Chapter 7
Summary and Scope for future work

This chapter contains the summary of the work contained in the thesis with emphasis on the important and new results that were obtained. The scope for future work, as an extension of and related to, the present studies is also indicated.

7.1 Summary of results obtained

The thesis is devoted to the study of low latitude thermosphere-ionosphere system based on coordinated thermospheric and $F$ region measurements using a central-aperture pressure-scanned Fabry Perot Spectrometer operating on O I 6300 Å airglow, and a ground-based ionosonde located nearby. The focus has been on understanding the closed cycle of interactions that occur continuously between the neutral and the ionized species, in the presence of large scale geophysical processes in the low latitude region. Since the interaction mechanisms depend on the chemical, fluid dynamical and electrodynamical properties of the neutral-plasma medium, the behaviour of the thermosphere-ionosphere system as a whole is looked upon in terms of these properties. Earlier workers have employed the servo model of Rishbeth as a tool, in order
to understand and determine the nature and magnitude of the driving forces (like winds and electric fields) on the midlatitude $F$ region, and the resulting interactions. According to the servo model, the peak of the $F_2$ region lies at a level determined by neutral atmospheric parameters where chemical equilibrium prevails; the external forces perturb this level and the $F_2$ peak approaches a new equilibrium level. At the equilibrium $F_2$ peak itself, diffusion and chemical recombination are of equal importance. Assuming that the time required for diffusion at the $F_2$ peak is shorter than times associated with the largest variations in applied drifts, it has been shown by many workers that the midlatitude $F_2$ layer does behave in accordance with the expectations of servo model. Making use of the servo principle, several workers have derived meridional winds from the existing ground-based ionosondes. In spite of inherent assumptions and limitations involved in the methodology they have adopted, the pattern of derived winds showed overall agreement with direct measurements and empirical model predictions. This ability to derive meridional winds using the basic physical principles in turn had demonstrated the fact that the behaviour of the midlatitude thermosphere-ionosphere system has been fairly understood.

The behaviour of the low latitude region is complicated by large scale processes such as equatorial ionization anomaly, equatorial temperature and wind anomaly, equatorial spread $F$ and midnight temperature maximum, whose role in the energetics and dynamics of the upper atmosphere is largely unknown. Till recently, no attempts have been made to understand the basic interaction mechanisms that get significantly modified in the presence of these processes. As mentioned in Chapter 1, the reason for our limited knowledge on the behaviour of the low latitude thermosphere-ionosphere system had been the non-availability of a wider data base on both thermospheric and ionospheric parameters. In view of this fact, systematic coordinated measurements have been initiated and the results have formed a part of this thesis.
Line profile measurements of airglow emissions have been carried out from Mt. Abu (24.6°N, 72.7°E geographic; 33°N dip) for more than six years. Though the number of profiles that have been obtained by the central aperture-Fabry Perot Spectrometer was very large, there were severe limitations in retrieving useful information that led to the development of a comprehensive and more appropriate data analysis scheme described in Chapter 2.

The results were presented in four chapters in the following categories.

- Obtaining the variabilities of neutral temperature, which is important since the equilibrium height of the $F_2$ layer is determined by neutral temperature. The importance and applications of neutral temperature in understanding various physical processes have been illustrated in Chapter 3. The results from this chapter are as follows: Making use of the temperature measurements available during low and high solar activity periods, an exercise has been carried out to determine the effects of solar variability on the behaviour of the thermospheric temperatures over low latitudes. The limitations of the MSIS-86 model, one of the most comprehensive models available as on this day, in representing low latitudes, has been demonstrated by means of individual case studies. These studies show that significant enhancements occur in measured neutral temperatures at certain times considerably deviating from the model predictions. Next the response of thermospheric temperatures to changes in solar flux over a longer period was examined. A plot of mean measured temperatures versus mean model temperatures over the years covering half the solar cycle suggests that only about 65% of the variation in the measured temperatures can be accounted for and that most of the mean measured temperatures are higher than the mean model temperatures leading to the suggestion that there should be additional energy sources that significantly contribute to the energetics of
the low latitude neutral atmosphere.

Identification of these energy sources has been the next step in the presentation. The geophysical processes of relevance during quiet geomagnetic conditions are (1) the Joule heating associated with the fluctuating electric fields of equatorial spread $F$ irregularities, (2) the equatorial temperature and wind anomaly (ETWA) associated with the equatorial ionization anomaly (EIA) and (3) the midnight temperature maximum (MTM).

The possibility of significant amount of energy that might be deposited along magnetic flux tubes in the presence of fluctuating electric fields and drift velocities associated with equatorial spread $F$, causing enhancement in neutral temperatures, has been cross-checked, and it has been concluded that the excess heating cannot be ascribed to the possibility of spread $F$ associated heating alone. Owing to the renewed interest in EIA associated processes such as ETWA and the presence of vertical winds, the possibility of these processes acting as sources of energy has been explored. It has been shown that electrodynamic properties of the thermosphere-ionosphere system have the potential to be one of the controlling factors for the variabilities of thermospheric temperatures at the location of the crest of EIA.

- Having ascertained the variabilities of neutral temperatures and their possible sources, the next step has been to examine the validity of servo model for low latitude regions. It has been demonstrated in Chapter 4 that the servo model of Rishbeth is an ideal tool for investigating the behaviour of the thermosphere-ionosphere system since it incorporates the basic coupling mechanisms. Having given a description of servo principles, derivation of the servo equation and the earlier work done for midlatitudes, details of the simulation exercise that has been carried out in order to determine the latitude beyond which the servo model can be applied, were presented. Since the 'servo' response of the $F$ region
varies as \( \sin^2 I \) and the diffusion process becomes insignificant near the magnetic equator, the latitude from where on the servo model can be applied and tested against the actual behaviour of the \( F \) region, was determined to be beyond 20°. Several case studies have been made and the results presented in this chapter demonstrate the fact that the \( F \) region behaves according to the expectations of servo model at this low latitude station. The height of the \( F \) layer was shown to vary as \( 11 \pm 2 \) km for every 100 K change in neutral temperature. Based on servo principles and making use of measured temperatures and meridional winds, estimates of \( F \) layer peak height were made and compared with the independently obtained peak height values from the ground-based ionosonde. The results obtained for a few days have indicated fairly good to very good agreement. The deviations between the estimated and the measured peak heights were ascribed to zonal electric fields. Estimates of electric fields for all the days under consideration made with certain valid assumptions show considerable variability from season to season, at times becoming eastward.

* The servo model reveals a direct relationship to exist between the \( F \) layer displacement and the wind vector. Using the servo model principles, the importance of neutral temperature that determines the \( F \) layer peak height, and its variabilities, in influencing the derived meridional winds were demonstrated in Chapter 5 through case studies. Variabilities of measured meridional winds have been studied for two seasons, namely, the winter and equinox periods. Comparisons of these measurements with those from other low and equatorial latitudes have been made and they were found to be significantly different. The present estimates differ from both horizontal wind model and the vector spherical harmonic model. It has been concluded that solar radiation does not seem to be the sole agent that sets and governs the observed wind patterns.
The limitations of numerical models to describe the observed variation of thermospheric temperatures and winds over different time intervals ranging from a few hours on a given night to a solar cycle, over a low latitude station, demonstrates the need for incorporating the effects of geophysical processes into the models by means of a parameterization. Such an effort would need a thorough understanding of the processes themselves and coordinated measurements from a chain of stations in the near-equatorial zone are needed for this purpose. Work in this direction has been initiated and some of the results obtained were presented in Chapter 6.

The processes that were investigated in this regard are, (1) the MTM and (2) the EIA. After reviewing the mechanisms that are responsible for MTM, the results on the comparison of the variation of meridional winds from two different latitudes, namely, Mt. Abu (24.6°N geographic) where direct measurements are available and Sriharikota (13.7°N geographic) for which winds were derived from the ionosonde data, were presented. In the winter month of February (1991), there appeared to be a systematic phase difference in the variation ranging from 2 to 4 hours and always the Mt. Abu measurements were lagging in phase. This has been suggested to be probably due to the MTM occurring near the equator and giving rise to an associated wind pattern. However, for the equinoctial month of April, no such feature was seen probably due to the dominant role played by electrodynamic processes during this season.

The EIA associated processes in the low latitude region were studied under three categories: (1) behaviour of the post-sunset and nighttime $F$ region, (2) effects of EIA on the neutral atmosphere and (3) effects of thermospheric winds on equatorial spread $F$. Though we have results only for (1) and (2), the importance of (3) was highlighted in the text for the sake of completeness. The post-sunset behaviour of the $F$ region at the crest location of EIA has been
shown to be controlled by the EIA. The passage of the crest of EIA across the low latitude observing site would alter the neutral and ionospheric parameters significantly.

Though it is difficult to infer the wind systems associated with ETWA especially when no data on vertical winds are available, the results that were presented in Chapter 5 provide a positive indication for the neutral air circulation associated with ETWA to be active over the low latitude station. This has been demonstrated utilizing electron densities available from the ground-based ionosonde and the airglow intensities.

Finally, the potential of the all sky imaging Fabry Perot Spectrometer that has been designed and fabricated for the purpose of mapping temperature and wind fields was highlighted and its importance in studying the geophysical processes was emphasized.

7.2 Scope for future work

There are several areas that need to be explored in detail and the following suggestions in this direction are meant to be an useful extension of the present thesis.

It is proposed that more coordinated measurements of both thermospheric and ionospheric parameters be made at least from two stations making use of the available resources. The spatial variabilities of thermospheric parameters need to be brought out since they are capable of providing clues to the relative roles played by all known physical processes. It is important to estimate quantitatively the effect of each of these processes for a full understanding of the thermosphere-ionosphere system.

The existing models of neutral upper atmosphere need to be improved upon to represent better the low latitude observed features. The measurements from these
locations may be utilized for a parameterization of numerical models in terms of the competing effects of dominant geophysical processes.

The effects of geomagnetic storms were not touched upon in the thesis owing to limited data available for these occasions. Only recently, reports have come on the observed effects of storms on the thermospheric densities, temperatures and winds from other latitudes. Continuous, systematic, ground-based measurements are necessary to infer information regarding geomagnetic activity effects at low and equatorial latitudes.

The present spectrometer has a limitation of not being able to measure vertical winds of small magnitudes. Recent satellite measurements have revealed them to be present in significant amplitudes and the instrument could be improved upon to be able to make these measurements so that equatorial spread $F$ associated investigations could be carried out.

Mapping of the dynamical features is an attractive proposition for a region like ours which has several geophysical features. Relation of the neutral thermospheric parameters with ETWA, processes associated with geomagnetic storms, etc., are considered extremely important from the dynamics and energetics point of view.

More detailed investigations are being planned for the coming years.

With the sanctioning of TIMED (Thermosphere - Ionosphere - Mesosphere - Energetics and Dynamics) satellite mission, a comprehensive set of complementary ground-based measurements are a must. The capabilities developed during the course of the present work and the proposed improvements and scientific investigation are expected to play a crucial role in the understanding of the complex system namely 'The thermosphere - ionosphere system'.