National Aeronautics and Space Administration
Goddard Earth Science Data Information and
Services Center (GES DISC)

README Document for TIROS Operational Vertical Sounder (TOVS) Pathfinder Path-A Dataset

Last Revised August 1, 2018

Goddard Earth Sciences Data and Information Services Center (GES DISC)
http://disc.gsfc.nasa.gov
NASA Goddard Space Flight Center
Code 610.2
Greenbelt, MD 20771 USA

Prepared By:

Lena Iredell	**Dana Ostrenga** **Andrey Savtchenko**
Name GES DISC GSFC Code 610.2	Name GES DISC GSFC Code 610.2

July 17, 2018

Date

Reviewed By:

Reviewer Name	Date
Reviewer Name GES DISC GSFC Code 610.2	Date

Goddard Space Flight Center

Greenbelt, Maryland

Revision History

Revision Date	***Changes***	***Author***

Table of Contents

Figures

Tables

1.0 Introduction

This document provides basic information for using TIROS Operational Vertical Sounder (TOVS) Pathfinder Path-A Dataset legacy Level-3 monthly product. The TIROS Operational Vertical Sounder (TOVS) Pathfinder Path-A Dataset consists of temperature, moisture, and clouds products generated from a consistently processed retrieval system using the NOAA polar orbiting satellites TIROS-N through NOAA-14. This legacy dataset contains the Level 3 geophysical parameters derived using the physical retrieval method of Susskind et al. (1984). The data Satellite Data Utilization Office of the Goddard Laboratory for Atmospheres at NASA/GSFC processed the retrievals. This method, which is hydrodynamic model and a priori data-dependent, was designated as the so-called Path-A scheme by the TOVS Pathfinder Science Working Group. The data are archived at the Goddard Earth Sciences Data and Information Services Center (GES DISC). The primary goal of Pathfinder was the production of consistently processed, long term datasets for use in global change studies. TOVS Pathfinder was one of several Pathfinder studies initiated by NOAA and NASA (the others being 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, however Level 3 monthly mean data products for this TOVS Pathfinder Path-A data set are available from November 1978 through December 2004.

The 20 channel High resolution Infrared Radiation Sounder-2 (HIRS/2) and the four channel Microwave Sounding Unit (MSU) aboard the NOAA series of Polar Orbiting Satellites were used to produce global fields of the 3-dimensional temperature-moisture structure of the atmosphere. In addition to profiles of temperature and moisture, the HIRS2/MSU data were used to derive surface skin temperature, sea surface temperature, outgoing longwave radiation, cloud fraction, cloud top height, and precipitation estimates.

There were four TOVS Pathfinder algorithms used to process the TOVS data.

Path-A is described in this documentation. Please see the TOVS User's Guide for a brief description of Path-B, Path-C1 and -C2, and Path-P.

1.1 Dataset/Mission Instrument Description

TOVS was one of the first long-term sources of high resolution global information pertaining to the temperature and moisture structure of the atmosphere. Because similar HIRS/2 and MSU instrumentation flew on operational satellites from late 1978 to 2004, data from these instruments can make an important contribution to the 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, clouds, radiation, and precipitation, provided satellite drifts and cross-calibration of different satellites are taken into account. The full TOVS Pathfinder dataset was processed in a consistent manner and as such can potentially be useful for all of the applications listed above.

For specific description about each of the satellite's instrumentation and other information, see the NOAA Polar Orbiter Data User's Guide and the TOVS Pathfinder Path-A User's Guide.

1.1.1 The TOVS instruments

The TOVS system consists of 3 independent instruments, specifically:

- The 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 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 and reflected solar radiation in two 4.7 micron window channels

- The Microwave Sounding Unit (MSU)
  - atmospheric emission in three 56 GHz O_2 channels
  - surface emission in one 56 GHz window channel

1.1.2 Launch Dates and Orbits for Instruments used in the Path-A processing

Instrument	Launch Date	Path-A L3 processed dates	Orbit observing local time from launch through end of processing Reported in fractions of hours	Orbit
TIROS-N	October 13, 1978	December 1978- July 1979	3.00 to 3.28	470 nmi
NOAA-6	June 27, 1979	August 1979- March 1983	7.46 to 7.47	450 nmi
NOAA-7	June 23, 1981	August 1981- January 1985	2.46 to 4.03	470 nmi
NOAA-8	March 28, 1983	April 1983- May 1984	7:45 to 7.58	450 nmi
NOAA-9	December 12, 1984	January 1985 - December 1986	2.30 to 2.95	460 nmi
NOAA-10	September 17, 1986	January 1987- August 1991	7.50 to 7.05	450 nmi
NOAA-11	September 24, 1988	November 1988 - December 1994 (placed in standby then reactivated) August 1997 - December 1998	1.62 to 5.27 then after standby mode 7.80 to 9.00	470 nmi

Instrument	Launch Date	Path-A L3 processed dates	Orbit observing local time from launch through end of processing Reported in fractions of hours	Orbit
NOAA-12	May 14, 1991	June 1991 – November 1998	7.47 to 5.80	450 nmi
NOAA-14	December 20, 1994	February 1995 and April 1995 - December 2004	1.65 to 8.60	470 nmi

Table 1. Launch Dates for each TOVS instrument

1.2 Algorithm Background

The Path-A system steps through an interactive forecast-retrieval-analysis cycle. In each six hour synoptic period, a 4th order General Circulation Model (Kalnay et al, 1983) was used to generate the six hour forecast fields of temperature, humidity and geopotential thickness. These global fields are used as the first guess for all soundings occurring within a three hour time window centered upon the forecast time.

The satellite retrievals were then assimilated with all available insitu measurements (such as radiosonde and ship reports) in the six hour interval using a successive correction (SCM) analysis scheme (Baker, 1983). This analysis was then used to specify the initial conditions for the next six 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 multi-channel 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 Goddard Laboratory for Atmospheres (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, cloud top height and cloud amount are derived as described in detail in Susskind et. al. (1984).

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 six 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 six 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.

The algorithm’s steps are described in the following documents:
Baker, W.E., 1983, "Objective Analysis and Assimilation of Observational Data from FGGE", Mon. Wea. Rev., 111, 328-342. Kalnay, E.R., R. Balgovind, W. Chao, D. Edelmann, J. Pfaendtner, L. Takacs, and K. Takano, 1983, "Documentation of the GLAS Fourth Order GCM", NASA TM 86064.

Chahine, M. T., 1968, "Determination of the Temperature Profile in an Atmosphere from its Outgoing Radiances", J. Opt. Soc. Am., 58, 1634-1637.

Chahine, M. T. and J. Susskind, 1989: Fundamentals of the GLA physical retrieval method. Report on the Joint ECMWF/EUMETSAT Workshop on the Use of Satellite Data in Operational Weather Prediction: 1989-1993. Vol. 1, 271-300. T. Hollingsworth, Editor.

Kalnay, E., Balgovind, R, Chao, W., Edelmann, D, Pfaendtner, J., Takacs, L, and Takano, K., 1983, Documentation of the GLAS Fourth Order General Circulation Model, Volume 1: Model Documentation, NASA-TM-86064-Vol-1.

Kidwell, K., 2003, "NOAA Polar Orbiter Data User's Guide”, NCDC/SDSD, National Climate Data

Center, Washington, D.C.

Susskind, J., Piraino. P., Rockke, R., Iredell, L., and Mehta, A., 1997, Characteristics of the TOVS Pathfinder Path A Dataset, Bull. Amer. Meteor. Soc., 78, 1449–1472, https://doi.org/10.1175/1520-0477(1997)078<1449:COTTPP>2.0.CO;2

Susskind, J., J. Rosenfield, and D. Reuter, 1983: An accurate radiative transfer model for use in the direct physical inversion of HIRS2 and MSU temperature sounding data. J. Geophys. Res., 88, 8550-8568.

Takacs, L., A. Molod, and T. Wang, 1994, "Documentation of the Goddard Earth Observing System (GEOS) General Circulation Model Version 1", NASA Technical Memorandum 104606, April 1994.

1.3 Data Validation

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 collocated 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

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 to 1.0 deg	lt. 0.1 deg
Level Temperatures (excluding 10 mb)	1.0 to 2.0 deg	lt. 0.3 deg
Total Precipitable Water	20%	
Precipitable Water above levels	25 to 40%	
Specific Humidity	45 to 40%	
Sea Surface Temperature	0.5 deg	
Land Surface Temperature	2.0 deg	
Outgoing Longwave Radiation	5 W/m^2	1 W/m^2
Cloud Fraction	10%	
Cloud Top Pressure	50 mb	
Precipitation Estimate	3 mm/day	

Table 2. Monthly Mean Interannual Differences of Key Parameters

1.3.1 Confidence Level/Accuracy Judgment:

1.3.1.1 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.

1.3.1.2 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 degrees (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.

1.3.1.3 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 -0.07 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 Special Sensor Microwave Imager (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 collocated 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.

1.3.1.4 Surface Parameters

For March 1988, the mean difference over oceans 60N – 60S between the (Climate Analysis

Center (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.

1.3.1.5 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 labeled experimental for the TOVS Path A benchmark data because they have not been validated directly.

1.3.1.6 Longwave Radiation Parameters

For March 1988, the global mean difference of TOVS OLR and Earth Radiation Budget Experiment (ERBE) OLR was 1.8 W/m2 and the spatial standard deviation was 5 W/m^2. 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.

1.3.1.7 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 collocated 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 gauge, 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 gauges.

1.3.1.8 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.

1.4 Data Disclaimer

1.4.1 Acknowledgment

To acknowledge the data, please refer to Dr. Joel Susskind and the following paper:

J. Susskind, P. Piraino, L. Rockke, L. Iredell, and A. Mehta, Characteristics of the TOVS Pathfinder Path A Dataset, Bull. Amer. Meteor. Soc., 78, 1449–1472, https://doi.org/10.1175/1520-0477(1997)078<1449:COTTPP>2.0.CO;2

1.4.2 Contact Information

Data producer:	Dr. Joel Susskind Joel.Susskind@nasa.gov
For questions about data or products:	Lena Iredell Lena.Iredell@nasa.gov

1.4.3 Limitations of the Data

1.4.3.1 Coarse Layer 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.

1.4.3.2 Point Temperatures

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.

1.4.3.3 Surface Skin Temperature

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 Niño 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.

1.4.3.4 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 collocations were used to remove systematic errors from retrieved water vapor. Radiosondes have poor sampling (most are in extra-tropical 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 collocated 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.

1.4.3.5 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.

1.4.3.6 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 collocations 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.

1.4.3.7 Outgoing longwave radiation

OLR is computed from the retrieved products using the radiative transfer equation. Agreement of monthly mean OLR with that derived from Earth Radiation Balance Experiment (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 CO2 mixing ratio of 350 ppm and therefore does not reflect possible small changes due to changes of CO2 (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.

1.4.3.8 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 inter-satellite 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 inter-satellite 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:

Monthly Mean values for December 1986 NOAA 9 minus NOAA 10 (1 degree by 1 degree)		
Parameter	Mean	Standard Deviation
* Global Surface Skin Temperature (C)	0.37	1.58
Sea Surface Temp (C)	0.07	0.47
* OLR (W/m^2)	0.04	5.23
Surface to 500 mb layer mean temperature (C)	-0.17	0.89
500 mb to 300 mb layer mean temperature (C)	0.07	0.86
300 mb to 100 mb layer mean temperature (C)	0.19	0.87
100 mb to 30 mb layer mean temperature (C)	0.06	0.82
Total precipitable water (cm)	0.01	0.23
Precipitable water above 850 mb (cm)	-0.01	0.17
Precipitable water above 700 mb (cm)	0.00	0.09
Precipitable water above 500 mb (cm)	0.00	0.03
* Precipitation estimate (mm/day)	0.06	0.80
* Cloud Fraction (%)	1.00	7.10
* Cloud Top pressure (mb)	3.50	72.00
* Most sensitive to sampling difference in local time of day		

Table 3. Monthly mean Interannual Sample, December 1986 NOAA 9 minus NOAA 10 for key level 3 data fields

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 inter-satellite 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 inter satellite 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.

1.5 What's New?

The originally processed data was written in HDF2 format, the monthly mean Level 3 products are now rewritten into netCDF format. Additionally, after the processing of the TOVS data was complete, Dr. Joel Susskind developed methodology to account for the orbit drift of the satellites and to adjust the temperature and OLR to what they would have been if they were observed at 7:30 am. The methodology is described in the appendix of the following publication:

Pinheiro, A.C.T.; Descloitres, J.; Privette, J.L.; Susskind, J.; Iredell, L.; and Schmaltz, J. "Near-real time retrievals of land surface temperature within the MODIS Rapid Response System", Remote Sensing of Environment, Volume 106, issue 3, (2007) 326-336.
https://doi.org/10.1016/j.rse.2006.09.006

The data is found under the netCDF data group "Adjusted_to_730_am". By applying this procedure, the data producers attempted to alleviate many of the problems described in the previous section.

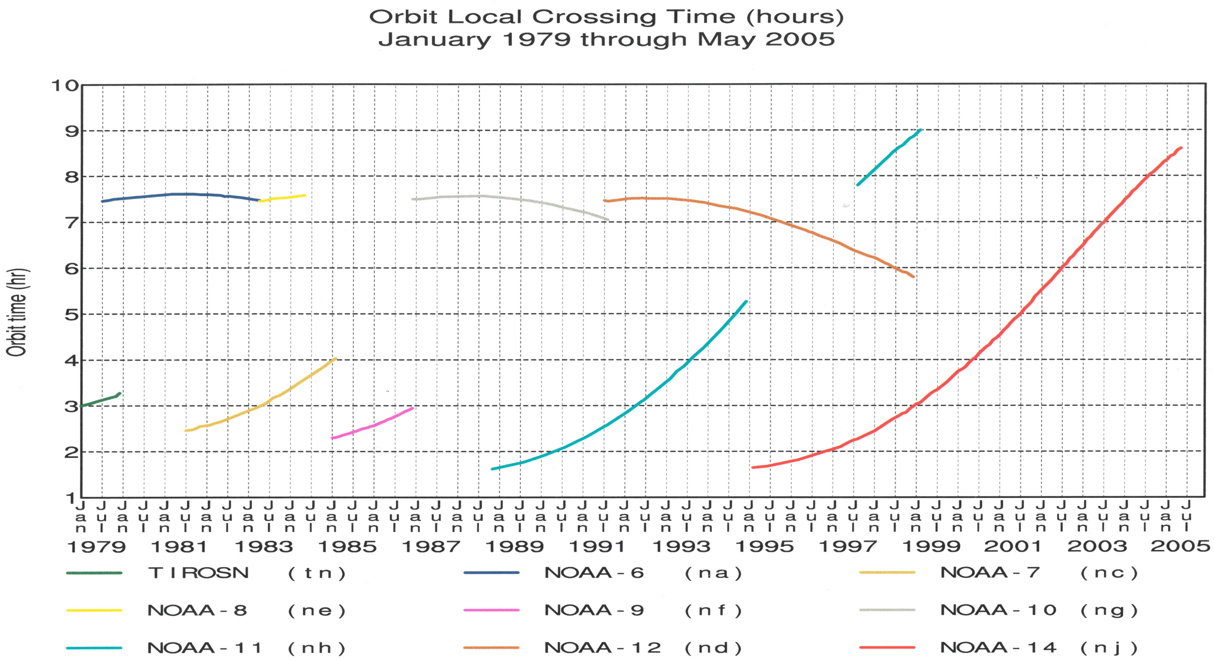

Figure 1 Local orbit crossing time for each of the satellites used in the TOVS Pathfinder Path-A data processing.

2.0 Data Organization

The data contains monthly mean Level 3 data products. The Level 2 data were quality controlled and gridded into a Level 3 product using a simple binning and averaging technique. Each Level 2 spot retrieval is assigned to a single gridbox according to which gridbox the spatial coordinates of the center of the nine Level 2 FOV falls within. For a gridbox with multiple observations, a simple unweighted average of all points within the box is used for determining mean values. No interpolation or data filling is used. For all means, a fill of -999.99 is used to indicate that data for that gridbox is either missing, invalid or suspect. For the count arrays, a corresponding fill value of 0 is used under these circumstances. The grid is 1 degree latitude by 1 degree longitude with the edges on the dateline. There are separate array dimensions for the descending (am) orbits and the ascending (pm) orbits. Included with the data variable are the counts of the number of observations contained within each grid box.

The Level 3 data products had quality flags applied to them at the time of gridding. All Level 2 retrievals were 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 were used in this validation: the absolute difference between observed and computed brightness temperatures for MSU channel 2 and the root mean square difference between observed and computed brightness temperatures for the remainder of the temperature sounding channels. If either value was greater than 1 degree, the retrieval was rejected and a fill value was written out for all parameters except those related to cloud properties, which were always computed and written out. If each difference was less than 1 degree, a quality flag indicator was then computed based on the sum of the two measures. This resultant value was grouped into one of four categories. A quality flag value of 0 indicates that the overall disagreement was rather small and the retrieval was assumed to be of very good quality. A quality flag value between 1 and 3 indicates either an increased difference between the observed and computed brightness temperatures and/or a higher RMS error.

2.1 File Naming Convention

TOVS Path-A monthly mean Level 3 data sets follows the following naming convention:

TOVS.PathA.L3.**instrument**.**instrument_id**.**retrieval_model_experiment**.**Mmm**.**yyyy**.V2.nc

Where:

- **instrument** is the satellite [NOAA6]
- **instrument_id** is the id given to satellite at launch [na]
- **retrieval_model_experiment** is the system used to process the data, it describes how many satellites worth of data were used as input to the model and analysis part of the system. However, each satellites data were retrieved independent of others. (The exception to this rule, is that at the end of the Path-A processing, all NOAA-14 (nj) data was processed using a retrieval_model_experiment named en11n14, even though only NOAA-14 was used as input to the model/analysis as NOAA-11 stopped in December 1998.) [en6n7]
- **Mmm** is the month of the data [Jan]
- **yyyy** is the year of the data [1982]

Filename example: TOVS.PathA.L3.NOAA6.na.en6n7.Jan.1982.V2.nc

2.2 File Format and Structure

All data is written in netCDF 4 format.

2.3 Key Science Data Fields

The key variables from this data set are 3-dimensional atmospheric temperature and moisture, surface, surface skin and surface air temperature; radiation budget parameters of outgoing longwave radiation, and cloud radiative forcing; and cloud properties of effective cloud fraction, cloud top pressure, cloud top temperature, and total precipitable water.

Key Science Data Fields	Variable Name
atmospheric temperature	AirTemp
moisture fields	PrecipWaterAboveSurf, PrecipWaterAboveLev, surface_specific_humidity, specific_humidity
surface skin temperature	SurfSkinTemp
surface air temperature	SurfAirTemp
radiation budget parameters	OLR, LongwaveCldRadForcing
cloud parameters	CldFrac, CldTopPres, CldTopTemp, CldFracLayer

Table 4. Key Science Data Field Variable Shortnames

3.0 Data Contents

3.1 Dimensions

Each variable is gridded on a 1 degree latitude (180) by 1 degree longitude (360), by the ascending or descending orbit (2). Fields such as atmospheric temperature, water, and cloud levels also have a height component. Table 2 describes these dimensions.

3.2 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)

3.3 Temporal Resolution

The level 3 gridded products are created separately for the AM or night (descending nodes on morning satellites) and PM or day (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 two 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.

3.4 Global Attributes

In addition to information containing variables and dimension sizes, global metadata is also stored in the files. Some metadata are required by standard conventions, some are present to meet data provenance requirements and others as a convenience to users of **TOVS Path-A Dataset** products. A summary of data dimensions present in all files is shown in Table 1.

Keyword	Value
comment	This data processed by the Sounder Research Team, led by Dr. Joel Susskind (NASA GSFC), for the NASA Pathfinder Project. The data was originally written in HDF2 format. This project rewrites the datasets into netCDF format. Each data field contains separate information for the descending (am) orbits and the ascending (pm) orbits.
keywords	ATMOSPHERE > ATMOSPHERIC TEMPERATURE > ATMOSPHERIC WATER VAPOR > WATER VAPOR , CLOUDS , LONGWAVE RADIATION, SURFACE TEMPERATURE
source	TOVS NOAA Polar Orbiting satellites, TIROS-N through NOAA-14, 1979 through 2004
processing_level	3
product_name_type_id	TOVS PATHFINDER Path-A
acknowledgment	Support for this research was provided by NASA.
instrument	TIROS-N, and NOAA-6 through NOAA-14, excluding NOAA-13
product_name_extension	nc
featureType	grid
data_structure	grid
summary	The Level-3 TOVS Pathfinder Path-A product includes atmospheric state retrieval products from the NASA SRT algorithm. These include surface skin temperature, surface air temperature, atmospheric temperature and water vapor profiles, clouds, and OLR products.
contributor_name	Joel Susskind, NASA GSFC
contributor_role	Retrieval PI
creator_name	NASA/GSFC GESDISC
history	Entire TOVS Path-A data processed includes 1979 through 2004
creator_email	Lena.Iredell@nasa.gov

Keyword	Value
creator_url	http://disc.gsfc.nasa.gov/
institution	NASA GSFC GES DISC
metadata_link	http://disc.sci.gsfc.nasa.gov/
references	Susskind, P. Piraino, L. Rockke, L. Iredell, and A. Mehta, Characteristics of the TOVS Pathfinder Path A Dataset, Bull. Amer. Meteor. Soc., 78, 1449–1472, https://doi.org/10.1175/1520-0477(1997)078<1449:COTTPP>2.0.CO;2

Table 5. Global attributes associated with each science data set.

3.5 Products/Parameters

3.5.1 Dimensions

Dimension	Size	Description
ntime	2	Indexes for the two orbits
time	1	Center of the month of observation, time in seconds since 1970-01-01 00:00:00Z
lat	180	Latitude starting at -89.5, by 1 degree increments
lon	360	Longitude starting at -179.5, by I degree increments
norbit	2	Approximate equatorial crossing time, 1 =pm, day, or ascending orbits, 2=am, night or descending orbits
temp_pres_level	12	Atmospheric temperature pressure levels
temp_pres_level_adj	10	Atmospheric temperature pressure levels for temperatures adjusted to observing time of 7:30 am
sphum_pres_level	5	Atmospheric pressure levels for specific humidity

Dimension	Size	Description
precwater_pres_level	4	Atmospheric pressure levels for precipitable water, above given level to top of atmosphere
cloud_frac_pres_level	5	Atmospheric pressure layers for 7 cloud fraction. The bottom level, stated as 1050, is actually the surface
Dimension	Size	Description
lmvt_pres_layer	10	Atmospheric pressure layers for virtual temp. The bottom level, stated as 1050, is actually the surface
lmt_pres_layer	4	Atmospheric pressure layers for four coarse temp layers

Table 6. Product/Parameter Dimensions

3.5.2 Key Metadata Variable Descriptions

Name	Type	Description
FillValue	float32	Floating-point value used to identify missing data. Will be set to -999.9 for data variables and to 0 for count fields.
long_name	string	Ad hoc description of the variable.
standard_name	string	Standard description of the variable as defined in CF conventions.
Units	string	The units of the variable.

Table 7 . Key metadata variable items

3.5.3 Level 3 Data Fields

3.5.3.1 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.

3.5.3.2 Water Vapor Profiles

Water vapor profiles are given in terms of specific humidity at five mandatory pressure levels. In addition, total precipitable water above the surface and above four 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.

3.5.3.3 Surface Parameters

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

3.5.3.4 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.

3.5.3.5 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.

3.5.3.6 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.

3.5.3.7 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 poorest 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.

3.5.3.8 Variables Shortnames, Dimensions, and Units

Data Field Name	Description	Extra Dimensions beyond time, orbit, latitude, and longitude	Units
SurfSkinTemp	Surface Skin Temperature		K
SurfSkinTemp_nobs	Number of observations for Surface Skin Temperature		count
SurfAirTemp	Surface Air Temperature, approximately equivalent to 2m temperature		K
SurfAirTemp_nobs	Number of observations for Surface Air Temperature		count
AirTemp	Atmospheric Temperature, surface upward to TOA	temp_pres_level	K
AirTemp_nobs	Number of observations for Atmospheric Temperature, surface upward to TOA	temp_pres_level	count
OLR	Outgoing Longwave Radiation		$Watt/m^2$
OLR_nobs	number of observations for Outgoing Longwave Radiation		count
LongwaveCldRadForcing	LongwaveCldRadForcing		$Watt/m^2$
LongwaveCldRadForcing_nobs	number of observations cloud radiative forcing		count
CldFrac	effective cloud fraction, 0 to 1		1
CldFrac_nobs	number of observations for effective cloud fraction		count
CldTopPres	Pressure at the top of the cloud		mbar
CldTopPres_nobs	number of observations for cloud top pressure		count

Data Field Name	Description	Extra Dimensions beyond time, orbit, latitude, and longitude	Units
CldTopTemp	temperature at the top of the cloud		K
CldTopTemp_nobs	number of observations for cloud top temperature		count
CldFracLayer	effective cloud fraction effective between seven ISCCP pressure layers percent, 180 mb down to surface	cloud_frac_pres_layer	1
CldFracLayer_nobs	number of observations cloud fraction effective between seven ISCCP pressure levels	cloud_frac_pres_layer	count
PrecipWaterAboveSurf	total column precipitable water		cm
PrecipWaterAboveSurf_nobs	number of observations total column precipitable water		count
PrecipWaterAboveLev	precipitable water above specific atmospheric pressure levels. Levels given in variable precwater_pres_level	precwater_pres_level	cm
PrecipWaterAboveLev_nobs	number of observations for precipitable water above pressure levels	precwater_pres_level	count
surface_specific_humidity	Specific Humidity at the Surface		g/kg
surface_specific_humidity_nobs	number of observations of specific humidity at 5 atmospheric pressure levels		count
specific_humidity	specific humidity at 5 atmospheric pressure levels	sphum_pres_level	g/kg
specific_humidity_nobs	number of observations of specific humidity at 5 atmospheric pressure levels	sphum_pres_level	count
surface_microwave_emissivity	microwave emissivity at the surface		frac
surface_microwave_emissivity_nobs	number of observations of microwave emissivity at the surface		count

Data Field Name	Description	Extra Dimensions beyond time, orbit, latitude, and longitude	Units
FracIceSnowCover	Fractional Ice and Snow Cover		1
FracIceSnowCover_nobs	number of observations for Fractional Ice and Snow Cover		count
IRZenithAngle	IR Zenith Angle		degrees
IRZenithAngle_nobs	number of observations for IR Zenith Angle		count
LayerMeanVirtualTemp	layer mean virtual temperature, lowest layer starts at the surface	lmvt_pres_layer	K
LayerMeanVirtualTemp_nobs	counter for layer mean virtual temperature, lowest layer starts at the surface	lmvt_pres_layer	count
LayerMeanTemperature	Layer Mean Temperature, surfto500mb, 500to300mb, 300to100mb, and 100to30mb	lmt_pres_layer	K
LayerMeanTemperature_nobs	number of observations for Layer Mean Temperature	lmt_pres_layer	count
MSU2Temp	MSU instrument channel 2 computed temperature		K
MSU2Temp_nobs	number of observations for MSU instrument channel 2 temperature		count
MSU3Temp	MSU instrument channel 3 computed temperature		K
MSU3Temp_nobs	number of observations for MSU instrument channel 3 temperature		count
MSU4Temp	MSU instrument channel 4 computed temperature		K
MSU4Temp_nobs	number of observations for MSU instrument channel 4 temperature		count
QualityInd	initial cut quality indicator 0, through 4 based on MSU2 residual, lower is better		0 to 4

Data Field Name	Description	Extra Dimensions beyond time, orbit, latitude, and longitude	Units
QualityInd_nobs	number of observations for initial cut quality indicator		count
IR_Precip	estimated IR precipitation		mm/day
IR_Precip_nobs	number of observations for Estimated IR Precipitation		count
RawIR_Precip	Raw IR precip estimator, used as input to compute IR_Precip variable		mm/day
RawIR_Precip_nobs	number of observations of Raw IR precip estimator		count
MSU2Residual	MSU instrument channel 2 residual field obs minus calc BT		K
MSU2Residual_nobs	number of observations of MSU instrument channel 2 residual field obs minus calc BT		count
RMSError	general RMS error indicator		1
RMSError_nobs	number of observations for general RMS error indicator		count
SSTAnom	SST Anomaly difference from Reynolds Climatology		K
SSTAnom_nobs	number of observations for SST Anomaly		count
UTime	Universal Time at Nadir Greenwich time		hr
UTime_nobs	number of observations for local universal time satellite nadir Greenwich time		count
EqCrossTime	am and pm orbits of Equatorial crossing time, upper and lower bounds of local time		hr
time_bnds	times of starting and ending data in month, in seconds since 1970-01-01 00:00:00Z		seconds since 1970-01-01 00:00:00Z

Table 8. Variables shortnames, dimensions, and units

3.5.4 Level 3 “forecast” Data Fields – Forecast Group

This set of data contains information from the Model/Analysis system products. They were used as the first guess input to the retrieval system.

Data Group Field Name	Description	Extra Dimensions beyond latitude, longitude, and orbit	Units
surface_air_pressure	surface_air_pressure		mbar
surface_air_pressure_nobs	number of observations for model forecast surface pressure		count
FGPrecipWaterAboveSurf	model first guess total column precipitable water		cm
FGPrecipWaterAboveSurf_nobs	number of observations for model first guess total column precipitable water		count
FGPrecipWaterAboveLev	model first guess precipitable water above atmospheric pressure levels	precwater_pres_level	cm
FGPrecipWaterAboveLev	number of observations of model first guess precipitable water above atmospheric pressure levels	precwater_pres_level	count

Table 9. TOVS model/analysis derived first guess variable list

3.5.5 Level 3 “Adjusted_to_730_am” Data Fields – Variables adjusted to 7:30 am local time

This set of data contains variables which were adjusted to 7:30 am local time, as if they had been observed at that time. This was done in to achieve data fields, such as temperature, where consistency in daily observing time is important. As these NOAA polar orbiting satellites tend to drift in time from the orbit they were launched in, this provides a method to compare products across the entire TOVS Path-A timeseries. See Figure 1 for a graphic of the observed local times for each satellite in the TOVS series.

Data Group Field Name	Description	Extra Dimensions beyond latitude, longitude, and orbit	Units
adjSurfSkinTemp	surface skin temperature adjusted to 7:30 AM due to satellite orbit drift		K
adjSurfSkinTemp_nobs	number of observations of surface skin temperature adjusted to 7:30 AM		count
adjSurfAirTemp	surface air temperature adjusted to 7:30 AM due to satellite orbit drift		K
adjSurfAirTemp_nobs	surface air temperature adjusted to 7:30 AM due to satellite orbit drift		count
adjAirTemp	atmospheric temperature adjusted to 730 am due to satellite orbit drift	temp_pres_level_adj	K
adjAirTemp_nobs	number of observations for atmospheric temperature adjusted to 730 am due to satellite orbit drift	temp_pres_level_adj	count
adjOLR	Outgoing Longwave Radiation adjusted to 730 AM due to satellite orbit drift		W/m^2
adjOLR_nobs	number of observations of Outgoing Longwave Radiation adjusted to 730 AM due to satellite orbit drift		count

Table 10. TOVS variable list of fields adjusted to a 7:30 am observing time.

4.0 Options for Reading the Data

4.1 Tools/Programs

ncdump

The ncdump tool can be used as a simple browser for HDF data files, to display the dimension names and sizes; variable names, types, and shapes; attribute names and values; and optionally, the values of data for all variables or selected variables in a netCDF file. The most common use of ncdump is with the –h option, in which only the header information is displayed.

ncdump [-c|-h] [-v ...] [[-b|-f] [c|f]] [-l len] [-n name] [-d n[,n]] filename

Options/Arguments:

[-c] Coordinate variable data and header information

[-h] Header information only, no data

[-v var1[,...]] Data for variable(s) <var1>,... only data

[-f [c|f]] Full annotations for C or Fortran indices in data

[-l len] Line length maximum in data section (default 80)

[-n name] Name for netCDF (default derived from file name)

[-d n[,n]] Approximate floating-point values with less precision filename File name of input netCDF file

Note: the ncdump tool will only display variables whose ranks are great than 1. In other words, you will not see one dimensional vectors such as *time* using this tool. The ncdump program can be found in bin directory of the HDF installation area. Consult your local computer system administrator for the specifics.

Panoply

NASA GIS provides the tool, Panoply, **https://disc.gsfc.nasa.gov/information/howto/5761bc6a5ad5a18811681bfc** which will read and plot netCDF files. For the TOVS data choose "lon" for the x-axis and "lat" for the y-axis.

A list of software able to read data files can be found at: https://hdfeos.org/zoo/index_openGESDISC_Examples.php

5.0 Data Services

If you need assistance or wish to report a problem:

Email: gsfc-help-disc@lists.nasa.gov

Voice: 301-614-5224

Fax: 301-614-5268

Address:

Goddard Earth Sciences Data and Information Services Center NASA Goddard Space Flight Center Code 610.2 Greenbelt, MD 20771 USA

6.0 More Information

The NASA follow on mission to the TOVS series of instruments is the AIRS/AMSU (Atmospheric Infrared Sounder/Advanced Microwave Sounding Unit) instrumentation. For more information about this project see https://airs.jpl.nasa.gov/index.html and for access to the data. https://disc.gsfc.nasa.gov/datasets?keywords=AIRS&page=1

7.0 Acknowledgments

The original processing of the TOVS Pathfinder Path-A products and the reformatting into netCDF4 were both provided by NASA.

References

Adler, R.F., G.J. Huffman, A. Chang, R. Ferraro, P. Xie, J. Janowiak, B. Rudolf, U. Schneider, S. Curtis, D. Bolvin, A. Gruber, J. Susskind, P. Arkin, and E. Nelkin, 2003: The Version-2 Global Precipitation Climatology Project (GPCP) Monthly Precipitation Analysis (1979-Present), *J. Hydrometeor.*, **4**, 1147–1167, https://doi.org/10.1175/1525-7541(2003)004<1147:TVGPCP>2.0.CO;2

Anyamba, E., Susskind, J., 1998, A Comparison of TOVS Ocean Skin and Surface Air Temperatures with other data sets, JGR Vol. 103, No. C5,pp 10,389-10,511. May 15, 1998, https://doi.org/10.1029/97JC03417

Anyamba, E., E. Williams, J. Susskind, A. Fraser-Smith, and M. Fullekrug, 2000: The Manifestation of the Madden-Jullian Oscillation in Global Deep Convection and in the Schumann Resonance intensity, *J. Atmos. Sci.*, **57**, 1029–1044, https://doi.org/10.1175/1520-0469(2000)057<1029:TMOTMJ>2.0.CO;2

Bony, S., K. Lau, and Y.C. Sud, 1997: Sea Surface Temperature and Large-Scale Circulation Influences on Tropical Greenhouse Effect and Cloud Radiative Forcing, *J. Climate*, **10**, 2055–2077, https://doi.org/10.1175/1520-0442(1997)010<2055:SSTALS>2.0.CO;2

Kidwell, K., 2003, "NOAA Polar Orbiter Data User's Guide", NCDC/SDSD, National Climate Data Center, Washington, D.C.

Baker, W.E., 1983, "Objective Analysis and Assimilation of Observational Data from FGGE", Mon. Wea. Rev., 111, 328-342. https://doi.org/10.1175/1520-0493(1983)111<0328:OAAAOO>2.0.CO;2

Chahine, M. T., 1968, "Determination of the Temperature Profile in an Atmosphere from its Outgoing Radiances", J. Opt. Soc. Am., 58, 1634-1637. https://doi.org/10.1364/JOSA.58.001634

Huffman, G.J., R.F. Adler, M.M. Morrissey, D.T. Bolvin, S. Curtis, R. Joyce, B. McGavock, and J.

Susskind, 2001: Global Precipitation at One-Degree Daily Resolution from Mutisatellite Observations, J. *Hydrometeor.*, **2**, 36–50, https://doi.org/10.1175/1525-7541(2001)002<0036:GPAODD>2.0.CO;2

Kalnay, E.R., R. Balgovind, W. Chao, D. Edelmann, J. Pfaendtner, L. Takacs, and K. Takano, 1983, "Documentation of the GLAS Fourth Order GCM", NASA TM 86064.

Lakshmi, V., Susskind, J., Choudhury, C, 1998, Determination of land surface skin temperatures and surface air temperature and humidity from TOVS HIRS2/MSU data, Advances in Space Research Vol 22, Issue 5, pp 629-636, https://doi.org/10.1016/S0273-1177(97)01123-X

Lakshmi, V., Susskind, J., 2000, Comparison of TOVS-derived land surface variables with ground observations, JGR, Vol 105, No D2, pp 2179-2190, January 27, 2000, https://doi.org/10.1029/1999JD900921

Mehta, A., Susskind, J. 1999, Outgoing Longwave Radiation from the TOVS Pathfinder Path A data set, JGR, Vol 104, No. D10, pp 12,193-12,212, May 27, 1999, https://doi.org/10.1029/1999JD900059

Mehta, A., Susskind, J. 1999, Longwave Radiative Flux Calculations on the TOVS Pathfinder Path A data Set, NASA Technical Report #19990110694

Myers, D.S. and D.E. Waliser, 2003: Three-Dimensional Water Vapor and Cloud Variations Associated with the Madden-Julian Oscillation during Northern Hemisphere Winter, *J. Climate*, **16**, 929–950, https://doi.org/10.1175/1520-0442(2003)016<0929:TDWVAC>2.0.CO;2

Pinheiro, A.C.T.; Descloitres, J.; Privette, J.L.; Susskind, J.; Iredell, L.; and Schmaltz, J. “Near-real time retrievals of land surface temperature within the MODIS Rapid Response System”, Remote Sensing of Environment, Volume 106, issue 3, (2007) 326-336. https://doi.org/10.1016/j.rse.2006.09.006

Susskind, J., J. Rosenfield, D. Reuter, and M. T. Chahine, 1984, "Remote Sensing of Weather and Climate Parameters from HIRS2/MSU on TIROS-N," JGR, 89D, 4677-4697, https://doi.org/10.1029/JD089iD03p04677

Susskind, J., P. Piraino, L. Rockke, L. Iredell, and A. Mehta, 1997, Characteristics of the TOVS Pathfinder Path A Dataset,   Bull. Amer. Meteor. Soc., 78, 1449–1472, https://doi.org/10.1175/1520-0477(1997)078<1449:COTTPP>2.0.CO;2

Weare, B.C., 1997: Comparison of NCEP-NCAR Cloud Radiative Forcing Reanalyses with Observations, *J. Climate*, **10**, 2200–2209, https://doi.org/10.1175/1520-0442(1997)010<2200:CONNCR>2.0.CO;2