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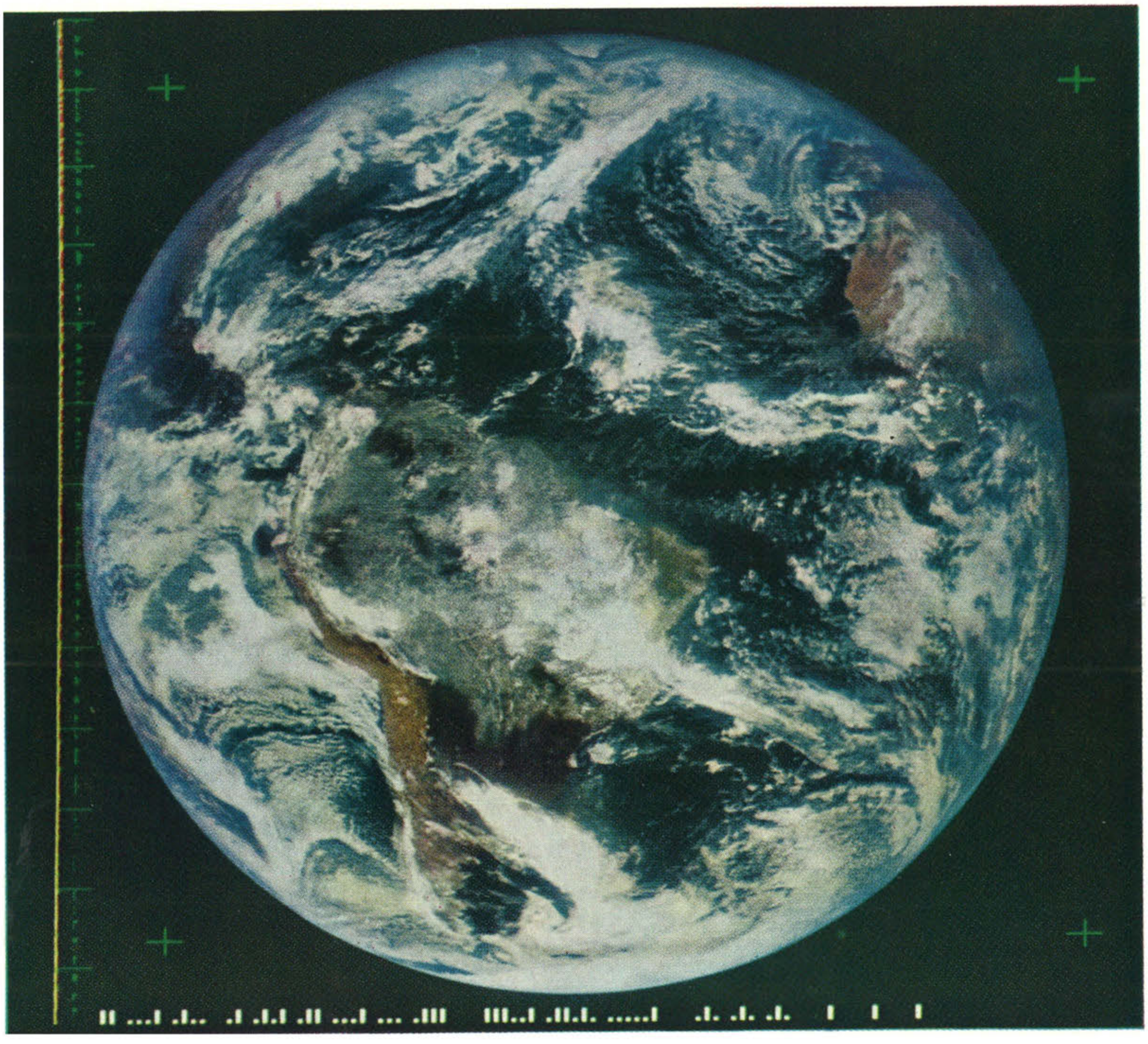

a color view of planet Earth

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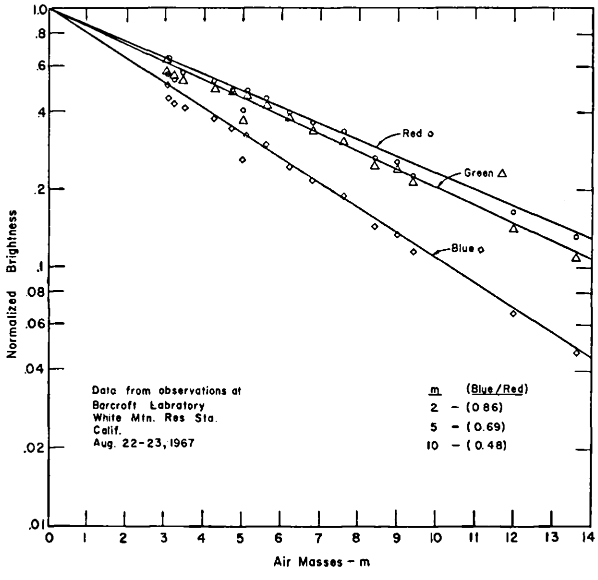
Madison, Wis.

The cover photo of this issue of the BULLETIN is a full color view of the Earth taken by the multicolor spin-scan camera on the applications technology satellite, ATS-3, which is in geosynchronous orbit 22,300 miles over the mouth of the Amazon River. Details of the camera, how it operates and how the color pictures are generated at the Rosman ground station are given in an accompanying article by Wendell Sunderlin, Assistant ATS Project Manager.

This experiment allows us to extend our studies of synoptic and subsynoptic systems of the tropics to the Atlantic as well as the Pacific. Now we also have a superb picture of convective activity over the continental tropics of Central and South America. The purpose of adding the color capability was mainly to help estimate the altitudes of the cloud tops. When one views a cloud in the terminator zone one has a long light path through the atmosphere due to the grazing angle of the solar illumination. Rayleigh scattering causes a change in the ratio of the energy in blue and red portions of the spectrum. Fig. 1 shows observations of this ratio change taken by Kirby Hanson in the clear air above Bancroft Laboratory of the White Mountain Research Station, California. A given blue to red ratio indicates the number of air masses in the path and to convert this to cloud altitude one needs the zenith angle of the radiation to the cloud from the Sun and the zenith angle of the radiation from the cloud to the spacecraft. Both of the angles are known very accurately.

Preliminary results show that the ratios do change in the way expected, but no quantitative estimates of cloud height have yet been made.



Response of Spot Photometer

A second difference of this camera over the one used in ATS-1 is its wider view angle to include the whole Earth disk. The full view is aesthetically far more pleasing. The full Earth disk also makes accurate navigation on the picture very much easier. One can number the first scan line that intersects the Earth at whichever pole is illuminated. Accurate navigation is essential if one is to measure cloud displacements between pictures in a computer. Displacements of selected clouds can yield winds at cloud level.

In the accompanying article, Dr. Guenter Warnecke has combined photos taken from ATS-1 and ATS-3 into a montage, and has described some of the main weather features which are visible.

We would like to use this opportunity to express our appreciation to the many individuals who made contributions to the camera, the spacecraft, the booster, the launch, the ground station data access, the imaging system, the color photography, and to the program management. These are the individuals who really make these beautiful color photos of the planet Earth possible.

the first color picture of the Earth taken from the ATS-3 satellite

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Abstract

The third Applications Technology Satellite (ATS-3) of the National Aeronautics and Space Administration (NASA) was launched into a geo-synchronous orbit at 35,800 km altitude over Brazil on 5 November 1967. One of the meteorological experiments onboard is the Multicolor Spin-Scan Cloud Camera. It provides instantaneous high resolution color pictures of the whole disc of the Earth in a 30-min sequence. Three images are obtained by simultaneous scanning through three different color filters (green, red, blue). The three separate signals are transmitted to the ground station where the multicolor picture is produced.

The first picture of 10 November 1967 is shown on the front page of this BULLETIN. The superiority over monochrome pictures (black and white) is demonstrated by the strikingly better contrast between clouds and the background (Earth surface).

A large number of interesting meteorological details are shown in the picture and pointed out in this article. A montage of the ATS-3 picture and an ATS-1 photograph taken on the same day over the Pacific Ocean provides a synoptic picture of the cloud distribution over more than two thirds of the globe.

These successful experiments constitute a large step in obtaining a complete survey on short-time changes of global cloudiness as required for the World Weather Watch.

1. Introduction

With the successful launch of ATS-3 into a geo-synchronous orbit on 5 November 1967, a further step was accomplished on the exploration of the feasibility of new techniques for the future global weather observation system known as the World Weather Watch.

[1] On leave from the Freie Universitaet Berlin, Germany, as a National Academy of Sciences-National Research Council Senior Postdoctoral Resident Research Associate with the National Aeronautics and Space Administration.

The Applications Technology Satellite (ATS) Program is characterized by a multiple mission spacecraft wherein the spacecraft is basically the same for all missions. Spacecraft "in-orbit" stabilization is achieved through either gravity gradient or spin-stabilization techniques.

Three NASA ground stations form an integral part of the ATS Project. The ground stations are the ROSMAN, North Carolina, facility with an 85′ antenna, the MOJAVE, California, site with a 40′ antenna and a transportable station located in Australia with a 40′ antenna.

In the meteorological area the stationary orbit offers particular advantages since the weather can be assessed as it develops through sequential observations which are close together in time. This kind of observation appears to be particularly important for detecting small violent storms, phenomena in cloud distribution of short duration, and cloud displacements of high accuracy. Three of the ATS meteorological experiments are directed toward production of high resolution pictures of the Earth from spinning satellites.

ATS-1, placed into a stationary position at 152W over the equator in an altitude of 36,600 km, has provided a wealth of meteorological information from the Pacific Ocean for over a year. ATS-3 was placed in an orbit similar to ATS-1 but about 95° further east and north of the Amazonas basin to provide simultaneous information from the Atlantic Ocean. Thus, for the first time, a complete coverage of daytime cloud distribution and short-time variation over an area from New Guinea across the Pacific, South America and the Atlantic Ocean to the west coast of South Africa was achieved.

The most spectacular achievement of ATS-3 beyond the very successful ATS-1 Spin Scan Camera Experiment, which provides daytime cloud photos in a 22 minute sequence, is the first useful color photography from this altitude by the Spin-Scan Color Meteorological Experiment. Gemini photography of the Earth has indicated that observations in natural color may represent a significant improvement over monochrome. The first color processed picture is reproduced on the front page of this journal, while a black-and-white version of the same photograph is included in the montage of Figs. 4 and 5.

Prof. V. E. Suomi, Department of Meteorology, University of Wisconsin, is the principal investigator with Prof. Robert J. Parent, Department of Electrical Engineering, co-investigator for the monochrome and color Spin-Scan Camera Experiments.

In the ATS-3 experiment, a high resolution color picture of the complete Earth's disc is made. The pictures are essentially instantaneous as far as meteorological parameters are concerned, each picture being completed in 28 minutes. The data are transmitted to ground receiving stations upon acquisition, and so no data storage is required in the satellite. With the synchronous orbit of the satellite it is thus possible to obtain a synoptic picture of the existing meteorological situation, and by proper manipulation of the received data, to obtain sequential pictures, or even simulate time lapse photography.

2. ATS-3 spacecraft

The ATS-3 is a spin-stabilized spacecraft with a large volume capable of adapting to a variety of experiments. The spacecraft is a cylinder 54 inches long and 57.6 inches in diameter with a solar-cell array mounted around its periphery. The general configuration of the spacecraft is shown in Fig. 1.

The communications subsystem is designed to operate at receive frequencies in the 6-GHz band and transmit at frequencies in the 4-GHz band. Receiving and transmitting antennas and traveling-wave tube power amplifiers are utilized in conjunction with two triple-mode repeaters. A bandwidth of 25 MHz is available for each repeater output.

A camera data mode is available, and designed primarily to transmit wideband data originating aboard the spacecraft. Voltage-controlled oscillators are provided which accept modulating frequencies up to 5 MHz.

The ATS-3 spacecraft was launched on 5 November 1967 from Cape Kennedy into a transfer ellipse by an Atlas/Agena launch vehicle. It was then injected into synchronous circular orbit at second apogee from the transfer ellipse by a solid propellant apogee kick motor contained within the spacecraft.

After apogee motor burn and initial drift orbit corrections, the spacecraft was precessed in yaw until the spin axis was normal to the orbit plane. This attitude permits

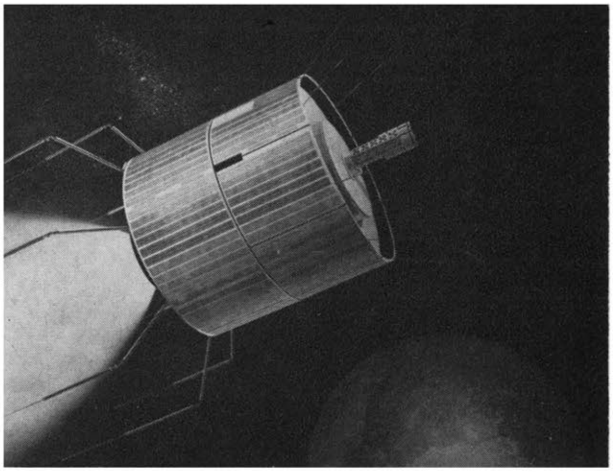

Fig. 1. Conceptual view of ATS-3.

the transmitting antenna beam to point at the Earth at all times, gives efficient solar power support illumination, and provides control of the period and elimination of orbital eccentricity by synchronous radial jet pulsing. The axial jet, operated continuously, rather than in a pulsed mode, permits elimination of inclination in this attitude. The spacecraft was then drifted to and stopped at its initial orbit position of approximately 57 degrees West longitude.

3. Camera system

The Multicolor Spin-Scan Cloud Camera shown in Fig. 2 consists of a high resolution telescope, three photomultiplier light detectors, and a precision latitude step mechanism. The latitude step motion, combined with the spinning motion of the ATS synchronous satellite, provides a scan of the complete Earth disc. The area is covered by 2400 horizontal (west to east) scan lines.

The latitude step mechanism is caused to advance south in one step increments by a command from the spacecraft Mechanical Antenna Control Electronics (MACE) system for each spacecraft revolution. When the step mechanism has completed the required 2400 steps (24 minutes for nominal 100 rpm spacecraft spin rate) a limit switch initiates retrace.

The instantaneous optical field of view is 2.2 statute miles when the telescope is pointed at nadir from a synchronous orbit of 22,300 statute miles.

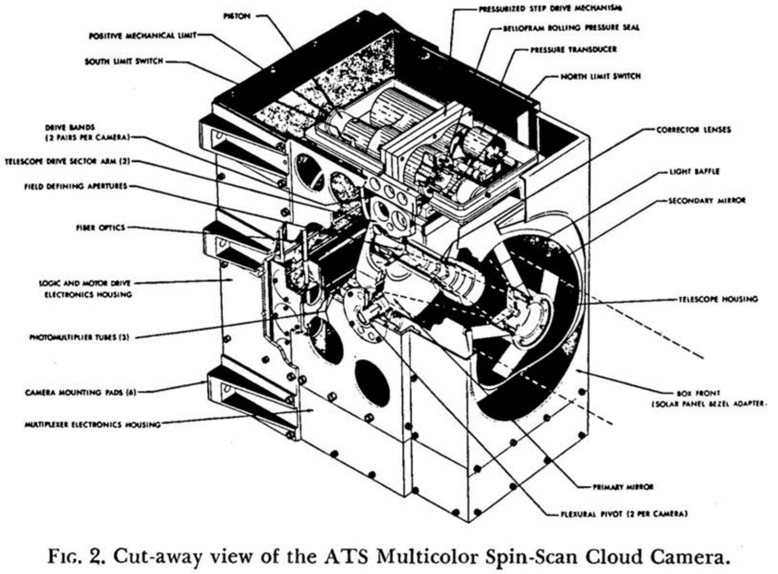

Fig. 2. Cut-away view of the ATS Multicolor Spin-Scan Cloud Camera.

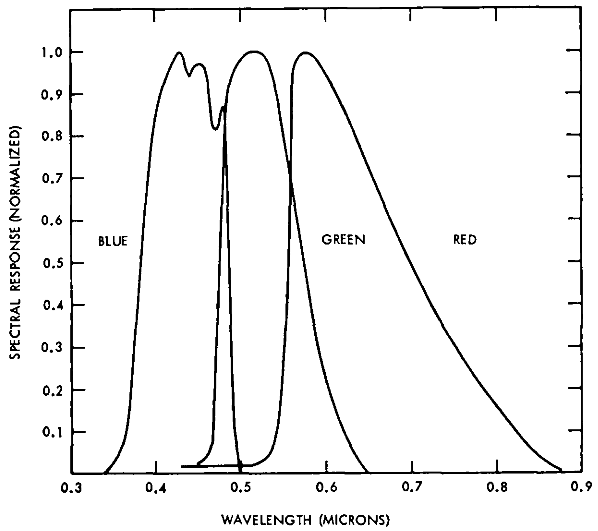

FIG. 3. Computed spectral response curves of the ATS-3 Color Camera.

The primary mirror, secondary mirror, and aperture plate are made of fused quartz for dimensional stability with temperature. The 5-inch diameter elliptical primary mirror combined with the 1.82-inch diameter spherical secondary gives an f/3 system with a focal length of 15 inches.

The three color signals are obtained through three separate apertures and filters in the image plane. Because of the physical displacement of the apertures in the optical system, there will be a time delay between the color signals which is corrected by the ground equipment. Since ATS-3 has a similar orientation in orbit as that of ATS-1, with the camera scanning from West to East, the scanning order is green, red, and blue. A light signal from each aperture is transmitted from the aperture in the telescope assembly to a filter-photomultiplier assembly located outside the telescope. Transmission of the energy collected by the moving telescope to the stationary photomultiplier tubes is via fiber optics.

The computed spectral response of the optics and the photomultiplier detectors is shown in Fig. 3.

The video output from the camera's three photomultiplier tubes are time division multiplexed, and transmitted to the Rosman ATS ground station. The ground receiver then provides the detected video signal to the demultiplexer where the calibration channel and three video channels are separated. The video channels are then sent to the video processor where the Sun pulse and video signals are separated. The separated Sun pulse is then used to generate the necessary timing signals to permit the recording of the video on the photofacsimile recorder and digital tape recorder.

4. The meteorological significance and contents of the first color photo from ATS-3 and of the corresponding ATS-1 photograph on 10 Nov. 1967

The first good color photo of the whole disc of the Earth from outer space was taken by the ATS-3 satellite from an approximate altitude of 36,000 km when located over the Amazonas mouth on 10 November 1967. This picture is not only a new technological triumph but it reveals a large amount of meteorological information and demonstrates a tremendous potential for meteorological research and operations. A striking advantage over black-and-white photographs is the improved contrast of clouds against the Earth background and the resulting higher effective resolution. Particularly over bright land areas with a high surface albedo, color photography obviously permits a better and even more detailed detection of cloud distribution and structure.

The colored figure on the front page covers the Earth from the mid-Pacific Ocean to Central Africa and from Antarctica to Central Greenland. Most prominant features are the entire South American continent and western North Africa. The coasts of Morocco and Mauritania clearly stand out in a cloud-free area. The Guinea Coast and the western coasts of Central and South Africa are delineated by the distinct band of intense convection of the sea-breeze front. The same is true, although less pronounced because of the earlier local time, for the coasts of Brazil, Guiana and Eastern Venezuela.

Large portions of the Andes are seen under clear sky conditions. Well recognizable are Lake Titicaca, Peru (dark) and the Bolivian Salars de Coipasa and de Uyuni (bright beige) while the Atacama Desert, Chile, appears only slightly brighter than the surrounding land areas. Extended patches of fog are recognizable over the Gulf of Guayaquil (Ecuador) and along the coast around Lima, Peru.

Of particular meteorological interest are a number of pronounced frontal cloud bands, as well as certain mesoscale structures between them, which permit one to infer some circulation characteristics. A pampero cold front is crossing southern South America with its main cloud mass over the La Plata region and a very sharp squall-line over Uruguay and northern Argentina. Over the Andes and just to the east of it, the frontal cloud system is dissipated but can again be traced over the Pacific Ocean although it is less distinct under more anticyclonic influence. However, in this region the cloud pattern itself makes it easy to distinguish between the pre- and post-frontal cloudiness because of the pronounced cellular and banded convection within the newer polar air mass. South of the front, heavy cloudiness is caused over Chile on the windward side of the Andes. A secondary cold front appears to follow farther south, where it just arrived at the southern tip of the continent. Toward the north a preceding front can be found over eastern Bolivia and southern Brazil. The divergent flow of the moderated polar air mass can be traced by a beautiful pattern of cloud streets over the lowlands of the Paraguay River and the southern Provinces of Brazil. The highly organized post-frontal cloud pattern can easily be distinguished from the completely un-organized convective cloudiness north of this front. Toward the west, traces of the frontal cloud structures can be found far out over the Southern Pacific Ocean. A significant break over the Andes and over the Peru or Humboldt Current should be taken into account. The cloud-suppressing effect of the cold water current off the Peruvian coast is very apparent in this picture as is also shown over the Benguela Current off Southwest Africa.

Large, highly un-organized convective cloudiness spreads all over tropical South America north of 15S. The cloudiness over the Amazonas is, however, less intense than over the Brazilian Highland area, which is experiencing the rainy season at this time of the year. The inter-tropical convergence zone is well shown by an extended band of strong cloudiness over Panama and northern Colombia, which is presumably of more orographic origin. An interesting detail is the strong cirrus outflow toward the northeast from the heavily convective cloud systems over Central America, east of an upper trough (see Fig. 5). The equatorial dry zone evident over the Pacific also extends across the Atlantic toward Africa.

Of extreme meteorological interest is the cloud structure over the southern North Atlantic. The intertropical convergence zone over Africa is defined in this picture by a cluster of individual convective storms with distinct indication of cirrus cumulonimbogenitus clouds blowing from the storm clouds toward the east, south of the Niger River. Over the ocean, the ITC exhibits a very remarkable structure of apparently three distinct but narrow lines of stronger cloud activity from the African coast to approximately 30W. From there on, only one very narrow, partly interrupted and meandering line of cloudiness survives along 10N and the broad band of main cloudiness turns toward the northwest, finally merging with an extra-tropical frontal system which extends from Honduras across the North Atlantic Ocean toward Iceland. Near 50W, a vortex-like structure of the heaviest cloud mass with an anticyclonically spiraling cirrus outflow on its northern rim is an indicator for a small surface cyclone. This storm developed out of the ITC during the previous days when the decaying tropical storm "Heidi" curved back into this region after a brief excursion to the Azores.

The cold front over Morocco is dissipating in the cloud picture over the ocean and can only be traced as a weak line of clouds for about 1000 km. On both sides of the ITC, the direction of the trade winds can be derived from the clearly visible cloud streets.

Off the Morocco coast a cyclonic vortex center is recognizable within the cellular convective cloud pattern of a cut-off low which is characterized by a number of cumulonimbus and shower reports in the surface observations. Another vortex center

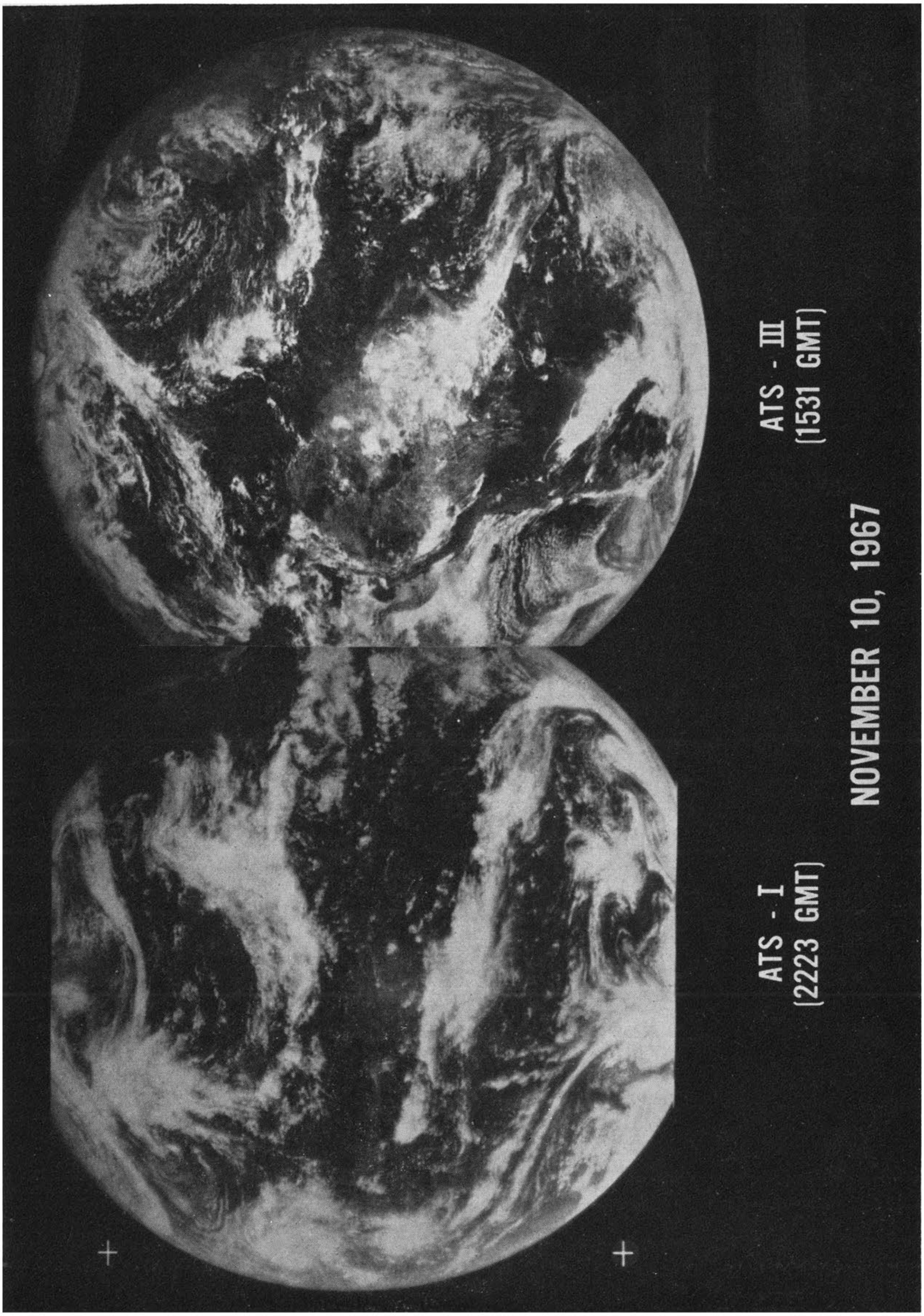

FIG. 4, Montage of ATS-1 and ATS-3 Spin-Scan Camera photographs taken on 10 November 1967.

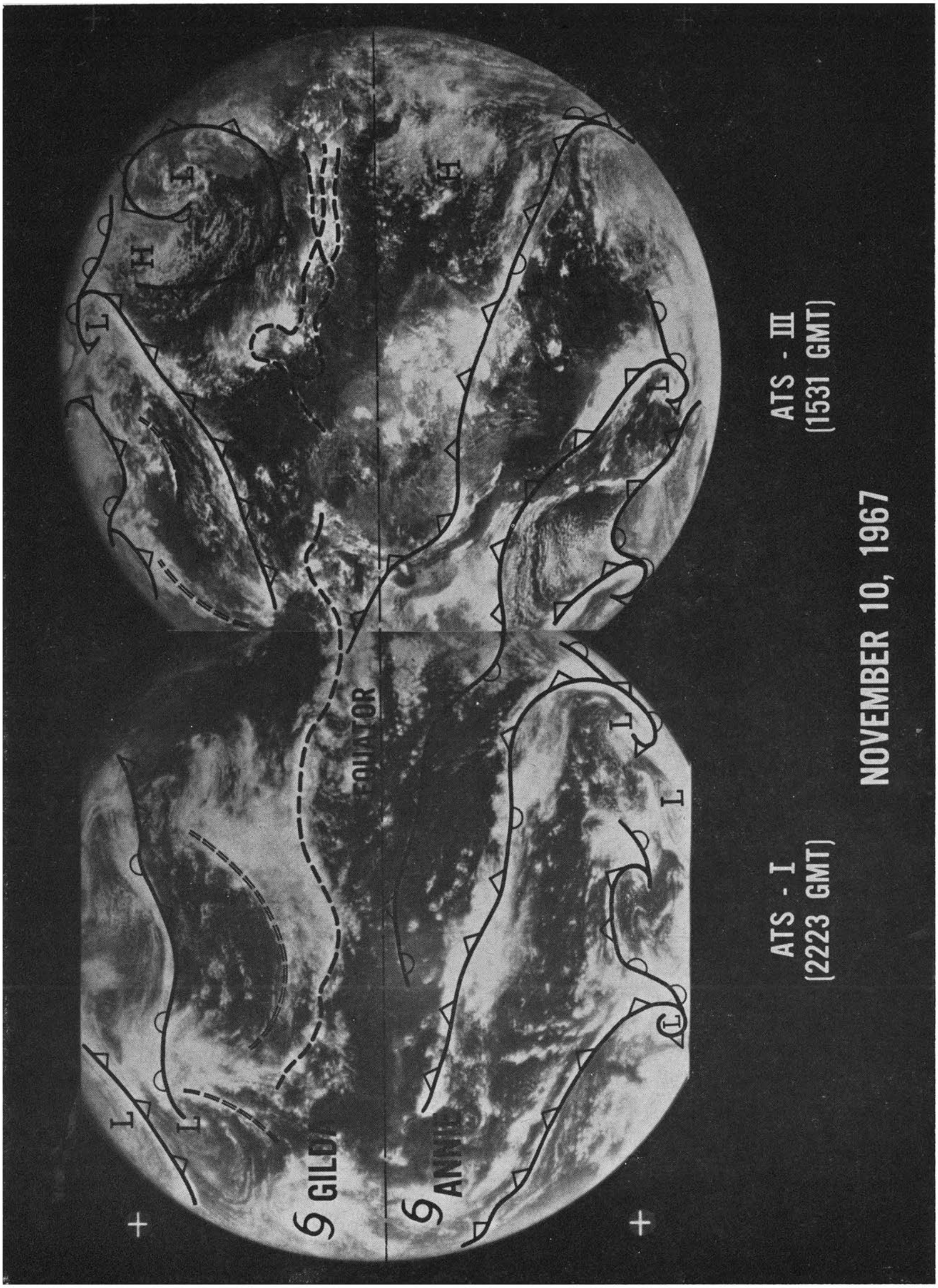

FIG. 5. (Same as Fig. 4) . . . with identification of the major cloud systems.

is shown southeast of Greenland connected with the frontal cloud band already mentioned extending from Cuba toward the northeast. Greenland itself is shown clearly by its bright ice-cap surrounded by open water under clear skies and within anticyclonic weather conditions. The small cloud-free strip along its coast is produced by the predomination of katabatic outflow and the superimposed anticyclonic subsidence.

North America is shown partly under clear skies. The east coast up to New York and the Gulf Coast east of the Mississippi delta can be well seen. Eastern Canada is covered by the cloudiness of a frontal system that extends from Baffin Island southwestward to the Great Lakes. The Midwest is covered by heavy rain clouds in connection with an upper trough extending as far south as Mexico.

The montage of the quasi-simultaneous ATS-1 and ATS-3 pictures of 10 November 1967, as reproduced in Fig. 4, gives an almost synoptic view of more than two thirds of the globe. Each half is really synoptic, both halfs are approximately seven hours apart and each close to local noon at the subsatellite point. The frontal analysis superimposed on the photographs (Fig. 5) agrees well with the conventional analysis. The intertropical convergence is represented by a dashed line. Four 300-mb troughs, being associated with distinct cloud structures, are delineated by a dashed double-line. The ATS-1 section of the figure shows the three Southern Hemispheric frontal cloud bands mentioned above extending far into the equatorial Pacific. These bands are not discernable as conventional fronts in any surface weather map, mainly because of sparse surface observations and a transformation of the frontal characteristics which become rather undetectable by conventional synoptic parameters when the fronts pass the subtropics.

A feature of particular meteorological interest is the extended cloud mass over the central North Pacific Ocean. This happens to have no direct connection with any frontal phenomena in the surface weather maps. However, the abrupt northern boundary of the cloud system is coincident with an extremely sharp 300-mb trough, and a strong diffluence can be observed in the 300-mb wind observations over the cloud system. Strong anticyclonic cirrus outflow can also be observed at the east side of this system. At its southern rim the trough cloud system merges into the well developed ITC cloud band which suffered a remarkable northward displacement by almost five degrees latitude within 24 hours under the influence of the approaching mid-latitude trough. The similarly large cloud system toward the northwest is connected with another 300-mb trough. In this case, however, a large surface cyclone is associated with it and also a surface frontal system which stretches between 35 and 45N latitude across the north Pacific to the Oregon coast. It is well marked by a distinct jet stream cloud band in the picture, indicating a double wavelike structure of the jet stream itself.

Over the western Pacific Ocean are visible the twin typhoons "Gilda" and "Annie," which formed two days earlier out of a single storm very close to the equator at 2.5N and 157.5 E.

5. Conclusions

The feasibility of meteorologically useful color photography from synchronous satellite altitudes has been successfully demonstrated. The wealth of meteorological detail information of even the single picture shown has not been exhausted with this brief interpretation. The main advantage of cloud photographs from synchronous altitudes is, however, the possibility of producing time series in 20 to 30 minute steps, at the present state-of-the-art, which has been demonstrated by a number of movies produced from the ATS-1 photos by V. E. Suomi and T. Fujita. The superiority of color photography is based on the ability to detect the color peak of the reflectance curve of the different natural objects like water, land, and clouds in addition to the integrated intensity, which is the only parameter detectable by black-and-white photography.

The simultaneous operation of two meteorological satellites in synchronous orbits is a large further step toward a complete meteorological observation system of three equally-spaced synchronous satellites in addition to one or two near-Earth satellites in quasi-polar orbits, as proposed for the World Weather Watch. This permits research workers to observe and investigate short-term variation of daytime cloudiness over more than two thirds of the globe, primarily over the vast tropical and subtropical oceanic areas. With regard to cloud coverage, there are only two requirements left at this time from the meteorologist: the introduction of high resolution infrared radiometry into the system in order to achieve full day and night coverage and the development of the present Nimbus and Advanced Technology Satellite techniques into a fully operational system in the near future.

Acknowledgments. The Santa Barbara Research Center, Santa Barbara, Calif., a subsidiary of Hughes Aircraft Company, under contract to the University of Wisconsin, designed and built the Spin-Scan Cloud Camera for use aboard the NASA Applications Technology Satellite.

The Westinghouse Defense and Space Center, Baltimore, Md., under contract to NASA Goddard Space Flight Center developed the ground equipment for synchronization and processing of the received camera data.

The Electronic Photofax Recorder was developed by Electronic Image System Corporation, Boston, Mass., under a NASA Goddard Space Flight Center contract.

The photographs were produced by the Nimbus-ATS Data Utilization Center at the Goddard Space Flight Center, Greenbelt, Md.

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news and notes

"Commencement" party for Gordon Dunn

"Commencement" festivities were held in Miami, Fla., honoring Dr. Gordon E. Dunn, long-time director of the Weather Bureau's National Hurricane Center, on the occasion of his retirement from government service. The banquet, held at the Kings Bay Yacht and Country Club, was attended by nearly 300 friends, colleagues, and associates. During the evening Dr. Dunn was presented with 16 awards and citations from the scientific community and from the public he served so successfully as director of Hurricane Warning Services. It was also announced that Dr. Dunn was to receive the AMS Award for Oustanding Service by a Weather Forecaster at the Society's Annual Meeting in San Francisco in January. Guests from 10 states and from the Dominican Republic, Puerto Rico, and Trinidad were present at the banquet.

The program, other than the awards and citations, consisted of the presentation of a series of events and reminiscences from Dr. Dunn's career prepared in TV studies across the country and collated into a professional kinescope by Channel 4 TV at Miami.

Less than a month before his retirement party Dr. Dunn was honored in Caracas, Venezuela, at the Fifth Technical Conference on Hurricanes and Tropical Meteorology, when the Department of Meteorology and Hydrology, Central University of Venezuela, awarded him a special medal for his contributions to the advancement of tropical meteorology.

Although Dr. Dunn continues to reside at 5111 Alhambra Circle, Coral Gables, and will be a frequent visitor at the National Hurricane Center (one block away), he also plans extensive visits to Africa and Latin America.

(More **news and notes** on page 107)

Top row l to r: Mrs. Robert Hairston, Col. Robert Hairston, Dr. Werner A. Baum, Dr. Joanne Simpson, Dr. Gordon E. Dunn (standing), Mayor Chuck Hall (standing), Dr. R. H. Simpson, Mrs. Gordon E. Dunn. *Bottom row* l to r: Mr. Cesar de Windt Lavandier, Mrs. Ana de Windt Lavandier, Dr. Mariano A. Estoque, Mr. Hartis Thompson, Mrs. Walter R. Davis.