MODELLI E MISURE DI PRECIPITAZIONI ATMOSFERICHE MEDIANTE RADIOMETRIA MULTISPETTRALE A MICROONDE DA TERRA

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Abstract

The potential of ground-based multispectral microwave radiometers in retrieving rainfall parameters is investigated by coupling physically-oriented models and retrieval methods with a large set of experimental data. Measured data come from rain events that occurred in the USA at Boulder, Colorado, and at the Atmospheric Radiation Measurement (ARM) Program's Southern Great Plains (SGP) site in Lamont, Oklahoma. Brightness temperature numerical simulations are performed for a set of frequencies from 22 to 60 GHz at zenith angle, representing the channels currently available on a commercially available ground-based radiometric system. A new statistical inversion algorithm, trained by synthetic data and based on principal component analysis is also developed to classify the meteorological background, to identify the rain regime, and to retrieve rain rate from passive radiometric observations. Rain rate estimate comparisons with simultaneous rain gauge data and results are also discussed.

INTRODUCTION

Ground-based microwave radiometry has been mainly investigated for estimating temperature, water vapor and cloud liquid profiles in the absence of precipitation [1]-[2]. The increasing use of multi-frequency radiometers in ground-based meteorological and receiving stations has raised the question of their potential for retrieving rainfall parameters [3]-[8]. This feature is even more appealing if the ground-based microwave radiometer can be equipped by automatic scanning in order to cover a large atmospheric volume in a manner similar to radar systems. Indeed, synergetic use of radiometric rain retrieval methods with weather radar systems is another important application, especially with constrained path-attenuation mitigation techniques [8]-[13].

In order to exploit the information content of the 12-channel radiometric system, we have adopted a retrieval approach based on a physical radiative model able to characterize both stratiform and convective precipitation, including spherical liquid, melt, and ice hydrometeors [5], [8]. A new non-linear statistical inversion procedure has been developed that is based on successive steps where rainfall is (1) detected, (2) classified with respect to its regime, and (3) estimated in terms of columnar water and rain rate. Results are illustrated by means of comparisons between multispectral measurements and model data in order to show that the observed radiometric signatures can be attributed to rainfall scattering and absorption. Finally, rain rate radiometric estimates are compared with available simultaneous rain gauge data.

EXPERIMENTAL MEASUREMENTS

As already mentioned, in order to interpret and test rainfall model simulations and rainrate estimates, a fairly large set of measurements acquired by Microwave Radiometer Profilers (MWRP's) manufactured by Radiometrics Corp. have been used. The MWRP radiometer observes the radiation intensity at 12 frequencies in a region of the microwave spectrum that is dominated by atmospheric emissions from water vapor, cloud liquid water, and molecular oxygen. The 12 observation frequencies (i.e., 22.035, 22.235, 23.835, 26.235, 30.00, 51.250, 52.280, 53.850, 54.940, 56.660, 57.290, 58.800 GHz) were chosen by an eigenvalue analysis to optimize retrieval accuracy.

For a preliminary statistical validation, about one year of MWRP radiometric observations at the ARM SGP site, from June 2001 to June 2002, have been analyzed in this work. A tipping-bucket raingage, located at about 500 m from MWRP instrument, has been also available with a temporal resolution of half an hour. Fig. 3 characterizes the set of observations in terms of TB histograms at different frequencies. It is evident from the dual-mode distribution of low-frequency TB's that rain cases represent just a small fraction of the entire data set. Absorbed channels around 60 GHz denote a smaller dynamics with respect to lower frequency channels and, moreover, do not show a peculiar histogram where rainfall signature is easily distinguishable. A detailed analysis of the rainfall microwave signature will be carried out when comparing measured and simulated data in the next section.

INVERSION METHOD AND RESULTS

The inversion technique developed in this work has been developed mainly by focusing on the multispectral nature of MWRP radiometric measurements and on its operational real-time features. Based on previous work [5], [8], we here have developed a new inversion technique suited for the MWRP multispectral observations. Such technique, when trained with simulations and applied to observations, provides estimates of a variety of rainfall parameters, such as columnar hydrometeor content and rain rate. In this work, we do not attempt to estimate a rain water profile, even though in principle it could be performed with some approximations [10]. This potential and capability to easily generalize and extend the results is one of the major advantages of a physically-based inversion algorithm with respect to an empirical one.

The inversion procedure, designed for MWRP, is structured in three subsequent steps, specifically extended and tuned for this application but easily extendible to any other sensor configuration. The three foreseen steps are the following:

i) classify the meteorological background scenario;
ii) detect rainfall and classify the cloud genera and, eventually, rain regime;
iii) estimate the rain columnar water contents and surface rain rate.

The entire inversion algorithm is formulated in terms of PC's. As justified in the previous section, the first 3 PC's (and EOF's) are sufficient in our case to explain more than 99% of the total variance. The PC transformation has several advantages, mainly its robustness to unknown noise and higher accuracy in best fitting predictands to predictor. These properties have been numerically proven by using the illustrated simulated dataset as well.

A way to check the consistency between modeled and measured data sets is to show the relationship between rain rate and TB in the weak absorption region (20-50 GHz), as in Fig. 1. Here black dots represent TB and rain rate extracted from the overall simulated database, while gray dots correspond to TB measured by the MWRP and rain rate estimates obtained from radiometric measurements applying the inversion technique previously described.

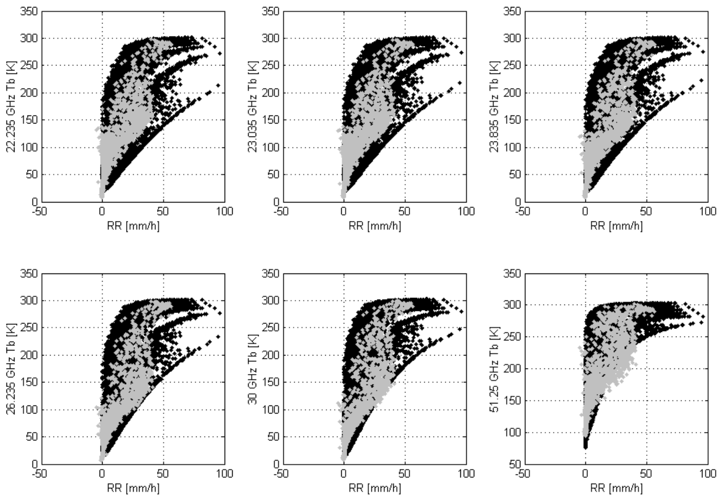

Fig. 1: Scatter plots between T_B and rain rate for the six MWRP lower frequency channels (22.235 to 51.25 GHz). Black dots represent simulated rain rate and T_B, while grey dots show radiometric observations and the respective rain rate estimates.

In order to have a statistical comparison between radiometric estimates and rain gauge measurements we have aligned the two data sets and averaged them into 30-min bins. This filtering operation results in 14,716 bins when both measurements were available. A first analysis concerning the capability of the proposed technique to detect rain is performed on the whole set. Here we use the statistics indexes as defined in [9] to measure the Probability of Detection of Rain (PODR), the Probability of Detection of No-Rain (PODNR) and the False Alarm Ratio (FAR). The discussed technique shows an excellent PODNR and fairly good PDR and FAR. The last two indexes might be also slightly affected by time-space variation of the rain field, since the MWRP and the rain gauge were sitting few hundreds meters apart.

A further analysis concerns the ability of the technique to retrieve quantitatively the value of rain rate, once raining conditions are detected using the proposed physically-based approach. Thus, we have limited the set of observations to those classified as rain, a selection which drastically reduces the number of bins to 98. This data set is plotted in Fig. 2. It is evident that there is a reasonable correlation between the two measurements, although the statistics is limited by the relative small range of variation. The bias and standard deviation of the error are about 0.5 and 1.8 mm, respectively, which results in a root mean square of about 1.9 mm.

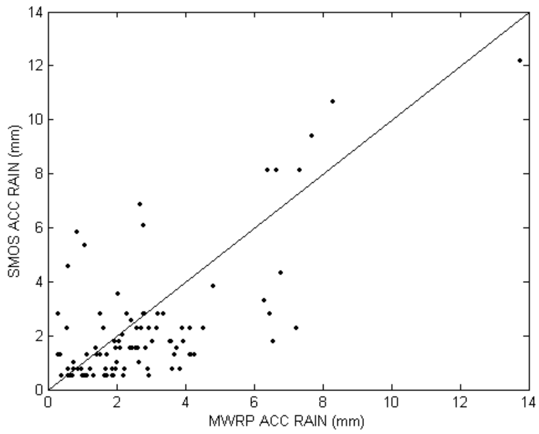

Fig. 2: Scatter plot of 30-min accumulated rain (mm) as measured by the rain gauge (SMOS) and as estimated by the MWRP. The sample size is reduced to 98 cases.

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