Abstract

Precipitation plays an important role in the earth’s fresh water resource, agriculture, ocean circulation, global climate etc. The variations in rainfall patterns affect the economy and management decisions of many countries in the world. Continuous spatio-temporal monitoring of rainfall fields is crucial for an agriculture predominant country like India. But sparse ground based measurements from instruments like rain gauges, automatic weather stations, weather radars etc, are inadequate to observe the high spatial and temporal variability of rainfall. In this context, satellite based rainfall estimation has acquired a larger role and acceptance by the meteorologists and remote sensing scientists. Along with the advancements in satellite technology, satellite based rainfall estimation techniques have grown tremendously. Many space agencies are providing operational rainfall estimations derived from satellite observations in visible, infrared (IR) and microwave (MW) bands of electromagnetic (EM) spectrum. Indian Space Research Organization (ISRO) with its meteorological satellites Kalpana, Indian National Satellite (INSAT)-3D, Megha-tropiques etc also are giving operational rainfall estimates based on satellite data.

Satellite based rainfall estimation is usually carried out in optical IR and MW frequency bands. IR based rainfall estimation algorithms depend on the radiation emitted from the top of the cloud. Tall convective clouds have higher probability of rain. IR based rainfall estimation algorithms derive the rain falling aloft the cloud based on cloud top temperature. Due to its non physical nature and inability of IR radiation to penetrate inside a cloud structure, estimation of rain rate based on such relation may not be accurate. Compared to IR based rainfall estimation methods MW frequency based rainfall estimation is more physical in nature. The MW radiation emitted by earth’s surface is interrupted by hydrometeors (rain drops, ice crystals etc) and the radiation gets modified by the process like scattering and emission. This Scattering and emission is employed as the metric to estimate rainfall from modified MW signals. Compared to ocean surfaces, the variable emissivity of land regions introduces errors to these algorithms. Along with the intrinsic problems due to the topography and other noises,
algorithms may also have inherent problems which may result in erroneous estimates of rain.

To explore the challenges and identify the issues in the satellite-based rainfall estimation over Indian summer monsoon region, rainfall estimates from simple IR based rainfall data using Kalpana-1 satellite, GSMaP based merged (IR and MW) rainfall data and TMI based microwave rainfall data are compared with the Tropical Rainfall Measuring Mission (TRMM)-3B43 rainfall product. TRMM-3B43 rainfall data is a merged precipitation data of MW, IR and rain gauges. The results show that compared to TRMM-3B43, IR, merged and MW based rainfall data underestimates rainfall over windward side of orographic terrain of Indian summer monsoon region. It is also noted that simple IR based rainfall estimation algorithm shows over estimation over east coast of Indian peninsula.

To overcome these issues in simple IR based rainfall estimation, an algorithm is developed; which is termed as experimental rainfall estimation algorithm over Indian region (EREI). This algorithm comprises of two parts: (i) Development of Kalpana-1 IR based rainfall estimation algorithm with improvement for orographic warm rain underestimation (ii) Cooling index to take care of the growth and decay of clouds and thereby improving the precipitation estimation.

In the first part, a power-law based regression relationship between cloud top temperature from Kalpana-1 IR channel and rainfall from the TRMM - precipitation radar (PR) specific to the Indian region is developed. This algorithm tries to overcome the inherent orographic issues of the IR based rainfall estimation techniques. Over the windward sides of the Western Ghats, Himalayas and Arakan Yoma mountain chains, separate regression coefficients are generated to take care of the orographically produced warm rainfall. Generally global rainfall retrieval methods fail to detect the warm rainfall over these regions. Rain estimated over the orographic region is suitably blended with the rain retrieved over the entire domain comprising of the Indian monsoon region and parts of the Indian Ocean using another regression relationship. While blending, a smoothening function is applied to avoid rainfall artefacts and an elliptical weighting
function is introduced for the purpose.

In the second part, a cooling index is developed to distinguish rain/no-rain conditions using Kalpana-1 IR data. The cooling index identifies the cloud growing/decaying regions using two consecutive half-hourly IR images of Kalpana-1 by assigning appropriate weights to growing and non-growing clouds. Intercomparison of estimated rainfall from the present algorithm with TRMM-3B42/3B43 precipitation products and the India Meteorological Department (IMD) gridded rain gauge data are found to be encouraging. The advantages of the present algorithm are that it requires only two IR images as input without depending on other sources of information and simple to implement. The present algorithm performs better than the existing Kalpana-1 IR based rainfall estimation algorithm.

An Artificial Neural Network (ANN) based technique is developed for estimating precipitation over Indian land and oceanic regions using Scattering Index (SI) and Polarization Corrected Temperature (PCT) derived from Special Sensor Microwave Imager (SSM/I) measurements. This rainfall retrieval algorithm is designed to estimate rainfall using a combination of SSM/I and TRMM-PR measurements. For training the ANN, SI and PCT (which signify rain signatures in a better way) calculated from SSM/I brightness temperature (Tb) are considered as inputs and PR rain rate as output. SI is computed using 19.35 GHz, 22.235 GHz and 85.5 GHz Vertical channels and PCT is computed using 85.5 GHz Vertical and Horizontal channels. Once the training is completed, the independent data sets (which were not included in the training) were used to test the performance of the network. Instantaneous precipitation estimates with independent test data sets are validated with PR surface rain rate measurements. The results are compared with precipitation estimated using power law based (i) global algorithm and (ii) regional algorithm. The power law based algorithms are derived following Ferraro et al. Overall results show that ANN based present algorithm shows better agreement with PR rain rate.

This study also includes the monitoring of the monsoon over meteorological sub-divisions during May-September, 2009 using Kalpana-1 measurements. INSAT
Multi-spectral Rainfall Algorithm (IMSRA) technique has been used for estimating rain from Kalpana-1 very high resolution radiometer (VHRR) measurements. The results have been compared with the IMD accumulated rainfall maps at monthly and seasonal time scales. The rain estimation using the present methodology is in good compliance both qualitatively and quantitatively with the IMD rainfall maps. The rainfall maps for the south-west monsoon season over the Indian land region are successfully utilized as a space input for the drought monitoring of the year 2009. This method can act as a complementary tool for in situ data based rainfall monitoring (meteorological sub-divisions) over the Indian land region and can be used for various meteorological and hydrological applications.

The variations in the summer monsoon rainfall over the equatorial trough (ET) play a crucial role in the variations of rainfall over India at intraseasonal timescale. In the present study, the long-term changes in the summer monsoon rainfall over the ET has been investigated for a 34 year (1979-2012) period using gauge adjusted multisatellite Global Precipitation Climatology Project (GPCP) rainfall data. Analysis of seasonal rainfall over the western and eastern ET suggest that the rainfall over these two regions is negatively correlated (correlation coefficient = -0.32). Linear trend analysis of area averaged seasonal rainfall shows an increasing trend of 0.40 mm day\(^{-1}\) decade\(^{-1}\) over the western ET region whereas no significant trend is observed over the eastern ET region. Moreover, the time-series analysis of the daily monsoon rainfall data available since 1997 shows a noticeable change in the frequency of daily rain events over the western and eastern ET regions during the last 16 years.