*Synopsis of the Doctoral Thesis entitled*

# Low Level Jet stream of Asian Summer Monsoon and its variability

Asian summer monsoon rainfall affecting Indian subcontinent and other Asian regions is the product of the global and local anomaly in the general circulation features. Traditionally in India, agricultural practices have been tied strictly to the annual cycle of the monsoon. A late or weak monsoon can have disastrous consequences for production of the crops and a strong monsoon can cause flood conditions, both affecting the normal life of people of India. So proper forecasting of location and quantity of precipitation is crucial to maintaining food stocks. Awareness of the need to understand and predict the monsoon over India have recently generated much interest in the possible relationships between the amount and distribution of Indian monsoon rainfall and antecedent regional and global features. The most important need in monsoon forecasting is to pick out with reasonable degree of success, the years of deficient and excess rainfall.

A strong cross-equatorial Low Level Jet-stream (LLJ) with core around 850 hPa exists over the Indian Ocean and south Asia during the boreal summer monsoon season, June to September. LLJ has its origin in the south Indian Ocean north of the Mascarene high as an easterly current, it crosses the equator in a narrow longitudinal belt close to the east African coast as a southerly current with speeds at times even as high as 100 knots, turns into a westerly current over the Arabian Sea and passes through India to the western Pacific Ocean.

LLJ has strong horizontal shear (vorticity) in the planetary boundary layer (maximum vorticity at 850 hPa) and is important for generation of convective rainfall and for the development of rain producing weather systems. The LLJ is the main conduit for transporting moisture generated over Indian Ocean to the monsoon area. The intraseasonal oscillation of LLJ controls this moisture distribution. In active monsoon condition a large convective region over the Bay of Bengal is maintained by the LLJ through peninsular India and in turn the convection maintains the LLJ. When convection over Bay of Bengal decreases and it gets established over the equatorial Indian Ocean, the LLJ bypasses India and it passes south of India transporting bulk of the moisture evaporated over the Indian Ocean to the west Pacific Ocean. Thus LLJ is important in monsoon rainfall distribution over the monsoon area.

The main objectives of the present study are,

- *To study Intraseasonal variability of LLJ and its relation with convective heating of the atmosphere.*

- *To establish whether LLJ splits into two branches over the Arabian sea as widely believed*

- *To study the role of horizontal wind shear of LLJ in the episodes of intense rainfall observed over the west coast of India.*

- *To perform atmospheric modeling work to test whether small (meso) scale vortices form during intense rainfall events along the west coast.*

- *To study the relation between LLJ and monsoon depression genesis.*

The doctoral thesis consists of 7 chapters. Chapter 1 describes relevance of the study and the general features of Asian summer monsoon. A detailed review of monsoon with special emphasis on Low level Jet (LLJ) is presented in this chapter. The review includes studies based on observation, modeling and synoptic features of LLJ. Data sets used for the present work are described in Chapter 2. Daily wind data, from NCEP/NCAR reanalysis project (1961-1990), Outgoing Long wave Radiation (OLR) data of NOAA

(1979-1990), Indian Summer Monsoon Rainfall (ISMR) series (June to September of (1961-1990) are the major data sets used for this study. Fifth Generation NCAR/Penn State Mesoscale Model (MM5) is used to simulate a few intense rainfall events along the west coast of India during summer monsoon.

The general climatology, structure and interannual variability of LLJ are studied using NCEP/NCAR wind data are presented in Chapter 3. The 30-year mean (1961-1990) monsoon flows at 850 hPa for each month from June to September describes the monthly climatology of LLJ. The mean vertical profile of the zonal component (u), by averaging over the longitudes 70°E to 90°E from latitudes 30°S to 50°N, from 1961 to 1990 for July and August shows the vertical structure of LLJ. During the 30-year period ISMR had large inter-annual variability with several DRY and WET monsoon years. The LLJ winds over the western Arabian Sea and the cross equatorial flow are stronger in the WET composite than in the DRY. In the WET case monsoon westerlies extend eastwards only upto the longitude of Philippines (~120°E). Easterly trade winds are found east of the Philippines. In the DRY composite monsoon westerlies extend further eastwards. The easterly trade winds over the south Indian Ocean are weaker in the DRY composite. The correlation between ISMR and monsoon winds over south Asia, Indian Ocean and West Pacific are also discussed.

In chapter 4, the intraseasonal variability of LLJ and its association with convective heating is described. The 12-year (1979-1990) composite of the onset pentad shows a large area of low OLR or high convection in the low latitudes of Indian Ocean. Composite wind at 850 hPa of the corresponding pentad shows a strong LLJ from the Mascerene High area, passing close to the east African coast and its turning east after crossing the equator off Somalia coast and moving towards India. A well-marked LLJ maximum is present in the southeast parts of India and over Sri Lanka. Composite pentad analysis of OLR for break monsoon conditions during July and August shows that the OLR minimum area of low latitudes as at the time of onset has moved northwards and lies over northeast India and neighbourhood. A fresh area of

OLR minimum has formed over equatorial Indian Ocean similar to that at monsoon onset. The LLJ of break monsoon is very much similar to the onset time and the LLJ axis touches the southern tip of Indian peninsula and passes through Sri Lanka. In the break composite a weak LLJ axis can be seen passing through north India towards the convectively active region over northeast India. During active monsoon periods when there is a band of strong convective heating in the latitude belt 10°N-20°N from about longitude 70°E to about 120°E, the LLJ axis passes eastwards from central Arabian Sea through peninsular India and emerges into the western Pacific Ocean. This period does not show splitting of LLJ into two branches as widely believed.

The relation between the convective heating of the atmosphere over south Asia and the LLJ through peninsular India is examined. The linear correlation coefficient between the daily value of OLR-Index and the U-Index for lags of –5 days to +5 days shows that the atmospheric heating by convection can accelerate the LLJ flow through peninsular India in about 3-4 days.

Chapter 5 gives the results of a study on intense rainfall (24 hr) events along the west coast of India. Cases of rainfall of 20 cm per day or more at 3 coastal stations viz., Bombay, Ratnagiri and Honavar for the period 1970-1990 have been studied. It is found that these rainfall events occur in the region of large cyclonic wind shear at 850 hPa of the LLJ. Literature has speculated on the existence of an offshore trough and and a mesoscale vortex embedded in it in the atmospheric boundary layer in association with these intense rainfall events. This aspect is examined with a Mesoscale model (MM5) with input data from NCEP/ NCAR Reanalysis but interpolated to a 15 x 15 km grid. With the inclusion of realistic Western Ghat orography, a mesoscale vortex appears after 24 hours of model run. The intensity of this vortex becomes less when orography is removed.

The results of a study on the evolution of LLJ prior to the formation of monsoon depressions are presented in chapter 6. It is well known that monsoon depressions form in the active phase of the monsoon, when LLJ is strong and its axis passes through central Bay of Bengal. A synoptic model of the temporal evolution of monsoon depression has been produced. There is a systematic temporal evolution of the field of deep convection and the strength and position of the LLJ axis leading to the genesis of monsoon depression.

Summary and conclusions are given in chapter 7. One of the significant outcomes of the present doctoral thesis is that the LLJ plays an important role in the intraseasonal and the interannual variability of Asian monsoon activity. Convection and rainfall are dependant mainly on the cyclonic vorticity in the boundary layer associated with LLJ. In turn LLJ is maintained by the convective heating of the atmosphere over the Bay of Bengal. LLJ has a large amplitude intraseasonal oscillation. Active and break monsoon are extreme phases of this oscillation. Monsoon depression genesis and the episodes of very heavy rainfall along the west coast of India are closely related to the cyclonic shear of LLJ in the boundary layer and the associated deep convection. Case studies by a mesoscale numerical model (MM5) have shown that the heavy rainfall episodes along the west coast of India are associated with generation of mesoscale cyclonic vortices in the boundary layer.

References cited in the texts are listed at the end of the thesis in alphabetical order.