6. APPENDICES

6.1. TOVS ATMOSPHERE GRIDDED DATA PRODUCT (TV)

6.1.1. OVERVIEW

As part of the ISCCP cloud analysis, information concerning the atmospheric temperature and humidity profiles and the ozone column abundances are used in the radiative model to account for atmospheric effects on the satellite radiances. Although these data are also available from the original sources, the version used in the ISCCP processing (called TV data) is archived with the cloud climatology to document the ISCCP data analysis procedure and to provide these data in a more convenient format especially suited to satellite data processing. A subset of the TV data is also included in the Stage D1 cloud product and summarized in the Stage D2 cloud product.

The **original atmospheric dataset** is obtained from the TIROS Operational Vertical Sounder (TOVS) System, flown on the NOAA Operational Polar Orbiting Satellite series since 1978 (Werbowetzki 1981). These data are supplied by and can be obtained from

ISCCP Central Archives
NOAA/NESDIS/NCDC
Climate Services Division/Satellite Services Branch
FOB3, Room G233
Suitland, MD 20233

Phone: 704-271-4800 (option #5)
FAX: 704-271-4876
e-mail: satorder@ncdc.noaa.gov

The TOVS system consists of three instruments (Kidwell 1995): the High Resolution Infrared Radiation Sounder (HIRS/2), the Stratospheric Sounding Unit (SSU, supplied by the United Kingdom), and the Microwave Sounding Unit (MSU). The measurements from these three instruments are processed by NOAA to produce the TOVS Sounding Product, which includes 15 layer-mean temperatures (from the surface to the stratosphere), precipitable water amounts for three layers (middle and lower troposphere), estimated surface pressure, tropopause temperature and pressure, ozone column abundance, and clear sky radiances. Although the original sounding measurements are often available from two polar orbiters that could be used to produce soundings for the whole globe up to four times daily, only about one sounding per day is available that contains complete (temperature and humidity) information.

To provide complete global coverage at all times, the TOVS dataset is **supplemented by two climatologies**: the NOAA GFDL temperature/humidity climatology from a global collection of rawinsonde balloon measurements (Oort 1983) and the ozone climatology from the NIMBUS 4 BUV data (Hilsenrath and Schlesinger 1981). The NOAA GFDL climatology, using data from 1958 to 1973, provides 15-year averages for each month of the year interpolated onto a regular map grid with an approximate resolution of 430 km. The climatology provides profiles of temperature and absolute humidity at 11 standard pressure levels with surface temperatures reduced to sea level according to standard practice. The NIMBUS 4 BUV ozone climatology, averaging satellite measurements from 1970 to 1977, gives the zonal mean total ozone column abundances at latitude increments of 10 degrees for each month of the year. Since there are no satellite data poleward of 81°, due to the orbit of NIMBUS 4, and no data poleward of 67° in the winter, due to the lack of sunlight, values from the London *et al.* (1976) climatology are substituted at these high latitudes. These datasets are combined with topographic height data from the National Center for Atmospheric Research to produce the CLIM MONTHLY dataset that contains the same type of information provided by the TOVS product.

6.1.2. ARCHIVE TAPE LAYOUT

Each TV data archive tape has four header files, 12 climatological data files, 12 TOVS monthly data files, and up to 366 TOVS daily data files arranged chronologically. The total number of files on a tape depends on the number of years of data reported. If more than one year of data is present on a tape, then the sequence of TOVS MONTHLY data files and DAILY data files is repeated for each additional year.

Table 6.1.1. TV Archive Tape Layout.

FILE	CONTENTS	FORMAT	RECORD LENGTH (BYTES)
1	README file	ASCII	80
2	Table of Contents	ASCII	80
3	Read Software	ASCII	80
4	Ancillary Data Table	ASCII	80
5-16	CLIM MONTHLY Data	Binary	16530
17-28	TOVS MONTHLY Data	Binary	16530
29-394	TOVS DAILY Data	Binary	16530

Note: *The GPC produces archive tapes using IBM standard label format which means that there are label records written before and after each file on the tape. On IBM systems, these labels provide information to the operating system about the name and format of the file and will appear transparent to the user. On non-IBM systems these label records will appear as extra short files surrounding each file listed above and should be skipped by the user. The presence or absence of these files depends on which archive supplies tape copies to the user, as they may either provide an exact copy (labels present) or a modified copy (labels absent).*

6.1.3. HEADER FILE CONTENTS

File 1 is the **README** file that contains ASCII text providing descriptive information about the tape format and contents, similar to what is in this section. The first line of text (80 bytes) gives the ISCCP tape designator code that identifies the contents and version (Table 2.5.12).

File 2 is the **Table of Contents** file that lists the date or date range of each data file on the tape in ASCII columns defined in Table 6.1.2.

Table 6.1.2. Table of Contents layout.

COLUMN	DESCRIPTION
1	File number
2	Data set name
3	Date range (YYMMDD - YYMMDD)

Note: *For CLIM MONTHLY files, the dates are given as 000000; for TOVS MONTHLY files, the beginning and ending dates are given. For TOVS DAILY files, a single date is given.*

File 3 contains **FORTRAN subroutines** for reading, decoding (see section 2.1.4), and using the atmospheric data as follows:

Program SAMPLE:	Example of how to use these subroutines
Subroutine TVOPEN:	Open a TV file and initialize
Subroutine TVREAD:	Unpack TV data for one latitude band
Subroutine RDANC:	Read ancillary data file
Subroutine EQ2SQ:	Convert equal-area map to equal-angle map

File 4 contains the **Ancillary Data Table** that lists characteristics of each map grid cell in ASCII columns defined in Table 6.1.3.

Table 6.1.3. Ancillary Data Table Layout.

COLUMN	DESCRIPTION
1	ISCCP map grid cell number (1 - 6596)
2	Equal-area latitude index (south-to-north = 1 - 72)
3	Equal-area longitude index (1 - 144)
4	Western-most equal-angle longitude index
5	Eastern-most equal-angle longitude index
6	Map grid cell center latitude in degrees
7	Map grid cell center longitude in degrees
8	Map grid cell area (km•)
9	Land cover fraction (%)
10	Topographic altitude (m)
11	Vegetation type (Table 2.5.3)

6.1.4. DATA FILE CONTENTS

Each data file contains 12 records of 16530 bytes each, representing complete global coverage. Each record contains a 30 byte prefix followed by data for 550 map grid cells. The last record has the last 120 bytes filled with values = 255 (Figure 6.1). Each map grid cell contains 30 variables (Figure 6.1). See Section 6.1.5. for definitions of the variables. Each variable is coded as a single binary byte with a value from 0 to 255. The value 255 is reserved to represent missing data. Conversion tables are provided in the READ program (Header file 3) to convert these into physical values.

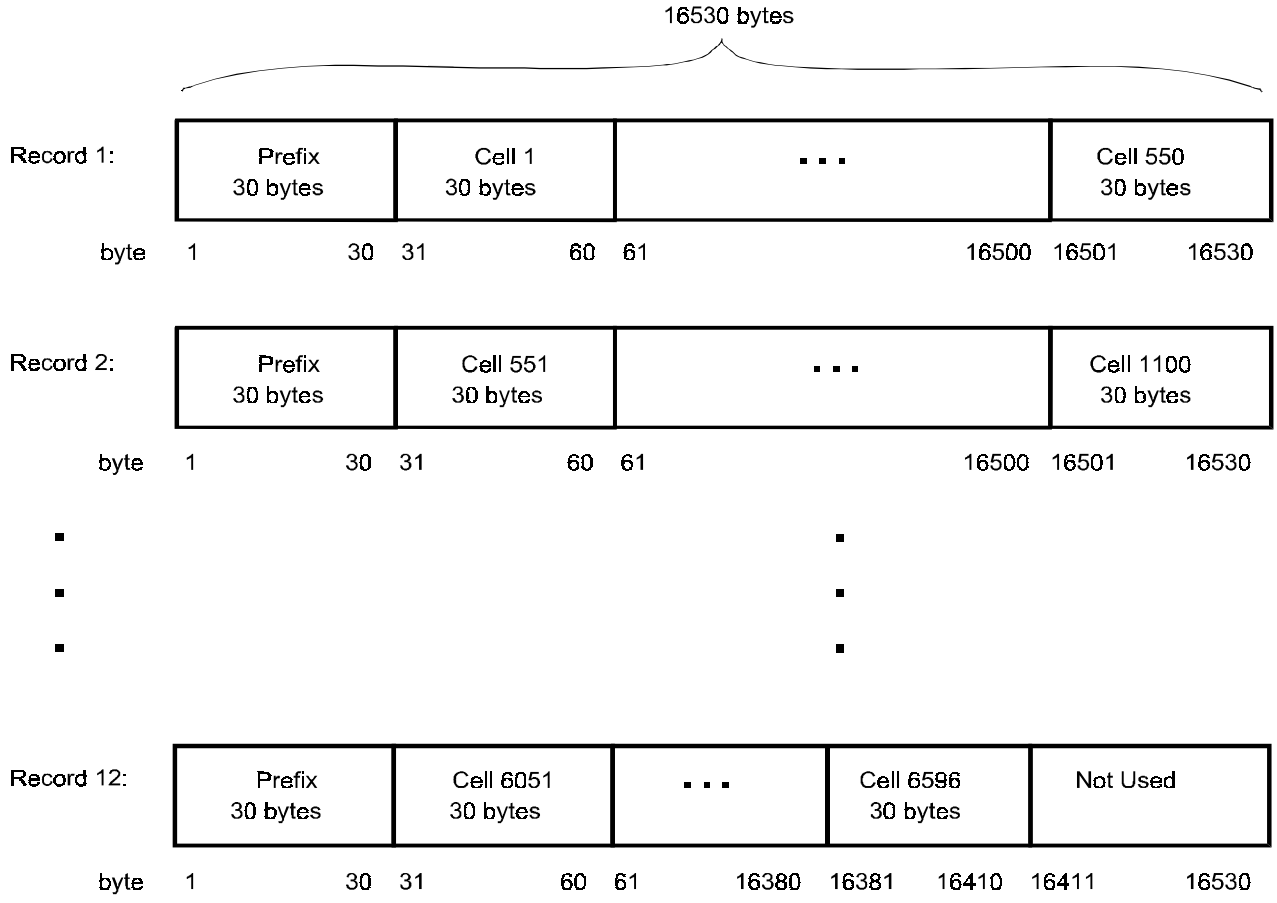

Figure 6.1. TV Data File Layout.

Table 6.1.4. TV Data Record Prefix Layout.

BYTE No.	DESCRIPTION
1	File number on tape (5-394)
2	Record number in file (1-12)
3	Data type (1 = TOVS DAILY, 3 = TOVS MONTHLY, 4 = CLIM MONTHLY)
4	Year of data (YY = 00 for CLIM MONTHLY)
5	Month of data (MM = 01 - 12)
6	Day of data (DD = 01 - 31; = 00 for CLIM and TOVS MONTHLY)
7	First latitude index in record
8	Last latitude index in record
9	First longitude index in record
10	Last longitude index in record
11-30	255 (no data)

Table 6.1.5. TV Data Map Grid Cell Layout. ***Note:*** *Bytes 4-11 are not used (= 255) in the TOVS MONTHLY and the CLIM MONTHLY datasets.*

BYTE No.	DESCRIPTION
1	Latitude Index (1-72)
2	Longitude Index (1-144)
3	Origin Code (0-5) (Table 2.5.8)
4	Original Latitude Index
5	Original Longitude Index
6	Hour of Sounding UTC (0-23)
7	Minute of Sounding UTC (0-59)
8	Quality Code from NOAA TOVS data (Table 6.1.6)
9	Cloud top pressure (PC)
10	Cloud amount (CA)
11	Topographic height (ZS, sea level = 0, 23m interval)
12	Surface temperature (TS)
13	Surface pressure (PS)
14	Tropopause temperature (TT)
15	Tropopause pressure (PT)
16	Precipitable water (PW) for 800 - 1000 mb
17	PW for 680 - 800 mb
18	PW for 560 - 680 mb
19	PW for 440 - 560 mb
20	PW for 310 - 440 mb
21	Atmospheric temperature (T) at 900 mb
22	T at 740 mb
23	T at 620 mb
24	T at 500 mb
25	T at 375 mb
26	T at 245 mb
27	T at 115 mb
28	T at 50 mb

29	T at 15 mb
30	Ozone column abundance

6.1.5. VARIABLE DEFINITIONS

The three atmosphere datasets, CLIM MONTHLY, TOVS MONTHLY, and TOVS DAILY, have the same contents except that some variables are not used in the two MONTHLY datasets. Each map grid cell has 30 quantities, each coded as a single byte COUNT value. The READ program contains look-up tables used to convert these count values to physical units. Pressures (P, PS, PT) are given in millibars, temperatures (T, TS, TT) are given in Kelvins, precipitable water (PW) is given in centimeters, total ozone abundance (O3) is given in Dobson units, cloud amount (CA) is given directly in percent, and surface topographic height above mean sea level (ZS) is given in intervals of 23 m. Negative values of ZS are set to zero to be consistent with the TOVS convention. The temperature table is non-linear in a way that resembles the sensitivity of satellite radiometers; i.e., lower temperatures are less precisely specified than higher temperatures. Observation origin codes are given in Table 2.5.8.

The NOAA Code from the TOVS data (Table 6.1.6) indicates the combination of instruments and retrieval algorithm used to obtain the temperature profile and the water and ozone abundances. One of seven possible combinations of instruments is indicated by the first digit of the two digit code number in Byte 8; one of three retrieval algorithms is indicated by the second digit. Since complete temperature and water profiles are required for the ISCCP analysis, only those observations that have this information are retained in the ISCCP dataset. In particular, the microwave-based retrieval used in cloudy locations does not contain water vapor information. If the tropopause parameters are missing, then the profile temperature minimum and corresponding pressure are used. If no minimum is found at pressures $\geq$ 30 mb, then the 30 mb values are used. Also, climatological values of ozone are substituted for missing ozone values in otherwise complete observations.

Table 6.1.6. NOAA Code Values in TV Data Record.

CODE	DESCRIPTION
33	all instruments (HIRS/2, MSU, SSU) used, tropopause parameters retrieved, clear observation available, statistical retrieval used
34	all instruments (HIRS/2, MSU, SSU) used, tropopause parameters retrieved, partially cloudy observation available, minimum information retrieval used
43	HIRS/2 and MSU used, no tropopause parameters retrieved, clear observation available, minimum information retrieval used
44	HIRS/2 and MSU used, no tropopause parameters retrieved, partially cloudy observation available, minimum information retrieval used
51	all instruments (HIRS/2, MSU, SSU) used, tropopause parameters retrieved, clear observation available, statistical retrieval used
52	all instruments (HIRS/2, MSU, SSU) used, tropopause parameters retrieved, partially cloudy observation available, statistical retrieval used
61	HIRS/2 and MSU used, tropopause parameters retrieved, clear observation available, statistical retrieval used
62	HIRS/2 and MSU used, tropopause parameters retrieved, partially cloudy observation available, statistical retrieval used
71	No MSU data used, no tropopause parameters retrieved, clear observation available, statistical retrieval used
72	No MSU data used, no tropopause parameters retrieved, partially cloudy observation available, statistical retrieval used
74	No MSU data used, no tropopause parameters retrieved, clear observation available, minimum information retrieval used

6.1.6. SPATIAL RESOLUTION AND COVERAGE

To produce the ISCCP version of the TOVS atmosphere data, single soundings are collected into the EQUAL-AREA map grid described in Section 3.1.1; there are 6596 cells in this grid. The TVREAD program supplied with the data can re-map the data into the EQUAL-ANGLE map, also described in Section 3.1.1.

The NOAA TOVS Product has a resolution of ≈ 2.5° latitude-longitude, the NOAA GFDL data have a resolution of 2.5° latitude and 5.0° longitude, and the ozone climatology has 10° latitude resolution. Each TOVS sounding is mapped to the ISCCP Equal-Area grid cell that contains the coordinates of the sounding. If more than one observation is available in a cell, the one closest to the cell-center coordinates is used. The NOAA GFDL and ozone data, having lower resolutions than the ISCCP grid, are mapped such that all ISCCP grid cells with centers within the range of the original data grid cells are filled with the same value. Estimated error of the temperature retrievals is ≈ 2-3 K (McMillin and Dean 1982) and ≈ 25-30% for water vapor retrievals (Smith *et al.* 1979).

The typical fractional coverage of the globe provided by TOVS on a given day within a three hour interval is 27%. (Note that observations at 0000 UTC are collected over the time period from 2230 UTC the previous day through 0130 UTC. The last time period for each day extends from 1930 UTC to 2230 UTC.) Although results from two polar orbiters can provide four samples per day, over the first ten years of ISCCP operations only about one quarter of the soundings were processed by NOAA and only half of those have both temperature and humidity information, so that the practical sampling frequency is once per day (the frequency has occasionally fallen as low as 0.7 per day averaged over the globe). With such sparse coverage, no attempt was made to retain information on the diurnal variability of temperature and humidity. All observations for a given day are composited into a DAILY map without regard to time of day. Tests of the variability of temperatures in the first layer show that the error associated with neglecting time-of-day is about 2-4 K, somewhat larger over land. The typical global coverage of the daily composites is about 67%. Original observations are indicated by Origin Code = 1.

Daily map grid cells lacking an observation are filled from nearby original values, as long as the two locations have the same surface types (land, water, coast) and their topographic heights differ by < 500 m. Based on the results of tests that simulate missing data by removing actual data, missing values are filled by nearby observations that are within two grid cells to the east or west (within ± 500 km). The average error grows with increasing distance and grows more rapidly in the north-south direction than the east-west direction. For ± 500 km distance, the estimated errors are ≈ 2-3 K in temperature, < 15% for precipitable water and ≈ 10% for ozone. After nearest-neighbor replication, typical global daily coverage is ≈ 85%. Replicated observations are indicated by Origin Code = 2.

If no observation is available for a particular location and day and no observation is near enough on that day, then the monthly TOVS values are used if available for that location. The monthly TOVS values are calculated from the daily TOVS data with spatial replications performed where needed; no value is reported if less than five observations are available during the month. The distribution of differences between daily and monthly mean TOVS values of layer one temperatures and humidities and the ozone abundances shows rms errors of ≈ 2 K, ≈ 0.3 cm and ≈ 10 Dobson units, respectively. By filling with the monthly mean values, the daily global coverage is ≈ 95%; TOVS Monthly values are indicated by Origin Code = 3.

If no TOVS monthly value is available for a particular location, then the CLIM Monthly values are used, indicated by Origin Code = 4. The distribution of differences between the TOVS daily temperatures, humidities and ozone abundances and the combined NOAA GFDL and ozone climatologies for the same locations and months indicate errors 5 K for temperatures, ≈ 25% for water abundances, and ≈ 15% for ozone abundances. This last step brings global coverage for each day to 100%.

The differences between the TOVS DAILY and MONTHLY water abundances in layer one include a few larger departures from the monthly mean values. The distribution of these differences with latitude and season reveals a small population (about 2-4% of the total) with values much larger than three standard deviations from the local monthly mean value. Other parameters in the original dataset do not exhibit this behavior. These "anomalous" values are removed with the following procedure: (1) distributions of differences between daily and monthly mean water abundance values for the first three layers in each grid cell are collected for eight latitude zones for each month, (2) a range of variations with respect to the monthly mean is determined by the width of these distributions defined by the differences within ± 5% of the mode frequency (approximately equivalent to three standard deviations), (3) daily values outside the range defined by zonal difference distributions and the local monthly mean are set equal to the nearest value within the range. Observations which have been changed in this way are indicated by Origin Code = 5.

6.1.7. VERTICAL PROFILES

In the collection of observations from the NOAA TOVS Product, several criteria are used to check the quality of profiles. Individual values in each profile are checked to see if they are in the allowed range: surface and tropopause pressures ($\geq$ 0 and $\leq$ 1200 mb), temperatures ($\geq$ 160 K and $\leq$ 360 K), precipitable water ($\geq$ 0 and $\leq$ 10 cm), and ozone ($\geq$ 0 and $\leq$ 600 Dobsons). Entire profiles are discarded if (1) the surface and first layer temperatures are missing or out of range, (2) more than two layer temperatures are missing or out of range, (3) a precipitable water value is missing or out of range, (4) surface pressure is out of range, (5) bad header information, (6) out of range latitudes or longitudes, and (7) any profiles that retrieved only stratospheric temperatures. If a profile is retained that has missing values, these values are interpolated from the available values.

The standard pressure levels of the original TOVS product define the 15 temperature layers: 1000, 850, 700, 500, 400, 300, 200, 100, 70, 50, 30, 10, 5, 2, 1, 0.4 mb. The standard pressure levels that define the three water abundance layers are 1000, 700, 500, 300 mb. The surface pressure is calculated from the topographic height above mean sea level and the estimated surface temperature. The ocean surface and all locations with heights at or below mean sea level are assumed to have a surface pressure of 1000 mb; if the height is above mean sea level, then the lower layers are truncated at the surface pressure. In addition to the standard layer temperatures, a surface temperature estimated from a combination of the Channel 8 ($\approx$ 11 μm wavelength) brightness temperature and the NMC forecast model is also reported; in some datasets, the tropopause temperature is also reported.

The ISCCP version of the atmosphere data is interpolated to two fixed stratospheric layers and up to seven layers in the troposphere that vary at each location and time according to the specific values of the surface and tropopause pressures. The temperature values for the new layers are obtained by linear interpolation in pressure coordinates of the original TOVS values (interpolation in ln P over these small pressure intervals does not change the results by more than about 1 K). The two stratosphere layers are fixed regardless of the location of the tropopause and defined by pressures of 70, 30 and 0 mb. The standard boundary pressures defining the tropospheric layers are 1000, 800, 680, 560, 440, 310, 180 and 30 mb. The surface and tropopause pressures modify the actual extent of the lower and higher layers in the troposphere. For example, if the surface pressure is 900 mb, then the first layer extends from 800 to 900 mb; if the tropopause pressure is 100 mb, then the seventh layer extends from 180 to 100 mb with a center at 140 mb. The tropopause temperature and pressure in each profile are taken to be either the originally reported values or the actual minimum temperature and corresponding pressure, whichever has the smaller pressure and temperature. If the tropopause pressure is < 30 mb, the tropopause temperature and pressure are taken from the 30 mb values. The layer-mean temperatures are taken to represent temperatures at the center pressures of each layer.

Interpolation of layer values of precipitable water begins by subdividing each layer into very small layers (2 mb thick) using the formula

$$PW = (g)^{-1} \int Q \, dP$$

where $Q = RH \times Q_s$ and the relative humidity, RH, for each original layer is assumed to be constant. g is acceleration of gravity. Q_s is the saturation specific humidity calculated for the smaller layers with center temperatures interpolated linearly in pressure from the temperature profile.

For temperatures $\geq$ 273 K,

$$Q_s = 0.622\ e_0 \times \exp\ [\ (\ 2500 / 0.461\ )\ (\ 1 / 273\ -\ 1 / T\ )\ ]\ /\ P;$$

for temperatures < 273 K, the ratio in the brackets is (2834 / 0.461). e_0 is the triple point vapor pressure of water. The final values at 2 mb intervals are adjusted so that their sum is equal to the original TOVS layer-mean water amount. Then, the values of PW for the new layers are obtained by summing over the appropriate 2 mb layer values.

The NOAA GFDL climatology reports temperatures on standard pressure levels, regardless of the location of the actual surface in pressure coordinates. To make the form of these temperature profiles compatible with the ISCCP version of the TOVS Product, the surface pressure and temperature for each location are calculated using the hydrostatic formula and the NCAR topographic height above mean sea level (taken to be at a pressure of 1000 mb):

$$PS = P_0 \exp\ [\ -\ g\ ZS\ /\ (R\ T_0)\ ]$$

$$TS = T_1 - (T_1 - T_2)\ (P_1 - PS)\ /\ (P_1 - P_2)$$

where R is the atmospheric gas constant per unit mass, ZS is the surface height above mean sea level, P_0 = 1000 mb, T_0 is the temperature at mean sea level, P_1 and P_2 are two adjacent pressure levels, and T_1 and T_2 are their respective temperature values. P_1, P_2, T_1 and T_2 are selected such that $P_1 \leq PS \leq P_2$.

The absolute humidities given in the NOAA GFDL climatology are converted to precipitable water amount using

$$PW = (g)^{-1} \int Q\ dP$$

where vertical profiles of Q are first linearly interpolated to much finer pressure resolution and the integral calculated over the ISCCP pressure intervals.

6.1.8. TIME AVERAGING

Since the pressures at the surface (PS) and tropopause (PT) vary with time, monthly mean profiles are calculated by projecting each profile onto a standard profile extending from 1000 to 30 mb and then averaging over the month. Monthly averages are calculated for each quantity at each pressure level separately. The column total PW for each day is also averaged and used to adjust the monthly mean column total to insure conservation of total water amount. The average profile is then projected onto a profile that extends from the monthly mean value of PS to the monthly mean value of PT.