STUDIES ON ESTIMATION OF RAINFALL FROM SPACE BASED OBSERVATIONS

THESIS SUMMARY SUBMITTED TO THE
UNIVERSITY OF ALLAHABAD
FOR THE REQUIREMENT OF THE DEGREE OF

Doctor of Philosophy
IN
Science

BY
RAJESH KUMAR
UNDER THE SUPERVISION OF
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FEBRUARY, 2012
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Submitted By Rajesh Kumar Under the Supervision of Prof. A. C. Pandey

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M. N. SAHA CENTRE OF SPACE STUDIES, IIDS, UNIVERSITY OF ALLAHABAD, ALLAHABAD, 211002. (INDIA) FEBRUARY, 2012
Dedicated to…

My Family Members

Parents (Shri Ras Bihari Singh & Smt. Shalkeshi Devi)  
Wife (Smt. Rekha Kumari), Son (Rushil Kumar)  
Brother (Shri Rakesh Kumar) & other members

(For their love, care and affection)

And

In the loving memory
Of
My Grandfather
(Late Shri RAM NATH SINGH)

&

My Mentor
(Late Prof. INDRA MOHAN LAL DAS)
DECLARATION

I hereby declare that the thesis entitled “Studies on Estimation of Rainfall from Space Based Observations” is my own work, conducted under the supervision and guidance of Late Prof. Indra Mohan Lal Das at M. N. Saha Centre of Space Studies (MNCSOS), IIDS, University of Allahabad, Allahabad, as approved by Research Degree Committee (RDC).

I further declare that to the best of my knowledge the thesis does not contain any part or any work which has been submitted for the award of any other degree or diploma either in this University or in any other University/Deemed-University without proper citation.

Bangalore
February - 2012

(Rajesh Kumar)
BACKGROUND:

Water is one of the most important and fundamental substance for existence of life on the earth. Three quarters of the Earth’s surface is covered up with water, only one quarter is the land portion. Again out of these three quarters of water, only 2.5% is fresh water and rest 97.5% is saline. So there is considerable shortage of the fresh water for our domestic consumption, as well as the suitable water for agriculture and industrial purpose in most parts of the world. Thus it plays a vital role in the economy of the entire globe. Water circulates within the hydrosphere known as hydrologic cycle. The hydrological cycle is one of the important components of Weather and climate system that is significantly affected by the precipitation and evaporation processes. The process through which the water mass is transported between the atmosphere and the earth’s surface is known as precipitation. Precipitation can occur in liquid as well as in solid form. However, the majority of precipitation, especially over the tropics, occurs in liquid form and hence commonly referred to as rainfall. Rainfall is indispensable in determining the character of our planet at the most fundamental level. Without rainfall most of the terrestrial forms of life would not exist and, in turn, the geology and chemistry of the planet would have been quite different. Providing pure and fresh water on the land is an important for sustaining life on the earth. Rainfall is vital as it provides pure and fresh water for sustaining life over land. Over ocean, it is the primary input for oceanic hydrological cycle and a regulator of salinity, which plays an important role in determining ocean dynamics and thermodynamics. The rainfall couples with other environmental variables in complex manners and causes global scale weather anomalies like El Nino, greenhouse effect etc. The quantitative assessment of precipitation is needed to improve the understanding of the behavior of global energy and circulation patterns as well as the nature of climate variability. The accurate rain rates are also important for the rain flagging criteria, while estimating wind vectors over the oceans from scatterometers based on radar backscatter measurements. The space borne measurement for monitoring of rainfall is, therefore, a
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Topic of major interest since they provide global coverage both on land and ocean for an extended period of time in a sustained manner.

Objective of the Study:

The main theme of the present thesis work is to develop the algorithm for the rainfall estimation over Indian land and Oceanic regions using the space based microwave observations. This becomes more relevant in view of the recently launched Indo-French Megha Tropique mission.

The specific objectives of the present study are as follows:

1. To study the various Radiative Transfer Models (RTM) for the simulation of the brightness temperature in microwave frequency band, and their sensitivities to the rainfall and other ocean and atmospheric parameters.
2. To develop precipitation estimation algorithm for Indian land and oceanic regions using satellite data.
3. Exploration of Precipitation features using microwave observations.

In this thesis a detailed study concerning Microwave technique using satellite data has been done for the Indian land and Oceanic regions. Here mainly the TRMM-TMI data have been utilized for the development of the algorithm. TRMM-PR data and ISRO’s AWS data have been used for the validation purpose. The thesis starts with the radiative transfer modeling with different atmospheric conditions for Indian subcontinent. Here the simulations of brightness temperatures have been carried out for different satellite sensors viz. TRMM-TMI and MEAGHATROPIQUES-MADRAS. This study is mainly aimed to select the suitable predictor variables for the combined use of different satellite sensors to retrieve rainfall as well as other geophysical parameters with greatest possible accuracy. After the sensitivity study of various radiometric channels with the help of radiative transfer models, an attempt has been made in third chapter to develop the rainfall algorithm over Indian land and Oceanic regions using the intelligent computing systems viz. Artificial Neural Network. The next chapter has been designed specifically to study the evaluation of precipitation features in high
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frequency SSM/I measurements over Indian land and Oceanic regions. Also it helped to find out PCT as a proxy suitable variable for rainfall estimation. After then a detailed study has been carried out in chapter 5 to study the various combinations, linear as well as non-linear, of PCT along with another rainfall proxy predictor variable known as scattering index in connection with the development of rainfall algorithm over Indian land and oceanic regions. The developed algorithm has been validated by the TRMM-PR and ISRO’s AWS data. Finally the evaluation of operational algorithm for rain measurement from TRMM has been carried out. The Chapter-wise summary is given as follows:

Chapter-1: INTRODUCTION

This chapter has described about the introduction of importance of precipitation estimation. Objective and area of study as well as Relevance of the study in the present scenario has been also dealt in detail. This chapter has also dealt in detail the Physics of remote sensing like Electromagnetic Radiation, Source of Electromagnetic Radiation in Remote Sensing, Various Wave properties of Electromagnetic Radiation, Black body radiation and its laws, Grey body radiation and Microwave Brightness Temperature etc.

The physical processes involved in precipitation formation are also discussed along with the types of precipitation. Brief introduction of the principle of the satellite remote sensing, interaction of radiations with atmospheric constituents etc is also discussed. The signatures of the clouds and precipitation with reference to the satellite remote sensing in various bands viz. Visible, Infrared and microwaves of electromagnetic spectrum are also described. The chapter contains a brief introduction of all the Satellite Remote Sensing techniques (viz. Infrared, Visible and Microwave) for the rainfall measurement.

Chapter-2: RADIATIVE TRANSFER MODELING

In the process of developing rainfall estimation algorithm, various experiments of simulation of brightness temperatures using radiative transfer models
with different atmospheric conditions, have been carried out in detail in second chapter. The proper selection of radiative transfer model helped in establishing the relationship between rain rate and brightness temperatures. The two different RT-models named Kummerrow’s Eddington model and Liu’s Discrete Ordinate Method have been used to simulate the brightness temperatures using the large real database. Eddington’s model uses 2-stream in order to solve the radiative transfer equation and takes into account a few terms of the phase function and radiation intensity in expanded Legendre Polynomial. On the other hand DOM model, a variable streams based (the stream numbers can be 4, 8, 16, 32, 64, 128, 256 or more), is used to calculate the scattering phase function, thus representing the three dimensional angular distribution of radiation more realistically. In case of DOM, the scattering phase function is calculated by using Henyey-Greenstein function while asymmetry factor is calculated using Mie theory. These simulations have been carried for different atmospheric conditions of varying winds, under clear sky (non-raining) and raining conditions. The raining atmosphere is characterized by the contribution from emission and scattering associated with the presence and absence of liquid hydrometeors (clouds and rainfall). The relationship between brightness temperature and rain rate for various frequencies have been studied. It covers the frequency of ongoing TRMM-TMI sensor viz. 10GHz, 19GHz, 21GHz, 37GHz and 85GHz as well as the recently launched Meghatropique-MADRAS sensor frequencies like 19GHz, 24GHz, 37GHz, 89GHz and 157GHz. Eddington approximation is used to calculate the scattering effects by large liquid hydrometeors, whereas Discrete Ordinate Method is applied to calculate the scattering from ice as well. In case of Eddington’s model simulations, the simulated Tb results are in good relation with the accumulated 3-days averaged Wentz TMI Precipitation for non-raining conditions characterizing all the possible dynamic ranges of input and output field vectors. The rainfall signatures are very well picked up by the lower channels under the clear sky conditions due to impact of cloud liquid water, while the higher channels show some discrepancy because of suppressed scattering. DOM method has successfully explained the sensitivity of high frequency channels to the ice contents in the clouds because of scattering. The present simulation has successfully revealed the dominant mechanism of absorption (below 22 GHz), both scattering and absorption
between 22GHz and 60 GHz and scattering above 60 GHz play dominant role in the atmospheric radiative transfer process. It is thus evident from the simulations that any of the channels are no longer good indicators of the rain through their emission signatures alone in the absence of ice aloft. The ice scattering signatures are well picked up at higher frequencies by the DOM model which corroborates with the actual measurements, e.g. the Tbs from TMI and rainfall from PR observations. The main objective of the RT-simulations is to delineate the more appropriate frequency channels that are most sensitive to the rainfall especially in the case of brightness temperatures. Therefore this type of study will contribute to select the suitable predictor variables for the combined use of different satellite sensors to retrieve rainfall as well as other geophysical parameters with greatest possible accuracy. This type of sensitivity study based on the simulation of brightness temperatures for non-raining, raining or cloudy conditions is also useful in interpretation of radiometric observations. The channels of lower frequencies are more sensitive to the rain as well as surface roughness whereas the higher frequency channels show greater sensitivity to the rain rate. Furthermore, the higher frequency channel, viz. 157 GHz has a great potential to sense precipitation due to ice contents in the clouds. Therefore the proper combination of emission and scattering channels are very much essential for the development of the advanced rainfall retrieval algorithm using any inversion techniques like multiple regression, neural network approach, fuzzy logic or genetic algorithms.

Chapter-3: RAINFALL ESTIMATION FROM MICROWAVE DATA USING ARTIFICIAL NEURAL NETWORK APPROACH

After the sensitivity study of various radiometric channels with the help of radiative transfer models, an attempt has been made in third chapter to develop the rainfall algorithm over Indian land and Oceanic regions using the intelligent computing systems viz. Artificial Neural Network. Now a day’s, Artificial Neural Networks (ANN) have been widely used in the business and economic domains as well as in Meteorology and Oceanography applications. In the field of Meteorology and Oceanography, the ANNs are not only restricted to research papers which mainly deal
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with meteorological and oceanographic details but also being applied for the operational purposes. Basically the ANNs are all mathematical algorithms which aim to solve a complex problem like genesis of rainfall. The Multilayer Perceptron and feed-forward neural network (FFNN) model have been utilized for the present study. The FFNN is composed of individual processing elements called units or nodes. These nodes are interconnected by links or weights in the same or different layers. The layers are referred to as input layers, hidden layers and output layers. The input nodes are connected to the output nodes through hidden nodes. The hidden nodes capture the non-linearity in the mapping between input and output information. The ANN learning can be either supervised, unsupervised or reinforcement manner. The most popular supervised learning scheme is error backpropagation, which have been used in the present study. Since the relationship between rain rate and brightness temperature is non-linear, an attempt has been made to develop a rainfall estimation algorithm as an alternative to the frequently used non-linear multivariate regression techniques and Bayesian approach. Though the database of input and output field vectors used here are generated by already operational GPROF algorithm, the ANN has been developed to assess the retrievability of rain rates in more efficient manner computationally. The “back propagation with momentum” has been used as a learning algorithm for the present ANN architecture. The TMI-brightness temperatures (TB) are used as input vectors while TMI-rain rates as output vectors for ANN architecture. The optimization of channels taken for the input vectors has been done on the basis of statistical studies of these channels to the rain rate. Thus many attempts have been made and finally the network designed for the present study consists of one input layer (six neurons i.e. six channels brightness temperatures corresponding to the 10.7 GHz (H), 19.4 GHz (H), 21.3 GHz (V), 37.0 GHz (H), 85.5 GHz (V) and 85.5 GHz (H)), one output layer (one neuron, TMI-rain rate) and one hidden layer (sixteen neurons). Thus the total number of connections 129 (112 weights and 17 biases) is less than the total number training patterns 10372, giving less possibility of overtraining. Now the training data has been split up randomly in three parts viz. training, validation and test data sets. After the training and cross validation, the performance of the ANN has been judged by the independent data sets (which were not included in the training). Depending on the
nature of activation function two models were developed and six networks, three for each model were trained for the rainfall estimation. The final output is taken as the average of the six networks output. Instantaneous precipitation estimates demonstrate very high correlation coefficients with the observed rainfall. Although the rainfall estimation using ANN are influenced by many factors such as the representativeness and sufficiency of the training dataset, the generalization capability of the network to new data sets, seasonal and location changes, it has been found that the model can still be used for the retrieval of precipitation at high spatial and temporal resolutions. Afterwards, the ANN derived rain rates have been compared with the estimates obtained from non-linear multivariate regression (MR) techniques using the identical set of data. It has been found that the ANN method, in general, is far more superior to the MR technique in its ability to reproduce rainfall intensity in a very short period of time, provided proper optimization of channels has been undertaken. Here the same algorithm for rainfall retrieval over ocean, land and coastal regions has been used with reasonably good accuracy. However, due to various reasons mentioned earlier separate treatment of land and oceanic areas for rainfall retrieval is necessary. Therefore, in near future, a separate rainfall estimation algorithm for land and oceanic areas will be developed based on the larger collocated sets of database from TMI, PR and ground based rapid response rain gauges and Doppler Weather Radars.

Chapter-4: EVALUATION OF PRECIPITATION FEATURES IN HIGH FREQUENCY SSM/I MEASUREMENTS OVER INDIAN LAND AND OCEANIC REGIONS

The fourth chapter has been designed specifically to study the evaluation of precipitation features in high frequency SSM/I measurements over Indian land and Oceanic regions. In this chapter, the radiative transfer model studies have been carried out at high frequency channel alone (85 GHz) to bring out the importance of the impact of frozen hydrometeors on the TBs, so that the retrieval and analysis can be understood more clearly. Simultaneously, it has also been studied with the real data of SSM/I that has been used to assess the impact of hydrometeor profiles on high frequency
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microwave radiometer channels. Based on RT simulations, the SSM/I TB’s are interpreted over the region, 30° S to 30° N and 40° E to 120° E, for the various case studies. Thus it is found that there is a considerable uncertainty in the interpretation of the SSM/I high frequency scattering features for the development of rainfall algorithms. Specifically the large areas of very low emissivity regimes showing false rain signatures due to the presence of low brightness temperatures that are often present in the vicinity of colder sea surface areas in the 85 GHz brightness temperature (TBs) from SSM/I. Thus the certain regions are detected where high scattering regimes in 85GHz TB’s are not having any link with simultaneous high emission regimes in lower frequency (19 & 21GHz) observations. It has been observed with the SSM/I 85 GHz TBs, that some of the low emission regions have the similar signatures as the high scattering TBs characterizing false occurrence of precipitation. Therefore in this connection the Polarization Corrected Temperature (PCT) defined by Spencer et al. (1989) with the help of 85 GHz channels (vertical (V) and horizontal (H) polarizations), has been explored to delineate these false surface features. These false scattering signatures, once corrected using PCT as a suitable parameter, significantly improve the quality of the SSM/I derived precipitation areas. The two independent data sources i.e. the cloud optical depth data from Moderate Resolution Imaging Spectroradiometer (MODIS) sensor onboard Aqua satellite and standard merged rain product (geostationary infrared and TRMM-microwave data) 3B42 from TRMM, also confirms the significance of these results.

Chapter-5: RAINFALL ESTIMATION FROM MICROWAVE OBSERVATIONS USING NON-LINEAR APPROACH

In continuation of the work carried out in chapter 4 regarding PCT as a suitable proxy variable for rainfall estimation, chapter 5 has dealt in detail the study of various combinations, linear as well as non-linear, of PCT along with another rainfall predictor variable known as scattering index. Grody (1991) has suggested that the scattering index (SI) is a good indicator of rainfall using microwave observations. Many other authors like Ferraro and Marks (1995), Chen et al. (2005) and Mishra et al
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(2009) also have significantly utilized the usefulness of SI in rainfall estimation. Ferraro and Marks (1995) have developed a global scattering index separately for land and ocean to estimate the rainfall. At the same time Chen et al. (2005) have shown the importance of SI in rainfall retrieval over Taiwan. Mishra et al (2009) have found that scattering indices are highly variable for different regions as well as seasons and therefore they have developed a regional scattering index for the Indian land and associated oceanic regions. The emphasis of this chapter is to estimate the rainfall from microwave observations using suitable combination of proxy rainfall predictor variables, PCT and SI by non-linear approach. A series of regression analyses based on 5764 collocated observations from PR rain rate and SI, PCT, and a combination of SI and PCT during 2008, 2009, 2010 and 2011 are attempted. Both linear and nonlinear regressions have been extensively analyzed and six equations, three for linear combinations and three for non-linear combinations of SI (alone), PCT (alone) and the combination of SI and PCT, have been developed. The usefulness of the technique was verified by applying it to a few independent heavy rainfall events one for July 25, 2006 and another September 4, 2010. After analysis of these two independent case studies, it has been confirmed that the linear algorithms are underestimating the heavy rainfall rates while nonlinear algorithms using single proxy variable (either SI or PCT) are overestimating the high rainfall values. On the other hand, it is confirmed that the nonlinear algorithm using both SI and PCT is able to retrieve the high rainfall events with a good accuracy. The rainfall rates estimated from this algorithm has been compared with PR observations and finally validated with the ISRO’s AWS rain gauges. Validations with PR and rain gauge have shown that the single proxy variable (SI or PCT) is not sufficient to give accurate rainfall estimates. Algorithm based on linear regression is not able to capture the high rainfall events efficiently. Linear regression techniques tend to underestimate the high rainfall values. Further, nonlinear algorithm using single proxy variable also fails to capture the rainfall events properly. On the other hand, nonlinear algorithms using both SI and PCT have shown a better agreement with the PR observations as well as AWS rain gauges.
Chapter-6: EVALUATION OF OPERATIONAL ALGORITHM FOR RAIN MEASUREMENT FROM TRMM

At last, Chapter 6 has presented the evaluation of operational algorithm for rain measurement from TRMM. This chapter focuses on the comparison of TRMM V5 and V6 rainfall products. The TRMM science project has released a newer version of precipitation products, version-6 (V6) from its various instruments in the year 2004. The V-6 data products were supposed to be more accurate and noise free than its predecessor V-5. Here an attempt has been made to analyze V5 and V6 products from two primary sensors on TRMM, the TRMM Microwave Imager (TMI) and the Precipitation Radar (PR), to unravel the quality of the V6 products vis-à-vis V5. Since GPROF precipitation rates are derived using the brightness temperature observations, it is worthwhile to first analyze the brightness temperatures from V5 and V6. It has been found that there is no difference between V5 and V6 brightness temperatures. Thus it is clear that any possible disagreement in the precipitation values from TMI V5 and V6 is due to the difference in the retrieval algorithm alone. Therefore we have first examined the percentage of rain area in V5 and V6, and found that the rain area has marginally changed from V5 to V6, which could be due to a change in the rain identification scheme. In order to analyze the rain product, the rain has been classified into three categories, low (< 1 mm h\(^{-1}\)), moderate (1 – 5 mm h\(^{-1}\)) and intense (> 5 mm h\(^{-1}\)) rain rates. It has been found that the GPROF V6 precipitation classifies higher numbers of pixels as raining than V5 at low rain rates while at moderate rain rates the case is reversed. And again at intense rain rates, V6 classifies a higher number of pixels as raining, but the trend reverses when there is a large difference of raining pixels in V5 and V6. But there is not much difference in PR- estimated rain rates between V5 and V6. And also it is observed that at lower frequency channels (<37 GHz), GPROF V6 precipitation, there is a depression in brightness temperature around 2 mm h\(^{-1}\) in almost every case and because of this depression the brightness temperature shows the increasing trend even at higher rain rates which is not expected as scattering at higher rain rates will make Tb to dip or remain steady. At the same time at higher frequency channel (85 GHz), V5 and V6 relationships are in better agreement except the
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depression at around 2 mm h\(^{-1}\). However, this anomalous behavior of Tb-rain rate relationship for GPROF precipitation may be due to the fact that V6 over classifies the lower rain rates while under-classifying the moderate rain rates. Thus from this study, it is concluded that the V6 GPROF precipitation shows higher bias especially at low to moderate rain rates than V5, while PR-estimated precipitation does not show much significant changes in V5 and V6. The reason for this may be that the difference between V5 and V6 algorithm is small in case of PR while in case of TMI it is significant.

Chapter-7: CONCLUSIONS AND FUTURE PROSPECTS

This chapter addresses the conclusion of present thesis work and proposes the direction for the future prospects research. The present study will be helpful for the retrieval of rainfall from recently launched Indo-French-Megha-Tropiques satellite as well as for coming in future GPM missions.
PUBLICATIONS OF THE AUTHOR RELATED TO THESIS WORK:

A. REFEREED JOURNALS:


4. Anoop Mishra, **Rajesh Kumar**, 2012: Rainfall estimation using a nonlinear method from TRMM Microwave Imager (TMI) observation over India, accepted for publication in *Journal of Hydrology*.

B. SYMPOSIUM/CONFERENCE PROCEEDINGS:


Author’s publications related to thesis work


C. SCIENTIFIC REPORTS:

1. Estimation of rainfall from microwave sensors of TRMM (passive and active) and its validation.

   Rajesh Kumar and I M L Das
   (SAC/MOP/MOG/April-2004)
   (SAC/MOP/MOG/April-2005)
   (SAC/MOP/MOG/April-2006)
   (SAC/MOP/MOG/April-2007)
   (SAC/MOP/MOG/April-2008)

2. Oceanic rainfall estimation from MEGHA-TROPIQUES-MADRAS and their validations with radar and buoys data.

   Rajesh Kumar and I M L Das
   (SAC/MT-UP/MOG/April-2008)
   (SAC/MT-UP/MOG/April-2009)
Mr. Rajesh Kumar was born to Mrs. Shalkeshi Devi and Mr. Ras Bihari Singh on 20th July, 1977 in Village-Salarpur, Dist.- Ghazipur, Uttar Pradesh, India. He completed his schooling in Science stream from Mathura, B. Sc. (Physics, Chemistry & Mathematics) from Maharshi Dayanand Sarswati University, Ajmer, Rajasthan, India. After completing his M.Sc. (Physics) from University of Jammu, J&K, India in 2001, he worked as a faculty member in Army School, Nagrota, J&K and Army School, Ranchi, Jharkhand, India for about two years. After then he joined in a SAC/ISRO (Space Applications Centre / Indian Space Research Organization) sponsored research project in M N Saha Centre of Space Studies, Institute of Interdisciplinary Studies, University of Allahabad as a Junior Research Fellow (JRF) in October, 2003. He worked as a JRF for two years and then Senior Research Fellow (SRF) for two years in the project “Estimation of Rainfall from microwave sensors of TRMM (passive and Active) and its validation”. In the month of November 2007, he joined in another SAC/ISRO research project “Oceanic rainfall estimation from MEGHA-TROPIQUES-MADRAS and their validations with radar and buoys data” and worked till June, 2009. In June 2009, he joined Geological Survey of India (GSI) as a Geophysicist (Geo-Scientist) through UPSC (Union Public Service Commission). He is presently involved in airborne multisensor geophysical survey operations of Remote Sensing & Aerial Surveys wing of GSI, headquarter at Bangalore. In the past he has worked on geophysical parameter retrieval using satellite remote sensing specially microwave. He has developed rainfall retrieval algorithm techniques for the Indian land and oceanic regions using microwave observations. He was doing his D.Phil. on the topic “Studies on Estimation of rainfall from space based observations” from University of Allahabad, Uttar Pradesh, India.