Precipitation estimation: from the RAO to Eurainsat and beyond

PRECIPITATION ESTIMATION: FROM THE RAO TO EURAINSAT AND BEYOND

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ABSTRACT

The key objective of the project "Use of the MSG SEVIRI channels in a combined SSM/I, TRMM and geostationary IR method for rapid updates of rainfall" is the development of algorithms for rapid-update of satellite rainfall estimations at the geostationary (GEO) scale. The new channels available with the Spinning Enhanced Visible and Infrared Imager (SEVIRI) radiometer in the visible (VIS), near infrared (NIR) and infrared (IR) portions of the spectrum provide new insights into the microphysical and dynamic structure of precipitating clouds thus allowing for a more precise identification of precipitation intensities. Passive microwave (PMW) radiometers on board low Earth orbiting (LEO) satellites are used to determine information on the vertical cloud structure. Key features of the new method(s) are:

1. Microphysical characterization of precipitating clouds with VIS/IR sensors;
2. Creation of cloud microphysical and radiative databases from cloud model outputs and aircraft penetrations;
3. Tuning of PMW algorithms for different cloud systems (maritime, continental, convective, stratiform,...);
4. Combination of data from different algorithms and application to a rapid update cycle at the GEO scale.

The project provided the background for EURAINSAT "European Satellite Rainfall Estimation and Monitoring at the Geostationary Scale", a research project co-funded by the Energy, Environment and Sustainable Development Programme of the European Commission within the topic "*Development of generic Earth observation technologies*". The project web site is accessible at http://www.isac.cnr.it/~eurainsat/. Moreover, it has represented the European framework for the launch of the International Precipitation Working Group (IPWG).

A brief account of the major research and organizational results will be given in the following.

1 CLOUD MULTISPECTRAL AND MICROPHYSICAL ANALYSIS

A sensitivity analysis of the radiance data in the NIR and IR channels at 1.6, 2.1, 3.7, 11 and 12 µm to various cloud microphysical properties and characteristics of the examined scenarios was conducted. A new retrieval algorithm to infer cloud top height, relative humidity above cloud top and effective radius of optically thick clouds from SEVIRI data at 3.7, 11 and 12 µm was implemented (see examples in Fig. 1 and 2). As a consequence of these studies it was found that switching the daylight operations of the 3.7 µm to the 1.6 µm waveband, while retaining the 3.7 µm waveband only for nighttime operations, for NOAA AVHRR/3 was wrong and has an impact on cloud retrievals and fire detection, among other things.

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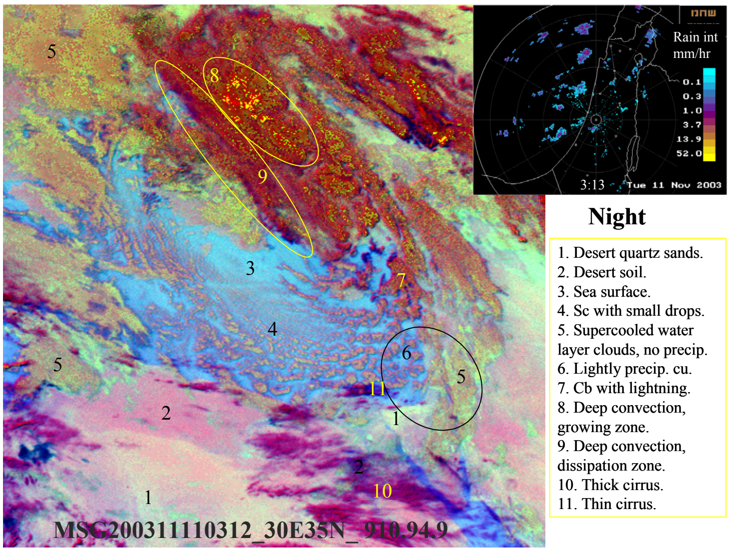

Fig. 1. Nighttime cloud classification over the Eastern Mediterranean using SEVIRI channel combination: R(12-10.8), G(10.8-3.9) and B(10.8). Reflectivity from the Israeli meteorological radar is shown in the upper right corner. (D. Rosenfeld, Hebrew Univ. Jerusalem).

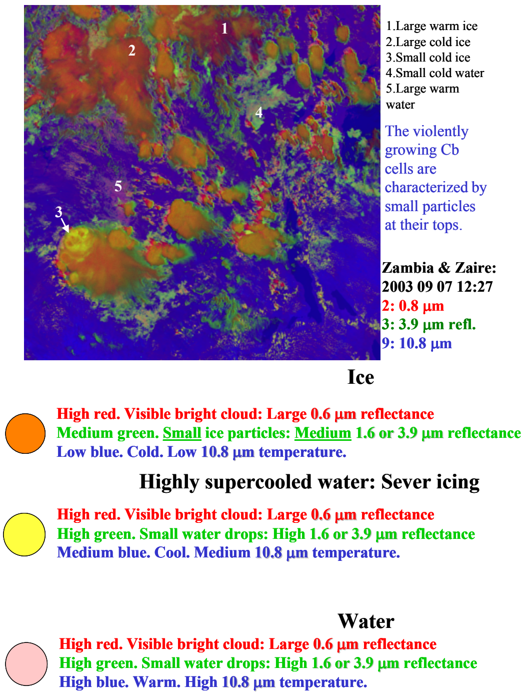

Fig. 2. Daytime convective development in severe storms over Zambia and Zaire, which display small particles at cloud top. (D. Rosenfeld, Hebrew Univ. Jerusalem).

Recommendations were given to NOAA and EUMETSAT for present and future sensors (Rosenfeld et al. 2004).

The SEVIRI VIS, NIR and IR wavebands also demonstrated to be instrumental for the documentation of precipitation formation processes and aerosol-cloud interactions (e.g. Lensky and Rosenfeld 2003; Melani et al. 2003; Rosenfeld et al. 2002).

Studies were conducted on the fore/aft observation strategy for PMW observations, the use of radar brighband observations (Battaglia et al. 2003), 3-D cloud effects, DSD analysis and the combined use of lightning measurements and modeling (Solomon et al. 2004) for the determination of precipitation type and aerosol-cloud interactions. Recommendations for the Global Precipitation Mission (GPM) and future European geostationary missions were given.

The Hebrew University Cloud Model, a spectral model with explicit microphysics, was further developed and contains a complete aerosol microphysics and turbulence effects, necessary to model precipitation formation. The model was used together with other models, like the Univ. of Wisconsin Numerical Modeling System (UW-NMS) for the analysis of heavy precipitation events and the generation of cloud physics profiles for rainfall retrievals (Tripoli et al. 2004).

2 SATELLITE RAINFALL ESTIMATION

2.1 MW based

Three existing algorithms were applied to several case studies and validation carried out: PR-Adjusted TMI Estimation of Rainfall (PATER), Physical Profile-Based Multisensor Algorithm (PPBMA), and Bayesian Algorithm for MW-based Precipitation Retrieval (BAMPR). A cloud radiation dataset based on a large number of simulations over the Mediterranean was produced as a basis for physical algorithms. Moreover, a physical–statistical approach to simulate cloud structures and their upward radiation over the Mediterranean was devised aiming to construct a synthetic database of PMW observations matching the local climatological conditions (Pulvirenti et al. 2003).

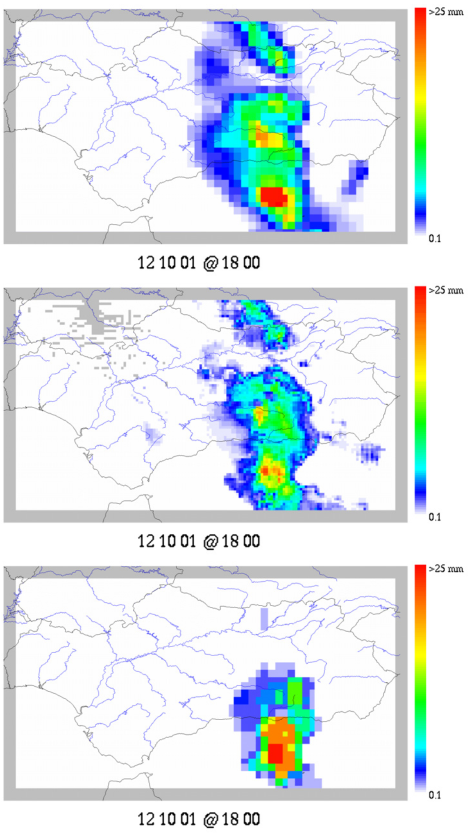

Fig. 3. 12 October 2001 1800 UTC. Rain retrievals from the SSM/I using the Polarization Corrected Temperature (0.1º, top), NN estimate (0.05º, middle) and the histogram matching estimate (0.05º, bottom). (F. J. Tapiador and C. Kidd, Univ. of Birmingham).

2.2 Combined MW-IR and MW-radar

Neural Networks (NN) fusing IR images with Special Sensor Microwave/Imager (SSM/I) rainfall estimates generated with a frequency difference algorithm were used (Tapiador et al. 2004a,b).

A new method to generate rainfall estimates for the tropical region was developed using a Maximum Entropy-based Histogram matching technique for operational rainfall estimates (Tapiador et al. 2004c). By applying a theoretically derived, SSM/I calibrated probability distribution function (PDF) to IR brightness temperatures using a probabilistic method 30 min, 5 km rainfall estimates at tropical scale are generated. The main advantage of the method is its simplicity, which makes it easy to apply by developing countries receiving METEOSAT format A or B images. The algorithm is made available upon request through the International Precipitation Working Group web site (http://www.isac.cnr.it/~ipwg/). An example of the application of these methods is shown in Fig. 3.

A new technique to generate half hourly, 12 km near global rainfall estimates derived from a combination of IR and PMW estimates using a histogram matching method was also conceived (Kidd et al. 2003). An advection-based method was also conceived that makes use of IR-derived wind fields to extract the dynamic features and modify accordingly the MW rainfall field.

Additional research has been undertaken to mitigate the effects of snow and ice on the PMW retrievals to improve cold-season products. Screening of false rainfall signatures caused by snow, sea ice, desert or semi arid surfaces is an essential part of any rainfall retrieval, despite often being warranted less importance than the rain rate retrieval step.

The Calibration of Infrared-derived Rain Areas by Microwave Measurements (CIRAMM) algorithm was applied to several heavy rainfall cases over the Mediterranean basin, where radar or raingauge rain maps were available at time-space scales suitable for comparison. Results show marked differences in the technique performances depending on the terrain physiography: over mountainous regions the satellite underestimates precipitation while over a flat background satellite and ground estimates are closer.

The Naval Research Laboratory (NRL) technique was extensively applied to precipitating events in the Mediterranean area to identify performances in this complex orographic and meteorological environment.

The design of a general approach to the statistical integration of PMW and IR satellite radiometric measurements to retrieve rainfall rate at the geostationary scale was addressed. One of the new approaches developed within EURAINSAT can be easily extended to any rainrate estimate source (such as

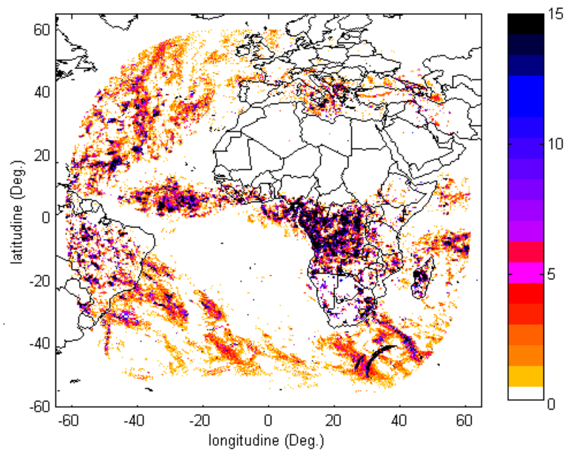

Fig. 4. Accumulated rainfall (mm h^{-1}) on 1-17 November, 1999 within the METEOSAT sector. (F. S. Marzano, Univ. L'Aquila).

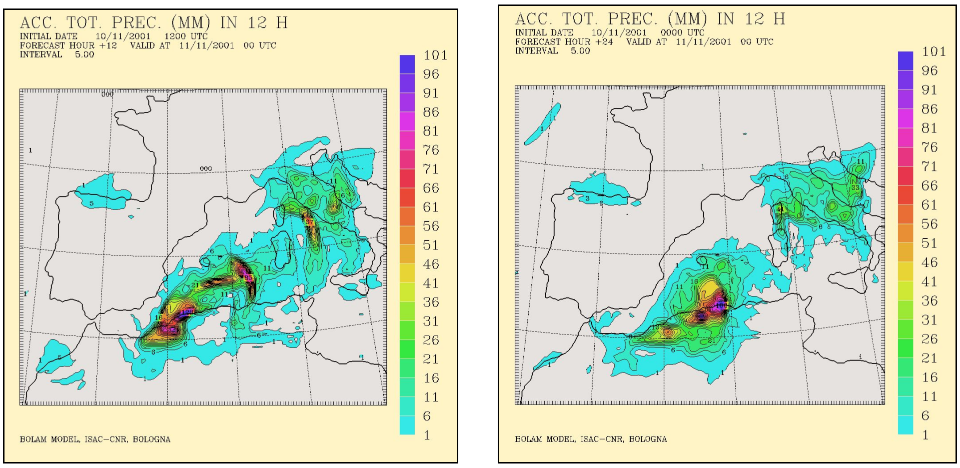

Fig. 5. 12-h accumulated precipitation, 0000 UTC, 11 Nov. 2001 for the BOLAM control run (left) and forecast (right). (A Buzzi, ISAC-CNR).

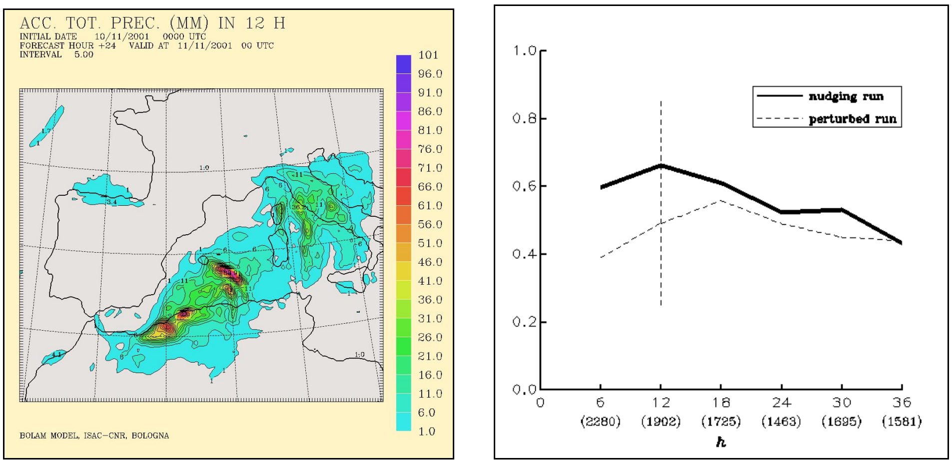

Fig. 6. Left: same as in Fig. 5, but for the assimilation run. Right: evolution of the ETS computed for 6-h accumulated precipitation, starting 10 Nov. 2001 1200 UTC. Within brackets are the number of observations exceeding the threshold value of 2 mm/6h. The vertical dashed line marks the end of the assimilation period. (A Buzzi, ISAC-CNR).

satellite radar, ground-based radar and radiometers, rain gauge) and multispectral IR data. The algorithm is called Microwave Infrared Combined Rainfall Algorithm (MICRA) (Marzano et al. 2004). An application to the MSG disk is shown in Fig. 4.

3 ASSIMILATION OF AREA DISTRIBUTIONS OF SATELLITE RAINFALL ESTIMATIONS INTO LAMS

The development and testing of a nudging scheme, based on modification of humidity profiles, has been performed and applied to the limited area model BOLAM. The activity has been mainly devoted to a more precise definition of the coefficients entering the nudging equation, based on idealized tests and realistic case studies. Moreover, an attempt of assimilating satellite data has been performed; in this case the nudging procedure has been confined over the sea. See Fig. 5 and 6 for an example of the assimilation results.

An assimilation algorithm was been developed for the Regional Atmospheric Modeling System (RAMS). The technique for convective rainfall assimilation into RAMS, by means of the inversion of the cumulus convection parameterization scheme, was ported to the operational chain. The technique for the assimilation of precipitation from the rapid update algorithm as a forcing for the consistent update of the soil and vegetation status (which in turn feedbacks into the atmospheric component by means of dedicated runs of the land-ecosystem-atmosphere feedback LEAF-3 scheme), called Antecedent Precipitation Index (API) was also ported into the project's operational chain.

4 APPLICATIONS AND OPERATIONAL TESTS

Several major case studies were selected for testing purposes: MAP IOP2B; Algeria November 2001 flood and subsequent severe weather over the Balearic Islands and western Mediterranean; Northern Italy flood event, 24-26 November 2002; rains in Andalusia; heavy rains in Africa; midlatitude events in Europe; the Dresden 2002 flood.

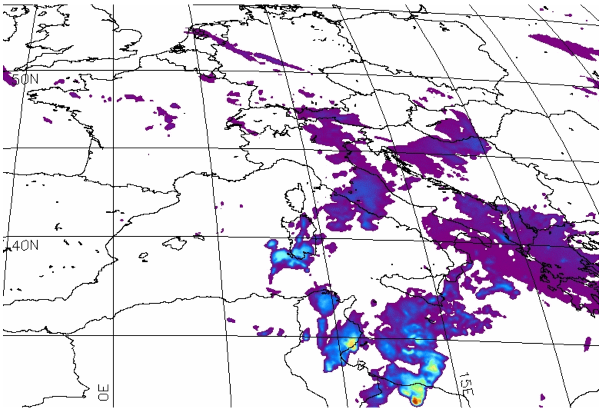

Fig. 7. Rainfall product from the operational chain implemented at LaMMA, Firenze (Italy). See http://www.lamma.rete.toscana.it/previ/eng/rainMETEOSAT.html. (S. Melani and A. Ortolani, LaMMA)

An operational site was set up at LaMMA in Firenze (Italy) by upgrading the rapid update satellite precipitation estimation operational chain (Fig. 7) and the RAMS model assimilation of rapid update satellite rainfall estimates.

Validation of some of the rainfall algorithms was performed concentrating on dichotomous assessment of the rainfall: rain retrievals from satellite data that can be thought of as comprising of two parts, rain delineation and rain rate estimation. To successfully delineate rainfall the algorithm has to distinguish the raining event from false rain signatures from the surface and non-raining cloud. As a heterogeneous surface, land presents the most problems in this respect due to its highly variable surface emissivity.

Rainfall MW attenuation models were produced and refined and a K-band attenuation prediction method using MW satellite data was proposed (Marzano and Roberti 2003). This approach represents a feasible alternative to the estimation of beacon path attenuation from surface rainrate. An example is given in Fig. 8.

5 SOCIO-ECONOMIC RELEVANCE AND POLICY IMPLICATIONS

The impact of more accurate and timely satellite rainfall measurements is to be found in weather analysis and forecasting, hydrogeological management, risk assessment, and climate change at global and regional scales (e.g. Porcù et al. 2003).

End-users include international organizations that have responsibilities for weather analysis and forecasting, the World Meteorological Organization (e.g. impacts in remote or insufficiently monitored areas), the Food and Agriculture Organization (FAO) of the UN (food production monitoring especially in developing countries), satellite exploitation organizations, weather forecasting offices at the national and regional scale, civil protection agencies. The European Union can benefit from additional powerful support to decision making authorities of its member states, as well as complete coverage Europe every 15 min. Updates at 15 min intervals have a possible direct impact on the monitoring of severe events in hazardous areas and are of fundamental importance to this activity.

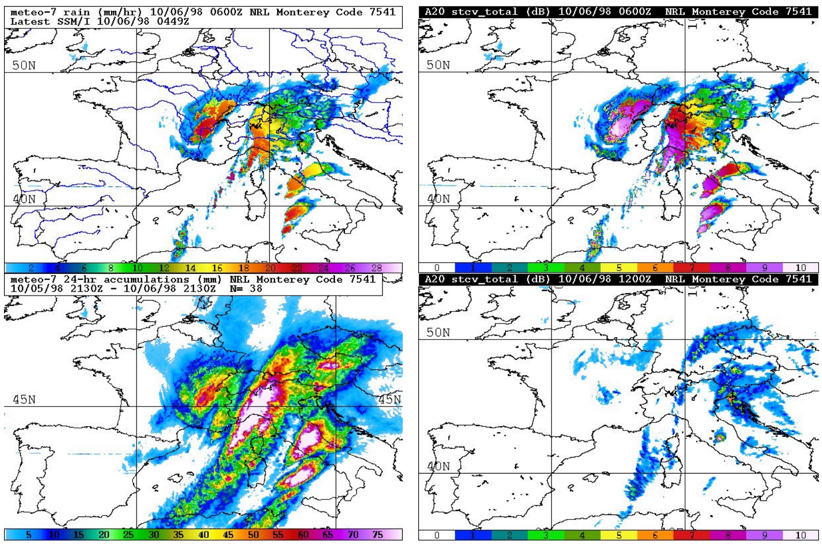

Fig. 8. Upper left: instantaneous rainrate (6 October 1998). Lower left: 24 h rain accumulation (5-6 October 1998). Upper right: 20-GHZ attenuation at 0600 UTC. Lower right: 20-GHz attenuation at 1200 UTC (6 October, 1998). (F. S. Marzano, Univ. L'Aquila and F. J. Turk, NRL).

6 CONCLUSIONS

The project has developed several satellite rainfall estimation techniques that can be applied to the operational meteorological environment. Advancements in the understanding of precipitation forming mechanism are also an important by-product. The assimilation of precipitation fields into limited area models for the improvement of numerical weather predictions is a key development area. A large potential exists for significant improvements of satellite rainfall products by using multispectral techniques, lightning detection, new sensor configurations (e.g. fore/aft view), physically based vertical hydrometeor profiles.

The project has succeeded in organizing the satellite rainfall research community at continental level and acted as an interface towards international organizations contributing to the creation of the European Research Area and the IPWG.

A book contributing to define the state of the art of satellite rainfall estimations will be soon published as a result of the project (Levizzani et al. 2004).

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