TECHNICAL REPORT

SATELLITES CAPABLE OF OCEANOGRAPHIC DATA ACQUISITION — A REVIEW

MAY 1969

U. S. NAVAL OCEANOGRAPHIC OFFICE
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ABSTRACT

Satellites currently capable of acquiring oceanographic data are limited to those which record information by infrared radiometry, by television or by photography. Although other methods of oceanographic data acquisition from space are possible, these are the only methods in present use.

The use of infrared radiometry to examine the sea's surface thermal structure has been limited to the Nimbus satellites. Cloud interference has hampered the utility of these data; however, a selective method of compositing several days' data has indicated that this difficulty is partially surmountable.

Black and white television pictures of the entire earth's surface have come from polar orbited Nimbus and ESSA satellites while color and black and white pictures of the entire earth disc have been received from geo-synchronous ATS satellites. These television pictures may be used to measure the extent of ice cover and to infer water structure from related cloud cover. ESSA satellite data have been enhanced further by computer treatment of the televised pictures.

Color photographs of selected ocean areas have been taken during Mercury, Gemini, and Apollo missions. These missions are inherently restricted and the oceanographic information gained is opportune temporally and geographically. Despite this, examination of spacecraft photographs has revealed abundant examples of surface water structure.

Future satellites, such as ITOS, promise refinements in existing techniques. Others undoubtedly will introduce new techniques. However, the oceanographic information from available satellite data has not been exhausted and, with imagination and care, may be further exploited.

by

PAUL E. LA VIOLETTI
and
SANDRA E. SEIM
Foreword

To look at an entire ocean at one time, to examine the atmosphere that covers it and the sun that heats it, or to measure the continents that restrict it -- these are but some of the things an orbiting spacecraft can do for oceanography now, and they are only the start.

T. K. TREADWELL
Captain, U.S. Navy
Commander
U.S. Naval Oceanographic Office
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Figure 1  Apollo 8, 24 December 1968

"The earth... is a grand oasis in the vastness of space"

Jim Lovell
SATIENTES CAPABLE OF OCEANOGRAPHIC DATA ACQUISITION --

A REVIEW

by

Paul E. LaViolette and Sandra E. Scim

1. Introduction

Our present knowledge of the oceans and their interaction with the air, the sun, and geographic surroundings is the cumulative result of thousands of measurements taken over more than a hundred years.

Today, with the aid of photographic and spectral sensors on spacecraft, synoptic oceanographic data may be obtained which are equivalent to a global network of ocean sensors. Oceanographers, normally tethered to slow-moving, weather-dependent ships, may now view all of the oceans during one day's travel of a polar orbiting satellite. Where clouds permit, ice fields are defined for the polar
explorer. At the Equator, cold currents are delineated by clouds over 8,000 miles of ocean in one television picture. The complex regions of strong thermal gradients, such as the Gulf Stream in the Atlantic, and the Kuroshio in the Pacific, are outlined by infrared sensors.

These views, however, have been limited initially by satellite weight limitation, cloud cover, sensor resolution, and orbit altitudes. Despite these limitations, oceanographers experienced in remote sensing are trying to capitalize on the advantages of satellites. First, they are refining present satellite sensors and exploring the use of new ones. Secondly, they are examining closely the satellite information now available, however gross, with the hope that they may infer physical relationships not immediately apparent. Finally, they are using satellites in conjunction with time-proven instruments on ships and buoys to improve data transmission and navigational accuracy.

Although future refinements in sensory instruments will provide better data for analysis, the information from present instruments will facilitate the development of new approaches and methods for an understanding of the oceans. It is with this hope in mind that this report is presented.
2. Possible Oceanographic Satellites and their Sensors

Until now, there has been no satellite which could be called an "oceanographic satellite." The oceanographic information which is available from satellites must be obtained from the data of satellite sensors whose primary function was not oceanography (Table 1)*. The method of data collection by these geo-sensors is limited to electromagnetic radiation. The oceanographic information directly obtainable in this manner is restricted to the immediate surface layers of the ocean, due to the limited transmission of electromagnetic waves in water. The broad synoptic knowledge of the surface provided by the satellites, however, can contribute much toward understanding the physical processes which occur at depth.

Table 1. Possible Oceanographic Satellites and their Sensors

<table>
<thead>
<tr>
<th>Satellite Type</th>
<th>Number Orbited (as of 31 Dec 1968)</th>
<th>Orbit</th>
<th>Sensor(s)</th>
</tr>
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<tbody>
<tr>
<td>Nimbus</td>
<td>2</td>
<td>Polar</td>
<td>Infrared, T.V.</td>
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<tr>
<td>ESSA</td>
<td>4</td>
<td>Polar</td>
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</tr>
<tr>
<td>ATS</td>
<td>3</td>
<td>Geo-Synchronous and equatorial</td>
<td>T.V.</td>
</tr>
<tr>
<td>Mercury, Gemini and Apollo</td>
<td>4, 10 and</td>
<td>Varied</td>
<td>Color Photography</td>
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* The various satellites carrying these sensors are a conglomerate with different orbits, launching dates, and investigative methods. To help alleviate this confusion, a list of these geo-satellites, their sensors, and pertinent related data is tabulated in Appendix A. A generic explanation of satellite names is given in Part II, Section 1.
The most promising remote sensing techniques that may be applied to the ocean are given in Table 2. Of the sensors listed, only three, the infrared radiometer/imager, and the television and photographic cameras, have been used on satellites. These three sensors, the satellites on which they have been used, and some of the methods with which they are being employed oceanographically, are discussed in the following sections.

Table 2. Remote Oceanographic Sensors

<table>
<thead>
<tr>
<th>Passive Sensors</th>
<th>Active Sensors</th>
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<tbody>
<tr>
<td>1. Infrared Radiometer/Imager*</td>
<td>1. Radar Imager</td>
</tr>
<tr>
<td>2. Television Camera*</td>
<td>2. Radar Scatterometer</td>
</tr>
<tr>
<td>3. Photographic Camera*</td>
<td>3. Laser Altimeter</td>
</tr>
<tr>
<td>4. Microwave Radiometer</td>
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</table>

* Have been or are being used aboard satellites
Figure 2 Characteristics of the electromagnetic spectrum significant in remote sensing
3. Infrared Radiometer/Imagery

Temperature information on the ocean's surface may be obtained by using infrared sensors to measure the water's equivalent blackbody temperature. To date, only the Nimbus satellites have provided infrared data with the detail necessary for oceanographic work. Two infrared sensors were used aboard these satellites.

The one most useful oceanographically was a scanning radiometer -- High Resolution Infrared Radiometer or HRIR -- operating in the 3.4 to 4.2 micron atmospheric "window" region. At zero nadir angle (i.e. directly below the satellite) the Nimbus 2 HRIR at an altitude of 1,100 km. (595 nm.) had a resolution of 9 km. (5 nm.)

![Diagram of atmospheric absorption from ground to top of atmosphere](image)

Figure 3    The Nimbus HRIR atmospheric "window"
The second infrared sensor -- Medium Resolution Infrared Radiometer, or MRIR -- was a five-channel scanning radiometer designed to measure electromagnetic radiation emitted and reflected in spectral bands from the earth and its atmosphere. (The range of one of the five channels of the MRIR actually extended slightly into the visible portion of the spectrum). A variety of information may be obtained from each of the channels as well as from a combination of channels (Table 3).

Table 3. The Five Channels of the Nimbus 2 MRIR

Channel 1 - 6.4 to 6.9 microns
Covers the 6.7 micron water vapor absorption band. Provides information on water vapor distribution in the upper troposphere and, in conjunction with other channels, provides relative humidities at these altitudes.

Channel 2 - 10 to 11 microns
Operates day and night in an atmospheric "window" to give measurements of surface or near-surface temperatures in clear sky areas. Also provides cloud cover and cloud height information.

Channel 3 - 14 to 16 microns
Centered about the strong absorption band of CO₂ at 15 microns, this channel measures radiation which emanates primarily from the stratosphere. Prime importance is to follow seasonal stratospheric temperature changes.

Channel 4 - 5 to 30 microns
Measures the emitted thermal infrared energy and, in conjunction with the reflected solar radiation channel, furnishes data on the heat budget of the planet.

Channel 5 - 0.2 to 4.0 microns
Covers more than 99% of the energy in the solar spectrum. Gives information on the intensity of reflected solar energy from the earth and its atmosphere.
As might be expected from the name, the MRIR's resolution was much coarser than that of the HRIR. For example, at an altitude of 1,100 km. (595 nm.), the 10 to 11 micron channel had a resolution of 55 km. (30 nm.) at zero nadir angle. Recent work has shown that despite the MRIR's lower resolution it may be possible to derive such things as sea surface temperature from the data, if the region is cloud-free and the projection scale used is approximately 1:5 million or greater.

The Nimbus satellites circled the globe in a polar orbit, their sensors constantly oriented to the earth and their orbits timed to occur always at approximately local midday on the earth's lighted side and at local midnight on the earth's dark side. Thus, each point on the earth's surface was viewed at least twice a day by the satellite. Overlaps in the satellite coverage increased toward higher latitudes with each of the poles being viewed fourteen times in twenty-four hours.

![Figure 4](image-url)  The Nimbus midday-midnight sun-synchronous orbit
The first known satellite pictures of an iceberg were taken in September 1964 by Nimbus 1. The iceberg showed clearly on both television (AVCS) and infrared imagery (HRIR). Note the contrast shown by the HRIR imagery. (Popham and Samuelson)
HRIR and MRIR data were processed for display in two ways: a digital form for quantitative analysis; and an imagery form, similar to television pictures, for comparative studies. Useful HRIR digital data were limited to those data collected during the night since the daytime measurements had reflected solar radiation added to the earth’s infrared emission (because of the attitude of the satellite and the angle of incidence of the sun’s rays, the satellite’s sun shields were sometimes ineffective at high latitudes on the night side and the HRIR data were occasionally contaminated).

Infrared imagery was found to be usable from both the day and night passage since the pictorial information was discernable despite the solar radiation. The use of HRIR imagery of icefields during the polar night has shown great promise. For example, HRIR and AVCS (Advanced Vidicon Camera System—see Section 4) pictures of the Weddell Sea during daylight hours show the position of a large iceberg in what may be either open water or thin ice.

In addition to the delineation of ice regions, HRIR imagery is useful in getting a visual survey of the cloud distribution. The Nimbus HRIR catalogues are presented as strip mosaics of HRIR imagery. Thus, the amount of HRIR data available for an area and a time can be assessed quickly by examining these visual presentations.

The areal coverage of the surface of the oceans by the HRIR and MRIR data was limited by the amount of cloud cover. This interruption by clouds is normally obvious in the data when the cloud temperatures are low. However, because the HRIR data were collected at night and
the MRIR's resolution was low, it is sometimes difficult to differentiate between low clouds and the sea's surface when their radiational temperatures are similar.

Therefore, in the examination of single-day HRIR data it is necessary to use clear-sky data.* Such information is possible by assigning threshold temperature values so high as to guarantee the exclusion of cloud data. Since some sea surface temperature information may be lost by this method, a second procedure of examining single-day data may be preferred. This method utilizes a minimum threshold grid made of historical minimum temperatures to exclude cloud data. (A maximum ceiling made of maximum temperatures may also be used to help exclude the more obvious of the electronic "noise"). Both of these methods are difficult to use in analyzing high latitude data where cloud and water temperature values are similar.

A method formulated by LaViolette and Chabot (1969) to remove transitory clouds artifically from the HRIR data involves a highly selective composite of several days' data. An example of this compositing is shown in Figure 8.

The region shown in the figure -- the Gulf of California and a small portion of the eastern Pacific -- has relatively simple sea surface temperature structure with distinctive land masses easily defined by infrared sensors.

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*A comparatively minor difficulty in the Nimbus 2 HRIR data was the presence of systematic and erratic electronic "noise" generated on board the spacecraft and by the data reduction system on the ground. This has been partially surmounted by the use of filter programs devised by NASA's Goddard Space Flight Center.
Because of the sparse amount of data available on the coastal upwelling as well as the region's large fishing potential, the coast of the Somali Republic has long been of interest to the authors. Scattered throughout this report (Figures 13, 14, and 22) are specific examples of oceanographic information provided by satellites on this remote region of the world. The charts shown on this page are a comparison of the sea surface temperature information from the two Nimbus satellites, an oceanographic cruise by the research ships ARGO and DISCOVERY, and an historical atlas of surface temperatures.

L. J. Allison indicated that from 9° to 12° North, Nimbus 1 temperatures less than 63°F. are related to the position of stratus and stratocumulus clouds located over the cold upwelled water. At this general time, an analysis of the ARGO-DISCOVERY data shows that the 57.2°F. to 71.6°F. isotherms appear to underlie the cloudy region.
All Nimbus 2 August data were cloud contaminated. On the night of 16 August, a fine haze seemed to cover the entire study area uniformly. Thus, the temperatures recorded by Nimbus 2 for this night were approximately 12° to 15°F lower in comparison to the historical mean August chart.

If the low temperature values are ignored, the horizontal gradients in the satellite analysis visible through the uniform haze seem to show the pronounced upwelling along the coast as well as the eastward extent of the cold water. The horizontal gradients are strongest between 10° and 11° North with the gradient change of 15°F. This pattern is close to the temperature differential found during the 1964 oceanographic cruise. If the position of the horizontal gradients of Nimbus 2 and the cloud cover of Nimbus 1 are taken as an indication of upwelling, the two satellite analyses are grossly similar. Both show a more eastward extent of the upwelling than was found in the analysis of the 1964 oceanographic cruise data.
Figure 7  The north wall of the Gulf Stream as seen by Nimbus 2

(Allison, Foshee, Warnecke and Wilkerson)
Figure 8  A study of sea surface temperatures in the Gulf of California using satellite infrared data - Nimbus 2

Five days of High Resolution Infrared Radiometer (HRIR) data, 11 through 15 November 1966, were examined individually and then combined in a selective composite designed to arrive at sea surface temperatures in a region of transitory clouds. An examination of the individual charts showed a small migration of warm water northward into the Gulf during the five-day period. The variation was small however, and the five-day High Daily Average (HDA) composite may be taken as representing the sea surface temperature conditions of the region with the transitory clouds removed.

(LaViolette and Chabot 1969)
Only a small section of the record represents terrestrial radiation. As the scan mirror rotates, it also measures the temperature of space and of the radiometer housing. In the example shown, the mirror made two complete revolutions and thus gave two "scans" or sweeps of the earth below the satellite. The distinctive "kick" of the space trace formed a convenient reference point in positioning the satellite, while the characteristic trace of the radiometer housing was useful in calibrating the temperature readout.

(LaViolette and Chabot 1968b)
The HRIR data for the region for each day were printed by computer using a Mercator projection of 1:2 million scale. The mesh size of the data printout at this scale formed the resolution of the study. The printed temperature value for each day for each point was an average of ten HRIR scan spots and represents an approximate area of 497 sq. km. (1,000 sq. nm.) within the nadir angle limitation of 50°. The temperature printed was a "corrected average" determined by excluding from the average all data lying outside boundary temperatures based on historical extremes.

The five-day composite, called a High Daily Average (HDA) composite, was made by examining the daily temperature average at a point for each of the five days, and printing the highest daily average which occurred during the period. This process was repeated for the entire HDA chart. The resulting printed values were designed to reflect either no clouds or the smallest concentration of clouds over each point for the five-day period.

The HDA composite method can be used in a variety of ways, the number of days used in the composite varying according to the magnitude of oceanic change in the study area. A study in preparation by Paul E. LaViolette of the Naval Oceanographic Office and L. J. Allison of the Goddard Space Flight Center involves a ten-day HDA composite of the North Pacific Ocean. This study has not been completed and is included here only as an example of work in progress.

Despite the short life span of the Nimbus 1 and 2 spacecraft, an enormous quantity of infrared data and imagery was collected. Properly used, these data can do much to increase our knowledge of the oceans. They have already proven to be a fertile testing ground for the development of techniques for future satellite applications.
This unusual AVCS picture, transmitted from ATS 2 at 2:00 P.M. EST 10 April 1967, shows the region of upwelling associated with the Peru Current, and its westward extension, the Pacific South Equatorial Current. These two current systems are outlined by the low surface clouds shown as light gray off the South American coast and are clearly defined as the dark region immediately west of South America and adjacent to the Equator. The picture also shows Baja California, Yucatan Peninsula, Gulf of Mexico, and the coastline from Colombia to Chile.

Visible to the north of the Pacific South Equatorial Current are the cloud patterns associated with the Intertropical Convergence Zone. (LaViolette and Chabot 1968a)
4. Television Pictures*

Television pictures of the earth's surface have been available from a number of satellites. However, only the polar orbited Nimbus and ESSA, and the equatorial and geo-synchronous ATS satellites have produced television pictures with the detail necessary for oceanographic work. Some of the oceanic features initially apparent to an investigator of satellite television pictures are the delineation made by clouds of large currents and upwelling. For example, the picture in Figure 10, taken by ATS 2, apparently defines the cold Peru Current as well as its westward extension, the Pacific South Equatorial Current. However, the actual location of these currents at the time has not been substantiated by ground observations. It can only be assumed that the low surface clouds off the South American coast and north and south of the Equator define what may be considered the general region of the two currents. The historical position of these currents, however, seems to substantiate this assumption and it is the opinion of the authors that the actual position of the currents as compared to the cloud delineation is within the resolution of the satellite picture.

Figure 11 is one of the few examples available of near-simultaneous (following day) current position measurement and satellite television coverage. In this instance, the alignment of the clouds was noticed by a Naval Oceanographic Office scientist, R.L. Pickett, aboard an aircraft using an airborne radiation thermometer to determine the

* The term television is used here in the broad sense to differentiate between pictures taken by an emulsion process and those taken by an electron scanner.
Alignment of cumulus clouds along the north wall of the Gulf Stream - ESSA 3

The radiation thermometer track of the northern edge on 27 February 1968, as defined by the Naval Oceanographic aircraft "El Coyote", is compared in this chart to an ESSA 3 satellite photograph of the cloud cover on 26 February 1968. The agreement is remarkable despite grid positioning errors in satellite data, navigational errors in aircraft data, and one-day separation in time.

On 26 February 1968 a cumulus cloud deck was observed 400 m above the Gulf Stream. Surface winds were northerly 10 to 15 m/sec, and air temperature was approximately 6°C. Water temperature varied from about 12°C in Slope Water to about 20°C in the Stream. Above the northern edge of the Stream there was a sharp demarcation between the clear skies to the north and the cumulus deck. (U. S. Naval Oceanographic Office)
position of the Gulf Stream. Upon returning to base, Pickett examined ESSA 3 pictures for the same period and made the remarkable correlation shown in Figure 11.

Cloud patterns, such as those outlining the currents shown in Figures 10 and 11, are visible on other satellite photographs and thus would seem to indicate a regular relationship between clouds and many of the large currents of the oceans. Further examination of the cloud patterns, however, reveals more than the mere delineation of these gross oceanic features by indirectly disclosing the thermal conditions of the water, both horizontally and vertically.

The Bay of Bengal during the spring inter-monsoonal period may be used as an example of cloud conditions indicating a change in the vertical structure of the water.

The actual time of the monsoonal advance into the bay varies yearly. For example, ESSA 5 pictures for 12, 14, and 16 June 1967 (Figure 12) show the movement of the first low pressure system of the summer monsoon in the Bay of Bengal. These pictures are of oceanographic interest because they reveal indirectly the actual period of the transition in the water column. At this time, the warm, stratified waters characteristic of the late winter (northeast) monsoon tumble and mix under the pressure of the winds of this first low. The water structure thereupon assumes the comparatively cooler, deeper, mixed layer and stronger thermoclineal conditions which are characteristics of the early summer (southwest) monsoon. During this transition period, the waters in the northwestern portions of the bay have the stratified structure typical of the winter monsoon whereas, behind the cloud front
of the advancing season's low, the waters have the characteristic structure of the summer monsoon.

The seasonal upwelling off the coast of the Somali Republic also may be indicated by the presence of clouds. In this area, the general cloud pattern is related to the monsoonal wind pattern, which in turn governs the beginning and end of the upwelling. Thus, the cloud pattern may be used to indicate the probable duration of upwelling.

An analysis of mean historical data indicates that seasonal upwelling along the coast starts in May and ends in November. The question, however, for any particular year is, "When in May does it start and when in November does it end?" The monsoonal pattern of clouds in ESSA 3 pictures (Figure 13) shows that in 1967 upwelling probably started before 28 May and that some upwelling may still have been occurring on 25 November.

In addition, examination of the low cloud cover visible in ESSA pictures during the period of upwelling shows the characteristic demarcation of the clouds made by the cold and warm water (Figure 14).

Of course, all of the cloud patterns peculiar to a region are not necessarily associated with the conditions of the water below. However, by combining the knowledge of a region's cloud patterns as shown by satellite pictures with a good comprehension of its physical conditions, one may determine the oceanic temperature conditions of the region.

Two television systems have been successfully used aboard polar orbited satellites: The Automatic Picture Transmission (APT) and the Advanced Vidicon Camera System (AVCS). These systems are being used on the ITOS satellites.
Figure 12  Bay of Bengal, 1967 spring transition - ESSA 5  (LaViolette and Seim)

Figure 13  Beginning-end of seasonal upwelling along the coast of the Somali Republic, 1967 - ESSA 3  (LaViolette and Seim)
Figure 14  The upwelling area along the coast of the Somali Republic as defined by low clouds, 6 June 1968 - ESSA 3
The even numbered ESSA satellites are equipped to transmit APT pictures to comparatively inexpensive facsimile receivers on the ground. The picture quality of these receivers, while well suited for meteorological work, is usually too poor for oceanographic use. Hence, for historical oceanographic studies only the AVCS is of interest, since the AVCS covers the same area as the APT with better resolution.

Figure 15    Nimbus 2 AVCS camera coverage
The following description of the AVCS systems is taken from the "Nimbus 2 Users Guide."*

The AVCS consists of three vidicon cameras and associated electronics. The central camera is oriented downward along the yaw axis (nominally the local vertical) while each of the side cameras is mounted in the yaw-pitch plane at an angle of 35 degrees to the central camera. Figure (15) shows the Nimbus (2) television coverage, an area of approximately 1,900 by 400 nautical miles. Successive frames are taken at 91-second intervals providing about 20 percent overlap of earth coverage at 600-nautical mile altitudes. Complete daylight orbital coverage can be obtained with 32 consecutive picture triplets. Successive orbits, displaced about 27 degrees westward in longitude at the equator, provide adjacent pictorial data, with increasing overlap from the Equator towards the poles.

The AVCS pictures from the Nimbus satellites covered only a short period of time -- Nimbus 1, part of August and September 1964, and Nimbus 2, late May through August 1966. AVCS pictures from the ESSA satellites, however, have been received on a nearly continuous basis since the launching of ESSA 1 in February 1966. As of December 1968, ESSA 3 has been turned off and 5 will be used on a standby basis; ESSA 7 is transmitting clear television pictures on a daily basis.

All of the AVCS pictures from both Nimbus and ESSA satellites are archived. However, the transmissions received after 1 January 1967 from ESSA 3 are unique because all meso-scale arrays are stored in a format suitable for computer manipulation. ESSA's National Environmental Satellite Center (NESC) at Suitland, Maryland has formulated several methods of working with the data, including global mosaics, brightness composites, and gray toned enhancements. Examples of these are given in Figures 16 and 17.

*Although the Nimbus AVCS system described utilized the three camera system, the ESSA satellite (TOS) achieves the same coverage with a single camera. (Actually two cameras are aboard each ESSA satellite, but the data from only one are used; the other acts as a backup camera).
Figure 17  Nine-day minimum brightness composites, 1 to 9 March 1967 - northern hemisphere, ESSA 3
The brightness composites (Figure 17) may be used to remove transitory clouds over ice fields and thus define the areal coverage of the ice during the period of days making up the composite. The method is similar to the HDA method of compositing discussed in the section devoted to infrared sensors. Within the time period of the composite, each day's meso-scale array is examined resolution point by resolution point and the darkest tone for each resolution point printed. If the proper number of days is chosen (minimum number so as not to hide ice movement and maximum number to discard transitory clouds) the only portion of the print that remains white is the ice field and any permanent cloud cover.

This method can not be used during the polar darkness portion of the year. However, it may be possible to tie infrared composites with brightness composites for year round observations. This has not yet been done.

ATS pictures are extraordinary because they cover nearly half of the globe in one picture. ATS 1, situated over 151° W., is able to make a picture of the entire Pacific Ocean approximately every half hour. When ATS 3 was positioned over the Amazon River, it complemented the ATS 1 Pacific Ocean coverage and gave a similar half hourly picture of the Atlantic Ocean. (As of 31 December 1968, ATS 3 was being moved to a new position of 73° W.).

Four "television" camera systems were used on the ATS satellites. ATS 1 used a Spin Scan Cloud Camera (SSCC), ATS 2 used a two-camera Advanced Vidicon Camera System (AVCS) and ATS 3 used a Multicolor Spin Scan Cloud Camera (MSSCC) and an Image Dissector Camera System (IDCS).
The SSCC used aboard ATS 1 consists of a five-inch telescope, a single photomultiplier and a precision latitude-step mechanism. The latitude-step motion, combined with the spinning motion of the satellite permits scanning of the complete earth disc. Ground resolution was approximately 4.6 km. (2.5 nm.) at the subsatellite point.

ATS 2's AVCS consisted of a tape recorder and two cameras. Camera 1 was to have viewed a 927 by 927 km. (500 by 500 nm.) section of the earth with a 200 mm f 16-f 4 lens. Ground resolution at zero nadir angle from the planned orbital height of 11,100 km. (5,990 nm.) was to have been 0.9 km. (0.5 nm.). Camera 2 was to view the entire earth disc with a 12 mm., f 11-f 1.5 lens with a ground resolution of 19 km. (10 nm.) from the same altitude and nadir angle.

Because of a failure in the booster rocket, the spacecraft went into a highly elliptical orbit which finally resulted in power failure and loss of television transmission. During the time before transmission failure, Camera 1 produced 19 useful pictures, and Camera 2 produced 33.

The first satellite picture to delineate clearly the Peru and South Equatorial Currents in a single picture (Figure 10) was taken by Camera 2 on 10 April 1967 from an altitude of 10,861 km. (5,860 nm.). Camera 2 obtained the first photograph of the full earth disc from an altitude of 10,739 km. (5,795 nm.) on 11 May 1967.

The ATS 3 MSSCC is similar to the ATS 1 SSCC and consists of a high resolution telescope, three photomultipliers (for red, green and blue detection) and a precision latitude step-mechanism. The ground resolution at nadir is 3.7 km. (2.0 nm.).

Difficulties occurred in the camera system shortly after the spacecraft...
was orbited and color pictures were received only intermittently. No color pictures were received after January 1968. Modification of the ground equipment has produced a clear green signal from the MSSCC and this is used for black and white pictures (see frontispiece).

The IDCS of ATS 3 consists of a telescope, a vidicon data processor and a sun sensing element. The camera produces a scan line with each revolution of the satellite. Direction of scan, north to south or west to east, is determined by ground command. In the longitudinal (i.e. north to south) mode, 1,328 scan lines provide an earth coverage from 50° N. to 50° S. and from 50° W. to 50° E. of the subsatellite point. West to east scan lines increase the field of view to include the limbs of the earth. Ground resolution is approximately 7.8 km. (4.2 nm.) at the subsatellite point.

An IDCS television system similar to that of ATS 3 will be installed on Nimbus B2 scheduled for launching Spring 1969 (See Part I, Section 6).

Although all of the pictures received from the ATS satellites are useful scientifically, aesthetically the most impressive were the color pictures taken by ATS 3's MSSCC. A time-lapse movie made from one day's color pictures gives a vivid example of low level cloud displacement over the ocean as well as conveying the idea of how some of these displacements are influenced by the ocean below. These amazing color pictures of the earth from space have only recently been surpassed in clearness by the photographs taken by the crew of Apollo 8.
The North Atlantic Ocean—Apollo 8

This view of the Eastern Seaboard of the United States, the Bahamas, Cuba, Hispaniola and Jamaica was photographed shortly after the Apollo 8 spacecraft left its earth orbit. Unlike television pictures taken by unmanned spacecraft, the details of this photograph, enhanced by the color contrast, are readily enlarged for close study.
5. Space Photography

Photographs of the oceans from space have proved a unique and tantalizing tool for oceanic investigations. The high resolution of these color photographs has shown a wealth of detail impossible to duplicate by television pictures. Surface and near surface conditions appear as sea scars, rips, sea state, bathymetric features, etc. Many of these features have been shown to exist over large areas on a scale previously unimagined. Close examination of such photos, especially those containing sun glint, has raised more questions than have been answered.

The fact that all of the pictures have been in color has aided visual examination. The contrast of color enhances the differences between oceanic structures of interest, delineating features that seem continuous when seen in black and white. Because the illustrations in this publication are in black and white, the full definition possible from these pictures cannot be shown. Thus, only a limited number of examples are presented.

Broad-band color film has its limitations, however, in differentiating phenomena close together on the spectral scale. Multi-spectral photography on future flights will be a welcome improvement over the presently used color systems.

The Gemini color pictures have been subjected to a series of experiments to extract spectral information for depth determination. One experiment, conducted by Don Ross of the Philco-Ford Corporation, is based on the idea that in shallow, relatively clear water, the amount of light reflected from the bottom is inversely proportional to depth. Consequently, areas of equal color intensity may be supposed to indicate areas of equal depth.
Figure 21 Arabian Sea, India, Ceylon, Laccadive Islands and the Bay of Bengal - Gemini 11

This Gemini photograph was taken on 14 September 1966 when shallow upwelling is normally occurring along the west coast of India. The abrupt end of the low clouds 30 to 40 miles offshore seems to indicate that the upwelling of comparatively cold water was occurring at this time. The picture is complicated by the cloud pattern on land which seems to indicate a sea breeze effect. However, a close examination of the photo shows an offshore flow of muddy water from the coastal lagoons and rivers. Other Gemini 11 photographs taken at this time also show this offshore outflow of muddy water. In addition, the meteorological chart for this day shows the mechanism for upwelling to be present, i.e., winds blowing along the coast from the northwest. (LaViolette and Seim)
As seen by the crew of Apollo 7 on 15 October 1968 from 100 miles in space, the waters around the islands of Socotra and The Brothers, caught in the sun’s reflection, reveal complex surface phenomenon impossible to view by ordinary means. Situated just off the East African coast and north of one of the strongest upwelling areas in the world, the islands form a deflective barrier to the northeastward movement of the cold, upwelled water. The vortices, slicks, swells, and other lines which are visible reveal current direction, internal waves, and regions of convergence and divergence. Such information is invaluable in understanding the oceanography of one of the world’s largest undeveloped fishing regions.
Photographs taken during the manned satellite missions have normally been limited to those taken from orbits which did not exceed the equatorial band of 35° N to 35° S. The path of these flights is typified by the orbits pictured above for Mercury mission MA-9. This mission lasted 22 orbital passes with the spacecraft landing near Midway Island in the Pacific Ocean.

(NASA 1963)
If false colors are assigned to certain isodensities an effective bathymetric chart may be formed. After the region is viewed several times, observations indicate that the transitory isodensities are sediment and the permanent ones are bathymetric features.

Photographs taken by the astronauts aboard Mercury, Gemini and Apollo spacecraft have been confined to obvious unusual oceanic conditions and to geographically limited flight paths. Thus, photographs of the Gulf of California, northern Gulf of Mexico, Florida, and the Red Sea abound, while the upwelled areas of Peru, and the fishing banks of Newfoundland, Iceland, and the North Sea have not been photographed.

The photographs that have been taken to date, however, provide a wealth of material for study and must be examined carefully to derive their total information.
<table>
<thead>
<tr>
<th>Designation</th>
<th>Approx. Prelaunch Date</th>
<th>Orbit and Altitude km. (nm.)</th>
<th>&quot;Oceanographic&quot; Sensor Complement</th>
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<td>Feb. 1969</td>
<td>Polar 1,390 (750)</td>
<td>2 AVCS</td>
</tr>
<tr>
<td>Nimbus B2</td>
<td>April 1969</td>
<td>Polar 1,110 (600)</td>
<td>1 HRIR 1 MRIR 1 IDCS 1 IRLS</td>
</tr>
<tr>
<td>ATS E</td>
<td>Aug. 1969</td>
<td>Geosync</td>
<td></td>
</tr>
<tr>
<td>TIROS M</td>
<td>May 1969</td>
<td>Polar 1,435 (775)</td>
<td>2 AVCS 2 APT 2 HRIR</td>
</tr>
<tr>
<td>Nimbus D</td>
<td>Mar. 1970</td>
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<td>1 IDCS 1 IRLS</td>
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<td>ITOS C</td>
<td>On call</td>
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<td>2 AVCS 2 APT 2 HRIR</td>
</tr>
</tbody>
</table>

Table 4: NASA-ESSA Meteorological Satellites Planned as of January 1969. (after Rados).
6. Future Satellites and their Sensors

At the time of this writing, two polar orbited satellites capable of providing oceanographic information are scheduled to be launched in 1969: Nimbus B2 -- in the spring, and TIROS M -- in the early fall. As mentioned previously, only the Nimbus satellites have given infrared data capable of oceanographic use and these did not function long enough to give full seasonal coverage. Both of these new satellites will have infrared and television capabilities.

Nimbus B2 will have nine experimental systems. Although all nine systems will provide general information useful for oceanographic studies, those systems providing direct oceanographic data are listed in Table 5. The first three of the systems listed in the table have been used successfully on former spacecraft. The fourth system is the prototype of a location and interrogation system that will result in the coupling of the remote sensing techniques of the satellite with the time-proven method of manned and unmanned ocean stations.

TIROS M will be the prototype of the ITOS (Improved TIROS Operational Satellite) series and will carry a new generation of infrared sensors. Its primary sensors will combine the daylight television picture functions of the existing AVCS and APT television systems and the capability of two-channel scanning radiometers. One of these radiometer channels, operating in the visible .52 to .73 micron range, will provide an additional source of daytime cloud pictures while the second channel, operating in the 10.5 to 12.5 micron atmospheric "window", will provide day and night measurements of the earth's infrared emissions.
ACTIVE THERMAL CONTROLLER LOUVERS

MOMENTUM WHEEL

SEPARATION RING

SOLAR PROTON SENSORS

APT CAMERAS

REAL-TIME ANTENNA

SOLAR PANEL B

SOLAR PANEL A

SOLAR PANEL DEPLOYMENT ACTUATOR

THERMAL FENCE OUTER RING

COMMAND AND BEACON ANTENNA

FLAT PLATE RADIOMETER

BASEPLATE

SCANNING RADIOMETERS

AVCS CAMERAS

REAL-TIME ANTENNA

SOLAR PANEL C

DIGITAL SOLAR ASPECT INDICATOR

S-BAND ANTENNA

*M SOLAR PROTON SENSORS SHOWN IN THIS CORNER FOR CLARITY. ACTUAL LOCATION IS IN CORNER CONCEALED BY MOMENTUM WHEEL.

Figure 24  ITOS (TIROS M)  (Radio Corporation of America)
Figure 25  Nimbus B2 Interrogation, Recording, and Location System (IRLS) as applied to oceanography

Table 5. Nimbus B2 Sensors Useful for Oceanography

1. HRIR (High Resolution Infrared Radiometer): Designed to measure thermal radiation from the earth in the 3.4 to 4.2 micron range. Provide day and night imagery and blackbody temperature equivalents at night.

2. MRIR (Medium Resolution Infrared Radiometer): Designed to measure the terrestrial, atmospheric and solar radiation of the earth in five wavelength bands between 0.2 and 23 microns. The channel and wavelengths are: (1) 6.7, (2) 10.0 to 11.0, (3) 14.5 to 15.5, (4) 20.0 to 23.0, (5) 0.2 to 4.0.

3. IDCS (Image Dissector Camera System): Designed to provide daytime television pictures of the earth to be transmitted in real time or be stored for data playback at CDA stations.

4. IRLS (Interrogation, Recording and Location System): Designed to locate ground stations and, when required, interrogate and record data accumulated at selected ground stations. On passing over Ground Acquisition and Control Station, the data is read out and a new command sequence for the next orbit started.
By using a longer wave length section of the infrared spectrum (Nimbus HRIR infrared sensors operate in the range of 3.4 to 4.2 micron "window") reflected sunlight will not contaminate the data during the daytime portion of the satellite orbit. Stations having APT facsimile receivers will be able, with minor equipment modification, to receive infrared data on the same receivers. However, the infrared data thus received may be of as low a resolution as the APT television pictures.
Part II

The Satellites
A Note About Satellite Names

The names of satellites and their operational systems are a confusing conglomerate of acronyms. It is hoped that the following discussion will help arrange them in some logical order.

The Television Infrared Observational Satellites (TIROS) were weather research satellites operated by the National Aeronautics and Space Administration (NASA). There have been ten of these research satellites launched between April 1960 and July 1965.

The successful development of TIROS led to the TIROS Operational System or TOS. As the name implies, the satellites used in the TOS system are operational rather than research satellites. These operational satellites are managed by ESSA's National Environmental Satellite Center (NESC) after being initially launched and checked out by NASA's Goddard Space Flight Center (GSFC). This system requires two TOS satellites to be in orbit at all times. One satellite carries APT for direct readout to ground stations and the other is equipped with AVCS for readout to command stations at Chincoteague, Virginia and Gilmore Creek, Fairbanks, Alaska.

The first satellites of the TOS system were the Environmental Survey Satellites (ESSA). There have been eight of these satellites to date, the odd numbered ones equipped with AVCS, the even numbered ones with APT.

With the launching of TIROS M in midyear 1969, the second generation of the TOS system will be inaugurated. Once in orbit, TIROS M will be redesignated as an Improved TIROS Operational Satellite (ITOS) and will be capable of performing the work of two ESSA satellites in addition to having infrared data collecting capabilities.
The numerical and alphabetical designation of the satellites within a series denotes their launch status. Prior to its launch, a satellite is given a letter designation for planning purposes. After launch and once it has attained orbit, it is reclassified with a numeral to designate its sequence in the satellite series.

Nimbus is pleasantly different in being named after the Latin word for rain clouds rather than being an acronym. It is aptly named as it was developed to study clouds with APT and AVCS television systems during the day and with HRIR and MRIR sensors at night.

Nimbus was originally designed to overcome basic limitations in the TIROS satellites and to become the first in a series of operational satellites. However, for various reasons, Nimbus was redesignated a research and development satellite and ESSA 2 replaced it as the first operational satellite.

The Applications Technology Satellite (ATS) series includes research satellites in geo-synchronous and equatorial orbits. There are two ATS satellites currently in operation: ATS 1 and 3.
Figure 26  The Nimbus Satellite (Nimbus 2)
The Nimbus Satellite

Nimbus is a meteorological research and development satellite built for the National Aeronautics and Space Administration. The Nimbus series involves the flight of a number of large earth stabilized spacecraft launched in 925 - 1,390 km. (500-750 nm.) altitude, near-polar orbits. Two Nimbus satellites have been put into orbit and a third is to be launched in early spring 1969.

The basic Nimbus satellite is approximately ten feet tall and consists of three major elements: the 8 by 3 foot solar paddles which provide the basic electric power supply with a maximum of 450 watts; the upper hexagonal package which contains the complete attitude stabilization and control system capable of keeping the spacecraft oriented towards the earth with an accuracy in all three axes of less than a one-degree error; and finally, the lower sensory ring which consists of a 54-inch diameter toroidal structure containing eighteen bays which house the major electronic elements of the spacecraft. The open central portion of the torus holds large and bulky elements such as cameras and tape recorders. The weight of Nimbus 1 at launch was 832 pounds.

The spacecraft carries several meteorological sensors. The Advanced Vidicon Camera System (AVCS) of Nimbus 1 and 2 was designed to meet the needs of the national meteorological services for global weather data (Nimbus B2 will carry a different television system; see Part I, Section 6). The data were stored on board in a magnetic tape recorder and played back on command to either of two Command and Data Acquisition (CDA) sites at Gilmore Creek, Fairbanks, Alaska, or Bosman, North Carolina; these CDA sites transmitted the data to the Goddard Space Flight Center.
at Greenbelt, Maryland and to the National Weather Satellite Center at Suitland, Maryland where they were referenced and made available for historical use in strip mosaics.

The Automatic Picture Transmission System (APTS) provided similar cloud mapping photographs of somewhat lower resolution to local users who employed a simple inexpensive ground station. Since the coverage was the same as the AVCS and the data were not catalogued, Nimbus 1 and 2 APTS pictures are not considered of oceanographic use.

The AVCS provided pictorial information of daytime conditions. At nighttime, the High Resolution Infrared Radiometer (HRIR) system provided a continuous measurement of the earth's thermal radiation. These data were stored on tape in the spacecraft and read simultaneously with the AVCS pictures to the CDA sites in Alaska or North Carolina.

The Medium Resolution Infrared Radiometer (MRIR) used on Nimbus 2 was a five-channel camera system designed to give the heat balance of the earth-atmosphere system, the water vapor distribution, surface or near surface temperatures, and seasonal changes of stratospheric temperature distribution.

A number of catalogs and users guides are available for the Nimbus satellites and are listed in the bibliography section of this report. These catalogs and guides are available from NASA at the following address:

National Space Science Data Center
Goddard Space Flight Center
Code 601
Greenbelt, Maryland 20771

HRIR data requests will be fulfilled by making reproductions from transparencies which are stored at the National Space Science Data
Center (NSSDC) and at the Goddard Space Flight Center (GSFC), Greenbelt, Maryland. Reproductions of the 70-mm film can be made as positive or negative transparencies or as positive paper prints, including enlargements. Single data orbit swaths may be ordered. Most of these data are nighttime swaths; however, a considerable number of swaths are daytime HRIR imagery. Digital magnetic tapes and analog strip chart records may also be requested. HRIR data may be obtained by writing to the same address as given for the catalogs.

MRIR data positive and negative transparencies are stored at GSFC, Greenbelt, Maryland to fulfill users' requests. Reproductions of these data can be made as positive and negative transparencies and enlarged prints; requests should be forwarded to the same address as above. Digital magnetic tapes and analog strip chart records may also be requested.

AVCS 35-mm film data produced by NESC are forwarded to the National Weather Records Center (NWRC) in Asheville, North Carolina, for archiving. These film data are available as either positive or negative transparencies in increments of 100-foot rolls.

Reference to the Nimbus catalogs will enable the user to determine his data requirements as to time and geographical location and, in turn, the particular swaths of data he requires. Orders and inquiries should be addressed to:

National Weather Records Center
Environmental Science Services Administration
Federal Building
Asheville, North Carolina 28801

Nimbus 1 was successfully launched from the Western Test Range at Vandenberg Air Force Base in California on 28 August 1964.
An undetected leak in the Agena fuel transfer equipment at the launch pad resulted in an elliptical orbit rather than the desired circular orbit with a resulting apogee of 922 km. (503 nm.) and a perigee of 423 km. (228 nm.). As a result, not all data recorded on the spacecraft could be read out and there were gaps in the sensory data coverage for this reason.

On 23 September 1964, after 26 days of operation, the solar array drive jammed. Since the solar array was in the sunrise position, some solar power was received, but not enough to operate the essential spacecraft systems. After seven orbits, battery discharge reached a point where attitude control and telemetry failed.

During the 26 days of operation there were a total of 379 orbits. Of these, 125 were blind because spacecraft command was not feasible at either CDA site; 73 of these blind orbits were the result of the eccentric orbit. Of the 254 orbits on which data could have been obtained, some were missed because of short acquisition times, others because of a conservative doctrine which dictated the turn-off of sensory systems when spacecraft operational problems were encountered.

Despite its short life, Nimbus 1 made important contributions to the use of satellites as remote observatories. In the interest of ocean studies, Nimbus 1 proved the practicality of the HRIR system and provide the first high resolution infrared data and television pictures of the earth on a global scale.

Nimbus 2 was launched on 15 May 1966 from the Western Test Range in California. A near-circular orbit of an average altitude of 1,137 km. (614 nm.) was achieved, with an apogee height of 1,179 km. (636 nm.), a perigee height of 1,095 km. (591 nm.), and an inclination of 100.3°.
The nodal period was 108 minutes. Ascending nodes occur at 32 minutes before noon, local mean solar time. The orbit was very nearly sun-synchronous; the drift rate of the orbital plane relative to the earth-sun line was approximately half a degree per month.

The Nimbus 2 spacecraft was essentially the same as Nimbus 1. The major differences between the two spacecraft were the addition of the MRIR to the sensory ring and the provision for immediate broadcast of nighttime HRIR data that could be received by modified APT ground station equipment.
Figure 27  The Environmental Survey Satellite (ESSA 3)
The Environmental Survey Satellite (ESSA)

The ESSA series includes operational satellites providing routine, daily global coverage of the entire earth from space.

With the launching of ESSA 2, the TIROS Operational System (TOS) series was started (ESSA 1 was sponsored by the U.S. Department of Commerce). ESSA 2 was part of a pair of satellites which makes up the TOS twins: one Automatic Picture Transmission System (APT) satellite (even numbered ESSA) and one Advance Vidicon Camera System (AVCS) satellite (odd numbered ESSA). The APT satellites do not store video data but transmit data immediately for worldwide direct readout. The AVCS satellites store their global video data for readout at one of the Command and Data Acquisition (CDA) stations at Fairbanks, Alaska or Chincoteague, Virginia where the data is transmitted to ESSA's National Environmental Satellite Center (NESC) at Suitland, Maryland.

The odd numbered satellites are of greater interest oceanographically because their data are referenced and catalogued and therefore retrievable for historic study. The following discussion, therefore, deals with ESSA 3, 5, and 7.

The ESSA satellite is positioned in a "cartwheel" configuration in space to allow earth-oriented picture coverage. The spin axis of the satellite is normal to the plane of the orbit and the rim-mounted cameras view the earth once during each revolution about the spacecraft axis.

The cameras in the satellite are one-inch diameter vidicons of the AVCS type. Although one camera provides full global coverage, two cameras are operated to give full system redundancy. Each of the cameras independently takes pictures and stores them for later playback to one of the CDA stations. The CDA stations are able to get data from the satellite during thirteen of the fourteen daily orbital passes.
Pictures, taken once every 260 seconds, are usually obtained in sequences of twelve frames to a pass. During development at NESC, each frame is electronically gridded by computer with latitude and longitude lines, and geographic outlines are merged with the picture. An identification legend beneath each picture provides pertinent information.

ESSA_3 was launched on 2 October 1966 by the National Aeronautics and Space Administration and was put into a nearly circular, sun-synchronous, polar orbit, approximately 1,435 km. (774 nm.) above the earth's surface with an apogee of 1,486 km. (802 nm.) and a perigee of 1,382 km. (746 nm.). The orbit inclined 101.0° to the equatorial plane with a nodal period of 114.5 minutes which corresponds to slightly more than 13 revolutions of the earth each day.

Because of a drift problem with respect to its sun-synchronous position, ESSA_3 was put into standby mode on 9 October 1968. It is now considered completely inoperative with no chance of operational recovery.

ESSA_5 was launched on 20 April 1967. Like ESSA_3, it was put into a nearly circular polar orbit, approximately 1,386 km. (748 nm.) above the earth's surface, with an apogee of 1,423 km. (768 nm.) and a perigee of 1,351 km. (729 nm.). The orbit inclines 101.9° to the equatorial plane with an orbital period of 113.6 minutes which corresponds to 12.7 passes around the earth each day.

ESSA_7, the most recent AVCS satellite in the TOS series, was launched on 16 August 1968. It, too, was placed into a nearly circular, sun-synchronous, polar orbit approximately 1,452 km. (784 nm.) above the earth with an apogee of 1,473 (795 nm.) and a perigee of 1,430 km. (772 nm.). The orbit is inclined 101.7° to the equatorial plane.
Figure 28  The Applications Technology Satellite (ATS 1)
The Applications Technology Satellite (ATS)

The ATS series includes research and development satellites built for NASA's Goddard Space Flight Center. Launched into both equatorial and geo-synchronous orbits, these satellites have returned spectacular full-disc television pictures of the earth both in color and in black and white.

Two ATS satellites, ATS 1 and ATS 3, attained their designed orbit while a third, ATS 2, went into a highly elliptical orbit which eventually caused satellite tumbling and picture failure. ATS 4, a very sophisticated satellite, lasted 2 months in orbit, but due to stabilization difficulties was unable to send any data to receiving stations. A fifth satellite, scheduled to be launched in August 1969, will not have a camera system as part of its scheduled experiments.

The basic ATS spacecraft is a cylinder 54.0 inches long and 57.6 inches in diameter with solar cell arrays mounted around the periphery for power. ATS 1 weighed 775 pounds.

The geo-synchronous orbits into which ATS 1 and 3 were launched are prograde orbits (i.e. in the direction of the earth rotation) of 24 hour period. Thus, having matched the rotational period of the earth, these satellites appear to hover motionless over fixed locations.

The Spin Scan Cloud Camera (SSCC) of ATS 1 and the Multicolor Spin Scan Cloud Camera (MSSCC) and Image Dissector Camera System (IDCS) of ATS 3 take pictures every 20, 24 and 24 minutes respectively. Thus, they are able to discern diurnal cloud changes (and indirectly indicate possible oceanic changes in the surface structure of the ocean). These television pictures are transmitted to ground data acquisition stations at Rosman,
North Carolina, Mojave, California, and Cooby Creek, Australia, where they are then relayed to Goddard Space Flight Center at Greenbelt, Maryland.

**ATS Meteorological Data Catalogs are available upon request from:**

National Aeronautics and Space Administration  
Goddard Space Flight Center  
Greenbelt, Maryland 20771  
ATTN: NADUC Code 460

**Multicolor Spin Scan Cloud Camera and Image Dissector Camera System**

Photographic data are available in either positive or negative black and white transparencies in 125-foot rolls of 5-inch wide film. Appropriate grids are included with each roll.

Address requests for black and white film to:

National Weather Records Center  
Environmental Science Services Administration  
Federal Building  
Asheville, North Carolina 28801

Color prints and color positive transparencies of Multicolor Spin Scan Cloud Camera data are available in various sizes. Limited quantities of such data can be provided without charge to recognized research activities for use in specific studies. Address such requests to the GSFC address given above.

**ATS** was launched on 7 December 1966 from Cape Kennedy, Florida. A geo-synchronous orbit was established at 151° W. with an apogee of 36,616 km. (19,758 nm.) and a perigee of 36,612 km. (19,756 nm.). The satellite's mission was to perform six experiments. The one most interesting oceanographically was the Spin Scan Cloud Camera (SSCC) experiment.
ATS 2 was launched from Cape Kennedy, Florida on 6 April 1967. The Agena D failed to function for the second ignition resulting in the satellite being inserted into a highly elliptical orbit rather than the planned 11,100 km. (5,990 nm.) circular prograde orbit. An apogee of 11,181 km. (6,033 nm.) and a perigee of 186 km. (101 nm.) was attained with a period of 220 minutes. The last useful picture taken by the ATS 2 AVCS was from an altitude of 9,468 km. (5,109 nm.) on 19 July 1967.

The ATS spacecraft transmitters were silenced on 23 October 1967.

ATS 3 was launched from Cape Kennedy, Florida on 5 November 1967. A geo-synchronous orbit was achieved with an apogee of 35,705 km. (19,266 nm.) and a perigee of 35,330 km. (19,064 nm.)

Although the spacecraft was initially positioned at 47° W., it was soon allowed to drift to a position over the Pacific near 95° W. After a few months, the satellite was made to drift back to a position over South America. It is presently (December 1968) being moved to 73° W.

The satellite was scheduled to conduct eleven experiments; the two involving Multicolor Spin Scan Cloud Camera and the Image Dissector Camera Systems are of oceanographic interest.
Figure 29  The Astronauts  Artist: Paul Calle
5. The Manned Satellite (Mercury, Gemini, Apollo)

The crews of the manned spacecraft have returned from their missions with literally thousands of photographs of themselves, their vehicles, space, earth, and, in their latest odyssey, the surface of the moon.

With the exception of Apollo 8, the manned satellite photographs of the earth were visually limited to those taken from a height of approximately 185 km. (100 nm.) and from an equatorial band stretching from 35°N to 35°S. Their pictures were usually in color and on 70 mm film.*

The four manned orbital Mercury flights were tests of film, equipment and picture taking techniques. Color and black and white film of different ASA ratings, speeds, and resolutions; 35mm. and 70mm. stills; 16 mm. movie, hand held and fixed -- all of these films, cameras, and methods were used during this phase of the manned spaceflight venture. Unfortunately, the Mercury photographs are not available as a unit at this time, so their oceanographic value is difficult to determine. They are mentioned here for completeness and with the hope that someone will review them for their oceanographic content.

The more than 2,400 photographs from the ten Gemini missions were filed in a more orderly fashion, and a catalog of the pictures listing their locations, times, and subjects is available. (In this regard

* For study purposes, it is strongly suggested that examinations be made with transparencies on a light table using a 5 or 10 power lens. Color prints do not have the color contrast that are visible on the transparencies and much of the fine detail is lost.
the publication by Stevenson and Nelson listed in the bibliography is especially interesting). The improvement in both photographic skill and film quality over the Mercury missions is quite evident in the photographs.

The photographs of the four Apollo missions have been as interesting as those of Gemini. The tantalizing view of the partial earth disc offered by the unmanned flight of Apollo 4 was later accented by the startling full disc views taken by the Apollo 8 astronauts.

Requests for the photographs of entire missions or large quantities of prints or transparencies should be submitted to:

Technology Applications Center
University of New Mexico
Box 181
Albuquerque, New Mexico 87106
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<th>SATELLITE</th>
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<th>SENSOR</th>
<th>LAUNCH DATE</th>
<th>END OPERATIONS</th>
<th>OPERATIONAL PERIOD</th>
<th>ORBIT</th>
<th>INCLINATION (°)</th>
<th>APOGEE KM (NM)</th>
<th>PERIGEE KM (NM)</th>
<th>AVERAGE ALTITUDE KM (NM)</th>
<th>TOTAL PICTURES</th>
<th>PICTURE RESOLUTION KM (NM)</th>
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<td>4/4/68</td>
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<td>260 hr, 9 min, 45 sec</td>
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</table>

**Footnotes:**
1. Values are not meant for scientific purposes; they should be used only as a guide to the size and shape of orbit.
2. Where applicable, total number of pictures is cited for those satellites which were no longer in operation by 31 December 1966. Picture rate (time needed to take one picture) is cited for operational spacecraft.
3. Where values are applicable, resolution is measured at the subsatellite point. For example, the Nimbus 2 HRIR at an altitude of 1,000 km (5,955 NM) has a subsatellite ground resolution of 9 km (55 NM).
4. Color pictures from ATS 3 are available only through January 1968. Black and white pictures are presently received using the green signal.
5. Although launch date for ATS 3 was 11/3/67, the MSSC system did not commence operations until 11/17/67, the camera became operational on 11/17/67.
6. The oceanographic value of Mercury photographs is difficult to determine; these flights are included for completeness only.
7. Apollo 4 and 6 were unmanned flights; pictures were taken automatically every ten seconds.

*W.A. = Not Applicable*
APPENDIX B

Glossary and List of Abbreviations

Glossary

APOGEE: That point in an orbit farthest from the center of the earth. (see perigee)

ASCENDING NODE: The point at which an orbiting body crosses the Equator northbound; identified by time and longitude. (see descending node)

ATMOSPHERIC WINDOW: An area which allows good transmission of infrared radiation through the atmosphere with minimum absorption by water vapor or CO₂.

BLIND ORBIT: An orbit during which a satellite cannot be interrogated because it does not come within range of any ground station, or when no ground station is available due to schedule conflicts.

DEGRADATION: The lessening of picture image quality because of noise or any optical, electronic, or mechanical distortions in the image-forming system.

DESCENDING NODE: The point at which an orbiting body crosses the Equator southbound; identified by time and longitude. (see ascending node)

GEO-SYNCHRONOUS ORBIT: A prograde orbit of 24-hour period; the satellite appears to hover motionless over a fixed location, normally on the Equator. Also called earth-synchronous. (see sun-synchronous orbit)
INCLINATION: The angle between the earth's equatorial plane and the orbital plane of a satellite. The angle is measured at the ascending node, counterclockwise from the equatorial plane, looking toward the center of the earth.

NADIR: The point on the celestial sphere opposite the zenith, i.e., the point directly "below" a satellite. (see subsatellite point)

NADIR ANGLE: The angle measured at the satellite between a given axis or ray and the local vertical.

PERIGEE: The point in an orbit nearest the center of the earth. (see apogee)

PROGRADE ORBIT: An orbit in which the satellite moves in the direction of earth rotation. (see retrograde orbit)

RESOLUTION: The ability of a film, lens, combination of both, or a vidicon system to render barely distinguishable a standard pattern of black and white lines.

RETROGRADE ORBIT: An orbit in which the satellite has a westward component of motion, i.e., an orbit against the revolution of the earth. (see prograde orbit)

SUBSATELLITE POINT: The point of intersection of the local vertical through the satellite with the earth's surface.

SUN-SYNCHRONOUS ORBIT: An orbit such that the satellite maintains the same local sun time at each Equator crossing. (see geo-synchronous orbit)
List of abbreviations used in this publication:

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>APT(S)</td>
<td>Automatic Picture Transmission (System)</td>
</tr>
<tr>
<td>ATS</td>
<td>Application Technology Satellite</td>
</tr>
<tr>
<td>AVCS</td>
<td>Advanced Vidicon Camera System</td>
</tr>
<tr>
<td>CDA</td>
<td>Command and Data Acquisition</td>
</tr>
<tr>
<td>ESSA</td>
<td>Environmental Science Services Administration or Environmental Survey Satellite</td>
</tr>
<tr>
<td>GSFC</td>
<td>Goddard Space Flight Center</td>
</tr>
<tr>
<td>HDA</td>
<td>High Daily Average</td>
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<tr>
<td>HRIR</td>
<td>High Resolution Infrared Radiometer</td>
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<tr>
<td>IDCS</td>
<td>Image Dissector Camera System</td>
</tr>
<tr>
<td>IRLS</td>
<td>Interrogation, Recording and Location System</td>
</tr>
<tr>
<td>ITOS</td>
<td>Improved TIROS Operational System</td>
</tr>
<tr>
<td>MRIR</td>
<td>Medium Resolution Infrared Radiometer</td>
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<td>MSSCC</td>
<td>Multicolor Spin Scan Cloud Camera</td>
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<td>NASA</td>
<td>National Aeronautics and Space Administration</td>
</tr>
<tr>
<td>NESC</td>
<td>National Environmental Satellite Center</td>
</tr>
<tr>
<td>NSDC</td>
<td>National Space Science Data Center</td>
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<td>NWRC</td>
<td>National Weather Records Center</td>
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<tr>
<td>SCC</td>
<td>Spin Scan Cloud Camera</td>
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<tr>
<td>TIROS</td>
<td>Television InfraRed Observational Satellite</td>
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<tr>
<td>TOS</td>
<td>TIROS Operational System</td>
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Satellites currently capable of acquiring oceanographic data are limited to those which record information by infrared radiometry, by television or by photography. Although other methods of oceanographic data acquisition from space are possible, these are the only methods in present use.

The use of infrared radiometry to examine the sea's surface thermal structure has been limited to the Nimbus satellites. Cloud interference has hampered the utility of these data; however, a selective method of compositing several days' data has indicated that this difficulty is partially surmountable.

Black and white television pictures of the entire earth's surface have come from polar orbited Nimbus and ESSA satellites while color and black and white pictures of the entire earth disc have been received from geo-synchronous ATS satellites. These television pictures may be used to measure the extent of ice cover and to infer water structure from related cloud cover. ESSA satellite data have been enhanced further by computer treatment of the televised pictures.

Color photographs of selected ocean areas have been taken during Mercury, Gemini, and Apollo missions. These missions are inherently restricted and the oceanographic information gained is opportune temporally and geographically. Despite this, examination of spacecraft photographs has revealed abundant examples of surface water structure.
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