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CLIMATE OF AUSTRALASIA

IN REFERENCE TO ITS CONTROL
BY THE SOUTHERN OCEAN. . . .

By

PROFESSOR J. W. GREGORY, D.Sc., F.R.S.

MELBOURNE ;

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THE

Climate of Australasia

IN REFERENCE TO ITS
CONTROL BY THE SOUTHERN OCEAN.

*Expanded from the Presidential Address (delivered as an Evening Lecture) to
the Geographical Section of the Australasian Association for the
Advancement of Science, Dunedin, 11th January, 1904.*

By

PROFESSOR J. W. GREGORY, D.Sc., F.R.S.

*Author of the "Geography of Victoria," the "Austral Geographies,"
"The Teaching of Geography," etc.*

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PREFACE.

WHEN invited to deliver the Presidential Address to the Geographical Section of the Australasian Association for the Advancement of Science as an evening lecture, I thought it advisable to choose a subject of more general interest than that which I had previously selected. Meteorology is the branch of geography in which, at present, the widest interest seems to be felt in Australasia, and in which well directed research promises the richest reward. I accordingly resolved to attempt to explain the basis of hopes for the possibility of long distance weather forecasts, and to suggest some lines of research, which must be undertaken before Australasia can secure the incalculable benefits of such foreknowledge. Success in this work largely depends on the existence of a permanent weather cycle, which is now well established, and has only so long escaped recognition, because, owing to its dependence on changes in the sun, its length is variable, and it inevitably produces contrary effects in different geographical areas.

This cycle does not offer us any simple direct evidence as to the nature of the forthcoming seasons; for it affects the weather of the continents mainly by causing changes in the circulation of the oceans. Now we know that ocean currents vary from year to year, we can understand how the actual irregularities in the seasons are fully consistent with the obvious oceanic control of the climate of the lands in the southern hemisphere. As these irregularities are caused by processes which take a year or more to run their course, we have the means of watching in one year the evolution of the weather we shall experience in the next.

The problems of long distance weather forecasting may be solved by two methods, each applicable to special areas.

In this address I have referred mainly to the influence of the oceanic circulation, as its effects may be traced directly in the land masses of the southern hemisphere. In the more complex conditions of the northern hemisphere the oceanic control may not be recognised so directly ; and there seasonal weather changes are necessarily considered in relation to the atmospheric pressure systems, which have been investigated with such interesting results by the American meteorologists.

Some meteorologists still regard the prospects of seasonal weather predictions as an unattainable vision. But I find it difficult to understand this view. The work is no longer a mere speculative possibility. The Indian Meteorological Department has issued seasonal forecasts for the last 15 years, and with brilliant success (see Appendix III), where the extracts illustrate the Seasonal Forecasts issued by the Indian Meteorological Department, and show their dependence on the variations in the currents of the Indian Ocean. It is quoted from the Report of the Administration of the Meteorological Department of the Government of India, 1898-1899, pp. 26-29. There has been only one failure, which happened during a year when the conditions of the sun were abnormal, and which could have been avoided had the Lockyers' principle been then available.

Similar forecasts for Australasia will no doubt continue impossible until our meteorology has been advanced another stage. I have agreed to the separate publication of this address in the hope that it may do something to help the proposals for the establishment of a united meteorological service for Australasia, which should work in close co-operation with those of India and New Zealand.

J. W. GREGORY.

January, 1904.

The Climate of Australasia.

PART I.—INTRODUCTION.

GEOGRAPHY AND TECHNICAL EDUCATION.

THE great educational controversy of the 19th century was whether the study of literature and philosophy was of higher educational value than reasoning that can be checked by experiment and observation. In that conflict the defenders of the existing educational system ranged themselves round the standards of classics and authority. The attack came from those who were inspired by the new-growing enthusiasm for science. The results of the battle were the admission of science into the old schools of learning, and its predominant influence in all the new, a revolution in the methods of primary education, and a remarkable revival in classical research. The victory of science is so complete, and in one respect so unexpected that, even in Oxford, compulsory Greek at the

first examination—that last relic of the claim that some knowledge of Greek is indispensable to culture—cannot last much longer; and it need not in the seat of learning where the renewed activity in classical research has re-discovered for us the revenue laws of Ptolemy, and has revealed to us further sayings of Christ.

The old controversy is closed. With the new century, the centre of educational conflict is changing, and there are signs of a new strife, which has some analogies with that of the last century.

With the vast growth of the extent of science, no student can keep in touch with it all. Decade after decade the sciences are being further divided and subdivided, and the minor divisions of a subject to-day have a greater literature than the parent science had a century ago.

Men engaged in scientific research are not expected to know more of other sciences than is necessary for the efficient pursuit of their own. But our students still have to spread themselves over many subjects, although all of them are ever widening in their range, and ever increasing in the refinement and complexity of their methods. The time is approaching when a change in scientific education will be necessary to secure some limitation to its range.

The problem that is now pressing upon us, is the selection of the subjects which are of the

most educational value. There are branches of science which appear to be travelling on blind roads, or have already been driven far ahead in useless isolation. There are some, which, so far as we can judge, are at present as purely academic as the classics. On the other hand, there are branches of science in which any progress is at once turned to practical account ; while there are industries whose work is hampered because science does not give them as much help as it would do, had important lines of research not lagged far behind the rest.

Some of the modern advocacy of technical education is no doubt due to impatience with anything that is not immediately useful. To modify our educational system to satisfy that spirit, would injure education, would cramp scientific progress, and ultimately prove disastrous to industry. The best feeling in the advocacy of technical science seems to me due to the recognition of the alternative, that scientific teaching must inevitably be restricted in its range, or must become so superficial and elementary in its standard, that it will lose much of its value as a medium of education.

It is generally held that the essence of true education is method, not matter. As Mark Pattison has so well put it in his *Oxford Studies*, it is not knowledge, but a discipline that is required, not science, but scientific habit. In accordance with this principle,

the advocates of technical education claim that, in the selection of branches of science that are to be taught, if two subjects are of equal educational value, preference should be given to that which is also of economic value. Moreover, many teachers believe that the principles of a science can, in most cases, be best taught by the study of those branches of it which are of most practical service to man. To justify that belief, the teaching of the technical subjects must be improved, and, must give at all costs, a rigorous training in scientific method. Most branches of applied science afford excellent educational material, for their results are tested daily by experiment on a scale vastly larger than science could afford. Applied science can be so taught as to give an especially powerful stimulus to the imagination, owing to its victories over space and time, its conversion of waste matter into useful products, and those triumphs over disease which have dispelled the delusion that there is anything in climate to prevent the successful occupation of any part of the world by white races.

The claims of technical education may be resisted by the advocates of pure science, on the ground that, in education, it is better to concentrate the attention of the student solely on the methods of work, and not to distract him and excite his impatience by even glimpses of the goal. But teachers can be trusted to

convince their students that the goal will never be reached except by thorough and honest work ; and surely any student will work all the more cheerfully if he know that college work is arming him with ammunition for subsequent use, and is useful not only as an intellectual treadmill.

The fear that academic science will be neglected if technical science be used for educational work, seems to me somewhat exaggerated. The revival of classics since the loss of its educational monopoly is a valuable lesson. Academic science is even less likely to be neglected : it will always have its attractions for intellectual hermits, who prefer to work on subjects where they will not be worried by the practical man of the world ; and it will always have its appeal to the fancy with its true fairy tales. As applied science must always be dependent on theoretical science, the greater the prosperity of applied science, the more urgent will be its demands on pure science for further information, and the more generously the world will be prepared to pay for pure scientific research. The victory of science in the last century has not led to the predicted overthrow of culture. Instead of its having been fatal to the study of classics, it has inspired a period of unrivalled brilliancy in classical research. So far from its having destroyed all respect for past history, and led to the neglect of books of authority, it has caused the re-writing of history on more instructive lines, and

has brought the various scriptures into the category of popular literature. So far from being fatal to art, it has supplied the means for a modern renaissance.

I venture to introduce these general educational principles, because they have especial application to geography, the teaching of which has, of all familiar subjects, been the last to benefit by recent progress. What passes as commercial or economic geography is too often a mere catalogue of natural products and climatic conditions. Geography in British education has been too often treated merely as popular topography, and has suffered from its inclusion among the arts subjects, and by being pursued by the methods of the humanist studies. Geography must be studied as a science, with methods better adapted to its materials and problems, and with a more exact and adaptable terminology. It must also look below the surface, and seek deeper into the nature of things.

In the more crowded, settled parts of Europe, geography may not be so useful a subject educationally as it is in a new country, such as Australia. In Europe, with every parish mapped, every lake known, every mountain range explored, unsolved geographical problems do not present themselves daily; but here in Australasia, geography provides the most useful educational material that is available to us. On all sides we are confronted by the

unknown, or what educationally is perhaps even better—the imperfectly known. Geography accordingly gives us the readiest means of exciting that passion for research which is the life blood of science, and of stimulating that habit of independent enquiry which is the essential aim of education.

While in Australasia geography should be one of the chief subjects in elementary education, it should also receive more recognition as a good subject for the teaching of research. Geography on land has made excellent progress, owing to its practical value. The need for irrigation has caused the study of our rivers, which in some states, such as Victoria, have been investigated with unusual detail and accuracy. Interest in the rainfall has enlisted an army of volunteer observers, who collect rainfall statistics with admirable intelligence and patience. The cutting up of our vast territories has necessitated the preparation of lease plans, which form an admirable basis for fuller maps. But the oceans that surround Australia have been almost entirely neglected. What we know of them, except what our feeble eyes can see from the surface, we owe almost entirely to England and to Germany ; and an appeal that Australasia should herself take up the investigation of the adjacent oceans, can be fully justified by economic consideration alone.

PART II.—THE SOUTHERN OCEAN.

CHAPTER I.—NAME, RANGE, AND GENERAL CHARACTERS.

When on 25th September, 1513, Nuñez de Balboa and Francisco Pizarro, "silent from a peak in Darien," discovered the great ocean that divides the western from the eastern world, the part they saw lay to the south of them. So they called it the Mar del Zur, the South Sea. That inappropriate name was replaced by Magellan's more attractive title of the Pacific Ocean, which was given eight years later; and though the South Sea Islands is still a familiar expression, it was only in modern times that the name of Southern Ocean was revived for the unbroken belt of sea that encircles the southern hemisphere. The title of the Southern Ocean to recognition is not yet universally admitted. A committee of the Royal Geographical Society,* which, in 1845, considered the nomenclature of the oceans, recommended their division into five—the Atlantic, Pacific, Indian, Arctic, and Antarctic. The Southern Ocean was divided among the Pacific, Indian, and Atlantic, along arbitrary

*The report of this Committee was not published at the time, but its minutes have been issued in a note entitled "Nomenclature of the Oceans." *Geographical Journal*. Vol. I., London, 1893, pp. 535-6.

meridians, while it was cut short to the south by the Antarctic Ocean. This classification of the oceans has been so widely accepted by the compilers of British atlases, that it is in common use. Modifications in this simple scheme are, however, necessary. Thus the Antarctic Ocean,

Fig. 1.—Map of Antarctica.

which is defined as occupying the area within the Antarctic circle, must be abandoned ; for within that limit there is probably far more land than sea. Instead of the Antarctic area being occupied by ocean, it appears to consist of a great land mass, into which two seas—the Weddell Sea and the Ross Sea, project poleward from the oceans that lie to the north. A

second important change in the popular British classification has been made by calling the gathering of waters south of the latitude of 40° S., the Southern Ocean. This innovation has been sanctioned by the English Admiralty, and is adopted on recent charts; though the official Sailing Directories still divide the Southern Ocean between the South Atlantic, Indian, and South Pacific Oceans. Recent oceanographic work has supported the claim of the Southern Ocean to recognition as an independent geographical unit, but in a somewhat restricted sense. Its northern boundary is generally defined as the 40th parallel of south latitude; but this limit is artificial and is no longer necessary. The line that marks the northernmost extension of the Antarctic drift ice has also been proposed as the boundary of the Southern Ocean; but it also is useless, as the limit of the drift ice varies from year to year, and, in 1894, an Antarctic iceberg floated across the Southern Atlantic till it was within sight of the tropics. The natural boundaries of the Southern Ocean may be defined as a line from Graham's Land to Tierra del Fuego; from Patagonia, across the shallowest belt of the South Atlantic to Cape Colony; thence, approximately along the parallel of 36° S. latitude to the south-western corner of Australia. The Southern Ocean washes the whole southern shore of Australia, and may fairly be extended to include all the Tasman Sea. It runs down

the western shores of New Zealand and thence continues southward to the Antarctic Continent, near Cape Adair, at the point where the Atlantic coast-type of Wilkes Land joins the Pacific coast-type of Victoria Land. With our existing knowledge, it seems better to accept New Zealand as the eastern boundary of the Southern Ocean, and not to continue it into the Southern Pacific. The whole Pacific is thus left as one geographical unit, bounded entirely by coasts of the Pacific type. The Southern Ocean, when restricted to the great ocean belt that extends from South America, past South Africa to New Zealand, is also an independent geographical unit, bounded by coasts of the Atlantic type. Future work may show that the Southern Pacific includes a belt that should be regarded as an extension of the Southern Ocean; but geological evidence suggests that the natural boundaries of the Southern Ocean are South America and Graham's Land on the west, and New Zealand on the east (fig. 1)

Even when thus restricted, the Southern Ocean is a great sea, 12,000 miles long by 1800 miles broad, and is equal in area to the Atlantic. Of that vast sea our ignorance is deplorable. The chief facts that we know about it are that it is swept by the "brave west winds;" that there is accordingly a steady drift of water across it from west to east; that there is a movement of cold water from south to north upon or below the surface; and that in places

there is, beneath the surface, a zone of warmer water, which has been thought to be flowing from north to south. The Southern Ocean and the Southern Pacific, moreover, are known to be the great refrigerators that cool the deep waters of the tropical and northern seas. The water of the deep sea all the world over, is almost ice-cold, and may be even colder than the freezing point of fresh water. This coldness is attributed mainly to the melting of the Antarctic ice, the waters formed thereby sinking, and drifting northward; for the deeper parts of both the Northern Atlantic and the Northern Pacific are warmer than the corresponding positions in the southern parts of the same oceans.

The general idea as to the nature of the Southern Ocean at the close of the work of the Challenger Expedition is well expressed in Wild's "*Thalassa*."* (fig. 2). The northern boundary was taken as the parallel of 40° S., which was represented as crossing alternately meridional depressions, ranging from 2500 to 3000 fathoms deep, and submarine plateaus approaching to within 1500 fathoms of the surface. The Southern Pacific was thought to consist of one long depression occupying the area between the submerged plateau of Patagonia, the islands of the South Pacific Chain, and the shallow water beside the Antarctic lands. The Southern Atlantic was represented as divided into two

*London 1877, pl. 2, pp. 23-4.

troughs, separated by the plateau that runs southward down the central line of the Atlantic. South of Cape Colony was shewn another trough, from 2000 to 3000 fathoms deep, connecting the deep basin of the eastern Atlantic with the main basin of the Indian Ocean. This deep water, south of the Cape, was thought to be driven to the north by the projection of the Kerguelen plateau, extending from the Antarctic to north of latitude 40° . The platform on the southern border of the Atlantic and Indian Oceans was regarded as an extension of the Antarctic plateau; while the deep troughs of the South Atlantic and Indian Ocean are the channels by which the cold water, which chills the deeper waters of the great oceans, flows slowly northward from the Antarctic.

The Southern Ocean was supposed to shallow steadily southward to the Antarctic lands, and the Indian Ocean was charted as one great basin of unbroken depth. But the work of the last five years has changed most of that. The German deep-sea exploring ship, the *Valdivia*, found deep water in the Antarctic, where it expected to find shallow; and it found shallow water in the Indian Ocean, where it expected to find deep. The view that the Antarctic continent sloped gradually northward was founded on little direct knowledge. Up till 1898 only 15 reliable deep sea soundings had been made south of 50° S. The *Valdivia* expedition added 29, which showed that the old conception was erroneous.

Of the 17 soundings taken by the *Valdivia* on its voyage from Bouvet Island southward, 11 showed depths of from 2700 to 3310 fathoms; only one was under 1700 fathoms, and that was in the immediate neighbourhood of Bouvet Island. The work of the *Valdivia* showed that the Southern Ocean to the south of a line from South Africa to Kerguelen, instead of being a comparatively shallow plain, was a basin of abyssal depth. Moreover, the floor of this basin in places, as between Enderby Land and Kerguelen, is strongly folded, depths of 1300 fathoms alternating with depths of between 2000 and 3000 fathoms. As Dr. Schott showed in his paper before the British Association in 1899,* the shallow sea around Kerguelen Island, MacDonald Island and Heard Island, is very local, and instead of it extending southward to Antarctica, it ends abruptly at the edge of a steep slope down to a deep Antarctic basin.† The work of the *Valdivia* alone has shown, according to Dr. Mill,‡ that the mean depth of the Southern Ocean is twice as great as Karsten's estimate of 1894. Further, during the voyage of the *Valdivia* northward across the Indian Ocean, between the lines of soundings made by the German cruiser the *Gazelle* and by *H.M.S. Egeria*, it was found that at

*Geog. Journ., Vol. XV. pp. 518-528. 1900.

†The greatest depth is 3134 fathoms, at 58° 5' S., 35° 54' E.

‡The first volume of the *Valdivia* results, Geog. Journ., Vol. XXI. pp. 312-313. 1903.

For translation of Prof. Chun's official report see Geog. Journ. Vol. xiii. 1899, pp. 640-50.

30° S., the depth instead of being 2700 fathoms as was expected, was only 1100 fathoms.

The German Antarctic Expedition of 1901-1903 under Professor Drygalski has confirmed the general conclusions of the *Valdivia* as to the great depth of parts of the Southern Ocean, and it has discovered further ridges upon its floor.*

The "deeps" now proved to exist in the Southern Ocean and the transverse ridges found in it and in the Indian Ocean are of great meteorological importance. The deep basins are reservoirs for the cold waters, formed by the melting of the Antarctic ice. The deep, cold water is sucked northward by the movement of the surface waters; and this deep sea horizontal drift is deflected by the submarine ridges into vertical currents, which reduce the temperature of the surface waters.

The existence of deeps in the Southern Ocean is not geographically surprising. The coast of Southern Australia is no doubt of the same geographical type as that of the opposite coast of Antarctica. Twelve miles off Warrnambool the sea floor plunges rapidly from the coast shelf, the edge of which is only 30 fathoms deep, to the depth of 2600 fathoms; and a similar geographical structure may be reasonably expected in Wilkes Land—the opposite coast of the Antarctic continent. In the Southern

*A list of the soundings made by that expedition between Cape Town and Kerguelen is given in Appendix No. II, p. 93.

Pacific the ocean floor is probably of a different type ; for the land seen by Cook between Ross's Sea and Graham Land will probably be found to be of the Pacific type, formed of fold mountains, parallel to the shore, off which fragments of former island-festoons may still remain.

CHAPTER II.—THE TEMPERATURE OF THE SOUTHERN OCEAN.

The climatic effect of an ocean upon an adjacent continent depends mainly on its temperature ; and the little we know of the sub-surface temperatures of the Southern Ocean shows that they are unusually complex. The *Challenger* expedition, in both its traverses across the Southern Ocean from the Cape to the neighbourhood of Enderby Land, and thence to Southern Australia, found the coldest water in a sheet lying between the somewhat warmer waters of the surface, and of greater depths. The *Challenger* found a belt of warm water, 400 miles in width, overlying the cold tongue of Antarctic water projecting northward. The warmth of the surface was thought to be due to an influx of water from the Indian Ocean, flowing

was 33° ; thence it rose steadily to 35° , at 164 fathoms; below that depth it fell slowly to 31.4° at 1504 fathoms, while the bottom temperature at 2515 fathoms was 31.2° . The layer of warmer water between 70 and 900 fathoms remains beneath the colder water owing to the fact that it contains more salt; the increase in its weight, due to the salt, balances the lightness due to its warmth, and thus it floats sandwiched between the cold water layers. The *Valdivia*, generally speaking, found water colder than the freezing point of fresh water, extending from the surface to below 60 fathoms; then there was a layer of warmer water, 7000 feet thick, ranging in temperature from 32° to 35° ; and lastly, the bottom zone, 7500 feet thick, with water below 32° , but not quite so cold as the surface layer.*

CHAPTER III. — CURRENTS AND DRIFTS OF THE SOUTHERN OCEAN.

The currents of the Southern Ocean appear to be simple, so far as our crude knowledge of them goes. Ocean currents are mainly dependent on the winds; and the winds that blow across the Southern Ocean are arranged with

*The *Valdivia* and the *Challenger* both found the coldest water at the depth of about 50 fathoms; the striking difference between their results was that the *Valdivia* found a layer of warm water, and the *Challenger* a layer of cold water below that depth.

diagrammatic simplicity. Between the latitudes of 40° and 50° is the great belt of the variable westerly winds, which blow uninterruptedly round the world. To the north of the Southern Ocean are the north-easterly trades, which are developed unbroken only on the ocean. Along the coasts the winds blow off shore during winter, and inward during summer ; and in the northern part of the Indian Ocean there are the biennial monsoons, of which the winds are reversed in direction at spring and autumn, and indirectly affect the movements in the Southern Ocean.

These winds cause a steady drift of water from west to east, along the Southern Ocean and across the South Pacific.† Where corners of land project southward into this great drift, the water is heaped up against them ; and this accumulation of water is relieved by currents flowing outward in various directions. Most of this water, as will be shewn later, escapes northward as true ocean currents flowing along the western coasts of Australia, South Africa and South America, while some of that heaped up against Westralia escapes as a current along the southern coasts of Australia.

†The rate of this drift is shewn by the passage of bottles, casks of blubber and other flotsam and jetsam, to be on an average 10 miles a day. See Findley, *Indian Ocean Directory*, 1871, pp. 85-86. More precise and recent data have been given by Russell's current-papers, of which three crossed from Cape Horn to Australia, by voyages of 9517, 8617 and 9585 miles, at rates of 9, 7.9 and 10.3 miles respectively. H. C. Russell, "Current Papers, No. 2." *Proc. Royal Soc. N.S. Wales*, vol. xxx, (1897), pp. 202-210, pl. xii.

CHAPTER IV.—OUR INADEQUATE KNOWLEDGE OF THE SOUTHERN OCEAN.

From this brief reference to our limited knowledge of the Southern Ocean, we may pass to that vaster subject—our ignorance of the Southern Ocean. Our knowledge of the other oceans shows that the sea floors have geographical forms as varied as those of the land. They have their broad, sinuous valleys; their deep, steep walled canyons; their mountain chains, composed of numerous mountain ranges, of which the highest peaks project above the sea surface as islands. They have their broad plateaus, and their widespread, open basins, both floored by “the great grey level plains of ooze.” The submarine surface is as varied as that of the land, and we must know its contours before we can form any adequate idea of the undulations of the earth’s crust. Oceanographic work, in fact, during the last 30 years, has revealed to us a new world, vaster than that discovered by Columbus, with a geography as complex, and a geology as interesting, and an economic importance that is perhaps as great. We have as yet no adequate idea of the form of the floor of the Southern Ocean. What conception should we have of the structure of Australia, if we had to guess its contours from points as far scattered as those we know in the

Southern Ocean? After leaving the Victorian coast, the first known point would be further north than Sydney, and there would be only one more before reaching Brisbane. In

FIG. 4.—Distribution of soundings in part of the Southern Ocean, shown by reference to an equal area of Australia.

Victoria there would be only one known height, and going north westward, there would be only three more before reaching Lake Eyre. Our ignorance of the Southern Ocean is truly colossal, and it is very expensive.

PART III.—OCEANIC CONTROL OVER CLIMATE.

THE parts of the oceans which are nearer to Australasia than to any other continent (taking the average height of the land as 950ft. and the average depth of the sea as 11,000ft.), exceed the land by 127 times in bulk. Australia is an island surrounded by a belt of water several times its diameter. New Zealand is a thin line, which, at its widest, is less than one hundredth in width of the ocean belt in which it stands. Australia is small and New Zealand insignificant in comparison with the great sheets of water by which they are bounded, and by which they are in every way dominated. Australasia is dependent, all in all, upon its surrounding oceans. The rain that maintains the flow of our rivers, the life of our forests, and the growth of our food, is raised by evaporation from the oceans. That screen of moisture, which protects us from the intense heat of the midday sun, and from the utter cold of outer space at night, is oceanic in its origin. The stability of the composition of the air, the fact that it is always fit for our respiration is, in all probability, also due to the sea; the carbonic acid gas, with

which New Zealand volcanoes and Australian bushfires are steadily polluting the atmosphere, is removed by the all beneficent sea as fast as it is supplied ; should at anytime the growth of plants or the weathering of rocks reduce the amount of that gas below the necessary quantity, the sea at once breathes it forth and restores the equilibrium, which is necessary to our existence. The sea, in fact, in addition to its many other functions, automatically regulates the composition of our atmosphere.

The possibility of the human occupation of Australia and all that makes that occupation profitable and pleasant, we owe to the surrounding seas, and any variation in their condition inevitably affects our natural prosperity and welfare. It is incumbent on us therefore, to study these oceans more closely than we have done hitherto. To quote Newton's famous illustration, we are children, playing with shells upon the shore of a vast unknown ocean ; but at present we neglect the chances offered by the retreat of the waves to pick up finer and rarer shells, and we are careless of the advance of larger waves, which may sweep away all our collection.

It is unnecessary to consider in detail the effects of an ocean on the climate of a land adjacent to it. They are well known and are explained in elementary text-books. The superiority of insular climates like England and New Zealand, with their limited seasonal

changes, to those less favoured lands, where the people, in winter buy their milk by the pound, and in summer buy their butter by the pint, is usually attributed to the action of the surrounding seas. We know, too, that coastlands generally have a heavier rainfall than districts farther from the sea. In Victoria, for instance, there is a steady reduction of the rainfall as we go northward from the coast, we are apt, therefore, to think that the proximity of water necessarily insures a moist climate. The proposal to fill the basin of Lake Eyre with sea water is based on the expectation that such a feat would inevitably increase the rainfall of Central Australia, and restore the former fertility of the Lake Eyre region. But if we consider the barrenness of the coastlands, along which the Sahara meets the Atlantic, or read Eyre's account of the utter desolation on the shores of the great Australian Bight, and contrast the torrential rains of the upper Amazon with the almost absolute rainlessness of the coastal desert of Atacama and the guano islets off Peru, we shall realize that the proximity of an ocean is not alone sufficient to endow a land with a generous rainfall.

CHAPTER I.—MONSOONAL WINDS AND RAINFALL.

WE must therefore, briefly consider the effects of an ocean on the climate of the adjacent lands. It is well known that water has a higher specific heat than land; that is to say, it requires more heat (the ratio is about 5 to 1), to raise one pound of water one degree in temperature than to effect the same change in one pound of earth. Moreover, while water is more slowly heated on exposure to the sun, it gives off its heat more slowly. Thus in the case of equal areas of land and water, each receiving precisely the same amount of heat from the sun, the land becomes the hotter during the daytime and cools the more quickly at night. As in summer the days are longer than the nights, it follows that land will, on the whole, be warmer in summer, and colder in winter, than water adjacent to it.

Any area, which is warmer than the air above it, will give off some of its surplus heat to the air in contact with it; the air being heated, expands, and thus becomes lighter and rises as a warm ascending current. Cool air from the surrounding areas accordingly blows in to take its place, and, over these cooler areas, there is a descending air current, which, on reaching the earth's surface, flows to the warmer area.

Accordingly the warmer of two adjacent geographical areas will be covered by an ascending air current and the barometer in it will indicate low pressure ; it will be a "low pressure area." Conversely, the colder of two adjacent areas will be covered by a descending air current and will be a "high pressure area." Therefore in summer land is covered by a low pressure area ; it is said to be covered by a **cyclone**, while the prevalent winds will blow inward from the sea. Land in winter is covered by a high pressure area, and is said to be occupied by an **anticyclone**, and the prevalent winds will blow outward to the sea. This change of the inward and outward winds, or, as it is called, this **monsoonal change**, may take place daily in the case of a small island ; but when the change is seasonal and is due to the differential heating of great oceans and continents, then we have seasonal monsoons. In these cases the winds are reversed twice a year, as with the monsoons that dominate the climate of India and northern Australia. We can, therefore, understand why countries, which are subject to monsoonal conditions, receive most of their rainfall in the summer ; for then, the winds coming in from the sea, bring with them a great supply of moisture, which falls as rain. The incoming wind does not drop its rain at once ; for as it passes from the colder ocean to the warmer land, the air is warmed, and its capacity for holding moisture

is thereby increased. Hence instead of precipitating its moisture at once, it is ready to pick up more moisture ; it is a drying wind, in spite of the fact that it is coming straight from the sea. For example, the trade winds reach the shores of the Sahara as drying winds. It is not until they get far inland that they are chilled by contact with cold mountains or by being raised high above the earth's surface ; then their moisture is condensed and falls as rain.

Hence, the interior of Australia gets most of its rain in summer. The coast lands, on the other hand, receive most of their rainfall in winter, because under these conditions, though the prevalent wind may be outward, still, whenever the wind does blow inward, the air will be passing from a warmer to a colder area, and thus its moisture be at once condensed.

A coastal climate, we must remember, will partake of the characters of a marine climate. The interior of a continent will have cyclonic conditions (low pressure) in summer, and anticyclonic (high pressure) conditions in winter. An ocean has the reverse conditions ; it is anticyclonic in summer, and cyclonic in winter. The meteorological conditions of the ocean are exactly the reverse of those which prevail on the land.

CHAPTER II.—CYCLONIC AND ANTICYCLONIC SYSTEMS.

Another important fact to be considered in regard to the winds, is that they do not blow straight, but mostly in great spiral eddies. The air flows spirally in towards the centre of a cyclone, and outward from an anticyclone. In the southern hemisphere the spiral movement of the air around a cyclonic centre is in the same direction as the hands of a watch; the air blows round an anticyclone in a direction opposite to that of the hands of a watch. In winter, as the oceanic conditions are cyclonic, the winds of the southern hemisphere will then flow above the ocean spirally, in the same direction as the hands of a watch: whereas, in summer, they move in the opposite direction. There is accordingly a change in the prevalent wind-direction twice a year, causing the equinoctial gales and unsettled weather of spring and autumn.

The geographical units of the south temperate and tropical zones are six areas of land and water, arranged alternately in a girdle round the southern hemisphere. The units are South America, the South Atlantic, South Africa, the Indian Ocean, Australasia, and the Southern Pacific. During the winter each of the three continents will be a high pressure area, with the wind blowing outward, and

moving, on the southern side, from west to east; the three oceans will each be covered by a low pressure area, with the wind blowing spirally inward and the air on the southern side will move from east to west. These great wind systems are not stationary, but are moving from west to east; in winter the path of the anticyclones crosses the centre of Australia, and the cyclones which are hatched at sea, pass to north and south of the anticyclone track. The prevalent condition of the winter weather of Australia is a central anticyclone, from which the winds flow spirally outward, flowing from west to east in Southern Australia, and from east to west in Northern Australia.

CHAPTER III.—WINDS AND OCEANIC CIRCULATION.

The importance of the winds on the variations of Australian weather is mainly due to the fact that they cause ocean currents. The power of the wind to pile up water on the leeward side of a lake or to blow the surface water before it, can be noticed by anyone who cares to watch a pond on a windy day. These broad, indefinite, inconstant movements of the surface waters, under the action of the wind, are known as *ocean drifts*. In the Indian, South Atlantic

and South Pacific Oceans, the winds tend to cause a cyclonic drift in the winter, while they cause an anticyclonic drift in the summer. Maps of the Oceanic circulation in the Indian Ocean represent the waters as moving in the same direction as the wind in an anticyclone, namely, in the direction opposite to the hands of a watch. Hence the summer conditions prevail. This is largely due to external factors. From 40° S. to 50° S. is the belt of the "roaring forties" which is swept by the wild westerly winds that drive the waters from west to east across the Southern Ocean. The South-western corner of Australia, South Africa and South America, all act as groins against which the water is piled up by this drift. This heaped up water overflows, and as it is running down a slope, it may flow independently of the local winds and even in opposition to them. This overflow, therefore, takes place as true ocean currents.

Thus in the Indian Ocean, the westerly drift in the Southern Ocean causes a northward current along the western coast of Australia. As the water passes northward, it falls under the influence of the north-east trade winds; it is blown out to sea, and finally drifts westward across the Indian Ocean as the "Equatorial Drift." When this water reaches the coast of Africa it is again piled up; and this piled up water has to escape in currents. It cannot cross the equator, because it is kept back by

the action of the trade winds of the northern hemisphere ; its only outlet is southward, along the East African coast, as the East African or Mozambique Channel.

Such are the prevalent movements of the ocean waters in the Indian Ocean. A similar circulation exists in the Southern Atlantic, and

FIG. 5.—General Diagram of Oceanic Circulation. (J. J. Wild).

in the Southern Pacific ; for in both the surface waters are moved by the same forces as in the Indian Ocean.

Thus, in the South Atlantic, Indian, and South Pacific Oceans the typical circulation is a vast eddy, the water flowing in the direction opposite to the movements of the hands of a watch. On the southern side of the oceanic

eddy, the water moves as a drift from west to east ; on the eastern side the water flows northward as a current, along the western coast of the continent ; on the northern side the water drifts eastward ; and then on the western side of each ocean the water completes the circuit by flowing southward as a current down the eastern coast of the other bounding continent.

CHAPTER IV.—THE EFFECTS OF OCEAN CURRENTS ON CLIMATE.

We have now to consider the effects of these ocean currents upon the climate of the adjacent lands. A cold ocean current flowing along the shore of a warm land, has a drying influence. A warm current beside a cold land produces a very wet climate. An off-shore wind has a powerful effect in reducing the local temperature if there be very deep water off the coast ; for deep sea water is always very cold, and a wind blowing off shore drives the surface waters out to sea, and thereby causes the uprise of cold water from below. If, therefore, the water off a coast is deep, the temperature of that coast will be chilled by an off-shore wind. Thus is explained the coldness of the Pacific water off Chili and Peru, and the almost unrivalled dryness of some parts of the adjacent coast.

This effect is well shewn in the Indian Ocean, in the case of the Somali coast, described by Buchanan.* There the summer is the coldest time of the year, because at that season there is an off-shore wind, which sucks up the ice-cold water from the abysses of the Indian Ocean, and thus chills the sea surface all along the coast.

CHAPTER V.—IRREGULARITIES IN OCEANIC CIRCULATION.

These causes are permanent in their action. The oceans and continents always occupy the same positions. The change from summer to winter may disturb the wind, and produce very different types of weather at different seasons of the year. But as these causes are permanent, they can affect only the climate, that is, the constant average of the weather. They do not explain the great difference between the weather of different years. These causes determine that generalized climate which meteorologists give us out of tables, and not the weather that we feel and know, which ruins crops by a

* J. Y. Buchanan "On Similarities in Physical Geography of the Great Oceans" in *Proc. Royal Geog. Soc.*, Vol. VIII., 1886, pp. 733-768.

drought one year, and by a deluge the next. It is no consolation to a farmer to tell him that the average total of his rainfall is an ideal quantity, if his average of 25 inches is made up of a drought of 5 inches one year, and a destructive deluge of 45 inches the next. The agriculturist is more interested in the natural inconstant weather than in the artificial inconstant climate. Such factors as the alternation of summer and winter, and the positions of the oceans and continents do not explain the variations of the weather from year to year, because being fixed, they should have always the same effect. If, as was once thought, ocean currents flowed on fixed and permanent courses, like rivers on the land, then their effects upon the climate of the adjacent lands should also be unchanging; but as the air circulation varies with the seasons, it is only natural that the oceanic circulation should also vary at different times of the year; and, what is still more important, there is now abundant evidence to prove that the oceanic circulation also varies from year to year.

The *Valdivia* and the *Challenger* found the oceanic circulation of the Southern Ocean south of Kerguelen was very different at the time of their visits. As Dr. Schott put it, "the well-known series of temperatures observed by the *Challenger* in the south of Kerguelen towards the ice-limit, has not been found by us, perhaps because the *Valdivia* was not far enough to the

east, or because we were in the ice at another season (November and December).” *

That the ocean currents and drifts occupy different positions at the same time in different years, is now well established,† and there is good reason to believe that these irregular movements of the sea are the main cause of the irregular variations of the seasons. The powerful effect that may be produced by comparatively slight disturbances of the normal oceanic circulation, may be illustrated by the following case:—Off the western coast of Australia, in the latitude of 14° S., the surface temperature of the sea is about 81° F.; the average land temperature may be taken at about the same. According to the soundings of the *Valdivia*, the temperature of the water at the depth of 654 fathoms was 69° F.; and at the depth of 1640 fathoms the temperature was 48° F. So the upwelling of water from the depth of 650 fathoms would reduce the surface temperature by 12° , and from 1600 fathoms would reduce the temperature by 33° . Air at a temperature of 81° can carry $\frac{1}{45}$ of its own weight of water. At the temperature of 68° it will carry only $\frac{1}{60}$ of its weight of water. The uprise of water from 1600 fathoms to the surface would diminish the amount of moisture, which could be carried

* Geog. Journ., Vol. XV., 1900, p. 524. The *Challenger* was in that area in the months of January and February.

† Rev. D. C. Bates, of Wellington, has kindly called my attention to the numerous wrecks on the New Zealand coasts, e.g., the recent loss of the *Ben Avon* in December, 1903, due to vessels being carried out of their course by the unusual set of the ocean currents.

by the air moving across the Indian Ocean in the latitude of 14° S., to less than one-half that which it would have carried at the day the *Valdivia* made its observations. Anything that would cause the upwelling of the deep cold water of the Indian Ocean to the surface, would reduce the rain supply to the adjacent parts of Australia by one-half. Such upwellings of cold water are not improbable. The great pools of green water which appear at intervals in the Southern and Indian Oceans may be due to this uprising of the deep Antarctic waters.* It is certain that there is a great movement of water from south to north off Western Australia; and as this water is flowing over a very uneven floor, the movement of the water must be irregular. Schott has pointed out, in connection with the work of the *Valdivia* expedition, that the movement of the ocean waters at great depths is due to the movement of the waters on the surface. Though this view has not been generally held, it appears probable as a corollary from the well-known hydro-dynamic principle, that currents take advantage of the whole of the cross section that is open to them. We know, for example, that if a stream of water enter a reservoir at a point on one side, and escape at the opposite side, the stream will not be confined to a simple straight line from inlet to outlet; the whole of the water in the reservoir will in time, to some extent, take

* Findley, The Indian Ocean Directory, 1871, pp. 91-2.

part in the flow. Similarly any surface current will in time affect the deepest parts of the ocean basin. The deep, slow-moving water impinging against the ridges on the ocean floor, will be deflected upwards; thus the cold abyssal water chills the surface of the ocean, and lessens the rainfall on the adjacent lands.

PART IV.—THE WEATHER CYCLE.

IF our weather be determined by the remote upwelling of water from the deep seas, it may be thought to be absolutely at the mercy of irregular proceedings that we can neither control nor foretell. It may seem necessary once for all to abandon the quest for that Holy Grail of meteorology—the key to the succession of good and bad seasons. The highest aim of meteorology is to determine whether there is any regular succession of wet and dry periods, and, if there be, the discovery of the law that regulates them. Belief in ordered, periodic weather cycles has existed at least since the time when Joseph made the family fortune by predicting the seven lean and seven fat years in Egypt, and turning it to account by his preferential trade. The search for the secret of Joseph's success has engaged the attention of ambitious men from that day to this. The search has been stimulated by many encouragements on the way. Weather records often show remarkable periodicity, which has led man after man to think that the key was almost within his grasp. Meteorological literature abounds with remarkable cases of the occurrence of the same weather conditions at regular

intervals, though for long such cases were only sufficient to tantalize men with single instances, and inflict the keener disappointment when they were referred to the weather of the world at large.

Four chief weather cycles have been proposed. The first and most famous is a cycle of $11\frac{1}{9}$ years, in which the round of weather changes is attributed to the influence of sun spots. There is no doubt that our weather ultimately depends upon the sun. Rain, for instance, is the result of a process of distillation, by which water is raised from the sea by the sun's heat; the moisture thus produced is carried inland by air currents, which are driven by the sun's power; the moisture is then chilled till it falls as rain. The process is identically the same as in the distillation of water; the steam which is raised by the fire is chilled in a condenser. If the power of the fire lessen, the distillation must go slower. Lessen the evaporation on the Indian Ocean, and the rainfall in Central Australia is necessarily reduced. That connection is inevitable and obvious.

The sun's power varies in different years. Its surface is sometimes clear, bright, and unspotted; and at other times, as conspicuously last October, it is marked with black spots, due to a great change in the outer envelope of the sun. The number of these sun spots varies in a cycle, the length of which, on an average, is a

FIG. 6.—Melbourne Rainfall—1840-1899.

little over 11 years. It was therefore, natural to look for a corresponding variation in our weather; and it was soon found that many of the weather factors vary in a cycle of slightly over 11 years.

The connection between sun spots and rainfall was suggested by Sir Norman Lockyer and Dr. Meldrum in 1872. Since that time the suggestion has received much support, and been discussed in a now voluminous literature; but the 11 years cycle in rainfall is not yet fully accepted. Incredulity as to the fact is easily understood; look for example at a diagram (fig. 6) showing the rainfall at Melbourne. The line rises and falls in short waves; but the waves are irregular both in height and length. If we mark the year of the highest rainfall in Melbourne, and put other marks 11 years

apart from one another, they do not, by any means, coincide with the highest points of the rainfall curve. The diagram shows no particular agreement with an 11 years cycle. Take again a diagram that shows the rainfall over a much wider area. Fig. 7 shows the amount of water collected in different years by the greatest rain

FIG. 7.—Variations in the volume of the River Murray, near Mildura.

gauge in Australia—the River Murray. The river gaugings taken near Mildura show great variations in the volume of the Murray; and the variations show no agreement with the 11 years period. The floods of the Darling (fig. 8) also show no support to the 11 year cycle.

While Lockyer and Meldrum have advocated an 11 years cycle in connection with the sun-spots, other men have claimed that the weather varies in cycles of longer periods. Dr. Russell, of Sydney, to whom Australian meteorology is

FIG. 8.—Floods of the River Darling. (After Russell).

so greatly indebted, advocates a weather cycle of 19 years,* and Brückner of Vienna holds that the cycle is about 34 or 35 years. Again Wolf holds that, in addition to the 11 years period in sun spot variation, there is also a long period variation, 55 years in length, which has claims to consideration, in reference to weather cycles. In the face of such divergent opinions as to the length of the supposed weather cycle, we may well ask, is there any weather period at all? Ordinary weather statistics do not show any obvious periodicity. For instance, years of heavy rainfall at Melbourne appear to be simply capricious in their recurrence; and Symons, to quote a European authority, denies that there is any regular oscillation in the British rainfall, or that the rainfall increases and decreases regularly like the swing of the pendulum. Such indisputable irregularities and the different lengths assigned to the supposed cycle by different authorities, appear, at first sight, to be convincing proofs that there is no weather cycle at all. If there were, it may be thought, the cycle should be as easily discovered, and as well known as the succession of the seasons. The view is accordingly prevalent that the wind bloweth where it listeth. Practical men follow the fatalist creed of Ecclesiastes, "He that observeth the wind shall not sow, and he that regardeth the clouds shall not reap;" and

*H. C. Russell "On the Periodicity of Good and Bad Seasons,"
Proc. Royal Soc. N.S. Wales, vol. xxx (1897) pp. 70-115.

many meteorologists still adopt an agnostic attitude in regard to the existence of any regular periodicity controlling the weather of the world.

But the fact that inconsistent lengths are assigned to the weather cycle merely shows that there is no simple weather cycle of precise and unvarying length, which affects the whole world, in the same way, at the same time. But there is no reason to expect any such crude and simple arrangement. To search for such is to chase a Will o' the Wisp. The weather of our infinitely complex earth is not likely to be controlled by any governor so simple in its action. It does not follow that there is no system at all. If there be a system, we must expect one which is subtle, refined, and difficult to trace.

CHAPTER I.—BRÜCKNER'S WEATHER PERIOD.

As the possibility of a weather cycle is the fundamental problem of meteorology, let us look at some of the evidence that has been collected to determine its existence. Owing to the complexity of our world and the delicacy of our atmosphere, minor variations are sure to be so numerous and apparently capricious, that a vast mass of material must be examined in order to secure satisfactory results, and to eliminate local irregularities. The most serious attempt

to handle this question has been made by Brückner of Vienna, whose great book—"Klimaschwankungen," the Variations of Climate—published in 1891, first placed this subject on a satisfactory footing.* Brückner was led to his investigation by consideration of the changes that take place in the level of the Caspian Sea. It has long been known that the waters of the Caspian alternately advance and recede. The records go back to the tenth century, and they are complete since early in the eighteenth century. Brückner found that there was a regular cycle in the rise and fall of the Caspian waters, and that the average duration of a complete cycle was from 34 to 36 years. The dates of the maxima for the Caspian were about 1743, 1780, 1809, 1847, and 1879.

As the Caspian is an inland sea, its level must depend upon the amount of water supplied by rainfall, and on the rate of its removal by evaporation. The Caspian acts as a great rain gauge for its vast drainage area. A high level of the Caspian, therefore, indicates that the preceding years have been abnormally wet, or that the temperature of the Caspian was low, so that evaporation was slow, or else that both factors worked together. Lakes which have

*The best summaries of this work in English are in a paper by F. Waldo in the *American Journal of Science*, ser. 3, vol. xli., 1891, pp. 141-151. . There is a longer and admirable summary in Waldo's "Modern Meteorology," London, 1893, pp. 406-421; and some account in the recent translation of Hann's *Climatology*. (London, 1903). The three books are available for reference in the Melbourne Public Library.

no rivers flowing out of them, all act as rain gauges for their drainage basins ; and Brückner found that the levels of other inland lakes, without outlets, also varied in cycles of the same length, and reached their maximum at about

FIG. 9.—The variations in depth of the water in Lake George. (From Russell).

the same dates as the Caspian. Brückner therefore considered the rainfall of 321 localities, some of which have rainfall records for over two centuries. Thus the rainfall data of Paris go back to 1691. Brückner's study of the rainfall convinced him that it also varies in a cycle of

about 35 years; and Hann's more recent, and still more detailed study of the rainfall of Padua since 1725, and of Milan since 1764, has confirmed Brückner's conclusion.†

Brückner's study of the rainfall, therefore, showed that the variation of the lakes was the result of the variation in the rainfall. Thus the lake levels were lowest in 1720, 1760, 1800, 1835, 1865; they were highest in 1740, 1780, 1820, 1850, and 1880. Brückner found that there were dry periods in 1831-40, 1861-65, and wet periods from 1846-55 and 1876-80. So the lakes were at their highest, at about the time of the wet periods.

As rain is a product of distillation, variations in its amount probably indicate periods of warm and cold weather. Brückner, therefore, enquired whether there was any connection between the temperature records and these dry and wet periods. He found that from 1736-1885 there has been the same 34-35 years cycle of variation in temperature. Severe winters and the freezing over of European rivers are recorded in history since early times; records are available as far back as the year 800, but they are too incomplete to be of much use before the year 1000; and the records show a temperature variation of the same length as the rainfall and the lake levels. Thus, Brückner finds that there were cold periods from 1591-1600, 1611-35, 1646-65, 1691-1715, 1730-1750,

†Hann's Memoir is published in Sitzber. K. Akad. Wien., vol. CXI. II. a, 1902, pp. 1-120.

1766-75, 1806-20, 1836-55. Taking the cold periods, Brückner finds that from the years 1020 to 1190 the oscillation period was 34 years ; from 1190 to 1370 it was 36 years ; from 1370 to 1545 it was 35 years ; 1545 to 1715 it was 34 years, and from 1715 to 1890 it was 35 years.

The date at which the rivers of Northern Russia and Siberia are opened to trade by the melting of the ice in the spring, becomes on the whole, alternately earlier and later, and the length of this oscillation is consistent with the rest. The snouts of the Alpine glaciers advance down their valleys and then recede and advance again ; and though—owing to the local variation in snowfall—all the glaciers do not act simultaneously, the movement, as a whole, is also in a 34-35 years cycle. The beginning of the grape harvest in France, southern Germany and Switzerland is celebrated as one of the chief national festivals of the year. The harvest is ripe earlier when the summer is warm and dry, than when the season is cold and wet. And the dates of the first day of harvest are known far back into the Middle Ages. These dates show an advance and retreat in an oscillation of the same length as the other weather variations. The price of grain is a good index to the nature of the seasons ; and Brückner claims that the price, looked at broadly, shows the same vicissitudes as the various meteorological factors, which control it.

FIG. 10.—Diagram showing early and late harvests from 1501-1890. (From Brückner's data).

The weather cycle thus established, is not invariable in length, and it does not affect the whole world similarly and simultaneously. The figures above quoted show that the cycle has varied in different centuries from 34 to 35 to 36 years. The mean length is given as $34.8 \pm .7$ years. Moreover, it must be remembered that the variations of any one of the meteorological elements is the result of the action of a complex of varying and opposing agencies. It is inevitable that there will be irregularities, which will be exaggerated in appearance by the artificial divisions of our annual weather records. The calendar year is not altogether satisfactory meteorologically; the year from spring to spring or from autumn to autumn would give better results than the present system of dividing the southern summer and the northern winter between two years' records. We must be prepared for unexplained inconsistencies in the data, and when we consider the extreme sensitiveness of the weather to local causes, the surprising fact is that only

8 per cent. of Brückner's material gave discordant results. Brückner found that the rainfall records of Europe and Asia agree precisely ; and are in general agreement with those of North America ; but the records of South America and Australia are much less regular in their agreement.

CHAPTER II.—THE BALANCE OF OCEANIC AND CONTINENTAL WEATHER CONDITIONS.

The most important of the apparent inconsistencies were due to intelligible, geographical causes. Brückner found, early in his investigation, that, while the level of those continental lakes which have no outlets rises and falls in agreement with the Caspian, yet many other lakes, though they vary in a cycle of the same length, are highest when the Caspian is lowest. Brückner, therefore, described these lakes as being in areas of permanent exception. Such exceptions, in this case, verily prove the rule. The Caspian is lowest after years when the rainfall in its drainage area is at its lowest. These are years when the great continental mass of Europe and Asia is under conditions of especially high atmospheric pressure. A prevalence of such anticyclonic conditions results in comparative drought.

When anticyclonic conditions prevail on land, cyclonic conditions, with extra rainfall, are developed at sea. Thus, when a smaller percentage of rain falls on land, a larger percentage should fall on the sea. There are no records of the annual rainfall at fixed stations out at sea, and but too few on the small oceanic islands ; but the coast stations share in the meteorological conditions prevalent in the adjacent oceans. Hence, when the centre of the continents lie under their anticyclonic conditions, and are passing through dry years, the coastal regions are undergoing cyclonic conditions and periods of comparatively heavy rainfall. Therefore, the Caspian and great inland lakes should be emptiest, when the coastal lakes are fullest.

This fact is abundantly established by historical records, and it shews us that we cannot expect all the rainfall records or all the lake levels of a great continent to rise and fall together. The movement will be a great see-saw, the interior and coastal districts varying inversely. This important fact is well illustrated by the rainfall returns for Australia. For example, rainfall curves for localities in the western plains of New South Wales and at Horsham in north-western Victoria vary in common (fig. 11). If now we look at the rainfall curve for one of those localities and contrast it with that of Sydney, we find that the conditions are reversed (fig. 12). When the rainfall is heavy

FIG. 11.—The rainfall at Bourke, Wilcannia, Horsham, Deniliquin, and Bathurst, from 1855-1899.

Sydney, it is light in the interior. This fact is illustrated for the whole of New South Wales by the instructive rainfall maps of that State, prepared by Dr. Russell. The shaded areas in the maps (figs. 13 and 14) are the districts where the rainfall was above the average; and the plain areas are districts where the rainfall was below the average. In the

FIG. 12.—Departures from average rainfall on coast and interior of New South Wales.

year 1894, the whole of the inland or western district had a heavier rainfall than usual, while the coastlands had less than their average. The reverse arrangement is shown for the year 1899. The balance of the coastal and inland conditions is not always shewn with such diagrammatic simplicity, for in some years the coastal and continental rainfalls are both above the average; owing no doubt to an increase in

the amount of rain raised from the sea by evaporation. We cannot expect that rainfall will anywhere vary with mathematical regularity. Rainfall is one of the most complex of

FIG. 13.—Rainfall map of New South Wales for 1894, shaded area showing where the rainfall was above the average. (After Russell).

météorological products, and is the resultant of a series of conflicting agencies. The supply of moisture available depends on the evaporation at sea, on the strength and direction of the winds that carry it inland; the amount of rain that falls at any locality depends on the temperature of the soil in the district,

and also of that in the areas over which the moisture has had to pass ; and the temperature of the ground depends on the winds, on the cloudiness of the sky at night, on the tem-

FIG. 14.—Rainfall map of New South Wales for 1899, shaded area showing where the rainfall was above the average. (After Russell).

perature of the adjacent sea, on the amount of dust in the air, and on other factors. Whether the moisture will reach any given locality, and, if so, whether it will fall there, depends on such a complicated series of conditions, that it is idle to seek for any precise

FIG. 15.—Departures from Average Rainfall at Sydney and Adelaide.

and invariable cycle of change. Even the records may be apparently falsified ; two sets of heavy Christmas storms may fall into one year's record, and miss the alternate year altogether ; even the same storm at the passage of the year may fall into different years in different parts of the country.

The surprising fact in rainfall statistics is that the cycle should be as marked as it is ; but we cannot hope to recognise it unless we separate the various elements in the rainfall. For instance, we have already seen (fig 6) that the variations in the Melbourne

rainfall appear to be very irregular. The rainfall conditions for Sydney and Adelaide are less so, although, as Russell has pointed out, they are reversed (fig. 15). Years of heavy rainfall at Sydney are years of light rainfall at Adelaide, because Sydney has entirely a coastal rainfall, and the Adelaide rainfall is mainly continental. This fact explains the apparent caprice of the Melbourne rainfall. Melbourne is intermediate between the conditions of Sydney and Adelaide. It receives some of the rains of the Australian coastlands, while it shares the inland rains which are the most powerful at Adelaide. If we could separate the Melbourne rainfall into its two distinct sources, we should probably find that each of them would be represented by regular curves; but when combined the results are capricious and unintelligible. Looked at from this point of view, instead of the rainfall statistics of Adelaide and Sydney being fatal to a belief in a periodic system, they flash into agreement, and those of Melbourne are not inconsistent with the existence of the great cycle.

CHAPTER III.—THE WEATHER CYCLE IRREGULAR IN LENGTH.

There is another essential precaution to be observed in search for a weather cycle. We

must not expect periods, due to sun spots or any form of solar change, to be always the same in length.

The statement that the sun spot period is 11.1111 years in length, looks very precise ; but that period is only the average of nearly two centuries of records, and any one solar cycle may differ in length from the mean by as much as two years.* If, therefore, our weather cycles are connected with the sun spot period, they also will vary from 9 to 13 years.

We cannot expect maximum to follow maximum with the punctuality of clock work. There is no sanctity to the number 11, any more than the number 13 is unhallowed. The great variation in the length of the solar period shatters for ever any hope of our getting certain predictions as to the weather of future years from simple averages. Averages are useful, but they are easily misused. In trying to determine weather cycles we must not put our trust in the mere application of simple addition and division to haphazard collections of figures. Professor Armstrong once had a German chemical student, who, considering his nationality, was abnormally lazy but normally systematic, and who used to determine the weight of his precipitates by asking all the students in the laboratory to guess the amount, and then taking the average. That student's

* The precise length of the sun-spot cycle as given by Wolf, (1875) is 11.1111 etc. $\pm$ 2.030 years.

method was as unsuitable for chemical research as is the use of blind averages in meteorology.

The statements that you can prove anything by statistics, and that there is nothing so misleading as facts, is to some extent true of weather statistics of Australia. A careful selection of instances out of the Australian weather records would give any desired result. Owing to the oscillation between these coastal and inland conditions, it is obvious that the calculation of averages requires great judgment, in seeing that the stations included are equally distributed. Unfortunately Australian weather statistics, except for the coastal regions, do not date back for any considerable length of time ; so they are not particularly useful in the investigation of long period cycles. And the study of Australian meteorology cannot advance beyond a comparatively elementary stage, until the weather records of Australasia be divided amongst its natural meteorological provinces.

CHAPTER IV.—THE METEOROLOGICAL PROVINCES OF AUSTRALASIA.

Supan has divided Australia into four distinct climatic provinces. Most of the subtropical parts of northern Australia he includes in the "Indo-Australian Monsoon Province," which has

a tropical climate, with a very low yearly range of temperature. The eastern coastlands of Queensland, New South Wales, and the eastern part of Victoria, and the whole of Tasmania belong to the "East Australian Province." It has regular, plentiful rains, and a moderate annual range of temperature. The south-western corner of Western Australia forms another province, characterized by a subtropical

1. African Tropical. 2. Kalahari. 3. Cape. 4. Indo-Australian Monsoon.
 5. Inner Australia. 6. S.W. Australia. 7. East Australia.
 8. Polynesian Tropical. 9. New Zealand.

FIG. 16. — Map showing the Climatic Provinces. (After Supan.)

climate, with fairly equable annual conditions. The rest of Australia, extending from the western coast to the head of the Australian Bight and Spencer Gulf, and bounded eastward by the main divide of eastern Australia, and northward by the Indo-Australian Monsoonal Province, is the "Inner Australian Province." It is characterized by great extremes in temperatures,

and very scanty rains, which fall at irregular intervals. The recognition of these meteorological provinces is of primary importance, because it helps us to understand why the same meteorological variation affects some localities simultaneously, and others at different times. For the solar variation affects different regions by a different chain of circumstances. Thus Mauritius, being in a different meteorological province from Bombay, may feel the effects of the same variation in the great controlling agent at a different date.

Moreover, there are interesting cases in which areas on the earth's surface, which are antipodal in position, have their meteorological variations reversed. Some parts of India lie under high pressure, while their antipodes in North America are under low pressure.* This opposition is to some extent a necessary consequence of the antipodal positions of land and water on the globe. Nearly every point on the land of the globe has water at its antipodes. In fact, only $\frac{1}{27}$ of the land surface of the world has land at its antipodes. As there is then a see-saw oscillation between the conditions of continents and oceans, it is only natural that antipodal localities, though they may show the same cycle, have their meteorological circumstances reversed.

* Sir Norman and W. J. S. Lockyer, "On the Similarity of the Short-period Pressure Variation over large Areas," *Proc. Royal Soc.*, Vol. LXXI., 1903, pp. 134-5.

CHAPTER V.—BRÜCKNER'S PERIOD AND
THE SUN.

The existence of the 35 years periods, which Brückner has established with such a convincing array of evidence, is all the more remarkable because it is in agreement with a long period variation in the sun, which was unsuspected when Brückner wrote his monograph. Brückner was so convinced that his 35 years' cycle must be caused by changes in the sun, that he turned to solar records, confident that he would find in them some variation, of which the variation of the weather on earth was an echo. At the time of his work, it was believed that, in addition to the $11\frac{1}{9}$ years sun spot variation, there was a longer sun spot cycle, of which the length was 55 years. That cycle was claimed by Wolf. Brückner searched the weather records for any trace of this 55 years period. His elaborate data showed that the weather varies in a 34-5 years' cycle; and as astronomers told him that the sun spot variation was 55 years, he logically accepted the conclusion that sun spots had no influence upon the weather. Brückner therefore predicted that some other, and then unknown variation of the same period as his own, would be discovered in the sun. Brückner's confidence has been justified; and the main argument against any relation between sun spots and the weather has been removed.

It is now known that there are three solar cycles. There is a short $3\frac{1}{2}$ years' secondary period in sun spots, which is reflected by the

FIG. 17.—Long Period Variations of Sun Spots, Magnetic Phenomena and Climate. (W. J. S. Lockyer.)

records of atmospheric pressure in India and Argentina ;* there is the well-known cycle of $11\frac{1}{9}$ years ; and there is a longer period variation, of which the length has been established by Dr. W. J. S. Lockyer at about 35 years.†

CHAPTER VI.—HISTORIC RECOGNITION OF BRÜCKNER'S PERIOD.

It may be urged against the validity of Brückner's weather cycle that, if it exist, it should have been recognised centuries ago, and long since placed beyond the range of controversy. But the meteorological cycle will be obvious to the casual observer only in areas of unusual meteorological simplicity, and where one meteorological factor is of great importance. Holland occupies such a position. It is part of the meteorological province of West Europe, and floods are of extreme importance to it. Bacon's essay on the "Vicissitudes of Things" announces the Dutch belief in a 35 years' cycle

* Sir Norman and W. J. S. Lockyer, "On some Phenomena which suggest a short period of Solar and Meteorological Changes," *Proc. Royal Soc.*, Vol. LXX, 1902, pp. 500-504 ; "On the Similarity of the Short-period Pressure Variation over large Areas," *Ibid.*, Vol. LXXI., 1903, pp. 134-135, 2 pl.

† W. J. S. Lockyer, "The Solar Activity, 1833-1900," *Ibid.*, Vol. LXVIII., 1901, p. 294.

in the following remarkable passage :—" There is a toy, which I have heard, and I would not have it given over, but waited upon a little. They say it is observed in the Low Countries (I know not in what part), that every five and thirty years the same kind and sute of years and weathers comes about again ; as great frosts, great wet, great droughts, warm winters, summers with little heat, and the like ; and they call it the prime ; it is a thing I do the rather mention, because, computing backwards, I have found some concurrence."

Australia has also contributed to the evidence in favour of the Brückner period. Mr. Charles Egeson, of Sydney, a clear-sighted meteorologist, found by a study of some of the meteorological elements for Sydney for the month of April, that they varied in a cycle of from 33 to 34 years. Mr. Egeson's conclusions are of especial interest, as they were published* two years before the appearance of Brückner's great work.

CHAPTER VII.—THE LOCKYERS' LAW OF FAMINE RECURRENCE IN INDIA.

The Australian weather records, however are not in a suitable form for satisfactory treatment, and I, at least, have not had time to

* C. Egeson, " Weather System of Sunspot Causality," Sydney, 1889.

interpret them. The meteorology of India, which has had its weather more carefully studied than any other tropical country, affords more instructive lessons. It is naturally to India that meteorologists first turned for traces of the effects of the sun spot cycle. Some facts were found in agreement with this cycle, and some of them were so striking that even such cautious meteorologists as Blanford were impressed by them. But India, as a whole, gave no clear evidence of an 11 years cycle, and the few agreements were dismissed as mere coincidences. Even when there were local agreements with the cycle, the action was often reversed. Thus, while the evidence of some stations suggested that abundant sun spots accompanied a high rainfall, other stations showed exactly the reverse, as sun spots were most numerous at the time of lowest rainfall. This contradictory evidence was discouraging ; and the first study of Indian rainfall records gave only enough agreement with the theory to tantalize, but not to convince. But during the last three years Sir Norman Lockyer, in conjunction with his son, Dr. W. J. S. Lockyer, has found a clue to the apparent irregularities of the Indian weather.* Sir Norman Lockyer was one of the first to call attention to the possible connection of sun spots and the rainfall

* Sir Norman and W. J. S. Lockyer, "On Solar Changes of Temperature and Variations in Rainfall in the Region surrounding the Indian Ocean," *Proc. Royal Soc.*, Vol. LXVII., 1901, pp. 409-430.

variations; and his 30 years' pursuit of the rainfall cycle has at length been rewarded by the most fruitful and suggestive results yet obtained.

The Lockyers' explanation of the apparent caprice of the Indian rainfall is based on a study of the spectra of all the sun spots that have appeared since 1876. Their work has enabled them to use sun spots as chemical thermometers, showing the variations in the temperature of the sun. The Lockyers have studied the spectrum of every sun spot, since 1876, which was sufficiently large for spectroscopic measurement. The results show that the sun spots indicate changes in the heat of the sun, and are most numerous at periods of intense solar activity, when the sun is hottest. The Lockyers have found that at one time the majority of the lines in the sun spot spectrum are referable to elements which are known to exist upon the earth; they therefore are called the "known" lines. At other times the majority of the lines in a sunspot spectrum do not occur in the spectra of elements known upon the earth's surface. When these unknown lines are predominant in the spectrum, the lines are wider apart, indicating that the temperature of the sun at that period is hotter than when the lines are close together. The increased heat, the Lockyers suggest, breaks up some of the elements in the sun, and so the spectrum of such material is different from that given by it

under any conditions yet produced on the earth's surface.

The proportion of the known and unknown elements in the sun spot spectrum, of course, vary inversely. When the proportion of the known element is greatest, there is the lowest proportion of the unknown lines. When the numbers of the known and unknown lines are equal, the sun's temperature is at its mean. Accordingly the study of the sun spot spectra determines whether the heat of the sun is above or below the average.

After the Lockyers had established this point, their next step was to study the records of the rainfall in Mauritius and India, to see if these variations in the solar temperature had any recognisable effect on the rainfall. When the sun spots are most numerous, their spectra show the greatest predominance of unknown lines, and the solar temperature is therefore at its hottest. It is found that at this period the south-western monsoon gives India its maximum of rainfall, while India, as a whole, being continental, is under cyclonic conditions. At the same time, Mauritius, being an oceanic island, is naturally under anticyclonic conditions, and has a minimum of rainfall. The maximum rainfall at Mauritius occurs when the sun spots and solar temperature are at their minimum, and the island is under cyclonic conditions. The rainfall curve of Mauritius is comparatively simple, and shows an 11 years cycle; but the

rise and fall is inverted when compared with parts of India. But India, as a whole, gives no simple regular period. It has been pointed out by Archibald and Hill, that, while the south-western monsoons of India yield their maximum rains at the time of sun spot maximum, northern India receives most of its rain at the time of the sun spot minimum. This difference between northern and southern India at first seemed fatal to the belief in sun spot control. It is due to the fact that the Indian rainfall is a compound product, which has to be resolved into its elements before the influence of the cycle can be seen. The Lockyers' work has now shown that, while at Mauritius the rainfall curve is comparatively simple, there being one maximum and one minimum in the course of the 11 years, the Indian curve for the rainfall from the south-western monsoon is more complex. In India there are two maxima during the course of one sun spot cycle. In addition to its proper maximum of rainfall, corresponding to the Mauritius minimum, it has a secondary maximum at the same time as that at Mauritius; for the conditions that determine a year of high rainfall at Mauritius extend their influence to India, and thus produce there a secondary maximum. It is not surprising, therefore, that, if we lump the whole Indian rainfall together, we fail to find any simple agreement with the 11 years period.

The Indian rainfall, having two maxima during the course of the one sun spot cycle, has also two minima, which occur one on either side of that secondary maximum which corresponds to the minimum of Mauritius. Now the Indian famines have no 11 years period, and thus have hitherto appeared independent of sun spot influence. The Lockyers point out that all the Indian famines have occurred at the time of the minimum beside the secondary maximum. The relations of the Indian and Mauritius rainfalls from the south-west monsoon, and the position of the famine years are diagrammatically shewn in fig. 18. The agreement between the Lockyers' results and the distribution of famines in India, is so remarkable that it is claimed to be "clear from the above table that if as much had been known in 1836 as we know now, the probability of famines at all the subsequent dates indicated in the above tables, might have been foreseen." This great meteorological advance promises great assistance in the future administration of India. Sir John Eliot, the Meteorological Reporter to the Indian Government, has expressed his opinion* that the results "accord closely with all the known facts of the large abnormal features of the temperature, pressure, and rainfall in India during the last 25 years, and hence that the indications already arrived at will be of great service in forecasting future droughts in India."

* Lockyer, *op. cit.*, p. 411.

PART V.—THE SOUTHERN OCEAN AND AUSTRALASIAN WEATHER.

CHAPTER I.—THE INFLUENCE OF THE SOUTHERN OCEAN ON THE INDIAN CLIMATE.

AUSTRALASIA is more directly interested in a second outcome of the Lockyers' comparison of the rainfalls of India and Mauritius. Important meteorological events in India and Mauritius sometimes occur together, and at other times they occur a year apart. Thus the heavy rainfall which occurs when the sun is hottest, occurs simultaneously in India and Mauritius; but that maximum of rain which occurs at the minimum of solar intensity affects Mauritius a year earlier than it affects India. This fact the Lockyers explain by the probable assumption that the maximum of solar temperature affects the continental areas of Africa, Asia, and South America, directly, and thus India, the Cape, and Cordova in Argentina are influenced together. But the secondary maximum produced at the period of solar cold, affects India and Mauritius indirectly, through changes which

take place in the Southern Ocean. Such changes do not affect Mauritius in the same year as they influence India. To quote the Lockyers' own words :—" The delay of about a year in the effect of the Mauritius pulse being felt in Ceylon and India, is exactly what would

FIG. 18.—Diagram of the relations of the Rainfall Variation of India and Mauritius, according to the Lockyer principle.

F Famine Points.

be expected if the rain at sun spot minimum comes from the south, as has been surmised. The fact that the pulses at Mauritius, Ceylon, and India in 1882 occur simultaneously is very strong evidence in favour of an origin in the equatorial region itself for the Indian rain at

sun spot maximum. The pulse at maximum in the Indian south-west monsoon may depend to a large extent upon the action of the excess of solar heat on the equatorial waters to the south of India, and not on an abnormal effect on the south-east trade."

The partial dependence of the Indian rainfall upon changes south of the Indian Ocean, even in the Southern Ocean, has been frequently considered. The Lockyers quote the following extract from Eliot's report of 1896, in which the highest official meteorologist in India expresses his belief in the connection between the Indian weather and the circulation of the Southern Ocean.

"Mr. Eliot long ago conjectured that the rainfall of India was profoundly modified by events taking place from time to time in the Southern Ocean. In his 'Annual Summary' for 1896 he wrote as follows ; - 'It has apparently been established in the discussion that the variations of the rainfall in India during the past six years are parallel with, and in part, at least, due to variations in the gradients, and the strength of the winds in the south-east trade regions of the Indian Ocean. The discussion has indicated that there are variations from year to year in the strength of the atmospheric circulation obtaining over the large area of Southern Asia and the Indian Ocean, and that these variations are an important and large factor in determining the periodic variations in the rainfall of the

whole area dependent on that circulation, and more especially in India. It has also been indicated that these variations which accompany, and are probably the result in part of abnormal temperature (and hence pressure) conditions in the Indian Ocean and Indian monsoon area, may be in part due to conditions in the Antarctic Ocean, which also determine the comparative prevalence or absence of icebergs in the northern portions of the Antarctic Ocean.' "

N. and W. J. S. Lockyer, *op. cit.*, pp. 422-423.

CHAPTER II.—ICEBERG IRRUPTIONS IN THE SOUTHERN OCEAN.

That great periodic changes do take place in the Southern Ocean is shown by the distribution of the Antarctic ice. In some years the icebergs drift into comparatively low latitudes, and are a serious danger to shipping.* In 1892 one group of icebergs floated along the eastern coast of New Zealand, almost as far as Cook Strait. Three years later, one iceberg in the South Atlantic, in April, 1894, actually got within sight of the tropics (it was seen in latitude

*The movements of the ice are best recorded in Towson's paper published by the Board of Trade, in 1858, of which I have not been able to find a copy in Victoria. Dinklage, *Ann Hydrogr.*, Berlin, 1893, also 1894, 1897 and 1898. H. C. Russell, *Icebergs in the Southern Ocean*, *Proc. Royal Soc. N.S. Wales*, vol. xxix., 1895, pp. 286-315 pl. xii. Part II., *ibid* vol. xxxi., 1897, pp. 221-251.

26° 30' S.) In other years the ice is kept far to the south.

These Antarctic icebergs migrate northward at intervals.* One well known ice irruption occurred between November 1854, and March 1855, and another from 1892-95. Mr. Baracchi has recently stated (*Age*, 9th Feb. 1904) that "there is no year on record since 1855 in which we have had so much rain during the first two months as we have already had up to date." The recurrence of the 1855 weather with similar and exceptional ice conditions south of Australia is significant. Icebergs this year have travelled unusually far to the north and to the east. The northward voyage of these icebergs must reduce the temperature of the sea through which they flow, and chill the winds which pass them. But they are themselves perhaps more important than their effects. They are symptomatic of less conspicuous, but more powerful agencies. The long life of these icebergs may indicate the absence of the warmer waters in which, under ordinary conditions, they would soon melt; and probably the extremely cold, changeable weather of the past two months, (November and December 1903), is a consequence of the proximity of this ice. And Mr. F. W. Hales tells me that it is a matter of experience in Southern New Zealand, that years when abundant Antarctic icebergs

*Suggestions have been made that the ice came northward owing to the great quantities set free from the Antarctic area by the effect of earthquakes or earthquake waves.

are reported by ships between New Zealand and the Cape, "we, (in Southern New Zealand), invariably got a showery spring and summer with plentiful rains in the winter following."

CHAPTER III.—THE INTERVAL BETWEEN DISTURBANCES IN OCEANIC CIRCULATION, AND THEIR EFFECT ON THE WEATHER.

Unfortunately we cannot trace the full influence of these ice-masses on the Australasian climate, as we know so little of the temperature of the sea water in the Southern Ocean. Analogy with other oceans however, suggests that the lowering of the temperature of the sea water, which is in part the cause and in part an effect of the northern position of the icebergs, must influence the climate of Australia and New Zealand. One striking case in the North Atlantic, knowledge of which we owe mainly to the work of Mr. H. N. Dickson, the lecturer on Oceanography at Oxford, shows how an unusual condition of weather in north-western Europe was due to an unusual position of the North Atlantic anticyclone, 18 months before.* Dickson's comparison of the North Atlantic in 1896 and 1897, shows that there were several differences in the circulation, which were due to

*For a non-technical statement of this case see the *Argus*, 19th Sept. 1903.

the fact that the North Atlantic high pressure area extended unusually far to the north, and north-east in the first half of 1896. The result was the early driving of the tropical waters far to the north, and an early spring, followed by a cold spell due to the southerly movement of the Arctic ice ; then followed a hot summer after the ice had melted. The Arctic ice broke up very early that year, and going to Spitzbergen in the spring of that year, we had to encounter a phenomenally heavy pack in the Norwegian Sea. But by the end of summer that had all gone ; the Arctic Ocean north of Europe was comparatively ice free ; and northern Europe had a warmer summer than usual.

In 1897, the reduced Arctic ice broke up early and came south, giving England a cold spell in spring ; after which, as the North Atlantic was free of ice, there was a phenomenally hot, dry summer. That English drought was the result of the position of the Atlantic anticyclone, 12 or 18 months before.

PART VI.—CONCLUSION.

CHAPTER I.—WANTED, A UNITED METEOROLOGICAL SERVICE FOR AUSTRALIA.

WE have seen how changes in the Southern Ocean may affect the Australian climate ; that it is clearly recognised that movements in the Southern Ocean determine some of the most important events in the Indian weather ; and that it is claimed that the earlier discovery of the Lockyers' law would have enabled all the Indian famines of the last half century, to have been accurately foretold. Meteorology in Australia is far behind that of India, and will require to make up much ground before Australia is in the same position of vantage as India. The continent which gave meteorology that powerful agent of research, the Hargreave's kite, is the only continent which has not employed it for meteorological work, Professor Schuster, in a recent address to the British Association deplored the conservatism of meteorological work. He declared that meteorologists were enslaved to continuity, that the brilliant progress in the science during the past few years has been achieved, not by

meteorologists at their Observatories, but in spite of them, by experimental work along fresh lines. If Schuster could make such complaints in Europe, one wonders in what terms he would express his opinions on the condition of meteorology in some other places. If Australian meteorology is behind that of India, it is not the fault of our meteorologists, who have done wonderfully well, with the means at their disposal. Their means have been inadequate. Federal Australia wants a meteorological service, which will adopt the same methods of observation, and the same system of publication for the whole of Australia and for New Zealand; and which will be so organized, that the data collected will be fully and promptly used. We want a united meteorological service, working on a uniform plan and publishing uniform records; and that service should have a sufficient staff and sufficient money to undertake experiments outside the ordinary routine of Observatory work.

Such a service, to be efficient, must be as elastic, and free from red tape rules as a Government Department can be. Its officers must carry on their work, animated by a love of scientific research and not as a matter of business routine. The British Government largely relies on the Royal Society for advice in dealing with its scientific work. And in the case of the establishment of a Federal Meteorological Service, the Australian Government might well follow

the British precedent, and consult the Australasian Association for the Advancement of Science, in reference to the organization of that work.

The benefits such a meteorological service might confer on Australasia are incalculable.

Proposals have been made to introduce into Central Australia a sheet of salt water, which, though large enough to be somewhat costly, would be small in comparison to the vast waterless plains it is proposed to benefit. But in the summer, when rain would do the most good, the country is often already covered with a vast sea of water. Day after day, in the summer of 1901-2 the districts around Lake Eyre lay under a heavy pall of morose, grey cloud. The fall of one tithe of that sea of moisture would have broken the long spell of drought, which had laid that country waste. The clouds at times descended as if endeavouring to reach the earth; but the ground was too warm and they were repelled again to the sky. More than once we had a few drops of rain, which showed that the clouds were so near the precipitating point that the slightest impulse would have upset the balance and brought down heavy rain. How high those clouds were above us, how thick they were, how much their temperature was above the precipitating point, we could not tell. No one knows. As I watched those clouds drifting steadily overhead, I used to long for a

meteorological kite to sound that great sea of moisture ; and I dreamt of the time when kites would spray those clouds with liquid air, and discharge their now wasted contents on to the wasted plains below.

CHAPTER II.—PROSPECTS OF LONG PERIOD WEATHER FORECASTS.

Few investments promise Australia a higher return than meteorological research ; but to be successful that research must be conducted patiently, and on well considered lines ; it must sound the ocean of air that floats above us, and must watch, by the collection of water samples, the influential changes in the circulation of the seas around our shores. These studies are necessary for the solar changes, which act upon our weather, act indirectly, by variations in the temperature and currents of the oceans. The variations in solar radiation are probably insufficient to cause any appreciable direct change in the temperature of the surface waters. The changes in the sun probably act on the far more sensitive atmosphere, and the winds disturb the oceanic circulation and change the surface temperature of a wide expanse of ocean, and thus affect the temperature and rainfall of the adjacent lands.

It is this fact which, though it renders the problem of long distance weather prediction very complex, gives us the best hope of ultimate success. If the changes that take place in the sun affected our weather at once, we should always be liable to disturbances that are extra-terrestrial in origin, and which at present we cannot reliably foretell. But the main effect of solar variations upon our weather is an indirect effect, and it works by a series of changes which may take years to run their course. The weather we shall have a year or two ahead is already determined; it is advancing upon us as silently and irresistibly as fate. Man may never be able to mould it an iota; but he can watch its progress and be forewarned of its effects. Many men distrust the possibility of weather predictions for any sufficient distance ahead to be of any service to agriculturists; but I have more faith in the future progress of science. We can see a little ahead already. We cannot see farther because of our ignorance; and more knowledge would increase the penetration of our vision. Fortunately for Australasia, our meteorological conditions are far simpler than those of Europe, so that we may expect much greater certainty in weather predictions. I see no impossibility in future Australian meteorologists foretelling correctly a year ahead, the general nature of the approaching seasons. But such insight will never come to us until we have done our

part, and studied the hydrography of the Southern Ocean, with the same methods which have yielded such profitable results in the North Atlantic, and to India.

In meteorology each continent must work out its own salvation. Europe may help us with methods, but we must apply them ourselves, to our own waters, before we can share in the rewards. Patiently and excellently meteorologists all over Australia are recording the daily changes of our weather ; but far out in the Southern Ocean, the fundamental processes that are determining the nature of the seasons a year or two years ahead are passing unnoticed, and unknown. Australia has spent vast sums in irrigation works that have failed through lack of water, and undertakes the duty of recording the present weather, but, for the sake of some £300 or £500 a year, we are leaving unstudied the causes that produce and control it. We spend money freely in defence against hypothetical enemies who may never come ; while we stint the Intelligence Department, whose duty it is to watch the one foe whose onslaught is certain and merciless. What could add more to the commercial prosperity of Australasia than warnings to our vast agricultural and pastoral interests, whether next year our wide fields will be paralysed by drought or washed by a soil destroying deluge. The apparent fickleness and severity of our climatic changes

introduce as large an element of gambling into our farming as there is in many reckless mining ventures. The dragon of uncertainty that now preys on our agriculturists could be slain, if we had foreknowledge of approaching seasons of fair weather and of foul. That knowledge is available, if we seek it properly. It is true that science holds out no hope of any quack formula that will tell us future weather without trouble or expense ; and it directly warns us that the forces that cause the major variations in our weather are too majestic for us ever to control. As, however, they work by processes that take years to run their course, we can watch the abnormal weather epochs in their slow and mighty progress, and science may herald their approach. Like the seer of old, science assures us, "cast thy bread upon the waters, for thou shalt find it after many days," though only if we devote those days to earnest and patient search.

APPENDIX I.

TEMPERATURES IN THE SOUTHERN OCEAN.

1.—The following are the records at some of the chief stations at which observations were made by "The Challenger."

"Challenger" Expedition. Summary of Results : pt. 1., 1895 ; pp. 495-6, 505, 517-8, 523, 525-6.

No. of Station	Lat. S.	Long E.	Depths in fathoms.	Temp'res.	No. of Station	Lat. S.	Long E.	Depths in fathoms.	Temp'res.
153	65° 42'	79° 49'	Surface	29.5°	157	53° 55'	108° 35'	400	32.6°
			50	29.0°				500	32.8°
				29.0°				Bottom	32.0°
			100	29.0°					32.2°
				29.0°	158	50° 1'	123° 4'	Surface	45.0°
			200	30.5°				50	44.5°
				30.5°				100	43.4
			300	32.0°				150	42.3°
				32.0°				200	41.3°
			500	32.8°				300	39.5°
				32.8°				400	38.2°
			Bottom	33.0°				500	37.0°
				33.0°				600	36.3°
157	53° 55'	108° 35'	Surface	37.2°	159	47° 25'	130° 22'	700	36.0°
			10	36.8°				800	36.0°
			20	36.8°				900	36.0°
			30	36.6°				1000	36.0°
			40	36.6°				1100	36.0°
			50	36.6°				1200	35.7°
			60	36.6°				1300	35.3°
			70	33.0°				1400	35.0°
			80	32.5°				1500	34.7°
			90	32.5°				Bottom	33.5°
				32.7°				Surface	51.5°
			100	32.8°				50	50.0°
			200	33.0°				100	49.0°
			300	30.3°				150	48.1°

No. of Station	Lat. S.	Long. E.	Depths in fathoms.	Temp'res.	No. of Station	Lat. S.	Long. E.	Depths in fathoms.	Temp'res.
159	47° 25'	130° 22'	200	47·4°	160	42° 42'	134° 10'	Surface	55·0°
			300	47·2°				50	51·8°
			400	46·9°				100	48·5°
			500	44·8°				150	47·9°
			600	41·8°				200	47·7°
			700	39·4°				250	47·5°
			800	38·3°				300	47·2°
			900	37·9°				350	46·5°
			1000	37·7°				400	44·9°
			1100	37·5°				450	43·3°
			1200	37·3°				500	41·6°
			1300	37·1°				600	38·5°
			1400	36·9°				700	37·0°
			1500	36·7°				800	36·8°
			Bottom	34·5°				900	36·6°
								1000	36·4°
								Bottom	33·9°

2. LIST OF SOUNDINGS AND TEMPERATURE OBSERVATIONS IN THE SOUTHERN OCEAN BY THE "VALDIVIA."

"The German Deep-Sea Expedition in Antarctic Waters."
Geog. Journ. Vol. xiii., 1899, p. 647.

Lat. S.	Long. E.	Depth fathoms	Bottom temperature.	Lat. S.	Long. E.	Depth fathoms	Bottom temperature
36° 23'	17° 38'	2280	33·2° F	56° 29'	7° 25'	2758	—
37° 31'	17° 2'	2708	32·7° F	56° 16'	10° 53'	3018	31·2° F
40° 31'	15° 7'	1417	35·2° F	56° 30'	14° 29'	2784	—
41° 5'	14° 52'	2860	33·2° F	55° 26'	18° 2'	2236	31·6° F
42° 18'	14° 1'	2512	32·7° F	54° 54'	22° 13'	2207	(32·8° F)
43° 52'	13° 6'	2962	32·7° F	54° 46'	26° 40'	2517	31·5° F
46° 2'	11° 35'	2618	32·7° F	55° 27'	28° 59'	3025	31·4° F
49° 8'	8° 41'	2415	32·7° F	56° 44'	32° 6'	3010	31·4° F
50° 57'	7° 40'	1960	—	58° 5'	35° 54'	3134*	31·4° F
53° 31'	6° 14'	1240	33·0° F	59° 16'	40° 14'	2980	31·5° F
54° 22'	4° 37'	1891	32·0° F	58° 53'	43° 1'	2965	—
54° 29'	3° 43'	310	—	59° 1'	47° 38'	3009	32·2° F
54° 30'	3° 31'	240	33·8° F	60° 11'	49° 48'	3042	31·6° F
53° 49'	3° 57'	1011	32·7° F	62° 27'	53° 22'	2829	31·6° F
53° 52'	4° 6'	1270	32·4° F	64° 9'	53° 12'	2540	31·4° F
54° 29'	3° 30'	250	34·0° F	63° 17'	57° 51'	2534	31·2° F
55° 21'	5° 16'	1684	31·5° F	63° 32'	58° 40'	1504†	—

* Deepest sounding in Antarctic area.

† No bottom; sounding incomplete.

Lat. S.	Long. E.	Depths fathoms.	Bottom temp'tures.
61° 45'	61° 16'	1940	31·8° F
58° 55'	64° 49'	2527	31·6° F
56° 19'	66° 48'	1306	34·0° F
54° 33'	67° 52'	2690*	—
52° 48'	69° 13'	2145	32·5° F
51° 50'	69° 48'	1102	35·0° F
43° 45'	75° 34'	1878	34·5° F
41° 6'	76° 24'	1801	34·5° F
38° 41'	77° 36'	86	55·0° F
38° 40'	77° 39'	367	49·8° F
37° 45'	77° 34'	800	37·8° F
37° 47'	77° 34'	271	51·0° F

3.—LIST OF SOUNDINGS MADE AND DEEP-SEA
TEMPERATURES OBSERVED BY THE “GAUSS” BETWEEN
CAPETOWN AND KERGUELEN.

Lat. S.	Long. E.	Depth in fathoms.	Bottom temp'ture F.
37° 41'	20° 47'	2570	34·2°
39° 42'	24° 49'	1676	36·0°
40° 0'	27° 13'	1706	36·0°
42° 30'	33° 45'	2780	36·9° ?
43° 4'	36° 22'	1980	34·4°
44° 18'	41° 48'	1342	35·8°
44° 41'	43° 54'	995	36·3°
46° 18'	48° 51'	1020	35·8°
46° 48'	50° 31'	1277	35·4°
46° 40'	51° 23'	149	—
47° 12'	58° 8'	2674	32·4°
47° 46'	61° 23'	2512	32·6°
47° 51'	66° 32'	210	35·4°

No bottom ; sounding incomplete.

APPENDIX II.—SOME ICEBERG RECORDS IN THE SOUTHERN OCEAN, OCTOBER AND NOVEMBER, 1903.*

Vessel.	Arrived.	At Port.	Date of Sighting Ice.	Lat. S.	Long. E.	Captain's report from Newspaper reports except where marked * which are verified by Captain or Chief Officer.
Str. Ruapehu	1903. —	Hobart	1903. 15 Oct.	48°6	95°	Four bergs 200 ft. high and broken ice, one berg mile long.
"	—	"	16 Oct.	48°6	99°51	Six large bergs and several smaller pieces. Temperature mild at the time.
Str. Rimutaka	—	"	13 Nov.	47°15	104°11	Icebergs.
Str. Laeisz*	—	Sydney	8 Nov.	47°	100°	Large Icebergs. } The Captain says he has never known or heard of ice so far east.
"	—	"	10 Nov.	47°	107°	do.
Str. Kaikoura*	22 Nov.	Melbourne	16 Nov.	47°38	105°49	Iceberg, Height, 212 ft., Length, 920 ft., Air temp. 41 deg., Water temp. 40 deg. Chief Officer says never knew ice so far east, and both he and Captain were surprised to meet it after passing 90 deg. The C.O. has been on this route for years.
Ship Dimsdale	—	Adelaide	7 Nov.	43°29	103°24	Iceberg, third of a mile long, over 180 ft. high, passed within half a mile.
Str. Everton Grange	27 Nov.	Melbourne	—	41½	105°	Four immense bergs. Chief Officer says he was surprised to meet ice so far north and east.
Bque. Queen	28 Nov.	Adelaide	20 Nov.	42°	109°	Iceberg.

*Kindly supplied by Mr. F. W. Hales.

APPENDIX III.

“The forecast of the probable character of the rainfall during the south-west monsoon of 1898 was issued in the same form as in the preceding seven years in the *Gazette of India* of the 4th of June, 1898, under the heading of ‘Memorandum on the Snowfall in the Mining Districts bordering Northern India, and the abnormal features of the weather in India during the past year, with a forecast of the probable character of the south-west monsoon rains of 1898.’”

The following gives a statement of the forecast as published in the Memorandum:—“The consideration of the cyclical period through which India has passed indicates that the year 1897 was probably the last year of what may be termed the ‘negative phase.’ A period of fairly normal conditions is now probable for some time in the Indian monsoon and south-east trades regions. . .

“Taking all the facts into consideration, it is probable the monsoon currents will be at least of normal strength, but that there may be, in consequence of the abnormal snowfall (moderate however) in the Punjab Himalayas during the month of May, slight delay in the establishment of the Bombay current.

“Judging only from the conditions in India itself and the known conditions in the Indian Seas, it is, on the whole, very probable that the monsoon currents will be of normal strength, and probably they will be somewhat stronger than usual. The Bombay current is more likely to be above its normal strength than the Bay current; but the probabilities for this are small, not exceeding 5 to 2.

“Assuming that the currents will be of normal strength, the comparison with previous years (more especially 1883, 1888, 1890, and 1892) indicates that it is probable they will set in about the normal time on both the Bengal and Bombay coasts. The Seychelles observations are also in favour of this inference. It is possible that from the action stated above, the Bombay current may be slightly retarded, and there is a slight probability that it may be not so strong as usual in June. . . .

“The conditions in the Indian seas and the Indian Ocean are, so far as can be ascertained, satisfactory and favourable, and indicate that the conditions in the south-east trades regions are at least normal, and that the air movement in that area is somewhat stronger than usual.

“Conditions are favourable to the prevalence of monsoon currents of at least normal strength in the Bay of Bengal. The rains will probably commence about the normal date in Bengal.

“Conditions are also, on the whole, favourable to the prevalence of monsoon currents of at least normal strength in the Arabian Sea. The abnormal snowfall in the Punjab Himalayas may slightly retard the establishment of the monsoon on the Bombay coast, and cause it to be slightly warmer than the normal in June. The influence of the snowfall will very probably be slight, and, so far as can be judged, the monsoon ought to set in on the Bombay coast before the 7th of June.

“It should be carefully noted that the preceding probabilities are obtained on the assumption that the currents will be normal in strength or slightly stronger than usual, and that they will require to be considerably modified if the monsoon currents should be much stronger or much warmer than usual.”

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