WEATHER THAT IS NOT VISIBLE FROM EARTH:
HIGH-RESOLUTION TELEVISION PHOTOGRAPHY

N. F. Vel'tishchev

Paper presented at United Nations Conference on the Exploration and Peaceful Uses of Outer Space, Vienna, August 14-27, 1968

Translated by Techtran Corp.
Glen Burnie, Md.
under Contract NAS 5-14826
Item No. 42

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Television pictures of cloudiness which are now being received from artificial earth satellites have proved to be a very effective means of studying atmospheric conditions. The chief advantage of observation weather satellites is that they furnish a continuous picture of cloud distribution along the satellite's trajectory of flight. The vast amount of factual information that has been gathered at the present time makes it possible to confirm the fact that the earth's atmosphere is literally inundated by periodical motions which yield comparatively simple hydrodynamic interpretations.

Just as original cloud classification was created in accordance with morphological and genetical criteria, based on cloud observations from earth, so it is now necessary to create a new, dynamic cloud classification, based on the morphology of cloud cover as seen from space. Cloud classification in use at the present time and which evolved from earth observations, is based on a nonhomogeneous cloud cover which has dimensions on the order of 10^2-10^3 kilometers. Modern television apparatus cannot discern such minute heterogeneities, but does do an excellent job of detecting cloud formations having dimensions on the order of 1-10^3 kilometers. In this connection, the genesis of morphological features in the field of cloudiness which were observed earlier from earth and were not found on synoptical maps must now be studied. Once the conditions relating to the formation of basic cloud structures have been thoroughly studied, it will be possible to create a dynamic cloud classification which will be in accordance with observations from artificial satellites. There are reasons for thinking that this form of classification will be able to furnish the synoptic with a considerable amount of indirect information about weather conditions.

In actuality, clouds are, in themselves, a sort of mirror in which is reflected the activity going on in the atmosphere. One of the jobs of the modern meteorologist is to make possible a fuller physical interpretation of the various cloud structures observed in space. On the basis of this type of interpretation, the synoptic will be able to be thought of as the sum total of the weather, in connection with one or another cloud formations. Undoubtedly, this information will be particulary useful in those areas of the globe where the network of meteorological stations is sparce. Having information concerning the spatial structure of the cloud cover, it is now possible for meteorologists to make more valid interpolation of instrument measurements, thereby improving the original analysis of the fields of meteorological elements.

The emergence of new information on the structure of cloud cover makes mandatory more intensive research on the fundamental problems of meteorology: the theory of stability and evolution of atmospheric perturbation, interaction of disturbances of various magnitudes, and so on.

The overall range of problems related to dynamic interpretation of cloud classification based on satellite observations is very broad. We will attempt to examine only a few of the forms of ordered convections in the atmosphere and cloud structures related to the influence of rugged terrain profiles on air currents.

The television cameras mounted on the satellites of the experimental "Meteor" system have a resolving power in a nadir of 1.25 kilometers and, in this way, can detect heterogeneities in the cloud cover on the order of several kilometers. The high degree of resolving power of the television pictures received makes it possible to obtain detailed information concerning the structure of medium-scale atmospheric phenomena, which cannot be observed by the network of weather stations.

1. Cloud Systems of Ordered Convections.

Prior to artificial satellites, the meteorologists did not suspect that forms of ordered convections were often encountered in the atmosphere; these convections were only observed earlier in the laboratory. Drawing 1 serves as an example which shows the convective systems obtained under laboratory conditions and those received from "Kosmos-144." Cloud systems having this polygonal form are usually developed over oceans and cover an area of millions of square kilometers. The existence of rectilinear polygonal systems presupposes a quasi-stationary condition of convections and simplifies the problem of hydrodynamical interpretation of these phenomena. It should be pointed out that prior to the appearance of television pictures of clouds, the study of cellular convection was of a more academic nature, since research results were difficult to apply to the meteorologist's daily work. Now that the weather services of different countries have daily information available on the cloud structure over vast territories, the study of cellular convection became a reality from a practical point of view. The problem is this: what can we say about atmospheric conditions if we see a particular morphological feature in the field of cloudiness. Let us first take a look at the case of polygonal convection, in which cloud cells have a hexagonal or almost axially symetric shape and make their appearance in the center with either an ascending or descending movement. Drawing 1 illustrates just such a cloud formation.

In Drawing 1A are images of polygonal cells having upward movements in the center, while Drawing 1C shows them with downward movements in the center.

Theoretical and experimental research carried out in the Soviet Union has revealed that rectilinear polygonal cells are formed over cold ocean currents, where the difference in water and air temperatures does not vary more than one degree. The temperature gradient in the lower kilometer layer is usually 0.15-0.20 degrees/100 meters, and then increases to 0.5-0.6 degrees/100 meters. Earth observers identify the clouds of such convective cells, in the majority of cases, as stratocumulus, the lower boundaries of which are at an altitude of from 200 to 600 meters. There is rarely any precipitation from these clouds, while the wind velocity on the ocean's surface as a rule never exceeds five meters per second.

On the basis of such indirect information concerning cloud imagery, the meteorologist can make a reliable weather forecast according to the cloud information received from a Kosmos satellite.

Convective cells having a downward movement in the center, as research has shown, are formed during significant differences in water and air temperatures. The temperature gradient in the lower kilometer layer is usually 0.7-0.9 degrees/100 meters, but changes at altitudes by means of isothermy or inversion. Earth observers indentify clouds of open convective cells as cumulus in the vast majority of cases (cumulus, thick cumulus and, more rarely, cumulonimbus). As a rule, convective cells are formed when cold masses of air intrude on the warm underlying surface. The horizontal size of the convective cell is associated with the force of the convective layer: the size of the cell increases while the force of the convective layer increases. It is in this manner, then, that televized cloud imagery makes it possible to give due consideration indirectly to the force of the convective layer. Experimental data received from a "Meteor" satellite showed that during the formation of heavy convective cells, the force of the convective layer seldom exceeded an area of 2.5-3 kilometers.

Cumulonimbus Precipitation occurs only during the formation of heavy convective cells having a diameter of 50 kilometers or greater and when they consist of cumulonimbus clouds. The wind velocity at the ocean's surface in areas occupied by open convective cells seldom exceeds 8-10 meter per second.

The areas in which convective cells develop in the atmosphere often occupy vast territories covering hundreds of thousands and even millions of square kilometers over the water areas of the oceans. The network of meteorological and, in particular, radiosonde stations in these areas of the earth's surface is extremely sparse and falls far short of furnishing sufficient weather information; it is difficult to imagine that the number terrestrial meteorological observations over the water areas of the cceans will grow appreciably in the near future.

As far as the immediate future is concerned, the meteorologist will have to depend upon information received from satellites. The meteorologist, having high-resolution photography at his disposal which he has received from a satellite and knowing that the atmospheric conditions that have been televized to him aid in the formation of, say for example, convective cells, can now confirm the fact that calm weather prevails in these areas and that cumulus-type clouds have no significant vertical development; all this is made possible on the basis of television photography received from Kosmos.

In the case of symmetrical cells, the convective components are fully neutralized by the forces of vicosity. As soon as large-scale movements occur in the atmosphere, then inertial components inevitably emerge which exert a deforming influence on convective cells. The process of just such a form of distortion is shown very clearly on numerous high-resolution television pictures.

In the USSR's Hydrometeorological Center, an entire cycle of theoretical and experimental work was conducted, in which the influence of air flow and stratification of atmosphere on the geometry of convective elements in the atmosphere was studied. Conclusions were reached as a result of this research, which had definite applicable significance. It was revealed, specifically, that under conditions of atmospheric stratification approaching the adiabatical type, convective elements are drawn out and expanded when subjected to the action of air flow along the direction of the air flow only if the direction of the wind from higher altitudes changes significantly. The results of the statistical processing of a great number of satellite sightings showed that the direction of air flows in the lower troposphere can be identified with absolute surety, particularly over the water surface, by the banks of cumulus-type clouds

In areas occupied by cloud banks, increased wind velocities are observed which reach 20 to 25 meters per second. In Drawing 1D, a fragment of cloud cover with a cloud bank structure is shown over the water area of the Pacific Ocean. With this picture before him, the meteorologist not only can evaluate the amount and form of the cloudiness, but can also picture in his mind's eye the direction of the air currents and the nature of the atmospheric stratification; that is, he can reconstruct the nature of the weather over any given region of the earth's surface.

Data concerning medium-scale features of the field of cloudiness proved to be extremely useful when interpolating the various meteorological elements. In fact, homogeneous mesostructure of cloudiness usually arises during comparatively large homogeneity of large-scale movements in the atmosphere, while a rapid change in medium-scale features testifies to changes taking place in large-scale movements. Thus, nonlinear interpolation of those meteorological elements such as humidity, temperature and wind can now have a more well-grounded basis, physically.

Detailed information concerning clouds finds broad application in meteorological service as it relates to the different spheres of human endeavor. Analysis of weather maps is much more precise, optimum shipping lanes and flight routes are chosen over intercontinental and air routes; all of this is possible on the basis of both indirect and direct information obtained from high-resolution cloud imagery.

Interpolation of cellular and stratiform cloud structure, in the examples given above, shows that the morphology of cloud cover can be described in terms characterizing the atmospheric condition. It is needless to say that only the first steps were taken in this direction and that even more effort must be forthcoming in order to attain a complete comprehension of these conditions in which a particular morphological feature in the field of cloudiness can be formed, as well as in making more effective utilization of satellite-acquired information.

2. Orographic Cloud Systems.

The influence of the heterogeneity of the underlying surface on the cloud cover is shown to excellent advantage on high-resolution television pictures obtained from satellites of the "Meteor" system.

The well-known fact concerning the formation of waves, or billows, from the leeward side of mountain ranges is clearly displayed in the waviness of clouds. In Drawing 2B, an example of rolling clouds is shown behind the coastal range of the Sierra Nevadas. This picture is interesting in that it shows the simultaneous existence of wave movements at various levels. The length of the wave on the lower level is, on the average, nine kilometers, while the wind velocity at the level of the clouds is 10-15 meters per second. At much higher altitudes, the length of the wave is approximately 30 kilometers, while the wind velocity is correspondently equal to 20-25 meters per second.

Statisical analysis of similar conditions has made it possible to construct an empirical graph, which connects the length of the leeward wave with the velocity of the inflowing current. Comparison of experimental data obtained from the results of theoretical research reveals that, in the presence of cloud waves having great length, the theory, as a rule, gives the shearing speed of the wind. The intercommunications received can be used to indentify direction and velocity of the air current at the cloud level and can have a definite and practical influence on weather servicing of aircraft over routes above mountain masses.

Several excellent examples of an air current flowing around a rugged terrain relief are shown in Drawing 2A. In this picture, the process of a vortex forming can be clearly seen in the lower troposphere on the leeward side of Guadeloupe Island in the Pacific Ocean. The diameter of the vortex in the process of formation is approximately 100 meters. A similar type of situation can be successfully utilized in evaluating the general direction of air currents over the water areas of oceans, seas and other bodies of water.

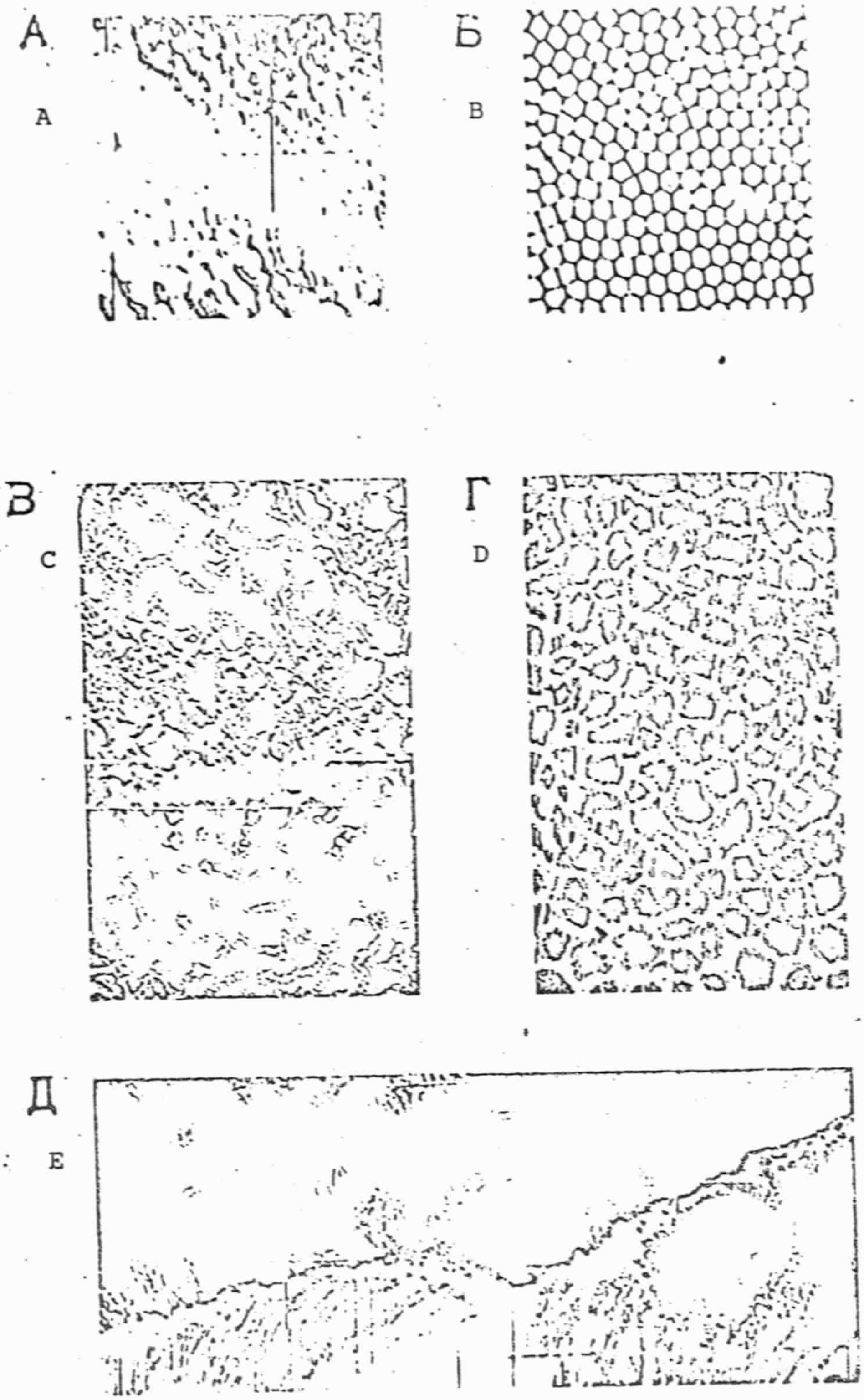
Cloud formations associated with sea-breeze circulation on the coastal regions of seas, oceans, lakes and even large rivers are clearly visible on television pictures received from satellites. In Drawing 2C, an example is shown of the influence of such huge bodies of water as Lakes Victoria, Alberta and Kioga in Africa on the distribution of cumulus and cumulonimbus clouds: the lakes' water areas and coastal zones are practically free of cloudiness, as thick cumulus and cumulonimbus clouds are evolving at a distance of 100 kilometers from the shores. A similar type of information is extremely useful in putting together local weather forecasts and in servicing air routes.

An example of a sea-breeze is shown in Drawing 2D, which is over the Somalian coast of East Africa.

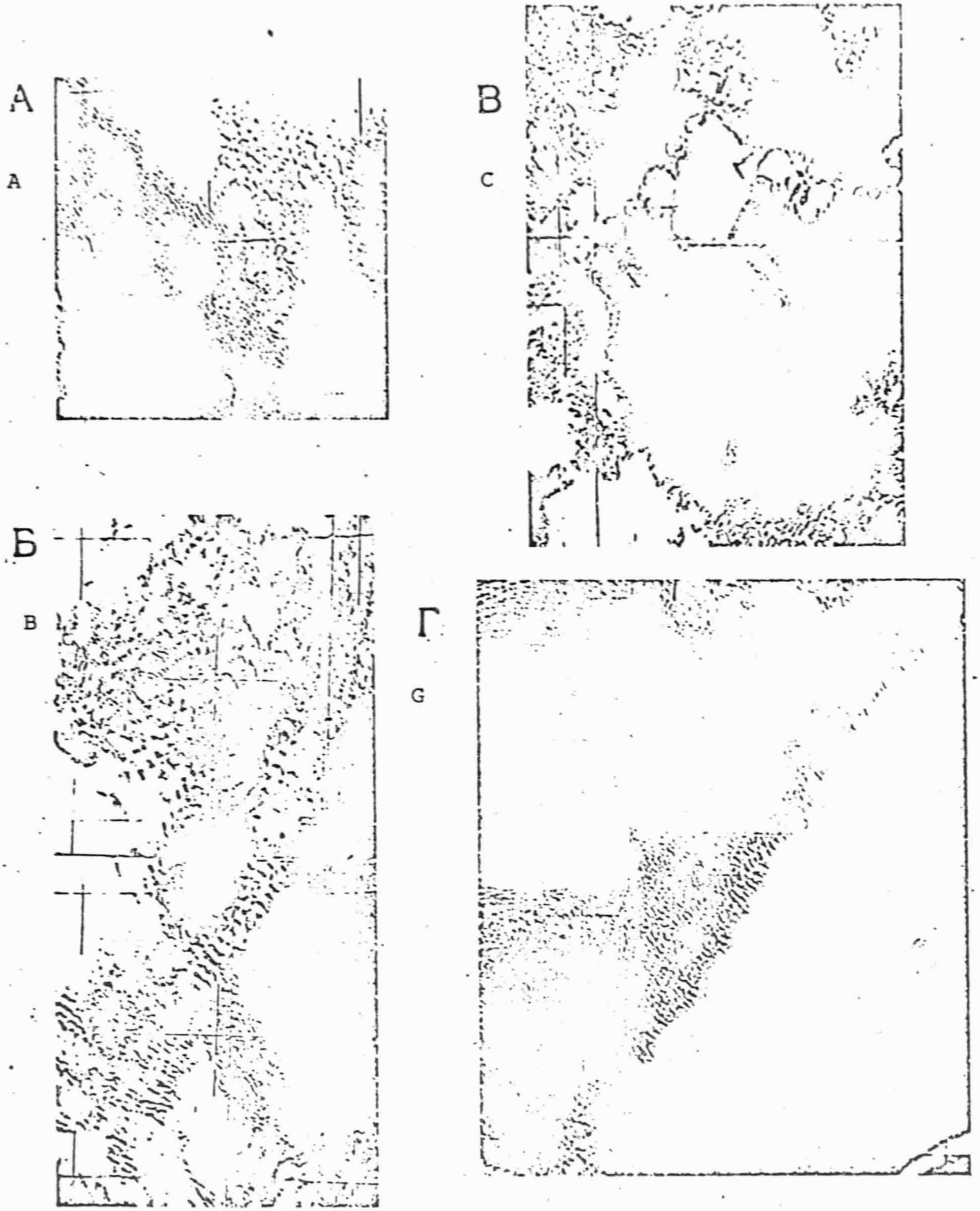
The horizontal scale of the sea-breeze cell can be very accurately estimated and a rough estimate of the sea-breeze's vertical force can be obtained with the help of television photography. An idea can be gotten concerning the nature of large-scale air currents by the degree of evolution of the sea-breeze and the configuration of the cloudiness associated with it.

The list of structural features in the field of cloudiness observed from Kosmos could be continued and expanded, but this is difficult to do within the framework of this report. The examples of physical interpretation of the various morphological features in the field of cloudiness shown above indicate that high-resolution photography of cloudiness can serve as a rich source of supplementary information for meteorologists. Essentially, the present-day meteorologist is more closely akin to a physics researcher engaged in studying the movement of liquids under laboratory conditions, using colored mixtures. The difference is the fact that, in the atmosphere, the clouds are of a particular type of color, while the meteorologist's laboratory is our entire planet.

Substantial difficulties are, in the final analysis, based on the fact that it is often difficult to control conditions conducive to the emergence of perturbation in the atmosphere. At the same time, there can be no doubt that these difficulties will be circumvented with time. Meteorologists will achieve a much greater understanding of thermal and dynamic conditions related to the evolution of various cloud systems and will learn to effectively utilize observations made from Kosmos in analyzing and forecasting the weather.



Drawing 1. Types of ordered convection.



Drawing 2. Types of orographical cloudiness.

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