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DMSR PROCESSING GUIDE

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DMSP PROCESSING GUIDE

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1. INTRODUCTION

The Defense Meteorological Satellite Program (DMSP) is frequently asked questions on processing of DMSP data from earth location of the data to radiometric accuracy. This guide provides information on how the data should be processed to extract most accurately the large variety of information that DMSP provides. In processing DMSP data, there are many alternatives for trading off speed and accuracy in the calculations. This guide provides the most accurate approach, although it may not be the algorithms that current DMSP ground processing systems use to extract the data. In many cases, to speed up the processing, the weather centrals use approximations that are not appropriate for accurate tactical use.

Many individual documents exist describing the DMSP operational linescan system, microwave imager, and microwave sounders. They do not provide, however, all the information that a developer needs to process the data; critical spacecraft parameters and data needed to do the processing are left out. This document provides all the information needed for processing DMSP data. It uses the metric system for describing all aspects of the system.

2. SPACECRAFT DESCRIPTION

The Block 5 DMSP spacecraft fly in a nominal orbit of 833 kilometers with an orbital period of 101 minutes. Normally, two spacecraft are in sun-synchronous or with ascending node times determined by Air Weather Service. Traditionally, one f an early morning earth terminator orbit and one flies a mid-morning orbit. The prima DMSP mission is to provide:

(a) Global Weather data, both visible and infrared, at a resolution of 2.5 kilometers.

(b) Tactical Weather data at a resolution of .5 kilometers

(c) Meteorological and Atmospheric Soundings to both Tactical and Strategi Users.

The primary sensor is the Operational Linescan System (OLS). This sensor provides nearly constant high resolution 0.3 km imagery in the infrared ther (10-12 microns) and visible light (.4 to 1 .1 micron) fine data. On board smoothing i done to decrease the data rate by a factor of 25, smoothing electronically the pixels the cross track direction and digitally averaging in the along track direction of the spacecraft. For the visible channel, automatic gain control is performed to handle th large radiance variation from night to day.

Satellites are known as F-xx when launched. Prior to launch, they are designated by S-xx. The 5D2 series of satellites encompassed S-6 through S-14, while the 5D3 series begins with S-15. At this time, satellites have been launched through F-11. Within each series, there will be different sensor complements. The particular serial number sensor flown may change up to 60 days to launch. It is therefore necessary to have the ground systems keep track of satellite configuratio as no two satellites are the same.

2.1 Spacecraft Transmissions

There are four main types of satellite data available on the F-10 through S-20 satellites:

- Real Time Data - High Resolution (RTD)
- Real Time Data Smooth (RDS)
- Stored Data (SD)
- Direct Telemetry Data

A combination of fine resolution (either visible or infrared) and the smooth resolution of the complementary image channel is provided in the High Resolution Real Time Data (RTD) channel. These data are transmitted at 1.024 Mbps on a directional 2252.5 MHz link over most remote sites, although it can be transmitted at 2207.5, 2237.5, and 2267.5 MHz links if needed at sites where there is interference at the primary frequency. The transmission times are scheduled to cover the remote sites needing the data.

Real Time Data Smooth (RDS) is transmitted at 66.56 kbps (F-10 through S-15) and at 87.75 kbps (S-16 through S-20). This data contains smooth resolution data from the OLS and all the mission sensor data. The visible and infrared channels are bit interleaved. In addition, this data stream contains earth location and time of the nadir satellite position. This data is transmitted on a directional down link at 2237.5 MHz, but can be also transmitted at 2207.5, 2267.5, and 2252.5 MHz if needed. A new S-band frequency is to be assigned to RDS beginning with S-16. Real Time Data Smooth is always encrypted on F-10, while on F-11 through S-20, it can also be transmitted in the clear. The transmission times are scheduled to cover the remote sites needing the data so as to conserve spacecraft power.

Stored Data (SD) is transmitted from on-board tape recorders at 2.66 Mbps over the Command Read-Out Sites (CRS), which are currently located at Fairchild AFB, Washington, Thule AFB, Greenland, and New Boston, NH. A Hawaii station (HULA) is used for several read-outs over the Pacific. This data is broadcast at 2267.5 MHz in an encrypted mode. The data order is reversed from normal time sequence because the tape recorders are played back without rewinding. The thermal and visible channels are bit interleaved, except in one non-interleaved mode of single channel fine data. There are two resolutions of stored OLS imagery. Complete global coverage is available at 2.5 kilometer smooth resolution, derived

from the high resolution .5 kilometer fine resolution data by averaging five cross trac pixels and five scan lines together. Tactical area coverage can be sent to the weath centrals at the high resolution, but only limited coverage is available because of the limited storage space on the tape recorders and play back time. Increased coverag can be obtained by recording only one of the two channels. The stored fine data is normally played back concurrently with the stored smooth data by using the 2252.5 MHz channel.

Finally, the spacecraft has a telemetry transmitter that is used over CR sites to relay the health of the spacecraft without going through tape recorders. Thi real time data is processed by the 1000 Space Operations Group (SOG) of Space Command to monitor commanding and the responses to the commands.

2.2 Encryption

All satellite space to ground transmissions are usually encrypted usin KG43 and KG46 encryptors. A bypass mode is provided so that data transmitted o the Antarctica can meet international agreements. This mode can be used elsewhe as determined from the OLS main memory.

If the ground system is to receive the real time high resolution data, it must use a KG44 box. Since each satellite has its own keys, the ground system ha to provide key selection depending on the satellite that is to be acquired. It may als be necessary to be able to schedule an unencrypted satellite in a group of encrypte satellites.

If the ground system is to receive the real time smooth data, it must us KG46 box (or equivalent). Again, each satellite has separate keys and later satellit will have multiple keys, so that the ground system must provide automatic key selection. The ground system has to allow the user to update the key. In addition, may also be necessary to schedule an unencrypted satellite in a group of encrypte satellites.

2.3 Earth Pointing

The spacecraft is specified to point to the assumed local nadir to an accuracy of .01 degrees. The local nadir is defined to a first order geoid of the earth's surface and does not take into account altitude variations. To do this, the satellite uses celestial star sensors, earth sensors, and sun sensors to maintain knowledge of the spacecraft pointing. The pointing is with respect to a star catalog and spacecraft ephemeris and time transmitted to the spacecraft once each day.

When the spacecraft is in precision attitude determination mode (PRADS), very small errors are seen in the pointing. These errors are of several types: Random Errors - caused by perturbations on the spacecraft body by solar array motion, OLS scanning motion, microwave imagers, etc.; and Systematic Errors - caused by sensor misalignment to the spacecraft axis, time errors, ephemeris prediction errors, All the ground processing systems should have the ability to remove the systematic errors and to update tables of the systematic errors for each spacecraft and sensor that is to be processed.

The spacecraft alignment axes and sensors defined in this manual are shown in Figure 1. The X-axis is the spacecraft normal, defined as positive towards the earth. The Z-axis is the normal to the plane formed by the X-axis and the spacecraft velocity vector, defined as positive towards the sun. Finally, the Y-axis completes the orthogonal right-hand X,Y, and Z coordinate system.

For a morning ascending orbit, the spacecraft velocity vector is in the +Y direction. For an afternoon ascending orbit, the spacecraft is rotated to keep the solar array pointing towards the sun. The spacecraft velocity vector in the afternoon orbit is in the -Y direction. Some sensors are moved on the spacecraft depending whether it is in a morning or afternoon orbit. In any case, all ground systems must take into account the orientation of a particular spacecraft in their ground processing.

2.4 Glare Obstruction Bracket Description

To reduce the amount of glare caused by direct sunlight on the OLS in terminator orbits, the satellite will have a glare obstruction bracket (GLOB) which is deployed at the end of the ascent phase. This large structure does not usually obscure any of the OLS imagery, but it does block readings from the microwave

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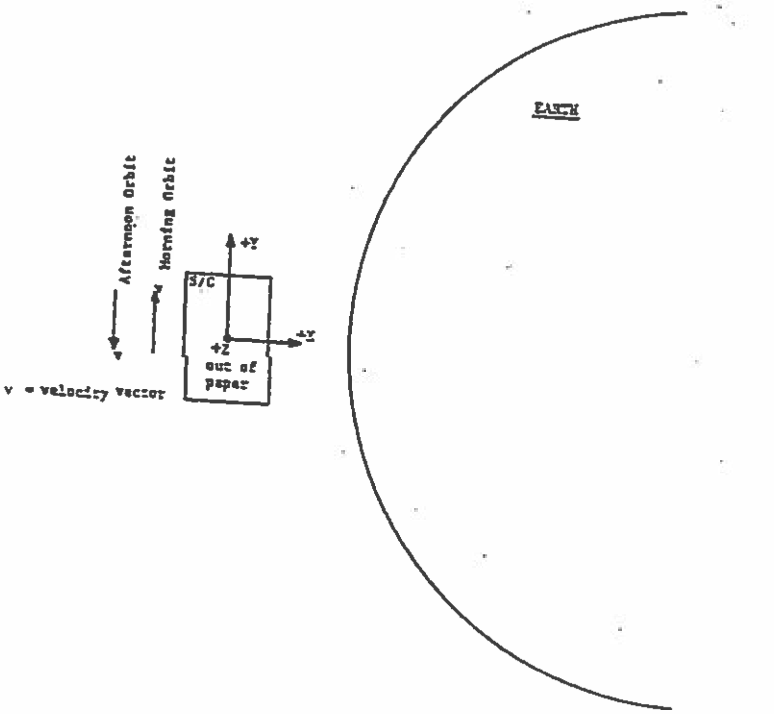

Figure 1. Spacecraft Alignment Axis.
The X-axis is the spacecraft normal, defined as positive towards the earth. The Z-
normal to the plane formed by the X-axis and spacecraft velocity vector. Y-axis completes right hand coordinate system.

sounders and ultraviolet sensors on the spacecraft. Ground processing software has to handle satellites with and without the GLOB, which means that the microwave sounders' (SSM/T and SSM/T2) software must delete scene stations that are blocked by the GLOB structure. In addition, OLS processing software should take into account. possible motion of the GLOB and allow the user to control the maximum scan angle towards the GLOB. More information on this aspect is given in the OLS processing section.

2.5 Orbital Variations

DMSP attempts to launch satellites into near perfect circular polar orbits; however, launch problems can occur that place the satellites into non-circular orbits. These satellites are still useful for ground processing, but their coverage may no longer be global.

In addition, the ground systems also need to take into account the altitude variation of the satellite above the assumed geoid, and for some sensors, may also have to take into account altitude variations of the land. All ground systems should handle altitudes above the true earth from 600 kilometers to 1000 kilometers. The systems should handle elliptical orbits up to an eccentricity of .02.

2.6 Ephemeris and Time

The spacecraft has an accurate time clock, which is set by ground command. This time clock is transferred to the OLS once a day, about 0 ZULU. At this time, the OLS Elapsed Time Counter (ETC) is updated. Prior to that update, the ETC counter may go over 86,400 seconds. Ground systems must take the ETC time modulo 86,400 if the spacecraft is not in the autonomy mode. In the autonomy mode, the ETC clock will roll over at 131,072 seconds and cannot be used for earth location of the data. Thus, tactical ground systems are encouraged to have their own source of time.

In the RDS data stream, ephemeris information is provided in the subsync frame. It takes five subsync frames to pass to the ground system the following

information: ephemeris time that the location data is valid, the geodetic longitude o the spacecraft, the geodetic latitude of the spacecraft, the cosine of the crossing ang the cosine of the solar azimuth, the solar elevation, the altitude of the spacecraft in terms of earth radii, the cosine of the lunar azimuth, the lunar elevation, and the lun phase.

In the RTD data stream, the line sync frame carries an alphanumeric message of 192 characters. This message contains ephemeris information in seve formats. For the OLS, which is transmitted in real time, the ground systems need to use their own clock as there is no clock in the data stream. However, for the missio sensors, the ETC time of the mission sensor block is available for use of the missio sensor processing.

To provide consistency among the DMSP ground systems, it is recommended that the SGP equations published by NORAD be used. Since the coefficients for the SGP are transmitted in the Direct Mode Data Message (DMDM) Special Message 8, SGP is the appropriate ephemeris to use. Although SGP is les accurate over short time periods, it has better stability over several days and weeks.

3.0 OPERATIONAL LINESCAN SYSTEM DESCRIPTION

The Operational Linescan System (OLS) is the primary sensor for DMSP. The system is designed to produce constant high resolution imagery as opposed to accurate radiometry and therefore differs significantly from the NOAA Advanced Very High Resolution Radiometer (AVHRR) system in many details in processing. The AVHRR processing is well described in NOAA documentation. The OLS provides highly accurate radiometry to meet the Air Force requirements, but because imagery and ease of processing on the ground was and still is of higher importance, some compromises in the end-to-end calibration technique that NOAA uses had to be made. The basic differences between the two systems are described below.

(1) In the visible, the day to night illumination varies over a dynamic range of 10^5. To handle this range, the OLS adjusts the gain continuously in the cross track direction to compensate for the variation in solar intensity caused by the solar elevation at the pixel location.

In 1985, Westinghouse and the Air Force agreed that the imagery should be further corrected. The signal was saturated at low solar elevations when the spacecraft was in position to receive direct reflections of the sun off the clouds or ocean. In addition, the constantly changing lunar illumination had created the need for daily updates of the gain curves on board the satellite. By assuming an "average" scene, various bidirectional reflectance distribution functions were averaged along with lunar location information from the spacecraft. By making this adjustment, the gain is reduced to prevent saturation of the data prior to the digitization of the data.

If the user of the data wants to back out these corrections to return to radiance, the user has to use the lunar location and sub-solar elevation and azimuth angle which are provided in the data stream. The exact coefficients used for the particular OLS need to be obtained from Westinghouse. During early orbit, each OLS is tuned to provide the "best" visible imagery over a wide range of lighting conditions. Thus the final coefficients are not known until after early orbit. For most Air Force applications, the location of the clouds, fog, ice flows, etc. is much more important than the accurate radiometry.

(2) For the thermal channel, the OLS on every scan is calibrated by a

hot and cold load. Unfortunately, the system design could not accommodate exter
targets, so calibration is done using two internal targets (after three mirrors) at abou
291 ° K and 240° K. Adjustments are made in a DC offset to account for radiance contributions of the three mirrors based upon measurements made at Westinghous
during system calibration. The radiance is converted to temperature before being digitized by a shaper network. If the instrument performs properly, the system therm
gain is monitored daily and electronic adjustments are made to the gain such that ground systems do not have to correct the temperature readings. Up until F-9, the slow drift in gain, if it did occur, was adjusted by the 1000 SOG. In the case of F-9, t
drift was much worse in magnitude than any ever experienced. The thermal data w
out of specification when the last available gain step was no longer enough to corre
for the continuing drift. Fortunately, all the ground systems at that time had the capability of inserting a correction table to "correct" the false temperature readings
the OLS to nominal values. Since this is a continuing possibility, all ground system
need to continue to be designed with the ability of inserting corrections to both the thermal and visible channels. These corrections would nominally be 1 to 1 for alm
all spacecraft.

(3) The third difference between the AVHRR and the OLS system is th
sampling. The AVHRR provides constant angle sampling as it is constantly rotating
10 revolutions per second. The OLS is designed with a sinusoidal scanner so that
sampling (which is constant in time at 40 kHz) is closer to a constant spatial sampli
across scan. Because it is not absolutely constant, corrections have to be made to resample the data to yield the Air Force primary display requirement of constant sc
in both the along track and cross track directions. This necessary computation is described in the OLS processing section. The mapping to constant scale is also a function of the altitude of the satellite, spacecraft velocity, and rotational velocity of t
earth.

(4) The OLS and the AVHRR system differ in the angle of the scan to t
spacecraft velocity vector. The OLS incorporates a motion compensation mirror to adjust for spacecraft velocity during a scan line. The OLS scan is absolutely perpendicular to the spacecraft velocity vector in space, whereas the AVHRR scan
a one degree angle to the velocity vector. The OLS scan is not perpendicular to the

ground track velocity vector due to the earth rotation.

(5) For the OLS, the ground processing of the sinusoidal scan needs to reverse every other scan line (in fine mode and real time data). This reversal has to be done carefully by accounting for scanner offset (the center of the sinusoidal motion to the nadir position) and, in the case of real time data, the deviations from a true sinusoid, and the delay time in the actual digitization of the data. The NOAA data, since it is from a rotational scanner, is automatically aligned at the start of every scan.

(6) The OLS uses a mechanical oscillator, formed by four springs and the mechanical mass of the telescope, as opposed to the constant stepper motor arrangement of the AVHRR scan mirror. To the ground processing, it means that there can be variability in the scanner period, not only from scanner to scanner, but even with the same scanner. The OLS scanner period will vary from season to season or within a single orbit due to temperature fluctuations in spring temperature, bearing friction changes, and long term spring constant changes. The OLS is within specification when it is within 1% of the nominal scan frequency of 11.88 scans/second. Ground systems need to plan for up to a 2% variation in scanner period.

(7) The OLS uses a five pole Butterworth filter to smooth data prior to digitization. This type of filter reduces the digitization noise without a large loss in resolution. A 40 kHz bandpass filter is used for fine data and an 8 kHz is used for smooth data. This type of filtering can cause over and undershoot in the imagery data when high contrast scenes are scanned. Consideration of a correction of the over and undershoot should be done if the data is to be used in numerical cloud classification. The single-sided nature of the Butterworth filter can cause a noticeable difference in a Z-scanned image between a line scanned from the left and one scanned from the right.

(8) The OLS achieves nearly constant resolution (as opposed to sampling) by the rotation of the field of view across two or three detectors and the switching between detector combinations. For the thermal channel, it is possible for the left and right detectors to have different response functions. All the current OLS's are designed to have separate gain controls for the left and right detector. Future ground systems should be designed to allow for three separate correction tables

depending on the pixel angle. Switch points may be noticeable within the scene, about one third and two thirds the way across the scan line. Detector switch points occur at separate positions for the visible/thermal channels, and the switch points c be modified on orbit.

(9) Night-time imagery is unique to the OLS. The OLS incorporates a photomultiplier tube and filter such that the difference between the solar and lunar reflective spectrum is taken into account. In addition to the lunar reflectance, the OL will pick up the aurora borealis because it is sensitive to the 6300 Å and 6364 Å lin 0 I and to many of the near infrared bands of N I. City lights also affect the image scene. At very low light levels (high gain states), the signal will be all noise. Small to 20 pixel length streaks can be seen in the night-time visible datawhen thunderst lightning reflects off the MI mirror. Night-time visible data has not been used in the automated cloud analysis programs.

The scanning telescope of the OLS has a 20 cm aperture with an effective collecting area of 239 cm^2. The telescope has an effective focal length of cm. The telescope has two calibration mirrors that intercept the normal field of view with a hot and warm load of known temperatures at the edge of scan. The light-day channel also uses one of the calibration positions for setting a dark reference point. The light from the telescope is split into two channels by a beam splitter: an IR char from 10.2 to 12.8 micrometers and a visible channel from .4 to 1 .1 micrometer.

Glare suppression is built into the system by a variety of sun shades, fiel stops, low scatter surfaces, and aperture stops. This reduces the amount of data lo the orbit due to sun light saturating the visible detectors.

The OLS utilizes three different types of detectors:

(1) In the thermal channel, a two segment Mercury-Cadmium-Telluride (HgCdTe) photoconductive detector is used. The detector is cooled down and stabilized at 108±0.1° K by a cone cooler and a heater. The spectral bandpass of 10.2 to 12.8 micrometers is achieved by the use of a double-sided interference filte (germanium and zinc sulfide). This wavelength band provides the best choice for removing interference from water vapor, carbon dioxide, and ozone.

The detector consists of two elements that are individually used on the fa left and far right parts of the scan, and are summed together in the middle (-41° to

+41°). For thermal smooth (used in RDS), the elements are summed across the entire scan. A fall back mode exists in case of a failure of one element where the other may be used across the entire scan. This mode has been used on F-10 after early orbit showed a problem in one of the amplifiers.

(2) For daylight visible data, a silicon photoconductive diode is used. There are three segments in the detector to provide for the nearly constant resolution scan. Two smaller segments are used for scan angles greater than 41°, and all three segments are summed together in the middle portion of the scan. In the event of a failure, any segment can be used across the entire scan.

(3) For night time visible data, a single photomultiplier tube is used. It is a cesiated gallium arsenide (GaAs) opaque photocathode, image dissector type, multiple dynode photomultiplier tube. To vary the field of view, the image dissector is magnetically adjusted. The PMT 1/9 mode is used on both left and right segments beyond 41° while the full aperture is used in the central part of the scan.

The signals from the detectors are passed through amplifiers, DC restoring circuits, switching, command level changes, and shaper circuits to linearize the thermal output to an equivalent blackbody temperature. The signal is then placed through a five pole Butter-worth filter to provide a 40 kHz low pass filter (fine data) or an 8 kHz low pass filter (smooth data). The OLS provides the ability to command gain adjustments to overcome slow degradation of the thermal transmission of the system. Readings of the warm and cold load are taken by the 1 G and are used to calculate the gain. Adjustments are made as needed.

4. MICROWAVE IMAGER (SSM/I) DESCRIPTION

The SSM/I instrument measures the microwave radiation from the ea atmosphere and surface. The advantage of the microwave region for viewing the earth's surface is that it is fairly insensitive to cloud cover and affected only by heav rain. Many of the algorithms defined for the instrument have tests for heavy rain. It important that the ground system be designed to handle "indeterminate" data wher heavy rain is occurring.

The SSM/I imager was first placed on the F-8 satellite in 1987. All satellites through S-15 will fly a microwave imager, except for F-9. The sensor was designed and built by Hughes Aircraft, with the basic algorithms developed by Hu Aircraft and modified by the SSM/I validation team headed by NRL.The SSM/I ima contains seven channels, two vertical and horizontal channels for each frequency, except for 22 GHz. The instrument takes readings in the following frequency regio 85 GHz, 37 GHz, 22 GHz, and 19 GHz.

The sensor conically scans the earth at a rate of 31.9 scans/minute (1 seconds per scan). The sampling provides 128 scene stations per scan for the 85 GHz channels (half Nyquist frequency) and 64 scene stations per two scans for the other channels (also half Nyquist frequency for 37 GHz channel). For a parabolic antenna size of 60 x 66 cm, the ground resolution for the 85 GHz channel is approximately 15 kilometers, while the 37 GHz channel has a 33 kilometer resoluti and the 19 GHz channel a 55 kilometer resolution.

Each scan consists of a cold reading, a warm load reading, and the scene stations. The cold reading utilizes a view to deep space (3° Black Body), an the warm load temperature (variable over an orbit) is read by three precision thermistors. Each sensor has a different calibration curve for each of these thermistors. The environmental data produced from the SSM/I measurements are varying quality, dependent upon background features and terrain and weather conditions. The ground systems have to allow the user to make corrections to the prior to the feeding of the information to other ground systems.

From the individual brightness temperatures, relationships have bee determined to be able to process microwave brightness temperatures into physica parameters. Table I shows the environmental parameters currently processed. N

Table I SSM/I Environmental Parameters

Parameter	Ice	Land	Ocean
Rain intensity		x	x
Soil Moisture		x	
Cloud Water	x	x	x
Liquid Water		x	x
Cloud Amount		x	
Surface Temperature		x	
Snow Water		x	
Snow Edge		x	
Ice Age	x		
Ice Edge	x		
Ice Concentration	x		
Surface Wind			x
Water Vapor			x

parameters are calculated along coast lines and are left indeterminate.

Since the coverage of the SSM/I (swath width of nominal 1394 kilometers) does not provide global coverage at the equator, the current ground systems provide a merged data base from all the satellites and all passes. The resolution of the merged database depends upon the use, but for tactical applications a 25 kilometer minimum resolution is required.

Each sensor has its own set of coefficients to determine the environmental parameters, as the coefficients depend upon antenna patterns, precise bandwidths, and noise figures of the channels. Some algorithm modifications are also made for the case of failed channels.

The microwave imager scans in a conical fashion, the beam center pointing 45° to nadir (see figure 2). This gives a nominal incident angle of 53.1° to t earth's surface, but this angle will vary depending upon the altitude of the spacecra The active scan area of 102.4° is ahead of the spacecraft for an afternoon ascendin orbit and behind the spacecraft for a morning ascending spacecraft.

The sensor electronics performs an integration and hold on each channel, timed so that the odd 85 GHz reading is centered with the 37 GHz reading this manner, all channels are precisely co-registered for the environmental parame calculations.

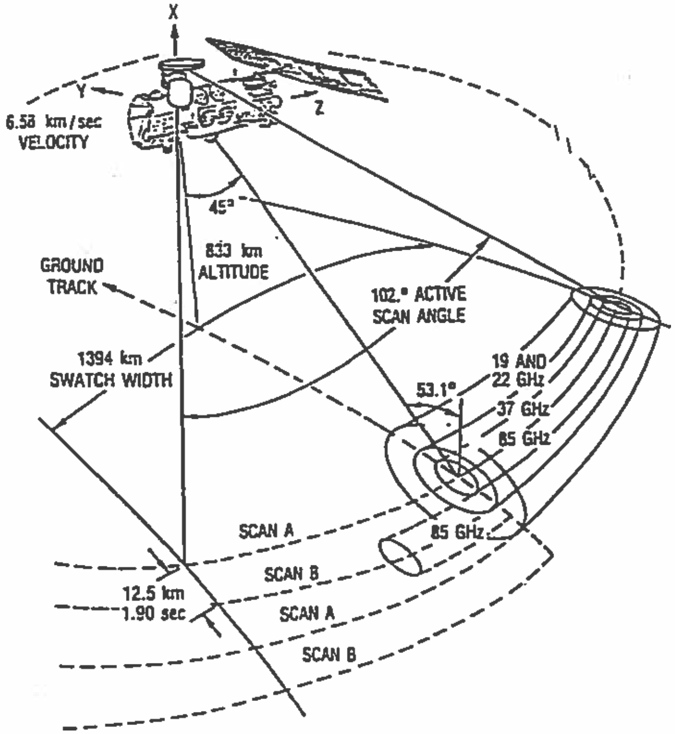

Figure 2. SSM/I Scan Pattern. The SSM/I does a 360° conical scan, with an active scan area of 104°. It looks out at 45° from the satellite nadir position.

5.0 MICROWAVE TEMPERATURE SOUNDER (SSM/T or SSM/T-1)

The SSM/T (also known as the SSM/T-1) is used to derive temperatur profiles of the atmosphere. The instrument was developed by the Aerojet Corporat and was first flown on F-4. It has shown excellent performance over the years.

The SSM/T consists of a rotating reflector (once every 32 seconds), a Dicke switched seven channel radiometer, a digitizer, and signal processor. It is a cross track scanner, taking readings at seven positions across the scan, 12 degree apart. It operates in the frequency range of 50 to 60 GHz, so that there is a negligib variation of resolution across the frequency range. Its nominal field of view is 14.5° The SSM/T is a step and stare type of sensor for each of the seven scene stations, then goes to a cold reference, followed by a warm reference. This yields a 175 km circular footprint at nadir, elongating to a 305 x 313 km (nominal altitude) ellipse at extreme viewing angles.

The warm and cold reference are used to set the stepped automatic g control attenuators. The gain step can change at any time during the orbit and nee to be taken into account when calculating the gain of the system for determining the brightness temperatures of scene stations. Each channel is digitized to 12 bits befo being multiplexed into the data stream. Contained within the multiplexed data are temperatures of receivers, hot load thermistors, and timing information. Each sens has a set of correction coefficients determined at the final acceptance test of each sensor. These correction coefficients need to be used in the ground processing.

The radiometric characteristics in the 50-60 GHz band are primarily determined by the oxygen molecules absorption and reemission. Table II gives the peaking height for the seven channels in a cloud free, non-precipitating environme

The instrument can be synchronized with the SSM/T2 sensor, in whic case it may pause at the first beam position before taking data. The direct imagery from the SSM/T sensor, even though of low resolution, is useful to the meteorologis view. In order to reduce the variation in limb darkening due to the look angle, it is necessary to apply a limb darkening correction before displaying the imagery. Thi correction should not be applied to the data to be used in the processing of the atmospheric temperature profiles.

Table II SSM/T Channels Peaking Height

Channel	Frequency	Peaking Height (km)	NEAT	
1	50.5	0	0.6	Window Channel
2	53.2	2	0.4	
3	54.35	6	0.4	
4	54.9	10	0.4	
5	58.4	30	0.5	
6	58.825	16	0.4	
7	59.4	22	0.4	

From Aerojet System Summary Report, page 2, 1977

The instrument's scan direction is not changed for launch times. Since the satellite orientation is reversed for an afternoon ascender, it is necessary to reverse the direction of scan on the ground. Scene stations l-3 are always opposite the sun, while 5-7 are in the direction of the sun. Two of the scene stations (6 and 7) are blocked by the Glare Obstructor Bracket (GLOB) on the F-7 through F-10 spacecraft and should not be processed on those spacecraft with a GLOB. On the S-11 through S-15 spacecraft, the sensor has been moved and raised up several inches so that the obscuration is only in scene station seven and only on those spacecraft that fly a GLOB. Several other instrument anomalies are known and are covered in the processing section of this guide.

Since the swath width is limited, merged data sets from several spacecraft are necessary to give good coverage over the tactical area.

6.0 Microwave Water Vapor Sounder (SSM/T2)

The SSM/T2 sensor is used to derive water vapor profiles of the atmosphere. The sensor, first flown on F-11, was developed by Aerojet Corporatio is very similar to the SSM/T1 and has to be used in conjunction with the SSM/T1 sensor for the best accuracy. The SSM/T2 can be used by itself if necessary.

The SSM/T2 has three channels centered on the 183.310 GHz water vapor line and two window channels. Table III provides the frequencies and noise figures for each of the channels. Similar to the SSM/T1, the SSM/T2 is a step scan system, but with 28 steps per scan versus seven. The scan period has been decreased to 8 seconds per scan from 32 seconds. Each scan consists of a warm load reading, a cold load reading, and 28 scene stations.

The 183 GHz channels have a 3.3° beam width, while the 150 GHz is approximately 3.7" and the 90 GHz is 6.0°. This is achieved through the use of 6.6 diameter aperture and a single feedhorn that provides coregistration of all the channels. The rotation of the reflector causes a rotation of the polarization, but sinc all the channels have the same polarization, this will not affect the water vapor resu The SSM/T2 uses a total power radiometer, similar to those used in the SSM/I. Thi provides for lower NEAT performance, but at the same time it allows a greater varia

Table III SSM/T2 Channels

Channel	Frequency (GHz)	Approximate Height (km)	NEAT (°K)	
1	183.310±3.000	8	0.6	
2	183.31 0±1.000	6	0.8	
3	183.310±7.000	10	0.6	
4	91.655±1.250	0	0.6	Window Channel
5	150.0±1.250	2	0.6	

in gain. The ground systems have to properly track the variation in gain and if necessary calculate gain as a function of time during the scan. A compromise between reducing the variation in cold counts by averaging over several scans and monitoring gain fluctuations will be necessary.

Each SSM/T2 instrument contains two Gunn Diode Oscillators to improve the reliability of the system. The data stream contains information as to which Gunn Diode is being used. Separate calibration tables are necessary for each sensor and each Gunn Diode.

The swath width of the SSM/T2 sensor is 43.5°. Scene station 28 may be partially obstructed by the GLOB on the spacecraft and should be deleted from all processing when the GLOB is flown. The direction of scan is away from the sun direction towards the sun side of the spacecraft. With the reversal of the spacecraft for morning ascending and afternoon ascending satellites, the ground systems have to reverse the effective scan direction on the ground. The SSM/T2 does not have a nadir scan position, with scene stations 14 and 15 located 1.5° on either side of nadir.

7. MICROWAVE IMAGER SOUNDER (SSMIS)

The microwave imager sounder (SSMIS) is based upon the SSM/I technology and spins at 31.9 GHz, but adds to the SSM/I system the temperature, humidity sounding, and a new upper air capability. The current channels are defin in Table IV. It is currently under development at Aerojet.

Table IV SSMIS Frequencies and NEAT

Channel Number	Center Frequency (GHz)	Ground Resolution Cross x Down	Polarization	NEAT (° K)
1	50.3	17.5 x 25.8	Horizontal	0.4
2	52.8	17.5 x 25.8	Horizontal	0.4
3	53.596	17.5 x 25.8	Horizontal	0.4
4	54.4	17.5 x 25.8	Horizontal	0.4
5	55.5	17.5 x 25.8	Horizontal	0.4
6	57.29	17.5 x 25.8		0.4
7	59.4	17.5 x 25.8		0.5
8	150.0	13.1 x 14.4	Horizontal	0.7
9	183.31~7	13.1 x 14.4	Horizontal	1.2
10	183.31~ 3	13.1 x 14.4	Horizontal	1.0
11	183.3121	13.1 x 14.4	Horizontal	1.0
12	19.35	42.4 x 70.1	Horizontal	0.7
13	19.35	42.4 x 70.1	Vertical	0.7
14	22.235	42.4 x 70.1	Vertical	0.7
15	37.0	27.5 x 44.2	Horizontal	0.5
16	37.0	27.5 x 44.2	Vertical	0.5
17	91.65	13.1 x 14.4	Vertical	0.3
18	91.65	13.1 x 14.4	Horizontal	0.3
19	63.283±0.235	17.5 x 25.8	H+V	1.9
20	60.793±0.358	17.5 x 25.8	H+V	1.9
21	60.793±0.358±0.002	17.5 x 25.8	H+V	1.4
22	60.793±0.358±0.006	17.5 x 25.8	H+V	1.0
23	60.793±0.358±0.016	17.5 x 25.8	H+V	0.6
24	60.793±0.358±0.050	17.5 x 25.8	H+V	0.7

The sensor adds one additional channel over the SSM/T to improve the measurement of the tropopause temperature and height. The frequencies chosen (channels 1 to 7 and channel 24) provide near uniform coverage in height. With the addition of five more channels (channels 19 to 23), the temperature retrievals will be extented up to 80 km. At these altitudes, the earth's magnetic field must be taken into account as it affects the splitting of the Oxygen lines that are being used.

Of benefit to the ground processing, the water vapor retrieval is much simplified because of the coregistration of channels 1 to 4, channels 8 to 11, and channel 18. The frequency selection of 183 channels is the same as the SSM/T2 as the affect of the higher incidence angle (53.1°) did not create a problem.

The scene spacing for all the sounder channels have been improved from the earlier instruments to 50 km for the lower atmosphere and to 75 km for the upper atmosphere measurements.

The SSMIS uses almost the same channels as the SSM/I for the environmental parameter extraction. The upper frequency (85 GHz) was changed to 91 GHz to save an extra channel in the system. With the SSMIS, the rain retrieval and cloud amounts will be augmented by channel 8 at 150 GHz.

The SSMIS has a two point (Hot and Cold Load) calibration, taken once each scan of 1.9 seconds in all 24 channels. The scan swath of the instrument has been increased from 104° to 144° by deploying the sensor farther out board on the satellite. Having six separate feed horns for each frequency range, requires that the flight software in the sensor realign the data before transmitting it to the OLS and then down to the ground. Fine realignment is done within the signal processing hardware on board. The sensor is asynchronous with the OLS and ships data to the OLS in two blocks per second. A complete scan is shipped in 1.9 seconds so that blocks in the sense of the SSM/I, SSM/T1 and SSM/T2 do not exist. Instead, the SSMIS data stream has to be searched for its own synchronization words to start the processing of the data.

The sounding data is only partially smoothed on board. The 183 GHz channels is sent down at 12.5 km resolution and has to be averaged to the 50 km spacing for sounding retrievals. But the 12.5 km resolution data is planned to be used for display purposes of the water vapor data. In addition, various sounding channels will also have to be averaged before doing the inversion of the data.

The system has redundant Gunn Diode Oscillators and Phase Lock L Oscillators. This will require the ground systems to have separate calibration tables the redundant elements. Of significant benefit to the ground system was the integration of a variable oscillator to take into account the Doppler shift of the spacecraft.

8. PROCESSING DMSP IMAGERY

The following sections give the processing necessary to convert raw OLS data into displayed imagery.

6.1 OLS Data Stream

The OLS provides four data streams, each carrying similar but different data: (1) Stored Data Fine (SDF), (2) Stored Data Smooth (SDS), (3) Real Time Data Smooth (RDS), and (4) Real Time Data (RTD). The SDF can be interleaved or non-interleaved on the tape recorders, allowing the user to select a larger area coverage with a single, non-interleaved channel or to select interleaved Light and Smooth over a small area. This data stream contains imagery only with ephemeris, time, location data.

The SDS data stream is the always used and is stored continuously on OLS tape recorders over the full orbit. It contains OLS smooth data, light and thermal, mission sensor data, ephemeris, time, location data, calibration data, and spacecraft telemetry. This data stream is played back in reverse order. The OLS data stream is formatted such that the high order bit is transmitted first in the play back mode.

The RDS is exactly the same data stream as the stored data smooth, except it exists in the prerecord format. The data stream is provided in a low order bit first format, which will require manipulation. The frame size of a single channel of the RDS data is 206 bits, but it is interleaved. Figure 3 shows the overall format of the RDS data stream from line sync to line sync. Note that blank frames are inserted as needed to adjust for the OLS scan rate. The number of pixels per line is fixed at 1465 for this format. Most video frames contain 26 pixels. Each scan line consists of 56 video frames and one 57th frame containing nine pixels. The data stream also contains mission sensor data in the overscan time and, in every frame, there are ten bits of mission sensor data in "word 2" after tag bits. The tag bits identify the non-interleaved stream. Light Smooth (LS) has tag bits of 3, and thermal smooth (TS) has tag bits of 7.

The RTD contains one channel of fine data (either thermal or visible) and one channel of "cross-track" smooth data (visible or thermal). The content of the fine

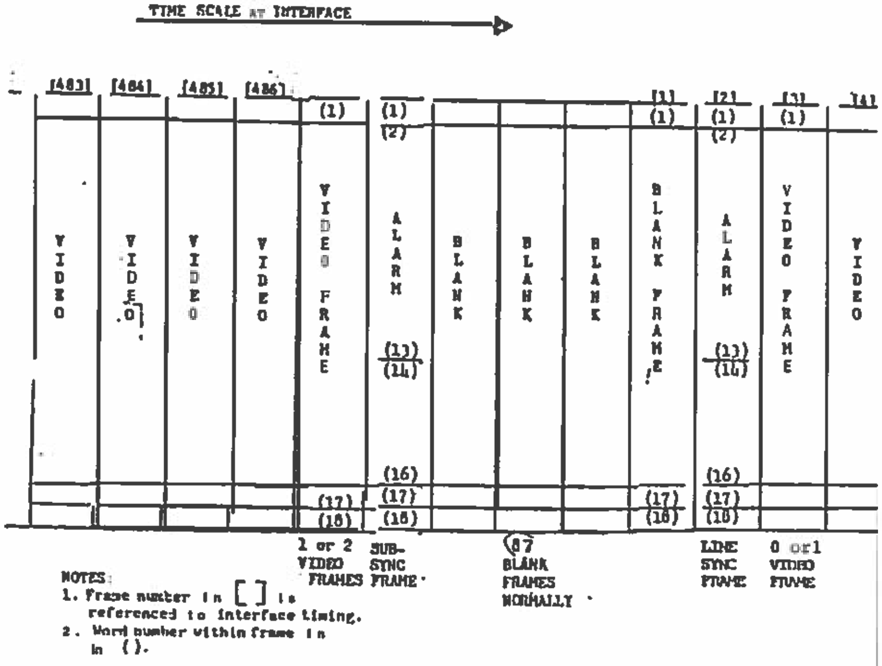

Figure 3 - OLS RTD Frame Format. This Figure shows the sequence of frame types that establishes one scan line of data.

channel can change with ground commands or on-board commands. It is extremely important for the ground system to be watching the "Z" tag bit to determine which channel is selected for the fine mode and to switch modes between scan lines. It is recommended that the ground system expand the Smooth" data to an equivalent "fine" data stream so that the transitions are handled smoothly, and that the system also map the data from six bits to eight bits to maintain a standard data format is contained within the system.

The RTD also contains a DMDM message, 192 characters of ephemeris information, broadcast in the line sync frame at about 12 characters per second. In addition, the tertiary data (TERDATS) frame also contains mission sensor data, which is described in Section 8.7.

8.2 Wow Flutter Processing

Wow and Flutter Processing is done on board the satellite for the stored data and real time data smooth. When the OLS was designed in 1974, the goal was to use as little hardware as possible in the real time data stream to increase the reliability of the system. Memory is not utilized in performing this correction, and the raw data stream from the thermal and light detectors are digitized directly at 102.4 kHz (fine mode) and 20.48 kHz (smooth mode). Absolute position angle pulses are generated every 0.0009855 radians from optical encoder. The on-board electronics uses the encoder pulses to generate a new clock whose frequency varies from the nominal 102.4 kHz as a direct function of the amount the actual scanner motion varies from the reference scanner motion. The wow-flutter clock uses a feedback loop that compares the oscillator output count from the beginning of scan to that required by the reference scanner motion. The pulses placed in the real time data stream therefore represent an accurate spatial measurement to use in calculating the actual scanner position as a function of time. Individual wow-flutter timing marks are placed in the real time data stream to be used for the geometric correction of the pixels as received from the scanner.

The scan angle ϕ for any pixel is defined as follows:

$$\phi = (-1)^{\delta} \phi_{max} \cos(.00619606\, \omega + \beta) - 0.0009855\, \sigma$$

where

$\delta = 0$ (Direction of scan = 0)
$= 1$ (Direction of scan = 1)
$\phi_{max} =$ peak scan angle = 1.009673 radians (57.85")
$\omega =$ number of wow flutter periods (including fractional perio between line sync and the pixel of interest
$\beta =$ 0.22332 radians for fine data
0.22115 radians for smooth data
$\sigma =$ signed value of scanner offset (01 -Q6 of line sync)

Normally the scanner is run using the Delphi detection electronics, but in case of ar electronics failure, a back-up mode is provided using the reference nadir and contr track pulses. This is the locked encoder mode.

The scanner offset can vary from ± 6 delphi, with the value of the scar offset given in fractional delphi (2^{-2}). In most systems, the offset has a magnitude c about 1 delphi.

Verifying the maximum angle of video data,setting ω=0, gives:

$\phi(0)$= 1.009673 cos (.22332) = .984600 radians (56.41') fine data

Q(O)= 1.009673 cos (.22115) = .98508 radians (56.44°) smooth data, which is the actual angle of the line sync pulse in the encoder.

The line sync pulse position has to be accurately determined from the information in the line sync frame. When the alarm code occurs, the scanner provi the frame bit count where the actual line sync pulse occurred from the encoder wh In the line sync frame, this is in addition to the wow/flutter bit code, which indicates location of the W/F pulse. From this bit information, the location of the line sync pul in "wow/flutter periods" can be determined:

$$W_{ls} = (\text{line sync bit - wow/flutter bit})/1\,66$$

Also, other information for correcting the earth location of the data is contained within the frame. The scanner offset (usually in whole delphi) is necessary to account for non-symmetrical scanning. The scanner offset is similar to a roll offset. The observed scanner offset from a number of systems has varied about ± 2 delphi, but it can range up to ± 6 delphi. The offset is usually stable, but processing should check for its stability.

RDS Implementation

For the RDS data stream, the Light and Thermal channels must be de-interleaved and the eighth thermal bit must be taken from the light channel and inserted with the thermal data. The Wow Flutter Correction is done on board, so that the equation for converting to look angle is dependent only on the pixel number and offset value.

$$\phi = -\phi_{max} \cos (2.6687426(P_i - 1/P_T) - \beta) + 0.0009855\sigma$$

where

ϕ_{max}= 1.009673 radians

P_i= sample number in order received by the ground

P_T= nominal number of samples = 1464.436

β= 0.2368551 radians for L data

β= 0.2359074 radians for T data

σ= signed value of offset in the line sync frame

8.3 Butterworth Filter Correction

Depending on the use of the data, consideration may be given to enhancing the high frequency spectrum of the signal, prior to manipulating the data. The OLS puts a five-pole analog Butterworth filter at 40 kHz fine data and 8 kHz smooth data, to reduce the noise for digitization. When going over high contrast scenes, this filter tends to have strong overshoot and undershoot characteristics.

8.4 Earth Curvature Correction

It is relatively easy to go from scan angle (ϕ) to earth central angle (β) if t altitude (h) of the spacecraft is known.

$$\beta = \mathrm{asin}\{ (1 + h/R_e) \sin \phi \} - \phi$$

where R_e= earth radius at nadir position= 6378.388 km $[1.0068 \sin^2 \Phi + \cos^2 \Phi]^{-1/}$ with Φ the geocentric latitude of the spacecraft.

For imagery purposes, all ground systems display the unmapped DMSP images with constant scale in both the along track and cross track directions. This is usually defined as 0.53 km for fine data and 2.65 km for smooth data. This provides the closest correlation between the scan rate of the sensor and the nominal satellite velocity of 6.3 kilometers/second.

Other constant ratio scales that allow the nominal swath of 3105 kilomete to be fully displayed on a soft copy screen are also acceptable. Preference should b given to saving the original data at the 0.53 kilometer resolution. To avoid aliasing problems, it is recommended that averaging be used if the depopulation to the disp scale is more than 2:1.

8.5. Radiometric Corrections

The RTD fine data is transmitted in six-bit bytes. The temperature can be derived from the pixel value (p) by:

T_b= 190° K + p * 1.905°

while for RTD thermal smooth data, transmitted in pixels of eight-bit bytes, the temperature is derived from :

Tb= 190° K + p . 0.4706"

For RDS data, the thermal values are transmitted with seven bits in the "thermal channel" and the least significant bit in the "light" channel. The conversion temperature should be:

$Tb = 190° K + p * 0.4706°$

For nominal OLS's, this has been true. F-9 had a problem where the sensitivity of the channel went beyond the on-board capability to correct the data. Tables were supplied that gave correction factors for both eight-bit and six-bit data. For imagery, the infrared numbers are usually left in the original transmitted values. The imagery is almost always displayed in inverted mode, with low temperatures (low pixel values) displayed as white and high temperatures (high pixel values) displayed as black. If used for a numerical value on a display screen, the temperatures should be appropriately converted.

In addition, for improved accuracy at the larger look angles, some correction for thermal attenuation by water vapor should be made when the user requests the information.

The visible light channel is usually sent down as six bits of linear "albedo" as the video gain is constantly adjusted for solar elevation, solar azimuth, and lunar illumination. RTD smooth data is sent down as eight bits directly from the A/D. The RDS signal is six bits, representing a smoothing of 25 pixels of fine data.

The night-time visible data has a resolution of about 2.5 kilometers, although if RTD fine data mode is set to visible, it will be sampled at a 0.5 kilometer interval.

A second mode, logarithmic, is sometimes transmitted. In this case, the output of the OLS equals

$$
\begin{array}{ll}
V_o = 2.5 \log (V_{in}/0.05) & V_{in} > 0.05 \text{ volts} \\
V_o = 0 & V_{in} \leq 0.05 \text{ volts}
\end{array}
$$

After the above corrections are made, some imperfections in the data will remain. Several anomalous points may appear in the imagery, caused by switching transients within the OLS. In the visible channel, two switch points about one third the way into the image are seen. It is most obvious in the night-time data.

In the infrared channel, there are also two switch points that are usually not obvious unless the gain settings on the individual detectors are slightly off. These minor blemishes are usually ignored by the processing.

Of more major concern are the glare problems that occur across the terminator. If the data is to be used for cloud models, areas with glare are usually deleted by choosing a maximum scan angle below which the glare is not serious, ar
setting a range of scan lines between certain latitudes. The regions of glare vary depending on the ascending node time and season. Therefore, ground systems ne
to have a means of clipping OLS data in both line extent and length of pass.

8.6 Earth Location

The earth location of OLS data is a complex task as it involves the satellite
the sensor, earth rotation, time, ephemeris predictions. For the RTD user, the time h
to be established by the ground system, while the RDS data stream contains the act
time of the previous scan line. The RDS data stream also provides a geodetic longitude and latitude if the developer of the ground system chooses. The closed fo
of ephemeris is generally easier to use to go from latitude/longitude to pixel/line.

The time has to be accurate to 0.2 seconds to keep the earth location with
2 kilometers. Some earlier tactical systems used WWV as a time source, correcting
the propagation delay to the site. The newer systems use GPS as the time source. The DMSP satellite clock can be off by up to 0.5 seconds, but for RDS that is accura
enough to be within one or two smooth scan lines.

Using the number of scan lines to keep track of the time is not recommen
as it leads to earth location errors. Unfortunately, the OLS is not a constant rate scanner. The nominal rate of 11.88 scans per second can vary up to 1%. The scan rate varies over the life of a given sensor due to temperature changes in the springs and wear in the bearings. In addition, since no two OLS's are exactly the same, sp
constants may vary. Thus it is very hard to extrapolate time over a large number of scans.

8.7 Mission Sensors Formats.

The OLS is responsible for handling all the mission sensors and formatting th
individual mission sensors into one data stream. Once a second, the OLS begins

reading data into a double buffer memory of 512 16-bit words. This memory contains: four sync words, two elapsed time count words (from the spacecraft), 12 format words, and 494 words of data (2030 words of data for S-16+). Once a second, the OLS interrogates the first mission sensor found in the first format word. This word contains the number of 36-bit words to be read from the mission sensor. The format word also indicates which sensor is to be interrogated. For S-11 through S-15, the mission sensors are assigned the following codes. The specific sensor can be identified by the four bits of Sensor I.D. The I.D.'s in Table V are valid for the SII - S15 satellites, and are preliminary for S-16 to S-20. The order and the number of words can be varied by ground command, so it is very important that ground systems utilize the format words to determine where to access a particular sensor.

Table V Sensor Identification Constants

	Mission Sensor	Code	Number of bits (words)
S-8 - S15 sensors			
	SSM/T-1	0010	144 bits (4 words)
	SSM/T-2	1000	324 bits (9 words)
	SSM/I	0110	3276 bits (91 words)
	SSM	1001	252 bits (7 words)
	SSIES-2	0001	720 bits (20 words) 756 bits (21 words) 1080 bits (30 words)
	SSJ/4	0111	360 bits (10 words)
	SS B/X-2	0101	180 bits (5 words)
	s s z	1010	72 bits (2 words)
S-16 + sensors			
	SSMIS	0100 L 0100 T	11124 bits (309 words) 3096 bits (86 words)
	SSF	1010	216 bits (6 words)
	SSM	1001	252 bits (7 words)
	SSIES-3	0001	1080 bits (30 words)
	SSJ5	0111	360 bits (10 words)
	SSULI	1000	2520 bits (70 words)
	SSUSI	1011	3816 bits (106 words)

After all the sensors are interrogated, the OLS places fill (a 36-bit word = 1) fo the remainder of the memory. The time that a particular sensor is interrogated (first read gate to the sensor) is determined from adding the elapse time count word to t number of bits of the previous sensors divided by 10,000. All time is measured fron the first read gate for most of the sensors. The number of bits is determined by addi the "36-bit word count" in each format word prior to the sensor for which the time is to be determined. Most sensors use multiple blocks for a single scan of data. A variety synchronization techniques have been established between the mission sensors ar the OLS. These are described in the individual sensor sections.

The final information in the format word contains information as to whether th mission sensor data will be found in the L smooth channel or the T smooth channel stored and RDS data. (For RTD data, the data is read continuously out of the missio sensor memory and not split into two separate formats.) Each channel contains the four sync words, ETC time, and the 12 format words.

The total number of bits transmitted each second is <u>variable</u> for stored data, RDS, and RTD data. The OLS guarantees a minimum of 5220 bits in the RTD data stream, 2160 bits in the LS channel, and 3888 bits in the TS channel. These numb include the 288 bits used as overhead for the mission sensor format words, time cou and synchronization words. The maximum number of words is not specified, depending upon a number of factors: OLS scan rate, overscan time, scanner offset. The number of bits transmitted will be an even multiple of 16, with a new synchronization word starting on a 16-bit boundary. For the S-I 6+ satellites, the number of mission sensor bits will be 24,480 in the RTD and 11,412 bits in the LS channel and 13,140 bits in the TS channel. Unfortunately, for the S-I 1 through S-I satellites, there are times when the number of mission sensor bits is greater than 52 When only 5280 bits are transmitted, about 336 bits are not transmitted in the RTD data stream. There is an attempt made to have those bits assigned to mission sens for which no tactical processing is desired (such as the magnetometer). With the heavy sensor complement of the newer satellites, this has not been completely possible, so that three to four 36-bit words of the microwave imager (SSM/I) are not transmitted about once every eight seconds. Some the SSM/I words will be lost ar the ground processing should interpolate scene stations, or use gain from another valid block. It is imperative that the ground systems be designed for this and have some error correction software.

The OLS communication format for the mission sensor data is specified in the IS-YD-821 B document, Figure 30. A major difficulty with the processing of the mission sensor data is the affect of drop-outs and bit flips in the transmission of the data, especially at low elevation angles. There is no checksum within the Mission Sensor Format to determine whether the entire block has been received properly. Insertion or deletion of six bits can occur because of the TERDATS word encoding that is used in Word 18 of the RTD block. Adjacency rules should be developed to recognize and overcome these errors when they occur. Until spacecraft S-16, the mission sensor data is found only in the overscan blocks between sub sync and line sync. After S-16, mission sensor data will be found in almost continuous fashion, except for the line sync word, which will contain the DMDM characters.

Each channel within the interleaved RDS data stream contains Special Sensor Messages. The corresponding tag bit in the format word for the particular sensor will indicate in which data stream (LS or TS) the data is found. For S-16, the SSMIS data will be partially in the LS channel and partially in the TS channel. Both channels have to be recombined to create an SSMIS data block.

9. Special Sensor Microwave Imager (SSM/I)

The processing of the SSM/I data is not as straight forward as the OLS data described above. In order to process the data into Environmental Data Records, th ground terminal needs additional data bases that control the processing of the data This data consists of sensor calibration data, parameter extraction coefficents, surfa type data base, climatic zone definitions, and processing limits. These data bases a subject to change and improvements over time.

9.1 SSM/I Data Format

The SSM/I data is transmitted to the ground in 3276 bit data blocks. Becaus the difference in the resolution of the various channels, the high resolution 85 GHz data is transmitted with every rotation of the sensor. The lower resolution channels transmitted in every other scan of the instrument. Seven blocks of data (Block types to 6) are required to transmit all the data collected during 4 scans of data (7.6 secon duration). Because of the difference between the 7.6 seconds scan time and the O one second time requests, about once every 12 seconds, a fill frame (block type 7) i inserted into the data stream for synchronization purposes, The fill frame will conta the 36 bit identification word follow by all zeroes.

For S-11 through S-15, there is not enough space in the mission sensor dat block to transmit every time the entire SSM/I data block. It is a probabilistic occurrence, that words 88-90 (or partial words) of any SSM/I data block (block type 7) may be lost. The real time systems must be looking for the mission sensor data block synchronization words occurring and use some fill technique for replacing th missing scene stations. Several of the data blocks are not affected by this data loss and fortunately the calibration data will not be lost.

The data quality pattern which initiates every data block is a fixed 14 bit code which can be used by the ground data processing for synchronization check. This word is useful for determining if there has been any bit skew in the preceding missi sensor processing bits.

Figure 4 provides the current format for all SSMI instruments that will be flow

Word	Bits 1	12	24	36	
0	ID WORD				
1		37V	85H	85V	
2		19H	19V	37H	1st Scene Station Pair
3		85H	85V	22v	of Sensor Scan A
4		37v	85H	85V	
5		19H	19V	37H	2nd Scene Station Pair
6		85H	85V	22V	of Sensor Scan A

REPEAT FOR OTHER SCENE STATION PAIRS

Word	Bits 1	12	24	36	
88		37V	85H	85V	
89		19H	19V	37H	30 Scene Station Pair
90		85H	85V	22V	of Sensor Scan A

BLOCK NPE 0

Word	Bits 1	12	24	36	
0	ID WORD				
1		37V	85H	85V	
2		19H	19V	37H	31st Scene Station
3		85H	85V	22V	Pair of Sensor Scan A
4		37V	85H	85V	
5		19H	19V	37H	
6		85H	85V	22V	

REPEAT FOR OTHER SCENE STATION PAIRS.

Word	Bits 1	12	24	36	
88		37V	85H	85V	
89		19H	19V	37H	60th Scene Station
90		85H	85V	22V	Pair of Sensor Scan A

BLOCK TYPE 1

Figure 4: SSM/I Data Formats (1 of 5)

Word	Bits 1	12	24	36	
0	ID WORD				
1		37v	85H	85V	
2		19H	19V	37H	61st Scene Station
3		85H	85V	22V	Pair of Sensor Scan A
4		37v	85H	85V	
5		19H	19V	37H	62nd Scene Station
6		85H	85V	22V	Pair of Sensor Scan A
7		37v	85H	85V	
a		19H	19V	37H	63rd Scene Station
9		85H	85V	22V	Pair of Sensor Scan A
10		37v	85H	85V	
11		19H	19V	37H	64th Scene Station
12		85H	85V	22V	Pair of Sensor Scan A
13		AGC1	Hot Load Temp 2	Hot Load Temp 1	A Scan Status Data
14		37v (CI)	AGC3	AGC2	
15		19H (CI)	19V (CI)	37H (CI)	Cold Load Readings
16		85H (CI)	85V (cl)	22v (CI)	(A scan)
17		19V (C2)	37H (C2)	37v (C2)	(5 for each channel)
18		85V (c2)	22v (C2)	19H (C2)	
19		85H (C3)	85V (c3)	85H (C2)	
20		19V (C3)	37H (C3)	37v (C3)	
21		85V (c4)	22v (C3)	19H (C3)	
22		85H (C5)	85V (C5)	85H (C4)	
23		19V (C4)	37H (C4)	37v (C4)	
24		37v (C5)	22v (C4)	19H (C5)	
25		19H (C5)	19V (C5)	37H (C5)	
26		37H (H1)	37V (H1)	22v (C5)	
27		22V (H1)	19H (H1)	19V (H1)	Hot Load Readings
28		37V (H2)	85H (H1)	85V (H1)	(A scan)
29		19H (H2)	19V (H2)	37H (H2)	(5 for each channel)
30		85H(H2)	85V(H2)	22V(H2)	
31		37V(H3)	85H(H3)	85V(H3)	
32		19H(H3)	19V(H3)	37H(H3)	
33		85H(H4)	85V(H4)	22V(H3)	
34		37V(H4)	85H9H5)	85V(H5)	
35		19H(H4)	19V(H4)	37H(H4)	
36		37H(H5)	37V(H5)	22V(H4)	
37		22V(H5)	19H(H5)	19V(H5)	End of A scan
38		85V	85H	85V	Start of B scan
39		85H	85V	85H	78 Pairs of 85V, 85H
		Repeat for a5 GHz Pairs			
a7		85H	85V	85H	
88		85V	85H	85V	
a9		85H	85V	85H	
90		fill	fill	fill	

BLOCK TYPE 2

Figure 4: SSM/I Data Formats (2 of 5)

Word	Bits 1	12	24	36	
1		ID WORD			
2		85V	85H	85V	50 Pairs of 85V
3		85H	85V	85H	85H readings -
4		85V	85H	85V	B scan
		Repeat for 85 GHz Pairs			
.					
32		85H	85V	85H	
33		85V	85H	85V	
34		0000	Hotload 3	85H	B scan status data
35		AGC3	AGC2	AGC1	
36		85V(C2)	85H(C1)	85V(C1)	
37		85H(C3)	85V(C3)	85H(C2)	Cold Load (B scan)
38		85V(C5)	85H(C4)	85V(C3)	5 for 2 channels
39		85H(H1)	85V(H1)	85H(C5)	Hot Load (B scan)
40		85V(H3)	85H(H2)	85V(H2)	
41		85H(H4)	85V(H4)	85H(H3)	End of B Scan
42		85V	85H(H5)	85V(H5)	Start of A' Scan
43		37H	37v	85H	1st Scene Station pair of
44		22v	19H	19V	Sensor Scan A'
45		85V	85H	85V.	
		Repeat for 14 scene stations			
.					
87		85V	85H	85V	
88		37H	37v	85H	
89		22v	19H	19v	16th scene station pair
90		fill	85H	85V	of Sensor Scan A'

BLOCK TYPE 3

Word	Bits 1	12	24	36	
0		ID WORD			
1		37v	85H	85V	
2		19H	19V	37H	17th Scene Station
3		85H	85V	22v	pair of Sensor Scan A'
4		37v	85H	85V	
5		19H	19V	37H	18th Scene Station
6		85H	85V	22v	pair of Sensor Scan A'
	Repeat for other scene station pairs				
88		37v	85H	85V	
89		19H	19V	37H	46th Scene Station
90		85H	85V	22v	pair of Sensor Scan A'

BLOCK TYPE 4

Figure 4: SSM/I Data Formats (3 of 5)

Word	Bits 1	12	24	36	
0		ID WORD			
1		37V	85H	85V	
2		19H	19V	37H	47th Scene Station
3		85H	85V	22V	Pair of Sensor Scan A'
4		37v	85H	85V	
5		19H	19V	37H	48th Scene Station
6		85H	85V	22V	Pair of Sensor Scan A'
7		37v	85H	85V	
.					
		Repeat for Other Scene Station Pairs			
.					
53		19H	19V	37H	64th Scene Station
53		85H	85V	22V	Pair of Sensor Scan A
55		AGC1	Forward rad temp	RF mixer temp	A' scan status data
56		37v (CI)	AGC3	AGC2	
57		19H (CI)	19V (CI)	37H (CI)	Cold Load Readings
58		85H (CI)	85V (CI)	22v (CI)	(A' scan)
59		19V (C2)	37H (C2)	37V (C2)	(5 for each channel)
60		85V (C2)	22v (C2)	19H (C2)	
61		85H (C3)	85V (C3)	85H (C2)	
62		19V (C3)	37H (C3)	37V (C3)	
63		85V (C4)	22v (C3)	19H (C3)	
64		85H (C5)	85V (C5)	85H (C4)	
65		19V (C4)	37H (C4)	37V (C4)	
66		37v (C5)	22v (C4)	19H (C4)	
67		19H (C5)	19V (C5)	37H (C5)	
68		37H (Hi)	37V (H1)	22v (C5)	
69		22V (H1)	19H (H1)	19V (H1)	Hot Load Readings
70		37V (H2)	85H (H1)	85V (H1)	(A scan)
71		19H (H2)	19V (H2)	37H (H2)	(5 for each channel)
72		85H(H2)	85V(H2)	22V(H2)	
73		37V(H3)	85H(H3)	85V(H3)	
74		19H(H3)	19V(H3)	37H(H3)	
75		85H(H4)	85V(H4)	22V(H3)	
76		37V(H4)	85H9H5)	85V(H5)	
77		19H(H4)	19V(H4)	37H(H4)	
78		37H(H5)	37V(H5)	22V(H4)	
79		22V(H5)	19H(H5)	19V(H5)	End of A' Scan
80		85V	85H	85V	Start of B' Scan 16 Pairs of 85V, H Readings
		Repeat for other 85 GHz pairs			
88		85V	85H	85V	
89		85H	85V	85H	
90		fill	85H	85V	

BLOCK TYPE 5

Figure 4: SSM/I Data Formats (4 of 5)

word	Bits 1	12	24	36	
0	.... ID WORD				
1		85V	85H	85V	112 Pairs of 85V
2		85H	85V	85H	85H readings -
3		85V	85H	85V	B' scan
.	Repeat for other scene station pairs				
.					
74		85H	85V	85H	
75		Ref Voltage	85H	85V	
76		AGC2	AGC1	Ref Return	B' scan status data
77		85H(C1)	85V(C1)	AGC3	
76		85V(C3)	85H(C2)	85V(C2)	
79		85H(C4)	85V(C4)	85H(C3)	Cold Load (B' scan)
60		85V(H1)	85H(C5)	85V(C5)	5 for 2 channels
81		85H(H2)	85V(H2)	85H(H1)	
82		85V(H4)	85H(H3)	85V(H3)	Hot Load (B' scan)
83		85H(H5)	85V(H5)	85H(H4)	
84-90		fill	fill	fill	

BLOCK TYPE 6

Word	Bits 1	12	24	36
0	0	.... ID WORD		
I-90	All Zeroes	All Zeroes	All Zeroes	Fill Words for Timing

BLOCK TYPE 7

ID WORD Definition

1..........14	15....17	18.......33	34.....36
Data Quality Pattern	Block Type (0-7)	Time Interval From Start of scan to first read envelope in seconds? 024	Number of Read Envelopes from start of scan to readout of data block

Figure 4. SSM/I Data Formats (5 of 5)

9.2 Radiometric Processing

A complete discussion of the radiometric calibration is in order. The original calibration procedure prior to the Calibration/Validation Report computed an estima of the hot and cold reference voltages by averaging across the five calibration measurements recorded for each reference on every scan. For central site process the Calibration/Validation team now recommends averaging reference voltages ac 10 scans (5A and 5B scans) in addition to the per scan averaging that was already being performed on individual scans. The tactical processing of the data will have t take into consideration data dropouts and calculate a smoothed gain over the lost transmission times.

In the following i represents the scene station (l-64 of lower frequency channels, and 1-128 for the 85 GHz channels) and j represents the channel (1-7).T gain of the individual channels is calculated by using the hot load counts and the c sky counts found in the data format. Five readings of the hot load and cold sky are taken every revolution of the sensor. These five readings should be averaged together so that the instantaneous gain:

$$G_j = (\text{Hot load temp} - 2.7'' \text{ K})/(\text{Hot counts}_{avg-j} - \text{cold counts}_{avg-j})$$

where the Hot load temp is determined from the three thermistors in the data format blocks 2 and 3.

$$\text{Hot load temp} = (\Sigma T_{hl}(i))/n$$

where n is the number of valid thermisters and Thl is the converted temperature.. it important that the software checks that the hot and cold counts are not equal as thi has happened on the first SSM/I due to the sensor malfunctioning.

The actual brightness temperature for an individual scene station is then:

$$TBj(i) = aj + Gj\ (\text{Scene counts}(i) - \text{cold counts}_{avg-j})$$

and a_j= Hot load temp + b_o -

The basic purpose of the Antenna Pattern Correction is to correct for feed horn spillover loss, cross polarization effects and side lobe leakage from adjacent scene stations. The severity of the necessary antenna corrections can be broken down into levels. Level 1 effects are basically those which only involve the current scene station and the cross polarized channel. A pseudo-22H T_B can be constructed using the 19H T_B. Level 2 effects are due to the side lobe leakage and can be compensated for by applying a correction term based on values measured in a 5x5 pixel neighborhood. Level 3 corrections are not recommended at this time. Due to the larger beam widths of the 19V, 19H, and 22V channels, it is no longer recommended that Level 2 corrections need to be applied to these channels. Level 2 corrections are recommended for the other channels and five sets of correction coefficients are used based on the current scan angle (i.e., scene number for current scan). When the initial SSM/I processing for Level 2 corrections was set up, it was decided to use four scene stations out of the possible 24 neighboring stations in a 5x5 grid. This is still the recommended approach.

$$TC_j(i) = T_{Bj}(i)C_j + T_{Bj'}(j)CP_j + \sum T_{Bj}(i")Cp(\Delta i)$$

where Cj is a correction coefficient which is dependent on the scene station number, CP_j is a cross polarization correction. The current software was designed to use a flexible approach to selecting which of the four neighbors is used in the correction, and this is still required as different sets of neighbors are used for the 5 different sets of correction coefficients. Also note that the SDR's for the beginning and ending scene stations on each scan are not computed, since the antenna pattern correction can be applied only when the necessary neighbors are available.

9.3 Earth Location

The existing earth location being done at the weather centrals needs to be modified tactical processing by deleting the interpolation modules that were added to speed processing at the central, sacrificing earth location accuracy. The first requirement i obtain the scene station acquisition time. This is done by using both the OLS time word and the time word within the SSM/I data block for block type 1. For each scan the time is calculated from the time found in block type 1. When the spacecraft is no autonomous mode operation, the OLS ETC word in the block type 0 frame gives the number of seconds from 0 Zulu time that the first OLS read gate occurred to the first mission sensor. To that time, the ground system must add the time to the first SSM/ read gate, which is equal to the number of bits given to the other mission sensors ahead of the SSM/I sensor in the format words of the OLS. Therefore the time of the actual SSM/I read gate for collecting block type 1 data is:

$$T_{read\text{-}gate\ 1} = OLS_{read\text{-}gate\ q} + (S_1+S_2+\ldots S_n)/9990 \quad \text{(bits/second).}$$

where q equals read gate 0 if the number of envelopes elapsed in the SSM/I ID wo equals 0, or equals read gate 6 (or 7 if it occurs) of the previous block. The SSM/I block 1 contains the time from the start of scan to that OLS read-gate. Therefore the start of scan time is:

$$T_{scan\text{-}start} = T_{read\text{-}gate\ 1} - \Delta t/1024$$

This is then the start of the "B" scan of figure 4. The A scan starts 1.89 seconds earli the A' scan 1.89 seconds later, and the B' scan begins 3.78 seconds later. If data dr outs occur, the time of the scans must be estimated using the SSM/I rotation time of 1.89 seconds from a valid "time". The ground software must be careful in validating the ETC times, by using the fact that ETC times are within 1.0±0.1 seconds of each other.

Since the time of the scene station 1 is known from the above calculation for each scan, the time of individual stations can be referenced to scene station 1:

$$T_{scene\ station\ i} = T_{scan\ start} + 0.0042i \qquad \text{(85 GHz)}$$
$$T_{scene\ station\ i} = T_{scan\ start} + 0.0084i \qquad \text{(19, 22, 37 GHz)}$$

This time can then be used in the SGP ephemeris equations to determine the locati of the spacecraft in geodetic coordinates.

From the altitude information, the azimuth angle of the sensor, the nadir position of the. satellite, alignment information on the sensor, and the nominal elevation angle of 45 degrees, the location of the ith scene station can be determined.

9.4 Environmental Parameter Extraction

The processing used to compute environmental data records (EDRs) from sensor data records (SDRs) currently makes use of a land-type data base to apriori decide if a particular scene station is located over ocean, coast, land, Antattica, ice, or possible ice.. Once the background is determined, screening logic, based on a decision tree approach, is first used to determine which EDR's need to be computed, then one of four approaches are used to compute the necessary EDR's. The basic approach in computing the majority of the EDR's is linear regression, or D-Matrix approach. Many of the EDR's depend on only a few channels. A separate D-Matrix is used for each of 20 possible climatic zones in which the scene station may lie. The definition of the climatic zones is given in Table VI.The recommended coefficients for each of the required EDR's are available on magnetic tape.

Table VI SSM/I Climatic Zones

Zone #	
1	Tropical - Warm
2	Tropical Cool
3.	Lower Lat. Transition - Warm
4.	Lower Lat Transition - Cool
5	Mid-Lat Spring/Fall
6	Mid Lat Summer
7	Mid Lat Winter
8	Upper Lat Transition - Cool
9	Upper Lat Transition - Cold
10	Polar Cool
11	Polar Cold

Note that the recommended algorithms involve a nonlinear term for the computation of water vapor. This precludes the use of a generic D-Matrix approach order to implement the most current algorithms. Additional non-linear algorithms ar also being discussed and researched. This may require the use of higher order ma language implementation for EDR retrieval algorithms in order to provide the necessary flexibility.

9.5 Out of Specification Corrections

With the failure of the 85V channel on F-8, a number of corrections had to be made. The first item was that all the gain equations had to make certain that there were no division by zeros. Then the 85 V channel was approximated by the 85 H channel for about one year. Secondary equations had to be derived. The software now has to handle both the primary and secondary equations depending on which satellite is being processed. This would indicate that care has to be taken to create data bases from only good channels.

10. PROCESSING SSM/T DATA

10.1 Data Stream Extraction

The SSM/T transmits a block of 144 bits to the OLS approximately every three seconds. Each block is formatted into twelve 12-bit words. The first seven words contain readings from the seven microwave channels, while the remaining words carry beam position indicators, SAGC values, and MUX data.

Data Word 1 :*Channel 1 50.5 GHz
Data Word 2: *Channel 2 53.2 GHz
Data Word 3: *Channel 3 54.35 GHz
Data Word 4: *Channel 4 54.9 GHz
Data Word 5: *Channel 5 58.4 GHz
Data Word 6: *Channel 6 58.825 GHz
Data Word 7: *Channel 7 59.4 GHz
Data Word 8: MUX Data (see below)
Data Word 9: MUX Data (see below)
Data Word 10: MUX Data (see below)
Data Word 11: ● 3 SAGC Readings (Ch 1, Ch 2-4, Ch 5-7) 4 bits each
Data Word 12: Beam Position (5 bits), Upper 7 bits are zero

MUX Data

Beam Position 15	Warm Calibrate	*Warm Load 1, *Warm Load 2, *Warm Load 3
Beam Position 23	Cold Calibrate	*Cold Load 1, *Cold Load 2, *Cold Load 3
Beam Position 1	Scene Data	OMT Temp, V-Mod Temp, H-Mod Temp
Beam Position 2	Scene Data	RF Filter Temp, Diplexer Temp, Mixer 1 Temp
Beam Position 3	Scene Data	Mixer 2 Temp, Mixer 3 Temp, Local Oscillator
Beam Position 4	Scene Data	IF Amp 1 Temp, IF Amp 2 Temp, IF Amp 3 T
Beam Position 5	Scene Data	Antenna Temp, DC/DC Conv Temp, IR Sync
Beam Position 6	Scene Data	MUX Zero, MUX Cal, MUX flag (all ones)
Beam Position 7	Scene Data	Spare, Spare , Spare

All data indicated by an asterisk (above) is required for the processing of SSM/T data. For each sensor, there is a table that converts each precision thermistor to degrees Kelvin (Table VII).

Other items that are needed to process the data are the warm and cold

calibration coefficents generated for the instruments during system test.

To process the data from brightness temperature to temperatures versus he a terrain field, a surface type field, and 1000 mb height fields are needed.

10.2 Radiometric Correction

The first step in the radiometric correction is to calculate the gain of the syste from the hot load and cold load references. In the equations below j indicates cha number (1-7), x is the beam pointing position (1-7), and i indicates time sequence.

The cold and hot references are:

$$T_{AC}(j) = \varepsilon(j) * TC + \gamma(j) * T_{CI}$$

$$T_{AH}(j) = \alpha(j) \, . \, T_H + \beta(j) * T_{HI}$$

where or(j), β(j), ε(j), and γ(j) are stored coefficients derived from the primary calibra of each instrument. In the current AFGWC code, they are all set to 1. A total of 28 coefficients are needed for each sensor. The measured T_{CI} and T_{HI} are given in Table VIII. T_H is the average of the three hot load thermistors and TC is the cosmic black body temperature of deep space, 2.7° K. Table IX provides the converson coefficients.

At this stage, the tactical processing of the data has to depart from that practi at the weather centrals, where a running average of 10 scans is used for the gain calculations. Ten scans represents five minutes of data time which is most of a standard tactical pass. Also during data drop-outs, some calibration data loss alsc occurs.

From the hot and cold reference positions, calculate

$V_H(j) = 1/N \, \Sigma \, V_H(j,i)$ i=-5 to +4, N= number of valid hot load readings

$V_C(j) = 1/N \, \Sigma \, V_C(j,i)$ i= -5 to +4, N= number of valid cold load readings, which gives a gain of:

$$G(j) = [T_{AH} - T_{CH}] / [V_H(j) - V_C(j)]$$

Table VIII SSM/T Radiative Correction Coefficients

	T_{CI}	T_{HI}		T_{CI}	T_{HI}
S/N A1			S/N A2		
Ch 1	+0.0100	-0.1300		+0.7700	-0.2800
Ch2	+0.2700	-0.0027		+0.7400	-0.3400
Ch3	+0.1700	-0.0500		+0.5900	+0.1100
Ch4	+0.4600	-0.1200		+0.6900	-0.3900
Ch 5	+1.1200	-0.4300		+0.6800	-1.3200
Ch6	+0.3500	-0.3400		+0.6100	-0.5200
Ch7	-0.3400	-0.2600		+0.6200	-0.1600
S/N A3			S/N B1		
Ch 1	+0.3731	-0.0338			
Ch2	+0.3723	-0.2434			
Ch3	+0.1353	-0.1350			
Ch4	+0.1836	-0.0884			
Ch 5	+1.1250	+0.0842			
Ch6	+0.3225	-0.0811			
Ch7	+0.2105	-0.0295			
S/N B2			S/N B3		
Ch 1					
Ch2					
Ch3					
Ch4					
Ch 5					
Ch6					
Ch7					
S/N B4			S/N B5		
Ch 1	+0.952	+0.383			
Ch2	+1.264	+0.558			
Ch3	+1.315	+0.234			
Ch4	+1.074	+0.167			
Ch 5	+0.684	+0.205			
Ch6	+0.819	+0.164			
Ch7	+0.807	+0.352			
S/N B6					
Ch 1					
Ch2					
Ch3					
Ch4					
Ch 5					
Ch6					
Ch7					

Table IX Thermistor Conversion Tables

Unit	Counts	Temp (°C)	Unit	Counts	Temp (°C)
S/N A1			S/N A2		
Therm2	0	0.24	Therm2	0	0.06
	459	5.36		470	5.29
	917	10.46		929	10.40
	1342	15.32		1357	15.26
	1665	19.05		1680	18.99
	2198	25.25		2215	25.19
	2621	30.32		2640	30.27
	3029	35.27		3050	35.22
	3436	40.29		3458	40.25
	3827	45.19		3851	45.15
	4095	48.56		4096	48.21
S/N A3			S/N B1		
Therm2	0	0.11	Therm2		
	452	5.28			
	898	10.39			
	1314	15.25			
	1629	18.97			
	2139	25.18			
	2553	30.25			
	2947	35.20			
	3341	40.22			
	3722	45.12			
	4096	49.93			
S/N B2			S/N B3		
Therm2	0		Therm2		

If the SAGC has changed in the middle of i=-5 to +4, then two separate average gain states should be calculated for before and after the switch. The second gain value should be adjusted by the step ratio of 2 dB, depending on the direction and then averaged with the first. Then the antenna temperature

$T_A(x,j) = T_{AH}(j) + [V(x,j) - V_H(j)]G(j)$

where V = sensor output counts for x=scene stations, H is the hot position, C is the cold position. To go from antenna temperatures to brightness temperatures, the antenna pattern coefficients need to be applied. The antenna pattern correction coefficients g(x,j) for the SSM/T-1 are in Table X. Table X provides the 49 antenna pattern correction coefficients as taken from the AFGWC version of the SSM/T code. The Tb's are adjusted as follows:

$T_b(x,j) = T_A(x,j)/g(x,j)$

where j = j th frequency
x = x beam position
T_b = measured brightness temperatures

Table X - SSM/T Antenna Pattern Coefficients

Channel Beam Position	1	2	3	4	5	6	7
1	.9972	.9962	.9964	.9965	.9961	.9956	.9948
2	.9974	.9972	.9972	.9972	.9977	.9969	.9959
3	.9978	.9972	.9976	.9978	.9985	.9981	.9976
4	.9978	.9986	.9984	.9983	.9989	.9985	.9980
5	.9975	.9983	.9979	.9978	.9986	.9983	.9979
6	.9975	.9981	.9983	.9983	.9981	.9977	.9971
7	.9971	.9970	.9969	.9969	.9966	.9962	.9956

The brightness temperatures (Tb) measured by the SSM/T-1 are a function of incide angle. To display the calibrated temperature channels, Tb must be adjusted to corre for the atmospheric attenuation/re-radiation. These adjustments at a given angle are presented in Table X. This effect is call limb darkening/brightening. This correction should be applied only for the display and not the processing of the temperatures at various heights. Figure 5 plots typical limb effects on SSM/T-1 Tb's.

10.3 Geometric Corrections

Geometric corrections to the observed Tb's are also required. For example, the SSM/T-1 has seven distinct beam positions (). The angle of incidence () for each beam position is a function of spacecraft altitude (h):

where R = earth radius

10.4 Parameter Extraction

There are 31 data vectors to be calculated for the SSM/T-1 as enumerated in Table XI. The current operational scheme to process the brightness temperatures to these data vectors or environmental parameters is multiple linear regression for parameters. There is a set of D-matrix coefficients for each look angl season, and zones. The four seasons are defined as

Fall - September 21 to December 20 (Season 1)
Winter - December 21 to March 20 (Season 2)
Spring - March 21 to June 20 (Season 3)
Summer - June 21 to Sept. 20 (Season 4)

The three zones are defined as:

30 ° S to 30° N zone 1
30° N to 60° N (and southern also) zone 2
60° N to 90° N (and southern also) zone 3

Figure 5 - SSM/T Limb Darkening/Brightening Corrections

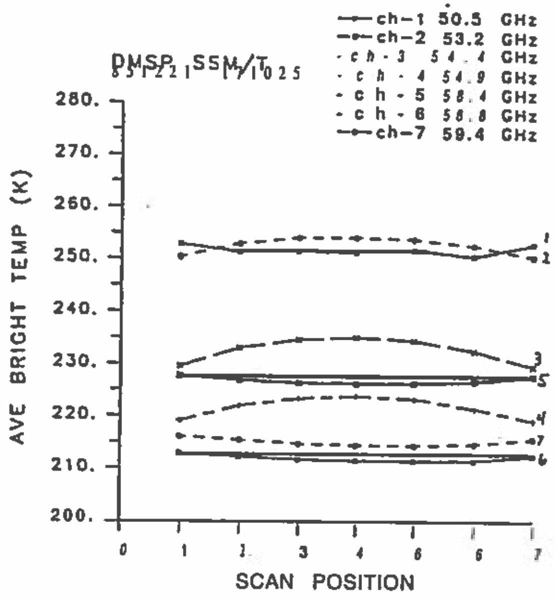

Table XI - SSM/T Parameter Vector

1	Air Temperature at 1000 mb
2	Air Temperature at 850 mb
3	Air Temperature at 700 mb
4	Air Temperature at 500 mb
5	Air Temperature at 400 mb
6	Air Temperature at 300 mb
7	Air Temperature at 250 mb
8	Air Temperature at 200 mb
9	Air Temperature at 150 mb
10	Air Temperature at 100 mb
11	Air Temperature at 70 mb
12	Air Temperature at 50 mb
13	Air Temperature at 30 mb
14	Air Temperature at 20 mb
15	Air Temperature at 10 mb
16	Atmospheric Thickness between 1000 mb and 850 mb
17	Atmospheric Thickness between 850 mb and 700 mb
18	Atmospheric Thickness between 700 mb and 500 mb
19	Atmospheric Thickness between 500 mb and 400 mb
20	Atmospheric Thickness between 400 mb and 300 mb
21	Atmospheric Thickness between 300 mb and 250 mb
22	Atmospheric Thickness between 250 mb and 200 mb
23	Atmospheric Thickness between 200 mb and 150 mb
24	Atmospheric Thickness between 150 mb and 100 mb
25	Atmospheric Thickness between 100 mb and 70 mb
26	Atmospheric Thickness between 70 mb and 50 mb
27	Atmospheric Thickness between 50 mb and 30 mb
28	Atmospheric Thickness between 30 mb and 20 mb
29	Atmospheric Thickness between 20 mb and 10 mb
30	Tropopause temperature
31	Tropopause pressure

Adjustments to the SSM/T radiometric brightness temperatures (Tb in watts m^{-2} sr Hz^{-1}) for channels 1 through 4 are required and are a function of the inversion technique chosen and the simplifying assumptions made. The current operational terrain height corrections involve a least squares fit to a quadratic representation terrain height field.

$T_j = Tbj + \Delta_a - \varepsilon_j(\theta,z,s)\Delta_b$ Channels j=1-4

$T_j = Tbj$ Channels j=5-7

where

$\Delta_a = A_j(\theta, z, s)\, h + B_j(\theta, z, s)\, h^2$

$Ab = A'_j(\theta,z,s)\, h + B'_j(\theta,z,s)\, h^2$

$\varepsilon_j(\theta,z,s) = [T_{b1} - S_1(\theta,z,s) + \Delta_a]/[C_1(\theta,z,s) + \Delta_b]$

h = terrain height in meters

Tbj = brightness temperature of channel j

θ = look angle

z = climatological zone

s = season

A, B, A', B', S_1, and C_1 matrices are functions of channel, look angle, zone, and season. There are 192 values in each matrix, allowing for the symmetry in the look angle. These matrices will be available with the D-matrix coefficients for each satellite. This particular correction is necessary due to the fact that the operational inversion scheme is statistically based using precomputed regression coefficients appropriate for sea level observations. For ocean backgrounds and land elevations below 25 meters, the correction is not applied. Consideration should also be given to flagging SSM/T-1 beam positions (ocean backgrounds only) that are potentially contaminated by heavy clouds and precipitation. Currently channel 1 is used to determine over ocean if there is precipitation in the field of view. A surface type data base is used to find the background of a given latitude/longitude. Table XII gives the precipitation limits currently used.

Table XII Precipitation Channel 1 Temperatures

Temperatures in °K

	Angle	1 (36°)	2 (24°)	3 (12°)	4 (0°)
Season	Zone				
1 (Fall)	Tropical	245	245	248	255
	Temperate	240	240	240	245
	Arctic	240	240	240	242
2 (Winter)	Tropical	245	245	248	255
	Temperate	240	240	240	245
	Arctic	240	240	240	242
3 (Spring)	Tropical	245	245	248	255
	Temperate	240	240	240	245
	Arctic	240	240	240	242
4 (Summer)	Tropical	245	245	248	255
	Temperate	241	241	244	250
	Arctic	240	240	240	242

The 31 data vectors are then derived by a matrix multiplication:

$$Pi = D_{ij}T_j + D_{i8}$$

where Pi = output parameter vector desired

D_{ij} = D matrix, one D matrix for each look angle, zone, season

D_{i8}= Constant parameter vector for each look angle, zone, season.

T_j = Terrain Height corrected brightness temperatures

Close to the seasonal and zonal break points, the data is smoothed across the zo and seasons is done. This is applied when within 2.5 degrees of the equator, 30°, 60°. A linear interpolation is used to create the new parameter vector. The Terrain Height corrected brightness temperatures are not recalculated for the second parameter matrix.

The total size of the D matrix is 31 x 8 x 4 x 3 x 4 = 11,904. It is potentially different for sensor and is updated at AFGWC on a quarterly to yearly basis. To obtain. the temperature as a function of height, it is necessary to have an external source for the 1000 mb height. Then the atmospheric thicknesses can be summed to each desired level to get the temperature versus height curve.

Constraints on choosing any particular inversion technique are: (potentially) limited computer resources, ancillary databases required (i.e., 1000 Mb height field), and operational expedience. It is not satisfactory, for example, to consume 30 minutes of wall clock time computing the 31 data vectors required for the SSM/T-1. Consideration should also be given to flagging SSM/T-1 beam positions (ocean backgrounds only) that are potentially contaminated by heavy clouds and precipitation. This type of indicator is very useful in assigning a quality flag to the environmental data since the SSM/T-1 microwave Tb's are heavily modified by precipitating clouds.

There are a host of other techniques being developed to perform environmental parameter extraction from microwave sensors. Aerojet is looking at developing an air mass based retrieval, eliminating the need for zones and seasons.

10.5 Out of specification Corrections

The primary out of specification condition that has to be handled is the obscuration of scene station 7 by the GLOB which is flown on terminator orbits only. For a spacecraft with the GLOB, scene station 7 should be used in the imagery, but not used to process temperature soundings.

Over the years, the software has been modified to handle the anomalous behaviors.. One current behavior is an incorrect beam position counter. Once in a while, the beam position indicator will count 1 ,1,2,3,4,5,6., instead of counting 1,2,3,4,5,6,7 The actual sensor is working fine with only beam position indicator incorrect. The software has to look for the anomalous pattern and correct it to the correct sequence.

The second anomalous behavior has been variation in the erratic variations i the cold load counts in several of the channels. Some broad limit tests should be made on the cold counts, such as delta's between scans no greater than 100 count (unless the SAGC has changed).

A third anomalous behavior was a case where the cold load counts went greater than 4095. In this case the cold load counts had to be approximated with a fixed number set by the user.

11. Special Sensor Microwave Humidity Profiles (SSM/T-2)

The SSM/T-2 major cycle is 32 seconds, representing four scans of data. Four eight subframes are contained within a 8 second minor frame of the data. Each second contains 324 bits, 27 twelve bit words. A filler block of all ones will occur once every 17 minutes due to the slight difference between the OLS reference clock of 9.99024 kHz. Figure 6 contains the individual frame formats beginning with cycle1 (in the stored data, cycle 4 comes first).

12 bit word	Description	12-bit word	Description
1	Data Identification 0	28	Data Identifiltion 1
2	Time Start Scan 1	29	BP 6, Ch 1
3	BP 1, Ch 1	30	BP 6, Ch 2
4	BP 1, Ch 2	31	BP 6, Ch 3
5	BP 1, Ch 3	32	BP 6, Ch 4
6	BP 1, Ch 4	33	BP 6, Ch 5
7	BP 1, Ch 5	34	BP 7, Ch 1
8	BP 2, Ch 1	35	BP 7, Ch 2
9	BP 2, Ch 2	36	BP 7, Ch 3
10	BP 2, Ch 3	37	BP 7, Ch 4
11	BP 2, Ch 4	38	BP 7, Ch 5
12	BP2, Ch 5	39	BP 8, Ch 1
13	BP 3, Ch 1	40	BP 8, Ch 2
14	BP 3, Ch 2	41	BP 8, Ch 3
15	BP 3, Ch 3	42	BP 8, Ch 4
16	BP3, Ch4	43	BP 8, Ch 5
17	BP 3, Ch 5	44	BP 9, Ch 1
18	BP 4, Ch 1	45	BP 9, Ch 2
19	BP 4, Ch 2	46	BP 9, Ch 3
20	BP 4, Ch 3	47	BP 9, Ch 4
21	BP 4, Ch 4	48	BP 9, Ch 5
22	BP4, Ch5	49	BP 10, Ch 1
23	BP 5, Ch 1	50	BP 10, Ch 2
24	BP 5, Ch 2	51	BP 10, Ch 3
25	BP5, Ch3	52	BP 10, Ch 4
26	BP 5, Ch 4	53	BP 10, Ch 5
27	BP 5, Ch 5	54	BP 11, Ch 1

Figure 6. SSM/T2 Frame Formats (1 of 5)

12- bit Word Number	Description
55	Data Identification 2
56	BP 11, Ch2
57	BP 11, Ch 3
.	.
80	BP 16, Ch 1
81	BP 16, Ch 2
82	Data Identification 3
83	BP 16, Ch 3
.	.
107	BP 21, Ch 2
108	BP 21, Ch 3
109	Data Identification 4
110	BP 21, Ch4
.	.
135	BP 26, Ch 4
136	Data Identification 5
137	BP 26, Ch 5
138	BP 27, Ch 1
	.
	.
	.
147	BP 28, Ch 5
148	SAGC, Ch 1
149	SAGC. Ch 2
150	SAGC, Ch 3
151	SAGC, Ch 4
152	SAGC, Ch 5
153	Spare
154	Spare
155	Spare
156	Therm Ref
157	Temp 1 Warm Load #1
158	Temp 2 Warm Load #2
159	Temp 3 Cold Path
160	Temp 4 Stepper Motor
161	Temp 5 Feed Horn
162	Temp 6 Mixer/Triplexer No. 1

Figure 6. SSM/T2 Frame Formats (2 of 5)

Word Number	Description
163	Data Identification 6
164	WC 1, Ch 1
165	WC 1, Ch 2
.	.
.	
.	.
182	WC 4, Ch 4
183	WC 4, Ch 5
184	Temp 7 Baseplate 32
185	Temp 8 Detector/Preamp Assembly
186	Temp 9 DC/DC Converter
187	Temp 10 91.65 GHz Oscillator A
188	Temp 11 91.65 GHz Oscillator B
189	Temp 12 75 GHz Oscillator
190	Data Identification 7
191	CCI,ChI
192	CC 1, Ch 2
.	.
.	.
210	CC 4, Ch 5
211	Temp 13 Baseplate No. 1
212	Temp 14 Channel 1 IF Amplifier
213	Temp 15 Channel 2 IF Amplifier
214	Temp 16 Channel 3 IF Amplifier
215	Temp 17 Channel 5 IF Amplifier
216	Temp 18 Channel 4 IF Amplifier
++++++++++++++++++++++++	
End Scan 1	
217	Data Identification 8
218	Time Start Scan 2
219	BPI,ChI
.	.
243	BP 5, Ch 5
244	Data Identification 9
245	BP 6, Ch 1
.	.
270	BP 11, Ch 1
271	Data Identification 10
272	BP 11, Ch2
.	.
297	BP 16, Ch 2

Figure 6. SSM/T2 Frame Format (3 of 5)

(3) Data identification words run 0 to 31, with 0 reserved for the first scan line of four which is synchronized with the SSM/T1 scan
(4) SAGC words - Lower 9 bits are the gain.
(5) Mode bits found in words 150,151, and 152 are used to determine the scanner operating mode. Word 151 contains the 91.5 GHz Gunn Diode oscillator selection, with a 1 for primary and 0 for redundant in bit 2.

Figure 6. SSM/T2 Frame Formats (5 of 5)

11.1. Radiometric Corrections

The SSM/T2 is very similar to the SSM/T1 in terms of performing the calibra of the data. The SSM/T2 has two thermistors which need to be changed from cou to temperature, using Table XIII for the specific sensor, and averaging the two readi

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Table XIII SSM/T2 Thermistor Conversion Tables

Unit	Counts	Temp (°C)	Unit	Counts	Temp (°C)
S/N B3			S/N B3		
Therm1	0	0.24	Therm2	0	0.06
	459	5.36		470	5.29
	917	10.46		929	10.40
	1342	15.32		1357	15.26
	1665	19.05		1680	18.99
	2198	25.25		2215	25.19
	2621	30.32		2640	30.27
	3029	35.27		3050	35.22
	3436	40.29		3458	40.25
	3827	45.19		3851	45.15
	4095	48.56		4096	48.21
S/N B4			S/N B4		
Therm1	0	0.11	Therm2		
	452	5.28			
	898	10.39			
	1314	15.25			
	1629	18.97			
	2139	25.18			
	2553	30.25			
	2947	35.20			
	3341	40.22			
	3722	45.12			
	4096	49.93			
S/N B5			S/N B5		
Therm1	0	-0.20	Therm2	0	-0.20
	400	4.40		400	4.50
	800	8.90		800	9.10
	1200	13.50		1200	13.70
	1600	18.10		1600	18.30
	2000	22.70		2000	22.90
	2400	27.30		2400	27.50
	2800	31.90		2800	32.10
	3200	36.50		3200	36.70
	3600	41.10		3600	41.30
	4000	45.80		4000	46.00
	4095	50.10		4095	50.30

Table XIII SSM/T2 Thermistor Conversion Tables (Continued)

Unit	Counts	Temp (°C)	Unit	Counts	Temp (“C)
S/N B6 Therm1	0	-.20	S/N B6 Them-i2	0	-0.10
	400	4.40		400	4.50
	800	8.90		800	9.10
	1200	13.50		1200	13.70
	1600	18.10		1600	18.30
	2000	22.70		2000	22.90
	2400	27.30		2400	27.50
	2800	31.90		2800	32.10
	3200	36.50		3200	36.50
	3600	41.10		3600	41.30
	4000	45.80		4000	46.00
	4095	50.10		4095	50.30

together. Then the gain of the channels are calculated using the cold counts and warm load counts and the correction coefficients given in Table XIV. These correction coefficients depend upon which mode (word 151-bit 2) has been selected for the operation of the Gunn Diode.

$$G_j = \frac{(\text{Hot Load Temp}_{avg} - 2.7° + EWRK_j - ECRK_j)}{(\text{Warm Load Countsj - Cold Sky Countsj})}$$

and the antenna temperature is then:

$$T_A = 2.7" + ECRK_j + G_j(\text{Scene Countsj - Cold Sky Countsj})$$

Table XIV - Radiative Correction Coefficients

Sensor #		Mode 0		Mode 1
Channel #	ECRK	EWRK	ECRK	EWRK
B3-ch 1	0.00	0.00	0.00	0.00
B3-ch 2	0.00	0.00	0.00	0.00
B3-ch 3	0.00	0.00	0.00	0.00
B3-ch 4	0.00	0.00	0.00	0.00
B3-ch 5	0.00	0.00	0.00	0.00
B4-ch 1	0.00	0.00	0.00	0.00
B4-ch 2	0.00	0.00	0.00	0.00
B4-ch 3	0.00	0.00	0.00	0.00
B4-ch 4	0.00	0.00	0.00	0.00
B4-ch 5	0.00	0.00	0.00	0.00
B5-ch 1	0.51	0.25	0.00	0.00
B5-ch 2	0.55	0.31	0.00	0.00
B5-ch 3	0.54	0.20	0.00	0.00
B5-ch 4	0.52	0.23	0.00	0.00
B5-ch 5	0.43	0.26	0.00	0.00
B6-ch 1	0.00	0.00	0.00	0.00
B6-ch 2	0.00	0.00	0.00	0.00
B6-ch 3	0.00	0.00	0.00	0.00
B6-ch 4	0.00	0.00	0.00	0.00
B6-ch 5	0.00	0.00	0.00	0.00

11.2 Geometric Corrections

Based on a SSM/T-2 study, the water vapor retrieval accuracy is largely independ of earth incidence angle effects and hence largely independent of scan type.

11.3. Environmental Parameter Extraction

The current operational retrieval technique for the SSM/T-2 is identical to that of th SSM/T-1, that is multiple linear regression. The retrieval of humidity profiles from spaceborne microwave radiometry is an extremely challenging non-linear problem

The operational scheme relies on decomposing this non-linear problem into well defined piecewise linear domains. The domains are quantitatively defined in terms of discriminates. For the SSM/T-2, the discriminates are air mass types (i.e.. continental, polar, maritime, etc.). Clouds in the field-of-view of the SSM/T-2 require flagging. A Calibration/Validation effort will follow to be completed by November, 1992 . Many retrieval schemes have been presented using the 183 GHz water vapor absorption line. Table XV contains the parameters which are to be calculated from the combination of the SSM/T-1 and SSM/T-2 data sets.

Table XV - SSM/T-2 Parameter Vector

1 Relative Humidity (%) at 1000 mb
2 Relative Humidity (%) at 850 mb
3 Relative Humidity (%) at 700 mb
4 Relative Humidity (%) at 500 mb
5 Relative Humidity (%) at 400 mb
6 Relative Humidity (%) at 300 mb
7 Specific Humidity (g/kg) at 1000 mb
8 Specific Humidity (g/kg) at 850 mb
9 Specific Humidity (g/kg) at 700 mb
10 Specific Humidity (g/kg) at 500 mb
11 Specific Humidity (g/kg) at 400 mb
12 Specific Humidity (g/kg) at 300 mb
13 Water Vapor Mass (kg/m^2) between 1000 mb and 850 mb
14 Water Vapor Mass (kg/m^2) between 850 mb and 700 mb
15 Water Vapor Mass (kg/m^2) between 700 mb and 500 mb
16 Water Vapor Mass (kg/m^2) between 500 mb and 400 mb
17 Water Vapor Mass (kg/m^2) between 400 mb and 300 mb
18 Water Vapor Mass (kg/m^2) above 300 mb
19 Water Vapor Mass (kg/m^2) Surface to 1000 mb

11.4. Earth Location

12. Special Sensor Microwave Imager/Sounder (SSMIS)

The SSMIS is in the development stage at the time of this writing. This section will be . updated when information permits.

1. Radiometric and Geometric Corrections
2. Environmental Parameter Extraction
3. Earth Location

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13. References

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2.	Aerojet Report 5542 23 Nov. 1977	System Summary Report, Passive Microwave Sound SSM/T
3.	Aerojet Report 9538 18 June 1990	System Summary Report for the SSM/T2 Water Vapo Profiling Sensor Hardware Segment
4.	Hughes Aircraft 1980	SSM/I System/Subsystem Summary Report
5.	Westing house March 1981	BVS 0969 Technical Operating Report Block 5D2 Operational Linescan System

Abbreviations and Acronymns

A/D	Analog to Digital Converter
AFB	Air Force Base
AFGWC	Air Force Global Weather Central
AVHRR	Advanced Very High Resolution Radiometer
Block 5	Current Series of DMSP spacecraft
cat	calibration
cm	Centimeter
CRS	Command Read Out Site
dB	decibels
DC	Direct Current
D_{ij}	D-matrix coefficients used to process SSM/I, SSM/T, SSM/T2
Delphi	An angle on the OLS equal to about a milliradian
DMDM	Direct Mode Data Message
DMSP	Defense Meteorological Satellite Program
EDR	Environmental Data Record
ETC	Elapsed Time Counter on the OLS
F-xx	Spacecraft Nomenclature for launch order
kbps	kilobits per second
kHz	kilo Hertz
G	Gain of a sensor
GaAs	Gallium Arsenide, detector material for the OLS visible night channel
GHz	Giga Hertz
GLOB	Glare Obstruction Bracket
GPS	Global Positioning Satellite
h	Terrain height
HgCdTe	Mercury-Cadmium-Telluride, detector material for the OLS infrared channel
HULA	Space Control Network Site in Hawaii
I.D.	Identification word for sensors in the mission sensor format
IF	Intermediate Frequency
IR	Infrared
IS	Interface specification
km	kilometers
KG	Crypto Boxes
L	Light Data
LS	Light Smooth
M1	Primary Mirror of the OLS
mb	millibars
Mbps	Mega bits per second

MHz	Mega Hertz
MOD	Modulator
MUX	Multiplexer Unit on the SSM/T
NEAT	Noise Equivalent Temperature
NOAA	National Oceanic and Atmospheric Administration
NORAD	North American
NRL	Naval Research Labs
OLS	Operational Linescan System
OMT	Orthogonal mode transducer
P_i	Parameter vector
PMT	Photomultipler Tube, used in the OLS for night time visible data
PRADS	precision attitude determination mode
RDS	Real Time Data Smooth
R_e	Radius of the earth
RF	Radio Frequency
RTD	High Resolution Real Time Data
s-xx	Spacecraft Nomenclature for build sequence
S-band	A reserved frequency band for spacecraft between 2200 and 2300 G
SAGC	Stepped Automatic Gain Control
SD	Stored Data, consists of SDFNI, SDFI, and SDS
SDF	Stored Data Fine, which can be interleaved visible and infrared, or si channel
SDFI	Stored Data Fine Interleaved - a mode of recording onto one of the spacecraft flight tape recorders consisting of visible and infrared data
SDFNI	Stored Data Fine Non-interleaved - a single channel, either infrared visible of fine (.5 km) data
SDR	Sensor Data Record
SGP	Simplified General Perturbation model
S/N	Serial Number
SOG	Space Operations Group of Space Command
SSB/X-2	Gamma Ray sensor flown on the DMSP spacecraft
SSF	A Sandia sensor flown on the DMSP spacecraft
SSIES-2	Ionospheric Sensor flown on the DMSP spacecraft
SSIES-3	Ionospheric Sensor flown on the DMSP spacecraft
SSJ/4	Ionospheric Sensor flown on the DMSP spacecraft
SSJ/5	Ionosopheric Sensor flown on the DMSP Spacecraft
SSM	Magnetometer flown on board DMSP spacecraft
SSM/I	Microwave Imager Sensor, built by Hughes Aircraft
SSMIS	Microwave Imager Sounder Sensor built by Aerojet Corporation
SSM/T	Microwave Temperature Sounder Sensor
SSM/T1	New Buy of Microwave Temperature Sounders - same as SSM/T
SSM/T2	Microwave Water Vapor Profiling Sensor flown in conjunction with SSM/T1.