TOVS PATHFINDER PATH A DATASET GUIDE

Abstract

The TIROS Operational Vertical Sounder (TOVS) Pathfinder Path A dataset contains atmospheric profiles (primarily temperature and humidity) and surface and cloud parameters derived using one of three conceptually distinct algorithms identified by the TOVS Science Working Group (SWG) in November 1991. The purpose of the Pathfinder Project is to make research-quality global change data sets easily available to the science community in support of the US Global Change Research Program (USGCRP) using long term space-based radiance measurements. The initial set of level 3 geophysical products have been derived for the Pathfinder benchmark period from April 1987 through November 1988.

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1. Document Information:

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2. Investigators:

Investigator(s) Name and Title:

Name:

Joel Susskind

Addresses:

Code 613.5
NASA/GSFC
Greenbelt, MD 20771

Telephone Numbers:

301-286-7210

Electronic Mail Address:

joel.susskind-1@nasa.gov

Title of Investigation:

TOVS Pathfinder Path A Interactive Retrievals

Contact (for Data Production Information):

Name:

Lena Iredell

Addresses:

Code 613.5
NASA/GSFC
Greenbelt, MD 20771

Telephone Numbers:

301-286-9773

E-Mail Address:

lena.f.iredell@nasa.gov

3. Dataset Information

Dataset Identification

TOVS Pathfinder Path A

Introduction:

This dataset contains the TIROS Operational Vertical Sounder (TOVS) level 3 geophysical parameters derived using the physical retrieval method of Susskind et al 1984) and processed by the Satellite Data Utilization Office of the Goddard Laboratory for Atmospheres at NASA/GSFC. This method, which is hydrodynamic model- and a priori data-dependent, is designated asthe so-called Path A scheme by the TOVS Pathfinder Science Working Group. The 20 channel High resolution Infrared Radiation Sounder 2 (HIRS2) and the 4 channel Microwave Sounding Unit (MSU) aboard the NOAA-xx series of Polar Orbiting Satellites are used to produce global fields of the three dimensional temperature-moisture structure of the atmosphere. TOVS data is also used to derive surface skin temperature, sea surface temperature, outgoinglongwave radiation, cloud fraction, cloudtop height, total ozone overburden and precipitation estimates. These geophysical parameters are mapped to a 1 degree by 1 degree latitude-longitude grid at 3 different temporal resolutions: daily, 5 day and monthly, separately for the AM and PM periods.

Objectives/Purpose:

The primary goal of Pathfinder is the production of consistently processed, long term datasets for use in global change studies. TOVS Pathfinder is one of several Pathfinder studies initiated by NOAA and NASA, the others being the AVHRR, GOES, and SSM/I Pathfinders. As a first step in the processing, a common benchmark period was selected to facilitate the analysis and intercomparison of geophysical fields derived from the various Pathfinders. The benchmark period covers the time period April, 1987 through November, 1988. Once the products from the benchmark period have been endorsed by the scientific community, the processing of the long-term dataset will commence using a fixed algorithm. The experience gained from the processing of these large datasets will serve to guide the EOSDIS (Earth Observing System Data and Information System) development effort in support of the next generation of remote sensing platforms to be launched in the late 1990's.

Summary of Parameters:

The geophysical parameters derived by the TOVS Path A method relate to the following:

- 3-dimensional temperature-moisture structure of the atmosphere
- Surface properties (surface skin temperature, sea surface temperature)
- Physical cloud properties (cloud fraction, cloudtop height, cloudtop temperature, precipitation)
- Radiation Budget (outgoing longwave radiation, cloud radiative forcing)

4. Theory of Measurements:

Future Entry.

5. Equipment:

All of the following material has been extracted from the instrument references given in section 15.1.

Instrument Description:

Collection Environment:

Satellite

Platform:

Available from GES DISC: TIROS-N, NOAA-9,10,11,12

Platform Mission Objectives:

The overall mission of the TOVS instruments aboard the NOAA Polar Orbiting Environmental Satellites (POES) is to provide continuous, global measurements of atmospheric temperature and moisture profiles. These profiles are then used to initialize numerical general circulation models for improved, operational weather forecasting capabilities.

Key Variables:

High resolution Infrared Radiation Sounder 2 (HIRS/2)

- atmospheric emission in seven 15.3 micron CO_2 channels
- atmospheric emission in five 4.3 micron CO_2 channels
- surface and H_2O emission in one 11.0 micron window channel
- surface and O_3 emission in one 9.6 micron window channel
- atmospheric emission in five 6.7 micron H_2O channels
- surface emission & reflected solar radiation in two 3.7 micron window channels

Microwave Sounding Unit (MSU)

- atmospheric emission in three 56 GHz O_2 channels
- surface emission in one 56 GHz window channel

Stratospheric Sounding Unit (SSU)

- upper atmospheric emission in three pressure modulated CO_2 channels

Principles of Operation:

- **HIRS/2:** The HIRS/2 instrument measures radiation emitted by the earth-atmosphere system in 19 regions of the infrared spectrum between 3.7 and 15 microns. A visible channel is also available to measure the albedo of the earth's surface. The central wave numbers of these channels are :
- `1)    667.70 cm-1 11)  1363.32 cm-1`
- `2)    680.23      12)  1489.42`
- `3)    691.15      13)  2191.38`
- `4)    704.33      14)  2208.74`
- `5)    716.30      15)  2237.49`
- `6)    733.13      16)  2269.09`
- `7)    750.72      17)  2360.00`
- `8)    899.50      18)  2514.58`
- `9)   1029.01      19)  2665.38`
- `10)  1224.07      20) 14453.14`

- A 15 cm diameter optical system is used to gather emitted energy from the earth's atmosphere and surface. The instantaneous field-of-view of all the channels is stepped across the satellite track by use of a rotating mirror. The energy received by the telescope is separated by a dichroic beam splitter into longwave (greater than 6.4 microns) and shortwave (less than 6.4 microns) energy, controlled by field stops and passed through bandpass filters and relay optics to the detectors. There are 56 steps per scan, each requiring 100 milliseconds for a total of 6.4 seconds per scan. The analog data output from the HIRS/2 sensor is digitalized onboard the satellite at a rate of 2880 bits per second, implying 288 bits per step. The data is digitized to 13 bit precision.

- **MSU:** The MSU instrument is a 4 channel Dicke radiometer making passive microwave radiation measurements in 4 regions of the 50 GHz oxygen emission spectrum. The central frequencies of these channels are:
- 1) 50.30 GHz 3) 54.96 GHz 2) 53.74 GHz 4) 57.05 GHz
-

The channel bandwidths are 200 MHz in each case, with a typical Noise Equivalent Differential Temperature (NEDT) of 0.3 degrees K. The instrument has two 4 inch scanning reflector antenna systems, orthomode transducers, four Dicke superheterodyne receivers, a data programmer and power supplies. The antennas are step scanned through eleven individual 1.84 second earth-viewing steps and require a total of 25.6 seconds to complete. The MSU data output represents an apparent brightness temperature after a 1.84 second integration period per step. The data is quantized to 12 bit precision and combined with telemetry and step position information to produce an effective output rate of 320 bits per second.

- **SSU:** The SSU employs the technique of pressure modulation to measure radiation emitted by carbon dioxide in the region from 1 to 20 mb. A cell of CO_2 gas in the instrument's optical path has its pressure changed in a cyclic manner. The spectral characteristics of the channel and therefore the height of the weighting function is determined by the pressure in the cell during the integration period. By using 3 cells at different pressures, weighting functions peaking at 3 different heights can be obtained. The instrument is step-scanned perpendicular to the subpoint track, and is composed of 8 individual 4 second steps implying a total of 32 seconds per scan. The integrated output signal level is sampled 8 times during each step, and the output is then digitized to 12 bit precision.

Instrument Measurement Geometry:

The instrument measurement geometry for the TOVS sensors are summarized in the following table:

Instrument parameter	HIRS/2	MSU	SSU
Cross track scan angle			
(+/- degrees from nadir)	49.5	47.4	40.0
Number of steps	56	11	8
Angular FOV (degrees)	1.25	7.5	10.0
Step Angle (degrees)	1.80	9.5	10.0
Ground IFOV (km)			
- at nadir	17.4	109.3	147.3
- at end of scan	59 x 30	323 x 179	244 x 186
Swath width (+/- km)	1120	1174	737

Manufacturer of Instrument:

- **HIRS/2:** Aerospace/Optical Division of ITT
- **MSU:** Jet Propulsion Laboratory
- **SSU:** MSDS, Frimley

Calibration:

Prelaunch calibration of the infrared and microwave channels are carried out by the instrument manufacturers to characterize their performance. The radiometer sequentially views the warm calibrated laboratory blackbody (representing the earth), a blackbody colled to about 77 degrees K (representing the space view), and it's own internal blackbodies. Temperatures of all blackbodies are sensed with thermistors or platinum resistance thermometers (PRTs). Data are collected as the laboratory blackbody is cycled through a sequence of temperature plateaus between 175 and 320 degrees K. This entire procedure is repeated for several instrument operating temperatures to simulate in-orbit variations in instrument temperature. Because of both short- and long-term variations in instrument sensitivity during its period of operation, the radiometers have been designed to view cold space and one or more internal warm blackbodies as part of the normal scan sequence in orbit. Using this information, the signal-to-noise and radiometric calibration coefficients can be monitored during the instrument's lifetime. See Frequency of Calibration for further information regarding in-flight calibration procedures.

Specifications:

Tolerance

Future Entry.

Frequency of Calibration:

- **HIRS/2:** During normal operations, calibration of the HIRS/2 instrument is performed once every 256 seconds (every 40 scan lines). In calibration mode, the mirror rapidly slews to a space view and samples all channels for the equivalent time of of one complete scan. The mirror is then moved to a position where it views a cold calibration target for the equivalent of a full scan. Finally, the mirror is stepped to view the internal warm target for an equivalent amount of time. With these measurements and an accurate determination of the warm and cold body temperatures using PRTs, calibration coefficients up to second order are obtained for that calibration sequence. These are then used with ensuing earth-view digital counts to obtain the corresponding radiances for each HIRS/2 channel.

- **MSU:** The MSU has no special calibration sequence that interrupts normal scanning. The calibration data is included in a scan line of data. From the last earth-view position, the reflector moves 4 steps to view space, then another 10 steps to view the internal blackbody, before beginning a new scan line. Using these measurements, calibration coefficients up to first order are determined for the scan line.

- **SSU:** A calibration sequence is initiated every 256 seconds (equivalent to 8 scans) during which the radiometer is stepped to a position to view cold space, then to an internal blackbody at a know temperature. Using these measurements, calibration coefficients up to first order are determined for that calibration sequence. These are then used with ensuing earth-view digital counts to obtain the corresponding radiances for each SSU channel.

Other Calibration Information:

- **HIRS/2:** No correction for non-linear instrument response is required for the HIRS/2 raw data prior to applying the radiometric calibration coefficients. To convert channel radiances to brightness temperatures, the inverse Planck function is used to obtain an "apparent" brightness temperature, which is adjusted using satellite-specific band correction coefficients. See the Polar Orbiter User's guide for more detailed information.

-
- **MSU:** A correction for non-linear instrument response is required for the MSU raw data prior to applying the radiometric calibration coefficients. A set of four coefficients is applied to the raw counts using a third order "normalization" equation. The inverse Planck function is used to convert the resulting channel radiances to brightness temperatures.

- **SSU:** No correction for non-linear instrument response is required for the SSU raw data prior to applying the radiometric calibration coefficients. The inverse Planck function is used to convert the resulting channel radiances to brightness temperatures.

6. Procedure:

Data Acquisition Methods:

7. Observations:

Data Notes:

None

Field Notes:

Not Applicable

8. Data Granularity:

A granule for the level 3 TOVS Pathfinder data is defined by the following characteristics:

- **Spatial Coverage:**

global

- **Temporal Coverage:**

daily, 5-day, or monthly (AM and PM separately)

Files are named using the following convention:

```
        File Name                            Size     Size (compressed)
        ---------                            ----    -----------------
TOVS_DAILY_pp_yymmdd.HDF                     29 MB        10 MB
TOVS_5DAYS_pp_Byymmdd.Eyymmdd.HDF            29 MB        22 MB
TOVS_MONTHLY_pp_yymm.HDF                     29 MB        26 MB
```

where "dd" denotes day of year, "mm" the month number, "yy" the year, and "pp" the AM or PM period. Since the files have been compressed, the extension ".Z" will be appended to the file names.

9. Data Description:

Spatial Characteristics:

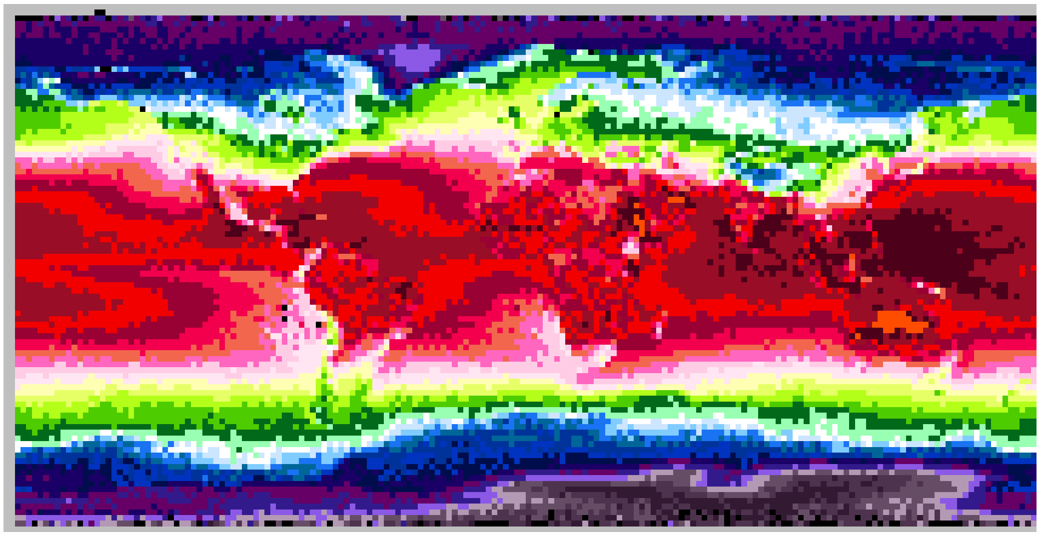
Spatial Coverage:

For the daily, 5 day, and monthly gridded data, the spatial coverage is global. However, in the case of the daily maps, there will be orbital data gaps present which will not be apparent in the 5 day and monthly averaged data products. See Spatial Coverage Map below.

Spatial Coverage Map:

Global, rectangular latitude-longitude grid

An example of a typical spatial coverage for a sample monthly (AM only, descending nodes) image of SKIN SURFACE TEMPERATURE is shown below:



The inter-orbital data gaps as well as the calibration scan lines (every 40th line for HIRS/2) are clearly visible in this image.

Spatial Resolution:

- **Horizontal Resolution :**

  All parameters : 1 degree latitude by 1 degree longitude

- **Vertical Resolution :**

  Temperature profile : 12 levels (surface, 1000, 850, 700, 500, 400, 300, 200, 100, 70, 50, 30 mb)
  Coarse layer temperatures : 4 layers (surface-500, 500-300, 300-100, 100-30 mb)

  Specific humidity profile : 5 levels (1000, 850, 700, 500, 300 mb)

Projection:

Not Applicable

Grid Description:

There are 360 cells in the longitude direction with the first grid cell centered at 179.5W (near the date line), and with a grid spacing of 1 degree. There are 180 cells in the latitude direction with the first grid cell centered at 79.5S (near the South Pole), and with a grid spacing of 1 degree. The vertical levels coincide with mandatory pressure levels in the case of the temperature and humidity profiles.

Each level 2 spot retrieval is assigned to a single gridbox according to which gridbox the spatial coordinates of the center of the level 2 FOV falls within. For individual gridboxes with multiple observations, a simple unweighted average of all points within the box is used when determining the value of the geophysical parameter to assign to that gridbox. No interpolation or data filling is used for gridboxes with missing data; the fill value for missing or suspect data is contained in the metadata file descriptor annotation accompanying each HDF file. Currently, this value is set to -999.99 for the mean and standard deviation arrays, and 0 for the count arrays.

Temporal Characteristics:

Temporal Coverage:

The temporal coverage of this dataset is currently July 1979 to July 1994. See list of satellite periods in Temporal Coverage Map.

Temporal Coverage Map of all TIROS-N series satellites:

SATELLITE	AVAILABLE DATA BASE
TIROS-N (2:30)	Dec. 1, 1978 - Jan. 20, 1980 Dec. 1, 1978 - Jan. 20, 1980
NOAA 6 (7:30)	Nov. 1, 79 - April 16, 1983
	(13 day gap March 26-April 9, '81)
	Nov. 1, 1979 - June 11, 1981
NOAA 7 (2:30)	July 1, 1981 - Feb. 5, 1985
	(6 day gap Sept. 24-29, 1982)
	July 1, 1983 - July 31, 1983
NOAA 8 (7:30)	April 26, 1983 - June 20, 1984
NOAA 9 (2:30)	Dec. 4, 1984 - Feb. 2, 1987
NOAA 10 (7:30)	Nov. 25, 1986 - May 31, 1991
	August 2, 1987 - Oct. 4, 1987
	May 1, 1988 - July 15, 1988
	Sept. 1, 1988 - Oct. 15, 1988
NOAA 11 (2:30)	Nov. 1, 1988 - Apr 11, 1995
NOAA 12 (7:30)	June 1, 1991 - Dec 14, 1998
NOAA 13 (1:40)	Aug 9, 1993 - Aug 21, 1993
NOAA J (2:30)	launched 1994, decommissioned 2007

Temporal Resolution:

The level 3 gridded products are created at 3 temporal resolutions: daily, 5 day and monthly. These products are created separately for the AM (descending nodes on morning satellites) and PM (ascending nodes for morning satellites) periods.

Local equator crossing time for even numbered satellites such as NOAA-10 is nominally 7:30 PM for the ascending node and 7:30 AM for the descending node. For gridding purposes, the global AM (PM) map is not created by including data from all descending (ascending) portions of the orbits between 00Z and 24Z. This would result in data from 2 consecutive days being included in either map since the satellite crosses the date line during this 24 hour period. Rather, the gridding is based upon the local date and time of the orbits, e.g., only those ascending orbits with the same local day and time (which is always 7:30 PM) are used in the construction of the PM map. A similar procedure is used in the construction of the AM map.

Data Description:

Parameter/Variable:

Temperature Parameters: Atmospheric temperatures are given at up to 12 pressure levels, including the surface. The surface air temperature is always given. If the model forecast surface pressure is less than a given pressure, the retrieved value for that pressure is given a fill value (-999.99). Average coarse layer temperatures are also derived between four sets of pressure levels.

Water Vapor Profiles: Water vapor profiles are given in terms of specific humidity at 5 mandatory pressure levels. In addition, total precipitable water above the surface and above 4 mandatory pressure levels are also derived and output as additional measures of atmospheric moisture. As in the case of temperature, a fill value (-999.99) is given at mandatory levels if the surface pressure is less than the mandatory level pressure level.

Total Ozone Index: The total ozone index is computed as an experimental parameter using HIRS/2 channel 9 (9.6 microns). The TOMS total ozone is used for tuning the TOVS ozone index on both a latitudinal and seasonal basis. However, unlike TOMS, both daytime and nighttime estimates of the total ozone are obtained using the HIRS/2 measurements.

Surface Parameters: Two surface parameters are provided, namely, the retrieved surface skin temperature (both land and sea) and forecast surface air pressure. The first quantity is derived from the TOVS radiances, and the second is generated by the General Circulation Model.

Cloud Parameters: Ten cloud parameters are derived. These are total effective cloud fraction (for clouds in any layer), effective cloud fraction for clouds with cloud top pressure levels situated in each of seven ISSCP layers, cloud top pressure and cloud top temperature. The cloud top pressure and cloud top temperature are those associated with the total effective cloud fraction. The sum of the cloud fraction in each of the seven layers is equal to the total cloud fraction.

Longwave Radiation Parameters: Longwave radiation parameters are computed from the retrieved cloud parameters and other geophysical parameters. Two quantities are written out: Outgoing Longwave Radiation, defined as the upward longwave flux exiting the top of the atmosphere, and Longwave Cloud Radiative Forcing, defined as the difference between the cloudy sky and clear sky Outgoing Longwave Radiation values.

Precipitation Estimate: The precipitation estimate is an experimental quantity inferred from retrievals of cloud parameters and the relative humidity profile. It is derived over both land and water surfaces.

Other Parameters: There are three other parameters written out in each file. The most important is a quality flag which indicates the degree to which the radiances computed from the retrieval match the observations. The highest quality indicator is 0 and the lowest is 4. By definition, differences between observed and computed radiances for all retrievals included in the data set matched sufficiently closely to be accepted. In addition, the effective HIRS2 observed zenith angle (zenith angles to the right and left of nadir have different signs) and the average local time of day in hours (between 0 and 23.99) are provided to facilitate the interpretation of the retrieval products. The effective zenith angle is defined as the arc-cosine of the average value of the cosines of the individual satellite zenith angles.

Variable Description/Definition:

The TOVS Path A dataset contains the following set of geophysical parameters derived from HIRS/2 and MSU radiance measurements:

```
Variable        Units           Description
---------       ----          ------------
TEMPSFC          K      Temperature at surface air
TEMP1000        K       Temperature at 1000 mb
TEMP850          K      Temperature at 850 mb
TEMP700          K      Temperature at 700 mb
TEMP500          K      Temperature at 500 mb
TEMP400          K      Temperature at 400 mb
TEMP300          K      Temperature at 300 mb
TEMP200          K      Temperature at 200 mb
TEMP100          K      Temperature at 100 mb
TEMP70           K      Temperature at 70 mb
TEMP50           K      Temperature at 50 mb
TEMP30           K      Temperature at 30 mb
TEMPGRD          K       Surface Skin Temperature
CLTEMP1          K      Mean temperature surface to 500 mb
CLTEMP2          K      Mean temperature 500 mb to 300 mb
CLTEMP3          K      Mean temperature 300 mb to 100 mb
CLTEMP4          K      Mean temperature 100 mb to 30 mb
PRWATSFC        cm      Precipitable water vapor above surface
PRWAT850        cm      Precipitable water vapor above 850 mb
PRWAT700        cm      Precipitable water vapor above 700 mb
PRWAT500        cm      Precipitable water vapor above 500 mb
PRWAT300        cm      Precipitable water vapor above 300 mb
FCLD *          %       Total cloud fraction
FCLDP1 *        -       Cloud fraction above 180 mb
FCLDP2 *        -       Cloud fraction between 310 and 180 mb
FCLDP3 *        -       Cloud fraction between 440 and 310 mb
FCLDP4 *        -       Cloud fraction between 560 and 440 mb
FCLDP5 *        -       Cloud fraction between 680 and 560 mb
FCLDP6 *        -       Cloud fraction between 800 and 680 mb
FCLDP7 *        -       Cloud fraction below 800 mb
PCLD *          mb      Cloud top pressure for FCLDTOT
TCLD *          K       Cloud top temperature for FCLDTOT
ZANGLE           deg    HIRS/2  satellite zenith angle
TIME             hrs    Local time of the day
QFLAG N/A       Quality flag (0 is best, 4 is marginal)
TOZ *           D.U.    Total ozone index
OLR              W/m^2  Outgoing longwave radiation
LCRF             W/m^2  Longwave cloud radiative forcing
PRECIP *        mm/day  Precipitation estimate
SPHUM1000       g/kg    Specific humidity at 1000 mb
SPHUM850        g/kg    Specific humidity at 850 mb S
PHUM700 g/kg    Specific humidity at 700 mb
SPHUM500        g/kg    Specific humidity at 500 mb
SPHUM300        g/kg    Specific humidity at 300 mb
PSURF            mb      Forecast Surface Pressure
```

The '*' indicates that these derived parameters were designated as experimental by the TOVS Implementation Team, pending further validation of the results.

Unit of Measurement:

See Variable Description/Definition above

Data Source:

The TOVS Path A methodology makes use of a combination of HIRS/2 and/or MSU channel radiances to infer information pertaining to the following groups of geophysical parameters:

```
Temp profile H2O profile Clouds Surf temp
------------      -----------     -----------     ---------
HIRS....1,2,4 HIRS....8,10 HIRS....4,5 HIRS...8,18,19 13,14,15 11,12
6,7,8 MSU.......3,4 Cloud Clearing Ozone
--------------     ---------
HIRS.....13,14 HIRS....9 MSU..........2
```

where the HIRS/ and MSU channel designations are listed in section 5.1.5 of this document.

Data Range:

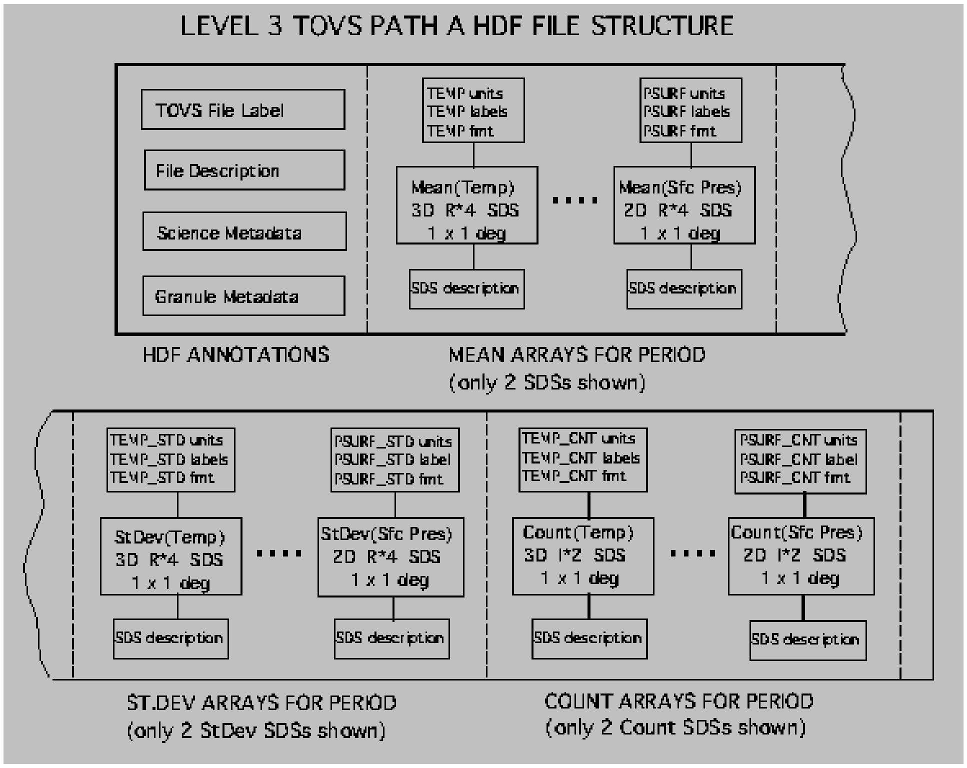
Future Entry.

Sample Data Record:

See Spatial Coverage Map

Data Format:

The TOVS Pathfinder level 3 output consist of binary files containing 2- and 3-dimensional geophysical parameters mapped to a rectangular latitude-longitude grid. For each parameter, each cell in the grid is characterized by a mean value of that parameter, the associated standard deviation, and the number of observations used in computing the first two quantities. All 3 of these statistics are stored as Scientific Data Sets (SDSs) in the Hierarchical Data Format (HDF). Means and standard deviations are stored as 32 bit floating point words, while the number of observations in each gridbox or the " gridbox counts" are represented as 16 bit integers. Version 3.2 release 4 of HDF (HDF3.2r4) was used to create all level 3 files The overall structure of a TOVS HDF file is shown in the schematic below:



For example, SDS #1 will be the 3 dimensional (360 x 180 x 12) array representing the temperature profiles at 12 pressure levels, while SDS #17 will consist of the 2 dimensional (360 x 180) array containing the forecast surface pressure. SDS's 18 through 34 will be completely analagous to SDS 1 through 17 except that the arrays will represent the standard deviations rather the means of the parameters. Similarly, SDS's 35 through 51 will contain the gridbox count arrays associated with each parameter. The order in which the SDS arrays are written out is as follows :

SDS	SDS Name	SDS Dims	SDS Description
1	TEMP	360x180x12	Vertical temperature profile at 12 levels
2	CLTEMP	360x180x4	Mean temperatures for 4 coarse layers
3	PRWAT	360x180x5	Total precipitable water above 5 levels
4	TSURF	360x180	Surface skin temperature
5	FCLD	360x180	Effective total cloud fraction
6	FCLDP	360x180x7	Effective cloud fraction, 7 ISSCP layers
7	PCLD	360x180	Effective cloudtop pressure
8	TCLD	360x180	Effective cloudtop temperature
9	ZANGLE	360x180	Effective satellite zenith angle
10	TIME	360x180	Time of day
11	QFLAG	360x180	Quality flag
12	TOZ	360x180	Total ozone index
13	OLR	360x180	Outgoing longwave radiation
14	LCRF	360x180	Longwave cloud radiative forcing

15	PRECIP	360x180	Precipitation estimate
16	SPHUM	360x180x5	Specific humidity profile at 5 levels
17	PSURF	360x180	Model forecast surface pressure

SDSs 18 through 34 and 35 through 51 will have the same names as those shown above, except with the suffixes "_STD" and "_CNT" appended, respectively. The individual SDSs are self-documenting in that ASCII labels containing the SDS name, description and units have been attached to each. Further information on the implementation of the data arrays into HDF can be found in the TOVS Path A README file.

Related Datasets:

- TOVS Pathfinder Path B (GES)
- TOVS Pathfinder Path C1 (MSFC DAAC)
- TOVS Pathfinder Path C2 (NOAA SAA)
- TOVS Path P (NSIDC DAAC)
- DAO 4D Time Series (GES DISC)

10. Data Manipulations:

Formulae:

The fundamental formulae used in the TOVS Path A methodology can be found in a postscript file in the anonymous ftp directory /pub/tovs/pathA/doc/appendixAB.ps located on eosdata.gsfc.nasa.gov.

Derivation Techniques and Algorithms:

The Path A system steps through an interactive forecast-retrieval-analysis cycle, whereby in each 6 hour synoptic period, the 6 hour forecast fields of temperature, humidity and geopotential thickness generated by the Goddard Laboratory for Atmospheres (GLA) 2nd order GCM (Takacs et al., 1994) are used as the first guess for all soundings occuring within a 3 hour time window centered upon the forecast time. These retrievals are then assimilated with all available insitu measurements (such as radiosonde and ship reports) in the 6 hour interval using an Optimal Interpolation (OI) analysis scheme developed by the GLA Data Assimilation Office. This analysis is then used to specify the initial conditions for the next 6 hour forecast, thus completing the cycle.

The retrieval algorithm itself is a physical method based on the iterative relaxation technique originally proposed by Chahine (1968). The basic approach consists of modifying the temperature profile from the previous iteration by an amount proportional to the difference between the observed brightness temperatures and the brightness temperatures computed from the trial parameters using the full radiative transfer equation applied at the observed satellite zenith angle. For the case of the temperature profile, the updated layer mean temperatures are given as a linear combination of multichannel brightness temperature differences with the coefficients given by the channel weighting functions. Constraints are imposed upon the solution in order to ensure stability and convergence of the iterative process. For more details see Susskind et al (1984).

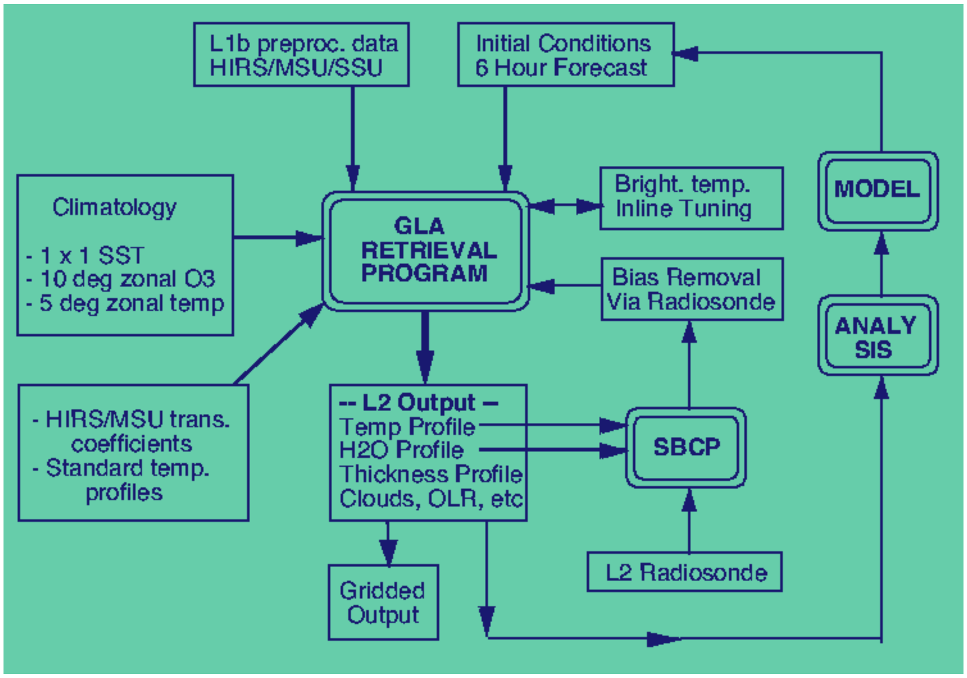
Two important procedures are necessary for the accurate retrieval of the geophysical parameters using satellite-based radiance measurements. The first involves the reconstruction of the clear sky radiances which would have been observed in the absence of cloud contamination. This is performed using a variation of the N* method applied to adjacent fields-of-view (over an area covering 2 along-track and 2 cross-track HIRS2 spots) using a combination of infrared and microwave channels (see Data Source). The second procedure involves the need for a bias correction stemming from a combination of instrument calibration errors and drifts and errors in the radiance computations. The systematic errors between computed and observed brightness temperatures are modeled as a function of latitude and satellite zenith angle, with the coefficients determined by a least squares fit to the radiance residuals resulting between the observed brightness temperatures and those obtained from the globally unbiased GLA forecast model. These coefficients are updated periodically throughout the day and the resulting radiance corrections are applied to all computed brightness temperatures used in the derivation of the geophysical parameters. See Special Corrections/Adjustments for more details on systematic error corrections used in the TOVS Path A method.

As part of the iterative process for the temperature profile, the surface characteristics such as skin temperature, sea surface temperature and microwave emissivity are determined so as to be consistent with the radiances measured in the window channels that are primarily sensitive to changes in these parameters (see Data Source). Once these are known, the remaining geophysical parameters, namely the humidity profile, total ozone, cloudtop height and cloud amount are derived as described in detail in Susskind et. al. (1984).

Data Processing Sequence:

Processing Steps (and Datasets):

The overall TOVS Path A processing flow can be illustrated by the following schematic:



The basic methodology used to retrieve geophysical parameters from the TOVS observations involves use of an interactive forecast-retrieval-analysis scheme in which the first guess information for the retrievals (surface pressure, temperature profile, and moisture profile) comes from a 6 hour forecast from a general circulation model initiated at time T (i.e., a forecast is produced at time T+6 hours). This information, together with the observed radiances, and other auxiliary information used for systematic error correction of retrieved quantities, is used to generate retrievals for the 6 hour period centered on the forecast time (i.e., between T+3 and T+9 hours). An analysis is then performed using these retrievals and all available in situ data for that time period. Another 6 hour forecast is made using the analyzed geophysical fields as input and the cycle then repeats.

The steps involved in the retrievals portion of the data processing (designated by the GLA RETRIEVAL PROGRAM box in this diagram) can be summarized as follows:

Calibration and grouping of radiance data : Starting from level 1B data, HIRS2 and MSU data is calibrated according to calibrations coefficients provided by NOAA on the level 1B data. Calibration is performed using the procedures set forth in the NOAA Polar Orbiter Data User's Guide. A 2 x 2 array of HIRS2 spots is grouped together and colocated with the nearest MSU spot. The HIRS2 radiances are grouped into two fields of views, containing 2 spots each. One sounding is performed on each 2 x 2 array of spots and assigned the latitude and longitude of the center of the four HIRS2 spots, as well as the time of the measurement. Also included are the average satellite zenith angle of the HIRS2 spots and the zenith angle of the MSU spots.

Retrieval first guess : The first guess for the retrieval at that spot comes from a six hour forecast from the General Circulation Model with 4 degree by 5 degree latitude-longitude horizontal resolution and 20 vertical levels, interpolated in space to the satellite location. First guess parameter fields provided by the model forecast are the surface pressure, the temperature profile, and the humidity profile. In addition, the first guess ozone profile is obtained by taking a zonally averaged climatology profile, which is a function of latitude and month, and multiplying its values by the ratio of the zonal mean TOMS total ozone at that latitude for the previous two days to the climatological total ozone. The forecast surface pressure remains fixed in the retrieval. All other retrieved geophysical parameters will be modified via an iterative procedure to be consistent with the channel radiance measurements.

Radiance computation for first guess : Radiances are computed for all channels at the appropriate zenith angle of observation (HIRS2 and MSU angles are different), using the first guess parameters in conjunction with a radiative transfer code. The first guess surface skin temperature is set equal to climatology over ocean and the forecast surface air temperature over land. Computed radiances are corrected for systematic computation errors to yield the clear column radiances expected from the first guess.

Cloud corrected observed radiances : Observed radiances in the two fields of view are cloud-corrected to reconstruct what would have been observed if the fields of view were clear. The cloud clearing depends to a small degree on the estimates of the geophysical parameters and is iterated in the retrieval. Beginning with radiances calculated from the first guess fields, geophysical parameters will be found which minimize the residual between reconstructed clear column radiances and radiances computed from the solution. Under some conditions, the scene is found to be too cloudy to reconstruct clear column radiances. This occurs about 10% of the time, typically with fractional cloudiness of over 80%.

Iterative ground temperature, temperature profile retrievals : Starting from the first guess profile and channel residuals, the ground temperature and temperature profiles are iterated to match the difference between the Nth iterative estimate of the clear column radiances and the radiances computed from the Nth iterative parameters. Retrievals are rejected if a close enough match cannot be found. The moisture profile and ozone profile are fixed at the first guess in these calculations. Channels used in the temperature retrieval are relatively insensitive to moisture and ozone profile. Systematic temperature profile error corrections, based on comparison with radiosonde reports, are added to the retrieved temperature profile. If the temperature retrieval is rejected, no retrieval for moisture profile or ozone retrieval is performed.

Moisture profile retrieval : Using the retrieved ground temperature, temperature profile, and reconstructed clear column radiances obtained from the previous step, the moisture profile is iterated to best match moisture sounding channel radiances computed from the solution with the reconstructed clear column radiances determined in the temperature sounding step. The retrieved moisture profile is modified according to a systematic error correction procedure, as done for the temperature profile.

Total ozone retrieval : The radiance for the ozone channel HIRS2 channel 9 is computed using all previously retrieved quantities and the ozone first guess and compared to the reconstructed clear column radiance. Total ozone is modified to achieve a match. The radiances computed for the ozone channel are adjusted for systematic errors, based on the zonal mean of the difference between retrieved total ozone values and those obtained from the TOMS data used to create the ozone first guess field.

Post retrieval computations : Post retrieval computations are now done for cloud height and cloud top pressure, OLR, longwave cloud radiative forcing, and precipitation estimate. Cloud parameters are always retrieved for all locations, based on matching observed radiances in four channels (HIRS 4-8) and radiances computed using the retrieved values of all parameters (or first guess if a solution could not be found) and the cloud parameters. OLR and Longwave Cloud Radiative Forcing is computed via radiative transfer calculations using the retrieved (or first guess) parameters and cloud products. Precipitation estimate is obtained as a function of retrieved cloud parameters and retrieved (or first guess) relative humidity profile.

Post processing : The retrievals are run for a six hour period. These retrievals are then used, together with all other in-situ measurements in that 6 hour period, to produce an analysis (best estimate of the state of the atmosphere) at time T+6 hours. These initial conditions are used to produce the forecast for T+12 and the cycle repeats. Details of the new forecast analysis system and its use in the interactive retrieved mode are shown in Appendix A. Every 24 hours, retrievals are gridded into daily 1 degree by 1 degree level 3 fields. Every 48 hours, retrievals are compared to colocated radiosondes to test the accuracy of temperature and moisture profiles and generate new temperature and moisture profile systematic error correction coefficients to be used for the next 48 hours of retrievals. In addition, every 48 hours, new zonal mean TOMS total ozone values are read into the program for ozone systematic error removal.

Processing Changes:

There have been many improvements to the old retrieval system, described in Susskind and Pfaendtner (1989), arising from research we have been doing and incorporated in the Pathfinder processing scheme. These include :

1. coupling the interactive retrieval system with a new higher vertical resolution General Circulation Model and Optimal Interpolation Analysis scheme
2. developing an improved iterative scheme for both temperature and moisture retrievals
3. developing improved methodology for systematic error correction for temperature and moisture retrievals
4. developing an on-line algorithm to compute Outgoing Longwave Radiation on a retrieval by retrieval basis.

Details of the new forecast analysis system and its use in the interactive retrieved mode can be found in the postscript file /pub/tovs/pathA/doc/appendixAB.ps on eosdata.gsfc.nasa.gov. The basic methodology to analyze the satellite data is unchanged from that of the previous retrieval system used to produce earlier versions of the data products, and is described in Susskind and Pfaendtner (1989) and the references therein. The cloud correction algorithm used to obtain the clear column brightness temperatures has not changed from that described in Susskind and Pfaendtner (1989). The computed radiances use exactly the same methodology as in Susskind and Pfaendtner (1989) except for the systematic error correction term, which is an empirical term added to a subset of computed brightness temperatures to account for biases between observed and computed brightness temperatures. Recent research has led to improvements in this term which are described in the file /pub/tovs/pathA/doc/appendixCD.ps on eosdata.gsfc.nasa.gov (also see Special Corrections/Adjustments section). The method of determination of the temperature profile has been simplified and takes advantage of the improved vertical structure of the first guess. In addition, the moisture profile retrievals are now determined in a manner that is analogous to that of the temperature profile retrievals. A more detailed description of these improvements is available in /pub/tovs/pathA/doc/appendixAB.ps. Finally, improved methodology has been developed for computations of OLR, which is described in detail in /pub/tovs/pathA/doc/appendixCD.ps.

Calculations:

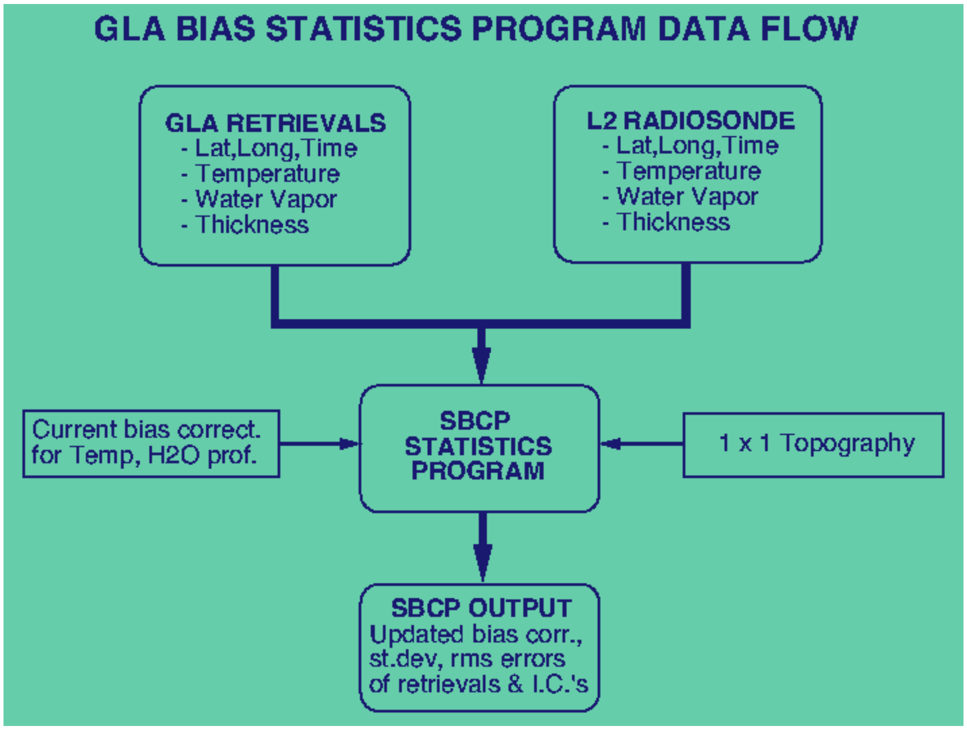
Special Corrections/Adjustments:

- **Corrections for radiance biases**

  Since the TOVS Path A physical retrieval method makes use of the difference between observed and computed brightness temperatures to iteratively adjust the values of derived geophysical parameters. Thus, inherent biases between computed and observed brightness temperatures (for the case where the derived set of parameter values equals the truth) can be particularly damaging from the point of view of monitoring climate variability and trends, as these biases will differ from satellite to satellite and spurious trends may result. The interactive system plays a critical role in the removal of systematic errors between observed and computed radiances which are accounted for in the GLA system as part of the retrieval process. The interactive retrievals are initialized with the first guess field obtained from a 6 hour forecast from the GLA general circulation model generated from an analysis which has utilized all sounding data and in situ data in the last 6 hour period. The global forecast field is assumed to have local errors but be globally unbiased. This assumption is used to help account for systematic differences between observed brightness temperatures and those computed from the forecast first guess. A detailed description of the steps involved in the brightness temperature systematic error correction can be found in the anonymous ftp directory /pub/tovs/pathA/doc/appendixCD.ps located on eosdata.gsfc.nasa.gov.

- **Systematic error correction in the retrieved parameters**

In addition to systematic error correction of computed brightness temperatures, a further systematic error correction is applied to retrieved values of both the temperature and moisture profiles based on comparisons of retrieved quantities with colocated radiosonde reports. This procedure is performed every 48 hours using about 1500 colocations to determine altitude-dependent regression coefficients based upon minimization of the rms difference of radiosonde and retrieved temperatures. A high-level schematic of the steps involved in the systematic error correction is shown below:



The topography dataset is included as an input file since it contains a land/sea indicator, upon which the systematic error corrections for the moisture profile depends. A more detailed description of the steps involved in the removal of systematic errors from the retrieved parameters can be found in the anonymous ftp directory /pub/tovs/pathA/doc/appendixCD.ps located on eosdata.gsfc.nasa.gov.

11. Errors:

Sources of Error:

Future Entry.

Quality Assessment:

Data Validation by Source:

The level 3 Path A parameters have been validated against independently measured data from both insitu and satellite sources. The errors quoted represent the "expected errors" using the RMS differences between the TOVS-derived values and the correlative values (area-weighted by latitude) summed over all gridboxes for a monthly period.

Temperature and humidity parameters have been compared to colocated radiosonde data. In addition, the total precipitable water above oceanic areas has been compared to data derived from the Special Sensor Microwave/Imager (SSM/I).

The surface skin temperature over ocean has been compared to values produced by the NOAA Climate Analysis Center (CAC) based on ship, buoy, and AVHRR data.

The total atmospheric column ozone burden was validated against Total Ozone Mapping Spectrometer (TOMS) data, which was also used in the zonal mean sense as part of the systematic error removal scheme for total ozone retrievals.

OLR has been validated against OLR determined by the ERBE team using the ERBE instruments on NOAA 10 and ERBS. ERBS is a tropical orbiting satellite and this adds a temporal sampling bias in the tropics. Longwave cloud radiative forcing has not been validated at this time.

The precipitation estimate has been compared with rain gauges, which are primarily over land.

In addition to these direct correlative data comparisons, errors between interannual differences computed for the TOVS data and the interannual differences computed from the correlative data have been provided based upon the monthly gridded results from July 1987 and July 1988. These results are shown in the table below:

MONTHLY MEAN INTERANNUAL DIFFERENCE PARAMETER	RMS ERROR	GLOBAL BIAS
Coarse Layer Temperatures	0.7 - 1.0 deg	lt. 0.1 deg
Level Temperatures (excluding 10mb)	1.0 - 2.0 deg	lt. 0.3 deg
Total Precipitable Water	20%	-
Precipitable Water above levels	25 - 40%	-
Specific Humidity	25 - 40%	-
Sea Surface Temperature	0.5 deg	-
Land Surface Temperature	2.0 deg	-
Total Ozone	5%	-
Outgoing Longwave Radiation	5 W/m^2	1 W/m^2

Cloud Fraction	10%	-
Cloudtop Pressure	50 mb	-
Precipitation Estimate	3 mm/day	-

Confidence Level/Accuracy Judgement:

Coarse Layer Temperatures:

- **Bias (monthly mean):** less than 0.3 degrees C
- **RMS error (monthly mean):** 1.0 - 1.2 degrees C
- **Spatial correlation (monthly mean):** 0.99.

- **Bias (interannual difference):** less than 0.l degrees C
- **RMS error (interannual difference):** 0.9 degrees C
- **Spatial correlation:** 0.90-0.95.

Note that errors in interannual differences compared to radiosondes are smaller than for monthly mean differences. This is because errors contain a systematic component that cancels out in the interannual sense. A substantial component of this may be due to sampling differences in the satellite and radiosonde, such as local time of day. The high spatial correlation and low bias of coarse layer temperatures with radiosondes show these coarse layer temperatures are potentially accurate climate indicators capable of showing regional and global trends.

Level Temperatures:

- **Bias (monthly mean, for pressures below 400 mb):** less than 0.2 deg C
- **Bias (monthly mean, for pressures 300-70 mb):** 0.3 - 0.4 deg C
- **Bias (monthly mean, for pressures 50-30 mb):** 0.6 - 0.9 deg C
- **RMS error (monthly mean):** 2.0 degress (for 1000 mb and 850 mb)
- **RMS error (monthly mean):** 1.3 degrees (for 700 mb - 400 mb)
- **RMS error (monthly mean):** 1.5 degrees (for 300 mb - 200 mb)
- **RMS error (monthly mean):** 1.8 degrees (for 70 mb - 50 mb)
- **RMS error (monthly mean):** 2.4 degrees (for 30 mb)

Interannual differences show smaller biases and RMS errors, as with coarse layer temperatures, with spatial correlations in the range .8 - .9. This shows that the level temperatures contain useful interannual difference patterns but are quantitatively less accurate than the coarse layer temperatures. They can be used to explain the detailed differences in coarse layer temperature patterns, however.

Water Vapor: Most radiosondes are over land, though a number of tropical island stations also exist. The precipitable water above the surface has a global mean bias of -.07 cm compared to a radiosonde mean of 1.79 cm (-4% bias) and the standard deviation of the difference from radiosondes is 0.33 cm, which is 19% of the radiosonde standard deviation of 1.67 cm. The bias comes primarily from tropical ocean stations where retrievals tend to be biased dry in moist cases. The spatial correlation is 0.98 between retrieved and radiosonde total precipitable water vapor.

Above other levels, biases are of the order of 15-20% compared to radiosondes and standard deviations of the order of 40%, with spatial correlations on the order of 0.9. Total oceanic precipitable water compared to the SSM/I product for March 1988 gave a bias of 0.23 cm, compared to an SSM/I oceanic mean of 2.87 cm (8% bias) and a standard deviation of 0.51 cm (18%). The TOVS retrievals tended to be drier than SSM/I in moist tropical areas and moister in drier areas. According to radiosondes, July 1988 was moister by 1.7 mm than July 1988 with a spatial standard deviation of the interannual difference of 5.8 mm. This shows considerable interannual variability in moisture between these two years. The colocated retrievals showed July 1988 0.7 mm moister than July 1987. The standard deviation of the difference between retrieved and radiosonde interannual differences was 2.7 mm with a spatial correlation of 0.76. Correlations of higher level interannual difference patterns were the order of 0.7.

Surface Parameters: For March 1988, the mean difference over oceans 60N - 60S between the CAC sea surface temperatures and TOVS-derived sea surface temperatures is -0.12 degrees C (TOVS colder) with a standard deviation of 0.7 degrees C. For the interannual difference July 1988 - July 1987, the patterns agree closely, but the amplitude of the local interannual difference patterns is considerably larger in the CAC analysis. The land surface skin temperature cannot be validated directly.

Total Ozone Index: Daily comparisons between TOMS and TOVS total ozone cannot be done directly because ozone features move rapidly in time and the TOMS data is taken at local noon, compared to 7:30 AM, PM on NOAA 10. Monthly mean comparisons for March 1988 show a global mean difference of 2 Dobson units, a standard deviation of 16 Dobson units, and a correlation of 0.9 when compared to the TOMS data used in the systematic error removal scheme. Unfortunately, all of 1988 was processed using results from an earlier version of the TOMS data than the current official TOMS product, though the correct version of TOMS data was used in processing 1987 TOVS data. For this reason, the TOVS total ozone index for 1988 was deleted from the TOVS benchmark period data set (fill values used at all gridpoints). The total ozone data is labeled as experimental pending further validation studies.

Cloud Parameters: The cloud parameters have not been validated directly but are an important element in the computation of OLR, and are validated indirectly by validation of OLR. Cloud parameters are labelled experimental for the TOVS Path A benchmark data because they have not been validated directly.

Longwave Radiation Parameters: For March 1988, the global mean difference of TOVS OLR and ERBE OLR was 1.8 W/m2 and the spatial standard deviation was 5 W/m2. This excellent agreement serves as a validation for all parameters which enter the OLR calculation, especially the cloud parameters and the surface skin temperature, which are the two most important parameters affecting OLR. The agreement also shows that the

TOVS parameters can be used to explain variations in space and time of OLR, which has been used as an important climate indicator. Interannual differences between July 1988 and July 1987 OLR shows a mean difference from ERBE of 0.5 W/m2, a standard deviation of 5.7 W/m2, and a spatial correlation of 0.92.

Precipitation Estimate: For March 1988, the mean rain gauge amount was 2.71 mm/day, with a spatial standard deviation of 3.50 mm/day. The mean TOVS precipitation estimate in colocated areas was low by .53 mm/day, and the standard deviation of the differences from rain gauges was 2.65 mm/day, with a spatial correlation of 0.67. The TOVS precipitation estimate were damped in amplitude compared to the rain guage, but spatial patterns are good. The differences between July 1988 and July 1987 showed good agreement with a bias of -.14 mm/day, standard deviation of 2.94 mm/day, and spatial correlation of 0.52. Again, the amplitude of interannual difference patterns was larger in the rain guages.

Measurement Error for Parameters and Variables:

Additional Quality Assessments:

All retrievals are objectively validated according to the agreement between observed (cloud corrected) brightness temperatures for the temperature sounding channels and those computed from the solution. Two measures are used in this validation: the difference (residual) between observed and computed brightness temperatures for MSU channel 2, and the root mean square difference (rms error) between observed and computed brightness temperatures for the remainder of the temperature sounding channels. If either value is greater than 1 degree, the retrieval is rejected and a fill value is written out for all parameters except those related to cloud properties, which are always computed and written out. If each difference is less than 1 degree, a quality flag indicator is then computed based on the sum of the two measures as follows:

QFLAG = (| residual | + | rms error |) * 2.

A quality flag value less than 1.0 indicates that the overall disagreement was rather small and the retrieval is assumed to be of very good quality. Quality flag values between 1.0 and 4.0 indicate an increasing difference between the observed and computed MSU channel 2 brightness temperatures and/or a higher RMS error for the remainder of the temperature sounding channels.

Data Verification by Data Center:

A checksum is used prior to data ingest to verify proper file transfer from the data producer to the archive center. Visual inspection of the level 3 data has been performed on a random basis using the IDL and Collage visualization packages to ensure proper HDF implementation and ready access to file contents.

12. Notes:

Limitations of the Data:

Temperatures: Coarse layer temperatures are better defined by the TOVS radiances than point temperatures and therefore the results should be less method dependent provided effects of clouds on the radiances and sources of systematic errors are handled appropriately. The coarse layer temperatures are best determined in the order starting from the lower troposphere, with quantitative accuracy decreasing with increasing height. Interannual differences of monthly mean surface to 500 mb layer mean temperatures have high quantitative accuracy (better than 0.1 degree C) compared to radiosonde reports and spatial correlations greater than 0.95. They are therefore useful for global and regional trend studies as well as climate variability studies, such as spatial and temporal correlations between interannual differences of lower tropospheric temperature with those of other layer mean temperatures, surface skin temperature, water vapor distribution, clouds, and precipitation. Other layer mean temperatures are potentially less precise. They are best used for interannual variability studies and should be used for precise trend studies with care. As in all other parameters, retrievals over polar regions are more difficult for a number of reasons and expected error bars are larger, perhaps by a factor of 2, than elsewhere.

Point temperatures are less quantitative and should not be used for detailed trend studies. They are potentially useful in climate variability studies and also provide the basic information going into the computation of the layer mean temperatures and OLR.

Surface skin temperatures have high precision over ocean but cannot be directly validated over land. They can potentially be used for trend studies. The most important use may be the relationship of interannual differences of surface skin temperature to that of atmospheric quantities, including the effects of El Nio on tropical and extra tropical circulation. We have also found very strong correlation between interannual differences of surface skin temperature with lower tropospheric temperature over extra-tropical land.

Water vapor parameters: Water vapor is difficult to measure quantitatively for a number of reasons, one of the major ones being there is no accurate data source to use to determine and remove systematic errors from the retrieved moisture parameters. Radiosonde colocations were used to remove systematic errors from retrieved water vapor. Radiosondes have poor sampling (most are in extratropical land) and have known moist bias in dry cases. In the methodology used to process the benchmark period, separate systematic error correction coefficients were derived for land and ocean cases. This was deemed to be consistent with different potential sources of error, such as unknown surface emissivity over land. In hindsight, this was an ill conceived idea because the bias correction errors were found to be substantially different in tropical land and ocean areas, giving apparent moisture discontinuities in the tropical fields. Nevertheless, comparisons of interannual differences of monthly mean layer integrated precipitable water with colocated radiosondes showed high spatial correlations of the order of 0.8 for total precipitable water and 0.6 for precipitable water above 500 mb. This means the data should be useful to study interannual variability. Of more significance was the finding that tropical upper tropospheric water vapor was highly correlated in space and time with tropical precipitation. Specific humidities at mandatory levels are even harder to measure quantitatively but are potentially useful in terms of interannual variability. They also are part of the information entering the OLR calculation and can be used to explain some of the variability of OLR.

Total ozone index: Total ozone is determined day and night by IR methods and as such is a useful addition to the NIMBUS 7 TOMS product, which is daytime only at local noon. TOVS ozone can be used to trace the rapid motion of fields of ozone throughout the course of the day and allow for further interpolation in time between the TOVS data (7:30 AM, PM; 2:30 AM, PM) and the TOMS data. TOVS also gives ozone fields in the polar night. It should be cautioned however that polar night values may have large errors due to decreased sensitivity of the TOVS measurements to ozone amount under conditions when the ground temperature differs only slightly from stratospheric temperatures. Under some conditions, the sensitivity of the measurement to total ozone is so low that no ozone retrieval is performed.

A wrong version of the TOMS product was used to remove ozone systematic errors for 1988 data. Because of this, as well as potentially noisy values at high latitudes, total ozone index was labeled experimental.

Cloud products: The main cloud products retrieved are cloud top pressure and effective cloud fraction, given by the product of the fractional cloud cover times the cloud emissivity at 11 mm. Because cloud emissivities are less than 1, especially for cirrus clouds, our global mean effective cloud fraction, which is of the order of 40%, is lower than other commonly quoted values closer to 50%.

The methodology of solution attempts to find a cloud fraction and cloud top pressure most consistent with the observations in five IR channels. There is often a modest range of cloud top pressures and corresponding cloud fractions (the higher the cloud top in altitude, the lower the cloud fraction) which give reasonable solutions to the radiative transfer equations. Therefore, cloud top pressures in individual cases may be uncertain up to 100 mb or more, but monthly mean pressures are probably better than 50 mb. The cloud parameters cannot be directly validated but form an important contribution to the calculations of OLR.

Clouds are most difficult to determine in polar cases with low thermal contrast between clouds and the surface. Under these conditions, the TOVS IR radiances do not depend appreciably on cloud parameters. Path A and Path B clouds were compared to each other and found to differ significantly from each other, especially over polar regions. For this reason, both sets of clouds were labeled as experimental pending further validation studies.

While individual cloud parameters should not be used for quantitative trend studies, they provide valuable quantitative information about interannual variability and response of cloud parameters to sea and land surface temperatures.

Precipitation estimate: Precipitation amounts can be estimated from the cloud parameters and relative humidities retrieved from the TOVS data. The method is based on empirical coefficients derived from colocations with monthly mean rain gauge measurements. While patterns are qualitatively good, the method will tend to underestimate heavy precipitation and potentially give light rain in some cases where no precipitation exists, or it does not reach the ground. The main use of this data should be to study interannual variability of precipitation and its relationship with variability of surface temperature, atmospheric temperature, and water vapor.

Outgoing longwave radiation: OLR is computed from the retrieved products using the radiative transfer equation. Agreement of monthly mean OLR with that derived from ERBE data is very good, with global mean differences of the order of 1 W/m2 and global standard deviations about 5 W/m2 on a 1 degree by 1 degree grid. This tends to validate all the TOVS products, including the cloud products. However, it should be remembered that a smaller (larger) amount of higher (lower) clouds could result in very similar values of OLR. This product is important for understanding interannual variability of OLR in terms of the variability of its key components: temperature, water vapor, and clouds. One important limitation of the data set is that it assumes a constant CO_2 mixing ratio of 350 ppm and therefore does not reflect possible small changes due to changes of CO_2 (about 3 ppm/year) over the time period.

Longwave cloud radiative forcing (LCRF) is another important indicator of climate variability. Like OLR, LCRF is a calculated quantity, based on the difference of OLR calculated using the retrieved clouds, and clear sky OLR calculated with otherwise the same profiles and ground temperature, but with no clouds present. It should be borne in mind that this is not the quantity determined by the ERBE science team, which determines clear sky OLR by observations under clear conditions. These conditions tend to have warmer temperatures, and possibly drier conditions, than those under cloudy conditions.

Known Problems with the Data:

Please refer to Limitations of the Data for a summary of the known problems.

Usage Guidance:

The products appear to be of sufficient accuracy to study interannual difference patterns and correlations in space and time between differences of surface and atmospheric quantities. Coarse layer temperatures and OLR are of high quantitative accuracy and may be useful for quantitative trend studies as well. The detailed temperature, moisture, and cloud distribution also provide information about the detailed factors entering the coarse layer temperatures and the OLR. See Limitations of the Data for more detailed information on dataset usage.

Any other Relevant Information about the Study:

For long term measurement of trends, or even climate variability studies, it is important to be able to analyze data from different satellites without having appreciable intersatellite biases. There are two potential problems involved: different instrumentation and different time of day. It is expected that the Path A methodology of systematic error correction for temperature, moisture, and ozone will be accurate enough to account for intersatellite instrumentation differences. Differences in time of day are not accounted for directly. It is up to the user to account for time sampling differences in their interpretation of the data.

Data beyond the TOVS benchmark period has been analyzed, comprised of NOAA 10 data (7:30 AM, PM) for December 1986 - December 1988 and NOAA 9 data (2:30 AM, PM) for January 1986 - December 1986. December 1986 is the only month where good TOVS data from both NOAA 9 and NOAA 10 exists. Validation studies of interannual differences between 1987 and 1986 (NOAA 10 and NOAA 9) show comparable accuracy to those between 1988 and 1987 (both NOAA 10). Of particular interest are comparisons of monthly mean values of parameters for December 1986 derived from NOAA 9 and NOAA 10. Comparison statistics are shown in the following table:

Parameter	Mean (NOAA9-NOAA10)	Standard Deviation 1 deg by 1 deg
* Global surface skin temperature (C)	.37	1.58
Sea surface temperature (C)	.07	0.47
* OLR (W/m2)	.04	5.23
Total Ozone (DU)	.15	9.13
Surf - 500 mb temp (C)	-.17	0.89
500 mb - 300 mb temp (C)	.07	0.86
300 mb - 100 mb temp (C)	.19	0.87
100 mb - 30 mb temp (C)	.06	0.82
Total precip water (cm)	.01	0.23
Precip water above 850 mb (cm)	-.01	0.17
Precip water above 700 mb (cm)	.00	0.09
Precip water above 500 mb (cm)	.00	0.03
* Precipitation estimate (mm/day)	.06	0.80
* Cloud fraction (%)	1.00	7.10
* Cloudtop pressure (mb)	3.50	72.00

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* Most sensitive to sampling difference in local time of day
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In interpretation of these comparisons, time of day sampling differences should be borne in mind. This primarily affects land surface skin temperatures and cloud parameters. In the results shown, the AM and PM values have been averaged together for each satellite. The results indicate that intersatellite differences are relatively small. An examination of the patterns shows the largest differences in atmospheric temperatures are generally at high latitudes, poleward of 60 degrees. This indicates the largest uncertainties exist in these area. Also noticeable are small intersatellite biases in water vapor fields which tend to be of opposite sign over land and ocean. This may result from use of different systematic error correction coefficients over land and ocean for each satellite, which in the case of NOAA 9 and 10 were of opposite relative magnitude. The last main difference in the fields was surface skin temperature, which was substantially warmer over land in NOAA 9 than NOAA 10. This is an expected result due to very warm land surface temperatures at 2:30 PM. Over ocean, most differences were less than 0.40 degrees C.

13. Application of the Dataset:

TOVS is the only long-term source of high resolution global information pertaining to the temperature and moisture structure of the atmosphere. Because similar HIRS/2 and 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 temperature, moisture, cloudiness, OLR, and precipitation, provided that quantitative results can be obtained which 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 full TOVS Pathfinder dataset, of which the NOAA-10 benchmark period is a subset, will be processed in a consistent manner and as such will be useful for all of the applications listed above.

14. Dataset Plans:

As of 2011, there are no plans to update this dataset.

15. References:

Satellite/Instrument/Data Processing Documentation:

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Archive/DBMS Usage documentation:

16. Related Software:

Software Description:

The **Path A and B** data currently supported by GES DISC are in HDF4 format, and are "externally" compressed. They need to first be "unzipped", before attempting to read the files with any HDF-compatible software package or tool. The utility "gzip" can do the unzipping. To open and read the uncompressed HDF file, various packages and tools can be used: IDL, MatLab, Fortran, HDFview, etc. (NASA does not endorse one commercial package over another.)

Command-line utilities from the HDF Group, like **ncdump** and **hdp**, can be used to quickly see the file content, and even dump out data in binary or text format. The HDF Group also provides a simple tool with java-based user interface; HDFView. Ii is very convenient to explore HDF files content, and produce simple graphic and image previews.

17. Data Access:

There are two basic ways to get TOVS Path-A and -B data from GES DISC: i) Anonymous FTP, and ii) Interactive search using Mirador.

- HTTP: Http://disc1.gsfc.nasa.gov/data/s4pa/tovs

  The directory tree on the FTP server have the patterns:

  TOVSA [D,5,M] [NT,NF,NG,NH,ND] Or
  TOVSB [D,5,M] [NG,ND]

  Where:
  A,B - Path-A,B
  [D,5,M] - stands for Daily, 5-day (pentad), and Monthly

  [NT,NF,NG,NH,ND] - which satellite, correspondingly: TIROS-N, NOAA-F,G,H,D

- Interactive, Mirador: **http://mirador.gsfc.nasa.gov**

Contacts for Archive/Data Access Information:

Name:

GES DISC Help Desk

Address:

Goddard Distributed Active Archive Center
Code 610.2
NASA/Goddard Space Flight Center
Greenbelt, Md. 20771

Telephone Numbers:

Phone: (301) 614-5224

Fax: (301) 614-5268

E-Mail Address: help-disc@listserv.gsfc.nasa.gov

Archive Identification:

Dataset = TOVS PATHFINDER

Dataproduct = GLA DAILY GRIDS (daily files)

Dataproduct = GLA 5 DAY GRIDS (5 day files)

Dataproduct = GLA MONTHLY GRIDS (monthly files)

Procedures for Obtaining Data:

Data can be obtained through the Mirador Search Tool.

Data Archive Status/Plans:

The data are no longer produced, but are archived at the GES DISC.

18. Output Products and Availability:

Tape Products:

Not Applicable

Film Products:

Not Applicable

Other Products:

Not Applicable