# Cyclonic Circulation and the Translatory Movement of West Indian Hurricanes

Rev. Benito Viñes

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**U. S. DEPARTMENT OF AGRICULTURE,**

**WEATHER BUREAU.**

# INVESTIGATION

OF THE

# CYCLONIC CIRCULATION AND THE TRANSLATORY MOVEMENT OF WEST INDIAN HURRICANES.

BY THE LATE

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WASHINGTON:
WEATHER BUREAU.
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## LETTER OF TRANSMITTAL

U. S. DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU,
*Washington, D.C., June 28, 1898.*

*Hon.* JAMES WILSON,
*Secretary of Agriculture, Washington, D.C.*

SIR: The accompanying paper upon the subject of West Indian hurricanes was prepared by the Reverend Benito Viñes, shortly before his death, for presentation to the Meteorological Congress at Chicago. It is regarded as the most satisfactory statement of the laws and phenomena of these storms which has yet been made.

It had been intended to publish this paper in Part IV of *Weather* Bureau Bulletin No. 11, but present circumstances render it especially desirable that the valuable information which it contains in regard to West Indian hurricanes should be made at once accessible.

I, therefore, recommend its immediate publication as an extract from Bulletin No. 11 of the Weather Bureau.

Respectfully,

Willis L. Moore,
*Chief of Bureau*

Approved:
JAMES WILSON,
*Secretary.*

# INVESTIGATION OF THE CYCLONIC CIRCULATION AND THE TRANSLATORY MOVEMENT OF WEST INDIAN HURRICANES.

***BY***


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Translated from the Spanish by Dr. C. FINLEY, of Habana, and in great part revised by the author before his death.


(Special extract from Weather Bureau Bulletin No. 11, Part IV, now in course of publication)

NOTE—The editor of the memoirs on dynamic meteorology presented to the International Meteorological Congress held at Chicago in August, 189, expresses his appreciation of the labors of Dr. C. Finley, of Habana, who, as a friend of the lamented Viñes, not only prepared the excellent translation here printed, but secured its final revision, except as to the last few pages, before the death of the author on the 24th day of July of that year. The few changes made by the present editor refer mostly to technical expressions and have not altered the general faithfulness of Dr. Finley's translation.—C. A.

# INVESTIGATION OF THE CYCLONIC CIRCULATION AND TRANSLATORY MOVEMENT OF WEST INDIAN HURRICANES

## I. — LAWS OF CYCLONIC CIRCULATION.

1st. *General law of cyclonic rotation.*—The aerial currents in a cyclone constitute a vast whirlwind around a central space of calm, of relatively small extent, called the "vortex" of the cyclone. It is an established fact that the direction of the rotary motion is always alike in the same hemisphere (northern or southern). *In our own the cyclonic rotation is invariably from right to left, in the direction from east to north to west to south*, or, as commonly expressed, in a contrary direction to that of the hands of a watch placed upon a horizontal plane, face upward. In the Southern Hemisphere the cyclonic rotation follows an opposite direction.

2d. *General law of cyclonic currents at different altitudes.*—A long experience (nearly twenty-three years) of assiduous and scrupulous observation, with frequent opportunities and under a great variety of circumstances, has afforded me ample evidence of the truth of the following statements:

*In the West Indian cyclones the rotation and the cyclonic circulation take place in such a manner that the inferior currents, as a rule, converge more or less toward the vortex; at a certain altitude the currents follow a nearly circular course, and higher still their course is divergent. It is particularly to be noticed that this divergence is all the greater as the currents occupy higher altitudes until a point is reached where the highest cirrus clouds are seen to move in a completely divergent radial direction.*

Thus, if the vortex lie due south, the wind will blow more or less from east-northeast, the lowest clouds will move from east, the alto-cumulus from east-southeast, the dense cirro-stratus from southeast, the cirro-cumulus from the south-southeast, and the light cirrus from south.

This gradation of the currents is of invariable occurrence, with greater or less perfection, in our West Indian cyclones, even when they present such incomplete organization as to be considered simple cyclonic perturbations of slight intensity. It constitutes what I have denominated *the law of cyclonic currents at different altitudes*,[1] a truly admirable law which is

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[1] The "law of cyclonic currents at different altitudes" was first indicated at pp. 243 and 244 of my "Apuntes relativos a los Huracanes de las Antilles en Setiembre [sic] y Octubre de 1875 y 1870," Habana, 1877, and subsequently in a pamphlet published by

undoubtedly founded on the very nature of the cyclonic movement, and on the essential mechanism of the storm, and, in my opinion, constitutes the *fundamental law of the cyclonic circulation*.[2] It will readily be seen that the law just enunciated is of capital importance in the theory of cyclones; but putting aside, for the present, all theoretical considerations, I may add that it is pregnant with practical results, and that its applications are of wider range and more useful than the so-called "law of storms," to far as the cyclonic rotation is concerned. The latter, in effect, only takes into account the lowermost current, the wind, which, far from being circular as that law implies, is perhaps among all the cyclonic currents that which forms most variable angles with the bearing of the vortex and, at the same time, is most liable to irregularities and to local influences. The law of cyclonic currents at different altitudes, on the contrary, takes into account all the currents within reach of observation in the different atmospheric strata; while, on the other hand, the fact of the general convergence of the lowermost currents, which it proves, rectifies the law of storms and gives it its real value. Through the gradation of the currents at different altitudes this law *discovers and evidences the cyclonic movement in the atmosphere*, and, finally, the observation and careful scrutiny of the different currents, which it implies, leads at once to a series of special laws, each of which under certain circumstances may assume an importance equal or superior to that of the law of storms; all the more so as some of the higher or intermediate currents present greater regularity than the inferior ones, and their course can be determined with greater precision than that of the wind. Before proceeding with the detailed examination and minute study of each of the cyclonic currents in particular, it is necessary to point out that the degree of *convergence or divergence of the different cyclonic currents* constituting the constant gradation mentioned in the above law *generally varies in different cyclones, and also on the different sides and in different positions of the same storm*; that is to say, according as the cyclone is of greater or less diameter, greater or less altitude, great or little intensity, perfect organization or otherwise, according as the front or the rear of the storm is considered, and, finally, according as the vortex of the cyclone lies within the Tropics or notably distant from them.

the U.S. Hydrographic Office,' at Washington in 1885, under the title of "Practical Hints in regard to West Indian Hurricanes;" this is simply a translation of a summary of my "Apuntes relativos a Huracanes;" a third edition of the American pamphlet was issued in 1887. The law referred to is also to be seen in my "Ciclonoscopio de las Antilles," Habana, 1898, in the "Pilot Chart of the North Atlantic Ocean," August, 1889, and in several papers recently published by Mr. Everett Hayden, Marine Meteorologist, with reference to his visit to Habana in 1888.

2 This law also accords with the more general law announced independently by J. Allen Broun in 1847, C. Abbe in December, 1871, and Clement Ley in 1872, i.e., that as we ascend in the atmosphere the direction from which the winds and clouds come, or the direction toward which they move, veers more and more to the right. This law seems to hold good for all movements whether of cyclones or anticyclones.-ED.

It is, however, well worthy of note that *the angle formed between the different cyclonic currents and the bearing of the vortex, according as the front or rear of the storm is considered, varies in obedience to a general law.*

Let us consider, in the first place, what observation has taught us in regard to these two general cases, provided the cyclone be situated within or near the Tropics, be properly developed, and display considerable strength as to its currents.

*A. Anterior portion of the storm.* — In the anterior portion (front) of the storm and, in general, when the winds blow from the northern quarters of the compass (east, north, and west, all included), the cyclonic currents are governed by the following particular laws:

*(a) Winds. — The winds, as a rule, converge toward the vortex*, so that, supposing the observer with his face to the wind, the direction of the center of the storm (the bearing of the vortex) forms with the direction of the wind, on the observer's right hand side,[3] an angle greater than 90°, embracing more than eight out of the thirty-two points of the compass. The magnitude of this angle varies, being generally comprised between eight and twelve points; that is to say, in some instances it does not much exceed eight, nor, except in extreme eases, does the greatest convergence give an angle exceeding twelve points, or 135°.

As a rule, then, a first approximation of no slight value in determining the bearing of the vortex will be obtained if we assume that the convergence of the cyclonic winds measures two points, or, in other words, that the direction of the wind forms with the bearing of the vortex an angle of ten points. So, for example, when the wind is from the northeast the vortex will be said to lie approximately to the south-southeast.

In the approximate determination of the bearing of the vortex by using

3 Whenever in this paper the vortex, cloud-bank, cirrus arc, etc., is said to lie more to the right or left, this must be understood with reference to an observer facing the vortex, cloud-bank, cirrus arc, etc. So, also, when the wind is said to veer or incline to the right or left, it must be understood that the observer faces the wind. But when the right or left of the storm track is considered the observer is supposed to be moving in that track and following the same direction as the vortex of the storm.

the direction of the wind, the following cautions must be borne in mind if we would avoid falling into lamentable errors:

1. When the vortex lies at a greater distance and the cyclonic winds are not yet well established, their convergence is apt to be greater and they are liable to many irregularities and to local influences.
2. The first squalls in front of the storm give divergent gusts. The squalls in fact proceed from the left-hand extremity of the cloud-bank and their gusts are directed outwardly, as happens with the ordinary thunderstorms; hence, during such squalls the wind veers to the right, that is to say, toward the cloud-bank, by four, six, and sometimes by eight points.
3. In the interior of the storm the gusts of the squall always bring the wind round to the right and therefore tend to lessen the convergence of the wind and sometimes almost to annul it.
4. As the wind increases in violence in the neighborhood of the vortex, its direction becomes less convergent, owing to the centrifugal force developed in that part of the storm, and, probably, also to the influence of the incessant squalls which, in that part of the hurricane, continually occur.
5. In the Island of Cuba cyclonic winds blowing from north to north-northeast present scarcely any convergence at all; hence, in this particular case, the law of storms[4] may be applied without notable error.
6. The trade wind, reinforced by the cyclone, modifies considerably the convergence of the cyclonic winds, sometimes (as in the above instance) suppressing it completely, and at others increasing it, so that the vortex may be lying to the south while the wind is from the northeast.

*(b) Low clouds. —The low clouds move in a direction nearly perpendicular to the bearing of the vortex.*

This intermediate current presents much greater regularity than the inferior winds, and the angle that it forms with the bearing of the vortex is far more constant, hardly presenting any noticeable variations when once the cyclonic currents are well established. In the generality of cases, therefore, in the front part of the cyclone, the law of storms may be applied to this current without notable error. The intermediate current under consideration includes the low cumulus of dark or leaden hue, the strato-cumulus, and the loose flakes of stratus and nimbus, which, in the interior of the storm, fly with great velocity. It must be remarked, however, that the less dense fracto-cumulus, which appear at the commencement, occupying a somewhat higher position, are apt to take a rather divergent direction.

*(c) Alto-cumulus clouds, cirro-stratus, cirro-cumulus. —The alto-cumulus, the dense cirro-stratus, and the light cirro-cumulus move from divergent directions, forming, with the bearing of the vortex, acute angles that are smaller in proportion as the currents to which they belong occupy a higher position*; that is to say, that the smallest angle is formed by the *cirro-cumulus* and the widest by the *alto-cumulus*; the intermediate angular magnitude corresponds to the *cirro-stratus* or the *dense veil of cirrus clouds.*

It must also be borne in mind that the angles which these currents form one with the other and with the bearing of the vortex are far from constant, the greater or less angle between them and the regularity with which they are disposed depending, apparently, on the degree of organization attained by the storm and on the height and force of the said currents. Thus, in a well-organized cyclone of considerable intensity, a great regularity is generally observed in those currents, not only with respect to the order in which they are always superposed, but, also, with respect to the differences between their directions of movement. In such cases they are apt to form, with the bearing of the vortex, angles, approximately, of six points for the high cumulus, four points for the cirro-stratus, and two points for the cirro-cumulus.

*(d) Cirrus clouds.* —Finally, *the light cirrus clouds* constituting the highest current that falls under our observation *move, as a rule, in a completely divergent or radial direction, forming with the bearing of the vortex an angle equal to zero or practically inappreciable.* This current is one of the most regular and generally forms a right angle with that of the low clouds.

To sum up briefly, we find that the cyclonic currents which exhibit the greatest regularity and point out best the bearing of the vortex are those of the cirrus and of the low clouds. The current of the cirrus clouds is that which should be selected in preference when the first indications of the approach of a cyclone are seen and the vortex is still far distant. In the interior of a storm the observer must be guided principally by the movement of the low clouds. In the absence of cirrus clouds the currents of the cirro-cumulus and cirro-stratus may guide one, and when there are no low clouds the wind and the high cumulus

[4] The author refers to the circular rule of the older cyclonologists, according to which the bearing of the vortex is eight points or 90° to the right if one faces the wind, a rule that was strongly opposed by Meldrum and others. -ED.

may be resorted to instead; always bearing in mind, however, that these indications are less reliable and the approximate inferences less satisfactory. In a well-developed cyclone of considerable intensity we can generally observe the following gradation and disposition of the currents. If the vortex lies to the south-southeast, the cirrus clouds will move from south-southeast, the cirro-cumulus from southeast, the dense cirrus-veil from east-southeast, the alto-cumulus from east, the low clouds from east-northeast, and the wind from northeast.

*B. Posterior portion (rear) of the storm. —In the rear of the storm and, in general, when the prevailing winds are from the south, or from the points of the compass between east-southeast, south, and west-southwest, it is observed that all the currents in general form wider angles with the bearing of the vortex than in the previous case, the gradation between then, however, remaining the same.* So that in the rear of the storm the inferior currents are *more convergent* and the superior ones *less divergent* than in the front. Thus, if the vortex, for example, lies to the northwest, the wind comes from south-southeast or south, the low clouds come from south or south-southwest, the alto-cumulus from southwest, the cirro-stratus from west-southwest, the cirro-cumulus from west, and the cirrus approximately from west-northwest.

*C. Cyclones moving off to the north of the Tropics.* —As the cyclone moves off to the north of the Tropics and is converted into a cyclone of middle latitudes, the currents gradually lose their regularity, although their gradation continues the same. Sometimes, however, the movements of cirrus clouds present great irregularities; thus, for example, when the vortex lies to the northwest or north-northwest in the Gulf States, the current of the cirrus clouds is apt to suddenly come from the northeast. In such a case I believe that the current observed is a resultant of the superior current of the cyclone acting together with the superior general current which at that time of the year comes from the eastern quarter. I might here enumerate as effects of the cyclonic circulation certain important phenomena which in practice are of effective assistance for discovering the presence of a cyclone, the bearing of its vortex, its diameter and relative intensity, etc., such as the arcs of cirrus clouds, the form and degree of convergence of the cirrus and cirro-stratus toward the vortex, the cloud-bank of the storm, halos, red appearance of the sky at sunset, etc.; but all this has been explained in my "Apuntes relativos a los Huracanes de las Antilles en Setiembre y Octubre de 1875 y 1876."

## II. —LAWS OF CYCLONIC TRANSLATION.

*1st. General law of translation of the West Indian cyclones.* —From its starting point the cyclone advances from the fourth quadrant[5] more or less nearly westward. Later on it gradually inclines toward the north, and finally recurves toward the first quadrant, so that in the final portion of its course it commonly moves northeastward or east-northeastward. The complete track forms, therefore, a sort of parabola with its vertex on one of the parallels of latitude and generally on the most western meridian reached by the curve, the opening between the two branches being directed eastward. The axis of the parabola is likewise directed approximately eastward, at times inclining more or less to northeast.

*2d. Law of the recurving of hurricanes in the different months of the cyclonic season.* —At the commencement of the hurricane season, about the end of May or beginning of June, the hurricane tracks keep very low, and the recurving also takes place at very low latitudes (some 6° or 8° below the tropic). As the season advances the latitude of the vertex of the track increases *rapidly*, so that in the second decade of June it reaches the vicinity of the tropic, and by the end of June it already lies 2° or 3° above the tropic. After this period, as the recurving takes place nearer to its maximum latitude, the latitude of the vertex advances slowly toward the north, so that in all the month of July it only rises by two or three degrees of latitude. Finally, in the month of August, between the 15th and 25th, the vertex of the track attains its maximum of latitude (between the thirtieth and thirty-third parallels). After reaching this maximum the latitudes of the vertices decrease symmetrically, in a similar order and with the same relative velocity as they increased. Hence, the curves in the month of September are analogous to those of July, and those of October to those of June, though it must be borne in mind that the first decade of October corresponds to the third decade of June, the second of the former to the second of the latter, and the third decade of October to the first one of June.

Having thus expounded this law in a general way, I shall now attempt to express it in more concrete terms, pointing out, as far as possible, the relation between the latitudes at which the cyclones recurve, and the dates on which this occurs. The season will be divided by months during the period corresponding to the maximum latitude of the cyclonic track, when the variations in the recurring latitude are slow and only comprise

[5] Through the second quadrant -ED.

a few degrees, but by decades during the months of June and October, in which the changes are rapid, covering an extent of more than 10°.

The law as expressed in the following table will, in my opinion, be found sufficiently exact and available for practical purposes:

| **Dates of the Recurving.** | **Latitude of the Recurving** ° |
|---|---|
| August | N. 29-33 |
| July and September | N. 27-28 |
| June (3d decade) and October (1st decade) | N. 23-28 |
| June (2d decade) and October (2d decade) | N. 20-23 |
| June(1st decade) and October (3d decade) | N. 35-20 |

In the absence of data I can not point out the minimum latitude reached by the hurricane's recurving point at the commencement and termination of the season; I think, however, that it can not be far distant from the fifteenth parallel. The hurricane of October 22, 1865, recurved between latitude 16° and 18°. I consider it possible, however, that some hurricanes may recurve in latitudes somewhat below 15°, though I have no positive proof that it is so. At the commencement of the season, cyclones are few in number, they generally form about the Windward Islands and keep in very low latitudes; so much so that, at times, they enter the Mexican continent and there dissolve without having reached the zone corresponding to their recurving latitude. At the end of October cyclones are rather more numerous, they generally form in the western portion of the Caribbean Sea and cross the western parts of the Island of Cuba or in the vicinity of the Yucatan Channel, moving in a northeast direction along the second branch of their track, without my being able to say whether they have previously recurved or otherwise.

According to the above statements we find that the annual oscillation in the latitudes at which West Indian cyclones recurve amounts to about 18°. This oscillation takes place in a *gradual, continuous*, and *symmetrical* manner, which might well be represented by a *regular, symmetrical, continuous* curve. Here arises precisely the difficulty of formulating the law so as to establish the connection between the months or decades and the latitudes of the recurring. It is evident that a cyclone which recurves on the 31st of August and another recurving on the 1st of September will both do so almost in the same latitude, according to the law which I have just explained. Nevertheless, if the law be adhered to, according to what has been formulated for months and decades, it would have to be said that the cyclone of August 31 ought to recurve between the twenty-ninth and thirty-third parallels and that of September 1 between the twenty-seventh and twenty-ninth. This will appear simply absurd without an appropriate explanation It must, therefore, be understood that the recurving latitudes, which, in formulating the law, I placed in July and September, are average values which correspond to the middle of the month or of the second decade. The gap would be greater still if for the recurvings of June and October we took the average either of the month or of the second decade. If we attend strictly to the division by months, and without explanation, the result would be reached that a cyclone of September 30 would have to recurve between the twenty-seventh and twenty-ninth parallels and one of October 1 between the twentieth and twenty-third, This, it will be easily seen, would be a tremendous jump and wholly inadmissible.

This is the flaw in the law which was given as mine without any explanation whatever by Mr. Everett Hayden.[6] It must be explained that Mr. Hayden copied the said law from a manuscript paper which I was preparing on the Cyclonoscope for my own use and in which the law was formulated by months. I must, therefore, declare that in the law thus published I referred only to the average latitudes at which the cyclones recurve in the different months and which correspond approximately to the middle portions of the months.

The theoretical and practical importance of the law of recurving in West Indian hurricanes will be readily appreciated by observers and seamen.

*A. Theoretical importance of the "law of recurving."*—Theoretically speaking this law is so intimately connected with the changes in the sun's declination and with the several positions occupied, according to seasons, by the equatorial zone of calms and rains, by the zones lying on the limits of the trade winds and by the anticyclone of the Atlantic, that, in my opinion, if this law had not been discovered *a posteriori* we would

[6] Pilot Chart of the North Atlantic Ocean for May, 1889, and subsequent issues.

have to suspect *a priori* that it existed.

This law is also connected with the changes of direction experienced by *the general upper current in the tropical regions*. In fact during the whole year, in Habana, if we except the hurricane season, the upper currents come from the west. In the first half of June and particularly in the second half of October the currents of the cirrus clouds incline to the south and southwest which is precisely where the cyclones come from at that time of the year, for they reach us as they are about to recurve, or just after recurving, since, according to the second law, they should do so below the tropic. From the end of June to the beginning of October the upper current sets from the east, and this is (without any exception whatever in all the observations that I have made so far) the only time of the year when the circus clouds come from that quarter. This fact, when taken in connection with the tracks of the cyclones, is very significant; for, precisely at that time, if a cyclone advances toward Habana it has necessarily to come from the east, since it must recurve to the north of the tropic and consequently we must receive it in the first branch of its track. On the contrary, excepting in the season just mentioned, in all the rest of the year, the cyclones that pass by Habana, or in its vicinity, are all more or less from the west and never from the east. In fact the cyclones of the end of October come all from the third quadrant, having previously recurved. Those of November, December, and January all pass to the north of Habana in a northeast direction, as cyclones moving along the second branch of their track. In all the rest of the year they pass to the north of and at a greater or less distance from Habana more or less in the direction mentioned above. The facts that I have brought forward seem to indicate that *the cyclones are directed along their tracks by the upper currents*, which to my mind seems highly probable.

The law of recurving has also intimate connection with the *greater or less cyclonic activity in the West Indian seas during the different months.*

*The maximum and minimum latitudes reached by the recurving point correspond respectively to the maximum and minimum of cyclonic activity.*

In the second fortnight of August the hurricanes are, in general, more numerous and more violent; they move along their tracks with greater velocity, reach greater altitudes, and the parabola which they describe is very wide, so that whatever be the force that, projectile-like impels the cyclone, its reach and amplitude are greater, and so consequently must be its impulsive energy. Besides, if the general currents direct cyclones in their courses, this fact would denote that at this time of the year these currents attain their maximum activity and reach higher latitudes. The second fortnight of August and the beginning of September are moreover the epochs for simultaneous or twin cyclones; so much so that in 1886, during the last decade of August, there were at one time four cyclones around Habana: One in the island to the east-southeast, one to the northeast, and two more in the Gulf of Mexico. Excepting at this season I only know of three cases of simultaneous cyclones near Habana, one occurred in September and two in October.

In July and September the cyclones are less numerous, generally less violent, they move along their tracks with less velocity, are more inclined to the west and describe narrower parabolas.

Finally, in June so few cyclones are observed that they are scarcely sufficient to establish a law. In October they are somewhat more numerous, but still few; some are quite intense; they move with but little velocity along the first branch of their track and while recurving.

*B. Practical utility of the "law of recurving*"—This law gives with much probability and sufficient approximation, directly and in the most simple manner, the latitudes of the cyclonic recurvings as a function of the dates. If to this law is added some knowledge of the following one which treats of the normal direction of the tracks for different months and latitudes, and is intimately connected with the "law of recurving," a seaman will obtain efficacious help for his timely maneuvers and an observer for his studies and forecasts. From the moment when an observer or a seaman recognizes the approach of a cyclone, by simply determining approximately the position of its vortex and merely considering the date, he can ascertain with a high degree of probability whether it is very near to or very far from its recurving point, and, knowing besides the normal direction of the tracks for that time of the year and in that latitude, he can also infer whether it will pass far from or near to the place where he is, or if he be placed in the very track or to the right or left of it.

To show the importance of these easy deductions, founded on the said laws, I shall mention a practical case, which I have often observed. Let us suppose that from my observatory I detect the presence of a cyclone to the southeast in the middle of September. To know whether it will pass far from or near to Habana I need only follow the following simple reasoning: The vortex of the cyclone lies approximately to the southeast, on the seventeenth parallel. At this date and with the vortex in that position the normal direction of the track is west-northwest, approximately, and the cyclone ought not to recurve until it has reached the twenty-seventh or twenty-ninth parallel; consequently it will past at large, at a distance in the southern sea, in the direction of the Yucatan Channel, touching, at most, the western extremity of this island. It will recurve at the coast of Texas, and in the second branch of its track will cross the United States and find its way to the Atlantic near Cape Hatteras, This case I have witnessed several times, and invariably the vortex of the cyclone has passed to the south of and at a great distance from Habana.

But let us now suppose that I recognize the presence of a hurricane to the southeast of Habana in the month of October, instead of in the middle of September. The proximity of the cyclone in this case would cause me much anxiety, for, by simple reasoning, I should infer that the vortex would pass very near Habana, if not through Habana itself. In fact the vortex would be lying to the southeast, about latitude l7°. At this date and latitude the direction of the normal track is northwestward, inclining to north-northwest, and the cyclone ought to recurve between the twentieth and twenty-third parallels; consequently it would do so to the south of this city and very near our meridian, so that on starting along the second branch of its track the vortex would pass through Habana or in its vicinity. During the years that I have been making observations in these regions I have witnessed two such cases, in both of which the inference just pointed out was fully verified. On Sunday, October 15, 1876, I recognized by the radiating point of plumiform cirrus a cyclone to the southeast, and on Thursday, 19th, at midday, the vortex of the cyclone, having now started along the second branch of its track, crossed Habana in a north-northeastward direction. This hurricane caused great damage in the island. On Thursday, October 17, 1878, by the radiating point of cirrus clouds I recognized another cyclone to the southeast, and in the night of the 20th–21st its vortex passed at only a few miles distance east of the observatory between Habana and Matanzas, having also just started along the second branch of its track in a direction approximately north-northeastward. Both recurved, according to the law, between latitude 20° and 23°.

Finally, taking another case, let us suppose that without notable difference in the date, that is to say, in September, I discover the proximity of a cyclone, not to the southeast, but to the east-southeast of the observatory. By a similar reasoning I immediately infer that I am either in the very track of the cyclone or very near it. In fact the normal direction of the track in its first branch, for that date and for latitudes between 18° and 23°, is approximately west-northwestward; consequently the vortex discovered in the east southeast is probably moving in that direction and would be coming directly toward Habana or its vicinity. Three cases of that kind have come under my observation, and in each one the vortex has passed through Habana or very near it. The first case occurred in September, 1875. The first indications observed (the radiating point of the divergent cirrus clouds) appeared exactly in the east-south-east in the afternoon of the 12th. From the appearance, form, and structure of the cirrus, I deduced that the cyclone was of great diameter, and, in fact, the vortex stood at that time over the western portion of the Island of Haiti, east-southeast of Habana, at a distance of some 550 miles. Of all those that I have seen below the tropic this is the one discovered at the greatest distance, on account of its great diameter. The track of this cyclone ran through the Island of Cuba from the Peak of Tarquin to Habana. In the night of the 13th the vortex passed over this city and entered the Gulf of Mexico with increasing velocity in the direction of Texas, where it recurved about latitude 28°, according to the law. In the second branch of its track it passed to the north of New Orleans and came out upon the Atlantic somewhere north of Cape Hatteras. The cyclone of September, 1878, which made its appearance in the same quarter, crossed the provinces of Cuba, Puerto Principe, and Santa Clara, and came out on the Atlantic near Cardenas. From this point it began to incline to northwest by west, and recurved in Florida about latitude 27°, so that on passing to the northeast of Habana it came pretty near us. Finally, the vortex of the cyclone of the beginning of September, 1882, passed first near Cienfuegos, then very near Habana but south of it, and afterwards devastated all the cultivated lowlands west of Havana.

*C. Influence of longitude on the recurving of cyclones*.—Longitude considered in itself and independently of other causes has, I believe, no influence whatever on the recurving of West Indian hurricanes. For example, of those of August some recurve north of the island of Haiti, some north of the Bahamas, some in the Gulf of Charleston, and others in Louisiana or on the coast of Texas. Those of September recurve, some northeast of Cuba, some in Florida, others west of Florida, and others finally near the coast of Texas. Of the cyclones in October I know of some that have recurved northeast of Puerto Rico, and the one called "the great hurricane" of October 12-18, 1780, recurved in the vicinity of the tropic north of the Island of Haiti. Others, finally, recurve either at the south of the Island of Cuba or in its western portion, or else in the eastern part of the Gulf.

*D. Influence of the configuration of the seas and continents on the recurving of cyclones*—The relative position of the seas and continents appears to have some influence on the recurving of hurricanes, for any one may observe that a great number of the cyclones of August do so in the Gulf of Charleston without extending to the continent and many of those of July and September recurve on the coast of Texas.

To conclude what I have undertaken to explain about the "law of recurving," I need only add that when the old authors, in establishing the "law of storms," supposed that cyclones recurved about latitude 30°, they were not far wrong. In reality most of them do recurve near the thirtieth parallel inasmuch as the hurricanes of August do so about latitude 29° to 33°, and those of July and September about latitude 27° to 29°, and they constitute the majority, for they correspond to the season of *maximum cyclonic activity or to dates not far removed therefrom*. The cyclones of June and October are few in number, and the old observers might very well have considered them as anomalies in the general law of storms.

*3d. Law of the normal direction of the tracks at different dates and latitudes.* — For the sake of brevity I shall formulate in the following table the law according to which the date and the latitude of the vortex are related to the normal direction of the track.

It must indeed be admitted that the said law, although we see that it exists, that it is intimately connected with the "law of recurving" and must be of great utility in practice (as already shown), nevertheless is undoubtedly extremely difficult to formulate, and even my own method is only an approximate one. Notwithstanding this, however, it offers in many cases great probabilities of truth, as shown by the examples cited.

*Normal directions of the tracks at different dates in different lattitudes.*

| **Dates.** | **Directions.** | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | W. | | WNW. | | NW. | | NNW. | N. | | NNE. | | NE. | | ENE. |
| | ° | ° | ° | ° | ° | ° | ° | ° | ° | ° | ° | ° | ° | ° |
| August | 10 | 15 | 15-20 | 20-25 | 25-27 | - | 28 | 29-33 | - | 34 | - | 35-40 | - | - |
| July and September | 10 | 15 | 15-24 | - | 25 | - | 26 | 27-29 | - | 30 | - | 32 | 33-35 | 35-40 |
| June, 3d decade, and October, 1st decade | 10 | 15 | 15-20 | - | 21 | - | 22 | 23-26 | - | 27 | 28 | 29 | 30 | 31-40 |
| June, 2d decade, and October, 2d decade | 10 | - | 12--24 | - | 15-16 | 17 | 18-19 | 20-23 | - | 24 | 25 | 26-30 | - | - |
| June, 1st decade, and October, 3d decade | 10 | 12 | 13 | - | 13-14 | - | 15 | 16-20 | - | 22 | 23 | 24-30 | - | - |

The difficulty in formulating this law with precision arises from the manner in which the "law of recurving" has been established. In fact in the second of the above laws I have had to allow a margin of from 3° to 5° for the recurving in the different months and decades. In August, for example, the latitude of recurving is between the twenty-ninth and thirty-third parallels; yet it is evident that the normal track in the vicinity of the vertex of the parabola can not be the same for a hurricane that recurves in the twenty-ninth parallel and for one which does so in the thirty-third; so that the normal directions of the tracks as noted down for the different months and latitudes are approximations or strong probabilities, so long as the hurricane moves in a westward, west-northwestward, or northwestward direction, that is to say, within the latitudes marked in the first three divisions of the table, whereas in the latitude noted in the three next divisions (when the normal direction of the track is north-northwestward, northward, or north-northeastward, in the vicinity of the recurving point), the direction may in many cases be notably different according to what I have explained before.

I must also mention that, according to the law as above formulated, the tracks in August have their branches wide apart, whereas those of July and September and those of the third decade of June and first decade of October generally describe an acute parabola with branches much less open, unless, indeed, the second branch of the track departs from the normal direction, as it sometimes does, inclining a good deal to the north, in which case the parabola has its axis directed east by northwardly or east-northeastwardly. Whenever this occurs, in order to apply the "law of recurving," one must take as the recurving point the vertex of the parabola, that is to say, the intersection of its axis with the curve and not the most western point of the latter, which lies a little more to the north.

The two above laws only give the *latitude of the recurving as a function of the* *date, and, the normal direction of the track as a function of the latitude of the vortex and the date*. They are, therefore, general laws in which no account is taken of the longitude of the different points of the track and they consequently apply to a series of indeterminate tracks which may lie more or less to the east or west. They give us no information, in any particular case, regarding the true geographical position of the track even when we know the date and the approximate latitude of the vortex. Now, if after determining, at a given moment, the latitude of the vortex I also ascertain its *longitude* (which offers no greater difficulty than does the determination of the latitude, either because I may happen to know of some place where the vortex has touched or because I have ascertained by observation the bearing and approximate distance of the vortex), then through that single known point of the track, having availed myself of the date and latitude of the vortex and having applied the above laws, I can draw the corresponding normal track and thus obtain the true geographical position of the *probable and approximate track* of the cyclone, as deduced from general laws and with no other information, I repeat, than the date and approximate position (in latitude and longitude) of a single point of the track.

The approximation would be greater if I were able to determine, as can often be easily done, the approximate position of a portion of the track. Through this known portion I should draw the corresponding normal track, and it would generally be found to deviate but little from the one which the cyclone has actually described.

4th. *Laws of the general routes or geographical zones pursued by West Indian hurricanes according to months*. —The two preceding laws are so general that they are applicable, as we have just seen, to innumerable tracks situated more or less to the east or to the west. They afford, therefore, no indication as to the general routes which in point of fact the cyclones pursue or to the geographical zones which in different months limit the general positions of the tracks within what Mr. Everett Hayden so properly calls "the Bay of North America."

From those two laws we deduce that every cyclone in August crosses the twenty-third parallel, but they do not tell us that none of these cyclones pass near Habana, which lies precisely in latitude 23°. From them, also, we infer that, generally speaking, every cyclone in October crosses the eighteenth parallel in a certain direction, but they do not inform us that it very rarely happens that an October cyclone passes near Puerto Rico, which lies in that very latitude. Nevertheless the fact exists, and is of such ancient belief that the ecclesiastical authority, from time immemorial, wisely ordained that priests in Puerto Rico should recite in the mass the prayer "Ad repellendat tempestates" during the months of August and September, but not in October, and that in Cuba it should be recited in September and October, but not in August. All of which proves that the ecclesiastical authority knew by experience that the cyclones of October are very much to he feared in Cuba, but not those of August, and that in Puerto Rico, on the contrary, the hurricanes of August are disastrous, while those of October are very rare.[7] This constant and well established rule, proved by experience, implies a general law which connects the geographical position of the tracks on the map of the West Indies with the circumstance that the season is more or less advanced.

Let us, therefore, try to unfold this law and formulate it in the best manner possible, for it will be of great utility to mariners, as it will indicate to them the points of greatest possible danger in the different months of the year.

I have already called attention to the fact that longitude in itself, considered independently of all other causes, does not appear to have any influence in the recurving of the cyclones; this can also be said of the normal direction of the tracks on the different dates and in different latitudes. But it is otherwise with respect to the geographical distribution of seas, islands, and continents, which not only influence the recurving, but also the localities in which the cyclones originate, according as the season is more or less advanced, and consequently also the general routes which the cyclones pursue in those particular regions. These geographical zones, or this route which hurricanes generally follow at definite dates and in given regions, do not alter in the slightest degree the other two laws already stated, which are more general ones. On the contrary, they enable us in particular cases to apply these universal laws to the general course of cyclones in the different months.

It must, of course, be admitted that the tropical cyclones do not form indefinitely at any point within the tropical zones, but that they single out, in preference, for their formation and development, particular and definite regions in those zones. The following geographical conditions generally and in a more or less perfect degree distinguish the cyclonic

[7] On October 29, 1867, there was a furious hurricane in Puerto Rico which bifurcated in the "Sierra del Luquillo." The cyclone was completely anomalous, its track being directed to west-southwest. It was a celebrated cyclone and is known as "el temporal de San Narciso."

regions within the Tropics: Large continents lie to the west, indented by numerous gulfs and bays whose coasts run more or less northward and southward, with vast and extensive seas to the east, overspread commonly with numerous islands. Such at any rate are the features that in a more or less perfect degree concur in the cyclonic regions of the Philippine Isles and in the China Sea, in the seas of India, and also in the Southern Hemisphere, in the region situated east of Africa, in the vicinity of the islands of Madagascar, Mauritius, Réunion, Rodriguez, etc. But of all the cyclonic regions within the intertropical zone the one which more perfectly and grandly combines all these conditions is the great "Bay of North America," with its wide Atlantic Ocean extending to the east as far as the coast of Africa and to the northeast as far as the coast of Europe and the northern seas. In my opinion this contributes much to the grandeur and regularity of the immense paths of the West-Indian cyclones. A cyclone of August or September may form in the vicinity of the Cape Verde Islands, near the coast of Africa, or to the east of the Lesser Antilles, cross the Atlantic along the first branch of its track and recurve either in the Gulf of Charleston or on the coast of Texas. In the latter case it may cross the United States in the direction of Cape Hatteras, sweep, with renewed strength and velocity a second time across the Atlantic, in a northeastward direction and enter Europe or be lost in the northern seas. We have, then, a series of cyclones which describe immense tracks over many thousands of miles with admirable regularity and normality, and subject to general laws. This is truly surprising and astounding. I do not believe that on the face of the globe there is another region where cyclones are met with that can compare with those of the West Indies, or, rather, I should say, with those of the great Bay of North America. Neither is there within the whole intertropical zone a grander bay than this one, nor one which offers more favorable conditions for the development and onward progress of gyratory storms.

The Bay of North America comprises, as I understand, that part of the Atlantic to the west of the fifty-fifth meridian (longitude west of Greenwich) from Newfoundland to Dutch Guiana, it is bounded on the east by the said meridian and on the north, west, and south by the coasts of Newfoundland, Labrador, and Gulf of St. Lawrence, by the coasts of the Atlantic, Gulf of Mexico, and Caribbean Sea from Yucatan to Dutch Guiana. It embraces the West Indies, the Caribbean Sea, the Gulf of Mexico, the Bahamas, the Bermudas, and the gulfs of Charleston and of the St. Lawrence.

Now, it is in the southern part of this great bay, that is to say, in the Caribbean Sea, and in that portion of the Atlantic which extends to the east of the West Indies, that hurricanes are formed and developed, with this peculiarity, that according to the position occupied by the equatorial zone of calms, by the Atlantic anticyclone, and consequently by the southern limit of the trade wind, respectively, the cyclones form either more to the north or more to the south, and *above all more to* the east or west. The point of origin and formation of the hurricanes depends, therefore, on time more or less advanced season of the year. Now, as the variations in the point or region where cyclones originate during the hurricane season principally affect the positions in longitude extending across the Atlantic from the Cape Verde Islands to the coasts of Honduras and Yucatan and to the eastern portion of the Gulf of Mexico, it results that the region where the cyclones originate during two months and a half, that is to say, from the middle of August (maximum of cyclonic activity and of the recurving latitudes) to the end of October, or from the beginning of June to the middle of August, will move in the space between the Cape Verde Islands and the western portion of the Caribbean Sea.

According to my opinion this seasonal change of origin takes place in the following manner: In the middle of August, when the anticyclone of the Atlantic is about latitude 30° or 35°, the trade winds of the Northern Hemisphere and those of the Southern (converted into southwest monsoon) generally meet somewhat to the south of the Cape Verde Islands, where lies the area of low barometer, and in this vicinity it is that the August cyclones are formed. At this time the isobars of the Atlantic anticyclone extend to the southwest of the Island of Cuba and Caribbean Sea, and on this side no cyclones are formed. In the month of September the Atlantic anticyclone draws near Africa, its isobars invade the eastern part of the Atlantic east of the West Indies, and leave the Caribbean Sea free; at this time the cyclones are formed somewhat to the east of the Lesser Antilles or in their vicinity. In the first decade of October the state of things varies but little. Some cyclones, however, form rather more to the west in the eastern part of the Caribbean Sea. In the second and third decades of October the 30-inch isobar, which surrounds the Atlantic anticyclone and that of the American Continent, only leaves free the western portion of the Caribbean Sea south of Cuba and part of the Gulf, the depressions or low barometric areas move to this region, and it is here that the hurricanes originate which prove so disastrous to the western half of the Island of Cuba at this season of the year.

The months of July and June in this particular do not quite agree with those of September and October. In some years the anticyclonic isobars of July invade the Caribbean Sea, and in those years there are usually no cyclones in July. In other years the anticyclonic curves lie rather farther north and leave the Caribbean Sea free; in such years cyclones are apt to form in those regions and follow the same laws as those of September, with the exception that they move in somewhat lower latitudes. The hurricanes of the third and second decades of June agree with those of the first and second decades of October, respectively. Those of the first decade of June are very few; they come from the windward, move in very low latitudes, penetrate Mexico, and dissolve without recurving. Many years pass without cyclones in June; nevertheless cyclonic perturbations following the same laws sometimes occur to the south and southwest of Habana, causing great inundations in the western provinces of Cuba. The year best suited for the study of cyclones in the Caribbean Sea is that of 1886. During that year there occurred an *uninterrupted series of cyclones and cyclonic perturbations from May to the end of October*. I witnessed some twenty myself, of which number fourteen or fifteen were real cyclones; two of them crossed the Island to the east and west of Habana, and some others passed very near to the north and south; the rest were cyclonic perturbations of more or less intensity. Having established these preliminaries, which were indispensable, I shall proceed to formulate the fourth law, by months and decades.

*(a) August.* —We have said that the August cyclones commonly form far to the east in the vicinity of the Cape Verde Islands. The initial track is nearly due west; it then gradually inclines to the north, gaining in latitude. In the Windward Islands, or their vicinity its direction is approximately west-northwest. In the neighborhood of Puerto Rico the general route of the August cyclones, or the geographical zone which their tracks occupy, is a little over 450 miles in width, i.e., from 100 miles, or a little more, to the south to about 350 miles to the north of the said island. In the vicinity of Cuba the width of this zone reaches from the Old Bahama Channel to about 500 miles to the northeast. The recurvings of these cyclones embrace a zone between latitudes 29° and 33°, and are generally limited to between the meridians of New Orleans and Puerto Plata, Santo Domingo, or between W. 90° and W. 71°. The part of this zone most frequently visited is comprised between the coast of the Gulf of Charleston and some 300 to 400 miles to the east. The width of the zone which the tracks embrace when recurving continue to increase more and more as the cyclones advance farther to the northeast, and this generally applies to every month.

*(b) September.* —The hurricanes of September enter the Caribbean Sea at some point between the vicinity of Barbados and St. Thomas. Some, nevertheless, cross to the north of St. Thomas, even at a distance of more than 200 miles. The width of the zone in the neighborhood of St. Thomas is from 400 to 450 miles. A section of this zone through the central region of the Island of Cuba gives a width of from 550 to 600 miles, that is to say, from a line situated somewhat north of the Bahamas and parallel to their direction to some 250 or 300 miles south of the island. The recurving zone extends from Texas to at least the meridian of Punta Maisi, W. 74°. In determining these zones I leave unnoticed such occasional cyclones as may occur much more to the east, running their course far to the north of the West Indies. Those move quite outside of the general and more frequent paths. If we had to take them into account it would not be possible to trace general routes for the cyclones of the different months, which, nevertheless are facts. These isolated cases must be looked on as anomalous with respect to the law we are discussing.

*(c) July.* —The cyclones of July follow a similar course to those of September, with the exception that they move in lower latitudes, generally cross the Caribbean Sea, and recurve on the coast of Texas. They are fewer than those of September and embrace a much narrower zone.

*(d) June (third decade) and October (first decade).* —Some of these hurricanes form to windward and others in the eastern portion of the Caribbean Sea. They generally run close to the Island of Cuba, cross its western provinces or the Yucatan Channel, and recurve between latitude 23° and 26°. The recurving generally takes place between the meridian of Matanzas and that of Cape Catoche, W. 87°.

*(e) June and October (second decades).* —These hurricanes form at the south of the Island in Cuba, commonly to the southeast of Habana, but some near Central America; they recurve about latitude 20° to 23°, and, generally in the second branch of their track, cross the western provinces of the island between Matanzas and Pinar del Rio. The cyclones *d* and *e* are most disastrous; they are, above all, very trying to the western part of Cuba, for they strike the island when recurving, or near that portion of their track, and advance but slowly; some have been felt during four, five, and six consecutive days, causing great havoc and terrible inundations.

*(f) October (third decade).* —These cyclones form near Central America and cross the Western portion of the Island of Cuba in the second branch of their track with increased velocity. They are much to be feared, for they are of great violence, and we have to be on the alert to discover them in time, for they are no sooner recognized than they are upon us.

*E. Practical application of the preceding law.* —The law that I have just expounded points out to mariners the most perilous regions for the different hurricane months so that they may keep out of them as much as possible, or, if they must cross them, they can try to ascertain whether the way be clear of danger or otherwise. If their courses lie through such regions then they should be on the watch for the first signs of a cyclone, so as to adopt the proper measures in time. Leaving to the prudence of mariners the care of applying this law as circumstances may suggest or their courses may allow, I shall merely bring forward some practical cases which may occur.

Sailing vessels running between the ports of South America end Habana in the month of August can sail by the Caribbean Sea without danger. In July and September they can also do so with advantage provided they keep in low latitudes; near the Yucatan Channel they must be on their guard. In the month of October it is very dangerous to make any voyage in the Caribbean Sea; but to the north of Puerto Rico there is no probable peril until very near Habana.

The voyage from Habana to Spain by steamers by the New Channel is not perilous if made with care. On leaving Habana the captain, through telegrams from the Windward Islands and observations made in the Island of Cuba, can in most cases be assured of safety during the time necessary for getting out of the channel. Once to the north of it let him make for the east, passing south of the Bermudas, and within forty-eight hours after leaving Habana he will have crossed the zone visited by August cyclones and entered the Atlantic anticyclone, with they advantage that should there be any cyclone it will pass him far to the north, and he can take advantage of the winds to further his trip. I know that the captains will object that they thereby lengthen their course, but they will lose more, probably, if they meet a cyclone. One of the most distinguished captains in the A. Lopez line of steamers, an intimate friend of mine, always followed that course in his trips, and never had reason to repent of it.

The steamers leaving Habana in August for New York ought to utilize the Gulf Stream by keeping within its eastern or right-hand portion, and those leaving New York for Habana in trying to avoid the Gulf Stream should, on leaving New York, not keep close to the coast of the Gulf of Charleston, but take the eastern or right-hand side of the current. This has two advantages, the first is that the most frequent route of the August hurricanes is thus avoided, and the second is that in this way they are not caught between the track of the cyclone and the coast, as was the case in the terrible shipwreck of the *City of Vera Cruz*. By keeping out of the current on the east side they will have open sea room, and on the approach of a hurricane, if they should see that it is going to recurve in the Gulf of Charleston, they can lay to under advantageous conditions, or if the cyclone is going to recurve farther to the east they can make for the New Channel[8] and continue their voyage, utilizing the cyclonic winds themselves.

The September hurricanes are still more easily avoided in the voyage to Spain, for they either recurve on the Texas coast, and therefore need not be feared, or they recurve in Florida and its vicinity, and these the captain can avoid if, in leaving Habana, he has ascertained that he will have time to clear the channel without danger.

The voyage from Habana to Puerto Rico, and vice versa, in September, and particularly in the beginning of September, is very dangerous, because the whole trip is made in the hurricane route. This voyage should always be avoided, if possible.

The captains of vessels leaving Santiago de Cuba for the United States in August and September, and having to cross the hurricane zone, should consult Mr. Ramsden [at that port] beforehand, lest there be any notice of a cyclone to the windward. This precaution has been the saving of several vessels.

Finally, captains of sailing vessels navigating in the Gulf of Mexico during the month of October, if they find themselves in the eastern portion of the Gulf and observe indications of the proximity of a cyclone, should make at once for the southwest; and if near the Yucatan Channel, let them enter the Gulf of Campeche, remembering that these cyclones in recurving do not usually reach beyond the meridian of Cape Catoche or of New Orleans.

*5th. Law of the relative velocity of translation in the different parts of the track.* —We can divide the cyclonic track into three parts: First branch, recurve, second branch. Having made this division, I shall now formulate the law. In the first branch of the track, from the origin of the

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[8] The Florida Straits or "New Bahama Channel."—ED.

cyclone to the vicinity of the recurve, the velocity of translation is generally slightly on the increase. In the vicinity of the recurve the hurricane moderates the velocity of its advance, which reaches its minimum in the recurve. Finally, the velocity of translation is rapidly on the increase in the second branch, and attains a maximum of more than 30 and even 40 miles per hour.

Whenever any notable anomaly in the velocity of translation of a cyclone is observed, there is reason to suspect an irregularity in the track, or some singular anomaly with regard to its normal direction or to the law of recurving. Such anomalies, as we shall see, are apt to take place in simultaneous or twin cyclones.

6th. *Law of the relative velocity of translation in the recurving of cyclones according as the parabola is more or less open.*—The velocity of translation, when recurving, depends on the parabola being more or less open. In formulating the law I say, therefore, that *in open parabolas the velocity of translation when recurving diminishes little, while in narrow parabolas the cyclone remains almost stationary in the recurve and its vicinity.*

The cyclone of very wide parabola which on the 17th of August, 1879, recurved somewhat to the north of the Florida Straits, in the Gulf of Charleston, maintained, when recurving, a velocity of 17 miles per hour. Many other examples could be cited. On the other hand the cyclone that passed by Matanzas in the night from the 7th to the 8th of October, 1870, and recurved, according to the law, between Matanzas and Key West, was of very narrow track, and in recurving the vortex was detained for nearly four days. The one which recurved in Florida on the 8th, 9th, and 10th of September, 1878, was also of a rather narrow parabola, and was three days in recurving; it then became anomalous in its second branch, and from the Gulf of Charleston moved northward. Finally, the cyclone that recurved on the coast of Texas on the 16th and 17th of September, 1875, was also of narrow parabola, and was detained three days and a half in recurving. In some of these cyclones the velocity of translation in the neighborhood of the vertex of the parabola did not exceed 1½ to 3 miles per hour.

*F. Not all cyclones recurve.*—In establishing the law of recurving I have not intended to imply that all cyclones recurve, but I have tried to establish the fact that those which do so (and they are the majority) recurve in certain latitudes according to the dates.

A cyclone may arise and may die out in any of the three parts into which I have divided the track. It can begin and end in the first branch; it can begin in the first branch and die off in the recurve; it may form in the recurve and vanish in the second branch; and finally, it may both originate and dissolve in the second branch.

A cyclone of this kind that does not describe more than one part of the track can, and generally does, follow the normal track in the portion that it describes and possibly may not deviate from the geographical zone which the tracks occupy according to the months nor infringe the law of recurving. It would be contrary to this law if, without recurving, they cross the zone of the recurving latitude corresponding to that month or decade; but if they die off before reaching the said zone or begin in the second zone at a higher latitude, they do not thereby infringe the law of recurving.

It is quite conceivable that a cyclone of incomplete track may or may not move contrary to the said laws for a very simple reason. The courses of cyclones along their tracks depend on general causes. Now a general cause ought to influence a cyclone that is eight days old just as much as one that is just formed. Whatever be the point where a cyclone originates there pre-exists, if I may so speak, a latent normal track which passes through that point and will become apparent in the direction followed by the cyclone. This latent normal track, directive of cyclones, is in my opinion the upper current, as I have said before.

What I have just expounded is of great practical utility as it is readily seen that the foregoing laws can generally be applied to these cyclones in any portion of the track which they describe.

Suppose that in Habana we receive in September a telegram from the United States in which we are told that a severe cyclone is devastating the coast of Texas; although I have not seen the cyclone pass, yet I should infer that it had formed in the Gulf, and that it is in the act of recurving on the coast of Texas, exactly as if it had come from windward, for example, from Barbados. In the second branch of its track it will cross the United States in the direction of the neighbor-hood of Cape Hatteras, and as it passes to the north of New Orleans, I shall probably see it from Habana. This case is not a mere supposition, it is an actual occurrence which took place on the 16th and 17th of September, 1877. I could cite many other examples of cyclones or cyclonic perturbations, which I have seen forming to the southeast, south, or southwest of Habana and in the Gulf region.

*G. Principal anomalies observed.*—Some of the first and last cyclones of the hurricane season begin their tracks to the south of west and move toward the west by south, or west-southwestward direction. These are very few in number and commonly of short duration ; their tracks are entirely anomalous as regards all the laws above indicated.

In the second branch of the track several anomalies may he observed; I have already said that some of the September cyclones have their second branch very much inclined to the north. There are other hurricanes that after recurving and continuing their course along the second branch suddenly turn to the north and west, and make a second recurve in a high latitude.

The principal anomalies, however, which are observed with regard to the 2d, 3d, 4th, and 5th laws are those which take place when simultaneous cyclones occur, many of which may be called *twin cyclones*, inasmuch as their formation is simultaneous in places at a short distance one from the other, and under the influence of the same general causes. These cyclones, as soon as the upper currents come in contact with each other, react one upon the other and tend mutually to repel each other.[9]

In order to show the great importance and controlling power of the profound perturbations and anomalies produced in the cyclone tracks by the cause now pointed out., and the scarcity or total want of means at the disposal of the observer to promptly foresee and protect himself, I shall briefly cite a few cases.

On the 17th of August, 1879, a cyclone recurved in the Gulf of Charleston to the north of the Florida Straits; on the 19th another cyclone passed westward south of Habana. This latter was out of the general route, nevertheless it continued on a normal track and recurved on the coast of Texas in the proper latitude, and at the same "height" [or northing[10]] as the former one, therefore it only failed in respect to the fourth law.

From the 20th to the 21st of August, 1880, a cyclone that had come from windward and passed in the neighborhood of Jamaica was recurving, contrary to the law, about latitude 20° near Manzanillo; another simultaneous cyclone was at the same time to the west of Habana, in the Gulf, and produced a strong current of cirrus clouds on that side.

[9] See the Appendix to the volume of "Observaciones Magneticas y Meteorologicas" for the year 1868.

[10] The Spanish word altura, here used, may possibly refer to the difference in latitude, or the northing of the vertex relative to the first location of the vortex; a sharp or narrow parabola implies a small northing.—ED.

On the 19th of August, 1886, a cyclone proceeding from the vicinity of Barbados was at the south of Jamaica. On the same day there was in the western part of the Gulf an extensive and very violent cyclone with a barometric minimum of 28.9 inches, giving a strong current of cirrus clouds from the west. The Barbados cyclone on the south of Jamaica began to incline to the north and recurred like the preceding one in a most unlikely manner in the Bay of Jucaro, Cuba, at about latitude 21°.

On the 10th of October, 1886, a cyclone which had just crossed the western extremity of Cuba was completing its recurve in the eastern portion of the Gulf. I said that in its second branch it would cross to the southwest of Florida in the direction of Charleston. I was mistaken in my prediction, as is generally the case when a simultaneous or twin cyclone intervenes of which I have no knowledge, for then the cyclone follows an anomalous track, and I, in my forecasts, always assign to the cyclone the normal track according to the general laws that have been explained, unless in some particular case I find out the contrary by observation. Well, to continue, this cyclone suddenly inclined to the northwest and then to the west, and recurved near Galveston.

My distinguished friend, Mr. Everett Hayden, very opportunely chose this case as the subject of one of his public lectures given in 1889 on his return from the Island of Cuba, illustrating it with lantern projections.[11]

His object was to prove that a powerful anticyclone that existed on the 9th in the United States, to the north by east of the cyclone, had blocked the track of the advancing hurricane and opposed a formidable barrier which the cyclone was unable to overcome, and found itself obliged to divide to the west and make its way out in the rear of the anticyclone. He showed how the anticyclone deviating and coming down to the northeast on the 10th, 11th, 12th, and 13th obstructed each time more and more the path of the cyclone to north-northeast and northeast, toward the coast of the Atlantic, and forced it to move off to the west. Eventually, on the 14th, the anticyclone moved nearer to the Atlantic coast and the cyclone was able to finish its recurve very far to the west, and reached the Atlantic, not by the Gulf of Charleston, but by the Mississippi Valley, the Lakes, and the St. Lawrence Valley. For this

[11] The work in which these lectures are described bears the title "West Indian Hurricanes and the March Blizzard, 1888, by Everett Hayden, Marine Meteorologist, U.S. Hydrographic Office, Washington, D.C. A lecture delivered before the Seawanhaka Corinthian Yacht Club, New York, February 9, 1889, and repealed before the U.S. Naval Institute, Annapolis, Md., March 21. Illustrated by 23 plates. New York, 1869."

demonstration Mr. Hayden showed six views taken from the weather maps of the 9-14th.

The demonstration was a brilliant one and very effective and fully convinced his hearers of what he wished to demonstrate. I will not deny that there is much truth in this explanation, for he explained the phenomenon by one of its immediate causes. I will add, nevertheless, that the explanation was not complete; there was omitted one of the principal causes of the phenomena that were being elucidated and without which I hold that the anticyclone could not have opposed any resistance to the progress of the cyclone. The principal cause that I allude to was another simultaneous cyclone to the northeast, which on the 10th (the very day on which the Gulf cyclone commenced to alter its course) lay at about latitude 30° and longitude 60° (west of Greenwich),[12] or some 1,300 miles distant to the east-northeast.

It was this second cyclone, acting together with that of the Gulf which formed, fed constantly, and retained the anticyclone as in a prison, that was the cause of its movements, obliging it while the two cyclones were moving apart, one from the other, to come like a wedge between them, tending to occupy the line of the two centers whenever they should be sufficiently separated; for this is the region where the anticyclonic rings of both cyclones are completely superposed. Hence the enforced tendency of the anticyclone in such cases is to seek the line between the centers of the cyclones. For this reason the anticyclone descended from the northeast, obstructing the path of the Gulf cyclone when it was about to recurve and obliging it to deviate toward the west. While the Atlantic cyclone was retreating to the northeast the anticyclone, on the 13th, occupied the line of the centers between the two cyclones and from that moment the Gulf cyclone had a free path to the Atlantic across the United States through the Mississippi Valley, the Lakes, and the St. Lawrence Valley.

The cyclone of the 4th and 5th of September, 1888, was not only contrary to all known laws but was so anomalous in its track that I know not another case like it, having never in my own experience seen, and never read of such a cyclone in the West Indies. It did not obey a principle which is held as axiomatic among authors who have written on this subject, inasmuch as a cyclone from the time it begins to gain in latitude never recedes and keeps always moving away from the equator.

[12] See the Summary and Review of International Meteorological Observations for the month of October, 1886, published by the Signal Service, December, 1887.

This one, on the contrary, moved from the neighborhood of Puerto Rico toward the west by north direction, gaining in latitude up to the neighborhood of Sagua; the track, in truth, was anomalous and the velocity of translation did not correspond to that of a cyclone at the end of August; but I did not stop to consider these circumstances at that moment. The cyclone from the neighborhood of Sagua turned to the west, passed south of Habana, inclined afterward to the west-southwest, and passing in the vicinity of Cape San Antonio and through the peninsula of Yucatan, advanced toward Veracruz. On the 6th, the twin cyclone appeared to the northeast, it crossed. Florida on the 8th, describing a normal track, and on the 9th recurved about the twenty-ninth parallel, its proper latitude west of Florida.

Mr. Hayden and the observers of the Signal Service attributed the deviation of the first cyclone to the anticyclone of the Atlantic coast. Let us see what foundation there was for this opinion.

In two ways an anticyclone might make a cyclone deviate from its course, either by its isobars, which oppose an insuperable barrier to progress of the cyclone (inasmuch as where a high barometric area exists one of low barometer can not simultaneously do so), or else by its anticyclonic rings, which drive the cyclone in a particular direction.

Now, in the case we are considering, the isobars of the anticyclone did not oppose the advance of the cyclone to the west by north. When the cyclone passed to the south of Habana, in the night of the 4-5th, the anticyclonic 30-inch isobar lay about over the northern limit of Florida, and thence curved to the northwest, toward the Mississippi Valley. The Gulf, therefore, remained free from any anticyclonic isobars that could obstruct the passage of the cyclone (see the weather maps of that day). There remains, then, only the hypothesis that it was solely the pressure of the anticyclonic winds that caused the cyclone to deviate from its course. This hypothesis I can not admit, for I can bring against it a general experience, admitted by all, but not explained, and also a theoretical reasoning of much weight, in my opinion.

The general and practical experience is that the trades are anticyclonic winds, and that during the passage of a cyclone this wind increases and becomes extraordinarily reinforced. Nevertheless, the cyclones of the West Indies more across the trade winds, day after day, in a perpendicular or almost perpendicular direction, describing normal tracks and without deviating to the south; so that while the trade wind is from northeast the tracks of the cyclones ran across in a northwestwardly direction.

The theoretical reason that I have for not admitting that the anticyclonic winds have any power to drive the cyclone one way or the other is the following: The cyclone must not be considered as a gyrating mass of air forming a body and moving wheel-like in a single piece that can be readily pushed aside and yield to impulse; a cyclone is rather to be considered as a partial vacuum that goes on spreading and renovating itself all along the track, drawing in at its base, from all sides, the air, to which it imparts a gyratory motion, and throwing it out in divergent currents from its upper part. Therefore, I can not think that a cyclone can suffer any impulse in a given direction from a current of air acting on its base. From the moment in which this current enters the storm area it is aspirated into the spirals of the cyclone, and its inertia is broken up into numberless component parts, acting in various and contrary directions, that mutually neutralize each other, remaining powerless so far as making the cyclone deviate one way or the other.

The cyclone of St. Thomas of the 3d-12th of September, 1889, which caused such devastation in New York from the 10th to the 12th, was another case of twin cyclones. I shall not stop to describe it. It can be found, minutely told, by Mr. Hayden in the Pilot Chart of October, 1889.

The cyclone of Martinique of the 18-29th of August, 1891, is another splendid case of twin cyclones. The deviation which the cyclone of Martinique suffered was like that of the cyclone of 1888, though not so decided. Instead of recurving in the Gulf of Charleston it crossed to the south of Florida and disappeared in the eastern portion of the Gulf of Mexico. (See Pilot Chart, October, 1891.)

Before concluding this matter I shall explain a case of simultaneous cyclones in the middle latitudes, in which, according to my opinion the cyclones mutually repelled each other in the same manner as do the tropical cyclones, at least in some cases. This case is taken from one of the magnificent publications of the Meteorological Office of London. [13]Examining in this publication the track of the cyclones of August, 1873 (which originated to the southwest of the Cape Verde Islands, about latitude 11° and longitude 28° followed a normal track as far as to the west of the Bermudas, and recurved, according to the law, about latitude 83°), I noticed that after advancing with increasing velocity toward the northeast, in the second branch of its track, the cyclone suddenly lessened its speed and its track began to incline toward the north, which produced a notable irregularity in this second branch, from the 25th to the 28th. This attracted my attention, and I began to search for its cause, which, in my opinion, was soon found. On the 25th there was another cyclone, in the Atlantic at a short distance to the northeast of the tropical cylone, and while this latter suspended its course and turned to the north the Atlantic cyclone took a precipitous march with a velocity four times that of the day before in an east by northward direction. At that moment, on the 26th, the anticyclone lay to the northwest of the line of the centers of the two cyclones, introducing itself like a wedge between both. On the 27th the two cyclones were far enough apart, and a species of crest or ridge of high barometer extended across the line of the centers; this was due to the overlapping of the anticyclonic rings of the two cyclones. This may not be the only case of this kind which has presented itself in the middle latitudes.

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The translator deeply laments that, owing to the death of Father Viñes on July 24, 1893, this portion of the translation (from the 4th to the end) has not had the advantage of the author's personal revision.—C. F.

[13] The work is entitled "The Meteorology of the North Atlantic during August, 1873; illustrating the hurricane of that month. By Capt. Henry Toynbee." It is accompanied by a collection of charts entitled "Synchronous Charts of the North Atlantic during August, 1873. London, 1876."