A new algorithm to generate global rainfall rates from satellite infrared imagery

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RESUMEN

Este artículo presenta un nuevo algoritmo para generar estimaciones de precipitación a nivel global utilizando imágenes de satélite en el IR. Para ello, en primer lugar, se modeliza la distribución de probabilidad (PDF) de las tasas de precipitación mediante el método de entropía máxima (MEM) para después de aplicar la técnica de asignación de histograma a las imágenes IR. El resultado es un algoritmo sencillo, reducible a una expresión algebraica. La aplicación inmediata del método consiste en derivar tasas de precipitación y precipitación acumulada a partir de satélites geoestacionarios, proporcionando un método directo cuyo único insumo es la información del IR, y que puede ser aplicado fácilmente a las estaciones receptoras de GOES o METEOSAT.

PALABRAS CLAVE: precipitación, IR, METEOSAT, GOES.

ABSTRACT

This paper presents a new algorithm to generate rainfall rates estimates from IR satellite imagery. The idea is to modeling the Probabilistic Distribution Function (PDF) of the rainfall rates through the Maximum Entropy Method (MEM) for applying next the Histogram Matching technique to the IR images. The resulting procedure is a straightforward algorithm that can be formulated as an algebraical expression. The main application of the method is the direct estimation of rainfall rates and accumulated rainfall from geostationary satellites. This provides a direct method using only IR information. The method can be easily applied to GOES or METEOSAT satellite reception stations.

KEY WORDS: rainfall, IR, METEOSAT, GOES.

INTRODUCTION and BACKGROUND

The modelling of the rainfall rates has a major importance not only in climatology but also in other fields such as natural hazards assessment or agriculture (Kedem *et al.*, 1990a, Kedem *et al.,* 1990b, Short *et al.,* 1989). Whilst rainfall rates are important by themselves in for example natural hazards, accumulative-derived values can be used to provide rainfall total statistics just multiplying the estimated rainfall rate value by the duration of the rain event.

Rainfall rates can be measured using ground-based devices such as optical or tipping bucket rain gauges or impact disdrometers. These measurements have the major drawback of high spatial scattering. Moreover, only a few countries are capable of providing a timely and accurate coverage. Due to this, rainfall rates are derived not from these instruments but directly from rain gauge stations. This approach has been proved as imperfect but valid in some extent as noticed by (Sanham *et al.,* 1998). However, if it is aimed to provide any kind of quantitative ground estimation, it is unavoidable to resort to this simplification.

On the other hand, some sensors aboard satellites are also capable to provide direct rainfall rates measurements. Based on the measurement of the natural microwave emission of the earth, passive microwave sensors (PMW) are capable of retrieving instantaneous rainfall. As raindrops affect the upwelling energy in these frequencies, radiation received by the satellite is in close relationship with actual rain. This represents an improvement over visible/infrared (VIS/IR) estimations insofar as the cloud top temperature is only indirectly related with cloud-base precipitation processes.

The Special Sensor Microwave/Imager sensor (SSM/I) aboard the Defense Meteorological Satellite Program (DMSP) satellites uses this physical principle to retrieve rainfall rates for an almost-global coverage. The quality of these satellite-based estimations have been tested in several intercomparison projects, such as the Algorithm Intercomparison Projects AIP 1, 2 and 3 (Ebert *et al.,* 1996) and the Precipitation Intercomparison Project (PIP-1, PIP-2, PIP-3). PIP-2 was specifically focused on PMW observations (Smith, 1998) PIP-3 also generated some results on PMW proving better capabilities in rainfall retrieval than the IR/VIS methods. Therefore, can be stated that the more accurate global rainfall measurement available are the estimations from the PMW sensors, such as the SSM/I.

Several attempts have been done to find a mathematical probability distribution function (PDF) matching as close as possible to these empirical data. (Wilheit *et al.,* 1991, Kedem *et al.,* 1990) used gamma and lognormal distributions obtaining encouraging results. In particular (Kedem *et al.,* 1994) present an axiomatically based lognormal and mixed lognormal probability distribution model instead of an empirical approach. That work is based on the theory of one-dimensional diffusion processes and presents a model based on hypotheses on the drift and diffusion coefficients of the theory. Another approach was taken by (Tapiador, 2002) using a theoretically derived sub-exponential distribution, proving a fit for tropical rainfall rates of ~0.90 R^2. The aim of this paper is to show some preliminary results of the application of these findings to generate global rainfall estimates using IR satellite data.

ALGORITHM DESCRIPTION

The algorithm proposed starts from the quantification of the rainfall rates following maximum entropy method (MEM hereafter). MEM states that the most probable PDF based on the information available is given by maximizing the entropy function subject to the constraints of the system (cf. Tapiador and Casanova 2001). In the rainfall rates problem we can assume the following constraints:

$$\int_a^{\infty} f(x_i)dx = 1 \qquad (1)$$

$$\int_a^{\infty} \log\left(\frac{x_i - a}{b}\right) f(x_i)dx = E\left[\frac{x_i - a}{b}\right] \qquad (2)$$

$$\int_a^{\infty} \log\left[\left(1+\frac{x_i - a}{b}\right)^{-c}\right] f(x_i)dx = E\left[\left(1+\frac{x_i - a}{b}\right)^{-c}\right] \qquad (3)$$

being a, b and c parameters and E the expectation. (1) is the normalization condition, (2) is a random walk on the logarithmic scale, and (3) is a random walk in the logarithmic scale of the accumulated PDF. Maximizing the entropy function:

$$S \equiv -\int_{-\infty}^{\infty} f(x_i)\log f(x_i) \qquad (4)$$

The application of the MEM yields (Tapiador, 2002):

$$f(X = x) = \frac{a \cdot c}{b}\left(\frac{x-a}{b}\right)^{-c-1}\left[1+\left(\frac{x-1}{b}\right)^{-c}\right]^{-d-1} \qquad (5)$$

Empirical work demonstrates that this PDF match rainfall rates derived from SSM/I with a high degree of accuracy (Figure 1).

Once the PDF has been stated, the next part of the algorithm is the direct application of the histogram matching technique. The histogram matching technique (Crosson et al. 1996) establishes a relationship between the probability PDF of the PMW rain rate and the IR brightness temperatures. The PMW rain rate PDF is matched by accumulating the IR starting from the warm end and generating a series of matched pairs. After processing the past statistics as described, the time update cycle writes out a file that contains a lookup table for each selected box, which relates the IR temperature to the PMW rain rate. This file is then used to match the histograms of the following images, providing the final rainfall rates estimates. Here, the histogram matching has been applied not to the PMW data itself but to the MEM modelled PDF.

RESULTS

Figure 2 shows the application of the algorithm to a METEOSAT IR image. The main rainfall patterns at geostationary scale are clearly visible, providing 4 km / 30 minutes rainfall estimates. Using the same procedure and the new METEOSAT Second Generation satellites more timely estimates will be available.

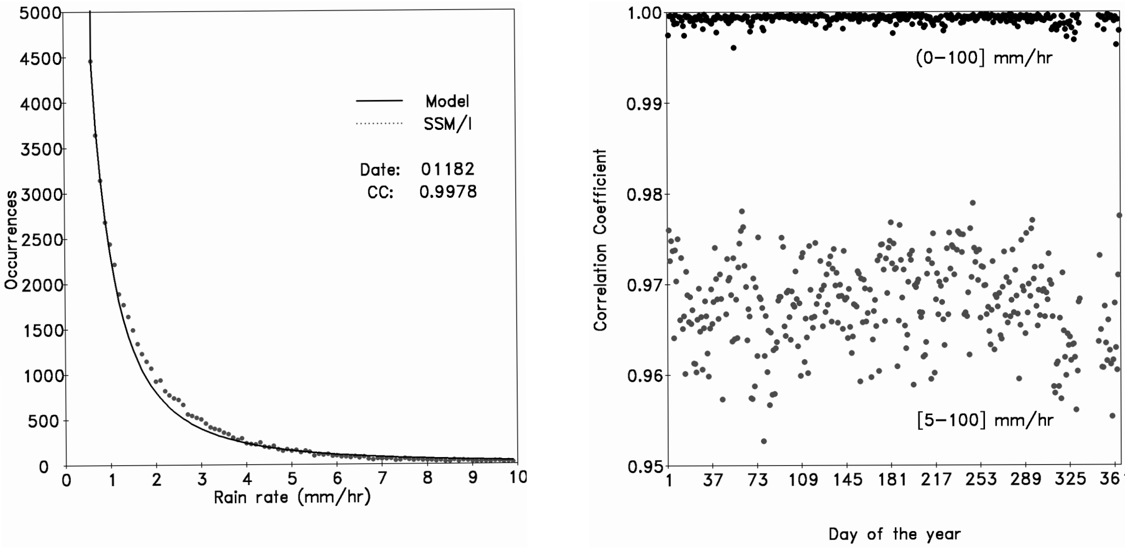

Figure 1. A sample of the fitting of the model with the observations (left) and results for the 2001 including conditional and inconditional correlations (right).

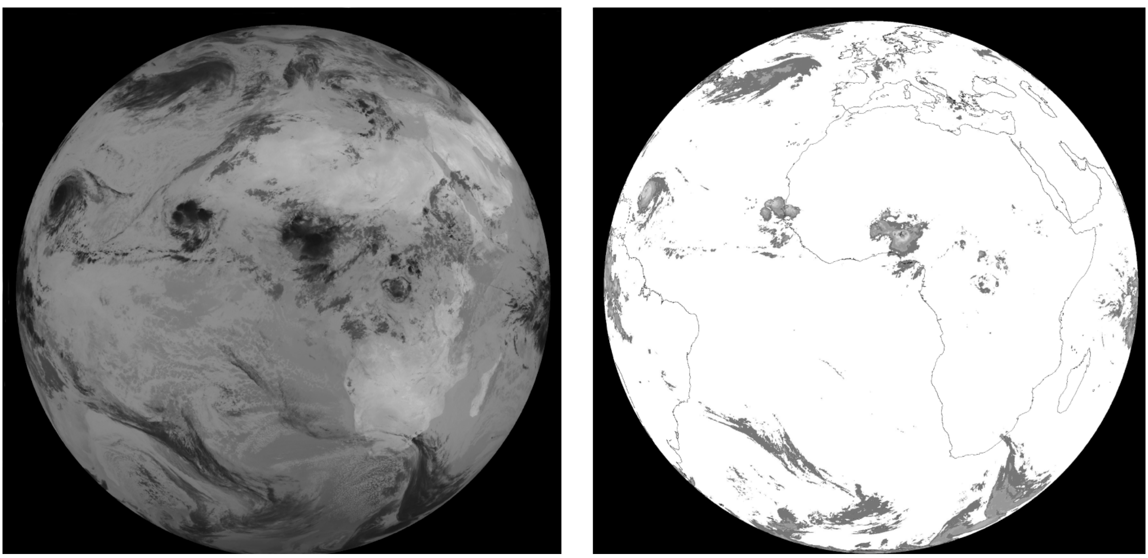

***Figure 2.** A raw *A* format Meteosat High Resolution (HR) image (left) and the rainfall estimate provided by the algorithm after post-processing (right).

Figure 3 shows routinelly-obtained Global estimates combining most of the geostationary satellites in a global IR database (Janowiak, 2001). The original resolution is 4 km. Preliminary validation work against land-GPCC 2.5∞ monthly estimates showed correlations above 0.7 R^2. However, more research is required to use appropriate validation tools (Ebert 2002) and a cal/val campaign is currently in progress.

The main application of this algorithm is to be used as an easy method to generate rainfall rates in real time using IR satellite imagery. Rainfall rates can be then accumulated to provide rainfall Climatologies at different time and spatial scales. The intended use of the method is not provide small scale, short term estimates but global and accumulated estimates. However, the algorithm can be used to a qualitative assessment at coarser scales.

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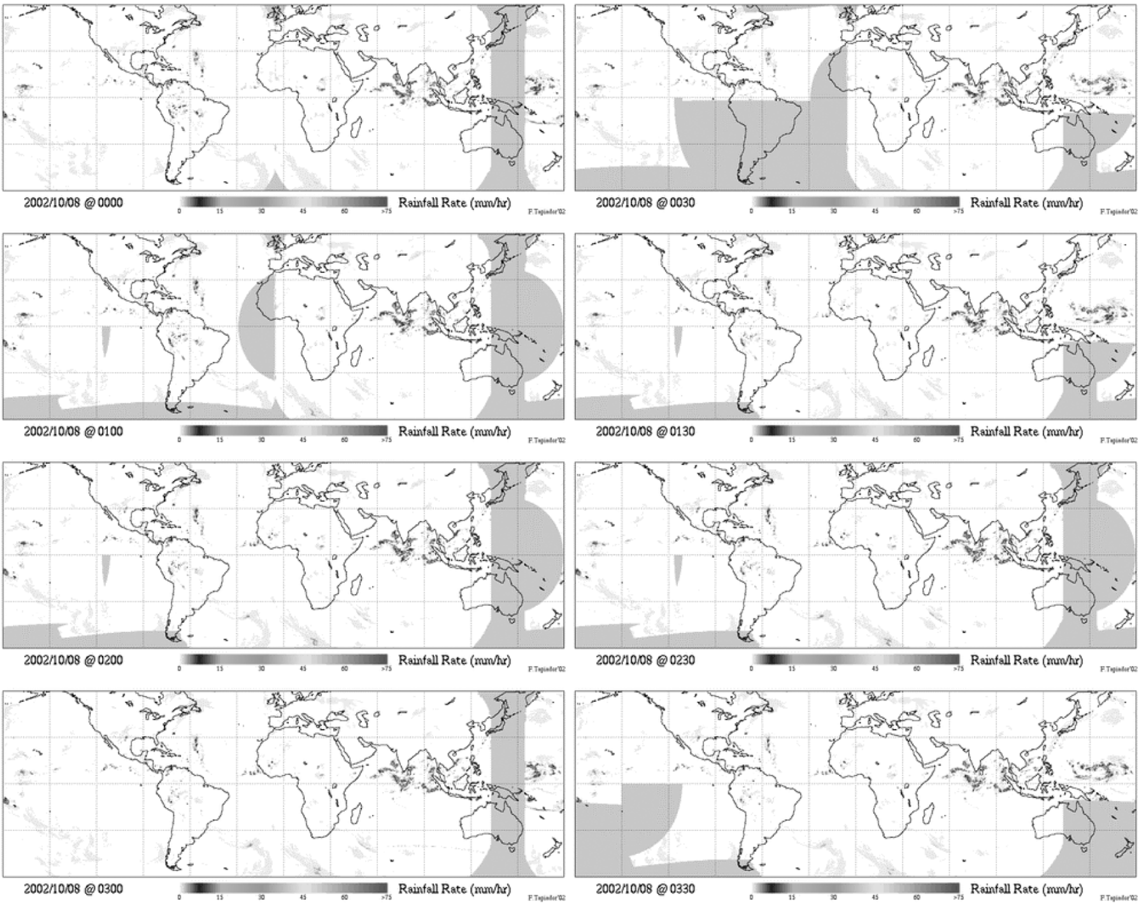

Figure 3. Global 30 minutes estimates. Grey colour indicates absence of IR information.

The algorithm presents several advantages on more popular methods such as the Global Precipitation Index (GPI). Since GPI does not use PMW information, the only physical rationale used is the relationship between rainfall rates and top cloud temperature. Moreover, GPI can only provide a threshold value for instantaneous rainfall rates. Compared with other more complicated methods such as Neural Networks, the algorithm presented here has also the major advantage of its simplicity.

CONCLUSIONS

A new straightforward algorithm to derive rainfall rates from IR satellite images has been presented. The method uses (5) equation to derivate the theoretical PDF of the rainfall rates at global scale and the histogram matching technique to assign these rainfall rates to the IR pixels. The rationale behind the procedure is the use of the maximum entropy method to establish the PDF of the global rainfall rates. This PDF has been fully validated against SSM/I measurements having fittings above 0.99 R^2 for unconditional estimates.

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