

NASA Technical Memorandum 100683

NASA Sea Ice and Snow Validation Plan for the Defense Meteorological Satellite Program

Special Sensor Microwave/Imager

SEPTEMBER 1987

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1987

PREFACE

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FORWORD

In 1982, NASA established a DMSP-SSM/I Science Working Group (SWG) for the purpose of preparing a coherent program to acquire the SSM/I microwave radiance data, to convert the data into useful sea ice parameters, and to archive the data for the scientific community. The NASA Ocean Data System (NODS) at the Jet Propulsion Laboratory in Pasadena, California was assigned the task of developing software to process and to map the geophysical parameters. The National Snow and Ice Data Center (NSIDC) in Boulder, Colorado will assume the long term responsibilities of processing and archiving these data. The SSM/I SWG under the chairmanship of Norbert Untersteiner (University of Washington, Seattle) reviewed the present state of passive microwave remote sensing for sea ice research and made specific recommendations for the utilization of the SSM/I data. The findings and recommendations of the SWG appear in a document entitled Passive Microwave Remote Sensing for Sea Ice Research published for NASA.

In early 1984, Robert H. Thomas, then NASA manager for Polar Programs, called together members of the polar science community including specialists in passive microwave remote sensing of sea ice for the purpose of implementing the recommendations made by the SSM/I SWG. As a result of this meeting, a NASA Sea Ice Algorithm Working Group (SAWG) was established and charged with the following tasks: first, to evaluate the current state of passive microwave sea ice algorithms; second, to select an algorithm for initial processing of the SSM/I data; third to provide guidance to NODS for the implementation of the selected algorithm; and finally, to develop and execute a plan for validating the algorithm and for identifying potential algorithm improvements.

In 1986, Kenneth C. Jezek, NASA manager for Polar Programs, established a program to implement this last task, the validation of the NASA SAWG algorithm. This document outlines a plan for monitoring the performance of the sensor, validating the derived sea ice parameters, and providing for the quality assurance of the data products before distribution by NSIDC to the research community. A NASA validation team for the SAWG algorithm has been chosen for executing the plan outlined in this document. A parallel program has been established by the Department of Defense under the leadership of James P. Hollinger

(Naval Research Laboratory) and will center on the validation of their sea ice algorithms. Coordination between the two validation efforts as far as possible will help maximize the use of limited resources. Because of recent advances in the application of passive microwave remote sensing to snow cover on land, the validation of snow algorithms is also addressed as an addition to the original objectives in this NASA document.

While this report presents a specific plan to validate the NASA SAWG algorithm, it does not address the ongoing activities of the SAWG which focus on the examination of alternate algorithms. A critical review of the data collected during the validation effort will be undertaken by the SAWG as a necessary condition for assessing alternate algorithms. It is anticipated that separate documents on algorithm modification or replacement will be issued approximately one year after launch of the SSM/I.

1.0 Introduction

A key requirement for studying the role of snow and sea ice in the global climate system and for understanding the interactive ice-ocean-atmosphere processes is the ability to acquire large-scale synoptic observations. Satellite microwave imagery, unhampered by clouds or by darkness, satisfies this requirement and provides the requisite large-scale coverage for undertaking studies of the cryosphere. Current problems in sea ice research and specific contributions of passive microwave remote sensing have been addressed in a report of the NASA Science Working Group for the Special Sensor Microwave/Imager (1984). Plans for the SSM/I data are based on over ten years of passive microwave imaging from several research satellites. The NASA report outlined the research required to realize the potential of the measurements to be made by the SSM/I.

With the launch of the Nimbus 5 Electrically Scanning Microwave Radiometer (ESMR-5) in December 1972, almost continuous coverage of the polar regions was obtained for the first time. Because of instrument degradation, the usefulness of the ESMR-5 data set was limited to four years. Nevertheless, these four years of data provided the basis for documenting the large spatial variations in ice extent and concentration on time scales ranging from seasonal to interannual in both the Arctic and Antarctic (e.g., Zwally, et al., 1983, 1983; Parkinson et al., 1987).

Two major limitations of the single-channel ESMR were its inability to distinguish among radiometrically different sea ice types within the field-of-view of the instrument and to accommodate variations in the physical temperature of the radiating portion of the ice and snow. With the launch of a Scanning Multichannel Microwave Radiometer (SMMR) in 1978 on both the SeaSat and Nimbus 7 spacecraft, some of these limitations have been overcome through the utilization of the multifrequency, dual-polarized radiances obtained with the SMMR. SMMR data have improved the calculation of sea ice concentration especially in the Arctic and have provided multiyear ice concentrations and ice temperatures. Additional parameters including snow-cover variability, areal coverage of melt ponds during the summer months, and the fraction of thin ice cover during winter may eventually be determined from passive microwave sensors.

Passive microwave remote sensing instruments also provide the capability to quantitatively measure snowpack and to respond to variations in snowpack properties, thereby providing information about snow depth and snow water equivalent. Observations from the Nimbus 7 SMMR have been used with some success to determine regional and global snow parameters. Areas with rugged terrain and heavy vegetation present a greater challenge in developing retrieval techniques. This problem can be partially overcome by using higher spatial resolution data from higher frequencies than are currently available from SMMR.

The next generation of multichannel microwave radiometers will be flown on a series of satellites operated by the Defense Meteorological Satellite Program starting in 1987 and extending well into the 1990's. This new instrument is the Special Sensor Microwave/Imager (SSM/I) which will fly in a sun-synchronous, near-polar orbit at an altitude of 833 km with a period 101 minutes. In contrast to the SMMR on the SeaSat and Nimbus spacecraft, the SSM/I will provide near global coverage every day. The SSM/I operates at four frequencies (19.35, 22.24, 37.0, and 85.5 GHz) with orthogonal (horizontal and vertical) polarizations measured at each frequency except 22 GHz, which will have only a vertical polarization channel. The 85.5 GHz channels will provide a spatial resolution of better than 15 km, a significant improvement over the SMMR. Details of the instrument's operating characteristics are given by Hollinger and Lo (1983), and a summary is given in Appendix A.

The purpose of this report is to outline a plan for (1) determining the degree to which the sea ice and snow parameters derived from the SSM/I meet the observational requirements as specified by the polar science community, (2) providing the SAWG with the necessary information in order for that group to make recommendations for possible algorithm changes and data reprocessing, and (3) monitoring the performance of the sensor and for routinely checking the quality of the data products before distribution to the user community. The justification for this effort stems from the need to supply the polar science research community with a usable passive microwave data set which has been quality checked and for which the derived geophysical parameters have been quantitatively validated (NASA Science Working Group, 1984). A summary of the SSM/I data sets

recommended for archival by the NASA Science Working Group is given in Table 1 and the geophysical areas in the northern and southern hemispheres to be covered by the NASA archive of gridded SSM/I data are presented in Figure 1.

Table I Summary of Data Sets Recommended for Archival

Data Set	Time Average (days)	Channels (GHz)	Parameters	Storage (MBytes/year)
SDR's	N/A (swath)	19.4 V,H 22.2 V 37.0 V,H 85.5 V,H	Global brightness temperatures in swath format	28,000
12.5 km brightness temperatures	1	85.5 V,H	Gridded average brightness temperatures (polar regions only)	2,150
25 km brightness temperatures	1	19.4 V,H 22.2 V 37.0 V,H	Gridded average brightness temperatures (polar regions only)	1,350
50 km ice maps	3	Combination	Gridded average total ice concentration and multiyear ice fraction (polar regions only)	240
Ice extent	1	85.5 V,H	Ice boundary	2
Monitor areas	1	19.4 V,H 22.2 V 37.0 V,H 85.5 V,H	Summary of brightness temperatures in monitor areas	0.6

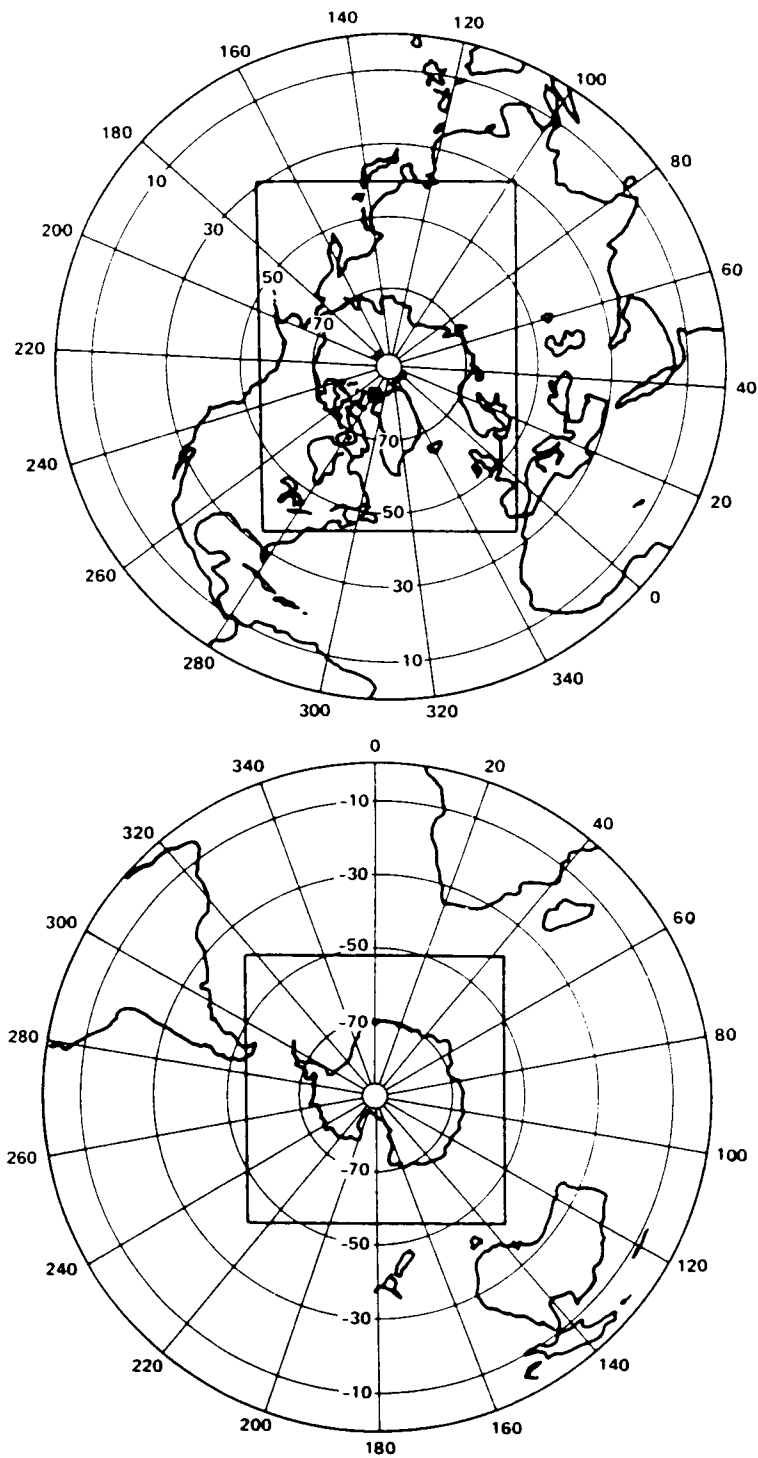


Figure 1. Geographical areas representing SSM/I data to be processed by the NASA Ocean Data System [Figure extracted from the NASA Science Working Group Report for the Special Sensor Microwave/Imager, 1984]

The plan consists of a summary of the observational requirements, specific validation objectives, an outline of both pre-launch and post-launch activities with essential and highly desirable tasks identified, guidelines for monitoring the sensor performance and for checking the quality of data products, and the rationale for recommending algorithm modifications and data reprocessing. An overview of this plan is schematically presented in Figure 2. The implementation of this plan is the task of the NASA SSM/I validation team. The organizational structure within the overall NASA SSM/I effort is illustrated in Appendix B. Team members and their respective responsibilities are given in Appendix C. Finally, this plan will be coordinated with a validation plan that has been developed for the Department of Defense.

2.0 Observational Requirements

The observational requirements for sea ice and snow parameters have been documented in several sources over the past number of years. Three such documents include: Ice and Climate Experiment (ICEX): Report of Science and Applications Working Group (1979); Passive Microwave Remote Sensing for Sea Ice Research: Report of the Science Working Group (1984); and Earth Observing System (EOS) (1984). All of these reports have addressed observational requirements to various degrees of detail, including those requirements that favor sensors other than microwave radiometers. Identification of pressure ridges and leads, for example, requires a spatial resolution of tens of meters that can only be provided by imaging radars or optical sensors. Those requirements which can be accommodated with microwave radiometer measurements are very well organized in the ICEX document, and excerpts of those requirements are summarized below in Table II for sea ice and in Table III for snow cover.

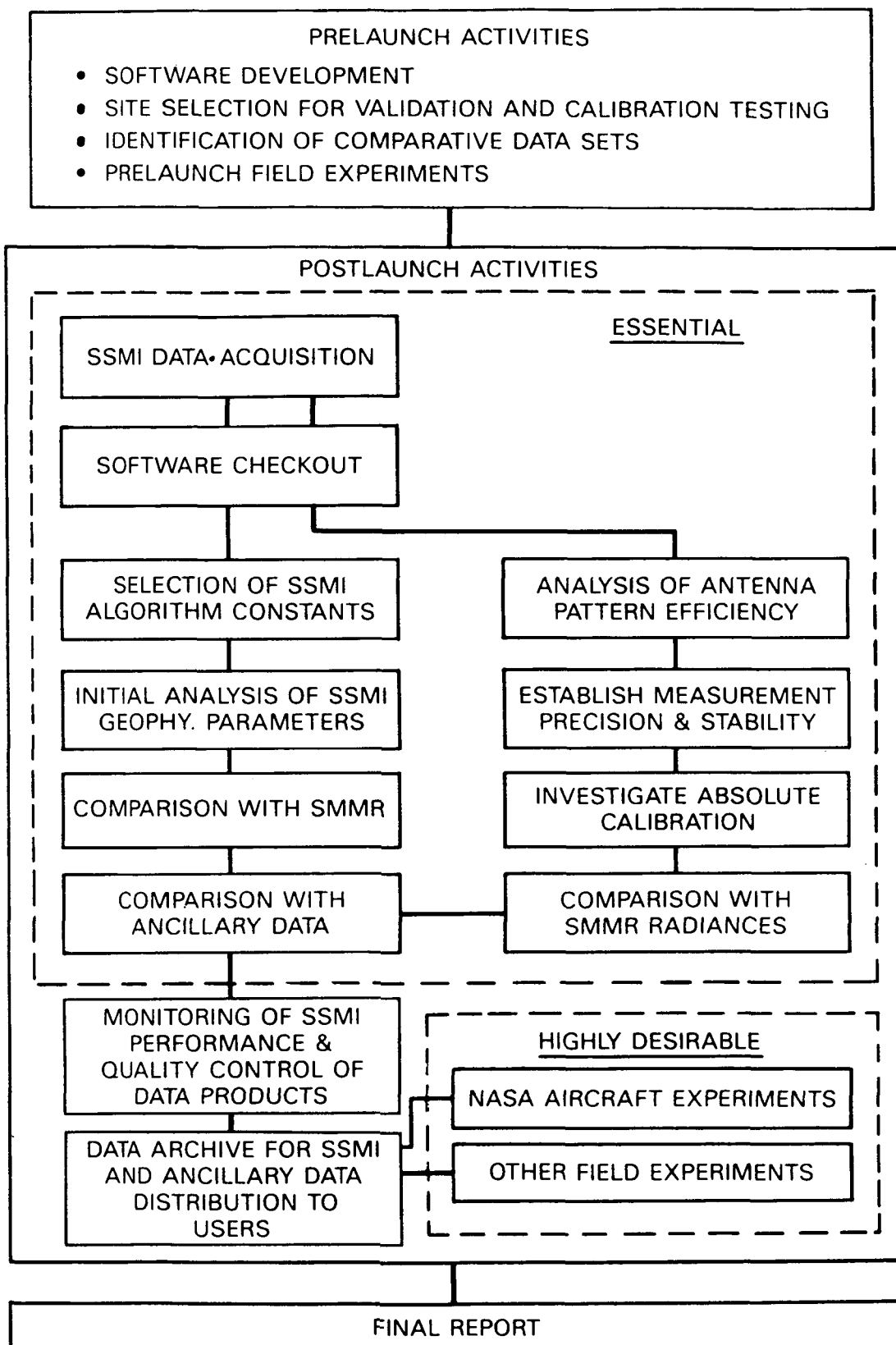


Figure 2. NASA SSMI Validation Plan.

Table II. Sea Ice Observation Requirements.

SEA ICE PARAMETER	CATEGORY			TYPE OF OBSERVATION	OBSERVATION REQUIREMENT						
	BASIC	CLIMATE	OPN/COMM		ACCURACY		RESOLUTION				
					DESIRED	MIN	SPACE		TIME		
Boundary	I	I		Line Position	5 km	20 km	5 km	20 km	1 day	3 days	
Concentration	I	I		% of Area	2%	5%	25 km	25 km	1 day	3 days	
				I	% of Area	10%	20%	5 km	25 km	1 day	3 days
				II	%of Area	2%	5%	1 km	10 km	1 day	3 days
Ice Type	I	I	II	Frac/ Area	5%	10%	1 km	25 km	7 days	1 month	
				By Type							
Surface Melting		II		Frac/ Area	Wet/Dry	Wet/Dry	25 km	25 km	1 day	3 day	
Surface Temperature	I	I		Area Average	1°K	3°K	25 km	100 km	1 day	3 day	
Ice Thickness	III	III		Area Average	20 cm	1 m	25 km	100 km	7 days	1 month	
(Limited thickness			III	Area Average	20 cm	1 m	50 km	1 km	1 day	3 days	
Information can be											
Inferred from ice type)											
Wind Velocity	III	III	III	Area Average	10°	20°	25 km	50 km	1 day	3 days	
(over oceans only)											

Table III. Snow Cover Observation Requirements.

SNOW PARAMETER	CATEGORY			TYPE OF OBSERVATION	OBSERVATION REQUIREMENT					
	BASIC	CLIMATE	OPN/COMM		ACCURACY		RESOLUTION			
							SPACE		TIME	
					DESIRED	MIN	DESIRED	MIN	DESIRED	MIN
Percent Coverage	III	II		Area Average	5%	5%	10 km	50 km	7 days	7 days
H ₂ O Content			II	Area Average	1%	5%	1 km	10 km	3 days	7 day
		II		Area Average	1cm/cm ²	3cm/cm ²	10 km	50 km	7 days	7 days
			II	Area Average	1cm/cm ²	3cm/cm ²	1 km	10 km	3 days	7 days

Sampling Key

- I - Continuous
- II - Frequent
- III - Occasional

It seems appropriate to discuss the sea ice and snow requirements in relationship to the capabilities of the SSM/I. Beginning with the temporal requirements given in Tables II and III, it should be noted that polar orbiting satellites always tend to give excellent coverage in the Arctic and Antarctic regions. Furthermore, the SSM/I will have a data swath of almost 1400 km., which is almost twice that achieved by the SMMR. Indeed, Figure 3 illustrates the expected coverage achieved by the SSM/I during a 12-hour period over the northern hemisphere. Twelve hours later, the remaining portions of the globe will have been observed, except for some portions near the equator and the poles. Thus, the desired temporal resolutions given in Tables II and III will be more than met by the SSM/I.

The typical minimum spatial resolution requirement given in Tables II and III is 25 km., which will be difficult to achieve using existing SSM/I sea ice algorithms. Figure 4 illustrates this problem by noting the SSM/I footprint dimensions. Because the near circular antenna scans about a constant cone angle of 49 degrees, the earth-located footprint will project an ellipse, with the semi-major axis oriented along the velocity vector of the space-craft. The instantaneous dimensions of the ellipse are $L \times C$ as indicated in the figure, with the cross-track dimension stretched to the dimension X by the finite integration time of the instrument. The existing algorithms will all utilize the 19 GHz channels to give an average spatial resolution approaching 50 km. Therefore, the initial algorithms will not satisfy the minimum spatial resolution requirements as defined in the ICEX document. One exception is the location of the ice edge, which will utilize the 85 GHz channel, resulting in a spatial resolution of approximately 15 km. Clearly, an advancement in algorithm or sensor development will be required to generally meet the ICEX minimum requirements for spatial resolution.

The other major requirements to be noted for sea ice relate to ice concentration and ice type accuracies. These requirements are coupled to current algorithm limitations and instrument precision (Swift and Cavalieri, 1985). At present, the accuracy of sea ice concentration using the NASA SAWG algorithm is limited to between 5% and 10% (e.g., Cavalieri et al., 1984; Burns et al., 1987; Martin et al., 1987). Larger uncertainties exist in regions of new ice production (Cavalieri et al., 1986). Significant improvements will most

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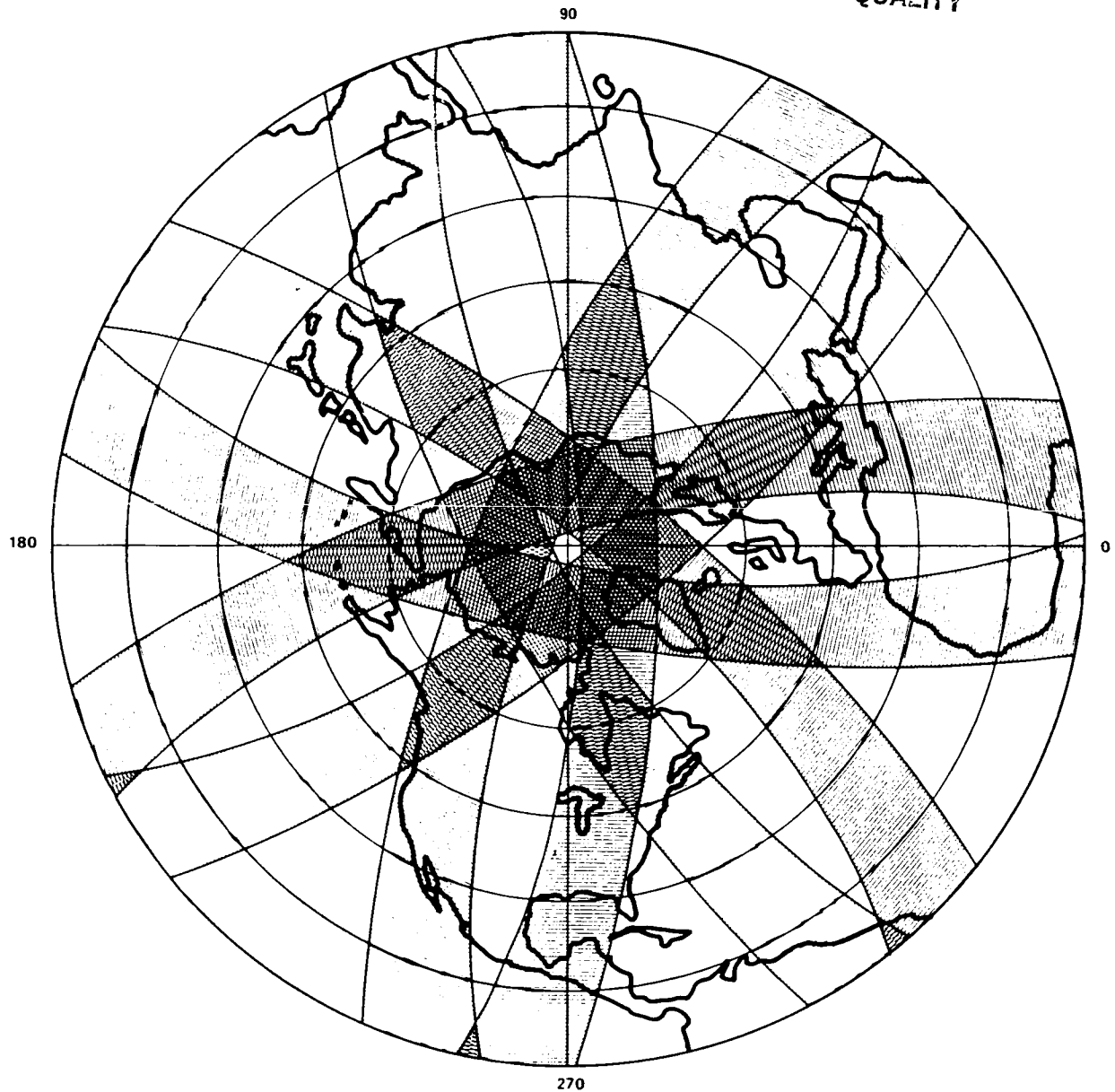
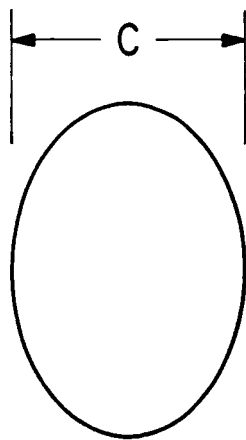
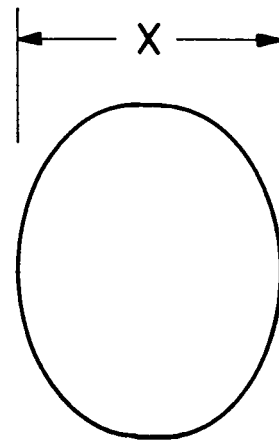
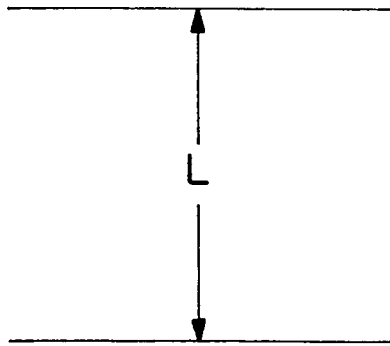


Figure 3. Polar Orbital Coverage by the SSM/I during a 12 hour period. In one day most of the earth is covered except for some small sectors near the equatorial regions and at the poles. [Figure extracted from the NASA Science Working Group Report for the Special Sensor Microwave/Imager, 1984].



IFOV



EFOV

<u>FREQUENCY, GHz</u>	<u>POLARIZATION</u>	<u>L</u>	<u>C</u>	<u>X</u>
19.35	V	68.9	41.4	44.3
	H	69.7	40.8	43.7
22.235	V	59.7	36.3	39.6
37.0	V	35.4	22.1	29.2
	H	37.2 „	21.0	28.7
85.5	V	15.7	9.5	13.9
	H	15.7	9.5	13.9

Figure 4. Footprint dimensions for each of the SSM/I channels. The sketch shows the footprint dimensions for both the instantaneous (C) and effective (X) fields of view. The effective field of view increases as a result of sensor integration time.

likely involve the use of region-specific algorithms or local tuning. The degree to which we can distinguish ice types, currently limited to first-year and multiyear, is not as good. Because there is a continuum of radiometric signatures from first-year, through second-year, to very old ice, regional tuning is again called for. At present, there are no unambiguous methods of distinguishing among multiyear ice types.

For snow, the resolution of the SSM/I limits the precision of the snowline on regional maps, but on hemispheric or global maps which are at a scale of $1/2^\circ$ latitude by $1/2^\circ$ longitude, the SSM/I resolution does not adversely affect the determination of the snowline. Due to the coarse spatial resolution of the present microwave radiometers, combinations of vegetation, terrain and snow information within a pixel complicate the development of snow retrieval algorithms and the interpretation of the microwave brightness temperature signatures (Foster, et al., 1984). During the snow accumulation season, satellite coverage is desirable once every five or six days, corresponding to the time it takes weather systems to develop and move along preferred storm tracks. However, as the snow begins to melt repetitious coverage every three or four days would be valuable because the snowpack can change rapidly in grain sizes, thickness and area/extent.

3.0 Validation Objectives

The specific objectives of the validation effort are (1) to verify the instrument's precision and stability including its calibration in an absolute sense, (2) to validate the geophysical parameters derived from the calibrated radiances, and (3) to provide documentation of how well each of the parameters meets the observational requirements specified in the previous section. The approach for evaluation of the sensor performance is relatively straightforward and is discussed in Section 6.0. On the other hand, the question of the validation of geophysical parameters is considerably more complex.

In general, validation means to substantiate, or to confirm. For remote sensing purposes, validation usually means comparing a geophysical parameter derived from a remote sensing instrument with a similar parameter derived either from insitu measurements or other ground "truth". The ground "truth" must have a known precision and accuracy; preferably an order of magnitude better than the measurement we are trying to validate. However, in practice, the ground "truth" can have as much uncertainty as the remote

sensing measurement under question. As a consequence, the validation effort becomes one of comparing two parameters obtained with different techniques. While such a comparison is not strictly a validation, the cross-comparison may provide very useful information.

Confidence in microwave-derived sea ice parameters will result from the compilation of numerous validation studies demonstrating a quantitative relationship with known and accepted data sets covering as many geographical areas as possible under both winter and summer conditions. In practice these validation studies will provide a statistical comparison of the SSM/I-derived sea ice parameters with alternative sources of data including visible and infrared satellite imagery, aircraft visual, photographic and high resolution microwave observations, and surface measurements made from manned-platforms and satellite-interrogated buoys.

The overall approach will attempt a true validation by identifying those ancillary data sets which have known precision and accuracy to be useful in ascertaining whether or not the SSM/I derived parameters meet the specified requirements. Once these established sources of data are identified then a comparative analysis will be carried out. In some cases, there will be a need to validate the ancillary data for the purpose of establishing the utility of the data set before comparison with the SSM/I geophysical parameters. This will be accomplished by using higher resolution sensor data or insitu observations over small test areas. Other comparative data sets (e.g., from field experiments) will be generated, if there are no established sources of data available for validating a specific parameter.

Another key requirement for establishing a meaningful intercomparison is the temporal and spatial coincidence of the two data sets. A familiar example of not satisfying this requirement is the problem of comparing a point measurement with an areal observation. Thus there is a need for multisensors in the same or different satellites, and well coordinated field experiments with aircraft flying mosaic patterns to cover a sufficient number of satellite footprints.

Although recent studies have demonstrated the utility of passive microwave satellite remote sensing for measuring snow pack properties, there exists no generally accepted algorithm at present for deducing snow depth and snow water equivalent (SWE) over land from microwave radiometer signals. Several algorithms, all still under study and

development, are available to evaluate snow presence and SWE for specific regions and specific seasonal conditions. A reliable SWE algorithm suitable for all seasons has so far eluded researchers.

For the purpose of developing an acceptable snow algorithm for large-scale studies and for furthering the understanding of the interaction between microwave radiation and the snow pack, the following objectives will serve as the focus of the snow validation effort. First, on the short-term, existing algorithms will be combined and refined for extracting SWE values so as to produce a single algorithm for a specific region valid over an entire snow season. Second, ground-based and airborne experiments will be conducted to gain detailed information about the microwave response to various snowpack parameters so that spatial variations within the field of view of the SSM/I can be better determined. Third, in conjunction with the International Satellite Land Surface Climate Project (ISLSCP), a radiative transfer model using SSM/I will be developed to better understand the interaction between microwave radiation and the snow cover properties.

It is anticipated that the SSM/I will provide more realistic values for snow density and snow grain size, important parameters in radiative transfer models, as a result of data acquired from the higher frequency channels (i.e., 85.5 GHz). Results from these types of investigations will be used to refine the current SMMR algorithms and should improve the accuracy of the microwave snow maps.

3.1 Summary Reports

Finally, the end product of this overall validation effort will be two reports; one each for sea ice and snow. The reports will summarize for each parameter the level of agreement between the SSM/I derived parameters and those obtained from other sources. For sea ice, the report will address the relative accuracy (relative to other observations) of the following parameters:

1. Position of the sea ice boundary
2. Total sea ice concentration
3. Multiyear sea ice concentration

Other key points to be addressed will be the accuracy to which the 85.5 GHz channels can locate the ice edge, the accuracy of the parameters in different regions (e.g., the central Arctic, the marginal ice zones, shallow seas such as the Bering Sea and deep ocean such as the Greenland Sea), the accuracy of the parameters under various weather conditions and the effectiveness of weather-effect filters, and the accuracy of the parameters in different seasons.

For snow, the report will focus on the ability of the algorithm(s) to measure snow pack properties, principally for specific regions and for specific seasonal conditions. An assessment of the feasibility of developing a reliable global algorithm for snow cover area and SWE will also be included.

These reports will provide the polar research community with documentation on how well the sea ice and snow algorithms meet the observational requirements. Furthermore, specific directions for research toward the development of algorithm improvements with special emphasis on the newly acquired 85.5 GHz data will be provided.

4.0 Sea Ice and Snow Algorithms

4.1 Sea Ice Algorithm

The two most important sea ice parameters that are currently derived from passive microwave satellite observations for studying global climate systems are the extent and concentration of the ice cover. The ice-edge position is relatively easy to acquire due to the large ice-water contrast at microwave wavelengths. The amount of open water within the instrument's field-of-view is more difficult to determine. This difficulty stems from the variability of the microwave emission of the sea ice which depends on a combination of factors including chemical composition, physical structure and temperature of the ice. Also included are the surface properties such as snow density, grain size, surface roughness, brine content and the degree of wetness. Thus, the accuracy to which the amount of open water can be determined depends on the degree to which all of these factors can be unambiguously distinguished.

After SMMR data became generally available as a reliable product in 1980, three groups became active in algorithm development and performance using satellite data coupled with in-situ observations. Each group developed an algorithm which appears in the

open literature, and each algorithm calculates both first-year and multiyear sea ice concentrations using only the 18 and 37 GHz channels. One of the algorithms was developed by members of the Nimbus 7 SMMR experiment team at the NASA Goddard Space Flight Center and is currently being used by the Nimbus project for deriving sea ice parameters from the SMMR data. The algorithm is described by Cavalieri et al. (1984) and is referred to as the Goddard algorithm. Another algorithm, developed jointly at the University of Massachusetts, Amherst, and at the Canadian Atmospheric Environmental Service, Ottawa, is termed the UMass/AES algorithm; it is described by Swift et al. (1985). The third algorithm, the Bergen algorithm, was developed by the remote sensing group of the University of Bergen, Norway who were involved in the Norwegian Remote Sensing Experiment (NORSEX). This algorithm is based on surface observations made during NORSEX, and is discussed by Svendsen et al. (1983). Details of the algorithm derivations and algorithm quality are discussed in these three papers.

In December 1984, The NASA Sea Ice Algorithm Working Group evaluated the results of sensitivity studies of each of these algorithms for the purpose of choosing one for use in processing the SSM/I data at the NASA Ocean Data System (NODS) at JPL. All three algorithms had merits and deficiencies; however, the Goddard algorithm was less sensitive to errors introduced by uncertainties in sea ice temperature. Furthermore, a weather filter (Gloersen and Cavalieri, 1986) was subsequently developed and tested, which greatly reduced false retrievals of sea ice over areas of open ocean. For these reasons, the Goddard algorithm (hereinafter the SAWG algorithm) was selected for implementation by NODS for the initial sea ice data products. A detailed discussion of the rationale for selecting this algorithm and the sensitivity study results are given in Swift and Cavalieri (1985).

The SAWG algorithm is nonlinear in brightness temperature and uses two ratios as the independent variables. The first is the polarization PR which is a normalized difference between the vertically polarized brightness temperature TBV and the horizontally polarized brightness temperature TBH and is defined for each frequency by:

$$PR = (TBV - TBH)/(TBV + TBH).$$

The polarization for either first-year ice or multiyear ice is considerably less than that for ice-free ocean. This property allows the polarization to be used for calculating sea ice concentration for each field of view of the sensor. The determination of multiyear ice concentration is based upon the increasing difference between the microwave emissivity of first-year ice and multiyear ice with increasing frequency. A parameter incorporating these spectral variations at 19 and 37 GHz is the spectral gradient ratio defined by:

$$GR = (TBV(37) - TBV(19)) / (TBV(37) + TBV(19)).$$

The GR parameter, which is independent of differences in polarization, is used to discriminate among ice-free ocean, first-year ice, and multiyear ice. Over open ocean, GR is positive; over first-year ice, GR is approximately zero; and over multiyear ice, GR is negative. These properties of the GR parameter also form the basis of the filter used to eliminate spurious sea ice concentrations over areas of open ocean resulting from weather-related effects such as heavy cloud cover and high surface winds (Gloersen and Cavalieri, 1986). This approach of using brightness temperature ratios for calculating ice concentration and type, discussed in greater detail by Cavalieri, et al. (1984), has the added advantage of greatly reducing the uncertainties in the derived ice parameters resulting from spatial and temporal variations of ice temperature. The sensitivity of the calculated ice concentration on ice temperature variations is reduced by over an order of magnitude (Swift and Cavalieri, 1985). The disadvantage of the SAWG algorithm is that it is more susceptible to errors associated with instrument noise fluctuations. However, the precision of the SSM/I measurements of the radiances is such that average errors in retrieval concentrations will not exceed $\pm 5\%$.

The SAWG established several ground rules for the implementation of operational algorithms, which are discussed in a subsequent section. The SAWG also recognizes that continuing research by various institutions will inevitably lead to improvements in the data products. Ground rules for implementing algorithm modification or algorithm replacement is discussed in Section 8.0.

4.2 Snow Algorithms

Currently, several algorithms are available to evaluate and retrieve snow cover and snow depth parameters for specific regions and specific seasonal conditions. These algorithms have been derived from an analysis of data obtained from a combination of microwave sensors on-board satellites, aircraft, and surface-based measurements (Hallikanen and Jolma, in press). Efforts to produce a reliable global snow algorithm using theoretical calculations have been made by several investigators (Kunzi, et al., 1982), (Hallikanen, 1984) and (Chang, et al., 1986). For example, Chang, et al., (1986) have developed an algorithm that assumes a snow density of .30 and a snow grain size of .35 mm for the entire snowpack. The difference between the SMMR 37 GHz and 18 GHz channels is used to derive a snow depth/ brightness temperature relationship for a uniform snow field. Microwave measurements have the capability to penetrate the snow and respond to variations in subsurface properties. In addition, the microwave portion of the spectrum is advantageous because of the large difference in the dielectric constant of liquid and frozen water, which causes a significant variation in the microwave signal when liquid water is present.

At present, radiometers at 0.8 cm wavelength (37 GHz frequency) are the most widely used sensors for snowpack monitoring. Scattering of the 0.8 cm radiation by the snow is strong since snow crystal sizes often equal or surpass the wavelength. In order to study the internal structure of snowpack metamorphism, microwave radiation which emanates from different portions of the snowpack at different microwave wavelengths can be better analyzed using the multifrequency approach.

During the 1983 Bering Sea Marginal Ice Zone Experiment (MIZEX - West) a 92 GHz sensor was employed on-board the NASA CV-990 aircraft. Over Alaska it was found that the 92 GHz data are even more sensitive to snow crystal scattering than the 37 GHz data (but also more sensitive to atmospheric constituents). Microwave brightness temperature patterns in the Alaskan study area at 92 GHz were found to be similar to the brightness temperature patterns from the 37 GHz data (Chang, et al., 1987).

This algorithm is presently being tested in several different regions in the northern hemisphere in order to verify the microwave response of varying snow conditions. One such region is in the western U.S., the Colorado River basin (289,600 km²), which includes

rugged terrain and heavy vegetation. This basin presents a greater challenge in developing snowpack parameter retrieval techniques than do flat, homogeneous prairie areas. SMMR data for the winter seasons from 1979 to 1983 have been studied in an effort to establish a relationship between microwave brightness temperatures and snow depth measurements made in different elevation zones and physiographic areas of the Colorado River basin. Three years of data (1979-1981) are being used to develop a snow parameter retrieval algorithm which will be tested by using the remaining two years. Preliminary results indicate that even in heterogeneous mountainous regions it may be possible to use remotely sensed microwave data to better estimate the water content of high elevation snowpacks.

5.0 Pre-launch Validation Activity

5.1 Sea Ice

In preparation for the validation/calibration of the SSM/I, a number of pre-launch tasks have been identified. These tasks include:

- Software development and testing
- Selection of sites for algorithm validation and instrument performance tests
- Co-registration of SSM/I with SMMR grids
- Instrument bias removal techniques with SMMR
- Identification of established data sets for comparison with SSM/I
 - Arctic Ocean Buoy Program and NOAA ocean buoy data
 - NASA/NOAA/DMSP/Landsat/satellite images
 - NAVY/NOAA/Canadian aircraft reconnaissance surveys
 - NAVY/NOAA/Canadian ice charts
- Identification of other data sources for comparison with SSM/I
 - rawinsonde
 - research ships
 - MOS I (Japanese remote sensing satellite)

- aircraft SAR data
- upward-looking radiometers
- downward-looking radiometers (aircraft/other satellite)

These activities will be completed before the launch of the SSM/I, and are well in progress as of the date of this plan. For example, Figure 5 which shows standard deviations of sea ice concentrations as derived from Nimbus 7 SMMR data, indicates several regions over the Arctic which have exhibited very stable ice concentrations for the winter microwave characterization of first-year and multiyear ice types at SMMR frequencies. Similar analysis in both Arctic and Antarctic will be used for the selection of SSM/I sea ice and ocean signatures. As of the date of this document, work is well underway at Goddard and NSIDC to map SMMR data onto the SSM/I grid in preparation for a comparison between the two data sets. Natural targets, such as the Amazon jungle, have been investigated at the University of Massachusetts as possible calibration targets for the SSM/I. In addition, UMass investigators have cross-compared NOAA buoy and SMMR data to estimate instrumental biases.

5.2 Snow

The pre-launch activities for validation of the snow parameters include site selection as well as a pre-launch field program. The specific sites and the rationale for their selection are as follows:

- Canadian and U.S. Great Plains
 - Primary study area will be in southern and central Saskatchewan, western Manitoba, and northern North Dakota and Montana.
 - Approximate latitudes and longitudes 47°N - 54° N, 100°W - 107°W.
 - This area includes principal grain growing areas of Canada (North America bread basket) - tall and short grass prairie areas, relatively homogeneous topography and vegetation - graduating to parkland (mixed grasslands and aspen stands)

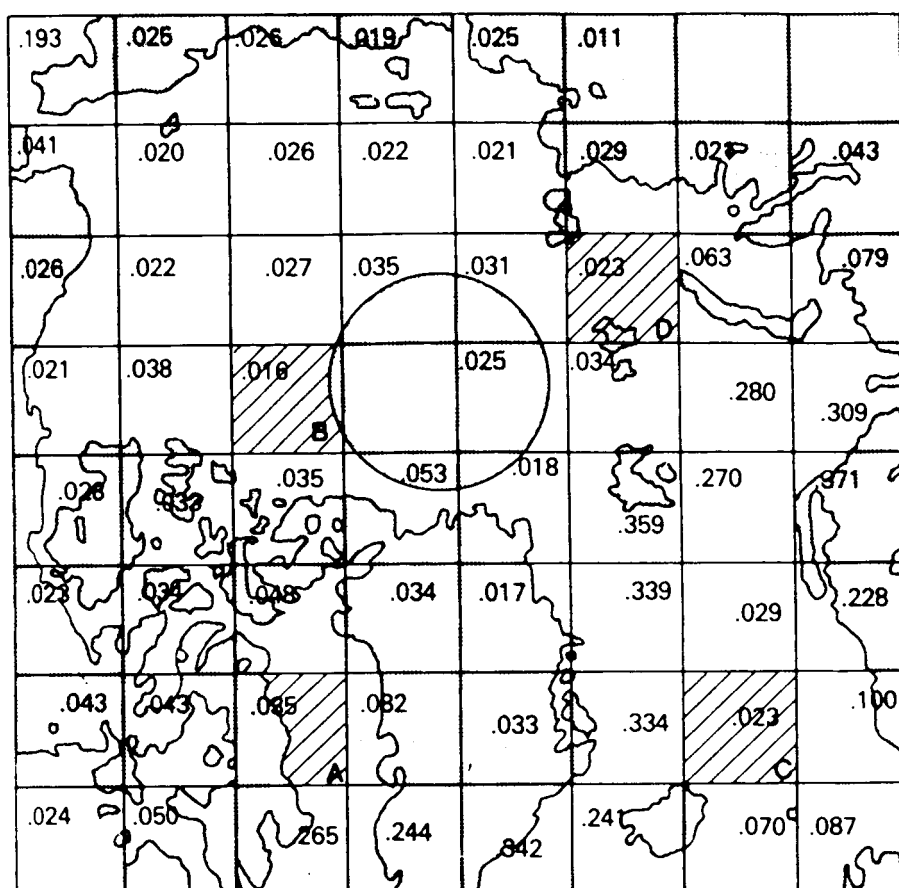


Figure 5. Gridded Standard Deviations of Derived Sea Ice Concentrations in the Arctic. The results are based upon analysis of several days of SMMR data. Detailed discussion is given in Cavalieri, et al., (1984).

and boreal forest in the northern-most part of the study area. Snow is generally shallow and cover is not always continuous.

- Colorado River Basin

- Secondary study area is in the central Rocky Mountains of the U.S.
- Approximate latitudes and longitudes 37°N - 44°N , 105°W - 112°W.
- This area encompasses high mountain peaks, tablelands, plateaus and broad basins - the topography and vegetation is complex and heterogeneous. Snow is generally shallow in basins but deep mountain packs common at higher elevations.

- Interior Basin of Alaska

- Tertiary study is in central Alaska near Fairbanks.
- Approximate latitudes and longitudes 64°N - 65°N, 145°W - 150°W.
- This area includes densely forested areas which drain into the Yukon River. Topography is hilly with mixed deciduous and coniferous stands. Deep snowpacks are typical in this region.

A pre-launch experiment took place in the Great Plains of Saskatchewan, the primary snow study area, during February 1987. The experiment included:

- testing and confirmation of snow sampling methods
- establishing flight lines for airborne gamma overflights and passive microwave overflights
- assuring representation of snow course sites
- conducting track-mounted scatterometer trials
- snowpack stratigraphy - determining preferred locations for depth hoar development (large depth hoar crystals readily scatter microwave radiation).

6.0 Post-launch Validation Activities

6.1 Sea Ice

Post-launch efforts for both sea ice and snow will group into two categories: essential and highly desirable. This division of work results primarily from the need to carry out basic instrument and algorithm verification in as short a time as possible and to provide the lead time required to carry out a well focused field program. This decision also reflects the maximum utilization of limited personnel resources.

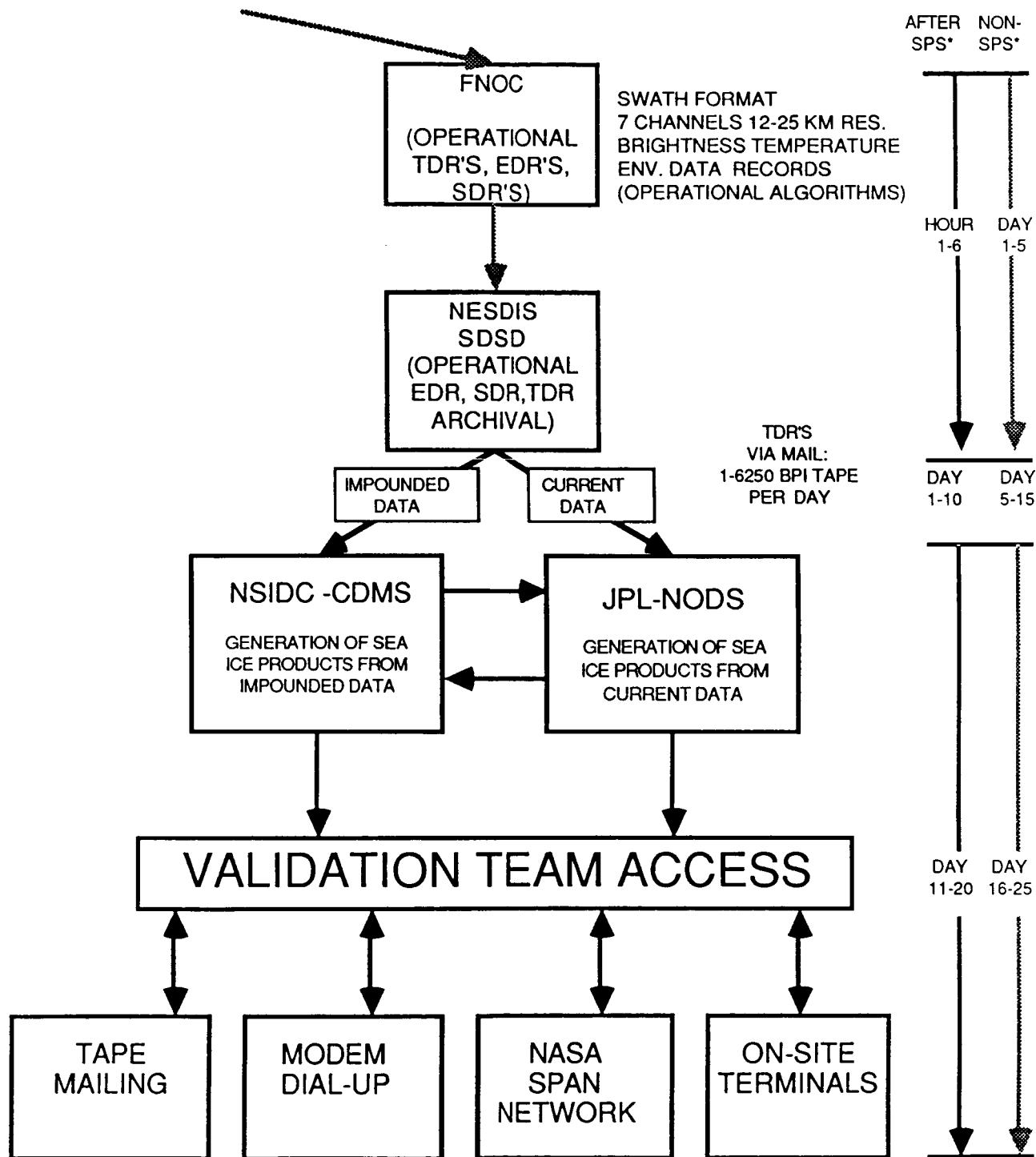
6.1A Category A - Essential Activities

This category covers activities to be completed within a 12 to 18 month period following launch. This work includes, but is not limited to the following tasks:

6.1A1 Acquisition of SSM/I data by validation team members.

Figures 6a - 6c illustrate the flow of data from satellite to the investigator. Figure 6a shows a schematic representation of the data flow during the first 12 to 18 months after launch. SSM/I data received at FNOC will be sent to the Satellite Data Services Division (SDSD/NSIDC) for operational use within six hours (assuming that the Shared Processing satellite link between FNOC and SDSD is in operation). Data tapes will then be mailed to NODS within 10 days. NODS will generate the sea ice products from these data within 10 days of receiving the data and will be responsible for distributing them to the NASA validation team. It is anticipated that the data will be on the NODS archive within 20 days from satellite acquisition (within 25 days prior to the Shared Processing link). During the initial shakedown period of the NODS SSM/I software, it is possible that additional delays will be encountered. In addition, the schedule assumes that both FNOC and SDSD will expedite the transfer of data to NODS.

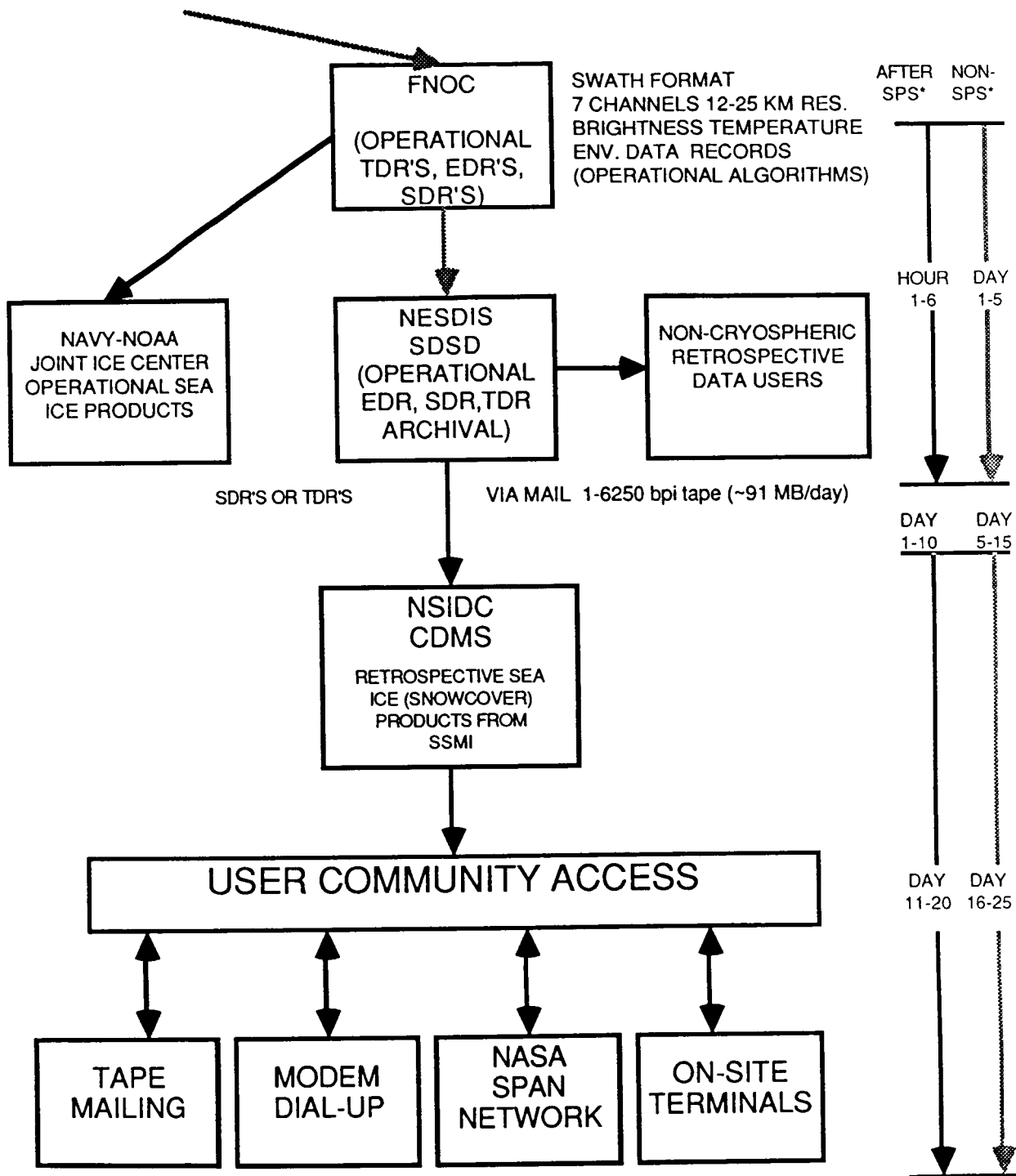
During the first 90 days after launch, the DoD is expected to impound all SSM/I data so that they can evaluate the performance of the instrument.



*SPS = NOAA-DOD SHARED PROCESSING SYSTEM

RLW: 4/87

Figure 6(a). Data Flow for NASA Validation Effort.
(First Year)



*SPS= NOAA-DOD SHARED PROCESSING SYSTEM

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Figure 6(b). Cryospheric Data Management System Post Validation Data Flow.

SSM/I DATA FLOW

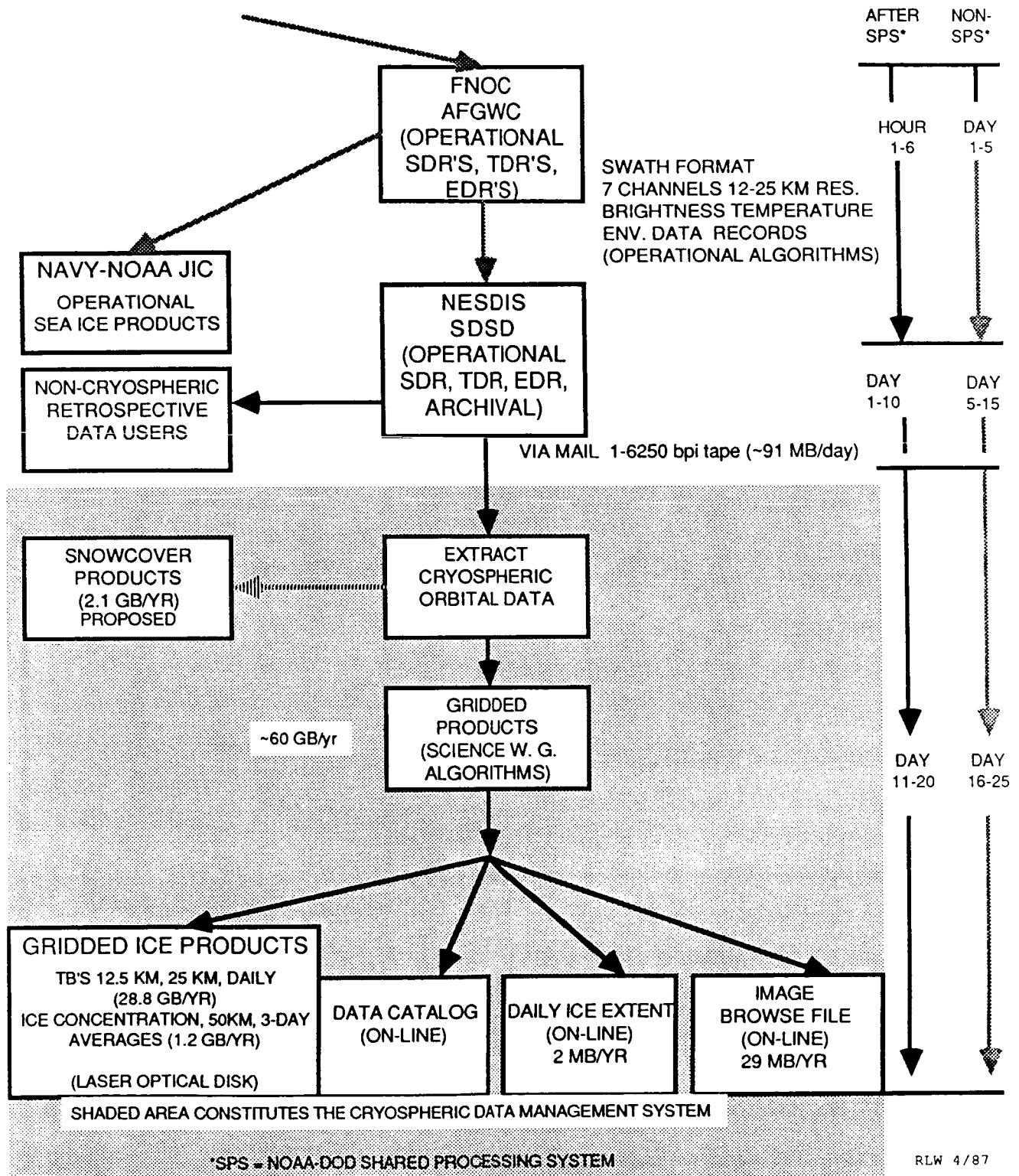


Figure 6(c). Cryospheric Data Management System at the National Snow and Ice Data Center.

It is anticipated that these data will be released after the impound period. NSIDC will be responsible for processing and distributing the impounded data for the NASA validation team.

After the initial 12 to 18 months after launch, NODS will turn over all processing and distribution responsibilities to NSIDC. This transition will occur only after the concurrence of the NASA Validation Program Manager so that the impact, if any, on the validation effort will be minimal. The data flow during this period is illustrated in Figure 6b. Figure 6c outlines the overall NSIDC data management system.

6.1A2 Selection of SSM/I algorithm coefficients for the interim sea ice and snow algorithms.

This is a task that will be carried out expeditiously so that the SSM/I geophysical algorithms have correct coefficients for comparison with the ancillary data sets. Interim coefficients were estimated both from Nimbus-7 SMMR data for those channels which most closely match the SSM/I channels and from surface radiometric measurements for the 85.5 GHz SSM/I channels. Brightness temperatures from sites selected in the Arctic and Antarctic during the pre-launch activity will be analyzed and the algorithm coefficients defined.

6.1A3 Establish sensor precision and stability.

This is a task that can be done independent of the use of geophysical algorithms. The easiest way to obtain an initial estimate, or "delta-tee" of the radiometer precision is to generate histograms of the hot and cold reference temperatures for all of the SSM/I channels. This will not only establish instrumental precision, but the results can subsequently be used to determine geophysical precision. Such a strategy has been investigated and reported by Swift and Cavalieri (1985). System linearity can also be estimated by comparing the hot "delta-tee" with that derived from the cold reference. It would also be advisable to observe the "delta-tee" associated with natural, stable targets. This exercise will serve both as a total systems check and as a correction factor if system non-linearities are present. Examples of such natural targets are the York peninsula of Australia (black

body), and the Southern Greenland and Antarctic ice sheets (cold target). Time series of key reference temperatures will provide an estimate of temporal stability of the instrument.

6.1A4 Investigation of antenna pattern efficiency.

This task is also algorithm independent. As was done with SeaSat, the antenna sidelobe level can be determined by observing the radiometric response as the satellite passes over a land boundary. Several such interactions with land boundaries will be studied in order to determine the azimuthal structure of the antenna side lobes. The study will not only determine how close to land that geophysical retrievals can be accommodated, but also how accurately ice edge location can be determined. This task will be done for all of the SSM/I channels. An example of the technique is illustrated in Figure 7 for a SeaSat 6.6 GHz channel. It was through studies such as this that it was determined that the 6.6 GHz data could not be used closer than 600 km from shore. Much better results are expected with the SSM/I.

Additional activity should include a comparison of T_A with T_B and observations of brightness temperature as the satellite passes over islands of various sizes.

6.1A5 Investigations of absolute calibration of the sensor.

A systematic approach to verification of absolute system calibration will be undertaken. Data will first be selected under cloud-free and ice-free conditions. Under these ideal conditions, there are only three unknowns, namely wind speed, water vapor, and sea surface temperature and five data channels. The data will be compared with supporting measurements such as those obtained from NOAA buoys. The deployment of these buoys are shown in Figure 8. Any inconsistencies between the satellite retrievals and reliable supporting measurements will be attributed to instrumental biases, and appropriate corrections to the instrument constants will be identified. This has been a useful indicator in the analysis of SMMR data, which has experienced significant biases.

The procedure will be repeated when the selected sites are covered with clouds, and finally with sea ice. The strategy is to start with the simple conditions, and build up to

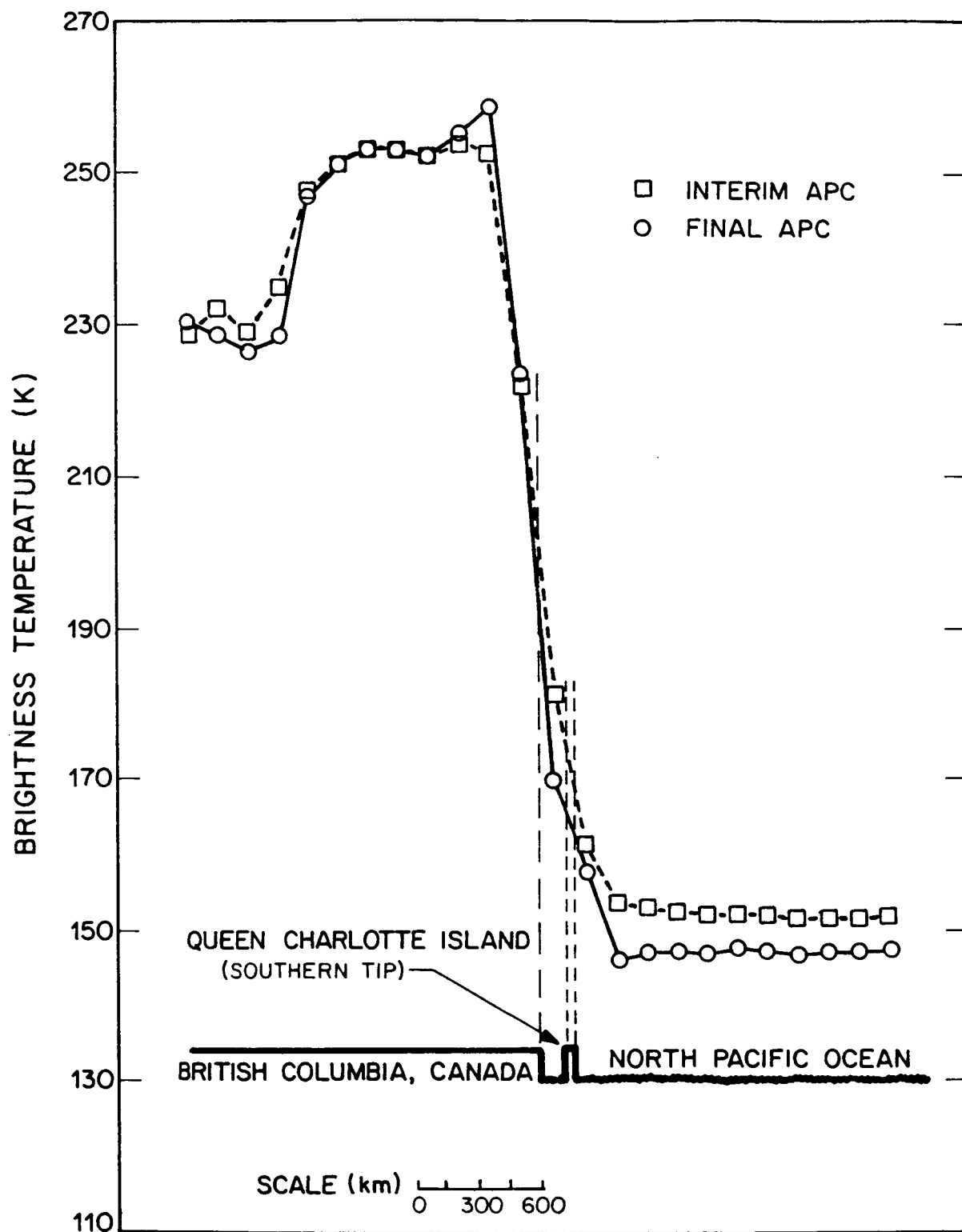


Figure 7. SMMR Brightness Temperature at 6.6 GHz for a Land/Ocean Boundary Crossing. (Analysis by the Jet Propulsion Laboratory)

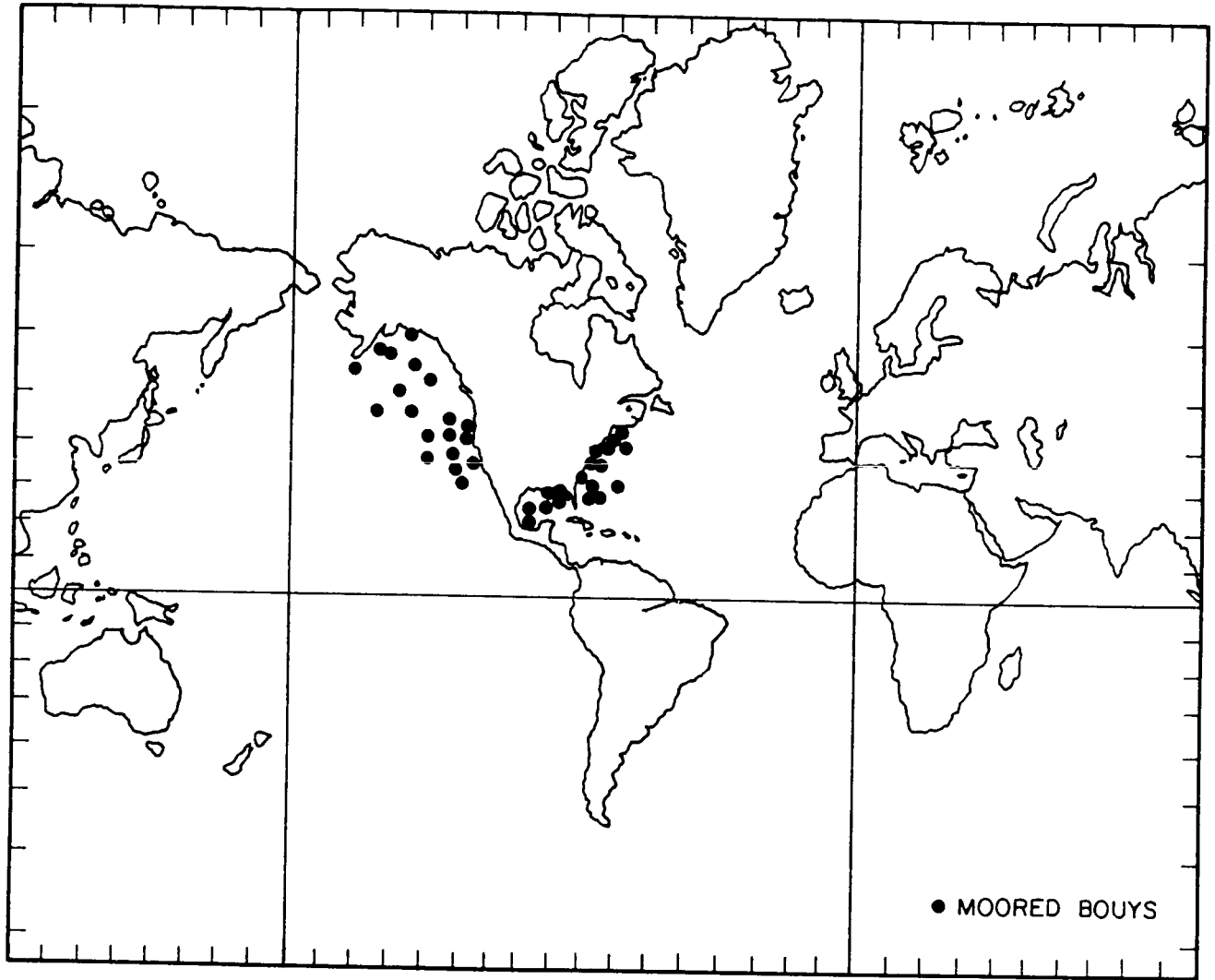


Figure 8. Location of Moored Buoys maintained by the National Oceanic and Atmospheric Administration.

more complex environmental conditions.

6.1A6 Analysis of the precision and accuracy of geophysical parameters.

Analysis of the geophysical parameters will be based on statistical techniques developed for use with the SMMR data. For sea ice, the Arctic analysis area shown in Figure 5, will be used to derive statistics of both the SSM/I brightness temperatures and the derived sea ice parameters including total and multiyear sea ice concentrations. A similar analysis grid has been developed for the Antarctic. The maximum, minimum, mean and standard deviation values of each quantity will be derived for each grid element. Time-series of each statistic over an annual cycle will provide an estimate of the precision or sampling variability of each parameter. Absolute accuracy will be inferred from a comparison of the SSM/I derived parameters with independent determinations of each quantity as outlined in 6.1A8.

6.1A7 Cross-Comparison with SMMR Data.

If the Nimbus-7 SMMR does not suffer a catastrophic failure before the launch of SSM/I, a unique opportunity will be available to derive sea ice and snow cover parameters from two spacecraft. Such comparisons will alert investigators to potential problems, whose solutions will only enhance and accelerate the verification process. In addition, there are small, but geophysically meaningful differences in frequencies, which, in effect may add more retrieval capability if both sensors are used.

It is worth noting that if SMMR fails gracefully, the data will still be extremely useful. For example, the loss of SMMR mechanical scan or a channel will not represent a complete failure as far as the successful completion of this task is concerned. For these purposes, software is being developed for mapping SMMR data onto the SSM/I grid. Tables IV and V summarize the instrumental characteristics of the SMMR and SSM/I, respectively. Note that there are significant differences between the two instruments.

Table IV. SMMR Instrument Characteristics.

FREQUENCY, GHz	6.633	10.69	18	21	37	37
WAVELENGTH, cm	4.52	2.81	1.67	1.43	.81	
POLARIZATION	V/H	V/H	V/H	V/H	V	H
ANTENNA BEAMWIDTH, deg						
Specification	4.2	2.6	1.6	1.4	0.8	
Actual	4.56/4.51	2.93/2.91	1.80/1.81	1.50/1.49	.93	.93
POLARIZATION ISOLATION, dB						
Specification		25				
Actual	-21.5/-19.9	-16.6/-16.1	-21.2/-20.1	-19.5/-18.4	-17.9	-17.4
ANTENNA BEAM EFFICIENCIES, %						
Specification		87				
Actual	79.7/83.4	83.8/86.2	85.2/88.7	84.2/85.8	88.2	90.0
EARTH INCIDENCE ANGLE, deg		49				
FOOTPRINT DIMENSIONS, km	136 × 89	87 × 58	54 × 35	44 × 29	28 × 18	
SWATH WIDTH, km		600				
INTEGRATION TIME, ms	126	62	62	62	30	
BANDWIDTH, MHz		250				
TEMPERATURE RESOLUTION, K						
Specification	.9	.9	1.2	1.5	1.5	
Actual	.65	.70	.86	.96	1.39	1.25
ABSOLUTE TEMPERATURE ACCURACY, K						
Specification		2				
Actual		?				

Table V. SSM/I Instrument Characteristics.

FREQUENCY, GHz	19.35	19.35	22.235	37.0	37.0	85.5	85.5
WAVELENGTH, cm	1.55		1.35	0.81		0.35	
POLARIZATION	V	H	V	V	H	V	H
ANTENNA BEAMWIDTH, deg							
Specification	1.98		1.72	1.06		0.45	
Actual							
POLARIZATION ISOLATION, dB							
Specification	← 20 dB →						
Actual							
ANTENNA BEAM EFFICIENCY, %							
Specification	← 90 →						
Actual							
EARTH INCIDENCE ANGLE, deg							
	← 53.1 →						
FOOTPRINT DIMENSION, km	70 × 40		60 × 40	38 × 30		16 × 14	
SWATH WIDTH, km							
	← 1390 →						
INTEGRATION TIME, ms	7.95		7.95	3 7.95		3.89	
BANDWIDTH, MHz	500		500	2000		3000	
TEMPERATURE RESOLUTION, K							
Specification	0.8		0.8	0.6		1.1	
Actual	0.37 0.36		0.82	0.34 0.42		0.77 0.74	
ABSOLUTE TEMPERATURE ACCURACY, K							
Specification	← 1.5 →						
Actual							

6.1A8 Comparison with Other Sources of Data.

An essential component of the overall validation will be the estimation of the absolute accuracy of both the calibrated brightness temperatures and the derived geophysical parameters. Determination of the accuracy of the absolute radiances necessarily involves the use of radiative transfer models. For the accuracy of the sea ice and snow parameters, in situ, aircraft and other satellite measurements of the parameters will be used. Determination of the absolute accuracy of any of the geophysical parameters depends, of course, on the accuracy of the ancillary data sets used for comparison. For these purposes near-simultaneous observations from a multitude of sources will be used for comparison with the SSM/I. Established sources of primary data include:

- Arctic ocean buoy data
- NOAA ocean buoy data
- NASA/NOAA/DMSP/Landsat/satellite imagery
- Navy/NOAA/Canadian reconnaissance aircraft surveys
- Navy/NOAA/Canadian ice charts
- Submarine data

Arctic ocean buoys cover a large portion of the Arctic basin as shown in Figure 9 and have been maintained since 1979 giving twice daily measurements of air pressure, buoy temperature and location (Untersteiner and Thorndike, 1982). These data converted to surface winds, air temperatures, and ice motion respectively will provide useful information for interpreting the observed changes in SSM/I brightness temperatures.

The NOAA data buoys provide a wealth of information for instrument verification (see Figure 8 for buoy locations). The buoys now provide eight-minute averages of the following parameters that are broadcasted every hour: sea surface temperature, air temperature, ocean surface windspeed and direction, and significant wave-height. These and other parameters have no direct bearing on sea ice, nevertheless, valuable information relating

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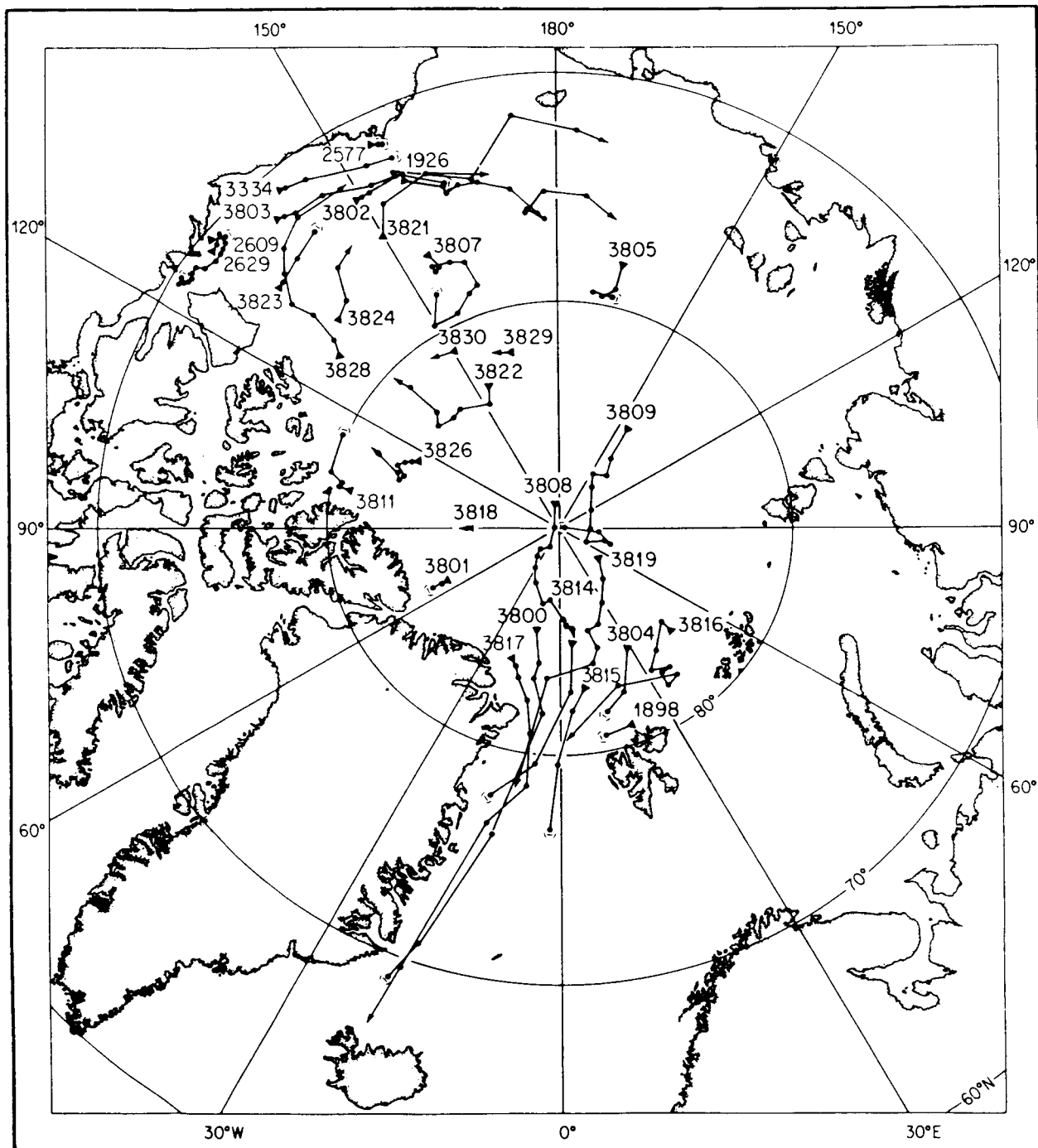


Figure 9. Typical Monthly Displacements of Arctic Buoys.

to instrument and algorithm performance is achieved by using these observations to model the radiative emission from the ocean surface for comparison with the SSM/I ocean radiances.

Analysis of visible and thermal infrared imagery as is done in generating routine sea ice and snow maps will provide basic data for comparison with the SSM/I derived parameters. AVHRR imagery from the NOAA polar orbiting satellites, and Landsat imagery will be the primary data used in this comparison. SPOT imagery will be used if Landsat data are unavailable. Finally, advantage will be taken of the unique opportunity of having both the OLS and SSM/I systems on board the same DMSP satellite by conducting an intercomparison between the derived sea ice parameters from both sensors.

Other sources of data include:

- Rawinsondes
- Research ships
- Marine Observation Satellite (MOS-I)
- Upward looking radiometers
- Downward looking instruments

Data from rawinsondes launched from islands such as Kwajalein, proved to be a valuable component of the Seasat SMMR validation effort. These data were used to determine the accuracy with which Seasat could measure atmospheric water vapor. Although atmospheric water vapor is not a prime retrieval parameter, errors could indicate possible calibration biases and provide information to correct for such biases. The research ships and upward looking radiometers also fall into this category. Accurate environmental data supplied by research ships will provide known continuous inputs such as surface winds, surface temperature, relative humidity, etc. to check the quality of the environmental algorithms. The upward looking radiometers provide a means of measuring integrated atmospheric water vapor and cloud liquid water content. A near operational dual-channel

system has been built by the NOAA Wave Propagation Laboratory (WPL). If these sensors could collect data away from land, the accurate results inferred by these sensors could aid in the calibration of SSM/I.

It is conceivable that the Japanese MOS I satellite will be in orbit while the SSM/I is functional. The MOS I will collect microwave radiometer data at 23 and 31 GHz, which can be cross-compared with the SSM/I results. Other downward looking instruments that provide environmental parameters relevant to the SSM/I may provide worthwhile information. TOVS, for example, may provide atmospheric water vapor profiles.

6.1B Category B Highly Desirable Activities

6.1B1 NASA Aircraft Expeditions

The longer term validation effort will focus on specific problems identified during the category I program. This will very likely include a dedicated SSM/I field program utilizing the NASA DC-8, P-3, or the ER-2 aircraft which will be instrumented with a complement of radiometers simulating very closely those on the SSM/I.

Although costly, this aspect represents an important element of credibility to the program. Visual photographic and high resolution microwave observations will document actual conditions at the time of the satellite overflight. Such documentation will also include surface observations of ice type, concentration, surface air temperature and snow/ice interface temperature and snow cover parameters. Ice buoys will provide surface temperature and atmospheric pressure data.

6.1B1.1 Arctic Flights

A prelaunch aircraft mission is planned for May 1987 over the central Arctic and in the Greenland Sea region. The NASA P-3 aircraft at Wallops will be used to fly the Goddard radiometers over areas of multiyear and first-year sea ice. This will enable an evaluation of the spatial variability of the multiyear ice microwave emissivity at 18 to 37 GHz and an investigation of possible causes of the observed variability. The mission will

also fly photographic and video equipment, a PRT-5 and a laser profiler to study the surface physical characteristics and topography during the period. Although the SSM/I will not be launched in time for this mission, the results from this study could be used to assess the Arctic ice type distribution providing information for evaluating SSM/I Arctic data.

Underflights of the SSM/I with NASA aircraft are strongly recommended by the SAWG. At present, there are plans to carry out a series of dedicated SSM/I underflights with the NASA DC-8 aircraft in February/March 1988. It is expected that the DC-8 will carry radiometers operating at frequencies and polarizations closely matching those on the SSM/I. The high resolution aircraft microwave measurements of sea ice concentration and ice type will be compared with corresponding measurements made from the satellite over several footprints thus providing a direct check on the spacecraft algorithm over a large region of the Arctic. Analysis of coincident aerial photography will allow an independent determination of the ice parameters. Finally, the high resolution capability of the aircraft sensors will allow a focused study of sub-SSM/I footprint conditions in the vicinity of surface parties providing data needed to understand microwave variability due to variations in snow depth, ice type, and surface roughness.

There are also plans to utilize the NASA DC-8 in October 1987 to overfly the western Arctic including portions of the Chukchi and Beaufort seas. In addition to validating the SAWG algorithm during freeze-up conditions at this time of year, these flights will provide the requisite data for the development of thin ice algorithms utilizing the SSM/I 85 GHz channels. Scientists from JPL and Goddard will participate utilizing both the JPL C- and L-band SAR and the Goddard complement of aircraft passive microwave sensors. The passive sensors include dual-polarized, fixed-beam radiometers operating at 10, 18, 21, 37 and 92 GHz. Since the Arctic series of flights will originate from Fairbanks, data will also be obtained over snow-covered areas of Alaska.

6.1B2 Other Aircraft Expeditions

Other NASA aircraft experiments to address specific problems may include flights over the Great Lakes, The Laborador Sea, Baffin Bay, and the Greenland ice sheet. Suitable aircraft are the DC-8 and Wallops P-3. The DC-8 should carry the Goddard radiometers, which span a frequency range of from 10 to 183 GHz. The P-3 should carry the UHF, L-band and the UMass C-band SFMR. In addition, it is possible that the 64 channel UMass 20-24 GHz spectral radiometer will be available. The UHF and L-band sensors will be used for sensing thin ice types, which will aid in related SSM/I algorithm development. Finally, the NASA ER-2 is also available to carry Goddard's passive radiometers. It would provide high altitude, large-area coverage for comparison with the SSM/I data.

It is anticipated that other aircraft will be participating in related verification activities in support of the SSM/I. Certainly, the NRL P-3 will be conducting underflights as discussed in a subsequent section on the DoD/Canadian verification plan. In addition to the NRL flights, it is anticipated that NORDA will also fly a P-3 with the 33.6 GHz KRMS instrument . In addition, NOAA plans to collect coincident aircraft photography to cross-register with the KRMS data and to generally document the ice conditions at the time. The NOAA P-3 has flown a few missions to the Arctic , and it may be possible that additional flights may materialize during the SSM/I validation period. This aircraft deploys the UMass SFMR on an "as available" basis. The ERIM plans occasional aircraft flights to the Arctic, and Intera conducts commercial data collection flights on a regular basis. Both of these latter aircraft collect SAR data, which can be used for interpretive purposes during SSM/I validation. Whenever possible, field activities should be coordinated.

6.2 Snow

6.2A Category A - Essential Activities

6.2A1 Comparison With Other Sources of Data

Data will be selected before snow covers the test sites and during mid-winter when the snowpack is well established and not yet melting. The data will be compared with

supporting measurements from a ground-based network as well as satellite and aircraft observations. A systematic approach will be taken so as to monitor and measure the test sites with and without snow.

Concurrent measurements and observations from a number of agencies and sources will be used for comparison with the SSM/I. The following list of governmental agencies have agreed in, principle, to support the DMSP/SSM/I snow validation plan:

- Atmospheric Environment Service of Canada (Canadian Climate Centre)
- Canadian Centre for Remote Sensing
- National Hydrology Research Centre of Canada
- Saskatchewan Research Council
- Saskatchewan Water Corporation
- Manitoba Water Resources Branch
- Saskatchewan Water Resources Branch
- U.S. National Weather Service (Minneapolis)
- U.S. Navy
- NASA/Goddard Space Flight Center

Data will be obtained from a number of sources including ground-based measurements and satellite and airborne sensors.

- Ground-Based Snow Surveys
 - Detailed sampling along established flight lines will occur at approximately every 5km depending on the length of the flight line and the level of participation of the various supporting agencies. If aircraft overflights cannot be made for whatever reason then ground-based sampling will be more extensive and set-up to facilitate satellite pixel size and orientation.
 - data to be collected at each sampling site or transect include snow depth, density and water equivalent and also information about the underlying soil (wet, dry, frozen, unfrozen). Additionally a pit will be dug at each sampling location to

extract information concerning snowpack stratigraphy i.e., the presence of ice lenses and or depth hoar crystals, temperature and free water content of the snowpack.

- depth hoar is of special interest because it has been demonstrated that large crystals such as depth hoar crystals scatter radiation at microwave frequencies much more effectively than do smaller snow grains. Therefore an attempt will be made to assess the real and temporal significance of depth hoar on microwave brightness temperature.
- data from routinely monitored snow courses in Saskatchewan and Manitoba will be used to supplement the ground data collected during this experiment.

6.2B Highly Desirable Activities

6.2B1 Aircraft Overflights

6.2B1.1 Gamma Aerial Surveys

It seems likely that the U.S. National Weather Service will be able to provide gamma ray overflights in conjunction with this validation experiment. Soil samples are required if the gamma flights are approved. Gamma overflights would be needed during the fall before snow accumulates (background data) and during at the same time as the validation experiment in mid winter. Gamma data and airborne microwave data have compared favorably in prior investigations.

6.2B1.2 NASA Flights

NASA aircraft will provide simultaneous microwave data for snow depth and snow water equivalent determination as well as visible data to assess the location of the snowline. The validation effort will make use of the NASA DC-8, P-3 or the ER-2 aircraft which will be instrumented with a complement of radiometers with approximately the same frequency and sensitivity as those on the SSM/I (see 6.1B1 and 6.1B2). At present there are plans to carry out a series of dedicated flights over sea ice areas with the NASA DC-8 aircraft in February/March of 1988. Because snowpacks are typically well established and not

yet ripe or melting in February in the prairies and boreal forests of Canada, it should be feasible to conduct an airborne snow experiment in conjunction with the sea ice overflights. Aircraft will be used to make overflights of the selected study sites for validation of the satellite microwave data and for comparison with the "ground truth" snow depth data. Additionally the snow (no snow boundary will be identified from the overflights (using a panoramic camera)) and compared to the snowline as determined from airborne and spaceborne microwave data. A large airport with good servicing facilities is available at either Saskatoon, Regina or Moose Jaw in Saskatchewan as well as Minot Air Force Base near Minot, North Dakota.

6.2B1.3 Other Data Sources

Auxillary data as provided by the NOAA and GOES series of satellite and possibly the Japanese MOS I satellite will be employed to corroborate snow depth and snowline estimates as measured by SMMR and SSM/I data.

7.0 Monitoring Sensor Performance and Quality Control of Data

7.1 Monitoring Sensor Performance

Two indicators describe sensor performance; namely, accuracy and precision. Precision is a measure of receiver noise fluctuations, or "delta-tee", which is straightforward to evaluate. This activity will consist of monitoring the means and standard deviations of hot and cold calibration sources throughout the verification phase. The results should also be indicative of the performance of the instrument square-law detector.

Monitoring absolute accuracy of the instrument is a much more involved process. The activity here will consist of (1) monitoring the brightness temperatures of selected natural targets (NODS software automatically collects histograms of T_B s in four of these areas daily), (2) comparing with results of aircraft underflights, and (3) utilizing the NOAA buoy network and upward looking microwave radiometers to independently monitor all environmental parameters that would normally be measured by the SSM/I. Using a radiative transfer model, with an a priori knowledge of all environmental parameters, instrument

constants (and also algorithm constants) can be treated as unknowns. If these instrument parameters do not vary with time, then the absolute calibration of the SSM/I is established to within the accuracy of the radiative transfer model and the monitored environmental parameters. If there is temporal variation, this procedure will be used to upgrade the instrument constants as needed.

Another element of this activity is monitoring the antenna beam efficiency. Time series of brightness temperatures will be generated as the swath of the SSM/I intersects with land boundaries at different aspect angles. This work will lead to the assessment of the quality of data for pixels in the vicinity of land and the ice edge. Good antenna performance may also result in a better ice edge data product.

Quarterly reports on instrument performance will be issued to the SAWG.

7.2 Quality Control: Pre-Launch Testing

As a pre-launch activity, the NODS staff has been performing an extensive number of tests on the NODS SSM/I software using simulated SSM/I swath data. These tests, carried out over several months, made use of simulated SSM/I data in the Data Exchange Format (DEF) obtained from Hughes and six days of simulated antenna temperatures generated by NODS.

The Hughes TDR data consisted of about one orbit of antenna temperatures. These antenna temperatures were converted to brightness temperatures using the NODS software and the values compared to the corresponding Hughes SDR (brightness temperature) file.

In order to test the full range of the NODS SSM/I software, six days of simulated TDR data were created. These data were designed to produce specific patterns of brightness temperatures and ice concentrations on the Earth's surface. The data were loaded into the NODS archive to test not only the creation of the various data archives, but also the resulting products (such as plots and images).

7.3 Quality Control: Post-Launch

Both NODS and NSIDC will receive the SSM/I TDR files from SDSD/NESDIS on magnetic tape. The quality control checks performed on these data include those performed by the software, spot checks by an analyst, and routine checks of outgoing products by a data specialist.

The NODS software has a number of built-in tests which either directly or indirectly check the quality of the data being loaded into the archive. Examples of these tests include testing for out of range antenna temperatures and out of range ice concentrations. Out of range data and missing data are flagged in the archive. In addition, the data must be time ordered for it to be loaded into the archive successfully. The loaders also provide a series of diagnostic messages if problems develop as the data are being loaded into the archive.

During the validation period, there will be extensive spot checks by an analyst of the products (gridded T_{BS} /ice concentrations and ice edge maps) produced by the system. These checks will evaluate the reasonableness of the results. SAWG will be advised if there appears to be any algorithm related problems. These spot checks will become less frequent as confidence is gained in the system. After the validation period, spot checks will be infrequent.

NODS has a data specialist who insures that data orders are filled properly. This person has a quality control program which verifies that magnetic tapes sent out are readable and provides the data specialist with a summary of the number of records and data points on a tape. In addition, the program lists the data gap history and, optionally for the ice concentration archive, checks for algorithm changes and provides a summary of the number of grid cells used to compute the ice concentrations and the number with missing or out of range data.

NSIDC will utilize the quality control features of the NODS software during the operational data distribution phase. NSIDC will also employ a data specialist who will assure that data requests are filled properly. The programs mentioned above for tape scanning/validation will be used in addition to existing NSIDC systems.

During the remaining period of the validation phase, the SAWG algorithm will be certified for distribution to the user community and the research tasks of the SAWG members will be reviewed to submit recommendations for modification or replacement of the SAWG algorithm. It is anticipated that the objectives outlined in Section 2 will be met and that a report will be drafted for general distribution at the end of the 12-18 month calibration/validation activity. This report will include an assessment of the accuracies and limitations of the SSM/I sea ice algorithm.

8.0 Rationale for Algorithm Modification and Reprocessing of Data

At the December, 1984 meeting of the SAWG, ground rules were established for the selection and implementation of a sea ice algorithm into NODS. These ground rules consisted of the following:

- Ice parameters will be initially derived from only the 19H, 19V, 37H, and 37V channels
- Ice-edge position will be derived from the 85 GHz channels
- There will be no external inputs (e.g., no buoy temperatures)
- A weather filter will be integrated into the algorithm
- The SAWG will periodically update the algorithm constants during validation
- Data products will include:
 - Color coded images of total ice concentration, first year and multiyear ice concentration
 - Contours of the ice edge (15% ice concentration) from the 85 GHz channel data

The rationale for some of these ground rules are as follows:

- Only the 19 and 37 GHz channels were selected based on extensive experience with SMMR data. At present, there is no extensive data base of 85 GHz data upon which a sound algorithm can be developed.
- The ice edge determination with the 85 GHz channels has a certain risk element attached to it; however, this is the most elementary of all data products, and deemed

worthy of the risk to achieve higher spatial resolution. If this algorithm fails, a substitute algorithm can easily be implemented using the traditional channels. Reduced spatial resolution will be the penalty that will be paid.

- The use of external inputs is an expensive proposition, and labor intensive. The use of external inputs was therefore rejected by the SAWG.
- A weather filter removes false indications of sea ice over open ocean areas.
- Based upon analysis of SSM/I data during the validation period the SAWG may decide to change algorithm constants. This option has been discussed with NODS, and provisions have been made for these minor adjustments of calibration constants.

As soon as possible after initial instrument verification, ice products will be generated by NODS using the SAWG algorithm. Primary data products will consist of images of ice concentration (Total, FY and MY), and contours of the ice edge. The 85 GHz channel will only be used to identify the ice edge. The results will clearly be labeled preliminary until the verification phase of the SSM/I is completed.

Following the initial validation period (12-18 months), the NASA SSM/I validation team will report to the SAWG on the performance of both the sensor and the geophysical algorithms. The SAWG will recommend to the NASA polar ocean manager any changes to the algorithm that are justified based on the validation results and on the following rationale for algorithm modification and data reprocessing.

The rationale for replacing or modifying the current NASA SAWG algorithm whether on the short-term or long term and for the subsequent reprocessing of the SSM/I data by NODS and NSIDC is based on the anticipated scientific returns in making such modifications. The philosophy of the SAWG is that improvements at the 10% level do not justify a recommendation for changing the algorithm. However, substantial improvements in overall algorithm accuracies would definitely result in a recommendation to update the algorithm. Because of uncertainties in our knowledge of the global sea ice and snow covers, we cannot specify precisely what a substantial improvement is, but our feeling at present is that an

improvement by a factor of two would indeed be substantial and a recommendation for updating the algorithm would be warranted.

Experience has shown that substantial improvements in the overall retrieval accuracies are likely to result from improvements in:

- increasing spatial resolution
- reducing noise levels
- reducing the dependency of the sea ice concentration on physical temperature of the radiating portion of the ice and on ice types or surface characteristics
- reducing weather effects especially in marginal ice zones
- improving retrievals under melt conditions
- discriminating unambiguously among various ice types

Finally, on the long term, it is anticipated that additional SSM/I channels including those at 21 GHz and 85 GHz, may well prove useful in improving overall algorithm performance. Work on research algorithms is underway. For example, recent results by Walters et al. (1987) suggest that progress is near on improving algorithm accuracies at low ice concentrations. Other anticipated improvements include the mapping of areas of new ice production, heavy snow accumulation and surface roughness.

9.0 Coordination with the DoD/Navy Verification Plan.

A draft validation plan has been prepared by Navy and Canadian investigators, and a line of communications has been developed between those investigators and the NASA SAWG. For example, Rene O. Ramseier, who is coordinating the sea ice validation effort for the Navy, is also a member of the NASA SAWG. Through communication with Ramseier, duplication of NASA and Navy efforts have been kept to a minimum. Calvin T. Swift is also a supporting member of the DoD/Navy windspeed validation activity, which further enhances communication between the two groups.

There are two principal elements of the Navy/Canadian program, the results of which will greatly enhance the NASA plan. First, James P. Hollinger of NRL regularly deploys

an airborne SSM/I simulator. This bank of radiometers has frequencies, polarizations, and viewing angles which exactly correspond to those utilized by the SSM/I. Hollinger plans to underfly his SSM/I simulator at regular intervals during the verification phase of the SSM/I. Flights will be conducted throughout the year to study seasonal variations in the radiating properties of sea ice.

The other major element of the DoD/Navy verification program that will greatly enhance this plan are the field experiments that are being planned by the Canadians. Table VI shows the time schedule of planned field experiments. In addition to high quality surface observations offered by the Canadians, they also plan to deploy aircraft to collect additional information, such as radar backscattering, and documentation of ice conditions by experienced ice observers. It is also of interest to note that the experiments will be done seasonally.

10.0 References

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APPENDIX A

Description of the SSM/I

The SSM/I is an approved instrument to be flown on satellites maintained by the Defense Meteorological Satellite Program (DMSP). In this program, two satellites are flown in circular, sun synchronous, near polar orbits at an altitude of 883 km. One satellite is designed to have a morning equatorial crossing. The satellites are launched "on demand", which means that launch of new satellites will not proceed until essential instruments begin to show signs of failure. A demand is issued 90 days before the launch of a replacement satellite. Because of added power requirements imposed by the installation of the SSM/I, the satellite will have a morning equatorial crossing.

The SSM/I utilizes an offset parabolic reflector antenna, approximately 65 cm in diameter fed by a single horn feed system which accommodates seven ports. Both the reflector antenna and the feed are mounted on a continuously rotating platform to achieve a cross-track scan which creates a 1,394 km wide data swath on the surface of the earth. As the antenna system rotates, the feed alternately observes cold sky reflected from a small reflector and a heated black body of known temperature. These targets provide hot and cold references to calibrate the sensor during the periods when the active data scan is complete; i.e., at the edges of the 1,394 km data swath. As a result, a total system calibration is done every scan period of 1.9 sec. A photograph of the SSM/I is shown deployed in Figure A-1.

The scan geometry of the SSM/I is shown in Figure A-2. The forward velocity of the satellite is 6.58 km/sec, which means that the satellite advances 12.5 km during the 1.9 second rotational period of the antenna system. A data swath 1,394 km is produced aft which covers an active scan of 102.4° , compared to 50° for the SMMR. The swath is organized into 64 pixels for the five lower frequency channels (denoted a scan A in Figure A-2), and 128 pixels for the 85 GHz channels for scan B. This organization of the data results in 25 km Nyquist sampling for the five lower frequencies and 12.5 km sampling for the 85 GHz channels.

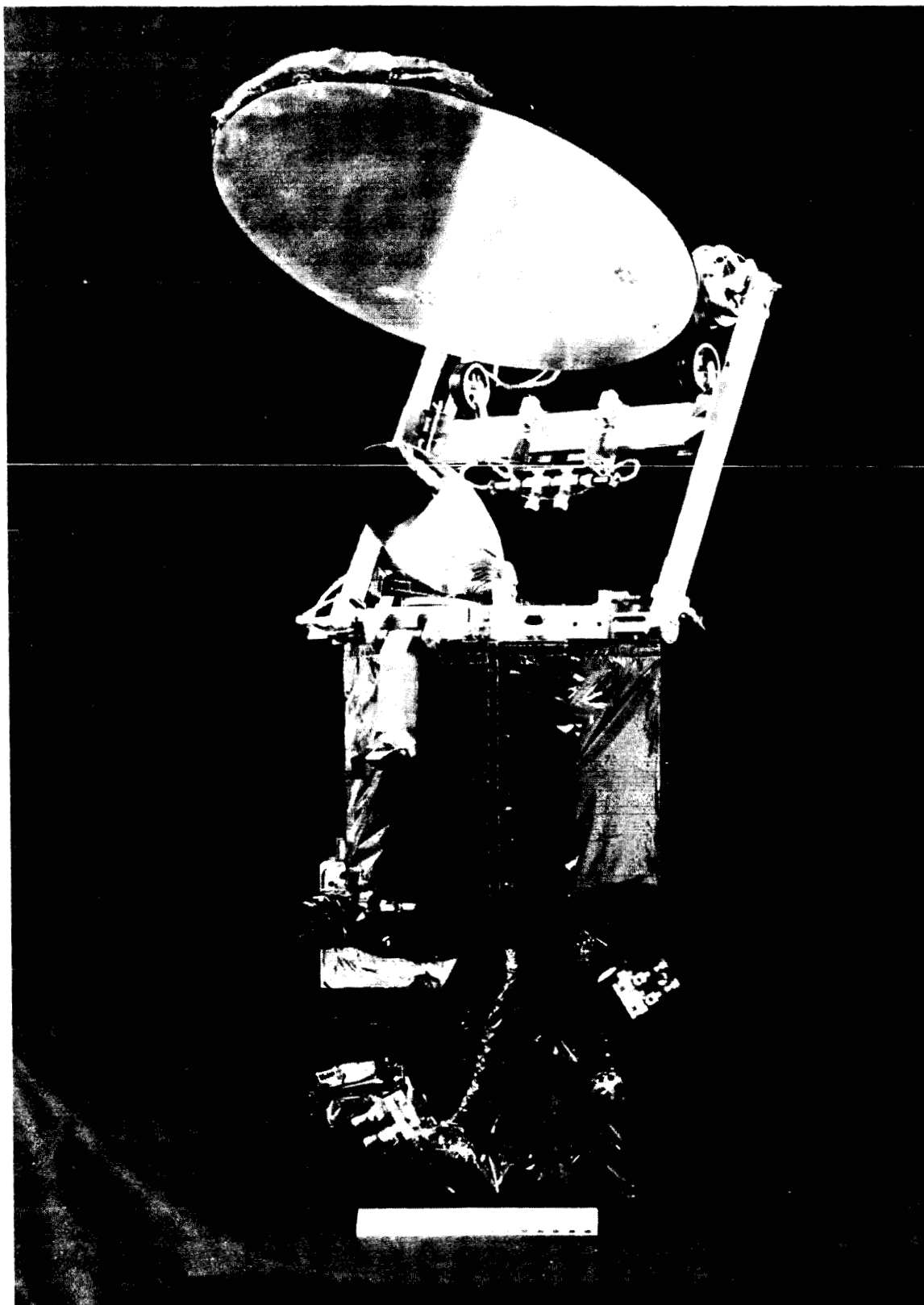


Figure A1. Photograph of the SSM/I Instrument in the Deployed Configuration.
(Courtesy of J. Peirce, Hughes Aircraft Company)

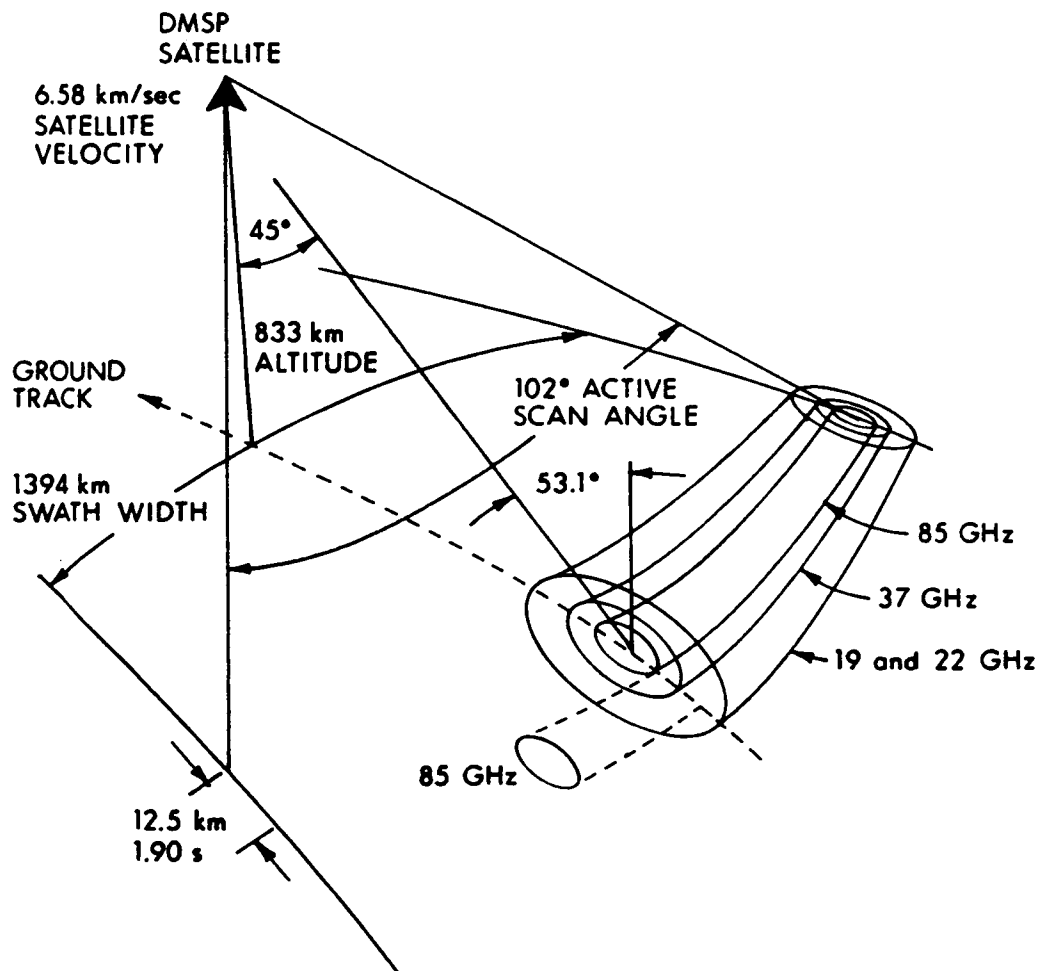
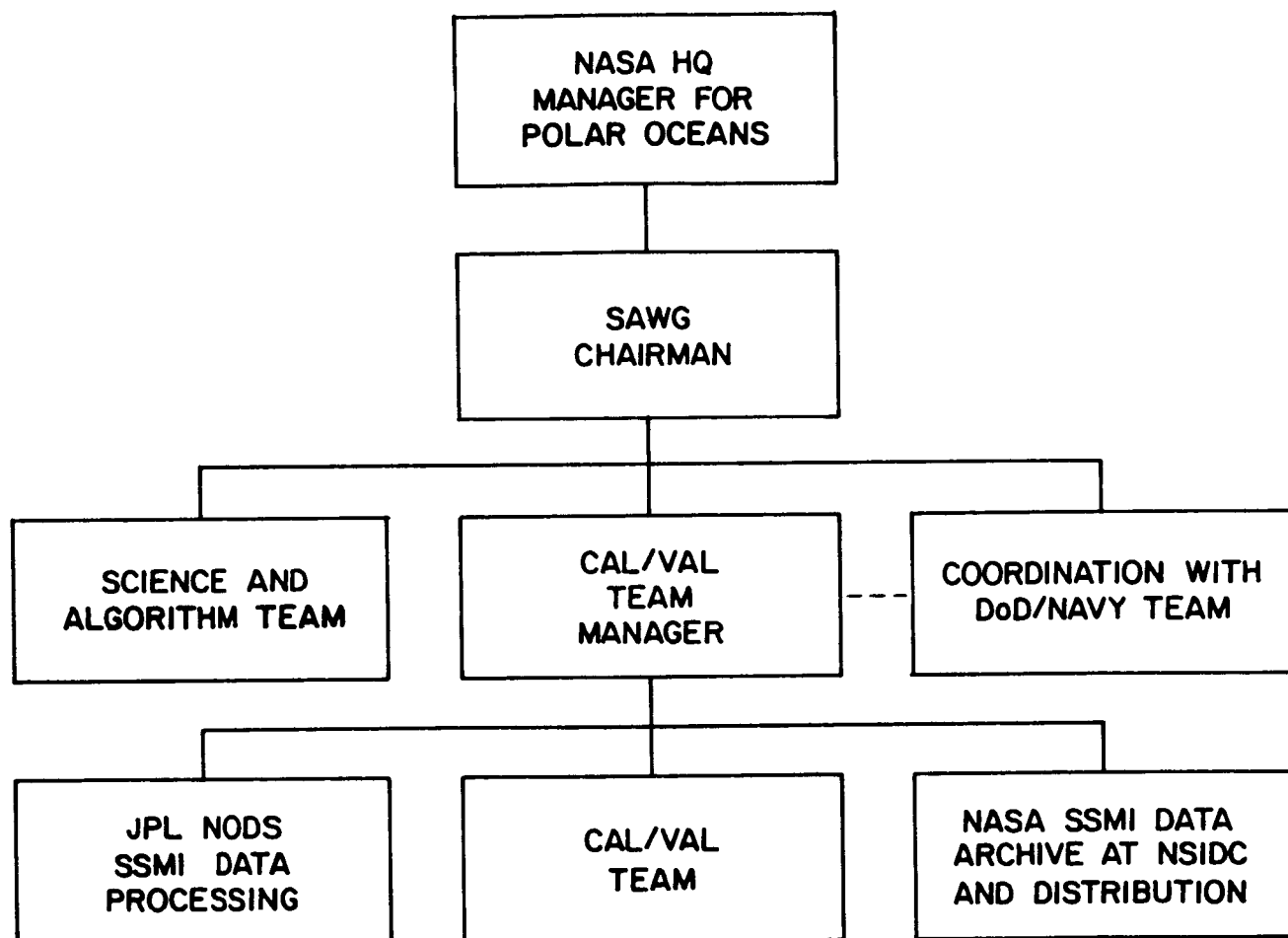


Figure A2. Scan Geometry for the SSM/I.

Further relevant details concerning the instrument are presented in Figure 4 and Table V. For reference purposes, the differences between SSM/I and the SMMR can be compared by cross-referencing Tables IV and V.

MANAGEMENT STRUCTURE FOR THE NASA SSMI VALIDATION PLAN



APPENDIX C
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Josefino Comiso NASA GSFC Code 671 Greenbelt, MD 20771 (301) 286-9135 FTS 888-9135	Cluster Analysis & SMMR Comp.
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Snow Algorithm Validation

Algorithm Tie-Point Selection
SSM/I & SMMR Comparison

Field Experiments and Distribution
of Arctic Buoy Data

NASA Polar Ocean Manager
MOS-I Comparison
with SSM/I

Aircraft ERIM SAR/SSM/I Comparison

NODS SSM/I Data Distribution to
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Field Experiments and DoD
Aircraft Observations

LANDSAT/DMSP/SSM/I Comparison
Comparison of OLS data with SSM/I

NASA SAWG Chairman & Sensor
Validation & Quality Control

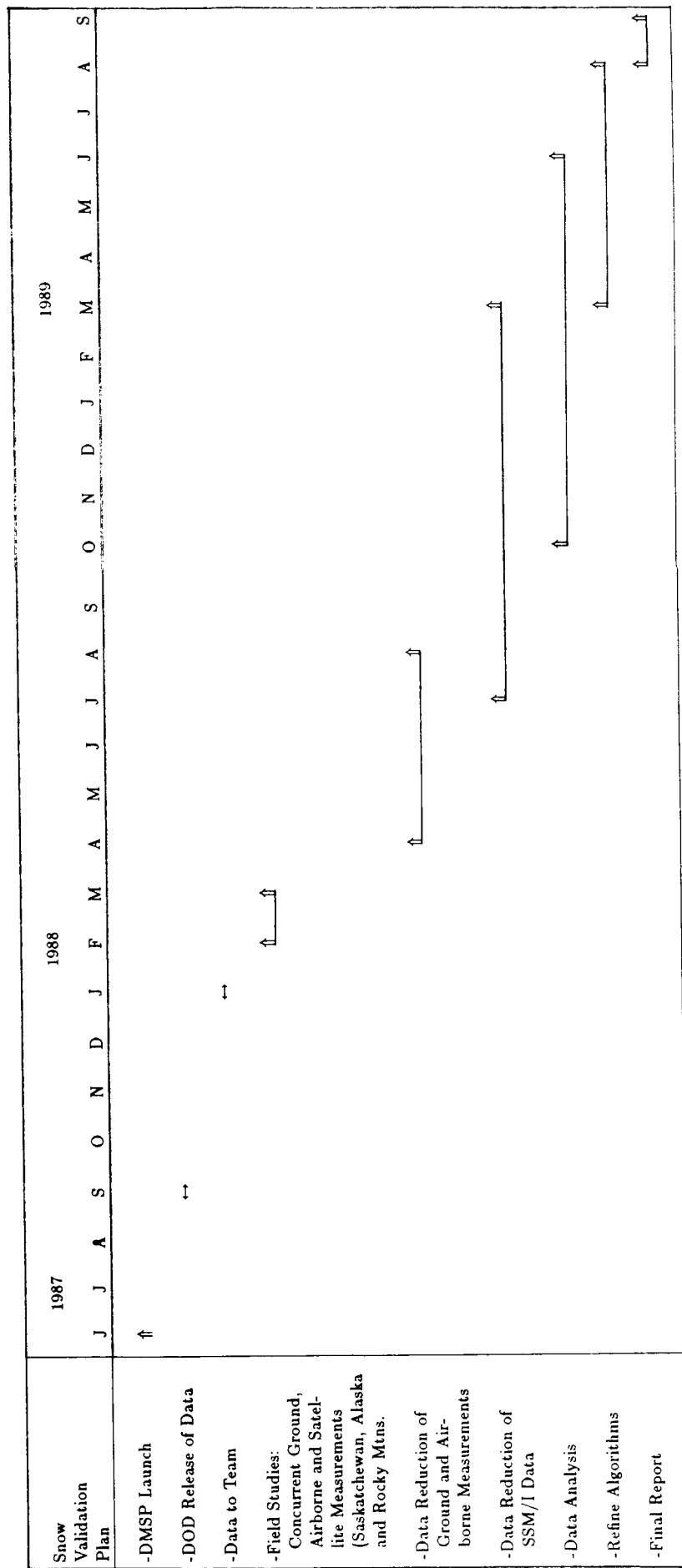
Analysis of Submarine Data
for Comparison with SSM/I

NSIDC SSM/I Quality Control &
Data Distribution to Users

SSM/I Comparison with NOAA/Navy
Ice Charts

APPENDIX D

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APPENDIX E

	MONTH																							
	1987												1988											
	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N					
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18					
<u>Event</u>																								
1. Experiment Polarstern LIMEX																								
2. AES Operations Gulf of St. Lawrence Newfoundland Water Laborador Coast Baffin Bay Beaufort Sea																								
3. U.S. Navy Operations East Greenland Area Alaska Area																								
4. Navy P-3/NRL PM Sensors																								
5. NASA Aircraft NASA DC-8 & P-3																								

Aircraft and Field Experiment Schedule

APPENDIX F
Schedule of Deliverables

Each member of the team (PI) will, at the end of the validation period, submit a report summarizing the contribution of their respective tasks to the validation effort. In particular, each report will contain a quantitative assessment of how well the NASA SAWG algorithm meets the observational requirements specified in Section 2 of this plan.

DELIVERABLE	DUE DATE	PI
Reports on sensor performance & calibration	Quarterly	Swift
Interim Arctic & Antarctic algorithm tie-points	Nov 1987	Cavalieri & Gloersen
Reports of changes in Algorithm tie points	Quarterly	Cavalieri & Gloersen
Reports on data products delivered to team members and quarterly reports on quality of data, processing problems, etc.	Monthly	Morris & Weaver
Distribution of Arctic Buoy Data to P.I.'s	Bimonthly	Grenfell
Analyzed AVHRR imagery & aircraft reconn maps compared with SSM/I parameters	Bi-monthly	Wohl
Mapped sea ice parameter derived from Landsat & DMSP OLS imagery & comparison with SSM/I-derived parameters	Quarterly	Steffen
MOS-I Comparison	June 1988	Jezek
Analyzed AVHRR data	June 1988	Emery
Reports of Navy/Canadian Aircraft and Field Experiments	June 1988	Ramseier
Mapped sea ice parameters derived from aerial photography	June 1988	Eppler

Mapped Arctic sea ice parameters from analyzed aircraft SAR & statistical comparison with SSM/I-derived parameters	June 1988	Carsey
Mapped Arctic sea ice parameters from analyzed aircraft radiometers & comparison with SSM/I-derived parameters	June 1988	Cavalieri
Report on analysis of NASA DC-8 and P-3 Fall 1988 Arctic Flight Data	May 1989	Cavalieri, Swift & Carsey
Maps of sea ice edge, concentration & type from SAR imagery comparison with SSM/I-derived sea ice parameters	Apr 1988	Burns & Milman
Results from the Weddel Sea Winter Experiment	Jan 1988	Comiso & Grenfell
Results from the 1987 winter MIZEX experiment	Mar 1988	Grenfell
Report on Analysis of Submarine Data and SSM/I Comparisons	June 1988	Wadhams
Regional cluster plots & histograms of SSM/I & coincident SMMR TBs	Quarterly	Comiso
Spatial and temporal statistics of SSM/I TBs & ice parameter variability	Quarterly	Cavalieri
Difference maps of a coincident SSM/I/SMMR TBs	Quarterly	Gloersen
Difference maps of SSM/I/SMMR sea ice parameters	Quarterly	Gloersen
Polarization & gradient ratio cluster plots	Quarterly	Gloersen
Analyzed TOVS data	June 1988	Emery

Analyzed up & downward radiometer data	June 1988	Emery, Swift
NOAA Buoy Comparison	June 1988	Swift
Final Arctic & Antarctic algorithm tie-points	Dec 1988	Cavalieri & Gloersen

Deliverable	P.I.	MONTH											
		1987						1988					
		A	S	O	N	D	J	J	M	A	M	J	J
		1	2	3	4	5	6	7	8	9	10	11	12
													13
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													18
V. Inter-Comparison of Data													
10. Analyze JIC maps & Air Recon. w/ NASA Sea Ice Products	Wohl												
11. JIC Charts	Wohl												
12. Difference Maps of Coinc. SSMI/SMR TB's and Ice Products	Gloersen												
13. Regional Cluster Plots	Comiso												
14. AVHRR Ice Product & Comparison w/SSM/I	Emery												
15. Analysed TOVS & Up/Down Radiometer	Emery/Swift												
16. Landsat/OLS Derived Parameters and SSMI Comp.	Steffan/Eppler/Hawkins/Emery												
17. Non-Microwave Intercomparison	Steffan/Eppler/Hawkins/Emery												
18. Mapped Sea Ice Conc. & Ice Type from Sub Data	Wadhams												
19. MOS-1/SSMI	Njoku/Jezek												
20. Arctic Ocean Buoy	Grenfell												
21. JIC/JPL NASA/Navy Algorithm Comparison	Crawford/Wohl												

APPENDIX G
Acronyms and Abbreviations

AES	Canadian Atmospheric Environmental Service
AFGWC	Air Force Global Weather Center
APC	Antenna Pattern Correction
AVHRR	Advanced Very High Resolution Radiometer
C-Band	Microwave Frequency Near 6.0 GHz
CDMS	Cryospheric Data Management System
DEF	Data Exchange Format
DMSP	Defense Meteorological Satellite Program
DoD	Department of Defense
EDR	Environmental Data Record
EOS	Earth Observing System
ERIM	Environmental Research Institute of Michigan
ESMR	Scanning Multichannel Microwave Radiometer
FNOC	Fleet Numerical Oceanography Center
FY	First-Year Sea Ice
GHz	Giga Hertz
GOES	Geostationary Operational Environmental Satellite System
GR	Gradient Ratio
GSFC	Goddard Space Flight Center
ICEX	Ice and Climate Experiment
ISLSCP	International Satellite Land Surface Climate Project
JIC	Navy/NOAA Joint Ice Center
JPL	Jet Propulsion Laboratory
KRMS	Ka-band Radiometric Mapping System
L-Band	Microwave Frequency near 1.4 GHz
Landsat	Series of NASA Earth Resource Satellites

LIMEX	Laborador Ice Margin Experiment
MIZEX	Marginal Ice Zone Experiment
MOS I	Marine Observation Satellite-1 (Japan)
MY	Multi-Year Sea Ice
NASA	National Aeronautics and Space Administration
NESDIS	National Environmental Satellite Data Information Service
Nimbus	Series of NASA Research Meteorological Satellites
NOAA	National Oceanic and Atmospheric Administration
NODS	NASA Ocean Data System
NORDA	Naval Ordnance Research & Development Activity
NORSEX	Norwegian Remote Sensing Experiment
NRL	Naval Research Laboratory
NSIDC	National Snow and Ice Data Center
OLS	Optical Line Scanner
PR	Polarization Ratio
SAR	Synthetic Aperture Radar
SAWG	Sea Ice Algorithm Working Group
SDR	Sensor Data Record
SDSD	Satellite Data Services Division of NOAA
SeaSat	Oceanographic Satellite launched by NASA in 1977
SFMR	Stepped Frequency Microwave Radiometer
SMMR	Scanning Multichannel Microwave Radiometer
SPAN	Space Physics Analysis Network
SPOT	Système Probatoire d'Observation de la Terre
SPS	Shared Processing System
SSM/I	Special Sensor Microwave/Imager

SWE	Snow Water Equivalent
SWG	Science Working Group
T_A	Antenna Temperature or Pixel Average of Scene Radiance
T_B	Brightness Temperature or Scene Radiance
TBH	Horizontally Polarized Brightness Temperature
TBV	Vertically Polarized Brightness Temperature
TDR	Temperature Data Record
TOVS	TIROS Operational Vertical Sounder
UHF	Ultra-high Frequency
UMass	University of Massachusetts at Amherst
WPL	NOAA Wave Propagation Laboratory

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16. Abstract In 1982, NASA established a DMSP-SSMI Science Working Group (SWG) for the purpose of preparing a coherent program to acquire the SSMI microwave radiance data, to convert the data into sea ice parameters, and to archive the data for the scientific community. A NASA Sea Ice Algorithm Working Group (SAWG) was established to implement the recommendations made by the SSMI/SWG, and was charged with the following tasks: first, to evaluate the current state of passive microwave sea ice algorithms; second, to select an algorithm for initial processing of the SSMI data; and third, to develop and execute a plan for validating the algorithm. This document addresses this last task, and outlines a plan for monitoring the performance of the SSMI, for validating the derived sea ice parameters, and for providing quality data products before distribution to the research community. Because of recent advances in the application of passive microwave remote sensing to snow cover on land, the validation of snow algorithms is also addressed. A NASA validation team has been chosen for executing the plan outlined in this document.					
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