Chapter-6

Conclusions And Future Directions
The present work addresses use of satellite-based remote sensing techniques for retrieval of useful ocean environmental parameters. The studies presented in this thesis focus on remote sensing of surface heat (latent and sensible) fluxes, their variability, and role in the development of tropical disturbance like cyclone. Intra-seasonal to interannual variation in the climate system are strongly influenced by the coupling between the ocean and atmosphere. Ocean surface heat fluxes (latent and sensible) play a key role in the surface energy balance. Their studies gives better understanding of air-sea interaction, short-term climate change and processes like hydrological cycle.

Remote sensing of surface heat fluxes at the air-sea interface requires combined information from different spectral regions, which is equivalent to use of different radiometers. For estimations of sea surface temperature the most commonly used algorithm (MCSST) has been used. In cloud free areas, this algorithm determines the sea surface temperature with an accuracy of 0.5-1.0 K. The near-surface wind speed is retrieved from measurement of the SSM/I radiances. The comparison with in situ gives an accuracy of 1.4 m/s. The estimation of near surface specific humidity from total precipitable water vapour gives an accuracy of 1 g/kg on a monthly time scale.

Novel techniques were developed to retrieve near surface air temperature and near surface specific humidity from microwave brightness temperature during non-precipitating conditions. The accuracies achieved for these parameters are about 1 g/kg for near surface specific humidity and 1 K for near surface air temperature.
These algorithms are in the process of refinement for precipitating cases also.

Monthly averages of sensible and latent heat fluxes over the global oceans were computed for the year 2000 using the stability dependent bulk formulae. These fluxes were computed from SSM/I wind speed and L86 -SSM/I retrieved surface specific humidity, AVHRR retrieved sea surface temperature, and MSMR retrieved near surface air temperature. The monthly mean surface heat fluxes and related variables of the four seasons during the year 2000 agree reasonably well with those estimated using COADS data. The seasonal variation is well produced by satellite estimated heat fluxes and related variables.

It is difficult to derive the absolute accuracy for the bulk formulae since only few accurate in situ measurements of heat fluxes are available. A comparison with ship data reveals an RMS error of approximately 30 Wm$^{-2}$ in latent heat flux and 8 Wm$^{-2}$ for sensible heat flux on a monthly time scale. Systematic differences in the LHF are found to correlate with differences in the air specific humidity $q_a$ and air temperature $T_a$, and wind speed, as derived from satellite fields with statistical relationships. The LHF is overestimated in strong subsidence region, mostly during the winter season in association with underestimation of $q_a$ and $T_a$. The LHF is underestimated mainly in the atmospheric convergence zones. In these regions, $q_a$ and $T_a$ are overestimated.

In an attempt to improve the global LHF estimate, a novel technique has been developed. In this approach the LHF can be directly computed from microwave observed brightness temperature and sea surface temperature. The accuracy of LHF retrieved by this technique is
better than the LHF computed using bulk formula. The overall LHF is found to agree within 20 Wm$^{-2}$. The technique developed assumes a linear relationship between LHF and the microwave brightness temperatures at different frequencies. In future, the non-linear behavior has to be taken into account to get more accurate LHF.

The month-to-month variation of surface heat fluxes for the year 2000 has been presented over northern Indian Ocean. During the pre-monsoon periods, the LHF shows an increasing trend due to the increase in the sea surface temperature, and starts decreasing after the onset of southwest monsoon.

Since the northward advance of the monsoon winds over the Arabian Sea completes only towards the end of the June, the latent heat flux maxima showed the peak during that period. During the months from July to October, the LHF values were lower over both the regions (Arabian Sea & Bay of Bengal). After the southwest monsoon season, the LHF values start rising and attain its second peak during November-December.

Sensible heat fluxes of the order of 10-20 Wm$^{-2}$ have been found during winter months over both the regions (Arabian Sea & Bay of Bengal). Drastic change occurs in the sensible heat flux over Arabian Sea during onset phase of Indian summer monsoon. During this period the transfer of sensible heat is from atmosphere to ocean. This is due to the cooling of ocean surface by strong wind. The inter-annual and seasonal variability of the surface heat fluxes should be studied over these regions in order to understand the role of surface heat fluxes in monsoon energetic.
Daily fields obtained for the year 2000 were used to study the surface latent and sensible heat flux variability. The intra-seasonal variability is examined by filtering the estimated fluxes and retaining period of 30-50 days period. Highest percentage of variance in 30-50-days mode is found over warm pool region (western Pacific and north Indian Ocean) in the temperature and moisture field. Wind and surface heat fluxes show more scattered percentage of variance in this band. About 40 percent of the total variance is explained by this mode over warm pool regions. This suggests a strong variability of 30-50 days mode. On this time scale, the latent heat flux was found to be around 20 to 70 Wm$^{-2}$ from ocean to the atmosphere. The maximum amplitude of surface latent heat fluxes on this time scale has been observed during winter season. During summer the amplitude is minimum. Maximum amplitude has been found over north Atlantic, north Pacific and over north Indian Ocean. The amplitude of sensible heat fluxes on this time scale is about an order of magnitude smaller than that of latent heat flux over the warm pool regions.

The results have been obtained by computing the surface fluxes generated by the low frequency modes. In the computations, we have left one variable at a time constant (time mean) in order to examine its contribution. The wind has significant influence on the surface fluxes; of the other three variables the moisture appears to be the one, which influences the latent heat flux the most. Sea surface and air temperature are equally contributing to the fluxes. Over the land, the behavior of these variables may be completely different. Some earlier studies suggest that temperature has strong impact on heat fluxes over land region.
Webster (1983) has used a model to explore a mechanism, which involves surface hydrological effects to explain the northward propagation of low frequency wave over India. In order to test his mechanism, the fields of precipitation, surface temperature, and surface heat fluxes (filtered in the 30-50 days period) for temporal sequence during which low frequency wave propagation is present. The relative patterns for the previous variables are in very good agreement with his mechanism. Thus, a temperature minimum zone is coincident with the precipitation maxima zone. The drop in the temperature is caused by evaporation of rain. In fact, a latent heat flux maxima area is observed over the same location, on the other hand a temperature maxima zone appears north of the precipitation. The increase of the sensible heat flux destabilizes the atmosphere and induces a northward motion of the disturbance, according to the Webster.

The role of surface heat fluxes (sensible and latent) has been studied in the genesis and development of tropical cyclone. Assimilation of scatterometer derived sea surface wind data over Bay of Bengal cyclone has been carried out with in-built assimilation scheme of MM5 model. These winds have improved the circulation field in the initial data. Assimilation of QuikSCAT derived wind field has positive impact on vortex generation.

The model predicted description of low-pressure system compare well with satellite observed low pressure system. During vortex generation the withdrawal of surface heat fluxes of sensible and latent heat had a substantial impact on the wind circulation. Simulation without surface energy fluxes completely dislocates the low-pressure area. Simulation
without latent heat release produces the similar wind circulation as produced by control simulation during vortex generation. The withdrawal of the surface heat fluxes had a moderate to stronger impact on the precipitation forecast during cyclone development. Surface heat fluxes have less impact on first 24-hour precipitation, except in spatial distribution of rain. Maximum 24-hour (ending at 00 GMT of 16th October) rainfall was 250 mm, which is only half of control experiment.

The requirements for heat flux fields are many and diverse. However, there are four main classes of the requirements as discussed in chapter 1. Satellite derived flux fields have the potential to be useful for all of these classes. Future satellite missions will deliver better temporal and spatial resolution so that those data will be applicable for the first class.

The length of the time period of available satellite data for heat flux determination has significantly increased, but great care is needed to provide flux estimates from sensors on successive satellite or from combinations of similar sensors on different satellites to ensure that final product may be useful for the detection of long-term trends in the surface heat fluxes. At the moment the length of the time records of satellite-derived heat fluxes allows only for analyzing annual and interannual variability, which might be useful for evaluating climate models. In this context any improvement of the flux estimates itself through improved sensors, sensor combination, or better algorithms is meaningful.

Today, most of the basic state variable necessary for estimating heat fluxes can be derived from satellite data. These quantities may be
directly derived using radar backscatter or from visible, infrared or microwave brightness temperature. The exception is near surface specific humidity and near surface air temperature. Air temperature is important to estimate the sensible heat flux and the transfer coefficients within the bulk approach. The near surface specific humidity is important for latent heat flux estimation. Present sensors mounted on satellites do not directly sense these parameters. There are empirical algorithms for obtaining these parameters. But the accuracies achieved are not enough, particularly for air temperature. In future, some sensor will be providing these basic parameters and hence fluxes will be improved. The few of these are discussed below.

MODIS (or Moderate Resolution Imaging Spectroradiometer) is a key instrument aboard the Terra (EOS AM) and Aqua (EOS PM) satellites. Terra's orbit around the Earth is timed so that it passes from north to south across the equator in the morning, while Aqua passes south to north over the equator in the afternoon. Terra MODIS and Aqua MODIS are viewing the entire Earth's surface every 1 to 2 days, acquiring data in 36 spectral bands, or groups of wavelengths (see MODIS Technical Specifications). It gives the vertical profiles of temperature, moisture, and atmospheric stability. All of these parameters are produced at 20 atmospheric pressure levels. Out of these two levels are in boundary layer. These parameters especially humidity and temperature, in the lower boundary layer will be used for fluxes computation with a higher horizontal resolution. Also these data will improve our understanding of global dynamics and processes occurring on the land, in the oceans, and in the lower atmosphere.
GIFTS (The Geostationary Imaging Fourier Transform Spectrometer) mission, scheduled for launch in 2004, is the first step towards incorporating technological breakthrough into the next generation of operational weather observing system. The GIFTS will improve all three basic atmospheric state variables (temperature, moisture, and wind velocity) allowing much higher spatial, temporal, and vertical resolution.

Another Future sensor, of relevance for surface fluxes study is AIRS (Atmospheric Infrared Sounder). This is an infrared sounder of atmospheric temperature and other properties of the atmosphere and will be available in EOS platform. AIRS will have capability of continuous soundings over entire swath. The temperature retrievals expected from AIRS will be accurate to approximately 1 °K. We have seen that near air temperature computation from present satellite is very difficult. In future air temperature retrieved from AIRS will improve the accuracy of heat fluxes.