Art. IX.—*Remarks on Tides and the Prevailing Currents of the Ocean and Atmosphere;* by W. C. Redfield.

[Read before the American Philosophical Society at their centennial meeting, May 27th, 1843.]

The summary remarks and suggestions which follow, relate chiefly to the systematic currents of the ocean and the atmosphere; and were drawn up on short notice in the summer of 1838 at the request of a gentleman attached to the U. S. Exploring Expedition,* and were designed for reference, correction, and verification, by the scientific observers of the Expedition.

The views thus submitted I had derived, in previous years, from somewhat extensive examinations of the observations which had been made by voyagers and travellers in different seas and countries, and they are offered without an array of particular references to the numerous facts and observations from which they have been derived. This course was adopted, on that occasion, as being the least laborious, and because it was the undoubted design of the observers of the expedition to subject all general views and theories to the test of direct observations.

As a substitute, however, for those specific observations from which my results had been drawn, I delineated on maps and charts which were furnished me for the purpose, not only the general outlines or courses of the systems of general winds and currents which I had found to prevail in the Pacific Ocean and other seas, but also, some of the particular observations by which in my view, the existence of these currents had been established. These maps, seven in number, were lost by the unfortunate wreck of the Peacock, near the mouth of the Columbia River.

It is not my design to bestow further labor upon this extensive subject till the observations and results of the expedition shall have been published. But as observations on meteorology and the cognate branches of terrestrial physics may have been more limited in the expedition than I could have had reason to apprehend, particularly in the Atlantic, I venture now to lay before the Society my unfinished memoir of that period, even without those specific delineations which would have been afforded by the lost maps, which I have not yet attempted to reconstruct.

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* James D. Dana Esq., geologist of the expedition.

I proceed now to the remarks which were addressed to the gentlemen of the expedition.

The preparation and departure of the Expedition fitted out by the goverment of the United States for the scientific examination of distant seas and countries, naturally awakens feelings of interest and expectation in the American public, as well as among the friends of science, in this and other countries. In such feelings the writer of these remarks fully participates, and the opportunities for useful observation which the Expedition is likely to afford, on various natural phenomena which have engaged his attention, may perhaps justify the following statements and suggestions, addressed to those who are to conduct the movements and perform the scientific labors of the expedition.

The instructions which have been drawn up by Sir J. F. W. Herschel, for observations in meteorology, and by M. Arago, for the discovery vessel, the *Bonite*, together with the valuable reports which have been made to the U. S. Naval Lyceum by its committee and other distinguished individuals, with direct reference to this expedition, have presented many important topics of investigation.* There are still, however, some points of interest and importance which seem to deserve more particular notice.

Indeed, the subjects of natural science which invite the investigation of the Expedition, are too numerous and important to be easily exhausted.

OF TIDES.

The valuable labors of Prof. Whewell and Mr. Lubbock have greatly enlarged our knowledge of the tides; owing chiefly to the fact that these gentlemen have followed the method of direct induction from actual observations, made at different localities. To the directions given by Prof. Whewell for obtaining the correct establishment, or true time of high water at the full and change of the moon, nothing more need be added.

It is a question of some importance, however, if it be not already determined, whether the main tidal wave of the North Atlantic be derived directly from the great Southern Ocean, as Prof. Whewell supposes, or, whether it mainly follows a circuit of revolution, north of the equator, around an elongated axis or

* See Naval Magazine for January, 1837, Vol II, p. 64, *et seq.*

neutral position, situated in mid ocean, somewhere between 18° and 26° north latitude, as had been suggested at an earlier period.*

A like question arises in regard to the tide-waves of both the North and South Pacific. The inquiry is therefore presented, whether the tidal wave in the North Pacific ocean does not move in a circuit, around a central position not greatly distant from the Sandwich Islands, the wave moving westerly in mid ocean in the intertropical or equatorial latitudes and easterly in the higher latitudes; and whether the tide-wave of the South Pacific does not follow a like course, around a central point or position at or near Tahita or the Society Islands. If this view of the course of the tide-waves should be sustained by observations in the Pacific, the tide-wave on the western coast of North America will be found moving southeastward, and together with the counter-wave from the South Pacific, might fully account for the extraordinary convergence and height of the tides in the Bay of Panama. Such a system of revolution in the tidal waves of the great oceans may account, also, for the absence of any considerable tides at the Sandwich and Society Islands, and at the Windward Islands of the Antilles.

Such circuits of revolution in the tides, would bear some analogy to those which, as I apprehend, are exhibited in the system of *currents* in the several oceans, as well as in the system of general winds, which likewise prevail. These systems of revolution and compensation, in the currents of the aqueous and aerial oceans, I have ventured to refer directly to the law of gravitation, as connected with unstable equilibrium and with the rotary and orbital movements of the several zones and meridians of the earth's surface.†

As connected with the enquiry on tides, it is important to ascertain the direction of the main stream of flood tide in the *offing*, at the several islands and prominent headlands which are most exempt from the local influences of reefs and shallows.

CURRENTS OF THE ATLANTIC.

The great system of aqueous circulation, which appears to be developed under various modifications in the several oceans on

* See note in Silliman's Journal for Oct. 1833, Vol xxv, p. 132.

† The law of equilibrium in our system, I apprehend, is a law of motion, not of rest.

both sides of the equator, has been glanced at in the foregoing remarks on tides. One of the most active, if not the best known current of this oceanic system, is the Gulf Stream of the North Atlantic. It appears to be established that a main portion of the Gulf Stream moves from the American coast towards the Azores and the Canary Islands, and thence along the coast of North Africa, turning westward till it again coincides with the equatorial current in its course towards the Caribbean Sea. This great circuit of the ocean current is found to coincide, mainly, with that which is also performed by the general winds in the basin of the North Atlantic. For the trade winds, on leaving the tropical latitudes, pass eastwardly through the temperate zone, but in a more irregular manner, sweeping around the track of ocean known as the *grassy sea* and the belt of summer calms, which lies a few degrees north of the tropic, known to navigators as the *horse latitudes*. It is in this extratropical region of calms that the major axis of this great elliptical circuit of general winds appears to lie. It is this calm region that separates the general westerly winds of the higher latitudes from the trade winds of which they are the counterpart; and it is chiefly these westerly winds of the higher latitudes which, in the performance of their great circuit of revolution, are again merged in the regular trade winds.* But let us return to the consideration of the more limited currents which prevail in the ocean.

* I may add, that so far as the writer is concerned, the first exhibition of this view is found in my communication published in Silliman's Journal for April, 1831, Vol. xx, p. 50. In this instance, however, I have ascribed the currents of the ocean solely to the force of the winds, in compliance with the common theory; a view which I soon after found reason to abandon. The outlines of the great systems of horizontal revolution in the winds I have also sketched in my summary of "Facts in Meteorology," which appeared in Silliman's Journal for October, 1833, Vol. xxv, pp. 122–135. Previous to this period, I had examined the journals of whalers who had cruised on the "off shore ground" of the North Pacific, in that belt of calms and light winds near the latitude of 30°, which is the favorite resort of the sperm whales in that sea, and which corresponds to the so called "horse latitudes" of the Atlantic. From this and other like evidence I had arrived at the conclusions which I now maintain.

Sir John F. W. Herschel maintains the connection or continuity of the trades with the prevailing westerly winds of higher latitudes; and refers to the well reasoned explanations of Capt. Basil Hall, based on the common theory. He also adds an important suggestion on the velocity of winds which subside from a higher position in the atmosphere, and which may serve to explain the steady violence which sometimes pertains to westerly gales in the United States and on the North Atlantic.—*Treatise on Astronomy, section* 200 *and ante.*

Having noticed that portion of the Gulf Stream which, on passing the bank of Newfoundland, moves towards the Azores and the African coast, we will now follow that considerable portion of the Stream which is found to pass towards the western coast of the British islands and along the coast of Norway, till it enters the polar basin. From this frozen region it again emerges in the great polar current, covered with floating ice, which, skirting the coasts of Labrador and Newfoundland, falls in with the Gulf Stream at the southern extremity of the Grand Bank, and now becomes, mainly, a subaqueous current, the deeper portion of which can be traced only by its propelling effect on the deeply immersed icebergs, which it forces athwart the warm tropical stream, till they become dissolved by the higher temperature of the latter.

Observations of the temperature made in sounding at various depths in the Gulf Stream, and particularly in the region where it overruns or crosses the polar current, would be of high interest, and of great value in estimating the dynamics of the ocean currents.

As connected with the foregoing outline of the main system of superficial currents in the North Atlantic, I propose now a particular inquiry, relating to a single branch of this system of ocean streams, which perhaps may serve to show the origin or character of some currents which pursue opposite directions in other oceans. *From what source, then, is that southwesterly current derived which commonly prevails along the coast of the United States, in the direction which is opposite to the Gulf Stream?*

I am aware that this is usually considered by seamen as an eddy current, derived from the Gulf Stream; but from this view I am compelled to dissent. For, in the first place, this current never assumes the gyrating form of an eddy; but continues its course, when unobstructed by gales, in a direction which is generally parallel to the coast. But, secondly, in case this current be derived from the Gulf Stream, it must necessarily partake of the same elevated temperature; whereas, the reduction of temperature which occurs on crossing the northwestern limit of the Gulf Stream is most remarkable, and is almost without a parallel in the Atlantic, except in the immediate vicinity of ice.

It appears vain to allege the proximity of soundings or shallows as explaining this extraordinary change of temperature, for this cannot avail if the waters of the counter current be derived

from the Gulf Stream, to say nothing of the erroneous character of the position here noticed.

From the evidence which is afforded by numerous facts and observations, it appears that the current in question is neither more nor less than a more sluggish prolongation of the polar or Labrador current, which sweeps along the northeastern shores of this continent and the island of Newfoundland. And this current, if I mistake not, may be directly traced in its gradations of temperature, by the thermometer, from off the southern coasts of Newfoundland and Nova Scotia through the entire distance to Cape Hatteras, if not to Florida.

An eddy current offsetting from the Gulf Stream, would no where be so likely to be met with as at the point of intersection of this stream with the extremity of the Grand Bank of Newfoundland, and sweeping from thence upon the southern shores of the island of that name; and yet, the harbor of St. John's on the southern coast of Newfoundland is known to have continued ice-bound in 1831 so late as the month of June, although in the latitude of Paris. This fact is a convincing proof of the unimpeded continuation of the polar current to the southward, in this region, notwithstanding the near proximity of the Gulf Stream.

That Col. Jonathan Williams and others should have ascribed the reduced temperature of the ocean near our shores simply to the effect of shoals or shallow soundings, need not excite our surprise, as such striking reductions of temperature are found on the Great Bank of Newfoundland, and on that of the Lagullas, off the Cape of Good Hope, and while so little has been known of the system of ocean currents, and the proximate origin and courses of the colder streams of this system. And it is well known, that the low temperature of the sea on these banks and shallows has been ascribed to the effects of radiation. But, if I mistake not, it has been shown that a non-luminous body is incapable of radiation through water; and should this be otherwise, any possible effect of this kind is wholly overborne by the cold of the great polar currents, which constantly traverse the banks and shoals referred to.

If I am correct in this view, it is the reduced temperature of the currents from the polar regions, or, from contiguous ocean depths, which has led Williams, Davy and others to support the erroneous, or at least very questionable generalization, which as-

cribes a reduced temperature to the sea on all banks and shallows. If the ocean was devoid of currents, I think we might expect an *increase* of temperature on shoals in summer, or in warm latitudes, and a *reduction* of temperature in winter. A friend who made a full set of observations in crossing the Atlantic, informs me that on arriving at soundings in the English Channel, he found an increase of 2° in the temperature of the waters.*

Perhaps I may be allowed to refer, for a moment, to the geological agencies of the polar currents. It is well known that extensive fields and packs of ice, including many icebergs of vast magnitude, are constantly carried by the polar currents towards the lower latitudes. On reaching certain regions, such as the banks of Newfoundland and the Lagullas of Southern Africa, the ice is brought into proximity or contact with the warm counter-currents of the system, which flow from the torrid zone, where the ice is soon dissolved. The numerous masses of earth, rocks, beach bowlders, and sedimentary matter, which are borne by the ice in great profusion from the cliffs, the shores and the sea-bottom of the Arctic regions, and probably also from the Antarctic, are thus added continually to the vast submarine deposits which there accumulate. May not the continuance of this transporting process, through a long series of ages, be deemed sufficient to account for the existence and present extent of the great banks referred to; without particular reference to the evidence of successive elevations and subsidences, in extensive areas of the earth's crust?

CURRENTS OF THE SOUTHERN AND PACIFIC OCEANS.

That the currents of the Atlantic Ocean are connected with, and form an extension of those of the Indian and Southern oceans, has been proved by the researches of Rennel and others. Hence it follows, that the drain of these currents must be compensated by other currents which pass from the Atlantic to those seas, by some unknown or unexplored route, currents which move either at the surface or at lower depths. If these compensating currents exist at the surface, as is quite probable, on what meridians of the extreme South Atlantic are they to be found?†

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* George W. Blunt, Esq.

† The consideration of the connection of the currents of the North Atlantic and the Arctic seas with those of the North Pacific, through Bhering's Strait, has been purposely omitted, as being less important in a general view, and beyond the expected range of observation by the expedition.

In view of an attempt to penetrate the Antarctic regions, it seems important to ascertain those routes by which the warmer currents of the great Southern ocean enter the polar basin, and on what routes or meridians they again emerge as ice-bearing currents, moving towards the lower latitudes. The thermometer will prove an important auxiliary in determining these localities, and the course of the polar currents from the Antarctic basin is now partially known, by the course of the icebergs which descend to the lower latitudes. It is by following the course of the warmer currents which enter the polar basin that the nearest approach will probably be made to the Antarctic pole; and the same system of continuous current might afford the means of final escape, should a ship be compelled to winter in the ice of that perilous region.

As regards the great system of currents in the Pacific, we may infer from the facts already known, that a current from the Antarctic region sets to the northward, several degrees west of Cape Horn, which unites its waters with those of the more temperate latitudes in their flow to the coasts of Chili and Peru, and thence towards the equator. If an ice current does not thus unite with that of the coast, the latter is mainly supported by the great afflux of the extratropical currents from the west, which, in performing their constant circuit of revolution, next sweep from the coast of Peru towards the equatorial latitudes, where they continue their course to the westward, again to leave the intertropical latitudes with an elevated temperature, which is in turn conveyed to the higher latitudes.*

The numerous archipelagos of islands and the extensive groups of coral reefs in the Pacific, serve to intercept the regular westerly progress of its warm intertropical currents, and to determine more than one circuit of compensation and revolution in each hemisphere. This class of obstructions partly supplies the place of a continent, in defining separate basins of revolution for the currents of this vast ocean, and this is particularly the case in the South Pacific, where these obstructions are scattered over wide areas. Hence, strong currents setting to the eastward have

* From information which I have gathered, I entertain no doubt of the blending of this ice current with the general current towards the equator on the west coast of South America; and the very reduced temperature which this current carries to the equator, at or near the Gallapagos Islands, is proof of the fact.

been found in various parts of the Pacific, below the latitude of 30°, moving in direct opposition to the influence of the strongest portion of the trade winds.* Thus the system of currents, as we shall find of the winds, becomes more complex and irregular in this vast ocean than in the Atlantic; which, at least so far as relates to winds, is contrary to representations which have been often erroneously made by scientific writers; representations which doubtless were founded in general reasonings on the calorific theory of winds.

Good observations on the direction, strength, and temperature of the currents, in all parts of the Pacific, will prove of great importance, and should be made and registered, most carefully, by the expedition.

The obstacles which thus modify the natural system of currents are least numerous in the North Pacific, where the trending of its continental coasts, except in high latitudes, is highly favorable to a strong development of the regular geographical currents, near to these coasts. Hence, on the coasts of China and Japan we find a current which fully represents the Gulf Stream of the Atlantic. This current, I find, was frequently noticed, incidentally, by the officers of Cook's last exploring expedition, and its velocity stated, in some instances, at five miles an hour. Other observations, to which I have had access, have confirmed the existence of this current, and have shown the elevated temperature which this stream carries from the lower latitudes; so that near one thousand miles east of the coast of Japan, in lat. 41° north, the temperature of the surface water has been found at 79½° of Fahrenheit.† In the South Pacific, near the coast of New Holland there is found, also, a like warm current, pursuing its southern circuit, through the higher latitudes of that hemisphere.

But owing as I apprehend, to the great width of the Pacific, and to the consequent absence of a defined ocean boundary near its central meridians, there is here less of apparent regularity and

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* This counter current, running to the eastward, is sometimes found in the equatorial regions of the Pacific and other seas, and bears some analogy to the westerly monsoons of the Indian and Pacific oceans.

† Voyage of Capt. Dupetit Thouars. Other and earlier observations had attracted my attention, particularly in the cruising voyages of our American whalers, but I now refer to this as a more recent and convenient authority.

system, both in currents and winds, than perhaps in any other ocean; the constant and reciprocal equatorial and polar tendencies of oscillation not permitting a single circuit of revolution to extend from Asia to America without deflection. Hence we find more apparent irregularity and complexity in the currents and winds of mid ocean, in this vast sea, than in those regions which are more nearly adjacent to the continental coasts.

A knowledge of the currents and winds of the Pacific Ocean, I am convinced, will serve to remove all mystery and all doubt from the once vexed question of the first peopling of its islands, from the Asiatic continent; in spite of the long urged objection of the opposition of the trade winds. A case is still recent where the wreck of a Japanese junk was drifted the entire distance to the Sandwich Islands, with its surviving crew; thus completing nearly half of the great circuit of winds and currents in the North Pacific. But we shall find an additional means of transport near the equator, which is afforded in the N. W. monsoon of the Indian and Pacific oceans, and which, according to my inquiries, is found to extend, at one portion of the year, as far eastward as the Society Islands; or more than half the distance from the Indian Ocean to the coast of South America.

OF GENERAL WINDS, OR PREVAILING CURRENTS OF THE ATMOSPHERE.

One of the most remarkable characteristics of the atmosphere is its constantly progressive action; exhibited in movements which are more or less rapid, and mainly horizontal.

To whatever general cause these movements may be ascribed, they are found in most countries to predominate in particular directions in the surface winds, but more uniformly at higher elevations. The greatest uniformity of the surface winds has been noticed chiefly in certain zones or regions which, for the most part, lie between the parallels of 30° latitude, north and south; limits which comprise half of the earth's surface. These more regular winds have hitherto been known best on the great routes of commerce, on the Atlantic and certain portions of the Indian oceans, and hence have been called the Trade winds.

In order to account for the supposed uniform character of the trade winds, a general theory of winds has been adopted, of much plausibility, founded on the alleged effects of calorific rarefaction

in the equatorial region. Aided by successive emendations, this theory continues to receive the general sanction of the scientific world.

It is not my design, in this communication, to discuss theories. But the facts and results which I have delineated on the accompanying maps,* indicate courses of circulation in the atmosphere which are nearly and mainly horizontal; while the common theory alleges a course or circuit of circulation, in each hemisphere, which is essentially vertical, the warm air being supposed to ascend near the equator to great elevations and there flow outwards, to supply the inward current from the higher latitudes; the obliquity from a north and south direction being of course due to the earth's rotation. I propose, therefore, to state in a summary way, some of the facts and considerations which, in my own view, serve to invalidate this calorific theory.

1. The specific difference of mean temperature in the intertropical winds as compared with equal zones of extratropical winds, is inadequate and wholly disproportioned to the dynamical effects which are exhibited in these winds. I am not aware that any successful attempt has been made to prove the converse of this objection.

2. The rising of the whole body of the trade wind in the equatorial latitudes, in the manner alleged, has never been confirmed by observation; and, as I apprehend, may safely be denied. Nor has any proof of the fact been offered, other than inferences drawn from common but very limited phenomena, which I think may be explained in a more satisfactory manner.

3. The perpetual snow line of the Andes has been found near one thousand feet higher in 16° to 18° south latitude than at the equator, or on the parallel of the equatorial calms of the Atlantic. This fact, in a region so favorable to an equable development of natural influences, I deem to be wholly conclusive against the theory.†

4. The semiannual change, to the north and south, of the locality of the trade winds and the belt of equatorial calms, which results from the change of seasons, bears no adequate proportion to

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* Those lost in the Peacock.

† See the observations of Mr. Pentland in the Journal of the London Geographical Society. Also, Penny Cyclopedia, Vol. VII, Art. CLIMATE.

the alternate geographical declination of the sun, nor to the actual geographical change in the zone of greatest temperature, which follows the sun's declination.*

The semiannual change of the locality in the trade winds is believed to be greatest in the Atlantic, where it does not appear to average more than 7° or 8° of latitude; while the annual range of the sun's declination exceeds 46°, and the actual transfer of the zone of heat, which follows the declination, appears to be nearly 40° of latitude. These facts, also, I deem to be conclusive against the theory.

5. Even within the ordinary geographical limits of the trade winds, there are extensive portions of the system of winds which, in their course and direction, do not accord with the received theory, but appear wholly irreconcilable with its requirements.

To illustrate this objection, I refer, first, to a circuit of intertropical winds in the equatorial basin of the North Atlantic, which appears to extend from the delta of the Quorra, the ancient Niger, for more than two thirds the distance to the coast of South America; in which circuit the winds revolve to the right, with more or less of regularity, around a central and probably elongated axis. And second, to the existence and great extension into open sea of those portions of the monsoon winds which blow obliquely *from* the equator, in directions where there can be none of the continental rarefaction which has been alleged as explaining these alternating winds. For if the winds of the equatorial latitudes rise to the higher regions, the monsoon winds of the Indian Ocean, on departing from the south side of the equator, could never be made to sweep eastwardly upon the earth's surface for even six thousand miles, as they now do annually, instead of ascending four or six miles in altitude, to flow off from the equator as superior winds.†

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* In other words, an essential geographical change in the locality of heat, of some months' duration, does not change, materially, the locality of the trade winds. Hence, these winds are not, mainly, the result of heat.

† M. Bougainville says, "from the 23d of February to the 3d of March, we had westerly winds, constantly varying between S. W. and N. W., with calms and rains; every day either a little before noon or soon after, we had sudden gusts of rain accompanied with thunder. It was strange to us to meet with this extraordinary wind under the tropic, and in that ocean so much renowned above all other seas for the uniformity and freshness of the E. and S. E. trade winds; which are

6. The sixth objection which I offer to the common theory of the trade winds, consists in the frequent occurrence, in our American climate, of the highest summer heats for several days in succession, sometimes irrespective of the immediate heat of the sun, which heated air, as appears from comparative observations, is mainly brought to us by geographical transfer along the earth's surface, and which appears to depart in the same manner. This could never happen if the most heated portions of the atmosphere necessarily ascend from the surface. A like objection is derived from the frequent interstratification and horizontal transfer of currents of unequal temperatures and hygrometrical conditions, which appear to move over great distances without any obvious change in their relative altitudes.

Having already noticed, in the course of these remarks, the system of horizontal circuits of revolution pursued by the winds on each side of the equator, it is now only necessary that I refer the observers of the expedition to the particular delineations of these circuits, and of the alternating system of monsoon winds, on the maps which are furnished herewith.*

It must not be supposed, however, that these circuits of revolution in the great winds, are generally uniform or strictly defined in their location or development, even on the open ocean. On the contrary, the winds which proceed outward from the trades, often overlie those which at the same time are returning into the trades. This often occurs extensively, on different meridians along the same parallel; besides the incidental fluctuations and disturbances to which the winds are always liable, and the shifting of their field of revolution to the north or south, by the change of seasons. But the general result, is a continued and

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said to reign in it all the year round. We shall find more than one opportunity to make the same observation."

This relates to the southern Pacific in long. 110° to 115° west from Greenwich, and serves to show an extension of the westerly monsoon winds at that season, even to the meridian of California. Numerous observations have tended to confirm the vast extension of these winds in the intertropical latitudes of the Pacific, opposite to the alleged course of the trade winds. Over the whole western coasts of intertropical America, the course of the winds is also at variance with the calorific theory.

* In the absence of the maps referred to, some general notion of the system of monsoon winds thereon delineated, may perhaps be obtained by referring to the summary description of these winds found in this Journal for October, 1833, Vol. xxv, p. 124–125.

successive series of laminated or stratified currents, overlapping and moving upon each other in like series of subordinate circuits, the major axes of which, in the northern summer, are principally found in the calms of the horse latitudes.

The calms and light winds which are peculiar to this last mentioned region in summer, result not so much from any general suspension of the aerial movements, as from the absence of that brisk relative motion which commonly prevails in other latitudes. For, the predominating movements of the atmosphere being either from the east or west, in conformity with the law of the earth's rotation, and there being little movement of the surface winds in these directions along the parallels in which lie the axes of atmospheric revolution, it follows, that only the more sluggish northerly and southerly winds chiefly prevail on these parallels, in mid ocean, at this season. And I may here suggest, that a like explanation is mainly applicable to the calms of the equatorial region, both between the regular trades, and the Indian monsoons.

Towards the eastern borders of a basin of revolution, such as the North Atlantic, there appears to be less of sluggishness in the aerial currents which move to or from the lower latitudes; which here appear more clearly defined and more strongly developed, and hence are more readily traced in their course; as is seen in the northerly winds which gradually merge in the N. E. trades, in the region between Madeira and the Canaries, and thence to the tropic. While, near the western borders of the Atlantic and over the adjacent coasts of America, the opposite southerly and southwesterly winds of the circuit are often well developed at the earth's surface, at least in the warm season. Like characteristics pertain to the system of winds in like latitudes, in other circuits of atmospheric revolution, in different oceans.

That the N. E. trade winds have not sooner been traced in their horizontal curves into the southwest winds, may be owing in part to the frequent overlying of the southwesterly upon the easterly winds, which occurs mostly towards the exterior portion of the trades; and partly, to a neglect to inquire into the actual and successively varying directions of the trade winds, in the central and western parts of the ocean basins, in the intertropical latitudes. In these latitudes, in the regions here mentioned, the N. E. trade winds are more often found nearly at east,

and veering to E. S. E. or S. E., than has been generally imagined.

But the courses traversed by storms, in the trade-wind latitudes of the western Atlantic, and in corresponding latitudes in the western portions of other seas, as shown by my own inquiries and those of Col. Reid, I conceive to have proved this horizontal course of atmospheric circulation, in the clearest manner; and it was this kind of evidence which first brought conviction to my own mind.* In pursuing this branch of the evidence we are thus able fully to establish the western half of the north Atlantic circuit of revolution in the general winds; while, the better defined courses of the regular winds from the latitude of Madeira to the trades, in the eastern Atlantic, is such as to remove all reasonable doubt of a nearly continuous circuit of revolution, from left to right, around the region of extratropical calms, called the horse latitudes.

I may add, on this occasion, that if further proofs were wanting of this horizontal circuit of revolution in these general winds, it is found in the *rotation* of the great storms, from right to left in the northern hemisphere, around their several moving axes, while pursuing their natural course of progression in this great aerial circuit. The question has often been asked, why should all these storms revolve in this direction, rather than in the opposite? And why the contrary rotation which is noticed in the southern hemisphere? Now I have been convinced for several years, that this law results from the conditions which necessarily attend the earth's rotation. For, in the westwardly movements of the atmosphere upon the earth's surface, obliquely from the equator towards the poles, the narrowing of the meridional spaces and the reduced velocities of rotation in the earth's crust on the parallels newly arrived at by the surface wind, with the constant retardations of eastern movement in the front of the mass which results

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* See my published maps of 1830 and 1835 containing the tracks of storms; also, my communications in Silliman's Journal and the Nautical and Naval Magizines, since April, 1831; likewise, the charts &c., of Col. Reid, R. E., published in the Professional Papers of the Royal Engineers, and his elaborate work on the Law of Storms, issued at the time these remarks were in preparation; a copy of which work was received and forwarded to the expedition. More recently the labors of Mr. Piddington of Calcutta have afforded much additional evidence, as relates to the Indian and China seas.

therefrom, conjoin to induce a rotary tendency in the incumbent winds, in the very direction in which the storms are found to revolve.*

This dynamical tendency to gyration in the atmospheric currents or winds which are in contact with the earth's surface, is constantly productive of sensible effects, particularly as we proceed from the intertropical to the higher latitudes. This, I apprehend, is the chief cause of the changes and variableness of the winds in these latitudes, and also of the remarkable increase of the barometrical oscillations, the great storms being only the more strongly marked cases of gyratory action; while the numerous weaker or abortive cases which go to fill up the intervals of space, and partly overlie each other, and which are also modified by the ordinary disturbances of temperature and locality, have excited little notice or inquiry. It is this law of terrestrial rotation which, as I apprehend, is maintained by Prof. Dové of Prussia, in his attempts to show the elements of gyration in the general winds; a writer with whose labors I have been but lately and partially acquainted.

The general correctness of the foregoing view of the prime cause of local gyrations in the atmosphere, as well as the rotation in great storms, may be shown by an experiment made on the surface of a common globe; which I have occasionally pointed out to friends interested in these inquiries. Let a concave surface of wood or other substance, of a circular form and a diameter equal to five or ten degrees of the globe, be prepared and perforated with a small hole in the center, through which a pin may be loosely placed, to serve as an axis. Then let the concavity be lined with flannel or other yielding material, and placed upon the top of the globe near the equator. Then cause the globe to revolve from west to east in the direction of the earth's rotation, while the concave body is guided, carefully, by the pin at the axis, in the direction of the storm tracks which are found on my

* It will be noticed that the rotation of the great storms, as well as more ordinary atmospheric gyrations, is opposite to that of the great natural circuit of winds in which they are carried forward. Thus, if a general current of revolution swept around such a lake as Ontario from left to right, the eddies and local gyrations near its borders and in the body of the stream would exhibit a contrary rotation, from right to left.

chart of 1835,* and so as to impinge with equal weight and surface on all sides of the pin or axis, and the incumbent body will be found to revolve from right to left, in the manner of the storms of the northern hemisphere.

This experiment requires delicate management, and is more difficult because of the necessary rigidity of the incumbent surface, causing one part partially to counteract another; but in the case of a fluid, where all the particles move freely upon each other, no such impediment exists.

As it is chiefly the lower stratum of wind which is thrown into gyration from this cause, it must be evident, as above suggested, that within the geographical limits of the trade winds the great circuit of aerial revolution must be a nearly horizontal one, and that the storm tracks mark distinctly the usual course of this revolution. Consequently, the main outflowing course of the trade wind from the equatorial latitudes is not in the upper regions of the atmosphere.†

It was my design to have followed these general remarks with a detailed explanation of the delineations of the several systems of prevailing winds which I have placed on the maps before referred to. This was particularly my intention as relates to the extensive developments of the monsoons, and the several belts of light winds and calms which may be viewed as the anticlinal and synclinal axes, so to speak, of the several systems of general winds. But the lateness of the call and my necessary avocations have prevented me from fulfilling this labor, in time for the expedition.

This imperfect summary of the results of inquiries which I have pursued with no little interest, is now commended to the gentlemen of the expedition for their impartial examination; and with the expectation, and desire, that truth only, as apart from any favored theories, will be the object of their researches in natural science.

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* This chart may be found in this Journal, Vol. xxxi, for October, 1836; also in London Nautical Magazine, April, 1836, and Col. Reid's work on the Law of Storms.

† This is also shown by the extraordinary heat of the summers in countries near the western boundaries of the great oceans, this heat being conveyed horizontally by the surface winds from the lower latitudes; while in winter the results are modified and an opposite state of temperature induced, by causes which are peculiar to continental meteorology.