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THE DEFENSE METEOROLOGICAL SATELLITE PROGRAM SENSORS: AN HISTORICAL OVERVIEW

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Forward

This document provides a top-level description of the DMSP sensors, from the early satellites flown in the mid-60's to the satellite block planned through the 1990's.

The document is intended to be used as a reference of which sensors have flown in the past, as a guide for choosing proven sensors for the future, and as an educational aid to inform new DMSP personnel of the DMSP sensors.

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1.0 DMSP Overview

1.1 DMSP Mission

The Defense Meteorological Satellite Program (DMSP) mission is to provide an enduring and survivable capability, through all levels of conflict consistent with the survivability of the supported forces, to collect and disseminate global visible and infrared cloud cover, and other specialized meteorological, oceanographic, and solar-geophysical data to support DoD operations and high priority programs. Timely data are supplied to the Air Force Global Weather Central (AFGWC), the Navy Fleet Numerical Oceanography Center (FNOC) and to deployed tactical receiving terminals worldwide.

1.2 DMSP Space Segment

The program's current space segment (Block 5D) consists of two satellites in 833 kilometer (km) sun-synchronous polar . Each satellite carries a payload of primary and mission environmental sensors. Mission sensor configurations vary for each satellite. The satellite and sensors are designed to support virtually any ascending node time. The ascending node time is the local time at which the ground track of the satellite crosses the equator from south to north.

1.3 DMSP System

DMSP satellites are launched from Vandenberg AFB CA. The satellites are operated and maintained by AFSPACECOM through the 6th Space Operations Squadron (6 SOPS) located at Offutt AFB NE with support, as required, from the Air Force Satellite Control Network (AFSCN). Real-time commands and stored command files are generated by 6 SOPS personnel at dedicated Command, Control, and Communications (C^3) facilities located at Offutt AFB, NE and Fairchild AFB, WA. These commands are relayed via commercial Domestic Communication Satellites (DOMSAT) to dedicated antennas at Fairchild AFB and Automated Remote Tracking Stations (ARTS) with specialized DMSP enhancements at Hawaii, Thule, and New Hampshire for uplink to DMSP satellites. Satellite telemetry data are returned via DOMSAT for use by 6 SOPS to verify success of satellite commanding and assess the satellite state of health.

Modifications have been made to the C^3 segment at Offutt AFB to provide operational and logistical commonality with the C^3 system at Fairchild AFB. Another modification provided some internetting capability with the AFSCN Mission Control Complexes at Onizuka AFB, CA and Falcon AFB, CO to allow secure voice and bent-pipe commanding through Remote Tracking Stations worldwide.

The meteorological data are processed by the Data Reconstruction Site (DRS) located within AFGWC at Offutt AFB. Some of this data is processed into hardcopy images for immediate use by weather forecasters. The data are also stored in computer data bases where they can be accessed by forecasters using the Satellite Data Handling System (SDHS) or directly from the UNISYS mainframe computer. The environmental data are also received by FNOC at Monterey CA. FNOC processes the data to meet the specialized requirements of the Navy. Additionally, real time meteorological data may be downlinked directly to tactical sites (both ground and ship based) for immediate analysis an utilization.

2.0 DMSP Satellite Blocks

2.1 Early Satellites:

The early DMSP satellites were flown in the mid-1960's. Table 2.1-1 shows the early satellites' performance. The satellites contained a 1.27 centimeter (cm) video camera and two infrared systems, the medium-resolution "C" system with 16 sensors in the 0.2 to 5 micron (um) and the 5 to 30 um bands, and a high resolution radiometer (HRR) working in the 7 to 14 um band. A set of Horizon Sensors was also used for attitude control and triggering the camera shutter as it crossed the earth horizon.

TABLE 2.1-1: Early Satellites' Performance

Vehicle	Sensors	Launched	End of Primary	Operational Days	Remarks
1	Video, C, HRR	10 Sep 65	17 Aug 66	341	C System & Transmitter failure
2	Video, C, HRR	7 Jan 66	---	0	Burner I failed to ignite
3	Video, C, HRR	30 Mar 66	Mar 68	720	Recorder failure, C System degraded, Camera failed Feb 68

Note: All satellites used the Thor/Burner I as the launch vehicle.

2.2 Block 4:

The Block 4 satellites consisted of F16 through F23 and were launched from 1966 to 1969. The last satellite, F23, was never launched and was donated to the Chicago Museum of Science and Industry. Table 2.2-1 shows the Block 4 satellites' performance. The Block 4 satellites contained enhanced versions

TABLE 2.2-1: Block 4 Satellites' Performance

Vehicle	Sensors	Launched	End of Primary	Operational Days	Remarks
F16	Video, C	15 Sep 66	3 Nov 68	780	Eventual Sensor Degradation
F18	Video	8 Feb 67	18 May 67	99	In Noon Orbit, Video System Failures
F19	Video, C, H	22 Aug 67	13 Mar 68	204	Eventual Sensor Degradation
F17	Video, C	11 Oct 67	26 Mar 68	167	In Noon Orbit, Cameras & Recorder Failure
F20	Video, C, H	23 May 68	11 Sep 68	112	Recorder, C System Failures
F22	Video, C, H	23 Oct 68	19 Sep 70	697	Recorder Failed
F21	Video, C, H	23 Jul 69	19 Mar 71	604	Recorder Failed
F23		Never launched, donated to a museum			

Note: All satellites used the Thor/Burner I as the launch vehicle.

of the early satellite's sensors (two 2.54 cm vidicon cameras with associated electronics packages and a tape transport). Nominal satellite spin was decreased to reduce smear, permitting a higher resolution television system for improved picture quality. The satellite also had two infrared systems. The "H" system was similar to the earlier HRR and the "C" system was modified to have two bands, 0.4 to 4 and 8 to 12 um. All the satellites previous to the Block 5 satellites were spin stabilized, affecting the sensor type and performance.

TABLE 2.3-1: Block 5A, B, and C Satellites' Performance

Vehicle	Date Launched	End of Primary	Operational Days	Remarks
24	11 Feb 70	30 Apr 70	780	S/C failed due to excessive brush wear in pitch control motor
25	3 Sep 70	15 Feb 71	164	Sensor failed due to excessive brush wear
26	16 Feb 71	3 Mar 73	746	V recorder failed, sensor failed due to excessive brush wear
27	14 Oct 71	27 Apr 72	196	Rapid satellite degradation due to damage from backflow of heat from Burner IIA plume
28	24 Mar 72	23 Feb 74	701	Sensor electrical failure
30	8 Nov 72	21 Jun 73	225	Sensor electrical failure
29	16 Aug 73	24 Jan 77	1257	Primary sensor degraded prior to spacecraft failure
31	16 Mar 74	27 May 76	802	Flight transmitter failure
32	8 Aug 74	22 Nov 74	114	Sensor mechanical failure
33	23 May 75	30 Nov 77	922	Primary sensor degraded due to temperature problems prior to spacecraft failure
34	18 Feb 76	19 Feb 76	0	Failed to achieve orbit due to booster motor performance data anomaly which caused improper fuel loading

Note: Satellites 24 to 26 used the Thor/Burner II and satellites 27 to 34 used the Thor/Burner IIA as the launch vehicle.

2.3 Blocks 5A, B, and C:

2.3.1 The Block 5 satellites offered increased sensor and spacecraft equipment for providing meteorological data. Table 2.3-1 shows the Block 5A through C satellites' performance. The previously used vidicon cameras were replaced by a constant speed, rotary scan radiometer, and more meteorological parameters were measurable through the use of new "special sensors". Starting with the Block 5 satellites, the sensors were mounted on a platform that kept a constant angle between the direction of motion and the earth.

2.3.2 Block 5A Sensors - The Block 5A Sensor Segment or Sensor AVE Package (SAP) was a radiometer. It consisted of three main data collection and processing channels. These channels were the IR data channel, the high resolution visible (HR) data channel, and the very high resolution visible (VHR) data channel. Auxiliary functional subsystems of the SAP were: (a) the zero resolution sensor and signal processing circuitry, (b) command logic for controlling the data formatting and synchronization, (c) sensor control, and (d) SAP voltage generation, regulation, and mode switching.

2.3.3 Block 5B/C Special Sensors - In addition to the sensors mentioned above in the Block 5A section, the Block 5B/C satellites added a high resolution infrared channel and had several sensors tasked with measurement of specific meteorological parameters. Table 2.3-2 shows the special sensor packages flown aboard each satellite. Normally, each satellite carried two special sensors. The sensor complement varied from satellite to satellite according to the planned orbit time period and the condition of various special sensors on older satellites. The data from all special sensors were low volume (on the order of 100 bits per second), The data were multiplexed into the primary sensor data stream and recorded on board the spacecraft. The tactical terminals received no real-time readout of special sensor data since some computer processing was necessary for all the special sensors' data.

TABLE 2.3-2: Block 5B/C Special Sensor Complement

Satellite	Date Launched	Special Sensor Complement
F27	14 Oct 71	SSB, HOG
F28	24 Mar 72	SSB
F30	8 Nov 72	PROTO SSE, SSJ
F29	16 Aug 73	SSB
F31	16 Mar 74	SSE, SSL, SSJ/2
F32	8 Aug 74	SSE, IRS, SSJ/2
F33	23 May 75	SSB, IRS, SSJ/2
F34	18 Feb 76	SSE, IRS, SSJ/2

2.3.3.1 Special Sensors

SSJ - Precipitating Electron Spectrometer

The SSJ was an electron spectrograph with one fixed channel and one stepping channel. The channels detected energetic electrons over ranges of energies associated with visible aurora. The fixed channel was set at 6 keV. The stepping channel measured 54, 98, 219, 600, 1400, 1970, 3540, and 8200 eV at a rate of approximately 1 data sample per second. The field of view was 3^{o} x 12^{o}. The sensor was built by the Aerospace Corporation.

SSJ/2 - Precipitating Electron Spectrometer

The SSJ/2 was the next generation SSJ. It consisted of a single stepping channel with six energy ranges. Nominally, the channels were 0.30, 0.68, 1.60, 3.50, 7.90, and 18.00 keV. The sampling rate was 0.0922 seconds per energy step and the FOV was 30^{o} in an anti-earth cone. The sensor was built by the Aerospace Corporation.

SSL - Lightning Detector

The SSL was a "one-of-a-kind" experiment. It operated at night to detect lightning flashes in the 0.4 to 1.1 um range. The peak response was near 0.8 um. The FOV was 2222 x 2963 km (due to the silicon photodiodes arrangement in the sensor).

SSB - Gamma Tracker

The SSB was supplied by Sandia National Lab and was used to track fallout and nuclear debris entrained in the atmosphere above 10 to 15 km. The sensor detected the fission gammas emitted by the debris.

SSE - Temperature Sounder

The SSE was an eight channel scanning filter radiometer. Six of the channels were in the 15 um carbon dioxide band, one was in the 12 um window, and the last was in the rotational water vapor band near 20 um. Radiance measurements of the earth's atmosphere data were processed to obtain vertical temperature profiles. The sensor weighed about 8.2 kg. Subsystems included a Chopper Filter Assembly, a Scanner Subsystem, and an Electronics Subsystem. In general, the SSE was capable of measuring the energy from scenes between 0 and 330^{O}K, but data were usually run between 150 and 330^{O}K. A prototype SSE was flown on F30. The sensor was built by Barnes Engineering.

HOG - Harmonic Oscillation Generator

The HOG and a spacecraft vehicle roll-rate gyro sensor were mounted as experimental sensors on the F27 satellite. These packages were flown to provide advance information concerning the dynamic interactions, due to uncompensated momentum, of a future oscillating primary sensor and the spacecraft.

IRS - Independent Roll Sensor

The IRS was added to the satellite design to provide backup roll attitude information via telemetry in the case of primary sensor failure. The primary sensor (SAP) provided roll attitude data in the primary data stream as the sensor imaged the space-earth-space background irradiation on the infrared detector. The IRS was mounted on the momentum wheel and viewed the earth with two sensors each pointed at the opposite earth-space transitions. The detectors output was downlinked as a telemetry symbol and was calibrated against the SAP. In the case of a SAP failure, the IRS would provide adequate roll attitude information so as to provide the sensors with an adequately stable satellite.

Block 5A SAP Enhancements on Block 5B/C

Sensors 6 to 11 were modified replacing the direct current (DC) scanner motor with an alternating current (AC) type motor. Sensors 6 and 7 contained instrumented passive radiator coolers to gain flight data for the implementation of the so-called fourth channel (also known as the WHR Channel). Sensors 8 to 10 were modified to provide automatic gain switching to increase the data collection capability of the sensor while scanning across the day-night terminator.

The AC Synchronous Motor - The brush-type DC torque motor used on sensors 1 to 5 developed operational problems (i.e., shortened lifetime due to brush wear). This was caused by high current density in the vacuum of space. The speed control was a phase-locked loop resulting in overspeed and lock-up problems. A major design effort led to replacement of the DC motor with an AC synchronous motor.

The WHR Channel - The WHR channel was added to provide very high resolution thermal IR imagery.

Automatic Gain Control - Sensors 1 - 7 and 11 had limited gain states for a given scan. In a terminator orbit, scene illumination varied up to six decades within a scan, so, these sensors provided only a very narrow band of usable data. The along scan automatic gain control mechanization provided a means of obtaining meaningful data over the full scan in a terminator orbit.

2.4 Blocks 5D-1 and 5D-2:

2.4.1 The Block 5D-1 satellites were flown from 1976 to 1980. The first Block 5D-2 satellite was launched in 1982. Block 5D-2 spacecraft are the designated satellites until the mid-1990's when the Block 5D-3 satellites are anticipated. Table 2.4-1 shows the Block 5D-1 and 5D-2 satellites' performance for satellites launched to date. The Block 5D satellites carry a varied complement of sensors. Some of the sensors were enhanced versions of Block 5A, B, and C sensors. Table 2.4-2 shows the sensor complements of the Block 5D-1 and 5D-2 satellites.

TABLE 2.4-1: Block 5D-1 and Block 5D-2 Satellites' Performance

Vehicle	Date Launched	End of Primary	Operational Days	Remarks
Block 5D-1:				
F-1	11 Sep 76	17 Sep 79	880	Battery failure
F-2	4 Jun 77	19 Mar 80	910	Spacecraft computer failure
F-3	30 Apr 78	Dec 79	580	OLS failure - the spacecraft operated in a degraded mode due to failure of the IR mode
F-4	6 Jun 79	29 Aug 80	430	Battery failure
F-5	14 Jul 80	---	0	Launch failure

Note: Block 5D-1 satellites were launched on LV-2F Thors with two solid upper stages.

TABLE 2.4-1 Continued: Block 5D-1 and Block 5D-2 Satellites' Performance

Vehicle	Date Launched	End of Primary	Operational Days	Remarks
Block 5D-2:				
F-6	20 Dec 82	24 Aug 87	1708	OLS bearing failure
F-7	18 Dec 83	17 Oct 87	1399	OLS bearing failure
F-8 (S-9)	18 Jun 87	13 Aug 91	1513	OLS bearing failure
F-9 (S-8)	3 Feb 88	---	--- ≈49 mo	~~Operational~~ OLS BEARING FAILURE
F-10	1 Dec 90	--- ---	LIMITED ≈48 mo until scanner off	Operational - First spacecraft with RDS capability - OLS SCANNER OFF
F-11 (S-12)	28 Nov 91	---	--- ≈45 mo until scanner off LIMITED	Operational - First spacecraft with SSM/T-2 OLS SCANNER OFF
F-12 (S-11) ~~S-11~~	~~TBD~~ 29 AUG 94	---	---	~~In Ground Storage~~ OPERATIONAL
~~F8~~-13	~~TBD~~ 24 MAR 95	---	---	~~In Ground Storage~~ OPERATIONAL
S-14	TBD	---	---	In Ground Storage

Notes: Block 5D-2 spacecraft are designated by "S-#" until launch. Then the spacecraft is given an "F-#" for on-orbit identification purposes.
Satellites F-6 to F-11 were launched on Atlas E boosters with a single integral solid upper stage.

2.4.2 Primary Sensor: OLS - Operational Linescan System

The OLS measures visible and thermal infrared bands, thus obtaining cloud cover and some temperature information. The main portion of the OLS is an oscillating telescope device driven in a sinusoidal motion by counter-reacting coiled springs and a pulsed motor. The motion moves the instantaneous field of view (IFOV) of the detectors across the satellite subtrack, with maximum scanning velocity at nadir and reversals at the end of each scan. Detector size is dynamically changed to reduce angular IFOV as it approaches each end of scan, thereby maintaining an approximately constant footprint size on earth. The swath width is 2963 km from the nominal 833 km orbital altitude.

The OLS provides global coverage in both visible (L data) and infrared (T data) modes. Fine resolution data with a nominal linear resolution of 0.56 km are collected as needed, day and night, by the IR detector (TF data), and as needed, during daytime only, by a segmented, silicon diode detector (LF data). A high resolution photomultiplier tube is used for nighttime visible imagery.

TABLE 2.4-2: Block 5D-1 and Block 5D-2 Sensor Complements

	Satellite	Date Launched	Sensor Complement
Block 5D-1:	F-1	11 Sep 76	OLS, SSH, SSJ/3, SSB, Contamination Monitor
	F-2	4 Jun 77	OLS, SSH, SSJ/3, SSB, SSB/O, IFM, SSI/E, SSI/P
	F-3	30 Apr 78	OLS, SSH, SSJ/3, SSB, GFE-3R
	F-4	6 Jun 79	OLS, SSH, SSJ/3, SSI/E, SSM/T, SSC, SSD
	F-5	14 Jul 80	OLS, SSH-2, SSJ/3, SSI/E, SSB/O, SSR
Block 5D-2:	F-6	20 Dec 82	OLS, SSH-2, SSI/E, SSJ/4, SSB/A
	F-7	18 Dec 83	OLS, SSM/T, SSI/E, SSJ/4, SSB, SSJ*, SSM
	F-8	18 Jun 87	OLS, SSM/I, SSM/T, SSI/ES, SSJ/4, SSB/X-M
	F-9	3 Feb 88	OLS, SSM/T, SSI/ES, SSJ/4, SSB/X
	F-10	1 Dec 90	OLS, SSM/I, SSM/T, SSI/ES, SSJ/4, SSB/X-2
	F-11	28 Nov 91	OLS, SSM/I, SSM/T, SSM/T-2, SSJ/4, SSI/ES-2, SSB/X-2
	S-11		OLS, SSM/I, SSM/T, SSM/T-2, SSJ/4, SSI/ES-2, SSB/X-2, SSM
	S-13		OLS, SSM/I, SSM/T, SSJ/4, SSI/ES-2, SSB/X-2 SSM, SSZ
	S-14		OLS, SSM/I (Navy Asset assigned to DMSP), SSM/T, SSM/T-2, SSJ/4, SSI/ES-2, SSM, SS BX-2

Note: Sensors shown for S-11, S-13 and S-14 are projected. The actual sensor complements may change due to user requirements.

For Block 5D spacecraft, tape recorder storage capacity limits the quantity of fine resolution data (LF or TF) which can be downlinked from the stored data fine (SDF) mode to each ground station readout. Data smoothing permits global coverage in both the IR (TS) and visible (LS) spectrum to be stored on the tape recorders in the stored data smoothed (SDS) mode. Smoothing is accomplished by electrically reducing the sensor resolution to 2.78 km in the along scan direction, then digitally averaging five such 0.56 x 2.78 km samples in the along track direction. A nominal linear resolution of 2.78 km results. An additional detector allows collection of visible data (LS) with a 2.78 km nominal linear resolution under low light level conditions. These data are used for nighttime cloud cover and aurora equatorward boundary determination. The visible daytime response of the OLS is from 0.4 to 1.1 um, chosen to provide maximum contrast between earth, sea, and cloud elements of the image field. The visible fine mode is provided for day scenes only.

The IR detector consists of two segments and is switched along scan to provide approximately constant ground footprint and image derotation. The detector is tri-metal (HgCdTe), passively cooled, and operates at approximately 110^{O}K. The OLS IR spectral response of 10.5 to 12.8 um was chosen to optimize detection of both water and ice crystal clouds. The dynamic range of the sensor is from 190^{O}K to 310^{O}K with an accuracy of 1^{O}K NEΔT from 210^{O}K to 310^{O}K.

The OLS data processing subsystem performs command, control, data manipulation, storage, and management functions for the entire sensor suite. The OLS receives and stores commands from the ground station and then processes them according to time codes. The OLS executes commands, accomplishes the smoothing of fine resolution data, derives gain commands from orbital parameters for normalization of visual data and dynamic signal control, and outputs the data to the spacecraft communications system. All data are processed, stored, and transmitted in digital format. The OLS also provides the data management functions to process, record, and output data for up to 12 additional environmental sensors. All DMSP transmissions (telemetry monitoring, satellite command and control, and sensor data) have been encrypted since F-8. The encrypted data can be output simultaneously with playback of two channels of stored data.

A combination of either fine resolution data and the complementary smoothed resolution data (i.e., LF and TS or TF and LS) can be provided in the direct digital transmission mode (RTD). For RTD, the size of the pixel for the fine data is 0.56 x 0.56 km and 0.56 x 2.78 km for the smooth data. The OLS system includes and controls four digital tape recorders and each one can record at any one of three data rates and play back at either of two data rates. The recorders for spacecraft through S-15 have the capacity for storage of at least 400 minutes of SDS (TS and LS) data, or at least 40 minutes of SDF (LF or TF) data, or at least 20 minutes of SDF (LF and TF) data. For spacecraft S-16 through S-20, added channels will decrease these figures (and increase the mission sensor data) to at least 300 minutes of SDS (TS and LS) data, or at least 30 minutes of SDF (LF or TF) data, or at least 20 minutes of SDF (LF and TF) data. All tape recorders are interchangeable in function to provide operational redundancy and enhanced system life expectancy.

Starting with spacecraft F-10, the realtime data smooth (RDS) capability was added to the DMSP satellites. RDS provides a survivable source of encrypted meteorological data to tactical users deployed worldwide. RDS is intended to serve users equipped with small portable terminals and offers data with the same resolution as SDS, that is, with a nominal linear resolution of 2.78 km. The same data stream is used for RDS and SDS. RDS is intended to serve in a demonstration mode on the 5D-2 satellites, and is expected to be fully operational for the 5D-3 satellites.

2.4.3 Mission Sensors -

SSM/I - Microwave Imager

The SSM/I is a passive microwave radiometer. It detects thermal energy emitted by the earth-atmosphere system in the microwave portion of the electromagnetic spectrum. AFGWC and FNOC meteorologists and oceanographers and certain tactical sites use the SSM/I to measure ocean surface wind speed, ice coverage and age, areas and intensity of precipitation, cloud water content, and land surface moisture. The data obtained are used for tropical storm reconnaissance, ship routing in polar regions, agricultural weather, aircraft routing and refueling, estimates of trafficability for Army support, communications management, and other missions.

The instrument is a conically scanning imager having a swath width of 1395 km. The sensor rotates with a nominal 1.9 second period and collects data during 102 degrees of each rotation. During the periods of the rotation that data are not being collected, the SSM/I collects calibration readings from both hot and cold sources. The SSM/I provides seven data channels of information. The resolution and the major environmental response of each channel depends upon its wavelength as indicated in Table 2.4.3-1. The channels make it possible to judge several environmental elements when the channels are processed multispectrally using three principles:

(1) The emissivity of natural surfaces depends on water content and roughness of the surface (among other things). This makes possible observations of surface moisture variations over land and ice

cover over oceans. It is also possible to judge the surface roughness or the surface wind speed over oceans from the microwave brightness temperatures.

(2) The energy measured at the SSM/I wavelengths is very sensitive to cloud drops and rain drops in the atmosphere. This is because energy in the highest frequency (85.5 GHz) is most affected by atmospheric water droplets and energy at the lowest frequency (19.35 GHz) is least affected by atmospheric water droplets. The 22.235 GHz channel responds much more strongly to the integrated water vapor in the atmosphere than any other channel.

(3) Microwave radiometers measure energy in either or both of two mutually perpendicular polarizations. Microwave energy emitted or reflected from surfaces like land or water tends to be polarized. The energy measured in the two polarizations is different. The amount of the difference depends upon the moisture content of the surface. Energy from atmospheric phenomena, (water vapor, clouds, and rain clouds), tends to be unpolarized. Both polarizations are measured at all SSM/I frequencies except 22.235 GHz. The different effects on the energy emitted and reflected through the earth's atmospheric system provide a unique signature for many different phenomena, permitting their detection and measurement from space.

TABLE 2.4.3-1: SSM/I Channels

Wavelength (mm)	Frequency 109 Hz	Polarization	Resolution (km)	Environmental Response
15.5	19.35	V/H	50	Ocean surface wind, Land surface moisture
13.5	22.235	V	50	Integrated water vapor content, Ocean surface wind
8.1	37.0	V/H	25	Rain, Cloud water content, Ice cover
3.5	85.5	V/H	13	Rain

Note: V = Vertical, H = Horizontal

SSM/T - Temperature Radiometer

The SSM/T is a seven channel microwave sounder. It measures atmospheric emission in the 50 to 60 GHz oxygen (O2) band. The SSM/T is designed to provide temperature soundings over previously inaccessible cloudy regions and at higher altitudes than those attainable with IR sounders such as the SSH and the SSH-2 flown on satellites F-1 through F-6.

The SSM/T is a cross-track nadir scanning radiometer having a FOV of 14.4^{o}. At the nominal 833 km altitude, the subtrack spatial resolution is an approximate circle of 174 km diameter at nadir. There are seven total cross-track scan positions separated by 12^{o} with a maximum cross-track scan angle of 36^{o}. At the far end of each scan resolution degrades to an ellipse of 213 x 304 km size. The SSM/T data swath is about 1500 km; therefore, there is a data coverage gap between successive orbits over much of the earth.

SSM/T-2 - Microwave Water Vapor Profiler

The SSM/T-2 is a modification of the SSM/T for water vapor sounding. This sensor has channels at 91.5 GHz, 150 GHz and the 183 GHz water vapor resonance line and has a resolution that ranges between 46 and 120 km. The system uses the same modular construction as the SSM/T. The sensor is packaged separately from the SSM/T to ease integration.

SSJ - Precipitating Electron Spectrometer

The SSJ counted ambient electrons with energies ranging from 50 eV to 20 KeV. It determined the number of electrons having energies within certain sub-ranges of the 60 eV to 20 KeV spectrum by utilizing a time-sequenced variable electrostatic field to deflect the particles toward the channeltron detector.

SSJ/3 and SSJ/4 - Precipitating Electron/Ion Spectrometers

The SSJ/3 and SSJ/4 are next generations of the SSJ and the SSJ/2 discussed earlier. The SSJ/3 was flown on all 5D-1 spacecraft with the exception of F-1. The SSJ/4 is scheduled to fly on all 5D-2 satellites. These sensors have the additional capability of measuring ions as well as electrons. The fluxes are measured in 20 energy channels in the range of 30 eV to 30 KeV using a cylindrical channeltron detector with a field of view of 15^{o}.

SSI/E - Topside Ionospheric Plasma Monitor

The SSI/E measured the ambient electron density and temperatures, the ambient ion density, and the average ion temperature and molecular weight at the DMSP orbital altitude. The instrument consisted of an electron sensor (Langmuir probe) and an ion sensor mounted on a 2.5 meter boom. The ion sensor is a planar aperture, planar collector sensor oriented to face into the spacecraft velocity vector at all times.

SSI/ES and SSIES-2 - Ionospheric Plasma Drift/Scintillation Meter

The SSI/ES is an improved version of the SSI/E. In addition to the Langmuir probe and planar collector which make up the SSI/E, the SSI/ES has a plasma drift meter and a scintillation meter. An upgraded version of the SSI/ES, the SSIES-2, is currently flying on F-11 and is scheduled to fly on the remaining 5D-2 spacecraft.

SSM - Triaxial Fluxgate Magnetometer

The SSM measures geomagnetic fluctuations associated with geophysical phenomena (i.e., ionospheric currents flowing at high latitudes). In combination with the SSI/ES (or SSI/ES-2) and the SSJ/4, the SSM provides heating and electron density profiles in the high-latitude ionosphere. The SSM is built by the NASA Goddard Space Flight Center.

SSJ* - Space Radiation Dosimeter

The SSJ* measured the accumulated radiation dose produced by electrons in the 1 to 10 MeV energy range, protons of greater than 20 MeV, and the effects of the occasional nuclear interactions produced by energetic protons. Accumulated dose was measured over a period of time (one year minimum).

SSD - Atmospheric Density Sensor

The SSD was designed to provide a measure of major atmospheric constituents (Nitrogen, Oxygen, and Ozone) in the earth's thermosphere by making earth-limb observations of the ultraviolet radiation from the thermosphere. The sensor measured radiation emitted from excitation of molecular nitrogen by impinging solar radiation.

SSC - Snow Cloud Discriminator

The SSC was a 1.6 um channel instrument. It was used to determine the presence of snow versus clouds. It was a proof-of-concept sensor intended to help determine if machine processing could make the snow/cloud determination.

SSB - Gamma X-Ray Detector

The SSB, just like the Block 5B/C sensor, was a gamma radiation sensor provided to DMSP by Sandia National Lab.

SSB/A - X-Ray Spectrometer

The SSB/A detected x-rays and gammas from bomb debris or those x-rays produced by the bremsstrahlung process when electrons precipitate from the earth's radiation belts. By sensing these x-rays, the SSB/A provided location of the aurora as it orbits the earth.

SSB/O - Omnidirectional Gamma Detector

The SSB/O was an experiment to determine if more accurate atmospheric measurements could be obtained by measuring the co-orbiting particles and the upward flux and subtracting it from the sub-satellite scene. The experiment was extremely successful. The SSB/O was sensitive to X-rays in the energy range of approximately 1.5 keV.

SSB/S - Scanning X-Ray Detector

The SSB/S detected the location, intensity and spectrum of x-rays emitted from the earth's atmosphere. The detector consisted of three sensors. The first two each consisted of an array of four 1 cm diameter mercury iodide (HgI) crystals collimated to a 10^{0} wide radial field of view. The third was a 0.635 cm x 7.62 cm diameter sodium iodide scintillator collimated to a 10^{0} wide radial field of view.

SSB/X, SSB/X-M, and SSB/X-2 - Gamma Ray Detectors

The SSB/X is an array-based system which detects the location, intensity, and spectrum of x-rays emitted from the earth's atmosphere. The array consists of four identical and independent directional detectors. The SSB/X-M and SSB/X-2 follow from the SSB/X and are also gamma-ray and particle detectors. The SSB/X-M and SSB/X-2 consist of two identical and independent gamma ray detectors and three particle detectors. The SSB/X-M and SSB/X-2 are also capable of detecting gamma ray bursts.

SSH - Infrared Spectrometer

The IR Spectrometer (SSH) was an infrared multispectral sounder for humidity, temperature, and ozone measurements. The SSH provided soundings of temperature and humidity and a single measurement of ozone for vertical and slant paths lying under and to the side of the sub-satellite track.

The SSH made a set of radiance measurements in narrow spectral channels lying in the absorption bands of carbon dioxide, water vapor, and ozone. The radiance measurements were mathematically inverted to yield vertical temperature profiles of temperature, water vapor, and the total ozone content. For temperature sounding, radiances were measured in narrow channels in the wing of the 15 um carbon dioxide absorption band. For humidity sounding, channels were selected to provide a range of absorption coefficients in the rotational water vapor band. Inversion yielded the vertical humidity profile.

SSH-2 - Infrared Temperature and Moisture Sounder

The SSH-2 provided soundings of temperature and humidity for vertical and slant paths lying under and to the side of the sub-satellite track. It was physically identical to the SSH, with different (and tighter) filter bands.

SSZ - (Laser Threat Warning Sensor)

The SSZ is a prototype Laser threat warning sensor. It is an earth facing sensor built by the Aerospace Corporation.

SSF - (Laser Threat Warning Sensor)

The SSF is an operational version of the SSZ. It is an earth facing sensor built by Sandia National Laboratory.

SSR and IFM (Integrated Flux Monitor) - (Classified Sensors)

The SSR and IFM were forerunners of the SSZ.

SSK - (Classified Sensor)

The SSK is a static earth-viewing sensor. It monitors electromagnetic radiation.

SSI/P - Passive Ionosonde

The SSI/P was a scanning radio receiver. It mapped the man-made radio spectrum to determine the critical (breakthrough) frequency of the F-layer of the ionosphere. The sensor automatically scanned from 1 MHz to 10 MHz in 20 KHz steps at a rate of one step per second.

2.5 Block 5D-3:

2.5.1 The Block 5D-3 satellites are scheduled to fly in the mid-1990's. The first Block 5D-3 satellite is S-15 and the last will be S-20. S-15 is a prototype satellite, with the new 5D-3 bus and a proven complement of 5D-2 sensors. The Block 5D-3 satellites are projected to carry a similar complement of sensors as the 5D-2 spacecraft. Table 2.5-1 shows the planned Block 5D-3 sensor complements. -

SSMIS - Microwave Imager Sounder

The SSMIS is a functional combination of the SSM/I, SSM/T, and SSM/T-2 sensors scheduled to fly on the Block 5D-3. It extends the temperature sounder range to 70 km and increases the swath width to 1707 km. The SSMIS provides an upper air sounding capability to 0.03 mb. - 24 CHANNELS - 19 to 183 GHz.

SSULI - UV Limb Imager

The SSULI is a remote sensing instrument which scans the earth limb in the orbital plane using a Silicon Carbide (SiC) scan mirror. It views tangent altitudes from 750 km to the earth disk, with a field of view of 5 km vertically and 100 km cross track. The SSULI measures UV airglow profiles and produces information on electron density profiles and neutral densities, on both the dayside and nightside of the satellite orbit as well as other products. The Naval Research Laboratory (NRL) is developing the SSULI.

SSUSI - UV Spectrographic Imager

The SSUSI is a remote sensing instrument which scans the earth's atmosphere across the satellite subtrack, including the earth limb. It consists of two sensing systems, the Spectrographic Imager and the Photometers. The Spectrographic Imager obtains horizon-to-horizon images in the wavelength range 1100 A to 1800 A with a viewing area of 3700 km X 153 km using a scan mirror system. It can also operate in a fixed mirror mode to collect spectographic data. The Photometers operate in 3 wavelengths (6300 A, 6290 A and 4278 A) and are designed to provide information on auroral energy deposition and for nightside measurements. The SSUSI measures UV emissions and provides information on auroral emissions and airglow, electron and neutral density profiles as well as other products. The John's Hopkins University Applied Physics Laboratory (APL) is developing the SSUSI.

SSIES3 - Plasma Monitor System

The SSIES3 is an in-situ sensor and is the follow-on to the SSI/ES-2. It is composed of 4 sensors: the Electron Sensor, the Scintillation Meter, the Ion Drift Meter and the Retarding Potential Analyzer. The Retarding Potential Analyzer utilizes a new plasma plate that measures the sensor plane potential with respect to the ambient plasma. The SSIES3 functionally performs the same mission as the SSI/ES-2, and is manufactured by the University of Texas, Dallas.

SSJ5 - Precipitating Particle Spectrometer

The SSJ5 is an in-situ sensor and is the follow-on to the SSJ/4, featuring new detector design. In the SSJ5, the cylindrical electrostatic analyzers have been replaced by a triquadrispherical ESA for an increase in the field of view from 15° to 90°. The channeltron detectors have also been replaced by microchannel plates for better efficiency while covering the same energy range. The SSJ5 will provide the same data stream to the user as the SSJ/4, with the option of using the more detailed modes if desired. The SSJ5 is manufactured by Amptek.

SSM - Boom Mounted Magnetometer

Starting with satellite S-15, the magnetometers will be attached to a 5 meter long boom. The SSM will be identical to those flown on the 5D-2 spacecraft, with a lower magnetic noise background resulting from the isolation from the spacecraft environment supplied by the boom.

2.5.2 Potential Sensors for the Block 5D-3: The following sensor is currently under consideration for the Block 5D-3 timeframe.

MOLS - Multispectral OLS

The MOLS is an upgrade of the Block 5D-3 OLS. It consists of adding a snow cloud (1.6 um) channel and/or a low cloud (3.7 um) channel to the current OLS.

TABLE 2.5-1: Block 5D-3 Planned Sensor Complements

Satellite	Proposed Sensor Complements
S-15	OLS, SSM/I, SSM/T, SSM/T-2, SSI/ES-2, SSJ/4, SSM, SSZ
S-16	OLS, SSMIS, SSIES3, SSJ5, SSM, SSF, SSULI, SSUSI
S-17	OLS, SSMIS, SSIES3, SSJ5, SSM, SSF, SSULI, SSUSI
S-18	OLS, SSMIS, SSIES3, SSJ5, SSM; SSF, SSULI, SSUSI
S-19	OLS, SSMIS, SSIES3, SSJ5, SSM, SSF, SSULI, SSUSI
S-20	OLS, SSMIS, SSIES3, SSJ5, SSM, SSF, SSULI, SSUSI

S-20 OLS, SSMIS, SSIES3, SSJ5, SSM, SSF, SSULI, SSUSI

Note: Sensors shown for S-15 to S-20 are projected. The SSJ/4 and SSJ5 sensors are purchased through PL as funds allow, and the SSM is provided to the DMSP by outside sources. The SSF sensor is not procured under a contract, it is procured under an MOA. The actual sensor complements may change due to user requirements.

2.6 Block 6:

2.6.1 The DMSP Block 6 system is planned to have an initial operating capability (IOC) in mid FY 2005. The first Block 6 satellite will be S-21. The primary objective of the Block 6 system is to continue the DMSP mission into the 21st Century in the most cost effective and efficient manner possible. Block 6 will provide current levels of DMSP environmental support along with improved margins for future payload growth and improved design and operational flexibility. Block 6 concept studies were conducted from Jan 1988 to Dec 1990 and system risk reduction efforts are expected to occur from Jul 1991 to Jan 1998.

2.6.2 The Block 6 sensing capabilities will not be finalized until the end of the risk reduction effort. However, the following sensing suites have been identified:

OMIS - Operational Multispectral Imager Suite

The OMIS is expected to be a multispectral imager or set of imagers that provides data on clouds, visibility, land and surface temperature, albedo, and other environmental parameters. A minimum of seven spectral imaging channels in both visible and infrared spectrums is expected.

MISS - Microwave Imager Sounder Suite

The MISS is expected to be a multispectral sensor or set of sensors that provides the three basic functions of microwave imaging, microwave temperature profiling, and microwave moisture profiling.

SESS - Solar Environmental Sensor Suite

The SESS is yet to be determined.

NAVY - Navy Sensor Options

The Navy will evaluate the possibility of adding both an Altimeter and a Scatterometer to the Block 6 satellite.

The technology for Block 6 must be "demonstrated at level 6 according to the Air Force Space Technology Center's (AFSTC's) definition. AFSTC defines level 6 as successful testing of the prototype/engineering model in the relevant environment" by 1997. The contractor must consider in his trade-offs the impact his concept will have on the system, space, and ground segments. The options consist of ten technical options and two other-service options (Army and Navy). The technical options include such items as active sensing, store and forward capability, satellite internetting, enhanced data (above the baseline system), dual launch capability (two ELVs or an ELV and the NASA STS), and extended autonomy. The other service options are for consideration of service specific requirements.

2.6.3 The Government will choose the ultimate Block 6 system based upon the concepts developed (as a whole, not just by individual concept) and any other technological advances developed by the Government and industry. Therefore, no specific sensors are planned for Block 6 at this time. Any sensor possibilities for the Block 6 period are mere suggestions for the future and do not imply or affirm a Government commitment to examine, construct, and/or fly said sensor in the future.

NPOESS now

3.0 Future Sensor Considerations:

3.1 In August 1986, the Joint Chiefs of Staff (JCS) issued a memorandum MJCS 154-86, "Military Requirements for Defense Environmental Satellites." This document contains a combined Department of Defense prioritized list of meteorological parameters. There are 43 parameters in all, with clouds ranked highest. Current DMSP satellites satisfy some of these parameters, although not necessarily completely, as detailed in Table 3.1-1. Future sensor considerations are aimed at satisfying these MJCS 154-86 parameters.

3.2 The following current DMSP sensors could be modified to better satisfy MJCS 154-86:

OLS to MOLS - Redesign for addition of one or more channels.

OLS - Upgrade software to allow for on-command variation of the gray shade to temperature granularity on thermal data based on seasonal and latitudinal changes.

SSMIS - Reduce the sensor footprint.

3.3 The following new or previously flown DMSP sensors are considerations for further satisfaction of the MJCS 154-86 requirement:

Atmospheric Sensors -

Multispectral OLS (MOLS) - Could be considered a new or upgraded sensor based on the required amount of sensor redesign. The MOLS will include the channels proven necessary to accomplish the mission of the SSC, a sensor previously flown on DMSP Block 5D F-4.

LIght Detection and Ranging (LIDAR) - Develop a system to measure wind, aerosol concentrations, and moisture profiles. LIDAR could also obtain cloud top heights, but cannot penetrate clouds, except for cirrus, for which thin cirrus detection is possible.. Choice of the LIDAR system would depend upon what parameter is measured and how LIDAR technology progresses for space-based application.

TABLE 3.1-1: MJCS 154-86 Prioritized List of Parameters

- * 1. Clouds (Coverage/Type/Layers)
- * 2. Vertical Temperature Profile
- * 3. Absolute Humidity
- * 4. Wind (Horizontal & Vertical Components)
- 5. Electron Density Profiles
- * 6. Precipitation (Type, Rate)
- * 7. Sea Ice (Cover, Thickness, Age, Leads, Polynyas, Icebergs)
- * 8. Sea Surface Temperature
- * 9. Visibility (Aerosol Concentration and Size)
- *10. Soil Moisture
- 11. Pressure Profile
- 12. Neutral Density
- 23. Ocean Vertical Temperature Profile
- *24. Precipitating Electrons and Ions
- 25. Vegetation
- *26. In-Situ Electric Fields
- 27. Radiation Background
- *28. Solar Proton Emissions and Galactic Rays
- *29. Trapped Particles
- 30. Surface Pressure
- *31. Ionospheric Scintillation
- 32. Bathymetry (Deep Ocean and Near Shore)
- 33. Salinity

*13. Liquid/Solid Water Content and Cloud Droplet Size
*14. Snow Cover
*15. Landlocked Ice Cover
*16. Solar Radiation Imagery/Flux
*17. Land Surface Temperature
*18. Auroral Emissions and Airglow
19. Solar Wind
*20. Geomagnetic Field
21. Sea Surface Topography
*22. Ocean Waves (Sea, Swell, Surf)
34. Near Shore Currents
*35. Ocean Currents (Surface, Subsurface)
*36. Albedo
*37. Ocean Color (Chlorophyll)
38. Bioluminescence
39. Insolation
40. Ocean Tides
41. Net Heat Flux
42. Littoral Sediment Transport
43. Turbidity

Note: Those parameters denoted with a "*" are at least partially satisfied by the current DMSP system. Those parameters without a "*" cannot currently be measured by the DMSP system.

Millimeter Wave Radar - Complementary to LIDAR, millimeter wave radar works best in cloudy conditions (not in severe weather). Millimeter wave radar could be used to obtain cloud and wind information such as cloud layer and base height, and wind in clouds.

Space Environmental Sensors -

UV Limb Imager (SSULI) - As described in section 2.5.1, this sensor will fly on S-16 through S-20.

UV Spectrographic Imager (SSUSI) - As described in section 2.5.1, this sensor will fly on S-16 through S-20.

Gamma X-Ray Spectrometer (SSB/A) - As described in Section 2.4.3, this sensor was flown on DMSP Block 5D-2 satellite F-6.

Solar UV Sensor - Provide inputs for both ionospheric and neutral density models from solar observations.

Dosimeter (SSJ*) - Flown on DMSP Block 5D-2 F-7. Monitors space radiation hazards.

Other sensors include: Topside Ionospheric Sounder (Electron Density Profiles), X-Ray/EUV Imager (Solar Radiation), Parallel EP Particle Sensor, Magnetometer (SSM) (Geomagnetic Field), Electric Field Instrument, and a Scintillation Meter (Ionospheric Scintillation).

4.0 Summary: All sensors discussed in this document pertain to DMSP's commitment to satisfying the user and achieving the DMSP mission. Current plans for the future hinge upon the ultimate Block 6 design and the availability of funds to develop systems capable of providing the user with timely meteorological information. This document is intended to provide an overview of the sensors DMSP has flown, what it now flies, and what it could fly in the future. Ultimately, the future success of DMSP will rest on the efforts to continue to apply current technology while pursuing new or upgraded technology for satisfaction of the user's needs.

5.0 Acronyms

AC	Alternating Current
AFGWC	Air Force Global Weather Central
AFSCF	Air Force Satellite Control Facility
AFSTC	Air Force Space Technology Center
AVE	Aerospace Vehicle Equipment
C^3	Command, Control and Communications
Cd	Cadmium
cm	centimeter
CRS	Command Readout Station
DC	Direct Current
DMSP	Defense Meteorological Satellite Program
DoD	Department of Defense
DRS	Data Reconstruction Site
EDP	Electron Density Profiles
FNOC	Fleet Numerical Oceanography Center
FOV	Field of View
FY	Fiscal Year
Hg	Mercury
HOG	Harmonic Oscillation Generator
HR	High Resolution
HRR	High Resolution Radiometer
Hz	Hertz
IFOV	Instantaneous Field of View
IFM	Integrated Flux Monitor
IR	Infrared
IRS	Independent Roll Sensor
JCS	Joint Chiefs of Staff
km	kilometer
MH	SAP High Resolution Visible Data Channel
MI	SAP IR Data Channel
MISS	Microwave Imager Sounder Suite
MOLS	Multispectral OLS
MJCS	Memorandum, Joint Chiefs of Staff
MV	SAP Very High Resolution Visible Data Channel
mm	millimeter
OLS	Operational Linescan System
OMIS	Operational Multispectral Imager Suite
PMT	Photomultiplier Tube
PROTO SSE	Prototype SSE
RDS	Realtime Data Smooth
RTD	Real Time Data
6 SOP	6th Space Operations Squadron
SAP	Sensor AVE Package
SESS	Solar Environment Sensor Suite
SDHS	Satellite Data Handling System
SiC	Silicon Carbide
SSB	Gamma Tracker
SSB/A	X-Ray Spectrometer
SSB/O	Omnidirectional Gamma Detector
SSB/S	Scanning X-Ray Detector
SSB/X (SSB/X-2) (SSB/X-M)	Gamma Ray Detectors
SSC	Snow Cloud Discriminator

SSD	Atmospheric Density Sensor
SSE	Temperature Sounder
SSF	Laser Threat Warning Sensor
SSH	Infrared Spectrometer
SSH-2	Infrared Temperature and Moisture Sounder
SSI/E	Topside Ionospheric Plasma Monitor
SSI/ES (SSI/ES-2)	Ionospheric Plasma Drift/Scintillation Meter
SSIES3	Plasma Monitor System
SSI/P	Passive Ionosonde
SSJ & SSJ/2	Precipitating Electron Spectrometer
SSJ/3 & SSJ/4	Precipitating Electron/Proton Spectrometer
SSJ5	Precipitating Particle Spectrometer
SSJ*	Space Radiation Dosimeter
SSK	Classified
SSL	Lightning Detector
SSM	Triaxial Fluxgate Magnetometer
SSM/I	Microwave Imager
SSMIS	Microwave Imager Sounder
SSM/T(SSM/T-1)	Microwave Temperature Profiler
SSM/T-2	Microwave Water Vapor Profiler
SSR	Classified
SSULI	UV Limb Imager
SSUSI	UV Spectrographic Imager
SSY	Classified
SSZ	Prototype Laser Threat Warning Sensor
TBD	To Be Determined
Te	Tellurium
UV	Ultraviolet
VHR	Very High Resolution
WHR Channel	Fourth Block 5B/C SAP Channel

6.0 References:

The following documents are contained in the DMSP Technology Library. Requests for further information should be directed to:

> SMC/CIE
> 2420 Vela Way, Suite 1467-D9
> Los Angeles AFB, CA 90245-4659.

DMSP Compendium of Early Satellites, Nov 1975
DMSP Block 4 Compendium, Nov 1975
DMSP Block 5A, B, C Compendium, May 1976
DMSP Block 5D Compendium, Jul 1975
DMSP Block 5D Launch, 1976
DMSP Block 5D-2 Compilation, Apr 1986 *
MJCS 154-86, Military Requirements for Defense Environmental Satellites, Aug 86
DMSP 100, Vol I, System Requirements Document, Rev 1, Oct 88
Vol II, Technology Development Plan, (In revision).

The following document is not contained in the DMSP Technology Library, but may be obtained through the above address:

DMSP Technology Issues, Oct 88. **

The following document may be obtained from SAF/AQQX, Pentagon, Washington DC 20330-5040:

Space Technology Division Note, STDN 89-1, Assessment of Projected Defense Environmental Satellite Capabilities for the DMSP 5D-3 Satellite, Oct 88. *

Questions or comments concerning the IFM, SSR, SSZ, SSF, SSK and SSY sensors should be directed to the DMSP Current Satellite Systems Division, SMC/CIE.

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