Chapter 2

Review of Previous Work Done
2.1. Literature Survey

Atmospheric disturbances play a crucial role in promoting vertical circulations by transporting heat and moisture from the boundary layer to top of the atmosphere which leads to the growth of convective phenomena causing a series of hazards in human and animal life. As a result, remote sensing of temperature and humidity profiles is important in various walks of life. At present, many techniques are being used to measure the atmospheric properties of the lower atmosphere, namely, radar, radio-sounding or satellite imagery. Radiosondes launched from regional weather services measure and record the atmospheric profiles of temperature, humidity and wind-speed with a series of instability indices. However, radiosonde data are available only twice a day, which may not be adequate to reveal a rapidly varying state of the atmosphere. On the other hand, remote sensing of temperature and humidity from satellite imagery produces better temporal coverage but with a poor spatial resolution.

Ground-based microwave radiometers have the advantage of continuously monitoring the atmosphere up to heights of 10 km with a better temporal resolution and can cover the temporal and spatial gaps of synoptic networks by radiosonde and satellite measurements. In addition, these passive instruments can operate in all weather conditions. In the last few decades, profiling of various atmospheric parameters by MWRs has found numerous applications in atmospheric studies. As a result of latest technical improvements, radiometers can be used for profiling both temperature and humidity simultaneously. An additional advantage of MWR is the high accuracy of measurement of integrated liquid vapor content. This instrument measures the radiation intensity at a number of frequency channels in the microwave spectrum that are dominated by atmospheric water vapor and molecular oxygen emissions (Rose and Czekala, 2003; Knupp et al., 2009; Cadeddu et al, 2013; Wulfmeyer et al, 2016). It measures the radiated emission in the form of brightness temperatures and
converts them to humidity and temperature values by a suitable transformation at a number of heights, providing a continuous measurement of different parameters. Ground based microwave radiometers are useful in weather prediction and analysis. In the recent years, many attempts have been carried out to predict extreme weather events using microwave radiometers with a reasonable accuracy (Won at a. 2009; Madhulata et al. 2013; Maitra et al. 2014; Cimini et al, 2015; Chakraborty et al. 2014, 2016; Illingworth et al, 2015).

But the retrieval techniques used by a radiometer have to be periodically checked and modified to adapt to the changing weather conditions to obtain reliable profiles of atmospheric parameters and optimize retrieval accuracy. Issues related to the accuracy of retrieval techniques used by microwave radiometers have been a matter of interest to researchers over the past few decades. In the past, many separate attempts have been made to retrieve the temperature and relative humidity profiles from brightness temperature (BT) measurements by a radiometer (Westwater et al. 1999, Lüdi et al. 2003, Matzler and Morland, 2009; Löhnert and Maier, 2012; Stähli et al., 2013). According to Chan 2010, retrievals of thermodynamic profiles by MWR are done by two techniques, namely: regression analysis and neural networks. The neural network technique is found to be a more reliable technique as it provides more realistic humidity profiles than that obtained with radiosondes, particularly in rainy conditions. According to Knupp et al. (2009) and Chan (2009), the retrieval of temperature and humidity profiles from MWR is done by neural network methods based on radiosonde data and a radiative transfer model. Ramesh et al. (2015) have used an adaptive neuro-fuzzy inference system (ANFIS) to retrieve profiles of temperature and humidity up to 10 km over the tropical station Gadanki (13.5 N, 79.2 E), India and have obtained considerably better results in temperature and humidity profiles. Ware et al. (2003) compared the radiometric, radiosonde and forecast soundings for evaluating the accuracy of radiometric temperature and water vapour soundings. Cimini et al
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(2011, 2015) have used a retrieval technique 1-DVAR, to retrieve atmospheric profiles of temperature and water content from brightness temperatures and compared the retrieved profiles with radiosonde observations. The statistical analysis revealed significant improvements in both the profiles compared to other retrieval techniques. Sanchez et al. (2013) has reported a bias in the temperature and humidity measurements obtained by MWR and applied some correction using linear adjustment technique, which has significantly improved the accuracy of temperature and humidity profiles. Again, some research attempts have also pointed at the existence of a wet bias below 5 kms and a dry bias above it in the relative humidity profile (Chan 2009 and Xu et al. 2014). The wet bias might be due to the presence of an elevated, moist layer which is not measured by the radiosondes. Another possible reason might be the variable weather conditions generated due to water vapor and temperature variability in the lower troposphere. This variability may not be detected by the inversion technique used by the radiometer as it utilizes regression coefficients from a large number of radiosonde profiles which have an averaging effect. Apart from dry and wet biases, some other inaccuracies have also been reported by Löhnert and Maier (2013) and Paine et al. (2014). These types of errors are called open side-mount cryogenic calibration errors that appear as brightness temperature offsets in oxygen absorption bands and change after each absolute calibration due to water condensation on the aluminium plate reflector connecting the cold load and the radiometer during Liquid Nitrogen calibration. In order to prevent this, MWR radome blowers and heaters should be operated with maximum power. These types of errors can also be reduced by using pressurized, closed, top-mount cryogenic targets as in Radiometrics MP-3000 radiometers (Miacci et al. 2014) resulting in brightness temperature accuracies <0.5K. However, in the present case, this type of error is expected to be minimized since the radome blowers and heaters were in full power mode during calibration process. In the recent past, many other attempts have also been made to compare
the relative accuracy of temperature and humidity profiles obtained from radiosonde and radiometric measurements (Westwater, 1997; Miloshevich, et al., 2001, 2004, 2006, 2009; Löhner and Maier, 2013; Turner et al., 2003; Mattioli et al., 2007; Ebell et al. , 2010;Kottayil et al., 2011; Miacci et al, 2014; Chan and Lee, 2015).

Another portion of interest to researchers in the past few decades have been that tropical regions, like the present one experience heavy precipitation activities during pre monsoon period of March-May and monsoon period of June-September. These forms of precipitations are found to influence agriculture, aviation. So atmospheric studies on prediction of such activities have really been a matter of concern in the past few years. Conventionally, satellite and weather radar data are used to nowcast thunderstorms (Browning, 1982; Cluckie and Collier, 2010; Dutta et al., 2010; Mecklenburg et al., 2000; Sokol, 2006; Wang et al., 2009; Wilson et al., 1995; Zahraei et al. 2013). Reported prediction efficiencies are usually around 80% with false alarm rates above 25% for both radar and numerical weather prediction (NWP) based nowcasting (Johnson et al. 1998; Wilson et al. 1998; Lin et al. 2005). Temperature and humidity profiles of the atmosphere along with instability indices obtained from atmospheric sounding measurements such as, radiosondes can be useful tool for rain and thunderstorm predictions (Geerts, 2001; Manzato, 2003; McCann, 1994). Except radar, these instruments suffer from poor temporal resolution. However radars are costly and need involved maintenance for continuous operation.

Heavy rain events also create attenuation of microwave signals. So microwave propagation through the atmosphere can provide a useful signature of heavy rain events. In this connection atmospheric brightness temperatures measured by a microwave radiometer can be useful for nowcasting of rain (Koffi et al., 2007; Won et al., 2009). Güldner and Spänkuch (1999) showed that the liquid water content (LWC) and perceptible water vapor (PWV) increase before rain. So an increase of brightness temperature (BT) in water vapor
channels (22-31 GHz) can be observed about two hours before rain (Won et al., 2009). Many convective indices from radiometer have been utilized for nowcasting heavy precipitation events (Darkow, 1968; Faubush et al., 1951; Galway, 1956; Madhulatha et al., 2013; Showalter, 1953). There are some efforts to predict rain using a microwave radiometer. Dvorak et al. (2012) used BT at 10 GHz to predict rain with a hit ratio of 74% and a false alarm rate of 7%. Won et al. (2009) also used BT at 22, 30 and 51 GHz for rain prediction with a probability of detection 0.9 for rain accumulated below 20mm.

However, models using radiometric observations are not highly accurate for nowcasting rain (Chan and Lee, 2011; Wilson et al., 1998; Won et al., 2010). The primary reason could be that an increase of atmospheric water vapor has been taken to be the only precursor of intense convective activities. However, water vapor can also increase significantly in the absence of rain (Sherwood et al., 2010; Won et al., 2009). Hence, temperature profiles can also be needed for efficient rain nowcasting. In addition, it was also observed from previous studies that prediction of convective activities which eventually turns into rain can be used to increase the lead time obtained from conventional techniques in rain nowcasting.

In the past, short term prediction of convective activities is usually done using reflectivity echoes of impending storms using space borne and weather radars (Browning, 1982; Cluckie and Collier, 1991; Mecklenburg et al., 2000; Wang et al., 2009). However, there has not been much success in this regards because the less time span and localized nature of these activities make it difficult to predict them much in advance. Hermida et al. 2013 have studied the spatial variation and related climatological implications of hail storms which are accompanied with convective precipitation using a widely distributed network of 443 hailpads at various regions of France.
Knowledge based systems including radar, satellite, boundary layer profiler, lightning detector and upper air soundings are also being used for nowcasting intense convective activities. According to Kobler and Tafferner (2009), three parameters are important to understand the development of convection, namely, moisture, convective instability and lifting mechanism. Atmospheric temperature and humidity profiles and instability indices derived from atmospheric soundings like radiosondes can be very useful in nowcasting rain and thunderstorms (McCann, 1994; Geerts, 2001; Manzato, 2003; Midya et al., 2011; Saha et al., 2012, Chakraborty et al., 2016). However, radiosonde measurements suffer from poor temporal resolution. A microwave radiometer can generate humidity and temperature profiles of the atmosphere up to 10 km with high temporal resolution of 5 minutes and hence solves the problem faced by radiosondes. According to Chan and Lee (2011), alerting of wind shear can be done either by monitoring the stability of the boundary layer or by the standard deviations in the brightness temperature (BT) obtained from the microwave radiometer during both clear and cloudy skies at near elevation. The atmospheric water vapor and brightness temperatures around the water vapor absorption line measured by radiometer are used for such purposes (Won et al. 2009). The use of BT of oxygen absorption line along with water vapor can also predict rain with high accuracies (Chakraborty et al. 2014). In case of radiometric weather forecasting, two types of parameters are widely used - (1) utilization of level 0 products such as brightness temperatures and (2) parameters derived from BT measurements like Integrated Water Vapor (IWV), Liquid Water Content (LWC), Cloud Base Height (CBH) and instability indices (Koffi et al. 2009; Won et al. 2009). These types of measurements are reported from different temperate regions; however, limited performance assessment of such techniques is available for tropical regions (Wilson et al. 1998). Won et. al (2009) obtained that an increase of Brightness Temperature (BT) is observed in water vapor channels (22-30 GHz) at about two hours (2 hours) before rain.
Güldner and Spänkuch (1999) have also obtained similar observations for an increase in the LWC and Precipitable Water Vapor (PWV) at about two hours before rain. According to Chan (2009), the average values of K-index obtained from temperature and humidity profiles have a reasonable correlation with the tropospheric instability indicated by the number of lightning flashes within regions located about 10-40 km from the radiometer. Clifford et al. (2009) and Won et al. (2009) have studied the atmospheric conditions at boundary layer using radar, lidar, wind profiler and Radiometer. Many attempts have been made to predict convective activities using instability indices from atmospheric profilers (Faubush et al., 1951; Madhulatha et al., 2013; Showalter, 1953; Galway, 1956; Darkow, 1968; Chowdhury and Karmakar, 1986; Saha et al. 2014, 2016).

In the last few years, many attempts have been made to predict precipitation related activities. Dotzek et al. (2011) had employed Cb-TRAM prediction algorithm with ESWD dataset for six severe weather days in Europe from 2007-2008 to detect storms in advance. The maximum prediction efficiency obtained for 30-60 minutes forecast was around 58%. Kohn et al. (2011) employed WDSS-II algorithm to nowcast thunderstorms using one year lightning data over the Mediterranean region. The technique was successful in predicting thousands of thunderstorms about 30 minutes in advance with a minimal False Alarm Rate (FAR) of 0.03 but with a very low Probability of Detection (POD) of 0.46. Dvorak et al. (2012) had devised a technique to detect precipitation and cloudiness using brightness temperature observations at 10 GHz from a microwave radiometer with a prediction efficiency of 80% and false alarm rate of around 15%. Later, Merino et al. (2014) developed a technique to identify hailstorms using MSG data obtained from MEV valley in Spain from 2006-2010. The obtained technique called HDT employs two detection algorithms namely convective mask and hail mask algorithms to detect hailstorms. This technique has provided an accuracy of 76.9% with false alarm rate of 16.7%. As an extension to the previous work,
Gascon et al. (2015) has designed another technique using forward stepwise regression algorithm on five major instability parameters. This system has a high POD of 0.94 but the FAR obtained was 0.22 which is quite high. However, it may be noted that most of the above said techniques have provided prediction efficiency less than 80% or a false alarm rate greater than 20%.

An additional concern to researchers in the past few years has been that the rain prediction techniques are mainly designed to predict rain occurrences and not the rain amount. However, it has been noted that, precipitation intensities have a direct effect on flood monitoring which is a major weather hazard in those parts of the world. Hence, studies on precipitation intensity and accumulation have been a matter of separate interest in many fields of life. L’ecuyer and Stephens (2001) have utilized attenuation by both rainfall and cloud particles to estimate rain parameters using space borne radars at CLOUDSAT, though adequate accuracies could not be obtained at surface rain rates > 10 mm hr$^{-1}$. Some other techniques have obtained certain thresholds for brightness temperatures obtained with geostationary thermal infrared channel at 10.8 $\mu$m to predict rain intensities (Arkin, 1979; Arkin et al., 1987). Paola et al (2012) proposed a new technique precipitation evolving technique (PET), which projects the rainfall maps from AMSU and MHS observations by using IR TB maps of water vapor (6.2 $\mu$m) and thermal-IR (10.8 $\mu$m) channels from a SEVIRI radiometer. The mentioned technique provides a good lead time of 2-3 hours with a prediction efficiency of 70%, but the false alarm rate is very high (35%). Recently, Casella et al. (2015) has made a new technique based on canonical correlation and calculation of suitable thresholds to be provided to the linear combination of the brightness temperatures using SSMIS, TRMM-PR and AMSU satellite data. The ratio obtained from this technique is 0.55-0.7. Krakauer et al. (2015) developed a probabilistic precipitation technique utilizing 3B42RT generated from TRMM to obtain daily maps of precipitation accumulation on Nepal.
and surrounding areas with a minimal estimation error. Apart from these, there are many other attempts to predict rain using radiometers, radars and rain gauge networks (Wood et al. 2000; Goudenhoofdt and Delobbe 2009; Berg et al. 2010).

Convective precipitations also pose a direct effect on microwave propagation links in earth space paths especially at higher frequencies (>10 GHz). As a result, studies of rain induced attenuation has emerged as an important field of research in the past century. The statistical estimation of rain attenuation by was first proposed by Ryde, (1946). However, the estimation errors in this technique were detected by Medhurst (1965) after about two decades. However, later significant contributions have come up to devise a reliable rain attenuation model (Crane, 1975, 1977, 1980, 1985). Timothy et al., (1994) revealed that increase of rain drop size eventually resulted in an increase of rain attenuation. Besides having a regional as well as temporal variability, rain attenuation also depends upon the type of rain (Laws and parsons, 1943; Joss et al., 1968). Specific attenuation can be calculated from point rain rate measurements employing different rain drop size distribution (Olsen et al., 1978; Hendratoro et al., 2002; Laws and parsons, 194).

A comparative study with rain attenuation prediction models utilizing the INSAT-2C satellite data had been done by Rao et al. (2002). Theoretically estimated attenuation of radio waves at 11 GHz and 13.4 GHz over Delhi (Mondal et al., 1997) showed that ITU-R model underestimated the attenuation over India. Experiments were carried out at 20/30 GHz in India to reveal the horizontal characteristics of rain attenuation (Jassal et al., 1999). In 1996, Verma and Jha (1996) evaluated the specific rain attenuation on the basis of rain drop size data collected from India.

Radiometric observations can also be utilized to study atmospheric attenuation at Ku/Ka bands and also to study the vertical characteristics of rain. The role of brightness temperature in centimeter and millimeter wave communication and its relation with
atmospheric absorption was studied by Smith (1982). Some studies on rain attenuation (Raina, 1996; Sen et al., 1989) and rain height (Sharma et al., 2006, 2007) measurements utilizing radiometric observations are reported. Some radiometric studies over New Delhi, India were made by Raina and Uppal, (1984), but they were not enough for the interpretation of propagation mechanisms over the tropics.

Yeo et al. (1990,1993) and Li et al.(1994) worked on rain attenuation and rain drop size models which were successfully employed in the climate of Singapore. Later, Yeo et al (2001) extended their work for horizontally and vertically polarized waves in 10-40 GHz frequency band. The regional pattern of rain impairments was investigated over 37 stations of Nigeria utilizing the Ku, Ka and V-band data of NigComSat-1 (Omotosho and Oluwafemi, 2009) which revealed that decrease of such impairments could be found from south to north. Recently, a many measurement campaigns of rain attenuation over slant path have been arranged in other parts of world (Garcia, 2003).

However, from most of the studies, it can be concluded that even though ITU-R has provided an approach for predicting the rain attenuation, the model does not perform well in tropical climates (Mello et al.2007). In the tropics, particularly in the Indian region, strong monsoon occurs which have characteristics different from that in pre-monsoon rain. On the other hand, attenuations due to snow, fog, etc. are not so significant in the tropical environment. Most widely used rain attenuation models, namely, ITU-R (P.839, 2001), SAM (Stutzman and Dishman, 1982), Crane Model (Crane, 1971, 1980), DAH Model (ITU-R P.837-3, 2001; ITU-R P.618-8, 2003), all were established by utilizing rain attenuation data from different temperate climatic zones. As a result, these prediction models exhibit significant deviation while estimating rain degradation in the tropical regions (Maitra and Chakraborty 2005). Hence, the existing models need to be modified according to tropical rain characteristics. In view of complex rain climate in the tropical region, rain attenuation study
over the tropical region is inadequate (Ajayi et al., 1996; Moupfouma et al., 1990; Nirala and Cracknell, 2002; Sarkar, 1995; Chakravarty and Maitra, 2010; Das and Maitra, 2012a, 2012b; Das et al., 2010, 2011; Maitra and Chakravarty, 2005; Maitra et al., 2006, 2007) and scattered over a few countries like India, Singapore, Brazil, Nigeria etc.

2.2. Motivation

The above mentioned researches reveal that convective rain is of much concern in the tropical locations. Hence, a detailed and continuous study of the atmospheric parameters is essential to study such activities. A microwave radiometer can be useful to provide reliable profiles of atmospheric parameters in all weather conditions. But, the retrieval techniques used by it has to be updated with respect to changing climate. Also, very inadequate research has been reported on retrieval accuracy obtained at tropical location where variability of atmospheric parameters are more prominent.

It has also been found that microwave radiometric observations can be most suitable to predict convective activities. However, most of the prediction techniques employing radiometric observations have either provided prediction efficiency below 80% or false alarm rate above 20%. Thus it is necessary to develop a robust rain prediction system to manifest rain both qualitatively and quantitatively with a good lead time.

Also, sparse efforts have been given to study discrepancies in attenuation model performances in tropical locations; hence, it is a needed to develop an effective model to calculate rain attenuation using real time rain observations particularly at tropical regions.