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OCEANOGRAPHIC COMMENT ON APOLLO 501 MISSION PHOTOGRAPHY

Don Walsh, et al

Texas A&M University
College Station, Texas

November 1967

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OCEANOGRAPHY 52

OCEANOGRAPHIC COMMENT ON APOLLO 501 MISSION PHOTOGRAPHY

by

LCDR Don Walsh USN
James E. Arnold

30 November 1967

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The work reported herein is of a preliminary nature and the results are not necessarily in final form.

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LIST OF FIGURES

* Note: The reader is cautioned that these figures are photographic reproductions of color prints. The fidelity of reproduction is poor and serious study of these details can be accomplished only by obtaining copies of these prints from the NASA Manned Spacecraft Center at Houston.

ABSTRACT

This paper resulted from requests by the U.S. Naval Oceanographic Office and NASA Manned Spacecraft Center, Houston for an oceanographic appraisal of earth photography taken by the APOLLO 501 Mission on 9 November 1967.

A total of 755 70 mm color photographs were taken on this mission by a Maurer camera sighted through the pilot's window in the capsule. The area of photographic coverage was of the South Atlantic Ocean and Antarctica as seen from the tip of Africa. The altitude of the pictures ranged from 7,450 to 9,850 miles, however, coverage was limited by the location of the earth terminator along the west coast of Africa. As a result only a crescent shaped portion of the earth is seen.

Analysis of the information content of this photography was limited by a lack of hard data on surface oceanographic and meteorological conditions for the day of the mission. The authors therefore have relied on climatological data published in standard references as the basis for interpretation. This means that long term records were applied to analysis of a single day's conditions accepting the strong possibility of induced variance between the long and short term situations. One cannot consider this photography to be "data"; it is "information" and must be regarded in this light. In short, this analysis

provides educated speculation on this material as developed by an oceanographer and a meteorologist.

The goal of this speculation is to see whether or not future missions in this series should carry cameras and under what conditions should they be programmed.

As a result of this analysis the following recommendations are made:

1. As a minimum, a camera should be installed for the APOLLO 502 Mission in January/February 1968.

2. Pre-mission planning must include scientific pre-planning of photograph paths and must consider ground truth.

3. Photography should be a permanent part of all missions in this series. This will establish an early scientific return for the APOLLO Program.

4. The APOLLO photography should be published in an atlas format to increase scientific exposure of the data.

5. Considerations should be given to multi-camera installations. This will permit utilization of various photographic emulsions and filter combinations.

ACKNOWLEDGEMENT

The authors wish to acknowledge the assistance of Mrs. Rosemary E. Boykin of the Space Oceanography Project who did the bulk of the figures for this report.

Thanks are extended to Dr. John Dornbach of the Mapping Sciences Branch, NASA Manned Spacecraft Center in Houston for furnishing the APOLLO 501 Mission photography and supporting information.

BACKGROUND

The APOLLO 501 Mission which flew on 9 November 1967 was equipped with a 70 mm Maurer camera equipped with a 76 mm Kodak ektar lens and loaded with Kodak 368 Ektachrome film. A total of 755 photographs were taken of the Earth at altitudes varying from 7,450 to 9,850 miles. Despite the fact that there was no scientific pre-planning for photography of key earth features, these color photographs of the earth provide an important insight into the possibilities of this type of application. The total film capacity of the camera was expended in the span of two hours and twelve minutes during the third orbit while the spacecraft was being boosted out to its apogee of 9,850 miles. These results mark the highest photographic emulsion imagery ever made of the earth.

The Space Oceanography Project (SPOC) at Texas A&M University was invited on the 3rd of November 1967 to participate in the scientific viewing of this photography by Dr. C.C. Bates, Technical Director of the U.S. Naval Oceanographic Office. On the 13th of November a small group of scientific personnel from various activities met at the NASA Manned Spacecraft Center in Houston to examine the results of this mission. The Space Oceanography representatives in this group were the author and Dr. Robert Stevenson of the Bureau of Commercial Fisheries Laboratory at Galveston, Texas.

At the completion of the initial appraisal of the photographic data it was agreed that both Dr. Stevenson and the SPOC Project at A&M would prepare papers commenting on oceanographic features found in these pictures.

The copies of the photographic coverage (duplicate transparencies), and other data were received by the SPOC Project at A&M on the 22nd of November. The "other data" consisted of three color prints of key photographs, maps of the three 501 mission orbits, an overlay of the photographic part of the third orbit, and photographic reproductions of the ESSA 3 satellite coverage (passes 5060-5072) over the area in question on the date of the mission. No current meteorological or oceanographic ground truth data were available at the time of preparation of this paper.

PURPOSE AND SCOPE

The purpose of this comment is to provide an evaluation of the oceanographic features in this photography. While this imagery cannot be considered as "data" it does have informational content which may lead to insights as to how future mission photography can be profitably programmed and exploited. From this evaluation it is hoped that sufficient interest can be generated for a programmed photographic experiment on future missions of this series.

The scope of the paper is to regard the South Atlantic and the Antarctic region essentially as an air-sea system where surface circulation patterns can be interpreted in terms of cloud patterns or lack of same. For this reason meteorology plays a major role in this analysis. The scale of this photography is far too large to permit consideration of finite features; therefore the use of general climatological and oceanographic data from standard reference books is utilized. The various key features of the ocean and atmosphere in this region are displayed on a series of chartlets which are keyed to the photography of the region. A correlation is drawn between the historical (climatological) data and the situation as seen by the camera.

COMMENT

I. General comment:

1. The quality of the photography. This photography is technically excellent and far superior to any of the electronic imagery transmitted by unmanned satellites. While this remark is a truism it relates to the continuing importance of photographic imagery. The photography argues for the expanded use of cameras in this program.

2. Obscuration of land features. Study of the photography (with a light table and binocular microscope) reveals no clear indication of coastal areas in any of the exposures with the exception of a small portion of the west coast of Africa. Some other land areas are undoubtedly visible but they are not readily apparent due to cloud cover and lighting angles.

3. Lack of ocean detail. While the ocean surface is visible in the photographs as blue patches of varying shades there is no detail as was seen in the lower altitude GEMINI photography where color and circulation patterns were visible. With the exception of the glitter pattern the photography really breaks down into a dichotomy of "cloud and non-cloud".

4. The importance of cloud patterns. In space oceanography work one must look through an ocean of atmosphere before "seeing" the ocean of water. Atmospheric attenuation and obscuration must be understood and utilized to obtain data from the ocean surface. The APOLLO 501

Mission photography is dramatic evidence of the importance of understanding how cloud patterns relate to sea surface circulations and how they mirror ocean temperature patterns. This point is the main thrust of the paper. Such a concept is also important in the use of the more conventional remote sensing forms such as IR and microwave, etc.

5. Information versus data. Since the photographic coverage from this mission was not pre-programmed scientifically for specific areas one must consider it to be "information" rather than "data". No real numbers were available (at the time this comment was prepared) to correlate photographed weather patterns with hard weather data from this region nor was any ground truth available from oceanographic stations in the area. Thus, the comment must remain quite speculative... an educated guess. Nevertheless this does provide a useful insight into the viability of programming future efforts on a more scientific basis.

II. Specific comment:

As can be seen from Figure 1, the flight path of the APOLLO 501 Mission at the time the photography was taken passed from the tropical Atlantic near the western tip of Africa southwestward over Rhodesia and into the Indian Ocean. Maximum altitude of the vehicle was reached slightly southwest of Madagascar. The vehicle itself at the time of photography was over the terminator region so the photographs show the earth as a crescent. The illuminated portion of the globe, as seen in the photographs, extends from Central Africa to the extreme eastern part of South America. Camera altitude was such that good photography was obtained of a portion of the earth that is predominately water covered. Before the water or ocean can be observed, however, one must view through a sea of air and its contaminants, clouds, etc. In this respect, it is desirable to examine the ESSA satellite imagery for the overall cloud picture at the time the APOLLO photography was made.

The ESSA 3 photography (imagery) on November 9 is shown in Figure 2. The photography itself is a composite of several orbits of coverage and cannot in the strict sense be considered synoptic, as is the APOLLO photography. It can be seen that the region photographed on the APOLLO mission was dominated by at least one major low pressure system with their associated frontal systems extending northward toward the subtropics. In Figure 3 the major cloud features over the oceanic area have been transposed to a map base common to other chartlets used in this report. Prominent features common to both the ESSA and APOLLO photography are labeled.

Fronts and schematic streamlines have been shown in Figure 4. The area under discussion is dominated by a maritime polar air mass extending southwestward from the Antarctic with the leading edge marked by a well defined cloud band. A secondary Antarctic front is probably present with an important and prominent feature behind the Antarctic air mass being the cellular cloud form region. The area equator-ward of the

maritime polar air mass is dominated by the subtropical high common in that region. The area of the Intertropical Convergence Zone, although not apparent in the ESSA photograph shown, lies along the southern coast of Western Africa toward South America.

As can be seen from Figure 2, much of the oceanic area is cloud covered. Since it is the ocean surface we want to examine in this case and not the atmosphere, utilization must be made of indirect observations to infer the oceanic condition. This is true in the infrared as well as the visible spectrum and to some extent in the microwave. In this aspect it is useful to examine the color gradiations, resolution and obscuring features over and on the ocean surface.

The APOLLO photographs (Figures 5 and 6) may be preferred to the ESSA photographs shown in Figure 2 for general reference to major meteorological features useable to infer oceanographic information and their locations. In the APOLLO pictures themselves, it is possible to gain both direct and indirect information about the ocean surface as to temperature and surface conditions from six basic features. These are:

1. Sun glint pattern.
2. Development of open cellular cloud patterns in the continental air behind the Antarctic front.
3. Closed cell and strataform cloud mass off the southwestern African coast.
4. Oceanic cumulus configuration in the subtropical ocean.

5. Cloud patterns, i.e. major frontal features, to infer general atmospheric flow and induced oceanic circulation.

6. Ice location.

A basic outline of the features listed above, their location in the APOLLO photography, and their use in oceanic measurements is developed in the next section.

When viewing into the sun, the reflection of the sun on the ocean surface is readily apparent, note feature A in both Figures 5 and 6. The geometric considerations will not be dealt with here however, as the surface roughness increases the area of sun glint on the surface will become more diffuse. The general size and intensity of the sun glint itself serves as an indicator of the surface roughness and changes in glint density are indicative in changes in surface roughness of the ocean surface. In the present APOLLO photography, detection of these features seems especially promising as it is one feature which intermittent cloud cover does not greatly obscure. A region of prominent gradiation of sun glint density can be seen at A-1, where dark spots appear. A comparison between this area of Figure 5 and 6 reveals that with the changing viewing angle the intensity of the dark area changes to the point that it is no longer present by the time frame 410 is taken, some 38 minutes after frame 200. As the sun glint in the present series covers an area with a radius of about 10 degrees of latitude about the sun glint point it can be seen that a large area of the ocean surface can be examined for roughness by this method.

Measurement of the ocean surface temperature, a highly desirable capability, is somewhat restricted by cloud cover. Combined with remote sensing techniques in the infrared, microwave, etc., which are greatly limited by cloud cover, observation of the low level cloud field over oceanic areas can provide valuable information. It is generally recognized that the ocean and the atmosphere are in a very delicate balance in the boundary layer, thus each tends to reflect in each other very small changes in parameters such as temperature differences and wind flow in the friction layer of the atmosphere. Although the problem is by no means solved in the atmosphere, in fact far from it, concepts known to apply may be used to make inferences as to the space and time temperature changes of the ocean surface through the use of the oceanic low level cloud field. In the APOLLO series three different ocean-atmospheric cloud development types are observed.

The first and widely observed feature is the open cell convection behind the Antarctic front, labeled B in Figures 5 and 6. Such a cloud pattern is common in cold air that is carried over warmer water. This feature is commonly observed in the North Pacific. The intensity of the circulation, inferred from the distinctness of the cells is a function of the air-sea temperature difference while the cell size is greatly dependent on the depth of the vertical atmospheric circulation in which the cell is established, i.e. the height of the atmospheric temperature inverstion in the area.

A second region of sea-air interaction cloud pattern can be noted in the area designated as C in Figures5 and 6. These are the general oceanic cumulus clouds existing over areas where the sea is slightly warmer than the ocean, usually about one degree. The top of the clouds are usually situated at the base of the inversion dominated lower atmosphere in the tropics and immediate subtropics. A general idea of the wind stress in this region can also be obtained by the fine curling or meandering cloud bands which are especially notable in the vicinity of C. The height and intensity of the inversion in the region can be seen in Figure 9.

The third region of cloud patterns as a result of the sea and air interaction can be seen in Figures 5 and 6 in the region labeled D. Here a dense strataform cloud cover can be seen in the general area of cold water (shown in Figure 8). Such a cloud pattern is common when warmer moist oceanic air flows over a region of significantly colder water. This particular phenomena is common to the California coast, of which the western South African coast is a direct analogy.

While the specific mechanism operating in the formation of the three general cloud areas pointed out is uncertain (this type of circulation is generally referred to as Benard cell circulation) and thus immediate use of the knowledge of the particular cloud forms and its application to determining the sea surface temperature is difficult, several inferences of great importance can be made. First, it gives a direct picture of the direction of the heat flux from the ocean to

the atmosphere and is thus important in the prediction of ocean surface temperature changes. To some degree it gives us an idea of the ocean surface temperature as we do have some idea of the gross temperature fields of the ocean and the atmosphere. Perhaps of even greater significance, a general idea of the spatial variation of the ocean surface temperature can be inferred and used to determine the extent of departure from the normal or situation.

From the large scale flow features as depicted by general atmospheric frontal structure and cloud banding, an idea of the air motion at the ocean surface may be obtained. Such information can act as input data to determine the surface water movement and wave generation.

The average current direction and speed is shown in Figure 10. It can to seen on comparing the frontal structure and inferred from the atmosphere that there is close agreement. It would seem possible to determine departures of the oceanic circulation from the mean as a function of the global or hemispheric knowledge of the atmospheric motions and its short term changes.

In addition to the cloud and ocean areas visible there is a large area covered by the Antarctic ice pack. This is especially prominent in Figure 6. It is anticipated that knowledge of the ice structure and its geographic extent can be accurately determined from photographs of this type and used to gain information as to polar circulation. In this aspect perhaps color changes and gradations in the ice field will also aid in determining structure and type of sea ice from space.

FIGURE 1.

The flight path of the APOLLO 501 Mission during the photographic period. Flight altitudes and camera on - off times are shown.

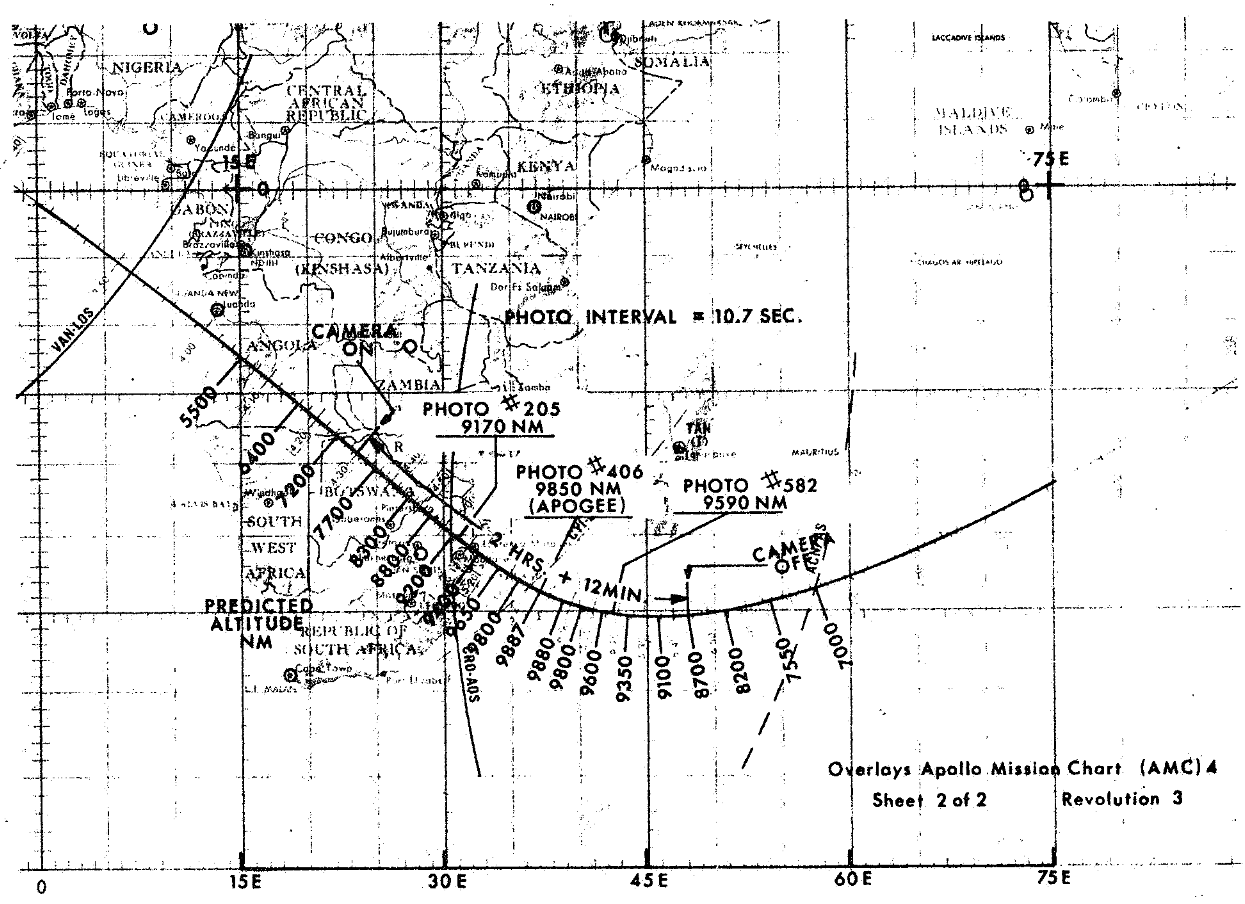
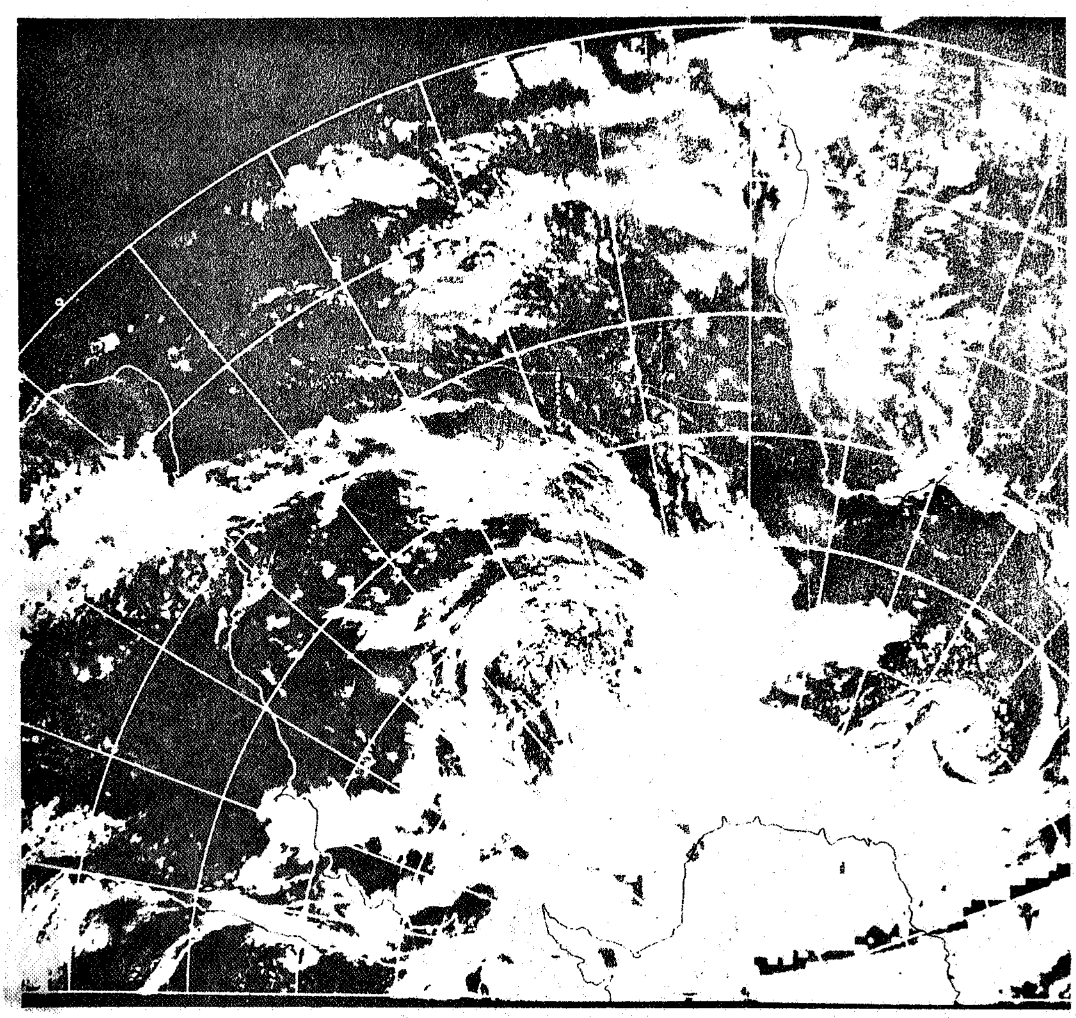


FIGURE 2.

ESSA 3 weather satellite imagery of the area of interest taken on passes 5060 - 5072 on 9 November 1967. Outlines of South America, South Africa and the Antarctic are shown. The grid spacing for latitude and longitude is 10°.



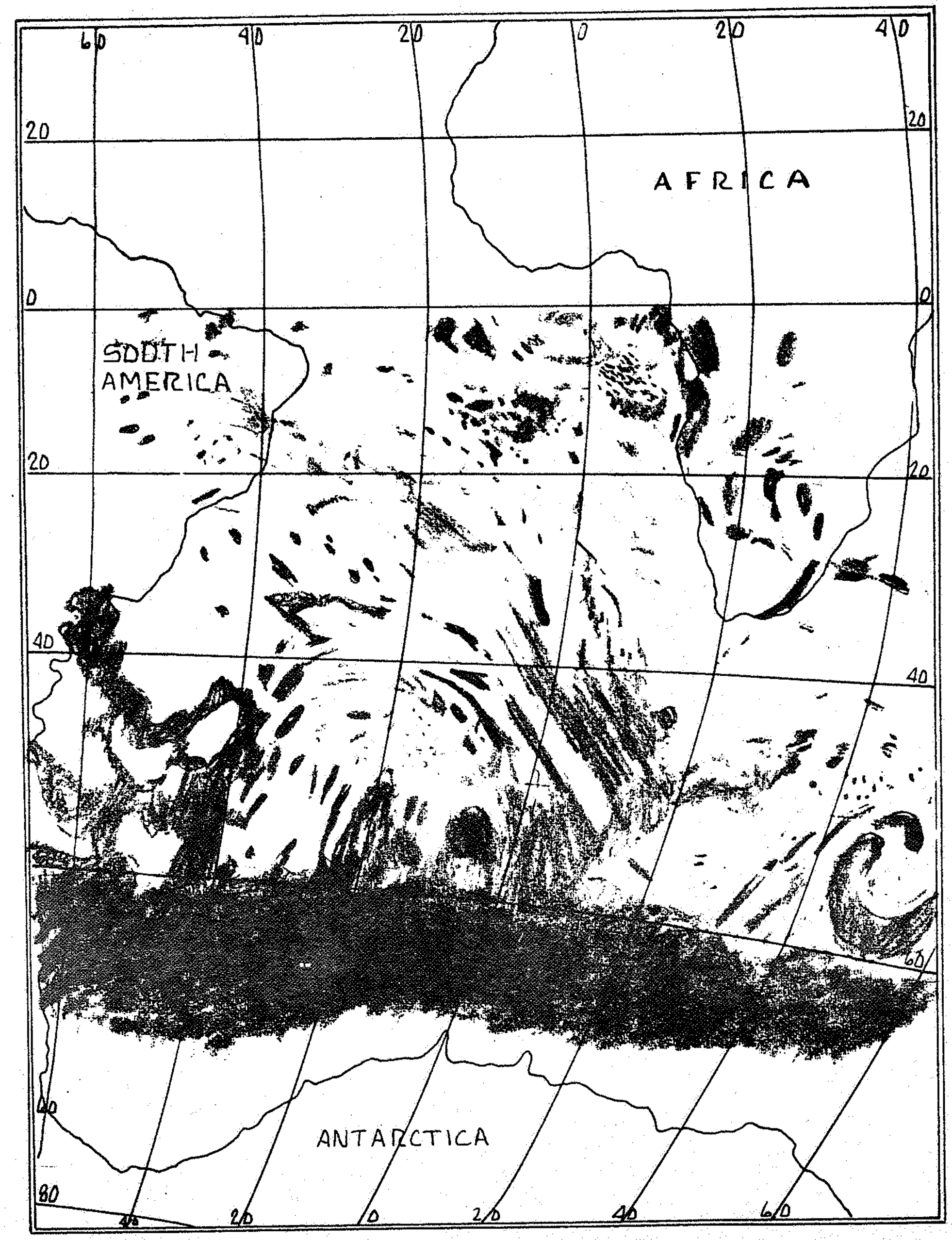
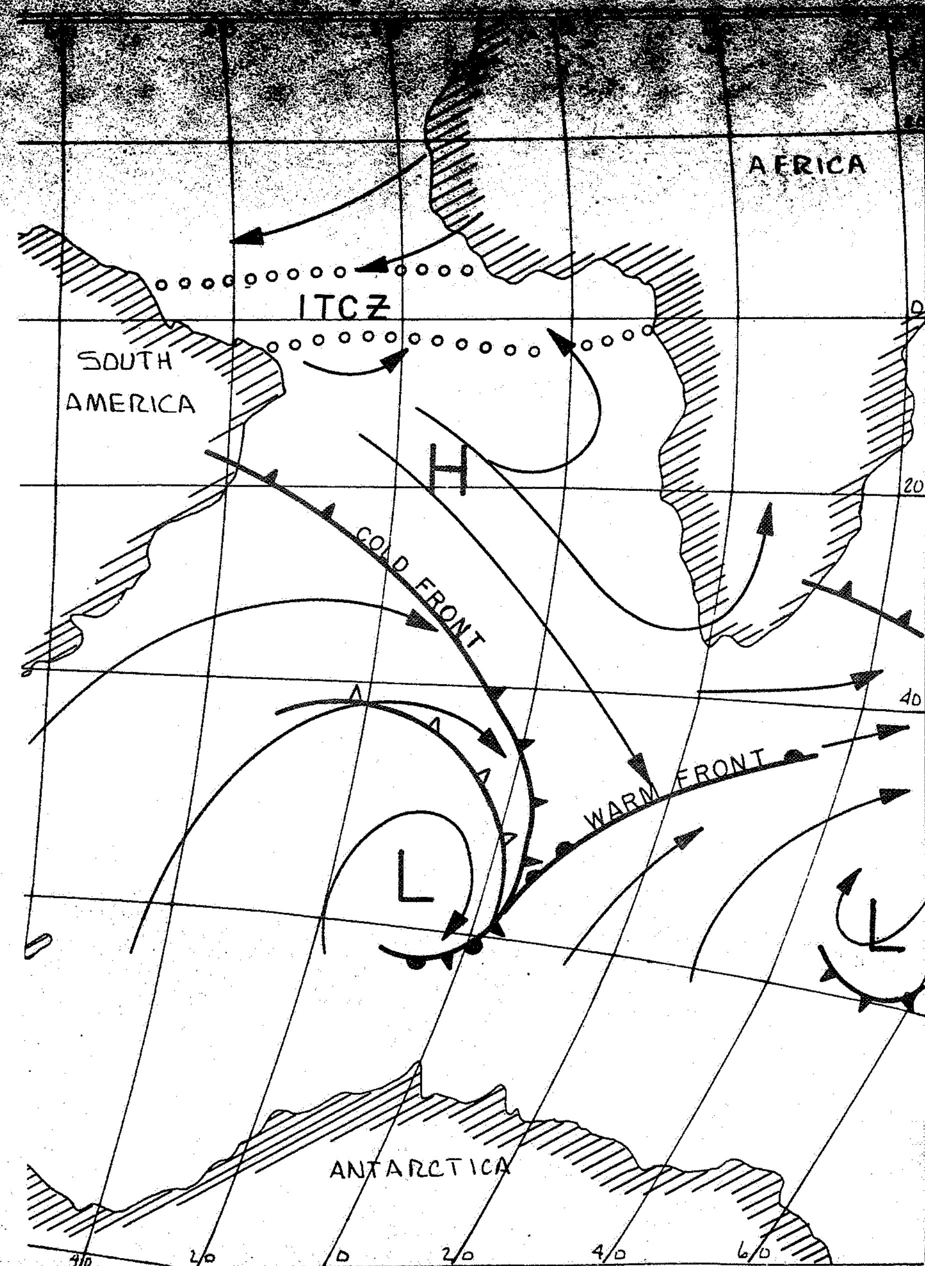


FIGURE 3.

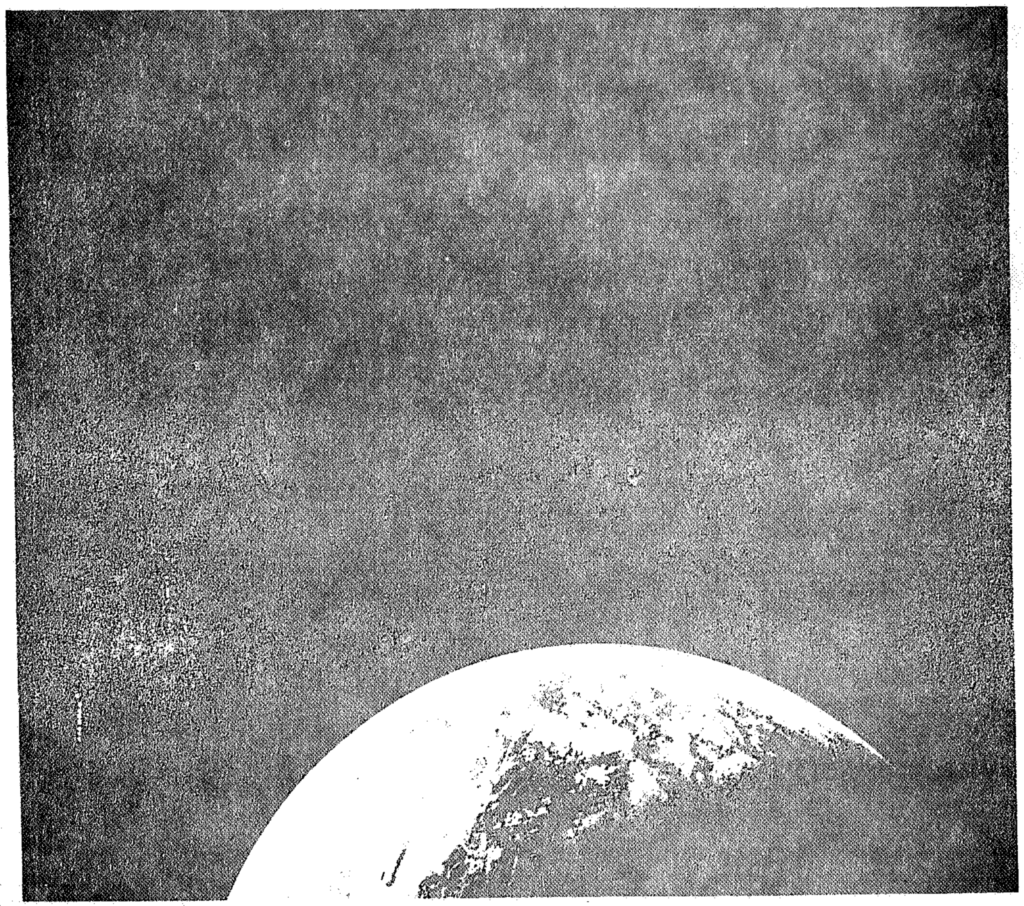
This is a schematic representation of the oceanic cloud patterns shown in Figure 2.

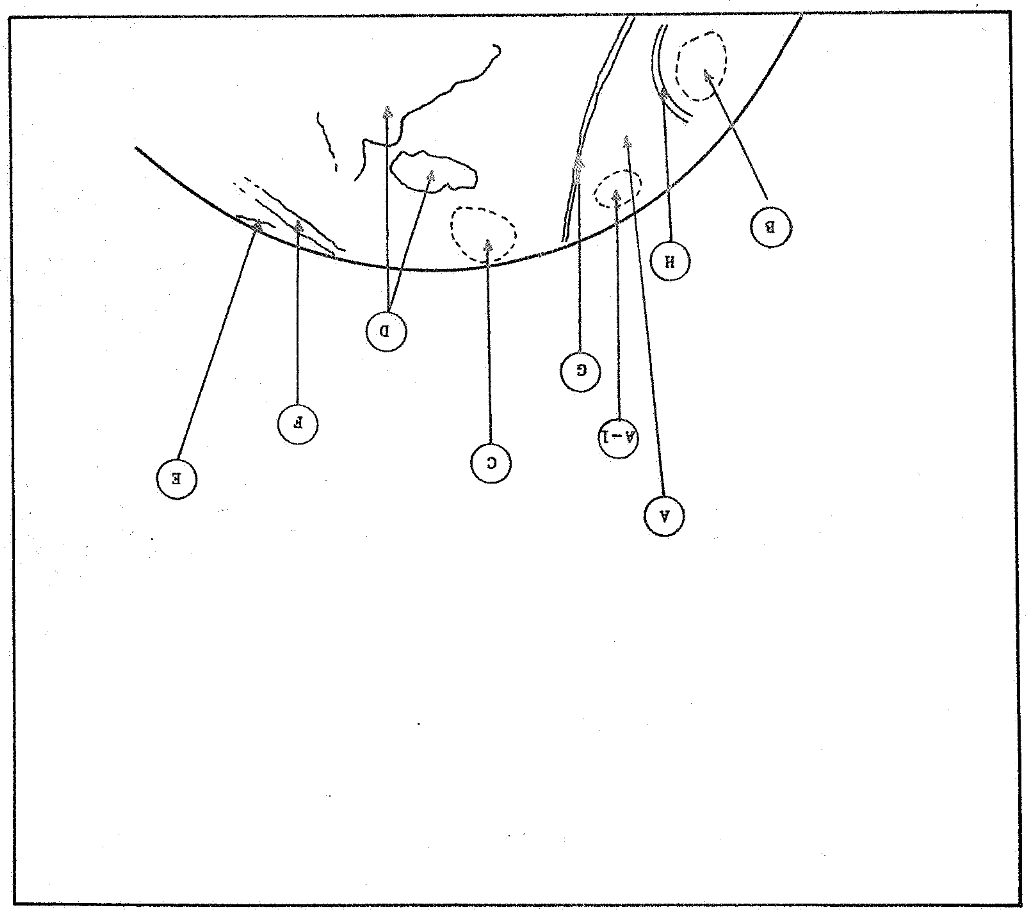
FIGURE 4.

Interpretation of meteorological features in the area of photographic coverage shown in Figures 2, 5 and 6. While the ESSA satellite coverage provides the bulk of this information the oblique coverage of the APOLLO photography was also used.



21-B





21-A

OVERLAYS MSC AS 4-1-200

KEY FEATURES

A. Glitter pattern. The characteristic bright region indicates reflection of sunlight from the sea surface.

A-1. Area of possible surface roughness. The indicated dark areas appear to be shadows on the ocean surface but analysis of other shadow patterns in the glitter area indicates that these dark spots probably are areas of greater surface roughness than the adjacent region.

B. Cellular cloud forms. The cold Antarctic air over warmer water shows in these cellular cloud forms behind the second frontal zone.

C. Subtropical oceanic cumulus. As with B above these clouds are formed by having warm water under cooler air.

D. Inversion dominated cloud patterns. These patterns reflect the situation of warm, moist air over a cold ocean.

E. Clear area off central west Africa. This area is located off Mauritania and marks a region where warm dry air flows out over the coastal waters.

F. Banding of the Intertropical Convergence Zone. The characteristic two band, east-west, structure of the Intertropical Convergence Zone can be seen near the equator.

G. Maritime polar front. This front is also shown in Figure 6.

H. Antarctic front. This front marks the northern arc of the low pressure system.

NOTE: Solid lines follow general trend of linear features and dashed lines indicate general areal coverage of regional features.

FIGURE 5.

NASA/MSC photograph MSC AS41-1-200. This is photo 200 of 755 taken on the mission. The overlay shows the area of coverage with a key to visible features. The page following explains the keyed features.

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KEY FEATURES

A. Glitter pattern. The characteristic bright region indicates reflection of sunlight from the sea surface.

A-1. Area of possible surface roughness. The indicated dark areas appear to be shadows on the ocean surface but analysis of other shadow patterns in the glitter area indicates that these dark spots probably are areas of greater surface roughness than the adjacent region.

B. Cellular cloud forms. The cold Antarctic air over warmer water shows in these cellular cloud forms behind the second frontal zone.

G. Maritime polar front. Location of this front is also noted on Figure 5.

I. Antarctic and its pack ice. The observation of the cloud pattern around the large low pressure area (the vicinity of the glitter pattern) indicates that the cutoff area to the south must be the ice pack rather than a deck of hard stratus clouds. The actual edge of the pack is not clear but careful inspection of the photography shows details of both Antarctica and the ice pack. Some cirrus and middle level clouds are located over the Antarctic which tend to blend in with ice features on the continent itself.

J. Large apparent clear area south of the Indian Ocean. This area appears to be centered at 60° South latitude and about 90° East longitude. A clear area in this region, according to climatological records, is not typical.

K. Upper level jet stream cirrus. This upper level pattern can be seen as a fairly sharp line in an east-west orientation.

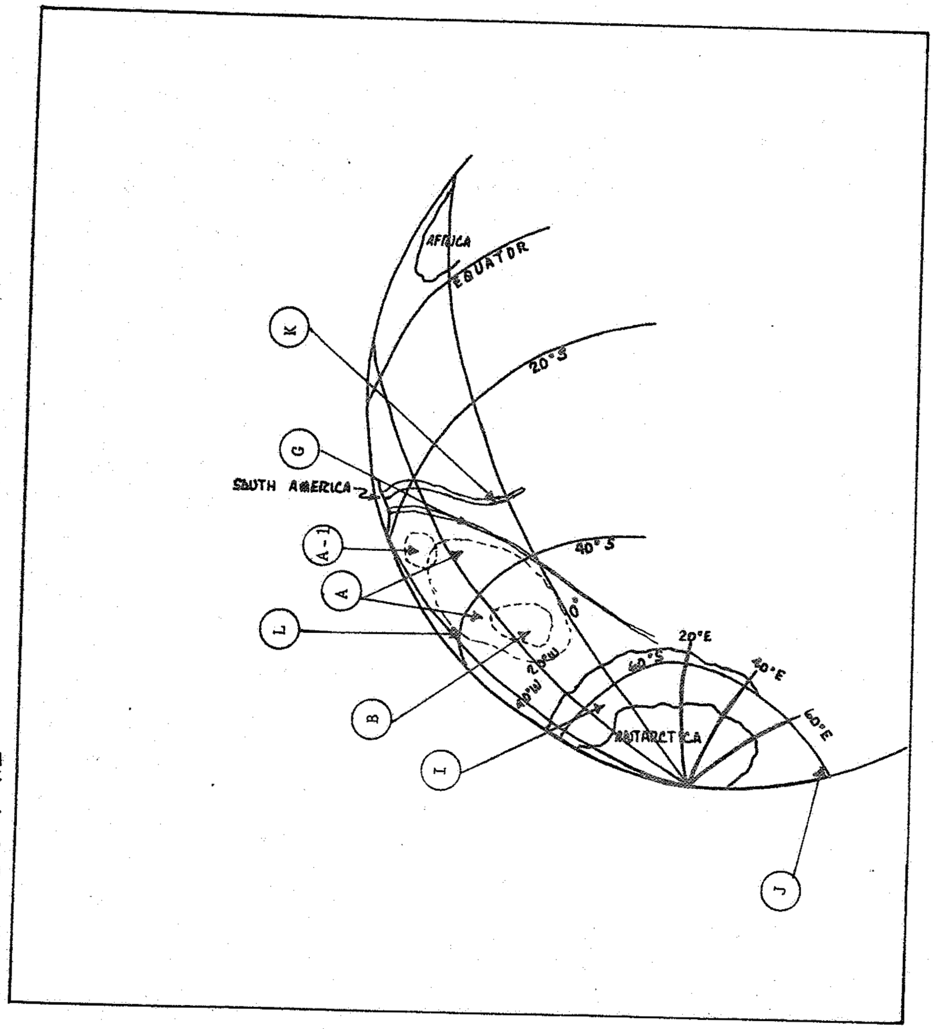
L. Large low pressure area. The extent of this depression can be seen on the ESSA satellite imagery in in Figure 2.

NOTE: Solid lines follow general trend of linear features and dashed lines indicate general areal coverage of regional features.

FIGURE 6.

NASA/MSC photography MSC AS4-1-410. This is photo 410 of 755 taken on the mission. The overlay shows the area of coverage with a key to visible features. The page following explains the keyed features.

OVERLAYS MSC AS 4 -1-91D



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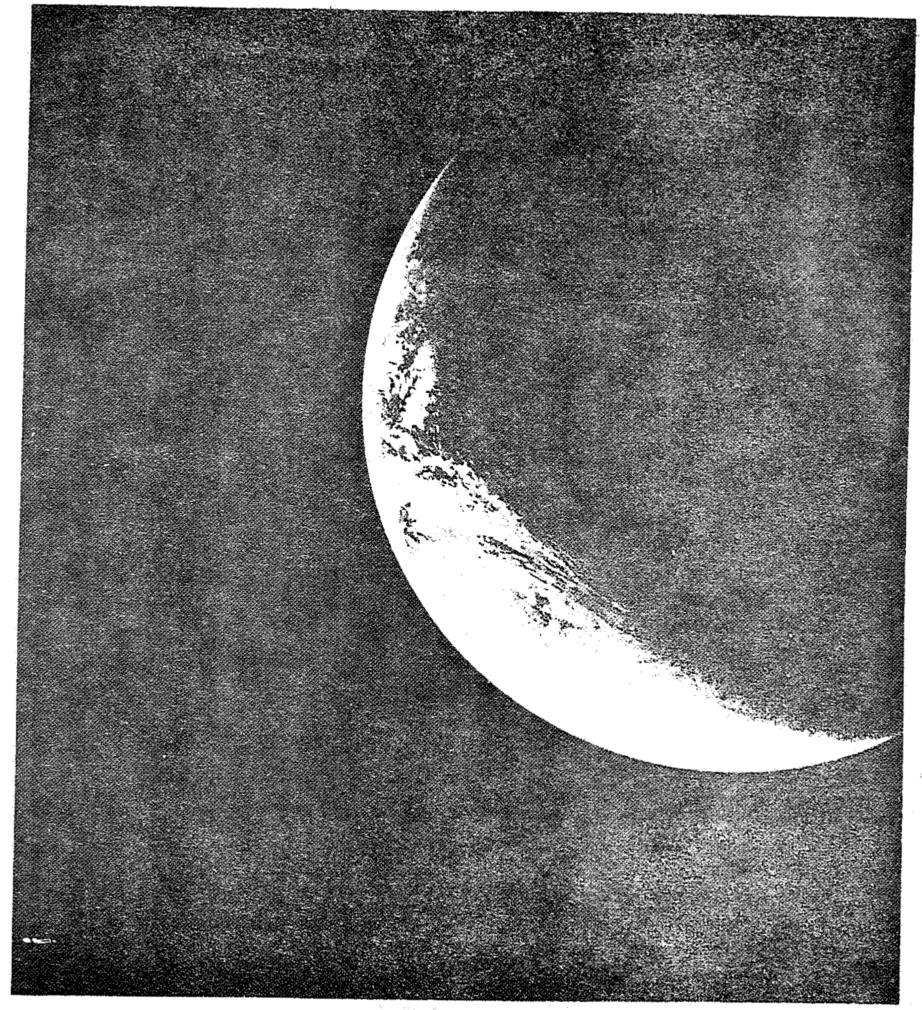

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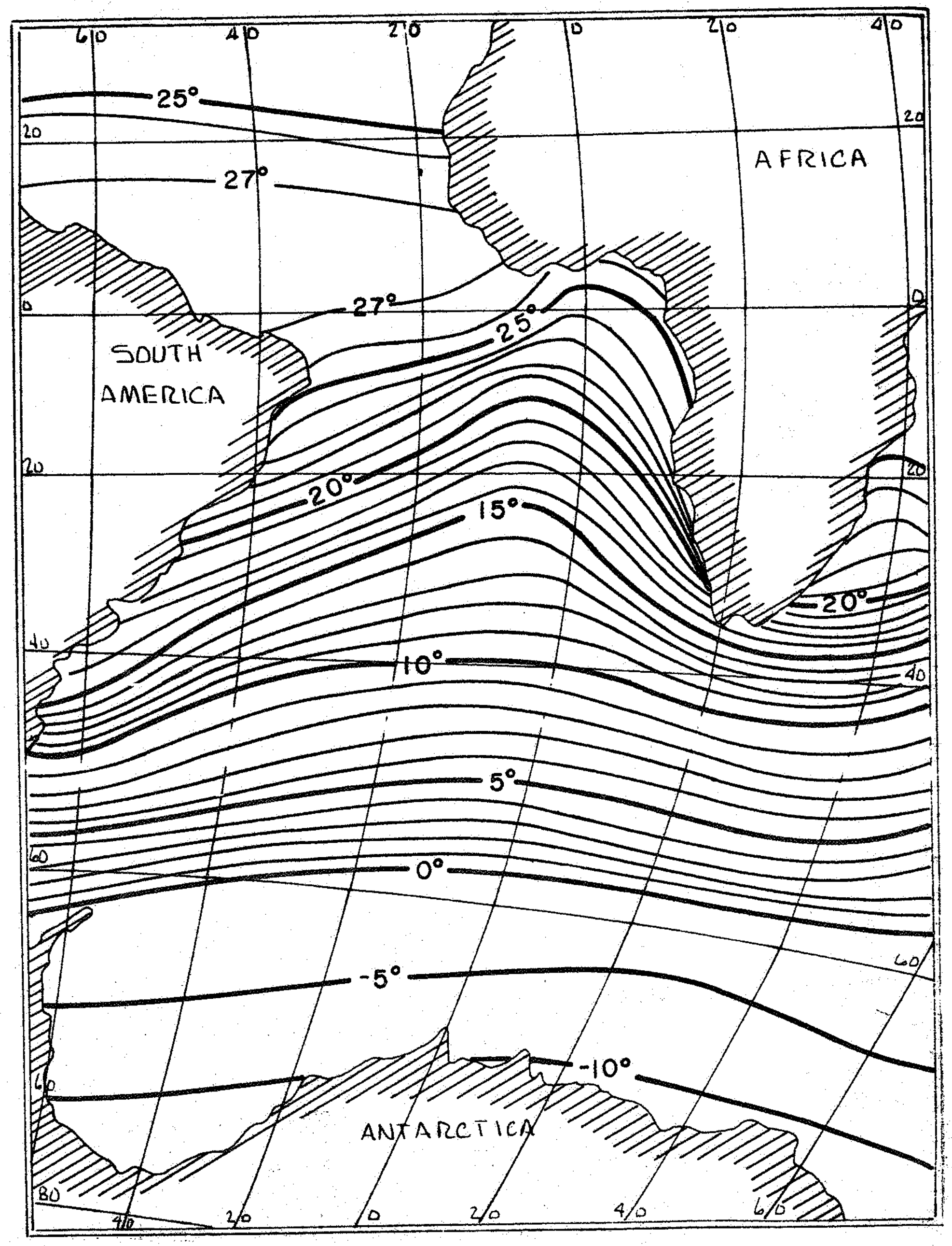
FIGURE 7.

Overlay representing climatological surface air temperatures for November.

FIGURE 8.

The sea surface temperatures for November. By overlaying Figure 7 the temperature gradients between the ocean and atmosphere at the surface can be seen. These differences lead to energy fluxes which influence cloud patterns.



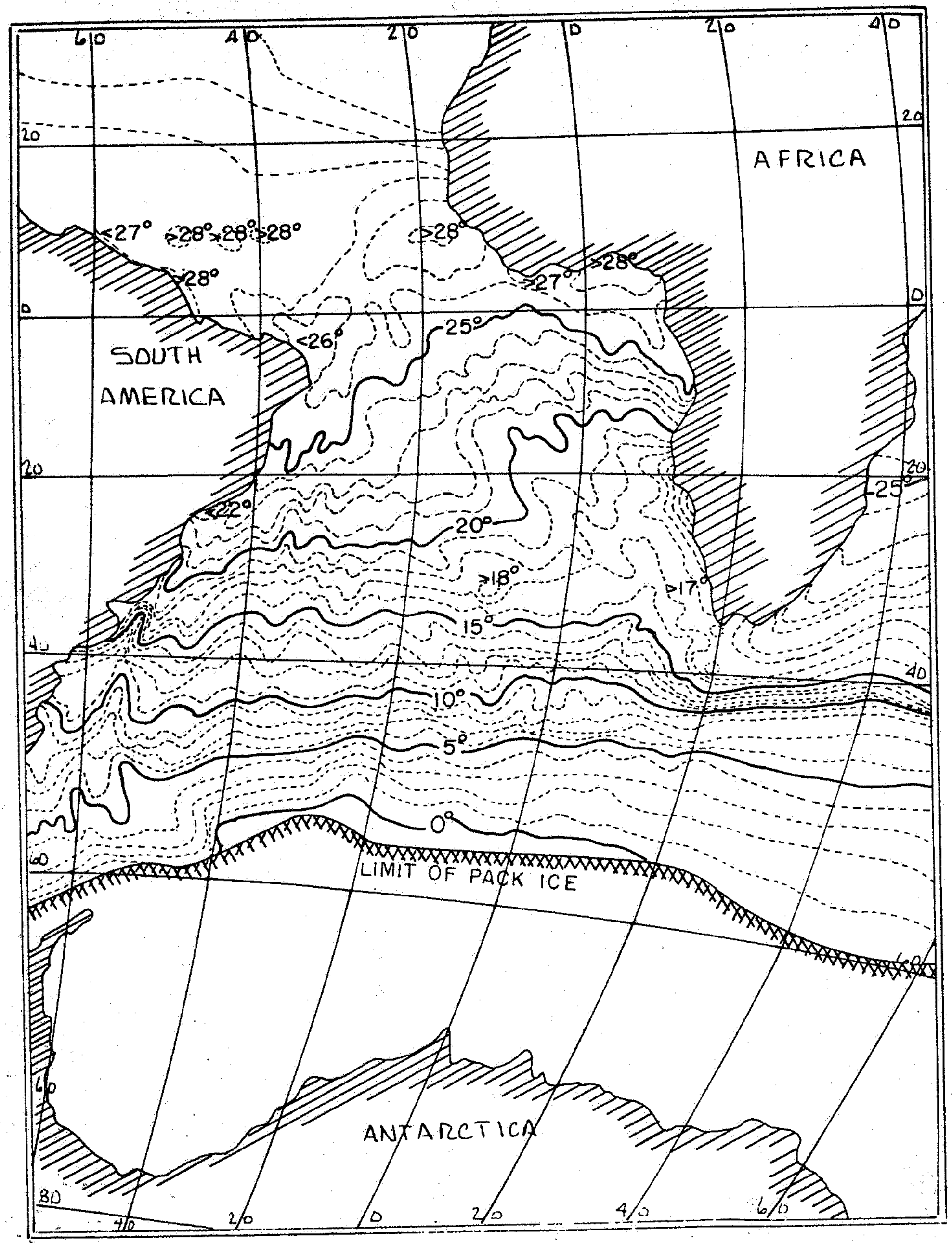


FIGURE 9.

Climatological representation of inversion heights and strengths in the tropical Atlantic. The strength and intensity contributes to the form of cellular convection observed in the observed region.

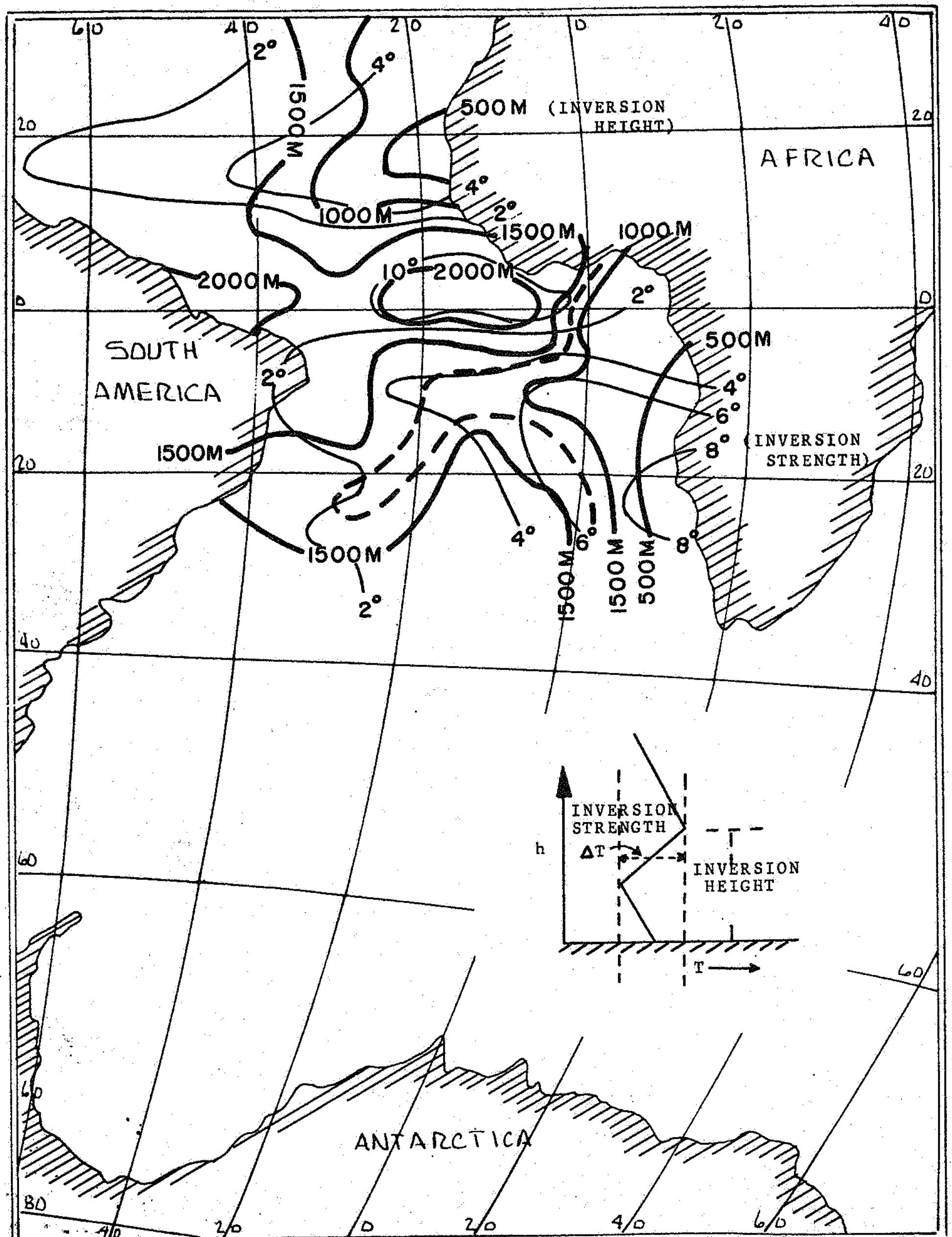


FIGURE 10.

Sea surface circulation in the area of interest. The arrows represent current velocities in the range of 0.5 to 2.0 knots. The heavier arrows indicate the highest current velocities.

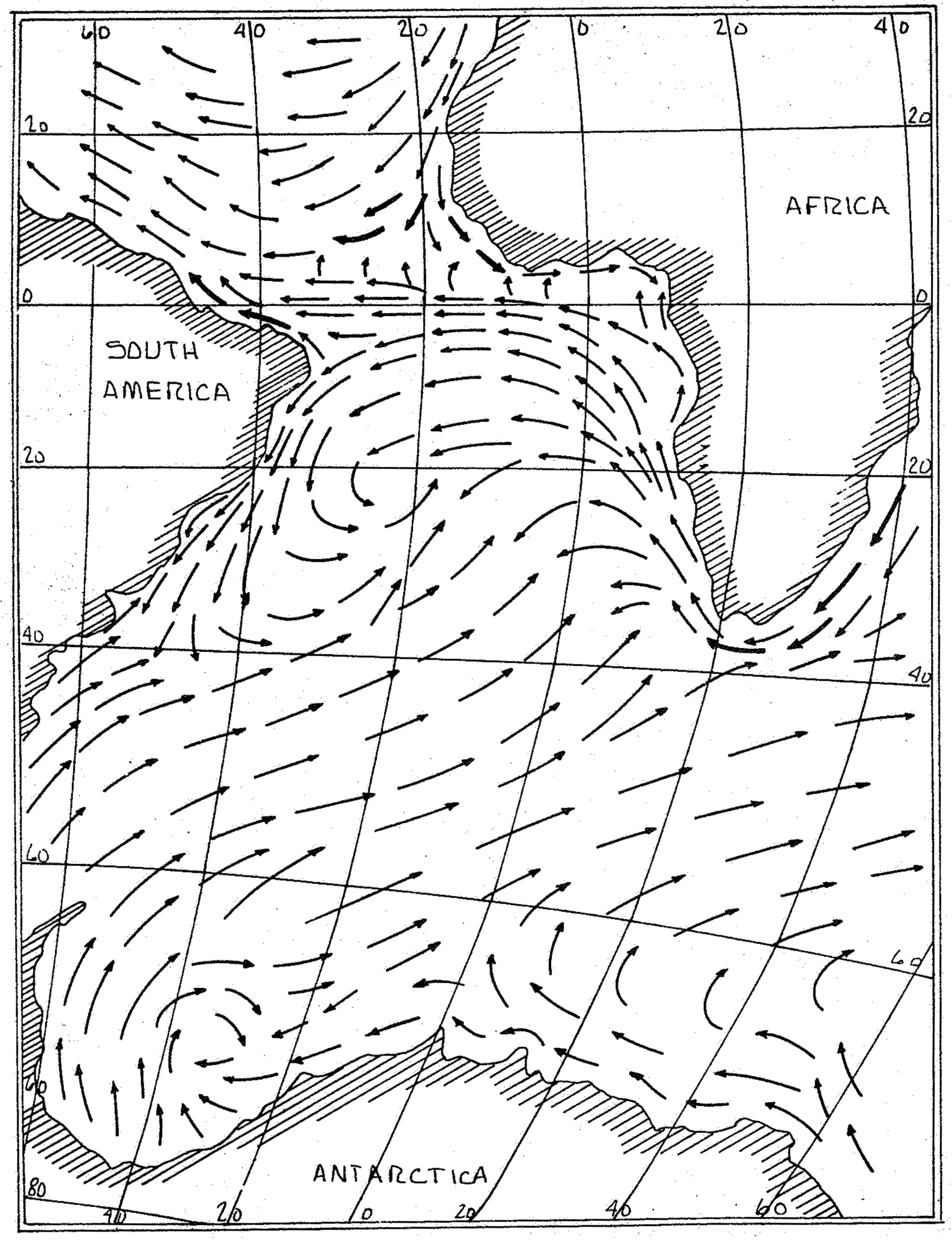
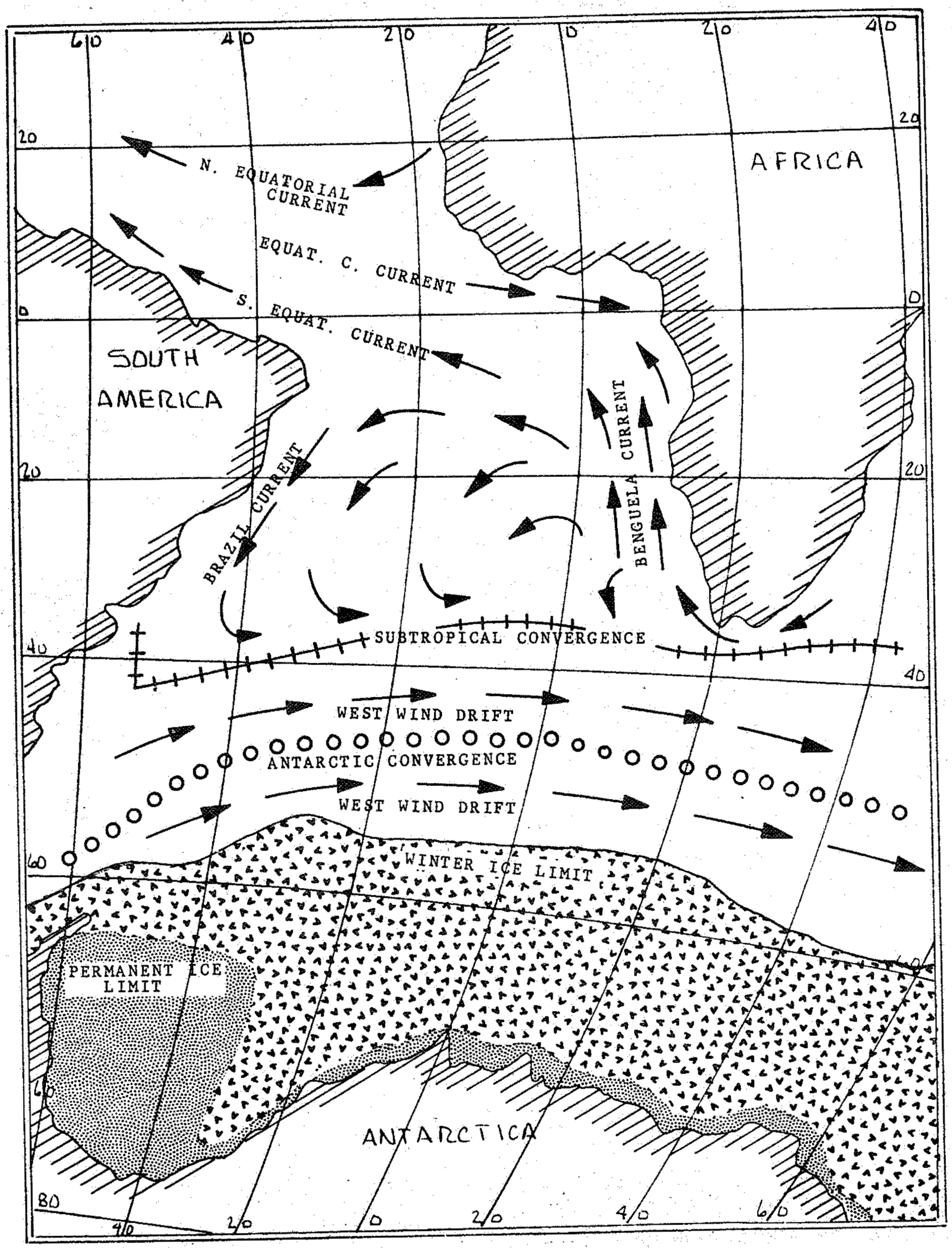


FIGURE 11.

Nomenclature of principal currents and other major oceanographic features of a semi-permanent nature in the area of interest.



CONCLUSIONS

1. Photography from all earth orbital missions can be scientifically important. The quality of this photography coupled with pre-programming of photo coverage could give the earth scientist new perspectives on areas of interest. The lower altitude GEMINI missions have already proved this.

2. The study of cloud patterns over the oceans must receive greater emphasis. It is apparent from this photography that synoptic data on ocean surface conditions can be greatly enhanced through understanding the relationship between cloud patterns and surface temperature patterns on the ocean.

3. Ground truth must be emphasized in pre-mission planning. Without some solid "numbers" from weather stations and oceanographic platforms much of the photography of this type will have to be analyzed in a speculative manner. This can be productive in developing generalized information and in planning future requirements but only hard data from the ground can lead to significant data for spacecraft oceanography. The lead time for establishing ground truth is much greater for the oceans than for terrestrial applications. This problem should be investigated now.

4. Pre-mission programming of photography is important to obtain optimum results. Since the costs of camera installation and operation are relatively fixed in this type of mission it is only on the flight

path where the camera is operated that determines scientific value of this installation. For example, photography from the highest part of the orbit in the 501 mission cannot be faulted but it is questionable if all 755 photos needed to be shot at essentially one point. A premission program, developed by appropriate environmental scientists, would have insured final results far more spectacular and considerably more useful from a scientific point of view.

5. A properly planned earth photography program can lead to early scientific payoffs for the NASA Earth Resources Survey Program. The degree of pre-planning outlined in paragraphs 1 through 4 above can mesh with the early APOLLO missions without any significant interference in the primary goals of these missions. The payoff in this photography would permit key areas of the Earth Resources Survey Program to move forward well in advance of the APOLLO Applications Program Mission 1-A in 1969. This will maximize NASA's investment in each and every mission.

RECOMMENDATIONS

1. As a minimum requirement, a camera should be installed for the APOLLO 502 Mission in January/February 1968. A select scientific team should be appointed to work out the photographic tracks for this mission and to provide an "on - off" schedule for the camera to be used by the NASA mission control personnel. Early appointment of the team would provide for adequate prior study of key earth areas and resolution of conflicting data interests between air, sea, and land scientific disciplines.

2. Pre-mission planning must include ground truth. Some ground truth, such as weather, requires only notification to appropriate agencies of a forthcoming data requirement on a specific data; while other requirements, such as oceanography will require prior determination of what ships will be in areas of interest and early requests to their operators for cooperation. As an example, ships from both Texas A&M and the Bureau of Commercial Fisheries (Galveston) will be in the Gulf of Mexico during the February mission. With sufficient notice they could provide some useful ground truth for both ocean and atmospheric parameters.

3. Ideally photography should become a permanent part of all missions in this series. Even though earth photography is not the purpose of these early missions it does provide NASA with an immediate scientific payback from this program providing requirements are

pre-planned and programmed as noted above. Primarily this could greatly help the scientific community in planning for the multi-sensor requirements for the late 1969 APOLLO Applications Program 1-A Mission.

4. The APOLLO photography should be published in an atlas form. The photography from these early engineering test missions should be made available to the scientific community through the means of a published atlas. This will bring more "trained minds and eyes" to bear on these data and improve planning input for the APOLLO Applications Program. As a minimum these atlases should be made for all principal investigators in the Earth Resources Survey Program. They should contain necessary ground truth and backup information to permit analysis.

5. Consideration should be given to multi-camera installations. During the past mission the camera was located behind the pilot's window. If in future mission cameras could be located behind all window openings in the capsule this would greatly enhance photographic results. Options would then be available for either selective filtering or using a variety of film emulsions. Specifically, color IR photography would be extremely valuable when paired with conventional color coverage. This would require a minimum of two cameras on board.

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13. ABSTRACT

This paper resulted from requests by the U.S. Naval Oceanographic Office and NASA Manned Spacecraft Center, Houston for an oceanographic appraisal of earth photography taken by the APOLLO 501 Mission on 9 November 1967.

A total of 755 70 mm color photographs were taken on this mission by a Maurer camera sighted through the pilot's window in the capsule. The area of photographic coverage was of the South Atlantic Ocean and Antarctica as seen from the tip of Africa. The altitude of the pictures ranged from 7,450 to 9,850 miles, however, coverage was limited by the location of the earth terminator along the west coast of Africa. As a result only a crescent shaped portion of the earth is seen.

Analysis of the information content of this photography was limited by a lack of hard data on surface oceanographic and meteorological conditions for the day of the mission. The authors therefore have relied on climatological data published in standard references as the basis of interpretation. In short, this analysis provides educated speculation on this material as developed by an oceanographer and a meteorologist.

The goal of this speculation is to see whether or not future missions in this series should carry cameras and under what conditions should they be programmed.

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