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DEPARTMENT OF COMMERCE
UNITED STATES OF AMERICA

POTENTIAL VALUE OF EARTH SATELLITE MEASUREMENTS TO OCEANOGRAPHIC RESEARCH IN THE SOUTHERN OCEAN

E. Paul McClain

Washington, D.C.
January 1975

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NESS 35 Modified Version of the Improved TIROS Operational Satellite (ITOS D-G). A. Schwalb, April 1972, 48 pp. (COM-72-10547)

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NESS 37 Some Preliminary Results of 1971 Aircraft Microwave Measurements of Ice in the Beaufort Sea. Richard J. DeRycke and Alan E. Strong, June 1972, 8 pp. (COM-72-10847)

NESS 38 Publications and Final Reports on Contracts and Grants, 1971. NESS, June 1972, 7 pp. (COM-72-11115)

NESS 39 Operational Procedures for Estimating Wind Vectors From Geostationary Satellite Data. Michael T. Young, Russell C. Doolittle, and Lee M. Mace, July 1972, 19 pp. (COM-72-10910)

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Robert M. White, Administrator

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David S. Johnson, Director

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ABSTRACT. Data from National Oceanic and Atmospheric Administration (NOAA) operational satellites as well as from National Aeronautics and Space Administration (NASA) research and development satellites such as Nimbus and the Earth Resources Technology Satellite (ERTS) have increasing operational and research use in oceanography. Methods are being developed to improve the mapping and monitoring of icepack concentration, character, and condition from satellite observations in the visible, near-infrared, and thermal infrared parts of the spectrum. Techniques also have been developed to map sea-surface temperatures and temperature gradients on regional and hemispheric scales from space. Recently acquired NOAA and ERTS measurements are higher in spectral and spatial resolution than those previously available, and the newest Nimbus carries the first passive microwave imager in space. Examples of some of this newly available data and their applications are presented, and a brief discussion of future sensor systems expected to be of interest to Southern Ocean researchers is given.

I. SEA ICE AND SEA-SURFACE TEMPERATURE IN THE SOUTHERN OCEAN

Fletcher (1969) has stated that about 10% of the ocean area in the Northern Hemisphere is covered by ice; in the Southern Hemisphere, the fraction is about 13% of a larger ocean area. At its maximum extent, the area of the antarctic pack has been estimated at approximately 1.7 times that of the arctic pack. More importantly, the seasonal variation in the Southern Ocean is believed to be much greater than that in the Arctic Ocean: 75-85% of the maximum extent compared with 20-25%. Although large variations in ice extent are known to occur, relatively long-term observations have been taken at only a few isolated locations.

The importance of the behavior of the sea-ice cover in the Arctic and the Antarctic on weather and climate and even on global climate has been receiving increasing attention in recent years as technological and scientific progress have made the effective investigation of these difficult problems possible. Maykut and Untersteiner (1971) have stated that the surface albedo, almost totally a function of the presence or absence of ice and its type or condition, is probably the most important regional factor affecting the heat and mass budgets of the Arctic Basin in summer. Similar statements have been made about the Southern Ocean by Fletcher (1969) and others. Ice is the major polar regions' factor that controls the exchange of heat and momentum between ocean and atmosphere in winter. Calculated in Badgley (1966), the heat flux into the atmosphere from a newly formed lead is about two orders of magnitude greater than from the surrounding ice. To monitor the seasonal patterns of surface heat exchange over the polar oceans, one systematically should observe the location and extent of pack ice, open leads, and polynyas.

Campbell (1974) has noted that "the seas bordering ice-infested seas in both polar regions are important heat exchange and cyclogenesis areas" and that "of prime importance are measurements of sea-surface temperature distribution and variation." He drew attention to the fact that such temperature measurements are now available from Earth satellites.

The Ad Hoc Working Group on Antarctic Oceanography (Baker 1974) has recommended that "the development of remote sensing techniques, e.g., satellite measurements ... be strongly encouraged" to help study the large-scale transient dynamics of the Antarctic Circumpolar Current. This group also recommended the prompt initiation of a program to study the distribution and variation of the ice cover of the Weddell Sea with the help of satellite images and "that planning for a program of measurement of exchange processes in the Southern Ocean draw heavily on satellite observations." Also, long-term monitoring of ocean frontal zones, the oceans' irradiance, and migratory cyclones and anticyclones important to the heat and water exchange between sea and air was suggested to be carried out with the aid of satellite data.

The Global Atmospheric Research Program (GARP) has set specific requirements for meteorological measurements in the Southern Hemisphere during the First Global GARP Experiment (FGGE) in 1977. Sea-surface temperature is included among these because the sensible heat transfer to and from the oceans is a major heat source or sink for the atmosphere. Sea-surface temperature and, particularly, its horizontal temperature gradients are often indicators of or are associated with current dynamics, upwelling zones, and marine life. Sea- and ice-surface temperatures are important factors in the surface heat balance in icepack regions.

If satellite measurements can aid substantially in defining the spatial and temporal variations of sea-surface temperature in the Southern Ocean and the temperature variations over the icepack and icecap, these measurements could contribute significantly to meeting the two major scientific goals set by the Ad Hoc Working Group on Antarctic Oceanography (Baker 1974). The first of these is "... studies of the time-dependent dynamics and air-sea interaction of large-scale ocean currents and frontal zones." The second includes the use of monitoring experiments to help understand the role of the Southern Ocean in the "global ocean-atmosphere circulation, in the global interaction of the sea and the atmosphere, and in the dynamics of climate."

Gathering the observations required for a number of fundamentally important studies of the Antarctic Ocean is totally impractical by use of ships, shore stations, or even aircraft because of the vastness and remoteness of the area and the need for repetitive coverage. Remote sensing from polar-orbiting satellites appears to be the only realistic means for obtaining these observations, although satellite data probably will never replace certain types of observations made at or below the ocean surface (although even here the satellite can be of assistance by data collection and relay).

II. SATELLITES AND SENSORS

The current Improved TIROS Operational Satellites (ITOS) are in near-polar, sun-synchronous, circular orbits at nominal 1500-km altitudes.[1] Among other sensors (Schwalb 1972), ITOS carries dual-channel (visible and thermal infrared) Scanning Radiometers (SR) and Very High Resolution Radiometers (VHRR).

Launched in December 1972, Nimbus 5 (U.S. National Aeronautics and Space Administration 1972) also includes among its sensors an Electrically Scanning Microwave Radiometer (ESMR) operating at a frequency of 19.35 GHz and a three-channel Surface Composition Mapping Radiometer (SCMR). Nimbus satellites, in near-polar orbits similar to ITOS orbits but at somewhat lower altitudes (about 1100 km), also have carried an Interrogation, Recording, and Location System (IRLS) capable of data relay from and positioning of fixed or moving instrument platforms at the Earth's surface or in the atmosphere.

The United States launched its first Geostationary Operational Environmental Satellite, SMS/GOES 1, in May 1974.[2] Until Sept. 23, 1974, the spacecraft was stationed at an altitude of about 36,000 km above the Equator at 45°W to provide support for the GARP Atlantic Tropical Experiment (GATE) centered west of Dakar in northwestern Africa. Following completion of GATE in September 1974, the satellite was moved to its operational position of 75°W. Presently scheduled for launch in January 1975, GOES 2 will be stationed at 135°W but probably will not be ready for full operational use for 2 to 3 mo after launch. Although the Visual and Infrared Spin Scan Radiometer (VISSR) aboard the GOES will provide no useful data to Southern Ocean researchers, a transponding system suitable for collecting environmental data from Earth-based instrument platforms could be utilized as far poleward as 70° to 75°S at longitudes about 35° either side of that of the satellite.

To conclude this brief overview of satellites and satellite sensor systems suitable for ocean studies, one should note the launch of the first Earth Resources Technology Satellite (ERTS) in July 1972 (General Electric 1972). Although also in a near-polar, sun-synchronous orbit, sensors on the ERTS system, unlike those on ITOS and Nimbus, do not provide daily

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[1]Television Infrared Observation Satellite (TIROS)

[2]Stationary Meteorological Satellite (SMS)

global coverage. ERTS has both direct readout and stored data capability, but the data swaths of its four-channel Multispectral Scanner (MSS) and its three-channel Return Beam Vidicon (RBV) are both 185 km wide; thus coverage over most areas in the world occurs only at 18-day intervals. Also, ERTS is equipped with a Data Collection System (DCS).

A summary of the spectral and spatial resolution characteristics of the sensor systems of the satellites briefly discussed thus far is contained in table 1. All of the sensors listed are primarily imaging systems; but in most cases, digitized data also can be derived from the sensor data, although not all sensors have provision for on-board calibration.

Table 1.--Satellite sensor systems*

Sensor	Satellite	Nominal spectral band (μm)	Nominal resolution at nadir (km)	Remarks
APT	ESSA 2, 4, 6, 8 ITOS 1, NOAA 1 Nimbus 1, 2	0.5 - 0.7	4.6	APT service replaced by SR on NOAA 2 and by HRIR or THIR on Nimbus 3 and 4
AVCS	ESSA 1, 3, 5, 7, 9 ITOS 1, NOAA 1 Nimbus 1, 2	0.5 - 0.7	1.9 - 3.5	Global coverage AVCS replaced by SR on NOAA 2 and by IDCS on Nimbus 3 and 4
ESMR	Nimbus 5	1.55 cm	25	Global coverage
HRIR	Nimbus 1, 2	3.4 - 4.2 0.7 - 1.3	8.0	Global coverage Thermal IR replaced by THIR on Nimbus 3 and 4 Near-IR on Nimbus 3 only
IDCS	Nimbus 3, 4	0.5 - 0.7	2.2	Global coverage and local readout
MSS	ERTS 1	0.5 - 0.6 0.6 - 0.7 0.7 - 0.8 0.8 - 1.1	100 m	Direct readout only since March 1973 due to tape-recorder failure
RBV	ERTS 1	0.5 - 0.6 0.6 - 0.7 0.7 - 0.8	100 m	Inoperative since August 1972
SCMR	Nimbus 5	0.8 - 1.1 8.3 - 9.2 10.5 - 12.5	0.8	Inoperative since January 1973
SR	ITOS 1 NOAA 1, 2, 3, 4	0.5 - 0.7 10.5 - 12.5	3.5 8.0	Global coverage and local readout
THIR	Nimbus 4, 5	6.5 - 7.5 10.5 - 12.5	22.2 7.5	Global coverage and local readout
VHRR	NOAA 2, 3, 4	0.6 - 0.7 10.5 - 12.5	1.0	Mostly direct readout

*See appendix I for a glossary of acronyms.

III. SEA-ICE APPLICATIONS

The usefulness of pictures taken by meteorological satellites for gross ice mapping was recognized quickly after launch of the first TIROS research and development satellite in 1960 (Wark and Popham 1963). Most use of satellite vidicon photographs for detection and mapping of sea ice in the Arctic or Antarctic has emphasized photo-interpretation techniques to delineate ice boundaries and features (Popham and Samuelson 1965, Aber and Vowinckel 1972). One of the basic problems encountered in this approach is to discriminate between ice (with or without a snow cover) and clouds that often have reflectances in the same general range as the pack ice. A simple but effective technique to separate ice from clouds takes advantage of the relatively conservative behavior of the ice fields in comparison with the often rapidly changing character of cloud masses. Careful study of a geographical area for several successive days generally permits differentiation of ice-covered areas from clouds. Also helpful in this problem is that ice and clouds frequently have characteristically different patterns, shapes, or textures and that clouds cross coastlines, cast shadows, or possess partial transparency. The better the spatial resolution of the sensor, the more effectively these factors can be used for interpretation, including the deduction of pack-ice type and concentration.

Filtering or suppressing the clouds from visual satellite images also can be achieved by computer manipulation of the satellite brightness values (or reflectances) after the data have been digitized and mapped (Booth and Taylor 1969). The brightness data usually are normalized with respect to solar zenith angle and corrected for system errors during this process. The minimum brightness at each mapped point during a selected set of successive days, usually 5 or 10, can then be composited to produce a Composite Minimum Brightness (CMB) chart in the form of an image or computer printout or contoured chart. McClain and Baker (1969) have demonstrated that the hightly reflective areas in the CMB correspond to close pack (7/10 to 8/10 coverage) or greater concentrations of pack ice. The longer the compositing period, the more effective is the cloud filtering but the more vulnerable the CMB chart becomes to errors caused by changes in ice extent. McClain (1973b) developed a procedure to calibrate externally the digitized CMB values by normalizing them with respect to natural Earth targets in which brightness varies within very narrow limits. Characteristic brightness values were found that corresponded to the icepack concentration and the presence or absence of extensive snow cover or puddling. Wendler (1973) used such a procedure to study ice movements in a small area of the Arctic Ocean off the north shore of Alaska and to derive monthly mean albedo maps. Fletcher (1969) recommended the systematic production of CMB charts "to establish a basic observational picture of time and space variations of Antarctic sea-ice extent."

Thermal infrared imagery and measurements from the infrared (IR) scanners on Nimbus satellites and the SR and VHRR scanners on the NOAA satellites are being used increasingly in operational and research applications for sea-ice surveillance [e.g., the studies by Barnes et al. (1972a, 1972b)]. These investigations have shown that, although the 8 km resolution

IR-band imagery provides a means of mapping gross ice boundaries during periods of polar darkness, it is generally inferior to the 3.5 km resolution visible-band imagery which can be used during periods of sufficient solar illumination. During times when visible and thermal IR can be used jointly, preliminary results indicate that additional ice information, such as ice concentration (and possibly thickness), can be inferred. Thermal contrasts between ice and water are not so large as reflectance contrasts; therefore, IR imagery generally requires some special treatment (e.g., enhancement) for optimum use in ice analysis. Nearly all clouds are opaque to radiation emitted at 10.5 to 12.5 μm, but many of these same clouds are partially transparent to energy in the wavelengths 0.5 to 0.7 μm; thus delineation of ice features is more often possible by use of the visible than the infrared.

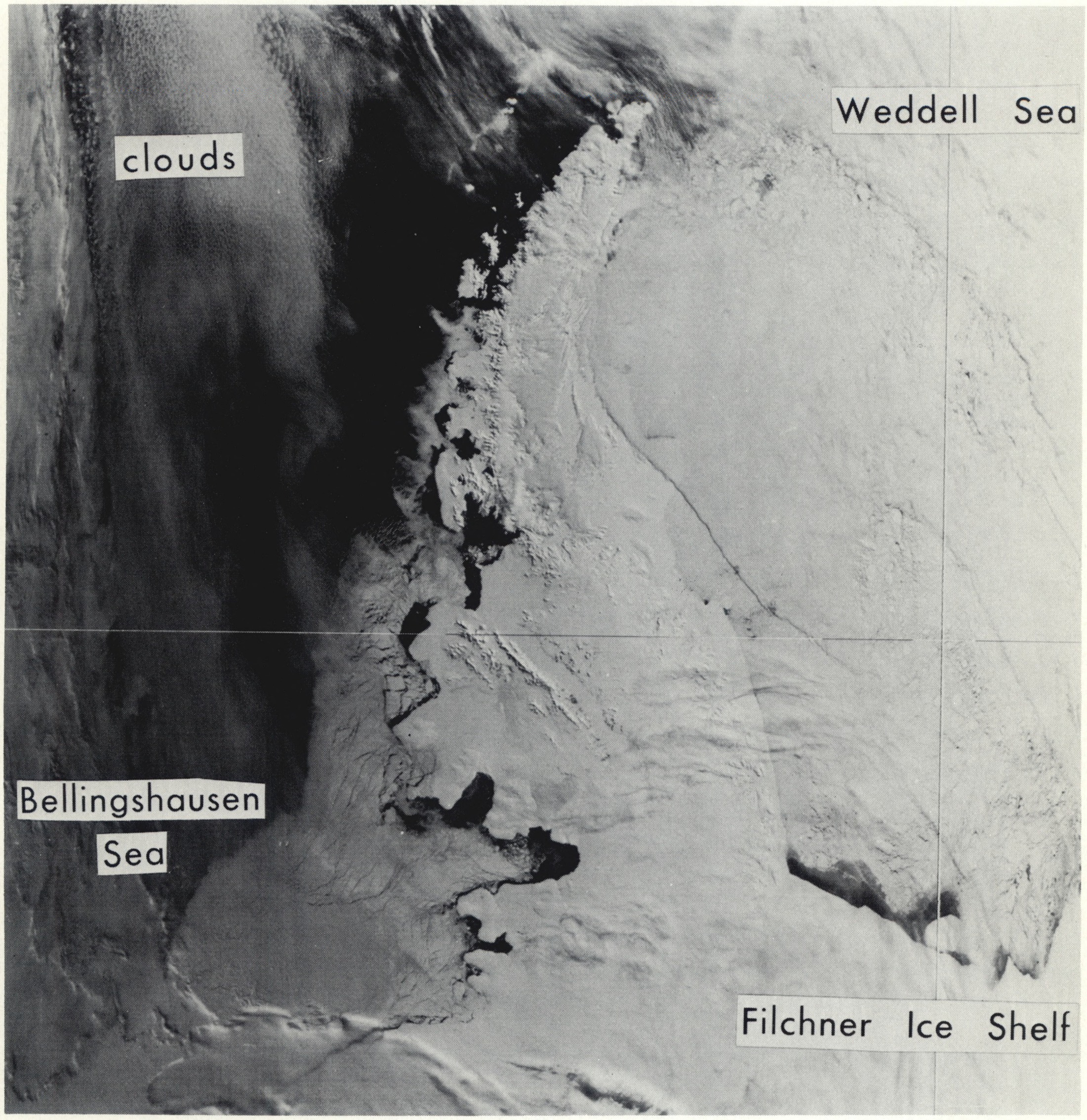

Figure 1.--VHRR visible-band image obtained by the NOAA-2 satellite in the Antarctic Peninsula area on 17 November 1973. Shorefast and pack ice are present in the Weddell and Bellingshausen Seas.

The newly available VHRR visible and thermal infrared data, in which a 1-km ground resolution yields a fourfold improvement over most previous visible observations and a tenfold improvement over previous IR measurements, represent a substantial gain in ice-mapping capability from space. Cloud-discrimination techniques are applied more effectively with the higher resolution images; furthermore, details of floe, lead, and fracture patterns stand out clearly in the new data (fig. 1). The improvement in ice-information content is especially marked in enhanced infrared imagery. Special stored VHRR data coverage was obtained over the Ross Sea area of Antarctica from November 1972 through January 1973 and for a similar period in 1973-74 to assist U.S. Navy ice forecasters in their support of resupply missions. VHRR coverage of the western Weddell Sea was obtained in February and March 1974. Some of these data series also have been used for research within NOAA/NESS, including a study of ice movement (DeRycke 1973) and the calving of tabular icebergs in the vicinity of the Ross and Getz Ice Shelves (fig. 2). Similar ice-motion studies have been made for the

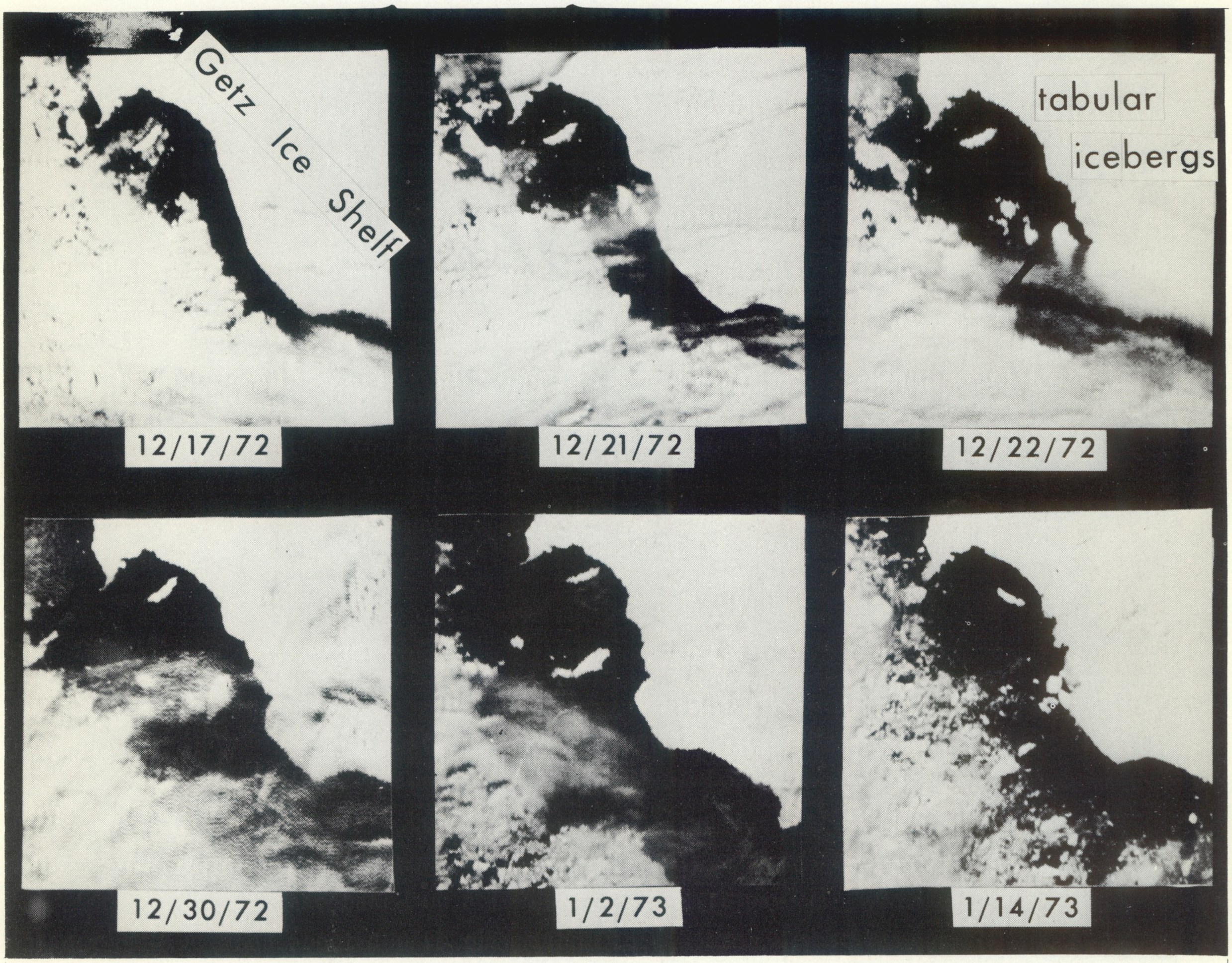

Figure 2.--Sequence of visible-band images obtained by the NOAA-2 satellite in the vicinity of the Getz Ice Shelf from mid-December 1972 through mid-January 1973. Large tabular icebergs are seen to have calved off the ice shelf on 21 and 22 December. Note the motion and rotation of the bergs during the remainder of the period.

Labrador Current area (figs. 3 and 4). Research using digitized VHRR data was initiated recently by NOAA/NESS to further develop ice enhancement methods and to investigate the information content of ice temperature variations. Computer resources constrain digitization of VHRR data to small areas; and rectification and mapping, which are requirements for production of CMB charts, are precluded for the near future.

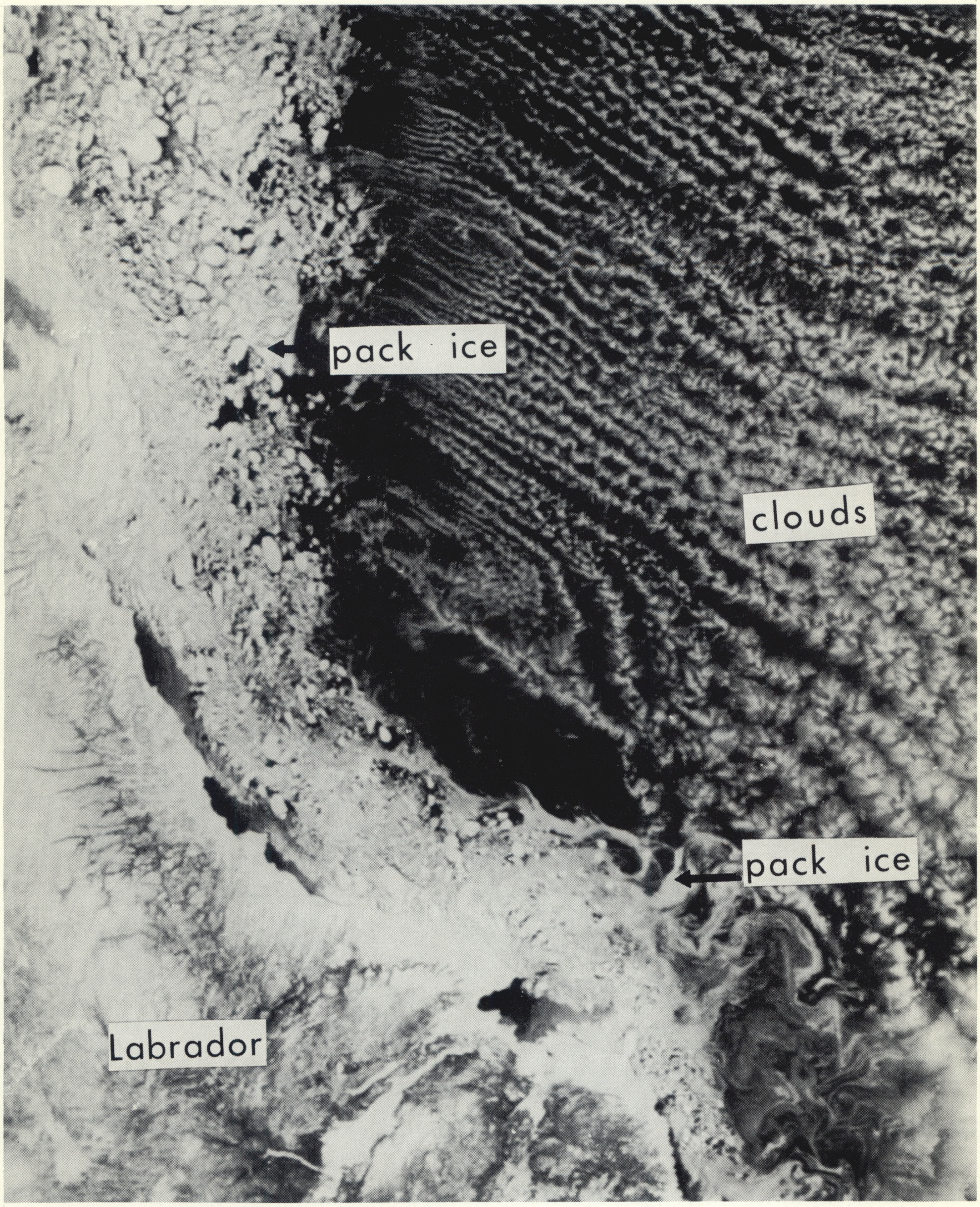

Figure 3.--NOAA 2 VHRR-VIS image of pack-ice stream moving southeastward in the Labrador Current on 31 March 1973. Identifiable ice features can be tracked over periods of a few days to a few weeks to obtain direction and speed of ice motion. See also appendix I.

The 100-m resolution of the experimental ERTS data permits the most detailed and precise interpretation and mapping of ice features (Barnes and Bowley 1974), coastal and shoal configurations, turbidity (Klemas 1973), and vegetative matter such as algae (Strong 1974) and kelp in surface waters to be possible from an Earth satellite; but the coverage provided by the 185-km-wide swath and the 18-day return cycle precludes virtually all operational use, especially when cloud obscuration and data-processing delays are taken into account. Overlapping ERTS coverage at high latitudes sometimes permits viewing the same small area for several successive days; thus it has been possible at times to track specific ice features over short periods to gain information on wind, current, and ice interactions. ERTS data

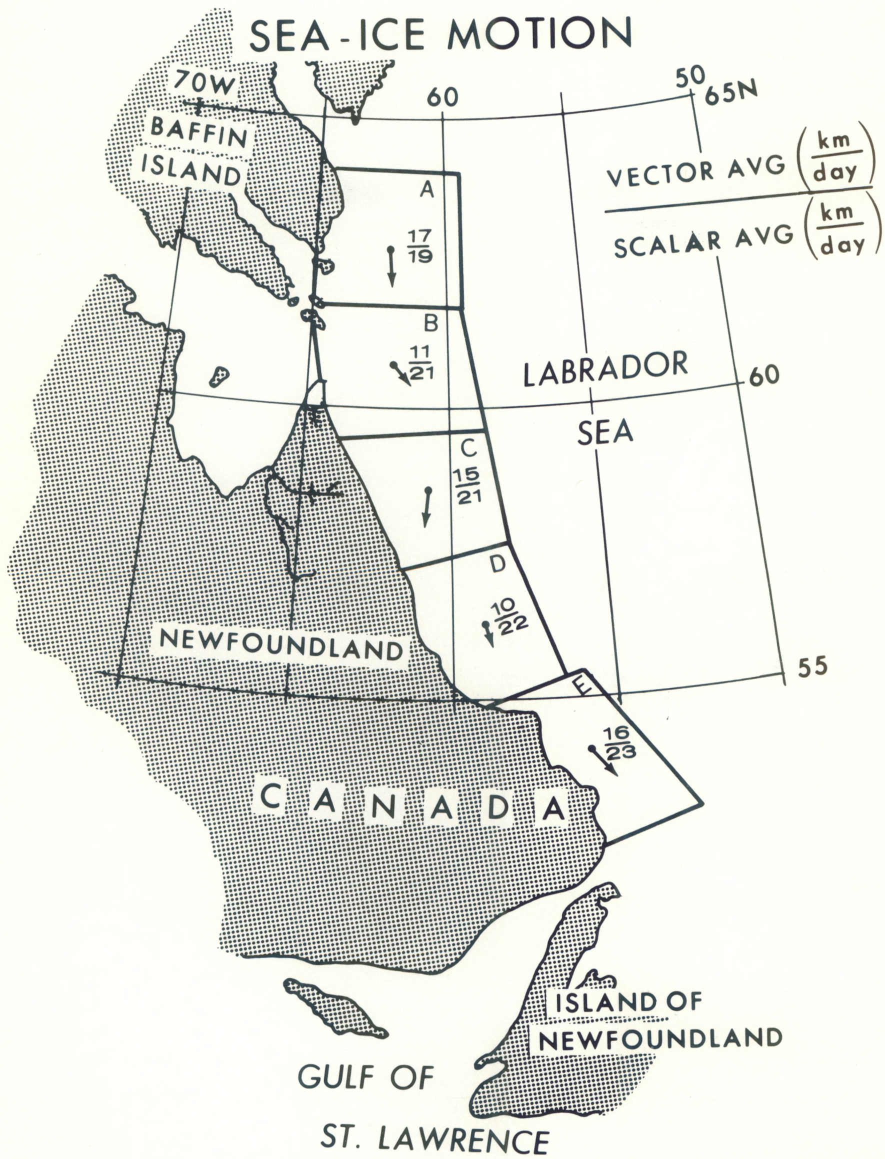

Figure 4.--Speed and direction of ice movements obtained from VHRR visible and infrared images during the late winter and early spring of 1973. The results agree well with published Labrador Current velocities, which are available from ship observations made only during the late summer and early fall seasons. See also appendix I.

also can be used to detect and delineate areas of melting pack ice and, thus, the extent of puddling [i.e., the presence of melt water pools (McClain 1973a)]. This capability, which was first demonstrated using the visible and near-infrared imagery from Nimbus 3 (Strong et al. 1971), derives from the circumstance that, when an ice or snow surface becomes wet, its reflectivity diminishes sharply in the wavelengths from 0.7 to 1.3 μm, but only slightly at visible wavelengths. The failure of the second tape recorder on ERTS 1 in March 1973 precludes further coverage of Antarctica until ERTS 2 is in orbit; launch is planned for early 1975.

The success of the ESMR on Nimbus 5 represents a significant advance in our capability to monitor sea ice throughout the year and in virtually all weather (Campbell et al. 1973). The single greatest limitation on satellite sensing of sea ice at visible and infrared wavelengths is cloud cover, but natural emission from Earth's surface at microwave wavelengths is attenuated only slightly by clouds typical of polar regions. Large brightness temperature contrasts--due to emissivity rather than physical temperature differences--found at ice-water boundaries are observed readily through clouds. Gloersen et al. (1974) have observed that the ice surface itself has emissivity variations, with first-year ice being somewhat more emissive than multiyear ice. The only drawback to the use of ESMR imagery for some types of ice studies is the relatively coarse spatial resolution of the data (viz, 25 km). Better resolution than this will require the orbiting of substantially larger antennas.

The IRLS on Nimbus has been used to track six drifting buoys emplaced in the pack ice of the Beaufort Sea as part of the Arctic Ice Dynamics Joint Experiment (AIDJEX) in 1972 (Martin 1972). The data buoys, designed for an operational lifetime of up to 1 yr, measure atmospheric pressure and near-surface air temperature when interrogated from Nimbus 4. These data and information on the buoys' location are telemetered to the data-acquisition station near Fairbanks, Alaska. Five of the buoys in this array were functional throughout the winter of 1972-73.

IV. SEA SURFACE TEMPERATURE APPLICATIONS

The development of satellite sea surface temperature mapping techniques has been underway for about 5 yr; the first experiments started with infrared scanner data from the early Nimbus satellites. By 1972, development had progressed to the point (Krishna Rao et al. 1972) where experimental operational sea-surface temperatures now are generated daily on a global basis. The sea surface temperature retrievals are based on a technique for multiday compositing of SR scanspot data, collected over areas about 100 km on a side, to achieve effective cloud filtering. The scattered and irregularly distributed (because of cloudiness variations) temperature retrievals obtained on any given day also are combined spatially and temporally by a rather complex analysis scheme. The product is a computer printout or contoured chart of spatially smoothed temperatures, corrected for atmospheric attenuation, on an approximately 50-km grid array over each hemisphere (Brower 1974).

More detailed depiction of sea surface temperature gradients are possible in cloud-free areas; in such areas, the daily SR or VHRR measurements are used with little or no spatial averaging or smoothing. Usually, this is done using two approaches: (1) displaying the infrared data in the form of enhanced gray-tone or false-color images (fig. 5) and (2) using computer scanline printouts of quantitative data. A number of articles (Krishna Rao et al. 1971, Strong et al. 1972) describe the usefulness of this type of satellite data in studies

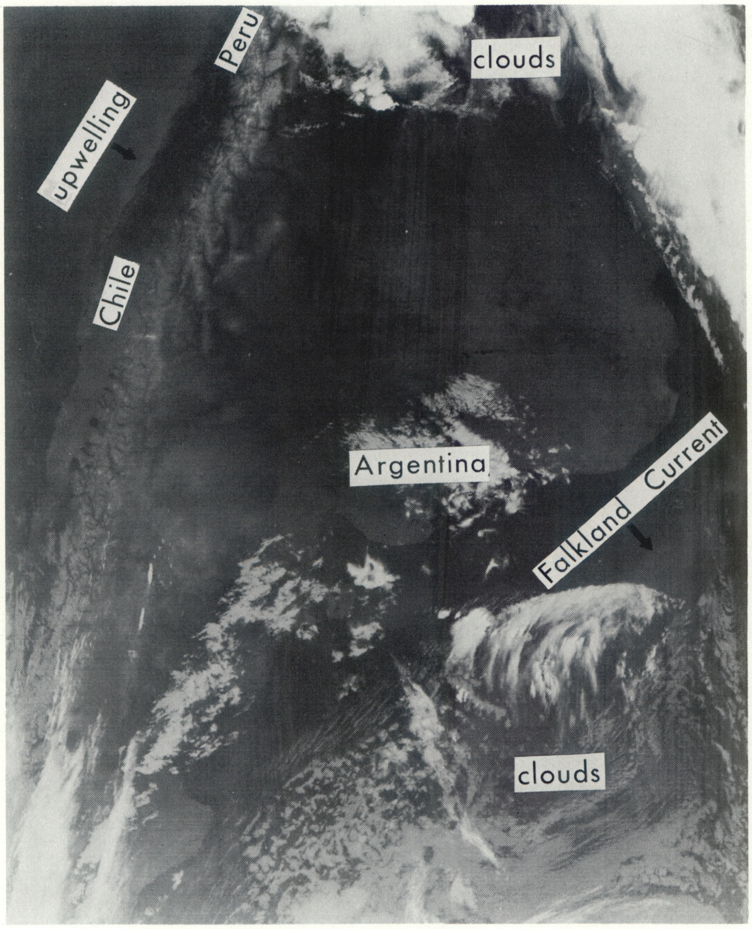

Figure 5.--Thermal infrared image of southern South America obtained by the VHRR on NOAA 2 on 13 January 1974. Thermal contrasts associated with apparent cold upwelling in the coastal waters of Peru and Chile and with the cool Falkland Current off the coast of Argentina are seen. The gray tones in this image are inversely proportional to the temperature of the radiative surfaces (i.e., the lower the temperature, the brighter the tone). The very cold features in this image are clouds.

of major currents such as the Gulf Stream (fig. 6), upwelling episodes (e.g., in Gulf of Tehuantepec and off the coast of northwestern Africa), and large oceanic warm and cold eddies. The absolute accuracy of these satellite sea surface temperature estimates has been established as 1.5° to 2.0°C, with relative accuracy near 1°C.

Although only applicable over limited areas, sun-glitter patterns often afford information on the roughness variations of the ocean surface. These roughness patterns can reveal the location of ocean currents; areas of calm or very light winds; and, indirectly, the presence of upwelling (Strong and DeRycke 1973, Strong et al. 1974).

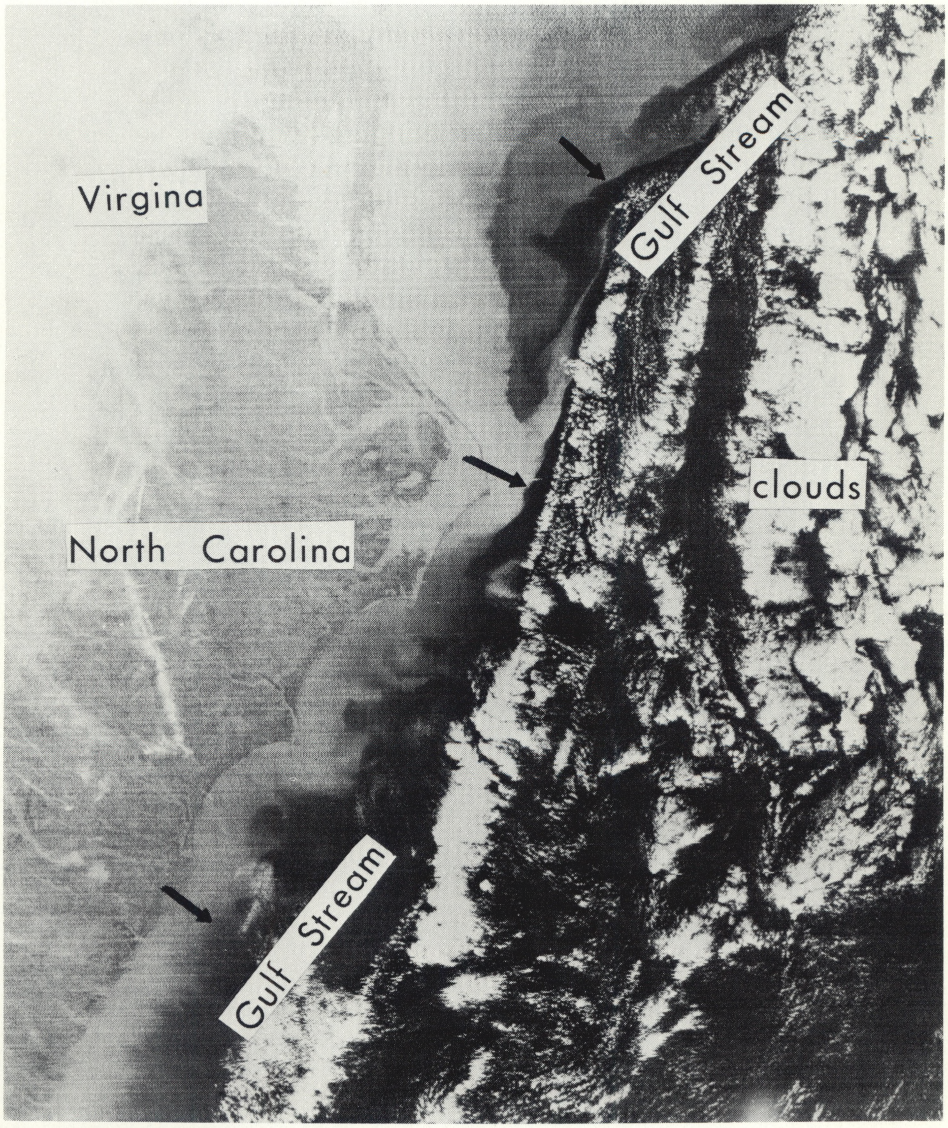

Figure 6.--Enhanced VHRR-IR image of a portion of the Gulf Stream on 1 March 1973 showing details of the thermal structure along the inshore area. As in figure 5, the coldest surfaces are the brightest in tone. Note the warm Gulf Stream, cool slope, and cold shelf waters and the complex thermal boundaries between them.

V. POTENTIAL FOR FUTURE CONTRIBUTIONS OF SATELLITE TECHNOLOGY TO OCEANIC STUDIES

The sensor complement of the NOAA series of polar-orbiting operational satellites will remain unchanged through about 1977, except that the visible channel will be widened to 0.5 to 1.0 μm on some of the SRs. The application of SR and, especially, VHRR measurements to oceanic problems is likely to increase rather quickly as the number of ground stations equipped to receive these data continues to grow and as better equipment and techniques for processing, displaying, and applying these observations are developed. The trend toward more quantitative, objective, and automated application of satellite data, rather than interpretation of images, is already apparent. Planned-for improvements to ITOS after about 1977 include the replacement of the SR and the VHRR by the Advanced Very High Resolution Radiometer (AVHRR) and a conversion to on-board digitizing and direct transmission of data from the satellite. This will be accomplished by an on-board data processor, which also will "degrade" the stored 1 km resolution data to about 4-km resolution for global meteorological coverage. Full-resolution measurements will be available for direct readout service to suitably equipped ground stations and for limited area coverage via the stored data mode. Conventional Automatic Picture Transmission (APT) service also will continue. The AVHRR will have four channels: visible (0.5 - 0.9 μm), reflected IR (0.75 - 1.0 μm), and thermal IR (3.6 - 4.1 and 10.5 - 12.5 μm). That later versions split the 10-μm window channel to permit even more accurate surface temperature measurements is proposed. A data-collection system also will be added to ITOS.

The next two satellites in the Nimbus series, now designated F and G, with launches tentatively planned for the first half of 1975 and 1978, respectively, also will carry sensor or data-relay systems of interest to ocean researchers. In addition to a THIR and an improved ESMR (0.8-cm wavelength), Nimbus F will be equipped with a Scanning Microwave Spectrometer (SCAMS: 1.35- to 0.465-cm wavelengths), and a system known as TWERLE/RAMS (Tropical Wind Energy Conversion Reference Level Experiment/Random Access Measurement System). The latter is designed to obtain positions of and to collect data from unmanned drifting stations. Final selection of the sensor complement for Nimbus G has not been made, but potentially it will include a coastal zone color scanner or ocean color sensing experiment, or both; a multifrequency, mechanically scanning microwave radiometer; and, perhaps, a multiband sea surface temperature imaging radiometer.

ERTS 2, at present scheduled for 1975, will have the same RBV and MSS sensor systems as ERTS 1; an originally planned fifth channel in the thermal infrared will not be added to the second ERTS. Like ERTS 1, ERTS 2 will have a data-collection and relay capability but no direct ability to obtain positions of moving instrument platforms. Already demonstrated, however, is that with suitably equipped platforms location can be accomplished by means of signals from navigation-type satellites or the Omega system using ERTS, GOES, or the next-generation ITOS (Sperry Support Services 1973).

NASA is planning Seasat, the first Earth satellite dedicated to ocean measurements, for launch in 1978. The orbit of this sea satellite presently is envisioned as circular, high inclination, at an altitude of about 1000 km, and designed to provide 36-hr repeat coverage globally. Proposed sensors include a compressed-pulse, precision radar altimeter; a microwave wind scatterometer; a visible-infrared scanning radiometer; and, possibly, a synthetic aperture coherent imaging radar. These instruments are intended to provide qualitative and quantitative information on such factors as sea-surface topography, significant wave height, wind speed wave-directional spectra, and wave-refraction pattern, sea state, and sea ice.

VI. CONCLUDING REMARKS

This review has dealt exclusively with U.S. satellite systems, although we know that operational Meteor satellites and Cosmos research satellites of the Soviet Union have carried sensors useful for sea-ice and temperature studies. We hope that increased exchange of information and ideas among all countries engaged in ocean investigations will take place and accelerate effective application of satellite technology. Satellite data are used most effectively in ocean investigations when they can be calibrated and controlled with aircraft remote sensing and surface-based observational programs, such as in AIDJEX and GATE. Such an approach would be valuable, if not essential, to the upcoming POLEX (Polar Experiment) program or to research projects concerned with the Southern Ocean.

The Joint U.S. POLEX Panel recently has recommended (Campbell 1974) "establishment of a new polar climate record based primarily on satellite data and coupled with the sparse surface data to produce a systematic record for cause-and-effect studies of the polar regions and the way in which they interact with temperate and tropical regions."

The Glaciology Panel of the Committee for Polar Research (Weeks 1974) has advised that strong support should be provided to the development and application of new observational techniques and instrumentation. Among these are: ERTS data for coastal mapping and for observing changes in behavior and small-scale features of the Antarctic icepack; ITOS high-resolution visible and infrared imagery to record sea-ice and cloud motions as well as large-scale boundaries and features; and Nimbus TWERLE/RAMS for data collection and transmission from automatic unmanned recording stations on the ice-cap surface, on the sea ice, and on the open ocean. Finally, Untersteiner (1974) recently stated that "well planned, optimal use of satellite data is more important in the Antarctic than in any other part of the world."

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APPENDIX I. GLOSSARY OF ACRONYMS AND ABBREVIATIONS

AIDJEX	Arctic Ice Dynamics Joint Experiment
APT	Automatic Picture Transmission
AVCS	Advanced Vidicon Camera System
AVG	Average
AVHRR	Advanced Very High Resolution Radiometer
CMB	Composite Minimum Brightness
DCS	Data Collection System
ERTS	Earth Resources Technology Satellite

ESMR	Electrically Scanning Microwave Radiometer
FGGE	First Global GARP Experiment
GARP	Global Atmospheric Research Program
GATE	GARP Atlantic Tropical Experiment
GOES	Geostationary Operational Environmental Satellite
HRIR	High Resolution Infrared Radiometer
IDCS	Image Dissector Camera System
IR	Infrared
IRLS	Interrogation, Recording, and Location System
ITOS	Improved TIROS Operational Satellite
MSS	Multispectral Scanner
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
POLEX	Polar Experiment
RAMS	Random Access Measurement System
RBV	Return Beam Vidicon
SCAMS	Scanning Microwave Spectrometer
SCMR	Surface Composition Mapping Radiometer
Seasat	Sea satellite
SMS	Stationary Meteorological Satellite
SR	Scanning Radiometer
THIR	Temperature Humidity Infrared Radiometer
TIROS	Television Infrared Observation Satellite
TWERLE	Tropical Wind Energy conversion Reference Level Experiment
VHRR	Very High Resolution Radiometer
VIS	Visual
VISSR	Visual and Infrared Spin Scan Radiometer

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