The 21-year Clear-sky HIRS Radiance Pathfinder Data Set

By

Darren L. Jackson[1] and John J. Bates[2]

[1]Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder, Colorado

[2]NOAA Environmental Technology Laboratory, Boulder, Colorado

Abstract

1. Introduction

Debates of rapid global climate change have heightened our need to better understand the earth's climate. Reliance on sophisticated global climate models to understand the key components that regulate climate change require accurate observations as a backbone for validation and initialization. The TOVS sounding instruments on the NOAA polar orbiting satellites provide a continuous global set of temperature and moisture soundings of the troposphere and stratosphere since October 1978. This unique data set, whose original purpose was to provide data for operational forecasts, now spans a period worthy for considering climate change problems.

Traditional methods for computing tropospheric temperature and moisture profiles from the TOVS data involve inverting the radiative transfer equation. Susskind et al. (1997) and Scott et al. (1999) are TOVS Pathfinder efforts that provide multi-year retrievals of water vapor and temperature from the TOVS

instrument. However, inversion methods can be problematic for climate analysis since constraints placed on retrievals can often times introduce additional systematic bias in the retrieval step (ref?). Attempts to assimilate temperature and moisture retrievals in numerical weather prediction (NWP) models have only slightly improved the forecast skill (ref?). More recent efforts to assimilate TOVS radiance data directly into NWP models have shown improved forecast skill (McNally and Verperini, 1996; Derber and Wu, 1998). Such studies highlight the need for radiance data free of bias from instrument degradation, changes in filter response functions, changes in channel central frequency, orbit height changes and drift in time, and changes in cloud detection and limb correction algorithms. This paper will focus primarily on the later two effects.

Limb correction methods fall into two basic categories: statistically and physically based techniques. Statistical techniques such as Wark (1993) require gathering limb bias statistics from the observed data set. Physical techniques develop regression coefficients from model simulation of limb observations. Recent development of a blended physical-statistical approach (Goldberg et al., 2001) indicates good results for limb correction AMSU-A observations.

Cloud detection using TOVS typically utilize a battery of tests to account for different atmospheric, surface and daylight conditions. Some of the empirical tests include frozen sea test, an albedo test, window channel test, interchannel regression test, surface temperature test, adjacent spot test and maximum

temperature test. These tests are utilized in the improved initialization inversion (3I) algorithm (Stubenrauch et al., 1996) and the NESDIS operational algorithm (Ferguson and Reale, 2000).

A more simplified approach is adopted for this study. The ISCCP approach of Rossow and Gardner (1993) highlights the basic philosophy used to detect clouds for this study. While ISCCP seeks identify cloud type from satellite observations, this study uses a conservative approach to simply identify clear-sky regions. Results identified as mixed cloud or undecided are rejected here and visible observations are essentially not used in our approach.

Section 2 gives a description of the data set, section 3 outlines the quality control measures used in processing the data. Section 4 describes the limb correction method needed for the cloud detection algorithm and section 5 gives the cloud detection scheme. Section 6 gives details on the resulting processed data sets.

2. Data

The TOVS Pathfinder data set spans a time period of over 20 years beginning in October of 1978 and continues to the present day. Observations during this time period were taken from 10 different NOAA satellites. TOVS consists of three instruments used primarily to sound the troposphere and stratosphere for temperature and water vapor. The High resolution Infrared Radiation Sounder

(HIRS) consists of 19 infrared and 1 visible channel used to sound both temperature and water vapor and obtain concentrations of total ozone. The Microwave Sounding Unit (MSU) has 4 microwave channels used to obtain temperature soundings of the troposphere and lower stratosphere. The Stratospheric Sounding Unit (SSU) has 3 infrared channels used for temperature soundings of the upper stratosphere. The focus of the current study is centered on the HIRS data; however, analogous work with MSU is forthcoming.

Raw counts were converted to brightness temperature for the HIRS 1b data using the ITPP code. Calibration coefficients from the 1b data were applied to the raw counts in a manner consistent with the NOAA Polar Orbiter User's Guide. Very little modification was made to ITPP with exception to small changes in quality control that allowed for fewer rejected observations. Brightness temperature data then were processed in the quality control, limb correction, and cloud detection algorithms to arrive at the final clear-sky data set in its original resolution.

Figure 1 gives time series of the total number all-sky and clear-sky observations per month for the all satellites from 1978 to 2000. Typically, one satellite collects $7x10^5$ observations per day. Three periods are shown to have only one satellite with the longest period occurring from mid 1984 until 1987. This period used only afternoon satellites since the HIRS instrument failed prematurely on NOAA-8. Starting with NOAA-10 in late 1986, there has been continuous coverage from

both morning and afternoon satellites. Sharp spikes coincide with transitions for either morning or afternoon satellites. The one-year period of three satellites in 1997-98 results from reactivating NOAA-11 in July 1997 since problems with the NOAA-12 HIRS filter wheel degraded the HIRS observations from this instrument. The number of clear-sky observations is approximately an order of magnitude less than the total number of all-sky observations. Other features of the clear-sky observation time series coincide with those in the all-sky time series.

Figure 1 gives the appearance of continuous data since the data have been averaged with a 30-day running mean; however, breaks do occur in time series that exceed one day. Table 1 lists the calendar days for each year where no data exists from both the all-sky 1B data and the resulting clear-sky data. The cloud detection scheme causes the one extra day of missing data on either side of missing all-sky data. More missing all-sky data occurs earlier in the time period since there were a few periods with coverage from only one satellite.

3. Quality control

Quality control performed here removed spurious errors often found in many of the satellite data fields. These errors can manifest themselves as physically unreasonable brightness temperatures, incorrect time stamps, or erroneous calibration and geolocation. While the 1B data have already undergone a level of

quality control, inevitably erroneous data slips through. The following discussion highlights our quality control measures.

Several measures of quality control are applied within the ITPP processing code. A test is conducted to see if the satellite altitude lies within the nominal range of 760 and 920 km. If it lies outside this range, the altitude is specified either the nominal value or the last good value. Radiances are tested to lie inside of a nominal range for each channel. Radiance observations outside this range are assigned missing values. Scan quality flags are used to remove data with fatal and sync errors. Channel 1 is subjected to a simple QC test where it must be within 5K of average between channel 2 and 17. This test is applied to all satellites except NOAA-11 due to the change in central frequency of channel 17 for that satellite.

Additional quality controls were needed to improve the integrity of the data. Longitude and latitude values were tested for valid ranges. Problems in navigation resulted in some orbits mislocating the pixel data into valid longitude and latitude ranges. These orbits would result in thousands of the FOVs being assigned to the same location. Removal of these observations was performed by testing the number of FOVs in each 0.5 degree grid box constructed for the cloud detection. Other tests include testing for invalid time stamps and scan angles.

4. Limb effects

The limb effect results from lengthened atmospheric paths from cross-track observing geometry of the HIRS instrument. Limb effects act to darken or brighten an observation when compared to the nadir view. A limb correction adjusts all limb observations to the nadir FOV. Limb adjustments were necessary for channel 8 for the purposes of cloud detection since this channel is affected by water vapor particularly in the Tropics. The final clear-sky Tb data were saved without limb correction; however, the method presented here can be used to convert all HIRS observations to their limb corrected value.

4.1 Regression methodology

A multi-variable regression was developed for limb corrections for each of the 19 HIRS infrared channels. Coefficients for the regression were computed using a radiative transfer model that simulates HIRS clear-sky brightness temperatures. The model simulated brightness temperatures were computed for all channels, satellites and six selected view angles using a set of 1614 tropical and midlatitude profiles from the TIGR-3 profiles. Polar observations were not considered here. The regression equation developed from the simulate set is

$$T_n = A_0(\phi) + \sum_{m=1}^{M} A_m(\phi) T_m(\phi) \qquad (1)$$

Where φ is the view angle, T_n is the limb corrected brightness temperature for channel n, A_0 and A_m represent the regression coefficients and T_m are the predictor brightness temperature channels. Both A_M and T_m are also functions of satellite and channel. Five limb angles were selected using cosine ϕ of 0.9 to 0.5 (view angles from 26 to 60 degrees from nadir). Limb correction for each view angle is interpolated from these regression results. Coefficients are also categorized by day and night since near-IR channels of 13-19 are affected visible radiation. Thus the near-IR channels are not used for limb correction for daytime observations. The slope of the regression error determines the total number of channel predictors (N-1). This stopping rule eliminates over fitting the regression. The threshold slope used here is 0.01. A forward selection process was utilized to determine the channel predictors.

Results of the regression for channel 8 are given in figure 2 for two satellites. While channel 8 has a relatively small limb effect, it was chosen here since limb correction is applied prior to cloud detection. The regression errors are shown for each of the five angles for regression with all the HIRS IR channels and with only HIRS channels 1 to 12. The regression error reduces as we increase the number predictors and decrease the angle of view. The error reduction is substantially better for observations that can use channel 19 since channel 19 is a surface channel unaffected by water vapor. More predictors are needed for larger view angles due to an increasing limb effect. Simulations using only HIRS channels 1-12 have higher overall regression error since none of these channels

have a clear surface signal. Interestingly, the predictors for NOAA-14 are much different than NOAA-10 for the HIRS 1-12 case due to changes made to channel 10. The central frequency for channel 10 was changed from 1225 cm^{-1} to 797 cm^{-1} for NOAA-11 and NOAA-14. The new lower central wavenumber resides in more transparent spectral region giving more surface information thus improving the channel 8 regression error for these two satellites. In fact, all of the water vapor channels are used for NOAA-14 in the limb correction starting from the lower tropospheric channel while the NOAA-10 case tends to use the lower tropospheric temperature channels and the ozone channel. All other HIRS channels were limb corrected in a similar manner. Results of the limb correction will be presented in section 4.2

Limb corrections made for the near-IR channels are not as reliable for daytime observations. Visible radiation enhances the brightness temperatures and is dependent on solar geometry. Solar radiation was not accounted for in the simulated brightness temperatures. Therefore, all limb corrections for the near-IR channels during the day are subject to significant error.

4.2 Limb correction assessment

Validation of the limb correction was performed using the clear-sky data set. Comparisons presented for this section are for night observations since the 4.3-micron channels are not corrected for day observations. Figure 3 presents the

observed limb effect for 738,119 HIRS observations taken from NOAA-12 from January 1-10, 1993. The cloud detection method caused the distribution of clear-sky data to populate more bins near nadir. For this case, scan position 27 contains ~15,000 observations whereas position 1 contains 7630 points. Any asymmetry in the limb effect has been removed here. Stratospheric channels 1, 2 and 17 show limb brightening due to retrieval of temperature in the inverted temperature profiles of the middle stratosphere. Channel 3 show minimal limb effects since its observations reside in the tropopause. Tropospheric temperature channels 4 to 7 and 13 to 16 show limb darkening from 5 to 10 K. Limb darkening of this magnitude also occurs for channel 9 while the water vapor and surface channels see limb darkening of near 4 K. Figure 4 presents the limb correction applied to the observed data in figure 3. Temperature channels 1-7 are corrected within 1 K with exception to channels 5 and 7. Water vapor 11 and 12 channels appear overcorrected by 1 K whereas the ozone and surface channels still show darkening at the limb after correction. Surface channels are not expected to approach zero at the limb since variations in surface types could produce scan position dependencies.

So is this correction representative of all satellites? Table 8 gives the limb effect for each satellite for January 1-10 selected years. Most temperature and water vapor channels have limb effect differences within 1 K. Surface channels give the largest discrepancy between satellites. Instrument changes, discussed previously, can be seen for channel 17 where the limb effect goes from positive

to negative for N11 and N14. N09 shows significantly different limb effects in the surface channels and channel 16. The surface channels do not show the limb darkening like the other satellites and channel 16 gives a much larger limb effect. Table 9 gives the limb effect for the limb-corrected data. Most channels have the small bias that is independent of satellite. A larger bias of –2 K for channel 5 indicates radiative transfer error in simulating HIRS brightness temperatures for this channel. Garand et al. (2001) indicate MODTRAN underestimates the HIRS brightness temperatures by this amount. Surface channels generally warm the observed limb effect by 1-2 K, but still leave about 2-4 K cooling at the limb (WHY?).

Asymmetries in the limb effect can arise across a scan line for a number of reasons. One scan line can span several hours in local time causing a diurnal signal to impart an asymmetric limb effect. Surface channels can be affected by changes in surface type. Orbital geometry may result in day/night crossover for some scan lines that could affect channels sensitive to solar radiation. Figure 5 presents differences in brightness temperature for the 10-day periods shown in figure 3. Generally the 15-micron channels show the least amount of bias with bias generally less than 1 K. However, a periodicity is evident for several satellites of the stratospheric channels 1 and 2. This response is likely caused by electronic noise introduced from the SSU instrument. The amplitude of this signal tends to decrease with more recent satellites. Upper water vapor channels 11 and 12 tend to have biases that related to each other and our

satellite dependent and the 4.3-micron temperature channels have larger differences between channels per satellite than the 15-micron channels. The surface channels show significant differences between satellites with TIROS-N, N10, N11, and N14 showing negative differences and the other satellites showing positive differences. These differences represent sampling differences in surface emission over land. Asymmetries for the surface channels are significantly larger for observations over land (Figure 6) and explain most the differences seen between satellites. Daytime observations over land cause even larger asymmetries and these asymmetries relate directly to local time of the satellite observations as is demonstrated for the daytime/land observations shown in Figure 6d. Asymmetries show little dependence on day/night or surface type for channels unaffected by the surface.

5. Cloud detection

Cloud detection was achieved using a modified method developed by Rossow and Garder (1993). Their method utilizes spatial and temporal variations in the radiance field as a means for cloud detection. The modified-ISCCP approach utilizes variations in the radiance from the surface-observing channel 8 as means to detect clouds. Variations exceeding predetermined thresholds are seen as observations contaminated by clouds.

5.1 Methodology

All limb-corrected Tb8 observations for a three-day period are binned spatially onto a 0.5 degree grid and sorted temporally into four 6-hourly periods so to minimize diurnal bias. Statistics for each grid box include the maximum, the sum and number of Tb8 observations. This daily grid is then used for the spatial and temporal contrast test and used to construct long-term (15 and 30-day) statistics of the Tb8 data.

Three tests are applied to insure cloud-free observations. The spatial and temporal contrast tests are applied; these tests determine cloudy, clear, mixed or undecided outcomes for each FOV and then a logic table combines the results for both tests to determine clear conditions. A third test is applied to these clear-sky observations to remove observations residing in regions of persistent cloudiness. Long-term composite fields are utilized to remove these observations

The first test applied to each FOV is the spatial contrast test. Comparing the radiance with the maximum radiance in the surrounding region tests variations about a region surrounding each pixel. The size of this region is determined by surface type. Table 2 gives the size of each region and the thresholds for the contrast tests. Land contrast test uses smaller regions since natural surface variations are larger over land. The two possible outcomes presented in Table 3

are cloudy and undecided. Coastal regions are excluded from this test and are assigned as undecided.

The second test compares the FOV to the corresponding grid statistics on the previous and following day. Various cloud situations are determined by the threshold tests indicated in Table 3. Four possible outcomes are given in Table 4 when combining yesterday and tomorrows' tests.
These outcomes are combined with the spatial results in Table 5 to give the final cloud assessment. Only observations tagged as clear are saved.

The final cloud detection compares clear observations to clear-sky composite grids spanning longer time periods. This step is necessary in removing observations in regions of persistent cloudiness missed in the spatial and temporal contrast tests. The temporal test only compares maximum radiance values over a 3-day period that is not sufficient for regions of persistent cloudiness. Therefore composite grids of maximum and average Tb8 were constructed for 5-, 15-, and 30-day time periods so that a final threshold test could remove these observations. Table 6 gives the time scales and thresholds used for each surface type.

5.2 Cloud detection results

Figure 7 gives histograms of the cloud tests for NOAA-12 data on January 2, 1992. The spatial contrast test gives either a cloud or an undecided outcome. The cloudy observations tend to have colder brightness temperatures whereas the undecided results show for near the warmest values. The time contrast test gives not only the clear and undecided outcomes but includes mixed cloud and cloud outcomes. The clear and undecided histograms both peak for the warmest brightness temperatures that generally indicate clear observations. Mixed cloud and cloud outcomes have histograms peak for colder brightness temperatures. Combining these tests gives the histograms shown in Figure 7c. Clear observations have a pronounced peak near 297 K and a tail that extends down to 240K. While the undecided histogram clearly mimics the clear histogram and likely contains clear-sky observations, only observations deemed as clear are retained in the clear-sky data set.

Figure 8 gives histograms of the all-sky, short-term clear-sky, and long-term clear-sky results for NOAA-12 on January 30, 1992. Long-term test is required to remove cloudy regions that persist longer than 3 days. The all-sky histogram is relatively flat with frequency maximized near 290K. Cloud detection results indicate a 5-fold reduction of the total number of observations and observations reduced at all temperatures except near 300K. The long-term test further reduces the clear-sky observations by over 15000 observations and tends to remove more observations at the coldest brightness temperatures.

Cloud detection results were compared to ISCCP cloud detection results from the ISCCP DX data set. These ISCCP cloud data were computed from the AVHRR data collected by the same polar orbiting satellites as the HIRS. ISCCP processing re-mapped the high resolution to a 30-km grid-pixel format. Figure 9 show the all-sky HIRS channel 8 brightness temperatures for a region over Western Africa and the Eastern Indian Ocean in January 1992. Red areas are relatively warm areas and generally indicate cloud free regions whereas blue and greyscale areas indicate cloudy regions. Figure 10 shows the results of the cloud detection from the HIRS data. White regions are clear areas and indicate good correspondence with warm brightness temperatures. Figure 11 indicates the ISCCP clear-sky result. Clear regions are better defined here and relate nicely to the warm brightness temperature regions in figure 9. The conservative approach is evident in the HIRS pathfinder. Narrow clear regions detected by ISCCP method as is seen near 120W,20N tend not to be classified clear by the HIRS approach. This difference is caused by the lower spatial resolution of HIRS combined with the spatial contrast test that eliminates observations in highly variable Tb regions.

A grid by grid comparison of ISCCP and pathfinder cloud detection for these images have pathfinder and ISCCP in agreement for 75% of the grids. Pathfinder clear regions in cloudy ISCCP regions only account for 2% of the grid boxes. Detection of cloudy regions in ISCCP clear regions for about 23% of the grid boxes attests to the conservative nature of the pathfinder cloud detection

scheme. These percentages apply not only to this region but also to a larger domain that includes all of the tropics and mid-latitudes.

6. Data products

The data products can be separated into three categories: (1) Orbit-mean all-sky data, (2) swath data and (2) gridded data. The orbit-mean statistics contains mean and standard deviation all-sky brightness temperatures for all channels, maximum and minimum brightness temperatures for each channel and orbit, and number of good and bad observations as is defined by quality control flags. The swath data gives the clear-sky brightness temperatures for each available FOV. Gridded data are provided at the pentad and monthly time scales.

6.1 Orbit-mean all-sky statistics

First and second order statistics were computed for each orbit from the all-sky data for the entire time series. The mean, standard deviation, maximum and minimum brightness temperatures were compiled for each orbit, channel and satellite. Statistics on the number of all-sky observations, number of observations failing simple QC and missing data as is defined by ITPP.
Figure 12 gives the monthly mean and standard deviation for NOAA-10 channel 4 in January 1989. Orbit mean, maximum and minimum values show a small annual cycle, and both the maximum and minimum time series show outliers for

a few orbits. The standard deviation field increases at the solstice due to increased meridianal temperature gradient in the upper troposphere. The number of observations is typically 55,000 observations per orbit.

Orbit statistics can be used to diagnose problems for the data. Figure 13 shows an eight year time series of the NOAA-12 HIRS channel 12 data. While the orbit mean time series shows only one brief anomaly near the end of 1997, the other fields indicate a notable transition in May 1997. This transition relates to anomalies in the HIRS filter wheel that affected the integrity of the NOAA-12 data after May 1997.

6.2 Swath data description

The swath data format provides the clear-sky brightness temperatures at the original satellite FOV. These data are advantages for users needing high-resolution data and can be used for more direct comparison with other observing systems. Users with different needs can sift through the satellite view data and create their own grid data based on personal algorithms that may select a subset of the brightness temperatures.

Table 7 gives the parameters provided in each data record for the swath data. Scan position and altitude are used for constructing the limb corrected brightness temperatures. The cloud flag indicates if the cloud detection used either

temporal and spatial contrast tests or only the temporal test. Data records were organized into daily files for each satellite.

6.3 Grid file description

Grid files were constructed for pentad and monthly means. Grid files include the mean, standard deviation, and number of observations for each grid cell. Grid data are constructed from the swath data after applying limb corrections to each channel. Figure 14 gives an example of the monthly mean data for NOAA-11 channel 12 data in January 1990. The warmest mean brightness temperatures indicate regions of relatively low upper tropospheric humidity. The standard deviation field indicates areas of highest variability in these dry regions. The total number of observations shows higher populations over land areas because the spatial contrast test encompasses a significantly larger area over the oceans. Grid boxes with no data occur in regions of persistent cloudiness even for the monthly grids. Oceanic region around Antarctica, tropical west Pacific, and the northern hemispheric storm track regions all have missing data over the entire month. A conservative cloud detection method contributes to these missing regions. Areas of elevated terrain (> 1500m) have also been masked out.

6.4 Comparison

The NESDIS Operational soundings are produced in real-time and are used primarily forecast model validation; however, archival of these data have proven useful for long-term climate studies (Bates et al., 1996, Bates and Jackson, 2001, Geer et al., 1999). Cloud detection is done by using multiple channels and TOVS instruments (HIRS + MSU). Threshold tests for many of the channels are outlined in Ferguson and Reale (2000).

CONSTRUCT MONTHLY MEAN COMPARISON BETWEEN NESDIS OPERATIONAL AND PATHFINDER BEFORE EDF ADJUSTMENTS.

COMPARE CLIMATOLOGY MAPS

Figure 17 shows spatial fields of the number of observations for each data. The Pathfinder has over 10 times increase of observations and tends to cluster more clear observations over dry land regions. Persistent cloud regions in the tropical ITCZ, northern hemispheric storm tracks and near Antarctic are evident in both data. The NESDIS algorithm is more spatially balanced but has far fewer soundings per grid box. Dry regions for both data sets tend to have more observations. The NESDIS data has an artificial reduction of observations poleward of 60S.

7. References

Bates and Jackson (2001)

Bates et al. (1996)

Derber and ?

Ferguson and Reale (2000) 10th satellite conference proceedings

Garand et al. (2001)

Geer et al. (1999)

McNally and ?

Rossow and Garder (1993)

Scott et al. (1999)

Susskind et al (1997)

8. Tables

Table 1: Identifies days void of any HIRS clear-sky observations.

Year	Month	Clear-sky Day(s)	All-sky Day(s)	Satellite(s)	Comments
1980	6	6-8	7	TN,N6	Missing in 1B archive
1981	3	26-31	27-31	N6	Missing in 1B archive
1981	4	1-9	1-8	N6	Missing in 1B archive
1982	9	24-27	25-26	N6,N7	Missing in 1B archive
1983	8	5-7	6	N7,N8	Missing in 1B archive
1983	10	22-24	23	N7,N8	Missing in 1B archive
1984	1	13-16	14-15	N7,N8	Missing in 1B archive
1984	9	17-19	18	N7	Missing in 1B archive
1984	12	5-8	6	N7	Missing in 1B archive
1985	9	24-27	25-26	N9	Missing in 1B archive
1985	10	15-17	16	N9	Missing in 1B archive
1986	3	13-16	14-15	N9	Missing in 1B archive
1986	3	30-31		N9	Tape read error
1986	4	1		N9	Tape read error
1986	5	10-12		N9	Tape read error
1986	8	16-18		N9	Tape read error
1987	4	5-7	6	N9,N10	Missing in 1B archive
1991	11	1-3		N11,N12	Tape read error
1993	9	6-11	7-10	N11,N12	Missing in 1B archive
1994	12	4-7	5-6	N11,N12	Missing in 1B archive
1999	12	31			Cloud clearing routine error
2000	1	1			Cloud clearing routine error

Table 2: Resolution and threshold values for contrast tests.

	Resolution (FOV)	Delta1 (K)	Delta2 (K)	Delta3 (K)
Ocean	15x15	3.5	1.1	3.5
Land	9x9	6.5	2.5	8.0

Table 3: Spatial and Temporal contrast tests for cloud detection.

Test	Spatial Test	Temporal Test
Cloudy	T < (Tmax-Delta1)	|T-Tt| > Delta3
Undecided	T >= (Tmax-Delta1)	|T-Tt| <= Delta3
Clear		|T-Tt| < Delta3

Table 4: Logic table for temporal test.

		Tomorrow' Test		
		Cloudy	Undecided	Clear
Yesterday's Test	Cloudy	Cloudy	Cloudy	Mixed
	Undecided	Cloudy	Undecided	Clear
	Clear	Mixed	Clear	Clear

Table 5: Logic table for combined spatial – temporal tests

		Spatial Test	
		Cloudy	Undecided
Temporal Test	Cloudy	Cloudy	Cloudy
	Undecided	Cloudy	Undecided
	Mixed	Mixed	Mixed
	Clear	Mixed	Clear

Table 6: Time scales and thresholds for different surface types

Surface Type	Short term (days)	Long term (days)	Delta1 (K)	Delta2 (K)	Delta3 (K)
Ocean	15	30	2.0	2.5	4.0
Land	5	15	6.0	8.0	8.0

Table 7: Swath data record

Data Type	Description
Time	Time in seconds from GMT midnight
Longitude	Longitude in degrees
Latitude	Latitude in degrees
Solar zenith angle	Solar zenith angle in degrees
Altitude	Satellite altitude in degrees
Spot + line	Scan line and view angle position
QC flag	Quality control flag
Cloud flag	Cloud flag

Reflectance	Reflectance (0 to 1)
IR Brightness temperatures	Brightness temperatures for 19 channels in Kelvin

Table 8: Brightness temperature difference (position 27,28 – position 2,55) from Jan 1-10 for 1980 (N05,N06), 1983 (N07), 1984 (N08), 1986 (N9), 1987 (N10), 1990 (N11), 1993 (N12), and 1997 (N14). Observations are nighttime only and from latitude band 30N-30S. Units of Kelvin.

	N05	N06	N07	N08	N09	N10	N11	N12	N14	N15
Chn 1	3.77	3.94	3.76	3.43	4.04	3.13	4.09	3.82	3.96	
Chn 2	4.39	4.35	4.48	4.06	4.43	3.78	4.38	3.90	4.11	
Chn 3	1.25	1.42	0.80	0.87	0.76	0.31	1.32	0.93	0.85	
Chn 4	-5.64	-6.21	-6.59	-6.26	-6.33	-6.94	-6.47	-6.36	-6.88	
Chn 5	-8.05	-7.91	-8.45	-8.97	-8.73	-8.81	-8.22	-8.33	-8.40	
Chn 6	-8.60	-8.34	-8.90	-9.55	-9.23	-9.35	-8.78	-8.79	-8.98	
Chn 7	-6.66	-5.81	-6.47	-7.45	-7.05	-7.05	-6.62	-6.23	-6.47	
Chn 8	-3.42	-2.35	-3.81	-4.92	-3.34	-4.34	-4.22	-2.81	-4.04	
Chn 9	-8.55	-8.35	-9.44	-10.88	-9.22	-10.67	-9.66	-8.89	-10.02	
Chn 10	-4.16	-3.40	-4.47	-6.02	-4.26	-5.40	-4.07	-4.16	-3.79	
Chn 11	-4.67	-4.22	-5.45	-5.31	-4.66	-4.62	-4.53	-3.74	-4.65	
Chn 12	-4.83	-4.37	-5.22	-6.05	-4.90	-4.31	-4.62	-4.39	-4.76	
Chn 13	-7.39	-6.86	-7.19	-8.05	-7.97	-7.99	-8.28	-7.12	-8.51	
Chn 14	-10.01	-9.74	-10.06	-10.84	-10.57	-10.68	-10.48	-10.29	-10.61	
Chn 15	-10.18	-9.87	-10.80	-10.87	-10.47	-11.02	-10.38	-10.53	-10.83	
Chn 16	-4.32	-3.90	-4.38	-3.54	-10.39	-5.28	-4.32	-5.04	-4.64	
Chn 17	3.39	3.80	3.03	3.45	3.52	3.00	-6.93	3.17	-6.88	
Chn 18	-4.14	-2.93	-4.67	-5.57	-1.77	-5.25	-5.17	-3.44	-5.19	
Chn 19	-3.67	-2.46	-4.30	-5.04	0.04	-4.73	-4.74	-2.96	-4.76	

Table 9: Same as Table 8 except differences are after limb correction.

	N05	N06	N07	N08	N09	N10	N11	N12	N14	N15
Chn 1	1.09	0.87	0.49	-0.21	1.12	0.15	0.31	0.53	0.93	
Chn 2	0.79	0.59	0.74	-0.08	-1.60	0.18	-0.13	0.68	0.88	
Chn 3	0.25	0.61	0.87	0.71	-0.65	0.56	0.60	0.33	0.56	
Chn 4	0.88	0.10	0.11	-0.56	0.49	-0.43	-0.28	0.10	-0.19	
Chn 5	-1.37	-1.62	-1.93	-2.01	-2.71	-2.09	-2.25	-1.71	-2.58	
Chn 6	-0.78	0.29	-0.10	-1.41	-0.03	-1.40	-0.63	-1.07	-0.33	
Chn 7	-0.76	-0.52	-2.50	-1.73	-1.05	-1.09	-1.83	0.26	-1.61	
Chn 8	-2.50	-1.24	-2.68	-3.56	0.59	-3.31	-3.37	-1.32	-3.19	
Chn 9	-2.12	-1.72	-2.68	-4.06	-0.49	-3.93	-2.63	-1.81	-2.84	
Chn 10	-1.84	-0.65	-1.82	-3.10	0.89	-2.85	-1.69	-1.08	-1.49	
Chn 11	-0.71	0.49	-0.70	-1.85	0.45	-0.22	0.42	0.63	0.65	
Chn 12	0.49	1.16	0.23	-0.34	0.57	1.33	0.72	1.02	0.30	
Chn 13	-1.66	-0.89	-2.77	-2.78	0.49	-2.53	-1.83	-1.31	-2.45	
Chn 14	-1.31	-1.38	-3.67	-2.24	-1.70	-2.04	-3.40	-1.37	-3.21	
Chn 15	0.94	1.70	0.90	0.04	0.76	0.78	1.60	2.55	3.45	
Chn 16	0.71	-0.11	-1.07	1.39	-19.53	-0.47	2.33	0.85	2.01	
Chn 17	1.14	1.56	0.33	0.42	4.68	0.42	-3.43	0.23	-3.47	
Chn 18	-3.80	-2.39	-3.58	-5.04	-0.53	-4.96	-4.34	-2.75	-4.37	
Chn 19	-3.17	-1.87	-3.70	-4.27	1.83	-4.22	-4.20	-2.19	-4.24	

9. Figures