This chapter summarizes the important contribution of this thesis, and discusses the future scope of the work.
9.1.0 SUMMARY

This thesis explains the importance of Radar remote sensing for Land Surface characterization over the Indian region using C-band data from ERS scatterometer and Ku-band data from QuikSCAT scatterometer. The land surface variations within India were investigated covering multi-seasonal variations in vegetation densities, and moisture levels for the wide varieties of soil and vegetation types.

The flow of the discussion presented in the thesis starts with broad level land cover classification using C-band data. Subsequent to that, the investigations made for the ‘Thar’ desert are discussed in detail.

The simulated dielectric constant for the various bench-mark soils found in India is one of the key contribution from this thesis. The effect of soil moisture on the backscattering coefficients is also discussed at respective places.

As Ku-band data are sensitive to upper most variations observed over dense canopies, interesting findings are brought out from the study carried out in forest cover classification and investigation of forest phenology.

The discussion ends with important findings obtained from the study carried out using data from both the frequencies (C- and Ku-band).

The salient observations from this thesis are summarized below.

9.1.1 Landscape level land characterization

The $\sigma^0$ (sigma naught) at C-band, VV polarization, scatterometer aboard ERS-2 for the year 2000 data were used to investigate radar signatures of land surfaces over the Indian region.

The data showed a variability of $\sigma^0$ of the order of 12 dB (–18 to –6 dB). High backscattering was observed from forests in the North-eastern region, the Western Ghats and the forests spanning Central India. In general, increase in
backscattering coefficient was observed due to forest density. The backscatter showed a variability of 8 dB in backscattering coefficient due to density variation. Medium backscattering was observed for agricultural land whereas desert regions showed very less backscatter due to specular reflections. High moisture zones due to irrigated land in Rabi season was clearly seen with backscattering values of about $-10.5$ dB.

### 9.1.2 Characterization of Thar Desert

C-Band radar time-series backscatter response for the year 2000 covering the Thar Desert region was studied. The important outcomes of the study are:

(i) Major dune types were identified and their temporal trends were also studied. In general, high backscattering was observed in the months of July – August and low backscattering was observed in the months of May – June.

(ii) Over the Thar Desert region $\sigma^0$ values were very low and varied gradually from summer to monsoon, and winter seasons. The sharp change in the moisture level in the desert region is also reflected clearly from $\sigma^0$.

(iii) It can also be concluded that the dune types separation-using $\sigma^0$ is best possible in the month of June.

### 9.1.3 Soil wetness characterization

Soil wetness characterization using C-band scatterometer data using change-detection method has been studied. Rainfall was used as surrogate to soil moisture. Soil wetness Index (SWI) was found to be correlated with rainfall pattern. Thus, large scale observations on soil moisture seem to be feasible.

A study was carried out for the soil benchmark sites, which covers a majority of the variation in soil types existing in India. The important points emerging from the study are:

- Backscatter responds to surface soil wetness and vegetation on account of dielectric property of water existing in it.
SWI derived using space-borne scatterometer data provides the true indicator of soil moisture compared to rainfall measurements.

9.1.4 Characterization of forest cover and dynamics

In this thesis, a methodology for the assessment of vegetation dynamics of natural forests has been developed. We have explored the potential of Ku-band scatterometer data for Indian tropical moist deciduous forests at macroscopic level due to high repeat cycle of the data. It becomes possible to examine the dynamics of vegetation and temporal annual backscatter cycle. Models for temporal variation of radar backscatter for forested area were developed, which described dynamics of vegetation satisfactorily. Following are the salient features of the study:

(i) The relation of vegetation growth and senescence was investigated by comparing \( \sigma^0 \) time-series to NDVI and rainfall observations.

(ii) \( \sigma^0 \) was minimum during the deciduous period with prevailing high temperature and no rainfall condition. The temporal changes in backscattering coefficient were modeled for understanding the vegetation dynamics. The study showed the suitability of Ku-band space-borne scatterometer data for understanding the seasonal dynamics of different forest types.

(iii) The low correlation coefficients indicate that the direct relationship between \( \sigma^0 \) and NDVI is either very weak or absent. Therefore, inferring that, NDVI, which is a measure of the vegetation greenness or vigour rather than plant water-content or height, is not important for the explanation of the backscattering behaviour.

(iv) The results have shown the significance of Ku-band scatterometer in understanding the phenological events of different forest locations of Indian forests.
9.1.5 Comparison of C- and Ku-band signatures

Radar backscatter images at C-band and Ku band over Indian regions were derived from ERS-2 and QuikSCAT wind scatterometers at two different frequencies and polarisations. Signatures were analysed for assessing the potential of these datasets for land applications related to vegetation discriminate, dynamic, soil wetness and characterization of deserts.

The comparative performance of C- and Ku- band data indicated that:

(i) The backscattering coefficient values at Ku- band were higher than C-band in all the land cover classes due to increase in roughness with frequency.

(ii) Between the two channels, C-band showed better discrimination in vegetation density classification.

(iii) Polarization difference images at Ku-band showed clear-cut demarcation of irrigated land.

(iv) It was observed that the polarization difference was more for high NDVI than that of low NDVI classes. Thus, polarization can act as a discriminant for vegetation.

(v) The effect of view direction on backscatter was also analysed. It was observed that effect of view direction was more in the case of vegetated (dense) condition compared to other less vegetated classes.

9.2 FUTURE SCOPE

The study indicated the potential of C-band scatterometer data for retrieval of bio-geophysical parameters (soil moisture, vegetation type and density) at near-regional scale for modelling & monitoring forests ecosystem and desertification.
Decadal/Multi-decadal time series analysis using scatterometer data over many years (decades) may give better insight of the formation of the dunes, “dune shift” and spread of desertification.

Further, investigation of the C-band data for monitoring the aerodynamic roughness length, $Z_0$ over Indian Thar desert may be meaningful. The dune spacing using SRTM-DEM and its relation with $\sigma^0$ in the Thar can also be attempted in future. The study indicated the potential of C-band scatterometer data for monitoring temporal variability for modelling and monitoring desert ecosystem.

The use of spaceborne scatterometer is valuable for regional level study. Major advantage is in terms of high repeativity of the data, which may provide short-term variations. Annual variation due to changes in plant morphology could also be examined by developing vegetation scattering models.

Incorporation of the space-observation based phonological information into the vegetation/crop growth modelling may be one of the important activities in future.