Competition Sensitive

Raytheon Company	TITLE SSM/I Processing Guide	NUMBER PG32268-501	
		FSCM 82577	
		TOTAL PAGES 19	REV A

RELEASE AGENCY	RELEASED PRINT		
P	A	3/20/98	pm
CODE	REV	REL DATE	REL BY

APPROVALS	DATE	APPROVALS	DATE
ORIGINATOR: B. Swanson		QA: J. Marko	
TEST LEAD: J. Austin			
Signatures on File			
PROG MGR: R. Carpenter		CM: [signature]	3/20/98

Raytheon

SSM/I Processing Guide

Contract Number F04701-96-C-0026

02 March, 1998

PG32268-501 Revision A

Revision History

Rev.	Date	Description of changes
A	02 Mar 98	Changed all Hughes references to Raytheon

Table of Contents

1. Scope

This document describes procedures used for processing SSM/I data with the Sensor Data Processor (SDP) software. This document also includes some suggested improvements to the existing procedures.

2. Background

The Special Sensor Microwave/Imager (SSM/I) sensors provide measurements of atmospheric, ocean, and terrain microwave brightness temperatures at 19.35 GHz vertical and horiztontal polarizations (V & H), 22.235 GHz V, 37.0 GHz V & H, and 85.5 GHz V & H. The SSM/I rotates continuously about an axis parallel to the local spacecraft vertical. The swath width is about 1425 km. Each scan consists of 128 discrete radiometric samples of the two (2) 85 GHz channels and, on alternate scans, 64 discrete samples are taken at the remaining five (5) lower frequency channels.

The SSM/I sensor rotates at 31.6 rpm (1.899 revolutions per second) to produce a conic scan. The DMSP spacecraft is orbiting in a near polar orbit at an altitude of approximately 833 km and a speed of 6.58 km/sec. The elevation angle of the SSM/I sensor rotation is nominally 45 degrees. The active portion of the scan occurs over approximately 102 degrees of the sensor rotation. The center of the active scan is aft of nadir (relative to spacecraft velocity) for morning ascending spacecraft and forward of nadir for afternoon ascending spacecraft. For the 85 GHz channels, the 128 scene stations per scan occur at even time intervals of 4.22 milliseconds, which is equivalent to a sensor rotation angle of 0.80 degrees. This time interval and angle are both doubled for the 64 lower frequency channel scene stations per scan. (The geometry of the SSM/I scan is described in the DMSP Processing Guide [1] and the ICD for DMSP Block 5D-2 Mission Sensor SSMI [2].)

The MI_SDP module assumes an oblate spheroid model of the earth, using a flattening factor $f = 1/298.3$, or $f = 0.00335233$. MI_SDP uses an eccentricity of $e = 0.081816$. MI_SDP assumes the earth's equatorial radius, $Re = 6378.165$ km, and the polar radius, $Rp = 6556.788$ km.

3. SSMI data ingest

1. Process each valid, complete frame of SSM/I data between the first and last sets of on board ephemeris. A frame consists of a sequential set of seven blocks in reverse numeric order, starting with type six and proceeding down to block type zero.

2. If the data quality pattern is not intact for any block types other than type 7, discard the entire frame and skip to the next frame of SSM/I data.

3. If any data block type zero through six appears out of sequence in the input file, discard the entire frame and skip to the next frame of SSM/I data. Note that the blocks appear in reverse numeric order in the input file (for stored data), block 6 through block 0, and block 7 may occur in any position.

4. Discard all block type 7 data.

5. Possible improvement : account for possibility of partial block (missing words 88-90) as described in DMSP Processing guide p. 36, or does code already do this?

4. SSM/I surface type tagging

1. Identify the earth surface type of each scene station as land, ocean, coast, ice or possible ice using the scene station's computed earth location and the surface type file.

5. SSM/I Calibration

1. For each frame of data (4 scans), calculate each of the three hot load reference temperatures, *Thl(i),* from the hot load thermistor voltages, *Vth(i),* as follows:

$$Thl(i) = a0(i) + a1(i) \times Vth(i) + a2(i) \times Vth(i)^2 + a3(i) \times Vth(i)^3 + a4(i) \times Vth(i)^4 + a5(i) \times Vth(i)^5$$

where *a0(i), a1(i),...a5(i)* are constants for each of the three thermistors *(i),* determined at sensor calibration time and listed in table 5-1. These constants are contained in the files DMS_F*nn*.cal, where *nn* is the spacecraft ID.

2. For each frame of data (4 scans), calculate the preliminary average hot load reference temperature, *Thlp*, from all operational hot load thermistors (nominally three).

3. For each frame of data (4 scans), calculate the RF mixer temperature, *Tmix,* from the RF mixer thermistor voltage, *Vmix,* as follows:

$$Tmix = c0 + c1 \times Vmix + c2 \times Vmix^2 + c3 \times Vmix^3 + c4 \times Vmix^4 + c5 \times Vmix^5$$

where *c0,c1,...c5* are constants for the RF mixer, determined at sensor calibration time and listed in table 5-2. These constants are contained in the files DMS_F*nn*.cal, where *nn* is the spacecraft ID.

4. For each frame of data (4 scans), calculate the forward radiator temperature, *Tfr,* from the forward radiator thermistor voltage, *Vfr,* as follows:

$$Tfr = d0 + d1 \times Vfr + d2 \times Vfr^2 + d3 \times Vfr^3 + d4 \times Vfr^4 + d5 \times Vfr^5$$

where *d0,d1,...d5)* are constants for the forward radiator, determined at sensor calibration time and listed in table 5-2. These constants are contained in the files DMS_F*nn*.cal, where *nn* is the spacecraft ID.

5. Calculate the corrected average hot load temperature, *Thl,* from the preliminary average, *Thlp*, using the following formula:

$$Thl = Thlp + (\alpha \times (Tfr - Thlp))$$

where α is a constant determined at sensor calibration time and listed in table 5-2.

6. For each frame, calculate the slope bias, *B1(i),* for each channel *i*, using the following formula:

$$B1(i) = F0(i) + F1(i) \times Tmix + F2(i) \times Tmix^2 + F3(i) \times Tmix^3 + F4(i) \times Tmix^4$$

where *F0(i), F1(i),...F4(i)* are constants determined at sensor calibration time for each channel and listed in table 5-3. These constants are contained in the files DMS_F*nn*.cal, where *nn* is the spacecraft ID.

7. For each frame, calculate the offset bias, *B0(i),* for each channel *i*, using the following formula:

$$B(i) = G0(i) + G1(i) \times Tmix + G2(i) \times Tmix^2 + G3(i) \times Tmix^3 + G4(i) \times Tmix^4$$

where *G0(i), G1(i),...G4(i)* are constants determined at sensor calibration time for each channel and listed in table 5-4. These constants are contained in the files DMS_F*nn*.cal, where *nn* is the spacecraft ID.

8. Calculate the average hot load and cold load voltages, *Vh(i)* and *Vc(i),* for each channel *i*, for the most recent 10 scans (5 type B and 5 type A scans), using all 5 hot and cold load voltages measured on each scan. If fewer than 10 scans have been read, calculate the average *Vh(i)* and *Vc(i)* for the number of scans read.

9. Calculate the calibration equation slope and offset, *slope(i)* and *offset(i),* for each channel *i*, using the following formulas:

$$slope(i) = \frac{Tc(i) - Thl + B1(i)}{Vc(i) - Vh(i)}$$

$$offset(i) = Thl + B0(i) - \frac{Tc(i) - Thl + B1(i)}{Vc(i) - Vh(i)}$$

where Tc(I) is the sensor cold load temperature, determined at sensor calibration time and listed in table 5-5. These constants are contained in the files DMS_F*nn*.cal, where *nn* is the spacecraft ID.

10. For each scene station *j* for each channel *i*, calculate the brightness temperature, *Tb(i,j)*, from the sensor voltage reading, *V(i,j),* using the following formula.

$$Tb(i,j) = offset(i) + (slope(i) \times V(i,j))$$

Table 5-1 Hot Load Reference Thermistor Calibration Constants

		Spacecraft (SSMI Serial Number)				
		F08 (2)	F10 (1R)	F11 (4)	F13 (7)	F14 (5)
Hot load	a0(1)					
thermistor	a1(1)					
number 1	a2(1)					
	a3(1)					
	a4(1)					
	a5(1)					
Hot load	a0(2)					
thermistor	a1(2)					
number 2	a2(2)					
	a3(2)					
	a4(2)					
	a5(2)					
Hot load	a0(3)					
thermistor	a1(3)					
number 3	a2(3)					
	a3(3)					
	a4(3)					
	a5(3)					

11. Output the calibrated brightness temperatures in the TDR format. [region(s)?]

12. Possible improvement: calculate transmissivity. See Special Sensor Microwave/Imager (SSM/I) Computer Program Development Specification (Rev C). p. 3-17.

Table 5-2 RF mixer thermistor (c), Forward Radiator thermistor (d), and hot load gradient calibration (α) constants

	F10	F11	F12	F13	F14
c0					
c1					
c2					
c3					
c4					
c5					
d0					
d1					
d2					
d3					
d4					
d5					
α					

Table 5-3 Slope Bias constants for each channel

B1(i)	F10	F11	F12	F13	F14
19V					
19H					
22V					
37V					
37H					
85V					
85H					

Table 5-4 Offset Bias constants for each channel

B0(i)	F10	F11	F12	F13	F14
19V					
19H					
22V					
37V					
37H					
85V					
85H					

Table 5-5 Cold Load temperature for each channel (Kelvin)

Tc(i)	F10	F11	F12	F13	F14
19V					
19H					
22V					

37V					
37H					
85V					
85H					

6. SSM/I antenna pattern correction (APC)

1. Correct for the effects of antenna sidelobes and cross polarization coupling by recalculating the brightness temperature of each observation as follows:

$$Corrected = A \times Current + B \times Cross + C \times Previous + D \times Next$$

Corrected is the corrected brightness temperature.
Current is the calibrated brightness temperature (Tb) of the current observation.
Cross is the calibrated Tb of the opposite polarization of the same frequency at the same scene station.
Previous is the calibrated Tb of the same polarization of the same frequency at the scene station immediately prior to the current station along the scan direction.
Next is the calibrated Tb of the same polarization of the same frequency at the scene station immediately following the current station along the scan direction.
A, B, C and *D* are constants determined at sensor calibration time for each channel and for 5 distinct regions across the scan width, included in the sensor calibration files.

2. For scene stations at the beginning of a scan, the *current* observation replaces the *previous* observation in the correction algorithm.

3. For scene stations at the end of a scan, the *current* observation replaces the *next* observation in the correction algorithm.

4. For the 22 GHz channel, the cross polarization value for 22 GHz horizontal (*cross*) is estimated from the 19 GHz horizontal brightness temperature at the same scene station as follows:

$$Tb(22H) = E + F \times Tb(19H)$$

where Tb(22H) is the estimated brightness temperature for 22 GHz horizontal and Tb(19H) is the actual calibrated brightness temperature of the 19 GHz horizontal channel (before APC), and *E* and *F* are constants determined at sensor calibration time, included in the sensor calibration files.

5. Allow for different correction constants *A, B, C*, and *D* for five distinct regions across the scan. Determine the boundaries between the regions from the sensor calibration file.

6. Output the APC modified data in the SDR format.

7. SSM/I environmental parameter calculation

1. The SDP calculates the following parameters using calibrated and antenna pattern corrected data as a basis:

    1) Cloud water over ocean (CWO)
    2) Ice edge flag (IE):
    3) Ice age (IA)
    4) Ice concentration (IC)
    5) Surface type (TYPE)
    6) Rain flag (accuracy of wind speed) (RF)
    7) Rain rate (RR)
    8) Snow depth (SND)
    9) Soil moisture (SM)
    10) Surface temperature (ST)
    11) Water vapor over ocean (WVO)
    12) Surface wind speed (SW)

2. The SDP calculates the environmental parameters according to the officially algorithms accepted by DMSP SPO, as specified in the letter "Official Environmental Parameter Extraction (EPE) Algorithms for SSM/I Software", or a more current version issued by the SPO. These algorithms are stored in the SSM/I EPE notebook.

3. The SDP calculates each EDR at a resolution of 25 km.

4. [How is higher resolution 85 GHz data correlated to the lower frequency scene stations for EDR calculations?]

8. MI_SDP Earth location algorithm

8.1 On board ephemeris

The ephemeris information included in the data stream is often called on board ephermeris. According to Don Bucher at Aerospace Corp., the ephemeris information is uplinked to the spacecraft once per day, and errors in this information is the primary source of location error in the data stream; that is, other factors such as clock drift are insignificant compared to on board ephemeris errors. The nadir point is determined by the bevel vector set, which provides more accurate location than a standard 2-card element set.

8.2 Bounding ephemeris vectors

In addition to the current satellite position, the earth location algorithm requires the position of the satellite at two additional points in the orbit: one prior to the current position and one after the current position. These two positions should be separated by no less than 60 seconds. In the first versions of MI_SDP, predicted ephemeris were used at one minute increments and thus were called minute vectors. This ephemeris information is now taken from the spacecraft data stream itself (on-board ephemeris) to improve the earth location accuracy. These positions are still sometimes referred to as minute vectors. The ephemeris information consists of a time, the spacecraft altitude, and the sub-satellite geodetic latitude and longitude at that time. In the MI_SDP code these locations are called *GDLAT1, GDLON1, GDLAT2*, and *GDLON2*, for the first position geodetic latitude and longitude, and second position geodetic latitude and longitude, respectively. Note that the bounding ephemeris vectors need not be calculated every scan, but only when the current spacecraft position is no longer between the bounding ephemeris positions.

In order to account for the rotation of the earth between the two ephemeris vectors, MI_SDP adjusts the longitude of the second ephemeris location and finds the longitude difference DAL as follows:

$$\text{GDLON2} = \text{GDLON2} + \text{EARROT} * (\text{T2} - \text{T1})$$
$$\text{DAL} = \text{GDLON2} - \text{GDLON1}$$

where EARROT is the rate of rotation of the earth (15 deg./hour) and T2 and T1 are the times associated with the second and first ephemeris vectors, respectively.

MI_SDP then converts the ephemeris geodetic latitudes to geocentric latitudes and determines the sine and cosine of each geocentric latitude (SINTH1, COSTH1, SINTH2, COSTH2).

$$\text{COSTH1} = \cos(\text{GDLAT1}) * (1 + e^2 * \sin^2(\text{GDLAT1}))$$
$$\text{SINTH1} = \sin(\text{GDLAT1}) * (1 - e^2 * \cos^2(\text{GDLAT1}))$$
$$\text{COSTH2} = \cos(\text{GDLAT2}) * (1 + e^2 * \sin^2(\text{GDLAT2}))$$
$$\text{SINTH2} = \sin(\text{GDLAT2}) * (1 - e^2 * \cos^2(\text{GDLAT2}))$$

where e is the eccentricity of the earth spheroid model. Note that in general, geocentric latitude *GCLAT* is related to geodetic latitude *GDLAT* as follows:

$$\tan(\text{GCLAT}) = (1 - e^2) * \tan(\text{GDLAT})$$

MI_SDP then calculates the geocentric angle between the ephemeris vectors *PSIO* as follows:

$$PSIO = \cos^{-1}(COSTH1 * COSTH2 * \cos(DAL) + SINTH1 * SINTH2)$$

where DAL = GDLON2 - GDLON1 as described above.

8.3 Nominal sensor boresight vector

MI_SDP calculates a vector which describes the direction in which the SSM/I is pointing at a number of evenly spaced scan angles. If the spacecraft is between 60 deg. South and 60 deg. North latitude, MI_SDP calculates this vector for 10 base points, and at greater than 60 deg. South or North, MI_SDP calculates boresight for 16 points across the scan. The number of base points is represented by the variable *NBPT* in the code. The spacecraft frame of reference is defined as follows: the Z direction is opposite nadir, the Y direction is the same as the spacecraft velocity, and the X direction is such that the X,Y, Z axes form a right handed coordinate system. Figure 3.2-1 shows the spacecraft frame of reference.

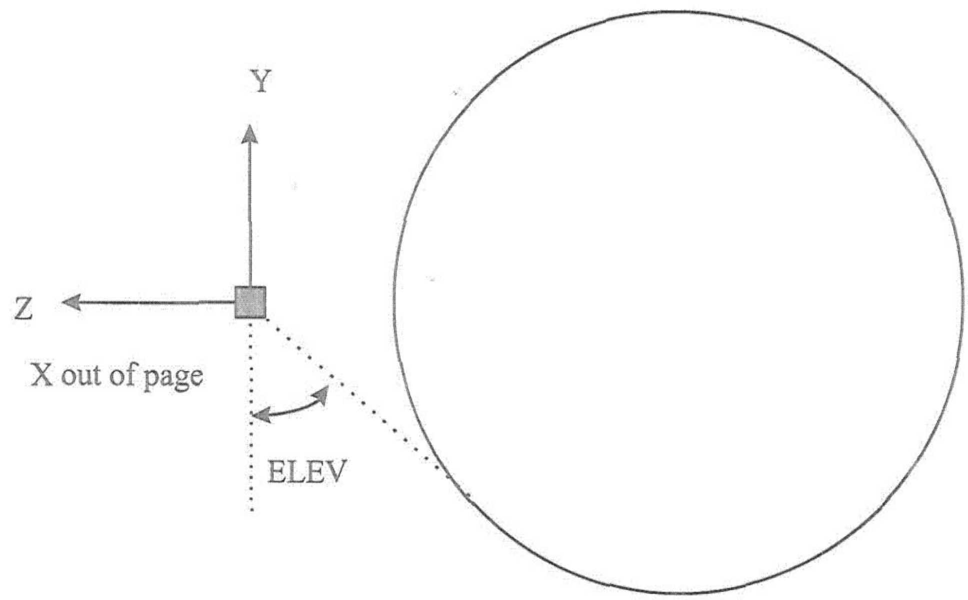

Figure 8.3-1 SSM/I Frame of reference

MI_SDP calculates the sensor elevation angle as follows:

$$ELEV = 45 \text{ deg.} + ELOFF$$

where ELOFF is the elevation offset defined for each sensor at calibration time. This value is stored in the spacecraft specific calibration file.

The initial sensor azimuth angle is determined as follows:

AZMTH = -51 deg. + SDNDIR * PI

where SCNDIR = 0.0 for an afternoon descending spacecraft and 1.0 for a morning ascending spacecraft. SCNDIR determines whether the active scan is fore of aft of the spacecraft. MI_SDP then calculates the azimuth angle AZMTH corresponding to each base point (either 10 or 16 as described above) and computes the sensor boresight vector [DXP, DYP, DZP] in the frame of reference defined above as follows for each base point:

DXP = cos(ELEV) * sin(AZMTH)
DYP = cos(ELEV) * cos(AZMTH)
DZP = - sin(ELEV)

8.4 Corrected sensor boresight vector

The Naval Research Laboratories compute SSM/I roll, pitch and yaw adjustments, relative to the spacecraft axes, for each sensor which are used to improve earth location accuracy. These factors are used to adjust the nominal boresight vector by rotating it in three dimensions. The Euler Symmetric Parameters method is used to make this adjustment, as described in Wertz, pp. 410-415 [5]. The Euler parameters are calculated from the pitch, roll, and yaw adjustments as described on page 6.5 of the SSM/I Calibration Validation Final Report Volume I [3] and included in each spacecraft specific calibration file. The Euler parameters are stored in the variables *EPS0, EPS1, EPS2*, and *EPS3* in MI_SDP. Note that the problem being solved by MI_SDP is the inverse of the problem described on pages 413-415 of Wertz [5], and thus the direction cosine matrix used in MI_SDP is the inverse of that shown in Wertz [5]. (Note that the direction cosine matrix A is a proper real orthogonal matrix, so $AA^T = 1$ and determinant(A) = 1 [5]). The corrected boresight vector at each base point [DXPC, DYPC, DZPC] is calculated as follows:

$$
\begin{aligned}
DXPC = {} & (EPS0^2 + EPS1^2 - EPS2^2 - EPS3^2) * DXP + \\
& 2*(EPS1*EPS2+EPS0*EPS3) * DYP + \\
& 2*(EPS1*EPS3-EPS0*EPS2)*DZP \\
DYPC = {} & 2*(EPS2*EPS1 - EPS0*EPS3)*DXP + \\
& (EPS0^2 - EPS1^2 + EPS2^2 - EPS3^2)*DYP + \\
& 2*(EPS2*EPS3 + EPS0*EPS1)*DZP \\
DZPC = {} & 2*(EPS3*EPS1 + EPS0*EPS2)*DXP + \\
& 2*(EPS2*EPS3 - EPS0*EPS1)*DYP + \\
& (EPS0^2 - EPS1^2 - EPS2^2 + EPS3^2)*DZP
\end{aligned}
$$

8.5 Subsatellite point for each base point

For each base point *i*, MI_SDP determines the time of base point *Ti* relative to the time of the first bounding ephemeris vector. The time Ti is then used to calculate the geocentric angle between the first ephemeris vector and the satellite *PHI*, and the geocentric angle between the second ephemeris vector and the satellite *POMPHI*. These angles are then used to calculate the sine and cosine of the geocentric subsatellite latitude, *SGCL* and *CGCL* respectively, and the subsatellite longitude *ALON*.

$$PHI = \frac{PSIO}{T2 - T1} \times Ti$$
$$POMPHI = PSIO - PHI$$
$$AL = \sqrt{\sin^2(PHI) + \sin^2(POMPHI) + 2 \times \sin(PHI) \times \sin(POM) \times \cos(PSIO)}$$
$$SGCL = \frac{\sin(POM) \times SINTH1 + \sin(PHI) \times SINTH2}{AL}$$
$$CGCL = \sqrt{1 - SGCL^2}$$

$$ALON = \tan^{-1}\left(\frac{\sin(PHI) \times COSTH2 \times \sin(GDLON2 - GDLON1)}{\sin(POM) \times COSTH1 + \sin(PHI) \times COSTH2 * \cos(GDLON2 - GDLON1)}\right) + GDLON1$$

where COSTH1, COSTH2, SINTH1,SINTH2, T1,T2,GDLON1,GDLON2, and PSIO are defined above.

MI_SDP then calculates the sine and cosine of the geodetic subsatellite latitude, *SGDL* and *CGDL* respectively.

$$SGDL = SGCL \times (1 + e^2 \times CGCL^2)$$
$$CGDL = CGCL \times (1 - e^2 \times SGCL^2)$$

8.6 Satellite altitude and heading

The satellite altitude at the time of each base point is calculated as a linear interpolation between the altitudes given by the bounding ephemeris vectors. This altitude is normalized by dividing by the mean equatorial radius of the earth and stored in the variable HT.

$$HT = \frac{(EPALT2 - EPALT1) \times \frac{Ti}{T2 - T1} + EPALT1}{R_{eq}}$$

where *EPATL1* and *EPALT2* are the satellite altitudes corresponding to the bounding ephemeris vectors, *T1* and *T2* are the times associated with those vectors, *Ti* is the time corresponding to the base point, and R_{eq} is the equatorial radius of the earth.

MI_SDP calculates the sine and cosine of the satellite heading, *SCHI* and *CCHI* respectively, based on the subsatellite points for two consecutive base points, i and i+1, as follows

$$X = CGCL(i+1) - CGCL(i)$$
$$Y = CGCL(i+1) \times (ALON(i+1) - ALON(i))$$
$$Z = SGCL(i+1) - SGCL(i)$$
$$R = \sqrt{X^2 + Y^2 + Z^2}$$
$$CCHI = \frac{Z \times CGDL(i) - X \times SGCL(i)}{R}$$
$$SCHI = Y \div R$$

8.7 Sensor boresight vector

MI_SDP calculates a unit vector in the direction which the antenna points [ALX,ALY,ALZ] in the ECR frame of reference, sometimes called the boresight vector, as follows

ALX = SGCL * (SCHI*DXPC - CCHI*DYPC) + CGDL*DZPC
ALY = CCHI*DXPC + SCHI*DYPC
ALZ = CGDL*(CCHI*DYPC - SCHI*DXPC) + SGDL*DZPC

8.8 Distance from spacecraft to scene along boresight vector

MI_SDP calculates the distance *RE* from the spacecraft to the base point along the boresight vector as follows

$$RSSP = 1 - \frac{e^2}{2} \times SGDL(1)^2$$

where SGDL(1) is the sine of the geodetic latitude of the first base point in the scan.

$$A1 = 1 + ACON1 \times ALZ^2$$
$$RSSPX = RSSP \times CGCL + HT \times CGDL$$
$$RSSPZ = RSSP \times SGCL + HT \times SGDL$$
$$B = RSSPX \times ALX + ACON2 \times RSSPZ \times ALZ$$
$$C = RSSPX^2 + ACON2 \times RSSPZ^2 - 1$$
$$RHO = -\frac{(B + \sqrt{B^2 - A1 \times C})}{A1}$$
$$REX = RSSPX + RHO \times ALZ$$
$$REY = RHO \times ALY$$
$$REZ = RSSPZ + RHO \times ALZ$$
$$RE = \sqrt{REX^2 + REY^2 + REZ^2}$$

where ACON1 is the constant 0.006738993 and ACON2 is the constant 1.006738993. (these values are hard coded).

8.9 Base point geodetic latitude and longitude

MI_SDP calculates the geodetic latitude and longitude of each base point as follows, correcting for earth rotation on the longitude value.

$$ST = \frac{REZ}{RE}$$

$$CT = \sqrt{1 - ST^2}$$

$$LAT = \sin^{-1}(ST) + e^2 \times ST \times CT$$

$$LONG = \tan^{-1}(REY \div REX) + ALON - Ti \times EARROT$$

where Ti is the time from the first ephemeris vector to the base point time, and EARROT is the rate of rotation of the earth (15 deg. / hour).

8.10 Interpolation of scene station locations

MI_SDP uses a Lagrange interpolation to locate the scene stations between the located base points. This interpolation algorithm is not described here.

8.11 Suggested improvements to earth location algorithm

In order to improve earth location accuracy, its is suggested that MI_SDP be modified to use the earth location algorithm described in the Calibration/Validation Report Volume I, section 6 [3]. Some of the details which are not specified in that document and corrections to that document are described here.

8.11.1 Base points and interpolation of locations

Rather than computing the locations of base points, which are a subset of the actual scene stations, and then performing a Lagrange interpolation to locate the scenes between the base points, it would presumably be more accurate to use the location algorithm to locate each scene station directly. The amount of computation required (and consequently CPU time required) should not be dramatically greater if each scene station is located.

8.11.2 Determination of the time at which a particular scene is observed

In the Calibration/Validation Report Volume I, section 6, the subsatellite geocentric position at pixel time *t* is calculated by interpolating between the bounding ephemeris vectors. The method of computing pixel time *t* is not obvious nor simple. Refer to the DMSP Processing Guide [1] page 44 for the method of determining the pixel time.

8.11.3 Correction to calculation of subsatellite position vector

In the Calibration/Validation Report Volume I, page 6-17, there is an error in the last term of the formula for calculating the second subsatellite position vector r_{s2}. The correct formula is

$$\hat{r}_{s2} = \cos\theta'_{s2}\cos(\phi_{s2} + \Delta\phi)\hat{x} + \cos\theta'_{s2}\sin(\phi_{s2} + \Delta\phi)\hat{y} + \sin\theta'_{s2}\hat{z}$$

8.11.4 Satellite altitude

Rather than interpolating between bounding ephemeris vectors to determine the satellite height, a more accurate method would be to use the satellite alititude supplied in the on board ephemeris information. Note that the altitude in the on board ephemeris is normalized by the mean equatorial radius (6378.145 km, according to the DMSP Data Specification p. 45) [6]. A correction should be made to account for the oblateness of the earth. The earth's radius at any latitude ϕ can be estimated by

$$R = \frac{R_e R_p}{\sqrt{R_e^{\,2}\sin^2\phi + R_p^{\,2}\cos^2\phi}}$$

$$R_p = R_e(1 - e^2)$$

where R_e is the earth's mean equatorial radius (6378.145 km), R_p is the polar radius, and e is the eccentricity of the spheroid.

8.11.5 Distance from spacecraft to scene station

In the SSM/I Calibration/Validation Final Report Volume I, p. 6-21 [3], the algorithm for earth location includes calculating the distance from the spacecraft to the scene station along the boresight vector, which is called the slant range, s. The document does not describe this formula, so it is described here.

$$s = \frac{B - \sqrt{B^2 - AC}}{A}$$

where

$$A = \hat{k}_z^{\,2} + (1 - e^2)(\hat{k}_x^{\,2} + \hat{k}_y^{\,2})$$

$$B = -sat_z\hat{k}_z - (1 - e^2)(sat_x\hat{k}_x + sat_y\hat{k}_y)$$

$$C = sat_z^{\,2} + (1 - e^2)(sat_x^{\,2} + sat_y^{\,2} - R_{eq}^{\,2})$$

and *sat* is the ECR vector to the satellite, k is a unit vector in the sensor boresight direction, e is the eccentricity of the earth, and R_{eq} is the equatorial radius of the earth. Note that the Calibration/Validation report calculates the satellite position as the vector sum of the geocentric subsatellite point plus the altitude in a direction normal to the spheroid.

9. References

[1] DMSP Processing Guide (draft). Aerospace Corp., 30 Mar. 1992.

[2] Interface Control Document for DMSP Block 5D-2 (S11-S14) Mission Sensor SSMI. (ICD-2617407) Prepared for Space Division, USAF, by General Electric Company, Astro Space Division. 07 June 1989.

[3] DMSP Special Sensor Microwave/Imager Calibration/Validation Final Report. Volume I. Naval Research Laboratory,1990.

[4] DMSP Special Sensor Microwave/Imager Calibration/Validation Final Report. Volume II. Naval Research Laboratory,1990.

[5] Wertz, James R., Editor. Spacecraft Attitude Determination and Control. Kluwer Academic Publishers, Boston.

[6] DMSP Data Specifications (28 April 1993) IS-YD-821 Rev. C., prepared for DMSP Headquarters Space and Missile Systems Center, USAF by Westinghouse Corp. Electronic systems Group, Space Division.

Special Sensor Microwave/Imager (SSM/I) Computer Program Development Specification (Rev C) for AFGWC (July 1986)

Sensor Data Processor Data Requirements Document (DRD). Raytheon Systems Company, March 1998.