Rainfall characterization by satellites and ground data for soil erosion estimation in Cape Verde

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1. Abstract

In semiarid regions, characterized by low annual rainfall but with occurrence of high intensities, variations in precipitation patterns may increase local runoff and soil erosion. For this reason, spatial and temporal rainfall characterization is important to determine its effects on land surfaces by for example rainfall erosivity. The limitations of rain gauges, especially in developing countries, where they are sparse or data is not always collected, make remote sensing techniques relevant for rainfall data acquisition. Diverse precipitation products from different satellite sensors are available. The precision of these estimates depends on the algorithms employed and the ground data used for calibration. The aim of this study is to compare rainfall estimates from different satellite sensors i.e., the TRMM Microwave imager (TMI) 2A12 and precipitation radar (PR) 2A25 algorithms, the precipitation estimates from the TRMM 3B42 merged HQ/Infrared algorithm and the Multi Sensor Precipitation Estimate (MPE) from the Meteosat SEVIRI and SSM/I sensors. Comparison is made with rain gauge data of Cape Verde, a group of small islands of the west coast of Africa. Cape Verde is a dry semi-arid country subject to very high rainfall variability. Data from Santiago, the largest island of the archipelago, was used for the purpose. A time series comparison for 9 years period was done between 3B42 and ground data, and a single storm was studied for comparing the different satellite estimates, using the ground data as reference. It was found that 3B42 underestimates the amount of rainfall, while for the single storm analysis 2A25 and MPE showed the best similarity when compared to ground data. In conclusion, rainfall satellite products, when complementary to gauge data, can be combined to produce an improved estimate of spatial and temporal rainfall fields, useful for improving agricultural forecasts, water balance and soil erosion evaluations.

2. Introduction

Climate variations affect rainfall patterns, especially in dry areas such as sub-Saharan countries. Rainfall influences vegetation growth and cover but is also one of the main driven factors for soil erosion. For a realistic prediction of runoff, sediments and erosion, it is necessary to know the amount of rain entering into a basin system. Rainfall can be measured using ground gauges and ground remote sensing such as radar, but can also be estimated using satellite imagery. One of the more known rainfall satellites is the Tropical Rainfall Measuring Mission (TRMM), which started collecting data from December 1997 onwards, at a global level with three rainfall sensors: the Visible/Infrared Scanner (VIR), the Precipitation Radar (PR) and the Microwave Imager (TMI). In 2002, EUMETSAT launched the first Meteosat Second Generation satellite or MSG-1, with on-board the Spinning Enhanced Visible and Infrared Imager (SEVIRI) sensor. This launch was followed in 2006 by the MSG-2 or Meteosat-9. The MSG satellites are relevant for Europe and Africa due to their geostationary position at Longitude 0° (respectively 6.5 West for Meteosat-8 at present) above the equator (latitude 0°) and a 15 minutes temporal resolution.

Satellite rainfall estimates rely on diverse algorithms that transform radiances emitted or scattered from clouds or raindrops into precipitation and that are verified and corrected by using ground station data around the world. Some of the products available for TRMM include the grid-based product 3B42 and the orbital-based products 2A12 (TMI), 2A25 (PR) amongst others. According to Ji (2006), the TRMM estimates have shown reliable results with a difference of

less than 10% between ground gauges and the PR and the TMI from TRMM for four sites. From Meteosat, the Multi Sensor Precipitation Estimates or MPE data is available since 2006.
There is however uncertainty on rainfall estimates related to the spatial-temporal variation of rainfall, when compared to satellite-sensed cloud radiances (Greene and Morrissey 2000), moreover on how they correspond to ground data, and this holds especially for certain small islands where the algorithms have not been tested. A good laboratory for validation of rainfall products is Cape Verde, a semi-arid African country composed of several islands that has a short rainfall season with strong intensities, and that has a relatively dense network of rain gauges.
The purpose of this research is to compare ground rainfall data of Santiago island of Cape Verde, with the rainfall estimates of three products from TRMM (3B42, 2A12 and 2A25) and with the Multi-Precipitation Estimate (MPE) of Meteosat. Once compared and if the data is reliable, the satellite rainfall values can be combined to produce a better rainfall estimate, useful as an input for physical hydrological and erosion models, which will be part of a future publication. The research described in this paper was conducted in the framework of the European 6th Framework Research Programme (sub-priority 1.1.6.3) - Research on Desertification - project DESIRE: Desertification Mitigation and Remediation of land – a global approach for local solutions.

3. Study Area

Cape Verde is an archipelago composed by 10 islands located around 500 km from the west coast of Africa (15.02N, 23.34W), in the North Atlantic Ocean (Figure 1). The total area of the archipelago is approx. 4,033. km^2. The climate of the country is arid to semiarid. Being located in the dry tropical zone its air temperatures range from 24°C in winter to 29°C during summer. Rainfall is strongly dependent from the relief and elevation above sea level and varies from less than 100 mm annually at sea level to over 500 mm per year in the higher mountain ranges. Rainfall is almost entirely concentrated in the months of August to October, when the ITCZ or Intertropical Convergence Zone is active over the archipelago and these latitudes in Western Africa (Mannaerts & Gabriels, 2000). The Cape Verde islands are of volcanic origin. The rugged relief and highly variable, scarce but intense rainfall events have made lithosols and immature soils to be predominant. Streams are not permanent and water flows only during the rainy season. The largest island is Santiago (991 km^2), which has been selected for this study and where Praia the capital of the country is located. The highest elevation in Santiago Island is Pico d'Antónia with 1,394 meters.

In Santiago island a network of more than 100 rainfall stations is available but not all of them work permanently.
From these stations up to 26 have continuous data between 1998 and 2007 which were used for this study.

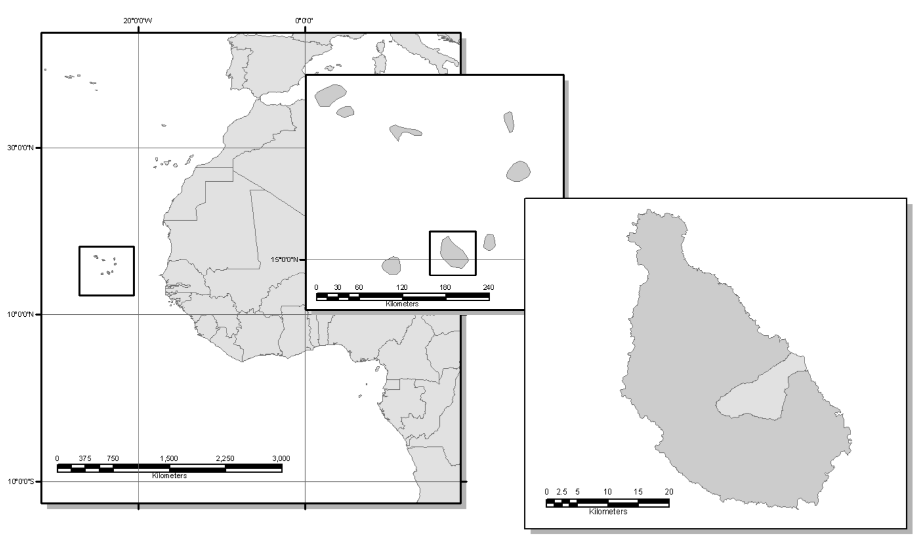

Figure 1. Study Area: Santiago Island, Cape Verde islands (Western Africa)

The irregular precipitation and lack of natural resources are the main causes of poverty and relatively slow development in Cape Verde. At least 27 famines and epidemics were registered in the islands between the 16th and 19th centuries, and just in the first half of the 20th century, 6 famines still occurred (Lesourd, 1995).

4. Methods And Materials

a. Data

The rainfall season in Cape Verde usually starts around August and ends in October. Satellite data - when available - has been retrieved starting from the 1st of August and until the 31st of October for all the sensors. Three different estimates from TRMM were studied: the 3B42, the 2A12 and the 2A25 products. The 3B42 data is a 3-hourly gridded rainfall estimate with a spatial resolution of 0.25° x 0.25°, and is a combination of different estimates. From the 3B42 the total daily precipitation (mm) was used. The 2A12 and 2A25 are orbital products with a spatial resolution of 0.5' x 0.5' and a short temporal resolution (91.5 minutes per orbit), having 16 orbits per day in total which implies that some days may pass until the next revisit. The TRMM orbits that passed over Cape Verde were found using the TRMM over flight finder. The 2A12 and 2A25 products were visualized and sub areas were created using the TRMM Orbit viewer software, freely available from the TRMM website. Data with rain values were exported as an ASCII gridded file that included a coordinate file and a rainfall data file. The subsets were imported and pre-processed in ILWIS 3.4 Open and ArcGIS 9.2. Meteosat MPE data was downloaded through the DVB-based Ku-band broadcast service of EUMETCAST, using a data receiver located at the ITC, The Netherlands. The rain gauges data was provided by the Meteorological Institute of Cape Verde. From the more than 100 stations located in Santiago Island, between 14 and 27 had complete daily rainfall data in the period from 1997 to 2007.

b. Method

Two types of comparisons were made: the total precipitation (mm) for the 1998-2007 time series and the rainfall intensities (mm/hr) for a single storm. The comparisons between satellite and ground data for the 9 years period were visually interpreted by plotting the rainfall time series on a daily, monthly and annual basis (see Fig.4 and 5). Also simple statistics such as R^2 and slope were used. These have been used successfully in other comparative studies of this type (Hughes 2006). In the initial stage the comparison was done between areas (satellite data) and point data (gauges). Afterwards a single storm has been studied (29th of August of 2007), because data was available from all the sensors. In order to make areal comparisons, a simple ordinary kriging with a spherical semi variogram model was employed to interpolate precipitation from the gauges in Santiago, but the available gauge network density for the selected day was not enough (15 stations for the day selected) and some bias may have been introduced. More details about kriging can be found in Oliver and Webster (1990). The interpolated rainfall from the gauges was considered the reference value for the comparisons. All the datasets were resampled to a size of 0.0045 decimal degrees (approx. 500 m, Figure 2).

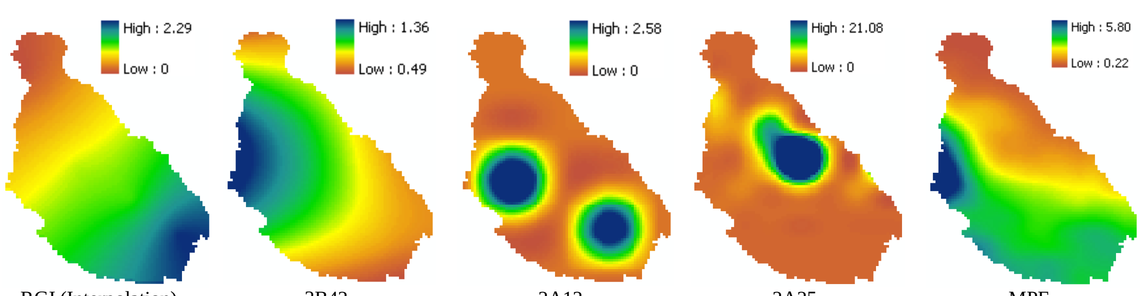

Figure 2. Rainfall rates (mm/hr) for 29th August 2007, after resampling and used in the comparison.

The statistics used for comparisons were bias, correlation coefficient (r), root mean square error (rmse) and Nash index (I), which give relationships between estimated and reference values. Details about the statistical parameters used for comparison can be found in Laurent et al. (1998) and Lamptey (2008).

5. Results

a. Time Series comparison

The comparison between rain gauge data and the precipitation values of the 3B42 TRMM shows a good coincidence between rain days, but the 3B42 underestimates the total amount of precipitation for Santiago island. The best correlation was found for year 2003 with a R^2 of 0.63 and the worse for year 2000 with a R^2 of 0.017. Figure 3 presents the rainfall daily series for 2003. Figure 4 (left) shows the monthly precipitation by year and the annual totals (right).

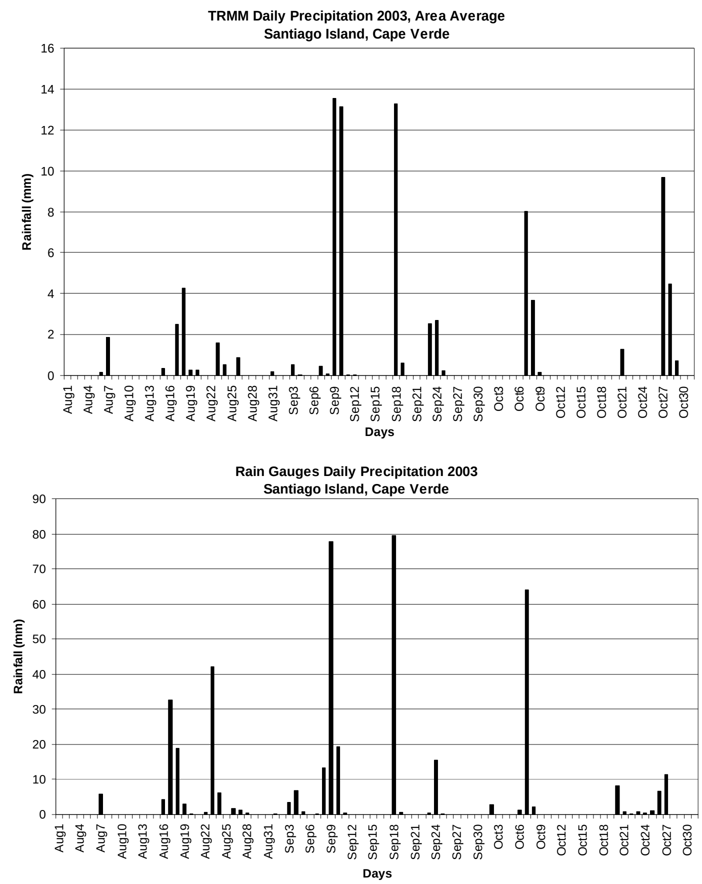

Figure 3. Rainfall daily time series comparison for the year 2003 for Santiago island. TRMM estimates are shown (above) and rain gauge data in mm (below).

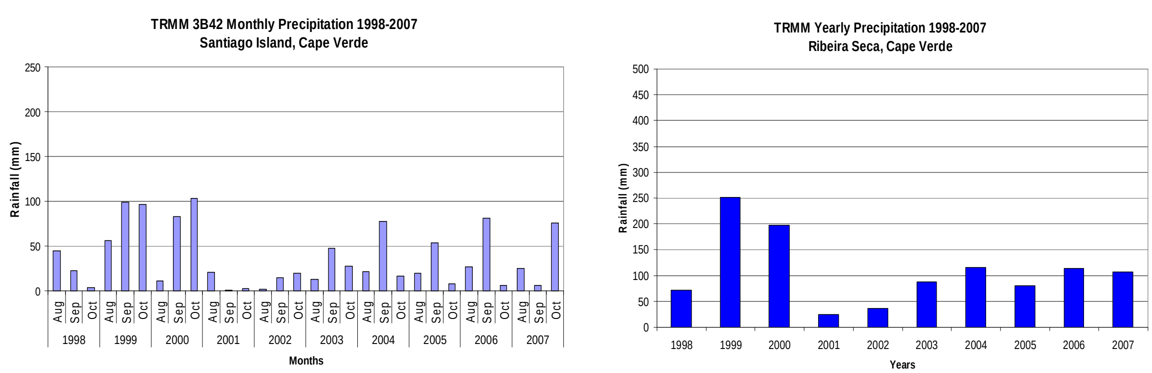

Figure 4. Total monthly and annual values of precipitation (mm) between 1998 and 2007, derived from the TRMM satellite.

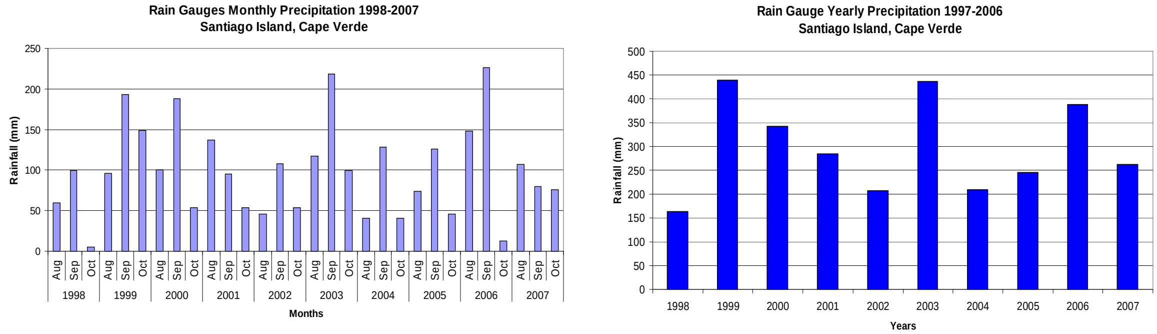

Figure 5. Total monthly and annual values of precipitation (mm) between 1998 and 2007, derived from the rain gauge network.

The initial intention was to compare estimates of the three TRMM sensors (3B42, 2A12 and 2A25) for the 9 years period, but data from 2A12 and 2A25 for Cape Verde are not continuous in time. These depend on the satellite revisit time and the available overpass data may not coincide with rainfall periods. It can be noticed that even though year 2003 presents the best r^2, (r^2=0.63), it has also a high root mean square error (rmse=163 mm). Besides the high r^2 for year 2003, there is a good coincidence between rainfall days from ground stations and the satellite data (Figure 3) when compared to other years, which showed lower correlations.

b. Single Storm Comparison

Table 1 presents the results of the comparisons made between interpolated data from rain gauges and the different satellite estimates for rainfall observed on the 27th of August 2007.

Table 1

Data	Average (mm/h)	Bias (mm/h)	STD	r	Rmse (mm/h)	I
RGI	1.16	-	0.58	-	-	-
3B42	0.88	-0.28	0.20	-0.60	0.77	-13.70
2A12	0.39	-0.77	0.65	0.23	1.08	-1.79
2A25	1.38	0.22	3.25	-0.13	3.38	-0.08
MPE	2.17	1.01	1.13	0.52	1.40	-0.53

The 2A25 estimate is less distant from the reference values (low bias and r), a Nash Index closer to 0 (best constant estimate) but with a relatively high standard deviation and rmse, and a low correlation coefficient r. The MPE estimate has the higher positive correlation and a low rmse, but also the highest bias and a Nash index closer to 1, (a value of 1 represents a perfect estimate). It is important to notice that the 2A12 and 2A25 detected rainfall on a relative small area of Santiago island (few cells with rain data), while the MPE estimate shows a total coverage of the island with rainfall values and the 3B42 estimate covers the whole island but with a low spatial resolution (see Figure 2).

6. Discussion And Conclusions

This study has as a main goal to compare different sensor estimates of precipitation against ground data from precipitation gauges to assess their usability in rainfall - runoff and soil erosion estimation. However there are other aspects to be considered that are not reflected from the simple comparison results. The first goal was the comparison between time series of rain, but only 3B42 from TRMM has the data required for the analysis. The other estimates from TRMM (2A12 and 2A25) have a higher spatial resolution but are not continuous in time. This implies that 3B42 data can be used for multi annual comparisons of rain but at a larger scale, and its use for assessment of erosion in small islands such as the Cape Verde requires its combination with other data. The 2A25 estimates presents more days of available data between

1998 and 2007 when compared to 2A12 (20 days with data of rain available) and these estimates can be used for single storm analysis. The Meteosat MPE estimate has a better ground and temporal resolution and is suitable for time series and single storm analysis, but requiring considerable data storage and pre-processing. When a single storm was compared, unfortunately data from all the estimates is not always available for comparisons and for the particular year and day when satellite data was available the rain gauges number with data was inferior to previous years. From the 2A12 and 2A25 estimates, rainfall values were only obtained for 8 and 20 days respectively for the period 1998 -2007. Besides, while TRMM 3B42 and Meteosat are continuous rainfall data estimates for a single day, the 2A12 and 2A25 are estimates for a single instant (a few minutes) during an orbit (90 minutes) in one day. From these preliminary results alone, it is not conclusive which estimate is closer to the ground values of rain. Overall, the 2A25 and MPE rainfall estimates seem to present the best parameters when compared to the other estimates. On the other hand, 2A25 has a low temporal resolution and data when available may not coincide with rain days. Meteosat MPE has a fair spatial resolution and a very high (15-minute) temporal resolution that makes it very suitable for erosion studies. Given the relatively low number of stations available for the storm day studied an important bias has been introduced which has affected the results. The comparisons made are a fair first approach before making more strict comparison between the different datasets. The enhancement of TRMM and Meteosat estimates requires the installation of more validation stations around the world, particularly in small isolated areas, in order to make the data valid on a global scale. Also the improvement and calibration and validation of the estimation algorithms need a continuous updating. From a combination of precipitation values obtained from ground stations and satellite estimates, it is possible to expect a better rainfall characterization of Santiago island, after combining different datasets.

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