Analysis and modeling of a tropical-like cyclone in the Mediterranean Sea

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With 19 Figures

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Summary

The storm formed over the warm waters between Sicily and Libya in a region of weak flow ahead of a cold, upper-level trough. During its 5-day lifetime it moved erratically before dissipating off the Turkish coast. As the storm developed, it diminished in size, assuming a hurricane-like appearance in satellite imagery. Ships near the vortex center reported near-hurricane force winds.

An attempt to simulate the storm development with a state-of-the-art mesoscale model met with mixed success. The most serious errors occurred after the initial deepening when the predicted track departed substantially from the observed and the contraction of the storm to mesoscale dimension was missed. A number of forward and adjoint sensitivity experiments were conducted to identify factors influencing the development and to explore ways of improving the prediction. The most realistic prediction was achieved by implanting a vortex, in the manner commonly done in tropical cyclone prediction, at an early stage in the storm’s history and by using, in addition, adjoint sensitivity to further modify the initial conditions.

1. Introduction

Warm-core, subsynoptic-scale vortices that have been likened to tropical cyclones have been observed occasionally over the Mediterranean Sea (Billing et al., 1983; Ernst and Matson, 1983; Mayengon, 1984; Rasmussen and Zick, 1987). The systems in question are typically about 200 km in diameter and in satellite imagery appear as small comma-shaped or nearly circular cloud patterns, often with a distinct eye at their center. They occur in an unstable environment, as evidenced by the presence of deep convection in their vicinity and, in the rare instances where nearby soundings exist, by conditional or neutral stability through a substantial depth of troposphere (Rasmussen and Zick, 1987). Because they form in polar air masses that are heated and moistened by a warm sea and are situated within the large-scale environment of an upper-level cold trough or low, they have also been likened to polar lows (Rasmussen and Zick, 1987; Businger and Reed, 1988). Ship reports reveal that surface winds in the vortices rarely exceed 50 knots (26 m s⁻¹), stopping short of the 33 m s⁻¹ threshold required for a hurricane. However, because of their structural resemblance to the latter and their appearance in satellite imagery, the vortices are sometimes described as hurricane-like (Billing et al., 1985; Rasmussen and Zick, 1987).

Few attempts have been made to simulate the development of these mesoscale convective systems with the use of regional or mesoscale prediction models. To the authors’ knowledge, only two cases have been simulated, both reported in unofficial publications (Blier, 1995; Blier et al.,...
In both cases some success was obtained in predicting the behavior of the systems in one-day simulations. Here, we report on the results of a simulation of longer duration, carried out with the Penn State/NCAR mesoscale model MM5, for a striking case in which the cyclone took shape between North Africa and Sicily on January 23, 1982 and attained tropical storm-like characteristics over the Ionian Sea three days later. Limited descriptions of the case appear in Billing et al. (1983), and Ernst and Matson (1983). A more comprehensive description will be given here (Sect. 2) to serve as background to the numerical modeling effort (Sect. 3).

As will be seen from the model results (Sect. 3), a modest degree of success is achieved in predicting the early stages of the development when the system is better described as being of small, synoptic-scale dimension than of tropical-storm scale. However, upon attaining its maximum depth near the southeast coast of Sicily, the observed system stalled and looped, undergoing a 90° change of direction and taking on a hurricane-like appearance as it proceeded eastward towards the coast of Greece (Fig. 1). The abrupt change of path near Sicily is poorly handled by the model and it is this failure, coupled with the failure to produce a sufficiently intense vortex, which provides the main motivation for the present study.

In an attempt to understand the causes of the forecast failures and to achieve an improved prediction, we have conducted a number of experiments (also described in Sect. 3) aimed at determining the sensitivity of the development to various physical factors and to initial conditions. The experiments are of two types, which will be referred to here as forward sensitivity experiments and adjoint sensitivity experiments. In the former, physical parameters and/or initial conditions are altered a priori, and the model is rerun to determine the impact of the alterations on the forecast. In the latter, an adjoint model (Zou et al., 1997) is used to determine the sensitivity of a selected measure of the model forecast to changes in the initial state. With the help of the adjoint sensitivity fields, it is possible to modify the initial state in such a manner as to improve the result when the model is rerun. This procedure allows for identification of shortcomings in the initial analysis that may have contributed to forecast error, but as noted by Rabier et al. (1996), the improved model...