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Comments on "Simulation of hurricane-type vortices in a general circulation model"

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In a recent paper, Bengtsson et al. (1982) (hereafter referred to as B82) describe intense tropical vortices which appear in the operational ten-day forecasts of the ECMWF global primitive equation model. This note takes up their invitation for further discussion. Below a number of the major differences between the model and real cyclones are documented in the hope of adding insight on the relevance of their simulations to tropical cyclones in the real atmosphere.

(i) As discussed in B82, the frequency and distribution of model generated cyclones correspond approximately to that observed climatologically. Certain important differences exist, however. According to Gray (1979) 28% of the world's cyclones develop in the North-West Atlantic and the North-East Pacific. The model simulations, however, produce only 4 developments (1% of the annual total) in these two basins. Also in the historical record cyclones have never been observed in the Australian region in the months of July–September; yet the model develops several. The picture that emerges is one whereby the model cyclones are dependent on certain parameters in common with real cyclones but are independent of others. Inspection of world maps of climatological sea surface temperature (e.g. Alexander and Mobley, 1974) reveals a remarkable similarity between the model cyclone distribution and the seasonal distribution of areas of sea surface temperature greater than 29 °C. This simple observation can explain (a) the model cyclones being most frequent in the western North Pacific (attributed by B82 to the larger size of cyclones in that region), (b) the occasional southern hemisphere cyclone being generated near the equator in July–September, (c) the relative lack of North-West Atlantic and North-East Pacific cyclones, and (d) the realistic absence of cyclones in the South Atlantic. In the atmosphere sea surface temperature is only one of a number of parameters important on the seasonal time scale (Gray, 1975).

(ii) Despite similarities to reality in the mature stage, the structure of the model cyclone in its early stages is quite unrealistic:

In the pre-development stage (B82 Fig. 6) the pre-cyclone weather system has a ratio of divergence to vorticity $|V_{\mathrm{Radial}}/V_{\mathrm{Tangential}}|$ of the order of 10. No tropical weather systems in the atmosphere have this ratio greater than about 0.5 (Reed and Recker, 1971; Ruprecht and Gray, 1976).

The pre-development stage shows intense convection as evidenced by a vertical velocity of 0.5 Pascal s^{-1} ($\sim$430 mb day^{-1}). This indicates quite a vigorous predevelopment weather system and yet there is approximately zero vorticity associated with it.

The early development stage (B82 Fig. 7) has a vertical velocity of 2.8 Pascal s^{-1} (2400 mb day^{-1}). Assuming the inflowing mass carries a mixing ratio of 15 g kg^{-1}, this is equivalent to a rainfall rate of 360 mm day^{-1}, yet is described by the authors as a stage where "strong convective heating and the formation of the warm core have not yet started". For comparison, Frank (1977) composited vertical motion and precipitation over the 0–2° radius area for *fully developed* North Pacific typhoons and found mean values of only $\sim$350 mb day^{-1} and 95 mm day^{-1} respectively (see Frank's Figs. 19 and 21).

The temperature anomaly diagram in Fig. 7 of

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B82 indicates that the lower stratosphere may play an important role in the early development, although these intense lower stratospheric temperature gradients are not observed in nature.

Figs. 6–9 of B82 depict the evolution of a model vortex over 4 development stages. The vertical motion field in these figures shows the *opposite trend* to reality, decreasing from 2.8 Pascal s^{-1} in the development stage (Fig. 7) to approximately 1.0 Pascal s^{-1} in the mature stage (Fig. 9).

(iii) The antecedent conditions for development also have a number of unrealistic features:

Twice in B82 it is stated that the model cyclones form at the point where sea temperature is highest. In the atmosphere, above a threshold of 26½°C (Palmén, 1948) the observational literature reveals an apparent insensitivity of cyclone development to sea surface temperature variations (Ramage, 1972, 1974; Riehl, 1979, p. 466).

In the atmosphere tropical cyclone development is strongly dependent on a pre-existing large scale vorticity field (Gray, 1979; McBride and Zehr, 1981). The model vortices, on the other hand, do not require the pre-existence of large scale vorticity, as is evidenced by the lack of any appreciable tangential wind in Fig. 6 of B82.

The model cyclones appear to depend on a pre-existing divergence field of large magnitude, whereas McBride and Zehr (1981) conclude that in the atmosphere the potential for a tropical weather system to develop into a cyclone is not well related to the magnitude of the large-scale divergence field.

In light of the above differences, it seems unlikely to the current author that the physics of tropical cyclone development in the model is the same as in the atmosphere. Indeed with the model parameterizations and resolution of $\sim$200 km this would be an unreal expectation. Nevertheless it is clear that the model developments should be further investigated so that their physical cause can be understood.

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