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Abstract

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A THEORETICAL SCHEME OF AIR CIRCULATION OVER ANTARCTICA

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The circulation of air over Antarctica is one of the most powerful circulations on the globe. It determines to a considerable extent the climate of the greater part of the Southern Hemisphere and is, without doubt, connected with the circulation of air in the Northern Hemisphere. In its physical nature, the circulation of air in Antarctica has analogues in the Northern Hemisphere; but since it is almost symmetric with respect to geographic coordinates, its laws are more accessible to theoretical investigation. Thus, in solving the problem of air motion in the south-polar regions, we shall at the same time find a key to the solution of analogous, but more complex, problems pertaining to the Northern Hemisphere.

The circulation we are studying arises as the result of the thermal interaction of the cold icy surface of Antarctica and the relatively warm waters of the oceans surrounding it with the atmosphere. A characteristic feature of such circulations should be their two-layer structure: in the lower layer, a cold continental air flow should descend toward the sea; in the upper layer, warmer maritime air should move onto the continent. As a result, at some height in the air there arises a deep temperature inversion. The baric sources of such circulations are permanent regions of high and low pressure.

If the Earth did not rotate, then the surface separating the two flows in the circulation considered by us would be horizontal. But under the action of the Coriolis force such a surface is inclined in accordance with Margules' formula. Since the surface separating the two flows in the case under consideration has a circular form, and since the magnitude of the Coriolis force varies, the separating surface must acquire a dome-like form. The difference in temperature and density of the air of the two flows does not remain constant along the separating surface. As one approaches the anticyclonic region, i.e., with increasing distance from the sea, this difference decreases; and somewhere in the center, where the descent of air masses begins, this difference may disappear, unless an inversion of another origin arises. The opposite side of the separating surface, at some distance from the center depending on the magnitude of the angle of inclination, comes into contact with the Earth' s surface; moreover, on both sides of the surface a very considerable temperature difference may still persist. The line of intersection of the separating surface with the Earth' s surface will

Fig. 1

Figure 1: Fig. 1

be nothing other than a meteorological front, and in the example considered by us—an Antarctic front.

As we see, disturbances of a wave character may arise on the separating surface of this circulation. Thus, if the average picture of the process under study determines the climate, then the disturbances arising in the process condition the weather in these regions and a number of features of the thermal and wind regimes.

What, then, are these disturbances? If the speed of the principal, i.e., upper and lower, currents undergoes periodic or individual changes, then the angle of inclination of the surface will begin to change, and waves will begin to propagate along it along the radii. The most probable and most interesting wave for the problem under study is a wave in the form of a single-node seiche, in which the separating surface will oscillate relative to a circle passing through the midpoints of the radii. During these oscillations the surface of the dome

of cold air will alternately become denser and bulge upward, while the frontal line will move over the earth' s surface. The second system of waves arises on the separation surface as a result of the relative motion of two streams of air of different temperature and density. The dimensions of these waves, propagating along the circumference, will depend on the relative velocity of the two streams, their density, and the radius of circulation; and the form of the waves will depend mainly on the direction of the streams relative to one another.

Fig. 1

Oscillations of the inclined surface of separation of two air streams were investigated by N. E. Kochin ([1]). He considered the plane problem for the case of small oscillations propagating across and along the plane.

In the work of A. M. Gusev ([2]) the possibility of applying N. E. Kochin' s conclusions to studies of air circulation over Antarctica was indicated; the principal results from them were presented, the simplest scheme of this circulation was given (Fig. 2 from ([2])), and a method was set forth for computing the magnitude of displacement of the lower edge of the separation surface (in our case, the line of the Antarctic front) from the magnitude of the disturbance of the basic flow (formula (2) from ([2])).

N. E. Kochin solved the problem for the case of an ideal fluid. Later, other authors solved certain particular questions of it for a barotropic medium and a baroclinic fluid (i.e., for conditions closer to natural ones), but we know of no attempts to solve this problem for a spherical separation surface, even under the conditions of an ideal fluid. The solution of such a problem is associated with enormous difficulties.

Fig. 2

Figure 2: Fig. 2

All this compels us, in studying the circulation of air over Antarctica, for the time being to make use of the conclusions from the solution of the plane and ideal problem, expecting subsequently to refine these studies, in particular with the aid of experiment. Therefore at present, in comparing the theory with the natural phenomenon, one can count only on agreement in orders of magnitude.

Of great importance in the problem under consideration is the determination of the lengths of waves propagating around the circle of the surface of discontinuity, since these waves are nothing other than mobile baric formations. In the problem of N. E. Kochin there is no answer to this question, since it studies only the conditions for the existence of waves of various lengths superposed on the basic regime of rectilinear flows. To answer this question one must resort to experiment. The results of experiments in aero-hydrodynamic annular basins have shown that the maximum length of the waves arising in this case is close in magnitude to the mean radius of the basin. Similar results were obtained by us in an experiment with internal waves in an annular basin, when water and olefine were used to obtain a two-layer flow.

Fig. 2

The results of observations carried out in Antarctica both by the Soviet expedition and by expeditions and stations of other countries make it possible to judge the correctness of the proposed scheme. Let us first consider the distribution of air temperature, and the direction and speed of the wind. Around all of Antarctica a deep and permanent inversion has been found; moreover, in the interior regions the depth of the inversion reaches 25°. This inversion can also be traced at a considerable distance from the coast toward the sea.

It has also been found that the southeasterly winds, predominant on the coast, become weaker in the interior regions. In the higher layers of the atmosphere, above the inversion layer, which in coastal regions is at an altitude of 1000-2000 m, and over the continent at an altitude of 200-300 m, transport of northwesterly direction is observed on average. At such points as the South Pole and at Komsomolskaya Station (about 850 km from Mirny in the direction of the geomagnetic pole), there have repeatedly been observed—

were interspersed with days of calm. All this indicates that somewhere in the central area of the continent, at the pole of cold, the heat coming from the sea, where it reaches its minimum amount, must be situated in a calm region corresponding to the region of the baric center. The distribution of wind in the atmosphere over the continent is characteristic of an anticyclonic regime, but we still cannot say anything about the pressure field in the interior and especially in the central regions of Antarctica, since the available information is still insufficiently reliable. In any case, if an anticyclone is located over the continent, it is a special type of baric formation, distorted by the influence of the ice dome reaching a great height.

Maximum wind speeds are observed on the coast. Therefore it is precisely here, around the Antarctic continent, that one should expect the greatest development of wave processes on the interface surface. Reality confirms this supposition, since it is precisely here that series of cyclones move, which are enormous waves arising on the interface surface as a result of the relative motion of two flows. These waves we see on the synoptic charts compiled by B. L. Dzerzeevskii (Figs. 1 and 2) in the form of centers of low pressure, ridges, and troughs, which indicates the possibility of the occurrence of both plane and three-dimensional waves. The length of these waves, determined from synoptic charts, proved to be variable and to range from 1000 to 3000 km. These quantities are of the same order as the magnitude of the circulation radius, which agrees well with the results of the experiment in annular basins.

Observations confirm the existence of transverse oscillations caused by changes in the angle of inclination of the interface surface in the latitudinal direction. These oscillations are detected by changes in the position and direction of the trajectories of cyclones moving around the continent. On synoptic charts we see that in some cases cyclones move at a large distance from the shore out at sea, while in others they move directly along the coastline.

A distinctive feature of most storms in Antarctica is their rapidity and short duration. Storms lasting one day, or even less than a day, are frequent. This also agrees well with the theory. If the period of the most probable oscillations of the interface surface is calculated by Kochin' s formulas (see formula (1) from (2)), it proves to be approximately 15–20 hours. The periods of longitudinal waves are usually longer than a day, and therefore the short duration of storms at each given point can be explained only by transverse oscillations of the interface surface.

Slower transverse oscillations of the interface surface, leading to prolonged displacement of the frontal line and, consequently, of the trajectories of cyclone motion, are connected with a gradual change in the velocities of the principal flows, one of which is seasonal change.

In the present communication, for the sake of brevity, we have compared theoretical conclusions with observations in nature only for several examples that are basic for the given phenomenon and most striking. The available material makes it possible to increase the number of such examples to a considerable extent.

In conclusion it should be said that the thermal symmetry and, consequently, the baric field around Antarctica may be disturbed as a result of interaction with processes in the atmosphere and in the ocean not taken into account in our problem; this sometimes leads to disturbances of the picture of the phenomenon described. But these disturbances are insignificant and do not contradict the fundamental propositions of the scheme. Circular isobars may shift asymmetrically relative to the continent, but the trajectories of cyclones never cross its central regions.

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CITED LITERATURE

1. N. E. Kochin, *Collected Works*, **1**, 1949.

2. A. M. Gusev, DAN, **109**, No. 4 (1956).

Note: Figure translations are in progress. See original paper for figures.