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6.1 Summary and conclusions of the present work

6.2 Future prospects
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6.1 Summary and conclusions of the present work

This thesis work addresses use of satellite based remote sensing techniques for the precipitation retrieval over Indian land and associated oceanic regions. The studies presented in this thesis focus on the development of precipitation retrieval algorithm using space based satellite data from infrared, microwave and merged infrared and microwave techniques. The standard threshold based GPI (infrared based) technique is utilized for the rainfall estimation the Indian tropics. Intercomparison with the other satellite products such as TRMM-3B42 and GPCP as well as the validations using DWR and AWS rain gauges have been attempted in this thesis. Results show that although GPI works well for the larger temporal and spatial scales (daily/monthly over 1°X1°/2.5°X2.5° GRID box), it does not work for the smaller temporal and spatial scales. Results further show that these estimates are not always accurate over land and particularly over the mountain regions, where rainfall is more orographic than convective also these threshold (235degree Kelvin) may not hold well where the rainfall is originating predominantly from warm clouds. In spite of such shortcomings GPI technique does in fact yield useful information about rainfall over the oceans and other land regions where radar and rain gauge data are sparse or not available. Since the results show that the technique works better for the larger temporal and spatial scales, it may be is used to study climatology and rainfall variability over larger scales. The thesis also describes the modification in the infrared based GPI technique by using the environmental moisture correction factor. It implements an environmental moisture correction factor (NCEP-GFS model data parameters, integrated relative humidity factor in fraction and precipitable water factor converted in to inches are multiplied and this product is called environmental moisture correction factor, this factor is multiplied by the rainfall from GPI estimates) in the GPI technique and it is named as MGPI technique. The intercomparison of the rainfall estimates from MGPI technique with the TRMM-3B42 rain products and validation using rain gauge data and DWR is also attempted in the thesis. The comparison of the developed MGPI and the GPI technique with the TRMM-3B42 indicates that before the application of the environmental correction factor high rainfall values (greater than 72 mm/day) were not well picked up (GPI technique) while the application of this factor helps in picking up the high rainfall values accurately.
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at smaller temporal scale (3-hourly) which is highly desirable in now-casting applications. The quantitative comparisons with the TRMM-3B42 indicate that the error statistics is improved with the applications of the environmental correction factor in the MGPI technique. Validation results with the AWS rain-gauges show that the MGPI technique shows the significant improvement in GPI technique for retrieving the high as well as the low rainfall events. Further validation with the DWR shows that the application of the environmental moisture correction factor yields in retrieving the rainfall with a very good accuracy at smaller temporal and spatial scales. It indicates that the GPI technique shows the greater bias and root mean square error as well as the poorer correlation, while the MGPI shows significant improvements both quantitatively and qualitatively. So the validation results show that the MGPI technique provides better scope of using it for the operational applications, like now-casting and validation of NWP model results etc using Indian INSAT/KALPANA data on real time basis as intended in the objectives of the present investigation. This study is taken up to enhance the capability of rainfall retrievals in near future using INSAT-3D data.

In the thesis description of the development of a new regional scattering index technique for the rainfall estimation over the Indian tropics by using of SSM/I F13 microwave data is also given. The study shows that the regional scattering index scheme works better than the global scattering based scheme developed by Ferraro et al. (1995). A regional scattering index (SI) has been developed for the Indian land and oceanic regions separately based on the measurements at 19.35, 22.235 and 85.5 GHz channels of SSM/I Satellite. These regional scattering indices were co-located against rainfall from Precipitation Radar (PR) onboard Tropical Rainfall Measuring Mission (TRMM) to develop a new regional relationship between the SI and the rain-rate for the Indian land and oceanic regions separately. A non-linear fit between the rain-rate and the SI is established for rain measurement. Two different relationships between the rainfall and the SI have been developed for the land and oceanic regions separately, while Ferraro global scheme rely on the single relationship between the rainfall and the SI applicable for both land as well as the ocean. Intercomparison of the rainfall based on regional scheme developed in the thesis has been attempted with that from TRMM-2112 algorithm
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(GPROF). In order to have confidence in the present regional scheme developed for the Indian land and oceanic regions, rainfall from the Ferraro global scheme is also calculated. The validation of these two schemes with the ground observation (AWS rain-gauges) indicates that the present regional scheme is able to retrieve the rainfall with better accuracy than that from Ferraro global scheme over Indian land and oceanic regions which is based on a single set of coefficients for its applicability for global rainfall retrieval. Further, inter-comparison of the present technique with the GPROF (2A12 rain product) algorithm has been attempted in this thesis. The intercomparison shows that present regional scheme is able to retrieve the rainfall with good accuracy both qualitatively as well as quantitatively which is highly desired particularly over the south-west and north-east monsoon dominated regions of Indian sub-continent. The qualitative comparison (different case studies during the monsoon period over both land and oceanic regions) indicates that although rainfall from the present technique matches very well with that from the 2A12 rainfall products, there may be slight difference due to different observational orbital pass time. The quantitative comparisons with the 2A12 rainfall products indicate that the developed regional scheme is able to retrieve the rainfall with a very good accuracy. These results also show that this scheme works better over the land region than the ocean. In general the oceanic rainfall algorithms (due to the homogeneous background of ocean) perform better than algorithms over land (due to highly varying emissivity of the land). However, in the present case the region specific empirical algorithm performs better over the land than the oceanic regions which was confirmed by the comparison of the present regional scheme with the GPROF algorithm. Despite the different system configurations and the geometry of PR and SSM/I observations, the rainfall from present technique is quite close to the standard operational products from GPROF algorithm which is not as simple in operation as the present one. In the thesis validation of the regional scattering index scheme has also been attempted using DWR data during the N-E monsoon season and these validation results clearly show that the present regional scheme developed for the Indian land and oceanic region is able to retrieve the rainfall with a very good accuracy. The results based on the global scheme also indicate that such empirical rainfall retrieval (as attempted in this thesis) should be developed regionally based on the different climatic zones of the globe.
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separately. This regional scattering index scheme technique is taken up to enhance the capability of rainfall retrievals in near future using MADRAS (Microwave Analysis and Detection of Rain and Atmospheric Structures) channel of Indo-French satellite Megha Tropiques to be launched sometime in 2011.

In this thesis an attempt has been made to utilize the advantages of both the infrared as well as the microwave estimates. The development of a new rainfall estimation technique for 3 hourly to daily rainfall rates with \(0.25^\circ\times0.25^\circ\) grid based on both TIR and MW observations from Meteosat/Kalpana and TRMM-PR data has been attempted. In order to make the algorithm robust a two step procedure was employed, first, a cloud classification scheme adopted by Roca et al. (2002) has been applied to TIR measurements using the 6.7 \(\mu\)m water vapor channel and TIR radiances to delineate the rain bearing clouds. In the final step, these Meteosat/Kalpana TIR are collocated against PR observations to establish a regression relation between them. The precipitation rates are derived from a power-law regression relationship between the TIR TB's and the PR-rain rates after duly classifying the clouds using TIR and WV channel. The relationship between the rainfall and the TIR brightness temperature thus established is used to estimate rainfall from TIR measurements by applying it to rain producing systems during different atmospheric conditions like South-West (S-W) and North-East (N-E) monsoon and the tropical cyclones over the Indian land and oceanic regions. The relationships between the rainfall and the brightness temperature for different seasons like monsoon, pre-monsoon and post monsoon has also been analyzed. Validation of the rainfall from the technique developed in this study has been attempted using DWR and the AWS rain gauges. Intercomparison with the other satellite products such as TRMM-3B42 and GPCP has also been attempted. For the qualitative comparison of the rainfall with that from TRMM-3B42 different case studies have been performed, which indicate the close agreement between the two estimates. Further it is observed from the comparison, that there is low areal coverage of TRMM-3B42 as compared to present technique (PR-based). It may be due to the fact when compared with TMI (3B42 uses TMI rainfall as well as other satellite estimates), PR detects more rain events (Varma, 2008). Also it is observed that in general TRMM-3B42 underestimates the rainfall, the reason of underestimation in the TRMM-3B42 may be due to inherent weakness of passive microwave
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measurements for warm rain detection. The IR also has the problem of detecting warm rain but possibly it does better in the present algorithm because of rain classification scheme and calibration with PR.

Quantitative comparisons using large data base for both S-W and N-E monsoon periods show that the rainfall from present technique exhibit good error statistics with TRMM-3B42 estimates and thus both the estimates are quite close to each other. Further the comparison with TRMM-3B42 was made separately for the land and oceanic regions, and this comparison showed that rainfall from the present scheme is matching better with that from the TRMM-3B42 over the ocean than over land. Further comparison of the rainfall from this technique is attempted with that from GPCP. This comparison attempted at monthly scale and at 2.5°X2.5° grid shows that the present technique is showing very good comparison with GPCP over large temporal and spatial scales. In order to compare the utility of the present technique with the TRMM-3B42 an attempt has been attempted to Validate the rainfall from present technique and that from TRMM-3B42 with AWS rain gauge observations and the validation results show that the present technique is able to retrieve the rainfall with better accuracy than TRMM-3B42. Further, in order to compare the rainfall rates from TRMM-3B42 and the present technique for the different rainfall ranges, rainfall from present technique and that from TRMM-3B42 were averaged in bins of AWS rain and comparison was attempted for the different rainfall ranges which shows that both TRMM-3B42 and the present technique matches up the low-moderate, but high rainfall was underestimated by the TRMM-3B42 as compared to the present technique. Finally the qualitative and quantitative validation of this technique with the DWR has been attempted and it shows that the rainfall rate from the present technique was very well matching with that from the DWR observations. So, it is clear from the results of inter-satellite comparison of rain products (present technique and TRMM-3B42, GPCP) and validation with the ground truths (DWR, AWS) that present technique is able to retrieve the rainfall with a very good accuracy over Indian land and oceanic regions. The results presented in the thesis indicate that sparsely available low orbiting satellite active microwave observations can improve the performance of IR based rainfall significantly especially in the areas where there is lack of sufficient ground rainfall observations. This study can be taken up to enhance the capability of precipitation
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retrievals in near future using synergy from Indo-French satellite Megha Tropiques and INSAT-3D to be launched sometime in 2011.

Out of above stated techniques, MGPI and merged IR and WV are used as operational rainfall estimation technique at Space Applications Center and regional scattering based technique is under research and development.

6.2. Future prospects

In this thesis an attempt has been made for precipitation estimation using satellite remote sensing over Indian land and oceanic regions. The present study uses Infrared, Microwave and merged infrared and microwave technique to estimate the rainfall over Indian tropics. Although these methods work well for the Indian land and oceanic regions, more regress examination of these techniques and thereby further improvements need to be done. For example, the threshold temperature of 235 ° K needs to be calibrated for the Indian region and the cirrus clouds need to be delineated as they are sources of errors in this threshold based technique. The value of the constants 3mm/hr and 71.2 mm/day also need to be recalibrated for the land and oceanic regions separately.

In addition to this the value of these constants need to be recalibrated for the different brightness temperature ranges. Furthermore, as it is evident from the results that multiplication of the environmental moisture correction factors to the GPI rainfall reduces (in some cases eliminated the rainfall values) the rainfall intensities over the mountainous regions (Himalaya region) so special care should be taken in case of orographic rains. So hydrometeors need to be examined before the multiplication of the environmental moisture correction factors. Since a single proxy variable scattering index is used for the precipitation estimation using SSM/I microwave data, more proxy variables may be used to estimate the precipitation estimation. These proxy variables include Polarization Corrected brightness Temperature (PCT) (Todd and Bailey 1994), and polarization difference (D) (Rodgers et al. 1979; Grody 1984) etc. In addition to this, in order to improve the rainfall over ocean another measure of rainfall scattering signal, designed to minimize the effects of cloud liquid water, water vapor, and sea surface roughness ocean-orographic scattering index (OSI) (Spencer 1986; Todd 1993). Further more, since the rainfall estimation technique from the synergistic use of multisatellite
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sensors PR and Meteosat/Kalpana is developed for both land and oceanic regions, further effort may be made to develop the technique for the land, ocean, and coastal region separately in order to make the technique more robust. Further since TRMM-3B42 might have certain problems over India, more work on evaluating this product over India in future is planned. Thus a lot need to be done in the area of precipitation retrieval and further efforts will be continued unabated in the future.