TL
798
.M4
R45
1961

Reichelderfer, Francis Wilton.

Meteorological satellite systems in weather research and services...

LIBRARY
MAY 10 1961
WEATHER BUREAU

Reprinted from AEROSPACE ENGINEERING
Copyright, 1961, by the Institute of the Aerospace Sciences and reprinted by permission of the copyright owner
VOLUME 20, No. 3
MARCH, 1961

TL
798
.M4
R45
1961

113 828

National Oceanic and Atmospheric Administration
TIROS Satellites and Satellite Meteorology

ERRATA NOTICE

One or more conditions of the original document may affect the quality of the image, such as:

Discolored pages
Faded or light ink
Binding intrudes into the text

This has been a co-operative project between the NOAA Central Library and the Climate Database Modernization Program, National Climate Data Center (NCDC). To view the original document contact the NOAA Central Library in Silver Spring, MD at (301) 713-2607 x124 or Library.Reference@noaa.gov.

HOV Services
Imaging Contractor
12200 Kiln Court
Beltsville, MD 20704-1387
January 26, 2009

Meteorological Satellite Systems in

F. W. Reichelderfer, FIAS
U.S. Weather Bureau

DURING THE 78 days immediately following its launching on April 1, 1960, meteorological satellite Tiros I provided some 23,000 photographs of earth and clouds, most of them for areas of 500,000 square miles or more as viewed from an orbit about 450 miles from earth's surface. Since then Tiros II has given many more photo cloud maps. Earlier (October 13, 1959), Explorer VII began telemetering the first long series of infrared data for much of the earth. The epochal significance of these successful meteorological satellites may best be seen by comparison of meteorological data now available with what is required to satisfy man's needs for weather information. The great disparity is often overlooked in view of the very large number of synoptic weather reports now received every day in national meteorological centers.

Usually, when one wants to know about the weather at a particular time and place the desired information can be stated in a few words. But weather reports and forecasts for an aircraft operator may be quite inapplicable for the agriculturalist, the engineer, the industrialist, the mariner, or the sportsman. The aviator wants to know about cloud ceilings, terminal airport visibility, clear air turbulence, jet streams many thousands of feet above the ground, icing in clouds, and so on. These conditions have little interest for the farmer engaged in harvesting or the horticulturalist seeking to protect his crop from frost damage.

For much of the information given in this paper the author is indebted to Dr. Harry Wexler, Dr. Sigmund Fritz, David S. Johnson, and others on the staff of the Meteorological Satellite Section, and to F. W. Burnett, as well as other members who worked on the plans summarized here.

The different combinations of physical conditions of the atmosphere near the ground and up to the heights now frequented by man are almost legion. The conditions usually change from hour to hour. Moreover, the many changes in weather and storm behavior from place to place compound the vagaries which the national weather reporting system must try to observe, report and analyze. The international weather code lists 99 different states of the weather referring primarily to hydrometeors, that is, cloudiness and precipitation. This number does not exhaust the list of significantly different states of weather. In addition, the air temperatures at different altitudes, the humidities, the winds with their endless fluctuations in direction, speed and gustiness, level by level, the barometric pressures and other atmospheric conditions must be included in the descriptions of weather required for various practical purposes.

Stated in brief, the requirements placed by modern society on national meteorological services include knowledge of practically *everything* with regard to the physical conditions of the atmosphere, almost *everywhere* from the surface up to 50,000 ft. or more. Questions of long-range weather forecasting—and perhaps modification or control of undesirable weather conditions and destructive storms—are outside the scope of this article, but for a complete list of ever-pressing meteorological "requirements" these would have to be considered.

Fragmentary Data

The point made here is that although millions of weather observations and reports are made each day, their world total represents only a fraction of what is needed—probably less than 20 per cent of

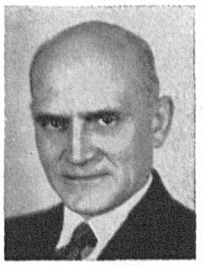
Weather Research and Services

Hurricane, cyclone, tornado, typhoon?

Tiros cloud photographs fill in many serious gaps in our observation and measurement of the atmosphere

requirements for purposes of general analysis and broad scale forecasting. For detailed local analysis and predictions of airport terminal weather or other specialized local weather forecasts for agriculture, boating, etc., the data coverage probably is only about 5 per cent of that required and in some parts of the atmosphere much less than this.

In their efforts to obtain much-needed measurements of atmospheric conditions, early meteorologists established observatories on mountain tops. Later, they sent simple instruments aloft on kites, balloons and airplanes. Eventually, they developed radiosondes, rockets, radar and other radio and sonic sounding devices. The latest means for telemetering atmospheric conditions is the meteorological satellite. It will supplement data obtained by several of the preceding methods and will not in general replace them. The significance of meteorological satellites in the national and international systems of synoptic weather reporting can be seen in the estimates that Tiros types can provide about 10 per cent of the total observations required for weather analysis and forecasting on the local scale and about 20 per cent of those required for very broad scale and extended period (5-day) forecasting. The comparable figures for satellites of advanced design operating at capabilities within present design knowledge are 60 per cent for local forecasting and about 90 per cent for very general-area and extended-time-range forecasting. These estimates are only indicative and approximate and since satellites give, for the most part, information not obtainable in other ways the percentages should be considered as going to reduce present data deficiencies represented in the 80 per cent or greater difference between data now available and total data required.



Dr. Reichelderfer started his career in science as a chemist, having graduated from Northwestern University in 1917. Incident to aviation training during World War I, he took further studies in meteorology, supplemented later by work in the Geophysical Institute, Berger, Norway, and other meteorological institutions. He completed aviation flight school in 1918 and received the Naval aviation pilot's certification. Later in airship operations in Lakehurst, N.J., he obtained the pilot's certificate for airships and free balloons also. In the early 1930's, he served as station Executive Officer at Lakehurst and on the U.S.S. "Utah," gunnery experimental battleship. Some 30 years of his career have been in active meteorological positions, among them President of World Meteorological Organization, 1951–1955, and he is now Chief, U.S. Weather Bureau.

Satellite Capabilities

For many regions, particularly over oceans, where weather observations are relatively sparse and upper air soundings very infrequent or in much of the southern hemisphere, practically unknown, the meteorological satellite appears to be the only likely means for obtaining information of the state of the atmosphere and its never-ending changes. As an instrument for achieving the comprehensive coverage in weather reporting that is recognized as a responsibility of the national meteorological service of every modern country, the satellite has unique and far-reaching applications for international exchange of weather information. This is illustrated in Fig. 1 which shows interrelated storm systems and associated air masses and fronts extending from Canada, Mexico, and the United States across the ocean to the western Pacific. The chart and photograph illustration are described in a later paragraph. International aspects of the output from satellites

(*Continued on page 91*)

Meteorological Satellite Systems

(Continued from page 23)

are obvious in this and other Tiros photo mosaics of cloud systems over large areas.

Although meteorological satellites so far are best known for their cloud photographs and infrared measurements, they have several other capabilities of importance in research and applied meteorology. Among those presently known are measurements of:

(1) Mean temperatures of the clear air column.

(2) Temperature of the visible surface—cloud tops, ground or ocean surface.

(3) Various radiation values, solar and terrestrial, for studies of earth's heat budget and basic mechanism of the "heat engine" that produces weather and climate.

(4) Precipitation areas, ice and snow covers.

(5) Vertical distribution of ozone, water vapor, carbon dioxide (narrow-band emission), and certain other constituents of the atmosphere.

(6) Unique features of clouds useful in early detection of incipient severe storm developments (Fig. 2).

Research results already obtained from Tiros experimental satellites suggest that future studies based on data from advanced operational types will bring major changes in meteorological theory, knowledge, and techniques. Probably these will lead to

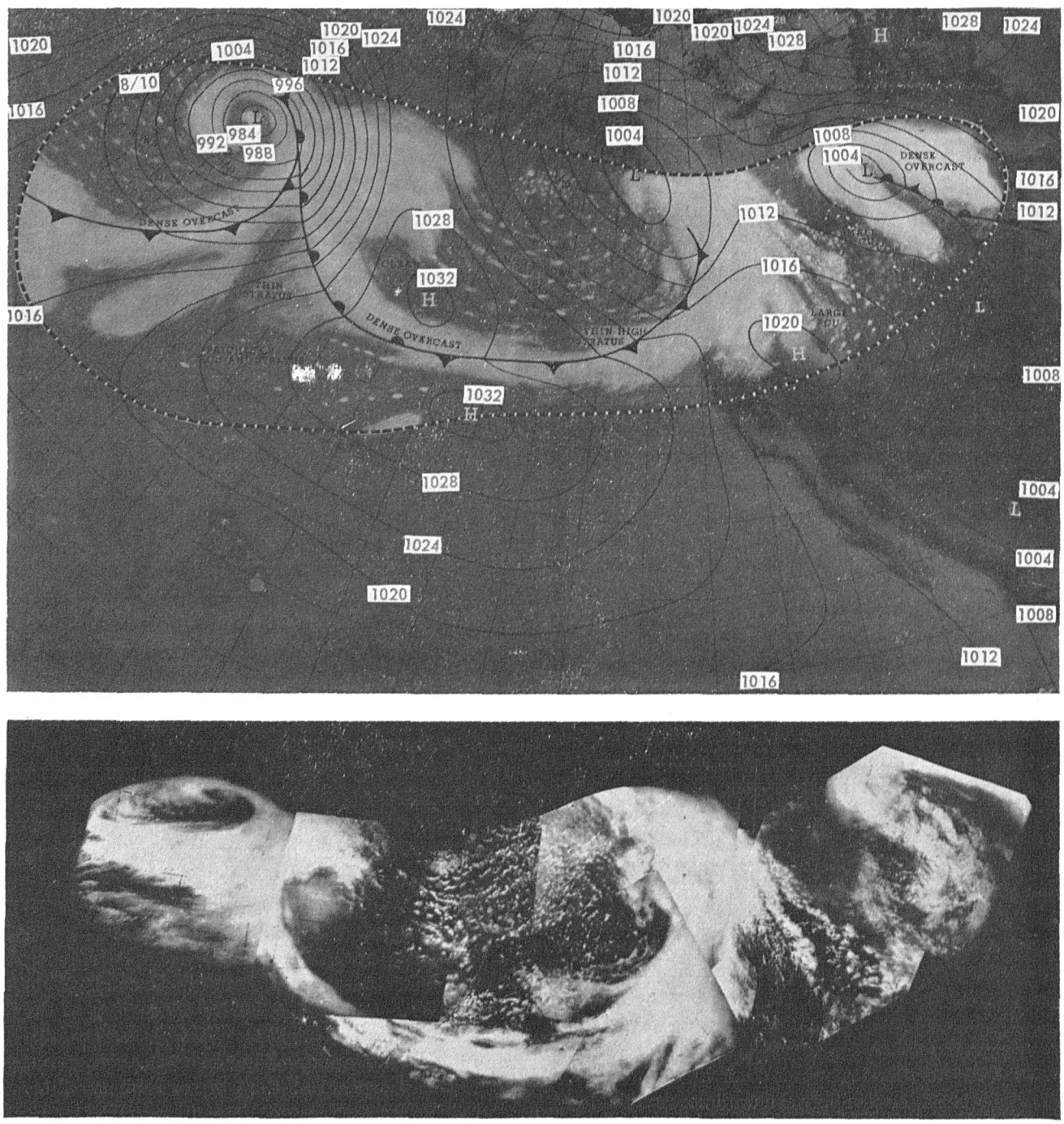


Fig. 1. Pacific storm family observed by Tiros I, May 19–20, 1960 (after Oliver[6]). (Top) Experimental cloud depiction chart prepared from Tiros pictures superimposed on NAWAC 0000Z map analysis of May 20, 1960. (Bottom) Actual Tiros photographs taken on May 20, 1960.

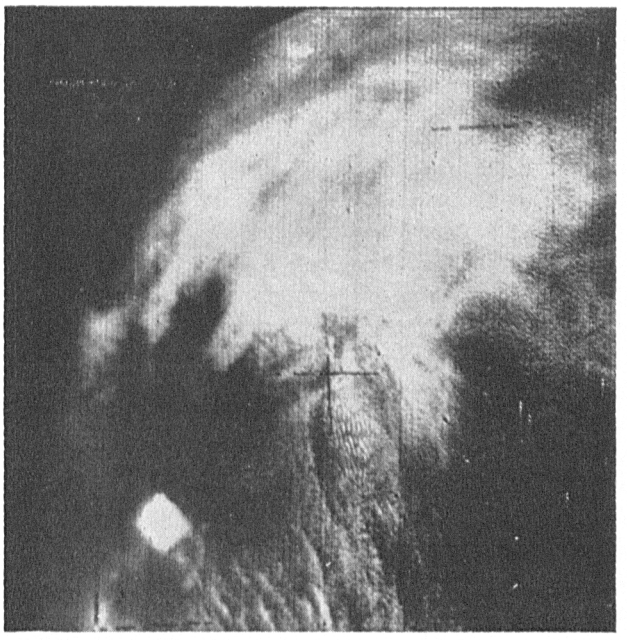


Fig. 2. Quadrilateral cloud formation (*lower left*) precedent to tornadoes in central Oklahoma, May 19, 1960.

refinements in design of sensors and new capabilities not given in the foregoing list. Some of the data will be useful mostly for research, but much will have immediate applications in daily weather services. The volume of material for study and the potentialities for research in detail are immense, and much will be suitable for more or less independent studies. For these purposes satellite data will be distributed widely for research in universities and other private institutions, as well as in the several interested Government agencies. Fig. 3 shows the main channels for flow of satellite data to research and service users.

Results So Far

Fritz, Kaplan, Stroud, Wexler, and others have published recent papers relating to Explorer VII and Tiros I.[1–4] Ultimately, important advances in meteorological knowledge will doubtless come from the data of radiation phenomena, but the Tiros cloud photographs have already added directly to knowledge of certain broad features of storms and much more can be inferred indirectly about air masses, jet streams, and other conditions in the atmosphere of importance in aeronautics and general weather forecasting. Photo mosaics of clouds over large areas give an outline of the broad-scale weather analysis; in fact, clouds represent "nature's own weather map." Principal fronts and changes in weather are associated with clouds. Consequently, cloud maps identify the main features of weather analysis. Where the sky is cloudless, it usually means an expanse of stable air mass and absence of significant changes in weather.

Without repeating in detail the studies that are being presented currently in other technical papers, a brief account of some of the research conclusions and practical applications in aviation and other fields is offered here. The cloud mosaic shown in the lower part of Fig. 1 is made from 30 photographs transmitted during two orbits of Tiros I, May 19–20, 1960. With nothing more than this cloud map, it is possible to locate the cold and warm fronts and visualize the most likely path of the associated jet streams aloft. The upper part of the figure shows the cloud map after being rectified and superimposed on the system of fronts and isobars drawn from the relatively few reports from ships and islands in the North Pacific for the date concerned. Rectification of cloud photos is necessary to correct for distortion by the oblique angle at which the Tiros camera lens viewed portions of the area. Neither the cloud map nor the isobar and frontal map would be complete or accurate taken alone. This analysis based on the

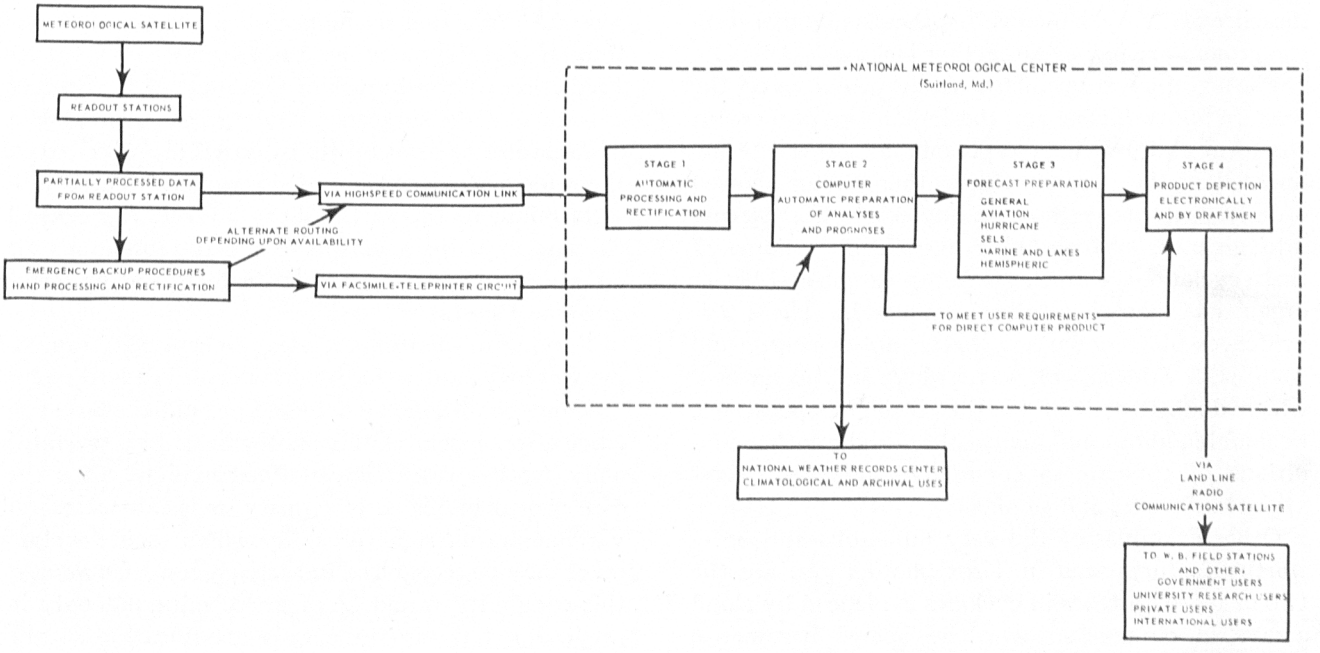


Fig. 3. Flow chart—utilization of meteorological satellite data

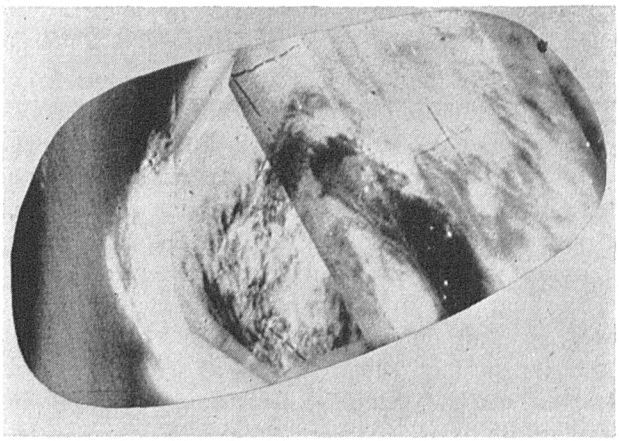


Fig. 4. Tiros I photographic mosaic from orbit 731, at about 2000 hours, Z,[9] May 21, 1960.

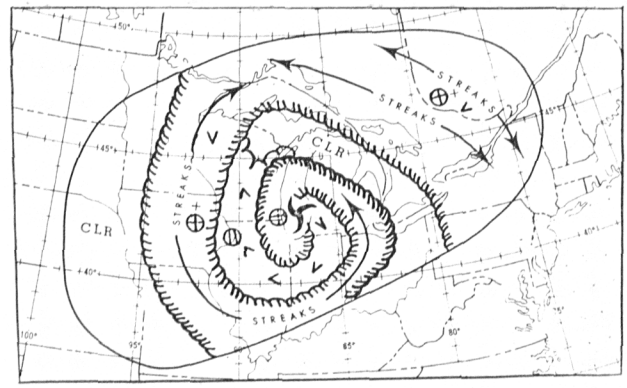


Fig. 5. Rectified neph-analysis[9] based on Fig. 4.

two supplementary sources of data bears striking resemblance to the classical Norwegian model of the structure of moving cyclones as published by J. Bjerknes, T. Bergeron, and others from their studies beginning about 1915. Other features of significance to the aviator and the mariner can be deduced from analyses such as this. Naturally, the greater the accuracy in mapping the air mass and frontal formations, the more complete and reliable the forecasts made therefrom.

Of significance also are the cloud masses arrayed in more or less orderly fashion in the wake of the cold front over the ocean. These masses are too large for their dimensions to be determined in eye observations by an observer on a single ship and too small to be recognized for what they are in the reports from the synoptic network where their dimensions are lost in the wide open spaces between stations.

In other Tiros photographs, the jet stream over the Andes was clearly identified by its associated cloud pattern. This gave information not usually available for air navigation in the region where upper air measurements by balloons or other soundings from the ground are few or altogether lacking.

Photographs transmitted from orbits over the western South Pacific and the Indian Ocean revealed the form and extent of typhoons not otherwise delineated in the reports. Still other photos showed orderly patterns in the spiraling winds that stream into gigantic cyclones over the Pacific. Some of these cyclones are much greater in extent and better organized than heretofore supposed. There are evidences of secondary cyclones, anticyclones, and small-scale atmospheric waves along frontal surfaces which doubtless affect weather in flight operations, terminal landings and many other local weather conditions of concern to commerce, industry, recreational interests, and so on.

Other examples of the very numerous and noteworthy features seen in Tiros photographs are the two or more vortexes in cyclones evidenced by cloud arrays in circumstances where sparse barometric data indicated only one vortex; narrow cloud strips like that paralleling the Gulf Stream for several hundred miles; cloudless strips as pictured over Madagascar in an otherwise overcast sky covering the entire region; a complex family of cyclones over the Indian Ocean; alternating "streets" of cumulus clouds and clear strips in cold, unstable air masses; irregular fields of sea ice in the Gulf of St. Lawrence and snow fields covering the mountain tops in the Alps, the Andes, and the Himalayas.

For research, the foregoing phenomena and many others suggested in Tiros photographs offer excellent material. What are the causes and significance of the elongated cloud masses of some 30 to 50 miles in length shown in Fig. 1? Their typical shapes seem to occur more frequently than would be expected at random. Do some of the cloud cells have the characteristics of Bénard cells and, if so, why? What is the explanation for the orderly arrangement of cloud systems, and how may these be used in improving the techniques for weather forecasting? Further studies should bring out relationships between features of the spiral bands in cyclones and the stage of development of the vortex and its accompanying storm. Quite possibly new knowledge of atmospheric hydrodynamics will be gained and applied to methods of weather prediction by numerical process under continuous development in the Numerical Weather Prediction establishment in Suitland, Md. Studies of some of these subjects and also of the general field of radiation measurements by satellites are cited in the references at the end of this paper. These subjects relate to the earth's heat budget, the general circulation of the atmosphere and the fundamentals on which weather forecasting in quantitative terms must be based.

Turning to questions relating to research in mesometeorology and severe local storms, can tornado-breeding conditions be detected in unique characteristics of precedent clouds photographed by satellite? Only further research can determine whether the case shown in Fig. 2 is a rarity or is illustrative of various storm "signatures" by which their development may be recognized in early stages. Obviously, this capability would be of great value not only in predicting but also in speedy modification of the storm if that ultimately becomes practicable.

Data Transmission and Utilization

The general steps and channels for transmission and processing of meteorological satellite data from its receipt by read-out stations to its final utilization by public and private users is sketched in Fig. 3. New ways for depicting essential features in weather analysis are under development. Undoubtedly, transmission of maps, diagrams, and photographs by facsimile will be an important means for getting the results of satellite output into the hands of users with minimum delay. It now appears that in most cases the finished product can be transmitted by facsimile to field weather offices within five or six hours of the time the raw data are sent by the satellite. This will be somewhat speedier than the present interval between hour of standard synoptic weather observations all over the globe and issuance of maps based on these reports.

As in all general meteorological systems, the satellite program is an interagency operation and depends much on interdepartmental cooperation. Responsibility for research and development of meteorological satellites in their experimental stages is vested in the National Aeronautics and Space Administration (NASA). Other agencies including the military departments, the Weather Bureau and several university and private research laboratories have worked closely with NASA in these developments. The Weather Bureau's expanded program in this field has been funded almost entirely by NASA up to the present time.

Plans for programing satellites that have reached the stage of regular service performance are now under development. Since the output of operating satellites will have immediate and far-reaching uses in the national meteorological service of the Weather Bureau and since satellite data will find greatest immediate value in its role with global synoptic weather data from all sources now processed in the National Meteorological Center and used in numerical weather prediction, the Weather Bureau hopes to have responsibility for operational satellite data-processing and utilization. Preliminary plans for this have been prepared and are now under interdepartmental consideration.

Fig. 4 shows a mosaic of Tiros photographs of storm clouds over central North America on May 16, 1960. The cloud chart or neph-analysis obtained from this mosaic is reproduced in Fig. 5. Neph-analysis is one of the forms in which weather intelligence from satellites can be transmitted to field forecasting stations and other meteorological offices and to users who find the cloud analysis valuable in their forecasting. A study of Fig. 5 shows that the passing weather in any locality within the analysis area is much more understandable when the patterns and formations are shown in more detail than is possible with use of regular synoptic reports only.

Important steps in the central processing of satellite data are the rectification of cloud photographs so that they faithfully present a plan view and are accurately positioned geographically and in relation to other synoptic weather parameters, and their

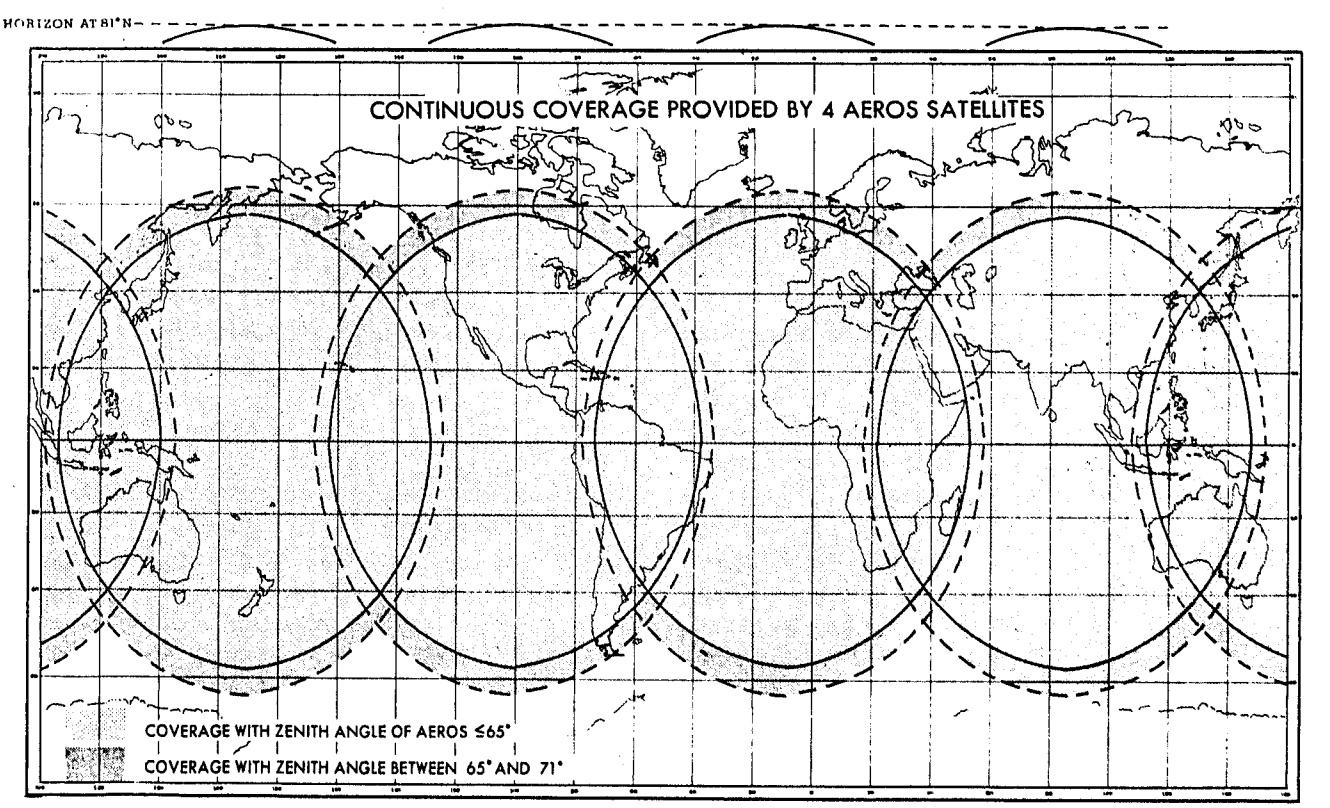


Fig. 6.

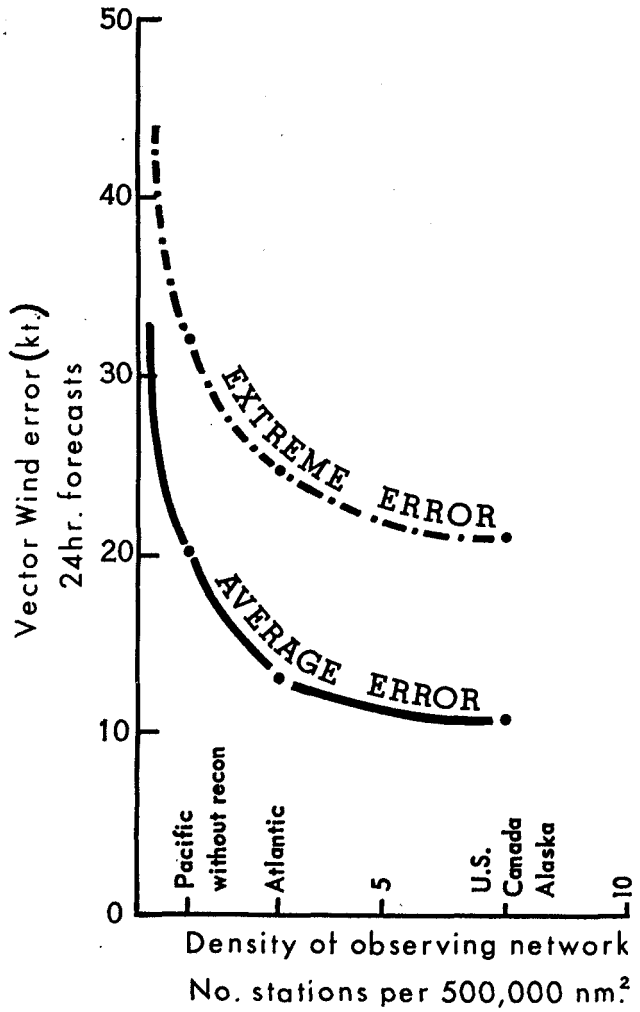


Fig. 7. Forecast errors proportional to sparsity of data[7] (for general wind velocities aloft).

integration into the three-dimensional depiction of atmospheric conditions in an analysis based on all available synoptic reports. Provision is made for these steps in the proposed operating plans.

The communications facilities for transmission of weather reports are already extensive but they are far short of "requirements." Communications satellites appear to be peculiarly suited to the problems of exchange of meteorological data. In general, the main meteorological centers everywhere need representative reports from other weather stations practically everywhere, particularly for air traffic scheduled to every country on earth. In plans for advanced types of satellites like the Nimbus and Aeros series[12, 13] there should be provisions for communications relays by satellites, thus speeding up exchange of weather reports and synoptic analyses and relieving radio and cable channels of some of the increasing load of meteorological communications. References 10, 12 describe some of the features of Nimbus and Aeros satellites. Essentially the Nimbus series is visualized for launching into polar orbits at distances approximately 600 miles from earth. In order to provide observations of every area at least four times daily, two Nimbus satellites would be in orbit at all times. The Aeros series is proposed for equatorial orbit at distances about 19,400 miles above earth. This would give each Aeros satellite an angular velocity equal to that of the earth and thus keep the satellite "hovering" over the same point. With four Aeros satellites in orbit at all times, the continuous coverage shown in Fig. 6 would be given. Instrumentation of Nimbus and Aeros satellites would give improved outputs of cloud photographs, radiation measurements, communications relays, and eventually other parameters listed in an earlier paragraph.

Satellite programs implied in preceding paragraphs are directed primarily toward improvements in the methods of weather forecasting. The loss in accuracy of forecasts in proportion to sparsity of data required for daily weather maps to show analysis of initial conditions as the basis for forecasting is indicated in Fig. 7. This illustrates the rapid loss in accuracy of wind forecasts when the reporting network falls below an average of three well-spaced stations for every 500,000 square miles. This minimum figure for network density applies only to broad-scale wind forecasts and not to detailed local forecasts for which much closer spacing of stations is necessary. Data from satellites will fill the gaps in many regions where more stations are impracticable.

Meteorological records contain many instances of severe storms and destructive hurricanes which could not be forecast in definite terms because the location, configuration and intensity of the storm were unknown. Synoptic reports from the storm area were too few and too irregularly spaced for satisfactory analysis, and consequently there were insufficient data on which to base definite forecasts. Among the many examples are Hurricanes Ione (1955), Audrey (1957), and Donna (1960) whose position, course, and shape of the central vortex were uncertain during part of their life. Such uncertainties are even more frequent with typhoons in the Pacific and cyclones in the Indian Ocean where these storms sometimes reach intensities exceeding most hurricanes. Satellites with their possibilities for complete cloud map coverage of storm areas will remove much of the uncertainty about the position of the center and extent of the destructive winds. Losses in life and property can thus be reduced to the minimum.

In summarizing some of the plans and possibilities of meteorological satellites it is not suggested that all meteorological problems can thus be solved. Atmospheric measurements by other means that give observations not within the capabilities of satellites will still be necessary. Moreover, there are meteorological problems other than the sparsity of basic data that await solution. Among these are the need for communications to transmit and disseminate essential data, maps, and forecasts speedily; imperfections in present techniques for quantitative analysis and prediction; and limitations in present means for "display" or visualization in needed detail

of the current atmospheric conditions. But the first step is to obtain sufficient basic data. Satellite systems will go far in correcting the present serious gaps.

Conclusions

The Explorer VII and Tiros satellites have shown that this new source of atmospheric observations and measurements will contribute greatly to knowledge of storm systems, air masses, and fronts, as well as give basic data on radiation and other phenomena that must be understood if the general circulation and its resulting changes in weather and climate are to be analyzed and predicted quantitatively. Although satellites cannot be expected to satisfy all remaining requirements for atmospheric data, they can directly or indirectly give much of the information now lost in the gaps in existing synoptic weather and upper air sounding networks. They are uniquely suited to contribute to comprehensive coverage of weather conditions which the national weather bureau of every modern country seeks to provide for its citizens. In effect, satellites view "nature's weather map" and picture much of the daily weather of interest to almost every person and business activity. Although many problems remain, the advantages and benefits of information provided by meteorological satellites are likely to lead to national and international support for the launching and maintenance of satellite systems.

Research possibilities from satellite data are relatively unproved but are certainly of great significance. Evidence supports the view that major advances in meteorological theory and understanding of the general circulation and its secondary systems, large and not so large, will come eventually in no small measure as the result of data provided by satellites.

References

[1] Fritz, S., and Wexler, H., *Cloud Pictures from Satellite Tiros I*, Monthly Weather Review, Vol. 88, No. 3, pp. 79–87, Mar. 1960.

[2] Wexler, H., and Fritz, S., *Tiros Reveals Cloud Formations*, Science, Vol. 131, No. 3415, pp. 1708–1710, June 10, 1960.

[3] Hanel, R. A., and Stroud, W. G., *Infrared Imaging from Satellites*, Journal of Motion Picture and Television Engineers, Vol. 69, pp. 25–26, 1960.

[4] Kaplan, Lewis D., *Inferences of Atmospheric Structure from Remote Radiation Measurements*, Journal of the Optical Society of America, Vol. 49, pp. 1004–1007.

[5] Wark, D. Q., *On Indirect Temperature Soundings of the Stratosphere from Satellites*, Journal of Geophysical Research, Vol. 66, No. 1.

[6] Oliver, V. J., *Tiros Pictures a Pacific Frontal Storm*, Weatherwise, Vol. 13, No. 5, Oct. 1960 (front cover, inside).

[7] Staff, Meteorological Satellite Lab., U.S. Weather Bureau, *Some Meteorological Results from Tiros-I*, Report to NASA, U.S. Weather Bureau, 1960.

[8] Ludlum, *Tiros I Concludes Mission; Tiros II Readied*, Weatherwise, Vol. 13, No. 4, pp. 159–161, 180.

[9] Staff, Office of Forecast Development, *Depiction of Satellite Cloud Observations for Facsimile Transmission*, OFDEV Report, No. 1, U.S. Weather Bureau, Washington, D.C., Dec. 1960.

[10] Panel Report, *A National Plan for Common System of Meteorological Observation Satellites*, U.S. Weather Bureau, Washington, D.C., Oct. 1960.

[11] Panel Report, *Plan for Meeting Meteorological Observation Requirements Over Sparse Data Regions*, Technical Planning Study No. 1, U.S. Weather Bureau, Washington, D.C., June 1960.

[12] Staff, Report on NASA, *Industry Program Plans Conference*, pp. 74–76 (Aeros Satellite), July 28–29, 1960, Supt. of Docs., Washington, D.C.

[13] U.S. Senate Hearings Before NASA Subcommittee of Committee on Aeronautical and Space Sciences, *Scientific and Technical Aspects of NASA Program*, 86th Congress, 2nd Session, on H.R. 10,809, Part II, pp. 643–668, June 30, 1960.

223 628