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INTRODUCTION

It is generally recognized that the first experimental and operational satellites were designed to monitor weather phenomena and provide data of value to the meteorologist for both short and long time forecasting. As sensors were improved, new instrumentation and techniques for presentation and manipulation of data were developed and acceptance and utilization by both meteorologists and other members of the scientific community has expanded. The amount of information useful to the oceanographer and to the fisheries scientist in particular, has also expanded to the extent that a few quasi-operational programs directly related to fisheries research are in progress. This report briefly describes in general terms, these programs.

The operational and research and development satellites and their sensors presently in service and used by the aforementional programs, have been completely described in several publications. However, for convenience, a brief description of these platforms and the data they provide is included as Appendix A, together with a brief glossary of acronyms. In addition, this report briefly describes the two satellites presently scheduled for launch in 1978. The advent of these platforms specifically instrumented to monitor oceanographic parameters will provide data of considerable value to the fishery scientist.

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On-going programs directly related to fisheries cited here actually fall into the realm of research and there is no routine operational fisheries program singularly based upon satellite derived data. The several programs which make significant use of routinely received satellite data include:

(1) The National Marine Fisheries Service's Southeast Fisheries Center's LANDSAT Follow-on Experiment. This is a 22-month study initiated in April 1975. It is being conducted cooperatively by U. S. Federal and State Government Agencies and private industry to demonstrate the feasibility of using satellite data for improving the management and utilization of coastal fishery resources in the northern Gulf of Mexico. Menhaden (Brevoortia patronus) and thread herring (Opisthonema oglinum) were selected as target species in areas located in Mississippi Sound and off the coast of Louisiana. Correlations are being sought between the fishery resources and oceanographic parameters measurable from aerospace platforms. Synoptic ground truth data are being obtained from oceanographic and fishing vessels, offshore oil platforms, and fishery (spotter) aircraft for correlation with the data obtained from aircraft and satellites. The investigation is expected to produce new information on coastal water ecology, provide techniques for converting remotely acquired data into measurements of oceanographic parameters, identify satellite techniques for minimizing the search time required for commercial harvest and assessment of coastal fishery resources, and define requirements for future satellites. A description of the on-going investigation is available in the form of SEFC Contribution No. 414 (MARMAP Contribution No. 98) prepared for Goddard Space Flight Center (Kemmerer 1975). The satellite sensed information which the initial ERTS-1 (now LANDSAT-1) (Kemmerer et al 1974) seemed to correlate significantly with Menhaden distribution was water clarity or

transmissibility. Menhaden schools observed photographically seemed to be most abundant in more turbid waters. The LANDSAT 4 channel (Band 5 0.6-0.7μ in particular) permits considerable differentiation of water mass by color and/or turbidity. In the first experiment, higher chlorophyll (in situ measurement) was also coincidental with areas of menhaden abundance. The present follow-on study will attempt to differentiate between waters of high turbidity (silt load) and chlorophyll-a.

This LANDSAT program qualifies as quasi-operational only by virtue of the fact that it looks at predetermined parameters on a scheduled basis for correlation with coordinated surface truth data supplemented by additional satellite information as available from NOAA operational satellites (GOES and NOAA-3 and -4).

(2) Data routinely provided by the National Environmental Satellite Service are being used by the National Marine Fisheries Service (NMFS) Atlantic Environmental Group (AEG) to study variations in the shelf water front off the Atlantic coast and to correlate the effects of these variations upon the fish stocks of the study area. The nature of this study is best described by the following excerpt from a draft manuscript by Dr. Merton C. Ingham, Director of the Atlantic Environmental Group (Ingham 1975).

"Using charts of sea surface temperature fronts prepared by the National Environmental Satellite Service (NESS) and collaborative data from ship-of-opportunity XBT drops, scientists of the Atlantic Environmental Group (AEG) are working to monitor and analyze the position of the Shelf Water front as an aid to determining the relationship between this feature and pelagic and demersal fishery stocks over the continental shelf and slope.

"The variation in the location of the Shelf Water front is certain to have a short-term effect on the distribution and may have a longer-term effect on the abundance of resource species. The convergence zone which is associated with any persistent surface front acts to accumulate living and non-living particulate materials in the surface layer, which in turn will attract food chain organisms, including pelagic climax predators such as tunas, swordfish, and sharks. Fishermen in search of these species may find information concerning the front's whereabouts quite useful in developing more efficient fishing strategy.

"With the knowledge that the front may extend to the bottom over the continental shelf, as revealed by XBT transects, we anticipate that the variation of the front's position should influence the distribution of epibenthic organisms also. Once again, knowledge of the front's position could be useful in the strategy employed in harvesting demersal species.

"In addition to contributing to the development of more efficient harvest strategies, knowledge of the variation of the position of the Shelf Water front can help explain changes in water mass characteristics in spawning and nursery areas and the consequent variations in recruitment and year-class strength. Satellite surveillance of the front's position and configuration during critical periods in the early life history of resource species could provide information useful in making predictions of their year-class strengths.

"The interface between the cool, low-salinity Shelf Water mass and the warmer, higher salinity Slope Water mass, or occasionally with the still warmer and more saline Gulf Stream water, off the Atlantic Coast of the United States frequently is expressed at the sea surface as a thermal front.

The front can be observed by satellite-borne infra-red radiometers, clouds permitting, and the National Environmental Satellite Service of NOAA has been plotting the position of this front on charts made available to the public at about weekly intervals since June 1973 (example fig. 1). The observations are made by a very High Resolution Radiometer on the NOAA II (recently NOAA IV) Satellite, which senses radiation in the 10.5-12.5μ m range and has a resolution of about 1 km at nadir. The charts of the coastline and oceanic thermal features are drawn either from the best image of the week or a composite of several. The completed charts are sent to a mailing list of users and transmitted by facsimile to National Weather Service stations in the Atlantic coastal area."

In addition the AEG is using satellite data together with ground truth (XBT) information to follow the rather persistent eddies often as much as 8°C warmer than shelf waters which are cut off from the Gulf Stream but continue to move along the Atlantic coast. These eddies may affect not only pelagic but demersal species as well since they have been found to affect waters of the shelf from the surface to the bottom.

(3) Drs. Merrit R. Stevenson and Forrest R. Miller of the Inter-American Tropical Tuna Commission (IATTC) have, for several years, utilized remote sensing data from the experimental (NIMBUS, LANDSAT) and operational (NOAA series) satellites. Much of this work was done under contract to the Spacecraft Oceanography (SPOC) Group of the National Environmental Satellite Service (NESS) (Stevenson and Miller, 1972, 73, 74, 75). These two scientists have made many contributions to the processing, analysis, and presentation of satellite data relative to improving its accuracy and applicability for measuring sea surface temperature (SST) and describing the disposition of thermal fronts and upwelling. The primary purpose of their

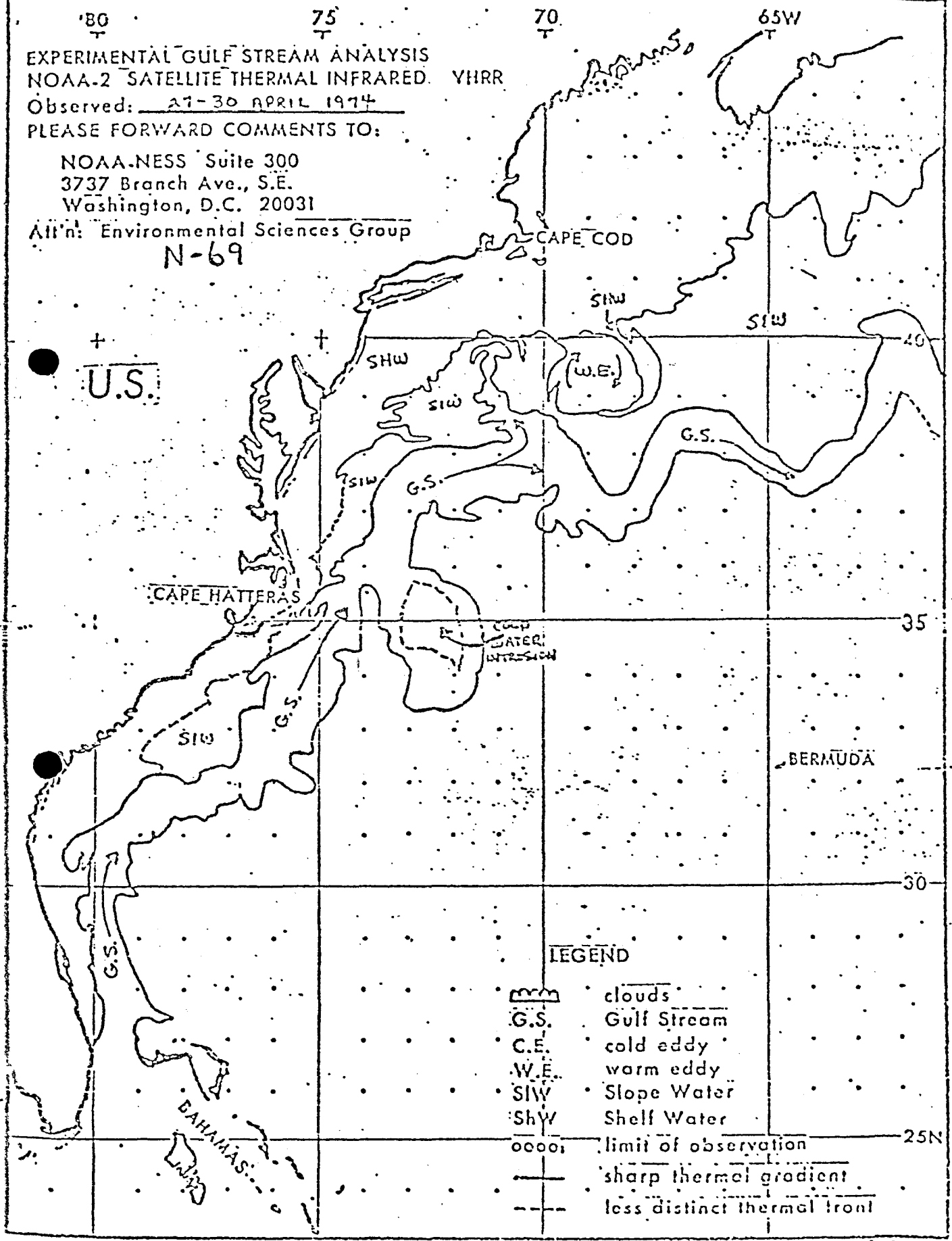

Figure 1. Example of weekly frontal analysis chart produced by the National Environmental Satellite Service of NOAA.

investigations has always hinged upon the desire to understand, map and predict SST relative to organic production and the assessment and prediction of the maximum sustainable yield (MSY) of pelagic species, specifically the tunas.

Initial studies in the 1970-72 time frame were concerned with temperature data applications to fishery oceanography. Satellite data included NIMBUS-4 THIR and NOAA-1 HRIR for the eastern tropical Pacific. The relationship between thermal fronts and tuna distribution were instrumental in the desire of IATTC to incorporate remote sensing in their studies and improve synoptic coverage for assessment and conservation of tuna stocks. Atmospheric attenuation problems were early recognized by workers seeking to obtain more accurate remotely sensed SST and Stevenson and Miller have made significant contributions to processing, analysis and data programming techniques to correct for attenuation differences. This continued effort to improve the quality and usefulness of output products are an important facet of their research efforts.

IATTC research efforts have continued from 1973 through the present to utilize data provided by NESS from the NOAA satellites and from specially acquired LANDSAT imagery. Some results of these studies have led to cooperative efforts with the NMFS Southwest Fisheries Center and with the Environmental Prediction Research Facility at Monterey, California to incorporate direct reading infra red (DRIR) data with the NESS supplied GOSSTCOMP experimental sea surface temperature plots (or contoured maps). The combination of DRIR data, in situ (BT-XBT) temperatures and improved accuracy and large scale detail shown on the NESS product has been used to enhance the details in upwelling and frontal areas off the west coast of the United States and Baja California, Mexico.

Considerable work has been done with respect to studying cloud top temperatures of low stratus which characteristically mask the nearshore ocean surface in areas where upwelling occurs adjacent to strongly heated land. Temperature of low stratus cloud tops as measured by SR systems aboard NOAA satellites have been found to demonstrate linear relationships from which SST below the cloud deck could be estimated.

Most recent work by Stevenson and Miller, reported in 1975, concerns the correction of VHRRIR data to within 1°C of ground truth. This improved resolution provided more significant data from which the first signs of upwelling were detectable off the Spanish Seaboard coast.

This continuing program is presently using VHR data (corrected) to monitor surface thermal fronts, particularly the Equatorial Current off Peru and Ecquador to archive and analyze data for both El Nino and non-El Nino years. In addition, LANDSAT MSS data together with NOAA VHRR and VHISSR data are being examined to determine the ability to recognize chlorophyll and suspended particulates and study their relationships to temperature and fish abundance.

Stevenson, recognizing the problems of trying to relate data which varies spacially and temporally, is endeavoring to develop methods for integrating this data to provide a product useful for the location, delineation and tracking of areas of high biological productivity.

(4) While the aforementioned programs are cited as major "routine" users of satellite data for fisheries other programs routinely acquire and utilize satellite data and should be briefly considered:

(a) The Marine Advisory Service (MAS) office at Humboldt State College at Arcata, California, is experimenting with routinely supplied (once or twice per week) NESS, SFSS imagery to project a temperature front onto a chart which is in turn provided salmon and albacore fishermen. This

product has been generally well received by the fishermen who report that it decreases search time and saves fuel.

(b) The NMFS NEFC utilizes satellite data from NESS VHRR and VHRIR as well as the Gulf Stream Reports to study the effects of Gulf Stream excursions and eddies upon the Georges Bank fishery. This information is used to plan research cruises conducted by vessels from that center.

(c) The NMFS NWFC uses NESS supplied remote sensing information concerning ice conditions in the Bering sea regions to plan cruises and on a real-time basis to modify cruises in progress. This center also supplements its in situ studies of upwelling conditions along the north Pacific coast of the U. S. with satellite data when continuity of imagery (as governed by cloud cover) permits.

(d) The NMFS SWFC is using remotely sensed SST data to study mid-ocean effects of temperature fronts upon Albacore migrations.

The SWFC also broadcasts two facsimile charts on a regular basis to the fishing fleet. One of these is weather oriented and received from the NWS at Redwood City, California and provides wave height, wind speed and direction and, by cloud distribution, indicates the location of the inter-tropical convergence zone.

The second facsimile broadcast is made up at SWFC from NWS reports, SST data relayed from fishing vessels at sea and subsurface temperature data from the Fleet Weather Center at Monterey, California. This provides the fishermen with both SST and layer depth information.

(5) While not in the realm of remote sensing from the satellite itself, a very important phase of satellite technology lies in the field of communications. Several satellites have the capability of relaying surface measurements from ships and barges to shore stations in real or mean real-time. In instances where very remote surface stations are queried, the satellites may store the data to dump at a later time when in closer proximity to the home station.

As stated in the Introduction, it is not the intent of this report to discuss the possible future application of satellite remotely sensed data to fisheries, but to address those programs that utilize presently available information. With respect, however, to the possibilities for satellite utilization, Joseph and Stevenson 1974 provide an excellent summary and discussion of the potential application of remote sensory research and commercial fisheries.

A second publication presently in a preliminary draft status but due for final edition publication in early 1976, is the Fisheries Remote Sensing Manual assembled for the NMFS Remote Sensing Working Group which is made up of one or more representatives of each of the NMFS Centers. The manual is intended to assist the fisheries investigator in selecting a remote sensing technique for detection and/or measurement of oceanographic parameters related to biological phenomena.

Two ocean-oriented satellites are planned for launch in 1978, both of these are specifically instrumented to look at oceanographic parameters:

SEASAT-A is the first ocean dynamics satellite. Its planned 108° circular orbit will be at a height of about 800 kilometers, the interval of repetitive coverage varying from about 36 hours for the wide scan radiometers to 72 days for the narrow footprint altimeter.

The planned suite of instruments and their main mission measurements are a radar altimeter for wave height and sea surface topography (for currents, tides, storm surges, geoid); imagery radar for wave directional spectra, ice fields and fine coastal structure; scatterometer for surface wind speed and direction; and the visible and infrared radiometer with the imagery radar for current patterns.

It is readily seen that none of the above measurements are fishery oriented but sea state, ice conditions, current movements, all influence fishing conditions (storm warning) and contribute environmental data of value as a supplement to data from other sources for productivity forecasts.

NIMBUS G, while having the same orbital characteristics of its predecessors, will include a Coastal Zone Color Scanner (CZCS) designed to measure ocean color in narrow spectral regions for the purpose of assessing water mass characteristics and chlorophyll content. The planned spectral regions for the scanner are .443 micrometers (chlorophyll absorbtion), .520 micrometers (chlorophyll correlation), .550 micrometers, .670 micrometers (chlorophyll absorbtion), .750 micrometers (surface vegetation), and 11.5 micrometers (surface temperature).

The Scanning-Multi-Channel Microwave Radiometer (SMMR) planned for this platform will include frequencies of 37, 22, 18 and 10.7 gigahertz to measure ocean features and map sea ice.

In addition to the possibilities of determining chlorophyll concentration and distribution, water color can provide information concerning sediment content, plankton, nutrients and pollutants. This information will be available daily for a near real-time tracking of color identified water masses.

APPENDIX A.

Satellites Currently in Service and Utilized in on-going Fisheries Programs

Operational Satellites

NOAA-3 and -4 - These satellites are in sun-synchronous near polar orbits at a nominal altitude of 1500 km with equator crossings at about 9:00 pm (descending node) and 9:00 pm (ascending node) local sun time. The instrument package contains four primary environmental sensors:

(1) A two-channel Scanning Radiometer (SR) which obtains imagery in the visible (0.5 to 0.7 micrometer) and infrared (10.5 to 12.5 micrometers) portions of the spectrum giving both day and night coverage of the earth. The instrument scans continuously line-by-line from horizon-to-horizon across the orbital track of the satellite. The nominal ground resolution at nadir is about 5 km for the visible and 8 km for the ingrared. Under favorable conditions the absolute thermal accuracy of the SR infrared temperature data is about 2°C.

(2) Very High Resolution Radiometer (VHRR) - This scanner operates like the SR with the same two spectral intervals with a resolution of 1 km in both channels. Although a small portion of global coverage (about 8 minutes on each orbit) can be programmed for storage on the satellite, most of the data are obtained by direct readout at three NOAA stations: Gilmore Creek, Alaska; San Francisco, California; and Wallops Station, Virginia. A number of other countries have installed reception stations also. The thermal data obtained by the IR portion of the VHRR is accurate to about 1.5°C under favorable conditions.

(3) Vertical Temperature Profile Radiometer (VTPR) - This instrument is designed to obtain measurements of the vertical temperature structure

of the atmosphere. Energy will be measured at 6 discreet, narrow intervals in the 15 micrometer (μm) CO_2 region, at an interval in the 11 μm window and at an interval in the 18 μm water vapor retion. Measurements from the 8 channels of the VTRR will be used to compute temperature profiles from the earth's surface to 100,000 feet (30,480 m).

(4) A Solar Proton Monitor designed to detect and count the proton and electron fluxes encountered during orbit.

Geostationary Operational Environmental Satellites (GOES-1 and -2) - These satellites are at geostationary altitude (approximately 36,000 km) spinning in an axis nearly parallel to the earth's spin axis. GOES-1 and GOES-2 are presently stationed at 75°W longitude and 115°W longitude respectively. This gives complete and overlapping coverage of the entire U. S. and its surrounding waters.

Day and night views of the earth's oceans are obtained by the GOES Visible/Infrared Spin-Scan Radiometer (VISSR). As the satellite spins at 100 revolutions per minute, the VISSR's scanning mirror faces the earth for one-twentieth of each complete 360 degree rotation, scanning from west to east in eight identical visible channels and two redundant infrared channels. While the spacecraft completes its revolution the mirror moves to the next southward step, and scans again when it faces the earth. Within 18.2 minutes the radiometer accomplishes its 1821 scan steps required to provide a full globe image. The resulting visible images have a resolution of nearly 0.9 kilometers. Infrared images have an 8 km resolution. Picture transmissions are normally scheduled at half-hour intervals during about 22-1/2 hours of each day. Partial disc pictures at more frequent intervals may be scheduled to meet special requirements.

In addition to the remote sensing capabilities, the GOES platform carries a Data Collection System (DCS) which collects and relays data from

in situ platforms. Tests have been conducted using the DCS to relay oceanographic data from ships and moored buoys. Another GOES service, the Weather Facsimile (WEFAX) system permits the broadcasting of weather maps and satellite products to remote stations.

Data from the above mentioned operational satellites is distributed in real-time to meteorological, marine, and hydrologic users throughout the country. In addition to the raw data, enhanced images and analytical services are provided through NESS's Satellite Field Services Stations (SFSS) located in Washington, D. C.; Miami, Florida; Kansas City, Missouri; San Francisco, California; Honolulu, Hawaii; and by November in Anchorage, Alaska.

Fisheries related services are presently being provided through SFSS's in Washington, D. C.; Miami, Florida; and San Francisco, California (actually Redwood City, California). Other oceanographic data and products which may be relative to fishery studies are available in "real-time" and retrospectively. "Real-time" data are available in the form of film, magnetic tape or hard copy. Products include such items as: (a) Gulf Stream Analysis, and Weekly Arctic Ice Analysis produced once per week and distributed on facsimile circuits and by direct mail.

Description of other products is available in Catalog of Operational Satellite Products, NOAA Technical Memorandum, NESS 53, Washington, D. C., March 1974 and Central Processing and Analysis of Geostationary Satellite Data, NOAA Technical Memorandum NESS 64, Washington, D. C., March 1975.

Archived data from NOAA (ITOS) series satellites and from GOES are also available. From the NOAA series orbital swaths on 25 x 25 cm negatives, Northern Hemisphere visible and Northern Hemisphere daytime IR on one negative, Southern Hemisphere visible and Southern Hemisphere daytime

IR on one negative, Northern and Southern Hemisphere nighttime IR on one negative, and (2) Sea Surface Temperatures available in quantitative form on magnetic tape.

GOES-1 and -2 archived data includes: (1) Infrared pictures, for full disc with 8 km resolution on 25 x 25 cm negatives; (2) visible pictures for full disc with 4 km resolution on 25 x 25 cm negatives; (3) TV movie strips on 16 mm film negatives; (4) operational movie strips (Winds Section) on 16 mm film positives; and (5) wind vectors on magnetic tape. These wind vectors at about the 900 mb pressure level are derived by computer over ocean areas at 2-1/2° latitude-longitude intervals, using low level clouds as tracers. Currently, vectors are derived for 12Z, 18Z, and 00Z synoptic times, utilizing cloud motions for each 30-minute scan during the period three to one hours prior to synoptic time. The archive begins with the vectors for July 29, 1974. The data are available on 9-track magnetic tape (1600 bpi) and contain earth-located wind vectors over ocean areas with estimated temperature and pressure level of cloud tracers. About 570 vectors per satellite are produced daily.

Research and Development Satellites

Only two R&D satellites-LANDSAT (formerly ERTS) and the NIMBUS series are discussed here since they continue to provide data routinely incorporated in on-going fisheries programs.

LANDSAT-1, launched on July 23, 1972 and LANDSAT-2, launched on January 22, 1975 by NASA in a sun synchronous orbit with a 102 minute period and at an average altitude of 920 km. Of the three data acquisition systems on LANDSAT: (1) Multi-Spectral Scanner [MSS]; (2) Return Beam Vidicon [RBV]; and (3) Data Collection System [DCS], the first on MSS is the system providing data of value to fisheries investigations. The MSS is a line

scanning device which uses an oscillating mirror to continuously scan perpendicular to the spacecraft orbital track. At each mirror sweep, six adjacent lines are scanned simultaneously in each of four spectral bands; two in the visible green (0.5 to 0.6 and 0.6 to 0.7 micrometers) and two in the near infrared (0.7 to 0.8 and 0.8 to 1.1 micrometers). Resolution of 100 meters is obtained in all four channels. Image swaths are obtained routinely on all passes over North America and adjacent coastal waters.

MSS data are available on 70 mm negative film with image frames coverint 200 x 200 km on the earth. Frames from the 0.5-0.6 micrometer channel for one orbital pass are followed by the same sequence of frames from each of the other three channels.

NIMBUS series - This series of satellite operates in a sun synchronous orbit at about 1100 km altitude. The platform series has provided infrared imagery for mapping daily the SST and cloud cover day and night. This series gave the first look at surface thermal properties of the oceans and its Automatic Picture Transmission (APT) capability allowed anyone with an appropriate ground receiver to obtain satellite images.

Most recent modification of sensors on the NIMBUS series has been on numbers 5 and 6 which included experiments with the Electrically Scanning Microwave Radiometer (ESMR) designed to provide improved data on sea ice and precipitation over ocean areas even in the presence of clouds.

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GLOSSARY

AEG	Atlantic Environmental Group (U.S. NMFS, Narragansett, R.I.)
BT	Bathythermograph
ERTS	Earth Resources Technology Satellite
GOSSTCOMP	Global Operation Sea Surface Temperature Computation - (A statistical histogram method applied to compensate for a partial satellite view in the presence of clouds to derive additional data for global coverage, added to cloud-free satellite data to provide global operational sea surface temperature charts.)
IATTC	Inter-American Tropical Tuna Commission
LANDSAT-1	Formerly ERTS-1, 1st Earth Resources Technology Satellite - Terrestrially oriented satellite
LANDSAT-2	2nd launched Earth Resources Satellite
MARMAP	Marine Resources Assessment Program (of NMFS)
MSS	Multispectral Scanner
NEFC	U. S. NMFS Northeast Fisheries Center (Hqtrs. Woods Hole, Mass.)
NESS	U. S. National Environmental Satellite Service
NMFS	U. S. National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NOAA-1 thru 4	NOAA operational designation for NASA TIROS series
NWFC	NMFS Northwest Fisheries Center (Hqtrs. Seattle, Wash.)
NWS	National Weather Service
PEG	Pacific Environmental Group (U.S. NMFS, Monterey, Calif.)
SEFC	NMFS Southeast Fisheries Center (Hqtrs. Miami, Fla.)
SFSS	Satellite Field Service Station
SPOC	Spacecraft Oceanography (Group)
SR	Scanning Radiometer

SST	Sea Surface Temperature
SWFC	NMFS Southwest Fisheries Center (Hqtrs. La Jolla, Calif.)
THIR	Thermal Humidity Infrared Radiometer
TIROS	Television Infrared Observation Satellite (Satellite series designation from pre-launch through launch and test prior to acceptance by NESS when they became NOAA series; i.e., TIROS-B = NOAA-2).
VHRR	Very High Resolution Radiometer
VHRRIR	Very High Resolution Radiometer - Infrared
VHRRVIS	Very High Resolution Radiometer - Visable
VISSR	Visual and Infrared Spin Scan Radiometer
XBT	Expendable Bathythermograph