MSU LIMB93 DAILY DEEP LAYER TEMPERATURE AND OCEANIC PRECIPITATION DATA SET

1. DATA SET OVERVIEW

This is a supporting document for the Microwave Sounding Unit Daily Deep Layer Temperatures and Oceanic Precipitation data sets. These data sets contain the Limb 93 correction and are stored in a native binary format as well as in the Hierarchical Data Format (HDF). This document also supports the Pathfinder TOVS Path C1 Daily, Pentad, and Monthly data sets stored in HDF. The NOAA satellites contributing to these data sets are, in order of their launch, TIROS-N, NOAA-6, NOAA-7, NOAA-9, NOAA-10, NOAA-11, and NOAA-12. NOAA-8 data were not used due to poor data quality. Each of the data sets have their own error characteristics, which are discussed in detail in Section 3.2.2. The dataset period of record is 1979-1994 for the temperatures, and 1979 through May 1994 for oceanic precipitation.

The Daily Deep Layer data sets include daily 2.5 degree grids derived from the Microwave Sounding Units for:

* Lower Troposphere Temperatures (LTT)
* Upper Troposphere Temperatures (UTT)
* Lower Stratosphere Temperature (LST)
* Oceanic Precipitation (OP)

These data sets were produced by Dr. Roy Spencer and Ms. Vanessa Griffin of the Global Hydrology and Climate Center (GHCC), NASA Marshall Space Flight Center (MSFC), Huntsville, Al. The data sets are archived by the GSFC Distributed Active Archive Center (GDAAC).

1.1 Sponsor

The production and distribution of this data set are being funded by NASA's Mission To Planet Earth program. The data are not copyrighted, however, we request that when you publish data or results using these data please acknowledge as follows:

> The authors wish to thank Dr. Roy Spencer of the Marshall Space Flight Center and the Distributed Active Archive Center at Goddard Space Flight Center, Greenbelt, MD, 20771 for the production and distribution of these data, respectively. These activities were sponsored by NASA's Mission to Planet Earth program.

1.2 Original Archive

These data were originally produced, archived and distributed by the Marshall Space Flight Center Distributed Active Archive Center (MSFC DAAC). The data were transferred to the Goddard DAAC in 1996 as part of a general transition of earth science data holdings from MSFC to other archive centers.

1.3 Future Updates

The LIMB 93 data set is static; thus no updates to this product are expected in the future.

2. THE DATA

2.1 Characteristics

* Parameters, Units, Range

PARAMETER	DESCRIPTION	UNITS	DATA RANGE
LTT	Lower Tropospheric Temperature	K	170 - 300
UTT	Upper Tropospheric Temperature	K	150 - 290
LST	Lower Stratospheric Temperature	K	150 - 290
OP	Oceanic Precipitation	mm/day	0 - 100

* Temporal Coverage: January 1, 1979 - December 31, 1993 (Temperatures)
* Temporal Coverage: January 1, 1979 - May 31, 1994 (Precipitation)
* Temporal Resolution: Daily
* Spatial Coverage: Global (LTT, LST), 30N-30S (UTT), 60N-60S (OP)
* Spatial Resolution: 2.5 degree x 2.5 degree

2.1 Source

The MSU instruments are carried aboard National Oceanic and Atmospheric Administration (NOAA) Polar Orbiting satellites POES. The Microwave Sounding Units (MSU) were built by the Jet Propulsion Laboratory for NOAA to fly as part of the TIROS Operational Vertical Sounder (TOVS) instrument complement aboard the TIROS-N series of sun-synchronous polar orbiting satellites. The MSU is a four-channel Dicke-type scanning passive microwave radiometer with radiation at 50.3, 53.74, 54.96, and 57.95 GHz, which are frequencies in the 50 to 60 GHz oxygen absorption complex. As the instrument scans, it measures microwave radiation at eleven beam positions over a swath about 2000 km. The scan period is 25.6 seconds and the scan-to-scan separation is about 150 km. The spatial resolution of the measurements as defined by the half-power (3 dB) beamwidth of 7.5 degrees and the ranges from the satellite to the observed point on the earth, vary from about 110 km at the nadir (#6) beam position to near 200 km at the extreme (#1 and #11) beam positions.

Once every scan, the instrument makes calibration measurements, viewing deep space, assumed to be 2.7 K, and high emissivity warm targets. There is one target for the two lower frequencies, channels 1 and 2, and another for the two highest frequencies, channels 3 and 4. The temperature of each target is monitored with redundant platinum resistance thermometers (PRT's). Conversion of the instrument digital counts into brightness temperatures (Tb) is a linear interpolation of the Earth-viewing measurements between the space and warm target measurements (Spencer et al., 1990). Refer to Smith et al. (1979) for further details of the MSU.

The instrument measurement geometry for the MSU sensor is summarized in the following table:

INSTRUMENT PARAMETER	MSU
Cross track scan angle (+/- degrees from nadir)	47.4
Number of steps	11
Angular FOV (degrees)	7.5
Step Angle (degrees)	9.5
Ground IFOV (km) - at nadir	109.3
Ground IFOV (km) - scan end	323 x 179
Swath width (+/- km)	1174

The NOAA Polar Orbiter Data User's Guide (Kidwell 1991) gives a more detailed description of the instruments and the NOAA series of satellites.

3. THE FILES

3.1 Format

Each of the MSU LIMB 93 temperature and oceanic precipitation files is a gridded product that was produced from the full resolution orbit data and consists of 2.5 degree latitude by 2.5 degree longitude grids. Separate files are provided for the 4 MSU parameters (LTT, UTT, LST, and OP). The data are available in two formats: the Hierarchical Data Format (HDF) and a native format (binary or ASCII).

The data are temporally binned by local days with ascending and descending orbits combined. Each scan line of the full resolution data contains 11 scan positions, or footprints. For the spatial gridding, all footprints that partially cover a particular 2.5 x 2.5 degree grid are included in the average for that grid. A weighted average is used to calculate the value of the geophysical parameter assigned to each 2.5 degree gridbox. A weighted east-west interpolation has been performed to help fill empty gridboxes.

3.1.1 MSU Files in HDF Format

The MSU LIMB 93 HDF files contain daily gridded objects of each product for each day covering the data period. Each file contains a full year's worth of data; thus there will be either 365 or 366 Scientific Data Sets (SDS gridded arrays) present in any particular file. The following table shows the file naming convention and typical file sizes for the MSU LIMB 93 HDF files:

Parameter Name	FileSize (comp)	File Size (uncomp)	File Name
LTT	5.5 MB	15.6 MB	L93ch23.YYdaygrd_temp_msu.hdf
UTT	1.2 MB	15.6 MB	L93ch34.YYdaygrd_temp_msu.hdf
LST	4.5 MB	15.6 MB	L93ch44.YYdaygrd_temp_msu.hdf
OP	1.6 MB	15.6 MB	L93rain.YYdaygrd_msu.hdf

where the "YY" designator in the file names denote a 2 digit year. The data are stored in HDF as 4 byte floating point words. Each record contains the 2 digit year (79-94), the Julian day (0-265), and the gridded average temperature array of 72 x 144 elements where 72 is the number of latitude bands and 144 is the number of longitude bands. Gridbox (1,1) is centered on 88.75N, 178.75W, with consecutive grids advancing south in latitude and east in longitude. The elements of the data array and their corresponding latitude and longitude boundaries are shown below:

Latitude --> Longitude	90N	87.5N	......	87.5S	90S
180W	(1,1)	(2,1)		(71,1)	(72,1)
177.5E	(1,2)	(2,2)		(71,2)	(72,2)
.					
.					
.					
177.5E	(1,143)	(2,143)		(71,143)	(72,143)
180E	(1,144)	(2,144)		(71,144)	(72,144)

3.1.2 MSU Files in Native Format

All temperature and precipitation values are multiplied by 10 and stored as integers to retain a 0.1 K and 0.1 mm/day accuracy. Therefore, to obtain the true temperature or precipitation value, divide the stored value by 10. Missing data are identified by a missing data flag. The approximate data ranges, precisions, scale factors, and missing data flags are given in the following table:

PRODUCT	RANGE	ACCURACY / SCALE FACTOR	FILL VALUE
LTT	170-300 K	0.1 K	-9999
UTT	170-250 K	0.1 K	-9999
LST	150-290 K	0.1 K	-9999
OP	0 - 100 mm/day	0.1 mm/day	-9999

The LTT, UTT, and LST native format temperature files share the same file structure. Each file contains the global gridded temperature data for the period 1979-1994, i.e., the daily grids for all years are contained in a single file. The data are stored in an IEEE binary format. The file names and corresponding file sizes are identified in the following table:

PARAMETER NAME	FILESIZE (comp)	FILE SIZE (uncomp)	FILE NAME
LTT	74 MB	114 MB	L93ch23.7994daygrd_temp_msu.nat
UTT	14 MB	114 MB	L93ch34.7994daygrd_temp_msu.nat
LST	60 MB	114 MB	L93ch4.7994daygrd_temp_msu.nat

All values are stored as 16 bit integers. Each record contains the year of the century (79 - 94), the Julian day (1 - 365), and 72 x 144 elements of gridded average temperatures where 72 is the number of latitude bands and 144 is the number of longitude bands. The first element is centered on 88.75N, 178.75W, the second element is centered on 88.75N, 176.25W with consecutive elements east in longitude through all 144 elements then advancing south in latitude. The following is a graphical representation of the file format:

```
Year    First Julian Day     1st latitude element, 1 - 144 longitude elements
                             2nd latitude element, 1 - 144 longitude elements
                             3rd latitude element, 1 - 144 longitude elements
                                     .
                                     .
                                     .
                             72nd latitude element, 1 - 144 longitude elements
                             4 bytes of header information
Year    Second Julian Day    1st latitude element, 1 - 144 longitude elements
                             2nd latitude element, 1 - 144 longitude elements
                             3rd latitude element, 1 - 144 longitude elements
                                     .
                                     .
                                     .
```

```
                              72nd latitude element, 1 - 144 longitude elements
                              4 bytes of header information
             .
             .
             .
Year    Last Julian Day       1st latitude element, 1 - 144 longitude elements
                              2nd latitude element, 1 - 144 longitude elements
                              3rd latitude element, 1 - 144 longitude elements
                                      .
                                      .
                                      .
                              72nd latitude element, 1 - 144 longitude elements
```

The OP native format precipitation files contain one year of gridded precipitation estimates from 60N to 60S, 180W to 180E for the period from 1979-1994. Any grids outside the 60N to 60S latitude range have the precipitation estimates set to -999. The file names and file sizes are identified in the following table:

PARAMETER NAME	FILESIZE (comp)	FILE SIZE (uncomp)	FILE NAME
OP	~1.2 MB	15.6 MB	L93rain.YYdaygrd_msu.nat

where "YY" denotes year. All values are stored as formatted (ASCII) integers. Each record contains the 2 digit year (79-94), the Julian day (1-365), the number of observations used in the precipitation estimate, the index for identifying the latitude band (1-72), and 144 precipitation estimates for the longitude bands. The data can be read using the format (I3, I3, I7, 144I4).

A conservative ice mask was used to screen anomalous precipitation over ice, and any footprint identified as containing ice was not used in the gridded average.

3.2 Companion Software

Read programs in FORTRAN and C are available for interpreting the contents of the MSU HDF And native format files. Some details on these programs are given below.

3.2.1 MSU Files in HDF Format

A sample FORTRAN program is available to read the HDF version of the MSU data. It can be downloaded from the World Wide Web (WWW) at the following URL:

ftp://daac.gsfc.nasa.gov/data/lim93/msu23/hdflist.f

It is an interactive program designed to allow the user to select a particular array in the file, and then output the array values either for the entire globe or for user-specified regional subsets. In order to use this program you must have the HDF library installed on your system. Pre-compiled HDF library binaries for Unix, VAX/VMS, MacIntosh, and Windows/NT can be freely downloaded from NCSA's anonymous FTP site at the following URL:

ftp://ftp.ncsa.uiuc.edu/HDF/HDF_Current/

3.2.2 MSU Files in Native Format

For the MSU temperature files in native (IEEE binary) format, the following C program can be used to access the data in the file:

```
/*************************************************************/
#include

/*  Written by Evans A Criswell, UAH, 09-06-95   */

int main (int argc, char *argv[])
{
  FILE *infile;
  short int nn, jj, dum1, dum2, dum3, dum4;
  short int tmapii[72][144];
  int i, j, k;

  if ((infile =
      fopen("/server/ftp/outgoing/shah/L93ch34.7994daygrd_temp_msu.nat",
               "rb")) == (FILE *) NULL)
  {
    fprintf (stderr, "Error opening file.\n");
    exit (1);
  }

  while (1)
  {
    if (feof (infile))
    {
      printf ("End of file reached.\n");
      return (0);
    }

    fread (&nn, sizeof (short int), 1, infile);
    fread (&jj, sizeof (short int), 1, infile);
    for (i = 0; i < 72; i++)
      fread (tmapii[i], sizeof (short int), 144, infile);
    fread (&dum1, sizeof (short int), 1, infile);
    fread (&dum2, sizeof (short int), 1, infile);
    fread (&dum3, sizeof (short int), 1, infile);
    fread (&dum4, sizeof (short int), 1, infile);

    printf ("nn = %hd, jj = %hd\n\n", nn, jj);
    for (i = 0; i < 72; i++)
    {
      for (j = 0; j < 144 / 8; j++)
      {
        printf ("tmapii[%02d][%03d] :  ", i, j * 8);
        for (k = 0; k < 8; k++)
          printf ("%6hd ", tmapii[i][j * 8 + k]);
        printf ("\n");
      }
      printf ("\n");
    }

    printf ("dum1 = %hd, dum2 = %hd, dum3 = %hd, dum4 = %hd\n\n",
```

```
                dum1, dum2, dum3, dum4);
    }

    return (0);
  }

  /*****************************************************************/
```

4. THE SCIENCE

4.1 Theoretical Basis of the Data

The MSU was designed to be used together with the High Resolution Infrared Sounder (HIRS) and Stratospheric Sounding Unit (SSU) to obtain vertical atmospheric temperature profiles from space. Compared to the HIRS channel weighting functions, the MSU has poorer vertical resolution in the troposphere and better vertical resolution in the stratosphere. It has considerably poorer spatial resolution than the HIRS, but this gives the advantage of a much lower data rate and thus a more manageable data volume for analyses of the fifteen year data archive. The MSU is essentially insensitive to non-precipitating cirriform clouds, and so should provide a more robust air temperature signal than the HIRS. It is considerably less sensitive to liquid phase clouds than the HIRS. Neither instrument can measure air temperatures within precipitation.

MSU channel 1, 50.3 GHz has only weak oxygen absorption and therefore is sensitive to air temperature in only the lowest few kilometers of the atmosphere. However, this temperature information is heavily contaminated by other influences such as surface temperature and emissivity, as well as water vapor, liquid water and precipitation-size ice hydrometeors in the troposphere. This limits the utility of channel 1 for monitoring lower tropospheric temperatures. MSU channel 2, 53.74 GHz, is sensitive to deep layer average tropospheric temperatures with a weighting function peaking near 500 hPa. It is very slightly affected by variations in tropospheric humidity (Spencer et al., 1990), but is contaminated by precipitation-size ice in deep convective clouds, which can cause Tb depressions of up to 15 degrees C in midlatitude squall lines. High elevation terrain protruding into the MSU channel 2 weighting function results in proportionally less of its measured radiation coming from thermal emission by the air and more coming from the surface. The MSU channel 3, 54.96 GHz, weighting function peaks near 250 hPa and so often straddles the extratropical tropopause. MSU channel 4, 57.95 GHz, has its peak weighting at 70 hPa and provides a good measure of lower stratospheric deep-layer temperatures.

Because the four MSU weighting functions overlap, they can be combined to retrieve information over thinner layers than the individual weighting functions represent (Conrath, 1972). This is the fundamental basis of satellite temperature retrieval schemes. For instance, a fraction of channel 3 can be subtracted from channel 2 to eliminate the lower stratospheric influence on channel 2 for middle and lower tropospheric temperature monitoring. Similarly, a fraction of channel 4 can be subtracted from channel 3 for monitoring of upper tropospheric temperatures in the tropics, where the tropopause is near 100 hPa. The MSU scans across the satellite subtrack at eleven different beam positions: six different Earth incidence angles symmetric about the center footprint. Therefore, each channel actually has six slightly different weighting functions due to the variations of the view angle through the atmosphere. These different view angles can also be combined into a new weighting function. This is done at the expense of any information about temperature gradients across the swath. Also, if the combinations are symmetric about the nadir measurement, then the resulting retrieval represents an average temperature for the entire swath (Spencer and Christy, 1992b). This technique is more useful for gridpoint temperature monitoring over long time scales or zonal averages over short time scales.

The lower tropospheric air temperature influence on channel 1 is small compared to other influences, such as land emissivity and oceanic air mass humidity and liquid water path. In particular, channel 1 is used to retrieve oceanic precipitation since its variability over the ocean is dominated by cloud and rain water activity.

MSU channels 2, 3, and 4 respond primarily to air temperature through their sensitivity to thermal emission by molecular oxygen, a well mixed and temporally stable atmospheric constituent. The weighting functions for these channels are quite broad in their response to temperature fluctuations at different altitudes. By linearly combining two or more channels, sensitivity to shallower layers than the raw MSU channels represent can be achieved. For the datasets described here, linear averaging kernels (Conrath, 1972) are produced for the lower troposphere and tropical upper troposphere. The lower stratospheric measurements are taken from MSU channel 4 alone.

4.2 Processing Sequence and Algorithms

4.2.1 Deep Layer Temperatures

4.2.1.1 Lower Troposphere Deep Layer Temperature (LTT)

MSU channels 2 and 3 are combined using the equation

$$Tb23 = 1.6 * Tb2 - 0.6 * Tb3$$

to form an averaging kernel which peaks near 500 hPa and has most of its radiant energy originating below about 300 hPa. This is called the "lower tropospheric" temperature (LTT). In regions of high terrain, especially over Greenland, the Andes, Himalayas, and portions of Antarctica, most of the energy comes from the surface and so can not be interpreted as an air temperature measurement. The Tb23 data will have little utility in these regions.

4.2.1.2 Upper Troposphere Deep Layer Temperature (UTT)

MSU channels 3 and 4 are combined using the equation

$$Tb34 = 1.35 * Tb3 - 0.35 * Tb4$$

to form an averaging kernel which peaks near 250 hPa and receives most of its energy from the 500 - 100 hPa layer. This retrieval is called the "upper tropospheric" temperature (UTT). However, it is only calculated for latitudes 30S to 30N because the retrieval is only applicable in the tropics where the tropopause generally lies above 100 hPa. Tb34 is only slightly affected by high terrain.

4.2.1.3 Lower Stratosphere Deep Layer Temperature (LST)

The estimates of the lower stratospheric temperature are derived from MSU channel 4 using the method of Spencer and Christy with the LIMB 93 limb correction and processed by the Earth Observing System Branch of the space Science Laboratory at NASA/MSFC. This channel 4 retrieval is calculated as the limb corrected brightness temperature of MSU channel 4. The channel 4 weighting function has a peak in the lower stratosphere (near 70 mb).

4.2.1.4 Calibration Drift Corrections

MSU channels 2 and 4 have no statistically significant drift in their calibration. Inter-satellite comparisons show no differences above 0.02 degrees C (Spencer and Christy, 1992a, Spencer and Christy, 1993).

The NOAA-6 and NOAA-9 MSUs had considerable drift in channel 3. This drift seems to have only a low frequency component and occurs on a time scale of months to years, with the exception of an abrupt change on November 1, 1986 for NOAA-9. Since theaveraging kernels for the LTT and the UTT depend on channel 3, the gridded data are adjusted for this drift.

To achieve this adjustment for the LTT, the monthly 30 degree zonally averaged anomalies are adjusted to match those produced by channel 2R (Spencer and Christy, 1992b). Channel 2R is a lower tropospheric retrieval which depends upon channel 2 alone and which uses the different view angles of channel 2 to produce a lower tropospheric averaging kernel. The channel 2R averaging kernel peaks somewhat lower in the troposphere than the channel 2/3 kernel, but the differences in monthly zonally averaged anomalies are small. The channel 2R procedures used for satellite intercalibration differ somewhat from those in Spencer and Christy (1992b), and so can be expected to produce small differences in the resulting anomalies and trends. The adjusted LTT data can be used for long-term trend analyses on global, zonal, or gridpoint scales.

The drift in channel 3 inferred from comparisons to channel 2R is used to adjust the UTT measurements, but these adjustments have been based upon only the tropical drifts. Due to the questionable long term stability, the UTT gridded data are provided as an experimental product only. The data continue to undergo evaluation and refinement. The interannual variability in the tropics should be quite stable. This data is available for distribution because of the interesting day-to-day and interannual variability in the deep tropics.

The channel 4 gridded data have the best long term stability. Satellite intercomparisons show no evidence of drift. However, the NOAA-12 MSU showed an annual cycle in polar temperatures that was significantly different from the other satellites. This can be corrected with a simple linear scaling of the data which can be interpreted as a calibration slope error of about 2%.

4.2.1.5 Limb Correction and Satellite Intercalibration

The MSU is a through-nadir scanner, therefore the eleven footprints across the MSU swath come from six different earth incidence angles: nadir and two each at 11, 22, 33, 44, and 55 degrees on either side of nadir. Due to the longer atmospheric path lengths of the non-nadir views, the corresponding weighting functions are set to higher levels. Thus, some sort of "limb correction" must be performed for the deep layer temperature measurements to produce a spatially uniform field of temperatures, i.e., temperatures on a constant pressure "surface".

The Deep Layer Temperature limb correction procedure relies on the compilation of statistics spanning several years. The basis for these statistics is the average relationship between nadir and non-nadir measurements where the independent variables are: 1) the grid location of the data, 2) the month the data were recorded, 3) the local ascending node time of the satellite from which the data were recorded, and 4) the direction of travel of the satellite (ascending or descending) at the time that the data were recorded.

Third order polynomial regression equations based on the statistics provide the Tb adjustments necessary to "correct" the non-nadir measurements to nadir. Thus, for each of the three atmospheric layers, there are approximately 480,000 limb correction equations involving 72 latitude bands, 144 longitude bands, 12 months, 2 local ascending node times, and 2 nodal crossing times. These equations account for seasonal and geographical variations in both atmospheric lapse rate and surface temperature.

In the case of the LTT and the UTT, drift in the calibration of channel 3 is inferred from the difference in LTT and channel 2R for monthly 30 degree zonally averaged anomalies for the entire period of record.

Since there is no evidence of drift in channel 4 (Spencer and Christy, 1993), intercalibration of successive satellites is accomplished by limb correcting and gridding the daily channel 4 data. Adjustments are made to account for channel 4 differences between the satellites. The adjustments are averaged for each of 12 months and divided into 10 degree latitude bands.

4.2.1.6 Limb Correction Errors

The deep layer temperature products have varying residual effects resulting from imperfect limb correction procedures. These effects can sometimes be detected by animating daily imagery and looking for eastward patterns in successive days for the grids which have a spatial separation coinciding with the orbit sampling of the earth. When these patterns are present, a spectrum analysis of the time series at these individual gridpoints reveal spectral peaks near 4.5 days and 8 days. These correspond to the rate at which the satellite orbits progress across the sky.

The current UTT limb correction works significantly better in the deep tropics than in the extratropics. Currently, work is progressing on an improved limb correction procedure. Detailed daily analyses of UTT patterns in the middle latitudes should await the implementation of the improved limb corrections.

The channel 4 limb corrections perform very well for the 15 year data set.

4.2.2 Oceanic Precipitation:

The precipitation estimates are derived from MSU channel 1 using the Channel 2/3 value to correct for air mass warming. MSU channel 1 warming above a threshold of 15% is attributed to precipitation, whose magnitude has been calculated through linear regression with coastal and island rain gauge data. Ascending and Descending orbits have been combined in the precipitation product.

Daily gridded oceanic precipitation estimates equatorward of 60 degrees latitude use a procedure similar to that described by Spencer (1993). Numerous details, such as algorithm justification and detailed rain gauge comparisons, are documented by Spencer (1993).

Rainfall is diagnosed when a channel 1 Tb threshold is exceeded. The threshold is a function of the air mass temperature deduced from the LTT. For each 1 degree increment of the LTT, a 15% cumulative frequency distribution was calculated for the base year of 1982 (NOAA-6 and NOAA-7). The 15% thresholds were approximated by a linear curve fit. There are six of these linear relationships, corresponding to the six view angles of the MSU. These six relationships are used for all satellites. Channel 1 Tb warming above the appropriate threshold is assumed to be linearly related to a footprint-averaged rain amount.

The conversion into precipitation units was performed after compilation of approximately 15 years of average channel 1 Tb warming above the threshold from multiple satellites. To accomplish this, careful intercalibration between satellites during overlapping periods of operation is performed in two steps. Step one is to calculate a channel 1 Tb "offset" of the second satellite to produce the same frequency of precipitation estimates as that of the first satellite. This offset is typically on the order of 15%. Next, the average difference between channel 1 Tbs above that threshold is forced to equal that from the first satellite through a magnification factor. This factor is a function of beam position and satellite. These two corrections ensure that the rain estimated during the overlap period are equal for the two satellites. The overlaps in satellite coverage which were used for intercalibration throughout the 15 year period ranged from three months to 1 year.

Due to the insufficient rain gauge data at high latitudes, the additional step for an air mass temperature correction described in Spencer (1993) was not used in the precipitation data sets. However, cursory comparisons of the few high latitude gauges suggest that the resulting MSU precipitation estimates may be biased low during the cold season. Therefore, studies of the annual cycle in extratropical precipitation with this data set might be compromised.

Monthly gridpoint averages of the channel 1 Tb warming were compared to approximately 10 years of monthly rain gauge totals for 123 island and coastal locations. A single scale factor was derived for the conversion of the Channel 1 Tb differences to rain estimates. The locations of these gauges was shown by Spencer (1993). The subsequent production of daily rain grids simply used the monthly calibration factor divided by 30.4, the average number of days in a month.

Passive microwave emission schemes for measuring precipitation are sensitive to cloud water as well as rain water. Due to the high frequency of the channel 1 signal, 50.3 GHz, this ambiguity is particularly strong. Due to the strong response of the 50.3 GHz radiation to liquid hydrometeors, in general, channel 1 is not sensitive to vertically integrated water contents exceeding effective rain rates of approximately a few mm per hour. Beyond this point the water path becomes essentially opaque to the transfer of the radiometrically cold radiation emitted by the ocean. Thus, the variability in the MSU channel 1 precipitation estimates is related primarily to the coverage of the grids by cloud and rain activity rather than to variations in the rain intensity. Therefore, the accuracy of the precipitation estimating method is dependent upon a high positive correlation between the true footprint averaged precipitation estimates and the areal coverage by cloud and rain water for that footprint.

The Special Sensor Microwave/Imager (SSM/I) has a more effective range of microwave frequencies than does the MSU for radiometric sensitivity to local rain intensity. Thus, using the SSM/I will provide more accurate precipitation retrieval algorithms than are possible by using the MSU. The MSU is superior to the SSM/I in sampling areas since the MSU has a 50% greater spatial coverage than the SSM/I. Another positive aspect of the MSU is the 15 year period of record, the longest for a passive microwave instrument.

4.2.2.1 Precipitation Errors due to Sea-Ice

The oceanic precipitation data set was restricted to the region of 60N to 60S in order to screen out the majority of regions of multi-year ice. However, a few regions remain in the data sets where seasonal ice occurs and produces false precipitation signatures. These include areas near Antarctica, the Bering Sea, Labrador Sea, and Hudson Bay. Users of the data in these regions should be aware of these false rain signatures during the cold season and screen the data accordingly.

4.2.2.2 Precipitation Errors due to Climatology

Minor changes in the precipitation estimation algorithm have caused significant changes in the annual cycle of the estimated precipitation at high latitudes. In particular, change in the assumed slope of the channel 1 vs. channel 2/3 15% cumulative frequency distribution line caused changes in high latitude precipitation estimates. Thus, uncertainity in the MSU precipitation climatology is evident, especially in high latitudes. Therefore, research examining the high-latitude annual cycle in MSU precipitation could be compromised.

Spencer (1993)) discusses the appearance of excessive precipitation in the extratropical storm tracks. However, this assumption is difficult to validate with the sparse rain guage data available. The inherent ambiguity between cloud water and rain water signatures could produce a higher cloud/rain water ratio in the storm track regions as compared with other regions.

4.3 Scientific Potential of the Data

The TOVS suite of instruments (which includes the MSU sensor) provides the only long-term source of high resolution global information pertaining to the temperature structure of the atmosphere. Because similar MSU instrumentation has flown on operational satellites from 1979 to the present, data from these instruments can make an important contribution to our understanding of the variability of atmospheric and surface parameters as well as the correlations between spatial variations of atmospheric and surface quantities. In addition, the data can potentially be used to identify and monitor trends in atmospheric temperature and precipitation, provided that quantitative results can be obtained that account for differences in instrumentation on different satellites, as well as sampling differences in local crossing time. A prerequisite for such studies is an algorithm that does not change during the course of the processing. This is required since algorithm changes can introduce spurious "climate changes." The MSU data set satisfies this important criterion and as such will be useful for the applications listed above.

4.4 Validation of the Data

4.4.1 Deep Layer Temperatures:

The precision with which daily gridpoint Tb values can be measured depends upon the quality of the limb correction scheme. It also depends, to a lesser extent, upon the sampling errors inherent in estimating a daily average with 1-4 "snapshots" provided by one or two satellites and the limiting radiometric resolution of a single MSU measurement. There are other sources of error such as slight variations in different MSUs' weighting functions for the same channels. It is important to note that all statistics reviewed below are for a single satellite. The corresponding errors are smaller during dual satellite coverage, which includes about 75% of the 15 year record.

Estimates of the single-satellite standard error of measurement (SEM) for the daily deep layer temperatures are computed by measuring the relative levels of disagreement between two satellites' variations in daily Tb at individual gridpoints. The SEM is calculated as:

SEM = (sqrt(2) / 2) * sigma (T(sat1) - T(sat2))

where sqrt is the square root, sigma is the standard deviation, T is the Tb for any deep layer temperature product, and (sqrt(2) / 2) is the single-satellite factor. The single-satellite factor assumes that each satellite contributes equally to the total error. The sigma is actually an average of the standard deviations for the individual years of 1982 (NOAA-6 and NOAA-7) and 1990 (NOAA-10 and NOAA-11).

The LTT SEMs show that the daily gridpoint errors in the deep tropics generally range from 0.3 to 0.4 degree C, except over land areas where they usually range from 0.4 to 0.6 degree C. Most mid-latitude areas have from 0.5 to 1.0 degree C SEMs. Many high altitude regions, especially portions of Antarctica, Greenland, and the Andes Mountains, show high standard errors of measurement of over 1 degree C. The highest errors occur in strongly sloping terrain such as coastal Antarctica and Greenland.

The daily gridpoint noise estimates for UTT are generally less than 0.3 degrees C in the deep tropics, increasing to 0.5 or 0.6 degrees C in the middle latitudes. The errors improve again at the high latitudes. The current limb correction scheme for UTT does not perform well in the middle latitudes.

The daily gridpoint noise estimates for channel 4 are usually below 0.2 degree C in the deep tropics, increasing to 0.3 to 0.4 degree C in the Northern Hemisphere middle latitudes, reaching 0.5 to 0.6 degree C in the Southern Hemisphere middle latitudes. The large noise figures are believed to be caused by the variable conditions near the boundary of the winter polar vortex occurring in each hemisphere.

4.4.2 Oceanic Precipitation:

Information not available at this time.

5. DATA ACCESS AND CONTACTS

5.1 FTP Site

The MSU LIMB93 temperature and oceanic precipitation data set resides on the GSFC DAAC anonymous FTP server. You may access the files as follows:

```
ftp daac.gsfc.nasa.gov
login: anonymous
password: < your internet address >
cd /data/lim93/
```

or via the World Wide Web (WWW) at URL ftp://daac.gsfc.nasa.gov/data/lim93/.

5.2 Points of Contact

For information about or assistance in using any DAAC data, contact

EOS Distributed Active Archive Center (DAAC)
Code 902
NASA Goddard Space Flight Center
Greenbelt, Maryland 20771
email: daacuso@daac.gsfc.nasa.gov
301-614-5224 (voice)
301-614-5268 (fax)

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