

Wind Increases in Rapid Marine Cyclogenesis

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1. Introduction

When Sanders and Gyakum (1980) documented the climatology of rapid cyclogenesis events, they defined these events in terms of pressure change over given time periods, usually 24 hours. Others have examined cyclone deepening over shorter periods.

In their paper, Sanders and Gyakum expressed interest "... in this phenomenon because of its great *practical* (italics by AIW/FS) importance to shipping ...". In discussing cyclogenesis in the naval community, a common query regards the strongest *wind* in these storms. This note responds to these calls for a parameter of more *practical* importance than pressure change by relating pressure fall in rapidly intensifying marine cyclones to a common measure of wind, *geostrophic* wind. We chose *geostrophic* wind because observed winds are sparse under the hostile conditions present in severe storms at sea. In addition, wind observations at sea are difficult to compare because they are made at different heights. These heights range from 100 m on towers, through a variety of heights on ships of different sizes, to as high as 13.8 m or as low as 5 m on buoys. All such measurements must be brought to a common height, usually 10 m, using empirical relationships developed from land observations. Finally, we chose *maximum* geostrophic wind as an upper bound, or worst case measure.

2. Data

We used data from research analyses of ten rapid deepening events over the North Atlantic ocean, west of 50°W, between January and March 1985. The sea level pressure analyses were prepared by FS using all available transmitted data, including those arriving too

late for the operational analysis, but not archived data mailed to the National Climatic Data Center.

We used the maximum geostrophic wind anywhere in the cyclone, and analyzed the changes over 6, 12, and 24 hour periods. The duration of events varied from 24 to 90 hours, thereby providing samples of 49, 45 and 27 cases of 6, 12, and 24 hour deepenings, respectively. We did not include periods when the deepening occurred over land, or when filling occurred. Due to short period increases in pressure during otherwise sustained pressure falls, the latter qualification reduced the number of cases in the six hour periods the most, by 11.

3. Geostrophic wind

Ideally, observed winds should be used. However, owing to the sparse nature of observations at sea, maximum winds are rarely observed. Observed winds, if they could be reliably measured, would likely yield somewhat lower speeds than geostrophic due to friction and other ageostrophic effects. Frictional drag is poorly understood over water, particularly under strong wind conditions, making any ad hoc or theoretical correction difficult. Finally, winds are measured at a variety of heights at sea and must be reduced to a common height, using semi-empirical relationships that were derived over land and never well verified over water.

These arguments notwithstanding, Fig. 1 shows the relationship between maximum observed and geostrophic winds in the events used in this analysis. The maximum observed winds, presumably reduced to a common height, were rarely in the same quadrant as the maximum geostrophic because ships normally try to avoid the maximum wind if they can. This observation bias that geostrophic winds calculated from sea level pressure analyses can overcome, leads to the linear and logarithmic relationships shown in the inset. The reduction of variance, r^2 , for both relationships gives correlations greater than 0.8, lending credence to the

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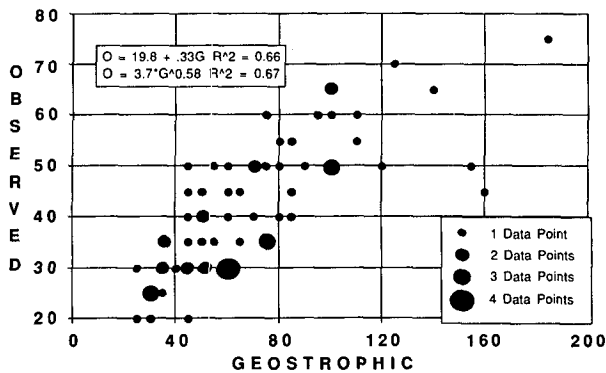


FIG. 1. Maximum observed (O) vs maximum geostrophic (G) winds in deepening cyclones in the North Atlantic. Winds are in knots. Upper left inset shows the linear and logarithmic best fit relationships and the reduction of variance. Lower right inset shows multiple data points.

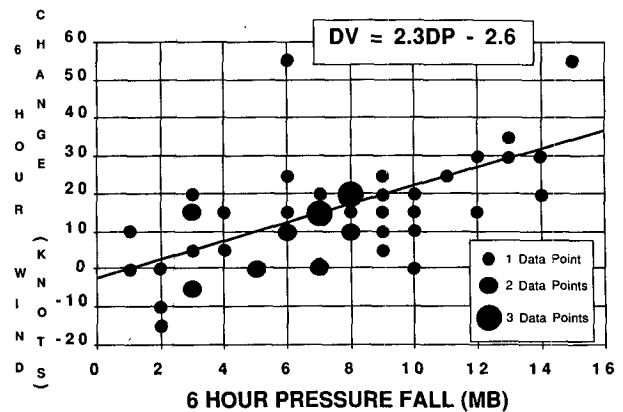


FIG. 2. Six hour change in geostrophic wind (DV) as a function of 6 h pressure fall (DP). Solid line is linear least squares best fit. Lower right inset shows multiple data points.

use of geostrophic wind to overcome any heavy weather avoidance bias inherent in observations at sea.

There are other ageostrophic effects besides friction that might suggest use of some other calculable measure, such as *gradient* or *isallobaric* wind. For gradient winds, centrifugal accelerations become important. In our sample of 69 maps, the maximum geostrophic wind was found with approximately equal frequency in the northwest and southeast quadrants, where the centrifugal force is expected to be maximized and minimized, respectively, for our generally northeastward moving cyclones. The maximum *observed* wind, as sparse and unreliable as it was, tended to be in the southeast and southwest quadrants, with a distinct minimum in the northwest quadrant. Clearly, there is a gradient wind effect.

For pressure falls of the order observed here, isallobaric accelerations are comparable to the centrifugal ones discussed above. Petterssen (1956) gives an excellent discussion of all ageostrophic effects that is beyond the scope of this note to reproduce. Suffice it to say that in almost all regions of deepening low pressure systems, the *real* wind is less than the *geostrophic*. Hence, it is prudent to say that any relationships derived for geostrophic winds, should be reduced to account for ageostrophic effects.

4. Results

Figures 2-4 show the results of the analyses for the indicated time periods. The slope of the linear least square line is approximately two for all time periods. Hence, to a first approximation, the maximum geostrophic wind, in knots, can be said to increase at approximately *twice* the rate of pressure fall, in mb, for all time periods from 6 to 24 h. In mks units, the geostrophic wind increase, in $m s^{-1}$, is approximately *equal* to the pressure fall, in 100 Pa. Hence, as defined by Sanders and Gyakum (1980) a "bomb," with a pressure

fall of $1 mb h^{-1}$ for 24 h, equates to a maximum geostrophic wind increase of $2 kt h^{-1}$ (or $1 m s^{-1}$) for the same 24 h.

The constancy of the slope of the relationship suggests that, assuming that the radial and azimuthal distribution of pressure gradient remains constant as storms deepen, their diameters also remain approximately constant. If the storms grew in size as the pressure fell, the geostrophic wind would increase more slowly for the longer time periods of sustained pressure fall. In the limit, if the pressure fall was matched by the correct size increase, the geostrophic wind would not increase at all. Clearly, that is not the case. Also, the relationships suggest that the storms have approximately the same diameters. Otherwise, different size storms would generate different straight lines on individual scatter charts for a single storm. When merged together, the total scatter would be broader than if the storms all had approximately the same diameters.

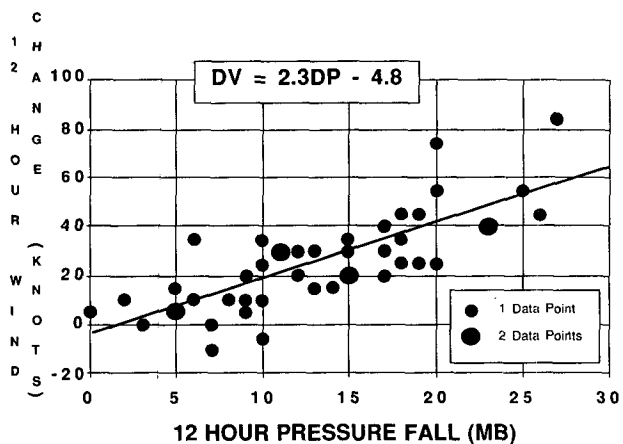


FIG. 3. Twelve hour change in geostrophic wind (DV) as a function of 12 h pressure fall (DP). Solid line is linear least squares best fit. Lower right inset shows multiple data points.

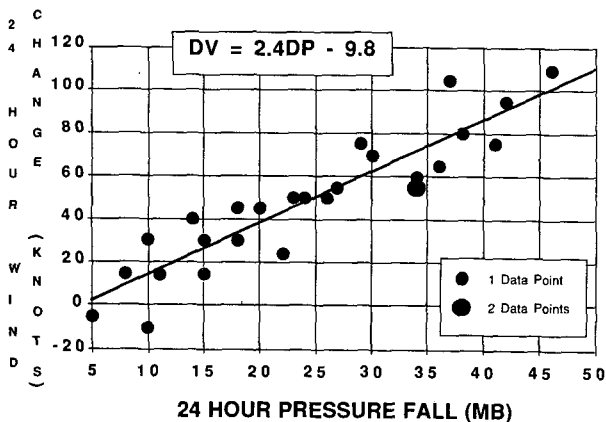


FIG. 4. Twenty-four hour change in geostrophic wind (DV) as a function of 24 h pressure fall (DP). Solid line is linear least-squares best fit. Lower right inset shows multiple data points.

The correlation between pressure fall and wind increase improves from below 0.4 for 6 h, through 0.6 to 12 h, to above 0.8 for 24 h. This indicates that there are small-scale pressure fluctuations that affect this

analysis. As the time period increases, these fluctuations tend to cancel each other, thereby allowing the correlation to improve.

5. Summary thoughts

Marine meteorologists should begin expressing rapid cyclogenesis in terms of more practical parameters for shipping than pressure fall. From a limited analysis of surface pressure charts in the North Atlantic, it appears that one such parameter, the maximum geostrophic wind, in knots ($m s^{-1}$), increases approximately twice as fast (at the same rate) as the pressure falls in mb for disturbances where rapid development occurs.

Future analyses should be refined to use a more rigorous measures of wind. Still more work might lead to consideration of even more practical parameters such as wave height or sea state.

REFERENCES

- Petterssen, S., 1956: *Weather Analysis and Forecasting, Vol. I. Motion and Motion Systems*. McGraw-Hill, 428 pp.
- Sanders, F. and J. R. Gyakum, 1980: Synoptic-dynamic climatology of the "bomb". *Mon. Wea. Rev.*, **108**, 1589-1606.