

Development of a Procedure to Make Better Use of SSM/I Data Including Navigation Errors

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Abstract

In the course of preparing the observation data for JRA-55, some navigation errors were found in special-sensor microwave imager (SSM/I) data obtained from Defense Meteorological Satellite Program (DMSP) satellites. We therefore developed a method of eliminating from the SSM/I TDR/SDR files any erroneous data caused by such navigation errors. Based on a very simple satellite navigation model, this method enables most of the errors to be eliminated without the need for any information other than that contained in the SSM/I data files. A description of a computer program for navigation error compensation that we developed based on this method is also provided.

1. Introduction

The special sensor microwave imager (SSM/I) installed on Defense Meteorological Satellite Program (DMSP) satellites is an important data source for the assimilation of meteorological data in a long-term reanalysis project (JRA-25¹) being conducted by the Japan Meteorological Agency (JMA) that covers a 26-year period from 1979 to 2004. The JMA has just started its next reanalysis project (JRA-55), which covers the 55-year period from 1958 to 2012. We reviewed the treatment of observation data so as to properly assimilate as many of them into the project as possible. SSM/I data are, of course, one of various types of observation data that needed to be reviewed. In the course of our review, we discovered that a small number of SSM/I data were erroneous. The errors found were mainly related to navigation and observation time. We found that these could be eliminated or corrected through the implementation of a proper quality check

(QC) procedure, and so developed a computer program for this purpose. We are now in the process of adopting this computer program for the JRA-55 project.

Section 2 of this paper describes the SSM/I data we investigated, section 3 describes the problems we identified with these data and the solutions we found to these problems, and section 4 contains some remarks on the characteristics and the usage of the SSM/I data.

2. SSM/I data used for the JRA-25 and JRA-55 projects

In this section, we describe the data that we used in the earlier JRA-25 project and will be using in the ongoing JRA-55 project. The SSM/I data used in both these projects are basically identical. SSM/I data from DMSP-08, DMSP-10, DMSP-11, and DMSP-13 were provided by the National Climatic Data Center (NCDC) of the National Oceanic and Atmospheric Administration

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¹<http://jra.kishou.go.jp/>

(NOAA) on magnetic tapes when we started the JRA-25 project. Covering the period from July 1987 to 1997, the data provided on these tapes was in the antenna brightness temperature data record (TDR) format. Unfortunately, we were unable to extract a few of the data from the tapes. We have downloaded post-1998 SSM/I data from NOAA's web data services, obtaining historical data from NOAA's Comprehensive Large Array-data Stewardship System (CLASS²) and real-time data from its National Weather Service Telecommunication Gateway (NWSTG).

The quality of the SSM/I data was mainly checked by manual observation for the JRA-25 project, and this manual QC revealed that a few of the data had navigation errors and were poorly calibrated. We were aware that a few erroneous data that escaped detection in the manual QC had been included in the project's assimilated data, but felt that the effect that such errors had on the reanalyzed meteorological data could be ignored.

For the JRA-55 project, we review the SSM/I data stored at the JMA to enable us to provide better observation data. NCDC kindly provided us with a complete inventory for the period from 1994 to 2008 of the SSM/I data stored in their CLASS archive. Using this inventory, we were able to obtain all the data that had been unavailable to us for the JRA-25 project. CLASS's data cover the period from July 1994 to the present date (as of December 2009, the range of data stored on CLASS had been extended to cover the period up to December 1990). As the pre-1997 SSM/I data on CLASS are in netCDF format, the pre-1997 data held at the JMA that were downloaded after the completion of the JRA-25 project are also in this format.

We now download SSM/I data from the NWSTG on a daily basis. These data are then compared with the SSM/I data inventory on CLASS every month. If our comparison reveals that the inventory contains some data that we had not obtained through our daily downloads, we

download the missing data from CLASS to ensure that we have all the available data. We have been able to acquire almost identical data as those in the CLASS archive by following this careful acquisition process. Inventories of SSM/I data possessed by the JMA are provided in Excel files named "inventory_fNN.xls" (where "NN" represents the number of the DMSP satellite from which the data were obtained) together with information regarding any erroneous data which we detected in a QC.

3. Problems with and solutions to the collection of SSM/I data

While decoding and preprocessing the SSM/I data, we found a few problems with regard to data quality. Some of these problems have arisen quite regularly since satellite observations were begun. There were too many erroneous data for the problem to be ignored or for a manual check and correction to be performed. We therefore developed a method of identifying navigation errors in the data, and then created a computer program for navigation error compensation based on this method. We have not developed a QC algorithm for brightness temperature, but presume that such data will be treated in the QC process of the assimilation. The computer program corrects erroneous data where possible and discards them if correction is impossible. The SSM/I data that is output by the program will be assimilated in the JRA-55 project.

The remainder of this section describes the navigation errors found in the SSM/I data, as well as the method used to correct/discard such errors.

3.1 Navigation errors (1)

We identified several types of navigation errors. The most frequently occurring of these was that the

²<http://www.class.ncdc.noaa.gov/saa/products/welcome>

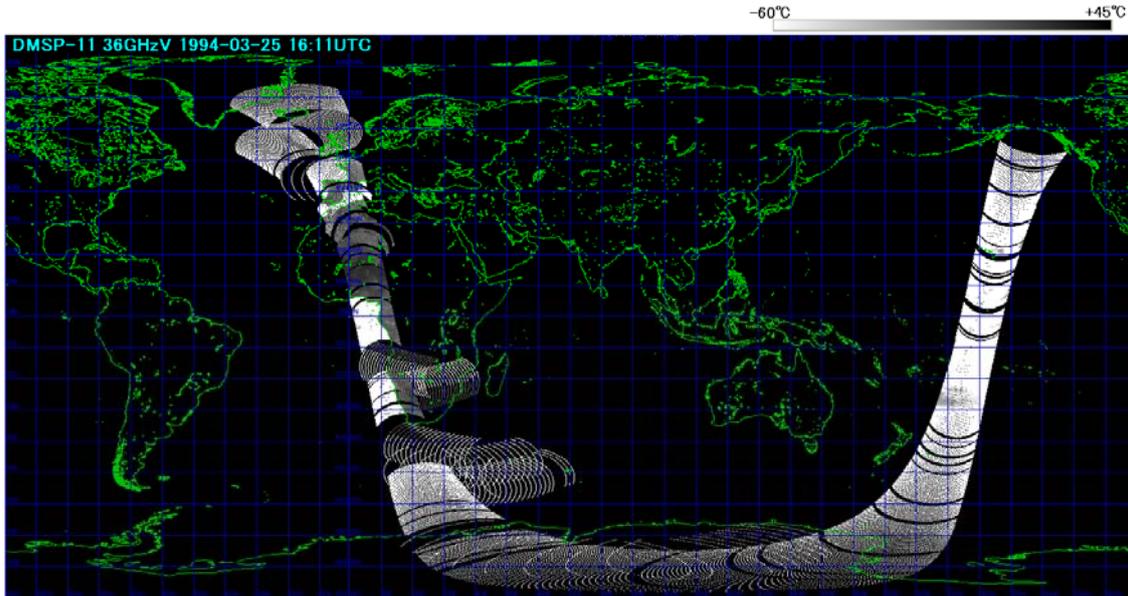


Fig. 1 Brightness temperatures for the SSM/I 37-GHz vertical channel based on data obtained from DMSP-11 at 1611UTC on 25 March 1994 (NPR.TDRR.S5.D94084.S1611.E1739.A0011983.NS)

positioning of some segments of the data stream seemed odd. Fig. 1 shows the most obvious example of this type of error. In a single file, such errors are usually found in only a few scan lines (mostly 1 or 2 lines). However, the number of files that contain this kind of navigation error is quite large (this problem was encountered in more than 70% of files containing post-1995 data obtained from DMSP-10).

Another type of navigation error that we found may have been caused by the use of data from different observation times. An example of this type of error is shown in Fig. 2. This figure shows a composite of the brightness temperatures for the SSM/I 37-GHz vertical channel based on seven files of data obtained from DMSP-13 on 29 December 2006. There is clearly a discontinuity in the data obtained over the Pacific Ocean, resulting in an unusually wide space in areas to the west of this point. The reason for this inconsistency is that the relevant data in NPR.TDRR.S7.D06363.S0330.E0523.B6073031.NS were from several days prior to the observation in

question. There are cases in which data from other satellites are misinterpreted in this way, as well. Errors of this kind are not common, but there were a few days for which almost half the day's data were erroneous.

We developed a method of detecting and eliminating navigation errors by adopting a very simple navigation technique. Fig. 3 shows brightness temperatures processed by using the method. Almost all the erroneous scan data have been eliminated. (This method does not allow us to completely eliminate all errors, however, as evidenced by the erroneous line that can be seen in data for an area near the Antarctic.)

3.2 Detection of navigation errors (1)

The following is an explanation of the method used to detect navigation errors. Because the orbit of a DMSP satellite is almost circular, we assume the angular velocity of a DMSP satellite to be constant. The position of the satellite is given in latitude and longitude. Relative time progress is measured from the time at which the satellite

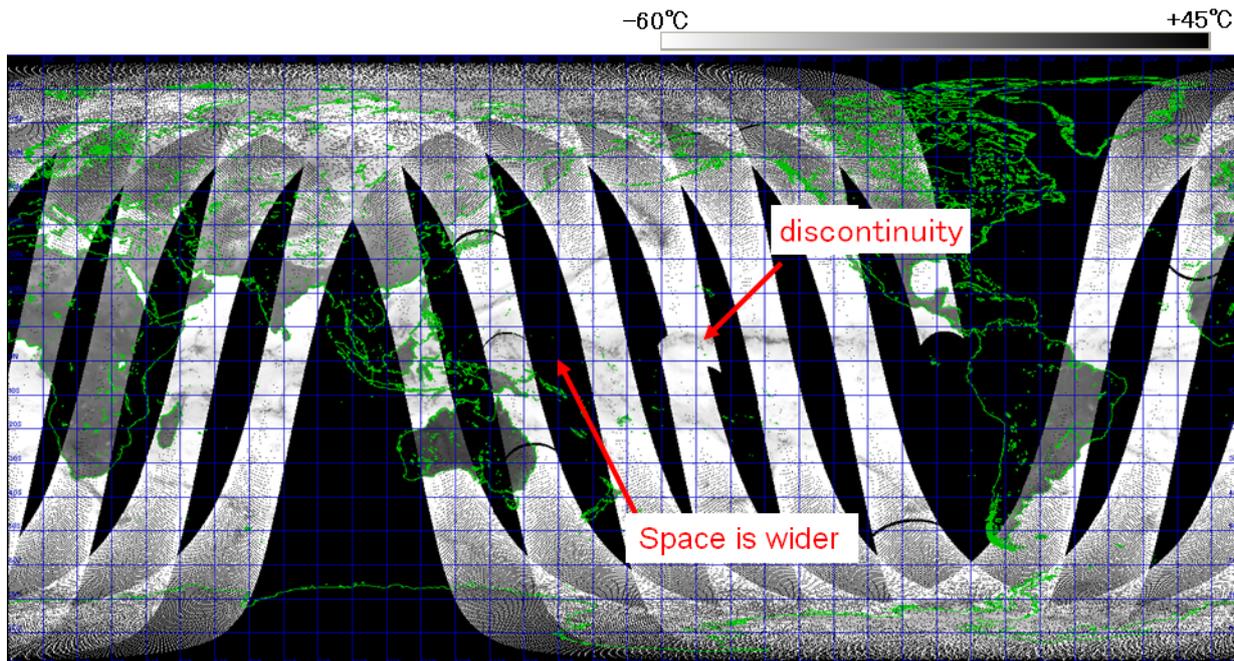


Fig. 2 Composite of the brightness temperatures for the SSM/I 37-GHz vertical channel based on data obtained from DMSP-13 on 29 December 2006 (NPR.TDRR.S7.D06363.S0330.E0523.B6073031.NS)



Fig. 3 Same as Fig. 1 but with erroneous data eliminated

crosses the ascending node, and the longitude is measured from the ascending node. First, we will explain the navigation model and estimate the satellite position from the footprints of the scan lines contained in a TDR file.

After that, we will describe the procedures used to check for navigation errors.

3.2.1 Prediction of the satellite’s position from the navigation parameters

Let us assume that we know the satellite’s inclination, the period of its rotation around the Earth (T), the time that has elapsed since it crossed the ascending node, and its ascending node (the time and the longitude). Using these parameters, we can predict the future position of the satellite.

Let A be the distance from the ascending node to the satellite, B the latitude, and C the relative longitude of the satellite, where α, β, γ are the angles shown in Fig. 4. Notice that $\beta = \pi -$ the inclination of the satellite orbit. The distance A at the elapsed time ΔT from the node can be expressed as follows.

$$A = 2\pi / T \times \Delta T . \tag{1}$$

Provided that $\alpha = \pi / 2$, spherical trigonometry yields the following equation, where the longitude and latitude of the satellite at ΔT are:

$$\begin{aligned} \sin B &= \sin \beta \times \sin A, \\ \sin C &= \frac{\sin A \times \cos \beta}{\cos B}. \end{aligned} \tag{2}$$

Longitude C needs to be modified to take into consideration the period of the Earth’s rotation (Te). Because the Earth rotates by $2\pi / Te \times \Delta T$ in ΔT , C should be modified as follows.

$$C' = C - 2\pi / Te \times \Delta T$$

Given this, the satellite longitude C'' is shown as:

$$C'' = C_0 - C' \tag{3}$$

We can now estimate the position of the satellite at ΔT , provided we know the longitude of the node C_0 and the inclination.

3.2.2 Estimation of orbital parameters from the SSM/I data stream

Orbital parameters such as β (inclination), and the timing and longitude of the satellite’s ascending node can be estimated by using the footprints in a scan line from the SSM/I data stream.

First, we estimate the satellite’s position from the footprints. Fig. 5 shows the relationship between the satellite’s position (P, Q , and R) and the footprints in a scan line (A, B, C) given that the SSM/I is a conical scan sensor. While the SSM/I sensor scans the Earth from A to

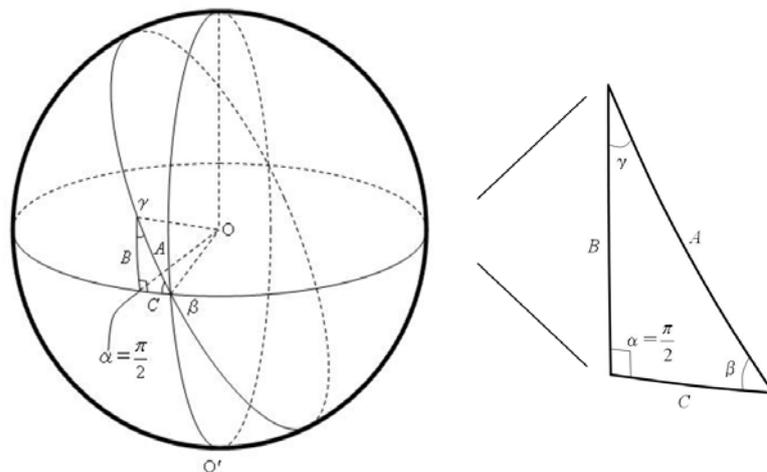


Fig. 4 Illustration of a satellite orbit

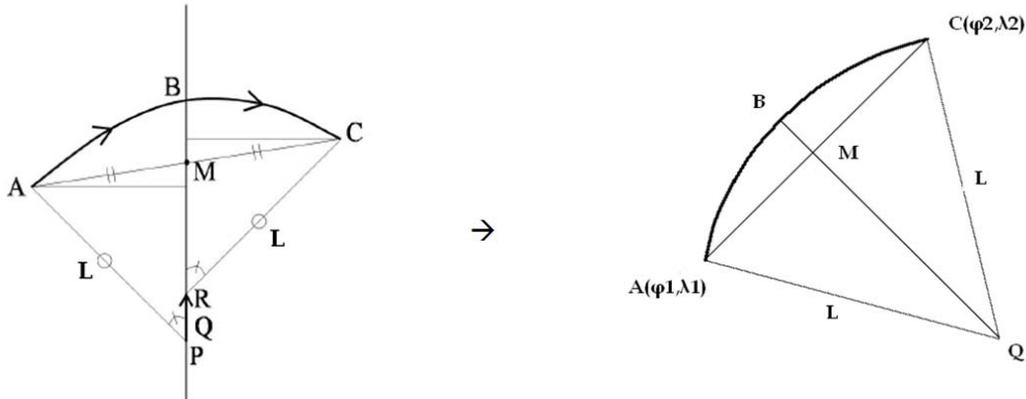


Fig. 5 The relationship between a scan line and the movement of the satellite

C, the satellite moves from P to R and the shapes of the footprints deviate slightly from being perfect semicircles. However, we have been able to confirm that we can approximate with sufficient precision that the footprints make a circular arc from A , B to C with the center at Q , as shown in the right hand side of Fig. 5 (if the direction from P to R is constant, the two situations shown in Fig.5 lead to the same result).

The latitudes and longitudes of A , B , and C are included in the TDR data stream, and L is a constant that is known from the DMSP satellite specifications. By using the spherical trigonometry shown in Appendix 1, we can perform the following procedure.

- (a) Calculate the distance between A and C and the related angles (equations 1 and 2 in Appendix 1).
- (b) Determine the latitude and longitude of M , which is the central point between A and C (equation 3 in Appendix 1).
- (c) Determine the angle of NBQ (where N represents the North or South Pole). We are able to determine this because we know the latitudes and longitudes of B and M (equation 2 in Appendix 1).

Determine the latitude and longitude of Q (the position

of the satellite). We are able to determine this because the distance between B and Q is equal to L (equation 3 in Appendix 1). We can also determine the direction from P to B , which is assumed to be the direction of the velocity of the satellite.

We now know the values for the following parameters shown in Fig. 4: γ , B and $\alpha = \pi/2$. If we apply spherical trigonometry again, we can determine the inclination β :

$$\cos \beta = \cos B \sin \gamma . \tag{4}$$

Once we know that, we can also determine the remaining two parameters shown in Fig. 4, A and C , by means of trigonometry, and then calculate the timing of the ascending node by using equation (1) above.

With the exception of T (i.e. the period of the satellite's rotation around the Earth), all of the parameters that we need to perform a navigation error compensation can be estimated by using the procedure described above. We can find out the nominal value of T (about 110 minutes) from the specifications for DMSP satellites, but this value is not precise enough for our purposes, and we found that T changes over time. We can therefore obtain T from the SSM/I data stream by monitoring the time at which the

latitude of a scan line moved from the Southern Hemisphere to the Northern Hemisphere in the observations obtained from each orbit.

3.2.3 Correction of navigation errors (1)

The procedure for correcting navigation errors is as follows.

1. Obtain the satellite position from a scan line of the SSM/I data and calculate the orbital parameters from the satellite position (see section 3.2.2).
2. Calculate the satellite position for the next scan line by using the navigation model with the parameters calculated in step 1 (see section 3.2.1).
3. Obtain the satellite position from the next scan line as described in step 1 (see section 3.2.2).
4. Compare the satellite positions obtained in steps 2 and 3. If the difference between the positions is greater than the specified criterion, the data for the second scan line is discarded.
5. Repeat the above steps for the remaining scan lines.

When we calculate the satellite position and the orbital parameters, we check whether the values obtained are appropriate by comparing them with the nominal values for the period of rotation T , the inclination β , and the specified timing of the ascending node.

In step 4, criteria are empirically chosen and set for the direction and speed of the satellite's movement. The precision of a satellite's positioning is worse at higher latitudes, and the precision with which a satellite's position can be predicted by using the orbital parameters obtained based on this positioning is also worse at higher latitudes. Therefore, the criteria set for higher latitudes are greater than those set for lower latitudes. All scan lines after the second one are checked according to the above procedure, but the first scan line cannot be checked in this way. Given this, if a QC of the second line results in a fail, the first scan line is discarded instead of the

second one.

The type of navigation error shown in Fig. 1 can be easily eliminated by following the above procedure, but the type shown in Fig. 2 cannot be detected using this procedure. The latter type of error can be detected by using T , which is obtained from the TDR data. For the purposes of our study, we assumed that the node is the position located at the center of a scan data item when it passes from the Southern Hemisphere into the Northern Hemisphere, and so documented the longitude and time for each orbit of the satellite. We then calculated T for each orbit. The longitude of the node for the orbit under observation was then compared with the longitude of the node estimated by using the value for T obtained when the node for the orbit was documented. If the difference was greater than the specified criterion, the observation in the file was discarded (in such cases, the data for the whole day were discarded). However, the monitored T is not precise enough to predict the ascending node beyond a few days in advance. Consequently, in the computer program we used, this method of performing a QC is only efficient for up to three days.

3.3 Navigation errors (2)

An example of another kind of navigation error is shown in Fig. 6. This figure shows brightness temperatures in the 37-GHz vertical channel from DMSP-08 at 2249UTC on 24 August 1987. Although the presence of navigation errors is clearly visible in this figure, no such errors were identified in the QC of the data files. In microwave images, the brightness temperatures of sea and land are quite distinct, so the coasts of the continents are clearly visible in such images and they should match a geographical map, as is the case in Fig. 2, for example. However, the brightness temperature distributions in Fig. 6 do not match the geography, as the dark area in the brightness temperatures around the east coast of North America should correspond

to the South American continent. We presume that the positions and observation times recorded in the data file are out of phase with the brightness temperature data. This kind of error seems to occur only with pre-1994 data files.

The method we adopted for dealing with this kind of navigation data error is simple. We made use of the fact that the brightness temperature of land is much higher than that of an ocean. We counted the number of observation points in the ocean area for which the brightness temperature with a vertical polarization component of 19 GHz was higher than the brightness temperature criterion of 253 K. (This criterion is considered to be the highest ocean temperature). Therefore the data in which a brightness temperature in the oceans exceeds the criterion should be discarded. However, we often encountered data that were corrupted by observation noise and geographical mapping errors. After a few trials, we concluded that data should be discarded if 10% of the observation points had higher

brightness temperatures than the criterion, on the basis that this meant the data were navigationally erroneous. This method works well in most cases, the exception being cases where the number of ocean scans was very small or the regions scanned were at high latitude because the land–ocean temperature contrast is small at higher latitudes. Given this, we only performed this QC for data obtained from observation points located lower than 70 degrees latitude. This method will have to be further refined in the future.

3.4 Format error encountered in converting the original SSM/I data into netCDF format

The CLASS web site began offering SSM/I data in netCDF format in August 2008 and, at present, SSM/I TDR data before August 1997 are only available in netCDF format. On finding out that there were some data in netCDF format on CLASS that we did not have, we downloaded the data and tried to make use of them.

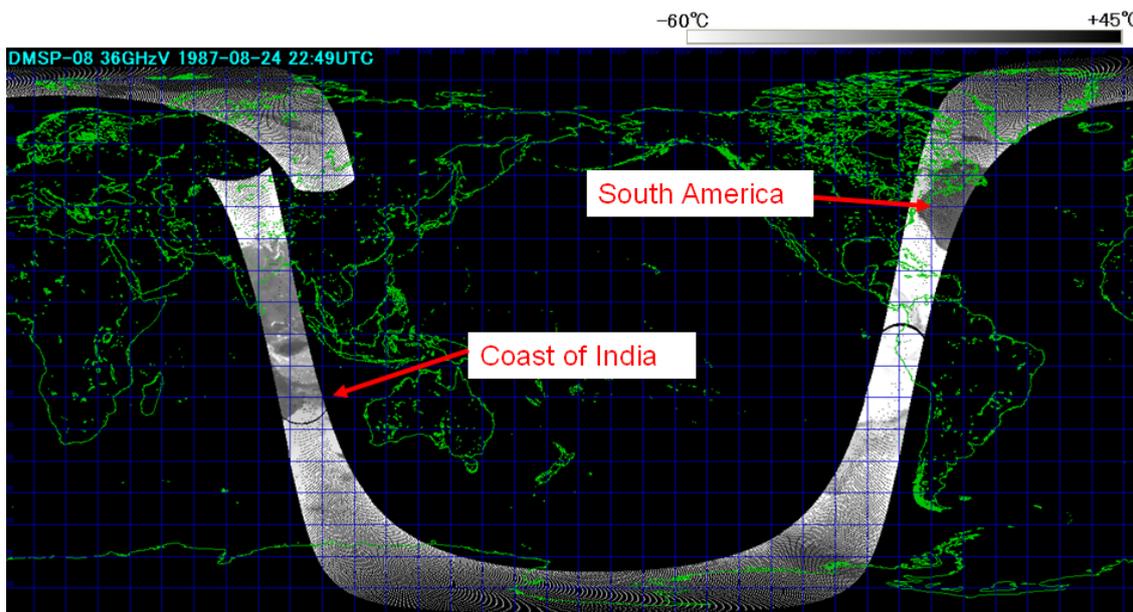


Fig. 6 Brightness temperatures for the SSM/I 37-GHz vertical channel obtained based on data from DMSP-08 at 2249UTC on 24 August 1987 (NPR.TDRR.N8.D87236.S2249.E0032.B0093233.FN)

However, we soon found that there was a problem with the data. The data appeared to be valid if the observation times attached to each scan line were ignored, but there were some navigation errors like those found in the original TDR data files. It appears that the SSM/I data in netCDF format are not identical to the original TDR file data. Instead of data having been extracted from every scan line, they were extracted from every few scan lines (i.e. certain data were culled), and it appears that in the process of doing so, correspondence between the observation time for each scan line and the relevant data was lost. We need the precise observation time for each scan line in order to be able to perform the navigation QC. All of the netCDF files failed the QC we performed on them, so we have not yet been able to use any SSM/I data in the netCDF format. This problem needs to be resolved in the next reanalysis project.

According to the communication that we received from NCDC on 30 January 2010, this problem affects only netCDF files containing data from between early 1993 and February 1997. NCDC are working to resolve this problem (see the CLASS home page³ for further details).

4. Conclusion

The concluding remarks of this paper are as follows.

1. SSM/I data are very useful for obtaining information regarding the surface of the Earth and its low-level atmosphere. The long observation period over which these data are collected makes them a particularly attractive option.
2. However, the data contain some errors related to navigation and brightness temperature. Although in most cases such errors are found in just a few lines of a TDR data file, we find a few TDR files in which all of the data are rendered useless by navigation errors. Appendix 3

tabulates the TDR files of this kind.

3. We developed a method of mitigating navigation errors, and adopted it for the preparation of observation data for the JRA-55 reanalysis project. This method can eliminate quite a few of the navigation errors found in SSM/I data from DMSP satellites.

This method is not perfect, however, and we will have to refine its performance or develop a better method. The review and reprocessing of data on CLASS might prove useful as a part of this development.

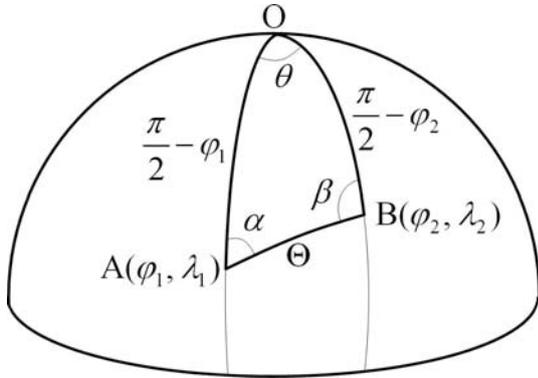
The source code for the computer program we developed for navigation error compensation is given in Appendix 2. The subroutine Chk_orbit is called each time the data in an entire scan line is read out, and the program then reports whether any navigation data errors have been identified. Those interested are free to use this code, either in part or in whole, without restriction. This computer program is intended to be applied to a time-ordered series of data files because it needs to monitor the ascending node of the satellites. The efficiency and reliability of the program is therefore limited. Persons using this program will need to monitor the performance manually, especially at the beginning of the process and on days for which there are a lot of erroneous data.

Reference

- Kazutoshi Onogi, 2007: The JRA-25 reanalysis, *JMSC*, 85, 369-432.

³ As of August 2010, the problem with the netCDF files on CLASS as described in this section has been completely resolved. The correct version of the netCDF file is VER2_5. The authors are grateful for the NCDC's prompt response to this issue and for their efforts to confirm and resolve the problem.

Appendix 1: Some results obtained using spherical trigonometry



If we construct a triangle on the above globe with vertices A , B and O (where O represents the North Pole), we can obtain the following formula.

$$\cos \Theta = \sin \varphi_1 \sin \varphi_2 - \cos \varphi_1 \cos \varphi_2 \cos(\lambda_2 - \lambda_1) \quad (1)$$

$$\frac{\sin \Theta}{\sin \theta} = \frac{\cos \varphi_2}{\sin \alpha} = \frac{\cos \varphi_1}{\sin \beta} \quad (2)$$

We can determine α and β from equation (2) if we know φ_1, λ_1 and φ_2, λ_2 , because we can determine $\sin \Theta / \sin \theta$ from equation (1).

In addition, if we know $\varphi_1, \lambda_1, \Theta$, and α , then we can determine φ_2 using equation (3), and because we know θ from equation (2), we can then determine λ_2 using equation (1).

$$\sin \varphi_2 = \sin \varphi_1 \cos \Theta + \cos \varphi_1 \sin \Theta \cos \alpha \quad (3)$$

Appendix 2: Source codes of navigation check subroutine

```

/* ----- orbit_utility.h ----- */

int Chk_orbit(int, double *, int *, int *, int *, char *);
int sign(double);
double deg2rad(double);
double rad2deg(double);
double trim_angle(double);
double diff_angle(double, double);
double mean_angle(double, double);
double cnv_lat(int, double);
double get_dist(double, double, double, double, double *, double *);
void get_point(double, double, double, double, double *, double *);
int orbit(double, double *, double *, double *, double *, double, double);
void footprint(double, double, double, double, double *, double *);
void keep_data(double, double, double, double, double, double, double, int *, int *);
void save_pp_lat(int *);
int t_local(double, double);
void orbit_para(int, double, double, double, double, double *, double *, double *);
void set_hm_TH(int *, int *, int, double, double, int);

/* ----- end of orbit_utility.h ----- */

/*****
*
* -----
* orbit_utility ver 3
* -----
*
* some subroutines to handle satellite orbit and attitude to chek DMSP satellite
* data.
*
* The subroutines are based on the document "Development of a Procedure to Make
* Better Use of SSM/I Data Including Navigation Errors" by Kumabe and Egawa in
* "Meteorological Satellite Center Technical Report" No 55, published in 2011
*
* ver 1 Ryoji Kumabe 2009. 6. 12
*
* ver 2 Ryoji Kumabe 2009. 7. 31
*
* ver 3.1 Ryoji Kumabe 2010. 2. 9
* codes for DMSP-17 are added.
* some streamlining of the code
* were done.
*
* -----
* usage: Call Chk_orbit() subroutine each time you read out a data et of
* a scan line.
*
*****/

/* -----
Definitions which should be adjusted according to
SSMI and SSMIS
----- */

/* ----- These should be defined in a parente program ----- */

// #include <math.h>
// #include <time.h>
// #define HIRES 128 /* points in a scan line SSMI */
// #define HIRES 180 /* points in a scan line SSMIS */
// #define ANGL 102.0 /* effective angle of senser scan SSMI */
// #define ANGL 144.0 /* effective angle of senser scan SSMIS */
// #define S_INT 4.389562165 /* time interval of scans SSMI */
// #define S_INT 1.9 /* time interval of scans SSMIS */

#include "orbit_utility.h"

/* ----- Constants for the earth and satellites ----- */

double PI = 3.1415926535897932384626433; /* circle ratio */

```

```

double Re_0 = 6371.2; /* mean radius of the earth [km] */
double Te = 24 * 3600; /* period of the Earth spin [minutes] */
double T = 102.0 * 60; /* period of a satellite rotation [minutes] */
//double T = 102.33 * 60; /* period of a satellite rotation [minutes] */
#define DECLINE 98.9 /* declination of satellite orbit [degree] */
#define THRESHHOLD 0.1 /* general threshold of checking 10 % */
#define ARM 720.0 /* length of SSMI(S) scan arm on the Earth (km) */
double R_FINE=1.22; /* latitude for fine orbit checking (about 70 degrees) */
double TH_d_1 = 0.5, TH_a_1 = 0.36; /* threshold for orbit continuity chk (low lat) */
double TH_d_2 = 0.5, TH_a_2 = 1.0; /* threshold for orbit continuity chk (high lat) */
int DT_EQ = 5; /* threshold for equator crossing time check (minutes) */

```

```
/* ----- Global variables for the subroutines ----- */
```

```

double p_xtime = 0, p_ttime; /* observation time of previous scan */
int p_lon[HIRES]; /* longitudes of previous scan */
int p_lat[HIRES]; /* latitudes of previous scan */
int pp_lat[HIRES]; /* latitudes of previous scan */
int pp_new = 1; /* flag of validity of pp_lat (0 for valid) */
double p_clat, p_clon, p_Gamma, p_t0, p_C0, p_Beta; /* parameters to store */
char *fn_period = "sat_period.txt"; /* file name to keep satellite period of rotation */
char *fn_equator = "equator_crossing_time.txt"; /* file name to keep equator crossing time */

```

```
/* -----
```

```

check footprint from satellite orbital consideration
return value
    2: check passed but obs time modified
    1: check passed
    0: orbit error (sat_pos or foot prit obs_time)
   -1: orbit error (orbit prediction)
   -9: orbit error (critical: process should be terminated and
       whole data in the file should be discarded)
input:

```

```

sat: satellite number (08 - 17)
*x_time: observation time at TDRSH#2 for the line
        [sec from 1987/01/01]
        this is modified if necessary
lat[HIRES] : latitudes in a scan [degree * 100]
lon[HIRES] : longitudes in a scan [degrees * 100]
*new : a flag to refresh the process
      1: refresh the process
      else: continuou the process
*msg : container of the return message
      (at least 80 bytes of memory has to be occupied
       before you call the subroutine)

```

```
----- */
int Chk_orbit(int sat, double *x_time, int *lat, int *lon, int *new, char *msg)
```

```

{
    static int errors = 0;
    static int rep= 0;
    static int hm_equator = -999;
    static double Beta = 1.726131; /* 98.9 degrees */
    int i, rtn = 1;
    int dir;
    double f_lat, f_lon;
    double c_lat, c_lon, f_lat_1, f_lon_1, f_lat_2, f_lon_2;
    double d1_dist, d1_angle1, d1_angle2, d2_dist, d3_dist;
    double d2_angle1, d2_angle2, d3_angle1, d3_angle2;
    double Gamma;
    double dT;
    double A, C;
    double t0, dt, C0;
    double Length = ARM / cos(deg2rad(39.0));
    double f_phi[HIRES], f_lambda[HIRES];
    int hm;
    int H_L, H_U;
    static double r_C0, r_t0, f_tmp;

```

```
/* ----- initialize and obs time check ----- */
```

```

// printf("obs time = %f %n", *x_time);
if (*new == 1)
{
    p_ttime = *x_time;
    switch (sat)

```

```

{
case 8:
    T = 101.87 * 60;
    break;
case 10:
    T = 100.64 * 60;
    break;
case 11:
    T = 101.9526403 + ( 101.9526403 - 101.899738111111) / (160221386.857926 - 286158629.312525)
        * (*x_time - 160221386.857926);
//    T *= 60;
    T = 101.95 * 60;
    break;
case 13:
    T = 101.83 * 60;
    break;
case 14:
    T = 101.81 * 60;
    break;
case 15:
    T = 101.74 * 60;
    break;
case 16:
    T = 102.00 * 60;
    break;
}
hm_equator = read_hm(fn_equator, sat, *x_time, &r_t0);
rep = 0;
}
else
{
    double diff_time, tmp_t;

    diff_time = *x_time - p_ttime;
    if (diff_time < 0)
    {
        tmp_t = *x_time + 24*3600.0;
        diff_time = tmp_t - p_xtime;
        if (diff_time < 0)
        {
            sprintf(msg, "error time goes back ");
            errors++;
            return 0;
        }
        else
        {
            rtn = 2;
            *x_time = tmp_t;
        }
    }
    if (diff_time > 50 * 60)
    {
        sprintf(msg, "error time goes too far ");
        errors++;
        return 0;
//    }
    }
    p_ttime = *x_time;
}
rep++;

/* ----- get satellite position at this time ----- */
for (i = 0; i < HIRES; i++)
{
    f_phi[i] = cnv_lat(1, deg2rad(lat[i] / 100.0));
    f_lambda[i] = deg2rad(lon[i] / 100.0);
}
if (sat_pos(sat, f_phi, f_lambda, &c_lat, &c_lon, &Gamma, Beta, msg) == 0)
{
    errors++;
    save_pp_lat(lat);
    return 0;
}

/* ----- get orbital parameters ----- */

```

```

if (Gamma < - PI / 2)
  dir = -1;
else
  dir = 1;
orbit_para(dir, c_lat, c_lon, Gamma, *x_time, &t0, &C0, &Beta);
/* ----- check with equator crossing time (1) ----- */

hm = t_local(C0, t0);
set_hm_TH(&H_L, &H_U, sat, *x_time, c_lat, hm_equator);
if (H_L < H_U)
{
  if ((hm < H_L) || (hm > H_U))
    rtn = 0;
}
else
{
  if ((hm < H_L) && (hm > H_U))
    rtn = 0;
}
if (rtn < 1)
{
  sprintf(msg, "error for equator crossing time %d ", hm);
  errors++;
  if ((pp_new == 0) && (lat[0] * pp_lat[0] <= 0))
  {
    save_pp_lat(lat);
    return -9;
  }
  else
  {
    save_pp_lat(lat);
    return 0;
  }
}

/* ----- footprint check ----- */

if (chk_footprint(lat, lon, 2) == 0)
{
  errors++;
  save_pp_lat(lat);
  return 0;
}
if (chk_footprint(lat, lon, 3) == 0)
{
  errors++;
  save_pp_lat(lat);
  return 0;
}

/* ----- process for the first time ----- */

if (*new == 1)
{
  keep_data(c_lat, c_lon, Gamma, t0, C0, Beta, *x_time, lat, lon);
  *new = 0;
  save_pp_lat(lat);
  return 1;
}

/* ----- predict the satellite position ----- */

dT = *x_time - p_t0;
orbit(dT, &A, &C, &f_lat, &f_lon, p_C0, p_Beta);

/* ----- Navigation check ----- */

d1_dist = get_dist(p_clat, p_clon, f_lat, f_lon, &d1_angle1, &d1_angle2);
d2_dist = get_dist(p_clat, p_clon, c_lat, c_lon, &d2_angle1, &d2_angle2);
f_lat_1 = cnv_lat(1, deg2rad(p_lat[Hires / 2] / 100.0));
f_lon_1 = trim_angle(deg2rad(p_lon[Hires / 2] / 100.0));
f_lat_2 = cnv_lat(1, deg2rad(lat[Hires / 2] / 100.0));
f_lon_2 = trim_angle(deg2rad(lon[Hires / 2] / 100.0));
d3_dist = get_dist(f_lat_1, f_lon_1, f_lat_2, f_lon_2, &d3_angle1, &d3_angle2);
if (fabs(c_lat) < R_FINE)
{

```

```

// double th_a = TH_a_1 / (*x_time - p_xtime) * 4.389562165;
double th_a = TH_a_1;

if ((fabs(d1_dist - d2_dist) > TH_d_1 * d1_dist) && (fabs(d1_dist - d3_dist) > TH_d_1 * d1_dist))
{
    sprintf (msg, "error in Chk_orbit_FINE (distance) d1=%6.4f d2=%6.4f d3=%6.4f ", d1_dist,
d2_dist, d3_dist);
    rtn = -1;
}
if ((fabs(d1_angle1 - d2_angle1) > th_a) && (fabs(d1_angle1 - d3_angle1) > th_a))
{
    sprintf (msg, "error in Chk_orbit_FINE (angle) d1=%5.2f d2=%5.2f d3=%5.2f ", d1_angle1,
d2_angle1, d3_angle1);
    rtn = -1;
}
}
else
{
// double th_a = TH_a_2 / (*x_time - p_xtime) * 4.389562165;
double th_a = TH_a_2;

if (*x_time - p_xtime < 80)
    d1_dist = 0.004 * (*x_time - p_xtime) / 4.389562165;
if ((fabs(d1_dist - d2_dist) > TH_d_2 * d1_dist) && (fabs(d1_dist - d3_dist) > TH_d_2 * d1_dist))
{
    sprintf (msg, "error in Chk_orbit_ROUGH (distance) d1=%6.4f d2=%6.4f d3=%6.4f ", d1_dist,
d2_dist, d3_dist);
    rtn = -1;
}
if ((fabs(d1_angle1 - d2_angle1) > th_a) && (fabs(d2_angle1 - p_Gamma) > th_a))
// if (fabs(d1_angle1 - d2_angle1) > TH_a_2)
{
    sprintf (msg, "error in Chk_orbit_ROUGH (angle) d1=%5.2f d2=%5.2f att=%5.2f dir=%2d d1_angle1,
d2_angle1, p_Gamma, dir");
    rtn = -1;
}
}
if (rtn < 1)
{
    errors++;
    save_pp_lat(lat);
    return -1;
}

/* ----- check with equator crossing time (2) -----
when the satellite is on teh equator ----- */

if (lat[0] * pp_lat[0] <= 0)
{
    if (hm_equator > 0)
    {
        /* ----- test by local time ----- */
        int HM, HM_EQ;

        HM = (hm / 100) * 60 + (hm % 100);
        HM_EQ = (hm_equator / 100) * 60 + (hm_equator % 100);
        if (fabs(HM - HM_EQ) > DT_EQ)
        {
            sprintf(msg, "error with equator crossing time %d:%d ", hm, hm_equator);
            save_pp_lat(lat);
            return -9;
        }
    }
    /* ----- test by UT ----- */
    /* ----- this process is very dangerous ----- */
    dt = fabs(modf((t0 - r_t0) / T, &f_tmp));
    if ((dt > 0.05) && (dt < 0.95)) // threshold = 5 %
    {
        sprintf(msg, "error with equator crossing time %f ", dt);
        save_pp_lat(lat);
        return -9;
    }
}
/* ----- update hm_equator ----- */
if ((lat[0] >= 0) && (p_lat[0] < 0))
{

```

```

FILE *fp_p;
if ((fp_p = fopen(fn_period, "a+")) != NULL)
{
    double period = (t0 - r_t0);
    if (dt > 0.5)
        f_tmp++;
    if (period != 0)
        period = period / (f_tmp * 60);
    fprintf(fp_p, "%f %f\n", t0, period);
}
hm_equator = hm;
r_t0 = t0;
write_hm(fn_equator, hm, *x_time, sat, CO, t0);
}
}

/* ----- test for prediction of orbit -----
{
FILE *fp_o;
int ilat, ilon, idt;

if ((fp_o = fopen("orbit.txt", "wt")) == NULL)
{
    sprintf(msg, "orbit file open error ");
    save_pp_lat(lat);
    return 0;
}
ilat = rad2deg(f_lat) * 1000;
ilon = rad2deg(f_lon) * 1000;

fprintf(fp_o, "%4d-%02d-%02d %02d:%02d:00 %6d %7d\n", 2009, 5, 29, 10, 0, ilat, ilon);
fprintf(fp_o, "%4d-%02d-%02d %02d:%02d:00 %6d %7d\n", 2009, 5, 29, 15, 0, -ilat, -ilon);
for (dt = 0; dt < 6000; dt += 4.38956216506849 * 5)
{
//    dT = p_xtime + dt - t0;
//    dT = 1.0 + dt;

orbit(dT, &A, &C, &f_lat, &f_lon, CO, Beta);
ilat = rad2deg(f_lat) * 1000;
ilon = rad2deg(f_lon) * 1000;

footprint(f_lat, f_lon, A, C, f_phi, f_lambda);
for (spotH = 0; spotH < HIRES; spotH++)
{
    ilat = rad2deg(cnv_lat(-1, f_phi[spotH])) * 1000;
    ilon = rad2deg(f_lambda[spotH]) * 1000;
    fprintf(fp_o, "%6d %7d %6d\n", ilat, ilon, 300000);
}

//    fprintf(fp_o, "%6d %7d %6d\n", ilat, ilon, 300000);
//    fprintf(fp_o, "%6d %7d %6d %7.2f %9.2f %9.2f\n", ilat, ilon, 300000, f_lat, f_lon, C);
}
fclose(fp_o);
return -1;
}
*/

/* ----- prepare for next scan ----- */

keep_data(c_lat, c_lon, Gamma, t0, CO, Beta, *x_time, lat, lon);
save_pp_lat(lat);
return rtn;
}

/* ----- */
/*
/*      Some routines which are called by Chk_orbit()
/*
/* ----- */

/* check the sign of a variable */
int sign(double value)
{
    if (value == 0)
        return 0;
    int a = value / fabs(value);
}

```

```

    return a;
}

/* conversion from degree to radian */
double deg2rad(double angle)
{
    return(angle * PI / 180.0);
}

/* conversion from radian to degree */
double rad2deg(double angle)
{
    return(angle * 180.0 / PI);
}

/* -----
   angle is trimed between -PI and PI
   input  angle: [radian]
   output [radian]
   ----- */
double trim_angle(double angle)
{
    int s = sign(angle);
    angle = fmod(angle, 2 * PI);
    if (fabs(angle) > PI)
        angle = -s * (2 * PI - fabs(angle));
    return angle;
}

/* -----
   get the difference of angles between
   a and b
   input a, b [radian]
   output [radian]
   ----- */
double diff_angle(double a, double b)
{
    double sa, sb, d;
    a = trim_angle(a);
    b = trim_angle(b);
    sa = sign(a);
    sb = sign(b);
    if (sa == sb)
        d = a - b;
    else
    {
        d = a - b;
        if (fabs(a) + fabs(b) > PI)
            d += sign(d) * -2 * PI;
    }
    return d;
}

/* -----
   get the mean of angles of
   a and b
   input a, b: [radian]
   output [radian]
   ----- */
double mean_angle(double a, double b)
{
    double sa, sb, d;
    a = trim_angle(a);
    b = trim_angle(b);
    sa = sign(a);
    sb = sign(b);
    if (sa == sb)
        d = (a + b) / 2;
    else
        if (fabs(a) + fabs(b) < PI)
            d = trim_angle((a + b) / 2);
        else
            d = trim_angle((a + b + 2 * PI) / 2);
    return d;
}

```

```

/* -----
   conversion of latitude:
   gravitational <-> earth center
   if para = 1   gravitational -> earth center
   if para = -1  gravitational <- earth center
   lat: [radian]
   output [radian]
----- */
double cnv_lat(int para, double lat)
{
    double f = 1.0 / 300.0;          /* flattening of the Earth */
    double tan_phi, tan_psi;        /* refe to
http://wwwsoc.nii.ac.jp/geod-soc/web-text/part2/2-1/2-1-6.html */
    double b_a = 1.0 - f;
    double phi, psi;

    if (para == -1)
        b_a = 1 / b_a;
    tan_psi = tan(lat);
    tan_phi = b_a * tan_psi;
    phi = atan(tan_phi);
    return phi;
}

/* -----
   get the distance between A(phi1, lambda1) and B(phi2, lambda2)
   on a sphar surface.
   angle NAB is set in a1 (clockwise)
   angle NBA is set in a2 (clockwise)
   N = north pole
   all variables are in [radian]
----- */
double get_dist(double phi_1, double lambda_1, double phi_2, double lambda_2, double *a1, double *a2)
{
    double a, b, c;
    double cos_a, cos_b, cos_c, cos_B, cos_C;
    double sin_a, sin_b, sin_c;

    lambda_1 = trim_angle(lambda_1);
    lambda_2 = trim_angle(lambda_2);

    cos_a = sin(phi_1) * sin(phi_2) + cos(phi_1) * cos(phi_2) * cos (lambda_1 - lambda_2);
    if (fabs(cos_a) > 1)
        cos_a = sign(cos_a);
    b = PI / 2 - phi_2;
    c = PI / 2 - phi_1;
    a = acos(cos_a);
    sin_a = sin(a);
    cos_b = cos(b);
    sin_b = sin(b);
    cos_c = cos(c);
    sin_c = sin(c);

    cos_B = (cos_b - cos_c * cos_a) / (sin_a * sin_c);
    cos_C = (cos_c - cos_a * cos_b) / (sin_a * sin_b);
    if (fabs(cos_B) > 1)
        cos_B = sign(cos_B);
    if (fabs(cos_C) > 1)
        cos_C = sign(cos_C);
    *a1 = acos(cos_B);
    *a2 = acos(cos_C);
    if ((lambda_1 * lambda_2 < 0) && (fabs(lambda_1) + fabs(lambda_2) > PI))
    {
        if (lambda_1 > lambda_2)
            *a2 = -*a2;
        else
            *a1 = -*a1;
    }
    else
    {
        if (lambda_1 < lambda_2)
            *a2 = -*a2;
        else
            *a1 = -*a1;
    }
    return a;
}

```

```

}
/* -----
   get the point of B(phi_2, lambda_2) from A(phi_1, lambda_1)
   aperted a with the angle NAB = C on a sphere surface
   N = north pole
   C is taken clockwise from N direction
   all variables are in [radian]
   ----- */
void get_point(double phi_1, double lambda_1, double a, double C, double *phi_2, double *lambda_2)
{
    double b, c, A;
    double cos_a, cos_b, cos_c, sin_a, sin_b, sin_c, cos_A, cos_C;

    C = trim_angle(C);
    b = PI / 2 - phi_1;
    sin_a = sin(a);
    cos_a = cos(a);
    sin_b = sin(b);
    cos_b = cos(b);
    cos_C = cos(C);
    cos_c = cos_a * cos_b + sin_a * sin_b * cos_C;
    if (fabs(cos_c) > 1)
        cos_c = sign(cos_c);
    c = acos(cos_c);
    sin_c = sin(c);
    *phi_2 = PI / 2 - c;
    cos_A = (cos_a - cos_b * cos_c) / (sin_b * sin_c);
    if (fabs(cos_A) > 1)
        cos_A = sign(cos_A);
    A = acos(cos_A);
    if (C > 0)
        *lambda_2 = lambda_1 + A;
    else
        *lambda_2 = lambda_1 - A;
    *lambda_2 = trim_angle(*lambda_2);
}
/* -----
   prediction of footprint
   This routine is for checking the performance of orbital check
   and dosen't run in the routine process
   all variables are in [radian]
   f_lat: latitude of the satellite
   f_lon: longitude of the satellite
   f_phi[]: series of latitudes of the observation cell
   f_lambda[]: series of longitudes of the observation cell

   See the document for A and C.
   ----- */
void footprint(double f_lat, double f_lon, double A, double C, double f_phi[HIREs], double f_lambda[HIREs])
{
    double sin_Gamma, Gamma;
    double sin_A, sin_C, sin_phi;
    double gsi = deg2rad(ANGL) / 2.0;
    double Length = ARM / cos(deg2rad(39.0));
    double Theta2 = Length / Re_0;
    double d_angle = deg2rad(ANGL / (HIREs - 1));
    int spotH;

    if (f_lat < 0)
        f_lat = f_lat;
    A = trim_angle(A);
    sin_A = sin(A);
    sin_C = sin(C);
    if (sin_A > 0.00001)
        sin_Gamma = sin_C / sin_A;
    else
        sin_Gamma = sin_C / A;
    if (fabs(sin_Gamma) > 1)
        sin_Gamma = sign(sin_Gamma);
    Gamma = asin(sin_Gamma);
    if ((A > PI / 2) || (A < -PI / 2))
        Gamma = sign(Gamma) * PI - Gamma;
    for (spotH = 0; spotH < HIREs; spotH++)
    {

```

```

double dir;
double b, c, a, A2;
double sin_dphi, cos_dphi, dphi, sin_dlamba, dlamba;
double cos_A2, cos_C, cos_c, sin_c, cos_a, cos_b, sin_a, sin_b;

dir = Gamma - gsi + spotH * d_angle;
dir = trim_angle(dir);

get_point(f_lat, f_lon, Theta2, dir, &f_phi[spotH], &f_lambda[spotH]);
}
return:
}

/* ----- prediction of orbit -----
predict the position of the satellite at the time of
dT
return value:
1: prediction successful
0: prediction failed
all vairables except dT are in [radian]
f_lat: predicted latitude of the satellite at time present + dT
f_lon: predicted longitude of the satellite at time present + dT
See the document for A and C.
----- */
int orbit(double dT, double *A, double *C, double *f_lat, double *f_lon,
double C0, double beta)
{
int rtn = 1;
double sin_A, cos_A, sin_B, cos_B, sin_C;
/*
double sin_Beta = sin(deg2rad(DECLINE));
double cos_Beta = cos(deg2rad(DECLINE));
*/
double sin_Beta = sin(beta);
double cos_Beta = cos(beta);
double ds = 2.0 * PI / Te; /* spin rate of the earth */

*A = trim_angle(2.0 * PI / T * dT);
sin_A = sin(*A);
cos_A = cos(*A);
sin_B = sin_Beta * sin_A;
cos_B = sqrt(1 - pow(sin_B, 2));
*f_lat = asin(sin_B); /* latitude expected */
sin_C = sin_A * cos_Beta / (cos_B * sin_Beta);
if (fabs(sin_C) >= 1)
{
*C = -*A;
rtn = 0;
}
else
{
*C = asin(sin_C);
if (cos_A < 0)
*C = sign(*C) * PI - *C;
}
*f_lon = *C - ds * dT + C0; /* longitute expected */
*f_lon = trim_angle(*f_lon);
/*
if (*f_lon < 0)
*f_lon += 2 * PI; // longitude always positive
if (*f_lon > 2 * PI)
*f_lon -= 2 * PI; // longitude smaller tan 2PI
*/
return rtn;
}

void keep_data(double c_lat, double c_lon, double Gamma, double t0, double C0, double Beta,
double xtime, int lat[HIRE], int lon[HIRE])
{
int spotH;

p_clat = c_lat;
p_clon = c_lon;
p_Gamma = Gamma;
p_t0 = t0;
p_C0 = C0;

```

```

p_Beta = Beta;
/* --- if xtime < 10000 the program presume xtime is relative time difference --- */
if (xtime > 10000)
    p_xtime = xtime;
for (spotH = 0; spotH < HIRES; spotH++)
{
    p_lat[spotH] = lat[spotH];
    p_lon[spotH] = lon[spotH];
}
return;
}

void save_pp_lat(int lat[HIRES])
{
    int spotH;

    for (spotH = 0; spotH < HIRES; spotH++)
    {
        pp_lat[spotH] = lat[spotH];
    }
    pp_new = 0;
    return;
}

/* -----
   get satellite attitude from its latitude
   with the supposition that satellite attitude
   is parallel to its velocity
   variables are in [radian]
   lat: latitude of the satellite
   Beta: declination of the satellite orbit [radian]
   ----- */
double get_att(double lat, double Beta)
{
    double cos_Beta = cos(Beta);
    double cos_B, sin_gamma, gamma;

    cos_B = cos(lat);
    sin_gamma = cos_Beta / cos_B;
    gamma = asin(sin_gamma);
    return gamma;
}

/* -----
   get satellite position from the data on one scan line
   return value
       0: satellite position estimation failed (maybe orbit is odd)
       1: function returns good satellite position
   sat: satellite number [8 - 17]
   f_lat: latitudes in a scan line [radian]
   f_lon: longitudes in a scan line [radian]
   *c_lat: latitude of the SSP [radian]
   *c_lon: longitude of the SSP [radian]
   *gamma: attitude of the satellite [radian]
   Beta: declination of the satellite orbit [radian]
   *msg: return message
   ----- */
int sat_pos(int sat, double f_lat[HIRES], double f_lon[HIRES], double *c_lat, double *c_lon, double *gamma,
double Beta, char *msg)
{
    int rtn = 1;
    double phi[4], lambda[4], r[3], a[4], b[3];
    double Length = ARM / cos(deg2rad(39.0));
    double Theta2 = Length / Re_0;
    double c_gamma1, c_gamma2, d_angle, d_dist, d_gamma1, d_gamma2;
    int i;
    double angle = ANGL / 180 * PI;
    double th_angle;

    phi[0] = f_lat[0];
    lambda[0] = f_lon[0];
    phi[2] = f_lat[HIRES-1];
    lambda[2] = f_lon[HIRES-1];
    phi[1] = (f_lat[HIRES/2-1] + f_lat[HIRES/2]) / 2.0;
    lambda[1] = (f_lon[HIRES/2-1] + f_lon[HIRES/2]) / 2.0;
    lambda[1] = mean_angle(f_lon[HIRES/2-1], f_lon[HIRES/2]);

```

```

r[0] = get_dist(phi[0], lambda[0], phi[2], lambda[2], &a[0], &a[2]);
r[0] = r[0] / 2;
get_point(phi[0], lambda[0], r[0], a[0], &phi[3], &lambda[3]);
r[0] = get_dist(phi[3], lambda[3], phi[1], lambda[1], &a[3], &a[1]);
get_point(phi[1], lambda[1], Theta2, a[1], c_lat, c_lon);

/* check the consistency of points 0, 1, and 2 */
for (i = 0; i < 3; i++)
{
    r[i] = get_dist(*c_lat, *c_lon, phi[i], lambda[i], &b[i], &a[i]);
    d_dist = fabs(r[i] - Theta2) / Theta2;
    if (d_dist > (THRESHHOLD * 1.0))
    {
        /*
            printf ("error in sat_pos()_d ");
            printf ("%2d lat = %5.2f lon = %6.2f r=%5.2f th=%5.2f\n", i, phi[i], lambda[i], r[i], Theta2);
            mean_angle(f_lon[HIRES/2-1], f_lon[HIRES/2]);
        */
        rtn = 0;
    }
}
for (i = 1; i < 3; i++)
{
    d_angle = (fabs(diff_angle(b[i], b[i-1])) * 2 - angle) / angle;
    if (d_angle > (THRESHHOLD * 0.5))
    {
        /*
            printf ("error in sat_pos()_a ");
            printf ("%2d lat = %5.2f lon = %6.2f angle=%5.2f\n", i, phi[i], lambda[i], diff_angle(b[i],
b[i-1]));
        */
        rtn = 0;
    }
}
*gamma = trim_angle(b[1]);
if (sat == 8)
    *gamma = trim_angle(*gamma + PI);
c_gamma1 = get_att(*c_lat, Beta);
c_gamma2 = trim_angle(-PI - c_gamma1);
d_gamma1 = fabs(diff_angle(c_gamma1, *gamma));
d_gamma2 = fabs(diff_angle(c_gamma2, *gamma));
th_angle = THRESHHOLD; // about 6 degrees
if (fabs(*c_lat) > R_FINE)
    th_angle *= 3.3;
if ((d_gamma1 > th_angle) && (d_gamma2 > th_angle))
{
    /*
        printf ("error in sat_pos()_g ");
        printf (" lat = %5.2f lon = %6.2f gamma=%5.2f c_gamma1=%5.2f c_gamma2=%5.2f\n", f_lat[HIRES/2],
f_lon[HIRES/2], *gamma, c_gamma1, c_gamma2);
    */
    rtn = 0;
}
if (rtn == 0)
{
    sprintf (msg, "error in sat_pos() ");
    return 0;
}
return 1;
}

/* -----
chek the consistency of footprint in a scan line.
checking is performed by cheking the shift of latitude and longitude
according to the increase of the pixel number of 2 because the difference
in lat. and lon. in the successive pixels are too small to evaluate.
usually this routine is called twice with neighbouring start points.

return value
    1: check passed
    0: check failed
lat: latitudes in a scan line [radian]
lon: longitudes in a scan line [radian]
start_point: start point of checking
----- */

```

```

int chk_footprint(int lat[HIREs], int lon[HIREs], int start_point)
{
    int spoth, rtn = 1;
    double d1, d2, a1, a2, b1, b2;
    double phi1, phi2, lambda1, lambda2, phi3, lambda3;
    double d_angle = deg2rad(ANGL / (HIREs - 1)) * 4;
    double Length = ARM / cos(deg2rad(39.0));
    double Theta2 = Length / Re_0;
    double step = Theta2 / (HIREs - 1) * 2;
    double da;

    phi1 = cnv_lat(1, deg2rad(lat[start_point-2] / 100.0));
    lambda1 = deg2rad(lon[start_point-2] / 100.0);
    phi2 = cnv_lat(1, deg2rad(lat[start_point] / 100.0));
    lambda2 = deg2rad(lon[start_point] / 100.0);
    for (spoth = start_point; spoth < HIREs-2; spoth += 2)
    {
        phi3 = cnv_lat(1, deg2rad(lat[spoth+2] / 100.0));
        lambda3 = deg2rad(lon[spoth+2] / 100.0);
        d1 = get_dist(phi1, lambda1, phi2, lambda2, &a1, &b1);
        d2 = get_dist(phi2, lambda2, phi3, lambda3, &a2, &b2);
        if (fabs(d1 - d2) / step > (THRESHHOLD / cos(phi2)))
            rtn = 0;
        b1 -= PI;
        b1 = trim_angle(b1);
        da = trim_angle(a2 - b1);
        if (fabs(da - d_angle) > (PI / 4))
        {
            printf("error in chk_footprint() ");
            rtn = 0;
            return 0;
        }
        phi1 = phi2;
        phi2 = phi3;
        lambda1 = lambda2;
        lambda2 = lambda3;
    }
    return 1;
}

/* -----
   get orbital parameters from the satellite position and time
   you can use this function for any satellite
   with the supposition that the orbit is pure circle
input:
    dir:   direction of satellite
           1: ascent
          -1: descent
    c_lat, c_lon: satellite position [radian] at the
                  time r_xtime [sec]
    Gamma: attitude of the satellite [radian]
output:
    *t0: the time when satellite cross the equator [sec]
    *CO: longitude of SSP at the time of t0 [radian]
    *beta: declination of the satellite orbit [radian]
   ----- */
void orbit_para(int dir, double c_lat, double c_lon, double Gamma, double r_xtime, double *t0,
               double *CO, double *beta)
{
    // double beta = deg2rad(DECLINE);
    double ds = 2.0 * PI / Te; /* spin rate of the earth */
    double sin_Beta, cos_Beta, sin_B, cos_B, sin_A, cos_A, sin_C, cos_C, A, C, d_lat;
    double dt;
    double sin_Gamma;

    sin_B = sin(c_lat);
    cos_B = cos(c_lat);
    sin_Gamma = sin(Gamma);
    cos_Beta = cos_B * sin_Gamma;
    if (fabs(cos_Beta) > 1)
        cos_Beta = sign(cos_Beta);
    *beta = acos(cos_Beta);
    if (fabs(DECLINE - rad2deg(*beta)) > 1.0)
    {
        *beta = deg2rad(DECLINE);
        cos_Beta = cos(*beta);
    }
}

```

```

}
sin_Beta = sin(*beta);
/*
sin_Beta = sin(beta);
cos_Beta = cos(beta);
*/
sin_A = sin_B / sin_Beta;
if (fabs(sin_A) > 1.0)
    sin_A = sign(sin_A);
cos_A = sqrt(1 - pow(sin_A, 2));
sin_C = sin_A * cos_Beta / (cos_B * sin_Beta);
if (fabs(sin_C) > 1.0)
    sin_C = sign(sin_C);
cos_C = sqrt(1 - pow(sin_C, 2));

A = asin(sin_A);
C = asin(sin_C);

if (dir < 0)
{
    A = PI - A;
    C = -PI - C;          /* C is always negative */
}
dt = T / (2 * PI) * A;
*t0 = r_xtime - dt;
*CO = c_lon - C + ds * dt;
if (*CO > 2 * PI)
    *CO -= 2 * PI;
sin_Gamma = sin_C / sin_A;
Gamma = asin(sin_Gamma);
}

/* -----
   get a local time at longitude CO [radian] for
   a GMT t0 [sec]
   return value : hhmm
   hh: hours
   mm: minutes
   ----- */
int t_local(double CO, double t0)
{
    time_t c_time, r_time;
    struct tm *ti;
    int year, month, day, hour, minute;
    double td_local;

    time(&c_time);
    ti = localtime(&c_time);
    ti->tm_year = 1987-1900;
    ti->tm_mon = 0;
    ti->tm_mday = 1;
    ti->tm_hour = ti->tm_min = ti->tm_sec = 0;
    r_time = mktime(ti);
    c_time = t0 + r_time;
    td_local = (24.0658 * 60 * 60) / (2.0 * PI) * CO;
    c_time += td_local;
    ti = localtime(&c_time);
    year = ti->tm_year + 1900;
    month = ti->tm_mon + 1;
    day = ti->tm_mday;
    hour = ti->tm_hour;
    minute = ti->tm_min;

    return (hour * 100 + minute);
}

/* -----
   read out equator crossing times in hhmm
   (hh: hour, mm: minutes) and accum_sec_from(1987)
   input
   *fn: name of the history file of equator crossing time
   sat: satellite number [ 8 -17 ]
   x_time: observation time [sec]
   output
   *r_t0: accumulated seconds for 1987/01/01/ when the
         satellite crossed the equator for the last [sec]
   ----- */

```

```

        return value: equator crossing times in hhmm
----- */
int read_hm(char *fn, int sat, int x_time, double *r_t0)
{
    FILE *fp_eq;
    int hm_equator = -999, rsat;
    double r_CO, rtime;
    if ((fp_eq = fopen(fn, "rt")) != NULL)
    {
        fscanf(fp_eq, "%d %f %d %f %f", &hm_equator, &rtime, &rsat, &r_CO, r_t0);
        if ((sat != rsat) || (fabs(x_time - rtime) > 3 * 24 * 3600)) /* if dababase is older than 3 days */
            hm_equator = -999;
    }
    return hm_equator;
}

/* -----
    save equator crossing time
    hhmm xtime sat_num longitude accum_sec_from(1987)
----- */
int write_hm(char *fn, int hm, double x_time, int sat, double CO, double t0)
{
    FILE *fp_eq;
    if ((fp_eq = fopen(fn, "wt")) != NULL)
    {
        fprintf(fp_eq, "%d %f %d %f %f", hm, x_time, sat, CO, t0);
        fclose(fp_eq);
    }
    return 0;
}

/* -----
    set criteria for equator crossing time check.
    criteria are returned in *H_L and *H_U.
    sat: satellite number [ 8-17 ]
    x_time: observation time [sec]
    c_lat: latitude of SSP [radian]
    hm_equator: equator crossing time of the satellite
               [hhmm] hh: hours mm: minutes in local time
----- */
void set_hm_TH(int *H_L, int *H_U, int sat, double x_time, double c_lat, int hm_equator)
{
    int window;

    if (hm_equator >= 0)
    {
        if (fabs(c_lat) < R_FINE)
            window = 100;
        else
            window = 200;
    }
    else
    {
        switch (sat)
        {
            case 8:
                hm_equator = 600;
                break;
            case 10:
                hm_equator = 2030;
                break;
            case 11:
                hm_equator = 1850;
                break;
            case 13:
                hm_equator = 1700;
                break;
            case 14:
                if (x_time < 470000000.0)
                    hm_equator = 1900;
                else
                    hm_equator = 1600;
                break;
            case 15:
                if (x_time < 445567241.0)
                    hm_equator = 2100;
        }
    }
}

```

```
    else if (x_time < 470000000.0)
        hm_equator = 1900;
    else if (x_time < 680000000.0)
        hm_equator = 2100;
    else
        hm_equator = 1900;
    break;
case 16:
    hm_equator = 1900;
    break;
case 17:
    hm_equator = 1730;
    break;
}
if (fabs(c_lat) < R_FINE)
    window = 200;
else
    window = 500;
}
*H_L = hm_equator - window;
*H_U = hm_equator + window;
if (*H_L < 0)
    *H_L += 2400;
if (*H_U >= 2400)
    *H_L -= 2400;
}
```

Appendix 3: List of the TDR files in which navigation error are critical and all scan data should be abandoned.

This is the lists of TDR files which we abandoned all scan data because of navigation errors. Navigation check is performed with all DMSP TDR files in the period from June 1987 to December 2009.

DMSP-08 file name	year	month	day
NPR. TDRR. N8. D87201. S0614. E1829. B0041219. FN	1987	7	20
NPR. TDRR. N8. D87202. S0423. E1254. B0042530. FN	1987	7	21
NPR. TDRR. N8. D87213. S2107. E2108. B0060404. FN	1987	8	1
NPR. TDRR. N8. D87217. S0834. E1309. B0065356. FN	1987	8	5
NPR. TDRR. N8. D87217. S1321. E1352. B0065656. FN	1987	8	5
NPR. TDRR. N8. D87218. S0457. E0630. B0066566. FN	1987	8	6
NPR. TDRR. N8. D87218. S2139. E2322. B0067476. FN	1987	8	6
NPR. TDRR. N8. D87221. S1234. E1401. B0071213. FN	1987	8	9
NPR. TDRR. N8. D87226. S0454. E1451. B0076470. FN	1987	8	14
NPR. TDRR. N8. D87236. S2249. E0032. B0093233. FN	1987	8	24
NPR. TDRR. N8. D87246. S0439. E2254. B0104657. FN	1987	9	3
NPR. TDRR. N8. D87246. S0442. E1411. B0104652. FN	1987	9	3
NPR. TDRR. N8. D87247. S0432. E1358. B0106066. FN	1987	9	4
NPR. TDRR. N8. D87247. S1343. E1525. B0107981. FN	1987	9	4
NPR. TDRR. N8. D87249. S0622. E1513. B0108995. FN	1987	9	6
NPR. TDRR. N8. D87250. S0613. E1500. B0110309. FN	1987	9	7
NPR. TDRR. N8. D87250. S1107. E1140. B0112121. FN	1987	9	7
NPR. TDRR. N8. D87251. S0801. E2154. B0111927. FN	1987	9	8
NPR. TDRR. N8. D87252. S0757. E2142. B0113241. FN	1987	9	9
NPR. TDRR. N8. D87253. S1413. E1539. B0116465. FN	1987	9	10
NPR. TDRR. N8. D87255. S1018. E1207. B0119092. FN	1987	9	12
NPR. TDRR. N8. D87259. S0748. E0929. B0124547. FN	1987	9	16
NPR. TDRR. N8. D87268. S2135. E2316. B0138082. FN	1987	9	25
NPR. TDRR. N8. D87273. S1509. E1637. B0144748. FN	1987	9	30
NPR. TDRR. N8. D87285. S2128. E2310. B0162022. FN	1987	10	12
NPR. TDRR. N8. D87292. S0206. E1807. B0169504. FN	1987	10	19
NPR. TDRR. N8. D87292. S0207. E1451. B0169502. FN	1987	10	19
NPR. TDRR. N8. D87292. S0823. E1629. B0169803. FN	1987	10	19
NPR. TDRR. N8. D87293. S0200. E1439. B0170916. FN	1987	10	20
NPR. TDRR. N8. D87294. S1751. E0040. B0174650. FN	1987	10	21
NPR. TDRR. N8. D87295. S0146. E1235. B0173643. FN	1987	10	22
NPR. TDRR. N8. D87295. S0148. E0906. B0173641. FN	1987	10	22
NPR. TDRR. N8. D87300. S0016. E1316. B0180614. FN	1987	10	27
NPR. TDRR. N8. D87300. S0021. E2200. B0180619. FN	1987	10	27
NPR. TDRR. N8. D87301. S0015. E2148. B0182033. FN	1987	10	28
NPR. TDRR. N8. D87302. S0010. E1251. B0183542. FN	1987	10	29
NPR. TDRR. N8. D87302. S0013. E0921. B0183540. FN	1987	10	29
NPR. TDRR. N8. D87303. S0425. E1238. B0185156. FN	1987	10	30
NPR. TDRR. N8. D87304. S0359. E0546. B0187880. FN	1987	10	31
NPR. TDRR. N8. D87304. S1433. E2252. B0187176. FN	1987	10	31
NPR. TDRR. N8. D87305. S0003. E0024. B0189191. FN	1987	11	1
NPR. TDRR. N8. D87305. S0006. E1355. B0187785. FN	1987	11	1
NPR. TDRR. N8. D87306. S0228. E1343. B0189299. FN	1987	11	2
NPR. TDRR. N8. D87306. S0231. E1014. B0189297. FN	1987	11	2
NPR. TDRR. N8. D87307. S0209. E0501. B0192022. FN	1987	11	3
NPR. TDRR. N8. D87307. S0215. E1331. B0190613. FN	1987	11	3
NPR. TDRR. N8. D87308. S0206. E0949. B0192025. FN	1987	11	4
NPR. TDRR. N8. D87308. S0537. E2203. B0192232. FN	1987	11	4
NPR. TDRR. N8. D87309. S0741. E0924. B0195153. FN	1987	11	5
NPR. TDRR. N8. D87310. S0738. E0050. B0196676. FN	1987	11	6
NPR. TDRR. N8. D87310. S2318. E0051. B0197676. FN	1987	11	6
NPR. TDRR. N8. D87311. S0429. E1421. B0196470. FN	1987	11	7
NPR. TDRR. N8. D87311. S0741. E2127. B0196574. FN	1987	11	7
NPR. TDRR. N8. D87311. S1409. E1536. B0198384. FN	1987	11	7
NPR. TDRR. N8. D87312. S0421. E1229. B0197883. FN	1987	11	8
NPR. TDRR. N8. D87312. S0731. E2115. B0197988. FN	1987	11	8
NPR. TDRR. N8. D87313. S0523. E0023. B0199304. FN	1987	11	9
NPR. TDRR. N8. D87313. S1214. E1305. B0201011. FN	1987	11	9
NPR. TDRR. N8. D87316. S0756. E1500. B0203641. FN	1987	11	12
NPR. TDRR. N8. D87317. S2139. E2322. B0207274. FN	1987	11	13
NPR. TDRR. N8. D87318. S0741. E0053. B0207989. FN	1987	11	14
NPR. TDRR. N8. D87318. S1421. E1602. B0208284. FN	1987	11	14
NPR. TDRR. N8. D87319. S0438. E1424. B0207783. FN	1987	11	15
NPR. TDRR. N8. D87319. S0744. E2130. B0207887. FN	1987	11	15
NPR. TDRR. N8. D87320. S1537. E2258. B0209802. FN	1987	11	16
NPR. TDRR. N8. D87321. S0209. E0350. B0211819. FN	1987	11	17
NPR. TDRR. N8. D87321. S0425. E1220. B0210510. FN	1987	11	17
NPR. TDRR. N8. D87322. S1346. E0014. B0212531. FN	1987	11	18
NPR. TDRR. N8. D87323. S0223. E1336. B0213239. FN	1987	11	19

METEOROLOGICAL SATELLITE CENTER TECHNICAL NOTE, No.55, FEBRUARY, 2011

NPR. TDRR. N8. D87323. S0226. E1008. B0213237. FN	1987	11	19
NPR. TDRR. N8. D87324. S0205. E0455. B0216062. FN	1987	11	20
NPR. TDRR. N8. D87324. S0214. E0955. B0214651. FN	1987	11	20
NPR. TDRR. N8. D87324. S0545. E2209. B0214858. FN	1987	11	20
NPR. TDRR. N8. D87325. S0155. E1629. B0216069. FN	1987	11	21
NPR. TDRR. N8. D87325. S0536. E2157. B0216272. FN	1987	11	21
NPR. TDRR. N8. D87326. S0527. E0109. B0217688. FN	1987	11	22
NPR. TDRR. N8. D87326. S0530. E2145. B0217686. FN	1987	11	22
NPR. TDRR. N8. D87326. S0800. E0056. B0219302. FN	1987	11	22
NPR. TDRR. N8. D87327. S0446. E1427. B0219096. FN	1987	11	23
NPR. TDRR. N8. D87327. S0803. E2132. B0219200. FN	1987	11	23
NPR. TDRR. N8. D87328. S0439. E1235. B0220409. FN	1987	11	24
NPR. TDRR. N8. D87329. S0639. E2249. B0221929. FN	1987	11	25
NPR. TDRR. N8. D87329. S0641. E1405. B0221924. FN	1987	11	25
NPR. TDRR. N8. D87330. S0158. E0327. B0224546. FN	1987	11	26
NPR. TDRR. N8. D87330. S0427. E1531. B0223239. FN	1987	11	26
NPR. TDRR. N8. D87330. S0429. E1203. B0223237. FN	1987	11	26
NPR. TDRR. N8. D87330. S1008. E1158. B0225051. FN	1987	11	26
NPR. TDRR. N8. D87331. S0225. E0510. B0225961. FN	1987	11	27
NPR. TDRR. N8. D87331. S0232. E1339. B0224552. FN	1987	11	27
NPR. TDRR. N8. D87331. S0235. E1011. B0224550. FN	1987	11	27
NPR. TDRR. N8. D87332. S0219. E1327. B0225966. FN	1987	11	28
NPR. TDRR. N8. D87332. S0222. E0958. B0226064. FN	1987	11	28
NPR. TDRR. N8. D87333. S0205. E0446. B0228789. FN	1987	11	29
NPR. TDRR. N8. D87333. S0210. E1315. B0227380. FN	1987	11	29
NPR. TDRR. N8. D87333. S0212. E0946. B0227478. FN	1987	11	29
NPR. TDRR. N8. D87333. S0932. E1119. B0229193. FN	1987	11	29
NPR. TDRR. N8. D87335. S0441. E1430. B0230309. FN	1987	12	1
NPR. TDRR. N8. D87335. S0740. E2136. B0230413. FN	1987	12	1
NPR. TDRR. N8. D87336. S0807. E2304. B0231928. FN	1987	12	2
NPR. TDRR. N8. D88018. S0924. E1112. B0299799. FN	1988	1	18
NPR. TDRR. N8. D88020. S0459. E1423. B0300915. FN	1988	1	20
NPR. TDRR. N8. D88020. S1537. E1720. B0302830. FN	1988	1	20
NPR. TDRR. N8. D88021. S0649. E0850. B0303940. FN	1988	1	21
NPR. TDRR. N8. D88021. S0756. E2116. B0302533. FN	1988	1	21
NPR. TDRR. N8. D88022. S0410. E1539. B0303744. FN	1988	1	22
NPR. TDRR. N8. D88022. S0412. E1215. B0303742. FN	1988	1	22
NPR. TDRR. N8. D88022. S0537. E0835. B0305254. FN	1988	1	22
NPR. TDRR. N8. D88023. S0406. E1528. B0305158. FN	1988	1	23
NPR. TDRR. N8. D88023. S0407. E1206. B0305156. FN	1988	1	23
NPR. TDRR. N8. D88023. S0857. E2233. B0305362. FN	1988	1	23
NPR. TDRR. N8. D88025. S0500. E0756. B0309496. FN	1988	1	25
NPR. TDRR. N8. D88025. S0824. E2208. B0308190. FN	1988	1	25
NPR. TDRR. N8. D88026. S0137. E1806. B0309202. FN	1988	1	26
NPR. TDRR. N8. D88026. S0138. E1450. B0309200. FN	1988	1	26
NPR. TDRR. N8. D88026. S0803. E2156. B0309604. FN	1988	1	26
NPR. TDRR. N8. D88026. S0805. E1628. B0309601. FN	1988	1	26
NPR. TDRR. N8. D88026. S2322. E0108. B0311819. FN	1988	1	26
NPR. TDRR. N8. D88027. S0129. E1439. B0310614. FN	1988	1	27
NPR. TDRR. N8. D88027. S0131. E1114. B0310612. FN	1988	1	27
NPR. TDRR. N8. D88028. S1048. E1234. B0313941. FN	1988	1	28
NPR. TDRR. N8. D88030. S0416. E1222. B0315156. FN	1988	1	30
NPR. TDRR. N8. D88030. S0912. E2248. B0315361. FN	1988	1	30
NPR. TDRR. N8. D88031. S0351. E1531. B0316471. FN	1988	1	31
NPR. TDRR. N8. D88031. S0352. E1210. B0316469. FN	1988	1	31
NPR. TDRR. N8. D88031. S0844. E2236. B0316675. FN	1988	1	31
NPR. TDRR. N8. D88031. S0903. E1339. B0318184. FN	1988	1	31
NPR. TDRR. N8. D88031. S2232. E0004. B0318990. FN	1988	1	31
NPR. TDRR. N8. D88032. S0410. E1518. B0317885. FN	1988	2	1
NPR. TDRR. N8. D88032. S0411. E1157. B0317883. FN	1988	2	1
NPR. TDRR. N8. D88032. S1143. E1326. B0319698. FN	1988	2	1
NPR. TDRR. N8. D88033. S1806. E2159. B0321517. FN	1988	2	2
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DMSP-10

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NPR. TDRR. S4. D93253. S2313. E2317. A0014514. NS	1993	9	10

METEOROLOGICAL SATELLITE CENTER TECHNICAL NOTE, No.55, FEBRUARY, 2011

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METEOROLOGICAL SATELLITE CENTER TECHNICAL NOTE, No.55, FEBRUARY, 2011

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METEOROLOGICAL SATELLITE CENTER TECHNICAL NOTE, No.55, FEBRUARY, 2011

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DMSP-11

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DMSP-13

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DMSP-14

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NPR. TDRR. S8. D99329. S2340. E0038. B1361920. NS	1999	11	25
NPR. TDRR. S8. D99346. S0234. E0330. B1386162. NS	1999	12	12
NPR. TDRR. S8. D99363. S2313. E0010. B1409900. NS	1999	12	29
NPR. TDRR. S8. D00014. S2132. E2307. B1432526. NS	2000	1	14
NPR. TDRR. S8. D00083. S2004. E2140. B1531213. NS	2000	3	23
NPR. TDRR. S8. D00092. S0105. E0225. B1542829. NS	2000	4	1
NPR. TDRR. S8. D00133. S2106. E2242. B1601920. NS	2000	5	12
NPR. TDRR. S8. D00346. S2220. E2326. B1902930. NS	2000	12	11
NPR. TDRR. S8. D01342. S0458. E0642. B2413536. NS	2001	12	8
NPR. TDRR. S8. D02021. S2227. E0104. B2475455. NS	2002	1	21
NPR. TDRR. S8. D02081. S2341. E0052. B2560203. NS	2002	3	22
NPR. TDRR. S8. D02188. S2042. E2216. B2712728. NS	2002	7	7
NPR. TDRR. S8. D03097. S1703. E1758. B3099999. NS	2003	4	7
NPR. TDRR. S8. D03175. S0319. E0441. B3209494. NS	2003	6	24
NPR. TDRR. S8. D03230. S0652. E0851. B3287475. NS	2003	8	18
NPR. TDRR. S8. D03292. S2312. E0022. B3376060. NS	2003	10	19
NPR. TDRR. S8. D04011. S2321. E0037. B3494848. NS	2004	1	11
NPR. TDRR. S8. D04027. S2254. E0003. B3517474. NS	2004	1	27
NPR. TDRR. S8. D04149. S1016. E1121. B3689292. NS	2004	5	28
NPR. TDRR. S8. D04313. S0612. E0858. B3920910. NS	2004	11	8
NPR. TDRR. S8. D04361. S0817. E0953. B3988990. NS	2004	12	26
NPR. TDRR. S8. D05025. S2109. E2238. B4032122. NS	2005	1	25
NPR. TDRR. S8. D05043. S1654. E1737. B4057373. NS	2005	2	12
NPR. TDRR. S8. D05081. S2312. E0016. B4111414. NS	2005	3	22
NPR. TDRR. S8. D05147. S2350. E0128. B4204849. NS	2005	5	27
NPR. TDRR. S8. D05150. S0758. E0954. B4208182. NS	2005	5	30
NPR. TDRR. S8. D05205. S1504. E1600. B4286363. NS	2005	7	24
NPR. TDRR. S8. D06018. S0338. E0447. B4537474. NS	2006	1	18
NPR. TDRR. S8. D06075. S2234. E0118. B4619192. NS	2006	3	16
NPR. TDRR. S8. D06115. S1809. E0007. B4675457. NS	2006	4	25
NPR. TDRR. S8. D06347. S0913. E0945. B5003030. NS	2006	12	13

NPR. TDRR. S8. D06350. S2335. E0007. B5008181. NS	2006	12	16
NPR. TDRR. S8. D07008. S2258. E0341. B5040608. NS	2007	1	8
NPR. TDRR. S8. D07041. S2135. E0128. B5087274. NS	2007	2	10
NPR. TDRR. S8. D07051. S2227. E0324. B5101316. NS	2007	2	20
NPR. TDRR. S8. D07066. S2357. E0448. B5122729. NS	2007	3	7
NPR. TDRR. S8. D07068. S2328. E0419. B5125557. NS	2007	3	9
NPR. TDRR. S8. D07110. S2322. E0415. B5184951. NS	2007	4	20
NPR. TDRR. S8. D07134. S2247. E0004. B5218888. NS	2007	5	14
NPR. TDRR. S8. D07134. S2247. E2355. B5218888. NS	2007	5	14
NPR. TDRR. S8. D07144. S2154. E0424. B5232932. NS	2007	5	24
NPR. TDRR. S8. D07147. S2350. E0342. B5237274. NS	2007	5	27
NPR. TDRR. S8. D07239. S2046. E2225. B5367273. NS	2007	8	27
NPR. TDRR. S8. D07244. S1940. E0126. B5374245. NS	2007	9	1
NPR. TDRR. S8. D07331. S2355. E0057. B5497575. NS	2007	11	27
NPR. TDRR. S8. D08043. S2231. E0007. B5606364. NS	2008	2	12
NPR. TDRR. S8. D08044. S2155. E0044. B5607778. NS	2008	2	13
NPR. TDRR. S8. D08091. S2354. E0256. B5674344. NS	2008	3	31
NPR. TDRR. S8. D08099. S1316. E1456. B5685051. NS	2008	4	8
NPR. TDRR. S8. D08125. S2359. E0130. B5722424. NS	2008	5	4
NPR. TDRR. S8. D08155. S2221. E0006. B5764748. NS	2008	6	3
NPR. TDRR. S8. D08178. S2255. E0021. B5797373. NS	2008	6	26
NPR. TDRR. S8. D08199. S2302. E0200. B5827071. NS	2008	7	17
NPR. TDRR. S8. D08203. S2332. E0051. B5832627. NS	2008	7	21
NPR. TDRR. S8. D08232. S0220. E0400. B5872425. NS	2008	8	19

DMSP-15

file name	year	month	day
NPR. TDRR. S9. D00088. S2302. E2359. B0150405. NS	2000	3	28
NPR. TDRR. S9. D00110. S1927. E2110. B0182526. NS	2000	4	19
NPR. TDRR. S9. D00136. S0256. E0440. B0218384. NS	2000	5	15
NPR. TDRR. S9. D00162. S1307. E1359. B0255758. NS	2000	6	10
NPR. TDRR. S9. D00220. S1735. E1918. B0337980. NS	2000	8	7
NPR. TDRR. S9. D00340. S0555. E0730. B0506970. NS	2000	12	5
NPR. TDRR. S9. D01069. S2029. E2200. B0642122. NS	2001	3	10
NPR. TDRR. S9. D01285. S2145. E2224. B0947677. NS	2001	10	12
NPR. TDRR. S9. D01315. S1509. E1648. B0989798. NS	2001	11	11
NPR. TDRR. S9. D01352. S0601. E0642. B1041415. NS	2001	12	18
NPR. TDRR. S9. D02010. S1720. E1903. B1074748. NS	2002	1	10
NPR. TDRR. S9. D02113. S0643. E0806. B1219798. NS	2002	4	23
NPR. TDRR. S9. D02122. S0617. E0731. B1232425. NS	2002	5	2
NPR. TDRR. S9. D02161. S2354. E0111. B1287273. NS	2002	6	10
NPR. TDRR. S9. D02169. S0445. E0619. B1298889. NS	2002	6	18
NPR. TDRR. S9. D02174. S1211. E1303. B1306364. NS	2002	6	23
NPR. TDRR. S9. D02186. S0850. E1236. B1323233. NS	2002	7	5
NPR. TDRR. S9. D02209. S0807. E0958. B1355657. NS	2002	7	28
NPR. TDRR. S9. D02221. S2359. E0144. B1373536. NS	2002	8	9
NPR. TDRR. S9. D02234. S2359. E0141. B1391920. NS	2002	8	22
NPR. TDRR. S9. D02244. S2137. E2320. B1405960. NS	2002	9	1
NPR. TDRR. S9. D02250. S2337. E0100. B1413132. NS	2002	9	7
NPR. TDRR. S9. D03210. S2359. E0144. B1874445. NS	2003	7	29
NPR. TDRR. S9. D03265. S0459. E0634. B1951112. NS	2003	9	22
NPR. TDRR. S9. D03270. S0209. E0302. B1958080. NS	2003	9	27
NPR. TDRR. S9. D03270. S0210. E0302. B1958080. NS	2003	9	27
NPR. TDRR. S9. D05112. S2249. E0024. B2770001. NS	2005	4	22
NPR. TDRR. S9. D05185. S2242. E0012. B2873334. NS	2005	7	4
NPR. TDRR. S9. D05212. S1330. E1332. B2911010. NS	2005	7	31
NPR. TDRR. S9. D05345. S2331. E0108. B3099899. NS	2005	12	11
NPR. TDRR. S9. D06022. S2242. E0027. B3159394. NS	2006	1	22
NPR. TDRR. S9. D06090. S1758. E1758. B3255252. NS	2006	3	31
NPR. TDRR. S9. D06190. S1204. E1313. B3396465. NS	2006	7	9
NPR. TDRR. S9. D06307. S2324. E0102. B3562627. NS	2006	11	3
NPR. TDRR. S9. D07037. S2242. E2315. B3697171. NS	2007	2	6
NPR. TDRR. S9. D07078. S2348. E0144. B3755253. NS	2007	3	19
NPR. TDRR. S9. D07126. S2109. E2145. B3822930. NS	2007	5	6
NPR. TDRR. S9. D07134. S2238. E0015. B3834344. NS	2007	5	14
NPR. TDRR. S9. D07181. S0220. E0355. B3899798. NS	2007	6	30
NPR. TDRR. S9. D07248. S2317. E0112. B3995859. NS	2007	9	5
NPR. TDRR. S9. D07349. S2253. E0035. B4138788. NS	2007	12	15
NPR. TDRR. S9. D08006. S2330. E0114. B4169900. NS	2008	1	6
NPR. TDRR. S9. D08049. S1224. E1328. B4230001. NS	2008	2	18
NPR. TDRR. S9. D08071. S2359. E0103. B4261819. NS	2008	3	11
NPR. TDRR. S9. D08085. S2337. E0059. B4281617. NS	2008	3	25
NPR. TDRR. S9. D08137. S2340. E0115. B4355253. NS	2008	5	16
NPR. TDRR. S9. D08171. S2316. E0048. B4403334. NS	2008	6	19
NPR. TDRR. S9. D08213. S0021. E0153. B4461516. NS	2008	7	31
NPR. TDRR. S9. D08217. S2313. E0049. B4468485. NS	2008	8	4

NPR. TDRR. S9. D08237. S2304. E0000. B4496768. NS	2008	8	24
NPR. TDRR. S9. D08273. S2355. E0130. B4547778. NS	2008	9	29
NPR. TDRR. S9. D08280. S2348. E0123. B4557677. NS	2008	10	6
NPR. TDRR. S9. D08295. S2317. E0052. B4578889. NS	2008	10	21
NPR. TDRR. S9. D08358. S2351. E0127. B4668081. NS	2008	12	23
NPR. TDRR. S9. D08359. S2332. E0112. B4669495. NS	2008	12	24
NPR. TDRR. S9. D09026. S2338. E0105. B4716262. NS	2009	1	26
NPR. TDRR. S9. D09033. S2322. E0057. B4726061. NS	2009	2	2
NPR. TDRR. S9. D09036. S0014. E0018. B4729090. NS	2009	2	5
NPR. TDRR. S9. D09067. S2300. E0035. B4774142. NS	2009	3	8
NPR. TDRR. S9. D09093. S2310. E0036. B4811010. NS	2009	4	3
NPR. TDRR. S9. D09097. S2340. E0115. B4816667. NS	2009	4	7
NPR. TDRR. S9. D09103. S2348. E0123. B4825152. NS	2009	4	13
NPR. TDRR. S9. D09124. S2325. E0100. B4854849. NS	2009	5	4
NPR. TDRR. S9. D09132. S2302. E0037. B4866162. NS	2009	5	12
NPR. TDRR. S9. D09201. S2344. E0119. B4963839. NS	2009	7	20
NPR. TDRR. S9. D09208. S2336. E0111. B4973738. NS	2009	7	27
NPR. TDRR. S9. D09243. S0034. E0218. B5022021. NS	2009	8	31
NPR. TDRR. S9. D09243. S0218. E0358. B5022121. NS	2009	8	31
NPR. TDRR. S9. D09243. S0355. E0539. B5022122. NS	2009	8	31
NPR. TDRR. S9. D09243. S0537. E0743. B5022224. NS	2009	8	31
NPR. TDRR. S9. D09243. S0744. E0924. B5022425. NS	2009	8	31
NPR. TDRR. S9. D09243. S2258. E0033. B5023233. NS	2009	8	31
NPR. TDRR. S9. D09250. S2247. E0027. B5033132. NS	2009	9	7
NPR. TDRR. S9. D09254. S2343. E0132. B5038990. NS	2009	9	11
NPR. TDRR. S9. D09287. S2338. E0100. B5085656. NS	2009	10	14
NPR. TDRR. S9. D09289. S2123. E2303. B5088384. NS	2009	10	16
NPR. TDRR. S9. D09305. S0110. E0258. B5110001. NS	2009	11	1
NPR. TDRR. S9. D09310. S2238. E0004. B5118081. NS	2009	11	6
NPR. TDRR. S9. D09312. S2345. E0116. B5120910. NS	2009	11	8
NPR. TDRR. S9. D09315. S2249. E0029. B5125152. NS	2009	11	11
NPR. TDRR. S9. D09318. S2348. E0123. B5129495. NS	2009	11	14
NPR. TDRR. S9. D09323. S2230. E0005. B5136465. NS	2009	11	19
NPR. TDRR. S9. D09332. S2329. E0109. B5149293. NS	2009	11	28
NPR. TDRR. S9. D09333. S2314. E0053. B5150607. NS	2009	11	29
NPR. TDRR. S9. D09334. S1927. E2112. B5152021. NS	2009	11	30

DMSP-16

file name	year	month	day
NPR. SDEB. SA. D07008. S1815. E2018. B1664142. NS	2007	1	8
NPR. SDEB. SA. D07150. S1711. E1842. B1864647. NS	2007	5	30
NPR. SDEB. SA. D07175. S1304. E1320. B1899697. NS	2007	6	24
NPR. SDEB. SA. D07220. S1710. E1854. B1963536. NS	2007	8	8
NPR. SDEB. SA. D07230. S0614. E0800. B1977071. NS	2007	8	18
NPR. SDEB. SA. D07269. S0611. E0000. B2033132. NS	2007	9	26
NPR. SDEB. SA. D07328. S1431. E1613. B2116061. NS	2007	11	24
NPR. SDEB. SA. D07330. S2335. E0006. B2119394. NS	2007	11	26
NPR. SDEB. SA. D07335. S1319. E1447. B2125859. NS	2007	12	1
NPR. SDEB. SA. D08045. S2045. E2230. B2232223. NS	2008	2	14
NPR. SDEB. SA. D08073. S1129. E1315. B2271213. NS	2008	3	13
NPR. SDEB. SA. D08096. S2149. E2149. B2304243. NS	2008	4	5
NPR. SDEB. SA. D08136. S0238. E0000. B2360809. NS	2008	5	15
NPR. SDEB. SA. D08142. S2341. E0127. B2369495. NS	2008	5	21
NPR. SDEB. SA. D08143. S1152. E1337. B2370102. NS	2008	5	22
NPR. SDEB. SA. D08147. S1231. E1231. B2375758. NS	2008	5	26
NPR. SDEB. SA. D08181. S2039. E2215. B2424344. NS	2008	6	29
NPR. SDEB. SA. D08186. S2248. E0034. B2431516. NS	2008	7	4
NPR. SDEB. SA. D08214. S0313. E0457. B2469900. NS	2008	8	1
NPR. SDEB. SA. D08216. S0256. E0433. B2472728. NS	2008	8	3
NPR. SDEB. SA. D08216. S0429. E0613. B2472829. NS	2008	8	3
NPR. SDEB. SA. D08217. S0557. E0742. B2474344. NS	2008	8	4
NPR. SDEB. SA. D08227. S0029. E0213. B2488182. NS	2008	8	14
NPR. SDEB. SA. D08232. S0107. E0251. B2495253. NS	2008	8	19
NPR. SDEB. SA. D08260. S0015. E0211. B2534748. NS	2008	9	16
NPR. SDEB. SA. D08263. S0119. E0303. B2539091. NS	2008	9	19
NPR. SDEB. SA. D08264. S0634. E0840. B2540708. NS	2008	9	20
NPR. SDEB. SA. D08264. S1007. E1152. B2540910. NS	2008	9	20
NPR. SDEB. SA. D08264. S1200. E1346. B2541011. NS	2008	9	20
NPR. SDEB. SA. D08264. S1408. E1552. B2541112. NS	2008	9	20
NPR. SDEB. SA. D08282. S0811. E0957. B2566263. NS	2008	10	8
NPR. SDEB. SA. D08296. S0607. E0754. B2585960. NS	2008	10	22
NPR. SDEB. SA. D08306. S0507. E0545. B2599900. NS	2008	11	1
NPR. SDEB. SA. D09006. S2046. E2212. B2694142. NS	2009	1	6
NPR. SDEB. SA. D09189. S1620. E1804. B2952324. NS	2009	7	8
NPR. SDEB. SA. D09208. S1221. E0000. B2979596. NS	2009	7	27
NPR. SDEB. SA. D09209. S2005. E2150. B2980809. NS	2009	7	28

NPR. SDEB. SA. D09209. S2146. E2322. B2980910. NS 2009 7 28

DMSP-17

file name	year	month	day
NPR. SDEB. SB. D08162. S1214. E1320. B0824849. NS	2008	6	10
NPR. SDEB. SB. D08182. S2103. E2249. B0853637. NS	2008	6	30
NPR. SDEB. SB. D08183. S0207. E0351. B0853940. NS	2008	7	1
NPR. SDEB. SB. D08183. S1243. E1421. B0854546. NS	2008	7	1
NPR. SDEB. SB. D08216. S0223. E0337. B0900506. NS	2008	8	3
NPR. SDEB. SB. D08236. S2311. E0054. B0930001. NS	2008	8	23
NPR. SDEB. SB. D08262. S0926. E1112. B0965960. NS	2008	9	18
NPR. SDEB. SB. D08262. S0953. E1112. B0965960. NS	2008	9	18
NPR. SDEB. SB. D09077. S1143. E1328. B1221718. NS	2009	3	18
NPR. SDEB. SB. D09106. S2215. E0000. B1263334. NS	2009	4	16
NPR. SDEB. SB. D09170. S0019. E0205. B1352425. NS	2009	6	19
NPR. SDEB. SB. D09223. S1808. E1953. B1428384. NS	2009	8	11

SSM/I に含まれるナビゲーションエラーの除去について

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要 旨

気象庁長期再解析（JRA-55）のための観測データの整備の過程で DMSP 衛星の SSM/I データにナビゲーションエラーが存在することが分った。これらナビゲーションエラーを除去する手法を開発し SSM/I の TDR 及び SDR ファイルに適用した。この手法は非常に簡単な衛星軌道計算に基づいており、衛星軌道データなど SSM/I データファイル以外の情報を用いることなくエラーを除去することができる。このレポートではこの手法を実現するコンピュータプログラムも紹介する。

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