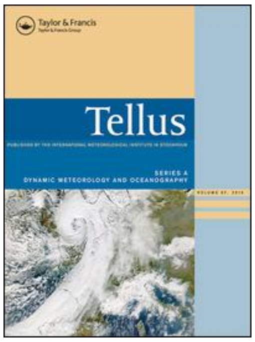

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Prediction of a typhoon using a fine-mesh NWP model

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ABSTRACT

The ECMWF operational grid point model (with a resolution of 1.875° of latitude and longitude) and its limited area version (with a resolution of ~0.47° of latitude and longitude) with boundary values from the global model have been used to study the simulation of the typhoon Tip. The fine-mesh model was capable of simulating the main structural features of the typhoon and predicting a fall in central pressure of 60 mb in 3 days. The structure of the forecast typhoon, with a warm core (maximum potential temperature anomaly 17 K), intense swirling wind (maximum 55 m s^{-1} at 850 mb) and spiralling precipitation patterns is characteristic of a tropical cyclone. Comparison with the lower resolution forecast shows that the horizontal resolution is a determining factor in predicting not only the structure and intensity but even the movement of these vortices. However, an accurate and refined initial analysis is considered to be a prerequisite for a correct forecast of this phenomenon.

1. Introduction

The continuous and increasing interest in simulating tropical storms for operational and research purposes is reflected in the long lists of numerical models developed during the 1960s and 1970s as described by Anthes (1982). These models are divided by Anthes in two major categories: research models (two-dimensional axisymmetric and three-dimensional asymmetric) and three-dimensional forecast models. Among these, the primitive equation models are found to be those that appear to give the best performances and to be susceptible to improvement (Neumann and Pelissier, 1981; Fiorino and Harrison, 1983). These vary in the sophistication of their physical parameterization; the operational dynamical models are always nested in larger models because of the need of both high-resolution and large-scale formation. Examples of models which use a movable nested grid are the highly sophisticated Movable Fine Mesh (MFM) model developed at NMC (Hovermale and Livezey, 1977), the Movable Multi-Nested Grid (MNG) developed by the Japanese Meteorological Agency (Ookochi, 1978, 1983), and the Navy's Nested Tropical Cyclone Model (NTCM) (Harrison, 1981). In these models a high-resolution grid, embedded in a larger coarser grid, moves with the tropical cyclone. Therefore large-scale data are supplied to the fine grid as well as small-scale data being fed back from the fine to the coarse grid. In this way, the fine structure of the tropical storm can be described as well as its movement which is mainly driven by the large-scale flow.

While earlier modelling efforts were chiefly concerned with the physics and dynamics of the tropical cyclone (Anthes, 1972; Kurihara and Tuleya, 1974; Jones, 1977), recent operational models as described above put the emphasis in predicting the motion of the cyclone (Harrison and Fiorino, 1982; Ookochi, 1983). In previous resolution experiments (Jones, 1977), the improvement in the structure and strength of the tropical cyclone with resolution was evident, but, due to the nesting, it was not possible to give a clear indication of the effect of the resolution on the movement of the cyclones. The models mentioned above have specifically been developed with the purpose of predicting tropical cyclones per se. This approach is different from ours, since our objective is to investigate the potential of high-resolution general circulation type of models.

In a previous article by Bengtsson et al. (1982)

(hereafter referred to as B82), the possibility of forecasting warm-core, hurricane-type vortices with a general circulation model was discussed. It was shown that intense vortices, with a structure resembling tropical cyclones, can be predicted from an initial state with no initial disturbance, provided favourable conditions for cyclogenesis are generated by the large-scale flow. It was stressed that lack of resolution was probably the cause of the weak intensity of the simulated vortices and their somewhat different behaviour as compared with the observed ones.

In a comment to B82, McBride (1984) expressed some doubt concerning both the possibility of forecasting tropical cyclones in a GCM, and the physics of tropical cyclone development in the model. In a reply to McBride (1984), Bengtsson et al. (1984) expressed the opinion that the increase of the horizontal resolution, equivalent to a grid size of 50 km or less, would presumably be required before operational forecasts of tropical cyclones with a GCM-type model could be a reality. To run such a model on a global domain is not yet feasible, but it may be possible at the end of the decade.

In order to substantiate this opinion and to investigate the effect of horizontal resolution, a numerical experiment was undertaken with the ECMWF global grid point model (resolution 1.875° of latitude and longitude) and with its limited area version with horizontal resolution 0.46875° of latitude and longitude.

The ECMWF's limited area model (hereafter called ELAM) is a "derivative" of the Centre's model with the identical physics package, including Kuo parameterization, and with the same characteristics as the global model described in B82. It has previously been successfully used in the study of extra-tropical disturbances and to simulate flow over and around steep and irregular terrain (Dell'Osso, 1983). In those circumstances, it was found that the high-resolution model was capable of giving a more accurate and detailed description of orographically forced flow, as well as a simulation of phenomena influenced by the meso-scale processes.

The so-called super typhoon Tip was selected for this forecast experiment. A detailed synoptic account of this phenomenon has been given by Dunnavan and Diercks (1980). This typhoon was probably the most powerful tropical storm of this century with the lowest ever observed sea level pressure of 870 mb. Estimated surface maximum wind speed of 85 m s^{-1} was reached during the peak of its intensity on 12 October 1979. The extent of the circulation pattern was also the largest on record; the diameter of the last closed isobar as seen from the centre of the storm was about 2000 km. The scale and intensity of the storm and the fact that it occurred during the Global Weather Experiment in 1979, with its enhanced observing system, made this typhoon a desirable case study for a numerical experiment.

The present experiment was organized in a truly operational context and the global forecast was run prior to ELAM so as to provide boundary values for the high-resolution forecast. These values, as well as the initial data, were interpolated from the global model to the ELAM grid without any change in the vertical resolution; a technical description is given in Dell'Osso (1984).

In Section 2, we will compare the results of the ELAM and the global model and attempt to answer the following questions:

(i) is the general structure, evolution and the track of motion realistically predicted?;
(ii) what is the rôle and importance of the resolution?;
(iii) is it feasible to consider tropical cyclones forecasting within the framework of a general forecasting system?

A detailed study of the typhoon itself will be the subject of a separate report.

2. The forecast experiment

2.1. *Analysis and observations*

The initial data were obtained from the 1.875° resolution analysis and interpolated to the 0.46875° resolution of the ELAM grid over an area of integration sufficiently large to include a considerable part of the north Pacific Ocean: 37°N–7°S, 112°E–197°E (97 × 182 grid points).

The analysis of the initial data at 0000 GMT, 9 October 1979 shows a large weak depression over the Pacific Ocean with a centre just to the east of Guam. The sea surface temperature over this area was 29°C or above, with a maximum of 31°C around 11°N, 148°E. The lowest value of the surface pressure of the vortex given by the FGGE level IIIb analysis was 1005 mb (Fig. 1), while the

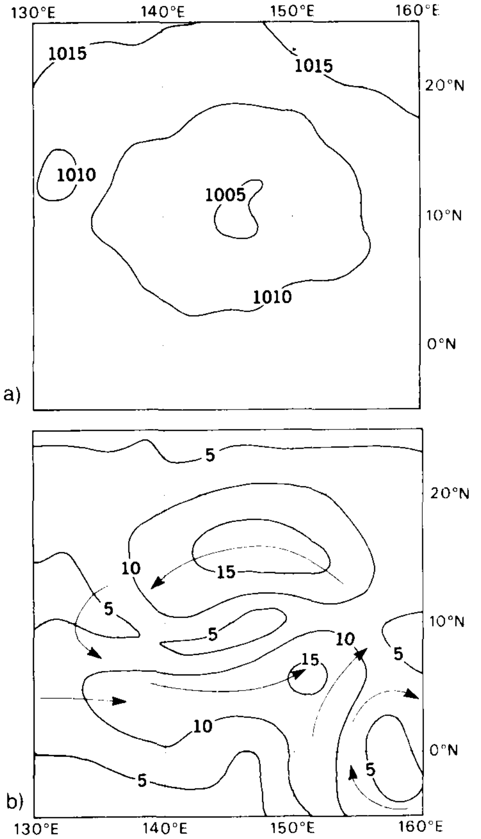

Fig. 1. (a) Analysed mean sea level pressure and (b) streamlines (unit m s^{-1}) for 0000 GMT 9 October 1979.

high resolution analysis published by Dunnavan and Diercks (1980) was 15 mb lower at this time. The flow from the anticyclonic circulation southeast of the vortex merged with the westerly flow and advected warm moist air from the south into the vortex region. The observed maximum wind speed was 25 m s^{-1} with gusts of 33 m s^{-1}, and was analysed as 15 m s^{-1} to the south and the north of the centre of the vortex at 850 mb. This so-called "onset vortex" constituted the initial stage of the typhoon (Ooyama, 1982), from which a 3-day forecast was started. B82 already demonstrated that the global model is capable of forecasting the onset vortex of a tropical cyclone. Our main objective here is therefore to examine the intensification and evolution of the typhoon with the low- and high-resolution models, and compare the results with the observations as presented by Dunnavan and Diercks (1980).

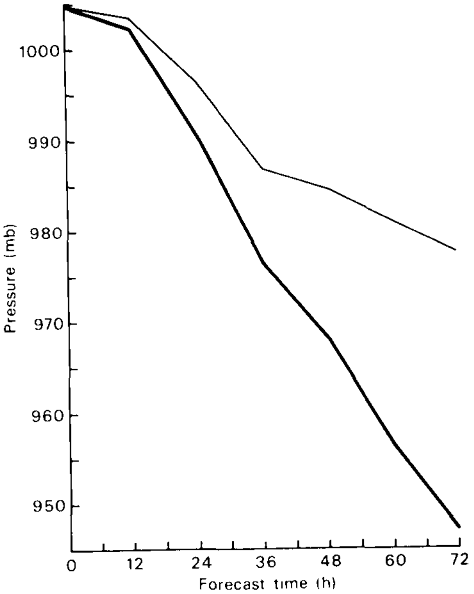

Fig. 2. Variation of the central pressure with time from the high-resolution (thick line) and low-resolution experiments.

From 9 October 1979, the typhoon moved westward and intensified rapidly with a drop of central surface pressure of more than 90 mb during the next 48 h. Surface wind speeds reached super typhoon values (65 m s^{-1}) during this time, as recorded by reconnaissance aircraft. The FGGE level IIIb analyses gave a minimum surface pressure of only 998 mb, since the analysis system *a priori* excludes features of this scale. During the next 24 h, the typhoon intensified still further, and, during 12 October, it reached its most intense phase with sea level pressure of 870 mb and sustained surface winds of 85 m s^{-1}.

The typhoon simulations are less dramatic, in particular for the coarse-mesh resolution model. The pressure falls 37 mb during the first 2 days in the ELAM, but only 21 mb in the coarse-mesh model (Fig. 2). As the initial vortex gradually intensifies and shrinks, the overall structure becomes complex in the high-resolution case; convective cells are continuously being created and subsequently absorbed into organized meso-scale systems. Already after 12 h, there are 3 maxima of upward vertical motion predicted at 700 mb, reaching 1.5 Pa s^{-1}, and at 200 mb, there are two well-defined centres of divergence. The coarse resolution forecast gives a weaker vortex with a less complex structure. The 3-day forecast verifying at 0000 GMT, 12 October, gives a lowest pressure of 947 mb and maximum wind of 55 m s^{-1} for the high-resolution model (Fig. 3); the corresponding values for the low resolution are 977 mb and 35 m s^{-1}.

Lack of relevant initial data and the fact that the large-scale data-assimilation system *a priori* excludes small-scale features (Lorenc, 1981) is certainly a major reason for the error in the forecast.

2.2. *Motion of the typhoon*

In both the experiments, the typhoon takes a more northerly track, but less so for the high-resolution model (Fig. 4). In fact, the path followed by the ELAM typhoon in the last 48 h of the forecast, though displaced towards the north by about 4° of latitude, is similar to that observed. The errors in the objective analysis of data, certainly too coarse for the size of the vortex at the initial stage, seem particularly important and are probably responsible for the inaccurate prediction of the typhoon. As we have seen, the central pressure of the analysed vortex is almost 15 mb higher than the actual one, and its position is about 300 km too far southwest. This shallow large vortex does not represent the actual tropical storm that reached typhoon strength shortly after 1200 GMT, 9 October. In the first 24 h of the forecast, the "erratic movement" of the vortex, similar to the path followed by Tip during the period 5 to 7 October, represents the period of development of the model storm. After 24 h of the ELAM forecast, the predicted tropical storm reaches typhoon strength and its central pressure reaches the value that the actual typhoon had at the initial stage.

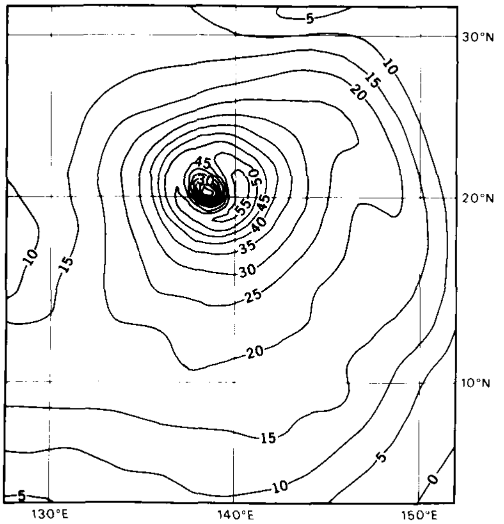

Fig. 3. Wind field at 850 mb from day 3 of the high-resolution forecast verifing at 0000 GMT 12 October 1979 (Isotaches every 5 m s^{-1}).

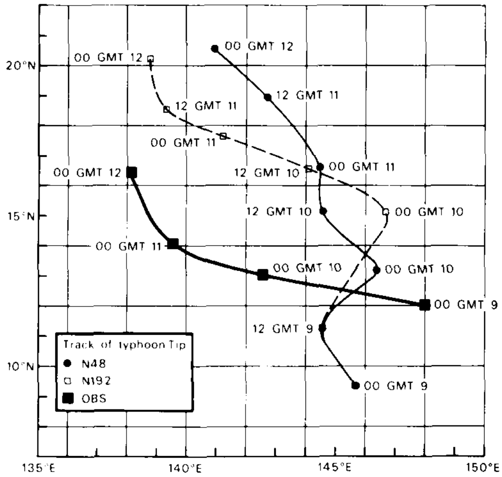

Fig. 4. Track of the observed and forecast typhoon Tip at resolution N48 (1.875° lat/lon) and N192 (0.47° lat/lon).

Considering the tropical cyclone as a moving envelope with an "effective radius" (Holland, 1983), it appears that the change in the direction of motion of the cyclone depends on the change of its radius (Holland, 1984). In our case the radius of the typhoon Tip changed considerably in the first 24 h. Furthermore, the "steering flow", which is one of the factors affecting the direction of motion, varied in the first 24 h. In the initial stage, the 500–1000 mb layer was mainly dominated by the westerly and southerly flow. Then, when the typhoon moved to northern latitudes, it was subject to the easterlies and finally to the westerlies in the last 12 h.

The movement of tropical cyclones has been a matter of extensive investigation and the importance of predicting it is reflected in the effort of the operational forecast centres to continuously try to improve their models in order to reduce the distance error in their forecasts. It is worth noticing that the error of the position of the ELAM forecast is well inside the 72 h mean forecast distance error presented by Neumann and Pelissier (1981), Fiorino et al. (1982), and Fiorino and Harrison (1983) (and in fact not very much larger than the initial distance error).

2.3. *Structure of the typhoon*

Let us now consider the structure of the predicted vortex. Fig. 5 shows the zonal vertical cross section of the typhoon from day 3 of the forecast. The warm core structure surrounded with intense swirling winds is characteristic of a tropical cyclone, e.g. Anthes (1982). Significant features include an increase of the wind speed in the eye-wall and rapid decrease in the eye. Near the surface, the wind speed is reduced by frictional dissipation and the maximum is found at 850 mb. Cyclonic circulation is maintained from the surface

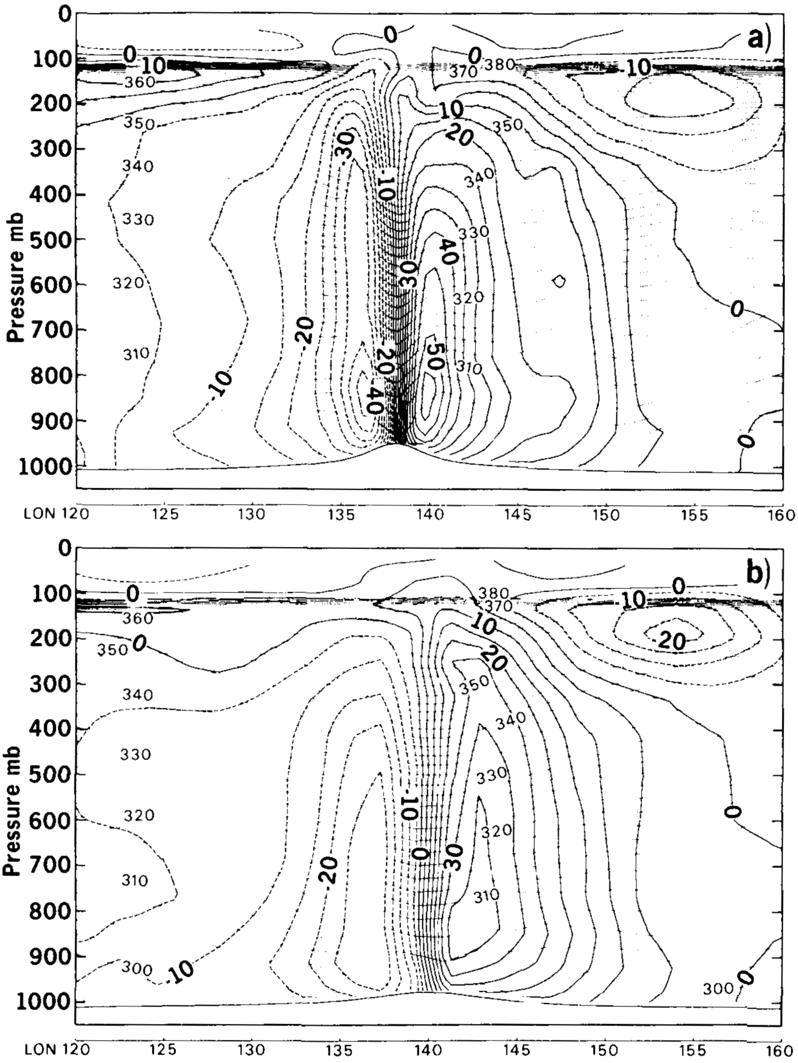

Fig. 5. Zonal vertical cross section from 120° E to 160° E along latitude 20° N from day 3 of the forecast with (a) high- and (b) low-resolution verifying at 0000 GMT 12 October 1979. Thin lines are isentropes (every 2 K), thick and dashed isolines are lines of equal wind speed with direction perpendicular to the plane (every 5 m s^{-1}, positive into the plane). The bottom contour represents surface pressure.

up to 200 mb by the strong ascending motion, with anticyclonic flow above this level. The maximum vertical wind velocity, 3 Pa s^{-1}, obtained on day 3 of the forecast, agrees with values found by Frank (1977) for an average typhoon, but the resolution of the model must be taken into account. The warm core in the centre of the vortex extends to about 200 mb, with a maximum potential temperature anomaly with respect to the surroundings of 17 K around 300 mb, and temperature in excess of 15 K from 450 up to 250 mb. These are features common to the vortex produced with the low- and high-resolution models. However, a comparison of the two cross sections in Fig. 5 indicates the effects of the resolution on the typhoon. In the high-resolution experiment, the position is approximately 2° further to the west; the central pressure is 30 mb lower; the horizontal wind is more than double; the maximum of the wind is 20 m s^{-1} higher; the anomaly of the temperature of the core with respect to the surroundings is closer to the centre of the vortex and stronger than in the low-resolution forecast. The anticyclonic flow in the layer 300–100 mb is weaker on the west and stronger in the east side in the high-resolution than in the low-resolution case. This is due to the interaction of the large-scale flow with the divergent flow from the typhoon; in the lower resolution, the divergent flow is closer to the upper level southerly flow on the east side and farther away from the westerly flow on the west side.

Finally, the ELAM forecast of the 24 h accumulated precipitation between day 2 and day 3 (Fig. 6a) shows two spiral bands, with a maximum of over 400 mm near the core. The region of precipitation north of 30° N is due to the outflow of moist air from the typhoon that merges with the westerly flow of the mid-latitudes. Distribution and amount of precipitation are typical of tropical cyclones (Frank, 1977) and in particular of the typhoon Tip where the wall cloud "looked like a double helix spiralling from the base to the top" (Dunnavan and Diercks, 1980). A comparison of the predicted distribution of precipitation during the 24 h of 11 October (Fig. 6a) with the composite satellite picture between 1719 and 1921 GMT 11 October (Fig. 6b) shows that, in the limits of the described errors and taking into account the different projections, the maxima of precipitation and the overall shape of the forecast typhoon coincide rather well with the actual typhoon Tip. The instantaneous structure distribution of the vertical motion during the period to which Fig. 6a refers is shown in Fig. 7, where the 700 and 500 mb vertical velocity from the 48 h (Fig. 7a and b) and the 60 h (Fig. 7c and d) forecast are presented. The band structure is visible with higher vertical wind in the upper level where a larger release of latent heat takes place (Mathur, 1975). The complex nature of typhoon Tip is visible in Fig. 7: at 48 h, the convergence of moist air enhances the southern system that loses energy in the next 12 h; the northern system then develops considerably.

3. Concluding remarks

In this note we have demonstrated that an operational model is capable of simulating a tropical cyclone in spite of the fact that the initial state has been obtained by a large-scale data assimilation system. The limited area version of the ECMWF global grid point model was used to perform a 3-day forecast with a resolution of 0.47° of latitude and longitude. This model is in all respects identical to the global grid-point operational model (resolution 1.875° lat/lon) and not built *ad hoc* to forecast tropical cyclones as the MFM, MNG or the NTCM. By using a large area of about 45° of latitude and 85° of longitude at a resolution of ~0.47°, it avoids the limitation of the above-mentioned nested models. The interaction of the typhoon with the large-scale flow happens naturally at the various scales, and this clearly results in an improvement of the typhoon tracks when the fine-mesh model is used. The initial data, as well as the boundary values, were interpolated from the global grid-point model. These initial data contained errors in amplitude and phase of the initial vortex and no symmetric vortex was superimposed on them, as in the MNG (Ookochi, 1978). Despite that, the higher resolution typhoon, differently from that at lower resolution, was able to deepen the central pressure considerably and follow a track parallel to that observed in the last 48 h of the forecast.

The thermodynamic structure of the typhoon was realistically reproduced. The warm core, the rapid intensification of the vortex, the fall of the surface pressure, the increased wind speed and the rainfall distribution show the characteristics of a tropical cyclone. The values of the predicted

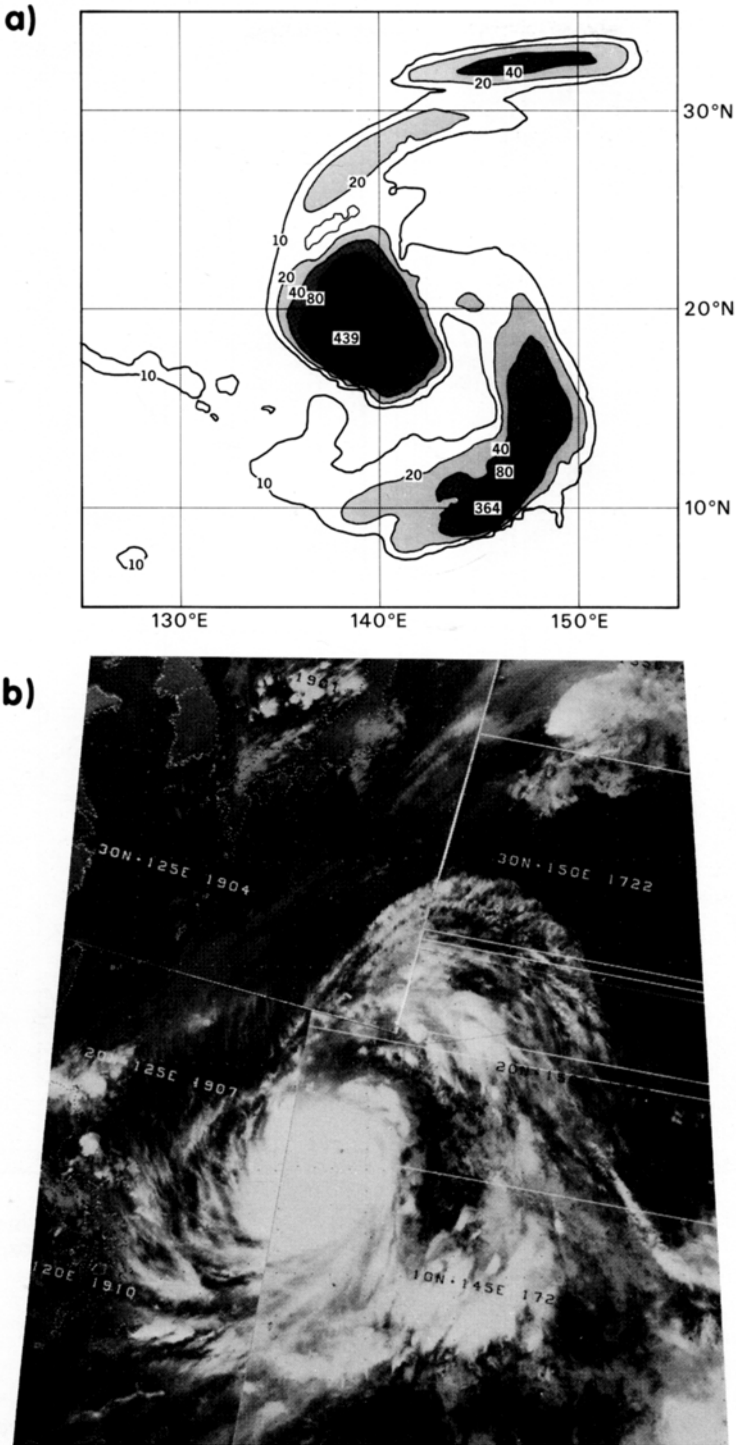

Fig. 6. (a) 24-h accumulated precipitation (mm) from the high-resolution forecast between 48 and 72 h (0000 GMT 11 and 0000 GMT 12 October 1979); (b) composite satellite picture (TIROS-N, visible) between 1719 and 1912 GMT, 11 October 1979.

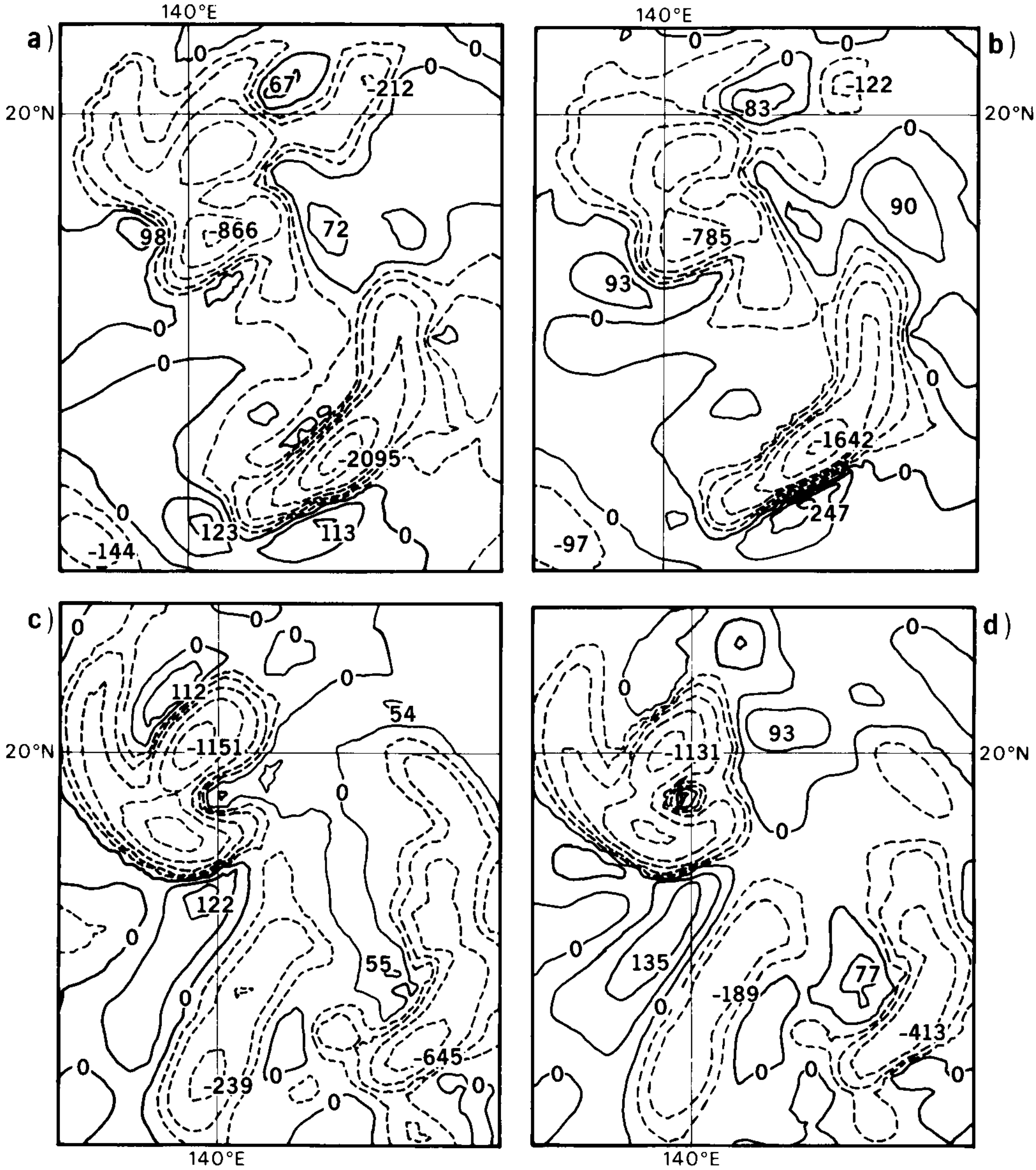

Fig. 7. Vertical wind ($\omega = dp/dt$ in 10^{-3} Pa s^{-1}) at 500 mb (left) and 700 mb (right) from the (a), (b) 48 h and (c), (d) 60 h high-resolution forecast verifying at 0000 GMT 11 and 1200 GMT, 11 October 1979, respectively. (Contours every 50, 100, 200, 400, 800 10^{-3} Pa s^{-1}; positive contours are solid lines.)

parameters become more realistic with high resolution, which reinforces the belief expressed by Bengtsson et al. (1984) that the next generation of super computers will allow a higher resolution which may permit forecasts of tropical cyclones on a global scale. It should be said, however, that the typhoon Tip was a particularly intense and large-scale feature which is simulated even in the low-resolution forecast. Therefore, it is our intention to carry out experiments with various resolutions for tropical cyclones of medium size and intensity to confirm the present results. However, while the resolution used in the ELAM forecast may be adequate to represent typhoon Tip, there is certainly need for an accurate and more refined analysis. In fact, there is clear evidence that the model atmosphere is able to organize and build up features with the characteristics of a typhoon within a sufficient period of time. However, an accurate initial state is a prerequisite for an accurate prediction, and, in some respects this may be more important the shorter the range of the forecast.

REFERENCES

Anthes, R. A. 1972. Development of asymmetries in a three-dimensional numerical model of the tropical cyclone. *Mon. Wea. Rev. 100*, 461–476.

Anthes, R. A. 1982. Tropical cyclones. Their evolution, structure and effects. Am. Met. Soc., Boston, 208 pp.

Bengtsson, L., Böttger, H. and Kanamitsu, M. 1982. Simulation of hurricane-type vortices in a general circulation model. *Tellus 34*, 440–457.

Bengtsson, L., Böttger, H. and Kanamitsu, M. 1984. Reply to a comment by J. L. McBride. *Tellus 36A*, 94–96.

Dell'Osso, L. 1983. High-resolution experiments with the ECMWF model: a case study. ECMWF Tech. Report No. 37, 50 pp.

Dell'Osso, L. 1984. A practical approach to the problems of limited area modelling. Proceedings of the ECMWF Seminar on Numerical Method for Weather Prediction, 5–9 September 1983, ECMWF.

Dunnavan, G. M. and Diercks, J. W. 1980. An analysis of super typhoon Tip (October 1979). *Mon. Wea. Rev. 108*, 1915–1923.

Fiorino, M., Harrison, E. J., Jr. and Marks, D. G. 1982. A comparison of the performance of two operational dynamic tropical cyclone models. *Mon. Wea. Rev. 110*, 651–656.

Fiorino, M. and Harrison, E. J. Jr. 1983. Recent results from the Navy nested tropical cyclone model. Typhoon Operational Experiment, Report 9, WMO, 225–226.

Frank, W. M. 1977. The structure of the tropical cyclone (1). Storm structure. *Mon. Wea. Rev. 105*, 1119–1135.

Harrison, E. J., Jr. 1981. Initial results from the Navy two-way interactive nested tropical cyclone model. *Mon. Wea. Rev. 109*, 173–177.

Harrison, E. J., Jr. and Fiorino, M. 1982. A comprehensive test of the Navy nested tropical cyclone model. *Mon. Wea. Rev. 110*, 645–650.

Hovermale, J. B. and Livezey, R. E. 1977. Three years performance characteristics of the NMC hurricane model. Preprints 11th Tech. Conf. Hurricanes and Tropical Meteorology, Miami, Amer. Meteor. Soc., 122–124.

Jones, R. W. 1977. A nested grid for a three-dimensional model of a tropical cyclone. *J. Atmos. Sci. 34*, 1528–1553.

Kurihara, Y. and Tuleya, R. E. 1974. Structure of a tropical cyclone developed in a three-dimensional numerical simulation model. *J. Atmos. Sci. 31*, 893–919.

Lorenc, A. C. 1981. A global three-dimensional multivariate statistical interpolation scheme. *Mon. Wea. Rev. 109*, 701–721.

Mathur, M. B. 1975. Development of banded structure in a numerically simulated hurricane. *J. Atmos. Sci. 32*, 512–522.

McBride, J. L. 1984. Comments on "Simulation of hurricane-type vortices in a general circulation model". *Tellus 35*, 92–93.

Neumann, C. J. and Pelissier, J. M. 1981. Models for the prediction of tropical cyclone motion over the North Atlantic: an operational evaluation. *Mon. Wea. Rev. 109*, 522–538.

Ookochi, Y. 1978. Preliminary test of typhoon forecast with a moving multi-nested grid (MNG). *J. Meteorol. Soc. Japan 56*, 571–582.

Ookochi, Y. 1983. On the performance of typhoon track forecast model with a movable multi-nested grid scheme. Typhoon Operational Experiment, Report 9, WMO, 223–224.

Ooyama, K. V. On basic problems in theory and modelling of the tropical cyclone. In: *Intense Atmospheric Vortices*. Springer-Verlag, Berlin, Heidelberg. New York, 21–34.