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Defense Meteorological Satellite System
System Requirements Document
Volume III
Technology Development Plan

Prepared by

Systems Integration Directorate
Defense Meteorological Satellite Program Office
The Aerospace Corporation
El Segundo, California

for

Deputy for Defense Meteorological Satellite Systems
Space Division
Los Angeles Air Force Station, California

When Appendix B is removed,
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Technical Coordination and Approval

John S. Bohlson

John S. Bohlson, Lt Colonel, USAF
Special Assistant - Air Force/Army
Deputy for DMSS

Richard E. Wolff

Richard E. Wolff, Cdr, USN
Deputy Program Manager
Deputy for DMSS

Gary L Duke

Gary L. Duke, Major, USAF
Chief, Technology Division
Deputy for DMSS

M. B. Gold

M. B. Goldware, Manager
Integration and Test
Defense Meteorological Satellite Program

Denzel D Waltman Jr

Denzel D. Waltman, Jr., Lt Colonel, USAF
Director of Program Management
Deputy for DMSS
Program

Vernon E Olson

Vernon E. Olson, Systems Director
Integration and Test
Defense Meteorological Satellite

APPROVED:

Justin A Curtis

Justin A. Curtis, Colonel, USAF
DoD Executive Manager
Defense Meteorological Satellite Program

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Technology Development Plan (TDP)

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ACRONYMS

AVHRR-2	Advanced Very High Resolution Radiometer (second generation)
AFGWC	Air Force Global Weather Central
DIAL	Differential Absorption Lidar
DIPS	Dynamic Isotope Power Supplies
DMSP	Defense Meteorological Satellite Program
DMSP II	Future Block Series of Spacecraft after 5D-3 (Shuttle compatible)
DMSP 5D-2	Current Block Series of Spacecraft (1982-1992) Launched on Atlas
DMSP 5D-3	Next Block Series of Spacecraft (1993-2000). Planned to be launched on Titan II.
DMSS	Defense Meteorological Satellite System
DOD	Department of Defense
EDP	Electron Density Profile
FNOC	Fleet Numerical Oceanography Center
GOES	Geostationary Orbiting Environmental Satellite
GPS	Global Positioning System
IR	Infrared
NASA	National Aeronautic and Space Administration
NOAA	National Oceanic and Atmospheric Adminstration
NOAA ERL	NOAA Environmental Research Laboratory
NRL	Naval Research Laboratory
NROSS	Navy Remote Ocean Sensing System
OLS	Operational Linescan System
RAIDS	Remote Atmospheric and Ionospheric Detection Systems

RTG	Radioisotope Thermoelectric Generator
SSB/A	Special Sensor Gamma Ray Detector
SON	Statement of Operational Need
SSC	Special Sensor, Snow Cloud Discriminator
SSD	Special Atmospheric Density Sensor
SSI	Special Sensor, Topside Ionosonde
SSIE	Special Sensor Ionospheric Plasma Monitor
SSIES	Special Sensor Ionospheric Plasma/Scintillation Monitor
SSH	Special Sensor Infrared Temperature and Moisture Sounder
SSJ/4	Special Sensor Precipitating Electron Spectrometer
SRD	Systems Requirements Document
SSM	Special Sensor Magnetometer
SSM/I	Special Sensor, Microwave Imager
SSM/T	Special Sensor Microwave Temperature Sounder
SSM/T-2	Special Sensor, Microwave Water Vapor Profiler
SSUV	Special Sensor Ultraviolet Imager
TDP	Technology Development Plan
TEC	Total Electron Content
TIROS-N	Television and Infrared Observation Satellite (third generation)

SECTION 1

1.0 Introduction. The DMSP Program Management Directive (Ref 1) directs the DMSP Systems Program Office to "...plan and carry out a program of DMSP technological development to satisfy DOD requirements. ...All technological development goals and SON requirements will be consolidated in a Defense Meteorological Satellite System (DMSS) system requirements document and assessed against Block 5D capabilities to establish technological and development priorities ..." The DMSP Technology Development Plan has been prepared to fulfill this directive. "The JCS Statements of Requirements*,.... will be used as goals (these documents are unrestrained by resource limitations) for technological development. Current DMSP priorities as stated in MJCS 195-81** and operational impacts of DMSP data loss .... will also be used as a guide. A Statement of Operational Need (SON) must be validated prior to the initiation of any full-scale development effort ...." (Ref 1).

1.1 Purpose. The DMSP Technology Development Plan (TDP) provides in one top-level document a road map for the development of necessary new technology to facilitate meeting all the validated environmental user requirements. These requirements for remote sensing from a DMSP spacecraft platform are previously described in the DMSS System Requirements Document (SRD) published on 14 December 1983 as volume 1 (unclassified) and volume II (classified). As stated in the SRD, the TDP is the third document to be published in the set.

The TDP reviews user validated requirements versus DMSP 5D-2 and 5D-3 capabilities, identifies the unfulfilled requirements up to that time frame, and discusses concepts that, if implemented, could satisfy the requirements. The TDP also prioritizes sensor technology development in order to establish a base for the eventual design of new sensors to meet those unfulfilled requirements. This document can be used for detailed technology planning,

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* Ref 2

** Ref 3

Program Objective Memorandum development, or to define new program starts. Major changes to spacecraft, spacecraft subsystems and ground system segments are identified and briefly discussed.

1.2 Document Format. This document has been written in a format which is easily updated. As new concepts evolve, they can be presented as alternate or supplemental methods for measuring meteorological parameters and can be used to update the prioritized plan. The SRD lists all the DOD environmental data requirements and the TDP identifies those unfulfilled validated requirements that appear satisfiable in either the near-to-mid-term, or far-term time frames.

1.3 Document Overview. Section 2 reviews the validated requirements documented in Volumes I and II of the SRD, and identifies the current unfulfilled requirements. It provides a baseline for the subsequent sections. Section 3 describes technology concepts that have potential for meeting those deficient requirements. It also identifies research and development that must be accomplished for new sensors to meet the validated requirements. Descriptions of these concepts include projected functional characteristics, performance parameters, and identification of the technological issues associated with each concept. While specific concepts are described, it is not the intent of the DMSS TDP to zero in on a particular design at the expense of other alternatives. Concepts are chosen as representative of the broad range of potential systems that could be developed by the year 2000. The concept descriptions presented are intended to act only as points of departure to (1) indicate levels of performance and (2) to serve as a basis for technology planning. Section 4 is similar to Section 3 but describes impacts of new sensor systems on the spacecraft platform, spacecraft subsystems, and the ground systems. Tradeoffs are identified to facilitate system planning. The data type parameters listed as Data Refresh Period and Timeliness are also discussed in this section. These requirements are limited by the present orbital characteristics of a polar orbit, the total number of operational satellites and the present ground processing system. Section 5 presents a prioritized set of Technology Road maps to fulfill the deficiencies described in Sections 2, 3, and 4. Two time frames are considered: (1)

Near-term applications from 1985 to 1998. This time frame represents improvements to the 5D-2 and 5D-3 program. (2) Far-term applications after 1998 which represents developments applicable to DMSP II.

SECTION 1 REFERENCES

1 Program Management Directive (PMD) for Defense Meteorological Satellite Program (DMSP) (U) PMD No. R-S 3015 (22)/PE35160F/35162F/PE35111F/ PE71112F, Current Issue.

2 MJCS 251-76 dated 31 Aug 76, Revalidation of Military Requirements for Meteorological Satellite Data (Memorandum from the Joint Chiefs of Staff to the Director of Defense Research and Engineering).

3 MJCS 195-81 (S) dated 5 Oct 81, Requirements for DMSP (U) (Memorandum from the Joint Chiefs of Staff for the Chief of Staff, USAF).

SECTION 2

2.0 Review of Validated, Unfulfilled Requirements. The detailed requirements for all meteorological data types are referenced and described in Systems Requirements Document, Volume I, paragraph 3.2.3.* This section will briefly review the current status of each validated requirement. The validated, but unfulfilled requirements will be divided into three categories: (1) Capability requires technology development (TD). No present capability exists (including sensors up through Flight 19 in 1998) to meet the requirement. This category has a far-term application during the late 1990's. (2) Expand capabilities of present sensors (EC). A capability exists at present, but does not completely satisfy the requirement. The capabilities of the current sensors, or the processing of data, can be increased or enhanced to meet the requirement with the technology base available. This category has a near-term application during the next ten years. (3) Capability to meet the requirements is limited by the system configuration (i.e., orbital altitude, number of satellites on orbit and the number of operational Ground Stations). The symbol (SL), is used for this category. Therefore, fulfillment of these requirements is limited by monetary resources.

A summary of these categories is given in Figure 1. These categories are listed for each requirement under the Required Action column in the tables throughout this section. If the requirement is presently being met, it is listed as Meets Requirement (MR). Source documentation is listed at top of each table opposite its subject title together with its publication date, and with the validation and date in the remarks column as applicable.

Definitions of the data type parameters have been described in Volume I, paragraph 3.2.2.1 and are reproduced here for the reader's convenience.

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*MJCS 251-76, MJCS 195-81 and SMOP are presently being updated and combined into a new document which will be validated and distributed later this year.

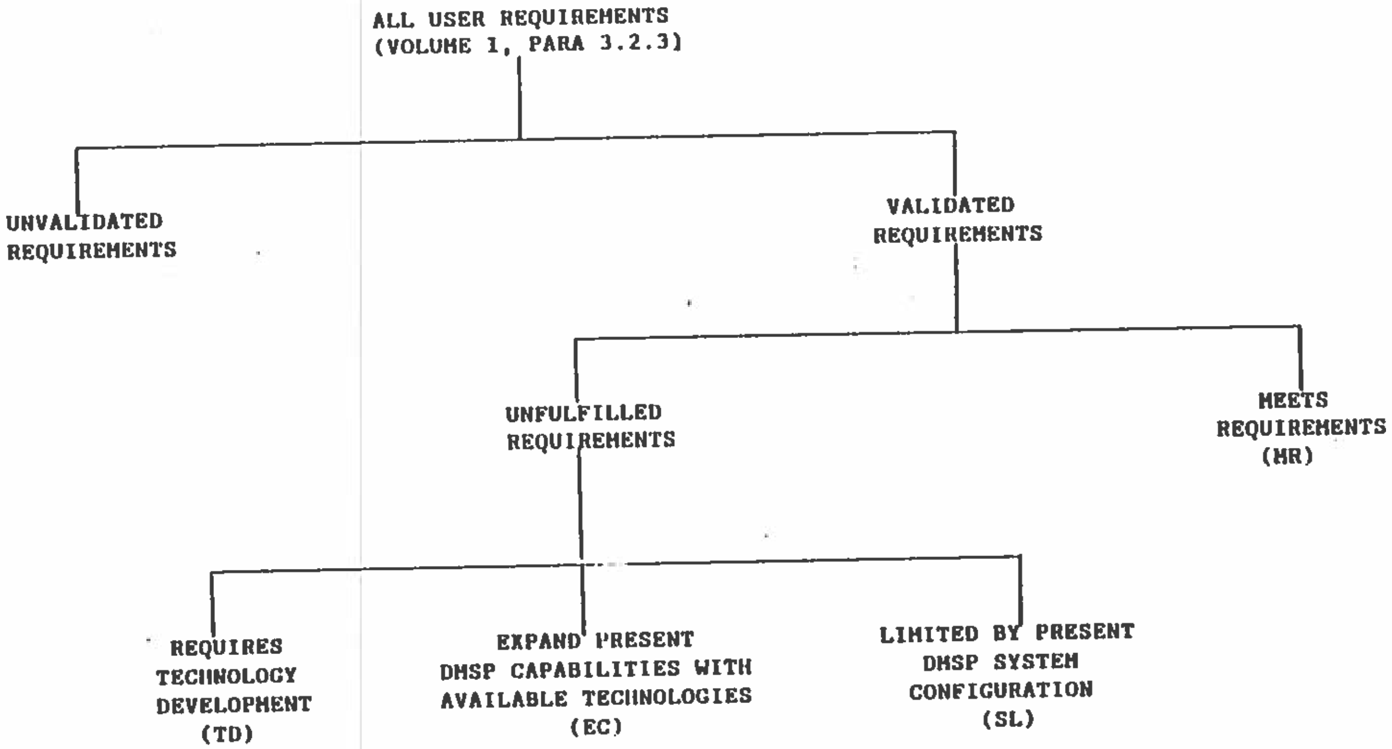

FIGURE 1: BREAKOUT OF REQUIREMENTS

2.0.1 Definitions

2.0.1.1 Data Type Parameters

Absolute Accuracy - See Measurement Accuracy

Data Refresh Period - Average time interval between consecutive measurements of a kind, covering the same geographical area. This parameter replaces the 'Frequency' terminology used heretofore.

Frequency - See Data Refresh Period

Location Accuracy - See Mapping Accuracy

Mapping Accuracy - Error in geographic location of the measured data (relative to geodetic coordinates) incurred by uncertainties in spacecraft internal alignment and attitude control, ephemeris prediction, and ground data processing. This parameter replaces the previous 'Location Accuracy' terminology.

Measurement Accuracy - Accuracy of measurement required by the Air Force, expressed in same units as the measurement or as Δ with an upper absolute limit. This parameter represents the extent to which the measuring device output approaches the true value of the measured quantity. It replaces the 'Absolute Accuracy' terminology used heretofore.

Measurement Precision - Resolution of measuring device and associated data processing equipment, equivalent to the standard deviation of the measurement process as defined by the Navy.

Measurement Range	-	Range of parameter wherein it must be measurable with the measurement accuracy specified.
Parameter Range	-	Range which parameter is expected to cover wherein extremes may or may not be measurable.
Resolution, Horizontal	-	The dimension of the smallest object - or horizontal area represented by the parametric value - distinguishable by a satellite sensor.
Resolution, Vertical	-	The smallest height increment discernible by a satellite sensor.
Timeliness	-	Elapsed time from data acquisition by satellite until delivery of processed data to user.

2.0.1.2 Other Terms

Central	-	A military unit with a capability of routinely performing, on a real time basis, the functions of environmental data collection, processing analysis, prediction, and dissemination of macro-, meso-, and microscale environmental applications to multiple organizations in support of DoD operations worldwide.
Macroscale	-	Covers horizontal dimensions in excess of 1,000 km and time scales on the order of weeks.
Mesoscale	-	Covers horizontal dimensions over the range from approx. 2 km to about 1,000 km and time scales ranging from hours to days.
Microscale	-	Covers horizontal dimensions less than 2 km and time scales below 1 hour.

Tactical Station	- A military unit with a direct meteorological satellite readout capability that provides direct weather support to tactical operations.

The parameters listed as Data Refresh Period and Timeliness in Volume I will be discussed in Section 4. The following subsections describe the current capability (5D-2 and 5D-3) with respect to the validated requirements. The corresponding subsections in Section 3 describe new technology concepts to meet the requirements assessed as needing technology development (TD). The definition and application of these requirements are discussed in detail in the SRD, Vol. I, section 3.2.3.

2.1 Cloud Cover (including smoke, haze, and smog). Validated requirements are summarized in Table 1. This broad requirement can be divided into the following subcategories: cloud coverage, cloud type, identification of cloud layers, altitude of cloud tops and bases, and water and ice content. The following paragraphs elaborate on current capabilities and describe technology development needs.

Present 5D-2 and planned 5D-3 capability to measure cloud cover globally meets the strategic data collection requirement imposed by the AFGWC/FNOC centrals within the constraints of the fixed data collection sites and the limited capacity of the on-board tape recorders. Data can be recorded by four OLS recorders. Storage capacity consists of 400 minutes per recorder when recording smooth data with horizontal resolution of 1.5 nmi. The capability also exists to record data with a finer resolution of 0.3 nmi at selected areas of the globe with 20 minutes per recorder storage capacity. Longitudinal coverage at the tactical stations is met after two or three spacecraft passes over the station. The 5D-2 and 5D-3 latitude coverage at the tactical stations (limited to line of sight real time read-outs) is 3000 nmi. The requirement of latitude coverage at the tactical stations is 4000 nmi. The only way this requirement can be fulfilled is by increasing the altitude of the polar orbiting satellites or internetting with data relay satellites. Needless to say, raising the altitude will also reduce the number of orbital passes required to meet the longitudinal coverage.

The present capabilities of the Operational Linescan System (OLS) almost meet the stated requirements for horizontal resolution and mapping accuracy. Development of a new capability to increase the horizontal resolution from .3 nmi to .25 nmi is not warranted since Air Weather Service considers the present capabilities as satisfactory in meeting operational requirements (Ref. 1). Thus, the present capability for horizontal resolution is listed as MR.

Requirements for mapping accuracy of cloud fields are a function of the particular operations that must be supported. Their satisfaction is constrained by the achievable horizontal resolution and can at best equal that parameter. It may be possible to improve the 5D-2 capability by using the Global Positioning System (GPS) to improve the satellite ephemeris data. The ephemeris error contributes the major portion of the error in the total pointing error budget of the Stellar Inertial Attitude Control System. For DMSP, 27 arc seconds out of the total 36 arc seconds pointing error is due to the ephemeris error. Therefore improved ephemeris data will also improve the sensor platform pointing performance.

There is no OLS capability to directly measure altitudes of cloud tops and bases. Cloud top altitudes can be estimated to within a few thousand feet by correlating IR imagery from the OLS with the atmospheric temperature profile obtained from the Microwave Temperature Sounder (SSM/T). The IR imagery should be adjusted for varying amounts of water vapor in the atmosphere using data from the Microwave Imager (SSM/I) when it becomes available.. However, even if the water vapor correction is implemented, it would not satisfy the vertical resolution requirements of ± 100 feet. Active sensing using Light Detection and Ranging (Lidar), has the potential to more satisfactorily meet the requirement for the measurement of cloud tops. Another concept for measuring cloud height is stereographic correlations from two Geostationary Orbiting Environmental Satellite (GOES) type spacecraft.

No current state-of-the-art space capability is available to detect cloud bases or determine their altitudes. Data from the 183 GHz radiometer (moisture profiler) combined with the SSM/T temperature profiles may provide a rough capability to compute cloud bases in the near term. A far-term approach for measuring cloud bases accurately is a range-gated, millimeter wave radar.

The SSM/I should have an accuracy for cloud water of ± 0.1kg/m^2 over a range from 0 to 1.26 kg/m^2 over the oceans. The accuracy is about 0.2 kg/m^2 over land surfaces (see Table A.4). At best this is 8 percent. For liquid water, the SSM/I should have an accuracy of ± 2.0 kg/m^2 over a range from 0 to 6.1 kg/m^2 which corresponds at best to a measurement accuracy of 33 percent.

Based on projected Differential Absorption Lidar (DIAL) capabilities, the measurement accuracy of water content should improve when these systems become operationally available. It should be emphasized, so as not to appear unduly optimistic, that extensive development needs to be carried out before space qualified and operational Lidar systems are flown on a DMSP satellite. In addition, semi-quantitative data on the nature of water/ice content of cloud tops may also be derived from the polarization effects produced in the backscattered signal from other ranging Lidar systems.

Data Type Parameter	At Tactical Stations	At Centrals	Remarks	Source/Date	Req'd. Action	Block 50-2 Capability
1. CLOUD COVER (Including smoke, haze, and smog, type, water content, altitude of base and top)			Validated 31 Aug 76 Validated 5 Jun 79 Validated 3 Jun 81	MJCS 251-76/31 Aug 76 MAC 507-78/28 Dec 78 MAC 505-79/30 Sep 79		OLS for cloud cover and cloud type. SSM/I for cloud water content from S-10 on at Centrals only; no current capability for snow/ice/cloud discrimination.
Area Covered	2,000x4,000 nmi (3,500x7,500 km)	Global	Detect all cloud levels	MJCS 251-76	SL MR	Tact Sta max. coverage: OLS - 1,575x3,000 nmi SSM/I - 753x3,000 nmi Global at Centrals
Horizontal Resolution	0.25 nmi (0.5 km)	0.25 nmi (0.5 km)		MJCS 251-76	MR	OLS: 0.3 nmi SSM/I: 8-30 nmi
Mapping Accuracy	0.25 nmi (0.5 km)	0.25 nmi (0.5 km)	JCS Operational Goal incl. Dropsize Distribution	MJCS 251-76	EC	OLS: 2-5 nmi SSM/I: 10 nmi
Vertical Resolution	±100 ft (30 m)	±100 ft (30 m)	Below 10,000 ft (3,000 m) above ground level (AGL)	MJCS 251-76	TD	No OLS capability. Correlation with SSM/T and/or SSH data, and with SSM/I data, may yield limited capability to detect cloud tops
	±1,000 ft (300 m)	±1,000 ft (300 m)	Above 10,000 ft AGL (3,000 m)			
Measurem't Accuracy	±1 pct	±1 pct	Water/Ice Content Equivalent inches (mm) of water in a column to top of atmosphere	MJCS 251-76	MR	OLS provides percentage of cloud cover. SSM/I should yield total water content as follows: Cloud water ±0.1 kg/m^2 Liquid water ±2.0 kg/m^2
Data Refresh Period	On call	30 min	See Sec. 4.3	MJCS 251-76	SL	12 h for each satellite
Timeliness	5 min	15 min	See Sec. 4.3	MJCS 251-76	SL/ EC	Tactical: OLS soft copy in RT, hard copy 10-30 min Centrals: 15-415 min

2.2 Vertical Moisture Profile. Validated requirements are summarized in Table 2. The following paragraphs elaborate on current capabilities and technology development needs.

Present 5D-2 and planned 5D-3 capabilities fulfill most of the requirement for global coverage by the centrals. Global coverage could be partially obtained with infrared sounding data (SSH-2), but this sensor has coverage gaps between orbital swaths below 55 degrees latitude. Moreover, SSH data is unable to be processed at present and there is no present plan to continue with these sensors on future spacecraft. Total liquid water content measured by microwave imagery (SSM/I) should improve quality of data but the SSM/I coverage will contain gaps below 65 degrees latitude. At present tactical stations are not configured to receive or process secondary data. If the tactical terminals could receive and process SSM/I data, the sensor scan angle would need to be increased in order to fulfill the area coverage requirement for tactical stations.

The capabilities of the SSM/I when it becomes operational on S-10 should meet the horizontal resolution requirements at the centrals and could almost meet them for tactical stations. The SSM/I does not have any vertical profile capability. It simply measures the total water content in a unit column of the atmosphere. The SSM/I should also meet the 10 nmi mapping accuracy requirement for the centrals. Meeting the stated mapping accuracy at tactical stations requires an improvement in horizontal resolution as well.

Vertical profile resolution is very meager. Current 5D-2 capability is limited to the SSH. This instrument is constrained to providing moisture profiles in cloud free areas since clouds contaminate the altitude dependent radiance measurement needed for retrieval of the moisture profile. Because the level of confidence in the vertical moisture profiles is very low, SSH data is not being processed. The planned addition of a 183 GHz band (SSM/T-2) to the SSM/T will provide some moisture profiling in the near term. Differential Absorption Lidar (DIAL) techniques also show promise of achieving the more stringent requirements for tactical horizontal and vertical resolution in the far-term.

Data Type Parameter	At Tactical Stations	At Centrals	Remarks	Source/Date	Req'd. Action	Block 5D-2 Capability
2. VERTICAL MOISTURE PROFILE			Validated 31 Aug 76	MJCS 251-76/31 Aug 76		SSH (not being processed)
			Validated 3 Jun 81	MAC 505-79/30 Sep 79		From S-10 on, SSM/I will provide total water vapor, cloud water (drop size ≤100 μm) and precipitating or liquid water (drop size >100 μm)
Area Covered	2,000x4,000 nmi (3,500x7,500 km)	Global		MJCS 251-76	EC/ SL	Tact Sta coverage not operat'l: SSH – 1,000x3,000 nmi SSM/I – 753x3,000 nmi
Horizontal Resolution	5 nmi (10 km)	50 nmi (100 km)		MJCS 251-76	EC/ MR	SSH: 112 nmi in-track 31.5-84.6 nmi x-track SSM/I: 8-30 nmi total water content only
Mapping Accuracy	1 nmi (2 km)	10 nmi (20 km)		MJCS 251-76	EC/ MR	SSH: 50 nmi SSM/I: 10 nmi total water content only
Vertical Resolution	±100 ft (30 m)	±100 ft (30 m)	Surface – 10,000 ft (Surface – 3,000 m)	MJCS 251-76	TD	SSM/T-2 will provide data in four atmospheric layers
	±1,000 ft (300 m)	±1,000 ft (300 m)	10,000 ft – Stratopause (3,000 m – Stratopause)			
Measurement Accuracy	± 1 pct	± 1 pct	See Sec. 2.1	MJCS 251-76	TD	OLS provides percentage of cloud cover. SSM/I should yield total water content as follows: Cloud water ±0.1 kg/m^2 Liquid water ±2.0 kg/m^2
Data Refresh Period	1 h	3 h	See Sec. 4.3	MJCS 251-76	SL	12 h for each satellite
Timeliness	1 h/30 min	1 h	See Sec. 4.3	MJCS 251-76	SL/ EC	Tactical: No current capacity Centrals: 15-415 min

2.3 Vertical Temperature Profile. The validated requirements are summarized in Table 3. The following paragraphs describe current capabilities and technology development needs.

Present 5D-2 and planned 5D-3 capabilities presently meet, to a limited degree, the requirement for global coverage by the centrals. Global coverage is provided daily by the SSM/T with gaps between orbital swaths below 60 degrees latitude. Tactical station coverage is not operational since the tactical terminals are not configured to receive or process secondary data. If the tactical stations could receive and process SSM/T data, the scan angle would need to be increased in order to fulfill the area coverage requirement for tactical stations.

The requirements for horizontal resolution and mapping accuracy currently cannot be met by either the SSM/T or SSH. The horizontal resolution and accuracy can be increased by increasing the antenna size on the SSM/T.

The vertical temperature profile requirements are currently being met to a limited degree by the SSH and the SSM/T sensors. The SSH, however, is constrained to provide data in cloud-free areas since clouds contaminate the altitude dependent radiance measurement needed for retrieval of the temperature profile. Because of the low level of confidence in the vertical moisture profile from the SSH, its data is not being processed. Because the SSM/T can provide some temperature profile information over clear and cloudy areas, it is the preferred instrument even though its vertical resolution does not meet requirements. The seven SSM/T channels provide data corresponding to seven altitude regions (2 to 32 km in height). This resolution does not begin to approach the ± 100 ft requirements for measurements between the surface and 10,000 ft altitude. DIAL is a potential system for meeting the vertical as well as horizontal resolution requirements.

The present rms measurement accuracy of the SSM/T (2-3°K) almost meets the requirement above the boundary layer (>700mb). This should improve if a DIAL Lidar system (±1°K) is developed to meet the vertical resolution requirement. The rms measurement accuracy of the SSM/T in the boundary layer ranges between 4-7°K. Correlation with surface temperature measurements may decrease this error.

Data Type Parameter	At Tactical Stations	At Centrals	Remarks	Source/Date	Req'd. Action	Block 5D-2 Capability
3. VERTICAL TEMPERATURE PROFILE			Validated 31 Aug 76 Validated 3 Jun 81	MJCS 251-76/31 Aug 76 MAC 505-79/30 Sep 79		SSM/T or SSH
Area Covered	2,000x4,000 nmi (3,500x7,500 km)	Global		MJCS 251-76	EC/ SL	Tact Sta coverage not operat'l: SSM/T – 861x3,000 nmi SSH – 1,100x3,000 nmi
Horizontal Resolution	5 nmi (10 km)	50 nmi (100 km)		MJCS 251-76	EC	In-track: 112 nmi – SSM/T + SSH X-track: 96 nmi – SSM/T at nadir 31.5-84.6 nmi – SSH
Mapping Accuracy	1 nmi (2 km)	10 nmi (20 km)		MJCS 251-76	EC	SSM/T or SSH: 50 nmi
Vertical Resolution	±100 ft (30 m)	±100 ft (30 m)	Surface – 10,000 ft (Surface – 3,000 m)	MJCS 251-76	TD	Data derived from 7 SSM/T channels provide data corresp. to 7 altitude regions. The SSH sensor's one window and 6 CO_2 channels yield data for 7 altitude ranges up to 30 km.
	±1,000 ft (300 m)	±1,000 ft (300 m)	10,000 – 30,000 ft (3,000 – 10,000 m)			
	±2,000 ft (600 m)	±2,000 ft (600 m)	30,000 – 200,000 ft (10,000 – 60,000 m)	MJCS 251-76		...
Measurement Accuracy	± 1°K	± 1°K		MJCS 251-76	EC	SSM/T or SSH: 2.5-3°K
Data Refresh Period	1 h	3 h	See Sec. 4.3	MJCS 251-76	SL	12 h for each satellite
Timeliness	1 h/30 min	1 h	See Sec. 4.3	MJCS 251-76	SL/ EC	Tactical: No current capacity Centrals: 15-415 min

2.4 Albedo. Validated requirements are summarized in Table 4. The earth/atmosphere albedo can be derived within 6% from the visible imagery of the OLS, given the sensitivity of the OLS and the solar fluence. At present only daytime data is being processed to determine these parameters and the specified mapping and measurement accuracies are not fully met. The current requirement for mapping accuracies needs to be modified since it is tighter than the requirements for horizontal resolution and, therefore cannot be satisfied.

Data Type Parameter	At Tactical Stations	At Centrals	Remarks	Source/Date	Req'd. Action	Block 5D-2 Capability
4. ALBEDO			Validated 31 Aug 76	MJCS 251-76/31 Aug 76		OLS
Area Covered	800x800 nmi (1,500x1,500 km)	Global		MJCS 251-76	MR MR	Tact Sta max. coverage: OLS – 1,575x3,000 nmi Global at Centrals
Horizontal Resolution	5 nmi (10 km)	25 nmi (45 km)		MJCS 251-76	MR	0.3 nmi
Mapping Accuracy	1 nmi (2 km)	5 nmi (10 km)		MJCS 251-76	EC/MR	2-5 nmi
Measurement Accuracy	±5 pct	±5 pct		MJCS 251-76	MR	±5 pct
Data Refresh Period	1 h	3 h	See Sec. 4.3	MJCS 251-76	SL	12 h for each satellite
Timeliness	1 h	1 h	See Sec. 4.3	MJCS 251-76	SL/ EC	Tactical: OLS soft copy in RT, hard copy 10-30 min Centrals: 15-415 min

2.5 Visibility. Validated requirements are summarized in Table 5. Measurement of visibility from a DMSP space platform is by its very nature limited to a qualitative evaluation based on vertical and slant path visibilities using the OLS. While the horizontal and slant path visibilities can be inferred from the location of clear path regions, no capability exists to measure visibility ranges nor to provide any vertical resolution. Since visibility is directly related to the aerosol content along the slant path between the target and an optical sensor, the physical quantity that should be measured is the vertical aerosol extinction coefficient profile at wavelengths larger than 0.5 microns. For wavelengths smaller than 0.5 microns the quantity that actually becomes the dominant factor and determines visibility is molecular extinction. This effect could be exploited to measure the atmospheric density at the ozone altitude, or lower, depending on the wavelength used. A potential active technique for measuring these parameters, although not proven yet, is the possible use of a multiwavelength Lidar system.

Data Type Parameter	At Tactical Stations	At Centrals	Remarks	Source/Date	Req'd. Action	Block 50-2 Capability
5. VISIBILITY			Validated 31 Aug 76 Validated 3 Jun 81	MJCS 251-76/31 Aug 76 MAC 505-79/30 Sep 79		OLS provides qualitative data only in identifying regions with clear vertical and slant visibilities
Area Covered	800x800 nmi (1,500x1,500 km)	2,000x4,000 nmi (3,500x7,500 km)		MJCS 251-76	TD	Tact Sta max. coverage: OLS - 1,575x3,000 nmi Cloud free areas only.
Horizontal Resolution	5 nmi (10 km)	5 nmi (10 km)	Surface-15,000 ft (4,500 m)	MJCS 251-76	TD	OLS: 0.3 nmi Cloud Free areas
Mapping Accuracy	1 nmi (2 km)	1 nmi (2 km)		MJCS 251-76	TD	OLS: 2.5 nmi Cloud Free areas:
Vertical Resolution	500 ft (150 m)	500 ft (150 m)	Surface-15,000 ft (4,500 m)	MJCS 251-76	TD	No capability
	1,000 ft (300 m)	1,000 ft (300 m)	15,000-40,000 ft (4,500-7,500 m)	MJCS 251-76 MAC/XPPE deletes upper limit		No capability
Measurement Accuracy	±0.5 nmi (1 km)	±0.5 nmi (1 km)		MJCS 251-76	TD	No capability
Wavelength	0.4-0.7 m	0.4-0.7 m		MJCS 251-76	MR	Satisfied by OLS
Data Refresh Period	1 h	1 h	See Sec. 4.3	MJCS 251-76	SL	12 h for each satellite
Timeliness	1 h	1 h	See Sec. 4.3	MJCS 251-76	SL/ EC	Tactical: OLS soft copy in RT, hard copy 10-30 min Centrals: 15-415 min

2.6 Precipitation. Validated requirements are summarized in Table 6. The following paragraphs give current capabilities and technology development needs.

The addition of the SSM/I sensor on S-10 will fulfill most of the requirements by the centrals for global coverage of precipitation. Global coverage will be provided daily with gaps between orbital swaths of microwave imagery (SSM/I) below 65 degrees latitude. Tactical station coverage will not be operational until they are configured to process secondary data.

The requirements for horizontal resolution, mapping accuracy and measurement accuracy cannot be met by the SSM/I. The resolution of the SSM/I can be increased by increasing the antenna size. Increasing the size of the antenna would also improve the measurement accuracy as well as the horizontal resolution. Millimeter wave radar is an active device which may have spaceborne application for measuring precipitation.

Data Type Parameter	At Tactical Stations	At Centrals	Remarks	Source/Date	Req'd. Action	Block 50-2 Capability
6. PRECIPITATION			Validated 31 Aug 76 Validated 5 Jun 79	MJCS 251-76/31 Aug 76 MAC 507-78/28 Dec 78		No current capability until SSM/I incorporation on S-10 Liquid water drops > 100 μm
Area Covered	800x800 nmi (1,500x1,500 km)	Global			EC	Tact Sta coverage not operat'l: SSM/I – 753x3,000 nmi
Horizontal Resolution	0.5 nmi (1 km)	2.5 nmi (5 km)		MJCS 251-76	EC	8-30 nmi
Mapping Accuracy	1 nmi (2 km)	5 nmi (10 km)		MJCS 251-76	EC	10 nmi
Measurement Accuracy	±0.1 in/h (2.5 mm/h)	±0.1 in/h (2.5 mm/h)		MJCS 251-76	EC	±5 mm/h
Data Refresh Period	On call	3 h	See Sec. 4.3	MJCS 251-76	SL	12 h for each satellite
Timeliness	15 min	15 min/ 1 h	See Sec. 4.3	MJCS 251-76	SL/ EC	Tactical: No current capacity Centrals: 15-415 min

2.7 Winds. The validated requirements are summarized in Table 7. There is no direct measurement capability for winds planned until a non-scan Doppler Lidar sensor is flown in the late 1990s.

The horizontal and vertical resolution requirements of wind velocity are not being met using present approximate analytical derivations based on the use of the ideal gas laws relating the geostrophic wind speeds (see section 3.7 for definition) to the gradient of the atmospheric temperature fields. The SSM/I mission sensor on S-10 will add the capability of measuring ocean wind speeds; however, the resolution requirements still cannot be met. Furthermore, this capability is not available under conditions of precipitation or in the presence of clouds with large water content. Better measurement of ocean surface winds (speed and direction) is obtainable using an active microwave scatterometer operating at 13.9 GHz. This instrument (known as the scatterometer) has been flown on SEASAT and is planned to fly on N-ROSS.

Lidar techniques using Doppler shifts have been demonstrated on the ground to be capable of accurately measuring wind speed, range and direction. The same potential capability exists for space applications. However, extensive development needs to be carried out before a space qualified and operational Doppler Lidar system is flown.

Data Type Parameter	At Tactical Stations	At Centrals	Remarks	Source/Date	Req'd. Action	Block 5D-2 Capability
7. WINDS			Validated 31 Aug 76 Validated Dec 79 Validated 3 Jun 81 Validated 10 Feb 77	MJCS 251-76/31 Aug 76 MAC 508-78/28 Dec 78 MAC 505-79/30 Sep 79 SMOP/10 Feb 77	SL	Tact Sta coverage not operat'l: SSM/T - 861x3,000 nmi SSH - 1,100x3,000 nmi SSM/I - 753x3,000 nmi
Area Covered	2,000x4,000 nmi (3,500x7,500 km)	Global		MJCS 251-76	EC	Geostrophic winds at mid to high latitudes only SSM/I from 5-10 only Ocean surface wind speeds only
Horizontal Resolution	5 nmi (10 km) 10 km 10 km	5 nmi (10 km) 25 km 30/25 km	USN Ops Goal for speed USN Ops Goal for direction	MJCS 251-76 SMOP SMOP	TD	In-track: 112 nmi - SSM/T + SSH 8.5-37.2 nmi - SSM/I X-track:96 nmi - SSM/T at nadir 31.5-84.6 nmi - SSH 7.5-23.9 nmi - SSM/I
Mapping Accuracy	1 nmi (2 km)	1 nmi (2 km)		MJCS 251-76	TD	SSM/T or SSH: 50 nmi SSM/I: 12.5 km
Vertical Resolution	±100 ft (30 m)	±100 ft (30 m)	Surface-10,000 ft (Surface- 3,000 m)	MJCS 251-76	TD	Data derived from 7 SSM/T channels provide data corresp. to 7 altitude regions. The SSH sensor's one window and 6 CO_2 channels yield data for 7 altitude ranges up to 30 km altitude.
	±1,000 ft (300 m)	±1,000 ft (300 m)	10,000-30,000 ft (3,000-10,000 m)			
	±2,000 ft (600 m)	±2,000 ft (600 m)	30,000-200,000 ft (10,000-60,000 m)			
Measurement Range Speed:	1-75 m/s	3-25//1-25/1-75 m/s		SMOP//OR 78/OR 80	TD	SSM/T or SSH: TBS SSM/I: 3-25 m/s
Direction:	0-360°/No req't	0-360°		MJCS 251-76/SMOP		No capability
Measurement Precision Speed:	5 pct	20 pct		SMOP	TD	SSM/T or SSH: TBS SSM/I: ±1 m/s
Direction:	±5°	±10°		SMOP		No capability
Measurement Accuracy Speed:	±5 pct, 2 m/s 2 m/s	±5 pct, 2 m/s 4 m/s		MJCS 251-76 SMOP	TD	SSM/T or SSH: TBS SSM/I: ±2 m/s
Direction:	± 5° ±10°	± 5° ±22.5°		MJCS 251-76 SMOP		No capability
Data Refresh Period	On call 3 h	3 h 12 h	See Sec. 4.3 See Sec. 4.3	MJCS 251-76 SMOP	SL	12 h for each satellite
Timeliness	On call	1 h	See Sec. 4.3	MJCS 251-76	SL/ EC	Tactical: No current capacity Centrals: 15-415 min

2.8 Surface Temperature. The validated requirements are summarized in Table 8. Measurement of surface temperature is satisfied at AFGWC by relative infrared data from the OLS in cloud free regions and is calibrated from surface measurements. The SSM/I mission sensor on S-10 may provide additional capability to provide land surface temperature using microwaves. This sensor may be able to determine land surface temperature in clear to cloudy regions but not under conditions of precipitation or in the presence of clouds with a large water content. Other factors such as dense vegetation or mountainous terrain may also adversely affect the determination of the land surface temperature. Tactical station coverage is not operational since the terminals are not configured to receive or process secondary data. However if the tactical terminals could process SSM/I data, then the sensor scan angle would have to be increased in order to fulfill the area coverage requirements for tactical stations. With present available technology base, the only requirement the OLS and SSM/I sensors may not be able to meet is the measurement accuracy of ± 1° K. A low frequency microwave radiometer is being developed for N-ROSS to meet Navy requirements for measurement of sea surface temperature.

Data Type Parameter	At Tactical Stations	At Centrals	Remarks	Source/Date	Req'd. Action	Block 5D-2 Capability
8. SURFACE TEMPERATURE Land (LST) and Sea (SST)			Validated 31 Aug 76 Validated 3 Jun 81 Validated 10 Feb 77	MJCS 251-76/31 Aug 76 MAC 505-79/30 Sep 79 SMOP/10 Feb 77		OLS under cloud free conditions SSM/I from S-10 on for land areas at Centrals only
Area Covered	800x800 nmi (1,500x1,500 km)	Global	Temperature of radiating surface	MJCS 251-76	EC	Tact Sta max. coverage: OLS - 1,575x3,000 nmi SSM/I - 753x3,000 nmi
Horizontal Resolution (10 km)	5 nmi (10 km)	5 nmi		MJCS 251-76	EC	In cloud free regions: (LST) OLS 2-5 nmi
(SST)	10 km	25 km		SMOP		SSM/I: 8.5-37.2 nmi in-track 7.5-23.9 nmi x-track
Mapping Accuracy	1 nmi (2 km)	5 nmi (10 km)	0.5 nmi for SST with IR (1 km)	MJCS 251-76	EC	In cloud free regions: OLS: 2-5 nmi SSM/I: 12.5 km
Measurement Range (SST)	271-308°K	271-308°K		SMOP	MR	OLS: 190-310°K
(LST)	210-310°K	210-310°K			MR	SSM/I: 0-375°K
Measurement Precision (SST)	0.25°K	0.80°K		SMOP	EC	OLS: 0.80°K global SSM/I: TBD
Measurement Accuracy	±0.5°K	±1.0°K		MJCS 251-76/SMOP	EC	OLS: 5°K - reducible by correcting for moisture info down to 2°K at best SSM/I: 4-5°K on land
Data Refresh Period(LST)	1 h	3 h		MJCS 251-76	SL	12 h for each satellite
(SST)	12 h	72 h		SMOP		
Timeliness	On call	1.5 h		MJCS 251-76	SL/ EC	Tactical: OLS soft copy in RT, hard copy 10-30 min Centrals: 15-415 min

2.9 Snow and Landlocked Ice Cover. The validated requirements are summarized in Table 9. The following paragraphs describe current capabilities and technology development needs.

Present 5D-2 and planned 5D-3 capability to measure cloud cover globally meets the strategic data collection requirement imposed by the AFGWC/FNOC centrals within the constraints of the fixed data collection sites and the limited capacity of the on-board tape recorders. Data can be recorded by four OLS recorders. Storage capacity consists of 400 minutes per recorder when recording smooth data with horizontal resolution of 1.5 nmi. The capability also exists to record data with a finer resolution of 0.3 nmi at selected areas of the globe with 20 minutes per recorder storage capacity. Longitudinal coverage at the tactical stations is met after two or three spacecraft passes over the station. The 5D-2 and 5D-3 latitude coverage at the tactical stations (limited to line of sight real time read-outs) is 3000 nmi. The requirement of latitude coverage at the tactical stations is 4000 nmi. The only way this requirement can be fulfilled is by increasing the altitude of the polar orbiting satellites or internetting with data relay satellites. Needless to say, raising the altitude will also reduce the number of orbital passes required to meet the longitudinal coverage. Tactical station coverage is not operational to receive or process SSM/I data.

The requirement for horizontal resolution can be met by the OLS in cloud free areas. The capability to distinguish clouds from snow and ice using OLS data could be enhanced significantly by adding a detector channel at 1.6 μm. The experimental SSC (snow/cloud) sensor successfully flown on F-4 demonstrated this capability during daylight periods but is not planned to be flown again aboard a DMSP spacecraft.

The OLS meets the requirement for mapping accuracy by the centrals and almost meets the tactical station requirement. The mapping accuracy of the SSM/I could be improved by increasing the size of its receiving antenna.

No demonstrated capability exists to measure the thickness of snow and ice cover from space. The SSM/I may provide a measure of snow depth. A range-gated millimeter wave sensor may be able to measure the thickness of snow and ice cover but not within the required accuracy. The required accuracy of ± 2 inch is physically impossible for a millimeter device.

Data Type Parameter	At Tactical Stations	At Centrals	Remarks	Source/Date	Req'd. Action	Block 5D-2 Capability
9. SNOW AND LANDLOCKED ICE COVER			Validated 31 Aug 76 Validated 5 Jun 79	MJCS 251-76/31 Aug 76 MAC 507-78/28 Dec 78		SSM/I at Centrals for ice only, from 5-10 on. Snow detection capability may be achieved by development of additional algorithms OLS under cloud-free conditions. Snow/cloud discrimination by SSC Sensor in conjunction with OLS was demonstrated on F-4; No plans for operational use.
Area Covered	Tactical areas 800x800 nmi (1,500x1,500 km)	Global		MJCS 251-76	EC	Tact Sta max. coverage: OLS - 1,575x3,000 nmi SSM/I - 753x3,000 nmi
Horizontal Resolution	5 nmi (10 km)	25 nmi (45 km)		MJCS 251-76	EC	OLS: 0.3 nmi cloud free areas SSM/I: 8.5-37.2 nmi in-track 7.5-23.9 nmi x-track
Mapping Accuracy	1 nmi (2 km)	5 nmi (10 km)		MJCS 251-76	EC	OLS: 2-5 nmi SSM/I: 6.7 nmi (12.5 km)
Thickness Accuracy	±2 in (5 cm)	±2 in (5 cm)		MJCS 251-76	TD	No capability
Data Refresh Period	3 h	6 h	See Sec. 4.3	MJCS 251-76	SL	12 h for each satellite
Timeliness	On call/30 min	90 min	See Sec. 4.3	MJCS 251-76	SL/ EC	Tactical: OLS soft copy in RT, hard copy 10-30 min Centrals: 15-415 min

2.10 Sea Ice Cover, Bergs and Leads. The validated requirements are summarized in Table 10. The following paragraphs elaborate on current capabilities and technology development needs.

Present 5D-2 and planned 5D-3 capabilities fulfill the requirement for global coverage by the centrals. Total global coverage can be recorded by the OLS (400 min per recorder) with a horizontal resolution of 1.5 nmi. The capacity of the present tape recorders however limit the amount of .3 nmi resolution data that can be recorded for the centrals to about 20% of a full orbit (20 minutes per recorder). Longitudinal coverage at the tactical stations is met after two or three spacecraft passes over the station. The requirement of latitude coverage at the tactical stations requires increasing the altitude of the polar orbiting satellites or internetting with data relay satellites. Needless to say, raising the altitude will also reduce the number of orbital passes required to meet the longitudinal coverage.

The present capabilities of the OLS meet the stated requirements for horizontal resolution under clear conditions or light cloud cover. There is no space platform capability to measure the age or the thickness of ice cover other than to record changes as they are observed in OLS imagery. The capability to distinguish clouds from ice cover using data from the OLS could be enhanced significantly by adding a detector channel at 1.6 µm. The SSC, successfully flown on F-4, demonstrated this capability during daylight hours but is not planned to be flown again aboard a DMSP spacecraft. The SSM/I can provide data in clear to cloudy regions but not within the range of Air Force requirements. The SSM/I does meet Navy requirements. The spatial resolution of the SSM/I sensor could be significantly enhanced by increasing the size of its receiving antenna.

The present capabilities of the OLS or SSM/I cannot meet the stated requirements for mapping accuracy. It may be possible to improve the 5D-2 capability by using the Global Positioning System (GPS) to improve the satellite ephemeris data. The ephemeris error contributes the major portion of the error in the total pointing error budget of the Stellar Inertial Attitude Control System. For DMSP, 27 arc seconds out of the total 36 arc seconds pointing error is due to the ephemeris error. Therefore, improved ephemeris data will also improve the sensor platform pointing performance.

No demonstrated capability exists to measure the thickness of sea ice from space. The utility of using a range gated millimeter wave sensor to measure the thickness of ice remains to be determined.

Data Type Parameter	At Tactical Stations	At Centrals	Remarks	Source/Date	Req'd. Action	Block 5D-2 Capability
10. SEA ICE COVER, BERGS AND LEADS			Validated 31 Aug 76	MJCS 251-76/31 Aug 76		OLS under cloud-free conditions
			Validated 10 Feb 77	SMOP/10 Feb 77		SSM/I from S-10 on at Centrals only
Area Covered	Tactical areas 3,500x7,500 km	Global		MJCS 251-76	SL	Tact Sta max. coverage: OLS – 1,575x3,000 nmi SSM/I – 753x3,000 nmi
					MR	Global at Centrals
Horizontal Resolution	0.5 nmi (1 km)	0.5 nmi (1 km)		MJCS 251-76	MR	OLS: 0.3 nmi cloud free areas SSM/I: 8-30 nmi
Area Cover	0.5 km	25 km		SMOP		
Thickness	2 m	50 m		SMOP	10	No capability for Icebergs
Age	10 km	50 km		SMOP	10	
Icebergs & Leads	15 m	15/100 m		MJCS 251-76/SMOP	10	
Mapping Accuracy	0.5 nmi (1 km)	0.5 nmi (1 km)		MJCS 251-76	EC	OLS: 2-5 nmi cloud free areas SSM/I: 6.75 nmi (12.5 km)
Position Accuracy of Icebergs & Leads	±0.5 km	±2.0 km		SMOP	10	
Measurement Range						
Area Cover	0-100 pct	0-100 pct		SMOP	MR	0-100 pct
Thickness	0-25 m	0-25/0-50 m			10	No capability
Age	1-36 months	1-36 months			10	≤1 or ≥1 year
Measurement Precision						
Area Cover	10 pct	25 pct		SMOP	MR	±5 pct
Thickness	0.25 m	2 m			10	No capability
Age	6 months	12 months			10	≤1 and ≥1 year
Concentration or	±10 pct	±10 pct		MJCS 251-76	MR	±12 pct
Area Cover Accuracy	±12 pct	±30 pct		SMOP		
Thickness Accuracy	±5 in (12.7 cm) ±0.5 m	±5 in (12.7 cm) ±2.0 m		MJCS 251-76 SMOP	10	No capability
Age Accuracy	±6 months	±6/12 months		MJCS 251-76/SMOP	10	≤1 and ≥1 year
Data Refresh Period	6 h 24 h	12 h 48/120 h	See Sec. 4.2 Bergs and Leads/Ice Cover	MJCS 251-76 SMOP	SL	12 h for each satellite
Timeliness	On call	3 h	See Sec. 4.3	MJCS 251-76	SL/ EC	Tactical: OLS soft copy in RT, hard copy 10-30 min Centrals: 15-415 min

2.11 Soil Moisture. The validated requirements are summarized in Table 11. The following paragraphs describe current capabilities and development technology needs.

The addition of the SSM/I mission sensor on S-10 will provide the initial capability to determine surface soil moisture (top 1 cm) for open land areas. Global coverage of surface soil moisture will be provided daily with gaps between orbital swaths below 65 degrees latitude. It will provide data under all conditions other than precipitation or the presence of clouds with a large water content. Tactical station coverage will not be operational since the tactical stations are not configured to process secondary data.

The horizontal resolution and mapping accuracy of the SSM/I almost meets the requirement for the centrals. The resolution and mapping accuracy can be increased by increasing its antenna size.

The measurement accuracy requires a measurement within 10 percent moisture saturation of the soil. The exact accuracy of the SSM/I has yet to be calibrated. There is no capability, however, for measuring the moisture content in frozen ground. Additionally, any soil moisture depth measurement requires an active ranging device with frequencies in the lower microwave region.

Data Type Parameter	At Tactical Stations	At Centrals	Remarks	Source/Date	Req'd. Action	Block 5D-2 Capability
11. SOIL MOISTURE			Validated 31 Aug 76	MJCS 251-76/31 Aug 76		SSM/I from S-10 on, at Centrals only
Area Covered	2,000x4,000 nmi (3,500x7,500 km)	Global		MJCS 251-76	SL/EC EC	Tact Sta coverage not operat'l: 753x3,000 nmi Global at controls with gaps below 65°
Horizontal Resolution	1 nmi (2 km)	5 nmi (10 km)		MJCS 251-76	EC	8-30 nmi
Mapping Accuracy	1 nmi (2 km)	5 nmi (10 km)		MJCS 251-76	EC	6.75 nmi (12.5 km)
Measurement Accuracy Depth of Saturation	±10 pct	±10 pct	If frozen, depth to nearest ±3in (7.5 cm)	MJCS 251-76	TD	Qualitative only for surfaces No capability for frozen ground
Data Refresh Period	On call	6 h	See Sec. 4.3	MJCS 251-76	SL	12 h for each satellite
Timeliness	On request/15 min	90 min	See Sec. 4.3	MJCS 251-76	SL/ EC	Tactical: No current capacity Centrals: 15-415 min

2.12 Sea State/Waves. The validated requirements are summarized in Table 12. The following paragraphs describe current capabilities and technology development needs.

Wave and swell significant height (defined as the average height of the one-third highest waves in a given wave group) are currently analyzed twice per day and forecasts made for the northern hemisphere by the Fleet Numerical Oceonography Center (FNOC) at Monterey. This computational analysis is based on surface observation of wind fields. At present there is no direct space capability to determine sea state. A scatterometer has been flown on the NOAA Seasat and the data has been used to determine sea surface wind speeds and sea states. The OLS can provide a rough assessment by evaluation of sun glint. The addition of the SSM/I sensor on S-10 will add a rough assessment of worst case combined sea height from the sea surface wind data. Tactical station coverage is limited to OLS data, because they are not configured to process secondary data. Acquisition of SSM/I data is limited to conditions other than precipitation or in the presence of clouds with a large water content.

The radar altimeter is a potential sensor for directly measuring the significant wave height, from which the combined sea height may be determined. Current planning includes a radar altimeter on N-ROSS. The capability of that sensor is limited to a region immediately below the satellite track. Direct measurement of wave height and direction, or of wave energy spectra, would greatly increase the accuracy of the analysis and forecasts made at FNOC.

Data Type Parameter	At Tactical Stations	At Centrals	Remarks	Source/Date	Req'd. Action	Block 5D-2 Capability
12. SEA STATE/WAVES			Validated 31 Aug 76	MJCS 251-76/31 Aug 76		Rough qualitative assessment by evaluation of sun glint from OLS. Addition of SSM/I from S-10 on will add rough assessment of worst case combined sea height at Centrals only
			Validated 10 Feb 77	SMOP/10 Feb 77		
Area Covered	Tactical areas 3,500x7,500 km	Global		MJCS 251-76	SL	Tact Sta max. coverage: OLS – 1,575x3,000 nmi SSM/I – 753x3,000 nmi
					MR	Global at Centrals
Horizontal Resolution	1 nmi (2 km)	1 nmi (2 km)		MJCS 251-76	EC	OLS: 0.3 nmi SSM/I: 8.5-37.2 nmi in-track 7.5-23.9 nmi x-track
	10 km	25 km	For Significant Wave Height	SMOP		
	1 km	25 km	Amplitude and Wavelength Components	SMOP		
	1 km	50 km	Direction of Wave Motion	SMOP		
Mapping Accuracy	1 nmi (2 km)	1 nmi (2 km)		MJCS 251-76	EC	OLS: 2-5 nmi SSM/I: 12.5 km
Measurement Range	1-20 m 1-20 m 1-1,000 m 0-360°	1-8 m 1-8 m 50-500 m 0-360°	Significant Wave Height Amplitude Component Wavelength Component Direction of Wave Motion	SMOP	EC	Qualitative only
Measurement Precision	0.3 m 0.3 m ±5 pct ±10°	10 pct 0.7 m ±15 pct ±30°	Significant Wave Height Amplitude Component Wavelength Component Directional Component	SMOP	EC	Qualitative only
Measurement Accuracy	0.3 m 0.3 m ±5 pct ±10°	10 pct 0.7 m ±15 pct ±45°	Significant Wave Height Amplitude Component Wavelength Component Directional Component	MJCS 251-76/SMOP ±10° and ±30°, resp., per MAC/XPPE 78	EC	Qualitative only
Data Refresh Period	On call 3 h	3 h 12 h	See Sec. 4.3	MJCS 251-76 SMOP	SL	12 h for each satellite
Timeliness	3 h	3 h	See Sec. 4.3	MJCS 251-76	SL/ EC	Tactical: OLS soft copy in RT, hard copy 10-30 min Centrals: 15-415 min

2.13 Clear Air Turbulence. Validated requirements are summarized in Table 13. There is no direct or indirect measurement capability for clear air turbulence from a spaceborne platform. The first potential capability may be the non-scan Doppler Lidar sensor to be flown in the late 1990s. Although the primary mission of this sensor is the measurement of the atmospheric wind speed profile, it may provide information on air turbulence especially in the jet stream band. Further feasibility of this technique needs to be studied.

Data Type Parameter	At Tactical Stations	At Centrals	Remarks	Source/Date	Req'd. Action	Block 5D-2 Capability
13. CLEAR AIR TURBULENCE			Validated 31 Aug 76	MJCS 251-76/31 Aug 76		None
			Validated 3 Jun 81	MAC 505-79/30 Sep 79	. . .	
Area Covered	800x800 nmi (1,500x1,500 km)	Global		MJCS 251-76	TD	
Horizontal Resolution	5 nmi (10 km)	25 nmi (45 km)		MJCS 251-76	TD	
Mapping Accuracy	1 nmi (2 km)	5 nmi (10 km)		MJCS 251-76	TD	
Vertical Resolution	1,000 ft (300 m)	1,000 ft (300 m)	below 10,000 ft (3,000 m)	MJCS 251-76	TD	
	2,000 ft (600m)	2,000 ft (600m)	above 10,000 ft (3,000 m)			
Measurement Accuracy	±3 knots (1.5 m/s)	±3 knots (1.5 m/s)	Vertical Gusts	MJCS 251-76	TD	
	±1.0 m/s	±1.0 m/s	Vertical Gusts	MAC/XPPE 78		
Data Refresh Period	On call	1 h	See Sec. 4.3	MJCS 251-76	TD	
Timeliness	15 min	15 min	See Sec. 4.3	MJCS 251-76	TD	

2.14 Neutral Density. Validated requirements are summarized in Table 14. Neutral density is defined as the density of uncharged molecules and atoms in the near-earth environment (0-1,300,000 ft or 0-400 km). This parameter is different from atmospheric density, which includes both charged and uncharged particles. The unvalidated requirement to measure atmospheric density is discussed in Section 3.2.3.28 in Volume I of the SRD.

There is no measurement capability planned for measuring the neutral density. A derivative of the SSD limb scanner flown on DMSP F-4 has potential for acquiring neutral density data in the higher altitude regions (60-400 km). The requirement for the higher altitude regions is labeled EC on the premise that no new technology need be developed as a result of data already obtained from the SSD sensor. A derivatve of the SSD instrument is scheduled to be flown on the Navy Remote Sensing Atmospheric and Ionospheric Detection (RAIDS) experiment. At least for lower altitudes DIAL also has the potential of determining particle species and density. Ground based Raman Lidar has been used to study specific atmospheric gases up to an altitude of about 3km (9,842 ft). Background molecular Rayleigh scattering has been measured from ground based Lidar systems and neutral gas density has been deduced from this data up to 90 km (295,000 ft).

Other sensors, such as the magnetometer (SSM), the precipitating electron Spectrometer (SSJ/4), or the vacuum ultraviolet imager (SSUV), may be able to yield information regarding processes which affect the neutral density above approximately 100 km altitude; such information may also be valuable as input to future upper atmospheric models.

Data Type Parameter	At Tactical Stations	At Centrals	Remarks	Source/Date	Req'd. Action	Block 50-2 Capability
14. NEUTRAL DENSITY			Validated 31 Aug 76	MJCS 251-76/31 Aug 76		None
			Validated 3 Jun 81	MAC 505-79/30 Sep 79		
Area Covered	Not applicable	Global		MJCS 251-76	EC/TD	
Horizontal Resolution	Not applicable	25 km		MJCS 251-76	EC/TD	
Mapping Accuracy	Not applicable	5 km		MJCS 251-76	EC/TD	
Vertical Resolution	Not applicable	1,500 m 3,000 m	0-60 km 60-400 km	MJCS 251-76	EC TD	
Measurement Accuracy	Not applicable	±5 pct		MJCS 251-76	EC/TD	
Data Refresh Period	Not applicable	1 h	See Sec. 4.3	MJCS 251-76	SL	
Timeliness	Not applicable	10 min	See Sec. 4.3	MJCS 251-76	SL/EC	

2.15 <u>In-Situ Particle Environments</u>. Validated requirements are summarized in Table 15. There is no requirement for this data at tactical stations. The SSIE Ionospheric Plasma Monitor (F-6 and F-3) satellites and the SSIES Ionospheric Plasma and Scintillation Monitor (S-8 and subsequent satellites) measures electron and hydrogen and oxygen ion densities as well as their temperature at the satellite altitude. The SSIES mission sensor operates at a higher sample rate (24/sec vs 7/sec) and has more energy resolution levels (32 vs 4) than the SSIE. It thus provides more dynamic data at much finer resolution. The SSIES will also measure the fractional change in electron density (ΔNe) at the DMSP satellite altitude. This parameter can be used, in conjunction with appropriate models, to estimate phase and amplitude scintillation effects on radio waves propagating through the ionosphere. Although the SSIE data is presently available, only the electron data is being processed due to processing software deficiencies.

Data Type Parameter	At Tactical Stations	At Centrals	Remarks	Source/Date	Req'd. Action	Block 5D-2 Capability
15. IN-SITU ENVIRONMENT			Validated 3 Jun 81	MAC 02-80/21 Mar 80		SSIE on F-6 and F-7 SSIES on S-8 and on
Area Covered		Global		MAC 02-80	EC	Electron and proton density measured in-situ around orbit
Horizontal Resolution						In track resolution (SSIE/SSIES) Electron, ion densities: nominal 1.00 km optional 0.25 km Mass and Temperature 26 km, optional 421 km.
Vertical Resolution						5 km Scale Height at Satellite altitude by modeling

2.16 Electron Density Profiles. Validated requirements are summarized in Table 16. There is no requirement for this data at tactical stations. At present there is no operational method for measuring electron density profiles (EDP) from satellites. Ground based measurements can determine the profile below the F region peak. At present the EDP is estimated by using a historical data base of EDPs, extrapolating to 450 nmi and calibrating at that one point with data from the SSIE or SSIES sensor. The error in this method varies for different latitudes and altitudes, different global regions and different seasons, as well as diurnally by as much as two orders of magnitude.

There are several new sensor concepts under study measuring electron density profiles. The SSI Topside Ionosonde sensor is an active sensor which would provide EDP data above the F-layer maximum at nadir only. The Vacuum Ultraviolet Spectrometer (SSUV) is a passive sensor which would provide 3-dimensional vertical density profiles in the auroral E region and low to mid latitude ionosphere. This sensor is being considered for implementation on 5D-3. Other alternative concepts which can provide relevant data for calculating the EDP are the NRL RAIDS sensor or the SSB/A Gamma Ray Spectrometer which was flown on F-6. The SSB/A, however, can only be used in the auroral region.

Data Type Parameter	At Tactical Stations	At Centrals	Remarks	Source/Date	Req'd. Action	Block 5D-2 Capability
16. ELECTRON DENSITY PROFILES			Validated 3 Jun 81	MAC 02-80/21 Mar 80		Models deduced from SSIE(S) data. SSUV planned for S-16, will have profile capability.
Area Covered		Global	1. Nominally from 60-1000 km 2. Electron density fluctuation (RF phase scintillation)	MAC 02-80	TD	Currently SSIE(s) provides electron density at satellite altitude only
Horizontal Resolution		2,000 km	Worldwide	MAC 02-80	TD	
Data Refresh Period		1 h	See Sec. 4.3	MAC 02-80	SL	12 h for each satellite

2.17 Total Electron Content. Validated requirements are summarized in Table 17. There is no requirement for this data at tactical stations. Data collected by the SSIE and SSIES mission sensors on electron densities and temperatures along the satellite path can be used as inputs to a 4-dimensional ionospheric model at AFGWC to globally determine the total electron content. Total electron content may be determined more accurately by the GPS receiver technique described in Section 3.17.

SECTION 2 REFERENCES

1. Letter dated March 7, 1985 from AWS/SYP to SD/YDM, entitled "Review of the DMSP Technology Development Plan (your letter, 29 Jan 85)"

Data Type Parameter	At Tactical Stations	At Centrals	Remarks	Source/Date	Req'd. Action	Block 5D-2 Capability
17. TOTAL ELECTRON CONTENT (TEC)			Validated 3 Jun 81	MAC 02-80/21 Mar 80		Deduced from SSIE(/S) data. Integrated electron density (TEC) may be obtained from SSUV profile. Use SSIE/S data in modeling.
Area Covered		Northern Hemisphere		MAC 02-80	EC	SSIE(s) provides electron density at satellite altitude only.
Horizontal Resolution		2,000 km		MAC 02-80	EC	
Data Refresh Period		1 h	See Sec. 4.3	MAC 02-80	SL	12 h for each satellite

SECTION 3

3.0 Technology Concepts for Advanced Sensors. This section describes new spaceborne sensor concepts to meet requirements described in Section 2 within the present orbital constraints. Concepts chosen are likely candidates for development by the year 2000. The description of these concepts includes functional capabilities, performance parameters, and identification of the technological issues associated with each concept, where applicable. While the concept descriptions in this section appear to be point designs, it is not the intent of this document to zero in on a particular design at the expense of other alternatives. The concept descriptions presented are only intended to act as points of departure to (1) indicate levels of performance required and (2) serve as a basis for technology planning. Advantages and disadvantages of each concept are discussed.

The format for this section parallels the previous section. Sensor concepts for each data parameter are grouped together and discussed. A schedule for sensors to be flown on 5D-2 and 5D-3 as well as detailed descriptions of each sensor are included in Appendix A.

3.1 Cloud Cover. Both passive and active techniques are applicable to the satellite sensing of cloud cover. Cloud cover generically includes cloud coverage, cloud type, identification of cloud layers, altitude of cloud tops and bases, and water and ice content. A variety of analysis techniques exist that exploit satellite imager and sounder data to determine these parameters. Cloud analysis methods may be roughly classified into four general classes (threshold, statistical, bispectral, and sounder techniques) and are discussed further in Ref 1, pp 21-32. Most of the techniques require two channels of imagery; the visible channel ranges from 0.4-1.1μm, and the infrared channel ranges from 8-12μm. Visible radiance measurements depend on fractional cloud coverage in the field of view, cloud top temperature, and cloud emissivity. Infrared radiance measurements depend on these same parameters and also on surface temperature and emissivity. Thus the accuracy in determining the parameters often depends on the accuracy of emissivities and temperature used for known cloud types. Cloud types and layers often have well defined vertical layers and cloud-emitted infrared radiances are characteristic of those layers.

Cloud coverage is determined from the imagery since the clouds generally appear brighter (colder) than the background visible (IR) imagery. The main problem associated with the present two channels of imagery from the OLS is that the background radiance is nonuniform. Snow cover and sun glint can trick visible processing. High terrain, and temperature inversions can trick infrared processing. Additional data such as ground observations or additional spectral channels are required to resolve these discrepancies. A 1.6μm channel was added to F-4 to test its discrimination capability between snow cover and clouds, as well as between fog and high cirrus clouds. Although its lifetime was limited, its discrimination capability was proven. NOAA has successfully used radiometric data to discriminate between low clouds/fog and snow at night. A multispectral OLS which includes all the channels on the AVHRR-2, in addition to the 1.6μm channel, would improve Air Weather Service (AWS) capabilities to discriminate snow and clouds, describe surface characteristics (vegetation index), and monitor volcanic eruptions and aerosol transport.

Cloud top height determination is fairly straightforward. It is usually determined by comparing the infrared brightness temperature, which also depends on cloud emissivity, to a vertical temperature profile of the atmosphere. Methods for determining the vertical temperature profile are described in Section 3.3. Cloud top height can also be determined from geometric considerations using concurrent visible data from two geostationary satellites with overlapping fields of view. The advantage of this technique is that cloud top height determinations are not subject to errors in cloud emissivity or vertical temperature profile data. However, the technique only works during daylight periods, requires coordinated readouts, and is limited to the overlap area.

Cloud top height can also be determined through active sensing using the range information from a space borne laser ranging system.

At present, there are no space remote sensing approaches for measuring the altitude of cloud bases. Cloud bases may be inferred by combining temperature and moisture profiles. This is an area that should be studied after the SSM/T-2 is flown in the mid 1990s. It is doubtful, however, given the broadness of the weighting functions if the bases could be determined within ± 100 ft. For clouds which are optically thin, range-gated visible lidar could determine both cloud top and base altitudes. Rain clouds, however, are optically thick and represent a technological dilemma. Visible and infrared lidars sense only the top few meters of a dense rain cloud due to the large extinction coefficients at these wavelengths. Conversely, at centimeter wavelengths or larger, there is no backscatter to provide a return signal with which to make a measurement. Since the backscattered power decreases with frequency, this implies that the more dense a cloud is, the lower the frequency required to penetrate it. Preliminary studies described in Ref 1, p 109-113 indicate that pulsed radars at millimeter frequencies have the potential for determining cloud top levels and identifying altitudes of cloud bases from on-board a spacecraft. Recent technological advances in millimeter wave devices have made possible a new generation of millimeter wave radars. These should be studied to determine an optimum set of radar characteristics for the detection of the tops and bases of various cloud types.

3.2 Vertical Moisture Profile. Both passive and active techniques are applicable to the remote sensing of water vapor. Current methods are based on passive techniques and will be discussed first.

Passive sounding for water vapor retrieval is accomplished by measuring radiation over a set of spectrally distributed bandpasses. These water vapor absorption bands include rotational-vibrational bands near 6.7 μm, pure rotational bands near 20 μm, and microwave rotational levels at 22 and 183 GHz. Thermal emission measurements in the above bands also depend on the surface emission, the temperature profile, and the water vapor profile. The radiance contribution of a particular atmospheric layer to the total measured radiation is primarily a function of the air temperature at that layer and the product of two competing factors - namely, the emission per unit volume, which decreases monotonically with height due to decreasing air density and the transmission of the atmospheric path above the layer under consideration, which increases with height. This product results in a weighting function which peaks at some altitude level and decreases away from it. By choosing frequencies which have different absorption coefficients, weighting functions peaking at preselected altitudes can be obtained. The problem of profiling the atmosphere is then reduced to inverting the radiance measurements obtained at a variety of frequencies with vertical distribution weighting functions for the representative moisture value at each level.

The main problems associated with passive water vapor profile sounders include:

1. Inability to resolve vertical structure due to the broadness of the weighting functions. At present it is physically impossible, using this technique, to achieve the requirement for 100 ft vertical resolution.
2. Sensitivity of the water vapor profile near the surface to surface emissions. Below 2 km, any increase in water vapor both increases the atmospheric emission and decreases the contribution from surface emissions.
3. A nonlinear dependence on temperature.
4. The dependence of the broad water vapor weighting functions on the water vapor abundance profile.

The large variability of both water vapor and temperature vertical profiles result in a wide range of potential water vapor weighting functions.

This makes it difficult to preselect a set of sensor channels that optimally span the vertical domain (Ref 1, p 60). The infrared temperature and water vapor sounder (SSH/2) is a passive water vapor sounder of this type. It is described in more detail in Appendix A. Due to the poor accuracy (± 35%) and the fact that its operation is limited to temperature profile measurements under clear conditions, this instrument will probably not be flown on any spacecraft after F-6 and F-8. By employing higher spectral resolution and careful channel selection to define channels with decreased surface contributions in the lower atmosphere, better vertical resolution and accuracy (± 20%) can be achieved (Ref 1, p 64).

Microwave and infrared techniques can be used to determine the total water content in a unit column of atmosphere. These techniques do not yield a vertical profile however, and they are still susceptible to varying surface emissivities over land. Microwave measurements have the advantage that they are relatively insensitive to cloud cover and measurements can be made under nearly all weather conditions. Simulation results indicate the ability to retrieve relative humidity over the ocean and land with rms accuracies of 20% and 45% respectively (Ref 1, p 64).

Measurements in the strong water vapor absorption line at 183 and 150 GHz, in conjunction with the lower frequencies measured by the SSM/I, offer a potential for obtaining water vapor concentration in at least four broad layers (surface-5,000 ft, 5,000-10,000 ft, 10,000-18,000 ft, above 18,000 ft) if the corresponding vertical air temperature profile is known. Surface emissivity effects over land still pose a problem.

The active technique of using Lidar to measure the differential absorption of atmospheric gases shows great promise in achieving high accuracy and vertical resolution. DIAL (Differential Absorption Lidar)systems however cannot provide profiles when there are clouds in the field-of-view. The large signal return due to the much larger scattering that occurs in the cloud can be used as a flag to prevent incorrect profiles from being calculated. The DIAL technique has been applied in ground experiments to measure the upward looking water vapor profile. DIAL systems require a minimum of two frequencies for an integrated path measurement. The primary frequency is centered on an absorption band of the species to be measured (i.e., water vapor). The absorption cross section at the primary frequency thus needs to be well known. The second frequency is offset (1 nm)* from the primary absorption band but is still subject to the same attenuation from the various scattering and absorption processes as the primary frequency. Comparison of the two signals gives direct measurement of the concentration of the absorbing species. This requires both frequencies be emitted simultaneously. Simultaneity can be approximated by sequential measurements at both frequencies within 10^{-4} seconds. The lack of laser sources tunable within that time period has led to the continued use of two independent laser sources with sequentially gated outputs in most DIAL systems (Ref 2). Range (vertical) resolution requires that a range-gating technique be used to measure the total transit time of the backscattered pulse.

Selection of the probing wavelengths is critical. The reference frequency cannot be on the same absorption line as the primary frequency. Selection of the primary frequency depends on the atmospheric species to be measured and the strength of the absorption band. For measurements near the earth's surface from space, the absorption band must be relatively weak. But, if it is too weak, range resolution will suffer. Since the absorbing species is sampled directly, the problems of thermal emissions from moisture near the surface, characteristic of passive methods, are avoided. Both temperature and humidity may be measured using the same sensor by using water vapor lines that are temperature dependent. For upper atmospheric gases, measurements on stronger absorption bands must be used due to the reduced concentration of the absorbing species.

Moisture profiling is accomplished by centering the primary frequency on a water vapor absorption line. Simulations have shown that a DIAL system using the 724 nm H_2O band can determine profiles with a vertical resolution of 2 km from 0-12 km with less than 10 percent error in relative humidity (Ref 3). For accurate measurements above 10 km the stronger absorption band at 920 nm must be used.

DIAL system technology issues include:

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*1 nm = one nanometer = 10^{-9} meter = 10 Angstrom

1. Tunable laser sources are required that can output the desired frequencies (e.g., 724 nm, 920 nm H_2O, and 768 nm O_2). Dye lasers are tunable over large frequency ranges but their limited lifetimes make them unsuitable for spaceborne applications. New tunable solid state lasers are being developed: Alexandrite (730-790 nm) and Titanium Sapphire (660-950 nm). Research efforts are necessary to increase stability, output power and damage thresholds. Alexandrite currently requires flashlamp pumping, which also is lifetime limiting. Titanium Sapphire lasers can be pumped by diode pumped Nd:YAG laser sources. A third technique would frequency shift a Nd:YAG source using RAMAN scattering in high pressure gas cells (Ref 4).

2. Critical to all DIAL systems is the system efficiency, including detector quantum efficiencies. Current projections indicate that DIAL systems may never achieve more than a 1 percent total ("wall plug") efficiency. This has severe impacts on the power required for the sensor.

3. Thermal control of the waste heat generated is an area that requires a detailed study.

4. Light weight and cost effective optics are another critical area. For 2 km vertical resolution, at least 1.25 m optics are required. For even finer resolution, tradeoffs have to be made between laser power and eye safety versus the size of the optics.

DIAL Water Vapor Profiler Characteristics (Ref 4)

Vertical Resolution:	2 Km (Less than 10% error below 12 km
Laser Source Output:	
Power	1 Joule/pulse
Wavelength	724 nm
Pulse Repetition Rate	5 Hz
Optics Diameter:	1.25 m
Average Power:	650 watts assuming 1% eff.

3.3 Vertical Temperature Profile. Both passive and active techniques are applicable to the remote sensing of the vertical temperature profile. Current methods are based on passive techniques and will be discussed first.

Passive sounding of the atmospheric temperature profile is accomplished by measuring radiation over a set of spectrally distributed bandpasses. Two gases, carbon dioxide (CO_2) and oxygen (O_2), have both uniform mixing ratios and emission bandpasses in spectral regions which can be measured from satellite sensors. The radiance contribution of a particular layer to the total measured radiation is primarily a function of the air temperature at that layer and the product of two competing factors - namely, the emission per unit volume, which decreases monotonically with height due to decreasing air density and the transmission of the atmospheric path above the layer under consideration, which increases with height. This product results in a weighting function which peaks at some altitude level and decreases away from it. By choosing frequencies which have different absorption coefficients, weighting functions that peak at preselected altitudes can be obtained. The problem of profiling the atmosphere is then reduced to inverting the radiance measurements obtained at a variety of frequencies with vertical distribution weighting functions for the representative temperature value at each level.

The main problems associated with passive atmospheric temperature profile retrieval include:

1. Inability to resolve vertical structure due to the broadness of the weighting functions. Current DMSP sounders (SSH-2 and SSM/T) have vertical resolutions which correspond to layer thickness of 5-6 km in the troposphere. It is physically impossible, using these passive techniques, to achieve the requirement for 100 ft vertical resolution.

2. Sensitivity of the temperature profile near the surface to variances in surface emission.

The infrared temperature and water vapor sounder (SSH-2) is a passive sounder which measures six infrared frequencies in the CO_2 absorption band around 15 μm and one frequency at 12 μm for determining surface temperature. Due to the poor accuracy and limited operation under only clear conditions, data from this instrument is not being processed. It will probably not be flown on any spacecraft after F-6 and F-8.

The microwave temperature sounder (SSM/T) is a passive sounder which measures seven frequencies in the 50-60 GHz band of the O_2 molecule. It is designed to provide temperature soundings over clear and cloudy regions from altitude levels near the surface to 30 km. This instrument currently is being flown on F-7 and provides approximately 15,000 soundings per day to the AFGWC upper air data base. The rms retrieval error is ±2.5° K with the largest errors near the surface. (See Fig. A2 in Appendix A.) Correlation with surface temperature measurements (OLS or SSM/I) may decrease the error in the boundary layer (<20 km). Correlation of SSM/T data with improved cloud top altitude measurements from a simple Lidar sounder has the potential of reducing the rms error to ±1° K, (Ref 21).

The active technique of Differential Absorption Lidar (DIAL) shows great promise in achieving high accuracy and much improved vertical resolution. The DIAL technique has been applied in ground experiments to measure the upward looking temperature profile. DIAL systems are described in more detail earlier under Vertical Moisture Profile in this section. The proposed DIAL temperature techniques use one of the oxygen A bands located at 768 nm. This absorption coefficient is extremely temperature sensitive. Temperature is derived by measuring two lines and solving the Boltzmann density distribution for temperature (Ref 3). Expected accuracies for temperature sensing DIAL systems are ±1° K with 2 km vertical resolution. Due to the weakness of the 768 nm absorption band, the DIAL system requires considerable spacecraft power. Since these bands are located in the visible part of the spectrum, measurements would be limited to cloud free regions.

<u>DIAL Temperature Sensor Characteristics (Ref 3)</u>

Vertical resolution:	2 km
Laser Source Output:	
Power	2 J/pulse
Wavelength	768 nm
Pulse Repetition Rate	10 Hz
Optics Diameter:	1 m
Average Power:	2800 Watts assuming 1% efficiency

3.4 Albedo. Albedo is defined as the ratio of the total amount of electromagnetic radiation reflected by the earth to the amount of radiation incident on it, primarily from the sun. Since the electromagnetic radiation from the sun is nearly a constant (1395 w/m^2), only a simple passive earth-facing radiometer is required to measure the variances in reflected radiation. The albedo varies primarily with angle of incidence, type of surface, and degree of cloudiness.

The OLS measures both visible and infrared radiation at .4-1.1μm and 8-12μm. It is described in more detail in Appendix A. These ranges provide sufficient energy information so that the total albedo can be approximated.

3.5 Visibility. Visibility is required for both visible and infrared precision-guided munitions. A potential active technique for measuring visibility is a multiwavelength Lidar system. This technique uses several wavelengths to measure the aerosol and molecular backscattering in order to determine the combined extinction coefficient as a function of wavelength.. Aerosol and molecular profiles may be obtained from the amount of atmospheric scattering and absorption for each wavelength. Lidar systems cannot provide visibility profile information when there are clouds in the field of view. When clouds are present the large signal return due to the large scattering that occurs in the cloud is used as a flag to prevent incorrect profiles from being calculated. The range resolved nature of pulsed Lidar systems can be used to provide visibility profile information. This can be accomplished through a relatively simple Lidar sounder design. A technology issue is the design of a multiwavelength Lidar system that does not demand exorbitant power. The optimum wavelengths to adequately describe the aerosol/molecular profile also needs further research.

Lidar Sounder (Ref 4)	
Vertical Resolution:	2 km (averaged over 8 pulses)
Laser Source:	Nd: YAG
Power	1 J/pulse
Wavelength	1.06 and .53 or .35 μm
Pulse Repetition Rate	10-20 pulses per minute
Efficiency	1.1%
Optics Diameter:	.5 m
Average Power:	120 Watts
Weight:	162 lb
Detection System:	Photon counting

3.6 Precipitation. Both passive and active techniques are applicable to the remote sensing of precipitation. Both techniques are limited to the microwave or millimeter wave regions. Higher infrared frequencies are absorbed by water droplets and lower frequencies are not attenuated by them at all. Precipitation cannot be determined from the passive measurement of a single frequency due to the large range in size of water droplets, their density in clouds, the precipitation layer thickness and the surface background radiation. Thus, a range of microwave frequencies is required for passive or active techniques.

The unit of measurement commonly employed in microwave radiometry is the brightness temperature, since at centimeter wavelengths the earth surface and atmospheric radiances are linearly proportional to temperature. The brightness temperature of the earth's surface depends on surface type and condition. Water generally has a low emissivity, while land has a high emissivity. Ocean emissivity, however, may increase with wind speed, and land emissivity may decrease with increased soil moisture. Surface roughness and vegetal cover tend to scatter microwave radiation and thus reduce polarization differences, while sea ice signatures change primarily with the type and age of the ice. In all cases, the amount of change in microwave signature depends on the specific microwave channels used. This is due to the effects of frequency and polarization differences and to the wavelength dependent depth of penetration. Near-term methods are based on passive tecniques and will be discussed first.

Retrieval of precipitation information from a range of frequencies is based on the D-matrix approach. The D-matrix is a statistical model, which calculates the most probable atmospheric and surface properties (precipitation, surface temperature, snow/ice cover, soil moisture, etc.) that produced the set of measured brightness temperatures. This type of statistical model assumes some linear combination of brightness temperatures exist which uniquely describes each geophysical parameter. Many regression techniques exist, but the simplest is linear regression with brightness temperature as the independent variable. The regression coefficients are determined using geophysical models, radiative transfer models, an inversion algorithm, and climatolology. The elements of the D-matrix are actually the minimum mean square error between the predicted and actual brightness temperatures of the geophysical parameters. Half of the measured data is used in the geophysical and radiation transport models to calculate correlation matrices and make predictions. The other half of the data is used to test the validity of these calculations and predictions. The advantage of this method is that geophysical parameters that cannot be measured in any other passive way can be predicted. The disadvantage of the method is it is statistical in nature and requires more computing power than direct radiance measurements. At present AFGWC is limited to using four or less frequencies in deriving a geophysical parameter. To simplify calculations and reduce higher order terms in the regression equations, climatological zones are selected in which the regression equations are assumed linear. At present this requires eleven different D-matrices, depending on climate and season. The computer capacity at FNOC will permit improvement of the SSM/I geophysical algorithms following on-orbit performance test and evaluation.

In deriving the precipitation parameter several different assumptions and equations must be used, depending on the rain rate. The difference in absorption and scattering of microwave radiation between light rain and heavy rain results in the application of different physical equations. For the case of light rain, multiple scattering can be ignored. Liquid water content can be directly related to rain rate by the Marshall-Palmer distribution function (Ref 5). For heavy rain, multiple scattering effects must be included in the algorithms, as well as the drop size distribution. The Mie scattering theory can be used to calculate extinction coefficients and the single scattering reflection coefficient. Based on experimental data (Ref 5) an empirical function is available which parameterizes the rain drop size distribution as a function of rain rate. The rain layer ceiling, as well as the thickness, must be input into the model. These values are normally based on climatology. Thus the derivation of the precipitation parameter is an iterative process and depends on several empirical functions as well as a climatology data base.

The microwave imager (SSM/I) is a passive sounder which measures four frequencies and seven polarizations. Different combinations are used to determine precipitation over oceans and land. Rain is highly absorptive and results in an apparent warm brightness temperature in contrast to a cold ocean background. The difference in brightness temperature between two polarizations at a given frequency, however, tends to decrease as the rain rate increases. The SSM/I data channels selected for retrieval of rain over oceans are 19.35 H, 22.235 V, and 37.0 V&H GHz. In contrast, rain causes a reduction in the apparent brightness temperature over a warm land background. The backscatter of the cold upper atmosphere in this case begins to dominate the forward scatter from the land surface and the self emission from the atmosphere. This effect is absent over the ocean because of its much lower background temperature. The SSM/I data channels selected for retrieval of rain over land are 37.0 V&H and 85.5 V&H GHz (Ref 5).

Millimeter wave radar is an active device which may have spaceborne application for measuring precipitation. The advantages of an active device over a passive device are millimeter devices can determine the size of water droplets, their density, and the precipitation layer thickness, without relying on a climatological data base. As with passive techniques, a range of frequencies would probably be required to cover the broad absorption due to different rain rates. A compliment of an active millimeter wave sensor at one frequency and a set of passive microwave sensors at other frequencies and polarizations may provide the optimum information within spacecraft power, weight and size constraints. A feasibility study should be undertaken to determine an optimum set of frequencies to be used for either active or passive sensing.

3.7 Winds. Vector winds stress measurements are needed for input to global atmospheric and oceanic dynamic forecast models for improvements in forecasting. In addition, accurate surface to upper level wind data is required to support all aspects of military operations, such as assessing radioactive fallout conditions, movement of weather systems, and predicting winds for weapons delivery and tactical operations.

Presently winds are inferred from variances in pressure profiles and correlated with data available from ground based stations and rawinsondes released over limited areas. Pressure profiles are derived primarily from horizontal pressure gradients due to the Coriolis force. Temperature profile measurements and knowledge of the air density are used to refine the pressure profile through the use of the ideal gas law. This technique is inadequate. Although rawinsondes can obtain vertical wind profile information, it is impossible to use them to provide global information.

Wind information can be obtained from geostationary meteorological satellites using cloud imagery animation. Tracking the cloud movement however only yields the wind at the cloud altitude or as is can only be used where there are distinguishable clouds. Accuracies of the order of 2 m/s are required (see Sec. 2.7) and winds derived from tracking cloud movements cannot meet this criteria.

In the near future the scatterometer, an active radar device, will be used to measure both wind speed and direction near the ocean surface. The scatterometer determines wind speed in a manner similar to the SSM/I but infers surface wind direction from two or more orthogonal azimuthal measurements. Experimental investigations show that as the radar azimuth angle (off-nadir) changes one observes maximum backscattered signal power in the upwind and downwind directions with decreased backscattered signal from the crosswind direction. The ocean surface wind speed algorithm therefore is based on the empirical observation that the normalized sea surface reflection coefficient (radar cross section) is anisotropic. This technique requires a large data base of normalized radar cross sections versus incidence angle and azimuth angle at different wind directions.

There are several Lidar techniques for spaceborne wind sensing. All of these techniques require the field of view to be cloud free. This condition also allows the use of the single scattering version of the Lidar equation, which greatly simplifies data processing. Proposed spaceborne Lidar wind sensors make use of backscattered radiation from aerosols suspended in the atmosphere. The aerosol particles move with the wind and can be used for detecting wind motions. Most Lidar wind sensors detect the Doppler frequency shift between the incident and backscattered radiation due to the motion of the aerosols relative to the Lidar transmitter. The frequency shift is used to determine the radial wind velocity. This information is then processed to retrieve the vertical and horizontal components of the wind velocity.

There are two types of conically scanning Doppler Lidar systems. The first type utilizes a coherent laser source and heterodyne detection to increase the signal-to-noise ratio (Ref. 18, 19). Heterodyne detection requires a transmitter and local oscillator (both frequency and phase matched) and linearly sums the two colinearly traveling waves with different frequencies. This requires that the optical train (transmitter and receiver) be diffraction limited to insure colinear waves. Most ground based and proposed spaceborne coherent Lidar wind sensors use a CO_2 (10μm region) source. Recent measurements show that the ratio of backscattered signals from aerosols at 0.7μm to 10.6μm is larger than 400 to 1 in the lower troposphere (Ref 3). This has led to a second type of conically scanning Doppler Lidar system. The Doppler Lidar wind sensor proposed has incoherent Nd:YAG as a source and uses the interference pattern produced when both the incident and backscattered light are passed through a Fabry-Perot interferometer. The distance between the rings of the interference pattern determine the Doppler frequency shift. To achieve 2 m/s and ±10 degree wind velocity information, a conically scanning Lidar wind sensor is required.

There are two non-scan incoherent Doppler Lidar techniques that will provide horizontal wind information. They both utilize two Lidar transmitters and receivers, one pointing at 45° and the other at 135° from the spacecraft direction of travel. Both techniques require the transmitters to be pulsed on and off so that the second transmitter illuminates the same footprint region as the first transmitter. One technique uses the Doppler frequency shift from both orthogonal pulses to determine the wind velocity (Ref 7). This Doppler technique also requires that both transmitters and receivers be pointed 45° from nadir. The second technique requires an imaging detector array (and the necessary processing) to determine the displacement of recognized aerosol patterns over time by comparing the two images at a given range resolved altitude. The processing requires pattern-matching algorithms similar to those used in cloud tracked winds.

All proposed Lidar wind sensors use range gating of the backscattered return signal to determine the altitude and vertical resolution of the measurements. The apparent wind velocities due to spacecraft motion and the rotation of the earth must also be treated in any data processing algorithm. The volume of data produced by a conically scanning Lidar wind sensor (424 kbits/s) requires some onboard processing. Preprocessing of the data performed onboard the satellite could reduce the data rate to 960 bits/s (Ref 7).

Lidar wind sensor technology issues:

a. The efficiency and lifetime of laser transmitters is a critical area. Nd:YAG laser flashlamp pumping is limited to 3×10^{6} to 10^{7} pulses. This would limit operational lifetime to a few months depending on sensor duty cycle as compared to 3 to 4 years for the rest of the satellite. Diode pumping is required for increased lifetime and efficiency.

b. Providing the power required by active Lidar sensors (500 to 2500 watts, see sensor descriptions below) is a key technology issue. Advances in solar arrays and battery storage or nuclear power sources can meet these power requirements. These will be discussed in more detail in Section 4.1

c. Thermal control is another key spacecraft integration area which must be investigated (see Sec. 4.1). Lidar sensors will be putting out 90 percent of the energy in the form of waste heat. Laser diode output frequencies are tuned by varying the diode temperature. The absorption bands of the material being pumped are also shifted by temperature change. This makes it an interactive process to keep the laser diodes locked on the proper frequency for pumping the lasing material. This will be more difficult because of the amounts of waste heat emitted by a laser system. The fact that laser diodes are extremely sensitive to changes in temperature will affect pumping efficiency.

d. The production of cost effective and lightweight meter-size optics is another technology issue. The need to maintain optical alignment during launch and sensor operation is another important area. Production of optical systems is addressed in Section 4.

e. The impact of scanning meter-size optics on spacecraft attitude and control needs to be evaluated. The spacecraft attitude and control is discussed in Section 4.1

f. Faster data processing algorithms will have to be developed.

g. The subject of eye safety must be investigated in detail. The concern relates to an accidental interception of the lidar signal from the satellite by an observer scanning the skies through a 10 inch or larger telescope on the ground (see Ref 4).

Sensor Descriptions:

Scanning Doppler Lidar (coherent) (Ref 7)

Laser Source:	CO_2
Power	10 j/pulse
Wavelength	9.11μm
Pulse Repetition Rate	2 Hz
Optics diameter:	1.2m with conical scan
Average power:	560 Watts
Weight:	1021 lb
Detection mode:	Heterodyne
Accuracy:	1-2 m/s

Scanning Doppler Lidar (incoherent)

Laser Source:	Nd:YAG
Power	2 j/pulse
Wavelength	1.06 and .53 μm
Pulse Repetition Rate	10 Hz
Efficiency	assuming 5% diode pumping efficiency (current laser efficiency is more like 0.5 to 1%)
Optics diameter:	1.25 m with conical scan
Average power:	600 Watts
Weight:	800 lb
Detection system:	Fabry-Perot Interferometer
Accuracy:	1-2 m/s

Non-Scan Doppler Orthogonal Lidar Sounders (Ref 24

Laser Source:	Nd:YAG
Power	1.5 j/pulse
Wavelength	1.06 and .53μm
Pulse Repetition Rate	1 Hz
Efficiency	5%
Optics diameter:	.5 m
Average power:	800 Watts
Weight:	350 lb
Detection system:	Fabry-Perot Interferometer
Accuracy:	5 m/s

Non-Scan Orthogonal Lidar Sounder (Ref 3)

Laser Source:	Nd:YAG
Power	3.2 j/pulse
Wavelength	1.06 and .53μm
Pulse Repetition Rate	22 Hz
Efficiency	5%
Average power:	2500 watts
Detection system:	Aerosol pattern matching, 25x25 detector array required
Accuracy:	1-2 m/s

3.8 Surface Temperature. A straightforward method of remote sensing the surface temperature of land and oceans is to measure the radiated power from those surfaces with passive visible and infrared sensors. According to Planck's black body radiation law, the spectral power distribution uniquely depends only on one parameter namely the temperature of the body. Thus by measuring the radiated power level from a fixed surface at two or more wavelengths, the temperature of the black body can be determined. Errors associated with these measurements are attributable to the emissivity of the surfaces and to absorption by partial cloudiness in the field-of-view or by atmospheric aerosol or gaseous attenuation. Multiwavelength and dual view angle techniques have been suggested to provide the necessary atmospheric corrections. Generally, satellite infrared surface temperature fields have been found to be biased several degrees Kelvin. Over land, rms near-surface temperature errors are reported (Ref. 8) to be about 3 degrees Kelvin compared to radiosondes and 2 degrees Kelvin compared to hourly surface observations.

The radiation in the microwave region of Planck's law depends strongly on the emissivity of the body (whose value depends on the wavelength of observation) as well as the physical temperature of the body. Over oceans the emissivity is a function of the surface roughness which is strongly affected by the surface wind (Ref 9 and 10). Over land, the composition of the land and the presence of vegetation, ice or snow, underground oil or water supply, all could have an effect in altering the accuracy of the temperature retrieved from the measurements of remote passive microwave sensors. In spite of these difficulties sea surface temperatures have been retrieved experimentally from microwave radiometers (Ref. 11, 12, 13) with accuracies on the order of 1° K. Simulations have been used to investigate the ability of the SSM/I to retrieve surface temperature over both oceans (Ref. 14) and land (Ref. 15). The predicted rms errors over the ocean (assuming non-precipitating cases) are on the order of 2.0° K. Over land, variable surface emissivity increases error for operational conditions to a range between 3.7 and 4.7° K for atmospheres that are not too cloudy. These values also appear to depend on latitude and seasons. The advantage of the microwave sensors over visible and infrared sensors, is that the former provides an all-weather capability.

3.9 Snow and Landlocked Ice Cover. Both passive and active techniques can be used for remote sensing of the above parameters. Current methods are based on passive techniques and will be discussed first.

Snow and landlocked ice cover can be observed in OLS imagery on clear days. Automatic discrimination of snow-covered terrain or ice from cloudy areas is almost impossible, especially in high latitude regions in winter. Snow reflectance varies over a large range and depends on grain size, density, solar zenith angle and wavelength, as well as trace amounts of absorptive impurities. New-fallen snow has a small grain size and is the least dense. Density and grain size increase with age, making it a more efficient absorber at visible and infrared wavelengths. Snow reflectance measurements have been reviewed by Dodd and Escoe (Ref 16). They cited measurements which had been accomplished during several stages of metamorphosis. The reflectance of various ages of snow was found to decrease at different rates with respect to wavelength. It was discovered, however, that strong minima occurred for all snow types at wavelengths near 1.5 and 2.0μm where the absorption coefficient for ice reaches a maximum. Similarly, cloud albedo generally decreases with increasing wavelength because of the increased absorption by water droplets and ice crystals. However, the reflectance of snow at 15μm is relatively low (~10%) compared to clouds. In addition, since ice crystals are more absorbent than water droplets, water clouds can be discriminated from high cirrus clouds which contain ice crystals of about the same size. Dodd and Escoe displayed data obtained from the snow/cloud sensor (SSC) flown on F-4. The data demonstrates both of these discrimination capabilities.

The fraction of ice within the field-of-view and age of landlocked ice and perhaps snow should be determinable from the 37 GHz vertically and horizontally polarized channels of the SSM/I (Ref 5, pp 26-30). This technique is discussed in more detail in the next section. Extrapolating these algorithms for landlocked ice should be straightforward, but still needs to be investigated.

The above passive techniques can discriminate between snow and cloud cover and determine snow/ice age, but passive techniques cannot provide measurements of snow or ice depth. An active sensor is required to obtain range/depth information accurately. Recent technological advances in millimeter wave devices have made possible a new generation of millimeter wave radars. These should be investigated to determine an optimum frequency or set of frequencies for determining snow or ice depth.

3.10 Sea Ice Cover, Bergs and Leads. Both passive and active techniques are applicable to the remote sensing of this parameter. Current methods are based on passive techniques and will be discussed first.

Passive techniques presently consist of visual and infrared imagery from the OLS and microwave imagery from the SSM/I. Sea ice can be determined from imagery on clear days since it appears brighter (colder) than the warmer sea water background. Upwelling radiance of a scene containing sea water and various amounts of sea ice is a function of ice concentration, ice emissivity, physical temperature of the ice components, and the amount of water vapor and liquid water in the atmosphere and the amount of water on the ice and in the snow cover. Sea ice can consist of first year ice, multi-year ice, or first year thin ice. Each has a different emissivity, especially in the microwave region. The difference between the vertical and horizontal polarizations of the 37.0 GHz channel of the SSM/I is measured and combined with climatology data to determine the fraction of sea ice within the field-of-view, the fraction of first year ice, and the fraction of multi-year ice. The climatology data that must be input into the algorithms are the ice temperature, atmospheric liquid water content, and mean values of ice emissivities. Ice age (first year or multi-year) can be determined from the 37.0 GHz value and the computed value of sea ice concentration. Ideally all SSM/I frequencies and polarizations would be used to further discriminate age or ice type and concentration, but computing limitations at AFGWC prevent the use of more than four channels. FNOC has a greater computing capacity that will permit improvements in the retrieval algorithms.

The above passive techniques cannot provide a measurement of the ice depth or thickness. New sensors at various radar frequencies, especially at millimeter wavelength, should be investigated for possible application in fulfilling this requirement.

3.11 Soil Moisture. The description of land surface is extremely complex due to the many different surface types and the variation of physical characteristics within each type. The intensity of the upwelling radiation from the soil depends on the physical temperature of the soil and the local dielectric constant. Moisture increases both the real and the imaginary parts of the dielectric constant which reduces the emissivity of the soil. The emissivity of the soil at microwave frequencies can range from 0.9 for dry soils to 0.6 for very moist soils (Ref 5, p 23).

Both passive and active techniques are applicable to the remote sensing of soil moisture. The D-matrix approach (described in Section 3.6), is used to retrieve soil moisture from passive microwave measurements. The 19.35 V&H GHz channels of the SSM/I have been selected for retrieval of surface soil moisture because of the larger response at this frequency. Surface roughness, surface emissivity, and the amount of water vapor and liquid water in the atmosphere are required inputs in solving for the regression coefficients in the D-matrix. These values must be obtained from a climatology data base. Any depth measurement requires an active ranging device. For soil penetration, this would require frequencies in the lower microwave region. Millimeter and microwave radars should be investigated for possible application in fulfilling this requirement.

3.12 Sea State/Waves. Sea state can be calculated from surface wind speed under assumptions of equilibrium spectra and atmospheric stability.

A passive instrument for determining sea surface wind speed is the SSM/I. Wind speed can be directly related to sea surface roughness. The approach is described in more detail in Section 3.6. The 19.35 H, 22.235 V and 37.0 V&H GHz channels of the SSM/I have been selected to retrieve sea surface wind speed because of the large spread in sea surface brightness temperatures at these frequencies. Both wind driven waves and foam significantly alter the microwave emissivity of the ocean surface and thus affect the horizontal and vertical polarization differently. Precipitation, water vapor and liquid water in the atmosphere are required inputs of the SSM/I algorithms. In these algorithms, the sea surface is modeled statistically as a collection of plane facets with sizes larger than the impinging microwave wavelength. The variance in sea surface slope is defined to be a function of the wind speed. Based on this model the calculation of the emissivity of a plane facet is relatively straightforward and is based on the dielectric properties of sea water. The Fresnel equations for a plane dielectric interface are used to calculate the emissivity for a given viewing angle and polarization.

Foam is treated as partially obscuring the surface. It does not affect polarization, but does yield different frequency responses. The fraction of foam obscuring the surface increases linearly with wind speed exceeding 7 m/sec (Ref 5, p 23). Below that wind speed no foam develops.

The radar altimeter is an active device which can directly measure significant wave height. The 13.5 GHz radar measures the height above a point at nadir by measuring the time elapsed between emission and reception of the reflected pulse. The round trip time must be corrected for the variable index of refraction along the path as a result of the nonuniform vertical moisture profile. Characteristics of a radar altimeter flown on SEASAT are given on the next page. Whereas the radar altimeter can be used to measure significant wave amplitude and the SSM/I can be used to measure sea surface wind speed, neither instrument can determine the wind direction.

Another concept for measuring sea surface winds is based on the empirical relationship that sea state is directly related to the prevailing wind speed. As discussed in Section 3.7, the scatterometer can provide the necessary wind data, and therefore the sea state.

Several other concepts for measurement of directional wave energy spectra are emerging from basic research and exploratory development programs within the Navy and NASA. These include measurement of amplitude modulation, frequency modulation and phase shifts of the return signal. Trade-offs and performance assessments are under way at NRL, NASA and NOAA ERL.

SEASAT - Radar Altimeter Characteristics (Ref 17, pp 4-16)

Frequency:	13.5 GHz
Nadir swath width:	1.1-5.4 nmi (2-10 km)
Data rate:	10 kbps
Transmit pulse width:	3 microseconds
Peak power:	2.5 kw
PRF:	1500 Hz
Effective pulse width:	3 nsec compressed
Signal to noise ratio:	20 dB
Dimension:	39 in (1 m) antenna; 17.7 ft^3 (0.2 m^3)
Weight:	154 lb (70 kg)

SEASAT - Radar Scatterometer Characteristics (Ref 17,pp 4-18)

Frequency:	14.595 GHz
Instanteous Field-of-View (IFOV):	13.5 nmi (25 km)
Swath width:	270-405 nmi (500-750 km) both sides of subtrack beginning 108 nmi (200 km) from nadir
Grid spacing:	27 nmi (50 km)
Antenna:	Four 13 ft (4 m) fan beam sticks
Transmit pulse:	5 msec, PRF-34 Hz, average power 310 w at 100% duty cycle
Data Rate:	2-5 kbps
Volume:	Two units 13.8x15.7x39.4 in (35x40x100 cm)
Weight:	419 lb (190 kg)
Pointing control:	±3°

3.13 Clear Air Turbulence. Clear air turbulence is an important operational parameter required by tactical commanders to avoid areas that would be hazardous to air operations, such as airlift, airdrops, air-to-ground weapons delivery and transport of shock-sensitive cargo.

A Doppler Lidar wind sensor has potential to detect clear air turbulence. This active sensor is discussed in more detail earlier under Section 3.7. Resolution of the lower boundary level of the jet stream should be investigated using range resolved Doppler Lidar as a means of detecting clear air turbulence. For more quantitative measurements, rapidly varying vertical gradient of horizontal wind vectors with horizontal resolution of 1 km could be an indication of clear air turbulence. Further feasibility of this spaceborne technique needs to be investigated.

The technical issue specific to clear air turbulence measurements is the fine horizontal resolution required. This requires a trade-off between the pulsed laser's high repetition rates and high power. However, as discussed earlier, when radiating lasers from space to ground, eye safety must be included in the trade-off study. Development of laser transmitters capable of sustained high power and high repetition rates on orbit to support the high horizontal resolution requirements requires further research.

3.14 Neutral Density. Neutral density is a required data point for high precision targeting of artillery and ballistic missiles. Density measurement above 130 km are used to predict satellite drag, which is needed for control of low earth orbiting satellites.

Both active and passive techniques are applicable to the satellite sensing of neutral density. Passive techniques can be used above about 100 km, however active sensors must be used to obtain vertical resolution below that level.

The Atmospheric Density Sensor (SSD) was a passive earth-limb scanning sensor which measured emissions of major atmospheric constituents in the earth's atmosphere from 80 to 480 km which was flown once, on F-4. It measured emitted light by molecular nitrogen excitation at 1041 A and 3371 A, atomic oxygen at 1356 A, and Solar radiation at 913 A. The intensity of the emitted radiation is proportional to the excitation rate and the number of molecules at any given altitude. The analysis of the emission profiles was based on a radiation transfer model that included accepted excitation cross sections, branching ratios, photoelectron fluxes, etc. The atomic oxygen and molecular nitrogen density profiles would then be deduced from the shape of the limb profiles. Analysis of the data from F-4 indicated the thermospheric density could be remotely determined with an accuracy of about ±10%. The NRL RAIDS experiment, to be flown in 1989, is also a limb scanning device whose primary purpose is to obtain electron density profiles. Since it will provide emission information in 500-1000 A, 1200-1700 A, and 2000-4000 A regions it will also provide information for modelling the upper atmosphere and the ionosphere.

For lower altitudes, neutral density can be measured using DIAL techniques. DIAL systems are discussed in more detail earlier in Section 3.2. The absorption band of a gas species with a known absorption cross section is used to determine the height profile of species concentration. This measurement is then processed to provide the atmospheric density which is equivalent to the neutral density for measurements below 60 km.

There are techniques for measuring density which do not require a tunable laser transmitter. Above 30 km, a single wavelength Lidar can determine the density from the Rayleigh (molecular) scattering from atmospheric gases. Below 30 km, the contribution to the returned signal by the aerosols must be removed from the measured Rayleigh scattering. This requires the use of a two-wavelength Lidar (Ref 2).

The combined data from the SSM, SSIES, SSJ/4, and SSUV leads one to infer the electric potential distribution along the satellite track. This in turn can be used to estimate the amount of electromagnetic energy dissipated in the ionosphere in the form of Joule heating and thus obtain an estimate of the neutral density above 100 km.

3.15 <u>In-Situ Particle Environments</u>. Only passive techniques are applicable to the measurement of electron and ion densities at the satellite altitude. Electron and ion densities are typically measured using Langmuir probes or planar ion collectors. The temperature of the ions can differ significantly from that of the electrons, so both parameters should be measured. Particle temperature can be determined by measuring their average energy.

The data provides a measurement of the electron density and parameters for the calculation of the plasma scale height at the satellite altitude. The latter information could be a secondary input to the production of existing vertical electron density models.

3.16 <u>Electron Density Profiles</u>. The electron density profile (EDP) is one of the significant parameters used to characterize the ionosphere. The area of primary interest is the F region of the ionosphere. It is this region that reflects the HF transmissions that allow long distance communications. This same region is also used as a reflector for over-the-horizon backscatter (OTH-B) radar. The location of the F region maximum varies with the state of the ionosphere. The EDP is required to optimize RF communication and OTH-B frequencies.

Current efforts are directed at using passive, optical measurement of ultraviolet and visible emissions coupled with in situ electron density measurements and modeling of the neutral atmospheric density to determine EDPs from polar orbiting satellites. The dominant emissions and the processes that relate to the EDP vary depending on the time of day and the geomagnetic location. A brief description of measurement techniques follows.

<u>Daytime Mid-latitude</u>: The required quantities for determining EDP are the solar energy flux and the O to N_2 density ratio. The measured intensities of the N_2^+ and the O^+ leads to the ratio of O to N_2 densities. This ratio is used to determine the O^+ densities in the ionosphere. Since these are the dominant species a neutral atmosphere model capable of estimating the O^+ diffusion versus altitude will help determine the shape of the electron density profile in the F region (Ref 22). The atmospheric optical emissions that are to be measured by the SSUV sensor are the intensities at 1356 Å of the O^+ and the N_2^+ Lyman-Birge-Hopfield (LBH) bands in the 1500 - 1700 Å region. The NRL RAIDS experiment will monitor the 834 Å O^+ emmissions which will provide the electron density profile from 200 km to 500 km without modeling the neutral atmosphere.

<u>Nighttime Mid-latitude</u>: The molecular ions that make up the ionosphere undergo rapid recombination at night. The emissions due to these recombinations are direct signatures of the height and magnitude of the EDP. The emissions to be measured are the 1356 Å emission from O^+ recombination and the 6300 Å emission from O_2^+ recombination. The square root of the O^+ 1356 Å observed intensity is directly related to the electron density maximum, and the square root of the ratio of the intensities of the O^+ 1356 Å to the O_2^+ 6300 Å is directly related to the altitude of the electron density maximum. The shape of the EDP is given by a modified Chapman function. (For details and derivations of the above statements see Ref 23.)

Auroral E Region: In the auroral region, ionizations are due to both solar illumination and charged particle precipitation. In regions of auroral displays 90% of the total ionization in the E layer are produced by precipitating electron of kilovolt energies. The effects due to solar illumination and precipitating particle ionizations have to be combined at high latitudes. The precipitation source spectrum can be characterized using emissions from selected N_2^+ LBH bands and O^+ (1356Å). Once the source spectrum has been characterized, the O^+ (1356 Å) intensity as stated earlier can be used as a direct measure of the magnitude of the electron density (Ref 23).

Near-term developments will use passive monitoring of the ultra violet (UV) emission lines at 1356 Å to obtain the electron density profile (EDP). The emission lines at 6300 Å and 3914 Å will also be monitored for nighttime EDP. The N_2^+ Lyman Birge Hopfield (LBH) bands must also be monitored to provide O and N_2^+ density ratios to determine the production and loss ratios. Emissions from the three lines are used along with modeling of the neutral density to determine the O^+ density. Because O^+ is the dominant species in the F region, there is a direct correlation to the EDP. The in-situ measurements of the electron density by the SSIE/IES sensors will be used as a boundary value to anchor the end of the modified Chapman function. A more detailed description of the proposed operation of the SSUV in the various regions of the ionosphere is included in Appendix A.

Improvements in the far-term may come from the NRL's RAIDS experiment. This experiment will measure the 834 Å O^+ emissions. These emissions are expected to yield a more direct measurement of the O^+ density. Since it is known that the O^+ density approximates the electron density throughout most of the F region (200-500 km) a knowledge of the electron density profile is thus obtained.

Key technology issues:

a. The efficiency of microchannel plate detectors. Past experiments have used photomultiplier tubes. Unfortunately, these tubes are no longer manufactured. An evaluation of the available microchannel plate detectors should be made in the immediate future. These are required to provide the increased sensitivity required for the operational instrument.

b. Validation of data from operational sensors is a critical issue. The current available methods of validation include sounding rockets, incoherent scatter radars, etc.

c. Current efforts in this area will yield EDP in midlatitudes only. The work to develop algorithms to provide EDP in the more dynamic polar and equatorial regions must be continued. The monitoring of EDP in polar regions under disturbed conditions may require the development of an active sensor technique.

<u>SSUV sensor characteristics (Ref 23)</u>:

Visible: OI 6300 Å
- Detection Design: Nadir Scanning Imager and Tilting Filter Photometer (along track)
- Detector: Micro Channel Plate (MCP), Photomultiplier Tube (PMT)

Spectral Region: 6300 Å with 10 Å resolution and 2.5 Å resolution with tilting filter

Near UV: N_2^+ 3914 Å
- Detection Design: Nadir Scanning Imager
- Detector: MCP, PMT
- Spectral Range: 3914 Å with 10 Å resolution

Far UV: OI 1356 A, N_2 LBH Bands 1400-1700 Å
- Detection Design: Nadir Scanning Imaging Wadsworth Spectrometer/MCP Anode PMT
- Detector: 50 Anode MCP PMT
- Spectral Region: 1150 Å - 1800 Å with 35 Å resolution

- Average Power: 20 watts
- Weight: 30 lbs
- Data Rate: 4 K bits/sec

RAIDS Characteristics (Ref 25)

Visible:	N_a 5890 Å, OI 6300 A and 7774 Å Limb Scanning Photometers (3)
Detection Design:	Mirror Telescope/Filter/PMT
Near IR:	Oxygen IR System
Detection Design:	Limb Scanning Ebert-Fastie Spectrometer/PMT
Spectral Range:	5577-8450 Å at 15 Å resolution
Near UV:	N_2 2nd Positive Bands 3371, 3577, 4250 Å N_2^+ 3914 Å Herzberg Oxygen
Detection Design:	Limb Scanning Ebert-Fastie Spectrometer/PMT
Spectral Range:	3371-4250 Å at 5 Å resolution
Mid-UV:	NO Bands 1980-2350 Å Mg^+ 2851 Å OI 2972 A
Detection Design:	Limb Scanning Ebert-Fastie Spectrometer/PMT
Spectral Range:	1900-2972 Å at 7 Å resolution
Far UV:	OI 1304 Å, 1356 Å N^2 LBH 1326 A, 1382 Å, 1493 Å
Detection Design:	Limb Imaging Wadsworth Spectrometer with 256X64 element wedge/strip MCP array
Spectral Range:	1250-1550 Å at 5 Å resolution
Extreme UV:	O^+ 834 Å, 539 A, 617 Å OI 989 Å
Detection Design:	Limb Imaging Wadsworth Spectrometer with 256x256 element wedge/strip MCP array
Spectral Range:	525-1100 Å at 4 Å resolution
Weight:	80 lbs
Power:	50 watts
Data Rate:	8 K bits/sec

3.17 Total Electron Content. Total Electron Content (TEC) is a parameter used to help characterize the ionosphere and its propagation characteristics. This parameter is needed to predict effects on RF communication, OTH-B radar, and the detection and monitoring of space objects.

By definition the TEC is the integral of the electron density profile (EDP) from the earth's surface to an altitude where the electron density is negligible. The TEC has been estimated to be approximately 20 percent lower if measured at the DMSP altitude of 835 km as compared to a geosynchronous altitude.

Currently, TEC can be determined using ground monitoring of spaceborne RF beacons as follows: Phase coherent radio wave signals are transmitted from a spacecraft far above the altitude of the peak ionospheric electron density (e.g., GOES or GPS spacecaft). One can then deduce the total electron content by measuring the Faraday rotation of the ground received electric field. One may also obtain the same information on TEC (assuming that the contribution to TEC from above GPS altitude is negligible) by measuring the phase difference of the two GPS L-band signals transmitted at slightly different frequencies.

Another approach to determine TEC will make use of the following: Due to the index of refraction of the ionosphere, which in turn depends on the local electron density, the propagation path of the signal from the beacon to the ground deviates from a straight line. Since the index of refraction is inversely frequency dependent as the square of the frequency, transmissions at a lower frequency, together with a much higher frequency will determine the horizontal distance deviation which, together with the beam attenuation at these frequencies, can be used to determine the TEC.

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SECTION 4

4.0 Technology Impacts of New Sensor Systems on Other Segments. This section describes the anticipated impact the new generation of active sensors outlined in the previous section will have on the spacecraft and ground systems. Functional requirements, such as timeliness, data refresh rate, survivability, and ground systems autonomy will be discussed and concepts identified to meet deficiencies. The spacecraft hardware/software subsystems that might be impacted by the implementation of the new generation of active and passive sensors include:

- spacecraft structure
- command and control
- attitude control
- electro-optics and power
- structural dynamics
- thermal control
- data storage and formatting
- data (up and down) transmission
- on board processors

The new generation of remote sensors will also impact the hardware and software of the ground segment. For both spacecraft and ground systems, the nature of the hardware/software impacts will vary depending on the final sensor compliment carried.

Many of the impacted subsystems listed above can be accommodated using present day technologies or with the assistance of currently funded R&D programs. Most of these technologies are discussed in Volumes III to VI of Ref. 1.

A more thorough evaluation of the impact of the new sensors on the spacecraft and the ground segments cannot be completed until sensor designs are more complete. However, since the technology concepts for autonomy and survivability are of near-term interest, a more thorough discussion is presented on these topics in Appendices B and C. In the following subsections, technology forecasts related to DMSP are discussed.

4.1 Spacecraft System.

4.1.1 Spacecraft Structure. Lighter and structurally stronger materials for the spacecraft bus are needed to accommodate the heavier new sensors. Funding for development of lightweight composite materials is motivated by the requirements of other industries, such as the aircraft industry. Results of any technological advances will be available to this program and no new funding for DMSP is planned. The use of active low frequency RF transmitting sensors, such as the N-ROSS Xband altimeter will entail large antennas (several meters in diameter), depending on the required beamwidth. Such antennas will influence the size and shape of the spacecraft.

4.1.2 On-Board Processing. The addition of new sensors on board the spacecraft as well as their increasing complexity implies the need for a larger data base and increased computational speed. The additional on-board navigation and guidance equipment (see autonomy below) together with the increased performance requirements generating a larger data base requires larger analysis facilities, more computer power and comprehensive large-scale information management. These trends necessitate research and development in data compression, hardware miniaturization, increased computer power and rapid computational algorithms. The ongoing technology advances occurring in these fields should be available to the DMSP II satellites without major new allocation of funds by DMSP.

4.1.3 Command and Control. There exists a DOD recommendation to establish compatibility of communication at EHF frequencies for all U.S. space assets. This requirement would change the present all weather communication command link at S-band, which is susceptible to RF jamming, to a more anti-jam command frequency (20 GHz down and 44 GHz up) which is susceptible to absorption by rain. The determination of the proper frequency for the command link will depend on the outages experienced at these high frequencies by other systems and the future status of the recommendation.

4.1.4 Attitude Control. Different modes of scanning the various active and passive sensors will require more complex control algorithms. On-board navigation and guidance will require additional development of information processing and data management architecture. Technology advancements in fast miniaturized micro-processors can be applied to DMSP II satellites.

4.1.5 Power.

4.1.5.1 Power Sources. Depending on the combination of sensors flown, and assuming an active sensor such as a Lidar or a Radar is included, the on-board average power requirements could easily add up to several kilowatts. Thus the new generation of sensors necessitates large power sources. Nuclear power may be a viable alternative to additional solar arrays and batteries.

The most likely candidates for generating power are solar arrays (silicon or gallium arsenide, planar or concentrator), radioisotope thermoelectric generators (RTG), or dynamic isotope power supplies (DIPS). There are planar solar arrays in use that generate 2-3 kw. The technology to build hardened planar arrays in the 5 kw range exists. Use of concentrating arrays (with Si or GaAs cells) to achieve 5 kw power level is reasonable. Considerations, such as maneuverability and degree of laser and nuclear hardening can affect design and material selection, however. Solar array hardening should also include submillimeter metroids and possibly man-made debris impinging on the array. The recent recovery of materials from the NASA Solar Max Mission demonstrated that submillimeter meteoroids had penetrated several 2 mil Kapton layers.

As for nuclear power sources RTG's have been used to about the 1 kw level. Beyond 1 kw, the emphasis switches to reactor type systems such as DIPS. Such a system could be compact, hardened (almost by definition), and more maneuverable than a solar array. Questions of low orbit safety, high development and recurring costs, and technology availability remain.

4.1.5.2 Energy Storage. Present technology batteries (nickel cadmium and nickel hydrogen) support systems in the 2-3 kw range. Improved and larger nickel hydrogen batteries are in the final developmental stages. There is a need for lightweight, long lifetime (four to seven years) batteries capable of withstanding deep discharge/recharge cycles without incurring debilitating degradation.

Near term high energy battery development is concentrated on sodium sulfur and regenerative fuel cell technologies. These systems could be available within ten years in the 5-10 kw storage range. Space station efforts will further advance the technology.

4.1.5.3 Power Conditioning/Control. Work is proceeding on high voltage/high power systems. Additionally, the use of an alternating current system is also being examined to reduce line power losses. Nuclear hardening considerations could influence the choice of system.

4.1.6 Radar and Lidar Systems. The development of a space qualified operational (coherent, pulsed) Lidar system (see Section 3) with a lifetime corresponding to that of the DMSP satellites needs continued funding by the DOD Laboratories. Similarly, these comments apply to the research and development of solid state, high power, low noise RF transmitters in the frequency range of approximately 40 to 300 GHz.

4.1.6.1 Electro-optic Systems. Should there be a need in the far term to change the DMSP orbit from the present 450 nmi to higher altitudes, the sensitive electro-optical subsystems will have to be protected from energetic Van Allen particles, as was done for the GPS satellites. The study of the impact of these belts on electronics needs to be continued.

4.1.7 Structural Dynamics. Simpler analytical methods for analyzing the dynamic structural loads on more complex spacecraft during launch and in orbit need to be developed. These should be achieved by simplified dynamic spacecraft models. Methods for determining the location of failure modes become more important as the structural concepts become more complex due to the presence of a larger number of DMSP sensors on the spacecraft.

Another issue that will impact spacecraft dynamics is the requirement of longer lifetime DMSP satellites. One alternative for meeting this requirement is to repair and refurbish the satellites already in orbit.

4.1.8 Thermal Control. Some of the DMSP sensors, such as the SSM/I and SSM/T, and the proposed active sensors, such as lasers, RF altimeters and millimeter wave radars, generate large amounts of thermal energy. Rapid dissipation of this thermal energy into space is paramount to keeping the satellite subsystems thermally balanced. The thermal control problem and the research for effectively dumping thermal energies in a timely manner into space is being pursued by the DOD laboratories. (Ref 1, Vol III, Chapter 11)

4.2 Ground System. The ground system consists of fixed sites and mobile terminals. Additional sensors on the spacecraft implies greater volume of data to be transferred from the Space Segment to the Ground Segment. Therefore, the capability of the DMSP Ground Segment must be enhanced to handle an increasingly information-driven system. It must rapidly manipulate very large data flows of diverse meteorological data. The challenge will thus reside in the timely development of complex algorithms to process the data.

If the orbital altitude of the DMSP is not altered appreciably on future block changes, then the dumping of greater data volume during overhead pass necessitates a higher data rate than the present 2.6 Mbs. Although the telemetry data rate will be less affected, it too will probably increase from the present 2 Kbs to possibly 10 Kbs.

The vast increase in quantity of data requires increases in data storage, faster processing algorithms, and faster retrieval algorithms in order to meet the timeliness requirements of the users. The quality of the products will thus be limited not only by the maturity and limitations of the scientific technologies but also by the ability of the Ground Segment to process a much larger flow of diverse data sets in a timely manner and distribute it efficiently to the users.

The proliferation of mobile terminals with relatively smaller diameter receiving antennas implies either larger diameter transmitting antenna on the spacecraft, larger data transmitter power or both. The increased processing capability required of the mobile terminals due to the expected increase in data volume will necessitate further technological advances in miniaturization of hardware to reduce the space occupied by the hardware in the mobile terminals.

Trade-off studies need to be performed between a totally internetted communication capability connecting Ground Systems with the DMSP satellites via DOD space communication systems, versus communication through dedicated geosynchronous satellites for instant global data availability.

Further software technology advances are required to accelerate understanding and duplication of human thought processes by computers. This type of software will allow the computers (especially at the mobile terminals) the option of preparing weather charts with or without a man in the processing loop.

Although a more thorough study of the needed technology concepts required by the spacecraft and ground systems are required, those mentioned above must be part of any new list of further technological developments.

4.3 Functional Requirements and Concepts.

4.3.1 Timeliness and Data Refresh Rate. The data refresh time (frequency of observing a parameter at the same location) and the timeliness of the data (time from satellite transmission to user) drives the configuration of the overall DMSP system. Therefore, depending on user requirements for data refresh, timeliness of data, and final sensor designs, there may be a need for increasing the number of DMSP satellites in sun-synchronous polar orbits (12 would be required in the present orbit to satisfy a data refresh time of one hour) or adding from one to three geostationery satellites for continuous observations. Present geosynchronous satellites operated by NOAA are capable of a data refresh time of one-half hour, with instantaneous coverage from 55°N to 55°S latitude. The geosynchronous satellites also provide low quality wind velocity information, and could provide a communication platform for instant relay of data from the polar orbiting satellites to ground systems.

4.3.2 Survivability. Concepts to increase the survivability of both space and ground systems against hostile actions are discussed in Appendix B. An additional consideration is the survivability of a satellite against the natural threat of collisions with meteoroids and man-made debris. In this case, one of the survivability concepts is to armor-plate the sensitive subsystems of the spacecraft. Therefore, research should be pursued in the areas of high tensile strength, low mass density materials, such as Kevlar or carbon composites. Also the optimum manner of applying the plate, whether in a thick single layer or thin multilayers with energy absorbing material in between should be investigated. These armour plates could be designed to also shield the electronic subsystems from the effect of an electromagnetic pulse caused by a nuclear detonation.

4.3.3 Autonomy. There are two types of autonomy that apply to the satellite. One of these is the autonomy of housekeeping and self navigation for an extended time. The current plan is included in Appendix C. The second type of autonomy relates to the on-board ability of a satellite to process and provide data for a stipulated period of time without human intervention or ground support. This will require large on-board computational capabilities as more complex sensors are added. Research in computer software development, as well as the R&D studies of artificial intelligence are technologies that will benefit not only on-board processing but also the functions of the ground segment. Research in miniaturization of hardware will alleviate weight and space considerations on-board the satellite.

4.4 Conclusion. The conclusions of this chapter is that the proposed funding of technology research and development by the DOD laboratories should provide the necessary technological basis when needed for spacecraft software and hardware.

SECTION 4 REFERENCES

1. Military Space Systems Technology Plan (Draft) prepared by AF Space Technology Center. Technical Report Number WG RC 84-7309 (October 84).

SECTION 5

5.0 Prioritized Technology Development and Roadmaps. This section presents a prioritized set of technology development roadmaps for use by technology planners to insure the proper development of technology to meet the major deficiencies identified in Section 2 and discussed in detail in Sections 3 and 4. These areas were defined as TD (requiring technology development). The areas identified as EC (expand capabilities) are not included in the following roadmaps since they can be accomplished through redesign using present technology. The cost effectiveness of these enhancements to present systems should be examined. In general, the EC areas that should be studied further are (in unprioritized order):

a. Faster data processing and data distribution algorithms in order to approach the timeliness requirements (includes distribution from mobile terminals).
b. To develop Navy altimeter and scatterometer from existing prototypes.
c. The addition of 1.6μm channel to OLS for snow discrimination.
d. The improvement of ionospheric modelling using SSM, SSJ/4, SSIES, and SSUV data to determine neutral density or redesign SSD.
e. Complete 4D ionospheric model using SSIES and SSUV inputs for calculating Total Electron Content (TEC).
f. Increasing the scan angle for the SSM/I and SSM/T sensors.
g. Increasing the antenna size of the SSM/I to increase horizontal resolution and measurement accuracy.
h. Increasing spacecraft platform stability to increase mapping accuracy.

The technology roadmaps for new sensors presented in this section are based on generic sensor types and near-term plans for autonomy, rather than on data parameters as in earlier sections. This is because several data parameter deficiencies can be fulfilled by the same sensor development program.

5.1 Priority of Capabilities. The priority for the development of significant new capabilities listed in Table 18 is based upon Ref 1, 2, and 3. References 1 and 2 rank survivability the highest, on par with retrieval of primary mission sensor data. Autonomy has been ranked second since it is actually a subset of survivability. Without specific levels of survivability or autonomy, data could not be retrieved for any of the data parameters as a result of hostile actions. References 2 and 3 prioritize the Vacuum Ultraviolet Spectrometer and Doppler Lidar as first and second for development of new sensors. The priority of the DIAL and millimeter wave systems are based on generalizing the priority of specific sensor data in Ref 1. Vertical temperature and moisture profile information is inferred from Ref 1 to be more important then soil moisture or snow and ice cover information.

Table 18
Priority of New Capabilities

Priority	New Capability	Data Parameter	Deficiency
1	Survivability (See Appendix B, classified SECRET)	All	
2	Autonomy (See Appendix C)	All	
3	Ultraviolet Spectrometer	Electron Density Profile	Area Coverage Horiz. Resolution
4	Doppler Lidar	Wind (speed/direction)	Horiz. Resolution Vert. Resolution Area Coverage
		Clear Air Turbulence	Horiz. Resolution Vert. Resolution
5	DIAL	Vertical Temp. Profile	Vert. Resolution
		Vertical Mois. Profile	Vert. Resolution
		Cloud Cover	Cloud top altitude
		Visibility	Horiz. Resolution Vert. Resolution
6	Millimeter Wave Radar	Cloud Cover	Cloud Base Altitude
		Soil Moisture	Depth Msmt Accuracy
		Snow/Landlocked Ice Cover	Thickness
		Sea Ice, Bergs, Leads	Position of Bergs/ Leads

5.2 Programming Strategy. A computerized Generalized Availability Program (GAP) is used to predict the probability of need for a replacement satellite. It is a Monte Carlo simulation method of analysis. GAP inputs include reliability data for the launch vehicle, satellite, solid rocket motor, ascent guidance software, and the probability of infant mortality for the first six months of satellite life. A truncation time also must be specified. Truncation for "morning" 5D-2 satellites is at 42 months based on piece part irradiation and at 25 months for "noon" satellites based on battery life expectancy. GAP gives the projected 10, 50, and 90 percent probabilities of needing a replacement satellite. Launch dates listed in Table A-1 are based on 50% need dates, whereas sensor/satellite availability in the following roadmaps are programmed against 10% need dates. These need dates are updated as necessary and reviewed monthly to track Program status. It is recommended that organizations using these schedules for planning purposes, verify accuracy with the DMSP SPO due to periodic updates.

5.3 Technology Roadmaps. The roadmaps are comprised of both funded and proposed programs beginning in 1985 through the year 2000. They are technology limited and address a technology gap identified in Section 2. The next pages are provided to help explain each roadmap.

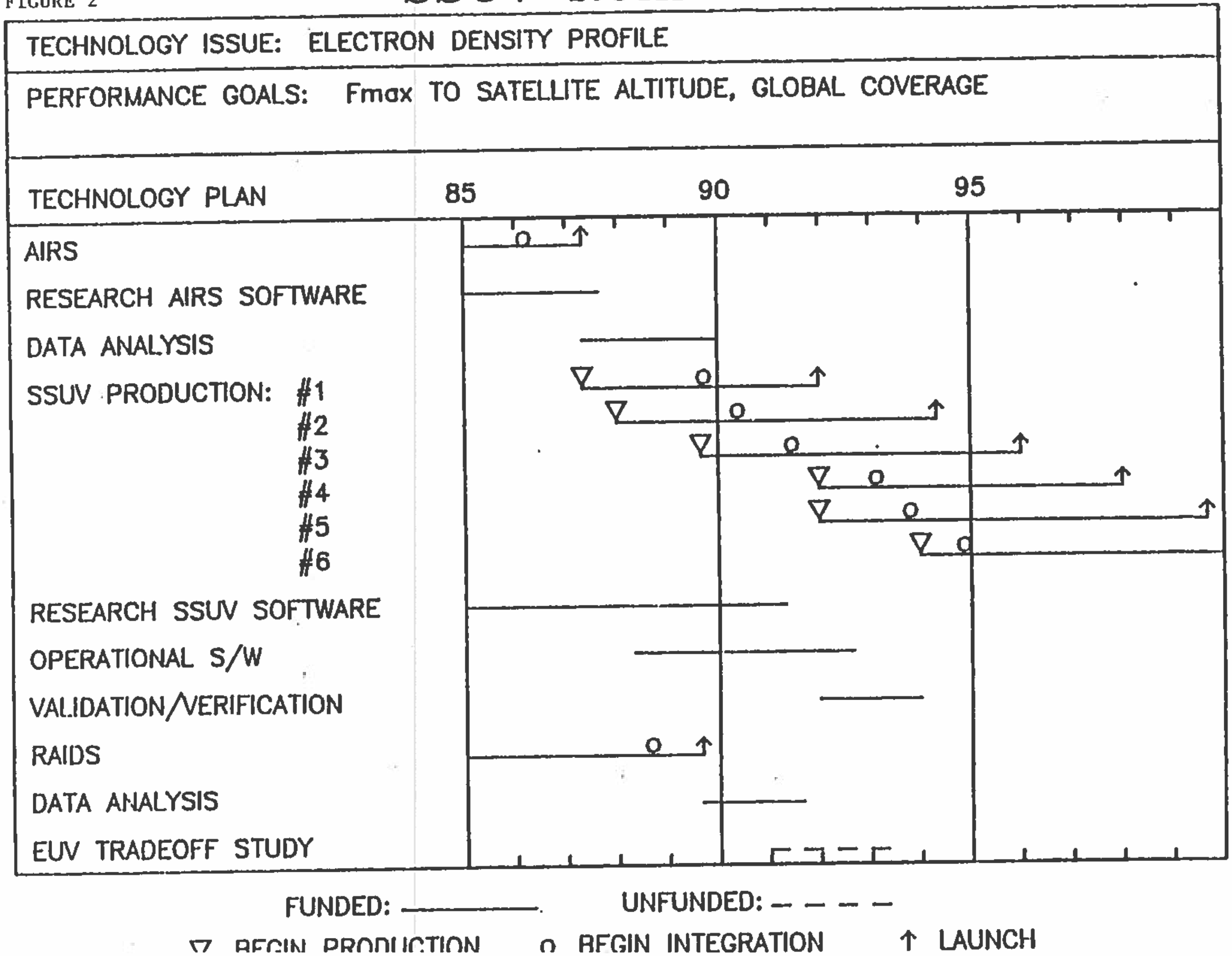
5.4 Ultraviolet Spectrometer (SSUV) Roadmap (see Figure 2). The initial prototype instrument, called AIRS, will be flown on Polar Bear in FY88. It is being built by the Applied Physics Laboratory at Johns Hopkins University. The software algorithms, data analysis, and instrument calibration are being accomplished at the Air Force Geophysics Laboratory.

Production of the first SSUV sensor is anticipated to start in FY87. Microchannel plate detectors are anticipated to replace the photomultiplier tubes used on AIRS and which are no longer in production. AFGL will furnish research codes to calculate the EDP for Mid-Latitude Day, Auroral E Night, Mid-Latitude Night, Auroral E Day, Equatorial Day, and Equatorial Night for the various regions of the ionosphere. Operational software will be developed from these research codes by an independent software contractor. A test plan for validation and verfication of the data needs to be accomplished.

DMSP is also supporting the Navy on their development of the RAIDS instrument. This is a limb scanning device which senses the extreme far, and near ultraviolet bands radiated from various sources in the ionosphere. The limb scanning nature of the instrument allows it to provide information required for determining the neutral atmospheric composition. Monitoring emissions such as the 834 Å O^+ line reduces the dependence of calculated Electron Density Profiles (EDP) on the neutral atmosphere information in the daytime. This has potential for simplifying the EDP modeling and forecasting procedures.

FIGURE 2

SSUV ROADMAP

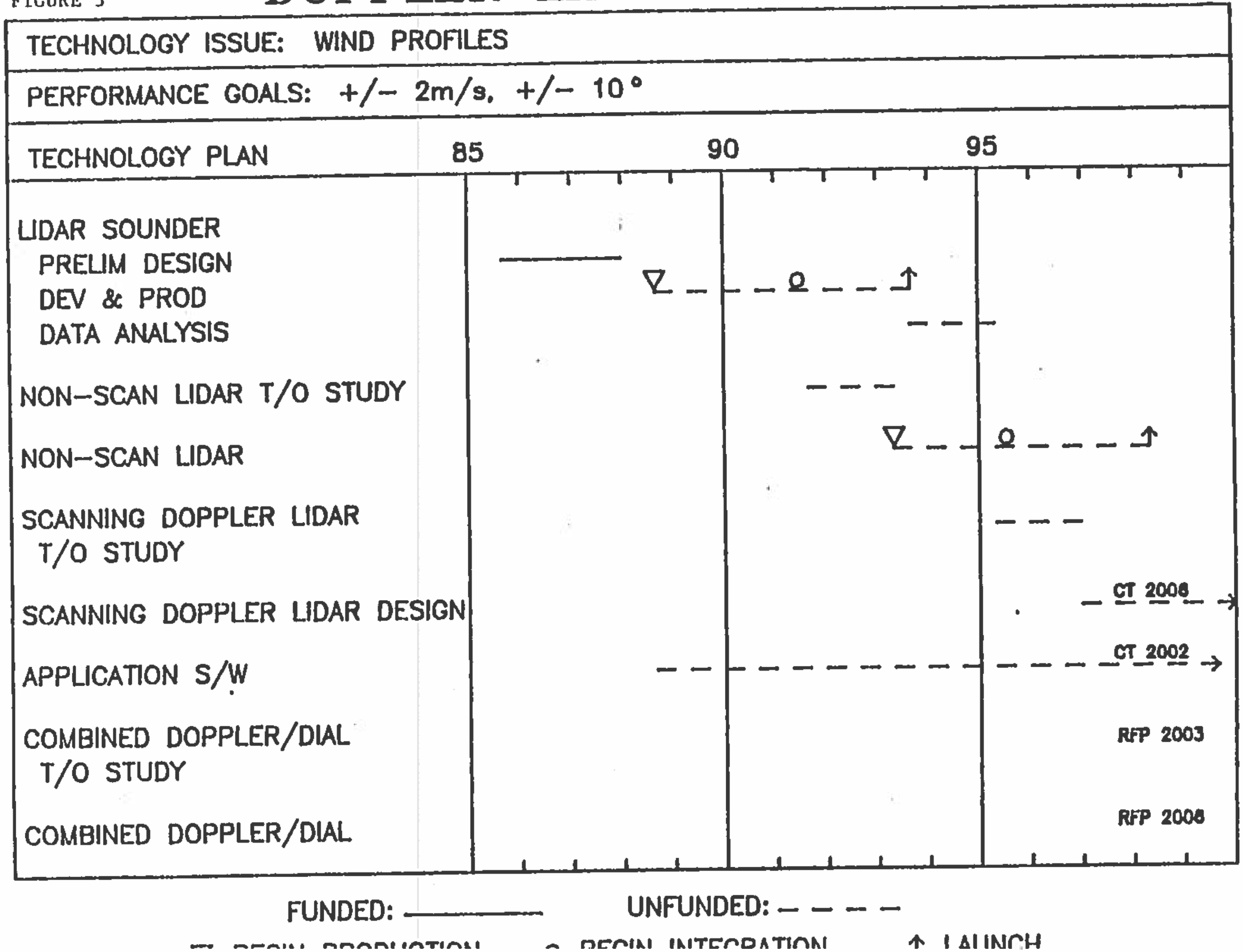


5.5 Doppler Lidar Roadmap (See Figure 3). This development program, which has as its objective the measurement of wind velocity, is divided into four sequential phases to reduce the technical risk. This risk is based on the technical issues described in Section 3.7. The first phase is the Lidar sounder which is a non-scan nadir viewing system which may be flown as an STP experiment on-board DMSP. The objectives of this phase are to demonstrate feasibility, determine the lifetime characteristics of a Lidar system in a space environment, and to determine the aerosol backscatter signal levels globally. The second phase is a non-scan Lidar consisting of two Lidar sounder type systems but looking fore and aft 45 degrees from nadir. The objective of this phase is to obtain horizontal wind information as soon as practical. The third phase is the development of a scanning Doppler Lidar system capable of measuring 3-dimensional wind velocity fields. Each instrument will also provide some aerosal profile information. The final phase will investigate combining Doppler and DIAL systems into one active sensor for wind, water vapor and temperature profiling.

Technical issues and tradeoffs to be investigated have been summarized in Section 3.7. This program represents a practical four-phased approach to minimize technical risk.

FIGURE 3

DOPPLER LIDAR ROADMAP

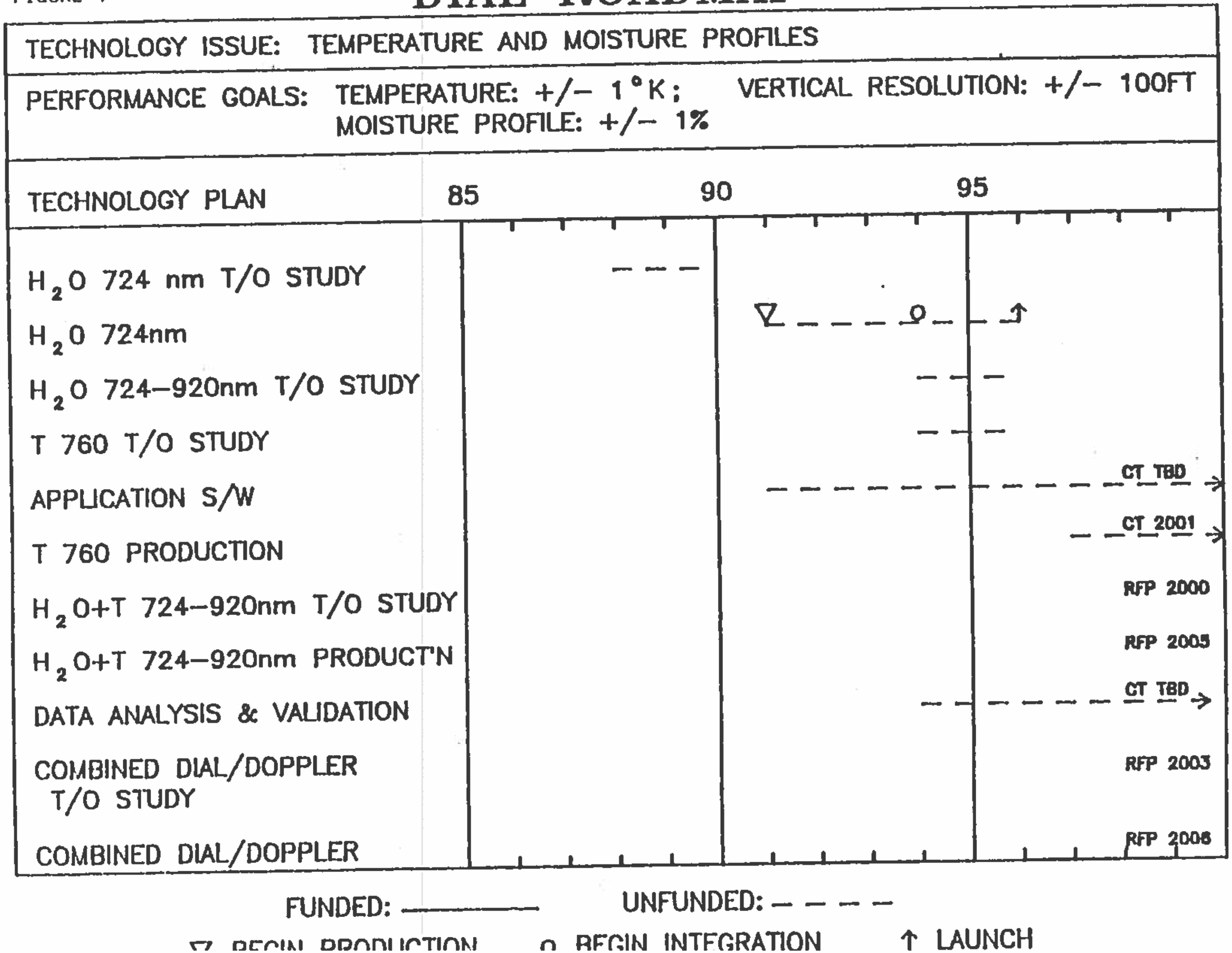


5.6 DIAL Roadmap (See Figure 4). This program consists of four chronological phases. The first phase involves using DIAL for water vapor profiling, first at 724 nm and finally at 724 and 920 nm. The second phase will focus on temperature profiling at 760 nm. The third phase includes both water vapor and temperature profiling using laser transmitters tuneable from at least 724 to 920 nm.

The fourth phase will attempt a combined DIAL/Doppler system for wind, water vapor and temperature profiling. All phases will provide some information on aerosal profiles.

FIGURE 4

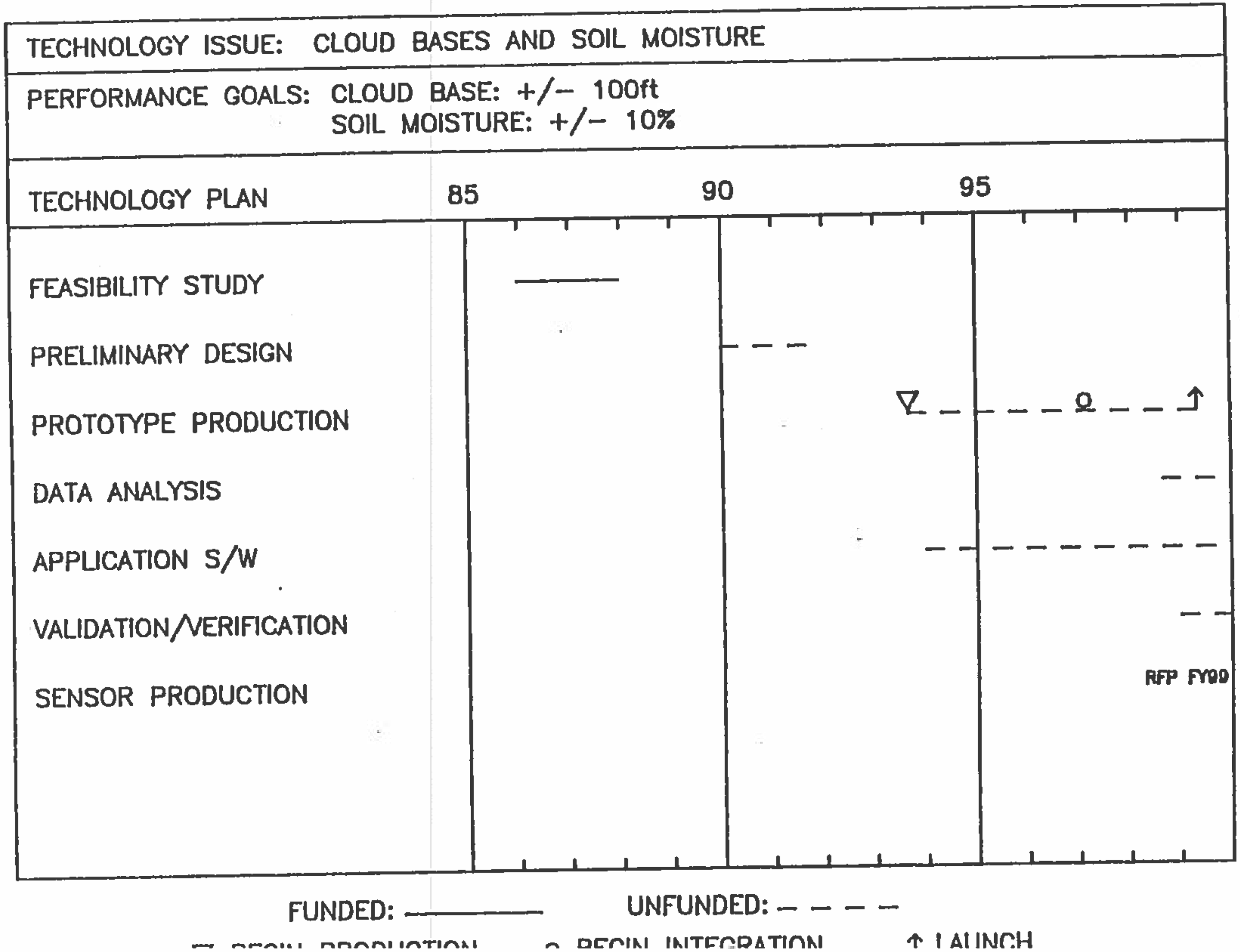
DIAL ROADMAP



5.7 Millimeter Wave Sounder Roadmap (See Figure 5). This program is based on a normal ten year sensor development program. It begins with a tradeoff study to examine the feasibility of using millimeter wave radar on a space platform to measure cloud bases, soil moisture depth, and snow and ice depth. Optimum frequencies to measure those parameters must also be determined. This program is scheduled to begin in FY86.

FIGURE 5

MILLIMETER WAVE SOUNDER ROADMAP



SECTION 5 REFERENCES

1. MJCS 195-81, "Requirements for the Defense Meteorological Satellite Program (DMSP)," dated 5 Oct 81

2. Letter from Maj Aufderhaar, HQ AWS/SYJP, "Proposed Change to MJCS 195-81, Requirements for the Defense Meteorological Satellite Program (DMSP), 5 Oct 81," dated 11 Jun 82

3. Letter from Maj Logan, HQ SD/YDMS, "DMSP Users' Working Group (USWG) Meeting Minutes," dated 30 Nov 84

APPENDIX A OF TECHNOLOGY DEVELOPMENT PLAN

DMSP 5D-2, 5D-3 FLIGHT SCHEDULE WITH SENSOR DESCRIPTION

The 5D-2 and 5D-3 flight schedule with each planned spacecraft sensor compliment is contained in Table A-1. Actual launch dates are based on need depending upon spacecraft attrition. Delivery dates in Table A-1 are current program estimates. Launch projection dates listed in Table A-1 are based on 50% need dates. These need dates are updated as necessary and reviewed monthly to track Program status. It is recommended that organizations using this schedule for planning purposes verify currency with the DMSP SPO due to periodic updates. Description of the sensors follow in the order that they occur in Table A-1. Sensors in the "Other Sensor" category are flown at the request of other programs or commands, other than Air Weather Service. They do not directly support the meteorological or environmental requirements described in Section 2.0. They are included in Table A-1 to display the complete sensor compliment for each spacecraft. Descriptions of these sensors are not included in this Appendix.

THIS APPENDIX IS UNCLASSIFIED

TABLE A-1 DMSP 5D-2 AND 5D-3 FLIGHT SCHEDULE WITH SENSOR COMPLIMENT

Spacecraft ID: Projected Delivery:	WGT(LB)	PWR(W)	F-6	F-7	S-8 3/85	S-10 11/85	S-9 5/86	S-11 4/87	S-12 1/88	S-13 10/88	S-14 7/89	S-15 12/89	S-16 2/93	S-17 2/94	S-18 1/95	S-19 1/96	S-20 1/97
Visible & IR Imagers																	
OLS #	295.0	170.0	8	9	10	11	7	12	13	14	15	16	17	18	19	20	21
Atmospheric Sounders																	
SSH-2	34.0	12.0	X		X												
SSM/T	25.3	14.0		X		X	X	X	X	X	X	X					
SSM/T-2	30.0	30.0								X	X	X					
SSM/T-W	TBD	TBD											X	X	X	X	X
SSM/I	121.0	45.0				X	X	X	X	X	X	X	X	X	X	X	X
Ionospheric and Space Environmental Sensors																	
SSJ/4	3.3	0.5	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
SSB/A	29.4	8.5	X														
SSI/E	5.9	3.5	X	X													
SSI/ES	16.0	10.0			X	X	X	X	X	X	X	X	X	X	X	X	X
SSJ*	8.0	6.0		X													
SSM	4.0	2.0		X					?	X	X	X	X	X	X	X	
SSUV	30.0	20.0											X	X	X	X	X
Other Sensors																	
SSB/S	21.0	8.5	X														
SSB/X	11.9	1.1			X												
SSB/X-M	20.3	1.1				X	X										
SSB/X-2	TBD	TBD						X	X	X	X	X	X	X	X	X	X
SSK	14.0	18.0			X												

OLS (Operational Linescan System)

The OLS, first flown in 1976 on the Block 5D spacecraft is the primary meteorological sensor of the DMSP. The OLS is a two-channel radiometer, but its operation is somewhat different from that of other radiometers (such as the TIROS/AVHRR) in that the mirror oscillates rather than rotates. This back-and-forth sinusoidal motion of the optical telescope system moves the instantaneous field-of-view of the detectors across the satellite subtrack, with maximum scanning velocity at nadir and reversals at the ends of the scans. The detector size of the optics is dynamically changed to reduce the field-of-view near the end of each scan, thus maintaining an essentially unchanged footprint size on the earth's surface. The gain of the sensor is also adjusted along the scan line to compensate for larger variations in the reflected light level as the satellite crosses the terminator. Furthermore, through use of a photomultiplier tube, it is possible for the OLS to collect reflected visible radiation at night, with illumination as low as that corresponding to a quarter moon.

The spectral bands of the OLS are 0.4-1.1 μm for the visible and 10.2-13.0 μm for the thermal infrared. Direct readout data at "fine" resolution (0.6 km) and "smoothed" resolution (2.8 km) can be received at the transportable terminals; data can also be recorded onboard the spacecraft at the smoothed resolution for transmission to the central receiving stations (low light level nighttime visible data are at 2.8 km resolution). The main features of the OLS are summarized on the next page and the instrument is described in more detail in Ref. 1 and 2.

Operational Linescan System (OLS) - Westinghouse Electric Corp.

Environmental Parameters Sensed/Derived

- Measures reflected sunlight and moonlight, and thermal radiation from clouds and the earth surface.
- Nominal spectral response of detectors.

HRD:	0.4 - 1.1μm
PMT:	0.45 - 0.95μm
Thermal:	10.2 - 12.8μm

- Derived parameters include cloud imagery, cloud top and sea surface.

Data Accuracy

- Visible data - 6 bit resolution (64 gray shades)
- Infrared data - 8 bit resolution (256 gray shades) for objects between 190 and 310°K
- Albedo ± 5%
- Sea surface temperature, cloud top temperature nominally accurate to ± 5°K, reducible by correcting for moisture down to at best ± 2°K

Data Coverage

- Global coverage
- Horizontal swath width 1600 nmi (3200 Km)

Data Resolution

- Horizontal: 0.3 nmi Daylight visible
  1.5 Night visible
  .3 nmi - IR
  Constant resolution as a function of scan angle

Other Comments

- Primary Sensor, on all DMSP spacecraft
  4 tape recorders - 20 min of visible + IR at .3nmi resolution
  400 min of visible + IR at 1.5nmi resolution

INFRARED TEMPERATURE AND WATER VAPOR SOUNDER (SSH-2)

The infrared multispectral sounder measures infrared radiation emitted by the earth's surface and atmosphere in 16 spectral bands. These have been selected to provide radiance measurements which may be inverted using physical radiative transfer models and data processing techniques to yield profiles of atmospheric temperature and water vapor content. Six of the bands are in the 15μm CO_2 absorption band and eight are distributed over the pure rotational water vapor absorption band near 20μm. The two remaining bands are at 3.7μm and the 12μm window region and measure ozone and surface temperature, respectively. Table A.7 identifies the SSH-2 bandpass characteristics.

The SSH-2 scans in 25 steps across the subsatellite track. During the one-second dwell at each scan station, a complete set of multichannel radiance measurements is made, from which atmospheric temperature and water vapor profiles can be calculated. After completion of the 25 step earth scan, the SSH-2 slews to positions that allow calibration looks at cold space and at an internal radiance source. It then returns to the starting point for another earth scan. The complete cross-track line scan and calibrating cycle takes 32 seconds. The SSH-2 has a 2.7 deg. field-of-view and scans 50 deg. across track.

Incoming radiance is directed into the SSH-2 collecting optics Cassegrain mirror system. The radiance signal is chopped at a frequency of 16 Hz and subdivided spectrally into three wideband channels by the use of two dichroic optical elements. The wideband channels are designated Channel E (650 cm^{-1} to 900 cm^{-1}), Channel F (350 cm^{-1} to 550 cm^{-1}), and Channel W (2425 cm^{-1} to 2900 cm^{-1}). In the E and F channels, the radiation is subdivided by the use of seven narrow band filters in the F filter wheel and eight narrow band channels in the E filter wheel. Table A.8 shows the precise division.

The water vapor retrieval accuracies obtained with the SSH-2 have been unacceptably poor. Also, operation of the instrument is limited to clear temperature profile measurements under nearly all weather conditions. For these reasons, there is question regarding whether any future DMSP launches will carry the SSH-2.

Table A.8 Central Frequencies and Bandwidths for the SSH-2 Sounder (Ref 12 p 84)

CHANNEL NUMBER (CODE)	WAVELENGTH (μM)	WAVENUMBER (CM^{-1})	HALFWIDTH (CM^{-1})	NESR ① (ERG SEC^{-1} CM^{-1} $STER^{-1}$)	ΔT_B ② (°K)	ABSORPTION (SPECIES)
1(E6)	13.4	747	12.5	.070		LEAST (CO_2)
2(E5)	13.7	731	12.5	.071		↓
3(E4)	14.1	708	12.5	.072		↓
4(E3)	14.4	695	12.5	.067		↓
5(E2)	14.8	676	12.5	.085		↓
6(E1)	15.0	668.5	3.0	.310		MOST (CO_2)
15(E8)	11.1	898	12.5	.054		WINDOW
16(H)	3.7	2700	2425-2900	.0012		WINDOW
7(E7)	12.5	797	12.5	.049	.03	LEAST (H_2O)
8(F1)	18.7	535	15.0	.138	.12	↓
9(F5)	20.1	497	17.0	.120	.12	↓
10(F6)	24.5	408	14.0	.105	.14	↓
11(F4)	22.7	441	20.0	.057	.06	↓
12(F3)	23.9	420	22.0	.087	.11	↓
13(F2)	25.2	397	12.5	.136	.19	↓
14(F8)	28.3	353	14.0	.268	.47	MOST (H_2O)

① Data for Operating Temperature of 25°C.

Noise Equivalent Brightness Temperature for a Star[illegible]d Atmosphere

Infrared Temperature and Moisture Sounder (SSH-2) - Barnes Engineering

Environmental Parameters Sensed/Derived

- Measures infrared radiation emitted by atmosphere and earth's surface at 6 frequencies in the 15 μm CO_2 absorption band, at 8 frequencies in the 20-30 μm water vapor absorption band and at 2 window frequencies near 10 μm and 3.7 μm.

- Spectral channels
    - CO_2: 13.4, 13.7, 14.1, 14.4, 14.8, 15.0 μm
    - H_2O" 12.5, 18.7, 20.1, 24.5, 22.7, 23.9, 25.2, 28.3 μm

  Window: 11.1, 3.7 μm

- Derived parameters include vertical temperature and moisture profiles from the surface to 30 Km

Data Accuracy

- rms temperature error = ± 2.5 - 3°K

- No useful moisture profiles have been retrieved

- Navy uses one channel to compute total water vapor in a column

Data Coverage

- Daily global coverage with gaps below about 55° latitude

- Horizontal swath width 1102 nmi (2204 km)

Data Resolution

- Cross track resolution of 25 scene stations ranges from 30 nmi (60 km) at nadir to 60 nmi (120 km) at edge of scan (± 48°)

- Along track resolution 112 nmi (224 km) one scan per 32 sec

- Vertical resolution, 6 independent pieces of temperature data between surface and 30 km

PASSIVE MULTICHANNEL MICROWAVE TEMPERATURE SOUNDER (SSM/T)

The SSM/T sensor system is a passive multichannel microwave instrument that is designed to provide atmospheric temperature measurements for pressure levels of 1000, 850, 700, 500, 400, 300, 250, 200, 150, 100, 70, 50, 30, 20, and 10 mb; 14 thicknesses between these levels; and the temperature and pressure of the tropopause. It consists of a mechanically scanned reflector antenna, a stepper motor/gear antenna drive, a seven-channel superheterodyne receiver, and signal processing/timing circuitry. Precise inflight calibration is achieved by viewing known radiometric temperatures through the antenna system. A temperature-stabilized internal source (300° K) and the cosmic background (2.7° K) are used for this purpose.

The SSM/T is a cross-track nadir scanning radiometer having a field-of-view of 14.4 deg. This provides a subtrack spatial resolution of about 174 km. The antenna beam is step-scanned through seven discrete earth-looking positions at a fixed rate and is then rapidly rotated to the calibration references before the scanning sequence is repeated. The dwell time at each scan position is 2.7 seconds, which provides NEDT values from 0.4 to 0.6° K for the seven channels. The channel and scan parameters are summarized in Table A.4.

Weighting functions for the SSM/T are shown in Figure A.1. These functions are designed to provide temperature soundings over previously inaccessible cloudy regions from altitude levels near the surface to 30 km. A test version of the instrument has already been flown on an earlier DMSP mission, but spacecraft power problems limited the amount of data collected. Post-mission analysis of the data indicated good quality temperature profiles. An example of retrieval accuracies available from the SSM/T is illustrated in Figure A.2. The expected rms retrieval error is about 2.5° K with the largest errors near the surface.

TABLE A.5 SSM/T CHANNEL PARAMETER REQUIREMENTS (Ref 11)

Channel	Peaking Height (km)	Frequency (GHz)	Bandwidth (MHz)	NETD
1	0 (window)	50.5	400	0.6
2	2	53.2	400	0.4
3	6	54.35	400	0.4
4	10	54.9	400	0.4
5	30	58.4	115	0.5
6	16	58.825	400	0.4
7	22	59.4	250	0.4

KEY SCAN PARAMETERS

Scan Type	Cross-track nadir
Cross-Track Positions	7
Calibration Positions	2-cosmic background and internal 300°K source
Total Cross-Track Scan	±36°
Total Scan Period	32 seconds
Dwell Time (Cross-Track and Calibration Positions)	2.7 seconds

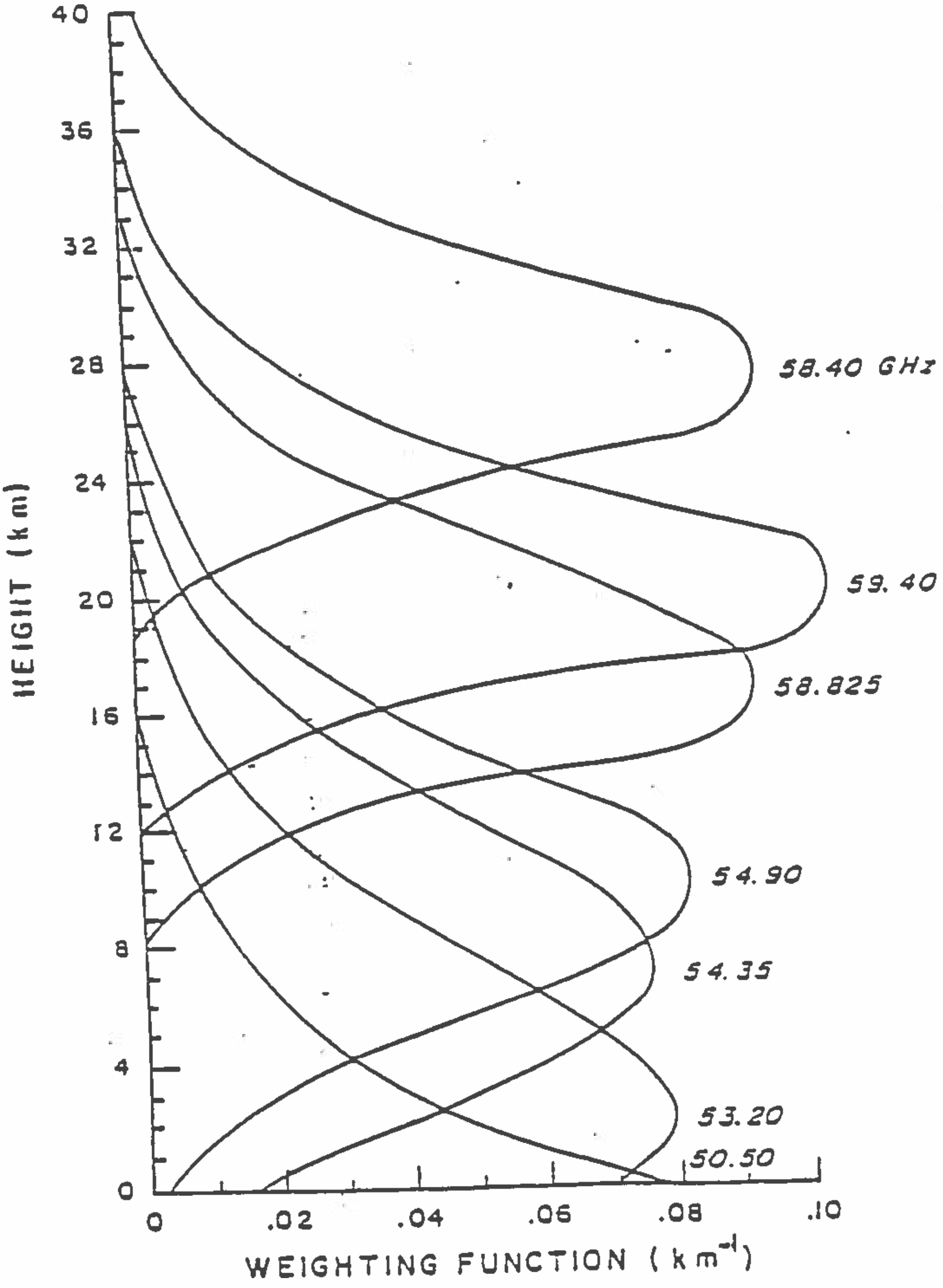


Figure A.1 SSM/T weighting functions (nadir) with antenna gain characteristics included for a surface emissivity of 0.97. (Ref 12, p 86)

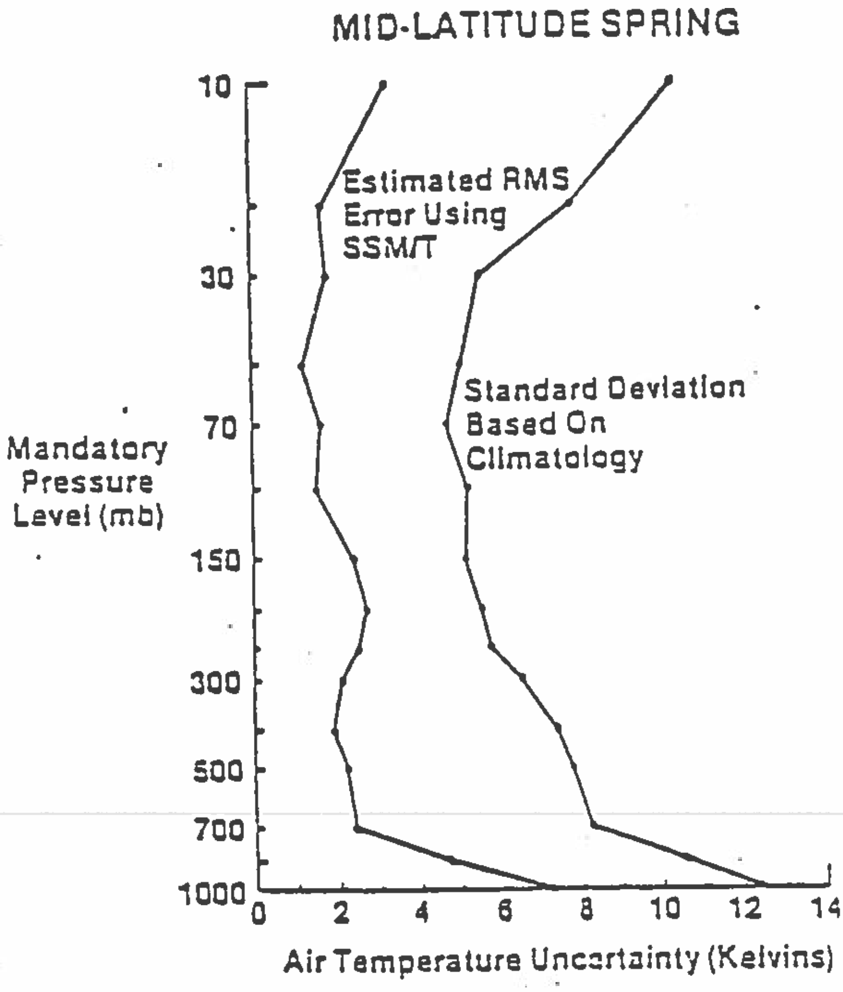


Figure A.2 Estimated rms retrieval error using SSM/T compared to climatology (Ref 12, p 87)

Microwave Temperature Sounder (SSM/T) - Aerojet Electrosystems Corp.

Environmental Parameters Sensed/Derived

- Measures microwave radiation emitted by the atmosphere at seven frequencies in the 50-60 GHz O_2 line.
- Spectral channels 50.5, 53.2, 54.35, 57.9, 58.4, 58.825, 59.4 GHz.
- Derived geophysical parameters comprise the vertical temperature profile from the surface to 30 km.

Data Accuracy

- rms temperature error = 2.5°K

Data Coverage

- Daily global coverage with gaps below about 60° latitude
- Horizontal swath width 861 nmi (1794 km)
- ±36° (± 600 km) from Nadir

Data Resolution

- Horizontal resolution of seven scene stations ranges from 93 nmi (186 km) at nadir to 160 nmi (319 Km) edge of scan (± 36°)
- Vertical resolution, seven independent pieces of data between 0 and 30 km
- One scan every 32 sec (~250 km in track)

Other Comments

- F-7 and all S/C beyond F-9

PASSIVE MICROWAVE TEMPERATURE/WATER VAPOR PROFILER (SSM/T-2)*

The SSM/T-2 is an upgrade to the current SSM/T microwave temperature sounder. The enhanced capability is a result of adding channels at 91.5 GHz, 150 GHz and the 183 GHz water vapor resonance line, to provide a moisture profiling capability. Water vapor mass would be recorded in four layers: surface to 850 mb, 850-700 mb, 700-500 mb, and 500-0 mb. Total integrated water vapor mass would also be determined. Successful retrieval of this profile information requires a calibration error of < 1.5° K and an NETD not exceeding approximately 1.0° K. The channel parameters for this proposed sensor are shown in Table A.5 and are the driving parameters for its electrical design.

The proposed system utilizes the same modular construction as the SSM/T, as well as additional features including a stepped cross-track scan, a shrouded closed-path calibration network, and passive thermal control.

The mechanically scanned paraboloidal reflector antenna system provides a planar scan by mechanically rotating the reflector surface. This allows the antenna feed system to remain fixed. The antenna beam is step-scanned across the earth at a fixed, programmed rate and then rapidly rotated, first to a warm calibration reference, then to a cold calibration reference, before the scanning sequence is repeated. The radiometric temperatures of the calibration reference provide absolute calibration points so that the absolute antenna temperatures can be determined. The calibration paths are closed and characterized by low losses, so that the equivalent antenna input temperature during calibration can be accurately determined.

The SSM/T-2 would scan 28 positions cross-track. The antenna beamwidth of three degrees at the subsatellite point provides a horizontal resolution of about 40 km. This is significantly better than the 174 km resolution of the SSM/T. The scan parameters and footprint geometry for this instrument are shown in Figure A.3. If operated with a collocated SSM/I instrument, improved water vapor profile calculations can be obtained using a first guess of integrated water vapor and cloud water content from the SSM/I. Table A.6

*Note: SSM/T is sometimes being referred to as SSM/T-1
SSM/T-W = capability of SSM/T + SSM/T-2

displays retrieval errors obtained by simulation. These numbers correspond to improvements by a factor of 2 to 10 and 2 to 4 over ocean and land surfaces, respectively, for both clear and cloudy conditions.

TABLE A.6 SSM/T-2 CHANNEL PARAMETERS (Ref 13, p 3)

Channel	Frequency (GHz)	Bandwidth (GHz)	Center Frequency Stability (MHz)	Integration Time (msec)	NEDT (deg K)	Calibration Error (deg K)
1	183 ±3	1.0	≤200	122	0.6	≤1.5
2	183 ±1	0.5	≤200	122	0.8	≤1.5
3	183 ±7	1.5	≤200	122	0.6	≤1.5
4	91.5	1.5	≤200	122	0.6	≤1.5
5	150	1.5	≤200	122	0.6	≤1.5

Table A.7 Simulated DMSP SSM/T-2 rms relative retrieval error vertical distribution over ocean and land for clear and cloudy cases (ref 14)

Parameter	Relative Retrieval Error Over Ocean (%)		Relative Retrieval Error Over Land (%)	
	Clear	Cloudy	Clear	Cloudy
M_V	14.0	12.6	43.0	36.3
M_V (SFC - 850)	17.9	31.5	48.5	60.5
M_V (850 - 700)	23.6	40.6	49.5	61.7
M_V (700 - 500)	33.6	58.6	37.8	50.4
M_V (500 - 0)	29.4	40.1	36.5	45.0

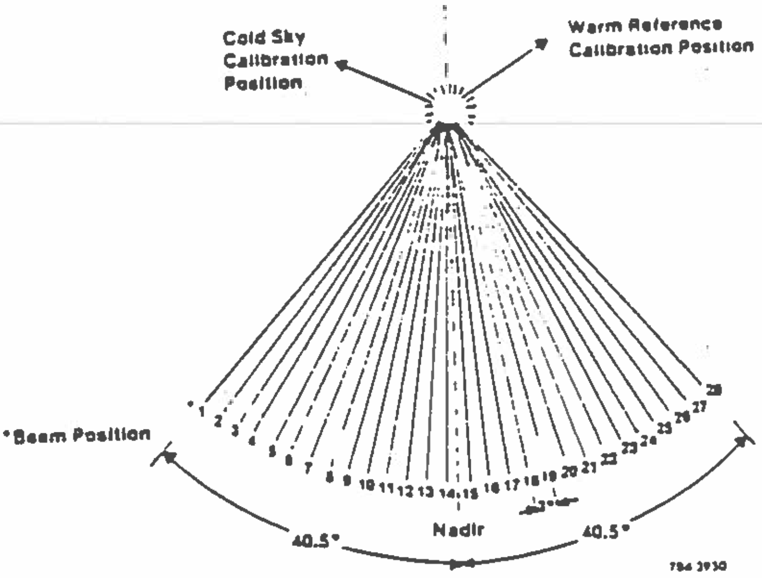


Figure A.3 SSM/T-2 Calibration and Scan Geometry (Ref 13, p 6)

Passive Microwave Temperature/Water Vapor Profiler (SSM/T-2)*

Environmental Parameters Sensed/Derived

- Atmospheric radiance at 91.5 GHz, 150 GHz and 183 GHz
- Parameters derived: Temperature profile, water vapor in four layers.

Data Accuracy

- Expected reduction of climatological variance of water vapor by a factor of 2-10.
- Temperature accuracy ±2.5K.

Data Coverage

- ± 40.5 deg. from nadir (± 750 Km)

Data Resolution

- Horizontal resolution 40 Km
- Scan time 8 sec (60 km along track)

Other Comments

	System Characteristics
Radiometer Type	Total power
Frequencies	91.5, 150, 1831 ±1, 183 ±3, 187 ±7 GHz
Spatial Resolution	46.5 x 46.5 km @ nadir and 183 GHz
Scan Angle	±40.5 degrees, 28 views
Swath Width	1596 km
Scan Increment	3 degrees
Antenna Beamwidth	3.0 degrees at 183 GHz
Thermal Sensitivity	0.6° to 0.8° K
Calibration Accuracy	±1.5° K
Weight	30 pounds
Size	8 x 16.5 x 11 inches (X x Y x Z)
Power	30 watts
Data Rate	324 (bits/sec)
Uncompensated Momentum	0.02 in.-lb-sec

This system is comparable to the SSM/T-1 system in physical characteristics with four times the resolution and scan rate and nearly equivalent thermal sensitivity and calibration accuracy.

*Note: SSM/T is sometimes being referred to as SSM/T-1
SSM/T-W = capability of SSM/T + SSM/T-2

MULTICHANNEL MICROWAVE RADIOMETER (SSM/I)

The scanning multichannel microwave radiometer (SSM/I) is a 4-frequency imaging microwave radiometer. It will measure dual-polarized microwave radiation from the earth's atmosphere and surface at frequencies of 19.35, 37, and 85.5 GHz. The fourth frequency at 22.23 GHz measures vertically polarized radiation in a water vapor absorption band. A variety of geophysical parameters can be derived from these 7 channels of data, as demonstrated through laboratory, aircraft, balloon, and spacecraft experiments carried out since the early 1960s. The microwave measurements of the earth's surface have the advantage that they are relatively insensitive to cloud cover and can be made under nearly all weather conditions.

The sensor spins at 31.6 rpm, which gives a 1.9 second period during which the spacecraft ground track moves 12.5 km. The constant scan and sample rates are synchronized from a common frequency reference which results in uniform footprint sizes and scene station spacing (distance between adjacent footprint centers) across the swath. The spacing is 12.5 km both along track and along scan at the highest frequency, and 25.0 km in both direcitons at all lower frequencies. Both polarization channels at each frequency are sampled nearly simultaneously to assure registration of the channel pairs. Table A.1 is copied from the SSM/I specification document and provides ground resolution values for the 7 channels. Effective field-of-fiew values include the effects of cross track antenna beam smear resulting from scan motion during the radiometer integration interval.

The sensor points forward to scan at an earth incidence angle of 53.1 deg. It measures hot and cold calibration sources during each rotation. The hot source is housed onboard the spacecraft and its temperature is monitored by 3 redundant temperature sensors. The cold reference source is the sky background. The SSM/I swath width is 1394 km. After about 1 day, or 14 full orbit revolutions, the surface swath largely overlaps the first orbit. Tracks "N" and "N+14" are separated by about 4.7 deg and overlap by about 63%. Thus, about two-thirds of the earth's surface will have repeat coverage on successive days.

TABLE A.2 SSM/I Ground Resolution (Ref 9, p 2-2)

Freq., GHz	Pol.	IFOV, km		Effective FOV*, km		Geometric Mean, km		Scene Station Spacing, km
		A-T	X-T	A-T	X-T	IFOV*	Effective	
19.35	V	68.9	41.4	68.9	44.3	53.4	55.3	25
	H	69.7	40.8	69.7	43.7	53.3	55.1	25
22.235	V	59.7	36.3	59.7	39.6	46.6	48.6	25
37	V	35.4	22.1	35.4	29.2	28.0	32.2	25
	H	37.2	21.0	37.2	28.7	28.0	32.7	25
85.5	V	15.7	9.5	15.7	13.9	12.2	14.8	12.5
	H	15.7	9.5	15.7	13.9	12.2	14.8	12.5

A-T = Along track dimension
X-T = Cross track dimension

*IFOV is equivalent 3dB antenna footprint
Effective FOV includes cross track antenna beam smearing.

TABLE A.3 SSM/I Data Parameter Resolution (Ref 9, p -2

Parameter	Desired Geometric Resolution, km	Range of Values	Quantization Intervals	Absolute Accuracy
Primary				
Ocean surface wind speed	25	3 to 25 m/s	1 m/s	±2 m/s
Ice				
Percent area covered	25	0 to 100%	5%	±12%
Age	50	1st, 2nd, multiyear	1, 2, ≥3 yr	Not applicable
Edge location	25	–	–	±12.5 km
Precipitation over land areas	25	0 to 25 mm/hr	0.5,10,15,20, ≥25 mm/hr	±5 mm/hr
Secondary				
Soil moisture	50	Dry to saturated	Dry to moist Wet to saturated	Not applicable
Cloud water	25	0 to 1 gm/cm^2	0.03 gm/cm^2	±0.07 gm/cm^2
Liquid water	25	0 to 6 gm/cm^2	0.1 gm/cm^2	±0.2 gm/cm^2
Precipitation over water	25	0 to 25 mm/hr	0.5,10,15,20, ≥25 mm/hr	±5 mm/hr
Ocean surface wind direction*	25	0° to 360°	5°	±20°
Ocean surface roughness* (significant wave height)	25	1 to 5 m	0.5 m	±1 m

*Not included in proposed SSM/I system.

SSM/I parameter performance requirements have been formulated for five primary and four secondary parameters. The primary parameters include ocean surface wind speed, ice coverage, age, and edge location, and precipitation rate over land. The secondary parameters are soil moisture, cloud water, liquid water (cloud droplets plus rain drops), and precipitation rate over water. These requirements are summarized in Table A.3 which was also copied from the specification document. Table A.4 shows the expected sensor performance for geographical locations and yearly seasons of highest moisture (note that in all four seasons the Arctic is a low moisture region; so is winter in mid latitudes), based on simulations performed by Environmental Research and Technology (ERT), the SSM/I algorithm development subcontractor. Comparison of Tables A.3 and A.4 reveal that it should be possible to retrieve all the parameters with the desired accuracy with three exceptions: 1) cloud water in the presence of heavy rain is indeterminate, 2) ocean surface wind speed in heavy rain is indeterminate, 3) cloud water over land is slightly above the specification.

It must be stressed that the retrieval accuracy estimates have been based upon results derived from simulated surface and atmospheric data. Brightness temperatures were predicted using climatological data as input to mathematical models which simulate the complex surface and atmospheric radiative interaction processes. Similar simulations preceding the launch of SMMR (a NASA microwave radiometer which has flown now for several years) were found to have greatly overestimated performance estimates for that instrument. In particular, ocean surface wind speed and precipitation rate values derived from SMMR have never met the initial expectations.

There are several reasons to hold the current performance estimates partly suspect. In the ERT simulations it was assumed that ice and snow particles in clouds may be neglected in the absorption and scattering calculations. Aircraft and SMMR measurements have proven this to be a poor assumption. Brightness temperatures below 175° K were measured over a thunderstorm for which simulations have predicted an asymptotic lower limit of 230° K. The low brightness temperature values were found to be a result of

Parameter / Climate Region	Cloud Water (kg/m^2)	Water Vapor (cm)	Soil Moisture (%)	Rain Rate (mm/hr)	Liquid Water (kg/m^2)
Mid-Lat Land Spring/Fall	.20*	.64	3.2	2.82	.63
Mid-Lat Land Summer	.19*	.80	2.6	2.52	.72

Parameter / Climate Region	Cloud Water (kg/m^2)	Water Vapor (cm)	Ocean Surface Wind Speed (m/sec)	Rain Rate (mm/hr)	Liquid Water (kg/m^2)
Tropical Ocean Summer	.036*	.18	1.21*	1.04	.24
Tropical Ocean Winter	.038*	.20	1.14*	1.09	.27

* INDETERMINATE AT RAIN RATES >5 mm/hr

TABLE A.4 SSM/I Accuracy (Ref 10)

significant scattering due to snow above the melting level in the cloud. A second deficiency is that effects of horizontal inhomogeneity have been ignored in the calculations. It is clear that several parameters often have large variations over spatial scales smaller than the cell sizes of SSM/I. Rain rate, ocean surface wind speed, and ice coverage are perhaps the most prominent of these parameters. A final error source is that, while the inversion process is basically a linear regression, the relationship between brightness temperature and several parameters is nonlinear. This has recently been discovered, for example, in the ocean surface wind speed measurements derived from SMMR. These deficiencies will be investigated and resolved through ground truth measurements during early orbit validation and verification.

It is clear that SSM/I will enable the measurement of parameter values with greater accuracy than those obtained in the past. The antenna design, frequency selection, and onboard calibration will all result in significant improvements. The Naval Research Laboratories SSM/I flight test program has demonstrated that all ocean parameters will be accurately calculated. The algorithm deficiencies cited above will likely be mitigated by improvements made shortly after the reception of the initial satellite data sets. The global coverage for these parameters will provide important meteorological and oceanographic measurements of benefit to all the DoD Services.

MICROWAVE IMAGER (SSM/I) - HUGHES AIRCRAFT CORP.

Environmental Parameters Sensed/Derived

- Measures microwave radiation emitted and reflected by atmosphere and earth's surface.
- Spectral channels

  19 GHz, H&V polarization
  22 GHz, V polarization
  38 GHz, H&V polarization
  85 GHz, H&V polarization

- Derived parameters include ocean surface wind speed, soil moisture, rain rate, cloud water, cloud liquid water and sea ice.
- Total water vapor and perhaps land skin temperature can be derived.

Data Accuracy

- Ocean surface wind speed: ± 2 m/sec (0 - 29 m/sec)
- Soil moisture: wet or dry (0 - 61%)
- Precipitation rate: land ± 5 mm/hr (0 - 29 mm/hr)
- : ocean ± 5 mm/hr (0 - 29 mm/hr)
- Cloud water: ± 0.1 kg/m^2 (0 - 1.26 kg/m^2)
- Liquid water: ± 2 kg/m^2 (0 - 6.1 kg/m^2)
- Ice concentration: ± 12.5%
- Age: 1st yr, multiyear
- Edge location: ± 12.5 Km

Data Coverage

- Daily global coverage with gaps below about 65° latitude.
- Horizontal swath width 697 nmi (1394 Km)

Data Resolution

- Horizontal resolution 12.5 nmi (26 Km) for all parameters except precipitation over land and cloud liquid water over land, 6.25 nmi (12.5 Km)

Other Comments

- First flight F-9
- Will fly on all DMSP spacecraft and NROSS
- Horizontal resolution limited by antenna size

PRECIPITATING CHARGED PARTICLE SPECTROMETER (SSJ/4)

The purpose of the SSJ/4 instrument is to measure the flux and energy spectrum of electrons and ions which precipitate from the earth's magnetosphere and cause ionization and visible aurora in the E-region of the ionosphere at high latitudes. In addition to its direct use as an indicator of regions undergoing intense auroral activity, data from the SSJ-4 and its predecessors have been used to develop models of the varying auroral boundary locations as a function of geomagnetic activity index. The data is also used in an algorithm to calculate the Hall and Pedersen conductivities of the auroral E-region as functions of latitude, local time, season and geomagnetic activity.

The SSJ/4 measures the flux of electrons and ions in 20 energy channels in the range from 30 eV to 30 keV. This is accomplished using a set of four cylindrical curved plate electrostatic analyzers arranged in two pairs. Each analyzer consists of three basic components: an aperturing system, a set of two concentric cylindrical curve plates and a pair of channeltron detectors. The aperturing system collimates the incoming particles, which are then acted upon by an electric field such that particles entering the space between the plates are accelerated toward the inner plate. If the incoming particle's energy is such that the centrifugal force experienced by the particle as its trajectory is bent by the electric field equals the electric field force, the particle passes along the gap between the plates, impacts the channeltron, and is counted. Complete spectra of electrons and ions are taken every 1 sec.

Precipitating Electron/Ion Spectrometer (SSJ/4) - AFGL

Environmental Parameters Sensed/Derived

- In situ sensor which measures flux of precipitating electrons and ions in 20 energy bands between 30 ev and 30 Kev

- Flux range is energy dependent

  Electrons: 10 - 2 x 10^8/cm^2-sec-sr-ev
  protons: 1 - 5 x 10^6/cm^2-sec-sr-ev

Derived Quantities

- Auroral oval location

- Energy flux from magnetosphere

- E-region ionization rate and conductivity

Data Accuracy

- Particle flux ± 1%

- Energy flux ± 3.5%

- Average energy flux ± 15 - 20%

- Auroral oval location ± 1° latitude evening side, ± 2° morning side

Data Coverage

- 14 revolutions per day along track at a spatial resolution of about 0.1° latitude

- AFGL has developed techniques for interpolating data at 10° longitude increments, lower boundary location is accurate to + 3°.

Data Resolution

- 0.1° latitude along track

Other Comments

- On all S/C beginning with F-6

X-ray Spectrometer (SSB/A)

The scanning X-ray spectrometer detects X-rays from bomb debris or those produced by the bremsstrahlung process when electrons precipitate from the earth's radiation belts. Those electrons interact with atmospheric atoms and molecules, primarily in the altitude range from 100 - 150 km. By sensing these X-rays, the SSB/A can provide the location of the aurora as it orbits the earth. Through well-proven data analysis techniques it can measure enhancement in the electron density and conductivity in the E-region of the earth's auroral ionosphere.

The SSB/A is developed and produced by the Space Sciences Laboratory of The Aerospace Corporation. The major improvement over its predecessors is its scanning capability, so that a swath of the earth's atmosphere 3000 km wide is observed with a horizontal resolution of 100 km. The two detector heads scan in opposition across a 110° arc which is perpendicular to the orbital plane and approximately centered on the nadir. One of the two heads carries the high energy sensor, which spans the energy range 15 - 100 KeV, while the other carries the low energy sensor, which senses X-rays with energies in the 2 - 78 KeV range.

The ionization rate and conductivity of the E-region can be calculated from the energy spectrum of the bremsstrahlung X-rays measured by the SSB/A. The energy spectrum of the precipitating electrons is deduced from the X-ray spectrum and is used in calculating the energy transport through the atmosphere. This yields the energy deposition and ionization rates as functions of altitude. The equilibrium electron density profile can be derived from the ionization rate and known recombination rates, and, given the neutral density profile, the conductivity profile can be derived. Details of the design of the SSB/A and use of X-ray data for ionospheric remote sensing are given in Ref. 5 and 6.

Gamma-ray Spectrometer (SSB/A) - Aerospace Corporation

Environmental Parameters Sensed/Derived

- CdTe detectors sense X-ray radiation from earth's atmosphere in 4 energy bands 15-30, 30-60, 60-120, 120 Kev.
- Proportional counters measure X-rays in 24 logarithmically spaced energy bands between 14 and 70 Kev.
- Lyman alpha sensor detects prominent proton events.
- 2 Geiger counters detect energetic electrons that produce local X-ray background.
- Primary function is to detect nuclear detonations.
- Parameters capable of being derived include ionospheric conductivity and vertical electron density profiles in the D & lower E regions of the ionosphere; total auroral X-ray index (TAXI).
- Derived geophysical parameters
    - location and distribution of aurora
    - precipitating electron flux
    - ionization rate versus altitude
    - equilibrium auroral E-region electron density profile
    - E-region electrical conductivity

Data Accuracy

- Energy levels measured to within ± 18%
- Retrieved electron density profiles agree within error bars of ground truth data (± 30%)
- TAXI is a qualitative index of auroral activity

Data Coverage

- Daily global coverage
- Horizontal swath width 1500 nmi (3000 km), -57° to +48° FOV
- Data updated every 50 minutes

Data Resolution

- 55 nmi (110 km) along track
- 110 nmi (220 km) across track

Other Comments

- One-of-a-kind sensor on F-6

TOPSIDE IONOSPHERIC PLASMA MONITOR (SSIE)

The purpose of the SSIE is to measure, at the altitude of the DMSP spacecraft, the ambient electron density and temperature, the ambient ion density, and the average ion temperature and molecular weight. The instrument consists of an electron sensor and an ion sensor mounted on a 2.5 m boom. Instrument details are described in Ref. 7 and 8.

The electron sensor is a spherical Langmuir probe which operates in either of two modes. In mode 1, continuous electron density measurements are obtained by maintaining a constant voltage relative to the spacecraft on the outer grid of the probe; in order to offset possible spacecraft charging effects due to the design of the solar panels, this voltage is chosen (ideally) to maintain the SSIE sensor within a few volts of the potential of the ambient plasma. In mode 2, a linear sweep voltage is applied to the outer grid; analysis of current collected versus applied voltage yields a mmeasurement of electron temperature and vehicle potential. The normal operation of the electron sensor consists of a 64 second sequence which contains one 10 second sweep of mode 2, two seconds of dead time, and 52 seconds of mode 1.

The ion sensor is a planar aperture, planar collector sensor oriented to face into the spacecraft velocity vector at all times. The ion sensor operates in two modes similar to those of the electron sensor, so that both ion density and temperature are measured. Detailed analysis of the swept voltage data can also be used to determine the ion mean molecular weight and plasma scale height.

TOPSIDE IONOSPHERIC PLASMA MONITOR (SSIE) - AFGL

Environmental Parameters Sensed/Derived

- Measure electron and ion densities, temperatures
- Ion mean molecular weight
- Plasma scale height
- All measurements are in situ (at spacecraft only)

Data Accuracy

- Designed to measure particle densities to within ±20% of ground truth measurements.

Data Coverage

- Daily global coverage
- At spacecraft location only

Data Resolution

- One measurement of electron and ion density every 1 km along orbit
- Temperature measurement every 500 km

Other Comments

- Flew on F-2, F-4, F-6, F-7
- Being replaced by SSIES

IONOSPHERIC PLASMA DRIFT/SCINTILLATION METER (SSIES)

The SSIES is an improved version of the SSIE, which has measured the ambient ionospheric thermal electron and ion density and temperature on several DMSP spacecraft. In addition to the Langmuir probe and planar ion collector which make up the SSIE, the SSIES has a plasma drift meter and scintillation meter. These two additional instruments will be described briefly here. Detailed descriptions may be found in Reference A.3.

The drift meter measures the angle between the face of the sensor (which is nominally orthogonal to the spacecraft velocity vector) and the direction of arrival of the thermal ions which exist in the ionosphere at the spacecraft altitude. From this information and a knowledge of the spacecraft attitude and velocity, the two mutually perpendicular cross-track components of the plasma motion can be determined. This type of instrument, which is supplied by the University of Texas at Dallas, has operated successfully on the NASA Atmosphere Explorer and Dynamics Explorer spacecraft and on the DoD HILAT (P83-1) spacecraft.

The scintillation meter is a high time resolution ion collector whose purpose is to make measurements of the variability of the ion density along the orbital track of the spacecraft. (Variations in ion density on spatial scales 10 m - 10 km can give rise to amplitude and phase fluctuations (scintillation) on radio waves that pass through the ionosphere.)

The electron sensor is a spherical Langmuir probe which operates in either of two modes. In mode 1, continuous electron density measurements are obtained by maintaining a constant voltage relative to the spacecraft on the outer grid of the probe; in order to offset possible spacecraft charging effects due to the design of the solar panels, this voltage is chosen (ideally) to maintain the SSIE sensor within a few volts of the potential of the ambient plasma. In mode 2, a linear sweep voltage is applied to the outer grid; analysis of current collected versus applied voltage yields a measurement of electron temperature and vehicle potential. The normal operation of the electron sensor consists of a 64 second sequence which contains one 10 second sweep of mode 2, two seconds of dead time, and 52 seconds of mode 1.

The ion sensor is a planar aperture, planar collector sensor oriented to face into the spacecraft velocity vector at all times. The ion sensor operates in two modes similar to those of the electron sensor, so that both ion density and temperature are measured. Detailed analysis of the swept voltage data can also be used to determine the ion mean molecular weight and plasma scale height.

Ionospheric Plasma/Scintillation Monitopr (SSIES) - AFGL

Environmental Parameters Sensed/Derived

- Collects in situ electrons and ions via boom mounted electrostatic analyzer and 3 body mounted planar electrostatic ion traps (Langmuir probes).

- Derived parameters include electron and ion concentrations and temperatures, and plasma drift and irregularities (Δ Ne/Ne)

Data Accuracy

- ± 20% for the following parameters over the indicated ranges

  electron and ion density: 100 - $10^6/cm^3$
  electron temperature: 500 - 10,000°K
  ion mass: 1 - 16 amu (H ions or O ions)
  ion temperature: 500 - 10,000°K
  irregularities (Ne/Ne): 10^{-4} (SSIES only)

Data Coverage

- 14 revolutions of along track data per day

- At spacecraft altitude only

Data Resolution

- Along track (SSIE/SSIES)

  Electron and ion density sampled every 1 km or optionally every 0.25 km
  Ion mass and temperature sampled every 42 km or optionally every 26 km

- Statistical algorithm used to estimate other values around a latitude belt

Other Comments

- SSIE on F-6, F-7

- SSIES on S-8 and out

SPACE RADIATION DOSIMETER (SSJ*)

The purpose of the Space Radiation Dosimeter is to measure the radiation dose from both electrons and protons as well as the number of nuclear star events occurring behind 4 different thicknesses of aluminum shielding. In addition, it provides some information on the integral flux of electrons and protons at energies above the thresholds defined by the shields. The experiment provides information on the relationship between the flux of high energy particles incident to the spacecraft and the actual radiation dose to which microelectronic components are exposed. This information is required for determination of the relationship between variations in the earth's radiation belts and the behavior and lifetime of microelectronic components.

The basic measurement technique is to determine the amount of energy deposition occurring in a simple solid state detector from particles with sufficient energy to penetrate an omniddirectional aluminum shield of known thickness. The solid state device used as the active measuring element is a p-i-n diffused junction silicon semiconductor with a guard ring. The specific devices are from the YAG series manufactured by EG&G, Inc. With such devices a threshold of 50 keV for the energy deposition in the device can be set. This allows the detection of both the high energy particle as well as most of the bremsstrahlung produced in the shield. Although many detectors in the past have used "volume" type devices (detection area dimensions comparable to device thickness), the devices used in the SSJ* are of the planar type (detection area dimension large compared to thickness). This choice was made in order to most nearly model real microelectronic components that are primarily planar.

Each device is mounted behind a hemispheric aluminum shield. The aluminum shields are chosen to provide electron energy thresholds for the four sensors of 1, 2.5, 5. and 10 MeV and for protons of 20, 35, 51, and 75 MeV. The 1 MeV threshold sensor has a detector area of .051 cm^2, and the remaining three each have areas of 1.00 cm^2. Both particles which penetrate the shield and bremsstrahlung produced in the shield that impact the active element will deposit energy in the device producing a charge pulse. Then charge pulse is shaped and amplified. Pulse height is proportional to the energy deposition in the detector. The characteristics of the detector and the threshold are such that energy depositions between 50 keV and 1 MeV are summed to give the low linear energy transfer (LOLET) dose. Depositions between 1 MeV and 10 MeV are summed to give the high linear energy transfer (HILET) dose, and depositions above ~40 MeV are counted as very high linear energy transfer (VHLET) events. The LOLET dose comes primarily from electrons, high energy protons (above 100-200 MeV), and bremsstrahlung. The HILET dose is primarily from protons below 100-200 MeV. The VHLET dose comes from nuclear star interactions of high energy protons, from heavier cosmic rays, and from the very small percentage of trapped radiation particles that have long path lengths in the detectors.

The dose is taken to be directly proportional to the total energy deposited in the detector. Each pulse is analyzed to determine whether it will be counted for electron or proton dose or a nuclear star event. The pulse height is then digitized and added to the sum of all other pulse heights measured in the accumulation interval. In addition, the total number of pulses measured in the accumulation interval is also recorded for both electrons and ions. In the absence of significant bremsstrahlung, this number of counts should be directly proportional to the integral flux of electrons and ions above the threshold produced by the aluminum shield.

Dosimeter (SSJ*) - AFGL

Environmental Parameters Sensed/Derived

- Measures flux of electrons and protons in the natural radiation environment with energies greater than 4 threshold levels.
- Derived parameters are accumulated radiation dose rads (Si) electrons and rads (Si) protons.
- Electron threshold levels are 1.0, 2.5, 5.0, 10.0 Mev.
- Proton threshold levels are 20, 35, 51, 75 Mev.

Data Accuracy

- ±5%, counter electronics for electron fluxes not exceeding 10^5 ±80% electrons/cm^2 - sec above 1 Mev, and proton fluxes not exceeding 10^3 ± 80% protons/cm^2 - sec above 20 Mev

Data Coverage

- Designed to measure maximum accumulated dosage of

  10^5 rads (Si) ± 80% electrons
  10^4 rads (Si) ± 80% protons

  over the course of F-7 DMSP lifetime

- Daily global coverage at spacecraft altitude

Data Resolution

- N/A - data collected continuously throughout the orbital track

Other Comments

- Flown as an STP sensor on F-7
- Also to fly on CRRES

FLUXGATE MAGNETOMETER (SSM)

The SSM was flown on the DMSP F-7 spacecraft to measure geomagnetic field fluctuations associated with geophysical phenomena, such as ionospheric currents flowing at high latitudes. Built by the Johns Hopkins University Applied Physics Laboratory, the SSM is a tri-axial fluxgate magnetometer similar to instruments which have been flown on spacecraft for years. A recent example is the fluxgate magnetometer flown on the HILAT (P83-1) spacecraft and described in Ref. 4. Unlike previous magnetometers, the sensor for this instrument is not mounted on a long boom (to isolate it from magnetic field fluctuations originating in the spacecraft) but is mounted on the outer skin of the satellite, under the thermal blanket. In spite of possible contamination of the geophysical data due to the presence of spacecraft strayfields, the signature of field-aligned (Birkeland) currents can be found in the data.

The SSM provides information on ionospheric currents in the auroral zone. Auroral zone electron density profiles may be inferred when this information is combined with data from the SSJ/4 and SSIES. In addition, auroral neutral densities and IR backgrounds may be inferred from the same data.

Data obtained from SSM, in conjunction with electron density measurements, can be used to infer the electric potential distribution along the satellite track. This in turn can be used to estimate the amount of electromagnetic energy dissipated in the ionosphere in the form of Joule heating. This is a measure of energy transferred to the neutral atmosphere in the form of winds and thermal heating. The latter quantity is responsible for enhanced IR backgrounds and satellite drag during periods of high geomagnetic activity.

Magnetometer (SSM) - AFGL

Environmental Parameters Sensed/Derived

- Measures, in situ, three components of the earth's magnetic field and their fluctuations.
- Derived quantity: ionospheric currents.

Data Accuracy

- ±14.6 nanoteslas over a range of 0 - 60,000 nanoteslas
- Possible constant offset of 200 nanoteslas along each axis

Data Coverage

- 14 revolutions of data daily
- Measurement at spacecraft location only

Data Resolution

- Along track resolution ± 0.015 degree equivalent to a resolution of 400 meters
- Sampling rate of 20 vector samples/sec

Other Comments

- STP sensor flown on F-7 only

VACUUM ULTRAVIOLET SPECTROMETER (SSUV)

The SSUV is an instrument which has been proposed for flight on future DMSP spacecraft for the purpose of measuring the electron density of the ionosphere above 90 km altitude. A follow-on to the Auroral Ionospheric Mapper (AIM) that was built by the Johns Hopkins Applied Physics Laboratory for the Air Force Geophysics Laboratory and flown on the STP HILAT (P83-1) spacecraft, the SSUV would make use of ultraviolet emissions from the earth's atmosphere to infer the electron density profile. The overall system concept includes use of the VUV sensor itself, the SSIE sensor currently flown on DMSP, ground-based ionosonde data, and total electron content measurements from ground-based GPS receivers. The latter two sources of data, although not global, would be used both to increase the data base that could be incorporated in the 4-D ionospheric model at Global Weather Central and to refine the electron density profile inferred from the VUV data. In the following paragraphs, details of the VUV portion of the overall concept are described.

The SSUV instrument, as currently conceived, would operate in four ionospheric subregions: (a) the daytime low- to mid-latitude region from 90 to 600 km altitude; (b) the nighttime midlatitude regions from 250 to 600 km altitude; (c) the daytime equatorial regions; and (d) the auroral E layer from 90 to 200 km altitude. Other regions, such as the polar cap, the auroral F region and the nighttime equatorial region, are excluded for various reasons. The spatial resolution of the inferred electron density profile is envisioned as 500 x 500 km everywhere except in the auroral region, where it would be 50 km x 50 km. The method of operation of the VUV instrument in each of these four regions is described below.

a. Daytime Low- to Mid-Latitudes .

Here, the emissions from atomic oxygen O at 1356 Å and from one or more lines of the N_2 Lyman-Birge-Hopfield (LBH) bands in the 1500-1700 Å region will be measured. A spectrometer will be scanned from limb to limb and through the nadir in order to map out these emissions from the earth's upper atmosphere. The concept involves inferring a measure of the solar flux that causes ionization in the daytime ionosphere and the ratio of the density of O and N_2, coupled with theoretical models of photoionization and photo-electron transport, to calculate, from first principles, the electron density profile. An additional measurement of the electron density by the SSIE will tie down the electron density at the altitude of the DMSP spacecraft and provide a measure of the importance of neutral winds in the determination of the electron density profile above $h_m F_2$.

b. <u>Nighttime Midlatitudes</u>

In this subregion, the ratio between the emissions from atomic oxygen at 1356 Å and 6300 Å has been shown to correlate well with $h_m F_2$, and the absolute flux at 1356 Å gives a measure of the electron number density at the peak of the F_2 region. The attached figures illustrate these relationships. Detailed analyses are being performed to determine the size of the optics required to make accurate measurements of these weak emissions.

c. <u>Daytime Equatorial Regions</u>

Here, the situation is complicated by large-scale electric fields which, at different times of the day, raise or lower the ionosphere. Presumably, the same atmospheric emissions which are proposed for use at midlatitudes can be used, but some additional measurements are needed to infer the effects of the electric field.

As currently conceived, the VUV sensor consists of one spectrometer, primarily for use during both the day and night, and two or three photometers for use at night. The spectrometer is a 1/8 m Wadsworth instrument designed to cover the 1100-1800 Å region of the spectrum, while the photometers view 6300 Å and 1356 Å emissions.

d. <u>Auroral E-Layer</u>

Here, the ionization is produced by energetic (keV) electrons precipitating from the earth's magnetosphere. The emission from atomic oxygen at 1356 Å and from the N_2 LBH bands provide a measure of the incoming electron energy spectrum and flux; this information is then used, in an equilibrium theoretical code, to deduce the electron density produced by the auroral electrons.

VACUUM ULTRAVIOLET SPECTROMETER (SSUV) Applied Physics Lab/AFGL

Environmental Parameters Sensed/Derived

- Measures ultraviolet and (possibly) visible radiation emitted by the atmosphere
- Spectrometric measurements in the 1100-1800 Å spectral region (with emphasis on atomic oxygen emission at 1356 Å and the N_2 LBH bands in the 1500-1700 Å region)
- Photometric measurements of the atomic oxygen emissions at 1356 and 6300 Å
- Derived geophysical parameter is the vertical profile of the electron density above ~ 90 km altitude, from which total electron content can be calculated.

Data Accuracy

TBD

Data Coverage

- Daily coverage of globe, with exception of nighttime low latitude and equatorial region, auroral F-region and polar cap
- Overlapping data from consecutive revs - like OLS
- Horizontal swath width ~ ±3000 km from nadir

Data Resolution

- Horizontal resolution
  50 x 50 km in auroral region
  500 x 500 km elsewhere
- Vertical resolution TBD

Other Comments

- Planned for flight on DMSP F-16
- Proof of concept on STP Polar Bear (1986)

APPENDIX A REFERENCES

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APPENDIX C OF THE TECHNOLOGY DEVELOPMENT PLAN

AUTONOMY: NEAR TERM PLANS AND CONCEPTS

This Appendix reviews the present three-phased plan for autonomous navigation and describes options that are being studied for future applications. The present goal is to achieve 60-day autonomy through improved software and hardware for on-board attitude control, as well as redundancy and sensor management. This program has been divided into three phases .

The first phase of the program emphasizes basic attitude control which is accurate to 0.1°. In this phase, an ephemeris end-around modification will be implemented to eliminate the need for a daily ephemeris upload. Phase one will be implemented by April 1986. A power and redundancy management system, currently unfunded, will need to be developed before phase two can begin.

The second phase of the program improves the precision of the attitude control in phase one to 0.01°. The major navigational improvement required for this phase is a one-week star catalog. Poly-trig ephemeris calculations, a more accurate system in which time is the independent variable, are also scheduled for phase two. Three other software imrprovements are also involved in this phase. First, the OLS memory will be made compatible with the new ephemeris system. Secondly, solar array pointing algorithms will be improved in order to optimize solar array positioning. Finally, algorithms for sun-moon interference need to be developed since the satellite has to know when to disregard its celestial detectors. Phase two is currently unfunded.

The program's third phase extends the 7-day autonomy to the 60-day goal. This phase improves the software developed in phase one. At present, no additional hardware is anticipated to be required to extend autonomy from seven to sixty days. As the period of autonomous operation extends past phase two's seven days, a trade-off occurs with the precision of the attitude control. A satellite autonomous for sixty days will have an attitude control accurate to 0.1°. Currently, phase three is unfunded.

With the advent of DMSP II in the 1990s, the opportunity exists to design in hardware changes. If pursued, these hardware changes would be able to extend autonomous operation past sixty days as well as returning the precision of the attitude control to .01° for the entire autonomous period. With respect to autonomous navigation there are presently three hardware options and two software options.

GPS processing software will be used with the first of the three hardware options - the GPS receiver. The current GPS system uses a receiver with a volume of approximately 1700 in^3, a weight of roughly 20 lbs, and a power requirement on the order of 20 W. The GPS theory involves a satellite determining its position relative to the position of other known satellites. The advantage of this method is that it effectively removes ground dependency. It does, however, have the disadvantage of introducing inter-satellite dependency. As a form of insurance against missed signals, satellites would be equipped with software which would enable it to approximate its position via orbital mechanics calculations. Of course, the accuracy of the calculations would decrease in a multiplicative manner if consecutive signals were missed.

A miniaturized GPS receiver (mini-GPS) is currently being designed and should be available in the early 1990s. This receiver has the following approximate parameters: volume - 6 in^3, weight - 0.51 lbs, and power requirement - 2 W.

The second hardware option is the Charge Transfer Device (CTD) Star Tracker. Several models are being examined by the Aerospace Corporation at this time. Representative statistics for such a system are: volume - 3500 in^3, weight - 50 lbs, and power requirement - 50 W. The star tracker could replace the space telescope and its slit type detector technology with an array of detectors which give the satellite a two-dimensional view of space. The Star Tracker's two axes system allows it to determine its direction in space more quickly and more accurately. By using an on-board clock to determine its position relative to the earth, the CTD Star Tracker carries an advertised accuracy of 0.5 nmi after 180 days of autonomous operation.

The final hardware option is the Magnetometer. The purpose of the SSM is to measure magnetic disturbances transverse to the main geomagnetic field at high latitudes which are associated with auroral field aligned currents. This information is needed to know when and in what direction to torque the magnetic coils to unload momentum. A prototype of the Magnetometer has already flown on F-7. The Magnetometer occupies 700 in^3, weights 8.0 lbs, and requires 5.0 W. With these parameters, the Magnetometer is lighter, smaller, and less power consuming than either the standard GPS receiver or the CTD Star Tracker. Based on practical experience, the Magnetometer has a reliability (probability of performing within specifications) of at least 0.8 for three years in orbit. It is also radiation hardened and thus more survivable. It is capable of withstanding a radiation exposure of 1E+05 (Si) total dose.

A second software attitude update is also being considered. A gyro-less attitude determination and control system is being examined as both a backup system and as a primary system. The motivation for this effort is the problem filled history of DMSP gyros.

It is reasonable to assume that 60 days of autonomy will make the satellite completely autonomous for all practical purposes. Thus, no major structural changes are included in the three-phased autonomy plan. Future actions will be defined in terms of how soon the ground system can be reconstructed. Sixty days should be more than sufficient given the state-of-the-art of replaceable ground antennas and mobile vans.

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