SCIENCE

VOL. 91 FRIDAY, MARCH 22, 1940 No. 2360

SCIENCE: A Weekly Journal devoted to the Advancement of Science, edited by J. MCKEEN CATTELL and published every Friday by

THE SCIENCE PRESS

New York City: Grand Central Terminal

Lancaster, Pa. Garrison, N. Y.

Annual Subscription, $6.00 Single Copies, 15 Cts.

SCIENCE is the official organ of the American Association for the Advancement of Science. Information regarding membership in the Association may be secured from the office of the permanent secretary in the Smithsonian Institution Building, Washington, D. C.

THE CURRENTS OF THE PACIFIC OCEAN AND THEIR BEARING ON THE CLIMATES OF THE COASTS[1]

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I FEEL greatly honored by addressing you here on this island which was made and made beautifully by man, the shores of which are washed by the waters of the Pacific Ocean, and which now during this great exposition offers a marvelous display of arts, crafts and industries from the many countries around that big ocean.

I stand here, however, with mixed feelings, partly because my personal experiences of the Pacific Ocean are limited and of recent years, and partly because I always feel that it is a shame to reduce winds and waves, the ever shifting sky of the sea, and the vast expanse of the ocean to a series of graphs in black and white such as those which I shall use to illustrate part of my address to-day. However, I can not bring to you the fogs of the Bering Sea, the blue waves of the trade-wind belts or the icebergs of the Antarctic. I have to present my subject in a cut-and-dried fashion, but I feel confident that you will not leave with the impression that the Pacific Ocean is as undisturbed and behaves in so law-abiding a fashion as appears from my graphs. You are familiar with the sea and know that it is ever-changing and tantalizing to those who try to understand its moods, but to-night I must generalize and simplify.

My address will fall into two distinct different parts. In the first place, I wish to give a review of the currents of the Pacific Ocean and, in the second place, I

[1] Address given at the Pacific Science Congress, July 27, 1939. Contributions from the Scripps Institution of Oceanography, New Series, No. 84.

wish to consider the influence which these currents exercise on the climates of the borderlands of the Pacific Ocean. The reasons for this division of the subject will be more clear when the factors which control the climate of any given region have been briefly discussed.

Under climate one understands, as you know, the average weather conditions during a long period of years, as expressed by means of average temperatures of months and seasons, maximum and minimum temperatures, amount of precipitation and distribution of precipitation, amount of cloudiness and sunshine, average and maximum winds and still other characteristics. I wish, however, to add that observations which in many localities have now extended over more than a century indicate that the climate of an area is not constant but is subject to variations the nature of which we know little about. In order to obtain a basis for comparison meteorologists have agreed that the climate of a region shall be defined by means of observations over a period of thirty years. Successive thirty-year periods will then show if changes take place and, before concluding to-night, I shall find opportunity to draw your attention to the fact that in certain regions conspicuous changes have occurred during the past few decades, changes which though probably not caused by ocean currents are related to them.

The climate of any region depends upon a number of factors, the most important being the latitude upon which is based the division in the three major climatic regions—the tropical, temperate and polar climatic zones. The climate is also closely related to the distribution of land and sea and to the character of the atmospheric circulation. The two most extreme types which are related to the distribution of land and sea are those which are known as continental and maritime climates. The continental type which is found over great inland areas is characterized by warm summers and cold winters and, therefore, by a wide range in temperature between summer and winter, and by warm days and cool nights and thus a wide range between day and night. Mostly, it is also characterized by little cloudiness and little precipitation. In contrast, the maritime climate which prevails over the oceans is characterized by a small annual variation in temperature, cool summers and mild winters, by a very small range of the temperature between day and night, and often by great cloudiness and considerable precipitation. In middle latitudes the general circulation of the atmosphere is directed from west to east, and east coasts are, therefore, greatly under the influence of winds blowing from a large continent, whereas west coasts are under the influence of onshore winds from the sea. In these latitudes the climate of the east coasts of the continents differs, therefore, characteristically from that of the west coasts, the east coasts having a more continental climate and the west coasts a more maritime climate. In equatorial regions the circulation is from east to west and the climatic conditions of the coasts are therefore reversed.

The great difference between the continental and the maritime climates is mainly due to the fact that the solid earth, in contrast to the ocean, does not store any appreciable amount of heat. Only the very surface is subjected to temperature changes and the surface temperature is, therefore, greatly raised in summer when heat is received from the sun, and greatly reduced in winter when excessive loss of heat by radiation takes place. Similarly, the temperature is increased during the day and reduced during the night. The ocean on the other hand can store large amounts of heat because in summer processes of vertical mixing distribute the heat absorbed from the sun over a relatively thick layer of water, the temperature of which will be only moderately increased. In winter the loss of heat similarly takes place from a considerable layer of water, for which reason the temperature decrease of the surface of the sea will be small. Even if no horizontal ocean currents existed there would be a marked difference between the climate of the land and that of the oceans, and a difference between the climate of the coast and that of the inland areas. The climate over the oceans would be much more uniform than that over the continents and the climate of the coasts would be milder than that over the inland. Even in such circumstances one could speak about the influence of the ocean on the climate of the coast. I do not, however, propose to discuss this general influence any further, because when dealing with actual conditions it must be taken into account that ocean currents exist which also tend to modify the distribution of temperature of the surface waters and to bring into one area waters which are abnormally warm and into another area waters which are abnormally cold. Thus, the circulation of the ocean will alter the climate over the sea itself and will modify the climate of the coasts, because the current flowing along one coast may be abnormally warm and the current flowing along another coast may be abnormally cold. The influence will evidently depend upon the character of the currents which, again, is controlled by the processes of heating and cooling to which the waters of these currents have been subjected in course of time. It is these particular modifications of the climates of the coasts which I propose to discuss, but before doing so it is necessary, as already stated, first to give a review of the character of the currents and especially to consider the distribution of sea-surface temperature which is related to these currents.

I have already mentioned that the climates of the coasts depend upon the prevailing winds. The same is true when dealing with the climates over the oceans and there the effect is intensified, because the currents in the upper layers of the ocean also depend on the wind, the waters being to a great extent set in motion by the wind blowing over the sea. For two reasons one can not expect, however, to find a perfect agreement between the direction of the prevailing winds and the direction of the prevailing currents. In the first place, the boundaries of the oceans place certain limits upon the motion of the water. If the wind blows permanently against a coast the water can not be carried against the coast but must deviate to the right or to the left and instead of a flow towards the coast a current along the latter will develop. I shall be able to show several examples of this process when dealing with the actual currents of the Pacific. In the second place it must be taken into account that the motion of the sea is also governed by certain laws, for which reason some ocean currents may be expected to deviate from the wind system. I shall find opportunity to show examples of such currents as well.

Let us first consider the prevailing winds over the Pacific Ocean in summer, as related to the distribution of atmospheric pressure (Fig. 1).[2] In this season we find one high-pressure area located over the eastern part of the North Pacific, and another over the eastern part of the South Pacific, separated by a broad belt of low-pressure extending clear across the Pacific Ocean somewhat north of the Equator. The high-pressure area of the North Pacific dominates completely the wind system over that part of the ocean. Near the American coast strong northerly or north-

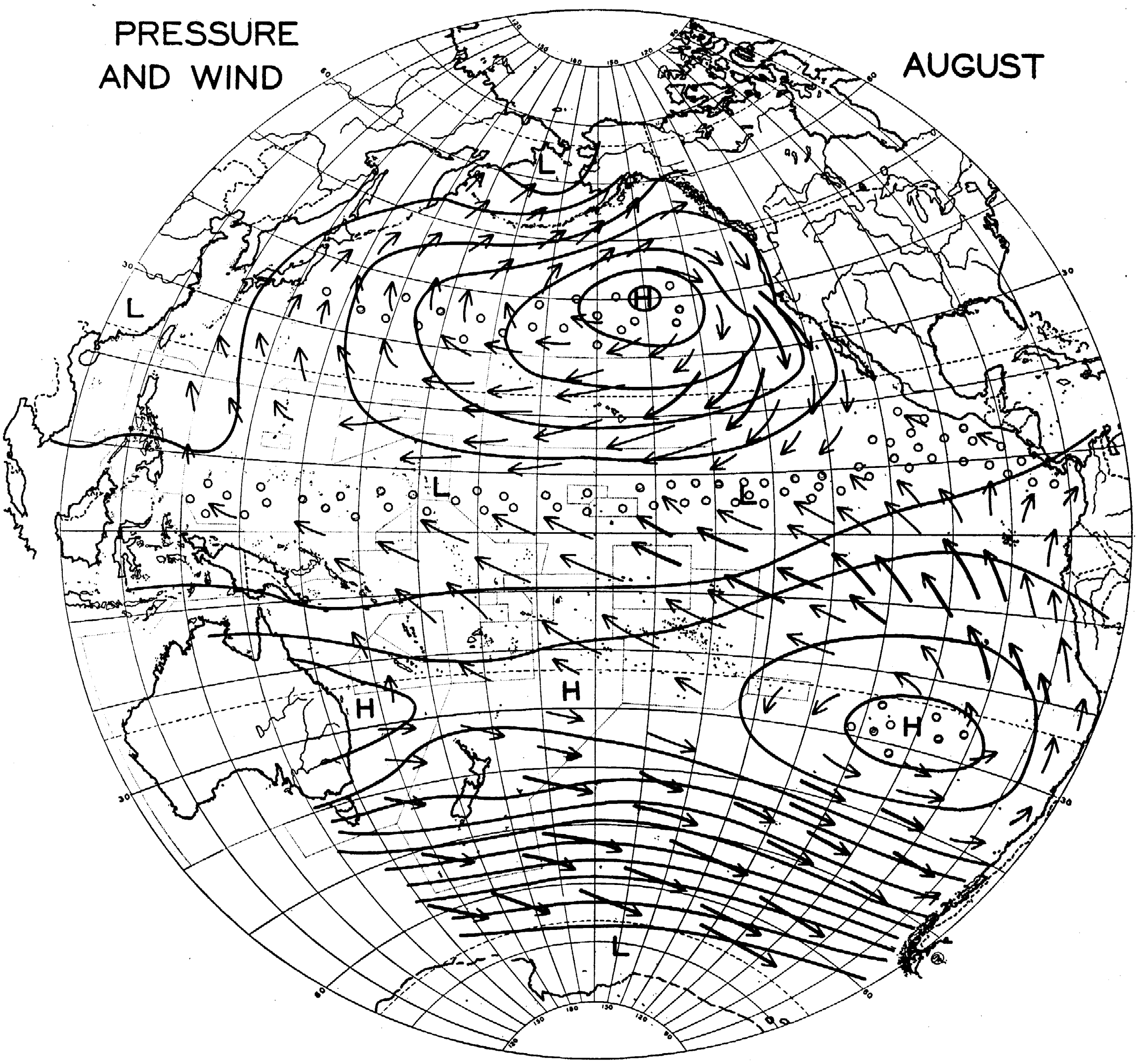

FIG. 1. Distribution of atmospheric pressure and prevailing winds over the Pacific Ocean in August (after Schott).

2 This and the following charts are based on the charts published by G. Schott in his book: "Geographie des Indischen und Stillen Ozeans," Hamburg, 1935. Maps 1–4 are reprinted from Robert B. Hall's "Series of Maps" published by John Wiley and Sons, Inc.

westerly winds prevail but, advancing south, the winds turn through northeast to east-northeast blowing as the steady trade winds between the latitudes 10° N and 25° N. The persistent northerly winds along the west coast of North America and the steady trade winds represent the most conspicuous features of the picture. Over the western and northern part of the Pacific the winds are more variable and blow there mainly from the south, and in the northern part from the southwest. It should be emphasized that this picture represents only the average conditions and that except in the trade-wind belt numerous disturbances occur associated with traveling low-pressure areas.

The high-pressure area over the South Pacific similarly dominates the wind system over that ocean. There, the southeast trade winds which blow with high velocity represent the most conspicuous feature, but to the south of the high-pressure area, strong westerly winds prevail between latitude 40° S and nearly to the Antarctic Continent. The southerly winds along the west coast of South America correspond to the northerly winds off the coast of California.

The surface currents in summer (Fig. 2) show a close relation to these prevailing winds, but it is immediately observed that in the northern hemisphere the prevailing current deviates to the right of the direction of the wind, whereas in the southern hemisphere it deviates to the left. Within the belt of the northeast trade winds the north equatorial current flows due west, and, similarly, within the belt of the southeast trade winds in the South Pacific the south equatorial current also flows due west. Along the coasts the currents must, naturally, follow the coast lines, but even there a tendency to deviate from the

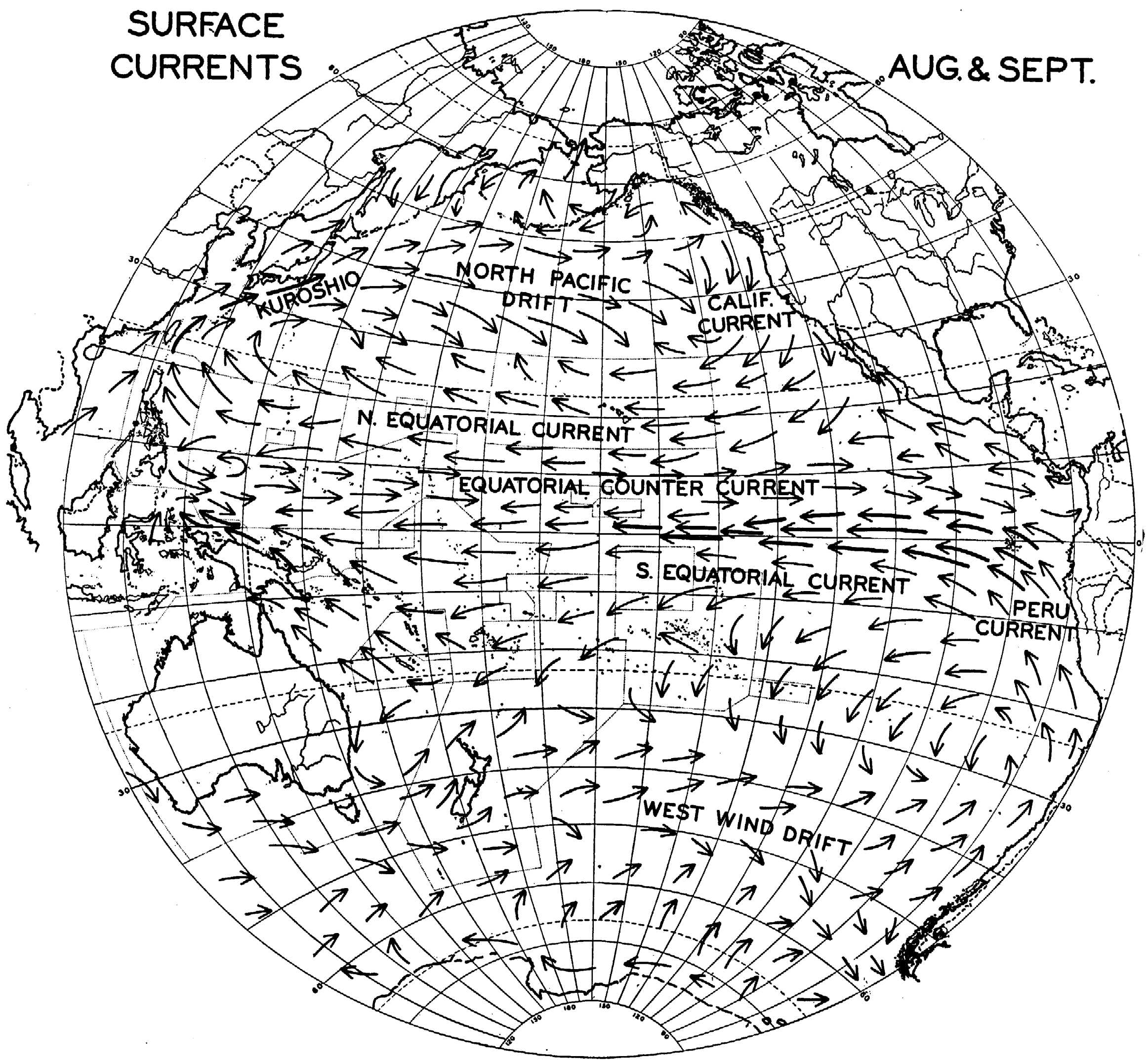

FIG. 2. Surface currents of the Pacific Ocean in August and September (after Schott).

coast is seen, corresponding to a deviation from the wind direction to the right or to the left. This deviation of the current from the direction of the wind is caused by the rotation of the earth but need not be further discussed here. The main point in this connection is that a general agreement between prevailing winds and currents exists. Attention is drawn, however, to the fact that the intensity of the Kuro Shiwo, the current flowing north along the southern coasts of Japan, is much greater than should be expected when considering only the weak and variable southerly winds. This current must, therefore, be regarded as a continuation of the north equatorial current. The flow to the south along the Island of Mindanao, the southern of the Philippine Islands, represents another branch of the same current. This current, which flows against the wind, represents a good example of the effect of the boundaries.

An even more striking exception from the agreement between wind and current is found. Between the two equatorial currents towards the west is imbedded a swift counter current running towards the east clear across the Pacific Ocean. The counter current is partly met with in the region of calms between the two trade wind systems, but in several instances the current runs directly against the prevailing wind. It has been found that this counter current is very shallow and that the development is probably closely associated with the entire dynamics of the flow, but here it is not necessary to enter upon these matters because the counter current has only a limited influence on the climates of the adjacent coasts. The counter current serves, however, to bring out the facts that the ocean currents depend not only upon the wind, but that the types of flow which can exist in the sea must also be considered, and that the relation between wind

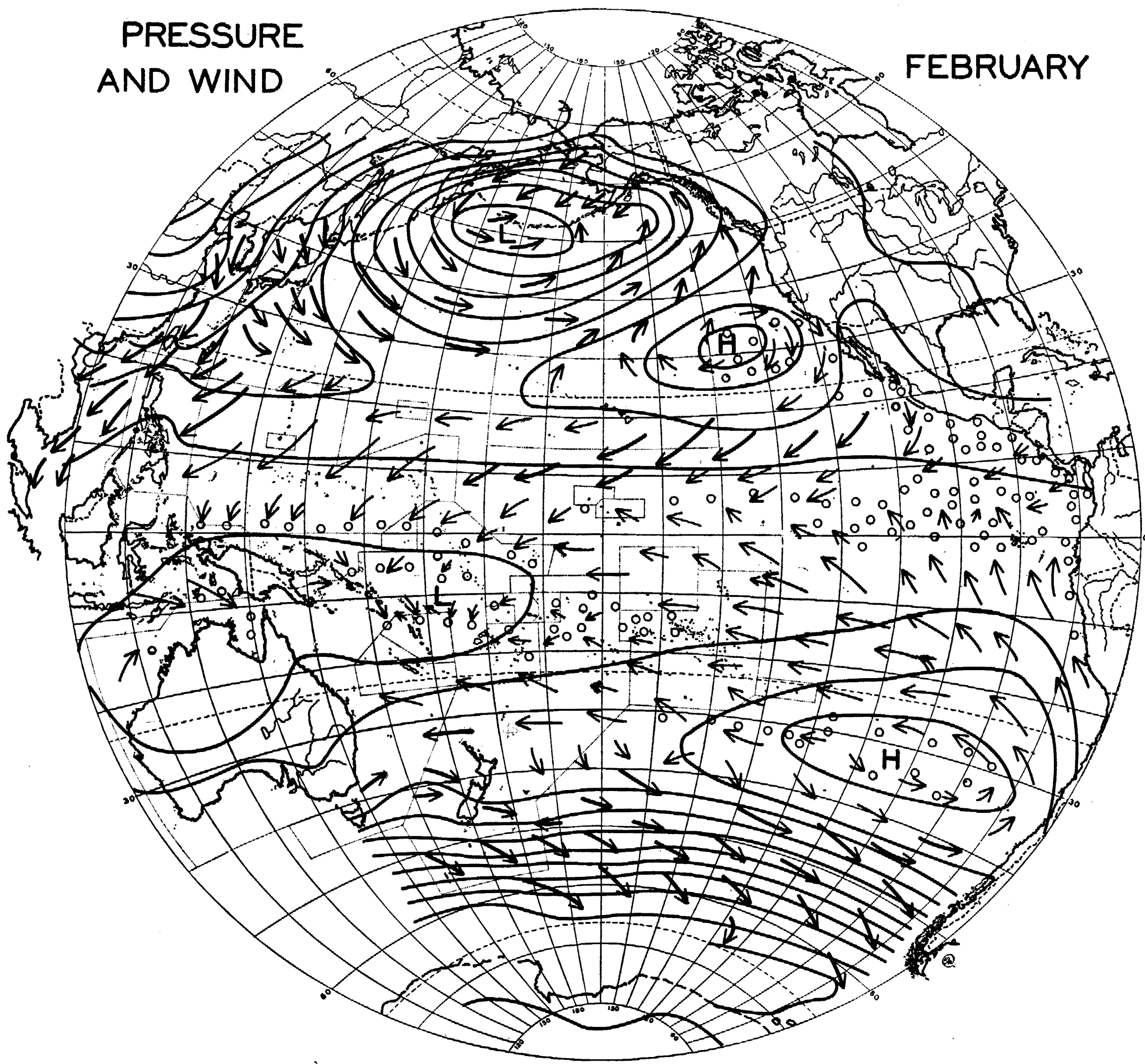

Fig. 3. Distribution of atmospheric pressure and prevailing winds over the Pacific Ocean in February (after Schott).

and current is more complicated than would appear from the brief presentation which is given here. It should also again be emphasized that the picture is greatly simplified and that superimposed on the average flow are numerous swirls and eddies and the currents are changing and shifting as are the winds.

In winter much greater discrepancies are encountered between the prevailing winds and currents. The been replaced by weak and variable winds, although the direction from the north is still the most frequent. The northeast trade winds are still very conspicuous and have increased in velocity because a steeper barometric gradient has been created by the approach of the high-pressure area towards the Equator. They blow with great permanency over a large area of the ocean between latitudes 5° N and 20° N. The most

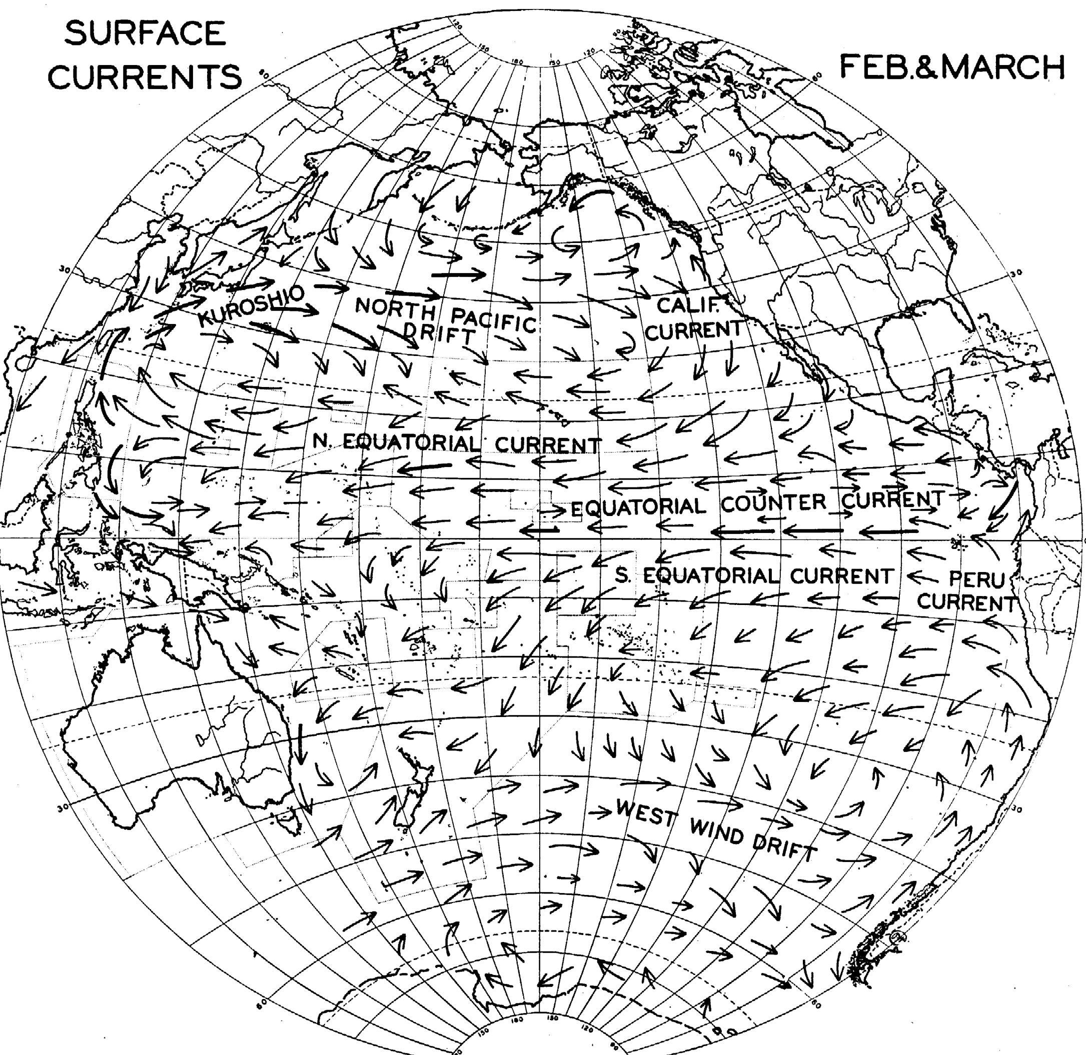

FIG. 4. Surface currents of the Pacific Ocean in February and March (after Schott).

high-pressure area of the North Pacific Ocean is in winter found further south and closer to the American coast (Fig. 3). This high-pressure area no longer completely dominates the circulation, as was the case in summer, but the more conspicuous feature is now presented by the low-pressure area in the region of the Aleutian Islands and by a tongue of high-pressure extending from the Asiatic continent. Along the west coast of America the prevailing northerly winds have conspicuous contrast between winter and summer is found in the western part of the Pacific, where the weak southerly winds of the summer have been replaced by strong northerly or northeasterly winds blowing from the Siberian high-pressure area, and in the northern part of the ocean, where strong westerly winds prevail.

The high-pressure area over the South Pacific Ocean is still the conspicuous feature over that portion of the sea, but it has moved away from the Equator. The barometric gradient has decreased, for which reason the southeast trade winds have decreased greatly in strength. The intensity of the westerlies in the southern part of the ocean has also decreased.

The surface currents do not show such conspicuous changes as the wind system does (Fig. 4). The north and south equatorial currents are still well developed and particularly the north equatorial current is more conspicuous than in summer. The counter current is still present but appears to be much narrower. A conspicuous discrepancy between the prevailing winds and the current is now found in the western part of the North Pacific, where the north equatorial current bends to the north and continues along the coast of Japan as the Kuro Shiwo, flowing nearly directly against the strong winds from the north. Along the coast of California the current still flows south at some distance from the coast, but an inshore current flowing north has developed. In the southern hemisphere the south equatorial current has decreased in intensity, but on the whole the picture has remained unaltered.

The turn towards the north of the north equatorial current and the continued existence of the Kuro Shiwo presents an excellent example of the effect of the boundary of the oceans upon the development of the currents. The flow of the north equatorial current towards the west is maintained by the permanent trade winds, and the North Pacific drift from the west to east in higher latitudes is intensified by the strong westerly winds. Water is therefore transported towards the coast of the Philippines and must bend north along the coast of Japan, or south along the Philippine Island of Mindanao, where the current is strengthened, probably owing to the northerly winds. The greater development of the cold Oya Shiwo north of Japan may also be greatly due to the stronger winds from the north.

The inshore flow along the coast of California is an interesting example of a counter current which probably can not be explained as the result of wind action but appears to represent a link which is dynamically conditioned, as is the case with the equatorial counter current.

The main feature of the Pacific surface currents is thus that along the western boundaries of the ocean equatorial water is transported towards higher latitudes, whereas along the eastern boundaries water from high latitudes is transported towards the equatorial regions. These transports of water are directly reflected in the distribution of surface temperatures. In the North Pacific Ocean water of a temperature of 70° (F.) is in August found off the coast of Japan in latitude 40° N, whereas off the American coast water of that temperature is met with in latitude 25°. The bend to the north of the isotherms in the western part of the ocean and to the south in the eastern part is closely associated with the movement of the water masses, the warm water of the Kuro Shiwo travels from the equatorial regions towards the north, whereas the cold water of the California currents flows from higher latitudes towards the south. In the Gulf of Alaska the flow is, however, from the south, and there relatively warm water is found.

Along the west coast of the United States the effect of the flow from the north is accentuated by the upwelling near the coast. North of San Francisco, in latitude 40° N, the average surface temperature of the water near the coast is on occasions as low as 50°, whereas in the same latitude off Japan the temperature is 70° or higher. The very low temperatures are due to upwelling, which is a direct effect of the prevailing winds blowing parallel to the coast. Owing to the rotation of the earth the surface current tends to be deflected to the right of the wind and, as a consequence, the light and warm surfaces of the waters are carried away from the coast and must be replaced by water from some greater depth. An overturning takes place and because the deeper water has a lower temperature cold water becomes accumulated along the coast. I wish particularly to point out that the upwelling water does not come from any great depth. The overturn takes place within the upper 500–600 feet and it is therefore essentially a process which takes place within the surface current. The upwelled water does not represent Arctic or Antarctic deep water as is occasionally stated.

In the southern hemisphere a similar process of upwelling acts along the coast of Peru where water of a temperature as low as 62° is found in latitude 2° S., whereas in the corresponding latitude on the coast of New Guinea the surface temperature is about 83°. A tongue of low temperature extends along the equator and is associated not only with the upwelling along the coast of Peru, but also probably with a divergence of the south equatorial current tending to raise the subsurface waters.

In the winter the effect of currents on the distribution of surface temperatures is much less conspicuous in the North Pacific than it is in summer. In middle latitudes there still exists a somewhat similar contrast between the coasts on the western side and the eastern side of the North Pacific. In somewhat higher latitudes the effect of the currents is more conspicuous. In winter the cold Oya Shiwo brings water of very low temperature to the northern coasts of Japan, whereas the North Pacific drift brings waters of relatively high temperature to the Gulf of Alaska. In the southern hemisphere the upwelling along the coast of Peru is as conspicuous as in winter and the tongue of low temperature along the Equator is still present.

Leaving the question of the ocean currents and turning to the climate I shall have to limit my discussion to a consideration of the temperature conditions. A chart of the air temperature over the Pacific and the adjacent coasts in summer shows that over the ocean the air temperature is very nearly the same as that of the surface waters. The isotherms show the same bends, and in the North Pacific the northward trend of the isotherms along the coast of Japan and the southward bend along the American coast are particularly conspicuous. Similarly, in the southern hemisphere the effect of the cold current along the coast of Peru is clearly visible.

From the course of the isotherms it is evident that the effect of the currents is limited to a very narrow coastal strip. This is particularly seen when examining the air temperature on the west coast of North America and the west coast of South America. Close to the coast the isotherms bend towards the Equator, but over the land they turn sharply away from the Equator. An air temperature of 70° is thus, on the coast, found as far south as off Lower California but, inland, north of the latitude of Vancouver. In the southern hemisphere a temperature of 70° is, on the coast, found nearly at the Equator, but inland south of latitude 30°. Along the coast of Japan the surface temperature of the sea also tends to reduce slightly the air temperature on the coast, but there the effect is very small as evident from the small bends of the isotherms. Thus it appears that in summer the influence of ocean currents is particularly conspicuous along the west coasts of the American Continents, but of small importance along the east coast of the Asiatic Continent.

In February the influence of the ocean current is in the northern hemisphere much less striking, except that in the Gulf of Alaska the coast has a much higher temperature than the inland, owing to the relatively warm water which flows through the Gulf of Alaska. Further south along the west coast of America the influence of the sea decreases. In the Japan region and along the east coast of the Asiatic Continent the air temperature is in winter much lower than the temperature of the adjacent sea, and there the cold air which flows out from the Siberian high-pressure area exerts a greater influence than do the ocean currents, but the latter tend to modify the winter cooling. Conditions in the southern hemisphere are, in February, naturally related to those which existed in the northern hemisphere in August.

The general features which have been discussed so far can also be brought out better by considering specific examples of difference in the annual march of temperature on both sides of the Pacific Ocean. Yokohama and Berkeley are nearly in the same latitude but the annual march of temperature in these localities is widely different, as evident from Fig. 5, in which are shown the mean monthly temperatures. At Yokohama the average temperature of the coldest month is as low as 37° but the warmest month has an average temperature of nearly 80°. The great range of 43° clearly demonstrates the continental character of the climate of Yokohama. In Berkeley on the other hand the coldest month has an average temperature of 48° and the warmest is 62°, and the small range of only 14° clearly demonstrates that Berkeley, from this point of view, has a maritime climate.

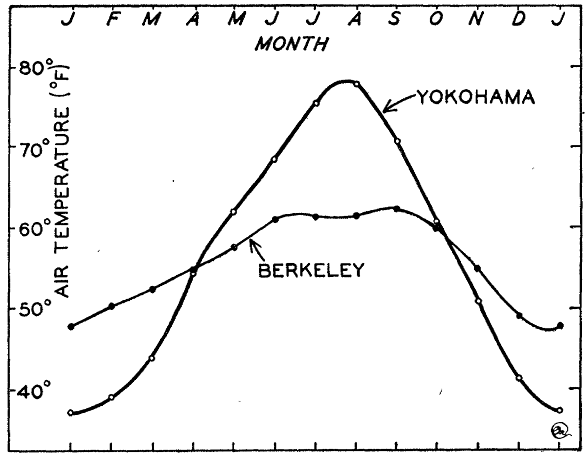

FIG. 5. Mean monthly air temperatures at Yokohama and at Berkeley.

A comparison of the air temperature with the water temperatures off the coasts is of further interest. Off Yokohama the water temperature varies during the year between 62° and 80°, and in nearly all months the water is warmer than the air. The great difference in winter is particularly striking and is due to the fact that the northerly winds bring air of low temperature. At Berkeley on the other hand the water temperature off the coast varies only between 52° and 58°. The coldest water is found in April and May because in these months the upwelling which was previously mentioned is most intense. The air temperature remains throughout the year very close to the water temperature but is generally somewhat higher. It is quite evident that the low spring temperatures at Berkeley are closely associated with the cold waters off the coast, and that at Berkeley the air temperature is to a great extent controlled by the temperature of the currents off the coast in contrast to the conditions at Yokohama. At Yokohama the warm water off the coast makes the winter milder, but the air temperature is not completely controlled by the water temperature. The difference is due to the fact that in Yokohama offshore winds prevail during the winter, whereas in Berkeley onshore winds prevail. The specific influence of the ocean currents gives Berkeley an abnormally low summer temperature and a relatively high winter temperature.

The annual march of precipitation in the two localities also shows a conspicuous difference. At Yokohama the precipitation is considerable in all months of the year, the mean monthly values varying between about 2.5 inches in winter up to 10.6 inches in the early fall. The excessive rains in the month of August, September, October are in part attributed to the influence of the adjacent sea because the path followed by the areas of low pressure will, to a considerable extent, be controlled by the temperature distribution over the ocean. The currents off the coast are therefore of considerable importance to the climate of Yokohama, although the continental character prevails as far as the temperature is concerned. At Berkeley on the other hand no precipitation falls in midsummer, but the winter months have up to 4 or 5 inches. The lack of precipitation in summer can in this case be ascribed partly to the effect of the inland and, as far as precipitation goes, Berkeley is more continental in character, although the temperature curve is distinctly maritime in type. Thus the bearing of the currents on the climate is a complicated one and it is here possible only to draw attention to some of the more outstanding features, and to pay particular attention to the distribution of temperature.

Turning to the southern hemisphere it is again of interest to compare conditions in the east and in the west, and for this purpose Fig. 6 shows the air and

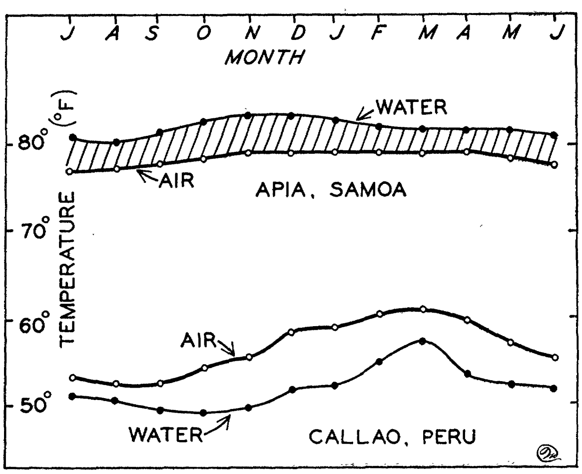

FIG. 6. Mean monthly air temperatures at Apia, Samoa, and at Callao, Peru, and mean monthly sea surface temperatures off the coasts.

water temperatures at Callao, Peru, and Apia, Samoa, which are located in 12° S and 14° S., respectively. The curves have been plotted with the month of January in the center, because January is a summer month in the southern hemisphere.

At Apia, Samoa, the annual range of the air temperature is very small and the air temperature always remains somewhat lower than the temperature of the water, which is about 80° throughout the year. At Callao, Peru, the air temperature is much lower than it is at Apia and varies between 52° in winter and 61° in late summer. The air temperature is throughout the year higher than the temperature of the waters off the coast which varies between 49° and 57°. It can not be doubted that both at Apia and at Callao the air temperatures are completely controlled by the temperatures of the water. At Callao the low water temperatures are the results of the character of the currents off the coast which carry cold water from higher latitudes towards the Equator and within which the surface temperature is further reduced by upwelling. The lowest water temperatures occur in the months of October, which in the northern hemisphere corresponds to April, the month of the lowest water temperatures off the coast of California.

The most striking conclusion which can be based on this very brief review is that a direct influence of the ocean currents upon the climates of the coasts is particularly found on the eastern side of the Pacific Ocean, whereas the coasts on the west side are only slightly influenced by the currents. On the eastern side of the Pacific the cool summers on the coast of South America and on the coast of North America between Cape San Lucas at the southern end of Lower California and towards the strait of Juan de Fuca are directly related to the character of the currents. Similarly, the mild winters of the coast of British Columbia and Alaska are directly related to the relatively warm currents which bend north into the Gulf of Alaska. The direct influence of the sea is, however, limited to a very narrow coastal zone, as you all know from personal experience.

When discussing the influence of oceans on climate, the effect of the northern branch of the Atlantic Drift, or the Gulf Stream, upon the climate of northwestern Europe is very often considered the most magnificent example of such influence. In this case the influence is not limited to a narrow coastal strip because the entire character of the atmospheric circulation appears to be modified by the surface temperatures of the ocean. The high temperature of the Atlantic water which enters the North Sea north of Scotland causes the atmospheric lows to take a more northerly path and thus to bring warm maritime air in over large portions of northwestern Europe. The areas which thus come under the influence of ocean currents are much greater than the coastal areas of the Pacific, but if attention is paid only to the very coasts the modifications of the climate which may be ascribed to currents are as great along the coast of the Pacific Ocean as anywhere else in the world.

In conclusion, it may be of interest to examine the question whether changes of climate can be attributed to changes of ocean currents. It has then in the first place to be observed that the development of ocean currents depends to a great extent upon the boundaries of the ocean and the depth to the bottom. Major changes of the bottom configuration or the coast lines may lead to major changes in the flow of the water and thus to appreciable alterations of the climate. Scotland and Iceland are connected by a submarine ridge. If this ridge should rise, the volume of Atlantic water flowing into the North Sea would be reduced, and if the passage should become completely closed the effect upon the climate of the Scandinavian countries would be disastrous, and these countries would perhaps face a new glacial period. On the other hand, if the Aleutian Islands should sink into the sea and Bering Strait should widen and deepen, the Pacific west wind drift might turn north; Alaska would probably receive a much milder climate than what it has now, and the Yukon Valley might become covered with orchards. Such changes may take place during long geological periods, and it is possible that changes of this nature have had bearing on the past climates of the Pacific area and may receive bearing on the climates of a very distant future, but in a discussion of climatic changes in geological periods many other factors enter in, particularly changes in solar radiation.

It is of more immediate interest to examine the question whether variations of short duration in the character of the currents occur, and, if so, whether these variations will be reflected in similar changes of the climates of the coasts. This question is a very complex one because the ocean currents are determined to such an extent by the prevailing winds that any change in the general circulation of the atmosphere will lead to a change in the ocean currents, but such a change in the general circulation will also have direct bearing upon the climate of any particular region. It is therefore difficult to discriminate between the direct influence upon the climate of a change in the atmospheric circulation and the indirect influence which is brought about by an alteration of the ocean currents. We have a striking example of this condition in northwestern Europe. During the last thirty years the winters of northwestern Europe have become milder, and the most conspicuous change has taken place in northern Norway and in Spitsbergen. In Spitsbergen the average winter temperature has, during the last decade, been about 15° above the average winter temperature of forty years ago. There is good evidence that this rise of winter temperature has been accompanied by a greater transport of Atlantic water towards the north. The increase in the volume of warm water flowing along the coast has certainly a bearing on the climate but the greater part of the change may not have been directly caused by such greater transport. Both the major effect on the climate of Spitsbergen and the effect on the currents of the North Atlantic Ocean may be due to a displacement towards the north of the tracks of the low-pressure areas. Such a change of the atmospheric circulation may again be due to a slight alteration of the amount of energy received from the sun which keeps the atmosphere running and maintains the ocean currents.

It should be borne in mind that the atmosphere and the ocean represent two delicate thermodynamic machines which are interdependent. A change in the performance of one of them leads to a change in the other which brings about a new reaction in the first one. A balance—a steady state is never attained. In order to understand the complex sequence of events and to be able to discriminate between changes in climate caused directly by changes in atmospheric circulation and indirectly by changes in ocean currents, it is necessary to acquire a better knowledge of both the atmosphere and the ocean and of the interaction between the two. At the present time it is possible only to state empirically how the climates of the coasts are influenced by the ocean currents. If we wish to comprehend the mechanism of this influence and to predict what changes we may expect as the circulation of the atmosphere is subjected to changes we have to know how the enormous machines represented by the atmosphere and the ocean really work. When dealing with the atmosphere great advances have been made in recent years, largely because it has been possible to secure and to interpret upper-air observations, but when dealing with the oceans progress is slow because of the difficulties of obtaining adequate data. This, however, should not discourage us but should be an added reason for increasing the efforts in the study of the currents of the oceans and particularly of the Pacific Ocean which, at the present time, is less known than any other ocean in the world.

OBITUARY

EDWIN MORRISON

ENDING an active life of seventy-eight years and an actual teaching career of half a century, Professor Edwin Morrison passed away on July 16, 1939, at his home in East Lansing, Mich.

For the last twenty years he had been a member of the department of physics at Michigan State College, retiring from active duty in 1936. He was born on March 5, 1861, at Bloomingdale, Ind., where his boyhood was spent and his education begun. While at-