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# NOAA Technical Memorandum NESS 51

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Environmental Satellite Service

# Skylab Earth Resources Experiment Package Experiments in Oceanography Marine Science

A. L. GRABHAM
JOHN W. SHERMAN, III

WASHINGTON, D.C.
September 1973

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# SKYLAB EARTH RESOURCES EXPERIMENT PACKAGE EXPERIMENTS IN OCEANOGRAPHY AND MARINE SCIENCE

Spacecraft Oceanography Group
A. L. Grabham and John W. Sherman, III

WASHINGTON, D.C.
September 1973

UDC 551.46.07:629.786.2SKYLAB

| | |
|---|---|
| 551.46 | Oceanography |
| .46.07 | Oceanographic equipment |
| 629.78 | Astronautics spacecraft |
| .786 | Space stations |
| .2 | Near-earth orbital space stations |
| SKYLAB | SKYLAB EARTH Resources Satellite |

CONTENTS

## ACRONYMS

| | |
|---|---|
| AFO | Announcement of Flight Opportunities |
| AGOR | Auxiliary General Oceanographic Research |
| ARC | Ames Research Center, Moffet Field, CA |
| CINECA | Cooperative Investigation of the Northern part of the Eastern Central Atlantic (FAO sponsored) |
| CUEA | Coastal Upwelling Ecosystem Analysis |
| EEP | Engineering Experimental Phase |
| ERB | Environmental Reporting Buoys |
| EREP | Earth Resources Experiment Package |
| ERTS | Earth Resources Technology Satellite |
| FAO | Food and Agriculture Organization of the United Nations |
| GARP | Global Atmospheric Research Program |
| GATE | GARP Atlantic Tropical Experiment |
| GEOS-C | Geodetic Satellite (NASA) that will carry radar altimeter |
| GSFC | Goddard Space Flight Center, Greenbelt, MD |
| HRIR | High-Resolution Infrared on Nimbus and NOAA satellites |
| IDOE | International Decade for Ocean Exploration |
| ITOS | Improved Tiros Operational Satellite |
| Little Window II | NASA/Navy experiments in Gulf of California to evaluate Nimbus |
| LRC | Langley Research Center (NASA), Hampton, VA |
| MFMR | Multifrequency Microwave Radiometer on NASA NP-3A |
| MSC | Manned Spacecraft Center, Houston, TX |
| MSS | Multispectral Scanner |
| MSS DAS | Multispectral Scanner Data Analysis Station |
| MOCS | Multichannel Ocean Color System |
| NASA | National Aeronautics and Space Administration |
| NDBP | National Data Buoy Program |
| NIMBUS | Meteorological research satellite series |
| NOAA | National Oceanic and Atmospheric Administration |
| NODC | National Oceanographic Data Center |
| NRL | Naval Research Laboratory |
| OSV | Ocean Station Vessel |
| OTSR | Optimum Track Ship Routing |

| | |
|---|---|
| PMIS | Passive Microwave Imaging System |
| RBV | Return Beam Vidicon |
| S-190 | EREP Multispectral Photographic Facility; S-190b earth terrain camera |
| S-191 | EREP infrared spectrometer |
| S-192 | EREP microwave system; microwave radiometer/ scatterometer and altimeter facility |
| S-194 | EREP L-band radiometer |
| SIO | Scripps Institution of Oceanography, La Jolla, CA |
| SIS | Scanning Imaging Spectroradiometer |
| SKYLAB | NASA Earth-orbiting manned workshop using Gemini and Apollo hardware. 1973 launch. Crew to perform a broad range of solar and Earth resources experiments |
| SLAR | Side-Looking Array Radar |
| WHOI | Woods Hole Oceanographic Institution, Woods Hole, MA |

# SKYLAB EREP EXPERIMENTS IN OCEANOGRAPHY AND MARINE SCIENCE

A. L. Grabham and John W. Sherman, III
Spacecraft Oceanography Group
National Environmental Satellite Service, NOAA
Washington, D. C.

ABSTRACT. This paper was prepared by the Spacecraft Oceanography (SPOC) Group, National Environmental Satellite Service (NESS), National Oceanic and Atmospheric Administration (NOAA) to provide a reference for marine scientists for coordination and exchange of information in connection with the SKYLAB Earth Resources Experiment Package (EREP) missions of 1973. The experiments planned, the experiment package used, the methods for handling data, and the schedule for ships for potential ocean ground truth data are listed and described.

## INTRODUCTION

The National Aeronautics and Space Administration (NASA) launched the first manned space laboratory in June 1973. This orbiting laboratory, known as SKYLAB, contains an assembly of six earth-looking remote sensing instruments called the Earth Resources Experiment Package (EREP).

SKYLAB will orbit the earth at an altitude of 435 kilometers (235 n mi) at an inclination of $50^{\circ}$. Three separate manned missions of 1, 2, and 2 months duration, respectively, are scheduled over an 8-month period. The manned missions are designated SL-2, SL-3, and SL-4. SL-1 is the launch of the laboratory facility.

During these missions, the three-man crews will engage in research covering several scientific disciplines using instruments, sensors, and support equipment developed specifically for the missions. Solar astronomy, space medicine, space physics, bio-science, materials processing, and earth observation are among the disciplines included. The EREP earth observations can only be conducted with the crew aboard; there is no provision for automatic, remotely controlled operation of the equipment.

SKYLAB is a solar-pointing, inertially stabilized spacecraft; it must be maneuvered to an earth-oriented position to use the EREP sensors. It is estimated that, as a minimum, the earth-observing EREP operations will be possible on 9 orbits during the 28-day SL-2 mission, and 18 orbits each during the 56-day SL-3 and SL-4 missions for a total of at least 45 orbits.

The specific EREP sensors for earth observation are:

| | |
|---|---|
| S-190 | A 6-band multispectral photographic facility using 70-mm film |
| S-190b | The earth terrain camera using 12.7-cm (5-in.) film |
| S-191 | A filter wheel infrared spectrometer (which additionally covers the visible spectrum) that scans from 0.4 to 2.4-$\mu$m and 6.2 to 15-$\mu$m wavelength intervals |
| S-192 | A 13-channel multispectral scanner operating from 0.4 to 12.5-$\mu$m wavelength intervals |
| S-193 | An X-band microwave radiometer / scatterometer and altimeter facility operating at a wavelength of about 2.15 cm (13.9 GHz) |
| S-194 | An L-band radiometer operating at an approximate wavelength of 21 cm (1.4 GHz). |

The earth oriented maneuvers of SKYLAB usually will be limited to the daylight period of single orbits and to conditions where the angle between the orbital plane and the earth-sun line is $50^{\circ}$ or less. In addition, for photographic coverage it is desirable that the sun elevation angle be greater than $30^{\circ}$ for the summer hemisphere and greater than $20^{\circ}$ for the winter hemisphere. During data acquisition, the EREP sensors are directed within $2.5^{\circ}$ of the earth's local vertical.

A more detailed description of the EREP sensors and their earth coverage is contained in appendix A. The manner in which data from these instruments will be handled is described in appendix B. Knowledge of the response and application of SKYLAB EREP sensors to ocean phenomena is important to participation in the ongoing, planned program of NASA. This topic is discussed in appendix C and serves as the basis of the experiments outlined in the section on planned experiments. Appendix D contains the tentative schedule for oceanographic ship operations during the SKYLAB timeframe. Appendix E is a bibliography for additional background in remote sensing applications to oceanography. Appendixes A to E were prepared as part of an earlier study.

Because of unscheduled delays and unforeseen problems, the dates, orbits, and overflight paths of SKYLAB for various missions and test sites could not be presented here. Bona fide users can obtain Skylab Mission Charts (SMC) from the Johnson Space Center (JSC) Houston, Texas.

## PLANNED EXPERIMENTS

This section lists EREP experiments in oceanography, the marine sciences, and certain ocean related disciplines -- particularly meteorology. These experiments were selected by NASA, with advice from the federal ocean community, from proposals submitted to NASA in response to the "Announcement for Flight Opportunities (AFO) using SKYLAB." The phenomena, test sites, instruments, sensors, and ocean-truth data associated with these EREP experiments are related to the mission, functions, and interests of the National Oceanic and Atmospheric Administration (NOAA). It is anticipated that this report will assist in developing a more comprehensive and coordinated experimental effort to support these experiments.

The spectral coverage of the S-190 and S-192 are similar to and generally correspond with the spectral coverage of the Earth Resources Technology Satellite (ERTS-1) Return Beam Vidicons (RBV) and the Multispectral Scanner (MSS). Where appropriate, relations between the SKYLAB EREP experiments and ongoing ERTS-1 experiments are noted.

The experiments to be conducted using SKYLAB data are divided into four basic groups: Ocean Dynamics, Water Mass Identification and Marine Biology, Coastal Processes, and Sea and Lake Ice.

The sea ice experiments are limited because of orbital constraints (see appendix C), and pollution studies are included primarily in the coastal processes group. The ocean related experiments also are tabulated. This section of the report is divided into two subsections: a SUMMARY in tabular form, and a SYNOPSIS OF EACH EXPERIMENT to be conducted. Each experiment carries a NOAA number, assigned as a convenience for use in this report, and an experiment number assigned by NASA in the overall remote sensing effort for SKYLAB.

### Summary

Listed below are the marine science experiments that NASA will support in the SKYLAB EREP program. The experiments are divided into the following categorical classifications: Ocean Dynamics, Coastal Processes, Sea and Lake Ice, and Ocean Related Experiments. A NOAA designator is assigned to each experiment in each category. For example, OD-1 is Ocean Dynamics experiment 1, OC-1 is experiment 1 under Water Mass

Identification and Marine Biology (the OC designator was chosen because this category relates strongly to Ocean Color measurements), CP-1 is Coastal Processes experiment 1, SI-1 is Sea Ice experiment 1, and OR-1 is Ocean Related (most of these are meteorological experiment 1).

The experiments chosen for support by NASA were carefully considered by a panel of marine scientists from government agencies involved in oceanography. In the summary list that follows, abbreviated short titles for each experiment are given. The subsection "Synopsis of Each Experiment" contains the longer title of the original proposal to NASA.

Ocean Dynamics

| NOAA NO. | NASA NO. | Title | Investigator | Site |
|---|---|---|---|---|
| OD-1 | 108 | Ocean Currents | S. A. Maul | Gulf of Mexico |
| OD-2 | 460 | Microwave/ Sea State | D. B. Ross | Gulf of Mexico |
| OD-3 | 440 | Altimeter/ Geodesy | A. G. Mourad | Puerto Rican Trench |
| OD-4 | 550 | Met-Ocean S-193 Evaluation | W. J. Pierson | Gulf of Mexico N. & W. Atlantic |
| OD-5 | 470 | Ocean Surface Radar Data | L. S. Miller | Gulf of Mexico N. & W. Atlantic |
| OD-6 | 384 | Microwave/ Sea Surface | J. P Hollinger | N. & W. Atlantic |
| OD-7 | 422 | SST/Clouds/ S-191 | D. C. Anding | Gulf of Mexico |
| OD-8 | 023-2 | Oyashio/ Kuroshio | K. Watanabe | E. Coast Japan |
| OD-9 | 568-2 | RADSCAT/ Sea State | Otterman | E. Mediterranean |
| OD-10 | 9636-5 | Thermal Features | F. de Mendonca | Brazil Coast |
| OD-11 | 9636-6 | Ocean Currents | F. de Mendonca | Brazil Coast |

## Water Mass Identification and Marine Biology

| NOAA NO. | NASA NO. | Title | Investigator | Site |
|---|---|---|---|---|
| OC-1 | 240 | Fisheries Resources | W. H. Stevenson | Gulf of Mexico |
| OC-2 | 518 | Upwelling Dynamics | K. H. Szekielda | Arabian Coast W. of Africa |
| OC-3 | 586 | SST, Currents, Chlorophyll, Depth | L. Korb | U.S. East Coast |
| OC-4 | 416-2 | Coastal Biology | H. G. Marshall | U.S. East Coast/ Chesapeake Bay |
| OC-5 | 565 | Currents/ Upwelling | H. Inostroza | Coast of Chile |
| OC-6 | 568-4 | Fisheries | Otterman | E. Mediter-ranean |
| OC-7 | 9610-3 | Greek Fisheries | E. Papachelas | Aegean Sea N. W. African Coast |

## Coastal Processes

| NOAA NO. | NASA NO. | Title | Investigator | Site |
|---|---|---|---|---|
| CP-1 | 458 | Estuarine Discharge | R. L. Swanson | New York Bight |
| CP-2 | 446 | Water Depth | F. C. Polcyn | Florida Coast Lake Michigan |
| CP-3 | 070 | Estuarine & Coastal Oceanography | E. Yost | Long Island Coast |
| CP-4 | 492 | Coastal Processes | D. Perie | California Coast |
| CP-5 | 517 | Circulation Analysis | W. J. Hargis | Chesapeake Bay |
| CP-6 | 477 | Ecological Investigation | V. Klemas | Chesapeake Bay |

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|---|---|---|---|---|
| CP-7 | 448 | Environmental Assessment | A. Higer | Biscayne Bay Tampa Bay |

Sea and Lake Ice

| NOAA NO. | NASA NO. | Title | Investigator | Site |
|---|---|---|---|---|
| SI-1 | 457-4 | Sea & Lake Ice | W. J. Campbell | Lake Ontario |
| SI-2 | 023-1 | Sea Ice Currents | K. Watanabe | Sea of Okhotsk |

Ocean-Related Meteorology Experiments

| NOAA NO. | NASA NO. | Title | Investigator | Site |
|---|---|---|---|---|
| OR-1 | 9611 | Cloud Physics | J. Alishouse | U.S.A. |
| OR-2 | 599 | Hurricanes | D. Leipper | Gulf of Mexico |
| OR-3 | 582 | Severe Storms | D. E. Pitts | Oklahoma |
| OR-4 | 556-1,2 | Cloud Features | W. E. Shenk | Mid-Latitude & Equatorial |
| OR-5 | 008 | Met Sat Data | M. Villevieille | Southern France |
| OR-6 | 022 | Monsoon Clouds | K. Tsuchiya | Japan |

Synopsis of each Experiment

Ocean Dynamics

OD-1
Title : Remote Sensing of Ocean Currents
Investigator : G. A. Maul
NASA No. : NOAA/AOML
Agency : Gulf of Mexico
Test site : East Coast of U.S.A.
Sensors : S-190, S-191, S-192

Description of experiment: NOAA/AOML investigators have shown that surface thermal signatures are related to subsurface thermal structure. Surface thermal signatures in the Loop Current of the Gulf of Mexico and near the Florida Current cannot be detected during several months of the year. This experiment will utilize optical properties from multiband photography and multispectral scanner imagery to help locate current boundaries that thermal sensors cannot detect. Thermal data from the SKYLAB infrared spectrometer (S-191) will be evaluated for sea surface temperature measurements; aircraft flights and surface ships will collect optical and physical data concurrent with the SKYLAB overflights. Existing software programs will be used to delimit color gradients. The contribution of SKYLAB techniques for finding biologically productive areas, for locating currents significant for marine transportation, and for determining sound propagation properties related to water masses will be evaluated.

| | | | |
|---|---|---|---|
| OD-2 | Title | : | Investigation of Passive Microwave Techniques for Sea State Determination |
| | Investigator | : | Duncan B. Ross |
| | NASA No. | : | 460 |
| | Agency | : | NOAA/AOML |
| | Test site | : | Gulf of Mexico |
| | Sensors | : | S-190, S-192, S-193 |

Description of experiment: Near-surface and aircraft microwave brightness temperatures have been related to wind speeds, sea roughness, foam, spray, precipitation, capillary waves, and other variables associated with the nebulous term "sea state." This experiment will acquire multiband optical imagery and microwave brightness temperatures from various microwave frequencies from aircraft and spacecraft heights. Concurrent with SKYLAB overpasses, aircraft and surface vessels will obtain wave height, foam density, surface wind speeds, air and sea temperatures, cloud conditions, and radiosonde data. The resulting collection of high quality data will provide an unprecedented opportunity to evaluate space acquired microwave data for "sea state" correlations.

| | | | |
|---|---|---|---|
| OD-3 | Title | : | Calibration and Evaluation of EREP Altimetry for Geodetic Determination of the Geoid |
| | Investigator | : | A. G. Mourad, Marine Geodesy Program Director |
| | Agency | : | Batelle Incorporated |
| | Test site | : | Puerto Rican Trench |
| | Co-Investigators | : | P. M. Fubara and A. T. Hopper, Batelle, Inc. |
| | Sensors | : | S-193 |

Description of experiment: The S-193 altimeter system data will be evaluated for its ability to provide geoidal profiles for use in geodesy, earth gravity models, and dynamic oceanography. Another objective is to provide a means for calibrating the SKYLAB altimeter.

Various degrees of accuracy for the global geoid are required for geodesy, oceanography, and charting the earth's gravity field.

Conventional means of collecting such data are slow and inaccurate. Satellites appear to be the only hope for rapid economical collection of geoidal data.

The expected results of this study include calibration techniques, rate and magnitude of altimeter drift, geoidal profiles, evaluation of data for sea state, sea slope, and sea level, and isolation of problems and recommendation for improvements for future space altimeters.

Although the Puerto Rican trench is a prime test site, data from the Gulf of St. Lawrence, the Indian Ocean, and all other areas from which altimeter data are available will be analyzed.

| | | | |
|---|---|---|---|
| OD-4 | Title | : | Meteorological, Oceanographical, and Sensor Evaluation Program for Experiment S-193 on SKYLAB |
| | Investigator | : | W. J. Pierson |
| | NASA No. | : | 550 |
| | Agency | : | New York University |
| | Test site | : | Gulf of Mexico<br>North and West Atlantic Ocean |
| | Sensors | : | S-193 |

Description of experiment: The microwave brightness temperatures and radar backscatter measurements from the RADSCAT S-193 SKYLAB sensor will be correlated to shipboard oceanographic and meteorological data, to aircraft laser profilometer and radar scatterometer data, to multifrequency airborne microwave radiometer data, and to wind and wave data from meteorological charts. An evaluation of the RADSCAT instrument as a global device for wind speed and sea roughness data acquisition will be made. A long-range objective is to provide computer input for wind speeds and wave conditions for a global prediction model for sea state.

| | | | |
|---|---|---|---|
| OD-5 | Title | : | Correlation of Ocean Surface Parameters with Radar Backscattering Data and Theory |
| | Investigator | : | L. S. Miller |
| | NASA No. | : | 470 |
| | Agency | : | Research Triangle Institute |

| | | | |
|---|---|---|---|
| | Test site | : | Gulf of Mexico<br>North and West Atlantic Ocean |
| | Sensors | : | S-193 |

Description of experiment: SKYLAB S-193 includes an X-band radar scatterometer/microwave radiometer (RADSCAT) and a radar altimeter. The RADSCAT obtains near simultaneous measurements of radar backscattering cross section at various radar beam angles to the band and/or ocean surface, and passive microwave emissibity measurements at various incidence angles from land and sea surfaces. The X-band altimeter operates independently from RADSCAT. This experiment will relate the radar backscatter data to the ocean surface roughness and to the surface wind speed that generates the water wavelengths that produce radar backscatter. Surface ship observations, meteorological data, and airborne laser profilometer data will be correlated to the radar backscatter from various radar beam angles to the sea surface. The various theories relating foam, spray, swell and capillary waves to radar backscatter will be tested to explain the radar signal returned to the SKYLAB RADSCAT receiver. Although other investigators will evaluate and analyze data from the test sites in the Atlantic Ocean and Gulf of Mexico, the analyses will be performed independently of existing theories.

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|---|---|---|---|
| OD-6 | Title | : | Determination of Sea Surface Conditions Using SKYLAB L-Band and RADSCAT Passive Microwave Radiometers |
| | Investigator | : | J. P. Hollinger |
| | NASA No. | : | 384 |
| | Agency | : | Naval Research Laboratory |
| | Test site | : | North and West Atlantic Ocean |
| | Sensors | : | S-193, S-194 |

Description of experiment: This investigation will utilize data from the X-band (S-193) microwave radiometer and the L-band (S-194) radiometer aboard the SKYLAB workshop. Sea surface truth will include meteorological and oceanographic observations from shipboard, and sea roughness measurements from airborne photography and laser profilometers. Airborne radiometer data will also be acquired during the SKYLAB overflights. The X-band data will be evaluated in terms of sea surface roughness and wind speeds. The L-band radiometer data will be related to salinity, sea surface temperature, wind speed, and wave conditions.

| | | | |
|---|---|---|---|
| OD-7 | Title | : | Use of EREP S-191 Data to Measure Sea Surface Temperature and Cloud Properties |
| | Investigator | : | D. C. Anding |
| | NASA No. | : | 422 |

| | | | |
|---|---|---|---|
| | Agency | : | University of Michigan |
| | Test site | : | Gulf of Mexico |
| | Sensors | : | S-190, S-191, S-192 |

Description of experiment: Aircraft data and meteorological soundings will be used in conjunction with SKYLAB infrared spectrographic data for estimating sea surface temperatures and cloud temperatures. Techniques previously developed by the investigator to accurately estimate sea surface temperatures using multiband infrared data will be tested. Techniques previously developed for correcting for atmospheric effects will be tested.

| | | | |
|---|---|---|---|
| OD-8 | Title | : | Study of Boundaries Between Oyashio and Kuroshio Currents |
| | Investigator | : | K. Watanabe |
| | NASA No. | : | 023-2 |
| | Agency | : | University of Kyoto Gakuen |
| | Test site | : | North East Coast of Japan |
| | Sensors | : | S-190, S-192 |

Description of experiment: Imagery from the various spectral bands in the visible region will be inspected and analyzed to locate boundaries associated with the Oyashio and Kuroshio currents. Surface truth data will be obtained from Japanese surface platforms.

| | | | |
|---|---|---|---|
| OD-9 | Title | : | Determination of Sea State with SKYLAB RADSCAT |
| | Investigator | : | Otterman |
| | NASA No. | : | 568-2 |
| | Agency | : | Tel Aviv University |
| | Test site | : | Eastern Mediterranean |
| | Sensors | : | S-193 |

Description of experiment: X-band (RADSCAT) radar scatterometer data and microwave radiometer brightness temperature will be related to surface wind speed and wave conditions in the Eastern Mediterranean.

| | | | |
|---|---|---|---|
| OD-10 | Title | : | Development of Methods for Mapping Ocean Surface Thermal Features |
| | Investigator | : | F. de Mendonca |
| | NASA No. | : | 9636-5 |
| | Agency | : | Brazilian Government |
| | Test site | : | South Coast of Brazil |
| | Sensors | : | S-190, S-191, S-192 |

Description of experiment: Subsurface topography and thermal features in the subtropical convergence zone will be investigated.

Surface, aircraft, and satellite data will be acquired in the test site area. Densitometric analysis of imagery and computer analysis of infrared and optical data will be the principle analysis techniques used.

Charting of dangerous nearshore navigation areas and sea surface temperature correlations to fisheries are applicational objectives.

| | | | |
|---|---|---|---|
| OD-11 | Title | : | Mapping Ocean Surface Currents |
| | Investigator | : | F. de Mendonca |
| | NASA No. | : | 9636-6 |
| | Agency | : | Brazilian Government |
| | Test site | : | Off Coast of Rio de Janeiro |
| | Sensors | : | S-190, S-191, S-192 |

Description of experiment: The capability of multispectral imagery from the SKYLAB S-190 and S-192 ocean color sensors will be evaluated as a tool for mapping ocean currents. Brazilian ships will provide surface oceanographic and meteorological data. The S-191 infrared spectrometer data will be compared to in situ sea surface temperature data.

Water Mass Identification and Marine Biology

| | | | |
|---|---|---|---|
| OC-1 | Title | : | Remote Sensing for Fisheries Resource Assessment and Monitoring |
| | Investigator | : | W. H. Stevenson |
| | NASA No. | : | 240 |
| | Agency | : | NOAA/NMFS |
| | Test site | : | Gulf of Mexico |
| | Sensors | : | S-190, S-191, S-192 |

Description of experiment: SKYLAB multispectral imagery and infrared spectrometer data will be obtained concurrently with aircraft and surface vessel data from the Gulf of Mexico. ITOS visual and infrared region data will be acquired and utilized before, during, and after the SKYLAB overflights. Reduction, analysis, and correlations of the spacecraft, aircraft, and surface data will be made. Interpretation of the space data as a means of data collection for locating environmental features related to fisheries monitoring will be made.

| | | | |
|---|---|---|---|
| OC-2 | Title | : | Dynamics of Plankton Population in Upwelling Areas |
| | Investigator | : | K. H. Szekielda |
| | NASA No. | : | 518 |

| | | |
|---|---|---|
| Agency | : | University of Delaware |
| Test site | : | Northwest Coast of Africa<br>Arabian Coast |
| Sensors | : | S-190, S-191, S-192 |

Description of experiment: Multispectral photography and thermal data will be acquired over upwelling regions in various test site areas. Color and thermal analyses will be related to "surface truth" data to verify the ability of SKYLAB sensors to locate color and thermal fronts and the presence of biologically productive organic matter in these upwelling regions.

Analyses will not require automatic data processing after receipt of prints and transparencies of imagery and infrared spectrometer measurements. Gradients of color and temperature will be related to chlorophyll, suspended materials, currents, upwellings, plankton, and oscillating boundaries of ocean properties. A model for fisheries exploitation will be created. The overall experiment will hopefully serve to demonstrate the use of satellite data to understand the dynamics and growth of biological organisms in the ocean food chain.

| | | | |
|---|---|---|---|
| OC-3 | Title | : | Determination of Sea Surface Temperature, Ocean Currents, Chlorophyll Concentration, and Water Depth |
| | Investigator | : | L. Korb |
| | NASA No. | : | 586 |
| | Agency | : | NASA MSC |
| | Test site | : | East Coast of U.S.A. |
| | Sensors | : | S-190, S-191, S-192 |

Description of experiment: Techniques using airborne and spaceborne remote sensors have been developed by various investigators to chart sea surface temperature, water depth, upwelling regions, major ocean currents, water mass boundaries, polluted areas, and areas of high biological productivity. The S-190 and S-192 SKYLAB sensors will be evaluated as ocean color sensors and the S-191 infrared spectrometer will be evaluated as a device for making relative and absolute sea surface temperature measurements. Surface truth data measurements are planned in the vicinity of the primary test site near the Gulf Stream off the East Coast of the U.S.A. The use of S-190 and S-192 sensors for water depth determination is planned for test site areas in the Bahama Islands.

| | | | |
|---|---|---|---|
| OC-4 | Title | : | Coastal Biological Productivity |
| | Investigator | : | H. G. Marshall |
| | NASA No. | : | 416-2 |

Agency : Old Dominion University
Test site : East Coast of U.S.A. /Chesapeake Bay
Sensors : S-190, S-191, S-192

Description of experiment: S-190 and S-192 spectral band imagery will be inspected and evaluated as sensors to detect ocean color caused by various physical, chemical, and biological properties of coastal waters. The S-191 infrared spectrometer data will be examined and evaluated against in situ surface temperature data.

OC-5 Title : Application of EREP Visual and Infrared Data to Detect Currents and Upwelling
Investigator : H. Inostroza
NASA No. : 565
Agency : Institute Hidrograf, Chile
Test site : Coast of Chile
Sensors : S-190, S-191, S-192

Description of experiment: Color and thermal data will be compared to surface information for locating the boundaries and extent of upwelling and surface currents in the oceans.

OC-6 Title : Application of Water Color and Thermal Infrared Analyses to Locate Fishing Areas
Investigator : Otterman
NASA No. : 568-1
Agency : Tel Aviv University
Test site : Eastern University
Sensors : S-190, S-191, S-192

Description of experiment: S-190 and S-192 SKYLAB sensor data from the Eastern Mediterranean will be evaluated for ocean color determinations related to fisheries environments, e.g., upwelling regions and areas of high biological productivity. The S-191 infrared spectrometer data will be compared to sea surface temperature data from the test site area.

OC-7 Title : Evaluation of EREP Imagery for Development of Greek Fisheries Resources
Investigator : E. Papachelas
NASA No. : 9610-3
Agency : Hellenic Development Bank, Greece
Test site : Northern Aegean Sea/West Coast of N. Africa
Sensors : S-190, S-191, S-192

Description of experiment: Environmental indicators, color and thermal, of fisheries environment will be examined for correlation to fisheries resources data in the Aegean Sea and off the West Coast of Africa.

## Coastal Processes

| | | | |
|---|---|---|---|
| CP-1 | Title | : | Estuarine Discharge Plume Study |
| | Investigator | : | R. L. Swanson |
| | NASA No. | : | 458 |
| | Agency | : | NOAA/NOS |
| | Test site | : | New York Bight |
| | Sensors | : | S-190, S-191, S-192 |

Description of experiment: Thermal and color anomalies of coastal oceans will be sought from the SKYLAB multiband photography (S-190), multispectral scanner (S-192) imagery, and infrared spectrometer (S-191) data. Sediments, pollutants, and other visible phenomena in coastal and estuarine areas will be measured and observed concurrently using surface, aircraft, and spacecraft sensors. The acquired data will be used to develop techniques for charting movements and flushing rates, and to predict patterns and boundaries of estuarine effluents.

In addition to the New York Bight area, data will be acquired from other test site areas such as the Hudson River, Delaware Bay, Chesapeake Bay, Mobile River, Mississippi River, Columbia River and other coastal and estuarine areas to be determined.

| | | | |
|---|---|---|---|
| CP-2 | Title | : | Use of Multispectral Ratio Processing for Water Depth Determination |
| | Investigator | : | F C. Polcyn |
| | NASA No. | : | 446 |
| | Agency | : | Environmental Research Institute of Michigan |
| | Test site | : | Puerto Rico, Lake Michigan, Florida Coasts |
| | Sensors | : | S-190, S-192 |

Description of experiments: The relative intensity of light reflected from the sea bottom in the various spectral bands of S-190 and S-192 SKYLAB sensors will be related to depth data. Computer programs already compiled by the investigator contain correction formulae for surface reflection and scattering. Wave refraction patterns will be used to determine depths in coastal areas using techniques already developed by the investigator. The limitations of spaceborne multispectral imaging systems to chart shoals and nearshore bathymetry will be tested. Hydrographic charts and surface measurements will be used for surface truth data for the test site areas. Research will be conducted on system calibration.

Optical and digital processing techniques already in existance will be used to determine resolution, spectral bands, sun angles, sea conditions, and other relevant factors affecting sensor specifications. The techniques will be applicable to checking existing bathymetry charts, studying storm effects, lake and estuarine phenomena, shoreline erosion, and navigation hazards.

| | | |
|---|---|---|
| CP-3 | Title | : Estuarine and Coastal Oceanography |
| | Investigator | : E. Yost |
| | NASA No. | : 070 |
| | Agency | : Long Island University |
| | Test site | : Coasts of Long Island |
| | Sensors | : S-190, S-192 |

Description of experiment: The details of the EREP proposal are not available. The investigator has a strong multiband photographic enhancement capability as well as facilities for oceanographic surface truth.

| | | |
|---|---|---|
| CP-4 | Title | : California Coastal Processes Study |
| | Investigator | : D. Perie |
| | NASA No. | : 492 |
| | Agency | : U.S. Army Corps of Engineers |
| | Test site | : California Coast |
| | Sensors | : S-190, S-192, S-194 |

Description of experiment: The U.S. Army Corps of Engineers will provide sea truth on the California coast concurrent with SKYLAB overpasses to develop research information on coastal processes based on multispectral imagery and L-Band microwave radiometer data. Nearshore current patterns, dredging dump discharges, seasonal sediment discharge, and linkage of surface, aircraft, and satellite data will be investigated.

| | | |
|---|---|---|
| CP-5 | Title | : Southern Chesapeake Bay Circulation Analysis |
| | Investigator | : W. J. Hargis |
| | NASA No. | : 517 |
| | Agency | : Virginia Institute of Marine Science |
| | Test sites | : Southern Chesapeake Bay |
| | Sensors | : S-190, S-191, S-192, S-194 |

Description of experiment: This experiment will investigate the utility of SKYLAB sensors to chart water color and circulation properties in Southern Chesapeake Bay. Water color indicators of pollution, circulation, suspended sediment, phytoplankton, and detritus will be examined.

The multi-discipline capabilities of VIMS will be utilized for surface truth and post data collection analyses.

| | | |
|---|---|---|
| CP-6 | Title | : SKYLAB Application of Ecological, Geological and Oceanographic Investigation of Delaware Bay |
| | Investigator | : V. Klemas |
| | NASA No. | : 477 |
| | Agency | : University of Delaware |
| | Test site | : Delaware Bay |
| | Sensors | : S-190, S-192 |

Description of experiment: An investigation will be conducted to determine the applicability of the SKYLAB EREP multispectral photographic and scanner data to map ecological, geological, and oceanographic parameters in Delaware Bay. Enhancement of multispectral imagery will be done by Bendix for the University of Delaware who will interpret, analyze, and annotate the data. Surface truth and aircraft underflights will be scheduled by University of Delaware. The sources, dispersion, and effects of pollution as well as the local estuarine oceanography will be studied.

| | | |
|---|---|---|
| CP-7 | Title | : Environmental Assessment of Benthic and Littoral Communities |
| | Investigator | : A. Higer |
| | NASA No. | : 448 |
| | Agency | : U.S. Geological Survey |
| | Test site | : Biscayne and Tampa Bays (Florida) |
| | Sensors | : S-190, S-192 |

Description of experiment: Surface truth and aircraft data will be arranged by the USGS in the Florida test sites. Enhanced maps from the SKYLAB multispectral imagery will be constructed and evaluated as a means of acquiring data for environmental quality assessment. The investigation will judge the quality and accuracy of environmental information through assessment of the degree of correlative data required for good results, and the potential of data processing methodology for specific themes in coastal mapping, geology, and marine processes.

## Sea and Lake Ice

| | | |
|---|---|---|
| SL-1 | Title | : Lake and Sea Ice Experiment with SKYLAB Microwave Radiometry |
| | Investigator | : W. J. Campbell |
| | Agency | : U.S. Geological Survey |
| | Test site | : Lake Ontario |
| | Sensors | : S-190, S-192, S-193 |

Description of experiment: The S-193 RADSCAT microwave data will be processed to show brightness temperature charts over ice, land, and water. Radar backscatter signatures will be examined for signature variance over rough and smooth ice surfaces. Surface truth data will be acquired by USGS ground data teams.

| | | |
|---|---|---|
| SL-2 | Title | : Sea Ice in the Sea of Okhotsk and its influence on the Oyashio Current |
| | Investigator | : K. Watanabe |
| | NASA No. | : 023-1 |
| | Agency | : University of Kyoto Gakuen |
| | Test site | : Sea of Okhotsk |
| | Sensors | : S-190, S-191, S-192, S-193 |

Description of experiment: Plans for data acquisition and analysis for this experiment are not available.

## Ocean-Related Meteorology Experiments

Descriptions of experiments OR-1 through OR-6 are not available.

| | | |
|---|---|---|
| OR-1 | Title | : A Cloud Physics Investigation to Determine Cloud Top Pressure Altitudes |
| | Investigator | : J. Alishouse |
| | NASA No. | : 9611 |
| | Agency | : NOAA/NESS |
| | Test site | : U.S.A. |
| OR-2 | Title | : Growth, Maintenance, and Oceanic After-Effects of Hurricanes |
| | Investigator | : D. Leipper |
| | NASA No. | : 599 |
| | Agency | : U.S. Navy |
| | Test site | : Gulf of Mexico |
| OR-3 | Title | : Severe Storm Environments |
| | Investigator | : D. E. Pitts |
| | Agency | : NASA/MSC |
| | Test site | : Oklahoma |
| OR-4 | Title | : Determination of Cloud Characteristics |
| | Investigator | : W. E. Shenk |
| | NASA No. | : 556-1, 2 |
| | Agency | : NASA/GSFC |
| | Test site | : Equatorial and Mid-Latitude Sites |

| | | | |
|---|---|---|---|
| OR-5 | Title | : | Meteorological Analysis and Forecasting Refinements |
| | Investigator | : | M. Villevieille |
| | NASA No. | : | 008 |
| | Agency | : | French Weather Bureau |
| | Test site | : | Southern France |
| OR-6 | Title | : | Study of Mesoscale Phenomena, Winter Monsoon Clouds, and Snow |
| | Investigator | : | K. Tsuchiya |
| | NASA No. | : | 022 |
| | Agency | : | Japanese Meteorological Agency |
| | Test site | : | Japan |

Appendix A

# EARTH RESOURCES EXPERIMENT PACKAGE (EREP) SENSORS

## S-190, THE MULTISPECTRAL PHOTOGRAPHIC FACILITY

The EREP Multispectral Photographic Facility is designed to obtain precision photographs at various wavelengths for use in a wide range of studies. This facility includes six high-precision 70-mm cameras with matched distortions and focal lengths. The focal length of the lenses is 15.2 cm (21.2$^{\circ}$ field-of-view). This will provide ground coverage in the form of squares approximately 88 n mi (163 km) on a side (26,000 km$^2$) from the 435-km altitude of the spacecraft (see fig. A1). The following wavelength-film combinations are available:

| | |
|---|---|
| 0.5 to 0.6 $\mu$m | PAN X B&W |
| 0.6 to 0.7 $\mu$m | PAN X B&W |
| 0.7 to 0.8 $\mu$m | IR B&W |
| 0.8 to 0.9 $\mu$m | IR B&W |
| 0.5 to 0.88 $\mu$m | IR COLOR |
| 0.4 to 0.7 $\mu$m | HI-RES COLOR |

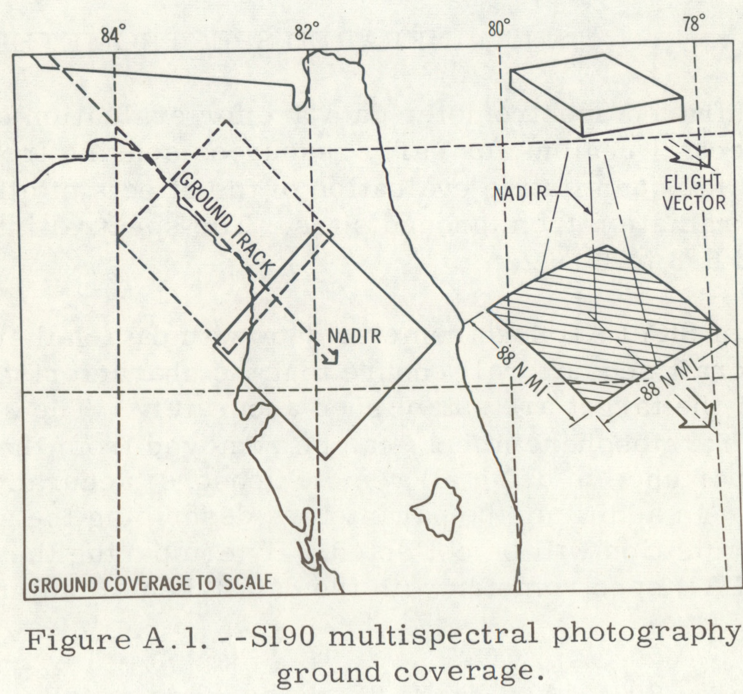


Figure A.1.--S190 multispectral photography, ground coverage.

Within these spectral regions various film filter combinations can be studied. The spectral regions were selected to separate the visible and photographic infrared spectrum into the bands expected to be most useful for multispectral analysis. The spatial resolution at low contrast ratios is approximately 30 to 80 m.[1] The two color films provide a preregistered cross-check of the black-and-white imagery in two proven color combinations. Although the system is designed primarily for the above wavelength-film combinations, it will provide the capability of evaluating various film-filter combinations over the different types of targets. Combinations to be evaluated will be based upon experiments and proposals.

Prior to each photo pass, the SKYLAB crew will receive for each photo sequence a ground update consisting of the time for the first exposure, the intervalometer and exposure settings, and the number of exposures. Each update will be based on current weather and trajectory information. The time for a photographic sequence can vary from 2 seconds (a single exposure) to 30 minutes.

The Earth Terrain Camera (S-190b experiment) is used with experiments designed for S-190. This camera is located on the scientific airlock and has a 46-cm (18 in.) color-corrected, high-acuity lens. The film is 12.7-cm (5 in.) format which should permit imaging a 92.5-km scene (50 n mi) with 10-m resolution. The film may be one or several of either hi-res black and white, SO242 color, or EK3443 color IR.

## S-191, INFRARED SPECTROMETER

The EREP Infrared Spectrometer data are for evaluation of the usefulness of specific spectral regions for earth resources sensing from orbital altitudes, and for quantitative evaluation of the effects of atmospheric attenuation of radiation from ground sites. The spectral intervals are 0.4 to 2.4 $\mu$m and 6.3 to 15.6 $\mu$m.

Correlation of SKYLAB spectrometer data with data gathered by ground-based and aircraft sensors will ensure that the characteristics of the radiance from the target are established accurately. The study of the extent to which atmosphere effects can be removed from the data is of particular importance in using all remote sensors; accuracy will be tested quantitatively. In addition, the parameters describing the atmosphere at the time of acquisition will be collected. By comparing the data collected from the SKYLAB spectrometer with the data taken simultaneously on the

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[1]NASA Handbook 8030.1A. Change 33 states 30-m resolution; the EREP Users Handbook gives the value at about 80 m.

ground and from aircraft, investigators in various disciplines will be able to assess their requirements for IR sensor capability, sensitivity, and spectral resolution, and to evaluate the utility of remote sensing from space for their disciplines.

The S-191 is a filter wheel spectrometer with the following characteristics:

| | |
|---|---|
| Field-of-view | 1 mr |
| Spectral range | 0.4 to 2.4 μm<br>6.2 to 15.5 μm |
| Spectral resolution | 1% to 4% in wavelength<br>(dependent on wavelength) |
| Scan rate | 1 $s^{-1}$ |

A viewfinder/tracking system (V/TS) is used to acquire and track targets during data acquisition. The V/TS has a look-angle capability of 45° ahead, 10° behind, and 20° to either side of nadir. Using this system, the astronaut should be able to acquire and maintain a fix on an approximate 0.46-km site within a 1.8-km circle for a period of several seconds. The coverage is shown in figure A2. The ability to acquire sites is expected to be a strong function of the presence of identifiable geographic features along the ground track leading to the site. Also contained in the V/TS is a 16-mm camera that records the scene as viewed by the astronaut through the tracker.

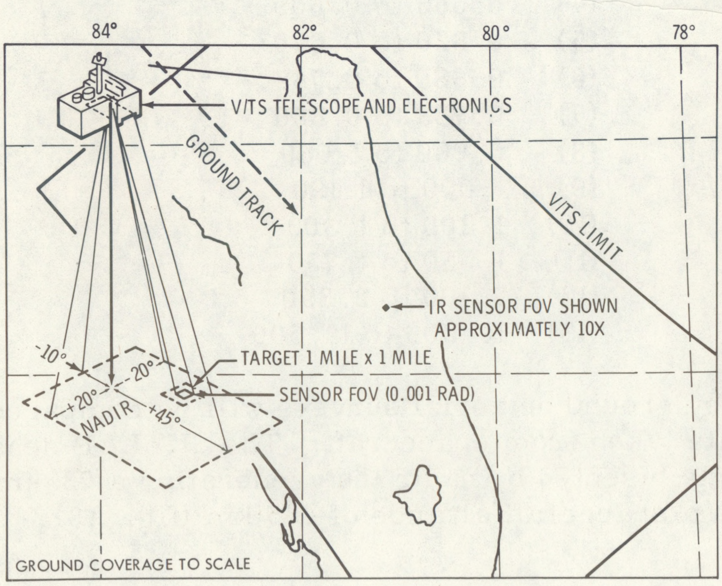


Figure A.2. --S191 infrared spectrometer, ground coverage.

## S-192, MULTISPECTRAL SCANNER

The EREP Multispectral Scanner is capable of providing quantitative radiance values simultaneously in several spectral bands. Data acquired over selected test sites in the United States and other areas will be used for evaluating the usefulness of these multispectral data for crop identification, vegetation mapping, land use determination, identification of contaiminated areas in large bodies of water, and surface temperature mapping. These data can be used to evaluate and determine the feasibility of using automatic data processing spectrum-matching techniques for the identification of earth resources features from space; to compare the results of automatic processing techniques with direct photointerpretation of scanner imagery; and to compare and evaluate the imagery with the photography obtained from the Multispectral Photographic Facility (S-190).

The Multispectral Scanner is designed to sense in the 0.4- to 12.5-$\mu$m region. The sensitivity of the visible and reflective infrared bands (noise equivalent reflectivity) will be about 1% and the sensitivity of the thermal band (noise equivalent temperature) will be 0.4 Kelvins. Each band will have an instantaneous field-of-view 80-m (200 ft) square. The approximate spectral bands are:

| | Bands ($\mu$m) |
|---|---|
| (1) | 0.410 to 0.460 |
| (2) | 0.460 to 0.510 |
| (3) | 0.520 to 0.556 |
| (4) | 0.565 to 0.609 |
| (5) | 0.620 to 0.670 |
| (6) | 0.680 to 0.762 |
| (7) | 0.783 to 0.880 |
| (8) | 0.980 to 1.080 |
| (9) | 1.090 to 1.190 |
| (10) | 1.200 to 1.300 |
| (11) | 1.550 to 1.750 |
| (12) | 2.100 to 2.350 |
| (13) | 10.200 to 12.500 |

Data collected by ground or aerial surveys will be compared for control purposes with data taken from spacecraft. The SKYLAB sensor scans through a $10^{\circ}$ angle bisected by nadir thus generating a 73-km (40 n mi) swath width from a spacecraft altitude of 435 km (fig. A3).

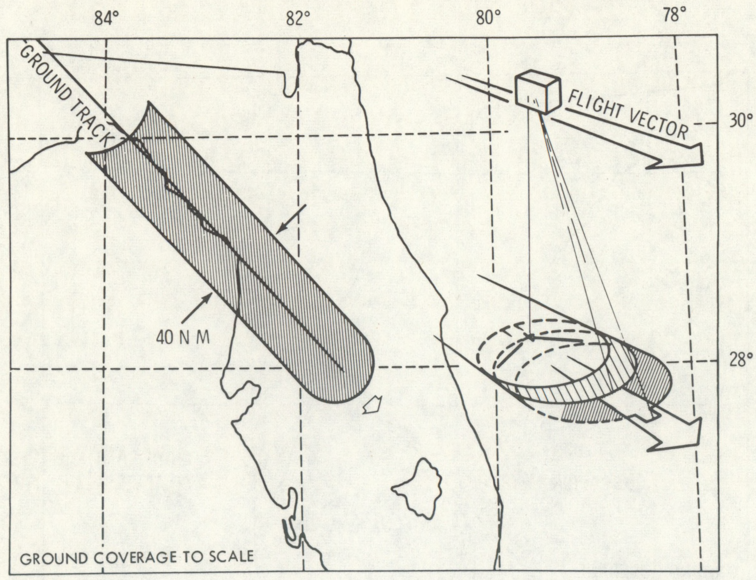


Figure A. 3. --S192 multispectral scanner, ground coverage.

## S-193, MICROWAVE RADIOMETER/SCATTEROMETER AND ALTIMETER FACILITY

The S-193 sensor will provide data for studying varying ocean surfaces, wave conditions, sea and lake ice, ocean clouds, snow cover, seasonal vegetation changes, flooding, rainfall, soil types and textures, soil moisture averages, heat output of metropolitan areas, interrelationship between radar return and microwave thermal emission at spacecraft altitudes, design data for future microwave systems, and dependency of impulse response on surface roughness measurements.

Operation in the RAD/SCAT mode requires nearly simultaneous measurements of the radar differential backscattering cross-section and of the passive microwave emissivity of land and sea surfaces. S-193 will operate at a single frequency (13. 7 GHz) and the RAD/SCAT and the altimeter will be capable of operating independently. The antenna will be a 1. 12-m mechanically scanning parabolic reflector generating a half-power, 1. 4$^{o}$ (approximate) conical pencil beam which scans in several modes. During scanning, the antenna can move in discrete steps (0$^{o}$, 15$^{o}$, 30$^{o}$, 40$^{o}$, and 48$^{o}$) from one cell to another for cross-track and along-track noncontiguous modes, dwelling on each cell a predetermined period of time. During contiguous scan modes, the antenna is moved continuously either along track (0$^{o}$ to 48$^{o}$) or cross-track ($\pm$11. 4$^{o}$ centered on roll angles of $\pm$30$^{o}$, $\pm$15$^{o}$, and 0$^{o}$ at 0$^{o}$ pitch or at pitch angles of 15$^{o}$, 30$^{o}$, 40$^{o}$, and 48$^{o}$). The possible modes are shown in figures A4 through A8.

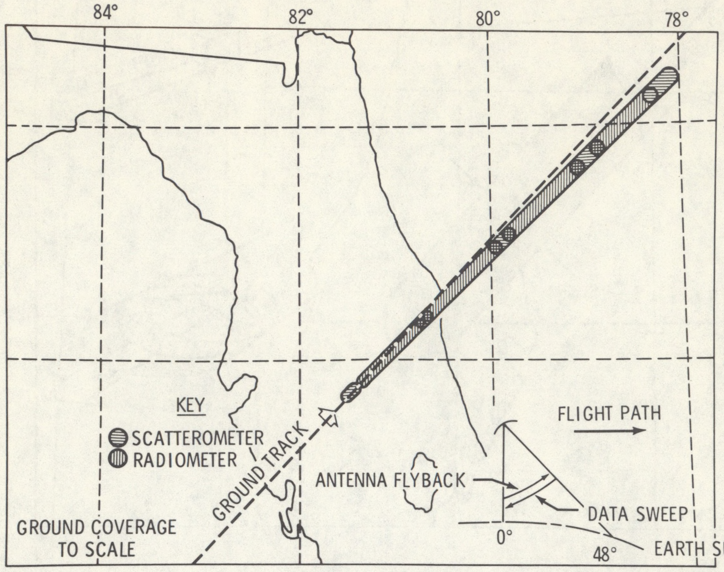


Figure A. 4. --S193 radiometer/scatterometer, in-track contiguous.

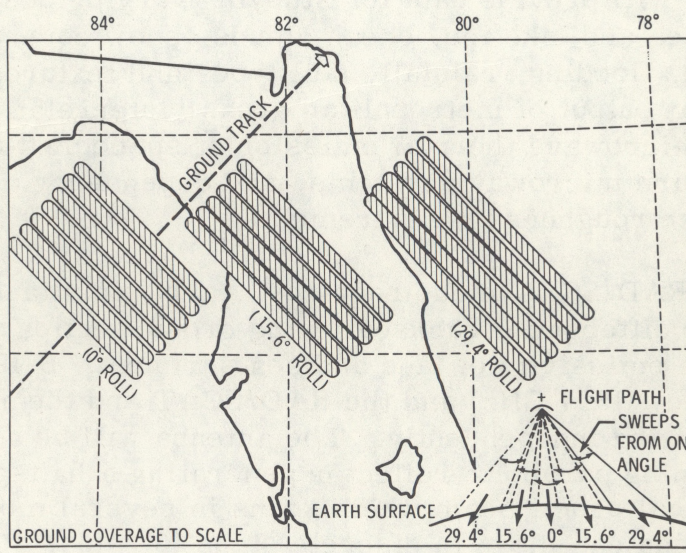


Figure A. 5. --S193 radiometer/scatterometer, cross-track contiguous mode ($O^{O}$ elevation angle).

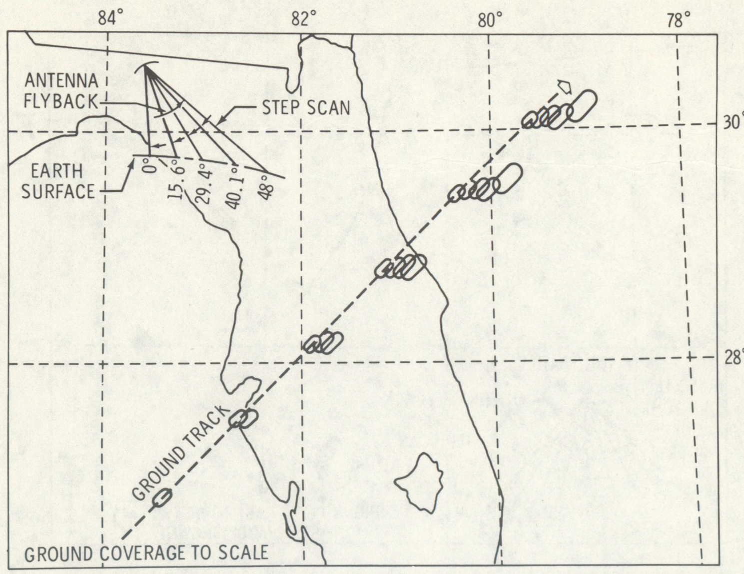


Figure A. 6. --S193 radiometer/scatterometer, in-track noncontiguous.

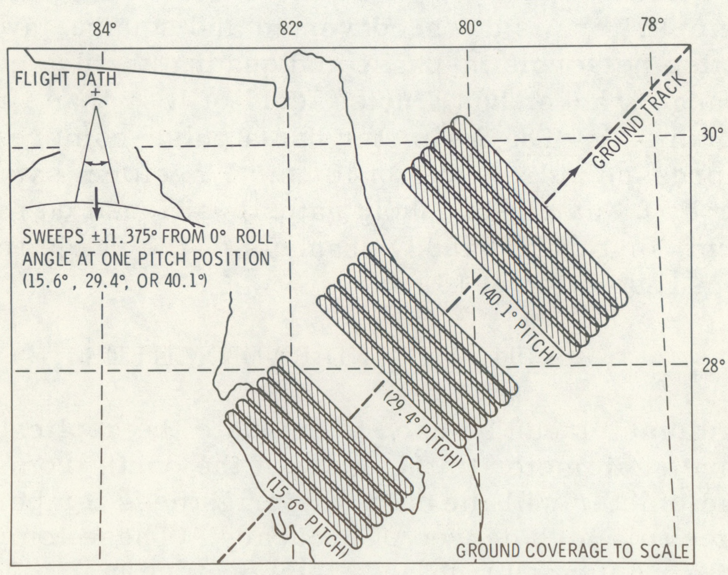


Figure A. 7. --S193 radiometer/scatterometer, cross-track contiguous mode ( nonzero elevation angle).

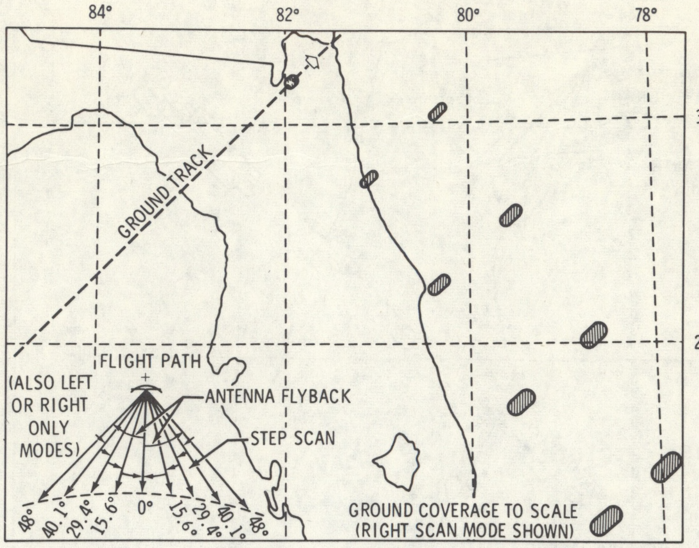


Figure A. 8. --S193 radiometer/scatterometer, cross-track noncontiguous mode.

The Radar Altimeter is a narrow-pulse radar system designed to transmit a 100-nanosecond (ns) or 10-ns pulse at a repetition rate of 360 pulses per second (pps) and a peak power of 2 kW. The received signal passes through a low-noise preampliflier, is down-converted and square-law-detected. The instrument also performs in-phase and quadrature detection. The threshold-type range tracker has a noise level of less than 1 m rms at S/N ratios of 20 dB or more. The Altimeter has a pulse-compression mode producing a compressed pulse width of 10 ns. Waveform sampling is performed either by 8 sample-and-hold gates positioned on the square-law-detected waveform, or by the I and Q channels of the range tracker. This provides a system resolution of 10 ns.

## S-194, L-BAND RADIOMETER

The L-Band Radiometer can be used to evaluate the applicability of a passive microwave radiometer to the study of the earth from orbital altitude. The radiometer will measure the brightness temperature of the terrestrial surface to a high degree of accuracy. These temperatures will be used to compile a surface brightness temperature map. The absolute brightness temperature will be measured at a wavelength of approximately 21 cm (a frequency range of 1. 4 to 1. 427 GHz). The long wavelengths will provide measurements minimally affected by meteorological conditions.

The sensor utilizes a hard-mounted phased-array antenna with a $15^{\circ}$

half-power beamwidth. The energy received by the antenna is integrated at a rate that insures a minimum of 80% ground coverage overlap (the integration time is 1). The receiver provides a digital representation of the $0^{\circ}$- to $350^{\circ}$-K input temperature range. The system has an internal calibration network.

The sensor generally will be operated over ground areas where ground truth data are available. Additional areas of interest include targets of opportunity such as hurricanes and storms. The resolution of the L-Band sensor from orbital altitude is a 115-km (60 n mi) ground width. The geometry is shown in figure A9. Typically, there will be two or more S-194 data taking periods per data pass.

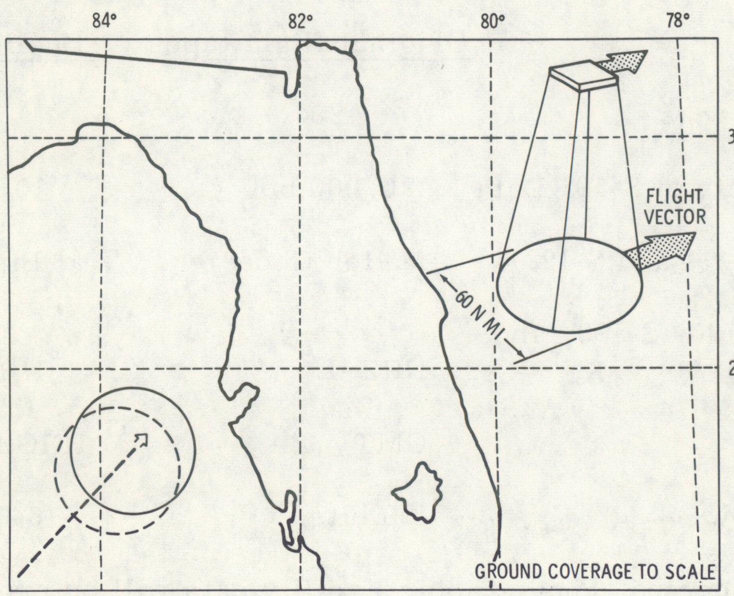


Figure A. 9. --S194 L-band radiometer, ground coverage.

## REFERENCES

A1. "NASA SKYLAB EREP Users Handbook," prepared by Science and Applications Directorate, Manned Spacecraft Center, NASA, Houston, Texas, Mar. 1971.

## Appendix B

## DATA HANDLING

All data from the EREP sensors will be recorded on film and analog magnetic tape for return at the end of each manned period of SKYLAB. Voice annotations relating to EREP data will be included.

The onboard tape recorder is an Ampex AR728 using 28-track, 2.5-cm tape. The original 28-track flight tapes will be reproduced and reformatted onto 14-track, 2.5-cm magnetic tapes. The following table shows the results of reformatting.

| | Original flight tapes | Duplicate tapes |
|---|---|---|
| Number of Tracks | 28 | 14 |
| Packing Density of S-192 Data | 20,000 bpi | 10,000 bpi |
| PCM Code (S-191 and S-192) | Miller Code | Biphase L |
| PCS Code (S-190, S-193, and S-194) | NRZ-L | NRZ-L |
| Time Code | GMT | IRIG A & GMT |
| Maximum Skew | 128 bits | 64 bits |

The S-190 Multispectral Photographic Facility data will be processed in the Manned Spacecraft Center (MSC) Photographic Technology Laboratory after densitometric and sensitometric tests. The original films and optical master will be made available for a period of one day during the Quick Look Screening to evaluate the sensor performance. All other quick-look and science analysis screening will be done using optical masters and other photographic products. S-190 supporting data will be tabulated against time for each shutter pulse of the camera system.

The S-191 infrared spectrometer data will be decommutated and processed by a digital computer program. The data will be made available either in raw form (digital CCT[2]) or processed by computer to produce required

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[2]Computer-Compatible Tape

data products.

The S-192 multispectral scanner data will be processed using the EREP Data located at MSC. This system will be used to produce quick-look film imagery and digital data on 732-m computer-compatible 9-track tapes with a packing density of 800 bytes per 2.5 cm. Computer-compatible 7-track tapes are also planned.

The S-193 and S-194 data will be decommutated and written on CCTs These tapes will be further processed by computer to produce required tabulations, plots, and magnetic tapes.

## MSC Quick-Look Screening

Quick-look screening of data will be conducted one week after the film, tape, and flight logs are received at MSC. The purpose of this screening is to evaluate the sensor performance to determine if corrections are needed for the next manned period.

## Preprocess Screening

Preprocess screening will start two weeks after receipt of the EREP film, tapes, and logs at MSC. This screening is to evaluate the quality of the data prior to processing. All photographic data, selected bands of Multi-spectral Scanner data, all S-193 and S-194 data, and all supporting data for all test sites will be screened.

## Data Services

All data will be cataloged, indexed, and entered into an information stowage and retrieval system. Lists will be published showing the data from the SKYLAB EREP and from the Earth Resources Survey Program. Maps will show the flight track and area covered by each sensor for all test sites.

Data packages will be made up for each approved investigator. Each package will contain appropriate items from the following list: film from S-190 and S-191 (positive and/or negative); quick-look film and digital CCTs of S-192 data; digital tapes, plots, and tabulations of S-193 and S-194 data; flight logs; best-estimate trajectory; voice transcripts; mission anomalies; and maps of flight track showing coverage.

All S-190 film will be annotated to show coordinates of the principal point and corner points of each photograph, latitude-longitude, time, altitude, wavelength band, film type, exposure time, f-stop, density and gamma used for processing, filter, and copy generation made.

# Appendix C

# RESPONSE AND APPLICATION OF SKYLAB EREP SENSORS TO OCEAN PHENOMENA

## I. GENERAL STUDIES

### A. Ocean Science Studies

The signal reading remote sensor is a composite of signatures from many ocean variables. This integrated signal, which varies according to the state of many independent environmental conditions, is difficult to interpret without ocean truth data. Indeed, the lack of ocean truth data has made it difficult to devise repeatable remote sensing experiments.

Where possible, the data collection capabilities of NOAA should be made available to the NASA-supported investigators and NOAA also should conduct its own program to resolve some of the ambiguities of remote sensing of ocean conditions.

Experiments are recommended in ocean dynamics, water mass identification, coastal processes, and marine biology. Feasibility has been established for each of the above experiments. These experiments are described in the following subsections. General references and background material are contained in the Bibliography (appendix E).

1. Ocean Dynamics

Ocean dynamics includes studies of surface roughness, surface wind and wave generation, currents, mean sea level, and sea slope (surface geoid undulations and deflection from the vertical). The ocean dynamics studies are divided into three basic areas: state of the sea by microwave observations, geodetic observations, and measurement of sea surface salinity. Small-scale ocean dynamic features, such as internal waves, are considered in water mass identification (section IV. A. 2).

a. State of the sea by microwave observations - The measurement of the state of the sea requires observations under clear sky conditions. It is known that while correlation exists between both active and passive microwave signatures and surface roughness features of the ocean, there also are discrepancies and ambiguities in these microwave data. The purpose of the state-of-the-sea study is to resolve these differences through a rigorous environmental program, and to assess quantitatively the feasibility of microwave sensors to measure gravity waves (sea state) and capillary waves (surface wind fields).

The following synoptic studies of the state of the sea are possible:

- Capillary wave dependency on surface wind, sea state and swells, sea surface temperature, and thermal stability; energy development and dissipation in capillary wave systems; and testing of Bragg Scattering Hypothesis;
- foam, whitecap, and wave-breaking phenomena, and their relationship to fetch, sea state, surface wind, sea surface temperature, and thermal stability;
- sea-state (gravity wave) development as a function of fetch, surface wind and duration; rates of development as a function of previous swell systems and hysteresis effects; energy spectra of developing and diminishing seas; testing of overshoot hypothesis in wave generation, and verification of wave models;
- studies of wind differential effects across major currents (effect on capillary structures);
- determination of spatial region over which the ocean surface may be considered to be homogeneous to determine best resolutions for oceanographic forecasting and prediction applications; and
- modification of the ocean surface by precipitation.

b. Geodetic observations - The objectives of geodetic observations are:

- To determine the overall feasibility of using a satellite radar altimeter to measure mean sea level;
- to monitor sea surface slopes dynamically;
- to measure directly small-scale departures of the ocean surface from overall mean sea level (e.g., depressions over the Puerto Rican Trench);
- to obtain a set of data over known ground features to provide cross-comparison and validation with the GEOS-C altimeter system;
- to determine the feasibility of using a satellite altimeter system to measure sea state, swells, and surface wind fields;
- to attempt to measure sea slope across a major current system; and
- to sample data from regions with large-scale geoidal departures from mean sea level.

The selection of geographical regions for small-scale geodetic observation is more critical than for the other ocean science studies. The prime areas are:

- Puerto Rican Trench, $18^{O}$N to $21^{O}$N, $64^{O}$W to $68^{O}$W.
- Marianas Trench, $10.5^{O}$N to $15^{O}$N, $147.5^{O}$E to $140.5^{O}$E.
- Japanese Trench, $27^{O}$N to $35^{O}$N, $144^{O}$E to $141^{O}$E.

The Puerto Rican Trench appears best for small-scale geodetic studies. The Gulf Stream, the North Atlantic Ridge, and the California Low should be the regions observed for other geodetic investigations.

c. Measurement of sea surface salinity - The L-band radiometer (S-194 operating at 1.42 GHz) can be used for certain state-of-the-sea measurements. It also introduces the opportunity to design an experiment to assess the feasibility of measuring sea surface salinity -- the prime objective of this study.

The 115-km (60 n mi) spatial resolution of this sensor is not ideally suited to the resolution needs for salinity. However, the frequency is the best available to discriminate salinity changes. Figure C1 shows the microwave brightness temperature at 1.42 GHz for a sea surface temperature of $20^{O}$C, and the effect of sea surface temperature on brightness temperature at a salinity of $35^{O}$/oo. The $90.5^{O}$K line connects the identical environment conditions on the two curves. The brightness temperature varies about $0.6^{O}$C per part per thousand salinity change, and $0.15^{O}$C per $^{O}$C temperature change. In addition, the brightness temperature varies about $0.25^{O}$C per meter per second ($0.12^{O}$C/kt) of surface wind velocity. All slopes related to brightness temperature are negative.

These negative slopes are important. The brightness temperature change across the Gulf Stream boundary, assuming a $10^{O}$C warmer temperature for the Gulf Stream and a salinity increase in Gulf Stream water of $2^{O}$/oo, will be about $2.7^{O}$C, well within the stated measurement accuracy of $1^{O}$C for the radiometer. Such L-band radiometer signature changes should be observed on an opportunity basis across the oceans and also used as a means of water mass identification.

2. Water Mass Identification and Marine Biology

SKYLAB EREP offers the first opportunity to observe variations in water mass from space. The prime discriminants for water mass are ocean color and sea surface temperature. Sea surface temperature is observable from space by infrared (IR) devices on meteorological platforms. The

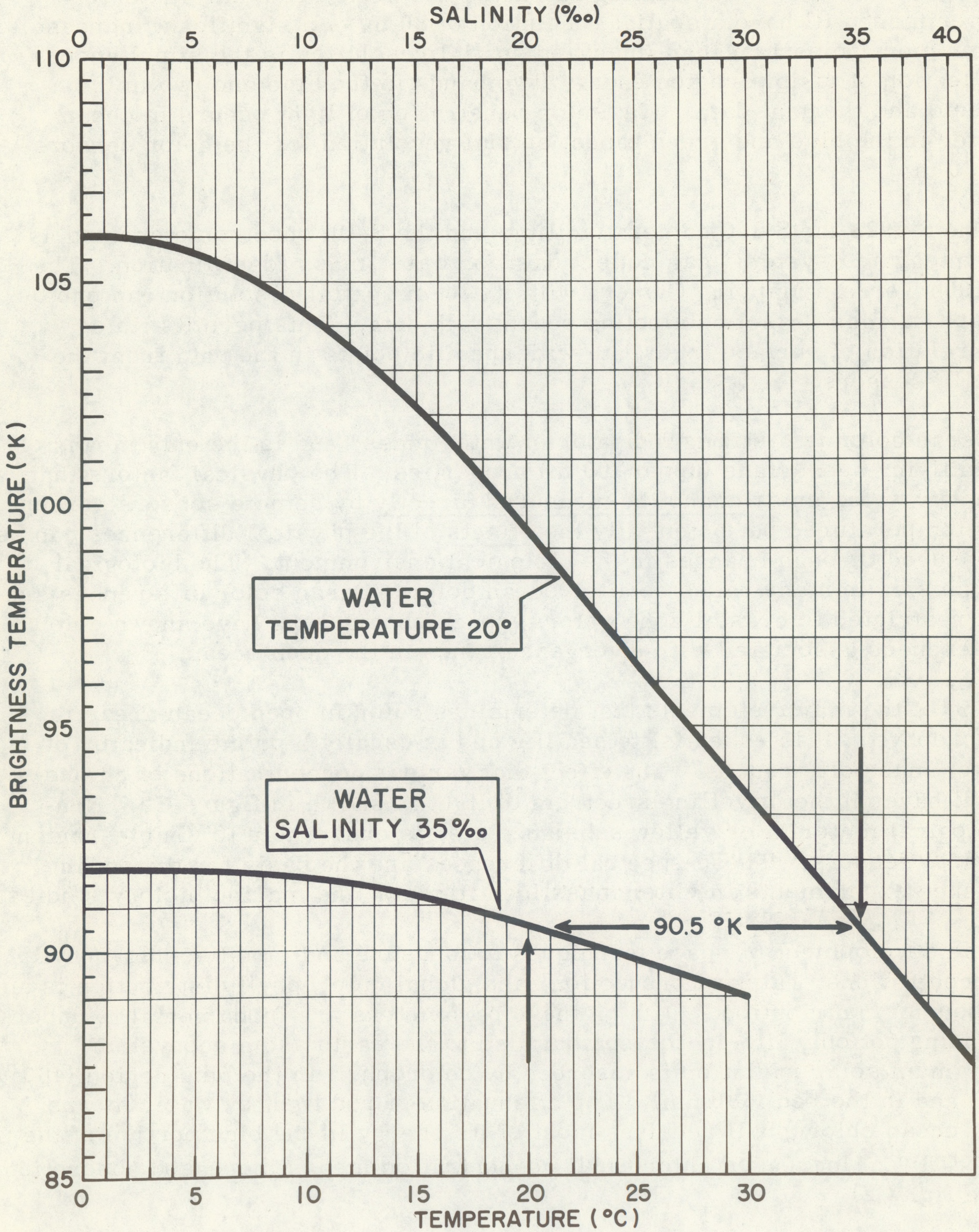


Figure Cl. --1.42 GHz frequency brightness temperature of the sea as a function of temperature and salinity.

spatial resolution from existing satellites has been 6 to 8 km; the S-192 experiment will have a spatial resolution of 80 m -- a significant increase. Even more important than improved spatial resolution is the simultaneous collection of visible region energy (two bands in the blue and two in the green) and thermal data. Maximum penetration of light occurs in ocean water in the blue and green bands; spatial resolution for the color sensors is 80 m.

The S-192, the S-190 camera facility, and the S-191 spectrometer used as an integrated system, can collect data for water mass identification. The S-190b Terrain Mapping Camera with its 10-m spatial resolution can photograph surface vessels collecting ocean truth data. This permits time correlation of surface truth data with specific points in the data from the EREP sensors.

Ocean color is a strong indicator of water mass, and is the only means of identifying subsurface (upper 100 m) properties. The physical factors that identify water mass cannot be measured directly by remote sensors, except for temperature, but potentially the effects of the physical differences can be measured through changes in the biological environment. The biological organisms in many cases do alter ocean color. Ocean color differences are not restricted to coastal zone waters; space photographs have shown color differences associated with divergence zones in the open ocean.

One of the major elements that determines color in open ocean areas is chlorophyll. It is essential to sea life and is usually a prime indicator of water mass differences. The effect that various concentrations of chlorophyll have on the upwelling spectrum of light is shown in figure C2. Non-biological material or yellow substance also is observable to visible-region remote sensors. These spectral differences are the basis for the ocean science experiments in water mass identification and marine biology studies.

The development of space techniques to measure and monitor chlorophyll concentrations, rates of production, and global chlorophyll distribution is an important contribution. Data on these parameters are fundamental to understanding not only life-in-the-sea but also to the earth as an ecosystem. Maximum solar radiation is absorbed by chlorophyll in the blue region (460 nm) and in the red (680 nm). The attenuation of red light by water means that ocean chlorophyll receives most of its energy in the blue portion of the spectrum[3]. Increased chlorophyll concentration means increased absorption (see fig. C2).

The rates of exchange of carbon dioxide from the air to form glucose and

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[3]See figures C4 and C5 for attenuation of light in ocean water.

the subsequent release of oxygen are absolutely essential to life on earth. The photosynthesis process which occurs in chlorophyll production is shown below[4]. The rates of chlorophyll production in the oceans remain largely unknown, with the minimum-maximum estimated values differing by a factor of about 50. Without the development of fundamental techniques to measure chlorophyll properties in the ocean, the carbon cycle in the earth as an ecosystem cannot be determined quantitatively.

Water mass experiments recommended for SKYLAB are surface studies and open ocean color. Ocean color in coastal waters will be considered in the coastal processes investigation. It is recognized that both ocean dynamics and water mass identification are factors related to general ocean circulation. SKYLAB itself probably will not provide a sufficiently large data base for general ocean circulation studies, but the studies and techniques developed among the SKYLAB experiments can contribute to the development of space systems for such studies.

a. Surface studies

(1) Thermal. The objectives of surface thermal studies are (1) to observe and delineate regions of water mass that are (a) thermally stable, (b) that are characterized by sharp gradients such as those associated with a major ocean current system (the Gulf Stream), and (c) by turbulence and mixing and hence nonhomogeneous in appearance, and (2) to examine the above set of observations at varying spatial resolution by comparing SKYLAB thermal data (80 m) to ITOS thermal data (0.5 km) and by integrating these data to the equivalent of 115-km resolution for comparison with microwave observations made in connection with ocean dynamics studies.

(2) Chemical. The surface chemistry of the sea plays an important role in the sea-air relations. Naturally occurring slicks formed from biologically produced, surface-active organic compounds cover a

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4 Photosynthesis

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | (from the air) | | solar radiation | | | | (to the air) |
| $H_2O$ | + | $CO_2$ | + | light energy $\xrightarrow{}$ | $\frac{1}{6}$ ($C_6H_{12}O_6$ | | + | $O_2$ |
| 18 grams | | 44 grams | | 112 kcal | 30 grams | | | 32 grams |
| water | + | carbon dioxide | + | light energy $\rightarrow$ | glucose | | + | oxygen |

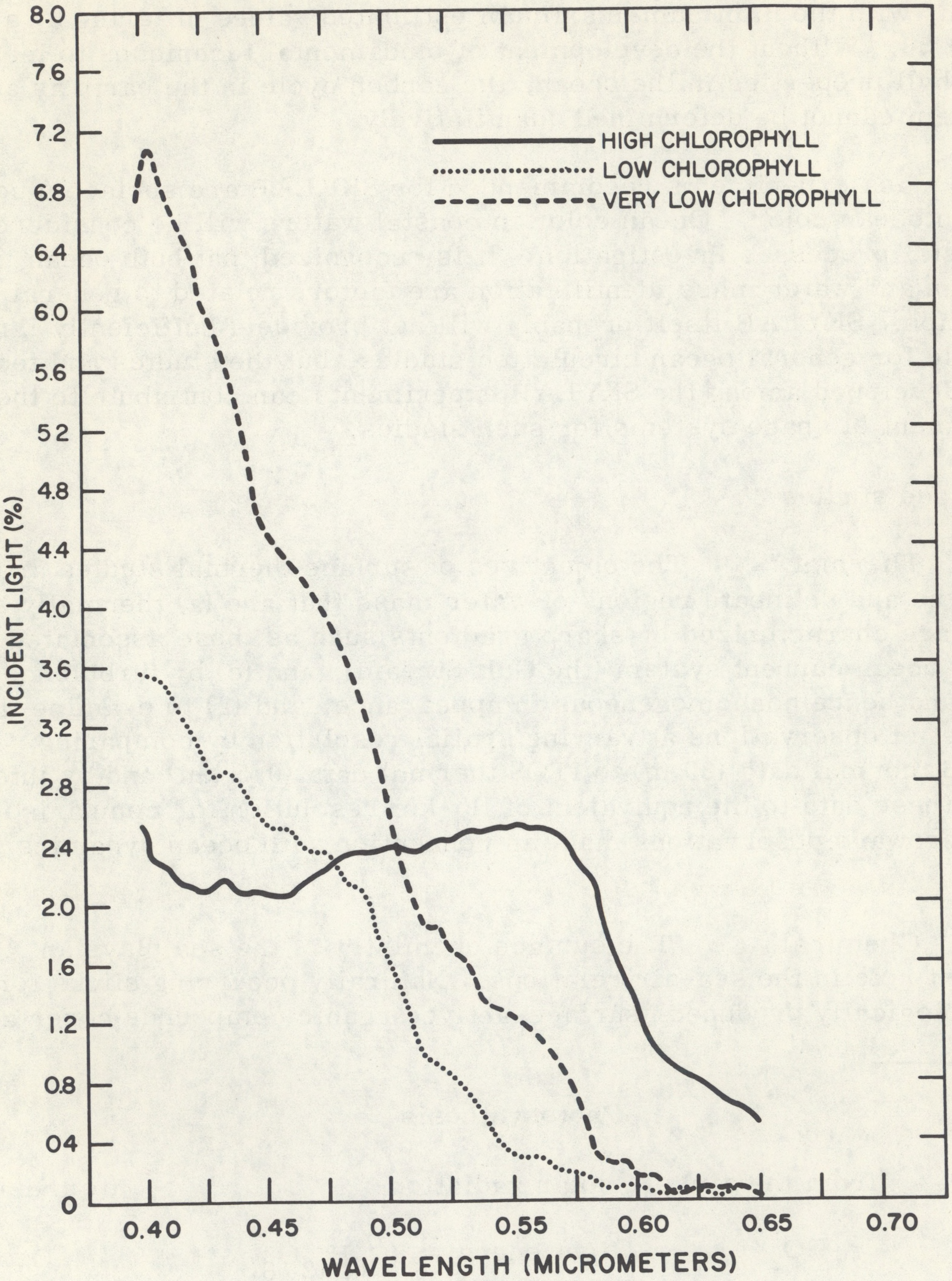


Figure C2. --Relative energy reflected from ocean water as a function of wavelength and the presence of chlorophyll.

significant fraction of the ocean's surface. These slicks are characterized by thermal changes as well as by changes in the reflectance levels in the visible region. This study will be correlated with thermal studies and the ocean color studies that deal with the near-surface properties of water masses.

(3) Internal Waves. Certain forms of internal waves generate surface slicks detectable by visual sensors. Frequently, internal waves coincide with regions where there is a strong density discontinuity. Imagery with spatial resolutions of 10 and 80 m will be examined for periodic surface features to distinguish regions composed of internal waves from nonhomogeneous regions. This experiment will be carried on when opportunities arise.

b. Open ocean color - The objectives of ocean color experiments are to observe quantitatively and to delineate regions that are:

- Biologically rich with chlorophyll
- Biologically sterile but contain yellow substance
- Sterile.

The sources and sinks of different kinds of particles will be studied and the rate of production of chlorophyll will be determined from spectral response, boundary extent, and insolation.

A correlation study will be conducted to relate the subsurface color features to the surface thermal conditions. The S-191 spectrometer data will be analyzed in specific water mass regions of ocean truth data in an attempt to establish a quantitative relationship between chlorophyll concentration and the optical data. Similar analyses will be conducted for yellow substance in the water.

Contrast between two water masses will be examined from the standpoint of reduced contrast due to surface effects, in particular sea breeze and foam. Attenuation, scattering and other effects due to the atmosphere, etc., are considered as part of the sensor studies in section IV.B.

c. Special comment on ocean color - Knowledge of ocean color is important for answering many of the problems that face the ocean scientists. These problems are thoughtfully considered in "Uses of the Seas," edited by Edmund A. Gullion, The American Assembly, Columbia University, Prentice-Hall, Englewood Cliffs, N. J., 1968. An excerpt from pages 17 and 18 is cited below:

"Not many years ago oceanographers assumed that the ocean environment changed so slowly that observations taken at one point in the ocean could be compared with similar observations at another point even though the observations were taken several years apart. Average conditions in the oceans could thus be established. With the availability of bigger and faster ships, improved instrumentation and data processing techniques, physical oceanographers are now concerned with dynamic fluctuations in the oceans both in space and in time. Present theories do not satisfactorily explain or predict all of the many fluctuations that have been observed over a wide span of time, but significant progress has been made in the development of theories which are permitting a basic understanding of the vast transport of water and energy throughout the total ocean system.

"In studies of life within the sea, marine biologists are now well beyond the stage of simply classifying the abundant marine life found in the oceans. They have thus far identified over 200,000 species of plants and animals. Now they are asking questions about the extensive variations of fertility found in the sea, and seeking an explanation to the distribution and evolution of these many different species."

Ocean color is intricately related to life in the sea. Some of the basic questions of biologists may be answered by data obtained from high-speed, synoptic views of the ocean surface from space platforms. The production of plant life in the oceans is great and has been estimated as being equal to or greater than the production of plant life on land.

Plant life in the oceans consists almost exclusively of the microscopic algae, or phytoplankton, that are dispersed throughout the water column to depths of 100 m. However, the production and growth of phytoplankton occur in the upper 10 to 30 m, where photosynthetic fixation of carbon occurs. The rate of chlorophyll growth strongly influences ocean color, and so can be studied by using data obtained by SKYLAB.

3. Coastal Processes

Processes in the coastal zone include sediment transfer, coastal currents and current generation, environmental modification, deltaic and estuarine changes (river-sea coupling dynamics), and wave action. The study of coastal environments involves a wide range of scientific fields, including geomorphology, sedimentology, hydrography, hydrodynamics, wave mechanics, geology, geography, climatology, biology, and chemistry.

The complex interactions, natural forces, and variable boundary conditions make the study of coastal zones a difficult process. There is much skepticism as to the applicability of remote sensor data to coastal region studies. This skepticism is based on two interrelated factors. First, a remote sensor used with apparent success for one application in one geographical region may fail miserably in another region or at another time. Second, many environmental factors have extremes which require rigorous surface measurements to understand the coastal process. It is not clear that such rigorous surface measurements are ever available in coastal studies. The impact of using remote sensors for coastal zone studies has not always been successful in terms of quantitative results.

The weaknesses in the coastal zone studies may, in time, be corrected through use of remote sensors. The synoptic view provided by a remote sensor survey may well delineate environmental extremes. The mere location of convergence and divergence regions of currents by remote sensing can be used to show where surface measurements may be made most efficiently. These regions may change with tides and seasons, so that positions for in situ surface studies are not fixed. Conversely, as conventional surface surveys improve through the "environmental reconnaissance" provided by remote sensors, interpretation of remote sensor data will improve.

Further improvement in the use of remote sensing for coastal studies is obtained by combining the discipline areas cited above into multidisciplinary programs. The importance of doing this is threefold. First, while the sedimentologist and hydrodynamicist may be disappointed when a remote sensing observation indicates a lack of suspended sediment, the biologist and hydrographer would rejoice. Second, more extensive and complete ground data are obtained and unnecessary duplication is avoided. And third, the ecological influence of one environmental factor on another can best be studied by multidisciplinary means.

The term "unnecessary duplication" can be ambiguous. In past remote sensing work, there has not been too much surface truth data. The combining of efforts in a regional study is best done before the experiment occurs, not afterward when data are combined for comparison. A second consideration is that each geographic coastal region is unique, hence phenomena in each region should be studied separately. For example, the U.S. Army Corps of Engineers usually is forced to develop a separate hydraulic model of each estuary system it studies. Even the development of techniques cannot be done solely in a single coastal environment. One should not be too hasty to criticize suspected duplication. Even if exact duplication of effort exists, which is improbable, progress can often be shown by comparison whether the results from different sources agree or disagree.

a. Sediment Transfer - Items to be studied in the sediment transfer experiment are: The mechanism of transfer, rates of transfer, sediment sources, sediment sinks, and diffusion. A comparison of SKYLAB EREP sensor data with data from the Earth Resources Technology Satellite (ERTS-1) will be made. The comparison will include investigation of spatial and spectral resolution tradeoffs and temporal coverage effects.

b. Coastal Current Dynamics and Current Generation - Without introducing manmade matter into surface waters, the approach to studying coastal circulation with remote sensors will include the observation of thermal properties, yellow substance including suspended sediment, and biological matter. Space photography has already shown the feasibility of mapping currents using natural contaminants in the coastal waters. The study of coastal circulation will include consideration of tidal currents, longshore currents, and the velocity and persistence of wind effects.

Longshore currents are generated within the breaker zone by waves approaching the beach at an angle. Their velocity increases with increasing wave heights, (or, more properly, with the available wave energy), the angle of the waves' direction to the beach, and the beach slope. Consequently, the long-shore currents depend largely on wave conditions (see Wave Kinematics, subsection e, below):

c. Environmental Modification - Data collection over a static coastal environment need be made only once. One aspect of the use of remote sensors for studying the coastal zone is that remotely acquired data can be used to define regions of change. These qualitative measurements can be used to determine which regions require repeated surface surveys and the frequencies with which the surveys should be repeated. Thus, remotely acquired data can be used to increase the efficiency of surface surveys in the coastal zone.

Because temporal coverage is required to observe changes in the environment, SKYLAB observations may not be appropriate. ERTS should provide 18-day coverage of any coastal region, but its sensor capability for oceanography is limited in comparison with that of the SKYLAB EREP.

d. Deltaic and Estuarine Dynamics - River outflow into the ocean modifies the normal coastal processes by the introduction of additional dynamic variables. Because many rivers are trafficable by vessels, the SKYLAB EREP study should include a study of an estuarine and delta environment that includes all aspects of coastal processes. The Mississippi Delta is the only one in the United States, but there are a number of estuaries that might be studied.

e. Wave Kinematics - Wave dynamics in the coastal region are connected mainly with the interaction of moving water and coastal features. This is in contrast to the wind-surface interaction of the ocean dynamics discussed in section A.1. The scale of effects in the coastal region is considerably smaller than on the high seas; hence it is essential to study wave action in the coastal zone by means of the high spatial resolution S-190 and S-192 sensors rather than the relatively low resolution S-193 and S-194 microwave instruments. The study of wave refraction includes the following:

(1) Longshore Current Generation. Wave refraction plays a role in the generation of conditions for longshore current formation. Since longshore currents are an effect of breaking waves, wave refraction and coastal current conditions should be studied together.

(2) Rip Current Generation. Depending upon the nature of coastal irregularities and the angle of attack, waves may lead to the formation of rip currents flowing out from the beach with a considerable movement of sand and soil. Whether a particular beach will have longshore flow or rip patterns, and at what spacing and velocity, cannot as yet be made satisfactorily. The high resolution (10-m spatial resolution) of the Earth Terrain Camera (S-190b) may provide valuable data for relevant analyses.

(3) Swell Compression over a Sloping Beach. The period of a wave decreases as water depth decreases to the order of a wave length and less. Knowledge of this foreshortening of wavelength can serve to determine water depth and is especially useful in turbid waters.

4. Upwelling: A Special Study

The physical and biological dynamics in an upwelling area deserve special consideration. These vertical motions, defined here as upwelling, are an integral part of oceanic circulation. The effects of upwelling and the physical process of upwelling are separate and distinct, and so must be considered separately in SKYLAB experiment design. The importance of studying upwelling in a major coastal region, such as one of the five shown in figure C3, is twofold. First, areas of upwelling are of great economic potential, and second, processes near coastal boundaries respond in a more accelerated fashion to time variables than do processes in the open ocean. Thus, techniques to study upwelling should be developed where the extremes are greatest and then should be refined to study open ocean and equatorial upwellings.

Remote sensors may be applied to upwelling studies in the following manner. Sea surface temperature (SST) can be used to define an area of upwelling. Combining SST data with knowledge of bottom depth, associated ocean currents, and the prevailing winds, permits determination of the rates of upwelling. Repeated monitoring of a specific upwelling area by a thermal remote sensor may then eventually permit translation of the thermal pattern into rates of upwelling. This procedure can be accomplished only through rigorous surface truth collection and analysis. SKYLAB sensors offer the opportunity to initiate a study that has not been possible before.

The biological environment resulting from an upwelling is observed and monitored by measuring ocean color. Ocean color is highly dependent on chlorophyll concentrations in the water (as previously discussed in subsection I. A. 2). Upwelling areas have been observed by means of space photography during several manned missions. An important SKYLAB sensor combination for studies of ocean color are the S-191 and S-192 instruments. S-191 will be used to define the spectra of ocean water quantitative, and S-192 will be used to define the water mass boundaries in both the thermal and visible portions of the spectrum.

The choice of geographical regions for studies of upwelling needs careful consideration. The five areas shown in figure C3 are the global upwelling areas of major significance. The U. S. west coast is the most logical

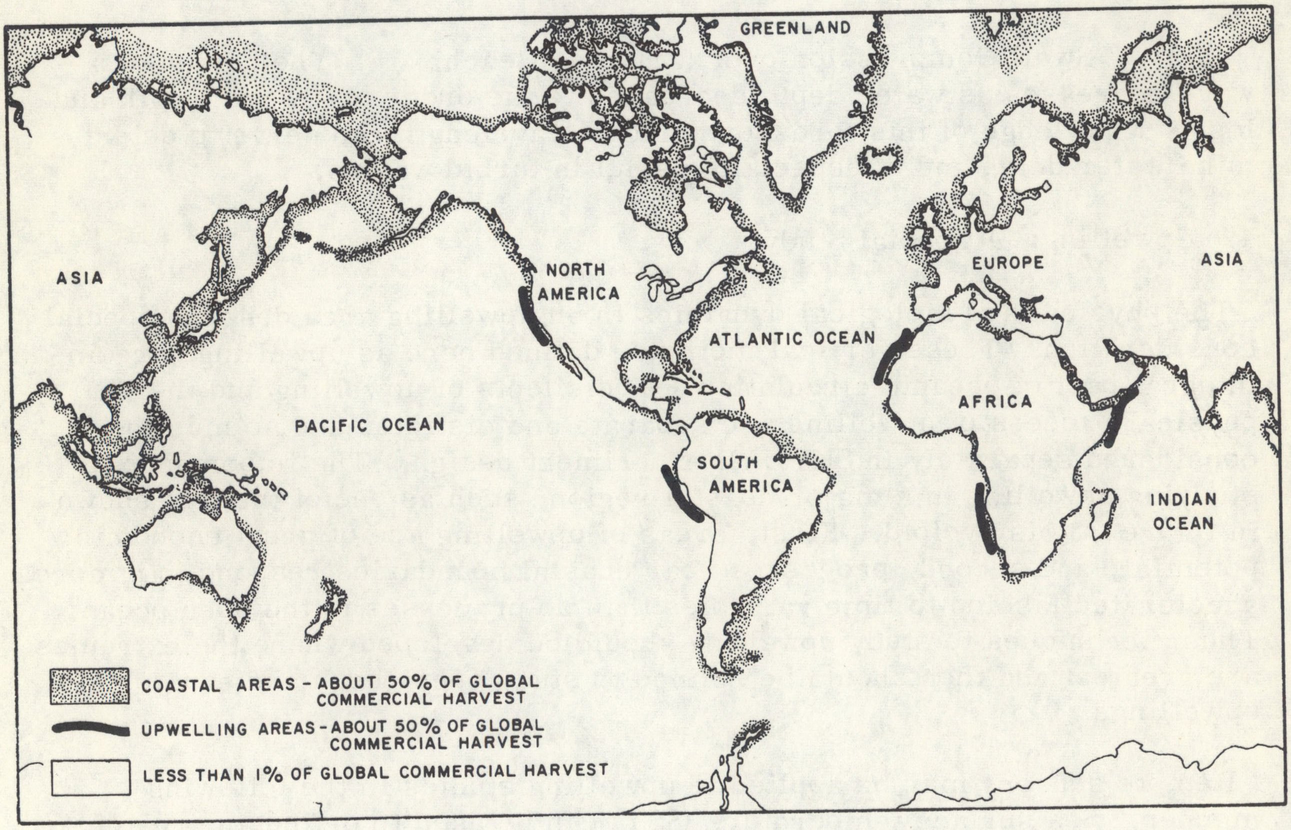


Figure C3. --Distribution of the world's fisheries.

location because of its economic importance to the United States and the best possibility of obtaining SKYLAB EREP data coverage. The U.S. west coast Coastal Upwelling Experiment (CUE) sponsored by the International Decade of Ocean Exploration (IDOE) would be a prime source for ocean truth data. The main drawback to studying the U.S. west coast upwelling region is the prevalence of cloud cover, which can hamper data acquisition in the visible and infrared portions of the electromagnetic spectrum.

An area with highly favorable atmospheric conditions is the Canary Current upwelling off the West Coast of Africa[5]. The Canary Current upwelling is to be subject to intensive oceanographic research sponsored by the Food and Agricultural Organization (FAO) of the United Nations. An ocean survey program plan in this area presently calls for approximately a dozen nations, including the Soviet Union, to conduct intensive physical and biological marine studies in this area. The program is officially identified as the Cooperative Investigation of the Northern Part of the Eastern Central Atlantic (CINECA). The first CINECA study is scheduled to begin the latter part of 1973. The NASA has looked favorably on this proposal so that there is a reasonable probability that SKYLAB data will be collected from this area. Suggestions have been made to the Global Atmospheric Tropical Experiment (GATE) to include the CINECA region.

It is important that the remote sensing community take advantage of CINECA and the extensive oceanic and atmospheric data to be obtained by ship, aircraft, and satellite during July and August 1973. The NASA tentatively plans RB-57F aircraft flights to collect oceanic data with a special ocean color instrument called a Scanning Imaging Spectroradiometer (SIS). A follow-on experiment to assess the capabilities of satellite infrared systems is being developed by the Navy for CINECA. Thermal surveys from low-altitude aircraft are planned. These aircraft data will serve as ocean truth for ITOS and NIMBUS and potentially for SKYLAB EREP.

The following items are possible for CINECA support:

- Ship support by approximately 12 nations (the United States has no ship support in 1973) conducting coordinated physical and biological experiments.

- Two U.S. Navy aircraft for low-altitude thermal surveys.

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[5]A quantitative examination of meteorological satellite data for July-August 1969 shows the region from the Canary Island to the Straits of Gilbralter has about 1/3 to 1/6 the cloudiness of the California-Oregon coast region.

- One NASA RB-57F with a special ocean color sensor for high-altitude flights; potentially two additional aircraft for ocean color measurement.

- ERTS-1 satellite.

- NIMBUS-5 with a two-channel infrared sensor for sea surface temperature and a microwave radiometer for atmospheric water vapor determination.

- ITOS thermal sensor with a 1-km spatial resolution, also for sea surface temperature.

- SKYLAB EREP sensor package.

## B. Sensor Studies

The primary purpose of the sensor studies is to investigate instrument signatures for use in designing instrumentation specifically for oceanographic and ocean surveillance applications. A secondary purpose is to determine the best way to prepare and format signatures so they are meaningful for ocean science studies. Each sensor is discussed separately; where two sensors, such as S-190 and S-192, have similar capabilities, the fact will be noted. (Appendix A lists the basic sensors of the EREP).

### 1. Properties of the Ocean

In the analysis of remote sensor signatures for oceanography, it is essential to discuss how electromagnetic energy interacts with water. The degree to which radio waves, microwaves, thermal energy, and visible light are attenuated by the water column is shown in figure C4. Significant water penetration occurs only in two general regions of the spectrum: at very low frequencies of about $10^3$ Hz (wavelength about 300 km) or less; and at a frequency of about $7 \times 10^{14}$ Hz (wavelength about 0.45 $\mu$m.) Because it is impractical to build remote sensors for oceanographic applications that operate at the extremely long wavelengths, the only portion of the spectrum where significant penetration is possible is in the blue/green region between 0.4 and 0.6 $\mu$m.

Figure C5 shows the attenuation coefficient of several types of water at wavelengths of 0.35 to 0.70 $\mu$m. Mean oceanic water attenuates only slightly more than distilled water so energy in the blue/green region (0.45 to 0.55 $\mu$m) is attenuated by $^1/e$ (about 37%) in distances of about 10 to 20 m, while in the red region (0.65-0.70 $\mu$m) this distance is reduced to only a few meters. This attenuation by water will limit the application of visible region sensors to a maximum depth of the upper 60 to 100 m of the surface.

A further feature shown in figure C5 is the shift in the region of maximum penetration from the blue to the green region as the water changes from that typical of the open ocean to that found in the coastal region. Depending on the type of ocean water, there can be a preference as to which portions of the visible spectrum are to be used. The S-190 and S-192 instruments can be used to study these features.

2. Multispectral Photographic Facility (S-190 and S-190b)

The NASA space photography used from the Mercury, Gemini, and Apollo for earth resource surveys has demonstrated several capabilities and potentials for space techniques applied to oceanography. The cameras previously used had resolutions which approached a 100-m spatial resolution. The 6-channel camera system of the S-190 instrument extends previous capability in several desirable ways that include: improved spatial resolution, six channels rather than three or four, forward motion compensation, film flexibility (three magazine sets), filter flexibility (12 filters more than those specified in appendix A), dynamic distortion match between cameras, first "blue" channel photographic possibility in space, and intervalometer settings of from 2 to 20 seconds. The S-190 sensor study will be composed of the five aspects discussed below.

a. Spatial Resolution Study - A fundamental study important in coastal region oceanography is the relationship between environmental information and spatial resolution. Spatial resolution requirements are not known and so require detailed examination. SKYLAB data potentially can be used to

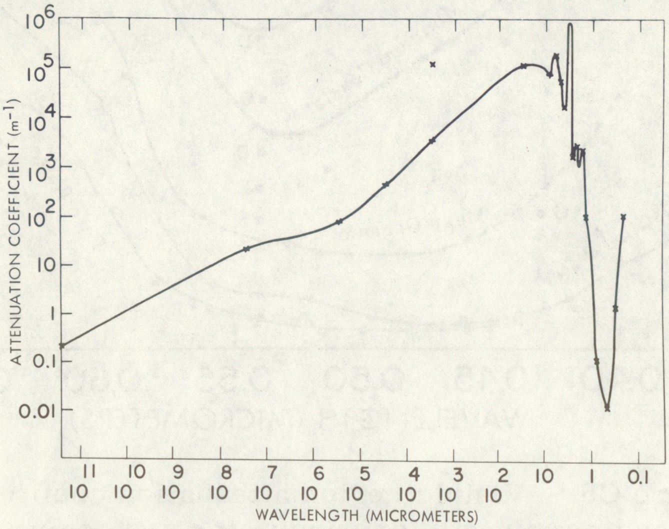


Figure C4. --Attenuation coefficient versus wavelength and frequency for sea water.

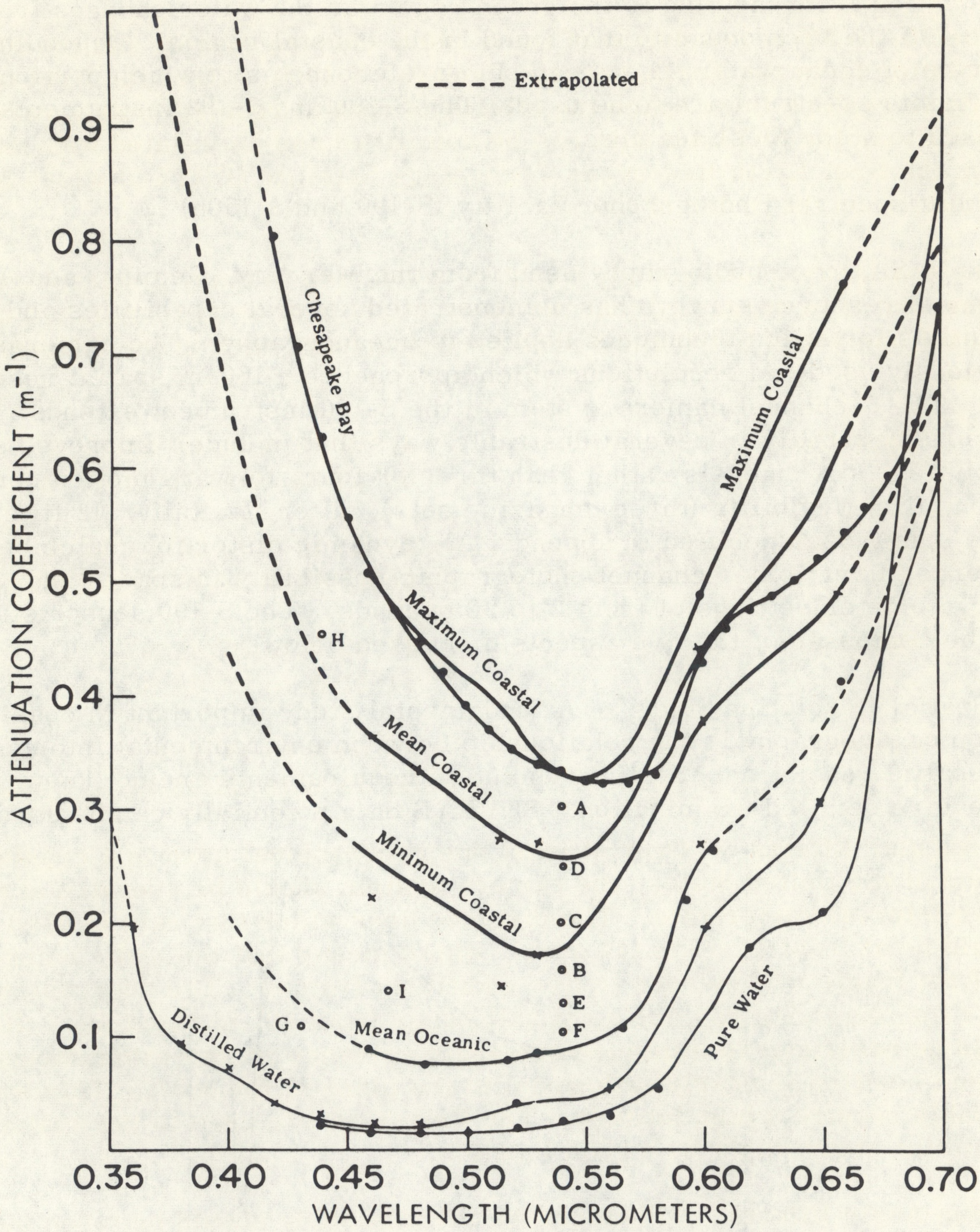


Figure C5. --Visible region attenuation coefficient versus wavelength for pure water and sea water.

address this problem.

The 30- to 80-m resolution of the S-190 6-camera system and the 10-m resolution from the Earth Terrain Camera, S-190b, offers the first opportunity to explore from space the effects of spatial resolution as a variable. In addition, the SKYLAB data can be compared and correlated with data from the first Earth Resources Technology Satellite (ERTS-1) which has a resolution on the order of 100 m.

The spatial resolution study might be conducted in many geographical areas, but it is suggested that the study might best be accomplished using at least one set of S-190 and S-190b photographs of each of the following areas.

| | |
|---|---|
| Cape Cod | 41°38'39"N to 42°03'45"N<br>69°57'38"W to 70°14'45"W |
| Key West | 24°27'10"N to 24°39'00"N<br>81°43'45"W to 81°52'45"W |
| Bahamas | 22°52'N to 26°42'N<br>74°51'W to 79°04'W |
| Arizona | 33°00'N to 33°31'N<br>111°45'W to 112°15'W |

b. Angular Effects - Over at least one geographical area in a coastal region of the United States, the camera system should be operated at the 2-sec intervalometer rate. The distance over which this rate is used should be at least 81.5 km (44 n mi), which means that the nadir point of the first frame will be seen in five additional frames. The depression angle for observing any one point will range from 90° to about 80°. It would be beneficial to minimize sun angle variance in this experiment, so the sun position is nearly orthogonal to the plane of the orbit. This would probably require a high latitude. The Cape Cod site used in the spatial resolution study might be a good location.

c. Sun Angle Effects - Photographs for this study should be taken over the same area used for the angular effects study, preferably with clear water conditions. Photographs should show as many sun angle conditions as are possible under existing orbital constraints. Sun angle conditions causing glitter patterns in the photographs must be included. The angular effects study could be a special case of this study.

d. Exposure Requirements Study - It is highly desirable to obtain coastal photography with varied exposures. Many ocean features have not been seen because previous space photographs were of terrain and cloud conditions. As a result, ocean features are often underexposed. To determine the best exposures for oceanographic purposes (usually 2 f-stops greater than for terrain photography for the same light conditions), pictures over the same geographical region should be taken at various f-stops varied with other conditions as similar as possible. If the astronauts can change f-stops rapidly between exposures, then the experiment could be conducted in a nearly optimum manner.

e. Blue and Blue-Green Water Experiments - At least one blue filter with a bandpass of 0.46 to 0.51 μm should be included in the filter package. This blue filter would best be used in camera station 6 of the S-190 system (thus replacing the color film). A second filter with a 0.52- to 0.56-μm bandpass in camera station 5 would provide a special green band. The remaining four cameras would use the normal filter arrangement. Photography over an upwelling region and over a clear water coastal region should be obtained.

3. Filter Wheel Spectrometer (S-191)

This is a unique instrument for space research that will acquire high spectral resolution data at 0.4 to 2.4 μm and at 6.2 to 15.5 μm at 1-sec intervals. The spatial resolution of this calibrated instrument will be a 1-mr instantaneous field-of-view (a 0.5-km, or 0.25-n mi diameter circle at nadir). Spectral resolution is variable depending on the wavelength (1 to 4%), but in the visible spectrum it is about 0.015 μm (150 A). This is an ideal resolution for ocean color analysis, and with pointing limits of $45^{o}$ ahead, $10^{o}$ back, and $20^{o}$ to the side, a considerable amount of data on ocean color can be acquired. Note specifically that this is not an imaging system, so all experiments conducted with S-191 should be accompanied by photography and/or imagery from either S-190 or S-192.

a. Emissive and Reflective Properties of Ocean Water - Sets of basic space data should be acquired over several water types (coastal, slope, upwelling, and deep ocean water) with the S-191 trained and maintained on a specific point. Angular effects can then be observed.

b. Upwelling Contrast Experiment - During approach to an upwelling region, it is highly desirable to obtain data on either side of the upwelling as a function of angle. This requires the astronaut to know coordinates of the upwelling and to be able to point to alternating spots on either side of the upwelling for durations of at least a second. The preferred sun angle should be about $30^{o}$ from the zenith for this measurement.

c. Variation in Open Ocean Color/Temperature - Quantitative information on the variability of open ocean color is completely lacking. Because color is an indicator of water mass in coastal regions, there is good reason to believe it will be a valid indicator of water mass in open ocean or deep ocean areas. However, contrast will not be as great as in coastal waters. A practical means of observing ocean color has not been available before. SKYLAB S-191 can cover a large segment of the ocean in a short time, so the environmental variables, in particular the atmosphere and sun angle, remain relatively fixed. It is recommended that a step-and-repeat cycle at near-nadir depression angles under the flight track is the best way to obtain data for this experiment. The step-and-repeat cycle should be used to collect data from one specific point after another. The system might be automated to step-and-repeat at, say, 20- to 40-km intervals (the closer the spacing the better), but it is believed that the astronaut could greatly facilitate the measurement by pointing between and around the cloud environment.

The flexibility in the experiment is such that the instrument should collect data within $5^{\circ}$ of nadir. At a velocity of 7 km/sec, the SKYLAB platform would move 7 km during data acquisition. Assuming 3 sec to repoint and train on a specific point (to within approximately a mile) the platform would move a total of 28 km while collecting data from a single point. Such data should be acquired for a period of about 5 min and from a number of areas. This could be tedious for the astronaut, but the data would be of great significance for ocean science.

Approximately 1200-n mi strip maps of ocean color/temperature might be obtained from the Atlantic coast toward Bermuda (including the Gulf Stream), the Gulf of Mexico, and the Pacific area, perhaps north of Hawaii. While strong surface support at each point of data acquisition is desirable, it is highly impractical. Surface truth at several data points under the track are necessary, but basically the purpose of this experiment is to monitor relative color changes in the ocean, and should serve as a precursor to future color/temperature experiments. It is as much an oceanographic science study as a sensor signature study.

4. Multispectral Scanner (S-192)

Ideally, photographic experiments should be repeated or conducted simultaneously with the S-190 experiment. The S-192 instrument with its 78-km (40 n mi) swath width and 80-m (260 ft) spatial resolution should be used in conjunction with each of the S-191 experiments outlined previously. The two blue and two green channels in the visible and the thermal infrared give the sensor designer several unique opportunities, not available prior to SKYLAB, to collect data from space.

a. Absolute Reflectance/Emittance - This instrument and the S-191 spectrometer should be used to determine the absolute levels of reflectance and emittance from the ocean at the conical scan angle ($5.5^{o}$) of this instrument. The radiometric qualities of the S-192 sensor make it more suitable for this use than the S-190. The measurements should preferably be made in conjunction with other experiments. In particular, the spectral resolution studies and the S-191 data should be used for SKYLAB instrument intercomparison. The following reflectance/emittance characteristics are to be determined by S-190 and S-192 measurements as a function of wavelength:

Sea breeze, surface wind,
foam and whitewater,
sediment and yellow substance,
chlorophyll concentrations,
surface oil slicks (opportunity -- natural and man-made),
water depth, and
bottom type.

b. Spectral Resolution Studies

(1) Background. This experiment to identify water masses should be conducted in conjunction with the variation in open ocean color/ temperature experiment (subsection I. B. 3. c). Possible data-recording limitations of the S-192, and the step-and-repeat feature suggested for the water mass measurement program will dictate the manner in which the S-192 instrument is to be used. Consider a 30-km step-and-repeat interval (section IV. B. 3. c) for the water mass identification study. If data recording can be accomplished by the S-192 during the period suggested in section I. B. 3. c, then a full 5 min of data, covering a length of about 1200 n mi, will be acquired. If data recording is a limitation, the alternative might be to collect data for only 1 sec out of every 4 with the S-192 scanner activated to record data simultaneously with the S-191 data acquisition. Difficulties associated with implementing this proposal, in terms of turning the recorders on and off, have not been assessed. Clouds can be avoided by having the astronaut point the S-191 sensor. The S-192 measurements will contain the complete spectral image data, including clouds, and S-191 measurements will contain detailed point-by-point spectral data within the image.

Experimenters also suggest that the blue, blue-green experiment using the S-190 sensor (section I. B. 2. e) be accomplished during this interval using an intervalometer setting of 4 sec (if a 30-km step-and-repeat cycle is used).

(2) Contrast Reduction by Spectral Resolution Degradation. Quantitative S-192 ocean signatures in the blue-green, red, and thermal IR channels are to be compared to data for the same spectral region from the S-191 instrument. Specifically, the discrete points of S-191 data (including

thermal IR) are to be degraded to S-192 spectral resolution. Scene contrasts are to be compared to determine the spectral resolution requirements for water mass identification and the best wavelengths to be used.

c. Multispectral Enhancement of Ocean Features - The objective of this S-192 experiment is to determine the feasibility of improving contrast between ocean color features by data-processing techniques. Data from both open ocean and coastal areas are to be considered. Software programs are to be developed to permit the subtraction of surface feature bands (red or near-infrared) from the subsurface feature bands (blue and green). Variable wind field/sea breeze effects should be included in the software programs.

d. Effects of Using a Conical Scanning System - The effects of using a conical scanning system instead of more conventional systems are to be determined for two regions of the visible spectrum and for the thermal infrared region. Comparison is to be made between S-190 and S-192 measurements over open ocean and coastal waters. It is believed highly desirable to make these comparisons using the special blue (0.46 to 0.51 $\mu$m) and green (0.52 to 0.56 $\mu$m) filters suggested in section B.2.e, so that effects due to differences in spectral resolutions can be minimized. Further, photographic data are to be digitized and the contrast is to be compared quantitatively.

e. Thermal Patterns - Assuming that either NOAA or NASA has an IR mapping system (NIMBUS- or ITOS-type HRIR systems) in orbit during the life of SKYLAB, nearly simultaneous data from these satellites, which have a spatial resolution of either 1 km or 10 km, can be compared to the 10.2- to 12.5- $\mu$m channel of S-192 which has approximately 80-m spectral resolution. The purpose is to identify the relative variance in sea surface temperature as a function of spatial resolution, and to determine the nature of the loss of surface temperature features as result of increasing the spatial resolution.

5. Microwave Radiometer/Scatterometer and Altimeter Facility (S-193)

The S-193 instrument offers several unique opportunities because it will be the first microwave system in space with resolutions necessary for observing several forms of ocean environment. One objective is to compile for all modes of operation a complete index of parameters for all environmental situations where ocean truth permits. These parameters are listed in subsections a and b, which follow:

a. Active Microwave Data Catalog - Backscattering as a function of angle, wave height, wind speed, wind direction, wind duration, developing seas, developed seas, diminishing seas, fetch, and pulse length, backscattering polarization features, cross-polarization effects, effects of sea surface temperature, effects of stability conditions, and cloud and atmospheric conditions.

b. Passive Microwave Data Catalog - Reflectance/emittance as a function of angle, wave height, wind speed, wind direction, wind duration, developing seas, developed seas, diminishing seas, fetch, sea surface temperature and foam cover, effects of stability conditions, and cloud and atmospheric conditions.

c. Spatial Resolution Analyses - In contiguous cross-track modes the uniformity of backscattering reflectance and emittance of microwave data is to be analyzed in terms of spatial resolution, with the average value of cross section over increasingly large areas (up to approximately 185 by 185 km on a side) and the variance in the cell-to-cell (11.5-km diameter) microwave signature determined.

d. Angle of Observation Study - Microwave signatures are to be evaluated to determine the incidence angles most suitable for observing the particular oceanographic features, such as surface winds, surface roughness, and polarization features.

e. Pulse-Compression Analysis - The objective of this sensor study is to use the altimeter mode of the S-193 sensor to determine the capabilities of phase-reversal-coded waveforms to provide reliable impulse response information, and to compare profiling properties of pulse compression and conventional waveforms. Also, anomalies arising from pulse-compression signals will be determined.

Pulse-compression techniques have been used in many radar systems. However, there are no data on the use of pulse compression in high-altitude altimeters to prove or disprove the concept that satellite geometry and velocities will not cause poor pulse-compression performance. If pulse compression introduces no basic anomalies in the signal returns, then it will be used more frequently to enhance the signal-to-noise ratio of radar altimeters. Spatial resolution is also enhanced by pulse compression. Benefits are the potential reduction in weight and power requirements of future space altimeters.

The prime modes of operation for this experiment are to be the 10-nsec brute-force pulse and the 130-nsec pulse compressed to 10 nsec. Quantitative comparison of data acquired in the two different configurations will be made to determine what differences, if any, exist between the two techniques as a function of environmental conditions. The experiment can be conducted over any geographical area of opportunity, but should be conducted over the Puerto Rican Trench area and over relatively rough ocean waters for studies of surface roughness effects.

6. L-Band Radiometer (S-194)

a. Signatures as a Function of Environmental Conditions - The nadir-looking radiometer signature will encompass a spot on the ocean surface 115 km across-track and about 122 km along-track. The signature is to be analyzed according to surface salinity, roughness and windfield, temperature, and foam cover.

b. S-193 Comparison Study - The microwave brightness temperature usually increases with increasing surface winds, foam, roughness, etc. The S-194 data are to be compared to S-193 data in the spatial resolution analyses suggested in section I. B. 5. c for an area of 115 by 122 km. These data will be used to verify existing frequency-dependent microwave models of the ocean.

## II. OCEAN TRUTH[6]

### A. Nature Of The Problem

A remote sensor responds to an integrated signal whose components include many variables. To fully interpret the remote sensor signature, these surface variables must be known. Once the details of the remote signatures are known, the advantage of remote sensing is that several features may be measured at one time. However, rigorous forethought is required to ensure that all variables are considered.

Remote sensor data remain meaningless and of little value unless analyzed and interpreted in terms of what is currently known and understood about the ocean. SKYLAB studies in the ocean sciences and applications cannot be comprehensive unless the best available knowledge and expertise are applied in the design and analyses of these remotely acquired data. Further, such experience in ocean science and exploration is needed to put the best overall plan into operation.

Remote sensing studies of the ocean have been hampered by too little "truth." It is believed that the development of remote sensing techniques will see an increasing amount of coordination among the disciplines of

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[6] The term "truth" is used to designate data gathered in situ or by remote sensors closer to the sea surface for comparison and corroboration with remote sensor measurements from high altitude aircraft or spacecraft.

physical, chemical, and biological oceanography. The marriage of at least physical and biological experiments within the framework of SKYLAB is believed essential to ensure success for the tasks and experiments outlined in section I.

The following sequence of questions should be asked in developing requirements for ocean truth for SKYLAB experiments:

a. Does the proposed ocean truth data collection lead to an oceanographic experiment that can stand on its own?

b. If so, is the experiment enhanced by the addition of other environmental data collected independently of SKYLAB?

c. Will the additional data in itself serve as an experiment that can stand alone?

d. Is there a proposed experiment within the framework of the SKYLAB ocean studies that covers this aspect of the investigation?

e. Can the experiments be colocated?

f. Are additional data required to make the data in these surface experiments relevant to the SKYLAB mission?

g. If so, are there proposed experiments that cover this aspect of data collection and analyses?

If the above sequence is used, the truth collected for SKYLAB ocean studies will always be useful per se and will serve to complement other experiments. Thus, if any component fails, meaningful experiments can still be conducted.

## B. Remote Sensing Data

The quantification of relationships between an ocean feature and a SKYLAB measurement requires that meaningful surface data in support of remote sensing data should be acquired. If electromagnetic energy passes through the atmosphere without modification, or in a fixed manner, remote sensors at the surface would not be required. Since the atmosphere is a dynamic medium which affects the radiation received by spaceborne sensors, accurate measurements and analyses of atmospheric effects are essential to the research program. Complete experiments using data from ships and aircraft sensors should be designed to assess atmospheric effects on remote sensor signals in spacecraft.

The sea surface itself is a dynamic medium which can also alter the remote sensor signals received in space. Thus, even if the atmosphere posed no problem, measurements of subsurface features would necessarily include the determination of the influence of the sea surface. An example of such an influence occurs in the measurement of ocean color. A sea breeze change from 10 to 14 knots can reduce chlorophyll contrast detectable at satellite altitudes by as much as an atmospheric change from a clear day with no clouds to a day with up to 1/10 cloud cover. Sensors on ships and aircraft can help to define such surface effects more realistically.

1. Remote Sensors on Ships

Three basic forms of remote sensors are considered necessary aboard research vessels supporting SKYLAB experiments and sensors for atmospheric measurements are highly desirable.

a. Thermal Radiation Thermometers - Infrared radiation thermometers operating in the 10.2- to 12.5- $\mu$m region are operated from a fixed boom on the bow of the ship. These data can be compared to conventional shipboard temperature measurements.

b. Spectrometers - Visible region scanning spectrometers are needed to measure the spectral distribution and intensity of upwelling light from the sea. These data should be collected from above the surface as well as immediately below the surface. Shadowing and sun-glitter effects should be minimized. The instrument's field of view and its height above water, and the effects of wave action, should also be considered.

c. Photography - Photography of the ocean surface is essential for use with aircraft and SKYLAB visible region and microwave data. The photography should sharply define capillary waves and foam, or white water cover.

d. Atmospheric Remote Sensing - Transmissometers should monitor characteristics of sky transmission in the visible spectrum; upward-looking cameras should record cloud cover conditions during SKYLAB passage; microwave brightness temperatures of the sky at near zenith should be monitored at both L- and $K_u$-bands. (1.4 GHz and 13.7 GHz)

2. Remote Sensors on Aircraft

The ocean truth experiments will need aircraft support at low, intermediate, and high altitudes. The remote sensors to be used at the various altitudes are listed below:

a. Low altitude (300 m or less)

- Laser wave profilometer
- Radiation thermometers (10.2 to 12.5 μm)
- High-resolution photography (image motion compensation required for optimum)
- Wide field-of-view spectrometers
- Differential spectrometers

b. Intermediate altitude (1 to 10 km)

- Radar backscatter cross-section measuring systems; L- and $K_u$-band needed as a minimum
- Microwave brightness temperatures; L- and $K_u$-bands needed as a minimum
- Thermal mapping system; 10.2 to 12.5 μm preferred
- Microwave brightness temperature images
- Radar images of the ocean surface
- Multispectral photography matched to SKYLAB S-190 photography
- Profiling spectrometers with variable angle of incidence preferred
- Multichannel scanner to match S-192 channels

c. High altitude (above 15 km)

- Multispectral photography
- Imaging spectrometer system
- Profiling spectrometers with variable angle of incidence preferred
- Thermal mapping system; 10.2 to 12.5 μm preferred.

## C. Conventional Oceanographic Data

Remote sensors in the visible region will obtain data from, at most, the upper 100 m of the ocean. All others will penetrate less. Infrared sensors penetrate the ocean surface by only tens of micrometers, while microwave sensors on SKYLAB will penetrate a few centimeters into the water mass.

Direct detection of the deep scattering layer by remote sensors will not be possible in most cases. However, it is recommended that conventional forms of ocean data be collected at least to this depth; or, as a minimum, the mixed layer depth be determined. The surface measurement program is divided into general ocean disciplines, beginning at the sea-air interface.

1. Atmospheric and meteorological measurements

   a. Radiosondes--temperature in the air column

   b. Wind velocity at three elevations including near-surface levels and 19.5 m

   c. Surface air temperature

   d. Surface air humidity

   e. Aerosols and particulates

   f. Fetch and duration of wind

2. Surface features

   a. Temperature

   b. Wave height and wave history

   c. Chemistry (oil slick, pH, etc.)

   d. Salinity

   e. Ship traffic

   f. Quantitative precipitation data

3. Physical parameters in the water column to the deep scattering layer

   a. Temperature

   b. Salinity

   c. Light attenuation as function of wavelength

   d. Light scattering as function of wavelength

e. Particle size and distribution

f. Index of refraction

g. Entrapped air bubbles

4. Biological components in the water column to the deep scattering layer

a. Phytoplankton

(1) Chlorophyll

(2) Taxonomy

b. Zooplankton

(1) Concentration

(2) Taxonomy

## III. TEST AREAS

### A. Coastal Regions and Fixed Geographical Locations

Separate test areas were considered for these experiments: those that must be fixed because of their unique properties, and those that can be located to accommodate the orbital characteristics of SKYLAB. The fixed regions that should be instrumented and studied are defined in terms of primary locations. The data desired are shown in terms of the instrument aboard SKYLAB.

1. Primary Locations

• Puerto Rican Trench (S-190, S-193 altimeter) 18°N to 21°N, 64°W to 68°W

• Canary Current upwelling (all sensors), west coast of Morocco from 28°N to 36°N, approximately from the Canary Islands to the Straits of Gibraltar

• U.S. east coast (all sensors) 32°N to 38°N, extending eastward at least to the Gulf Stream and including the Gulf Stream along the Carolina coast

• Mississippi Delta and Mississippi Sound (S-190, S-191, and S-192) 28°N to 31°N, 88°W to 92°W

•U.S. west coast (all sensors) 32°N to 38°N, displacement to the west variable

•Cape Cod (S-190, S-191, and S-192) 41°38'39"N to 42°03'45"N, 69°57'38"W to 70°14'45"W

•Key West (S-190, S-191, and S-192) 24°27'10"N to 24°39'00"N, 81°43'45"W to 81°52'45"W

## B. Open Ocean Locations

Ocean Station Vessels (OSV) are the only systematically deployed ships available to provide ocean environment data. Their locations (lettered) and tracks (numbered) in the Atlantic and the Pacific are shown in figure C6. While these vessels are not equipped with all the necessary surface instruments, they are platforms which can support the SKYLAB ocean studies. Appendix D gives schedules of NOAA ships for FY74.

### 1. The Atlantic

Figures 1, 2, 3, and 4 show that multiple SKYLAB flights over the area are possible. In general, the ground tracks across the Atlantic, especially over the coastal areas, are orthogonal to the SW-NE coastal orientation of the region for the descending node and parallel to this SW-NE orientation for the ascending node. The microwave sensors will not require sunlight for operation, but sun conditions are a major consideration for determining when the EREP sensors are earth oriented.

Because the ground track moves about 60 n mi (1.05°) to the west every 71 revolutions (5 days), SKYLAB should, ideally, collect microwave data in the Atlantic area on a 5-day cycle if at all possible during descending node and on an opportunity[7] basis during ascending node. The 5-day cycle will permit surface vessels to reorient and collect surface data at points displaced 60 n mi every 5 days. The impact of this 5-day cycle on SKYLAB cannot be assessed. Data will not be required for each of the three SKYLAB visitations. The SKYLAB-4 exercise in the fall of 1973 is the best period for these observations.

On the descending and ascending nodes, when lighting is satisfactory, data should be collected by S-190, S-191, and S-192. Otherwise, only S-193 and

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[7]Opportunity means that no planned coverage has been requested but the overflight orbit will be known well in advance, to prepare for surface support.

S-194 should be used. Surface platforms to support this operation are discussed in section IV.

2. The Pacific

Data from the open ocean in the Pacific should be collected on an opportunity basis so that there is minimum impact on the remainder of the SKYLAB mission. Data are requested only when sun conditions permit use of the S-190, S-191, and S-192 instruments in conjunction with those of S-193 and S-194.

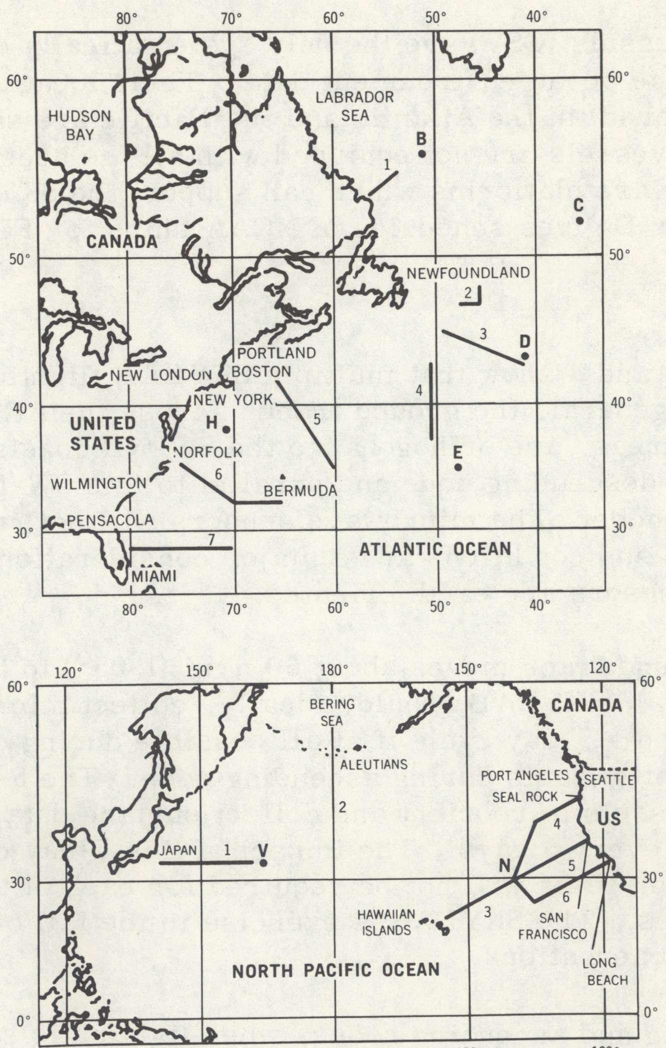


Figure C6. --Ocean station vessel (OSV) locations and tracks for standard monitoring sections.

3. Gulf of Mexico

The tentative locations for the National Data Buoy Program (NDBP) Engineering Experimental Phase (EEP) for the environmental reporting buoys in the Gulf of Mexico are listed below.

Station 1 - $27^{\circ}30'$N, $86^{\circ}30'$W
Station 2 - $25^{\circ}30'$N, $89^{\circ}30'$W
Station 3 - $25^{\circ}30'$N, $87^{\circ}00'$W
Station 4 - $25^{\circ}00'$N, $84^{\circ}30'$W
Station 5 - $24^{\circ}00'$N, $89^{\circ}00'$W
Station 6 - $26^{\circ}00'$N, $94^{\circ}00'$W

These coordinates should be considered in any mission over the Gulf. Data should be collected at these locations by all five SKYLAB sensors.

## IV. SUPPORT PLATFORMS AND EXPERIMENT DESIGN

### A. Relation Between Platforms And Experiment Design

A difficult problem in ocean studies is the simultaneous assessment of spatial and temporal change in the ocean. Surface vessels sample at points in the vertical column and, by station-keeping, can monitor temporal changes in the column. The vessel cannot move to a second station to collect spatial data and maintain continuity in temporal change. Two vessels are required. The situation becomes more complicated as the area is increased.

Remote sensors can be used to add to and extend the conventional coverage. Addition is accomplished by separating temporal from spatial change. Extension is accomplished by providing synoptic coverage, which, from satellite altitudes, can be global with the proper orbit and choice of swath width. Aircraft can provide high-speed surveys in more localized environments, for example, over areas between ships at sea, and over coastal and estuarine areas, etc.

The satellite approach cannot provide precise data on the water column, only an integrated assessment of, at most, the upper hundred meters. The use of ocean color has already been discussed (sections I.A.2 and I.C.2). Aircraft can provide a link between the ship and satellite systems because aircraft can add certain in situ capability to remote sensing. An example is the combining of remotely sensed sea surface temperature surveys with measurements of the vertical temperature structure by bathythermographs.

## B. Surface Support

### 1. Ships

Ship support can be provided from dedicated, semi-dedicated, and opportunity vessels. Since experiments to be conducted from SKYLAB are for purposes of research, it is believed important that all data be collected by experienced investigators. It is desirable to have as large a data base as possible, so a ship-of-opportunity program should be used. But observations by ships of opportunity and observations by experienced personnel will not necessarily be compatible.

Instrumentation available for ocean measurements on ships of opportunity most likely will be limited to sea surface temperature measurements. Some vessels may carry sufficient equipment to measure salinity. In no case should the measurements interfere with normal ship operations, so this limits the measurements to surface features. Because data used for ocean truth for SKYLAB will involve more than temperature, we do not recommend a ship-of-opportunity program over and above the current program.

a. Semidedicated Ships - Three general types of ship support are available on a semidedicated basis. These are the (1) ocean station vessels (OSV), (2) ocean research vessels, and (3) the ships used for launch, track, and reentry of the SKYLAB components.

(1) Ocean Station Vessels. The OSVs are dedicated to meteorological measurements and are under the control of the U. S. Coast Guard. However, the station-keeping requirement makes them attractive for oceanographic instrumentation platforms. In particular, stations E and H shown in figure C6 in the Atlantic and station N in the Pacific appear suited for SKYLAB support. Ideally, the equipment to be stationed at E, H, and N should include all measurement capabilities discussed in section I. C except a capability for measuring acoustical properties.

Neither the flexibility nor the sequence of the ship tracks shown in figure C6 have been assessed. If the tracks can be sequenced to the SKYLAB orbit and EREP data-collection periods, and if the ships' tracks can be interrupted for station-keeping during the actual SKYLAB overflight, the vessels involved should be seriously considered for further instrumentation for ocean measurements.

(2) Ocean Research Vessels. These ships are dedicated to ocean studies, but not in the systematic manner in which the OSV operate for meteorology. Essentially, these research ships conduct independent ocean research for many investigators.

The necessary synoptic data base can be obtained from these ships if a cooperative program is developed to maximize the deployment of the vessels during the SKYLAB mission periods, if the EREP data-collection ground tracks are specified well in advance for the ocean community to incorporate into its plans, and if the majority of the research vessel instruments can be utilized in a station-keeping mode during the days of overflight.

The ocean research ship program should stand alone as an experiment in temporal and spatial variation of ocean features. This program should include studies to depths that include the deepest extreme of the deep scattering layer. Both time and location of measurements should be carefully documented. A central point for collection of data should be the National Oceanographic Data Center (NODC) of NOAA. This would allow maximum dissemination of all data.

The interference of the SKYLAB EREP studies with the ongoing research activities of the ocean community should be held to a minimum. Yet there does appear to be a need to establish a review of the deployment schedules, sequence, and proposed locations of research activities by ocean vessels during 1973. For example, the review criteria would emphasize cruises south of 50°N, would consider the coastal region needs, and would attempt to prevent data holidays and provide uniform coverage in the areas of the western North Atlantic, Gulf of Mexico, and eastern North Pacific.

(3) Launch, Track, and Reentry Ships. Recovery ships are to be deployed to either the Atlantic or the Pacific about 1 to 2 weeks prior to reentry of each SKYLAB mission. An aircraft carrier will be the primary recovery platform. Because of the limited time on station, and because of instrumentation problems, surface support by these ships is not recommended.

## 2. Aircraft

Most oceanographic remote sensing experiments have been conducted from aircraft platforms; these aircraft will form the nucleus for remote sensor surface support for SKYLAB. The Navy has operated aircraft at low altitudes near the ocean surface to maintain near all-weather capability. Navy aircraft with microwave instrumentation operate to intermediate altitudes with instruments designed for multiple applications including oceanography. Each operational altitude will be used to acquire the ocean truth needed for SKYLAB EREP support.

Navigation is a major problem in operating aircraft over the open ocean. Few aircraft now have the navigational accuracy required for SKYLAB support. Small-scale fluctuations will be recorded along preplanned routes. It is not critical to the experiment that these flight tracks be flown with great precision, but it is critical that the location of the aircraft during data acquisition be known. Location information is least critical for microwave studies. Thermal and ocean color studies will require that flight tracks be located with an accuracy of about 1 n mi.

The general capability of U.S. Navy and NASA aircraft platforms are discussed separately. A special Air Force aircraft from the Cambridge Research Center also is discussed. We recommend that low-altitude (<300m) support platforms be provided by the Navy and that high-altitude (>10Km) support platforms be provided by NASA. Intermediate-altitude support platforms possibly will be provided by the Navy, NOAA, and NASA.

a. Navy Aircraft - Low-altitude thermal surveys of major ocean features such as the Gulf Stream are conducted systematically for Navy operations. C-121 aircraft are now used but are being replaced by P-3Cs as funding permits. We recommend at least one and preferably two of these aircraft for SKYLAB EREP support during each mission. In addition to the thermal measurements, we propose that both a filter wheel spectrometer and a differential spectrometer be added to the aircraft platforms for making calibrated ocean color measurements to support S-191 and S-192 measurements. The filter wheel spectrometers are obtainable from NASA/GSFC and would require only a modification in the field of view for low-altitude flight.[8] The differential spectrometer being developed specifically for chlorophyll measurements at low altitude may be obtained from NASA/ARC.

Unique capabilities have been developed by the Navy for profiling of ocean surface roughness. An S-band radar system and a helium-neon laser system have been developed by the Naval Oceanographic Office; both are needed for support for S-193 and S-194 measurements. Low-altitude operation is required for these sensors to perform optimally.

Navy active microwave (radar) instrumentation suitable for ocean studies has been flown primarily on the NRL C-121. The four-frequency (4-FR) system has made a significant number of ocean surface backscattering measurements at intermediate altitudes. This system will form the basis for calibrated radar data for SKYLAB EREP studies. However, the 13.7-GHz frequency ($K_u$-band) of S-193 is not currently available aboard the 4-FR C-121 aircraft.

The feasibility of measuring the short-pulse (impulse) response of the ocean at nadir can best be made from satellite altitudes. Although the response to this active sensor is not known, it is important to augment

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[8] This type of instrument has already been flown on C-121 aircraft.

the altimeter studies of S-193 with the existing 1-nsec NRL pulse radar system. This augmentation will provide a measure of performance of the S-193 altimeter. A cooperative program to use this system for GEOS-C development currently exists between NRL and NASA/Wallops. The Wallops C-54 may be capable of such measurements in the area of the Puerto Rican Trench.

b. NASA Aircraft - Aircraft from the NASA Manned Spacecraft Center (MSC), Wallops Station, and Ames Research Center can provide considerable support for ocean measurements. Most of these aircraft will provide underflights of SKYLAB EREP missions on request.

The prime capability for aircraft support is available from NASA MSC. An NP-3A, an NC-130B, and an RB-57F are currently used in the Earth Resources Aircraft Program. The NP-3A will carry essentially an all-microwave payload at the time of SKYLAB EREP; this includes a Multi-frequency Microwave Radiometer (MFMR, L-band to $K_a$-band) capable of scanning from nadir to $170^{\circ}$ from nadir, an X-band Passive Microwave Imaging System (PMIS), and a scatterometer system that operates in the $K_u$-band (13.3 GHz). Both the MFMR and the scatterometer have been plagued with instrument problems, but these instruments are expected to be ready for use for SKYLAB. Other NP-3A sensors significant for ocean support use include several camera systems, a laser profiler similar to that developed for the Navy, a dual-channel RS-14 IR scanner, and ancillary instruments to measure dewpoint, total air temperature, thermal radiation, and liquid water content. A 16.5-GHz side-looking array radar (SLAR) is also aboard the NP-3A, but the manner in which it might support the SKYLAB mission has not been assessed. Of great importance to the ocean studies is the excellent navigation capability of the aircraft, which includes an LTN-51 inertial navigation system. The NP-3A aircraft will be used primarily at intermediate altitudes.

The NC-130B instrumentation is dedicated to multispectral studies of the earth's terrain. While the aircraft will have an excellent multispectral scanner system (MSS) to support the S-192 instrument on SKYLAB, it is the NASA/MSC aircraft least suited for ocean studies. It is recommended that this aircraft be used only for coastal oceanography studies on an opportunity basis, i.e., only when the aircraft is scheduled to fly over terrain sites that include coastal features.

The RB-57F will carry the first sensor designed specifically for ocean color measurement. This instrument, the Scanning Imaging Spectroradiometer (SIS), will be an excellent sensor to support the S-190, S-191, and S-192 SKYLAB instruments. It is recommended that support of this aircraft be requested for all experiments related to ocean color. In addition to the SIS system, cameras and an RS-7 IR scanner are available for high-altitude measurements. Normal flight altitude for this aircraft is about 20 km, or above most of the mass of the atmosphere.

The NASA Ames Research Center has a Convair 990 instrumented for several classes of observations, including those related to astronomy, atmospheric measurements, and earth resources. The aircraft can be instrumented with several classes of spectrometers and can be flown at low, intermediate, and high altitudes in support of ocean color measurements. The platform appears especially suited to measurements needed for the CINECA experiment in the Canary Current upwelling. We recommend that this aircraft be requested for use during July-August 1973 in connection with the CINECA studies.

The C-54 flown by NASA Wallops Station might support altimetry studies in the Puerto Rican Trench area. The aircraft has limited range for significant ocean applications. Navigation to support the S-193 altimetry measurements is not believed a critical issue. We recommend that this aircraft equipped with a Navy altimeter be used in the vicinity of Puerto Rico during the SKYLAB mission period.

## Appendix D

## NOAA SHIP ALLOCATION PLAN FY74

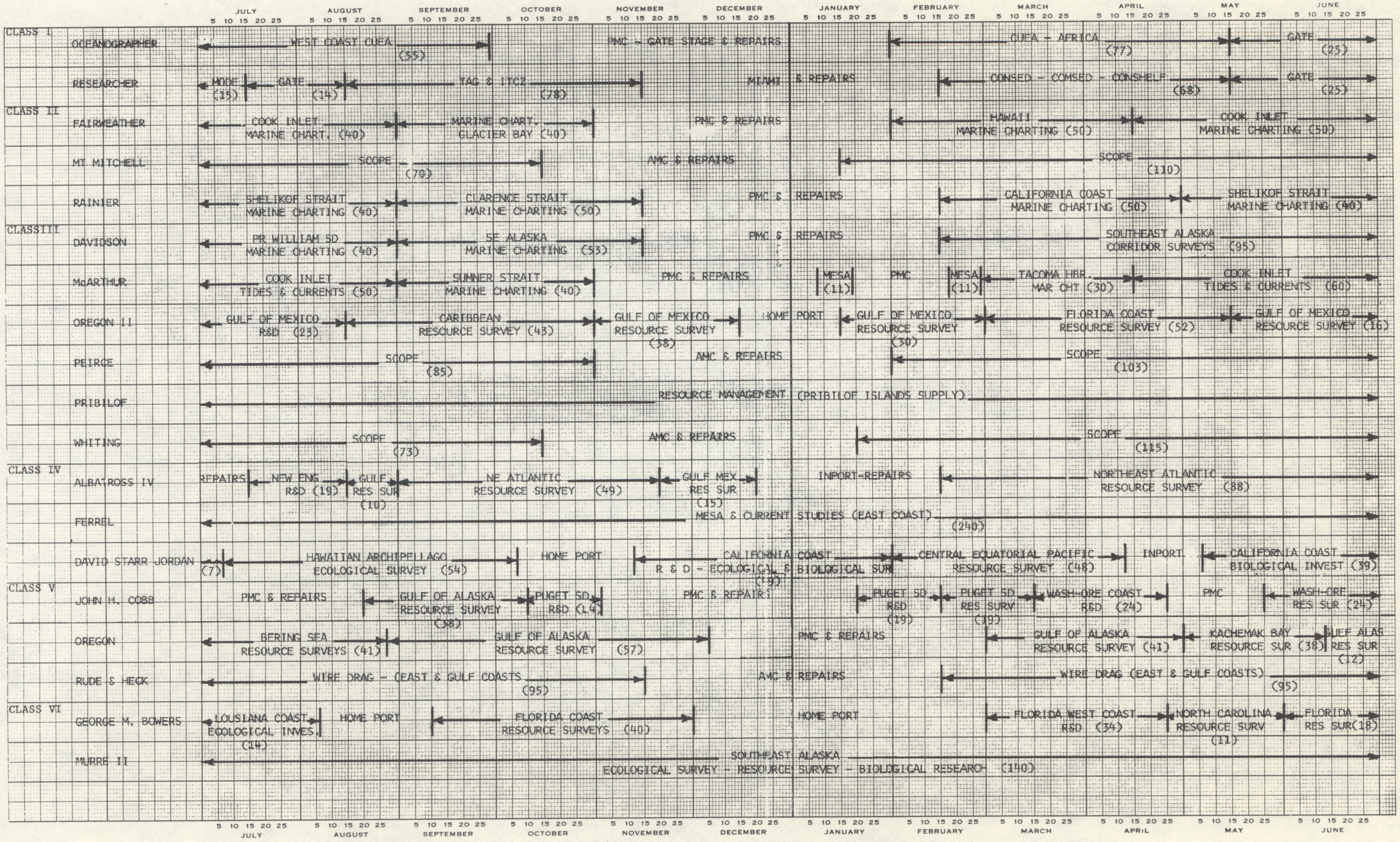
(July 1973 through June 1974)

The following page shows the locations and missions of various NOAA ships during the SKYLAB (SL-2, SL-3, SL-4) experimental periods.

Approved: [signature] Chairman, NOAA FAC

## NOAA SHIP ALLOCATION PLAN FY 74

REVISED 3-15-73



Appendix E

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