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Development of a new global rainfall rate model based on ERA40, TRMM and GPCC products

L. Castanet [1], C. Capsoni[2], G. Blarzino[1], D. Ferraro[2], #A. Martellucci[3]

[1] APR , ONERA – DEMR (Département ElectroMagnétisme et Radar)
Avenue Edouard Belin 2- BP 4025 - 31055 Toulouse cedex 4 – France, laurent.castanet@onera.fr

[2] Dipartimento di Elettronica e Informazione, Politecnico di Milano
Piazza L. da Vinci 32, 20133 Milano -Italy, capsoni@elet.polimi.it

[3] TEC-EEP, European Space Agency. ESTEC
Keplerlaan 1, PB 299, NL-2200 AG, Noordwijk, The Netherlands, Antonio.Martellucci@esa.int

1. Introduction

Advanced satellite communication systems are severely affected by the atmospheric propagation of electromagnetic waves. One of the current requirements for satellite communication systems is the capability to provide services on a global scale. Propagation models currently used for satellite communication systems operating at frequencies higher than 10 GHz are mainly based on data and measurements carried out in Europe, North America and Japan (e.g. OTS, OLYMPUS, SIRIO abd ITALSAT in Europe, COMSTAR and ACTS in the USA and Canada and ETS-II, CS, CS-2a, CS-2b, CS-3a and Cs-3 in Japan). Accordingly models development has been driven mainly by data collected in those regions. In other climates (like the tropical region) data have been collected mainly at Ku band. Nevertheless available measurements and climatic parameters put in evidence that new propagation models are needed the different (and more severe) tropospheric conditions (e.g. type of precipitations, gaseous absorption, cloud, etc.). As well, the seasonal and diurnal effects result to be different from those commonly experienced at mid-latitudes.

Along with ground based propagation or meteorological measurements (i.e. raingauges, beacon receivers, radiometers or Radar) also products from Earth Observation (EO) Missions (like the NASA-JAXA TRMM - Tropical Rainfall Measurement Mission, ESA ENVISAT, EumetSat METEOSAT 2nd generation, NASA-JAXA GPM, etc) can be used or will be applicable for the improvement of propagation models. At the same time, the Numerical Weather Predictions (NWP) performed by Meteorological Organizations are continuously increasing their accuracy, spatial and temporal resolution and provide a relevant amount of information on the global state of the atmosphere.

Being rain attenuation by far the most relevant effect a major effort on probabilistic models is still on-going, with particular regard to rainfall rate modelling on a global scale.

This paper presents a new global rainfall model developed in the framework of the ESA activity '*Assessment of radiowave propagation for SatCom in tropical areas*' managed by ONERA with Politecnico di Milano as responsible for the task of model development.

2. Background on rain Modelling and EO, NWP and climatological data

The current ITU-R recommendation P.837-3 can be used for deriving $P(R)$ for any location of the world. This recommendation is based on the Baptista-Salonen model [1] that was developed using as input the ECMWF ERA15 product [2]. A GPCP dataset of measurements from world-wide raingauge stations was used to assess the accuracy of the ERA15 dataset and to test ERA15 data correction procedures. The ERA15 dataset was used to generate world maps of probability of rainy 6-hourly periods (P_{r6}), mean annual rainfall amount of convective and stratiform rain (M_c and M_s). For the $P(R)$ distribution a double exponential function was used and model coefficients were derived by minimising the error with respect to a dataset of independent rainfall rate measurements

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constituted by the ITU-R Study group 3 database of propagation measurements (Table VI-1) and some additional measurements. Then the relationships between model and the ERA15 based parameters (P_{r6}, M_c and M_s) were derived. Apart from providing digital maps as input data the model exhibited a clear improvement on previous ITU-R model based on rain zones.

On November 1997 the NASA-JAXA t TRMM satellite was launched and its operations are currently planned to extend up 2009. It is equipped with three primary instruments (the TRMM Microwave Imager, a precipitation radar, an a Visible and Infrared Radiometer System). Several data TRMM products from level 1 to 3 are available. For the purpose of rain statistical modeling we selected the TRMM product 3B43 which is a level 3 grid dataset resulting from the merging of TRMM products, SSMI, AMSU-B, AMSU-R microwave data, CPC IR data and GPCP ground raingauge measurements. The main characteristics of the TRMM 3B43 are listed in Table 1 (left column).

With regard to new NWP data, in 2000 ECMWF started a new Reanalysis Activity called ERA-40 [3] as an improvement over ERA15. Major goal was to produce a comprehensive set of global analyses describing the state of the atmosphere from mid-1957 to 2001. In particular the ERA40 generated datasets included analysis and forecast fields from assimilating atmospheric model at full resolution. The ERA 40 in comparison with ERA15 is characterized by improvements of: the time period (44 years vs 15), the atmospheric model, the higher number of spherical harmonics for spatial representation of the fields (159 vs 104) and a higher number of vertical levels (47 vs 31). For the purpose of statistical modeling of rain precipitation the ERA40 surface parameters described in Table 1 (center column) have been selected. These parameters are produced by the ERA40 Forecast process.

Concerning current climatological projects (GHCN [4], GPCC [5] and GPCP [6]), GPCC was selected while data from GHCN [5] were also used for independent testing and verification. The Global Precipitation Climatology Centre (GPCC) of the Germany’s National Weather Service provides monthly grids of precipitation analyses based on in-situ observed data from rain gauge networks. For this study the GPCC “Full Data Product” has been choosen. This product it is obtained from a vast collection of rain gauge measurements worldwide distributed. The number of stations varies during the period varies and in-situ values are interpolated on regular grid points. For this analysis the 2.5 deg horizontal resolution proved to be the most appropriate to process ERA40 data. A summary of the selected product characteristics is given in Table 1 (right column).

3. ITU-R Model and Data Analysis and correction

The analysis of ITU-R maps, ERA15 and ERA40 products revealed that the original ERA15 and ERA40 parameters needed to be set to zero below a 0.1 mm/6 hrs threshold to remove small numerical fluctuations. Hence Maps of P_{r6}, M_c and M_s have been derived from ERA40.

The analysis of the ITU-R model sensitivity with respect to P_{r6}, M_c and M_s revealed that the model is mainly sensitive to the total amount of rain precipitation ($M_t = M_c + M_s$) followed by the ratio of convective rain over total rain ($\beta = M_c / M_t$) and then the P_{r6} parameter.

The TRMM 3B43 product was used to check ITU-R and the new ERA40 maps of M_t. Both the ITU-R model and the new ERA40 data are characterized by a severe overestimation of M_t in the tropical latitude belt mainly due to the convective precipitation forecasting process. ECMWF suggests a correction procedure only for sea pixels [7].

Concerning pixels over land a new global correction procedure for ERA40 M_t based on the GPCC product, was developed. The procedure consists in the following steps:

- ERA40 data have been divided into 3 temporal data streams (index j) as defined in [3].
- The ratio α_j between ERA40 rain and total precipitation averaged over each data stream is calculated for every pixel.
- For each year the ERA40 total amount of precipitation is converted from 1.125 to 2.5 deg resolution by averaging.
- A correction factor ε_j for each data stream and all the pixels is calculated by averaging the ratio between ERA 40 and GPCC total precipitation over the data stream period. If this average value is higher than 5 (usually in dry regions)

then the difference between ERA40 and GPCC is used.
Correction factor grid resolution is increased to 1.125 deg by standard bilinear interpolation.

- The corrected ERA40 total precipitation over the data stream period, P_{tj},is calculated for every pixel by multiplying the data stream average of the ERA40 total precipitation with the correction factor ε_j.
- The corrected ERA40 total rain amounts over the data stream period and for all the pixels, M_{tj}, is calculated by multiplying P_{tj} by α_j.
- The average ERA40 total rain amount is calculated by averaging the mean value of M_{tj} over all the 3 temporal data streams.

The effect of the calibration procedure is shown in Figure 1, where the latitude mean value of M_t of TRMM, ITU, ERA40 (corrected and not) is plotted. By inspection of M_t maps improvements of ERA40 corrected data are seen in South America (Brazil), Central Africa and India. The overall RMS value of the relative error of M_t over land with respect to TRMM 3B43 data is 11.72 and 29.46 % for the corrected ERA40 and original ITU-R respectively.

4. Model development

In the development of the model for *P(R)* the original analytical ITU-R function suggested by Baptista and Salonen is retained.

$$P(R) = P_0 \cdot e^{-aR\frac{1+bR}{1+cR}} \tag{1}$$

$$P_0 = P_{r6} \cdot \left(1 - e^{-x\frac{M_S}{P_{r6}}}\right) \qquad ;b = \frac{M_T}{y \cdot P_0} \qquad ;c = z \cdot b \tag{2}$$

A set of 31 multiple year rain distributions measured by raingauge stations distributed world-wide has been selected for modelling purposes and site specific values of the P_{0i}, a_i, b_i and c_i (or a_i, x_i, y_i and z_i) have been determined by running an iterative fitting procedure on each distribution *i*. The global values of *a*, *x*, *y* and *z* coefficients are the averages (arithmetic for *a* and geometric for *x*, *y* and *z* respectively) by using a site specific weighting factor w_i that accounts for the statistical stability of experimental *P(R)* due to the number of observation years and to the climatic zone of the site.

The performances of the ITU-R model and of the new model have been preliminary tested by using an independent database of about 68 multiple years rain. Also the testing procedure used the site specific weighting factor w_i.

The resulting rms value of the error of the new model based on corrected ERA40 is about 30 % while for the ITU-R model it is about 41 %.

5. Conclusions

In this paper a new model based on the *P*(*R*) function originally proposed by Baptista and Salonen and on the ERA40, TRMM and GPCC data, is presented. The model exhibits a clear improvement of accuracy on the current ITU-R model. The new model is characterised also by an improved spatial resolution (1.125 vs 1.5 deg of the ITU-R maps) and a higher statistical stability (41 years vs 15 years of the original ERA15 data). The longer period covered by ERA40 products will also permit future analyses of annual variability, seasonal and diurnal effects.
The total annual rainfall amount, M_t, resulted to be the most important input for the *P*(*R*) model, followed by the fraction of convective rain.
Concerning M_t, the TRMM and GPCC products have been used to assess accuracy of ITU-R and of ERA40 maps. From this analysis resulted that the ERA data are affected by a higher error mainly for total amount of rain precipitation in Tropical areas. This error has been corrected using the grids produced by GPCC as a reference. The proposed new correction procedure reduces the error over land significantly.

The model development has been carried out by collecting an extensive database of raingauge measurements used for both model parameter determination and model testing. In this framework a specific study to assess and weight properly the statistical uncertainty associated with the number of observed years and with the climatological region has been carried out.

Future activities shall pursue a similar analysis and correction for the fraction of convective rain, of particular relevance for the accuracy of design for high availability systems.

Table 1: Characteristics of TRMM, ECMWF and GPCC products

	TRMM **3B43**	**ECMWF** **ERA40**	**GPCC** **Full Data product**
Time Period	1998 - 2001	1959- 2001	1951- 2004
Coverage Area	Latit: 50 S – 50 N; Long: 180 W – 180 E	Latit: 90 S – 90 N; Long: 180 W – 180 E	Latit: 90 S – 90 N; Long: 180 W – 180 E Only land
Temporal Resolution	1 Month	6 hrs	1 Month
Horizontal Resolution (lat long)	0.25 × 0.25 deg	1.125 × 1.125 deg	2.5 x 2.5 deg
Parameter	Mean values of rainfall rate (mm/hr)	Large scale precip. [m /6hr] Convective precip. [//] Large scale snowfall [//] Convective snowfall [//]	Mean value of accum. precip. (mm)
Version	6	NA	

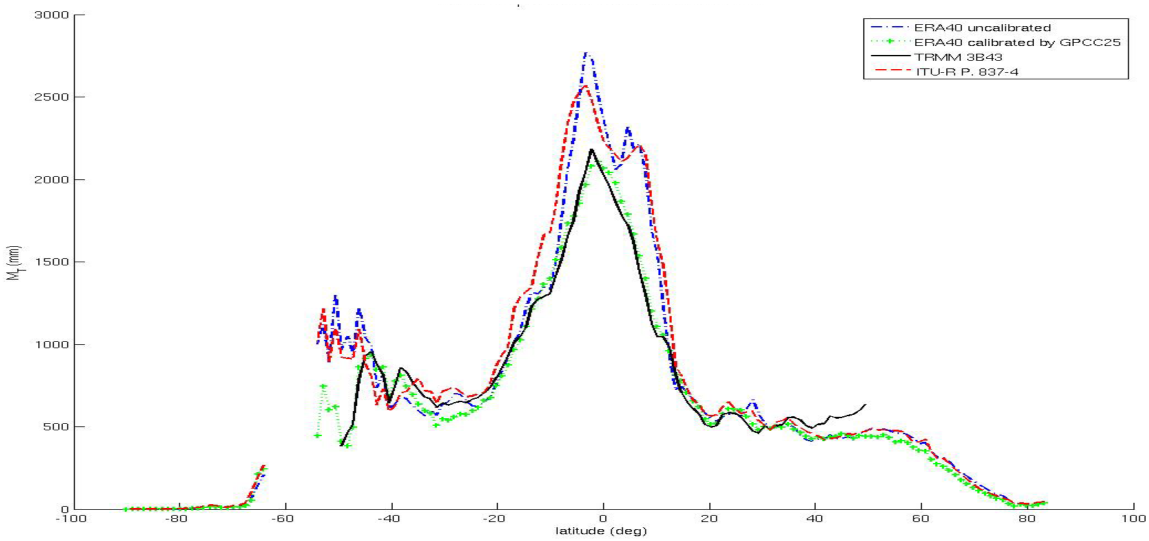

Figure 1: ITU-R, ERA40 (original and corrected) and TRMM 3B43 mean total annual amount of rain over land averaged over latitude belts.

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