# A METEOROLOGICAL STUDY OF THE ANTARCTIC REGION AND THE ATMOSPHERIC CIRCULATION OVER THE EXTREME SOUTHERN PACIFIC OCEAN

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Plans are being made for carrying out this coming summer (1928–29) two important aerial expeditions to the South Pole; one of these will be led by Señor Pauly, of Argentina, and the other by Commander R. E. Byrd, of the United States. Both expeditions are of great importance to science, especially for the study of meteorological conditions in the antarctic region, which appear to have a manifest influence on the climate of South America.

The Observatory of Salto is especially interested in the expedition under Señor Antonio Pauly, with whom we have had continuous interchange of communication. The scientific ability of Señor Pauly and his interest in the accomplishment of the expedition are qualifications highly favorable to success.

In the present paper we have made a general résumé of our investigations of the atmospheric circulation of the extreme southern Pacific Ocean and of the meteorological conditions over the antarctic region. First of all, study was given to the results obtained by the different antarctic expeditions, such as those of Scott, Charcot, Amundsen, and Shackelton. In addition we have had the cooperation of the *Oficina Meteorolojica* of Argentina and the Commonwealth Bureau of Meteorology of Australia.

## CIRCULATION OF THE ATMOSPHERE IN HIGH SOUTHERN LATITUDES

Two fundamental theories have been advanced to explain the circulation of the atmosphere of the antarctic region of our planet.

The first, supported mainly by the well-known meteorologist, Mohn, supposes that the pressure decreases gradually to the pole, a place that is probably occupied continuously by an area of low pressure, whose barometric minimum probably fluctuates around 720 mm. (28.35 inches). According to Mohn, supported by the observations made on Amundsen's expedition, there probably exists over the Great Ross Barrier, between 78° and 82° S., an area of relatively high pressure to the south of which there is a fall in pressure to the pole. The atmospheric circulation of the antarctic region takes place from west to east, but is "convergent" toward the area of low pressure around the pole.

The second theory, upheld chiefly by Simpson, of the Scott expedition, assumes that the region of the South Pole, which is situated within the antarctic continent, is occupied by an area of relatively high pressure, surrounded at the latitude of about 60° S. by a ring of low pressure with centers more or less well defined over Weddell Sea, over Ross Sea, and probably over Bellinghausen Sea, west of Graham Land. Simpson studied the distribution of atmospheric pressure at 3,000 meters' altitude in the antarctic region and came to the conclusion that there exist two regions of low pressure; one having its center at 80° S. and 80° W., the other lying between 20° and 60° E. and extending northward toward 62° S. Above this polar plateau the pressure increases with advance toward the pole. Simpson places the center of high pressure, at the altitude of 3,000 meters, at about 78° S. and 100° E. This distribution of pressure at 3,000 meters is in accord with the mean direction of the winds at the same elevation, which blow from the west at the polar circle, while in the vicinity of the pole they blow outward from that point parallel to the meridian of 160° E. According to this theory the atmospheric circulation of the antarctic region takes place from west to east around the ring of low pressure surrounding the pole; "it does not converge toward the pole, but parallels the Polar Circle."

## MOVEMENT OF THE DEPRESSIONS

With the indirect object of testing the theories we made a complete study of the displacement of the atmospheric depressions in the extreme southern Pacific Ocean. In case the first theory, held by Mohn, is true the paths of the depressions should be "convergent" toward the polar region with a general displacement from west to east, but in the contrary case the displacement should be along a parallel of latitude from west to east.

In studying the meteorological maps of the Commonwealth Weather Bureau of Australia we found that the atmospheric circulation of this southern region is exactly in obedience to general movement of LOWS from west to east. The barometric depression is observed first at Perth, Australia, then it moves to Melbourne on the eastern coast, and later passes on to New Zealand.

Another most important finding, especially with regard to forecasting weather in South America, was the general displacement of isobaric systems from west to east.

Graphs of pressure fluctuations in New Zealand and the region of Magallanes for different months show that the systems of high and low pressure appear to require 10 to 15 days in crossing the southern Pacific Ocean before manifesting their influences on the coasts of South America.

No less interesting are the studies made of the displacement of depressions between Graham Land on the west and the South Orkneys and South Georgia on the east. Some time ago Señor Rouch, meteorologist on the Charcot expedition, found that the depressions moved "parallel" to the polar region, following paths from Peterman Island to the western coast of Graham Land and on to the South Orkneys and South Georgia; our recent investigations have now succeeded in placing this movement clearly in evidence.

Thanks to the kindness of the chief of the *Dirección de Meteorolojica* of Argentina, Señor G. Plate, we have been able to construct various comparative graphs of the fluctuations of pressure in the region of extreme southern South America, the South Orkneys, and South Georgia and have proven that all of the depressions move from west to east, passing between Magellanes and Graham Land, and later, after three to five days according to the velocity of translation, reaching the South Orkneys and South Georgia.

We see, then, that the "parallel" displacement of the depressions as well as the different observations by Simpson rather tend to prove the existence of high pressure in the polar region.

We have the explanation of the cause of this phenomenon in the fact that all atmospheric depressions tend to move toward the "areas of least resistance." If these areas of least resistance should lie toward the pole the paths of the depressions would be convergent toward that region, but, on the other hand, if the areas of least resistance are found along the line of the ring of low pressure which surrounds the polar area the displacement will take place parallel to the Polar Circle.

With regard to the general circulation of the upper currents of the atmosphere the conclusions reached by Rouch on the Charcot expedition are of notable interest. In summer the mean direction of the cirrus and cirro-stratus clouds was from S. 36° W., in autumn from N. 75° W., in winter from N. 86° W., and in spring from S. 34° W. We see, then, that during the months of spring and summer the paths of the depressions as well as the upper currents of the air are inclined toward the south and that in autumn and winter they are inclined toward the north.

Rouch obtained similar results with the intermediate clouds, cirro-cumulus, alto-cumulus, and alto-stratus; in summer the mean path was from S. 50° W., in autumn from N. 55° W., in winter from N. 60° W., and in spring from S. 59° W.

ANNUAL VARIATION OF THE DIFFERENT METEOROLOGICAL ELEMENTS IN THE ANTARCTIC REGION

The annual variation in the different meteorological elements in the antarctic region is of great importance in studying the fluctuations undergone in the course of the year by the centers of action and the mean path of the areas of low pressure. The most complete series of observations that we have obtained is that made by Rouch on the Charcot expedition.

The atmospheric pressure reaches its crest in the summer months, between October and December, with maximum in the latter month, when the values fluctuate between 740 and 750 mm. (29.13 and 29.53 inches). After January the monthly means of pressure decrease rapidly, reaching the minimum in the autumn and winter months, between April and August, when the barometer fluctuates below 740 mm. (29.13 inches).

The mean monthly temperature remains above the freezing point (0° C.) from December to March, inclusive, but in April it falls abruptly and remains between −5° and −7° C. (23° and 19.4° F.) up to September, inclusive; in October it begins to rise rapidly.

The humidity of the air undergoes very irregular variations; well-defined maxima are observed in January, May, and September, separated by periods relatively less humid with minima in December, February, July, and August. The absolute humidity, however, follows a march entirely parallel to that of temperature.

In Graham Land the prevailing winds during the entire year are from the northeast; they reach their highest velocities at the end of winter and the beginning of spring, with maximum in August. In the summer months the mean velocity of the wind is much lower, with a well-marked minimum in January, when the velocity is only 5 km. (3.1 miles) per hour. In the month of August, on the other hand, the mean velocity exceeds 30 km. (18.6 miles) per hour.

Cloudiness presents a well-defined annual march with maximum in summer and minimum in winter. Mean cloudiness is highest in January (0.9) and lowest in April (0.7). Contrary to what might be expected, fog is by far most frequent in the spring; it has the following distribution by seasons: Summer, 6 per cent; autumn, 15 per cent; winter, 18 per cent; and spring, 34 per cent.

The greatest frequency of precipitation is observed in the months of autumn and spring as is shown by the following: Summer, 23 per cent; autumn, 26 per cent; winter, 24 per cent; and spring, 33 per cent.

The preceding statements relate to "means;" the accidental variations produced by atmospheric disturbances may frequently show extreme values in the antarctic region; in a few days the pressure can change from maxima of 760 mm. (29.92 inches) or higher to minima of 710 mm. (27.95 inches) or lower; the temperature on the Great Ross Barrier may fall as low as −60° C. (−76° F.). The following data will give an idea of the frequency of low minimum temperatures. On an average, the number of days with minimum temperature below −40° C. (−40° F.) is 4 in April, 12 in May, 16 in June, 16 in July, 26 in August, 19 in September, and 2 in October. The mean number of days with temperature below −50° C. (−58° F.) is 1 in May, 6 in June, 3 in July, 15 in August, and 7 in September. It follows that August is the severest month. With regard to wind it frequently happens that velocities of 30 to 40 meters per second (67 to 90 miles per hour) are encountered. The frequency of calms in the different antarctic regions is as follows: Ross Sea, 20 per cent; Antarctic America, 28 per cent; Cape Adare, Victoria Land, 69 per cent.

METEOROLOGICAL PREPARATION FOR AN AERIAL EXPEDITION TO THE ANTARCTIC REGION

After this general résumé of the meteorological conditions in the antarctic region we come to the most important point, that on which depends the success of the expedition; namely, the meteorological preparation for the flights (*raids aeros*).

In this matter I have considered well the results obtained on the two aerial expeditions to the North Pole made by Amundsen. On the first of these expeditions the meteorologist was the distinguished scholar, J. Bjerknes; on the second, Dr. Finn Malmgren, of the University of Upsala.

The results obtained by Bjerknes can be summarized as follows: Experience shows that in areas of low pressure there is much cloudiness and precipitation occurs frequently, while in the areas of high pressure there prevails fine weather with clear skies. Hence the aviator should not take off when a depression is advancing toward the pole and it appears that he will have to pass in the vicinity of the depression. In order to be more or less certain not to encounter foul weather it is important to wait for the approach of high pressure.

Then there is a second very important condition; the anticyclone should be situated to the north of Spitzbergen in order that the explorers shall not be exposed to foul weather after having traveled for several hours through a beautiful, sunny sky. An anticyclone at the North Pole brings northeast winds and low temperature in Spitzbergen. On the western island of this archipelago this northeast wind blows from the land and consequently brings fair weather. On the northern coast its effects are less certain; lifted by this current against the mountains the air rises at some distance from the mountain slopes and in this there is the possibility of the formation of cloud. Ordinarily these clouds cover only a limited area and the aviators pass through them quickly; in any case they can fly over them. It appears that the most certain indication in Spitzbergen of a stable meteorological condition is given by the existence of a northeast wind, prevailing not only at the ground but also at an elevation. When pilot balloons or upper clouds show this régime, they prove the existence of an anticyclone at the pole.

Along general lines we can apply these same conclusions in the antarctic region; the formation of an area of high pressure over Graham Land, with prevailing winds from south to southeast up to high elevations will be evident proof of the existence of an anticylonic régime in the region of the South Pole. However, I consider this insufficient; the meteorologist ought also to foresee the atmospheric changes that may take place in the succeeding 48 hours.

To this end it would be altogether necessary to install a meteorological station, with its corresponding radio station, on the northwest coast of Graham Land as far as possible to the west and far removed from the aerial base of the expedition. As the displacement of the depressions in the far southern region takes place from west to east this station would be able to telegraph daily the approach of the different atmospheric régimes.

The approach of a depression over Graham Land is announced first of all by the appearance of high cirrus clouds and almost simultaneously by a fall in pressure. If the path of the depression passes to the north or to the south of the place of observation there will be a shifting of the wind. If, as it frequently happens, the observer is north of the center of the LOW, the storm begins with wind from the northeast; as the center of the LOW approaches the wind shifts gradually to north, then to west and afterward to southwest and south in the rear of the depression. In the contrary case, the observer being south of the path of the center of the LOW, the storm will begin with wind from east or southeast which gradually changes to wind of great violence from the south when the center passes at the minimum distance. Innumerable examples can be cited from different polar expeditions.

However, the storm may remain stationary, blowing from northeast or south for several days in the special cases in which there is a rapid succession of secondary depressions; in such cases the hurricane lifts whirls of snow which limit visibility to a few meters and throws the pilot off his course. These "blizzards," as they are called, are the most dangerous storms of the polar region, but their prediction is entirely possible.

The data transmitted by the meteorological station situated on the northwestern coast of Graham Land would be supplemented daily by general meteorological information from southern Australia and New Zealand; these data can be of great usefulness in determining well in advance the approach of the periods of atmospheric stability or instability. The expedition led by Señor Pauly will receive regularly at its base station, Deception Island, meteorological reports from the South Orkneys, Ushuaia, and Australia.

Another very important point is the selection of the most favorable time of the year for carrying out the expedition. It will always be necessary to choose the months of greatest atmospheric stability, when fogs are rare and tempests are infrequent. The statistical data indicate that the most favorable months are those of the summer, and not of the spring as is the case at the North Pole. In the former months the frequency of fog is only 6 per cent and the mean velocity of the wind varies between 5 and 20 km. (3.1 and 12.4 miles) per hour.

### CONCLUSION

In this paper we have made a general summary of the meteorological conditions in the antarctic region and have discussed meteorological preparations for aerial expeditions to the South Pole. Many details of organizations are omitted; only the general lines are laid down.

Simultaneous observations made in different regions of the antarctic continent have demonstrated that the variations in atmospheric pressure have successively the same sign over Ross Sea, Antarctic America, and Emperor William II Land. When the pressure is high in the antarctic region it is low in the regions more or less in the vicinity of 40° south latitude, and vice versa.

This antarctic region constitutes one of the greatest centers of action on the globe. The polar observations do not merely have unquestioned theoretical interest, but from a practical standpoint they are of exceedingly great importance in weather forecasting in the temperate regions of the Southern Hemisphere, South America especially.

For this reason the expeditions of Pauly and Byrd assume very great importance in the progress of the meteorological world. The *Observatorio del Salto* takes the greatest pleasure in contributing this grain of sand to the realization of this great scientific expedition.—*Translated from the Spanish by W. W. Reed.*

## THE SOURCE OF THE WATER VAPOR OF THE ATMOSPHERE: A CRITICISM

ALFRED J. HENRY

It is well known that water vapor is continually passing into the atmosphere from the surface of the seas and lands at practically all temperatures and pressures and is as continually being withdrawn in the form of rain, snow, hail, sleet, and dew. In many respects the circulation of water vapor into and out of the atmosphere is, if not the most important, one of the most far-reaching importance in its effects both from a physical and an economic standpoint. The introduction of water vapor into the atmosphere, in varying quantities is one of the chief means whereby thermal energy is communicated to the upper levels of the atmosphere. The economic importance of a generous supply of water vapor is self-evident.

It is, therefore not surprising that geographers and others from time to time, beginning with Sir John Murray's work in 1887, have sought to determine a balance between the income of water vapor as realized in the phenomenon of evaporation and the outgo in the form of rain, snow, sleet, hail, and dew.

It will be admitted that our knowledge of the amount of precipitation that occurs over the surface of the globe is quite incomplete; there is a distressing lack of information concerning oceanic precipitation. And if so little is known of the distribution of precipitation, still less is known of the amount and seasonal distribution of evaporation over the globe, especially from the water surfaces.

The basic material used in deducing the total precipitation of the globe is, of course, such charts of annual precipitation as may have been prepared and published, and naturally the accuracy of the annual totals of rainfall are directly proportional to the fidelity with which the charts represent the true precipitation of the globe.

In the case of evaporation the circumstances with respect to mapping the distribution of evaporation are such that no attempt as yet has been made to portray the annual amount of evaporation even approximately. The most recent useful contribution on the subject is that of Dr. George Wüst,[1] abstracted in MONTHLY WEATHER