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**An Operational Checklist for the Forecasting of
Explosive Cyclogenesis in the North Atlantic Ocean**

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Editor's Note: This study has been keyed to the LFM. Do not attempt to apply it directly to the NGM. Generally features will probably be similar between the two models; however, specific threshold values will probably differ.

A meteorological "bomb" was originally defined by Sanders and Gyakum (1980) as an extratropical surface cyclone whose central pressure falls averaged at least 1 millibar per hour for 24 hours at 60 degrees north latitude with a correction at other latitudes.

In a later study, Sanders (1985) studied explosive cyclogenesis in the north Atlantic Ocean. A high correlation was found between upper-level cyclonic vorticity advection over the surface cyclone and simultaneous surface deepening rate. Thus, the explosive maritime cyclone is fundamentally a baroclinic disturbance in which the low-level response to a given upper-level forcing is dramatically large. An operational checklist for forecasting explosive cyclogenesis north of 40 degrees north latitude and west of 60 degrees west longitude is based upon this research.

Tracks and central values of surface low pressure centers and 500 millibar absolute vorticity maxima were gathered from operational analyses for 48 cases of explosive cyclogenesis which occurred in the north Atlantic between January 1981 and November 1984. These cases were stratified into strong, moderate and weak categories according to intensity. The sample included 12 strong, 16 moderate and 20 weak bombs. Weak bombs were omitted from this study based on the assumption that such events do not normally produce storm-force winds. A study of the mean behavior of the remaining 28 strong and moderate bombs lead to the development of the explosive cyclogenesis checklist.

In the Atlantic, the prominent region of high-frequency explosive cyclogenesis extends from Cape Hatteras northeast across Georges Bank to south of Newfoundland. The majority of the bombs studied generally followed the strong sea-surface temperature gradient along the north wall of the Gulf Stream. The peak occurrence of explosive cyclogenesis was in January. The months with the next greatest number of bombs were February, December, November and March in descending order of frequency.

In a companion paper, Sanders (1985) verified the limited-area fine-mesh (LFM) model performance with respect to the explosive deepening of the low-pressure center and storm track. In a comparison of central pressures from manual analyses with LFM initializations and predictions, the latter were insufficiently deep by an average of 10 to 15 millibars. The LFM also produced forecast tracks slightly faster and slightly to the right of the observed tracks. Sanders concluded that the LFM is able to capture the essentials of the baroclinic process, although the amount of response to baroclinic forcing remains elusive.

An operational checklist was designed to be a simple and convenient, although not infallible, method of forecasting explosive cyclogenesis using the LFM model. The checklist is comprised of six questions:

1. Does a 500 millibar absolute vorticity maximum of 15×10^{-5} radian per second or greater exist as an initial LFM condition in an area bounded by:

30 to 50 degrees north latitudes, and

85 to 110 degrees west longitudes?
2. Does this 500 millibar vorticity maximum maintain its initial intensity or strengthen on successive 12, 24, 36 and 48 hour LFM charts?
3. Is this 500 millibar vorticity maximum forecast to move an average of 30 knots or greater through 48 hours?
4. Does the initial LFM-produced 500 millibar vorticity maximum cross the coast between 32 and 42 degrees north latitudes?
5. Does a jet streak of 120 knots or greater exist at 250 or 300 millibars in a position just south of the initial 500 millibar vorticity maximum?
6. Does the LFM develop a surface low of 995 millibars or deeper over the forecast area during the 48 hour period?

The first four questions deal exclusively with LFM-produced 500 millibar absolute vorticity maxima whose characteristics were inherent to each of the 28 bombs examined. A vorticity maximum of at least 15×10^{-5} radian per second existed as an initial LFM condition within a spawning area bounded by 30 to 50 degrees north latitudes and 85 to 110 degrees west longitudes. Vorticity maxima between 15 and 18 were characteristic of moderate bombs, while strong bombs exhibited initial vorticity maxima of 19 or greater. With few exceptions, the LFM-produced vorticity maxima maintained initial intensity or strengthened through 48 hours. Movement averaged 30 knots for moderate bombs and 35 knots for strong bombs. All initial vorticity maxima crossed the coast between 32 and 42 degrees north latitudes.

The fifth question refers to jet streaks. At a workshop on oceanic storms held in Seattle at the University of Washington in September 1985, several notable examples of explosive cyclogenesis were presented. One unique signature was the presence of a jet streak in excess of 140 knots. In the early stages of explosive cyclogenesis, a jet streak is usually found just south of the 500 millibar vorticity maximum. A jet streak threshold of 120 knots was chosen for the checklist.

The last question on the checklist refers to the existence of an LFM-produced surface low of 995 millibars or deeper over the forecast area. The LFM usually develops a weak new surface low in the Atlantic along the temperature gradient of the Gulf Stream in response to upper-level forcing. Of the 28 bombs studied, the vorticity maximum responsible for rapid deepening pre-existed the surface low in each case. The motion of the vorticity maximum relative to the surface low is an inward spiral beginning northwest of the nascent bomb and ending to the south of the developed storm. Strong bombs are distinguished from moderate bombs by the substantially greater initial separation distance and the greater relative speed of the vorticity maximum.

The checklist should be completed for each LFM cycle. If all six checklist questions are answered in the affirmative, the situation should be closely monitored for the possibility of explosive cyclogenesis. Assuming a perfect prognosis of LFM-produced 500 millibar vorticity, time zero (the midpoint of the 24 hour period of maximum deepening) will occur when the overtaking 500 millibar vorticity maximum is approximately 300 nautical miles west of the surface low. Storm force winds will begin close to time zero. The strongest winds will occur in the west quadrant of the system.

It must be reiterated that the checklist is designed to provide the forecaster with clues that a low may deepen explosively. Once the checklist favors explosive cyclogenesis, the best forecasting tool is a detailed 6-hourly surface pressure analysis over the suspect area. Although this often requires the manual plotting of data, one well-placed ship report can be crucial to the forecast. At the University of Washington workshop on oceanic storms, a portion of one laboratory session was devoted to determining the validity of one such ship report. Many workshop participants chose to label the ship report suspect and withdrew the data from the surface analysis. Unfortunately, this particular ship report was the first clue to explosive cyclogenesis in the Pacific storm of October 11-12, 1984. Such data becomes more believable and operationally significant if a checklist was to favor explosive cyclogenesis.

Considerable research is still necessary to assess the full significance of the many meteorological and oceanographic factors responsible for explosive development. The checklist incorporates only the most tangible of these including: vorticity considerations (questions 1 and 2), strong baroclinicity (questions 3 and 5), strong sea-surface temperature gradient (question 4), and LFM model behavior (question 6). A comparison between the LFM model and the nested grid model (NGM) in handling offshore storms must also be undertaken. Reliance on the NGM, rather than the LFM, for forecasting such storms is not yet warranted. There has not been enough experience with NGM behavior in offshore storms to make a judgment as to which model is superior.

The explosive cyclogenesis checklist was implemented at WSFO Boston in December 1985. Since the occurrence of bombs in the area of study is an extraordinary event, verification of the checklist based on only a partial bomb season would be impractical. A verification study will be undertaken after the 1986-87 bomb season. Meanwhile, work toward improving the checklist will continue through research and input from the field.

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