ON THE WIND ASYMMETRY OF HURRICANES

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ABSTRACT

The difference in the wind speeds across hurricanes (from the "dangerous" to the opposite semi-circle) is often greater than twice the speed of propagation of the storm. The traditional explanation of the speed asymmetry of such storms must, then, be regarded as only a partial one. A speed asymmetry (in the same sense) must exist in the wind field as seen by an observer moving with the storm. Simple reasoning in terms of non-fluence lines (loci of points of parallel flow) applied to the simple model of a hurricane, consisting of a cyclonic indraft point plus its associated hyperbolic point, leads to the expected asymmetry in the relative field of flow.

1. Introduction

The discovery that storms were moving entities, made by Benjamin Franklin at the start of the nineteenth century, was followed in the early decades of that century by work which established the rotary nature of cyclonic wind systems (Redfield, 1831; Reid 1846). By mid-century, when Piddington coined the word *cyclone* (1855), the nature of tropical storms as cyclonic indraft systems was well established; mariners were well aware of the stronger winds to be encountered in the "dangerous semi-circle" of such storms.

The traditional explanation of this asymmetry in the distribution of wind speeds about the storm center, given, for example, by Ferrell (1884) and still widely accepted, goes somewhat as follows. Consider a rotary wind system of 40-kn speed, the system as a whole being moved along at a speed of 10 kn. To the right (in the northern hemisphere), the directions of the translation and of the rotary winds coincide; adding their speeds, one gets 40 plus 10 or 50 kn. To the left, they oppose each other; subtracting, one gets 40 minus 10 or only 30 kn. Thus, one is led to an asymmetry, with 50-kn speeds in the dangerous semi-circle, only 30-kn ones on the other side of the storm.

Notice that this explanation is *not* "the storm winds are the sum of a translatory 'basic' current and of a rotary 'storm' current." The translatory velocity which enters Ferrell's explanation is the velocity of propagation of the storm. It is, of course, true that meteorologists even then had recognized that the major factor in the determination of this velocity of propagation is often the "steering" of the basic current; but this hypothesis is not requisite to the explanation advanced by them for the wind asymmetry of such storms.

This explanation obviously rests upon the *a priori* assumption of symmetry in the field of flow, relative to the moving storm. Such an assumption is the simplest one; furthermore, it is quite consistent with the then more generally held convective theory of hurricane formation. True, Ferrell (1890) postulated an asymmetry due to the variation of the Coriolis term; but this asymmetry would be related to geography (the north *versus* the south side of the storm) rather than to the direction of movement. Aside from such a secondary effect (real or not), it is true that the traditional explanation gives good qualitative agreement with the facts. Because of this and of its essential simplicity, it has stood the test of time. However, it is only a partial explanation.

Asymmetries in the speed field greater than twice the speed of propagation of the storm cannot be explained simply as the consequence of a change from a coordinate system fixed to the storm (in which system the winds are presumed symmetric) to one fixed to the earth. However, such asymmetries are common. For example, when Edna of 1954 was moving toward the mainland, it passed the island of San Salvador to the north. That station reported no winds of more than 40-kn; yet, reconnaissance established the existence of winds of greater than 100 kn on the opposite side of the storm from San Salvador. Edna was then moving more nearly at 10 kn than at the 30 kn which would be required to explain this asymmetry on the traditional basis. Some asymmetry must exist in the field of *motion relative to the moving storm*. This article presents a simple reason for expecting such an asymmetry.

2. The complete hurricane disturbance

Considerations of the continuity of the wind field lead one to regard the disturbance of the general wind flow which is the hurricane (in the lower part of the atmosphere) to be not simply a cyclonic indraft

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pattern but such a pattern together with a companion hyperbolic point (Sherman, 1951; Palmer *et al* 1955). This concept provides for a continuous transition *in any direction* from the wind direction of the disturbance to that of the embedding general flow; more important to this discussion, it involves an essential asymmetry — with it, there are two singular points, not one. These two have an orientation with respect to each other. Thus a direction is associated with the relative field of flow, providing an asymmetry just as the direction of propagation did for the storm seen with respect to coordinates fixed to the earth in the traditional model. The two patterns, a simple cyclonic indraft system and a complete cyclonic indraft disturbance, are presented in figs. 1 to 3. Each pattern has been shown in two ways: In fig. 1, the symmetric cyclonic indraft pattern is shown first in terms of isogons and then in terms of streamlines; in figs. 2 and 3, the complete disturbance is similarly shown.

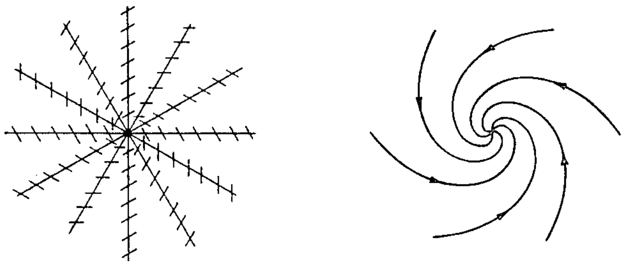

FIG. 1. Left: isogons for simple cyclonic indraft point. Right: corresponding streamlines.

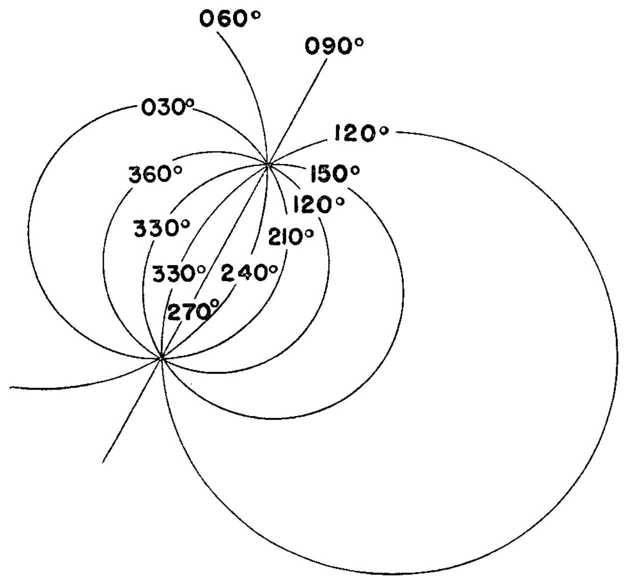

FIG. 2. Isogons for complete cyclonic indraft disturbance. Isogon between 150 and 210 deg erroneously labeled; should read 180 deg.

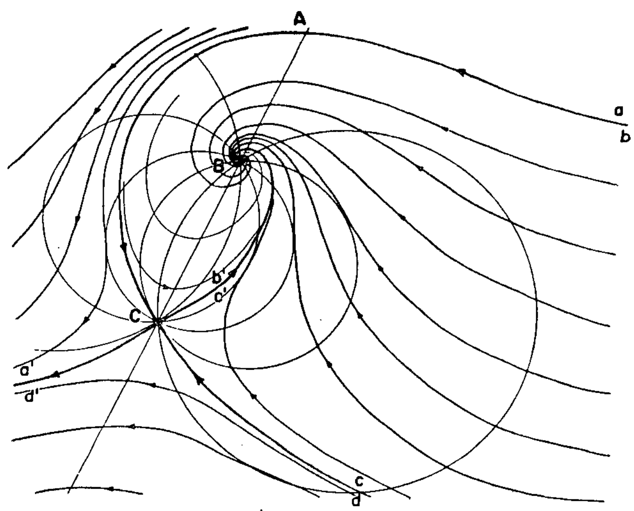

FIG. 3. Streamlines corresponding to fig. 2.

The cyclonic indraft disturbance shown in fig. 1 is one for which the indraft and cyclonic components of wind are everywhere equal; that is, it is one of a uniform angle of indraft of 45 deg, as may be noted from the rulings which have been entered along the isogons. The symmetry of the isogons' orientations, and this equality of indraft and rotary components of wind, are not essentials of the pattern. Similarly, in the complete disturbance shown in figs. 2 and 3, the isogons have been drawn as circles which intersect at equal angles for equal changes in isogon name at each of the singular points. These simplifications are in no way essential to the discussion, as will be seen below; nevertheless, it is of some interest to look at this simple model. It is one for which the angle of indraft along the straight isogon and along all the others in the immediate neighborhood of the cyclonic singular point is 30 deg. This, again, is not an essential of the pattern.

The two streamlines which begin as the axes of contraction and dilatation of the hyperbolic point (the bold lines in fig. 3) give the essential character of the field. The first separates the air which enters the system from that which passes around it; the second connects the two singular points and is probably a discontinuity in various associated fields. Air arrives at points along it (*e.g.*, at a′ from a, and b′ from b, or at c′ from c, and d′ from d) from widely separated initial positions; hence, any field of even a quasi-conservative quantity will tend to show a discontinuity along this asymptote. Further, it is likely that the first spiral cloud line (often described as a "button hook") will form in this part of the field *of relative flow*. These are all familiar considerations. The essential remark for our purpose is this: if all the air which passes across AB were to pass across BC, evidently the mean speed would have to be much greater along AB than along BC. However, because of the indraft nature of the pattern, not all of the air passing AB will reach BC. We are here tacitly assuming a steady state in the relative field of flow; hence, no air will cross the streamlines shown; however, some must escape upward. Were this not the case, the speeds would have to be infinite instead of the zero value required by the kinematics at the cyclonic indraft

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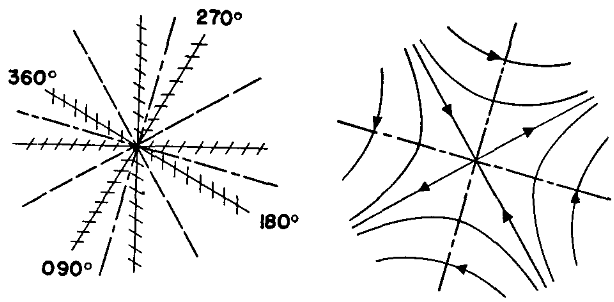

FIG. 4. Structure of hyperbolic point. Isogons at left, streamlines on right. Dot-dash line is non-fluence line.

center. Hence, even less air passes BC than AB; so the asymmetry in speed is even greater. This asymmetry in the speed field *as seen from coordinates fixed to the moving storm* is the one we seek. However, here we have simply pointed to it in an example; in the next section, we shall look to see why it is to be expected.

3. The "non-fluence" line across the storm

In streamline analysis by the isogon method, it is usually useful to construct inflection lines (Palmer *et al*, 1955). These are lines defined as the loci of points at which the rulings (*i.e.*, the streamlines) are tangent to the isogons. They divide the field of flow into areas of streamlines of cyclonic and anticyclonic curvature; thus, they are points at which the curvature term of the vorticity vanishes. From the duality between the vorticity of a flow and the divergence of the flow normal to it (Sherman, 1952), it is to be expected that those lines along which the curvature term of the divergence vanishes also should be of some importance. This turns out to be the case (Sherman, 1956). These lines divide the field of flow into areas of difluent and confluent streamlines; on the lines themselves, the flow is parallel. We shall call these lines "non-fluence" lines. Along them, any two streamlines chosen will have an extreme (either maximum or minimum) separation. Note, however, that their fundamental definition is in terms of separation of areas of confluence and difluence, not in terms of extremes of streamline spacing. Thus, it is *not* in general true that non-fluence lines change from loci of maximum streamline spacing to loci of minimum streamline spacing only at their points of mutual intersection. This will play a role in our discussion below.

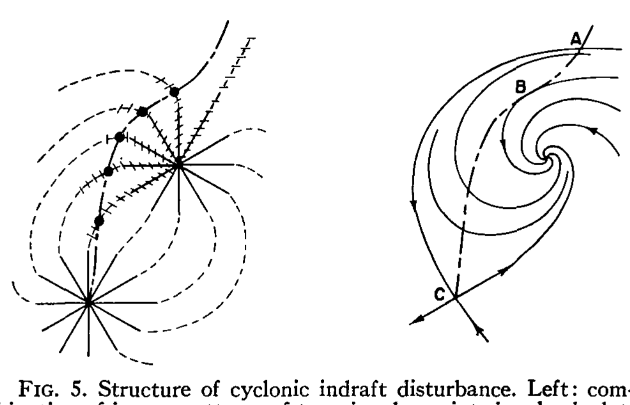

FIG. 5. Structure of cyclonic indraft disturbance. Left: combination of isogon patterns of two singular points involved; dot-dash line is non-fluence line. Right: corresponding streamlines.

Both inflection lines and non-fluence lines are associated with any hyperbolic point. Consider fig. 4. In that figure, we have isogons which define a hyperbolic point like that which forms part of the cyclonic indraft disturbance shown in fiig. 1. Rulings have been entered. In this example, the 330, 210, 240 and 060 isogons have tangential rulings. These, then, are the inflection lines; close in to the singular point, they coincide with the axes of contraction and dilatation (see right part of the figure). The dash-dot lines are loci of points at which the rulings are orthogonal to the isogons; these are the non-fluence lines. From the characteristics of a hyperbolic point, it is evident that in its neighborhood they are lines of maximum streamline separation. In passing, we make the obvious remark that the inflection lines of any set of streamlines are the non-fluence lines of the system of normals to those streamlines; this is an aspect of the duality mentioned above. Since the normals to the streamlines of a hyperbolic point form another such point (with its two axes being inflection lines), it follows that two non-fluence lines are to be found at each hyperbolic point.

A cyclonic indraft disturbance must be a combination of an isogon pattern at least somewhat like that shown in fig. 1 with one somewhat like that shown in fig. 4. They need not be joined so simply as are those shown in the simple pattern of circular isogons of fig. 3; however, they must have that inherent pattern. Such a joining together of these patterns is shown in fig. 5. All the isogons, save that which represents the basic-current direction, start and end at the two singular points. Thus, each of those forward (with respect to this basic-current direction[1]) from the cyclonic indraft point must eventually turn and curve toward the hyperbolic point in such a way as to be tangent at some point to a line orthogonal to its rulings. Sample points of tangency have been marked with dots in fig. 5. These evidently define a non-fluence line which passes through the hyperbolic point (compare the discussion of fig. 4). Furthermore, as we have seen, this line is a locus of maximum streamline spacing near the hyperbolic point. If we consider only that part of it between the hyperbolic point and the point at which it reaches the characteristic streamline (compare fig. 3) which separates the air which enters the storm from that which by-passes it, the streamlines crossing it will all have cyclonic curvature and will be reentrant. This means that they will

[1] Here the basic-current direction has been taken as east; this is not essential. For any other choice of direction, the page need only be rotated to yield appropriate drawings.

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be a minimum distance apart north of some point, B, at which a streamline is tangent to this non-fluence line. We, thus, have argued the need for minimal spacing of streamlines along AB of fig. 5 and maximal spacing along AC of the same figure. This was what enabled us to deduce the speed asymmetry of the relative field above; it may now be seen that this asymmetry was not an accident resulting from the simplicities and symmetries of the pattern used in the illustration (fig. 3).

We are led to expect an inherent speed asymmetry to the right and left of the storm along some line extending from the hyperbolic point and passing in front of the cyclonic indraft center. In general, this line will pass the cyclonic indraft center more closely as the indraft diminishes; for the less the indraft, the more nearly are the rulings already orthogonal to the isogons from the cyclonic point outward and, hence, the less is the amount of turning of the isogon required for normalcy.

4. Summary

The asymmetry in the speed field of a hurricane from the "dangerous" to the opposite side of the storm is frequently observed to be greater than twice the speed of propagation of the storm. This means that the traditional explanation, which assumed a symmetric disturbance in the field of flow as seen by an observer moving with the storm, is inadequate. That explanation goes fairly naturally with a convective hypothesis of storm formation. The transition to a streamline pattern consistent with a "breaking" wave hypothesis of genesis (in which a basic current plays a fundamental role) leads to an essential speed asymmetry of the sort required. Such an asymmetry is inherent in the combination of a hyperbolic point and a cyclonic indraft point, and can be deduced from the properties of a line of parallel flow, a "non-fluence" line, which is an essential topological property of the model. This asymmetry in the field of flow, as seen by an observer following the storm, adds to that which results from a change to a map of the storm seen with respect to the earth; together they give a more adequate explanation of the asymmetries actually observed.

REFERENCES

Ferrel, W., 1890: *A popular treatise on the winds.* New York, Wiley and Sons, 505 pp.

Palmer, C. E., C. W. Wise, L. J. Stempson, and G. H. Duncan, 1955: *The practical aspect of tropical meteorology.* [Special Rep. 2, Contract AF19(604)-546], Los Angeles, Univ. Calif., 195 pp.

Redfield, W. C., 1831: Article in *Amer. J. Sci.* (referred to by W. Reid, reference unavailable).

Reid, W., 1846: *The law of storms.* London, John Weale, 572 pp.

Sherman, L., 1951: A kinematic relationship in the field of motion of storms. *Trans. Amer. geophys. Union*, **32**, 849–852.

——, 1952: On the scalar-vorticity and horizontal-divergence equations. *J. Meteor.*, **9**, 359–366.

——, 1956: The use of "non-fluence" lines in streamline analysis. *Trans. Amer. Geophys. Union*, **37**, in press.

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