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POLAR EXPLORATION[1]

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IT was but yesterday in the procession of "the eternal years" that men sought knowledge of the higher will by consulting the oracle, the shrine where the voice could be heard that told what to do and what would happen. "There mighty Nations shall inquire their doom," and there the individual, if powerful enough, might even hope "to work the oracle" and bring private wish and future event into harmony. What men were striving after was fore-knowledge of the event, forecast, or, in another connotation and using the modern term of a scientist of the Indian Meteorological Department, "foreshadowing." It is rather striking that this early manifestation of human curiosity is reflected in the scientific era. Within the scope of its "laws," or, better said, its generalizations, science to-day sets up forecast as one of its highest aims. *Omitting California,* the most common question of civilization is, "What will the weather be to-day?" and, as Mark Jefferson has phrased it, if the forecaster can not tell us whether or not it will rain at least we wish him to tell us if it is prudent to carry an umbrella. In a state so well supplied with observatories and in the presence of such eminent astronomers I do not wish to draw upon even that nearer heaven, the sky, for further illustrations of forecast, but you will perhaps permit me to mention the tides and the celebrated tide machine of the U. S. Coast and Geodetic Survey that permits an operator to pull levers and scan indices and, at length, by what to the layman seems mystery as deep as an oracle, derive the future time of occurrence of the tide at a given point on the earth with all but mathematical accuracy!

It happens that polar exploration has participated in this advance from the place of wish-and-guess to the eye-piece of an instrument of precision and a knowledge of the workings of natural laws, and I have

[1] Public address under the auspices of the National Academy of Sciences given at the University of California on the evening of September 18, 1930.

been asked to outline its part in terms of modern science. Let me say at once that there was no thought of forecast in the beginnings of polar exploration. On the contrary, so far as the record permits us to learn, we see at first no other force in men's minds than that driving curiosity which is the motive power of most exploration everywhere and which impelled Pytheas of Massilia to the shores of Britain as it in like manner took Nansen to the inner Arctic where the secret of one part of the oceanographic puzzle might be found. Man insists on knowing what is in the outer world—the world outside the boundary posts of knowledge. Once it was discovered that such knowledge had utilitarian value, economics took a permanent place beside curiosity. "Scoresby Sound" in Eastern Greenland records a happy blend of business and curiosity on the part of that knight errant of Arctic exploration, Captain William Scoresby, who in thirty voyages to Greenland brought back rich cargoes of whale oil and even more valuable cargoes of geographical information from "a coast that was almost entirely unknown."

Exploration from earliest times to quite recent years began and ended in description of which the map was a kind of shorthand. Apart from adventure, the map told the story of what had been found: it enabled one to look at distant places "as if they were on the palm of your hand," to use the inscription employed in a Chinese atlas. To fill in the map has been one of the leading ambitions of explorers and will so remain until the last of earth's territory has been seen either by the eye or the camera, for if an electrically guided airplane and automatic camera should ever become feasible we may some day be able to map lands that no eye will have seen. When science had moved ahead to its modern position, exploration became a far richer enterprise. To-day it may be as varied as science itself. I remember receiving an inquiry from Professor Millikan for a lake in the Central Andes at the highest altitude which it was practicable to reach and of given size and depth, and fed principally by melting snow. So much of geographical requirement was laid down for the study of cosmic rays. The German Greenland Expedition has already experimented in ice-thickness measurements by echo soundings with an improved seismic device. Wilkins plans next year to explore the Arctic by submarine, his program including gravity determinations at sea and aerological work from the ice. Lars Christensen plans to have his captains make a census of Antarctic whales by airplane, the counting to be done from aloft in a single season possibly by the cooperation of several ships, each to take a sector of the waters off the south-polar continent if it should prove impossible for one vessel to make the circumnavigation.

It is natural in the face of all of these diversities of purpose, this extension of technology on a great scale to high latitudes, that the key to special types of forecast should also be sought in the polar regions. Man has learned that within certain narrow limits he can forecast a widening range of events in the physical world, and he finds that his new knowledge permits him to develop to increasing degree a more satisfactory "philosophy of the whole." It measurably satisfies man and it engrosses his interest to discover that there is an orderly scheme of things and that some of the workings and even the forecasts of such workings can become known to him. We are not surprised over the controversies of an earlier generation, and so recently even in our own, over questions of science and faith when we discover how lately science began to outline the physical universe and gain the power to forecast the effects of a few of the forces that are governed by law. It was not until just before the Revolutionary War that Franklin charted the approximate course of the Gulf Stream, and it was Franklin also who first traced the progress of cyclones. Ferell's law of behavior of the air in a cyclone was enunciated much less than a hundred years ago. The first self-recording instrument was taken into the Arctic (Parry) only a little more than a hundred years ago. The "polar front" or "squall line" theory with its important bearings upon the paths and character of cyclones, especially between Greenland and Norway, was outlined by Bjerknes only a few years ago.

There still remain in the world unexplored lands of total area at least twice that of the United States. The "Empty Quarter" of Arabia, lying almost within sight of the oldest routes of migration and trade in the world, measures 500 miles by 800 miles, and is therefore nearly a half million square miles in extent. So far as we can learn, no Western explorer has ever entered it. Though we weigh the stars and plot the courses of unseen planets we are yet without knowledge of much of the immediate world of mankind itself. We still live in the Age of Discovery, at whose threshold stood Herodotus and Prince Henry the Navigator and Eric the Red and Columbus. Indeed, if the men who made the Age of Discovery were to compare their lot with those of to-day they would vigorously assert that we, not they, live full within that age, for they would see an airplane flying upside down, human voices talking across ten thousand miles of space, an airship hitchhiking on the tail of a storm (*e.g.*, Eckener between the Sea of Okhotsk and Tokyo in his flight of August, 1929). However old the world may seem when judged by the record of the rocks, it is in an intellectual and exploratory sense tremendously new—it is indeed as new as its newest idea!

The new ideas in polar exploration are not airplane and radio—these are but instruments of discovery. They are astonishingly reliable and useful instruments but they are of mechanical interest only, apart from the ideas they serve. Science feared for a time that they would run away with the game, because the popular mind is still on the romance of flying and the magic of communication by wireless. The really big game of the polar hunt are the scientific ideas or laws upon which the polar regions, and in some cases they alone, can throw light. Science is searching for particular things, not just anything. Real exploration has ceased to be a blind and adventurous wandering into the unknown. Take the contrast in present-day life and fossil remains at the two ends of the earth. The ring of land about the Arctic Basin has a mean summer temperature above freezing and the ground may thaw a few inches in a very few days. There are over four hundred flowering plants, some of them luxuriant. Past land connections have been sufficiently short and frequent to permit life migrations from continent to continent at least in the subarctic zone, with the result that it is possible to reach rather definite conclusions about the lands and seas of the past in the northern hemisphere and how things came to be as they are. No such definite conclusions can yet be drawn for the Antarctic. That region is still so great a mystery that were a fossil marsupial to be discovered there the event would excite some scientists probably as much as direct radio communication with Mars. I have mentioned marsupials because of the apparent need for a land bridge across Antarctica to account for certain similarities of structure between those of Patagonia and those of distant Australia.

Professor Scott is of the opinion that the most probable explanation of the origin of Australian marsupials is that a land connection existed at one time "by way of the Antarctic continent," a land connection that existed in early Tertiary times and by means of which the ancestors of the Australian marsupials migrated from South America. Others suggest that a point of origin in the Antarctic with migration on the one hand into Patagonia and on the other into Australia may be found to satisfy the facts of the case. In opposition is Matthew, who believes that the marsupials of these southern land masses were derived from northern ancestors. He relies upon parallel adaptations to explain the absence of a really close affinity between the forms under consideration. Anderson, on evidence more recent than that employed by Matthew, finds closer affinities between Australian and Patagonian forms than were known hitherto. However, he points to the conflict of evidence derived from a study of frogs, mollusca and plants. There is no positive evidence of the presence of marsupials in Australia before the Pliocene, and there is even an astonishing "paucity of pre-Pleistocene marsupial remains" in Australia. One of the major problems of animal migration is still in the stage of hypothesis for want of critical evidence that Antarctica may yet supply.

It is the meagerness of Antarctic life that makes wide-ranging speculation concerning the past history of Antarctica so difficult. There are but two flowering plants in the Antarctic, and these have a precarious hold at the extreme limit of their range. One is a grass; the other represents a family of herbs. Both are dwarfed. There are only the tiniest patches of tundra. No month has a mean temperature above freezing and the summers last but a few weeks. The search for fossils in Antarctica is to-day keener than ever because not only past but present distributions of life seem to find their explanation through them. In addition the search has already revealed that the life of Antarctica was once far more abundant. In the Jurassic period the whole earth enjoyed a climate milder than that of to-day. At that time there lived in West Antarctica the Sequoia, the Araucaria and the beech. With life so much scantier to-day we can see why Professor Gould, of Admiral Byrd's expedition, attached so much importance to the *earlier* record, however scantily revealed, in the carbonaceous sandstones from Mt. Fridtjof Nansen. Even the contents of the stomachs of seals and penguins have been searched for rock specimens, and thus much valuable information has been found about coastlines where no exposed rock exists. The dredge has brought up from the bottom of the Weddell Sea, from a depth of 10,000 feet, fragments of coral rock of Cambrian age; and the ice tongues that pour out through the western mountain passageways of the Ross Sea depression have borne from distant points limestone fragments of the same age that throw light upon past conditions. Mawson has just found that the erratics on the sea floor off Enderby Land are all continental in type, thus pointing to the unity of the new territory he has added to the map with the continental mass of Antarctica between Enderby Land and the Ross Sea. The fact is of special significance in tracing past life migrations and in building up sound concepts of life habitats.

It is the higher forms of life, however, that interest us most, for here we are closer to the background of man himself. Where we now have a highly specialized group of birds of which three are exclusively Antarctic species (the skua, the Adélie penguin and the emperor penguin) there was once a greater variety. If we include fossil penguins of wider range the number of extinct species already known rises to twelve. It has been suggested that the diminished number of species and their higher specialization to-day were brought about by the advancing ice in a period of glaciation (not necessarily a colder period) even more extensive than the present one, for the ice at the present time has withdrawn from the wider limits it once claimed. If Antarctica to-day seems almost buried in ice, we can only say that in a still earlier period it was *overwhelmed.*

Among the leading objectives of all polar explorers of the past one hundred years are meteorological observations. In ever-increasing degree the polar explorer is besought by science to obtain exact records in increasing number in high latitudes. Less attention was paid to this feature of exploration in earlier years because the dynamics of the atmosphere were until recently so little known. Though Franklin had discovered the most significant feature of temperate-zone weather, it was many years before Ferell expressed the matter in dynamic terms. The first polar explorers could go only so far as the state of technology and theory permitted. The science of meteorology is a quite recent development. "Weather probabilities" were issued by Abbe at Cincinnati for the first time in 1869, and the first official weather forecasts were those of November and December, 1870. The word "probabilities" was displaced by "indications" in 1876, and the term "forecast" was adopted in April, 1889, only forty-one years ago.

The part that the polar regions had to play in the terrestrial wind system was only hinted at by the earliest observations, and theory took little account of the influence of great shifts of air from out of the polar regions to lower latitudes. In 1882–83 for the first time there was established through the work of the International Polar Conferences of Hamburg, Berne and St. Petersburg a chain of meteorological stations with the object of comparing simultaneous records at widely separated points. Eleven nations participated. Fourteen stations were occupied, three in the southern hemisphere. Following the first International Polar Year by an interval of two decades there were sent out a number of Antarctic expeditions in pursuance of plans discussed in outline at the International Geographical Congresses of London (1895) and Berlin (1899). Scott's first expedition represented the British, Bruce led the Scottish expedition, Nordensköld the Swedish, Drygalski the German and Charcot the French. The period 1901 to 1904 includes them all. A Belgian expedition had taken the field in 1898–99, and Charcot's second expedition operated in the period 1908 to 1910. These were animated, some in part only, others chiefly, by a desire to make comparable weather records at widely separated points about the border of the Antarctic.

The United States expedition to Lady Franklin Bay under the command of Lieutenant (now General) Greely, and an expedition to Point Barrow, Alaska, were the principal contributions of the United States to the first great international undertaking in the Arctic. Though more than a score of volumes have been published upon it, some of the results are still not completely worked up. It is argued by Henry that the first International Polar Year was held fifty years too soon. "There was left a gap between the polar stations and those of the middle latitudes entirely too wide to span by any sort of interpolation and thus the relation of polar weather to the weather of mid-latitudes failed of discovery." The daily weather charts constructed on the basis of the 1882–83 observations for a thirteen-month period revealed "a state of turmoil," as Sir Napier Shaw has expressed it, that "defies simplicity of description," and the formulation of laws of behavior of storms in the North Atlantic had to be deferred. The progress of cyclones and anticyclones across the Atlantic as revealed by these earlier studies was of little value in forecasting for western Europe.

But meteorological stations have been established in much greater numbers and much farther north in the interval of fifty years since the First International Polar Year. With the object of carrying out a more extensive program of observations (of possible value in future efforts to discover correlations between high and low latitude climatic conditions), there has been devised a program for a Second International Polar Year, 1932–33. An international committee of meteorological directors has taken the initiative in planning the position of stations and the precise nature of the observations on terrestrial magnetism, atmospheric electricity and meteorology, the observations to be carried through according to carefully devised techniques. In support of this proposal the American Geophysical Union has strongly endorsed the proposal that the United States government take a part in the establishment of certain stations and that the cooperation of private research organizations be solicited. Thus the National Research Council and the National Academy of Sciences will participate in what is believed will be one of the major scientific undertakings of the next few years.

The work of the Second International Polar Year and the meteorological observations of Arctic and Antarctic explorers in recent years are both inspired by a profound curiosity as to the suspected influence of weather conditions in high latitudes upon (or interaction with) those of the temperate regions as well as the tropics. The atmosphere is governed by physical laws and it is sought to discover the workings of those laws. We are here dealing with some of the greatest of the natural forces of the earth. To appreciate the magnitudes involved take the figures given by Shaw. He calculates that, subject to a correction of not more than 5 per cent. for air displaced by mountains, the mass of air in the northern hemisphere exceeds its mean value by over five billion tons in the month of January and falls short of its mean value by over five billion tons in July. This great shift of ten billion tons of air from hemisphere to hemisphere (timed to follow the curve of total power of solar radiation by twenty-seven days) is the equivalent of a mass of air thirty miles wide extending quite around the earth. So great a migration of air is not accomplished in a single simple movement, diagrammatically clear, mathematically precise, from point to point. There are many local variations, and there are also variations in time that appear when the figure is analyzed in detail.

Region by region it is the variations in the broad effects that are of concern to science seeking to learn the exact processes through which weather changes come about. Even the local or regional atmospheric displacements are represented by extraordinary magnitudes. The total energy of the motion of the winds of the earth has been calculated at "something near 20 billion horse-power-hours." Here we deal with figures that are akin to those of the astronomer, who deals with space, and the more we come to know of the atmosphere the larger the figures seem to become —in which respect at least we are gaining on the astronomer who, according to one of their high priests at a recent meeting of the American Astronomical Society, concluded that the astronomer must give up some of the territory over which he had extended claims of imperialistic magnitude!

A calculation of the forces involved in a single localized low-pressure area prepares one to believe that the polar regions include centers of action of astounding size and of direct interest and practical importance to mankind in the temperate zones. When the world was but thinly populated and wide spaces of excellent arable land awaited the settler we could afford to have little concern about the weather machine in its remoter manifestations of power. We see that in the historical development of our weather services. The Meteorological Office of Great Britain was established in 1854 "for the sea and navigation, not for the land and agriculture," and at its head was an admiral. The concern of Great Britain for meteorology grew out of the need for more precise information in making forecasts of value to ships and shipping. Our own weather service had its beginning in the United States Army in 1870. It was established primarily to serve agricultural interests. With the development of immense horticultural interests in the United States the need for precise forecasts has grown correspondingly. Plants that can not stand frost are grown up to the extreme limit of their range, the farmer demanding that science keep pace with him not merely in the selection of soil and seed but also in foretelling the weather.

Since the World War there has been a vast extension of settlement on the pioneer fringe of the habitable lands. Many thousands have gone into northern Canada, extending the edge of the plowed land far northward along a belt hundreds of miles in extent from the Rocky Mountains southeastward to the Laurentian Highland. In the past twenty-five years fifteen million Chinese have gone into Manchuria and hundreds of thousands of settlers are carrying the plow into the moister southeastern border of Mongolia. Pioneer development is in full swing in Southern and Northern Rhodesia and other parts of southern Africa. Australia has an immense territory of sun-baked land in which the marginal conditions of climate and settlement are maintained in delicate balance. We need not inquire at this time as to whether this immense thrust of modern civilization into land hitherto unoccupied is justified by an existing need of the world for additional food supplies. Despite the contention that in our machine age we do not need additional acreages of arable land, millions of settlers are still crowding the frontier. The pressure is not for more land but for cheap land that can not be found in the highly capitalized and overtaxed older communities. So long as people advance into the pioneer belts just so long must applied science follow them and attempt to ameliorate marginal conditions of living.

It is here that forecast should play a dominating rôle. Man does not ask the earth to be kinder to him; he asks only to be informed of its intentions that he may at least prepare for or deflect the effects of those great forces which he can not hope to neutralize or destroy. It happens that some of the pioneer land that remains in the world is on the poleward border of the so-called temperate zones, especially those of Canada, Siberia and Manchuria. Whatever connection may be found between polar or at least subpolar climates and those of the temperate zones will probably be of most direct benefit to the populations of the remaining pioneer lands which are still of great aggregate extent.

Once we knew the habit of the "spells" of Antarctic border weather we should be able to trace the connection, if such exists, between them and the rainy and dry periods in the cereal and pastoral lands of Australia, South Africa and Argentina. It is under the impulse of this idea that Captain Sir Hubert Wilkins has carried on his explorations in the Antarctic Archipelago for two seasons. He did not go down there just for fun; he has been searching for suitable bases for meteorological stations to be established by international cooperation. With a ring of such stations about the Antarctic, and with daily weather reports from them by radio, it may be possible to draw charts that trace the effects of cyclones and anticyclones as they move forward from breeding places out over the southern ocean. The problem is in no sense one that will be solved in a simple manner. Correlation is the basis of forecast and the laws of correlation can only be developed after an observational basis has been established.

To forecast seasons of drought in the lands of the southern hemisphere would be a practical achievement of the highest order, and no less important would it be to forecast seasons of exceptional rain. We have in Australia, Argentina and South Africa great areas of marginal lands where for several years on end it may be too dry to maintain flocks and herds and crops of normal extent. Even in years of sufficient rain the farmer needs notice of the event to enable him to take advantage of nature's bounty. It is not putting the case too strongly to say that the practical benefits to southern lands of meteorological studies in the Antarctic through the medium of a chain of weather stations outweigh all other Antarctic interests, of a material sort, put together.

Through a series of field expeditions in Greenland, Professor W. H. Hobbs has confirmed the theory of slope effect and revealed Greenland as one of the important centers of action in the Arctic on a scale smaller than similar centers in the Antarctic but quite as important in effect for large portions of northwestern Europe. Combining the flight observations of Captain Sir Hubert Wilkins and those of the Norwegian weather charts, Sir Napier Shaw has traced the march of a "cold front" from Greenland to the Norwegian coast from April 14 to 16, 1928, and has outlined the dynamics of the process of the flowage of air from Greenland "to take part in the formation of snow and rain about Spitsbergen." Southern Greenland, like the Aleutian Islands, appears to be a special center of conflict between polar and equatorial air and therefore among the most critical localities on the border of the Arctic region for the study of interchanges between these two great climatic belts.

The former director of the Dominion Meteorological Service of Canada, Sir Frederic Stupart (and others), has pointed to a persistent stream of low-pressure areas approaching the northeastern coasts of Canada and Alaska from the Pacific and passing into and perhaps across the continent of North America, while another stream passes from the Gulf of St. Lawrence eastward past southern Greenland and northwestern Scandinavia, with the polar regions lying between these two great streams. He points to the variations in atmospheric circulation caused by the difference in habit from season to season of the cyclonic areas that form in the Pacific and which move into America sometimes abnormally far toward the north, sometimes abnormally far toward the south. Science can not yet state either the dynamics of the case or the causes that lie back of these major changes, but it seeks light on the question in both high and low latitudes. It is not content with its present position in the matter. Its object is forecast as well as explanation. The two are the right and left hands of the argument. To see so far and yet not see farther, to know so many things about the atmosphere and yet be unable to forecast the major changes that produce profound effects upon the climate of inhabited regions—these are the things that challenge the ingenuity of the physical scientist and that inspire his curiosity as to the exact conditions to be found across the threshold of the Arctic.

Playing a part in the great meteorological set-up of the world is the habit of the ice both north and south. Krümmel estimates the volume of the drift ice which reaches the Atlantic Ocean yearly from the North Polar region at 20,000 cubic kilometers. An estimate of 30,000 cubic kilometers has been made for the Antarctic, or 50,000 cubic kilometers in all. This represents a column of ice with a base larger than twelve city blocks (1,400,000 square feet) and reaching out into space as far as the moon. If evenly distributed it would cover the entire land surface of the earth with a layer of ice a foot thick! These are of the first order of geographical magnitudes and their mere statement is enough to show why significance is attached to the meteorological relations of polar ice discharge. But this is not all. The ice discharge is subject to very great variations from year to year. Commander Smith reported about 1,200 icebergs south of Newfoundland in 1912, while in 1924 the total was only eleven! Taylor has described Antarctica as "a fluctuating refrigerator" on a colossal scale. In calmer periods ice gathers; in stormy periods it dissipates with wide effects because low-pressure areas "whose northern portions" bring precious winter rains to the nearest tips of the southern continents "move mostly over far southern waters."

The English meteorologist, Brooks, has made a statistical investigation of the influence of the Arctic ice on the pressure distribution of western Europe. From a study of ice conditions in spring and summer in a part of the Arctic made known to us from annual surveys of ice conditions by the Danish Meteorological Institute it has been sought to discover relationships between the quantity and the position of the ice and the pressure of the atmosphere at selected stations in Greenland, Norway and elsewhere. It has been found that when there is much ice in the Arctic definite increases of atmospheric pressure may be discerned in spring and summer at some stations and a diminished pressure at others. The pressure of the late autumn and winter is below normal over the British Isles and northern France when there is much ice in the Arctic. Similar effects tend to recur annually at northern stations for about three years following abnormal ice years. It must not be supposed from this statement of relationships that the matter is quite as simple as the phraseology would suggest. It has been found that the influence varies with the season and thus appears to be due to a combination of several factors, some acting in one direction, some in another. The "correlation coefficients," as the scientist calls them, are never high, but they are regarded by Brooks as being appreciable at times, and he concludes that they represent realities. Some of the Arctic ice correlations are more immediately useful. Commander Smith, of the International Ice Patrol, has described a method of ice forecasting that has been employed with "a high degree of success."

Certain ice and weather correlations were noted many years ago and again more recently by Dr. Otto Pettersson. Between 1892 and 1897 there was "an enormous outburst of ice from the Antarctic which filled the Southern Ocean with ice floes and icebergs to such an extent that traffic between South America, Africa and Australia had to seek a more northerly track." In Pettersson's view this outburst had far-reaching climatic repercussions. The monsoon region of the Indian Ocean was profoundly disturbed. Years of excessive rainfall (1893 and 1894) were succeeded by years of drought (1896 and 1899) followed by wide-spread famine. The loss of cattle ran into the millions. Australia also suffered. In New South Wales and Queensland almost continuous drought prevailed from 1896 to 1902. In these seven years it is estimated that there were lost over fifty million sheep at a value of over sixty million dollars. Ice dangerous to navigation was again reported in relatively low southern latitudes in 1922. The Humboldt Current was deflected westward early in 1925, and warm coastal waters running southward between the Humboldt Current and the Peruvian Coast brought an abnormal rainfall along the arid western border of Ecuador, Peru and Chile, with destructive effects upon plantations and houses, irrigation canals and ports and towns unaccustomed to the rain which comes only at intervals of several or many years. Whatever the relationships between the argument and the observational basis of Pettersson, it can hardly be supposed that the changes that take place on so colossal a scale in the movement of ice out of the Arctic Sea and off the Antarctic Continent and northward from surrounding waters are without their climatic effects.

Commander Smith, of the Ice Patrol, has found bottom water in the trough between Greenland and Labrador of such low temperature (2.6° C.) and high salinity (34.90) as to point to an Antarctic origin, which means a slow creep northward over the intervening 10,000 miles of distance. But until the scattered reports of ice conditions, current flow and climatic changes (now gathered largely at haphazard) are brought into some systematic relation, or, better still, until sustained and cooperative observation has taken the place of scattered and uncontrolled observation, we shall be without that specific information upon which alone can be based an outline of the dynamic relation between the ice discharges of high latitudes and the climates of the poleward margin of the northern and southern temperate zones. The study of the ice on the one hand and of the habits of the migratory high and low pressure areas on the other are two of the major interests of science in polar exploration to-day.

We can not hope that long-range weather forecasts will do more than show the direction which a predicted change will take, that is, that the year or years ahead will *tend* to be drier or wetter as measured by an average year. One has only to see Biel's recent world map showing the variability of the annual rainfall from region to region to observe that prediction can not be based upon a single sweeping law. So far as we can see at the present time it is only by the patient fitting together of at least the critical parts of existing records and those yet to be gathered in selected places that a substantial basis of forecast may be found. The variability of rainfall expressed on Biel's map runs from less than 10 to more than 40 per cent., and the zones of given variabilities are in general of most irregular pattern. It is significant that the only seasonal forecasts now attempted by government are in tropical regions where the meteorological conditions are fairly constant as compared with those of higher latitudes. They are the forecasts for India made by the Indian Meteorological Department, and those for Java made at the Batavia observatory. This lends added interest to meteorological studies in the polar regions, since one may hazard the guess that whatever basis of forecast may be found practicable in the tropics and temperate zones the forecasts for the higher latitudes of northern North America and northern Europe as well as those of South Africa and Argentina will be found to depend upon conditions that are at least influenced by what happens in polar centers of action.

This is getting a long way from the empirical studies (useful as they have been) that marked the first steps in the direction of forecast. It is also a quite different thing from the deductions and partial correlations based on a study of astronomical cycles or upon the simple supposition that because the climatic changes of the past have had a certain recognizable periodicity such periodicities will be repeated more or less regularly in the future.

One can hardly appreciate the value which the scientist attaches to meteorological observations in the polar regions if he supposes that physical science advances by precise laboratory methods alone. At the present time some of the leaders in the social sciences are striving to discover something akin to the precise techniques and exact measurements of the physical sciences in order that human behavior may be "scientifically" studied. There is danger that such a point of view may overlook a difficulty of the physical sciences that is clouded by the striking fact that it has so many precise results. I refer to "field relations." One may experiment with air in a laboratory or with a crystal or with an electric current or with a lens and obtain certain precise values. But in many if not in most cases this is not the object of the scientist who conducts the experiment. His ultimate objective is not merely the thing before him but the law involved; and once he has discovered the law he attempts to apply it to the field. Here is where he is confronted with quite special difficulties because the field is almost infinitely complex if he deals with anything more than broad generalities. To a large degree "the wind bloweth where it listeth," in spite of the laws of dynamic meteorology. There is a topography to be taken into account and a host of complicating conditions of land and sea and ice, earth's rotation and water vapor and changes in solar radiation.

To the complications of nature are added those of observation and record and the assembly of an infinity of figures. The meteorologist is obliged to use observations "which can never be repeated and which have been made by some one else" (Shaw). In forecast it is still true that no dependable sequence of events has been worked out except locally, as in India and Java. To this number should be added the rainfall predictions of the Scripps Institution of Oceanography, which by a study of the temperature of the adjacent sea has been able to predict the rainfall of parts of the Southwest (U. S.) "with encouraging accuracy" (nine successful forecasts in twelve years). There are suggestions of other correlations, as, for instance, those of Commander Smith, who seems to find in the recent temporary amelioration of Arctic climate some relation to what he calls a "heat reservoir of tremendous proportions," namely, a surface layer in the North Atlantic over 300 feet in thickness covering an ocean area 100,000 square miles in extent and showing a temperature five degrees higher than normal.

There are many events for which we need no forecast if we once know what the facts really are. We happen to know accurately enough the history of the Nile floods for 960 years, and we know that only four times in that millennium has the river been as low as it was in 1913–14. Merely to know that fact is to know of the negligibly small chance of an extremely low Nile within a limited period of years in the immediate future. Facts and more facts of this character are what has given man his mastery over the earth to a large degree—he has seized facts and at least here and there directed his destiny to a desired end. If we are ever accurately to state the events that precede, accompany and follow important changes in ocean currents, as, for example, off the Peruvian coast in 1925, we shall have to make studies of far wider scope and seek correlations of which at the present time we have in most cases no hint.

Once we have carried our thinking to this point we see the great importance of an expedition like that which Captain Sir Hubert Wilkins and Lincoln Ellsworth are proposing to take into the Arctic in the summer of 1931. On a route 2,200 miles long from Spitsbergen to Alaska they propose to make life studies, take gravity measurements, secure bottom samples, observe the conditions of terrestrial magnetism and study the currents, the ice and especially the temperature and salinity of the sea water, as well as take soundings by the echo depth sounding device and wherever possible send up balloons equipped with meteorological instruments that will reveal the condition of the upper air. That these studies are to be made in a submarine seems at first wholly fantastic. But no one who has studied the plans in detail can fail to be impressed with the practicability of the scheme, for it is based upon a thorough knowledge, on the part of the leaders, of ice conditions across the entire Arctic Basin. Captain Wilkins's flight of April, 1928, equipped him to study the surface ice from the standpoint of submarine navigation, and along a different path Ellsworth was able to observe the character of summer ice.

The layman might suppose from the definite conclusions which science has reached here and there or from the definite objectives which it sets up in every field that we should presently come to the end of things. Here and there one hears the phrase "when science has gone as far as it can" or "when we have learned all that there is to know." If such were indeed the case we should need to be in no hurry about the attainment of the end. Polar exploration, like all other forms of exploration or of creative thinking, could well afford to take its time. We might even go so far as to consider the suggestion that has come to us from the social sciences (none too seriously made, of course) that there should be declared a moratorium in the physical sciences. As a matter of fact, science can not be restricted by quotas. We can never declare a moratorium on curiosity. We can never know too much about this amazing universe unless we are to suppose that ultimate knowledge is evil. All that science has done up to the present is to provide glimpses into what we call the natural world. Each advance supplies a fresh incentive for further research. Each discovery is a springboard from which another jump is made into the unknown. Recently the head of an American institution announced that there had been "solved the problem of the Southwest." Apart from the fact that there is no one problem of the Southwest, the "Southwest" is hardly a thing to be solved! In making a proposal for a given study its sponsor remarked to me recently, "Let's get this thing settled once for all." He was dealing with a matter involving such variables as winds and ocean currents and the migrations of people of whom we have but the most fragmentary records.

The scientist does not seek the end of things in the sense of these two quotations. He is trying to discern the process, to discover the law. He does not say, "Here we are at last!" but "Where next?" This is the real spirit of discovery. It is true that we are able to express magnitudes so great that formulas have to be devised if the figures are not to escape human comprehension. It is true that we have girdled the earth with human speech, provided a partial postglacial chronology accurate almost to within a year, and measured the depths of the sea with a sound wave. But it is also true that we have not yet discovered a way to stop the scourge of cancer, that we have not provided mankind with a reliable long-range forecast of the weather however much we may know of the physics of the air, nor have we been able to put the vagrant energies of tides and winds to the service of the steadier purposes of mankind.

We have not been able to do these things and many others because the statesmanship of science is not equal to the task of developing the techniques of science fast enough to keep pace with our needs, or if techniques are developed we are not able to discern as rapidly as we should the wider unities without which technology has no meaning. From an enormous mass of facts science must comb out the accidental and discover that which has significance, that which is recurrent, that which seems to relate cause and effect. Polar exploration is no exception to this rule. The literature of the subject is filled with romance and adventure, with casual happenings. Thousands of pages are filled with wholly irrelevant details, from the scientific standpoint. Those who work upon the creative fringe of the sciences that are served by polar exploration must read far to find a little. Partly this is due to the fact that youth and leadership are required to face the hard conditions of Arctic and Antarctic living. The first essential, before the maturities of science are given a chance, is to get in and out safely or at least with reasonable chance of security. Hard work and great risks are the rule. This means that we can not put romance out of the business. We like to personalize expeditions and events, to build up a hero. The heavy financial requirements can be met apparently only through agencies that demand news, and polar news is largely polar adventure. Nor is it adventure to the layman only. The scientist himself is conscious of the unknown about him. And who can escape the sense of mystery that pervades the unknown? Under such circumstances one can not wish to set metes and bounds to the imagination.

There is a wider sense in which we need exploration of the ends of the earth and why curiosity drives men into the unknown places. From the philosophy with which science was at first closely associated it long inherited the concept of "system," and the need for text-books tended to cause still further devotion to system. The creative fringe of scientific thought is often lost sight of in the too rigid formulation of law. Men have escaped the pain of thinking by inventing words that defeat the spirit of curiosity. To take a familiar example, we have in science the word "anomaly." If a thing does not fit into the regularities of the accepted system it is labeled "abnormal" or at least "anomalous." So far as the earth sciences are concerned I should say that it is a distinctive feature of their development in the last twenty-five years that inquiry is largely directed to the investigation of the anomalous occurrence, for is not the anomalous occurrence itself obedient to law? The lexicographer defines the word *anomalous* as "exceptional" or "unusual." When he goes on to term it "irregular" we do not follow him. When the Humboldt Current is displaced by the warm water creeping out of the Gulf of Guayaquil and down the coast of Peru at intervals of years we look upon this commonly well-behaved stream as exhibiting an anomalous course and the popular mind regards the occurrence as freakish. But science concentrates upon the anomalous behavior of the Humboldt Current and sees that the unusual behavior of that stream has a certain regularity if not perhaps a periodicity. We have hints that its deflection is an annual occurrence and what we have termed "anomalous" in it becomes only an expression of degree. From many such occurrences the scientist takes a fresh view of his world of nature and at last begins to wonder whether the anomalies of that nature are not of more critical importance than the generalized systems that include only so-called "normal" occurrences.

We are all aware that the physical processes that control our weather are not uniform in their behavior. Aside from the purely accidental there are certain long-range changes in meteorological conditions. From time to time we are brought to a full realization of a long-range increase or decrease of rainfall by their calamitous effects—the starvation of millions in Russia and India or the disastrous losses in the live stock industry in South Africa and Australia. The drought in the United States during this past summer startles us into a realization that nature now and then seems to defy its own mode.

In the search for the causes of these unusual or anomalous changes the widest comparisons have been made of climatic conditions in different parts of the world. The records of thousands of stations have been scrutinized. In the United States a preliminary examination of the records shows that "the occurrence of wet and dry years seems to be wholly fortuitous." The most we can say is that there appears to be a general tendency toward years of lean rainfall, with years of greater rainfall making their appearance only when there is "an extraordinary disturbance in one or more of the dominant members of the atmospheric circulation" (Henry). Different parts of the country seem to have their return of wet or dry years with great variation, so that the probability of heavy rains becomes less the greater the area involved. This is a most striking conclusion for a territory so large as the United States, but its significance seems to be diminished by certain comparisons made in more recent years in which highly significant "correlations" seem to have been discovered in places far apart. Thus Darwin in Northern Australia occupies "a position of singular importance in world meteorology" (Quayle). Its air pressure records have proved valuable in forecasting Indian weather and striking correlations seem to appear in the comparison of its weather records with those of many other, chiefly tropical, stations. The Argentine Meteorological Office for a number of years made eight-day forecasts of the weather based in part upon the measurement of the intensity of solar radiation at Calama, Chile, nearly a thousand miles away. A remarkable correlation (coefficient of .88, 1 representing complete proportionality of change) has been discovered between the mean annual level of Lake Nyanza in Africa and sun-spot occurrences.

The discovery of the apparently critical relation of weather conditions at a few given stations to the weather changes at quite distant points adds greatly to the significance of studies in polar meteorology. Unusual localization of meteorological forces has been detected in both the Arctic and the Antarctic. Now it is hardly conceivable that such a habit of localization could continue without correspondingly specific (and in time, we hope, measurable) effects within adjacent areas of wide extent. But the study of localizations is not enough. We have to take account of all the air there is, not of a part of it. There is no reason to suppose that the wide-reaching correlations of lower latitudes may not find their counterpart in high latitudes. Thus the scientist seeks not merely the habit of the weather (or, in more general terms, the characteristics of the climate) of polar regions. He conceives himself as eventually discovering correlations between polar centers of action and those of lower latitudes. Where those key stations may be no one can guess, for the key stations that have been already discovered are far from being explained.

I must at least mention the importance of polar exploration to aviation, especially in view of the service that the airplane has rendered to Arctic and Antarctic expeditions of the past five years. You are familiar with the idea of a trans-Arctic route between Europe and the Far East so long advocated by Stefansson. The idea rests fundamentally upon the stability of meteorological conditions within the Arctic Basin from October to May. No one who has any doubt about that stability could fail to have it dispelled by reading De Long's account of the remarkable uniformity of the weather in the winter that he spent on the *Jeannette* during her drift into the Arctic Sea north of Siberia. But probably long before such flights become practicable we shall have shorter flights from point to point along the fringe of the Arctic. The British Arctic Air Route Expedition is seeking light on controlling local conditions at the present time in Greenland. The "stepping-stone route," as it has been called (Joerg), passes by way of the Faeroes and Iceland to Greenland and Labrador, thus restoring in the air the counterpart of the sea-way that was first pioneered by the Norsemen. We have at last entered the stage forecast by Leonardo da Vinci, who saw no reason why man should not become "lord of the winds and rise conqueror of space."

In so far as sea navigation shall become possible the high latitudes offer many advantages of shortened distances and natural stepping-stones, with man feeling safer, in the present condition of flight technology, in the knowledge that land is beneath him at intervals on the way. In weather forecasting the setting up of a line of meteorological stations along aviation routes would seem to be a first condition. There must also be a much wider coordination of the observations at stations already established. Finally, both the new and the old stations can not be grouped by countries, as in the past, but must be tied in with the airports at the ends of the routes as well as at points between, wherever they may fall with respect to international boundaries. It thus appears that aviation has its own special requirements. We see that clearly in air pioneering in the United States, where the habit of the weather is fairly well known from region to region. How much more important it becomes in high latitudes of the northern hemisphere where successful flights have already been made by airships and airplane around the earth!

[Following his paper Dr. Bowman showed about sixty slides arranged in eight groups as follows: (1) a map of world rainfall variability in relation to pioneer belts to show the importance to future settlement in relatively high latitudes of strong rainfall variations; (2) the position of high-latitude meteorological stations in the northern hemisphere and the paths of high-latitude low- and high-pressure areas that have weather effects in lower latitudes; (3) types of ice and the conditions of ice discharge in the Arctic and the Antarctic; (4) dynamic conditions in the Arctic and the Antarctic in relation to currents, and land and sea migrations of the present and of past time; (5) economic conditions related to the whaling industry and questions of sovereignty; (6) radio exchanges between New York and the field expeditions of Byrd and Wilkins to illustrate the possibilities of scientific consultation while work is actually in progress; (7) the routes and relations of the four main Antarctic expeditions of the past year; (8) physiographic features, especially in the Antarctic Archipelago.]

OBITUARY

GEORGE FOUCHÉ FREEMAN

1878–1930

DR. GEORGE F. FREEMAN, director of the Federal Experiment Station at Mayaguez, Porto Rico, since April, died suddenly on September 18. Interment was made at Manhattan, Kansas.

Dr. Freeman was born at Maple Grove, Alabama, on November 4, 1876, and was graduated from the Alabama Polytechnic Institute at Auburn, Alabama, in 1903. He was granted the degree of doctor of science by Harvard University in 1917. He began his career as a botanist, but became a plant geneticist and educational administrator. He was a member of the botanical staff of the Massachusetts Agricultural College during 1903, and of the Kansas State Agricultural College from 1904 to 1909. From 1909 to 1918 he was in charge of plant-breeding work at the Arizona Experiment Station. In 1919 he was called to Egypt by the Egyptian government to organize the cotton breeding work for the Sultanic Agricultural Society, where he remained three years, at which time he returned to the United States to accept a similar position with the Texas Agricultural Experiment Station. He remained in Texas for a year and was then appointed to an agricultural commission to Indo China by the French government, which work required a year. Upon his return to the United States he was nominated, by the President of the United States, director general of the Service Technique of Haiti, where he went in 1923 to build up a vocational educational system and an agricultural development program. He remained in Haiti until April, 1930, when he resigned to become director of the Federal Experiment Station at Mayaguez, Porto Rico, at which place he resided until death overtook him.

Dr. Freeman's scientific activities centered primarily around cotton. He gave considerable attention to a study of the various varieties of cotton and had made substantial progress on a monograph of the cottons of the world.

He did his greatest work, however, in Haiti, as an administrator and organizer of the Service Technique. He built up an organization of 476 employees in six years, of which 91.6 per cent. were Haitian, according to the "Annual Report of the Service Technique for 1928–1929."[1] The property valuation, which included school building, school land and school equipment, amounted to $1,475,000. A total of 11,430 pupils and students were being accommodated. While this represents a mere beginning towards reducing the estimated 85 per cent. illiteracy in the country and in building up a nation undeveloped both in agriculture and along industrial lines, it indicates something of the enthusiasm and energy with which this difficult task was undertaken. Dr. Freeman deserves the lasting gratitude of the Haitian people for what he accomplished. The complete realization of the program can not be expected before two or three generations.

Dr. Freeman was the author of numerous reports and scientific contributions. He was a member of sev-

[1] Annual Report, Technical Service of the Department of Agriculture and Professional Education, Port-au-Prince, Haiti, Bul. No. 17. 1929.