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FOREIGN TECHNOLOGY DIVISION

SATELLITES AND THE PROBLEM OF THE NATURAL RESOURCES OF THE EARTH

by

K. Ya. Kondrat'yev

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The author of the pamphlet - a well-known scientific and popular-science writer - discusses an interesting problem in contemporary astronautics - the problem of using AES and spacecraft for meteorological and hydrological research, surveys of natural resources on a planetary scale, and for geological, topographical, terrain and other types of photography over large areas.

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TABLE OF CONTENTS

U. S. Board on Geographic Names Transliteration System..... ii
Abstract..... iii
Introduction..... iv
Space Photography..... 1
Meteorology..... 2
Hydrology, Oceanography..... 12
Geography..... 17
Geology and Geomorphology..... 20
Spectrometry in Space..... 22
Indirect Sounding According to Data from Infrared Radiation Measurements..... 25
Indirect Sounding from Microwave Radiation Measurement Data..... 30
Microwave Radiation of the Underlying Surface..... 36
Short-wave Radiation and Reciprocal Problems..... 41
Spectrometry of Natural Formations..... 45
Spectrographic Investigation of Natural Formations from Piloted Spaceships..... 51
Conclusion..... 54
Bibliography..... 54

U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

* ye initially, after vowels, and after ъ, ь; e elsewhere. When written as ё in Russian, transliterate as yё or ё. The use of diacritical marks is preferred, but such marks may be omitted when expediency dictates.

Satellites and the Problem of the Natural Resources of the Earth

Moscow, "Znaniye," 1971, 48 pp. (New Developments in Life, Science, Technology. Series "Astronautics, Astronomy.")

The author of the pamphlet - a well-known scientific and popular-science writer - discusses an interesting problem in contemporary astronautics - the problem of using AES and spacecraft for meteorological and hydrological research, surveys of natural resources on a planetary scale, and for geological, topographical, terrain and other types of photography over large areas.

The book is intended for engineers and students of higher technical institutes, and also for any individuals interested in contemporary problems in the mastery of space.

INTRODUCTION

Scientific progress has led to the conclusion that it is necessary, from both a scientific and economic point of view, to carry out an overall study of the natural environment of humanity. The complete and overall view of the natural processes and phenomena became possible with the appearance of space vehicles. Study of the nature of our planet by means of space technology became the object of a new scientific field - space geography.

Our problem is to investigate the most intelligent utilization of the riches of the Earth and to avoid, so far as possible, the destructive action of elemental nature. Combining automation and the possibility of human operation on board a spaceship in using space technology, we find ourselves on the path to the stations and laboratories in space predicted by Tsiolkovskiy, not only for the study of the Solar System but also for surveys of the planet Earth from space.

The possibilities inherent in study of the natural environment from space are exceptionally broad. This is reflected, for example, in the variety of research methods. An important feature of the prospects for interpretation of data on the natural environment obtained by means of space vehicles is the complex character of the interpretation of these data. Therefore the most promising

path for solution of problems in space geography is a combination of different methods in order to achieve complex interpretation of the obtained results. On the one hand, such an approach permits combining the interests of various scientists and, consequently, making more complete use of the wealth of space information for different branches of science and the national economy - sharply increasing their effectiveness - while on the other hand it permits correcting the observations of a single cycle by means of other observations, a procedure which substantially increases their reliability and completeness.

Meteorological, communications, geodesic, navigation, and other satellites which are usually lumped together under the common term functional satellites symbolize the development of a major stage in space research and have already provided many results of practical usefulness. However, despite this we can assert that the enumerated functional satellites represent only the first step in the study of our planet by means of space technology. The possibilities for the study of the nature of the Earth and the riches of its lands and oceans are virtually unlimited. This is precisely why in recent years interest is continually intensifying in the application of satellites for the study of a wide variety of natural resources and natural phenomena. Geology and geomorphology, oceanography and hydrology, geobotany, soil science and agrobiology - this is far from a complete list of the sciences for which the use of artifical satellites has significance beyond evaluation.

The significance which contamination of the atmosphere and water basins has taken on recently is well known. The processes of pollution have reached a virtually planetary scale (recently the journey of Thor Heyerdahl and his crew on the raft "Ra-2" once again showed the seriousness of ocean pollution even in regions very remote from the continents and major sea lanes). For this reason a true idea of the pollution picture can be obtained

only by means of satellites. Even phenomena on such small scales as forest fires, dust storms, and soil erosion can be detected and tracked much more reliably with satellites than by any other technical approach. The same can be said with respect to problems in determining soil conditions (especially in the preplanting period), the condition of seedling crops, etc.

The success of the "Luna-16" and "Luna-17" demonstrated the broad possibilities and the virtually unlimited promise in the use of automation during space study. This means, in particular, that virtually all of the problems connected with investigation of the natural environment can be solved by means of automatic satellites. At the same time there is no doubt that the following circumstances, which necessitate the participation of humans and require the presence in space of specialists in the regions of meteorology, oceanography, geology, geobotany and other professions, are of decisive significance for the success of such experiments:

1. The requirement for conscious selection of objects of investigation. For example, for timely detection and study of the consequences of elemental phenomena it is not advisable to photograph the entire surface of the globe. A more practical approach is to maintain a space patrol in the form of an orbital station carrying specialists who will react to interrogation from the Earth and will themselves make decisions in selecting objects of study, with the help of the appropriate equipment.

2. The possibility of selecting objects from a number of similar objects under the least favorable photographic conditions (for example, with or without cloud cover).

3. The possibility of testing, checking, and adjusting (and sometimes eliminating failures) of complex equipment intended for space research.

Such factors as these are the primary determinants in combining automation with the human brain - a combination which is required for successful operation of orbital space laboratories. Among the variety of methods which have already found wide application for a study of the natural environment from space, various methods of obtaining images of the earth play the most important role. These include television and conventional photography and heat detection in the infrared and microwave regions of the spectrum. We will begin our discussion of the state of the problem with consideration of certain results which have been obtained in this area, intending after this to turn to the second section of the survey, concerned with space spectrophotometry of the Earth. We wish to emphasize that such a breakdown of material is, to a significant degree, conditional, since it has already become clear that the most favorable prospect consists in complex investigation of images and spectra. More than this, the use of multichannel scanning radiometers and multispectral photo and television equipment is a practical example of the simultaneous development of both spectra and images of investigated objects.

SPACE PHOTOGRAPHY

As was already noted, the equipment for space photography is extremely varied. The broadest materials are obtained by recording the electromagnetic radiation of the Earth by the methods of television and infrared photography. Such recording, carried out in different regions of the spectrum, gives ordinary photographs and television images in the visible region; representing large segments of the surface, these are extremely informative for analysis, for example, of the distribution of cloud cover.

Recordings in the infrared region of the spectrum - thermography and heat detection - make it possible to obtain a picture of cloud distribution on the night side of the planet and to form a judgment concerning the state of the terrestrial surface with respect to its thermal inhomogeneities. Heat readings can be used to determine the characteristics of surface waters and the conditions for vital activity of phytoplankton and marine vegetation near the coasts; it can be used to survey ice and to study ocean flows, and also to investigate volcanic formations in tectonically active regions and thermal zones. The same method can detect a forest fire and determine its boundaries under the cloud of smoke.

The developments of methods of microwave indication makes it possible to determine the moisture and water content of the depth

of the atmosphere, to locate icebergs, to evaluate the degree of ice cover and the level of wave activity in the seas. Experiments of this type carried out on the satellite "Kosmos-243" were extremely productive.

Radar survey can guarantee the most difficult aspects of ice reconnaissance. During the study and tracking of the hydrographic net on dry ground it is possible to detect river systems and even to determine the area of the drainage basin, the basin perimeter, the extent of tributaries, and the steepness of valley slopes. During geological research it is possible to clarify the features of the geological structure and the composition of the primary rock. During study of the vegetative cover and agricultural land the boundaries of fields and forests are determined, along with the areas and types of crops and the classification of the land. An advantage of radar survey is the fact that the radar emissions are not hampered by clouds and they penetrate to a significant depth into the ground (3-4 m). Different types of surveys present different pictures of nonuniformities in the Earth's surface, and by combining them the truest possible picture of the states and processes being observed can be obtained.

Meteorology

Of all the terrestrial problems, one of the most urgent is that of the weather. Its influence on our life is universal. The material damages attributable to catastrophic weather phenomena are enormous. For example, the Asiatic typhoons alone cause annual losses of five hundred million dollars. In 1969 typhoon "Vera" alone cost Japan more than 1,230,000,000 dollars, while the cyclone which struck Pakistan on 13 November 1970 represented a national disaster for that country. The losses, incalculable on a world scale, which are caused by elemental phenomena and the resultant economic usefulness of the development of meteorology in order to produce weather forecasts (of special importance for navigation, construction, agriculture, operation of various

systems and equipment, and for public-safety measures) long ago united meteorologists in one of the most active international organizations - World Meteorological Organization; preparations are underway at present for the creation of a World Weather Service and for the realization of a vast international program of research on global atmospheric processes.

The need for continuous planet-wide observations and the requirement for instantaneous information first led meteorologists to use space technology: in the USSR and the USA space meteorological systems were created, supporting daily weather patrol services. An important contribution to the development of meteorological research was made by scientific programs of manned spacecraft (an outstanding example is the work of the cosmonauts A. G. Nikolayev and V. I. Sevast'yanov on the spaceship "Soyuz-9").

Satellite meteorology has now become a large field in the science of the weather and it is the subject of a series of monographs and popular scientific publications. We will note only that through the use of television and infrared images of the Earth for daily analysis of peculiarities in the planetary distribution of cloud cover a substantial increase in weather forecast reliability has been achieved. Of special significance is the major progress achieved in improving storm-warning services with regard to such vast natural phenomena as typhoons, cyclones, etc.

The great volume of data obtained through meteorological satellites on the distribution of the planetary cloud cover has permitted the compilation of world cloud maps for various periods in recent years. Thus, for example, at the Hydrometeorological Scientific Research Center of the USSR such maps have been compiled since March 1965 and are being drawn for the Northern and Southern Hemispheres in stereographic projection in a scale of 1:30,000,000. Besides this, maps of cloud cover in tropical zones (45° N - 45° S) are being constructed in Mercator projection in the same scale.

Where possible the satellite data are supplemented with the results obtained by ground-station observations.

Analysis of maps of cloud cover has permitted detailed study of the regularities in the space and time variability of cloud cover. For example, it was found that although the distribution of clouds varies over the Northern Hemisphere in both space and time, as a whole the quantity of clouds above the hemisphere changes comparatively little from day to day or from month to month. In the period June, July, and August 1965 the variation in the area of the hemisphere covered by clouds did not exceed 10%. The spatial distribution of cloud cover on the middle charts is characterized by accumulation in the middle latitudes and close to the equator. Clouds are observed in the smallest quantities in the tropic and subtropic latitudes.

In the USA the construction of daily global maps of cloud cover and charts of the quantity of clouds averaged over various time intervals is carried out automatically by electronic computers for the near-equatorial band from 35°N to 35°S (Mercator projection) and for both hemispheres (polar stereographic projection). Figure 1 shows an example of the planetary cloud fields according to data from observations in both hemispheres for 29 October 1968. The construction of such maps is possible only through the use of the highest-capacity modern computers. In the course of processing television data the computers accomplish automatic geographic tying and plotting of grids of geographic coordinates. Along with the daily cloud-cover maps, construction of the planetary distribution of the cloud cover averaged for various time intervals is also carried out.

As an illustration, Fig. 2 shows an average map of cloud distribution in the Northern hemisphere for June-August 1967. This map reflects the known tendencies toward a reduction in the quantity of clouds in the tropic and subtropic latitudes (we will

note that during the construction of a chart of this type artificial intensification of image contrast is carried out; otherwise virtually the entire hemisphere would be quite bright). For example, the dark belt of the subtropical maximum of high atmospheric pressure is clearly visible, along with a narrow bright band of the intertropical convergence zone. It is obvious that the high brightness of the polar cap in Greenland is caused to a significant degree by the snow cover.

GRAPHIC NOT REPRODUCIBLE

Fig. 1. Maps of the planetary distribution of cloud cover. Northern (a) and Southern (b) hemispheres.

Fig. 2. Map of cloud cover in the Northern Hemisphere averaged over a season (June-August 1967).

Naturally, with averaging of the brightness field the influence of unstable cloud systems is smoothed. Only the individuality of the most stable cloud formations is retained. Complete elimination of the unstable background by constructing brightness fields in terms of minimum or maximum values is of interest for solution of a number of problems.

It is easy to understand, for example, that averaging brightness in terms of minimum values leads to "filtering out" of cloud cover. Figure 3 depicts an example of constructing a map of minimum brightness distribution in the Northern Hemisphere from data provided by the American meteorological satellite "Essa-9" for the five-day period 14-18 April 1969. The sharp contrast between the dark and bright zones on the map to the south is caused by the fact that there is a snow or ice cover north of the boundary between the zones (it is clear that when snow or ice is present the brightness of the earth is always high, without regard to cloud cover conditions; naturally, no television images could be obtained for the zone of polar night in view of the very low level of illumination). From this it is clear that maps of minimum brightness are a good means for tracing the boundaries of the snow or ice cover. Experience in constructing such maps has shown that the optimum averaging period (considering the necessity of "filtering" brightness and the variability of the snow cover or ice conditions) comprises 3 to 7 days.

If the brightness field is averaged only with respect to its maximum values, the dark regions will correspond to those regions where there were no elevated values of brightness (and consequently no clouds or snow) during the entire averaging period. On the contrary, the bright regions will reflect the existence of intensive cloud cover (or snow or ice). The brightest cloud cover of vertical development is usually accompanied by precipitation. Therefore the bright regions (if there is no snow or ice) can in this case be connected with precipitation zones. Still another

possibility for interpretation of maps of maximum brightness lies in using them to trace the paths of rapidly moving stable cloud systems.

GRAPHIC NOT REPRODUCIBLE

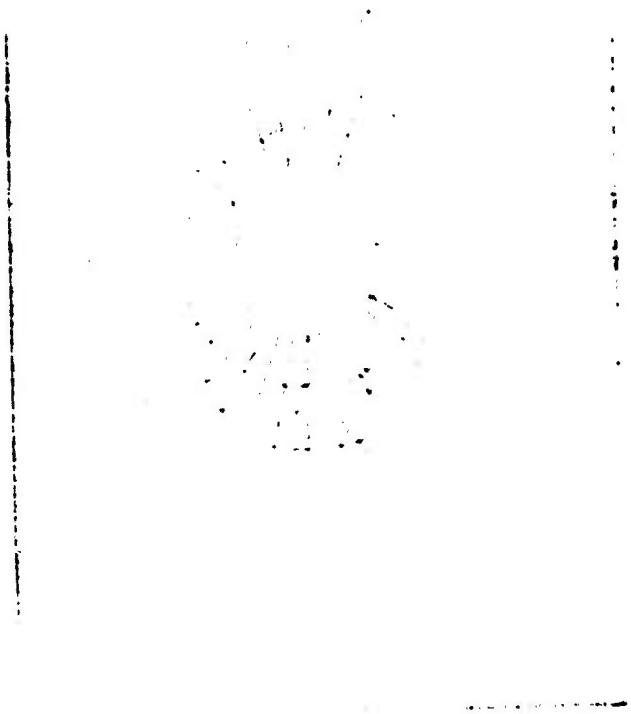

Fig. 3. Map of the distribution of minimum brightness for the Northern Hemisphere from the "Essa-9" satellite, averaged for five days (14-18 April 1969).

An essential difficulty in using procedures of simple or selective averaging of the brightness field is the fact that television equipment permits obtaining only an extremely distorted distribution of absolute magnitudes of brightness. Therefore in this connection the great urgency in the application of scanning photometers for adequately correct reproduction of a field of absolute brightness magnitudes should be emphasized.

The close connections between cloud fields and atmospheric movements allow, on the basis of empirical data, stating the

problem of determining the wind and the vertical motion over the cloud field and its variability. Therefore data from meteorological satellites at present make a major contribution to the study of atmospheric circulation in the tropics. Thus, for example, television images of the Earth have made it possible to study the influence of motions of various scales on the formation, development, and spatial structure of clouds and to trace all phases of the evolution of tropical cyclones. Cloud observations make it possible to obtain information on peculiar features of air streams.

Among the most important revelations concerning the general circulation of the atmosphere provided by the use of satellite television information are the following: 1) the subtropical jet streams on the northern boundary of the tropical zone of general circulation, detected by characteristic bands of spindrift clouds; 2) airstreams in the upper troposphere intersecting the equator (satellite data have shown that this phenomenon is far more typical than was assumed earlier); 3) air exchange between the lower and upper latitudes (occasionally moist tropical air, penetrating into the north, reaches 50°N); 4) bands of equatorial or intertropical convective cloudiness of enormous extent (the band which is most stable in the course of a year is located above the Pacific Ocean in the zone 5-10° N; similar bands over the Atlantic Ocean are characterized by significant seasonal migration); 5) tropical storms (it has been repeatedly confirmed, for example, that many Atlantic storms arise in Central Africa; it was found that usually the center of circulation of a developed storm is located in line with and not under the main system of a cloudy storm).

An exceptionally effective means of tracking the development of various synoptic formations is through geostationary [synchronous] satellites. Thus, for example, the satellite "ATS-1" made it possible to trace the evolution of typhoon "Sara" during its

travel across the Pacific Ocean (135° W-150° E) from birth in September 1967 as it moved to the southeast from the Hawaiian Islands up to its destruction after two weeks (west of Vancouver Island).

Images of the Earth obtained by means of the geosynchronous satellites "ATS-1" and "ATS-3" made it possible for the first time to study the dynamics of the cloud cover in the tropics - a question of great importance for understanding the weather-forming processes which occur in this region. Of particular significance were studies of cloud bands of the intertropic convergent zone [ICZ] (ВЗК). Analysis of individual images showed that the cloud cover of the ICZ represents the totality of all sky systems (cloud systems) in the form of bands with a transverse extent of 5 to 10° latitude. The average distance between these systems varies from 10 to 30° longitude - i.e., close in magnitude to the wave length (2000 km) of eastern waves in the tropics, whose development is accompanied by the expansion of the ICZ and frequently leads to the appearance of tropical storms. The large sky systems mentioned above have come to be called cloud "clusters" (accumulations).

Photography of the Earth from the automatic space station "Zond-5" carried out on 21 September 1968 at 12 noon Moscow time from 90,000 km yielded results of great interest to meteorologists. A photograph obtained from the "Zond-5" (Fig. 4) covers the entire disk of the Earth from 60° E to 120° W (the entire surface of the Earth from the polar regions of the Northern Hemisphere to the polar regions of the Southern was illuminated). The high resolution of the photograph permitted detailed analysis of particular features of the structure of the terrestrial surface and of the cloud cover. For example, features of cyclonic activity characteristic for the middle and high latitudes (see large-scale eddy systems of cloud cover) are clearly manifested north of 40° N. In the subtropic belt of 10-40° N clear anticyclonic weather is dominant. From the north to the equator there is a wide zone of

cloud accumulations. For the Southern Hemisphere the belt of subtropical anticyclones is less clearly expressed: here a variety of forms of cloud cover are observed.

GRAPHIC NOT REPRODUCIBLE

Fig. 4. Photograph of the day side of the Earth taken from the artificial meteorological station [AMS] (AMC) "Zond-5" on 21 September 1968 from 90,000 km (12 noon Moscow time).

As was already noted, visual observations and photography of cloud cover by cosmonauts have formed an important contribution to the development of meteorological research.

The first cosmonaut, Yuriy Gagarin, noted that the sunlit side of the Earth is clearly visible from altitude of 300 km. Observing the surface of the Earth, he saw clouds and light shadows from them which lay over fields, forests, and seas. The water-cover surface was dark, with bright highlights. He easily picked out the shores of the continents, islands, large rivers, large landlocked bodies of water, and natural terrain features. When he passed over our country he clearly saw the checkerboard of kolkhoz fields.

The cosmonauts in the spaceships "Soyuz-4" and "Soyuz-5" observed, at the request of the Hydrometeorological Center of the USSR, a number of weather phenomena; along this line, on 15

January 1969 V. A. Shatalov carried out observations of thick cloudy eddies connected with a deep cyclone above the Atlantic on the western shore of Europe. On 17 January B. V. Volynov observed flashes of lightning and vigorous thunderstorm activity over a broad extent of South America. On 18 January he noted a storm on the southeast coast of Africa. Here the storms were connected with the development of deep cumulonimbus clouds in a zone of convergence of moist air flows. Volynov observed a developing tropical cyclone over the Indian Ocean. The results of these observations were studied by meteorologists and forecasters. A broad cycle of visual observations was carried out by V. I. Sevast'yanov ("Soyuz-9").

These observations showed that piloted satellites can be successfully used for emergency information services with respect to the meteorological situation and, especially, concerning dangerous weather phenomena developing in different areas of the Earth.

The space forecaster first of all analyzes the picture of the distribution of cloud cover along the flight route which is presented to him and, judging by the character of the structure, dimensions, type, and brightness of the cloud formations he determines the corresponding weather-forming processes. He identifies the situation and evaluates the degree of development and direction of travel of cyclones, revolving storms, and typhoons; the activity of atmospheric processes; the probable direction of wind at the level of the clouds, etc.

Flying over the near-polar regions (and in winter above the middle latitudes) the cosmonaut traces the boundaries of snow and ice, evaluates the solidity of ice formations in seas and oceans, and notes the presence of channels and fracture zones in the ice fields to aid polar navigators. Oceanographic observations by the cosmonaut at the request of the institutions of the fishing

industry can improve the routes covered by the fishing fleets. Interpretation of photographs of the ocean and determination of its currents, temperature field, fluourescence, and other characteristics will assist in predicting the movement of schools of fish.

Hydrology, Oceanography

Exceptional importance attaches to hydrological problems connected with meteorology, such as the catastrophic onset of drought and flooding. Space technology can assist hydrologists in studying variations in the water level of rivers and in composing forecasts for low-water and high-water periods. Such forecasting is required for planning networks of hydrotechnical installations and their correct operation, solving problems in irrigation and water supply, and in predicting catastrophes connected with floods.

The development of ice forecasts is of great value to many countries, in particular in providing more effective navigation in the polar latitudes. Active navigation in very heavy and compressed ice began in the USSR in the 1960's with the introduction of the atomic icebreaker "Lenin" and diesel-electric ships of the "Moscow" class. The requirement arose for study of compact and open ice as a function of hydrological and meteorological conditions, with consideration of the influence of the tidal forces of the Sun and Moon and also for compilation of forecasts of these phenomena and charts of possible navigation routes. Space-borne equipment and rapid transmission of images with automatic data processing replaced ice reconnaissance and manual charting. The rational use of existing natural conditions in the Arctic seas, timely consideration of changes in the ice condition, planning of ship sailings on the basis of forecasts, and a reduction in idle time and damage of shipping by ice have led to more successful development of polar marine navigation.

The use of infrared images of the surfaces of seas and oceans plays a major role in the study of ocean waves, ice conditions, and ocean currents. Infrared images, obtained in the absence of cloud cover, make it possible to study the temperature field of the underlying surface.

Pausing on questions of the procedure for determining temperature from such data, we will examine several examples which illustrate the possibility of interpretation of infrared images of the underlying surface.

Figure 5 shows an infrared image of the Atlantic sector of the south polar cap taken from the American satellite "Nimbus-1" on 29 August 1964. Analysis of this image, carried out by V. Nordberg, showed that the temperature of the internal portion of the Antarctic ice cap comprises 210-215°K, with such low values of temperature being recorded in the course of the entire period of satellite operation (from the end of August to the end of September 1964). The temperature grows noticeably close to the edge of the Antarctic continent, reaching approximately 240°K. The edge of the continent is sharply marked due to the presence of bands of open water whose width reaches 100 km in places. The maximum temperature in this region reaches 256°K (this value of temperature indicates that not only water, but also ice lay within the field of vision of the radiometer). The higher temperature of the ice cover in the Weddell Sea and Atlantic Ocean zone, reaching 244°K, makes it possible to distinguish this zone from the continent. Fractured bits of sea ice are distinguished as narrow lines of increased temperature. The ice shelf extends to about latitude 57° S, where it encounters a band of open water with a temperature of approximately 275°K.

Analysis of infrared images, and also study of the quantitative data on the radiation field obtained by means of a scanning radiometer with high angular resolution installed on the meteorological satellite "Nimbus-II," demonstrated the possibility of

using them to trace the spatial distribution of ice fields. During examination of data relating to the water areas between Canada and Greenland the dark (warm) segments of the images can be interpreted as open water, since zones with grey tones (cold zones) are identified as ice. Comparison with aircraft reconnaissance showed that night infrared images permit reliable tracing of the distribution of ice, particularly its large-scale features. In this case the boundaries of the ice/water interface are fixed much more reliably than nonuniformities of the ice field itself (fresh and packed ice, etc.). If the ice/water temperature contrasts are sufficiently great it is possible to detect details as small as 8 km in size.

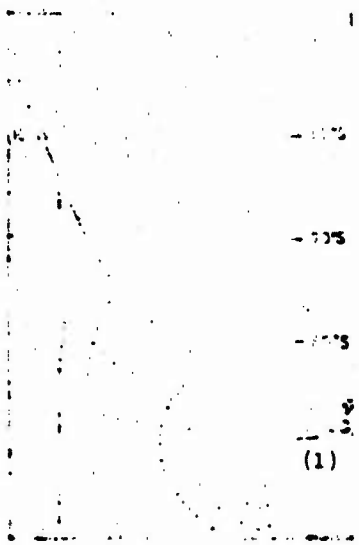

Fig. 5. Infrared image (spectral region 3.5-4.1 μm) of the Atlantic sector of Anarctica; image obtained from the satellite "Nimbus-1" around midnight (local time) 29 August 1964.
KEY: (1) South Pole.

GRAPHIC NOT REPPODUCIBLE

Although the presence of cloud cover hampers the use of infrared images for analysis of the ice situation, the actual frequency of observations is sufficient to obtain extremely useful data. Naturally, however, in winter (in the presence of temperature inversions) the problem of distinguishing the ice covering and clouds of the lower layer becomes difficult, especially since low density of cloud cover and a fresh ice coating can have very similar structure in infrared images. Solution of this problem may be favored by increasing the spatial resolution of the infrared equipment.

While daylight infrared images in the considered spectral region (3.4-4.1 μm) cannot serve as a means of distinguishing thermal heterogeneities, they can be analyzed together with data from measurements of radiation escaping into space, taken with a radiometer for the spectral segments 0.2-4.0 μm and 10-12 μm. As a rule, all of these data together will permit reliable distinguishing of sea ice from clouds with the same albedo (reflectivity) but lower temperature (this is a most difficult case during analysis of television images). Another advantage of data of this type as compared with television information is the possibility of using machine techniques for automatic analysis of multispectral data.

The possibility of using infrared images to study temperature fields of seas and oceans is particularly important. This not only opens the possibilities of constructing quite reliable climatological maps of surface temperature, but also permits studying its variability.

Figure 6 shows data on the variability of the ocean surface temperature (histograms) and the surface temperature field ("Nimbus-II") for the Gulf Stream region (the broken line shows the coast). The histograms were constructed from data for 1° latitude × 1° longitude squares. Analysis of the histograms showed that they have a single peak in the absence of clouds or with a solid cloud cover, while with partial cloudiness they have two or many peaks (in this case there is a correlation of the main maximum with the temperature of the ocean surface). Surface temperature values were taken as the maximum quantities for squares 0.5° on a side.

Since highly sensitive infrared equipment permits fixing small temperature contrasts, infrared photography can be used to detect and trace ocean currents. K. Ya. Kondrat'yev et al. (1966) carried out calculations which demonstrated the possibility, in principle, of solving such a problem. Analysis of infrared data

obtained from the satellite "Nimbus-II" confirmed these conclusions. Figure 7 shows the temperature field of the surface of the Atlantic Ocean in the region of the Gulf Stream, obtained through the use of an infrared image for the considered water area on 8 October 1966 ("Nimbus-II"). The Gulf Stream is clearly distinguished as a zone of elevated temperature values (the dark strip). The northern boundary of the current is outlined in high contrast.

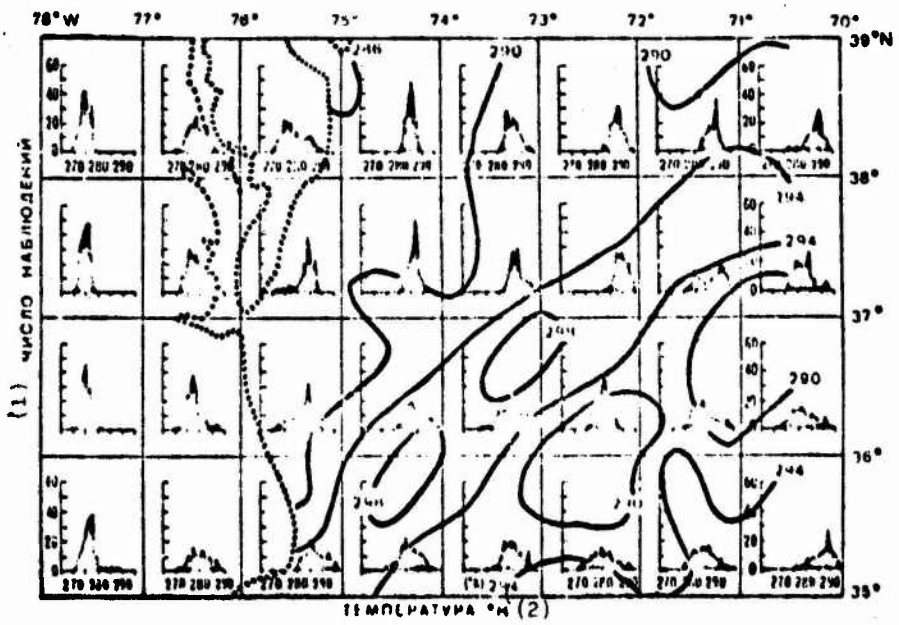

Fig. 6. Field of ocean surface average temperature and histograms of temperature at different points from "Nimbus-II" data for 15 November 1966 (the dotted curve shows the position of the shoreline). KEY: (1) Number of observations; (2) Temperature, °K.

The use of color photography of the mouths of rivers and near-coast zones was found to be very fruitful for studying the topography of the bottom in regions of shallow water, silting at river mouths, and dumping into the sea of particles suspended in river water.

GRAPHIC NOT REPRODUCIBLE

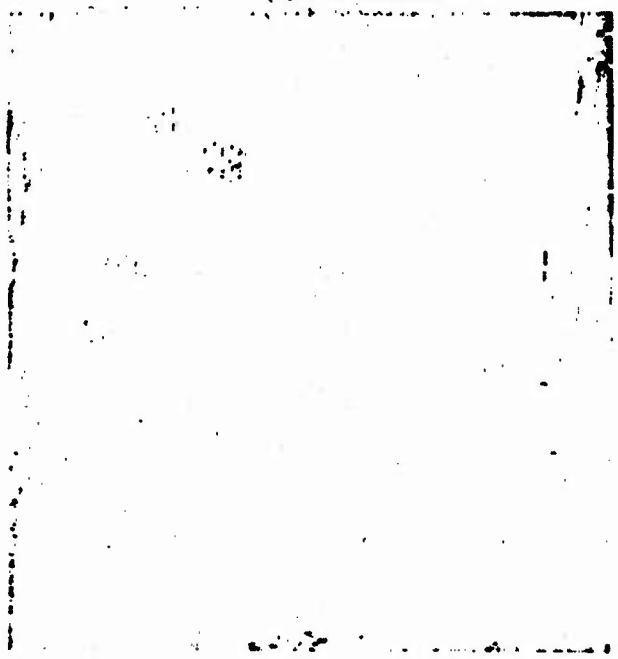

Fig. 7. Infrared image of an area of Atlantic Ocean in the region of the Gulf Stream from "Nimbus-II" data (8 October 1966).

Geography

Space technology is of interest to the geographer in application to such problems of the science as cartographic refinement of the broad remote territories in Africa, Asia, and the mountain massifs of the Antarctic. An important use of space technology is the study of the state of various types of terrestrial formations and clarification of the relief on the bottom of the Pacific Ocean. In particular, this will allow using new data to solve the problem of the origin of continents. If we had a fundamental theory of the evolution and distribution of the world ocean and dry land it would be possible also to predict the distribution of useful resource deposits - in particular, those in the Antarctic, which conceals reserves of coal, petroleum, metals, etc.

An example of the use of space technology in agricultural geography is the tracing of the development of agricultural crops and the state of natural conditions. This makes it possible to present recommendations on correct use of new territory and the arrangement of fields and crops on soils most favorable in terms of planting conditions and water supply; the configuration of fields as a function of illuminance could also be improved. We foresee the possible diagnosis and identification of certain crop diseases (even before they can be detected on the spot), especially epidemic fungus diseases carried by the wind, and also determination of conditions for their appearance. Prevention of erosion and catastrophic destruction of soil during dust storms, crop predictions, and increased effectiveness in using the soil - all these are possible results of space methods of geographic study.

Interpretation of space images in the geographic sense requires a system of characteristic key segments of the natural formations. The data for these segments should be used to develop the principles of interpreting various types of images, for the development of a procedure of space photography of given objects, and to clarify the rules for obtaining an image from space. For this purpose ground, aircraft, and space studies should be carried out simultaneously in the given regions; the results of all of these studies will serve as the key to understanding the subsequent information on spacecraft.

An example of the complex geographic interpretation of a photograph (obtained from the spaceship "Zond-5") is the refinement of the geobotanic and other charts of the African continent carried out by B. V. Vinogradov (1970).

Analysis of the photograph of the Earth depicted on Fig. 4 (obtained from "Zond-5") permitted, in particular, partial or complete identification of broad geographic zones of the African sector of the Earth, making it possible to trace their extent and to refine their boundaries. Figure 8 shows a map of geographic

zones illustrating these results. As is evident, the zone of subtropical evergreen forests and scrub forests of the extreme north and south of the African continent (Fig.8-1), the desert steppes and grassy-scrub semidesert in the subtropics and tropics (Fig. 8-2), tropical desert (Fig. 8-3), etc. are clearly identified on the photograph.

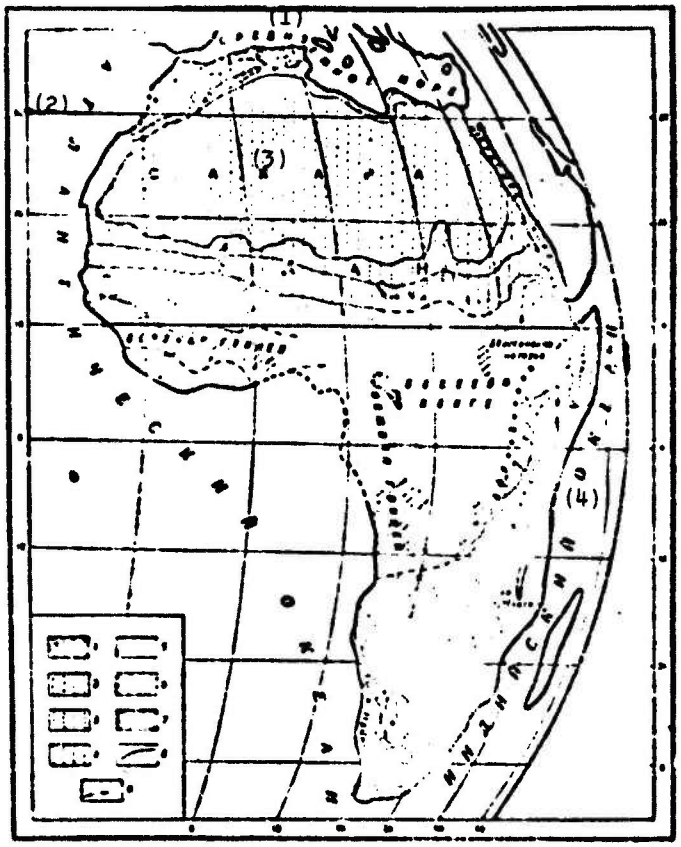

Fig. 8. Interpretation of the geographic zones of Africa by means of a global image of the Earth obtained from the AMS "Zond-5": 1 - Sclerophyllous evergreen forests and subtropical brush; 2 - Subtropical (a) and tropical (b) desert steppes and grassy-scrub semidesert steppes; 3 - Tropical deserts; 4 - Dry savannahs and tropical thorn trees; 5 - Tropical savannahs and thin tropical forests; 6 - Wet high-grass savannahs and tropical savannah forests; 7 - Equatorial rain forests; 8 - Boundaries of geographic zones and subzones on dry land, drawn by means of identification (a) and interpolation (b); 9 - Boundaries of cloud cover above the continent.
KEY: (1) Mediterranean Sea; (2) Atlantic Ocean; 3 - Sahara; 4 - Indian Ocean. (All other keys on the map are illegible).

Geology and Geomorphology

Investigations in the fields of geology and geomorphology, requiring high-resolution images, are presently based primarily on the use of photographs obtained from manned spacecraft. It should be noted that as yet these studies are not wide in scope, although their promise is unquestioned.

Interpretation of rock formations and tectonic structures with the level of detail of a 1:1,000,000 geological map made it possible to obtain new data on the structure of little-studied regions. It was found that photographs from space contain more information than geological maps on the same scale. Such photographs allow tracing of the erosion net in great detail. Sedimentary, metamorphic, and magmatic rocks and many elements of the tectonic structure are reliably identified from space photos (for example, many new lineaments - linearly oriented natural objects - have been detected).

Photographs from space are particularly valuable from the point of view of their geomorphological interpretation. The geomorphology of the investigated region is developed very clearly. The interpretation becomes even more complete if a stereoscopic pair of images is subjected to stereoscopic analysis (in this case it is easy to define the characteristics of the geometry of the relief).

The structure of irrigation systems is also clearly developed. Analysis of photographs of the Saudi Arabia and Yemen regions ("Gemini-4"), geologically a very diverse and complex example of broken arid terrain, illustrated the possibility of detailed investigation of the geomorphology of a territory with broken rocky relief consisting of igneous rock. For example, sedimentary rocks were clearly traced. The difference between igneous and sedimentary rock is determined by the laminar nature of the latter.

A sharply expressed fault separating regions of deposits of these rocks is clearly manifested. Sand dunes are observed very clearly. The lines of the dunes are arranged along the direction of the predominant wind. The clearest feature of the photographs are the clearly expressed differentiated structural lines of the igneous rocks.

At first glance the orientation of these lines appears random, but more careful statistical analysis showed that usually four dominating directions are observed. Apparently we can consider that the orientation of the lines is a reflection of the stresses arising in the Earth's crust. In some cases we can assume the presence of subsurface domed structures whose detection is of great significance in the search for petroleum and gas.

We will note in conclusion that from the point of view of the possibilities of geological interpretation the use of television and infrared images of the terrestrial surface obtained from meteorological satellites is of definite interest. As regards the promises for the future, there is no doubt that images obtained by passive and active radar methods will play an important role.

SPECTROMETRY IN SPACE

All of the material given above touches upon the interpretation of images of the Earth obtained from various spacecraft. The major advantages of the images are the territorial and factorial integration and the related possibility of complex analysis of the laws of change in space and time of the different characteristics of natural formations.

A basic difficulty in the interpretation of images consists in the fact that the obtained results are not, in principle, single-valued; this in turn is determined by the fact that data on the spatial distribution of the brightness field characterizing the image in some region of the spectrum does not provide a sufficient basis for a completely unique characterizing of the observed objects and their properties. The major (and sometimes decisive) role during analysis of images is played by experience (and even intuition) of the investigator conducting such an analysis (to a considerable degree this situation is analogous to the position of a weather forecaster during analysis of weather maps). Therefore the use of some sort of additional data which characterize the natural objects being studied might be of substantial importance. Information on the spectra of the studied objects is, from this point of view, the most informative material.

Investigation in the field of space spectrometry has only just begun. Here, as during analysis of images of the Earth made from space, the most significant results are obtained in the fields of meteorology and atmospheric physics.

The major goal of the use of AES in the interests of meteorological research is defined by the need to provide meteorological information for the entire terrestrial atmosphere. This need arose as a result of successful development of numerical methods of weather forecasting and of a theory of climate which (along with the possibility of using high-speed electronic computers) made a quantitative description of meteorological processes over the entire planet possible, given the availability of the appropriate initial information on the fields of meteorological elements and the physical characteristics of the atmosphere.

The first stage of the development of satellite meteorology was characterized by the obtaining and use of primarily two types of information: 1) television (daylight) and infrared (night) images of the earth; 2) information on the escaping radiation (escape of reflected solar or terrestrial heat radiation into space) in different regions of the spectrum.

As was already noted, television and infrared images, providing information on the planetary distribution of the cloud cover, have found wide use in forecasting practice.

As regards measurements of outgoing radiation, the results have been used primarily to study the laws of planetary distribution of the heat budget of the Earth, of which the incoming portion represents absorption of solar radiation by the atmosphere and the surface, while the consumption is represented by thermal radiation of the "terrestrial surface/atmosphere" system into outer space. Works in this direction have made it possible for the first time to obtain quantitative characteristics of the

heat budget of the earth, based on experiment, not only for brief time intervals but also for periods of great length, up to a year. Comparison with previously utilized calculation data indicated, in a number of cases, substantial divergence. In particular this concerns the magnitudes of solar radiation absorbed in the lower latitudes, which turned out to be considerably greater than had previously been assumed.

Information on escaping radiation in individual, comparatively narrow segments of the infrared region of the spectrum has been used to solve a number of so-called inverse problems of satellite meteorology. Thus, for example, data from measurements of thermal radiation of the Earth in the atmosphere transparency window 8-12 μm can be used to determine the temperature of the Earth's surface or of the upper boundary of the cloud cover. Information on radiation in the water-vapor absorption band around a wavelength of 6 μm makes it possible to evaluate the content of water vapor in the atmosphere. Outgoing radiation in the carbon dioxide band (wavelength 14-16 μm) reflects the peculiarities of the temperature field in the stratosphere.

Since the use of cloud-cover images is limited mainly to the framework of qualitative (sometimes semiquantitative) synoptic analysis, while the possibilities realized up to now for solving reciprocal problems in order to define the structural parameters of the atmosphere are very narrow, until very recently a huge volume of satellite meteorological information actually found no application in numerical methods of weather and climate forecasting. As was already noted, this case requires initial information on the fields of meteorological elements. Data on the distribution of atmospheric pressure at ground level and on the temperature field in the depth of the atmosphere is one of the adequate complexes of such information.

Only in 1969, with the first success in solving the problem of defining the vertical temperature profile (thermal sounding) up to altitudes on the order of 30 km from data on spectral measurements of escaping radiation in the 15-μm CO_2 region (meteorological satellite "Nimbus-III") did a new stage in the development of satellite meteorology begin. The first step was made toward solving problems in obtaining quantitative data on the fields of meteorological elements by means of AES.

Indirect Sounding According to Data from Infrared Radiation Measurements

For a number of reasons the accomplishment of this first step was found to be very difficult and required prolonged effort. One of the main reasons was the fact that the reciprocal problems of meteorology are improper in the mathematical sense. We will illustrate this from the example of the problem of thermal sounding of the atmosphere. The intensity of outgoing thermal radiation I_ν with frequency ν is determined by the following expression:

$$I_\nu = I_\nu^0 P_\nu(m_\infty) + \int_{p_0}^{p_1} B_\nu(T(p)) \frac{dP_\nu}{dp} dp,$$

where I_ν^0 is radiation from the surface of the earth (or from the upper boundary of the cloud cover, when the latter is opaque to radiation of the considered wavelengths); $P_\nu(m_\infty)$ is the transmission function characteristic to that fraction of the radiation which passes through the entire thickness of the atmosphere (m_∞ is the total content of material which absorbs radiation); $B_\nu(T(p))$ is the Planck function, dependent upon air temperature T (which, in its turn, is a function of atmospheric pressure p) and which characterizes the distribution of energy in the spectrum of an absolutely black body; p_0 and p_1 are the atmospheric pressures at ground level and at a certain conditional upper boundary of the atmosphere, respectively (thus integration in the right side of the given equation extends over the entire thickness of the atmosphere).

The considered problem consists in determining the function $B_\nu(p)$ (and, consequently $T(p)$, in view of the mutually unique correspondence between B_ν and T) in terms of the quantity I_ν, measured for a certain totality of frequencies (the free term in the right side of the equation can either be considered known or it can be placed under the integral sign). The principal possibility of solving this problem is determined by the fact that the derivative of the transmission function $\frac{dP_\nu}{dp}$, which is the kernel of an integral equation, has a clear-cut maximum at a certain altitude in the atmosphere; the position of this altitude depends upon frequency. Thus the scanning frequency which is accomplished in the process of measuring the spectral distribution of outgoing radiation is equivalent to a certain degree to sounding the atmosphere in depth (strictly speaking, the matter is substantially more complex, since the data for different segments of the spectrum are not completely independent and this determines the possibility of distinguishing a finite and comparatively small number of vertical profiles of temperature).

The practical difficulty in solving the problem consists in its improperness, which is expressed in the fact that the unknown solution depends strongly upon measurement error I_ν (small variations in I_ν lead to large changes in $B_\nu(p)$); in connection with this the initial equation has an infinite set of permitted solutions. Analysis of the possibilities of using different procedures for solving improper problems in this case showed that we should consider the method of regularization developed by A. N. Tikhonova as the most successful.

It was noted that from the point of view of the mathematical aspects of solution of the problem of thermal sounding there are three circumstances of primary significance:

1. The mathematical introduction of <u>a priori</u> information on the solution. The importance of this aspect lies in the fact that

the introduction of a priori information about the solution to be found makes it possible to single out the one solution sought from the infinite set of possible solutions. As regards the nature of the a priori information, it can be very diverse; it can range from general assumptions concerning the limited nature and smoothness of the solution to the use of observation data describing the statistical peculiarities of the vertical temperature profile being sought and predetermining its analytical form.

2. The selection of optimum conditions for measuring the spectral distribution of outgoing radiation. In the given case we are speaking here of selecting the minimum number of spectral intervals in which measurements will be made which permit obtaining the maximum possible information on the vertical temperature profile being sought.

3. Stabilization of the system of algebraic equations which approximate the initial integral equation in order to obtain a stable solution. The specific possibilities for realizing stabilization can be very diverse.

It should be noted that despite the diversity of procedures in interpreting data of spectral measurements of outgoing thermal radiation in order to determine the vertical temperature profile, the results of their application (from the point of view of accuracy of the obtained data) differ comparatively little.

A necessary condition for solution of the problem of thermal sounding is the requirement of high measurement accuracy; satisfying this requirement is far from easy. Another important requirement is the need for correct assignment of the kernel of the equation, which reduces to the as yet incompletely solved problem of exact determination (measurement or calculation) of the transmission function and its derivative. There is yet another circumstance which is essential in this connection; this is the fact

that generally speaking the transmission function depends upon temperature, which makes the problem nonlinear.

The most serious practical complication connected with solution of the problem of thermal sounding lies in the need to calculate the influence of partial cloudiness appearing in the field of vision of the spectrometer which is measuring outgoing radiation (since the measured radiation flows are very small it is necessary to increase the sensitivity of the equipment through an increase in the angle of vision). Clearly, the most natural and practically achievable method of overcoming this difficulty lies in using simultaneous readings from a scanning radiometer of very high angular (spatial) resolution for independent determination of the quantity of cloud cover in the spectrometer view field.

If data are available on the spectrum of outgoing infrared radiation it is also possible to solve problems in determining the vertical concentration profiles for ozone, water vapor, etc.

Comparatively wide use has been made of semiempirical procedures for processing data from measurements of outgoing thermal radiation in order to determine the temperature of individual layers of the atmosphere on the basis of establishment of a connection between outgoing radiation in a certain spectral interval and the temperature of the corresponding layer of the atmosphere. Thus, for example, it has been shown that outgoing radiation in the center of the 15 μm band (CO_2) is a quite reliable indicator of the temperature of the lower stratosphere.

A foundation has also been laid for the possibility of using data from measurements of outgoing radiation in the narrow spectral interval around 2339 cm^{-1} to determine the temperature of the layer of the stratosphere at high altitudes.

To illustrate real data from thermal sounding we will present results from vertical sounding of the atmosphere in terms of data from measurements of outgoing infrared atmospheric radiation made from the meteorological satellite "Nimbus-III."

Figure 9 shows the distribution of energy in the spectrum of outgoing infrared radiation as measured by means of an interference spectrometer. Interpretation of data from such measurements, related to various spectral ranges, made it possible to determine the vertical temperature profiles for the CO_2 band [15 μm (667 cm^{-1})], water vapor [6.3 μm (1600 cm^{-1})], and ozone [9.6 μm (1042 cm^{-1})]. Figure 10 outlines the results of determining the vertical temperature profile. As is clear, comparison with data from direct radiosonde measurements indicates satisfactory correspondence (substantial divergences are observed only close to the tropopause). Similar results were obtained for the vertical distribution of specific humidity. Data from indirect sounding of the ozone layer were less satisfactory.

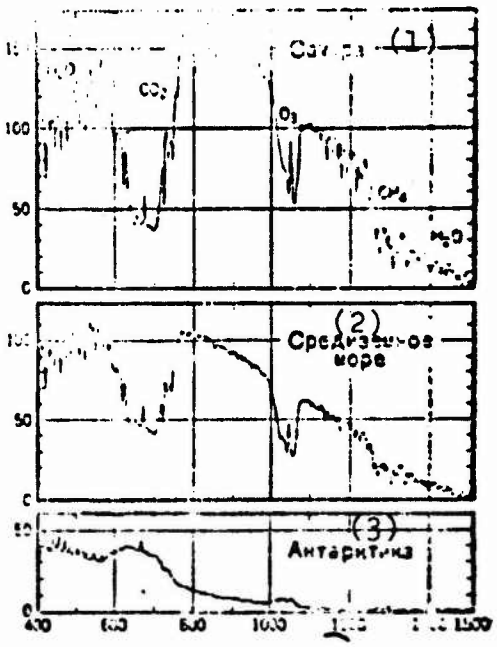

Fig. 9. Distribution of energy in the terrestrial thermal radiation spectrum (atmosphere and surface) into space according to data from the meteorological satellite "Nimbus-IV" (10 April 1970) for various regions of the Earth. The differences between the curves reflect the particular feature of the composition and structure of the atmosphere.
KEY: (1) Sahara; (2) Mediterranean Sea; (3) Antarctica.

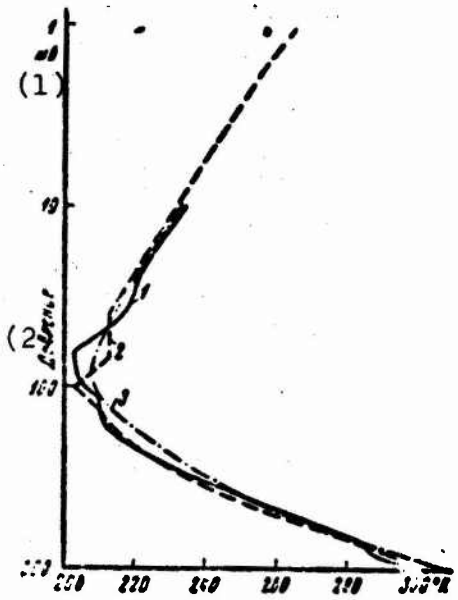

Fig. 10. Vertical temperature profiles obtained from the spectrum of outgoing radiation ("Nimbus-III") and by direct measurements: 1 - Radiosonde; 2 - Satellite data (Shakin method); 3 - Satellite data (regularization method). KEY: (1) mb; (2) pressure.

Indirect Sounding from Microwave Radiation Measurement Data

From the point of view of eliminating the influence of cloud cover it is more convenient to use the microwave region of the spectrum (as is known, clouds are transparent to radiation with wavelengths of 1-2 cm and more). This is precisely why major efforts have been undertaken in recent years to develop procedures for solving the reciprocal problems of satellite meteorology by means of microwave technology (according to data from measurements of outgoing microwave radiation at different frequencies).

For example, promise was noted in interpretation of data from measurements of outgoing microwave radiation in the region of the 5-mm band of molecular oxygen in order to determine the vertical temperature profile; this promise is due to the following favorable factors: 1) the possibility of achieving high spectral resolution of the measurements; 2) the constant nature of the oxygen content in the atmosphere; 3) the greater simplicity in calculating the influence of cloud cover than during interpretation

of data for the infrared region of the spectrum. Comparison of measured and calculated values of water vapor and oxygen absorption coefficient in the 30-80 GHz frequency regions showed that the calculated magnitudes of water vapor absorption coefficients in the 50-70 GHz range cannot be considered sufficiently reliable and therefore only experimental data should be used.

In solving problems of thermal sounding of the atmosphere the frequency interval 52-67 GHz can be used; here the absorption coefficients for oxygen are no less than an order of magnitude greater than the water vapor absorption coefficients. Results of calculating the dependence of the transmission function on frequency for layers of the atmosphere of different thicknesses indicate that the considered problem should be solved in terms of data from measurements of outgoing radiation in the spectral intervals between the lines. In this connection the vertical profiles of the derivative of the transmission function for winter and summer conditions were calculated for twelve spectral intervals characterizing the contribution of different layers of the atmosphere to outgoing radiation.

Numerical simulation of the solution to the thermal sounding problem revealed that in 14 out of 19 cases the mean square deviation of the calculated profile from the actual did not exceed 1°K (under the assumption of absolute measurement accuracy). The use of the method of successive approximations for calculating the dependence of transmission functions on temperature showed that it is usually adequate to limit oneself to the second approximation. Calculated temperature profiles reliably reproduced the presence of inversions and the position of the tropopause.

There is significant interest in solution of the problem of determining the total content of water vapor in the body of the atmosphere. From the point of view of solution of this problem useful information is found in the wavelength region in which

there is a substantial manifestation of absorption by water vapor. Use of the 1.348 cm line is most convenient. The results of calculations carried out by the Soviet scientists Yu. I. Rabinovich and G. G. Shchukin (1966) for the 1.35-cm wavelength and different stratifications of clear air over the ocean show that in this case there is a clear-cut dependence of the radio brightness temperature on moisture content in the thickness of the atmosphere. The influence of changes in atmospheric stratification and in the salinity is comparatively small. The total absolute error in determining moisture content is characterized by the following data:

Range of changes in moisture content.....	0-10	10-25	25-55
Absolute error in precipitated water, mm.....	2.5	3.5	4.5

Interpretation of aircraft measurements above the Caspian Sea and over Lake Ladoga led to completely satisfactory results (the average relative error in determining moisture content was 10%, while the maximum error did not exceed 16%).

Numerical experiments were carried out by another Soviet scientist, L. M. Mitnik (1969), in order to provide a foundation for a procedure to determine the total moisture content in the depth of the atmosphere above a quiet ocean surface according to data from measurements of outgoing microwave radiation on several wavelengths in the range 0.8-10 cm. Calculation of the optical thickness of the atmosphere in the vertical direction for the wavelengths 0.8, 1.35, 3, and 10 cm with different atmospheric stratifications indicated that the effect of stratification (as compared with calculation for a standard atmosphere model) does not lead to changes in the optical thickness of more than 15% if the magnitude of optical thickness falls within the limits 0.15-0.2 to 0.6-1.0.

Evaluations of variations in the weighted coefficients in the formula determining the connection of optical thickness of the atmosphere with total atmospheric moisture content and with the integral water content of clouds as a function of the nature of the vertical profile of specific humidity and the effective cloud temperature made it possible to calculate the related errors in determining the moisture and water content of the atmosphere. The obtained evaluations confirm the possibility of determining the total moisture content of the atmosphere above a calm water surface and in the presence of clouds from data obtained by measuring outgoing microwave radiation on several wavelengths.

Calculations of contrast of radial brightness temperatures of clouds and precipitation carried out in 1969 against a background of a water area showed that the contrasts reach 100-120°K and can be fixed reliably, since the variation in the radio brightness temperature of the ocean surface which is caused by different factors is not particularly great. The situation is substantially more complex in the case of dry land, when the emissivity of the underlying surface can vary from 0.6-0.7 (wet surface) up to values close to unity (forest massifs). Here there is major significance in the fact that a change in soil moisture in the process of fall of precipitation leads to a noticeable reduction in the emissivity of the ground surface. In this connection calculations were carried out for radio brightness contrasts with consideration of the wetting of the surface cover caused by precipitation for the following cases: 1) dry surface (cloudy and cloud-free atmosphere); 2) wet surface (clear and cloudy atmosphere, and also clouds and precipitation). The contrast calculations were carried out for vertical and horizontal polarization for the following ground covers: surface without vegetation (desert), forest masses, and grassy vegetation. The sighting angles relative to the nadir were 0, 30, and 60°. The water content of clouds varied from 0.5 to 4 kg/m^2 with an effective cloud temperature of 10°C, while rain was simulated by a uniform layer located between the level of

the zero isotherm and the underlying surface (the thickness of the rain layer was 4 km and the intensity of rain was taken as 1, 10, and 50 mm/h).

The calculations for the 0.8 and 3 cm wavelengths showed that in the case of intensive cloudiness and rain against a background of solid forest masses the radio brightness contrasts in temperature are not great and are negative (cloud cover has a lower radio brightness temperature). The contrasts vary substantially in the presence of cloud cover over a wet surface, without vegetation, especially for the 0.8 cm wavelength. A growth in the integral water content of the clouds will, as a rule, facilitate an increase in contrasts. In the case of rain the contrast in radio brightness depends little upon the intensity of the rain at the 0.8 cm wavelength, but varies strongly on the 3 cm wave. Evaluation of the effect on contrast in radio brightness temperature due to wetting of the surface by rainfall indicated a substantial influence of this factor, which in a number of cases even causes a change in the sign of the contrast. This leads to the conclusion that special checking of the state of the surface from measurement data on the 10 cm wavelength, where the measurements are free of atmospheric influence, should be carried out. The obtained results indicate that the multiwave radiometry procedure is most promising. The first measurements of thermal radio emission of the Earth (A. Ye. Basharinov et al.) were carried out on the satellite "Kosmos-243" by means of four radiometers on wavelengths of 8.5 and 3.4 cm (the radio brightness temperature sensitivity equaled 0.7°K) and also on the 1.35 and 0.8 cm wavelengths (sensitivity about 2°K). At all wavelengths except the first, antennas oriented to the nadir exhibited an identical half-power bandwidth of 3.5° (in the case of the first wavelength the radiation pattern was 2.5 times wider). On 23 September 1968 the satellite was inserted into an orbit with a perigee of 210 km, an apogee of 315 km, and an inclination to the equatorial plane of 71.3°.

Data from measurements on the wavelengths 8.5 and 3.4 cm, where absorption in the atmosphere is not great, characterized the radiation of the underlying surface. When the emissivity of the surface is a known quantity these data permit determination of surface temperature. The contrasts in radio brightness temperature which are caused by nonuniformity of the coefficients of reflection (radiation) of the underlying surface make it possible, in particular, to find the position of the edges of ice and certain characteristics of ice. Recordings of radio brightness temperature clearly demonstrate an increase in temperature above ice cover. When spaces of open water among the ice due to tidal currents are present reductions in the temperature are observed.

Radio emission of 1.35 and 0.8 cm wavelengths can be used to determine the total content of water vapor and liquid water in the atmosphere. This type of measurement is especially effective above the ocean, when the presence of water vapor and liquid water is manifested as a significant increase in the radio brightness temperature of the "surface/atmosphere" system as compared with the radio brightness temperature of the surface. For example, the boundary between moist tropical air and dry polar air in the 28-32° N region is very clearly traced above the ocean.

Data from measurements of outgoing radiation in the 1-12 μm interval clearly defined the cloudless layers in the atmosphere, which were then used for absolute calibration of the scales of the radiometers in brightness temperatures by tying to average climatic data. The accuracy of tying comprised 1-1.5°. The results of such calibration provided the basis for determining the moisture content of the atmosphere. Using the data for 24 September 1968, A. M. Obukhov and M. S. Tatarskaya (1969) constructed a chart of the geographic distribution of moisture content over the southwestern portion of the Pacific Ocean.

The characteristic overshoots on the radio brightness temperature profiles were used to detect the existence of 10

gradations of intensity of hydrometeors with cloud water contents ranging from 0.03 to 0.3 g/cm^2. Rainclouds and zones of precipitation were characterized by a spiked shape of the radial brightness temperature profile. During analysis of the fields of radio brightness temperatures over the continents a reduction in temperature by 30-50° was established in areas where the soil was wet due to precipitation. All of these results open broad promise for interpretation of data on outgoing microwave radiation.

Microwave Radiation of the Underlying Surface

One of the most important factors complicating interpreting satellite data on microwave radiation is the substantial space-time variability of the emissivity of the underlying surface, especially dry land. This is precisely why the solution of problems in determining surface temperature, moisture content, and the water reserve of the atmosphere above dry land is as yet impossible. Naturally, in the presence of a sufficiently extensive uniform surface (forest, steppe, desert, etc.) the situation is much more favorable, in particular when data are used from measurements on several frequencies for independent determination of the emissivity and temperature of this surface. The open surface of the oceans is much more uniform. Recently aircraft measurements have shown, however, that even in this case the situation is far from being as favorable as it appeared earlier. The results of aircraft measurements of microwave radiation on the 1.55 cm wavelength clearly illustrate that 1) in the presence of waves the radial brightness temperature is strongly increased, and 2) calculations do not predict such an increase. Both this divergence and the actual fact of a strong growth in radio brightness temperature with waves should be ascribed to the influence of foam, highlights, and air bubbles forming during strong wave effects - all factors which are not considered in the calculations.

It has been noted that the radiation which can be measured by a microwave radiometer at a given frequency and field of vision of the radiometer is determined by the following factors: 1) surface radiation (depending on its temperature and emissivity), 2) angle of sighting of the surface, and 3) transformation of the radiation from the surface by the intermediate thickness of the atmosphere. Theoretical calculations have shown that 1) horizontally polarized radiation depends essentially on the state of the surface of the sea and the angle of incidence, but is substantially less sensitive to surface temperature; 2) vertically polarized radiation is virtually completely resistant to change due to the state of the sea surface at angles of incidence of about 40°; 3) radiation of any polarization is independent of surface temperature at frequencies close to the absorption lines of water (for example, 30 GHz); and 4) the influence of the intermediate thickness of the atmosphere and also of ocean foam can be excluded.

For an experimental check of these conclusions it is necessary to undertake measurements of microwave radiation in atmospheric transparency windows on three frequencies selected in such a way that radiation is independent of surface temperature for one of them. It is also necessary to measure the vertically polarized component of radiation at a sighting angle such that the radiation does not depend on the state of the surface.

It has been shown that with such an experimental setup the use of data from measurements of radio brightness temperatures for both components of polarization at different altitudes above sea level will, when the true surface temperature is given, permit determination of the emissivity of the surface for both components and also of the contribution of radiation of the atmosphere. If the latter is known and if we also have the average temperature of the atmosphere along the path of the beam, it is possible to find the magnitude of microwave radiation attenuation by the thickness of the atmosphere. On the other hand, if the cited parameters are available it is possible to carry out simulation of

a satellite experiment with simultaneous determination of the emissivity and temperature of the ocean surface.

Ground measurements of this type were carried out on frequencies of 10.2, 30, and 38 GHz with simultaneous (successive) recordings of the horizontal and vertical components of polarization (the absolute measurement accuracy was better than ±0.5°K). The measurements were made on two dams in the Los Angeles region and they detected a strong influence of foam leading to a change in the radio brightness temperature by a magnitude of 20° to 100°K, depending on the fraction of water covered by the foam and the radiometer view field. Ripples also exerted a noticeable influence.

The existence of a strong dependence of radio brightness temperature on the state of the ocean surface led scientists to the conclusion that it would be advisable to use data from microwave radiation measurements to determine the true temperature of the surface even in the case of water basins. Along with this it is proposed that such data be interpreted in order to determine the state (degree of wave formation) of the ocean surface.

It is known from observations that foam appears on the surface of the ocean at wind velocities greater than 15 units. Since a sharp increase in radio brightness temperature is observed upon the appearance of foam, the possibility is opened of using a fairly simple method for determining wind velocities exceeding 15 units.

In September 1967 aircraft measurements of microwave radiation were carried out over the Gulf of Mexico, along the periphery of hurricane Beulah. These measurements showed that with an increase from 2 to 9% in the degree to which the ocean was covered with foam a growth in radio brightness temperature by 8°K (frequency 9.3 GHz) was observed; evaluations of data from "model" measurements gave a quantity of about 10°K. This indicates that "model"

measurements give fully satisfactory reflection of real conditions and simultaneously indicate the promise inherent in the use of data from microwave measurements from satellites to determine wind speed.

The existence of a connection between wind velocity and the radar cross section of reverse scattering from the ocean surface opens a possibility of obtaining information on the wind in planetary scales by using procedures of active satellite radar research. Since it is essential to consider the influence of the body of the atmosphere when thick clouds and precipitation are present, measurements of microwave radiation can, in this case, be used to determine the nature of the corrections and also to study the three-dimensional distribution of precipitation zones.

Simultaneous radar and radiometric measurements confirming the conclusions drawn above were also carried out. Although the radar measurements of back scattering by the ocean surface were undertaken long ago, only in the last two years have data from such measurements been obtained in the open ocean during strong wind and with proper angles of incidence. It was found that of the two parameters "wind velocity" and "wave height," the first has a determining influence on the formation of a recordable signal. This is explained by the fact that back scattering of radio emission is controlled mainly by that portion of the spectrum of wind waves which corresponds to a large wave number (i.e., the small-scale component). Data from a number of investigations with increased wind velocity indicate that the intensity of the reflected signal grows, but reaches "saturation" at a certain velocity.

Results of measurements made at 2.25 cm in the spring of 1968 (Iceland region) and the spring of 1969 (Ireland region) showed that in this case saturation occurs at velocities of 40-50 units, while in the case of a 75-cm wavelength it is manifested to a

much smaller degree; here the growth in wind velocity is accompanied by a reduction in the reflected signal. Since the data of other authors indicate a comparatively weak dependence of reverse scattering on wind velocity at a wavelength of 3.3 cm, this emphasizes the importance of selecting the appropriate wavelength to ensure maximum procedure sensitivity.

On the basis of analysis of results from aircraft measurements, the American scientists R. Moore and V. Pearson[1] proposed a satellite equipment arrangement representing a combination of a radar and a radiometer with a common radiation receiver. In such a case measurements can be carried out in the following sequence: generation of a radar signal, reception of the reflected signal, measurement of microwave radiation (these data also used for radar calibration), and calibration of the radiometer. Measurements can be accomplished at two angles of incidence: 10° and 35°, or (which, certainly, is better) one can use a scanning apparatus. Forecasting the spectrum of marine wave conditions requires averaged data on the wind. An averaging interval equal to 120 km can be considered adequate. In such a case with scanning in the range ±600 km (in a plane tilted forward with respect to the vertical to avoid excessively small angles of incidence) data will be available for 11 strips along the satellite trajectory. Repetition of the measurements after 6 hours is sufficient to guarantee virtually continuous forecasting.

Recently development has begun on procedures for studying the characteristics of the ground at different depths from data obtained by measuring microwave radiation on different frequencies. The author has shown, for example, that it is possible to determine the vertical profile of temperature in the surface layer of soil.

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[1]Translator's Note: Exact spelling of names not determined.

Microwave technology can be used also to solve the very important problem of determining the vertical profile of air density with respect to the change in frequency and phase of the signal from a radio transmitter, recorded by a receiver during passage of the radio beam through the body of the atmosphere. Such a procedure was first applied on the automatic interplanetary station "Mariner-4" to determine the density of the Martian atmosphere. Under terrestrial atmospheric conditions the realization of such a procedure requires the use of a system of satellite transmitters and a satellite which records the signal passing through the body of the atmosphere in the periods of "rising" and "setting." A similar "eclipse" procedure can be applied to determine the composition of the upper layers of the atmosphere on the infrared spectrum of atmospheric absorption by using the Sun as the radiation source. Such a method has been applied repeatedly during launches of high-altitude balloons.

Short-wave Radiation and Reciprocal Problems

K. Ya. Kondrat'yev, B. S. Neporent and A. G. Pokrovskiy (1970) developed a theoretical foundation for this procedure of "eclipse" sounding with application to the case of determining the content of water vapor in the stratosphere and the mesosphere.

A similar procedure is planned for the meteorological satellites "Nimbus," with a view toward its application to determine the vertical distribution of ozone in the atmosphere of the polar regions from data obtained by "eclipse" measurements of solar radiation absorption by ozone in the ultraviolet region during sunrise and sunset with respect to the satellite. The orbital parameters of the "Nimbus" satellites permit most successful solution of such a problem for bands in latitudes 60-80° in both hemispheres, where the role of ozone as a factor in atmospheric thermodynamics is especially significant. Thus, for example, upon

launching of a satellite at the end of November, in the first 48 hours of operation 26 "sunsets" will occur with respect to the satellite.

Investigations of peculiarities of polar circulation in the stratosphere and, in particular, of its seasonal variations (accompanied by rapid changes in the vertical distribution of ozone) are hampered by the extremely inadequate data on the atmospheric ozone in the polar regions, especially above its concentration maximum. Considering the fact that reliable measurements can be carried out only in a range of transmission values of 0.05 to 0.95 (corresponding to the optical frequency interval 3.0 to 0.05), it is possible to identify a set of wavelengths in the ultraviolet region for which it is necessary to measure absorption in order to find the vertical profile of ozone concentration in the altitude interval 20-70 km.

When radiation is recorded from a strip on the solar disk equal to 0.1 diameter in width, altitude resolution on the order of 3-4 km can be achieved. The duration of an individual series of observations comprises 25-30 s, while the scanning rate is 3.8 km/s in altitude - requiring an instrument time constant no greater than a fraction of a second and also requiring precise recording of the time of the measurements. An important advantage of the "eclipse" method is the possibility of "self-calibration" with respect to the Sun.

Still another possibility of using the satellite procedure for determining the vertical distribution of ozone concentration lies in interpretation of data from measurements of the outgoing ultraviolet radiation (UV solar radiation reflected into space by the Earth). To solve this problem by this method it is planned to install on the meteorological satellite "Nimbus D" a double UV spectrophotometer with a view field of 12° and a spectral slot width of 10 Å to measure the spectral distribution of the energy

of outgoing ultraviolet (back-scattered) radiation in the wavelength range 2555 to 3398 Å (spectrum scan time comprises 32 s). Data from measurements of radiation intensity for 12 spectral intervals within the indicated wavelength range will be used to determine the vertical profile of ozone concentration.

Even within the framework of meteorological and atmospheric physics interests the possibilities for interpretation of Earth spectra are exceptionally broad. Therefore we will limit ourselves here to a single example which illustrates the possibility of identifying clouds from peculiarities of their reflection spectra in the near infrared. In this connection spectral measurements of outgoing radiation in the near-infrared region of the spectrum were carried out on the American satellite "OV 1-5." Calculations carried out for comparison with the experiment were accomplished for 12 different particle size distributions; an essential influence of particle refractive index (water or ice) on the spectra of outgoing radiation was observed.

Comparison of calculation data with results of measurements for three spectra related to different scattering angles and solar zenith distances showed that in one case of the measurements, the cases of liquid-drop clouds examined in the calculations do not correspond to reality, since they give a brightness minimum on the wavelength 1.95 μm which does not exist on the experimental curves. Agreement is obtained only in the case of the model of a crystalline particle cloud if the influence of molecular absorption by water vapor and carbon dioxide is also taken into account. In the other cases analysis of the measured spectra made it possible to establish a transition from an ice cloud to a water cloud. Thus recording of the spectra of outgoing radiation in the near infrared makes it possible to distinguish the nature (type) of clouds, to evaluate their quantity, and to determine the content of gas components in the body of the atmosphere.

The main direction in the development of satellite meteorology (related to a number of problems in oceanology) is connected with further development and improvement of methods of solving various reverse problems through the use of AES inserted into solar-synchronous polar orbits at altitudes on the order of 1000 km. However, the requirement for continuous tracking of meteorological processes from vast territories brings out also a requirement for using geosynchronous satellites placed in an equatorial orbit at an altitude of about 36,000 km (in this case the satellite rotation period equals 24 hours and therefore it "hangs" above a certain point on the equator). As was already noted, even photographs of the Earth obtained from the space station "Zond-5" from 90,000 km were found to be very informative from the point of view of possible meteorological interpretation. It is therefore reasonable to consider that in the near future the idea of a lunar meteorological observatory, set forward earlier by the author, will be realized.

An additional important possibility of three-dimensional generalizations which can be achieved when images of the Earth are obtained from high altitudes is the prospect of solving a number of reverse problems of satellite meteorology by means of manned orbital stations. The possibilities of testing and using complex apparatus, conscious selection of objects of study, and the achievement of high spatial resolution are unique advantages in this case.

Investigations in the field of satellite meteorology are only a partial example of those vast possibilities opened by the use of AES to study the natural resources of the planet by obtaining images of the Earth in various regions of the spectrum, and also for the use of space spectrometry methods.

Another important example is the prospect for using spectral methods to investigate natural formations.

Spectrometry of Natural Formations

As was noted above, the atmosphere is a definite obstacle for spectrometry readings of natural formations. However, on the other hand, this signifies the possibility of using methods of space spectrophotometry to investigate the atmosphere. It is precisely this area in which work in the field of space spectrophotometry has been most active and rewarding.

The cosmonauts Ye. V. Khrunov and B. V. Volynov obtained the first spectra of the crepuscular aureole of the Earth from the spaceship "Soyuz-5"; these spectra made it possible to study the aerosol structure of the atmosphere (the content of dust particles at various altitudes) and provided an objective characteristic of the colors of sunrises and sunsets observed from earth, using a quantitative colorimeter.

The first space spectral measurements of reflections of natural formations were carried out from the Soviet spaceship "Soyuz-7." Spectra of the cloud cover and a desert-type underlying surface were studied. However, these data were not numerous and in all merely illustrated the possibility of solving certain problems by means of space spectrometric readings. Combined experiments with simultaneous ground, aircraft, and satellite observations are of great importance in solving problems of space spectrometry. The first effort at such a combined experiment was accomplished during the formation flight of the spaceships "Soyuz-6, 7, 8."

Laboratory, ground, and aircraft measurements of albedo and of the coefficients of spectral brightness of natural formations are comparatively numerous. In particular, such works have been carried out in order to determine the theoretical possibilities of space spectrometry of the terrestrial surface and, on the other hand, with a view toward defining the requirements for the design

of spectrometric equipment to be installed on artificial earth satellites. It should be noted in this connection that the infrared equipment used, for example, on meteorological satellites has too narrow a geometric and spectral resolution to provide material suitable for local analysis.

Investigations on the study of spectral brightness coefficients [SBC] and of the albedo of natural surfaces from aircraft have been carried out in the USSR and abroad for many years. These studies uncovered the great complexity and multiplicity of optical characteristics of natural objects. It was found possible to separate all natural formations into only four classes: 1) soils and rocks, 2) vegetation, 3) snow and ice surfaces, and 4) water surfaces. In addition to the above the class of cloud formations has been recently established. More detailed spectrometric investigations indicate the existence of extremely fine relationships between spectral brightness coefficients and albedo, on the one hand, and the composition of natural objects on the other.

If the spectral characteristics of the albedos of different surfaces are available it is possible to attempt to solve the reverse problem - i.e., to identify the surfaces from data on the spectral reflectivity. Naturally, the spectrum as a whole is the most informative. However, an effort can be made to find a simpler solution to the problem - for example, by examining the ratio of the albedos for two wavelengths.

From the point of view of interpretation of satellite measurement data we can seek the solution of the stated problem by, for example, studying albedo A for two segments of the spectrum, 650 and 850 Nm, and by determining the ratio $K = A_{850}/A_{650}$.

The selection of the indicated segments of the spectrum was based, on the one hand, on the good transparency of the atmosphere

for the corresponding wavelengths and, on the other hand, by the high "sensitivity" of the coefficient K to the type of natural formation. The use of data from ground observations and also of calculated magnitudes of albedo of clouds leads to the following values of K:

vegetation-covered surface: 4-15,

soil: 1.2-3.0,

snow surface: 0.75-1.0,

water surface and clouds (water): 0.9-1.0.

According to data from K. Buttner (1970), the analogous coefficient for the wavelengths 1.6 and 0.7 μm ($K = A_{1.7}/A_{0.7}$) gives the following average values: 5 (snow); 1.4 (sand); 0.85 (water cloud); 0.25 (fresh snow); less than 0.1 (field of compacted snow).

It is clear that a single ratio of albedos for two wavelengths is not a unique characteristic of the type of natural formations; this means that it is necessary to seek more complete and complex indices (for example, it is clear that the use of the absolute value of albedo in the visible region of the spectrum as an additional characteristic will itself introduce substantially greater definiteness). Only a green cover of vegetation is clearly identified by a high value of the coefficient K; this is due to the sharp increase in reflectivity in the near infrared region.

Studies have also been made of solutions to the problem of identifying different types of agricultural crops on the basis of data from the energy brightness of agricultural plantings in the wavelength interval 0.35-16 μm, using electronic computers for the data processing. It was found that for many problems of

identification the most important significance lies in such spectral peculiarities of reflection as the smooth hump in the green region of the spectrum which corresponds to vegetation; the dip in the red region corresponding to the chlorophyll absorption band, and the sharply expressed reflection maximum in the near infrared region. In this connection it was proposed that the following spectral intervals be selected for a natural-resources satellite: 0.52-0.58; 0.62-0.68; 0.72-1.1; 1.2-2.5, and 10.0-13.5 μm.

An effort to classify about 40,000 spectra from agricultural crops, carried out in 1969, led to the conclusion that from the point of view of maximizing measures of separability, the optimum data are those obtained by measurements of the spectral brightness in three wavelength segments. Naturally the composition of the set of indices to be used (selection of the totality of the spectral segments) depends on the specific features of the problem to be solved. Thus, for example, it was found that in solving the problem of distinguishing between fields of soy beans, corn, oats, wheat, and red clover the most effective indices are the spectral brightnesses for the intervals 0.40-0.44; 0.66-0.72; 0.72-0.80 μm. Table 1 gives specific data characterizing the success in classification.

As is evident, the higher sensitivity of the spectral "specimens" as a function of the state of the vegetation cover permits successful resolution of the differentiation problem. Apparently solution of more complex problems in determining the state of crops or of woody vegetation, evaluating the harvest, etc. is possible. Clearly the successful realization of such research by means of satellites is impossible without preliminary simulation and ground tests.

In terms of the spectral brightness coefficients vegetation can be broken down into life forms. Peculiarities of the distribution of spectral brightness coefficients serve to single out

formations of hygrophytes, masophytes, xerophytes, and halophytes. Various features of vegetation as functions of the phenological development and ecological conditions are also differentiated.

Table 1. Results of classification of certain agricultural crops.

(1) Класс	(2) Число объектов	(3) Процент правильной классификации	(4) Число объектов, отнесенных к классу					
			(5) соя	(6) кукуруза	(7) овес	(8) пшеница	(9) красный клевер	(10) отвергнутые по порогу яркости
(5) Соя	2627	88.8	2310	304	12	0	1	0
(6) Кукуруза	2907	81.5	170	2372	68	0	177	0
(7) Овес	2523	89.8	5	44	2266	0	238	0
(8) Пшеница	2803	91.8	7	3	218	2572	3	0
(9) Красный клевер	2811	86.6	4	220	152	0	2435	0
(11) Общее число	14071		[illegible]	2943	3006	2572	2854	0

KEY: (1) Class; (2) Number of objects; (3) % correct classification; (4) Number of objects per class; (5) Soy beans; (6) Corn; (7) Oats; (8) Wheat; (9) Red clover; (10) Rejected due to brightness threshold; (11) Total number.

Data on the spectral brightness coefficients are successfully used to carry out phytopathological surveys of forests and fields to detect diseases of the vegetation even before they are visible to the eye.

During aerial spectrophotometric surveying in the visible region of the spectrum rocks are differentiated mainly as a function of their mineral composition. Analysis of coefficients of spectral brightness in the visible region of the spectrum can show such strong differentiation that, for example, it is possible to distinguish sands of different origin (alluvial and eluvial, Kopetdag and Pamir-Alay, etc.).

In terms of spectral brightness coefficients soils are differentiated mainly with respect to their physical properties:

the degree of wetness, humus content, and mechanical and mineralogical composition. The solution to one of the most difficult problems of remote reading - the problem of distinguishing between snow and clouds - is based on the use of relative values of spectral brightness coefficients. Analysis of data from measurements carried out above clouds and over a snow-covered surface have shown that in this case additional data are required concerning the reflection around $\lambda = 1.6$ μm, where the contrasts between clouds and snow may reach 0.65-0.75.

It should be emphasized that successful solution of problems in spectrometric remote reading is prevented by the fragmentary data concerning coefficients of spectral brightness of natural formations. The development of methods of objective identification of natural formations from their spectra is also of great significance. The use of specimen identification methods is very promising for this purpose.

At the present we should consider the most urgent problem to be the development of procedures for interpreting data about the natural environment obtained by means of satellites, by applying the optimum combination of means of automatic (computer) processing and manual analysis.

As was already noted, at present equipment which puts out data in the form of images is used predominantly for remote indication. This type of presentation of results is most convenient from the point of view of analysis of the large volume of data characterizing the spatial field by the human being. But if we consider the enormous increase in the volume of information with which we are faced in the future it becomes clear that it is hardly likely that images will remain the predominant form of information presentation in times ahead.

Spectrographic Investigation of Natural Formations from Piloted Spaceships

The successful effort to carry out spectrographing of the crepuscular aureole which was realized during the flight of the "Soyuz-5" created favorable conditions for the further development of research in the field of space spectrometry. During the group flight of the spaceships "Soyuz-6, 7, 8" the program of complex optical experimentation was expanded and solution of the following basic problems was programmed:

1. Spectrophotometry of the Sun and of the crepuscular aureole of the terrestrial atmosphere under various visual conditions, illumination by the Sun, and with the observer in space in order to study the brightness and the light picture of the aureole and to investigate the vertical distribution of various components of the atmosphere.

2. Spectrophotometry of various natural formations in order to study the possibility of identifying them from the spectral reflective characteristics as measured from space.

3. Synchronized accomplishment of the complex program of ground and aircraft optical investigations of the atmosphere and of different types of underlying surfaces in the area beneath the satellite in order to obtain data characterizing the spectral transmission functions of the atmosphere and the spectra and spectral contrasts of natural formations as a function of the basic optical parameters.

The spectrophotometry of the twilight atmosphere and of the underlying surface from the spaceship "Soyuz-7" was carried out with a modified hand spectrograph, RSS-2.

Data on the spectra of different natural formations were obtained on 13 October 1969 from the spaceship "Soyuz-7" along a route from the Arabian Peninsula to the Aral' Sea. Spectrography of different segments of the terrestrial surface was carried out during a short time interval, from 1319 to 1329 hours Moscow time with solar altitudes of 35-50°.

During the flight of the "Soyuz-7" spectra of the following identified categories of natural surfaces were obtained: 1) solid cloud cover; 2) thin cloud cover; 3) rocky desert; 4) the dark segment of the desert.

The results of spectrography from the satellite were compared with the synchronized aircraft measurements of brightness and contrasts obtained with similar equipment (RSS-2) over the Ust'-Urt plateau in the region of the "crossing point" of the spaceship and the laboratory aircraft.

Spectrophotometry from the satellite was carried out from an altitude of 220 km, while the altitude of the aircraft was approximately 2.7 km. Comparison of the results of satellite and aircraft measurements of spectral brightnesses and contrasts for identical types of underlying surface shows that the influence of haze on the optical characteristics is comparatively small in comparison with the measurements made at an altitude of 2.7 km. As would be expected, the haze effect is maximum in the short-wave region of the spectrum, at $\lambda \leq 520$ mm. In the long-wave region, $\lambda \geq 520$ mm, scattering of the solar radiation by the atmosphere above 2.7 km has a very weak influence on the absolute values of the brightness of natural surfaces.

In conclusion we should note that the curve of spectral brightness of natural surfaces makes it possible to distinguish certain types of natural formations from the spectra measured from a spaceship. Along with this we should emphasize the fact that

the atmosphere distorts the shape of spectral brightness curves and reduces the spectral contrasts. However, the optical density of cloud-free terrestrial atmosphere is not extremely great. Therefore the totality of data on the reflectivity, radiation and temperature, and the complex of other reflective and emissive characteristics of the underlying terrain provide, in principle, the possibility of sufficiently fine distinction of natural formations from their spectra.

CONCLUSION

Space spectrometry has as yet taken only its first steps. However, the results obtained in the field of satellite meteorology (indirect sounding of the atmosphere) and in studying the characteristics of the underlying surface with respect to data from measurements of outgoing radiation in different spectral regions permit us to consider that space spectrometry is the most promising direction for the development of space methods of studying the earth. The soundness of this conclusion is determined by the fact that the use of data from spectral measurements opens the widest possibilities for quantitative determination of the characteristics of general scientific interest.

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