NO. 1.

AN ESSAY ON THE WINDS AND THE CURRENTS OF THE OCEAN,

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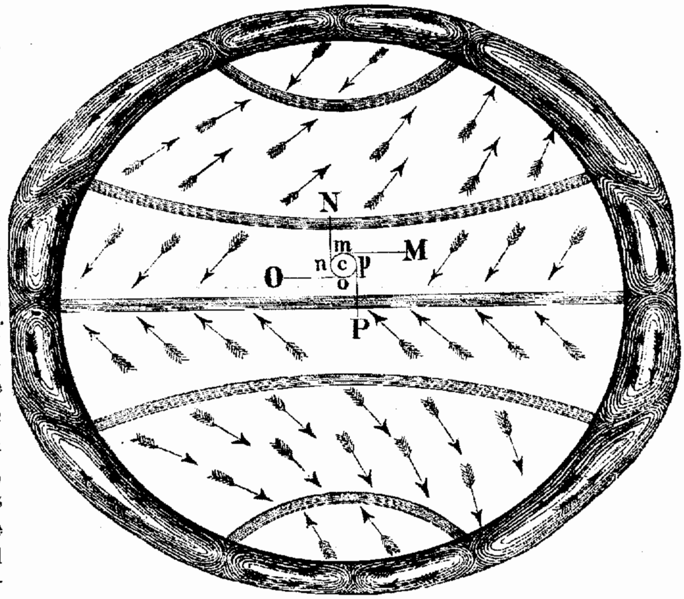
Introduction.—The earth is surrounded on all sides by an exceedingly rare and elastic body, called the atmosphere, extending with a diminishing density to an unknown distance into space, but pressing upon the earth with a force equal to that of a homogeneous atmosphere five and a half miles high. It is also partially surrounded by the ocean, which is of a very variable depth, and known to be, in many places, more than four miles. If the specific gravity of the atmosphere and of the ocean were everywhere the same, all the forces of gravity and of pressure which act upon any part of them, would be in exact equilibrium, and they would forever remain at rest. But as some parts of the earth are much warmer than others, and air and water expand and become rare as their temperature is increased, their specific gravities are not the same in all parts of the earth, and hence the equilibrium is destroyed, and a system of winds and currents is produced. It is proposed in this essay to inquire into the effects which are produced, both in the atmosphere and in the ocean, by this disturbance of equilibrium, and by means of a new force which has never been taken into account in any theory of winds and currents, to endeavor to account for certain phenomena in their motions, which have always been a puzzle to meteorology and hydrology. As there are some uncertain data connected with the subject, such as the amount of the disturbing force, the effects of continents, friction, etc., which render a complete solution of the problem impracticable, we shall aim at giving a popular explanation of observed phenomena rather than a complete solution of the problem; yet we shall give the result of some calculations, based upon known data, or at least upon very reasonable hypothesis, which will show that the causes which we have given are adequate to the effects which are attributed to them. We shall divide the subject into two parts, and treat, first, of the winds, and secondly, of the currents of the ocean.

The motions of the atmosphere.—From about the parallels of 28° on each side of the equator the winds on the ocean, where they are not influenced by any local causes, blow steadily towards the equator, having also a western motion, producing what are called the north-east and south-east trades. At the meeting of these currents near the equator there is a calm called the equatorial calm-belt, or doldrums, where the air rises up and flows in the upper regions towards the poles, until it arrives near the parallels of 28°, where it is met by an upper current flowing from the poles. The meeting of these upper currents produces an accumulation of atmosphere from under which the air flows out in both directions on account of the increased pressure; a strong and steady current, as we have seen, towards the equator, and another not so strong and somewhat variable over the middle latitudes, towards the poles, having at the same time an eastern motion, and producing what are called the passage-winds. As this current flows at the surface towards the poles, it gradually rises up and returns in the upper regions towards the equator, meeting the upper current from the equator near the tropics as has been stated.

Such are the general motions of the atmosphere as laid down by Lieutenant Maury, and as represented in his diagram of the winds.* But there are numerous observations which have been made in very high latitudes both in the north and the south, which show that the currents flowing over the middle latitude *towards* the poles, do not extend to the poles, but that the atmosphere above a certain latitude, has a tendency to flow *from* the poles, producing another meeting of the air at the surface near the polar circles similar to the one at the equator, except that the currents are comparatively feeble and consequently the belt of meeting not so well defined, and that here also the air rises

* Physical Geography of the Sea, page 70.

up and flows each way in the upper regions towards the equator and the poles. "Sir J. Ross has shown that there is a large prevalence of north winds over the southern ones in the middle of North America as low down as latitude 70° and longitude 91° 58′ west, not merely in winter, but in every month in the year. The northern winds were not only more than double as frequent as the southern, but more than double as strong; and he also found southern winds largely to predominate in latitude 77° south."* If then there were no continents, or other local causes of disturbance, the motions of the atmosphere would be as represented in the following diagram, in which the direction of the wind is represented by the arrows, and the external part of which represents the motion of the air in the plane of the meridian. This system, however, is found to prevail on the ocean only, and is very much interfered with in other parts on account of local causes of disturbance, especially in the northern hemisphere, where the uniformity of the earth's surface is most interrupted by land.



The pressure of the atmosphere.—The atmosphere everywhere presses upon the surface of the earth with a force equal to the pressure of a column of mercury of nearly thirty inches in height. This pressure, however, is not the same in all parts of the earth, but varies in different latitudes as well as from local causes. The barometer stands highest about the border of the trade-winds, and is about 0.25 of an inch lower at the equator, and seems to stand the lowest about the polar circle, where a very remarkable depression has been observed in many places. "It is a singular fact," says Mrs. Somerville, (page 268) "discovered by our navigators, that the mean height of the barometer is an inch lower throughout the Antarctic ocean and at Cape Horn, than it is at the Cape of Good Hope, or at Valparaiso." A similar depression has likewise been observed near the sea of Okhotsk in eastern Siberia. It also appears from the tables of the South Sea Exploring Expedition, by Captain Wilkes, that the barometer stands lowest near the polar circle, where it stands at a mean of about twenty-nine inches, and higher both north and south of it. After examining various authorities and all the circumstances connected with this subject, Professor Espy comes to the conclusion, that "there are three belts where the barometer stands below the mean, with almost constant rain and snow—one near the equator, one near the arctic circle, and one near the antarctic circle, and that these belts change their latitudes some degrees with the seasons, following the sun; and also that there are, *certainly* two belts in the outer borders of the trade-winds, where the barometer stands above the mean, and *almost certainly* two regions more—one around the north pole and the other around the south pole—where the barometer stands above the mean." It also appears from a great many observations made at different places on the Atlantic, at the level of the ocean, that the barometer stands more than half an inch lower at the arctic circle, than it does at the outer limit of the trade-winds, and that there is also a considerable depression at the equator.†

The forces concerned in producing the motions of the atmosphere.—There are four principal forces which must be taken into account in a correct theory of the winds. The first arises from a greater specific gravity of the atmosphere in some places than others, on account of a difference of temperature and of the dew-point; for, when it becomes heated or charged with vapor in any place to a greater degree than at others, it becomes specifically lighter, and hence, the equilibrium is destroyed. There is a flowing together, then, of the heavier air on all sides, which displaces the lighter air, and causes it to rise up and flow out in a contrary direction. This is the *primum mobile* of the winds, and all the other forces concerned are dependent upon it for their efficiency. A second force arises from the

* Professor Espy's Third Report on Meteorology, § 101. † See Kaemtz' Meteorology, by C. Walker, page 277.

tendency which the atmosphere has, when, from any cause, it has risen above the general level, to flow to places of a lower level. These two preceding forces generally produce counter-currents. Again, when, from any cause, a particle of air has been put in motion toward the north or south, the combination of this motion with the rotatory motion of the earth produces a third force, which causes a deflection of the motion to the east when the motion is toward the north, and a deflection toward the west when it is toward the south. This is the same as one of the forces contained in La Place's general equations of the tides, the analytical expression of which is $2\,n\,u\,r$ sin. l *cos.* l; l being the latitude; n, the motion of the earth at the equator; u, the velocity of the particle north or south; and r, the radius of the earth. The fourth and last force arises from the combination of a relative east or west motion of the atmosphere with the rotatory motion of the earth. In consequence of the atmosphere's revolving on a common axis with that of the earth, each particle is impressed with a centrifugal force, which, being resolved into a vertical and a horizontal force, the latter causes it to assume a spheroidal form conforming to the figure of the earth. But, if the rotatory motion of any part of the atmosphere is greater than that of the surface of the earth, or, in other words, if any part of the atmosphere has a relative eastern motion with regard to the earth's surface, this force is increased, and if it has a relative western motion, it is diminished, and this difference gives rise to a disturbing force which prevents the atmosphere being in a state of equilibrium, with a figure conforming to that of the earth's surface, but causes an accumulation of the atmosphere at certain latitudes and a depression at others, and the consequent difference in the pressure of the atmosphere at these latitudes very materially influence its motions. This force is also expressed by one of the terms of La Place's equations, the analytical expression of which is $2\,n\,u\,r$ sin. l; v being the relative eastern or western velocity of the atmosphere.

Hadley's theory.—This theory, which is the commonly received theory of the trade-winds, and with which the reader is no doubt familiar, is based upon the first three forces only given above, no account being taken of the fourth. But as it may be seen from the analytical expressions of the last two forces given above, that the latter is greater than the former, and the east and west motion of the atmosphere depends upon the former, we have reason to suppose that the latter also may have a very considerable effect, and that it should be taken into account in a correct theory of the winds. Accordingly we see that although Hadley's theory furnishes an explanation of the trade-winds, yet it does not account for many other remarkable phenomena in the motions of the atmosphere, but even requires motions to satisfy it entirely at variance with them. According to this theory, there should be a current on the surface of the earth from the pole to the equator in a kind of loxodromic spiral, and a similar counter-current in the upper regions from the equator towards the poles. The barometer also should stand highest at the poles where the air is coldest and most dense, and gradually fall as it is brought nearer the equator. But both of these, as we have shown, are contrary to observation. The position also of the exterior limits of the trade-winds near the parallels of 28°, the flowing of the atmosphere in the upper regions from both sides towards these parallels, and a low barometer near the polar circles, cannot be explained by this theory, and have not been satisfactorily explained by meteorologists. It is true Professor Espy says the highness of the barometer near the parallels of 28° is owing to the flowing over of the atmosphere which rises up at the equator; but this overflow of atmosphere could have no tendency to accumulate at these parallels, since it evidently would flow on gradually towards the poles to supply the draught caused by the flow towards the equator, as this theory requires. He also assigns as a cause of the low barometer about Cape Horn and the antarctic circle, the abundant rains which prevail there and the consequent disengagement of caloric, which rarefies the atmosphere there. But, if the belt of calms and rains near the equator is caused by the barometer's standing lower there than at the outer limit of the trade-winds, which causes a flow of atmosphere there at the surface, and, if rains generally in any region, according to Professor Espy's own theory of clouds and rains, is caused by a low barometer there, and a consequent flowing in from all sides and a rising up of the atmosphere, then the lowness of the barometer in these regions must be the cause of the rains, and not the rains the cause of the lowness of the barometer, as will appear for other reasons.

We shall now undertake to show that all these phenomena, and others connected with storms, which have never been accounted for by any theory, may be satisfactorily accounted for by taking into account the fourth force given above.

Why the outer limits of the trade-winds are near the parallels of 28°.—If from any cause the atmosphere receives a motion either towards or from the poles, the action of the third force above, causes a deflection of it towards the east, as it moves towards the poles, and towards the west as it moves towards the equator; and as the prime moving cause of the principal currents of the atmosphere has a tendency to cause it to flow towards and from the poles, the general result is, that towards the poles the atmosphere has a motion towards the east, but near the equator towards the west. But from the principle of the preservation of areas, the sum of the products of all the particles of the atmosphere, multiplied into their velocities and their distances from the axis of revolution, cannot be changed by the action of a central force, or by the mutual action of the particles upon each other; hence the sum of the products of each particle into its distance from the axis, and into its relative eastern velocity, must be equal to the sum of similar products, taken with regard to the particles having a relative western motion. But, as the portion of the atmosphere having a relative eastern motion, is nearer to the axis than that which has a relative western motion, and as the part of the atmosphere between the parallels of 30°, comprises one half of the whole, the part having a western motion, inasmuch as it is further from the axis, must be somewhat less than the part comprised between these parallels, in order to make the products equal, unless the relative velocity of the part having an easterly motion is very much greater. Hence, the dividing lines between the portions of the atmosphere having a relative east and west motion, must be within these parallels; and, as the outer limits of the trade-winds depend upon those lines, they must also fall within these parallels; and they are accordingly found to be about the parallels of 28°.

The cause of high barometer about the parallels of 28°, and the low barometer at the polar circles.— The greater pressure of the atmosphere at the parallels of 28° than at the equator and the polar circles can only be caused by an accumulation of atmosphere there. This accumulation results, necessarily, from the action of the new force which we have introduced into the theory of the winds. For, as we have seen, all the atmosphere between the parallels of 28° and the poles has, and, according to theory, must have, a general eastern motion; and this gives such a value to the analytical expression of the fourth force, enumerated above, as to cause the atmosphere to recede from the poles toward the equator. But the western motion of the atmosphere between the parallels of 28° gives that expression a negative value there; and, hence, this force causes the atmosphere to recede from the equator, also. This force, then, has a tendency to cause the atmosphere in the upper regions to recede both from the poles and the equator, and to accumulate about the parallels of 28°, and, as it may seem by merely inspecting the expression of this force given above, that for the same value of v, or motion of the atmosphere east or west, this force is much greater toward the poles than it is near the equator, it causes a considerable depression of the atmosphere at the poles, and only a slight one at the equator, as represented in the diagram. The amount of this elevation and depression is not indicated entirely by the barometer, for the height of the barometer depends upon both the height of the atmosphere and its density. Therefore, as the atmosphere is much denser at the polar circles than at the parallels of 28°, on account of its being much colder, the accumulation of atmosphere at these parallels and its depression towards the poles, must be considerable to cause the barometer to stand higher at these parallels than at the polar circles.

We shall now give the results of some calculations, based upon a reasonable hypothesis, which show that this new force introduced is entirely adequate to produce an accumulation of atmosphere at the parallels of 28°, and a depression of it at the poles to such an amount, that the difference in the height of the barometer at the parallels of 28° and the polar circles, may correspond with observations. As friction is a very important element in calculations of the motions of the atmosphere, and its effect cannot be determined, it would be impossible to calculate the motions of the atmosphere from the forces which act upon it, if they were even accurately known. We will therefore assume certain motions of the atmosphere, which are known not to vary much from observation, upon which we will base our calculations. If we assume that the east and west motions of the atmosphere may be represented by the expression 2 sin. $\frac{3}{2}\,p$ cos. $\frac{3}{2}\,p\,v$, p being the polar distance of the place, it would make these motions vanish at the poles and at the parallels of 30°, and we have reason to think, would pretty well represent the motions of the atmosphere east and west at all latitudes except near the equator, where it would make it a little too great. Upon this assumption it may be shown by calculations, the results of which only can be given here, that if v, or the maximum east or west motions of the atmosphere, were only ten miles per hour, it would cause a heaping up of the atmosphere near the parallels of 28° which would make the barometer, if the atmosphere were everywhere of the same density, stand two inches higher here than at the poles. The same hypothesis would also make the depression at the equator only one-ninth that at the poles. If we now suppose that the greater specific gravity alone of the atmosphere at the poles, is sufficient to cause the barometer to stand one inch higher there than at the equator, which would only require a difference of temperature of about 16°, it would still leave a difference in the height of the barometer between the poles and the equator about equal to the observed difference in the southern hemisphere. It would also add a little to the depression of the barometer at the equator, which would make it a little more than one-ninth of that at the poles, and consequently make it correspond with observation. We think therefore it is evident that the observed difference in the height of the barometer in different latitudes, is owing to the joint effect of a gradual increase of specific gravity from the equator to the poles, and of a heaping up of the atmosphere near the parallels of 28°, caused by the action or this new force which we have taken into account.

Explanation of the passage-winds and calm-belts at the limits of the trade-winds.—As the pressure of the atmosphere, on account of its accumulation there, is greatest about the parallels of 28°, this pressure has a tendency to cause it to rush out from beneath both, towards the poles and the equator. If the motions of the atmosphere were as great at the surface of the earth as in the upper regions, the force which causes a heaping up of the atmosphere about the parallels of 28°, would be as great below as in the upper regions, and would prevent the flowing out of the air below towards the poles. But, on account of friction, the eastern motion of the atmosphere cannot be so great at the surface of the earth as above, and consequently the accumulation of atmosphere mentioned above, is caused principally by the upper currents, and the pressure which causes it to flow out below towards the poles, where the barometer, as we have seen, stands much lower, is greater than the force below which causes the accumulation of atmosphere. The lateral pressure then of the atmosphere, and its horizontal motions north and south, depend upon three forces; first, the greater density of atmosphere towards the poles, which has a tendency to cause it to flow at the surface of the earth, from the poles towards the equator; and, secondly, the heaping up of the atmosphere at the outer limits of the trade-winds, which causes it to rush out below, both towards the equator and the poles; thirdly, the action of the force depending upon the east or west motion of the atmosphere, which we have seen, must be greater above than at the surface of the earth. Between the parallels of 28° and the equator, the first two forces combine against the latter, which is small near the equator, and produce a strong and steady current at the suface of the earth towards the equator, which, being combined with the rotatory motion of the earth, gives rise to the trade-winds. Beyond these parallels, the first and third forces are opposed to the second, but it may be seen from the analytical expression of this second force, obtained from our preceding assumption, and which cannot be given here, that this force is very great in the middle latitudes, and consequently it prevails over the two, causing a current towards the poles, which combined with the rotatory motion of the earth, produces the southwest winds in the northern hemisphere, and northwest winds in the southern hemisphere, called passage-winds. This force has its maximum about the parallels of 48°, and above these it decreases rapidly, so that at the polar circles the other two forces begin to prevail over it, and cause a current from the poles. The forces then acting upon the atmosphere at the surface of the earth, causes it to flow in opposite directions, from the parallels of 28° and the poles, and to flow together near the equator and the polar circles. Hence, there is a rising up of the atmosphere at the latter places, and a flowing thence in the upper regions to the former places, where it descends, and thus a system of current is produced as represented by the arrows in the external part of the diagram, which represents a meridional vertical section of the atmosphere. It was shown that about the parallels of 28°, the atmosphere can have no motion east or west, and it has now been shown that these are the parallels also of greatest pressure, whence the currents flow both towards the equator and the poles, consequently there must necessarily be here calm-belts, such as are well known from observation to exist.

We think now, it is manifest, that the introduction of our new force into the theory of the winds, exactly accounts for all the principal motions of the atmosphere, and clears up the difficulties which have heretofore puzzled meteorologists.

Maury's theory of the crossing of the winds.—In order to account for the motions of the winds and other phenomena, Lieutenant Maury advances the theory that there is a crossing of the winds or currents at the calm-belts of the equator and the parallels of 28°; that the currents flowing at the surface towards the equator, cross there, each one becoming the upper current in the other hemisphere after it crosses the calm-belt at the equator, and then flowing towards the poles until it meets the upper current flowing toward the equator about the parallel of 28°, where there is supposed to be another crossing, each current then becoming again the surface current, and flowing in the same direction as before.* He also makes, by his arrangement, the rains in each temperate zone depend upon the vapor received by the winds in their passage to the equator as a trade-wind in the opposite hemisphere. We think there is no necessity for resorting to such an argument to account for the phenomena of the winds, but that they are all satisfactorily accounted for, as above, by tracing out the effects of well-known forces without resorting to the mysterious agents of magnetism and electricity. Besides, there is no known principle by which two currents can interpenetrate and cross each other without mingling together, and, especially, is there none by which a current saturated with vapor can pass through a dry current and each one afterwards retain its distinctive character of a moist or dry current, which this theory requires.

The fact that Ehrenberg has discovered South American infusoria in the blood-rains and "sea-dust" of the Cape Verde Islands and other places, does not prove the crossing of the winds; for, according to the explanation of the winds given above, there are two currents flowing into each calm-belt, and also two flowing out in opposite directions, as it were from a common reservoir, and, consequently, whatever is carried into these belts from either side flows out again in each direction; and so infusoria in one hemisphere can easily pass to the other without a distinct crossing of the currents. And if even the moist currents of the torrid zone could pass through the dry ones to the temperate zones, they could not produce rain there; for Professor Espy has conclusively shown that no descending current, however saturated with moisture, can ever produce rain.†

Explanation of the winds at the Peak of Teneriffe.—We have stated that the greatest atmospheric pressure is about the parallels of 28°, but these can not be accurately the parallels of the greatest accumulation, for this pressure depends both upon the height of the atmosphere and its density, and, as the density increases gradually with the latitude, there must be an increase of pressure beyond the parallel of greatest accumulation, until the decrease of pressure from the one cause equals the increase from the other. But, as the calm-belts in the upper regions must be where the currents meet, and consequently where there is the greatest accumulation of atmosphere, it follows that the calm-belts are not exactly at the same parallels at the surface of the earth as in the upper regions, but that they incline above toward the equator, as represented in the diagram. And this explains the peculiarity in the winds at the Peak of Teneriffe. This peak stands near the outer limits of the trade-winds, and, as this limit moves north and south with the seasons, the northeast and southwest winds are found to prevail at the base alternately. But at the top of the peak the southwest winds always prevail, because, when the calm-belt is furthest north, it still leaves the top of the peak north of it, where the southwest winds prevail, while the northwest trades are blowing below. When this belt occupies its most southern position, it leaves both the top and bottom of the peak north of it, and, consequently, the southwest wind blows both at the top and the bottom. In the fall, as the calm-belt moves south, more of the peak gradually becomes north of the calm-belt, and hence the southwest winds, which always prevail at the top, should gradually descend lower on the peak until they reach the base, which is exactly in accordance with observation.

The effects of continents.—If the surface of the earth were all covered by the sea, uninterrupted by continents, the trade-winds and passage-winds, and also the calm-belts, would extend, without any interruption, entirely around the earth. But continents, and especially high mountain ranges, seem to have a very material effect in changing this regular system of winds. Thus the high table-lands and mountain ranges in Mexico and the western part of the United States, seem to turn the westward current of the trade-winds on the Caribbean sea and the Gulf of Mexico northward over the parallel of the calm-belt into the United States, where it arrives at the latitudes where the atmosphere has a general tendency to flow eastward, and thus a kind of aerial gulf-stream is produced. This is evident not only from observations on the general directions of the winds in the Gulf of Mexico and the United States, but also from the observed routes of storms, which must be governed very much by the general movements of the part of the atmosphere in which they occur. Instead of the regular trade-winds from the northeast in the Caribbean sea, the prevailing course of the lower current, is from a point south of east instead of north of east.‡ It is also found from observations at Barbadoes

*See "Physical Geography of the Sea," § 106. †Third Report on Meteorology, §§ 68, 69. ‡See W. C. Redfield, Esq., on three several hurricanes, etc., in Silliman's Journal, second series, vol. 1., page 13.

that, while the eastern winds are most prevalent, the southeast winds greatly predominate over the northeast ones. Of a great many hurricanes, also, which had their origin in the Atlantic, east of the Caribbean sea, and whose routes have been determined by Mr. Redfield, nearly all moved in a direction north of west, until they arrived at the longitude of Florida or the Gulf of Mexico, where they curved around towards the north, and after passing the parallel of the calm-belt, towards the northeast, in the direction of Newfoundland and the northern part of the Atlantic. And this is exactly the route we would suppose the westward currents of the lower part of the atmosphere, interrupted by the high mountain ranges of Mexico, would take. But on the west coast of North America, the eastward current of the northern part of the Pacific, impinging against the range of the Rocky mountains, is turned down towards the equator, and hence the prevailing direction of the wind on the Pacific, west of Mexico, is from the northwest. The eastern coast of Africa also seems to have a similar effect upon the westward current of air in the Indian ocean; for the hurricanes which originate in that ocean, on approaching that coast, are turned southward and finally towards the southeast into the southern ocean. The typhoons, also, of the China sea seem to be influenced in a similar manner by the eastern part of Asia. These changes of the general directions of the wind which prevail on the open ocean must be caused by the continents.

Hurricanes and storms.—Hurricanes are generally supposed to be produced by the meeting of adverse currents, which produce gyratory motions of the atmosphere at the place of meeting. That they may receive their origin and first impulse in this way, we think is very probable; but that violent hurricanes, extending over a circular area of nearly one thousand miles in diameter, and continuing for ten days, and proceeding with increasing violence from the torrid zone to high northern latitudes, depends upon any primitive impulse alone, we think is very improbable. For if even any part of the atmosphere should receive such an impulse as to produce a most violent hurricane, friction would soon destroy all motion and bring the atmosphere to rest. Besides, no gradually accelerated motion can depend upon a primitive impulse alone, even where there is no friction. Hurricanes then, and all ordinary storms, must begin and gradually increase in violence by the action of some constantly acting force, and when this force subsides, friction brings the atmosphere to a state of rest. This force may be furnished by the condensation of vapor ascending in the upward current in the middle of the hurricane, in accordance with Professor Espy's theory of storms and rains. According to this theory, all storms are produced by an ascending current of warmer atmosphere saturated with moisture, and this current is kept in motion by the continual rarefaction of the atmosphere above by means of the caloric given out of the vapor which is condensed as it ascends to colder regions above. Therefore, as long as this ascending current can be supplied with air saturated with vapor this continual rarefaction must take place, and also the ascent of the air in the middle of the hurricane and the consequent rush of air from all sides to supply its place. If, then, all the lower stratum of atmosphere over a large district were saturated with vapor, without some disturbing cause, it might remain undisturbed; but if from any cause an ascending current is produced, either by local rarefaction of air by means of heat, or by the meeting of two adverse currents, which produces a gyratory motion and consequent rarefaction in the middle on account of the pressures being taken away by the centrifugal force, as soon as the air below, saturated with vapor, ascends to the colder regions above, the vapor is condensed and the caloric given out continues to rarefy it so long as the ascending column is supplied with moist air, and consequently the surrounding colder air presses in below from all sides, and thus a hurricane of more or less violence is produced and kept up for ten or twelve days, moving with the general direction of the motion of the atmosphere where it occurs. The violence then of the hurricane, and also its duration, depends upon the quantity of vapor supplied by the currents flowing in below. Hence, it is, that the tropical hurricanes which originate in the Atlantic, east of the Caribbean sea, do not abate their violence until they reach a high northern latitude where the atmosphere is cold and dry.

The cause of the gyratory motions of hurricanes.—It has been well established by Redfied, Reid, Piddington, and others, that all hurricanes and ordinary storms have a gyratory motion around a center, and that these gyrations in the northern hemisphere, are from right to left *against* the hands of a watch, but in the southern hemisphere from left to right *with* the hands of a watch. There are some, however, amongst whom is Professor Espy, who deny the gyratory character of storms entirely, and contend that there is only a rushing of the air from all sides below towards a centre without any gyration. We think that this gyratory character of storms has been too well established to admit of any doubt. No one, however, has ever given any satisfactory reason why these gyrations in the one hemisphere are always sinistrorsal and in the other dextrorsal. It is true, Mr. Redfield* endeavors to account for the sinistrorsal gyrations of the hurricanes and storms which proceed from the Gulf of Mexico towards Newfoundland, by means of the peculiarities of the aerial currents in the region of the Gulf and the adjacent coast of the Pacific. But if there are the same kind of gyrations over the whole hemisphere, it is evident that the cause which produces them must be as extended as the hemisphere itself. It has also been suggested that this tendency to a distinct kind of gyration in each hemisphere, may be owing to the magnetism of the air.†

We shall now undertake to show that there cannot be a rushing of air from all sides towards a center, on any part of the earth except at the equator, without producing a gyration, and that the tendency to a distinct kind of gyration in each hemisphere, is owing, neither to any peculiarities of the winds or aerial currents, nor to the mysterious agent of magnetism, but that it results, as a necessary consequence, from the action, upon the atmosphere, of the four forces which we have taken into consideration in the first part of this essay.

It has been shown that when a particle of air receives a motion toward the poles it is deflected toward the east, as in the passage-winds, but when it receives a motion toward the south, there is a force which also turns it towards the west, as in the trade-winds. It has likewise been shown that when the air has a relative motion east, it has a tendency, on account of the greater centrifugal force, to move also towards the south, but that when it has a relative motion west, it has a tendency, on account of the diminished centrifugal force, to move also towards the north. If, then, we suppose that the air at M, N, O, and P on the diagram (page 8), has a tendency, on account of rarefaction or for any other reason, to flow towards c, from what has been stated, the air at M would not move equally towards c, but would be deflected northward a little towards m. In like manner the air at N would move towards n; that at O towards o; and that at P towards p. Hence it is evident that when there is any force which tends to make the surrounding air flow towards a center, the resultants of all the forces which act upon it must cause it to receive a gyratory motion, and that this motion in the northern hemisphere must be sinistrorsal, but in the southern hemisphere the contrary.

It may be observed here that these gyrations are not circular but spiral, gradually approaching the center; for the forces which tend to produce these gyrations depend for their efficacy upon a motion from all sides towards the center. First, the forces of which we have already treated tend to give the atmosphere a gyratory motion as soon as it begins to converge towards a center; and secondly, these gyrations, however slight, being once produced, the centripetal force, which causes the air to flow towards the center, accelerates these gyrations as they approach the center, upon the principle of the preservation of areas, just as the gyrations of a body, when it is made to gyrate around another by means of a string, are rapidly accelerated as the string becomes shorter. Hence, if the first of these forces be only sufficient to produce a very slight gyration, the latter or centripetal force may cause very rapid gyrations near the center. And it is only upon this principle that the rapid motion of the air in a hurricane can be produced, and any theory which does not take this principle into account is defective. This centripetal force is caused by the superior pressure of the denser atmosphere on the borders of the hurricane or storm, and consequently prevails only in the lower part of the atmosphere. In the upper regions it has a tendency to recede from the center for two reasons; first, on account of the gyratory motion which it has received below in approaching the center, which it still, in some measure, retains after ascending to the regions above, where the surrounding pressure does not prevail, and consequently the centrifugal force resulting from the gyrations, causes it to recede from the center; secondly, because the ascending current causes an accumulation of atmosphere above the general level, which gives it a tendency also to flow out in all directions from the center. These motions, however, are not distinctly towards and from the center, but in spirals, so that the currents below may be at right angles with the currents above; and hence it is that in our ordinary storms attended with rain, the clouds in the lower part of the atmosphere frequently move in a direction at right angles with the direction of those above.

It has been stated that the gyrations below approach the center in a spiral, but this approach must be slow towards the center; for, at a certain distance from the center, the gyrations become so rapid that the centrifugal force nearly equals the centripetal, produced by the external pressure of the

* Silliman's Journal, second series, vol. II., page 325. † Maury's Physical Geography of the Sea, § 224.

atmosphere, and then the further approach towards the center in a great measure ceases, and consequently the force which produces the gyrations. Hence, at a certain distance from the center the hurricane has the greatest violence, and within this circumference, friction in a great measure destroys the gyrations, so that the middle of our most violent hurricanes is a calm. The extent of this calm is a circle, varying generally from five to thirty miles in diameter.

If we examine the analytical expressions of the forces which produce these gyrations, we will see that at the equator they have no value, and hence no hurricane can have its origin exactly on the equator. Accordingly, of all the hurricanes which have originated within the tropics, none have been traced back to the equator, but always to some region from 10° to 20° from it.

The reason why the hurricanes which originate east of the Caribbean sea pass northward to the east of the United States, may be owing to the direction of the wind here and on the Caribbean sea, which generally blows north of west, as has been observed in the former part of this essay. If the general direction of the trade-winds prevailed here, they would be carried on towards the equator, as those without doubt are which originate at other places in the same latitude.

We come now to the second part of our subject, the currents of the ocean.

The general motions of the ocean.—Inasmuch as the atmosphere and the ocean are both fluids somewhat similarly situated, except that the latter only partially surrounds the earth, and are both subject to the same disturbing influences of a difference of a temperature between the equator and the poles, it is reasonable to suppose that there is a similarity of their general motions. This is known from observation to be the case, except that the continents interfere more with the motion of the ocean than with those of the atmosphere. The general motion of the ocean in the torrid zone, where it is not interrupted by continents, is toward the west with an average velocity of about ten miles in twenty-four hours. Towards the poles the motion, in general, is towards the east, which is a necessary consequence of the preservation of areas; for if one part have a western motion, another part must have an eastern one, as was shown with regard to the atmosphere. If, then, there were no continents, there would be a general flowing of all the tropical parts of the ocean westward, and of the remaining parts toward the east. But when the tropical or equatorial current impinges against the eastern sides of the continents as in the Atlantic, a part is turned along the eastern side towards each pole. Likewise, when the eastern flow towards the poles, strikes against the western side of a continent, it is deflected towards the equator. Hence the northern parts of both the Atlantic and Pacific, have a tendency to a vortical motion, their tropical parts moving westward, and then turning northward on the eastern sides of the continents and joining the eastern flow, and south again towards the equator on the western sides of the continents. And it is evident from observation, that the southern parts of these oceans, and also the Indian ocean, have a tendency, in some measure, to the same kind of motions, except that the continents do not extend so far south, and consequently only a part of the eastern flow is turned toward the equator, the rest flowing on and producing the general eastern motion of the waters observed in the southern ocean.

The forces which produce the motions of the ocean.—The *primum mobile* of the motions of the ocean, as of the atmosphere, depends principally upon the difference of temperature between the equatorial and polar regions. The temperature of the ocean, on the surface at the equator, is about 80°, and it has a temperature above the mean temperature of the earth, which is 39°.5, to the depth of 7200 feet. Towards the poles it is below the freezing-point, and continues below the mean temperature at the parallel of 70°, to the depth of 4500 feet.* As water expands about 0.000455 of its bulk for every degree of increasing temperature, and sea-water contracts down to the temperature of 28°, calculations based upon these data, supposing the temperature to increase or decrease in proportion to the depth, make the specific gravity of the part at the equator, so much less than that at the poles, that it would have to rise about ten feet above the general level at the equator to be in equilibrium at the bottom of the sea, with the part at the poles. But then the equilibrium at the surface would be destroyed, and the waters would flow there towards the poles, where the superior pressure at the bottom over that of the equator, would cause a current to flow back at the bottom of the sea, towards the equator. Hence, if this cause of disturbance existed alone, there would be a current at the bottom of the sea from the poles towards the equator, moved by a force equal to the pressure of a stratum of water of about five feet, and one at the surface from the equator towards the poles, moved by an equal force. But this

* Mrs. Sommerville's Physical Geography, page 202.

motion, combined with the rotatory motion of the earth, gives rise to other forces, just as in the case of the atmosphere, which greatly modify these motions, as will be shown hereafter.

The preceding are the principal forces concerned in giving motion to the waters of the ocean. Lieutenant Maury, however, lays little stress upon these, and seems to think that the principal agencies concerned in these motions, arise from evaporation, the saltness of the ocean, galvanism, &c.* But we think it may be shown that these agencies can have no perceptible effect.

First, Lieutenant Maury supposes excessive evaporation to take place within the tropics and this vapor to be carried away and precipitated in extra-tropical regions, and infers that this would have, at least, a very sensible effect in producing the currents of the ocean. He puts the amount of evaporation of a stratum of one-half of an inch per day. Now if a stratum of water one-half of an inch in thickness is evaporated in twenty-four hours in one place and precipitated in another, it produces a difference of level of one inch between the two places, and the currents which it produces must be such as are sufficient to restore this level in the same space of time. Now we may judge how exceedingly small a current this would produce when we consider that there is a rise of about two feet in the open ocean at one place and a fall of the same amount at another every six hours, caused by the tides, and yet the flowing of the water from the one place to the other to produce this rise at one place, and fall at the other, it is well known does not produce any sensible currents in the open sea. Again, this matter can be easily reduced to calculation. If a stratum of water, one-half of an inch in thickness were taken up by evaporation from the torrid zone, and none of it precipitated there but all conveyed to the temperate and polar zones, it may be demonstrated upon the supposition that the ocean is four miles in depth, that the flow of water towards the equator to restore the equilibrium in the same time would not amount to a velocity of one foot per hour.

We think it may be likewise shown by calculations based upon reasonable hypothesis, if not entirely upon well-known data, that the salts of the sea also can have but little influence in producing currents. Lieutenant Maury makes a similar hypothesis in treating of the influence of the salt of the ocean, which he does in treating of the influence of evaporation, and supposes that the excess of salt left in the torrid zone by the excess of evaporation there, and the great precipitation in the temperate and polar regions produces such a difference in the specific gravity as to destroy the equilibrium of the sea, and to have a very sensible influence in producing currents, and especially the Gulf-stream.

With regard to the latter, he supposes that the water of the Gulf of Mexico has a much greater specific gravity than the water in the Atlantic, on account of the great evaporation to which it has been exposed in its passage from the coast of Africa across the Atlantic and through the Caribbean sea, and that, consequently, it is forced out into the Alantic by its greater pressure. Now, suppose it takes the water a year, which is about the actual time, to pass from the coast of Africa to the Gulf of Mexico; in this time, according to the hypothesis, there is evaporated a stratum of water fifteen feet in depth, and, as the salt contained in this stratum can not be evaporated, it remains in the part left, and increases its saltness. But sea-water contains only about three per cent. of saline matter, and consequently the amount of salt contained in this stratum of fifteen feet only increases the weight of the rest to an amount equal to the weight of a stratum of water about six inches deep. Hence, it only gives the water of the Gulf a tendency to flow out into the Atlantic with a force equal to the force with which a homogeneous fluid would flow out with its surface six inches above the general level of the Atlantic. This is much less than the opposing force arising from the great specific gravity of the water in the northern part of the Atlantic on account of its lower temperature, as we have shown by calculations. The same reasoning may be applied to any other part of the ocean; for, if the salt of the ocean has any influence in producing currents, it must be to produce an under-current from the torrid zone, where evaporation is supposed to be in excess, toward the poles, and, consequently, a counter-current at the surface from the poles toward the equator. But, upon any reasonable hypothesis, the water at the surface cannot lose by evaporation in passing from the poles to the equator, a stratum of water of such a depth, that the amount of salt contained in it can increase the specific gravity at the equator as much as the lower temperature increases it toward the poles; hence, if the salt of the sea has any sensible influence, it is only in opposition to a greater influence, and, consequently, it has a tendency to diminish, rather than increase, the currents of the ocean.

* See Physical Geography of the Sea §§ 26, 34 and 300.

We think it, therefore, manifest that neither evaporation nor the salts of the sea can have much influence in producing currents, even upon Lieutenant Maury's hopothesis, that evaporation is greatly in excess of precipitation in the torrid zone. But is this a true hypothesis? Although there is a great evaporation in the torrid zone, there is also great precipitation; for, with few exceptions, more rain falls at the equator than in any other part of the earth, and it is only the amount of evaporation over precipitation that should be taken into account, which we have reason to think is very small, and, if Professor Espy's theory is correct, it can not be anything; for, according to this theory, no vapor can pass from the torrid to the temperate zones and produce rain, since the current bearing it there would be a descending current, and consequently could not produce it.

The ocean not level.—As it has been shown in the case of the atmosphere, that the resultant of the forces causes an accumulation about the parallels of 28°, so, as the motions of the ocean are somewhat similar, and it is acted upon by the same forces, it may be shown that there must be a slight accumulation about those parallels in the ocean also. Whatever may be the causes of the motions of the ocean, we know that in the torrid zone it has a small western motion, and in the other parts a slight motion towards the east. The great equatorial current of the Atlantic moves about ten miles in twenty-four hours; but if we suppose that the average motion of the water in the torrid zone is five miles only per day, and that the maximum velocity of the water eastward in the extra-tropical regions is the same, using the same hypothesis which we did with regard to the atmosphere, the forces which result from these motions must cause an accumulation of more than forty feet about the parallels of 28°, above the level of the sea at the poles, and about five feet above the level of the equator This, however, would be the amount of accumulation to produce an equilibrium of the forces at the surface, but as this accumulation would then produce a greater pressure there upon the bottom than towards the poles and at the equator, it would produce, as in the case of the atmosphere, a flowing out from beneath this accumulation towards the poles and the equator, and settling down of the surface above, below the state of equilibrium, sufficient to cause a counter-current at the surface from the poles and the equater to supply the currents below. The accumulation there would be only about one-half that stated above, and there would be a flowing of water at the surface from both sides *towards* the parallels of 28°, and below a current in both directions *from* these parallels, similar to the motions of the atmosphere.

That the water of the ocean has such a motion as has been stated, appears from observations of its motions and other circumstances. Says Lieutenant Maury, "There seems to be a larger flow of polar waters into the Atlantic than of waters from it, and I cannot account for the preservation of the equilibrium of this ocean by any other hypothesis than that which calls in the aid of undercurrents." It is well-known that in Baffin's bay there is a strong surface-current running south, and a strong counter-current beneath running north. Another evidence of this general tendency of the waters, is, that icebergs, in both hemispheres, are drifted from the poles towards the equator, and in the south Atlantic sometimes reach the parallel of 37°. It is also evident from the fact that, in both the north Atlantic and Pacific oceans, there are large collections of drift and sea-weed about the parallels of 28°, so thickly matted that vessels are retarded in passing through them.*

These collections can only be formed by the flowing of the water at the surface from both sides to these parallels. It has been supposed that these collections are owing to the slight vortical motions of these oceans, it being supposed that any floating substances on the surface would have a tendency to collect at the vortex. This, however, would not be the case, for on account of friction at the bottom, the surface would have a greater vortical motion than the bottom, and consequently the water would be driven very slowly at the surface by the centrifugal force towards the sides, where it would cause a slight elevation and increase of pressure, which would cause the water to return towards the vortex at the bottom and not at the top; and hence floating substances at the surface could have no tendency to collect at the vortex.

We have corroborated these deductions from theory by numerous experiments made with a vessel of water with light substances on the surface. When the vessel is first receiving a vortical motion, the substances collect in the middle; for, as it is the vessel which gives motion to the water by means of the friction, the vessel, and consequently the bottom of the water, has then a greater motion than the top; and hence the reverse of what is stated above takes place; but, if the vessel is now stopped,

* Humboldt's Cosmos, vol. 2, page 278.

and the water within allowed to continue its motion, the vortical motion at the bottom is retarded faster than at the top, and soon has a slower motion there, when the light substances on the surface are seen to recede from the vortex towards the sides, and if there are any light substances on the bottom, they collect in the centre, all of which proves, that the water recedes from the middle at the surface, and returns to it at the bottom, and exactly agrees with the deductions from theory. These collections of sea-weed, then, cannot be caused by the vortical motions of the ocean, but must be the result of a general tendency of the surface water, to flow from both the equator and the poles towards these parallels; and, as it is prevented from collecting on these parallels near either side, on account of the slight vortical motion of the ocean, it collects only in the middle.

Explanation of the Gulf-stream.—We come now to the Gulf-stream, which has been a puzzle to philosophers ever since it was discovered. Many explanations have been given, and all known forces which can have any influence, have been brought in to account for this wonderful phenomenon. The most usual explanation is, that it is the escaping of the waters which have been forced into the Caribbean sea and the Gulf of Mexico by the trade-winds, which have been supposed to raise their surface above the general level, and thus afford a head as it were for the stream. This, without doubt, has a very considerable effect, but it has not generally been deemed adequate alone to account for the phenomenon, nor does it, in connection with all other known influences, afford a satisfactory explanation. "What is the cause of the Gulf-stream," says Lieutenant Maury, "has always puzzled philosophers. Modern investigation and examinations are beginning to throw some light upon the subject, though all is not yet clear."

We shall now endeavor to show that the additional force which we have taken into account in explaining both the winds and the currents of the ocean, and which seems to have been overlooked heretofore, will at least throw much additional light upon the subject, if not afford a complete explanation. We have shown that this force, which results from the eastward flow of the water in the extra-tropical regions, and from the western motion within the tropics, has a tendency to drive the water from the poles towards the equator, and also slightly from the equator towards the poles, and to produce an accumulation of at least twenty feet on the parallels of 28° above the level at the poles, upon the supposition that the maximum of this east and west flow is only five miles per day. But if, from any cause, the force which results from this eastward flow should be cut off at any place, the water would flow northward at that place with a force equal to that which would result from a head on the parallels of 28°, at least twenty feet above the level towards the poles. Now, it may be seen from the configuration of the coast of the United States, that this force is actually cut off along that coast; for this force depends upon the eastward flow of the water there, which it cannot have, inasmuch as it must flow in both ways along the coast to fill up the vacuum which such a motion would produce. As the Gulf of Mexico, therefore, and the adjacent parts of the Atlantic, lie in the parallel of greatest accumulation, the water must flow from these parts along the coast with a force equal to that stated above. In addition to this, the momentum of the water flowing westward in the torrid zone, with a motion depending upon the prime moving course, due to a difference of specific gravity between the poles and the equator, in connection with the rotatory motion of the earth, and being independent of the effect of the trade-winds, must force the water in the Caribbean sea and the Gulf of Mexico considerably above the general level and add to the preceding force. When we consider that the motion of the water which produces tides on our coasts, is in general imperceptible in the open ocean, and yet, on account of the sloping bottom of the ocean, which causes a smaller volume of water to receive the momentum of a larger one, it causes considerable rise of the water along the coast, we have reason to think that the general tendency of water westward in the torrid zone may keep the water in the Gulf considerably above the general level, since its water and that in the Caribbean sea, if the bottom of the ocean be sloping, must in a great measure receive the momentum of the whole body of the water moving westward in the adjacent part of the Atlantic. The eastern tendency of the water in the northern part of the north Atlantic, due to the prime moving force mentioned above and independent of the winds which prevail there, causes the surface of the ocean in the latitude of Newfoundland to be somewhat depressed below the general level next to the coast, which also adds to the force of the Gulf-stream. All these forces, taken in connection with the influence of the trade-winds, to which this phenomenon has been mainly attributed, we think, furnish a complete and satisfactory explanation of that great wonder and mystery of the ocean, the Gulf-stream.

The Greenland and other currents.—The general eastward motion of the waters of the ocean in the northern part of the Atlantic, and consequent depression next the coast of North America, also furnish an explanation of the cold current of water flowing between the Gulf-stream and the coast of the United States, called the Greenland current. On account of the rotatory motion of the earth, the water of the Gulf-stream in flowing northward, tends to the east, and for the same reason the water flowing from Greenland and Baffin's bay to supply the eastern flow, tends towards the west, and consequently flows in between the Gulf-stream and the coast of the United States.

There must be a motion of the waters somewhat similar to that of the Gulf-stream and the Greenland current, wherever the great equatorial current impinges against a continent, and the eastward flow towards the poles is cut off. Hence, on the eastern coast of South America, there is a warm Brazilian current towards Cape Horn, and on the eastern coast of Africa, the Mozambique current which at the Cape of Good Hope is called the Agulhas current. Also, on the eastern coast of Asia, there is the warm China current, flowing towards the north, similar to the Gulf-stream, and the cold Asiatic current, insinuating itself between it and the coast, like the Greenland current.

On the western side of the continents a motion somewhat the reverse of this must take place. Hence, instead of a warm stream flowing towards the north, there is a cold current flowing towards the equator. On the west of Portugal, and the northern part of Africa, there is a flow of colder water towards the equator, and west of the southern part of Africa, is the cold Atlantic current, also tending towards the equator, both to join the great equatorial current flowing across the Atlantic. On the west coast of North America, also, there is a flow of colder water along the coast from the north, and on the west coast of South America, is Humboldt's current, 8° or 10° colder than the rest of the ocean in the same latitude, both tending towards the equator to there join the great western current across the Pacific, and to fill up, as it were, the vacuum which this current has a tendency to leave about the equator, on the western coast of America.

NASHVILLE, *October* 4, 1856.