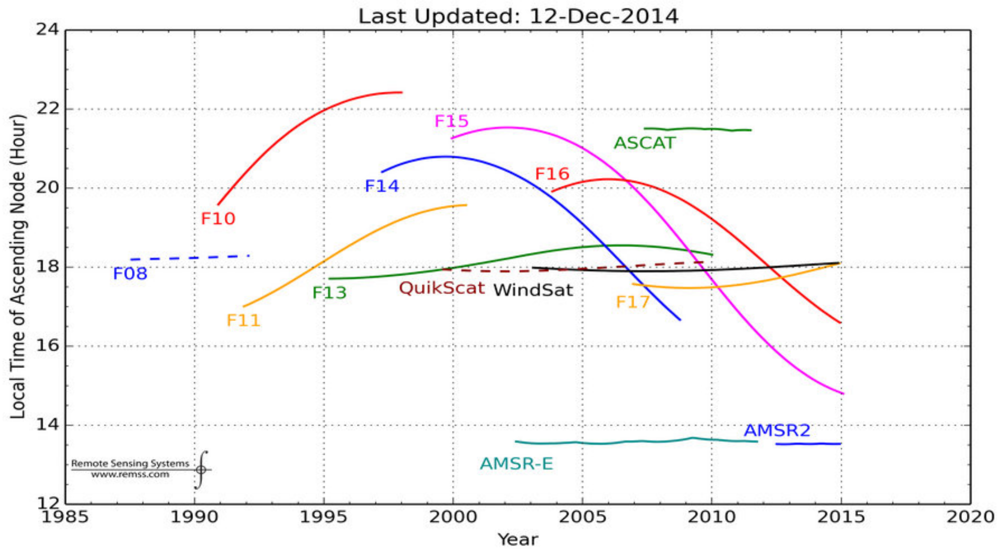

Figure 2: Local ascending crossing times for each microwave radiometer showing the change over the lifetime of the sensor. The SSM/I and SSMIS sensors are distinguished using the name of the DMSP satellite. F08 to F15 have the SSM/I and F16 and F17 have SSMIS. This plot is continually updated and available at www.remss.com/support/crossing-times. Though the plot represents all imaging radiometer data processed by RSS, only the SSM/I, SSMIS and WindSat data are used in this merged product.

5.2 Inhomogeneous sampling

The quality of the wind speed product is dependent on the number of data that are averaged into each grid cell. Sampling by polar-orbiting microwave sensors is not homogeneous. For a given day of measurement, polar-orbiting sensors measure some regions with greater coverage and some regions without any coverage. In the Arctic, there are an extremely high number of observations due to overlapping measurement swaths by multiple sensors. In areas where the first and last orbits for a day overlap, a greater sampling exits. Other regions have fewer values in the mean.

Land and ice proximity reduces the sampling as radiometers suffer from side lobe interference that prevents obtaining wind speed values near land. Due to variations in sensor resolution, look angle, geographic conditions and spatial footprints, some pixels have more observations than others. This results in varying numbers of observations for a given grid cell and poorer quality averages near coastlines and along ice edges. See Figure 3 for a typical map of the number of observations in a 1 degree by 1 degree cell in a regridded monthly map for a single SSM/I sensor.

Due to the effect of rain on wind speeds derived from microwave observations, we use an extended rain flag when developing this wind speed product. The removal of rain-affected or potentially rain-affected wind speeds reduces the number of values used to calculate the mean in rainy tropical regions. This can be seen in Figure 3 as the area of reduced number of observations near the ITCZ.

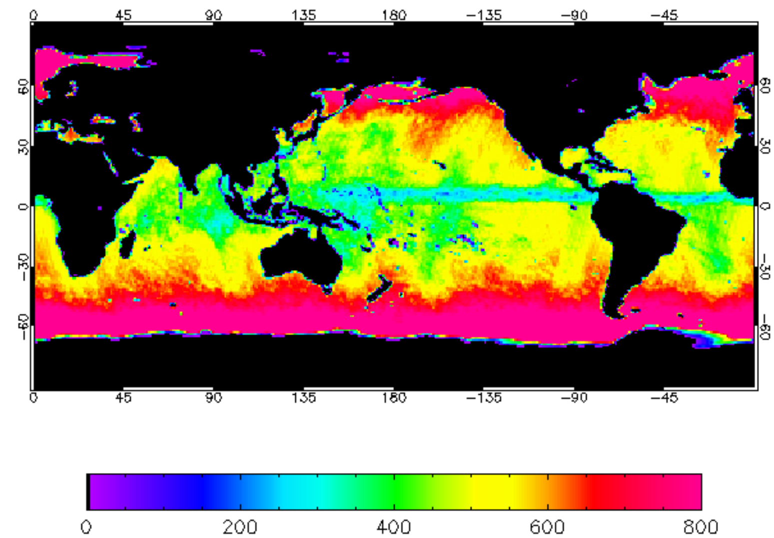

Figure 3: Number of Wind Speed observations included in the monthly average of May 1990 for one SSM/I sensor.

We account for sampling differences when constructing the product by requiring a minimum number of values for a mean to be calculated in any grid cell. We tested a variety of minimum observation requirements. We found that only along the coastlines and ice edges did the number of values drop below a threshold and poor quality data enter the product. We experimented to see how different thresholds affected resulting trends and determined little difference once a minimum threshold of 160 counts per cell per month was met. This requirement was therefore used in constructing the product.

5.3 Ice Effect on Product

Ice is likely to exist more at one end of a month than another (with the exception of floating icebergs) and ice removal is necessary. We developed a mean-day-of-month quality calculation to remove ice edge grid cells where the amount of ice increases or decreases throughout the month during seasonal changes. To handle icebergs which move between grid cells, we use the number of ice observations within a grid cell during the month to exclude when too much ice exists (number of ice observations must be <= 30). Even though these requirements are applied, it is still possible that some small ice effects remain in the product.

5.4 Rain Effects

Rain affects ocean wind speed values measured by microwave radiometers. The removal of values measured in rainy conditions can have adverse effects on this product. For the wind speed product, we find that we need to remove data in grid points adjacent to rain to ensure the highest quality merged wind product. We found that exclusion of data adjacent to rain creates a geographic sampling problem by removing data from primarily rainy, tropical areas. However, despite the complications, we feel it necessary to exclude any rain-affected data. An extended rain flag is applied during construction that consists of checking nearby data (within the 0.25 degree grid cells adjacent to the grid cell in question) and omitting those for which rain is present.

5.5 Accounting for Small Differences between Sensors

Even after our best efforts to intercalibrate the satellites at the brightness temperature level, small wind speed biases typically less than 0.1 m/s exist between the various satellites. These are characterized and removed via comparison the TMI sensor, which was recently recalibrated to Version-7 (Wentz, 2015), and not used in this product. In Figure 4, we show monthly-mean time series of the differences (satellite minus TMI) between collocated measurements made by each of the satellites used in the merged product and TMI. To be considered to be collocated, the observations must be in the same 0.25 degree grid cell, and separated in observation time by less than 30 minutes. The DMSP F14, F15, and F16 sensors all exhibited periods of anomalous performance (shown in red) that are excluded from further processing. Ignoring these red regions, the mean differences shown here are used to adjust the values for each of the satellites prior to merging. The biases applied to each satellite are shown in Table 1 below.

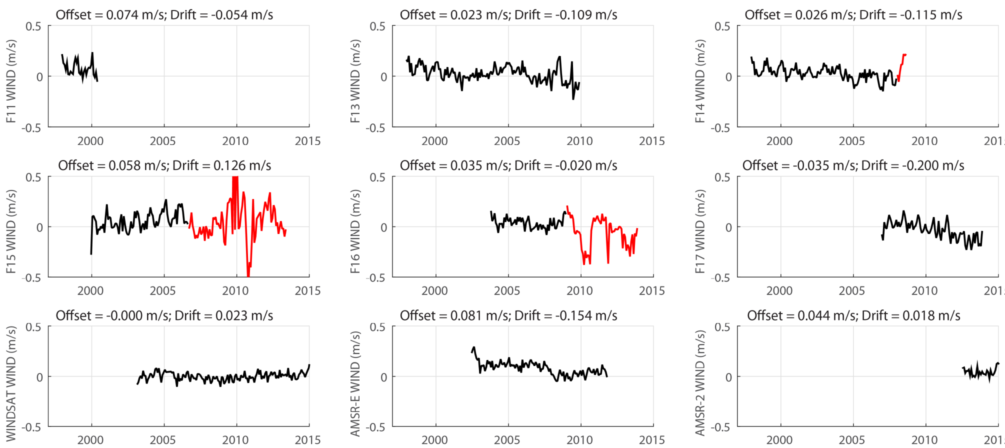

Figure 4. Time Series of monthly-mean differences (satellite minus TMI) of collocated measurements between each of the sensors used in in our data product and TMI. Note that TMI, AMSR-E, and AMSR2 are not used in the merged product. The F14, F15, and F16 sensors show periods of anomalous performance (red) and data from these periods are not used in making the merged wind product.

Table 1. Adjustments applied to sensor data prior to merging

Satellite	Adjustment (m/s)
F08	0.000
F10	0.000
F11	-0.074
F13	-0.023
F14	-0.026
F15	-0.058
F16	-0.035
F17	0.035
WindSat	0.000

To test the success of these adjustments, we plot in Figure 5 the mean wind speed difference between each satellite sensor and TMI for the latitude range 38.0S to 38.0N (roughly the extent of the TMI measurements). Any bias or drift in a single sensor would be seen as an offset or slope in these time series. No large biases or drifts exist. There is a slight downward drift in the F17 wind speed values. We will monitor this difference to see if it continues.

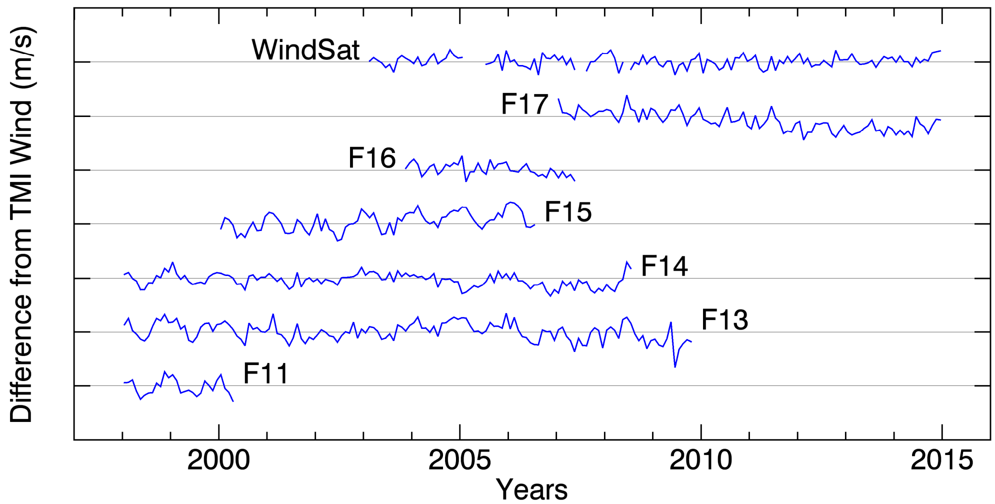

Figure 5. Monthly mean time series for each satellite relative to the monthly mean for TMI. The distance between tick marks on the y-axis is 0.5 m/s. Data from the F08 and F10 sensors are not shown, because these sensors did not overlap with the TMI operational period.

5.6 Requirements for Ancillary Data Sets

The RSS microwave radiometer data processing has minimal requirements for ancillary data sets. Since wind direction, in relationship to satellite look angle can impact the emissivity; wind direction is needed for the retrieval algorithm. Wind directions from the NCEP GDAS analysis are used. Any error in wind direction specification has little effect on subsequent wind speed retrieval errors.

6. Instrument Overview

The microwave radiometers used for this data product are very similar with the exception of WindSat (a polarimetric radiometer). At the time of product development, all microwave radiometers with Version-7 data were incorporated (F08, F10, F11, F13, F14, F15 SSM/I; F16 and F17 SSMIS; WindSat), except for AMSR-E which has a later crossing time and was therefore excluded. TMI was excluded because it was not yet processed to Version-7. We have not completed reprocessing, but choose to exclude it from the merged dataset. TMI is instead used as a calibration source to estimate any intersatellite sensor biases (Section 5.5). The F18 and F19 SSMIS are already operational, but RSS has not yet processed the data, so both are excluded. The GPM Microwave Imager (GMI) was launched in Feb 2014 just after we first created this wind product. We have just completed processing the GMI data to V7 and once we publicly release the data, GMI will be included in this wind product. We expect data from the F18 and F19 SSMIS sensors, and GMI will be added to the next merged product revision.

Each of the microwave radiometer sensors used have a rotating antenna fed by a collection of feed horns. Each is in a sun-synchronous orbit. Spatial resolutions vary based on instrument altitude and beamwidth. Channel frequencies are not identical between instruments but this is handled by our radiative transfer model. The microwave radiometers are used primarily for retrieving brightness temperatures from which we can retrieve ocean surface winds, total column water vapor, cloud liquid water and rain rate.

[SSM/I] The Special Sensor Microwave Imager (SSM/I) is carried aboard Defense Meteorological Satellite Program (DMSP) satellites F08, F10, F11, F13, F14 and F15 (no SSM/I on F09 and the F12 sensor failed soon after launch). The SSM/I have 4 frequencies: 19.35, 22.2, 37.0, and 85.5 GHz. All but 22 GHz have both vertical and horizontal polarizations [*Hollinger et al.*, 1990]. RSS downloads temperature data records from NOAA CLASS and processes the raw data to brightness temperatures and retrieves wind speed, TPW, cloud and rain rate daily maps. The daily maps are used in creation of this wind climatology product. More information about the SSM/I instrument is at http://nsidc.org/data/docs/daac/ssmi_instrument.gd.html.

[SSMIS] The Special Sensor Microwave Imager Sounder is carried on the Defense Meteorological Satellite Program (DMSP) satellites F16, F17 and F18. F16 launched in October 2003, F17 launched Nov 2006, and F18 launched October 2009. All remain in operation at the time of this document. The sensor has 24 distinct channels, but only the frequencies and polarizations matching SSM/I are used by RSS for data retrieval: 19.35, 22.2, and 37.0 GHz (V and H-polarization except for 22 GHz V only) [*Kunkee et al.*, 2008]. The temperature data records are downloaded by RSS from NOAA CLASS. More detailed information on the SSMIS is available at http://nsidc.org/data/docs/daac/ssmis_instrument/index.html

[WindSat] The Coriolis platform is an NPP project to demonstrate the capabilities of new sensors, including the polarimetric radiometer WindSat. The sensor began operation January 2003. It has 5 frequencies: 6.8, 10.7, 18.7, 23.8, and 37.0 GHz. The 10, 18 and 37 GHz channels are fully polarimetric. This allows for retrieval of not only wind speed, but also wind direction. The lower frequency channels are used for SST retrieval. The 23.8 GHz channel has dual-polarization and is highly sensitive to water vapor [*Gaiser et al.*, 2004]. More details on WindSat and its unique measuring capabilities are available at http://www.nrl.navy.mil/WindSat/Description.php

7. References

We advise users to cite this data product using the following reference:

> Remote Sensing Systems, 2014, updated YYYY. Monthly Mean Ocean Surface Wind Speed data set on a 1-degree grid made from Remote Sensing Systems Version-7 Microwave Radiometer Data, accessed on [date accessed]. Santa Rosa, CA, USA. Available at http://www.remss.com .

http://www.remss.com/measurements/wind/wspd-1-deg-product

Gaiser, P. W., et al. (2004), The WindSat spaceborne polarimetric microwave radiometer: Sensor description and early orbit performance, *IEEE Transactions on Geoscience and Remote Sensing*, *42*(11), 2347-2361.

Hollinger, J., J. L. Peirce, and G. Poe (1990), SSM/I instrument evaluation, *IEEE Transactions on Geoscience and Remote Sensing*, *28*(5), 781-790.

Kunkee, D. B., G. A. Poe, D. J. Boucher, S. D. Swadley, Y. Hong, J. E. Wessel, and E. A. Uliana (2008), Design and evaluation of the first Special Sensor Microwave Imager/Sounder, *IEEE Transactions on Geoscience and Remote Sensing*, *46*(4), 863-883.

Mears, C. A., D. K. Smith, and F. J. Wentz (2001), Comparison of Special Sensor Microwave Imager and buoy-measured wind speeds from 1987 - 1997, *J. Geophys. Res.*, *106*(C6), 11719-11729.

Meissner, T., and F. J. Wentz (2004), The complex dielectric constant of pure and sea water from microwave satellite observations, *IEEE Transactions on Geoscience and Remote Sensing*, *42*(9), 1836-1849.

Meissner, T., and F. J. Wentz (2009), Wind vector retrievals under rain with passive satellite microwave radiometers, *IEEE Transactions on Geoscience and Remote Sensing*, *47*(9), 3065-3083.

Meissner, T., and F. J. Wentz (2012), The emissivity of the ocean surface between 6 - 90 GHz over a large range of wind speeds and Earth incidence angles, *IEEE Transactions on Geoscience and Remote Sensing*, *50*(8), 3004-3026.

Meissner, T., D. K. Smith, and F. J. Wentz (2001), A 10-year intercomparison between collocated Special Sensor Microwave Imager oceanic surface wind speed retrievals and global analyses, *J. Geophys. Res.*, *106*(C6), 11731-11742.

Wentz, F. J. (2013), SSM/I Version-7 Calibration Report, *Technical Report Rep.*, 46 pp, Santa Rosa, CA.

Wentz, F. J., and R. W. Spencer (1998), SSM/I rain retrievals within a unified all-weather ocean algorithm, *Journal of the Atmospheric Sciences*, *55*(9), 1613-1627.

8. Revision History

Rev 0 – 15 Dec 2014 - This is a new document . [D.Smith]

Rev 1 – 15 June 2015 - Updated to reflect use of bias estimates from TMI, and to fix several issues identified by the OBS4MIPS team. [C.Mears]

Rev 2 – 03 July 2015 - Fixed typos, clarified a few sentences, moved some figures. [D. Smith]