CHAPTER VII

SUMMARY AND REVIEW OF THE THESIS
Chapter I of the thesis is for general introduction. In chapter II, temperature anomaly distributions from a few composite and a number of individual case studies of tropical storms have been discussed. A relatively simple equation has been devised to find out the temperature anomaly distribution at as many points as desired on any vertical plane through the axis of a steady state symmetric tropical storm from a few known values (including its maximum). A method to predict thereby the tangential velocity and pressure distributions has also been developed. Temperature anomaly profiles on any axial plane, tangential velocity and pressure distributions curves on sea surface calculated by assuming only the maximum temperature anomaly are found to be consistent with those of typical real storms. From numerical experiment it is found that the strength of the storm depends on horizontal as well as on vertical distribution of the temperature anomaly field. It is also seen that different storms with same central sea level pressure drop may not have same maximum tangential velocity. Two profiles one relating the maximum temperature anomaly with maximum tangential velocity and the other that (maximum anomaly) with minimum sea level pressure have also been constructed. It is found that these profiles have good agreement with typical real storm situations and seem to have predictive application.

To apply this technique the maximum temperature anomaly in the centre of the storm are to be measured accurately; otherwise accuracy will be lost. If the anomaly distributions in the centre and at least at one level in radial direction, preferably through the maximum anomaly are known, the results will be more accu-
rate. If more real data are available, the parameters used in the equation (2.1) can be further modified.

A model has been designed in Chapter III to study the surface boundary layer of a tropical storm. The numerical method consists of solving a two point boundary value problem for two systems of simultaneous non-linear differential equations by finite differences. A Stoke’s stream function suitable to represent the flow both in interior and exterior regions of a tropical storm boundary layer has been developed. The advantage of this method is that the boundary layer of a tropical storm can be studied starting from the outer region to the centre of the storm without neglecting the non-linear terms. In addition, there is no need for any assumption of the vertical profiles for tangential and radial velocities. The method is stable and converges within a few iterations.

To investigate the effect of turbulence on the boundary layer characteristics, the turbulence has been represented by four different variations of the eddy coefficients of viscosity with no slip boundary conditions, and solved taking 40 grid points in the vertical (which generates 79 equations). It is observed that if the eddy coefficient of viscosity is assumed to vary with the superimposed flow above the boundary layer, the solutions compare favourably well with observations including inflow angle and boundary layer thickness. The solution also shows an outflow from the inner core above the boundary layer which is favourable for the creation of an eye of the storm.

It is evident from the results that the magnitude and distribution of induced meridional circulation depends upon the
structure of turbulence. In the core region, it depends less critically on the vertical structure of turbulence than on radial structure; but in outer region, it depends upon both.

Though the vertical velocity in the boundary layer is a very small quantity in comparison to other components, its magnitude and distribution is very significant for the growth and maintenance of the storm. It seems that this model could simulate it well. The finite difference method developed in this work can be used to solved other non-linear simultaneous differential equations.

On the sea surface, only the no-slip boundary conditions for tangential and radial velocities have been tested. This is the drawback of the model. This work can be further extended incorporating suitable surface stress terms. To get the radial and vertical velocity distributions above the boundary layer, the solutions of Chapter II and III can be matched together in future work.

The three dimensional triply-nested grid primitive equation numerical model in Chapter IV is suitable to simulate tropical storm and study small scale weather phenomena. The variables are staggered in space to get better accuracy. A two way interactive method has been adopted to match the solutions between grids of different length. In this process two mesh areas interact dynamically with each other. A semi-implicit time integration method has been used in order to permit larger time step than explicit method. An iterative method has been devised to speed up the solution of the systems of Helmholtz equations arising out of the semi-implicit scheme. In order to examine the role of surface
friction and forced subsidence during early stage of development of a tropical storm, time integrations have been performed within 5022km x 5022km domain with three meshes of 18 km, 54 km and 162 km grid lengths each containing 32x32 grid momentum points enclosing 31x31 grid mass points.

From the results of three cases tested in this preliminary study, it appears that the grid scheme, the finite difference method, matching of the solutions between different grids and technique of integration have yielded smooth and encouraging results. The semi-implicit technique seems to have become more advantageous in respect of speed for nested grid model with introduction of the new iterative method for solutions of the system of Helmholtz equations. The scheme shows satisfactory performance from computational point of view.

The results show that the rate of intensification is higher without friction than with friction. The cyclonic flow in the upper troposphere slowly disappeared and anticyclonic outflow formed and intensified with time. As the vortex intensified the radius of the maximum tangential wind shifted towards the centre, much more with friction than without it. The magnitude of the vertical velocity also increased with time and the region of its maximum value moved towards the centre. The vortex remained nearly symmetric during the formative stage. It also remained stationary during this period, as could be expected, since the Coriolis parameter (f) was kept constant and there was no environmental flow. The results show that the smoothness of the dependant variables is well maintained.

The results indicate that a disturbance may develop without
surface friction. This suggests that surface friction may not play an essential role in the early developing stage of a tropical storm when the vortex is weak, since the frictional convergence at this stage may not be sufficient for its growth. That is, the CISK mechanism may not be very relevant to pre-cyclone disturbance maintenance and intensification. On the other hand, initiation of initial development to the storm's intensity may be attributed to the warming caused by forced subsidence in the central region of the disturbance as hypothesised by several authors. The structure of the disturbance obtained in frictionless case at 60 hour is different from the observed tropical storm in the sense that the stream lines show very feeble convergence in the boundary layer. The radius of the maximum tangential velocity is also much larger than the frictional cases. This suggests that surface friction comes into play when the strength of the vortex is increased and it is one of the important factors to determine the horizontal scale of the disturbance.

There are several deficiencies in the model. The heating due to forced subsidence has been included through analytical function. This is to be parameterized in terms of large scale flow. The vertical resolution of the model is poor. Heat transfer between ocean surface and the vortex has been formulated implicitly. Eddy coefficients of viscosity have been treated in a simple way. The model can be further extended and refined to study the life-cycle of tropical storms taking into account of the variation of the Coriolis parameter, environmental flow, more sophisticated parameterization of physical processes, smaller grid length etc., with movable nested grids, if high speed computer
is available.

In Chapter V, three classical and difficult hydrodynamical problems related to the motion of a two dimensional vortex in perfect fluid in presence of idealized topographical boundary walls with steady uniform stream parallel to the straight part of the walls have been solved analytically. In the first two cases the infinite straight walls have a semi-circular bay and a bulge. In third case, the boundaries consist of an infinite straight wall and a circular island near it. Suitable techniques of transformation have been developed to study the problems. In the first two cases, it has been found that for the negative ratio of the strength of the vortex and uniform stream, the path of the vortex makes loops in a region closed to the curved wall with stationary point(s). In the third case, it is seen that the vortex makes loops around the island, whether the uniform stream is present or not and stationary points exist on a line perpendicular to the wall through the centre of the island — one between the wall and island, for positive ratios of the strength of the vortex and uniform stream and two, in case of negative ratios, — one between the plane wall and island and the other away from the island. When the vortex is close to the wall, it can move in opposite direction to the uniform stream in all cases. It can also remain stationary at some particular positions. Available tracks of cyclonic storm along the Western Ghats of India are discussed in the light of the results.

The approach of this work can be extended to study the motion of more than one vortex in the vicinity of multiple boundaries and also for elliptical island.
Since, these are two dimensional cases in perfect fluid with uniform stream, their applications have limitations when applied to natural atmospheric three dimensional vortices. However, this investigation may indicate some qualitative information in studying the behaviour of the motion of storm or low pressure system in the vicinity of mountain ranges or high island.

In chapter VI, satellite and synoptic studies of an unusual tropical storm are made to investigate its genesis, intensification, movement and decay over the sea. The following conclusions can be drawn from the studies:

(i) Equatorial burst band surge from the Southern Hemisphere into a pre-existing low pressure area increased cyclonic shear which led to enhanced convection. Mechanically and dynamically induced subsidence aloft from convective cloud tops led to compressional heating over a localized comparatively cloud-free area which favoured the vortex to extend to the middle and upper troposphere, thus leading to initial cyclogenesis.

Genesis was also favoured by weak vertical wind shear and warm sea surface temperature.

(ii) Further intensification was favoured by suitable upper air conditions, warm sea surface temperature and by the high energy air fed into the storm's circulation along the feeder band from the equator.

(iii) It appears that initial movement of storm was guided by the \( \beta \)-effect and subsequent movement by its environmental steering current. New convective cloud mass growth was observed in the direction of its movement, and before recurving or changing its direction of movement, the speed of movement became slow.

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or it remained stationary for some time.

(iv) The changes in the shape of cloud pattern are highly correlated with the change in the direction of movement and gave good signals for its movement.

(v) Deformation of cloud pattern towards the end of its life suggested its increased interaction with the westerlies. This and penetration of dry and cold air into the cloud area led to its rapid decay. Low sea surface temperature also might be one of the causes for its rapid weakening right over the sea.

Though, this is a single case study, the results are encouraging and agree well with the hypothesis tested in Chapter IV. More studies are necessary in this new field. It may also be possible to forecast the movement of tropical storm using satellite cloud imagery, for which intense investigations are required.