The True Value of the Earth's Rotation as a Deflective Factor

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Introduction

The deflective effect of the earth's rotation has been known and generally understood since the days of Ferrel. The laws of deflection have been established, and scientists generally believe that all air currents must obey those laws. Unfortunately, however, the acceptance of the earth's rotation as a deflective factor seems to have resulted in a general failure to give due consideration to any other deflective factors which may be present. Consequently, certain atmospheric movements have been attributed to the deflective effect of rotation when, in reality, they may have been due to factors, concerning which little definite information is available to students and average readers. This suggests the urgent need for a further study and a better understanding of all the factors which seem to work together to produce a deflection of air currents.

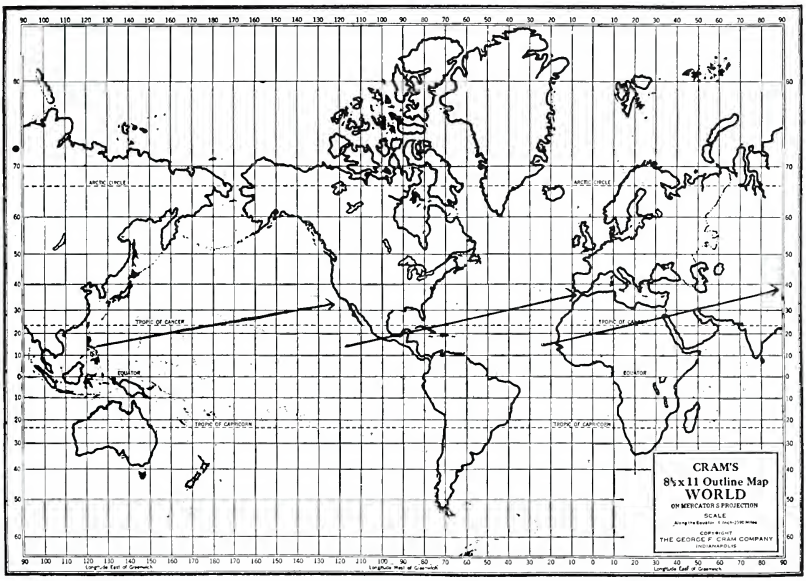

Fig. 1. Approximate positions and direction taken during years of sunspot minima of the three equatorial outflows moving into the northern hemisphere above the level of the surface winds.

Some evidence seems to indicate that the earth's rotation, when it acts alone, does not affect air currents in just the way that is now generally believed. Since the deflection seems to occur only when other

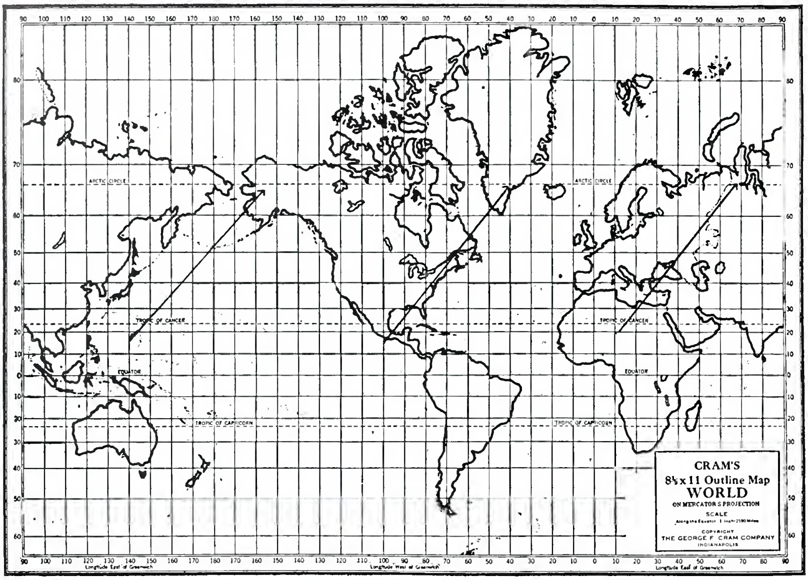

Fig. 2. Approximate positions and the direction taken during years of high sun-spot maxima of the three equatorial outflows moving into the northern hemisphere.

factors are present, it is suggested that the observed deflection may be due, at least partly, to other factors. If further studies by other investigators should indicate that this possibility is really a fact, it would shed new light upon many problems that are now not fully understood.

Variations in the other factors which may affect deflection should cause or permit variations in deflection even when there is no appreciable change in the earth's period of axial rotation. It is the purpose of this paper to call attention to certain atmospheric movements which are said to be due to the deflective effect of rotation, to show why the accepted explanation is not altogether satisfactory, to direct attention to certain factors which seem to aid in causing deflection, to suggest a new interpretation of the observed phenomena, and to show how the new interpretation may lead to a better understanding of some problems that are not yet fully understood.

Some Theoretical Effects of Rotation

When the deflective effect of the earth's rotation became generally understood and the theory became popular, all freely moving bodies were supposed to be affected. All air currents had to be affected. Some believed that the courses of ocean currents were affected. Others asserted that the water in the rivers bore more heavily upon the right bank than upon the left. The rotatory circulations around cyclones and anticyclones were attributed to the effect of the earth's rotation. When the southeast trade winds crossed the equator they were said to be deflected toward the right, and the major movements of the general atmospheric circulation, the easterly winds of low latitudes and the westerly winds of higher latitudes, were considered to be due to this deflective effect upon air currents moving between the equator and the poles.

These beliefs have been modified to some extent. Some scientists now readily admit that only air currents are appreciably affected, and probably not all of these. However, the great majority seem to believe that the effect of the earth's rotation is very real and that all air-flows must obey the laws of deflection.

Objections to the Accepted Theory

Scientists once believed that every air-flow that occurred was, in one way or another, the result of some convectional movement. The convectional theory of cyclonic formation was widely accepted. Briefly, the theory required an updraft of air with a horizontal current flowing at the top to carry away the rising air currents. Air was supposed to flow in from the surrounding areas toward the center of greatest activity, the inflowing currents being deflected toward the right in one hemisphere and toward the left in the other, producing the familiar rotatory movement of the cyclonic circulation.

This theory seemed to be fairly satisfactory for a time, especially in accounting for the formation of extra-tropical cyclones, but it could not give an adequate explanation for the cyclones of tropical origin. Cloudy, unsettled weather with showers, squalls, and irregular winds often prevailed throughout large areas in the hot humid sections of the tropical oceans. Theoretically, the conditions seemed favorable for cyclonic formation; yet the cyclonic circulation did not always develop. Since the earth rotates continually, the deflective effect of rotation should be ever-present. The frequent failure of the cyclonic circulation to develop seemed to indicate that rotation was an effective deflective factor only when all conditions were right. It also indicated the possible presence of some other factor which could assist the earth's rotation in producing the rotatory movement.

The convectional theory of cyclonic formation was followed by the polar frontal theory, which became increasingly popular following the advent of a new method of weather forecasting known as air mass analysis. The new theory seemed to offer a more satisfactory explanation of cyclonic formation, but difficulties were encountered in explaining the formation of tropical cyclones owing to the slight temperature discontinuity which prevailed in the lower latitudes. Some of these difficulties seem to have been removed by Scofield's suggestion (1) that "the temperature discontinuity must be slight and the wind discontinuity great."

The idea that tropical cyclones were of frontal origin was first established by Bjerknes in 1920, and there seems to be a growing tendency among meteorologists to accept this view. The term "frontal origin" should not be confused with the term "polar frontal origin." The polar front approaches from the northwest and is made up of polar continental or polar marine air. The term "frontal" may include the tropical fronts which mark the boundary between the trade winds of the oceanic anticyclones and the doldrums or, if the doldrums are absent, the boundary between the northeast trades and the southeast trades. The north tropical front is most clearly defined when the Bermuda-Azores High is very strongly developed. Tropical cyclones form in certain favorable areas and move along this front during the period when the pressure gradient is unusually strong. The unusual pressure gradient may have great significance. It may be the factor which assists the earth's rotation in producing the rotatory movement.

Deppermann (2), when discussing the typhoons that originate in the China Sea, concludes that the typhoon "arises at the junction of two or more of the main air streams, such as the trades, northers and southwest monsoon." According to this conclusion, the cyclonic circulation cannot be due to deflection of air currents directly to the right by the earth's rotation. It seems to be the natural result of converging air currents that move in nearly opposite directions.

Algue (3), after observing the formation of tropical cyclones in western Pacific waters for more than twenty years, concluded that the cyclone formed "neither in a region of low nor in a region of high pressure but in a neutral zone." A study of the pressure charts for the western Pacific and the adjoining areas of eastern Asia shows that the neutral zone was always bounded by one or more anticyclonic fronts. Air currents from these fronts could have been the direct cause of the rotatory movement.

Deppermann (2) makes the further suggestion that the typhoon may possibly arise from a surge of the trade throwing the front farther south than usual, against the opposition of the southwest monsoon. The results of such a surge or sudden extension of a front will be clearly understood after observing the following simple experiment: A deep basin is filled with water, the hand is completely submerged and given, from the wrist outward, a sudden movement toward the right. This movement represents the surge or sudden extension of a front. If the hand is in the proper position relative to the surface of the water, an eddy will form just beyond the fingers and move obliquely toward the right. This eddy always whirls in an anticlockwise direction. It is practically identical with the familiar rotatory circulation that surrounds the cyclonic storms of the northern hemisphere.

When the water has quieted, the experiment is repeated by moving the hand toward the left. A clockwise eddy forms and moves obliquely toward the left. Its whirling motion is practically identical with the circulation that surrounds the cyclonic storms of the southern hemisphere.

This experiment shows clearly that the cyclonic circulation may be the direct result of frontal action. It may be produced without any assistance from the earth's rotation.

These evidences and others found in the literature do not give satisfactory support to the view that the rotatory motion is the result of a direct deflection to the right in one hemisphere and toward the left in the other. If the earth's rotation is a factor in cyclonic formation at all, it must act indirectly and through the formation of anticyclonic fronts which move toward the right in the northern hemisphere and toward the left in the southern hemisphere.

Algue (3), who was once Director of the Philippine Weather Bureau, wrote at length on the normal winds of the Philippine Archipelago. He concluded that the southwest winds which sometimes prevailed in that area were not deflected southeast trades but winds of a cyclonic character. The proximity of this area to the region where the southwest monsoon is most fully developed seems to support his view. The winds in this region are not only affected by the Asiatic land mass but also by the Asiatic thermal depression. The winds at higher levels may also have some effect upon the surface circulation. Theoretically, a terminal anticyclone should lie over Asia during the summer months. The anticyclonic winds which should blow at higher levels, when aided by the geographical conditions that are found in that area, could conceivably produce cyclonic winds at the surface. When all things are considered, it seems unwise to attribute the observed circulation to the deflective effect of rotation until after due consideration has been given to the other possible factors.

Deflection seems to be a factor of major importance in determining world climates. Climatic changes of great magnitude possibly could not occur if rotation were the only or even the major deflective factor. The major winds of the general circulation now blow in a general east-west direction. Consequently, belts of similar temperatures also tend to develop in a general east-west direction, and the warm air of a given latitude tends to remain near that latitude. Some of the equatorial heat escapes upward and outward through the antitrades but this heat is carried eastward by the westerly winds. Some heat from the same region also escapes through the warm ocean currents, but they also are deflected eastward under the influence of the westerly winds. These conditions tend to produce a world climate that is marked by climatic zones. The formation of climatic zones seems thus to be partly due to the fact that the warm air and ocean currents from lower latitudes are deflected eastward before they reach the polar regions. If these currents were not deflected eastward, a period of relative climatic uniformity might prevail because the higher temperatures from lower latitudes would then be carried directly to higher latitudes. It seems, therefore, that deflection is a very important climatic factor. If the deflection is due mainly to the earth's rotation, world climates must have been marked by climatic zones throughout all the ages of earth history. Some modification of the zonal climate could have occurred as a result of changes in geographical conditions. Further modification could have occurred as a result of variations in the earth's period of axial rotation. Yet the climatic zones must have persisted from age to age. It seems that this would cause the normal climate of the polar regions to be either cool or cold. Warm climates in those regions would occur only under unusual geographical conditions. Yet mild climates have prevailed in polar regions throughout long periods and under geographical conditions that were apparently not especially favorable for the movement of warm ocean currents into such high latitudes.

Scientists generally recognize the difficulty of making an adequate explanation for the occurrence of such mild climates in the higher latitudes. Some feel that the problem is inexplicable. Many do not realize that much of the difficulty lies not in the problem itself but in the theory of circulation that is now generally accepted. More recent studies (4) of the general circulation indicate that it is a very complex phenomenon, but many scientists still cling to the earlier conclusions which held that the warm currents which move from the equator toward the poles must be deflected toward the right in one hemisphere and toward the left in the other as a result of the earth's rotation. Therefore, these warm currents can never reach the polar regions. If the old theory is correct, climatic changes of great magnitude are difficult to explain. The changes must necessarily be generally slight.

Scientists who have studied the matter have accumulated such a mass of evidence which points to climatic changes of great magnitude that such changes can no longer be doubted. The fact that the marked changes have occurred seems to support the view that deflection has not always been as great as it is today. In other words, rotation cannot be the only or even the major factor affecting deflection.

Several investigators have, without questioning the value of the earth's rotation as a deflective factor, attempted to show how the major climatic changes could have occurred. Their explanations include changes in the earth's orbital elements, continental drift, reversal of the deep sea circulation, changes in the oblateness of the earth, emission of solar electrons, changes in geographical conditions or land elevation, and other theories and hypotheses. This wide diversity of opinion among geologists and climatologists may be due to the fact that too much importance has been ascribed to the earth's rotation as a deflective factor.

Further evidence which seems to question the value of rotation as a deflective factor is found in the fact that the most important airflows in the world do not fully obey the established laws of deflection. Deflection is supposed to vary directly with the latitude and inversely with the velocity of the moving current. Evidence hitherto largely ignored suggests that it varies directly with the velocity of the general circulation rather than inversely with the velocity of the moving current.

The general circulation of the atmosphere is usually attributed primarily to the temperature inequality between the equator and the poles, the cold, heavy air from the higher latitudes presumably flowing toward the equator, while the warm lighter air rises in the equatorial region. Scientists once believed that the warm, lighter air rose to the top of the atmosphere and moved away into the higher latitudes as an overflow, but further studies revealed the astonishing fact that the warm air did not rise to the top of the atmosphere. Temperature recordings made by balloons sent aloft in different areas showed that the lowest recorded temperatures at high altitudes were found in the equatorial region, while somewhat higher temperatures were recorded at the same altitudes in the polar regions. This suggested that air currents in the stratosphere were descending in the equatorial region and rising at the poles. The circulation in the stratosphere has been described as a "mirror image" of the circulation that exists in the troposphere. In other words, according to present knowledge, the air at the top of the atmosphere moves from the polar regions toward the equator and then descends until it meets the warm air of the equatorial region which rises from below. The two currents then unite and move outward into the higher latitudes through the antitrades. This outflow from the equatorial region is not uniform throughout the earth's circumference, but, rather, it seems to flow in greater volume through three separate streams into the northern hemisphere. These three streams, with other similar streams that flow into the southern hemisphere, may be called the most important air-flows in the world because they are important factors in the formation of world climates. The air which flows outward through these streams moves obliquely downward toward the surface of the earth and forms belts of increased pressure near latitudes 30 degrees north and south of the equator and then continues onward into the higher latitudes as the westerly winds.

When air flows into a region, it causes an increase in the atmospheric pressure within that region unless this is counterbalanced by an outflow. If the inflow is greater than the outflow it should result in increased pressure until the air eventually breaks through at the weakest point and flows outward. A further flow into the region should cause the pressure to build up again, and the process might continue indefinitely.

The three atmospheric streams flowing into the middle and higher latitudes of the northern hemisphere should, theoretically, produce there a higher atmospheric pressure. During this particular age of earth history one of these equatorial outflows seems to terminate in the North Pacific, forming an area of increased pressure that usually lies between the Hawaiian Islands and the western coast of North America. It may be identified as the North Pacific anticyclone. This area of high pressure seems gradually to increase in intensity until a mass of air breaks away and moves eastward with the prevailing winds. The Pacific anticyclone then decreases in intensity, but it gradually builds up again until another mass breaks away and moves eastward as a migratory anticyclone. This process continues indefinitely.

The Pacific anticyclone does not always remain in a fixed position. Its outflowing currents which take the form of migratory anticyclones sometimes move northeastward or northward instead of eastward. The anticyclone does not always extend over its normal oceanic area but may reach eastward, forming the Great Basin anticyclone. When it extends so far eastward, it is usually associated with a greater number of deep lows that move rapidly eastward along the northern border of the United States. When the anticyclone does not extend eastward over the land area, it seems to be associated with a lesser number of lows which are usually of lesser intensity and which do not move so rapidly nor so directly eastward. When the anticyclone feeds northward toward Alaska, it seems to be associated with lows which move rather slowly more nearly from north to south than eastward. These associations seem to indicate that the position of the anticyclone and the direction taken by its outflowing current must be related in some way to the strength or the velocity of the inflowing stream. If the inflowing stream is stronger than normal or if it is flowing at a greater than normal velocity, it seems to terminate farther eastward, and the associated conditions suggest a more active general circulation. If the atmospheric stream is weaker than normal or if it is flowing at a subnormal velocity, it seems to feed northward toward Alaska, and the associated conditions suggest a more sluggish general circulation.

These observations seem to indicate that a strong or active equatorial outflow is deflected eastward more rapidly than a slower outflow. In other words, the deflection of the equatorial outflow varies directly with the velocity of the general circulation.

Deflection is supposed to vary inversely with the velocity of the moving current; that is, the greater the velocity, the less is the deflection from a straight course, and the less the velocity, the greater is the deflection. These theoretical movements are in direct opposition to the movements that have been actually observed. This discrepancy indicates that the entire subject should be given further consideration and suggests that the earth's rotation may not be the only or even the major factor which causes the deflection.

Factors Which Cause Deflection

In none of the cases which have been considered can the observed deflection be attributed positively to the earth's rotation. The rotatory motion of cyclonic storms seems to be the result of frontal action rather than a direct effect of rotation. The deflection of the southeast trades, wherever it occurs, seems to be due, at least partly, to the proximity of anticyclonic winds, large land masses, or thermal depressions, or to some interference in the circulation, due to mountain ranges, islands, etc. The variations in deflection that seem to correspond with variations in the velocity of the general circulation are clearly not due to variations in the earth's period of rotation but to other factors. Any factor which may affect the velocity of the easterly winds of the lower latitudes or of the westerly winds of the higher latitudes may also cause variations in the deflection of these outflows. In other words, a cyclone of great intensity could increase wind velocity over a wide area and thus cause temporary variations in deflection.

The deflective factors which have been considered may be regarded as of minor importance as compared with another, namely, solar activity. The writer has observed that the oceanic anticyclones seem to feed more directly eastward during periods of sunspot minima and more directly into the higher latitudes during years of sunspot maxima. The observations on this point have not covered the full sunspot cycle, but a search of the literature reveals some recent and very interesting investigations made by Clayton.

Clayton (5) investigated the relation between the eleven-year sunspot cycle and changes in atmospheric pressure, noting the departures from the annual means of pressures for about 200 stations scattered over the earth, as given in World Weather Records. When these data were plotted on maps of the world, they showed a tendency toward excess pressures in middle latitudes over the oceans and somewhat lower pressures over tropical lands and oceans at the time of sunspot maximum.

They also showed that the areas of excess pressure over the oceans were displaced northward with each increase in intensity in the sunspot maxima. When there was distinct evidence of excess pressure in middle latitudes over the Atlantic Ocean, there was a deficiency over a large part of the land areas.

These findings suggest an east-west elongation of the Atlantic anticyclone at the time of sunspot minimum. This east-west elongation seemed gradually to develop into a north-south elongation with each increase in intensity in the sunspot maxima. The north-south development over the ocean apparently was associated with a withdrawal of pressure from adjoining land areas.

Clayton's maps showed that the baroplion or area of excess pressure lay in high latitudes during years of high sunspot activity. In 1916-17 the baroplion lay above latitude 65°. It moved to lower latitudes in step with decreasing solar activity, and in 1923 it lay at about 30° latitude. The same progressive movement occurred throughout the eleven-year cycle. The maximum of pressure at Jacobshavn (Greenland) and at Haparanda (North Sweden) coincided with the sunspot maximum, but the pressure maximum occurred successively later at stations to the southwest until at Madeira and Helwan the maximum of pressure occurred at sunspot minimum. Also at Tanana, in Alaska, the maximum of pressure occurred at the time of sunspot maximum and successively later southward to San Diego.

Clayton's findings indicate that there is a real relation between solar activity and the areas of excess pressure that lie in middle and higher latitudes. This writer believes that these areas of excess pressure form in the region that immediately surrounds the ends of the equatorial outflows. These findings, when taken in connection with the writer's observations and interpretation, are illustrated in Figures 1 and 2. Figure 1 shows the approximate positions at the time of sunspot minimum of the three equatorial outflows moving into the northern hemisphere. Figure 2 shows the approximate positions of the same outflows at the time of sunspot maximum. These illustrations seem to show that the equatorial outflows suffer a greater deflection eastward during the period of sunspot minimum and a lesser deflection eastward during the period of sunspot maximum. Here is a variation in deflection which seems to be related to variations in solar activity. The deflection increases as solar activity diminishes and decreases as solar activity increases. In other words, the deflection of the equatorial outflows varies inversely with variations in solar activity.

This evidence suggests that solar activity must be considered as one of the factors which cause the deflection of air currents. The observed variations in solar activity have been relatively slight yet the variations in the deflection of the equatorial outflows have been relatively great. This indicates that solar activity may be a major deflective factor and may rank above the earth's rotation in importance. It is the opinion of this writer that the evidence does not give satisfactory support to the view that air currents are deflected to the right in the northern hemisphere and to the left in the southern hemisphere as a result of the earth's rotation. Much of the deflection that has formerly been attributed to rotation seems to be due directly to the effects of solar radiation.

A New Interpretation

The exact manner in which solar radiation acts to produce a deflection of air currents is not clear. Only the results are apparent. Variations in solar activity cause corresponding variations in the total output of solar radiation. Increasing solar activity seems to reduce the radiation of those frequencies which affect the velocity of the general circulation, and, consequently, the equatorial outflows move more directly toward the poles. Decreasing solar activity seems to permit a greater radiation of the frequencies which affect the velocity of the general circulation, and the equatorial outflows then develop more rapidly eastward. Air currents may be deflected by several factors, but solar radiation seems to be the primary one. Any factor which interferes with or weakens the effective frequencies of solar radiation before they reach the earth's atmosphere, such as increasing sunspot activity or increasing distance between the earth and the sun, may cause these deflections.

The evidence does not indicate that, when acting alone, either the earth's rotation or solar radiation causes the deflection. It seems that solar radiation and the earth's rotation work together to produce a deflection toward the right in one hemisphere and toward the left in the other, this tending to produce a longitudinal circulation with east-west movements predominating. Factors which weaken solar radiation decrease the deflection, and this tends to produce a latitudinal circulation with north-south movements predominating. These variations in deflection may result in weather and climatic changes of the most astonishing character.

Importance of This Interpretation

This interpretation should lead to a better understanding of the major movements of the general circulation. It suggests that the general circulation may be divided into individual units, all of which are formed according to the same general pattern. Each unit seems to be formed around an atmospheric stream that flows out of the equatorial region and terminates in an anticyclone in middle or higher latitudes. Three such streams move from the equatorial region outward into the higher latitudes of each hemisphere. In the northern hemisphere one stream leaves the equatorial region in the lower latitudes of the eastern Atlantic and terminates in the Asiatic anticyclone. A second stream moves outward from the equatorial region in the lower latitudes of the western Pacific and terminates in the Pacific anticyclone. A third stream moves outward from the lower latitudes of the eastern Pacific and terminates in the Atlantic anticyclone.

The terminal anticyclone of each stream makes contact with the equatorial air in the outflow adjoining it on the east. The line of contact between the cold front of the terminal anticyclone and the warm front of the next outflow becomes a region of cyclogenesis. The cyclones thus formed are carried along in the air-flow of the unit. The air which leaves the equatorial region and flows into the terminal anticyclone causes that air mass to increase in intensity until a mass of air breaks away from the terminal area and moves into the next unit as a migratory anticyclone. This procedure continues indefinitely. Thus the equatorial outflow with its terminal anticyclone and the attendant migratory pressure formations constitute an individual unit.

The air-flow over the North Pacific ocean furnishes an excellent example of such a unit. This seems to begin in the lower latitudes of the western Pacific and terminates in an anticyclone in the northeast Pacific. The line of contact between the Asiatic anticyclone and the warm air of the Pacific outflow becomes a region of cyclogenesis. The cyclones thus formed are carried along in the air-flow of the Pacific unit, and air masses that break away from the Asiatic terminal area move into the Pacific unit as migratory anticyclones. All migratory pressure formations are carried along in the Pacific outflow directly toward North America. They usually enter the continent from the northwest and continue their movement in approximately a straight line until they drift into the equatorial outflow of the next unit. The migratory formations then move in the direction followed by the American outflow which carries them toward northwestern Europe.

The line of contact between the cold front of the Pacific terminal anticyclone and the warm air of the next unit becomes another region of cyclogenesis. The cyclones which are thus formed usually move from the southwest toward the northeast, being carried along in the air-flow of the unit. This outflow terminates over the eastern Atlantic.

In years of sunspot minima the three terminal anticyclones form between latitudes 30° N. and 40° N. They become elongated in an east-west direction and tend to form a ridge of increased pressure that completely encircles the earth. The migratory cyclones roll rapidly along this ridge on its northern side. This is the typical longitudinal circulation. Increasing solar activity is accompanied by a lesser deflection of the equatorial outflows. Consequently, each terminal anticyclone forms in higher latitudes, and each movement into the higher latitudes is accompanied by lower temperatures in the terminal area. The west-to-east flow into the terminal area changes to a southwest-to-northeast flow, while the west to east flow out of the terminal area becomes a northwest-to-southeast movement. This shows a tendency for the longitudinal circulation to develop into a latitudinal circulation with north-south movements predominating.

Each successive increase in solar activity seems to cause a further decrease in the deflection of the equatorial outflows with a further movement of the terminal anticyclones toward the north and a further development of the latitudinal or north-south circulation. The terminal anticyclones, with their areas of increased pressure, eventually move into the areas that are now occupied by the oceanic areas of low atmospheric pressure. This causes a reversal of pressure conditions, the migratory and permanent cyclones being crowded southward, while high pressure fills the normal low pressure lane. Cyclones can then freely draw in warm, moisture-laden air from low latitudes and carry it directly into the cold front of the terminal anticyclones in high latitudes. This results in unusually stormy conditions with low temperatures and heavy snowfall.

According to the preliminary investigations made by the writer, a continued movement of the terminal anticyclones into the higher latitudes should lead to the formation of cold fronts in low latitudes, possibly accompanied by glaciation in certain areas if geographical conditions were favorable. The complete development of a latitudinal circulation should bring on a period of climatic uniformity.

Conclusions

The importance of the earth's rotation as a deflective factor has apparently been over-emphasized. Air currents may be deflected by several factors. Solar radiation and the earth's rotation, by working together, seem to cause a deflection of the major atmospheric streams that flow from the equatorial region into the higher latitudes. Variations in the effective frequencies of solar radiation permit variations in the deflection of the equatorial outflows. These variations in deflection may result in weather and climatic changes of significance.

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