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INFORMAL REPORT

SPACECRAFT OCEANOGRAPHY 1964-1967

MAY 1968

NAVAL OCEANOGRAPHIC OFFICE
WASHINGTON, D.C. 20390

INFORMAL REPORT

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SPACECRAFT OCEANOGRAPHY--1964-1967

by

Charles C. Bates
and
John W. Sherman

ABSTRACT

As part of its Natural Resources Program, NASA has sponsored for the past two years a government-wide effort to identify user requirements and to determine through a series of experiments the feasibility of employing earth-orbiting spacecraft to conduct peaceful and scientific studies and surveys of the world ocean. The U.S. Naval Oceanographic Office has served as NASA's prime agent in this area and has been assisted by an Advisory Group drawn from interested agencies of the Departments of Defense, Commerce, Interior, Health, Education and Welfare, Atomic Energy Commission, National Science Foundation, Smithsonian Institution, U.S. Coast Guard, National Academy of Sciences, and the National Academy of Engineering.

Approximately one million dollars of sponsored work has been conducted at eight universities and four industries in this spacecraft oceanography program. Ground truth test sites have been selected in the general area of Bermuda, Straits of Florida, the Gulf Stream, San Diego, and Point Barrow. Remote-sensor equipped aircraft of NASA's Manned Spacecraft Center, the U.S. Naval Oceanographic Office, the Naval Research Laboratory and of contractors are being used in various experiments over various ocean areas to gain an early appreciation of the problems and capabilities of spacecraft oceanography. Remote sensors tested to date include multi-band color cameras, radar scatterometers, infrared spectrometers and scanners, passive microwave radiometers, and radar imagers. As a result, some ten oceanographic sensors have been identified as possibly being worth including in final design of instruments to be considered for inclusion in a number of manned and unmanned NASA spacecraft under consideration for possible construction and launch during the next five years.

National interest is building up in the area of spacecraft oceanography and its related field of aircraft oceanography. The National Council on Marine Resources and Engineering Development has recently sponsored its own systems study of the area and issued in October, 1967 a most attractive brochure entitled, "U.S. Activities in Spacecraft Oceanography". The area, however, still suffers from a restricted funding level, from a lack of widespread knowledge on the part of classical oceanographers as to just what modern remote sensors coupled with telemetry from space can and cannot reveal about the ocean from aloft, and from a considerable degree of ignorance as to just what "skin" oceanography can tell us about oceanographic phenomena taking place below the surface.

Approved for Release: Charles C. Bates

CHARLES C. BATES
Scientific and Technical Director

SPACECRAFT OCEANOGRAPHY--1964-1967

To the uninitiated, "Spacecraft Oceanography" sounds like a contradiction of terms. How can one learn anything about the ocean from 100 miles or so above the sea, particularly when 60 percent of the ocean is always covered with cloud? Even as late as 11 December 1967, the Subcommittee on Oceanography of the House of Representatives' Committee on Merchant Marine and Fisheries was somewhat surprised when it heard testimony by Dr. Robert Seamans, Deputy Administrator of NASA, regarding NASA's participation in the National Marine Sciences Program. For example, Congressman Alton Lennon, Chairman of the committee, found cause to say:

> "This is an interesting colloquy which has been going on with respect to the participation of NASA in the fields of oceanography and the marine sciences. Some of these things we perhaps did not know about except for those members who are also members of the distinguished committee on space...I think it is rather tragic that we did not seize the opportunity to have you folks come to tell us about this earlier....."

Dr. Robert Seamans further delineated NASA's role in this new area when he testified:

> "At the last meeting of the Marine Council there was a question of what agency would coordinate the work which related to spacecraft...When they found we were ready to take this on, they were happy to have us take on this responsibility, and that is the way it will be done."

It is the purpose of this paper to relate briefly what has been going on in the area of spacecraft oceanography for the past three years and to provide a brief outlook for the future.

For decades, the oceanographer has been limited to the slow and costly process of sampling the ocean environment from surface vessels and basing his assessment of the ocean's properties and behavior on observations separated widely in time and space. For example, the International Indian Ocean Expedition, mounted between 1959 and 1964, involved 14 ship-operating countries. Some 180 research cruises were involved and cost approximately $60 million. This expedition has been termed "the largest, most diverse and extensive, and well-funded expedition there has ever been." U.S. participation was extensive, even to the extent of converting the presidential yacht, WILLIAMSBURG, into a floating biological laboratory. Once the expedition ended, however, data on the Indian Ocean have again become nearly non-existent. Moreover, only one United States oceanographic vessel is scheduled to work in the entire region anytime during the next 18 months.

Within the past decade, development of remote sensors and oceanographic employment of Navy aircraft have begun to permit obtaining broader coverage of the "skin oceanography" in a shorter interval of time than by use of ships. In addition, as far back as 1959, TIROS II, an early meteorological satellite, demonstrated on a pass over the ice covered Gulf of St. Lawrence the potential of obtaining useful oceanographic data from space. The results of this analysis led to Project TIREC (TIROS Ice Reconnaissance), a joint U.S./Canadian project to correlate satellite television readouts of ice cover with visual and photographic observations obtained from aircraft and surface units. The United States participants in this project were the Coast Guard, the Weather Bureau, and the Naval Oceanographic Office (NAVOCEANO).

As part of its Earth Resources Survey Program established in 1964, NASA decided to determine the oceanographic community's interest in the use of remote sensing and spacecraft. A joint conference was organized by Dr. Peter Badgley, NASA's Earth Resources specialist, with the Woods Hole Oceanographic Institution. The Proceedings, Woods Hole Oceanographic Institution Report 65-10, contain fifty pertinent papers and is the best early document regarding the potential of this new approach to studying the ocean for scientific and commercial purposes.

As an outgrowth of the successful Woods Hole Conference, NASA decided to initiate a government-wide effort to identify user interests within the oceanographic community. It was also decided to determine through a series of experiments the feasibility of employing earth-orbiting spacecraft for conducting peaceful and scientific studies of the world ocean. NASA requested the assistance of the 136-year old Naval Oceanographic Office in the coordination of the required efforts. This selection came about in part because its century-old law calls for NAVOCEANO to supply information about the world ocean to the merchant marine and the navigator in general. The

Office's pioneering effort in airborne oceanography was important, as was the Office's extensive relationships with dozens of foreign countries for the past two decades involving training of foreign hydrographers and oceanographers in modern aspects of applied hydrography and oceanography.

NASA's initial work order to the Naval Oceanographic Office in October 1965, backed up by a transfer of $900,000 of funds, called for developing a program of research studies that would lead to identification of experiments in the realm of oceanography and marine technology utilizing manned orbiting space stations. The Navy was further asked to enlist the support and obtain the advice of a broad spectrum of governmental, academic and industrial organizations in defining and designing the necessary scientific and technical experiments.

NAVOCEANO responded to the work-order by establishing the Spacecraft Oceanography, or SPOC, Project in Building 58 at the Naval Research Laboratory, Washington, D. C. NAVOCEANO also immediately formed an _ad hoc_ Spacecraft Oceanography Advisory Group with membership from all interested government agencies. The Advisory Group has met nine times to date since its first meeting in January 1966. As an index of interest, it might be mentioned that the last meeting at Texas A&M University and the NASA Manned Spacecraft Center, Houston, drew in excess of 80 attendees. Three of the participating agencies have named individuals who work as members of the SPOC team up to 50 percent of their time. These agencies and individuals are: Environmental Science Services Administration (ESSA), Mr. Robert Popham; Bureau of Commercial Fisheries (BuComFish), Interior Department, Dr. Paul Maughan; and for the U.S. Coast Guard, Transportation Department, Commander R. P. Lenczyk.

The various types of spatial and temporal variation of sea surface temperature are listed in Table I. To ensure a balanced research program, the potential areas to be studied for technical feasibility were broken down as follows:

(1) Sea State

(2) Biological Activity

(3) Thermal Conditions

(4) Coastal Processes (Including Effluents)

(5) Bathymetry and Hydrography

(6) Air/Sea Interaction Processes

(7) Sea Ice

Unsolicited research proposals were received, reviewed, and supported in each of these areas. The national participation within these areas during 1966 and 1967 breaks down as shown in Table II. In addition, a number of potential ground truth test sites were selected, as shown in Figure I, where various oceanographic parameters could be studied in detail under known conditions when remote sensors viewed the specified area. To provide a ready method for experimenting with looking at these and comparable parts of the ocean with the various types of remote sensors under test, NASA has made available to the oceanographic community a sizeable percentage of flight time on NASA's two remote sensing aircraft operated by the Manned Spacecraft Center at Houston, Texas, for the Earth Resources Survey Program. The applicable equipment installed or scheduled for installation aboard these aircraft (Convair 240 and Lockheed NP-3A) is listed in Tables III and IV. Between March, 1966 and November, 1967, twelve special oceanographic missions have been flown, as shown in Table V, in such diverse areas as Bermuda, the Mississippi Delta, the Florida Straits, the coastal waters of the Island of Newfoundland, the Goose Bay area of Labrador, and the Point Barrow area of Alaska. Flight time on these aircraft is in great demand and mission requests must be submitted in advance of quarterly scheduling conferences. The NASA/NAVOCEANO Spacecraft Oceanography Project participates in these quarterly aircraft scheduling sessions.

To date, the following remote sensors have been found to have oceanographic potential: black-and-white metric cameras; mutli-band color cameras; multi-band spectrophotometers; radar scatterometers and imagers; infrared spectrometers and scanners; and microwave radiometers. Oceanographic achievements to date may be highlighted as follows:

(1) Biological Indices: Fish schools and fish oil slicks have been detected on color aerial photography. Fish oils and vapors have been differentiated from petroleum by using ultra-violet and far infrared absorption band signatures.

(2) Sea State: Feasibility of detecting wave heights up to 13 feet in height and wind speeds up to 30 knots using a 13.3 GHz scatterometer has been determined off Newfoundland.

(3) Sea Surface Temperature: Infrared scanners flown over the Gulf Stream show that $2^{o}F$ temperature differences can be readily detected. Computer playouts of the high - resolution infrared data from NIMBUS II indicate that such major ocean currents as the Gulf Stream and the Kuroshio are readily visible under cloud-free conditions from orbital altitudes.

(4) Bathymetry and Hydrography: Photometric analyses using the density slicing technique, when applied to color photographs, have generated iso-lines of intensity that parallel depth contours in clear-water areas of the world such as Bahama Banks. Validation of the position of reef flats and poorly surveyed atolls has been acccomplished for Rongelap and Alingae Atolls, Marshall Islands.

(5) Coastal Processes: GEMINI photography has shown that river effluent patterns can be readily mapped from orbital altitudes when cloud cover is not present.

(6) Sea Ice: Both airborne radar imagery (K-band) and microwave imagery (19 GHz) have delineated ice boundaries and leads off Point Barrow through cloud cover. Satellite-Borne high-resolution infrared and television sensors have shown ice location and movements.

(7) Air/Sea Interaction: Time-lapse television photographs from the Advanced Technological Satellite System at near-synchronous altitudes has shown maritime cloud patterns that can be correlated to areas of major currents, upwelling zones, and sea-land breeze systems.

The interest in spacecraft oceanography is not limited to NASA or NAVOCEANO. Strong interest has been shown by the National Council on Marine Research and Engineering Development chaired by Vice President Humphrey. A comprehensive brochure entitled, "U.S. Activities in Spacecraft Oceanography", prepared by NASA, NAVOCEANO, ESSA, and the Bureau of Commercial Fisheries, was distributed at the Fifth Meeting of the Intergovernmental Commission on Oceanography in Paris, France in October 1967. The Council also sponsored a commercially prepared study of the probable technical effectiveness, economic contributions, and projections of benefits capable of being derived from observations of the sea from space during the early 1970's. This study was completed in December, 1967.

Because of this type of national interest, there is a steadily growing effort on the part of NASA to support spacecraft oceanography. Direct funding by NASA for Fiscal Year 1968 is expected to be $1.6 million. In addition, NASA separately funds the cost of the Earth Resources aircraft program and the data reduction center associated with these aircraft at several million dollars per year. NASA's Goddard Space Flight Center also has a most active program for developing the Interrogation-Recording-Location Satellite system, or IRLS, which is scheduled for its first spaceflight aboard NIMBUS-B in April 1968. At least three oceanographic addresses have been scheduled for interrogation in this maiden flight - a responder placed by NAVOCEANO and the Naval Research Laboratory aboard Ice Island T-3 in the Arctic Ocean; a responder aboard a radioisotope-powered oceanographic buoy of NAVOCEANO off the Virgin Islands; and a third NAVOCEANO responder on the ARGUS Island platform off Bermuda. Should this system live up to expectations, responders linked to oceanographic sensors will be placed aboard oceanographic survey vessels for later tests of the IRLS system.

At this very early stage of technological development, it is still difficult to tell whether spacecraft oceanography in its various possible forms will prove cost-effective. However, when one realizes that the sea is still so vast that man has barely scratched the surface, it is not too much to speculate that man will want to know more about the world ocean daily in much greater detail than today's technology permits. Even now, headlines from the newspapers for February 6, 1968 report: "59 Men Lost in 3 Weeks - Crew Sends Love From Doomed Vessel", and the accompanying text tells the story of a British 660 ton fishing trawler sinking with all hands under the weight of ice off Northwest Iceland. Moreover, we are told that the high-seas tuna fishing fleet spends up to 80 percent of their time "scouting" rather than catching fish. In addition, entire populations of commercial fish change their habitat by hundreds of miles without warning or apparent reason. For example, the Wall Street Journal for February 13, 1968 notes:

"...Iceland is in the midst of a crippling depression...The reason for the slump is a sharp and totally unexpected decline in the fish catch. Herring, which traditionally clustered only 100 miles from the coastline, suddenly migrated far to the northeast last year. Unusually fierce weather in the North Atlantic destroyed even the big nets of the trawlers."

Once man decides he truly needs this daily global look at the world ocean, orbiting and synchronous types of satellites should prove attractive all-weather oceanographic data gatherers for supplementing the higher-resolution data gathered by the much slower but more conventional means of ships, buoys and aircraft. Our current program in spacecraft oceanography is directed towards bringing that day closer technologically.

TABLE I

Range of Thermal Parameters for Oceanographic Phenomena

Feature	Area	Temp. Change Range	Time Period
Gross ocean thermal structure solar cycle	10^6 mi^2	0 to 12°C	Annual and semi-annual
Large current displacement or frontal displacement (wind belt shifts)	10^3 to 10^4 mi^2	0 to 5°C	Months
Monsoon type effects	10^3 mi^2	0 to 8°C	Months
Upwelling along lee coasts or driven by offshore transport	10^2 to 10^3 mi^2	0 to 8°C	Weeks to months
River influence	10^2 to 10^3 mi^2	0 to 5°C	Weeks to months
Wind mixing destroying thermal stratification	10^2 to 10^3 mi^2	0 to 3°C	Days to weeks
Solar heating reestablishing thermal stratification	10^2 to 10^3 mi^2	0 to 3°C	Days to weeks
Small short-term current displacements (meandering)	10 to 10^2 mi^2	0 to 5°C	Days
Convection cells breaking internal waves	1 to 10 mi^2	0 to 2°C	Hours to days
Land sea breeze, minor monsoonal effect Daily net radiation cycle	1 to 10 mi^2	0 to 1°C	Hours to days

TABLE II

Research Investigations Sponsored by NASA Spacecraft Oceanography Project--1966-1967

Technical Area of Interest	Organization
Biological Indices	TRW Systems, Inc., Redondo Beach, Calif. Bureau of Commercial Fisheries Experimental Fishing Laboratory, Pascagoula, Miss. Barringer Research, Ltd., Toronto, Canada
Sea State	Northwest Oceanographic Consultants, Seattle, Washington New York University University of Kansas
Thermal Conditions	Scripps Institution of Oceanography, La Jolla, California; Texas A&M University; Bureau of Commercial Fisheries Laboratory, Galveston, Texas University of Miami, Miami, Florida
Bathymetry & Hydrography	Massachusetts Institute of Technology University of Michigan Philco-Ford
Coastal Processes	Texas A&M University
Sea Ice Studies	Naval Oceanographic Office U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire
Air/Sea Interaction	Texas A&M University, College Station, Texas National Environmental Satellite Center, Environmental Science Services Administration Suitland, Maryland

TABLE III

SENSOR EQUIPMENT - CONVAIR 240A - NASA MANNED SPACECRAFT CENTER, HOUSTON

[The Convair 240A is a low altitude (500 to 15 000 feet) aircraft]

Instruments	Spectrum	Format	Resolution	Field of view	Status
Reconofax IV infrared imager	8 to 14μ	70-mm film	---	---	Operational
AAS-5 ultraviolet imager	2900 to 5000 Å	35-mm film	---	---	Operational
MR-62 and MR-64 microwave radiometers	9.3 GHz; 15.8 GHz; 22.2 GHz; 34 GHz	Magnetic tape	1° K	---	Operational
13.3 GHz scatterometer[a]	13.3 GHz	Magnetic tape	0.01° in flight direction 3° across flight line	120° in flight direction 3° across flight line	Operational
Itek multiband camera[b]	Near-UV to near IR	70-mm film	50 lines/mm	18° by 18°	Operational
RC-8 metric camera	0.4 to 0.7μ	9- by 9-in. film	48 lines/mm	74° by 74°	Operational
T-11 aerial camera[b]	0.4 to 0.7μ	9- by 9-in. film	3 ft at 3000 ft altitude	74° by 74°	Operational

[a]13.3 GHz scatterometer can be transferred to NP3A aircraft.

[b]Itek multiband camera and T-11 aerial camera cannot be used simultaneously.

Table IV

SENSOR EQUIPMENT - LOCKHEED ELECTRA NP3A[a] - NASA MANNED SPACECRAFT CENTER, HOUSTON

[The Lockheed Electra NP3A is an intermediate altitude (1000 to 30 000 feet) aircraft]

Instruments	Spectrum	Format	Resolution	Field of view	Status
RS-7 infrared imager	8 to 14μ	70-mm film	---	---	Operational
Dual-channel infrared imager	0.3 to 5.5μ 8.0 to 14μ	70-mm film Magnetic tape	3 milliradian	3 ft at 1000 ft altitude	8-1-68
Infrared spectrometer	6.5 to 13μ	Magnetic tape	0.1μ	0.4° by 0.4°	9-1-67
Infrared radiometer	10 to 12μ	Magnetic tape	1° K	0.4° by 0.4°	5-1-68
400-MHz scatterometer	400 MHz	Magnetic tape	---	Beam width 120° fore-aft 6° side-to-side	2-1-65
13.3-GHz scatterometer[b]	13.3 GHz	Magnetic tape	0.01° in flight direction 3° across flight line	120° in flight direction 3° across flight line	Operational
16.5-GHz side-looking airborne radar (SLAR)	16.5 GHz	Film	15 meters	10° beam width	4-1-68
Microwave imager[c]	8.9 to 9.9 GHz	70-mm film	200 ft at 2000 ft altitude	90°	---
Multiple-frequency microwave radiometer	1.4 Gc; 10.2 Gc; 22.2 Gc; 22.3 Gc; 32.4 Gc	Magnetic tape	---	1.4 Gc - 16° ± 0.5° Others - 5° ± 0.2°	8-1-68
RC-8 metric camera[d]	0.4 to 0.7μ	9- by 9-in. film	48 lines/mm	74° by 74°	Operational
Modified KA-62 camera cluster	Visible through near-IR	5-in. film	53 lines/mm	74°	3-1-68

[a]Aircraft is presently being equipped as indicated. The estimated operational readiness date for each instrument is indicated under Status.

[b]13.3-GHz scatterometer can be transferred to Convair 240A aircraft.

[c]Installed on aircraft, however, undergoing tests prior to becoming operational.

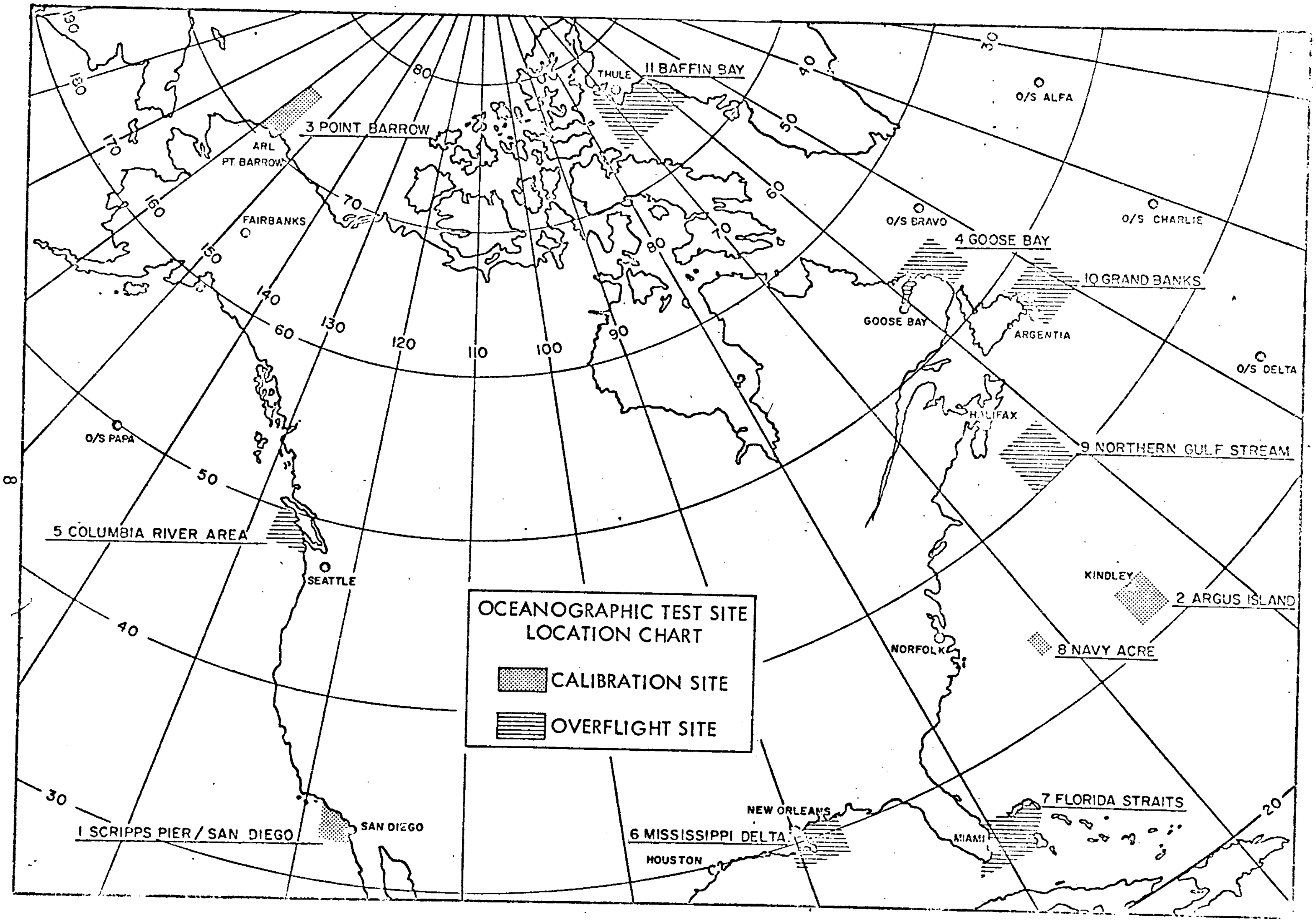
[d]Two RC-8 metric cameras are available.

TABLE V

SPACECRAFT OCEANOGRAPHY SUPPORT MISSIONS
NASA NATURAL RESOURCES AIRCRAFT PROGRAM

Mission Number	NASA a/c Model	Mission Start Date	Oceanography Sites	Major Investigators	Organization	Results or Objectives
20	Convair 240A	3/6/66	Bermuda	C.Beckner, A.Alexiou R.Nelson R.Moore	(NAVOCEANO) (ESSA) (Kansas U)	IR scanner and color film showed good discrimination of ocean features; MW radiometers fair at 15.8 and 22.2 GHz; good scatterometer data over 7' seas.
21	Convair 240A	4/16/60	Goose Bay, Labrador	A.Poulin	(USA CRREL)	Good B&W photos of ice features; MW radiometer showed appreciable change in brightness temperature at ice/water interface at 15.8 and 22.2 GHz, none at 9 and 34 GHz.
26	Convair 240A	10/10/66	Mississippi Delta	D.Walsh L.Grabham R.Nelson	(Texas A&M) (NAVOCEANO) (ESSA)	Good UV, B&W, & IR imagery over river outflow, fresh/saline interface, slicks and ribbon streaks.
34	Convair 240A	10/10/66	Miss. Delta, Florida Straits, Gulf Stream N.	A.Alexiou D.Walsh G.Williams A.Conrod R.Nelson	(NAVOCEANO) (Texas A&M) (Miami U) (MIT) (ESSA)	Good photos and IR imagery of Gulf Stream, and scatterometer data over 5' seas.
37	Convair 240A	12/14/66	Miss. Delta, Florida Straits, Navy Acres	D.Walsh G.Williams C.Bates	(Texas A&M) (Miami U) (NAVOCEANO)	Color and color IR photos and UV imagery over Miss. Delta, some cloud-cover data for correlation with sea-surface temperature.
38	Convair 240A	1/21/67	Argus Isle, Bermuda	L.Grabham, A.Alexiou A.Conrod, D.Staelin G.Williams	(NAVOCEANO) (MIT) (U of Miami)	Color and multiband photos showed need for lower exposures, lower reflectance and color changes in test targets.
40	Convair 240A	2/20/67	Florida Straits	G.Williams A.Conrod E.Mallon	(Miami U) (MIT) (OEP/NREC)	Color photos and MW radiometer strip charts obtained; MW calibration dubious.

FIGURE 1


OCEANOGRAPHIC TEST SITE
LOCATION CHART
CALIBRATION SITE
OVERFLIGHT SITE
1 SCRIPPS PIER / SAN DIEGO
2 ARGUS ISLAND
3 POINT BARROW
4 GOOSE BAY
5 COLUMBIA RIVER AREA
6 MISSISSIPPI DELTA
7 FLORIDA STRAITS
8 NAVY ACRE
9 NORTHERN GULF STREAM
10 GRAND BANKS
11 BAFFIN BAY
THULE
ARL
PT. BARROW
FAIRBANKS
SEATTLE
SAN DIEGO
HOUSTON
NEW ORLEANS
MIAMI
NORFOLK
HALIFAX
GOOSE BAY
ARGENTIA
KINDLEY
O/S ALFA
O/S BRAVO
O/S CHARLIE
O/S DELTA
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13. ABSTRACT

As part of its Natural Resources Program, NASA has sponsored for the past two years a government-wide effort to identify user requirements and to determine through a series of experiments the feasibility of employing earth-orbiting spacecraft to conduct peaceful and scientific studies and surveys of the world ocean. The U.S. Naval Oceanographic Office has served as NASA's prime agent in this area and has been assisted by an Advisory Group drawn from interested agencies of the Department of Defense, Commerce, Interior, Health, Education and Welfare, Atomic Energy Commission, National Science Foundation, Smithsonian Institution, U.S. Coast Guard, National Academy of Sciences, and the National Academy of Engineering.

Approximately one million dollars of sponsored work has been conducted at eight universities and four industries in this spacecraft oceanography program. Ground truth test sites have been selected in the general area of Bermuda, Straits of Florida, the Gulf Stream, San Diego, and Pt. Barrow. Remote-sensor equipped aircraft of NASA's Manned Spacecraft Center, the U.S. Naval Oceanographic Office, the Naval Research Laboratory and of contractors are being used in various experiments over various ocean areas to gain an early appreciation of the problems and capabilities of spacecraft oceanography. Remote sensors tested to date include multi-band color cameras, radar scatterometers, infrared spectrometers and scanners, passive microwave radiometers, and radar imagers. As a result, some ten oceanographic

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