Background

One of the most fascinating large-scale atmospheric phenomena that occurs year after year over the Indian subcontinent is the Southwest Monsoon. Generally, monsoon commences around early June over Kerala, advances to north and covers the entire country by middle of July. The south-west monsoon over Indian sub-continent directly affects the lives of over one billion people, providing almost 80% of the annual precipitation during the four month duration of June-September. The delay in the onset of monsoon by a few weeks would adversely affect the crop output while the early onset might not be utilized to advantage without an advance forecast. Thus, the monitoring and forecasting of the summer monsoon’s onset over Indian subcontinent is very much important for the economy of the country. The spatial and temporal distribution of summer monsoon rainfall over the country and its variability affects the agricultural output significantly. It shows large inter-annual variability in three important aspects namely, 1) the onset date, 2) quantum of monsoon rainfall and 3) the variability on sub-seasonal time scales with active periods of heavy rainfall interrupted by drier ‘break’ periods.

The vast oceans surrounding the Indian sub-continent provide a large source of moisture and continuously modify the thermodynamics of the atmosphere through latent heat release. The temporal and spatial variability of water vapour in the atmosphere is very significant due to its ability to change the phase and release of latent heat. The momentum and heat balance between low insolation polar region and high insolation tropical region is maintained by this unique property of water vapour and large-scale atmospheric and oceanic circulation. Thus it is very much important to understand the water vapour variability during monsoon season. Most of the numerical modeling efforts use humidity profiles, obtained from point observations (radiosonde). However good data with better temporal and spatial scales can be obtained through satellites over the oceanic regions. Most of the diagnostic studies on summer monsoon have been done using numerical weather prediction (NWP) model products, which suffer large biases
over vast oceanic regions in comparison to satellite observations. In view of the above stated facts major emphasis in the thesis has been given to the use of more accurate multi-satellite observation for the diagnostic studies and also the impact of satellite derived humidity profiles into the NWP models.

Objectives
The specific objectives of the thesis include:

1. Study of spatial and temporal evolution of water vapour fields over Indian Ocean during summer monsoon.
2. Estimation of moisture flux transport over Indian sub-continent from adjoining seas, prior and during summer monsoon season using satellite data.
3. To study intra-seasonal oscillations of geophysical parameters in relation to active and break phases of south-west monsoon.
4. Study of impact of satellite derived humidity and temperature profile in mesoscale process.

Chapter 1 Introduction
This chapter elucidates the importance of water vapour in summer monsoon and explains the relevance of the present study. The intra-seasonal oscillations and the role of water vapour flux in the Indian monsoon have been discussed. It also gives a brief idea about the importance of satellite derived water vapour fields for the input to various NWP models. The scope of the present study and its objectives are also discussed in this chapter.

Chapter 2: Data used and sensors relevant to the study
This chapter elaborates the data used and in brief explains the methodologies for obtaining it in the required grid and levels. The data include different levels water vapour, total tropospheric water vapour, sea surface wind speed, out going long wave radiation, sea surface temperature, zonal and meridional wind. A brief description of satellites
Chapter 3: Onset of south west monsoon

Most of the earlier studies on monsoon onset have been done using the reanalysis data sets. In this chapter the microwave and infrared sensor derived water vapour data have been used to identify the objective criteria for monsoon onset over the Kerala coast (southern tip of India). NOAA/TIROS Operational Vertical Sounder (TOVS) data analyses show almost 100% increase in middle (700-500hPa) and upper level (500-300hPa) water vapour over Eastern Arabian Sea during onset time. Tropical Rainfall Measuring Mission Microwave Imager (TMI) data analyses for 1998-2004 show almost 20-30% increase in tropospheric water vapour over Western Arabian Sea about two and half weeks before the onset. The wind data from both satellite and National Centre for Environmental Prediction (NCEP) reanalysis have been used to find out the accurate onset dates in the recent years. NCEP wind at 850hPa shows pronounced Somali low level jet during onset phase, which is maintained about 15-20 days after the onset. Madden Julian Oscillation (MJO) study using outgoing long wave radiation (OLR) data shows its association with the onset of monsoon over Kerala. The spatial and temporal variations of total water vapour, sea surface wind speed and sea surface temperature from microwave data sets have been studied in relation to onset of south-west monsoon.

Chapter 4: Evolution of water vapour fields during south west monsoon

Monthly distributions of satellite derived water vapour, sea surface temperature and sea surface wind speed have been discussed in this chapter. Comparison of TMI, NOAA/TOVS derived total water vapour and NCEP reanalysis total water vapour has been carried out. It has been shown that over the convectively active regions of the Indian Ocean, NCEP is underestimating the water vapour. The specific humidity at different levels has been derived from a variable scale height algorithm using three level NOAA/TOVS data and has been validated with the radiosonde observations. Monthly scale water vapour flux at different levels is then calculated using the specific humidity.
derived from variable scale height algorithm and the NCEP zonal and meridional winds
monsoon years show lack of cross-equatorial moisture flux from southern Indian Ocean
and reduced West-Pacific moisture incursion into the Indian Ocean for drought year.

Chapter 5: Intraseasonal Oscillations during active and break phase of south west monsoon

Intra-seasonal oscillation of area averaged water vapour and sea surface wind speed over
Eastern Arabian Sea (EAS) and North Bay of Bengal (NBB) during monsoon period has
been studied using state of art Morlet Wavelet Analysis as the tool. The Wavelet analysis
of middle and upper level water vapour suggested the presence of well marked 15-30
days oscillation before and during onset time and 30-60 days oscillation only after the
real onset over the Eastern Arabian Sea. TMI analysis for 1998-2003 over EAS shows the
time evolution of the quasi-biweekly 10-20 days and 30-60 days intra-seasonal modes
with 90% confidence level. Analysis over NBB shows, apart from the above stated
modes, presence of 6-9 days synoptic scale oscillation. The lead lag relation between sea
surface wind speed and water vapour shows sea surface wind speed is 3-4 days ahead in
phase over the EAS whereas it is 1-2 days over NBB. This gives an idea about the
mechanism of convection. The heavy rainfall events along the west-coast of India have
been studied in relation to the thermodynamical structure and the intra-seasonal
oscillation over the Eastern Arabian Sea. Highly active periods over west-coast of India
correspond to the simultaneous presence of positive phase of 10-20 days and 30-60 days
periodicity oscillation. West Coast generally receives heavy rainfall when both the
middle level moisture content and corresponding westerly winds are high. The composite
total water vapour analysis shows presence of simultaneous high water vapour content (~
55-65 mm) over Eastern Arabian Sea and over North Bay of Bengal during active periods
whereas its magnitude is less (~45-55 mm) during break periods of summer monsoon.
Chapter 6: Impact of satellite derived moisture and temperature profile in mesoscale process

The limitation to the improvements of regional weather forecast relates to the fact that the input observational information is limited, especially over vast data sparse oceanic regions. The remotely sensed satellite data with high temporal and spatial resolution is the only source of meteorological information, which can be used to provide initial condition to the numerical models. The impact of moisture profiles from Moderate Resolution Imaging Spectro Radiometer (MODIS) flown in TERRA/AQUA satellites and NOAA/TOVS is examined in a meso-scale model in simulating heavy rainfall events over Indian land and low-pressure systems/off-shore trough over oceanic regions. A positive impact has been observed in simulated rainfall, low and off-shore trough over Indian region.

Chapter 7: Conclusion and direction for future research

The extensive satellite observation studies give better understanding of the role of water vapour in Indian summer monsoon. The combined use of satellite and NCEP data in moisture flux transport suggests that the role of cross-equatorial moisture flux and west Pacific moisture incursion into the Indian Ocean is crucial in maintaining monsoon flow. Almost real time available satellite data gives a good lead-time for the understanding of the development of monsoon flow. Incorporation of humidity profile into the mesoscale numerical model shows positive impact in simulating heavy rainfall, lows and off-shore trough over Indian regions. The physical processes involved in the monsoon rain can be more accurately understood by the use of satellite data in diagnostic studies. The future satellite sounding data over the Indian region from Geo-Stationary platform, namely INSAT-3D will be able to give good temporal, spatial and vertical resolution data sets in real time. This can be used to understand the thermodynamics and dynamics of the atmosphere and hence will be helpful in improving the parameterization schemes in numerical models.