Challenges in flood modeling over data scarce regions: how to exploit globally available soil moisture products to estimate antecedent soil wetness conditions in Morocco

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16 Abstract: The Mediterranean region is characterized by intense rainfall events giving rise to devastating floods. In Maghreb countries such as Morocco, there is a strong need for forecasting 17 systems to reduce the impacts of floods. The development of such a system in the case of ungauged 18 catchments is complicated but remote sensing products could overcome the lack of in-situ 19 20 measurements. The soil moisture content can strongly modulate the magnitude of flood events and 21 consequently is a crucial parameter to take into account for flood modeling. In this study, different soil 22 moisture products (ESA-CCI, SMOS, SMOS-IC, ASCAT satellite products and ERA5 reanalysis) are 23 compared to in-situ measurements and one continuous soil moisture accounting (SMA) model for 24 basins located in the High-Atlas Mountains, upstream of the city of Marrakech. The results show that 25 the SMOS-IC satellite product and the ERA5 reanalysis are best correlated with observed soil moisture 26 and with the SMA model outputs. The different soil moisture datasets were also compared to estimate 27 the initial soil moisture condition for an event-based hydrological model based on the Soil Conservation Service Curve Number (SCS-CN). The ASCAT, SMOS-IC and ERA5 products 28 performed equally well in validation to simulate floods, outperforming daily in situ soil moisture 29 30 measurements that may not be representative of the whole catchment soil moisture conditions. The 31 results also indicated that the daily time step may not fully represent the saturation state before a flood event, due to the rapid decay of soil moisture after rainfall in these semi-arid environments. Indeed, at 32 33 the hourly time step, ERA5 and in-situ measurements were found to better represent the initial soil 34 moisture conditions of the SCS-CN model by comparison with the daily time step. The results of this work could be used to implement efficient flood modelling and forecasting systems in semi-arid 35 regions where soil moisture measurements are lacking. 36

Keywords: Soil moisture, floods, Morocco, ERA5, Rheraya, Issyl, High Atlas

- 40 **1 Introduction**
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42 The Mediterranean region is characterized by intense rainfall events generating floods with a very short 43 response time (Gaume et al., 2004; Merheb et al., 2016; Tramblay et al., 2011). The socio-economic 44 consequences of these floods are very important in terms of fatalities or damages to the infrastructures 45 in particular for Southern countries (Vinet et al., 2016). This highlights the need for forecasting systems 46 to reduce the impacts of floods. Unfortunately, the development of such systems is very complicated in 47 the case of ungauged catchments (Creutin and Borga, 2003) such as in North Africa and requires remote 48 sensing products to overcome the lack of in situ measurements. Furthermore, while several studies have 49 been focused on northern Mediterranean catchments for flood modelling, only a few studies are 50 available on southern basins, yet those probably the most vulnerable to floods.

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The Moroccan catchments are exposed to intense flash floods, such as the event of August 17, 1995 in 52 53 the Ourika river where the max discharge reached in 45 minutes a peak discharge of 1030 m3/s causing 54 extensive damages and more than 200 casualties (Saidi et al., 2003). Few studies have been carried out 55 in Morocco to minimize the impact of floods by improving the forecasting systems, either by event-56 based modeling of floods (El Alaoui El Fels et al., 2017; Boumenni et al., 2017; El Khalki et al., 2018) 57 or by hydro-geomorphological approaches (Bennani et al., 2019) to identify the areas at risk of flooding. 58 The severity of floods in these semi-arid regions is controlled by several factors including precipitation 59 intensity, soil permeability, steep slopes and soil moisture content at the beginning of event (El Khalki 60 et al., 2018; Tramblay et al., 2012). In Mediterranean regions, the soil moisture content varies between events and is known to strongly modulate the magnitude of floods (Brocca et al., 2017; Tuttle and 61 Salvucci, 2014) and particularly to be useful for flood modeling and forecasting systems (Brocca et al., 62 63 2011; El Khalki et al., 2018; Koster et al., 2009; Marchandise and Viel, 2010; Tramblay et al., 2012). However, studies in North African basins are lacking to document the rainfall-runoff relationship with 64 soil moisture during floods (Merheb et al., 2016). 65

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In most Mediterranean regions and particularly in North Africa, only a few measurements of soil 67 moisture are available. To represent spatial variability, several measurement at different locations are 68 needed due to the potentially large spatial variability of soil moisture for a wide range of scales (Massari 69 70 et al., 2014; Schulte et al., 2005; Western and Blöschl, 1999). However, even the in-situ data may not 71 represent the spatial variability over a very wide area in the case of large basins. On the contrary, satellite 72 soil moisture products provide coverage of the earth's surface by microwave sensors. There are two types of microwave sensors, active and passive, noting: 1) The Advanced Scatterometer (ASCAT) soil 73 74 moisture product is on board MetOp with good radiometric accuracy and stability. This product provides

a spatial resolution of 25 km with a temporal resolution of 1 day since January 2007 (Wagner et al., 75 2013). 2) The Soil Moisture and Ocean Salinity Mission (SMOS) product, which begins in January 2010 76 with a spatial resolution of 50km (Kerr et al., 2012). The improvement of the robustness of satellite soil 77 78 moisture products can be achieved by merging passive and active microwave sensors as initiated and 79 distributed by ESA-CCI (European Space Agency Climate Change Initiative) (Liu et al., 2011) 80 providing data from 1978 to 2018. However, remote sensing products might suffer from several 81 problems in complex topography or very dense vegetation and snow cover (Brocca et al., 2017). For this reason and before any use the data, it is necessary to validate them (Al-Yaari et al., 2014; Van 82 83 doninck et al., 2012; Ochsner et al., 2013), either by in-situ measurements, if they exist, or by using Soil Moisture Accounting models (Javelle et al., 2010; Tramblay et al., 2012) to simulate soil moisture in 84 85 the ungauged basins.

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87 In this context, with an increasing number of satellite products becoming available to estimate soil 88 moisture, clear guidelines and recommendations about the most suitable products to estimate the initial soil moisture content prior to floods are lacking for the semi-arid basins of North Africa. There is a 89 90 knowledge gap on the evaluation of soil moisture products in North Africa (Jiang and Wang, 2019) that 91 the present study aimed to fill. The purpose of this study is to compare different satellite soil moisture 92 products with in-situ soil moisture measurements and the recently developed ERA5 reanalysis to 93 estimate the initial soil moisture before flood events. The goal is to identify the best products to be used 94 for flood modeling that could improve forecasting systems. This comparison is performed for two basins 95 representative of medium-size catchments of North Africa that are the most sensitive to flash flood 96 events. The validation of the different soil moisture products is made with a Soil Moisture Accounting 97 (SMA) model, to test the capabilities of the different soil moisture products for the sake of estimating 98 the initial conditions for an event-based hydrological model for floods. The paper is organized as follow: In section 2, an overview of the study area and all used data (hydro-meteorological and soil moisture 99 products). Section 3 explains the methods adopted in this paper. Section 4 presents the results. The 100 101 conclusion and perspectives are given in the last section.

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103 2 Study area and data

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105 2.1 Rheraya and Issyl catchments

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The Rheraya research catchment (Jarlan et al., 2015) is located in the Moroccan High Atlas Mountains (Figure 1) with an altitude ranging from 1027 to 4167m and an area of 225km². The climate in the basin is semi-arid, strongly influenced by altitude, with a mean annual precipitation of 732mm, including 30% as snow in altitudes above 2000m (Boudhar et al., 2009). The geology is characterized by volcanic formations that are considered impermeable in the highest elevation areas, while the lowest elevation areas are made of granites with clays and marls. In the highest elevation areas very steep slopes are found with an average of 19% (Chaponnière et al., 2008). The vegetation cover is only located in the lowest areas with a concentration of cultivated areas found along the river channel. These natural conditions favor runoff generation. There is very low human disturbance for runoff, with only some local water uptake in the lower part of the river.

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118 The Issyl basin (Figure 1) is located in the foothills of the Moroccan High Atlas Mountains with an 119 altitude ranging from 632 to 2300m, an area of 160 km², and a mean annual precipitation of 666mm. It is an ephemeral river with discharge occurring only after rainfall events. The climate is semi-arid to arid 120 121 and the downstream part of the basin reaches the city of Marrakech. The geological formations in this 122 downstream are alluvial conglomerates that are relatively permeable. The upstream of the basin consists 123 of clays and calcareous marl. The basin area includes agricultural activities that are irrigated in the 124 downstream part of the basin. The irrigation comes from seguias, earthen-made channels that traditionally draw their water supply from the river itself, by building small diverting dams on the side 125 of the river (Pérennès, 1994). The seguias channels are usually filled up during floods, and water is 126 127 distributed to the neighboring agricultural parcels. The map on the seguias in the Issyl basin can be seen in Figure 1, covering the northern part of the basin. The system is unmonitored and in a context of high 128 129 evaporation rates the portion of runoff diverted from the stream is not quantified. Due to the temporary 130 nature of *seguias*, they can be partially destroyed during large floods and consequently their hydraulic 131 properties and the amount of water collected can be modified over time. In the Ourika catchment located 132 upstream of the Issyl, Bouimouass et al. (2020) estimated that irrigation by streamflow diversion due to 133 seguias could represent up to 65% of the total surface runoff.

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135 2.2 Hydro-meteorological data

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In the Rheraya basin, we used 8 rainfall stations (Table 1), 5 of them from the data network of the Joint 137 International Laboratory Télédétection et Ressources en Eau en Méditerranée semi- Aride ''LMI 138 TREMA" (Jarlan et al., 2015; Khabba et al., 2013) and the remaining ones from the Tensift Hydraulic 139 Basin Agency. The data is covering from 2008 to 2016. For the Issyl basin, only 2 rainfall gauges are 140 141 available from the Tensift Hydraulic Basin Agency, covering the years from 2010 to 2015. In this type 142 of basin, the spatial variability of rainfall is very important (Chaponnière et al., 2008). The hydrometric data was provided by radar sensor installed in each basin's outlet. The data is covering only the year 143 144 2014 for Rheraya, since the sensor was installed at the end of 2013, and the years 2010 to 2015 for Issyl. 145 The discharge data is provided with a time step of 10min converted into hourly time step as for rainfall. 146

The precipitation data is missing for some events, especially at at high altitude gauges during snowfall
events. The percentage of missing value ranges from 2.4% at PR5 to 10.85% at PR7. The highest

percentage of missing data is 19.7% at PR1 where the gauge underwent technical problems. Overall, 149 the total percentage of missing value (7.8%) is low, hence and no gap filling method is used. The 150 discharge data is missing in some events that are not selected. For this reason we considered only the 151 152 events with complete discharge data. Some of the flood events considered in this study (Table 2) 153 occurred in winter season, where rainfall can be in the form of snow above 2000m elevation. According 154 to El Khalki et al. (2018), the snow does not contribute to runoff during winter season in the Rheraya 155 basin because it does not melt during the coldest months (Hajhouji et al., 2018), where only 17% of basin area is occupied by snow. The runoff coefficient is calculated by relating the amount of direct 156 157 runoff to the amount of precipitation for each selected events. It is larger when the basin has low infiltration and lower for permeable basins. In our case, runoff coefficient ranges from 13.1 to 34.1% 158 159 for Rheraya and from 1.2 to 7.2% for Issyl. This indicates the important role of initial conditions in both 160 basins, with a much higher infiltration capacity in the Issyl basin in addition to potential water loss due 161 to irrigation. We used 5 temperature stations located in the Rheraya basin and one temperature station located in the Issyl basin with an hourly time step to calculate the average temperature over each basin, 162 ranging from 2008 to 2016. This data enabled us to calculate potential evapotranspiration (PET) with 163 164 Oudin formula (Oudin et al., 2005) requiring temperature only. This formula was previously applied in Morocco ((Marchane et al., 2017; Tramblay et al., 2013) and in Tunisia (Dakhlaoui et al., 2020). 165

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167 **2.3 Soil moisture data**

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We used 7 different types of soil moisture data over the Rheraya basin and 6 types in the Issyl basin due to the absence of measurements in this basin. Covering the same period of rainfall data mentioned in the 2.3 section, we used:

- In-situ measurement with three Thetaprobes at 5cm and 30cm depth in the Rheraya basin,
 located at the SMPR7 station (Figure 1).
- 174 2. Simulated soil moisture from a Soil Moisture Accounting model (SMA)
- 1753. ASCAT satellite soil moisture
- 1764. SMOS satellite soil moisture
- 177 5. SMOS-IC satellite soil moisture
- 178 6. ESA-CCI satellite soil moisture
- 179 7. ERA5 reanalysis soil moisture
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- 181 2.3.1 In-situ measurements
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Soil moisture measurements are available at one location with three Thetaprobes at two different depths (5cm and 30cm). In this study we used Thetaprobes with 5cm depth, which is comparable with the depths of satellite products (Massari et al., 2014). The site is located in Rheraya basin, with an altitude of 2030m and a slope of 30% (Figure 1). The data is covering the time period from 2013 to 2016, with
30min time step converted to daily time step.

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189 2.3.2 Soil moisture accounting model

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191 The SMA is a continuous Soil Moisture Accounting model that can be used in the absence of soil 192 moisture data to represent the degree of saturation for flood modeling (Anctil et al., 2004; Tramblay et al., 2012). In this study, a simplified version of the SMA model is used, adopting the same approach 193 used by Tramblay et al. (2012) and Javelle et al. (2010). The SMA calculates the level of the soil 194 195 reservoir (S/A), ranging between 0 and 1, by calibrating its single parameter, A, which represents the 196 maximum reservoir capacity of the soil. An interpolated daily rainfall dataset created by the Inverse 197 Distance method and evapotranspiration data computed from daily temperature with the Oudin equation 198 (Oudin et al., 2005) are used as inputs to the SMA model.

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- 200 2.3.3 Soil moisture products
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In this study we used three different types of satellite products and a Reanalysis product (Table 3):

- The Advanced SCATterometer (ASCAT) is a Soil Moisture product, onboard Metop-A and Metop-B and a Metop-C satellite is a C-band (5.255 GHz) scatterometer onboard the Metop satellite series. It has a spatial sampling of 12.5 km and 1 to 2 observations per day (Wagner et al., 2013). The SM product was provided within the EUMETSAT project (http://hsaf.meteoam.it/) denoted as H115.
- The Soil Moisture and Ocean Salinity (SMOS) mission is a radiometer operating at L band
 (1.4 GHz), providing Soil Moisture data with ~50km as spatial sampling and 1 observation
 per 2/3 days (Kerr et al., 2001). Centre Aval de Traitement des Données SMOS (CATDS,
 https://www.catds.fr/) provided the version RE04 (level3) for this study. This version is
 gridded on the 25km EASEv2 grid.
- 2143. The Soil Moisture and Ocean Salinity INRA-CESBIO (SMOS-IC) is an algorithm215designed by Insitut National de la Recherche Agronomique (INRA) and Centre d'Etudes216Spatiales de la Biosphère (CESBIO) for a global retrieval of Soil Moisture and L-VOD.217Two parameters of inversion of the L-MED model are used in the SMOS-IC (Wigneron et218al., 2007) with a consideration of the pixel as homogeneous. This version is 105 and has a219spatial sampling of 25km with EASEv2 grid (Fernandez-Moran et al., 2017).
- 4. The ESA-CCI soil moisture product (http://www.esa-soilmoisture-cci.org/) regroups active
 and passive microwave sensors to measure soil moisture, giving three type of products:
 Active, Passive and Combined (Active + Passive). In this paper, the ESA-CCI V4.5 –

Combined product is used (Dorigo et al., 2017; Gruber et al., 2017, 2019). The product has been validated to be useful by 600 ground-based measurement points around the globe (Dorigo et al., 2015), as well as it was compared with ERA-Interim products (Albergel et al., 2013). In the field of hydrological modeling, several global studies have used the ESA-CCI product to initiate the hydrological model (Dorigo et al., 2012, 2015; Massari et al., 2014) at the scale of Morocco (El Khalki et al., 2018). We extracted for each basin the pixel that corresponds to it.

5. ERA5 (Copernicus Climate Change Service (C3S), 2017) developed by European Centre 230 for Medium-Range Weather Forecasts (ECMWF), it is the latest version of atmospheric 231 reanalysis available for public since February 2019. The ERA5 replaced ERA-Interim with 232 233 improvement at different scales, particularly, a higher spatial and temporal resolution, and a better global balance of precipitation and evaporation. The spatial resolution is 31km 234 instead of 79km, hourly resolution is used instead of 6 hours, and the covered period will 235 be extended to 1950 in future. The ERA5 product was applied in some recent studies in 236 hydro-climatic field (Albergel et al., 2018; Hwang et al., 2019; Mahto and Mishra, 2019; 237 Olauson, 2018). We selected the volumetric soil water of the first soil layer. This new 238 product is tested in our study for the first time in Morocco. An alternative dataset, ERA5-239 Land using an improved land-surface scheme with a spatial resolution of 10km, was also 240 241 tested, providing the same results as ERA5 since there is a strong correlation between soil 242 moisture simulated by the two products.

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244 It should be noted that the soil moisture products have a different percentage of missing data over each 245 basin (Table 4). The ESA-CCI product show an important percentage of missing values over the Rheraya basin compared to ASCAT that is included in the ESA-CCI product. This is due to the filter 246 used in the ESA-CCI product to ensure the data quality. The difference in the percentage of missing 247 values between Rheraya and Issyl is related to the complex topography and also to the frozen zones in 248 the Rheraya basin, more description about the applied filters can be found in (Dorigo et al., 2017). 249 However, the percentage of missing values for the SMOS product are quite similar between the two 250 basins, which is related to the low temporal resolution (1 observation per 2/3 days). 251

252 **3 Methods**

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254 **3.1 Evaluation of different soil moisture datasets**

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In-situ data preparation consists of averaging the 5cm depth probes in order to get a single value to work with and take into account the plot-scale variability of the measurements. This data is considered as a reference for soil moisture data in the Rheraya basin, so that all the other soil moisture products are compared to it. The different soil moisture products are compared to the observed soil moisture over theentire period and also on a seasonal basis.

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262 The SMA model is used to represent the soil moisture aggregated at the catchment scale. The rationale 263 behind the use of such model here is that continuous rainfall and temperature series are often available 264 in monitored catchments, unlike soil moisture, and a calibrated SMA model can sometimes palliate the 265 lack of soil moisture measurements (Tramblay et al., 2012). For the SMA model, the A parameter, representing the soil water holding capacity, is calibrated to obtain the best correlation between observed 266 and simulated soil moisture (S/A). The calibration with observed data can only be performed in the 267 Rheraya basin where soil moisture is measured. In addition to this calibration, other values of A, ranging 268 269 from 1 to 1000mm, are tested in the SMA model to maximize the correlations with the different soil 270 moisture products. The choice of this approach is to check if there are any possible uncertainties that 271 can be related to the in-situ soil moisture measurements, located on a steep slope plot that may not fully 272 represent the average soil moisture conditions over the whole basin. In the case of the Issyl basin, since there is no observed soil moisture data, the model is run for a range of different values of the A 273 274 parameter. The best value of the A parameter is selected as the one yielding the best correlations with the different satellite products. 275

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The values from ASCAT and SMA are given in percentage (values are ranging between 0 and 1) while 277 SMOS, SMOS-IC, ERA5, ESA-CCI and observations are in m³ m⁻³. To allow a comparison for all soil 278 279 moisture datasets a rescaling procedure is needed. Before applying the rescaling procedure, according 280 to Albergel et al. (2010), a 95% confidence interval is chosen to define the higher and lower values to 281 exclude any abnormal outliers using equation 1 and 2. The resulted data is then rescaled to their own maximum and minimum values considering the whole period using the equation 3. The issue in the 282 validation of satellite soil moisture products and reanalysis product with in-situ measurements is the 283 spatial resolution (Jackson et al., 2010). Several studies mentioned that, in the case of the temporal 284 stability introduced by Vachaud et al. (1985), one in-situ measurement point can represent the soil 285 moisture condition of a larger area (Brocca et al., 2009b, 2010; Loew and Mauser, 2008; Loew and 286 Schlenz, 2011; Martínez-Fernández and Ceballos, 2005; Miralles et al., 2010; Wagner et al., 2008). 287 According to (Massari et al., 2015), the coarse satellite observations can be beneficial for small basins, 288 in the case if the in-situ observation falls in the satellite product pixel. This means that the in-situ 289 measurements can represent a good benchmark (Liu et al., 2011). In this study we considered the in-situ 290 291 measurement as a benchmark to validate different soil moisture products.

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$$Up_{SM} = \mu_{SM} + 1.96\sigma_{SM},\tag{1}$$

$$Low_{SM} = \mu_{SM} - 1.96\sigma_{SM}, \tag{2}$$

Where Up_{SM} and Low_{SM} are the limits of the confidence interval (the upper and the lower 95%)

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$$SM = \frac{SM - Low_{SM}}{Low_{SM} - Up_{SM}},$$
(3)

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The correlation coefficient of Pearson equation (4) and the Root Mean Square Deviation (RMSD) equation (5) are used to compare in-situ measurements and humidity modeled by SMA model and the different soil moisture products.

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$$r = \frac{N\sum SM_{sat}SM_{In-situ} - (\sum SM_{sat})(\sum SM_{In-situ})}{\sqrt{[N\sum SM_{sat}^2 - (\sum SM_{sat})^2][N\sum SM_{In-situ}^2 - (\sum SM_{In-situ})^2]}},$$
(4)

$$RMSD = \sqrt{\frac{\Sigma(SM_{In-situ}-SM_{sat})^2}{N}},$$
(5)

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303 With $SM_{In-situ}$ is the in-situ measurements of soil moisture or SMA model which are considered as 304 reference, SM_{sat} is the soil moisture from satellite or reanalysis and N is the number of values.

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306 3.2 Event-based hydrological model for floods

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In this study, we used the Soil Conservation Service Curve Number (SCS-CN) model for each basin, 308 implemented in the hydrologic Engineering System - Hydrologic Modeling System "HEC-HMS" 309 software (US Army Corps of Engineers, 2015). This model is known by its widespread popularity and 310 311 to the simplicity of the application method (Miliani et al., 2011). SCS-CN is often used in the semi-arid 312 context (Brocca et al., 2009a; El Khalki et al., 2018; Tramblay et al., 2010; Zema et al., 2017). Our 313 methodology is based on the use of SCS-CN model as a production function to compute net rainfall, by automatically and manually calibrating the Curve Number parameter (CN) in order to obtain a realistic 314 hydrograph shape. The value of CN is non-dimensional ranging from 0 (dry) to 100 (wet). The potential 315 maximum retention, S, is related to CN as follows: 316

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$$S = \frac{25400}{CN} - 254 , (6)$$

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The transformation of precipitation excess into runoff is provided by Clark Unit hydrograph model (transfer function). The calibration procedure is based on calibrating the Clark Unit hydrograph model parameters; Storage Coefficient (Sc) and Time of Concentration (Tc). The two functions (production and transfer) are calibrated separately to avoid the parameter dependence and the calibration is based on Nash-Sutcliff criterion.

325 The validation procedure is based on two steps; first, testing the relationship between soil moisture data (In-situ, SMA, ERA5, ASCAT, SMOS, SMOS-IC and ESA-CCI), at two different timescales (daily and 326 327 hourly) and the S parameter of the event-based model of all the flood events. The hourly time step 328 concerns only the in-situ data and ERA5 by choosing the soil moisture state 1 hour before the starting 329 time of rainfall for each event. Only the ERA5 product can be used in the Issyl basin at the hourly time 330 step due to the absence of observed data. Then, the soil moisture products that are well correlated with S parameter are used to validate the model by calculating the S parameter from the linear equation 331 332 obtained between soil moisture and S, using the leave-one-out resampling procedure; each event is successively removed and a new relationship between the remaining event is re-computed. The 333 334 relationship is good when the correlation is near to r = -1. The negative correlation is related to the fact 335 that, the storage capacity (S) is larger when the soil is dry (soil moisture is near to 0). The estimated S parameter for a given event is then used in the SCS-CN model in validation. For the Clark Unit 336 Hydrograph model, the average of the Sc and the Tc parameters are used in validation in the leave-one-337 out resampling method; the parameters are re-calibrated with the remaining events and the mean of 338 calibrated values are used in validation. 339

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For the evaluation of the flows simulated by the flood event model, we compared the simulated discharge with those observed using the efficiency coefficient of Nash-Sutcliffe (Ns) (Nash and Sutcliffe, 1970) equation (7) as well as through the bias on peak flow and on volume equation(8).

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$$Ns = 1 - \frac{\Sigma((Q_{obs}) - Q_{sim}))^2}{\Sigma((Q_{obs}) - (\overline{Q}_{obs}))^2},$$
(7)

$$BIAS_Q = \frac{\Sigma(Q_{sim} - Q_{obs})}{\Sigma Q_{obs}},$$
(8)

345

Where Q_{sim} is the simulated discharge, Q_{obs} is the observed discharge and n is the number of events The Ns ranges between $-\infty$ and 1, the 1 value of Ns indicates that the simulated discharge perfectly match the observed hydrograph

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350 4 Results and discussions

351

352 4.1 Relationship between satellite soil moisture data and in-situ measurements

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The comparison between measured soil moisture at 5cm depth and the different products of soil moisture show that the SMOS-IC and ERA5 provide the best correlations, with r=0.77 and r=0.67 respectively, but it should be noted that all the correlations with the different products are also significant. Figure 2 shows that SMOS-IC and ERA5 reproduce dry periods well, whereas ERA5 reproduces well wet periods. This result is in accordance with the results of Massari et al. (2014) who found that ERA-Land is well correlated with In-situ data. ASCAT product shows a correlation of r=0.45 which is less than the correlation given in Albergel et al. (2010) who found r values ranging from 0.59 to 0.64, the lower correlation may be caused by the orography and the coarse resolution. In fact, this results shows that the use of a combined product as ESA-CCI give an obvious advances in term of r values than one single satellite soil moisture product (Ma et al., 2019; Zeng et al., 2015).

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4.2 Relationship between the SMA model outputs and soil moisture products

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The best correlation between observed soil moisture and the soil moisture level (S/A) modeled by the SMA model is obtained for A=8mm with r=0.86. But it shows higher RMSD than observations (RMSD =0.23) which is due to the overestimation of the wet periods (Figure 3). This can be related to the averaging of rainfall data in the SMA model over the basin which could be higher than rainfall in the soil moisture measurement site. It should be noted that the value of the A parameter is very small by comparing to previous studies (Javelle et al., 2010; Tramblay et al., 2012), indicating a much lower soil storage capacity.

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375 We correlated the SMA model output (for A=8mm) with the Satellite Products of Soil Moisture, and 376 the best correlations are found for SMOS-IC and ERA-5, with r=0.74 and r=0.63 respectively (Figure 377 4). Other values of A that maximize the correlations with the different soil moisture products have also 378 been tested. Optimal values of A are ranging from 1 mm with ASCAT (with r=0.4), 8 mm for SMOS 379 (r=0.56), SMOS-IC (r=0.74) and ESA-CCI (r=0.59) up to 16mm for ERA5 (r=0.68). Comparing the Figure 2 and Figure 4 we notice that the soil moisture products better reproduce in-situ measurements 380 than modeled soil moisture with the SMA model, expect for ESA-CCI and SMOS. This improvement 381 is directly related to the SMA model performance, which overestimates soil moisture, and should be 382 compared to Figure 2 where ESA-CCI and SMOS products also overestimate in-situ measurements. 383

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For the Issyl basin,ss mentioned above, no observed soil moisture data is available to calibrate the A 385 386 parameter of the SMA model. Therefore, different values of A are tested to correlate the SMA outputs with the different soil moisture datasets. Over all datasets, the value of A best correlated to the majority 387 of soil moisture products is 30mm. The best correlation is given by A=30mm with r=0.78, 0.82 and 0.79 388 for ASCAT, SMOS-IC and ESA-CCI respectively. As for SMOS and ERA5, the best correlation is 389 given for A=40mm with r=0.7 and A=60mm with r=0.8, respectively. In order to choose a single value 390 391 of A that represents the basin, we have considered A=30mm, the optimal value yielding the best 392 correlations with the different soil moisture products. Figure 5 shows that the best correlation between satellite products and S/A is obtained with SMOS-IC (r=0.82) and ESA-CCI (r=0.79). As observed over 393

394 the Rheraya basin, the SMOS-IC and ERA5 products showed a good reproduction for dry periods with

a better reproduction of wet periods with ERA5, these results are similar to those of Ma et al. (2019)
who found that SMOS-IC performs well in arid zones with a median r value of 0.6. Overall, the higher

- 397 value for the A parameter found for this basin is coherent with the fact that this basin is located in a
- ³⁹⁸ plain area with a much higher soil moisture storage capacity than in the mountainous Rheraya basin.
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400 **4.3. Comparison of soil moisture datasets by seasons**

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402 Seasonal evaluation of satellite soil moisture and reanalysis data shows for the Rheraya basin that during 403 the summer season there are low correlations (average r=0.34) for all the products which is possibly due to very low precipitation amounts mostly as localized convective precipitation (Albergel et al., 2010). 404 405 On the contrary, better performance are obtained with the SMA model (r=0.59) that considers 406 catchment-scale precipitations. Better correlations are obtained in fall with an average of r=0.61 and 407 0.58 for the in-situ data and SMA respectively (Table 5). In the winter we found a poor correlation using SMOS and ESA-CCI that can be related to the important percentage of missing values. For the Issyl 408 watershed, the satellite products show good correlations with the SMA model outputs (on average 409 410 r=0.76) except for the SMOS product especially in winter. The highest mean correlations (i.e. averaged for all the different products) are found during fall in the Rheraya basin, with r=0.61 with in situ data 411 412 and r=0.58 with SMA soil moisture. It should be noted that correlations with SMA outputs in summer 413 are similar with r=0.59. For the Issyl basin, the correlations are also higher in the fall with a mean r=0.87414 for the SMA model. The ERA5 product shows good correlations for most seasons. Complementary to 415 this comparison of the different soil moisture products, an Extended Collocation Analysis has also been 416 performed, comforting the results obtained (see supplementary materials).

417

418 **4.4 Calibration of the event-based hydrological model**

419

420 Calibration results (Table 6) on the individual flood events of Table 2 show that the difference between the values of the potential maximum soil moisture retention (S) of each basin is very important with 421 larger values for the Issyl basin where the soil depth is prominent. We noticed that the temporal 422 variability of soil moisture can be important between two successive events like the events of 02/04/2012 423 and 05/04/2012 for the Issyl basin. The SCS-CN model reproduces well the floods of the Rheraya basin 424 425 with average Ns of 0.67 and bias on runoff peak (BIAS_Q) of 4% (Table 6). The SCS-CN model in calibration is able to reproduce the shape of the different flood events even for the most complex ones 426 427 (21/04/2014 and 22/11/2014). Similarly, for the Issyl basin the SCS-CN model gives good results with 428 average Ns of 0.66 and an average bias on runoff peak of 6.93%. The simulated hydrographs are in good agreement with the observations. The lower Ns coefficients obtained for the 23/01/2014 event in the 429 Rheraya and for the 03/04/2011 and 28/09/2012 events in the Issyl basin are caused by a slight shift in 430 431 the hydrograph probably due to a time lag in instantaneous precipitation measurements. For the Clark

432 Unit Hydrograph model, the averages of calibrated Tc and Sc parameters are considered for validation 433 (Sc = 1.42 and 2.54 hours and Tc = 2.85 and 3.64 hours for Rheraya and Issyl respectively).

434

435 The S parameters of the hydrological models, for the two basins, are then compared to the soil moisture 436 products. For the Rheraya basin, there are significant correlations of the S parameter with in-situ soil 437 moisture data, ERA5 and SMOS-IC (Table 7). The correlations using observed soil moisture, ESA-CCI 438 and SMOS data can be computed with only 8 and 6 events respectively, due to the presence of missing 439 values. The time step of the soil moisture data in the Rheraya basin seems to play a key role in the 440 representation of soil moisture conditions. Indeed, the daily time step shows a weakness to effectively represent the antecedent soil moisture conditions in the SCS model, which indicates the rapid change of 441 442 soil moisture content in such a semi-arid mountainous basin. For the Issyl basin, ESA-CCI is the only 443 satellite product that is significantly correlated to the S parameter at the daily time step. The ERA5 444 product is also significantly correlated with the S parameter but at the hourly time step. The daily output 445 of the SMA model is also able to estimate the initial condition of the model for the Issyl basin, with a correlation of -0.69 with S. Interestingly, the SMA model does not provide a good performance in the 446 447 Rheraya basin. It can be due to the fact that in such a mountainous basin, there is a strong spatial variability of rainfall and it is difficult to obtain reliable precipitation estimates for continuous 448 449 simulations (Chapponiere et al., 2005).

450

451 **4.5 Validation of the event-based hydrological model**

452

453 The validation of the event-based hydrological model is performed on the events of Rheraya and Issyl 454 using only the soil moisture datasets that show relatively good correlations with the initial condition (S) of the model from Table 8. These products include SMOS-IC, ERA5 and observed soil moisture for the 455 Rheraya, and ESA-CCI, ERA5, SMOS and SMA for Issyl. The validation of the event-based model is 456 performed with S calculated from the linear equation obtained from the correlation analysis between the 457 different soil moisture products and the calibrated parameter S. The validation results show that for the 458 Rheraya basin the events are well validated using both daily (Figure 6) and hourly (Figure 7) time step 459 460 of soil moisture products. The best validation result at the daily time step is obtained with SMOS-IC with an average Ns of 0.58 for all events (median Ns = 0.63). This result should be compared with the 461 results found in the previous sections where SMOS-IC showed the best correlations with observed soil 462 moisture. ASCAT and ERA5 show similar results in term of average Ns (~0.45). On the contrary, the 463 daily observed soil moisture shows a lower performance with an average Ns of 0.25 (median Ns =0.49). 464 465 The hourly time step enhanced the performance of the model, with an average Ns using the ERA5 466 product of 0.64 (median Ns = 0.73) and also a better performance with the hourly in-situ data with mean Ns = 0.54 (median Ns = 0.61). These results show that the hourly time step better represents the 467 468 saturation content before the flood events in this basin. For the Issyl, the validation results are quite

different (Figure 8). For only 5 events (the 03/04/2011, 02/05/2011, 19/05/2011, 05/04/2012 and 469 470 25/03/2015) the event-based model can be validated using the ERA5 hourly data with an average Ns coefficient of 0.46. For the events of the 16/05/2011 and 06/06/2011, an important spatial variability of 471 472 precipitation is observed, with no precipitation in the PQI station. In addition to these events, the flood 473 of the 28/09/2012 showed an overestimation of the validated value of S compared to the calibrated value. 474 This overestimation is related to the ERA5 estimation that considers the soil more saturated than it is. 475 For all other events and with different soil moisture products the Ns coefficients are negative and the 476 hydrographs not adequately reproduced. These validation results should be put in perspective with the fact that the Issyl basin has a land use characterized by agricultural activities with possible large water 477 uptake in the diver channel during floods for irrigation. Some simple methods to compensate for the 478 water losses due to irrigation, such as the application of a varying percentage of runoff added to the 479 480 observed discharge to compensate the part of water lost for irrigation, have been tested but with no improvement of the results. This is probably because the quantity taken for irrigation is not constant 481 482 from one event to another depending on the farmer needs, as shown by field surveys, and this amount 483 may also depend on discharge thresholds.

484

485 **5 Conclusions**

486

487 This study performed an evaluation of different soil moisture products (ASCAT, ESA-CCI, SMOS, 488 SMOS-IC and ERA5) using in-situ measurements and a Soil Moisture Accounting model (SMA) over 489 two basins located in the Moroccan High Atlas in order to estimate the initial soil moisture conditions 490 before flood events. The results indicated that the SMOS-IC product is well correlated with both the in-491 situ soil moisture measurements and simulated soil moisture from the SMA model over the two basins. 492 Beside satellite products, the new ERA5 reanalysis reproduced also well the in-situ measurements over the mountainous basin, which indicates the robustness of this product to estimate soil moisture in these 493 494 semi-arid environments. The seasonal analysis showed for both basins that the highest correlations are found in autumn, , which encourages the use of these remote sensing products for flood forecasting 495 because the majority of events occur in autumn and early winter in these regions (El Khalki et al., 2018). 496 497 One of the main finding of the present study is that different products, in particular SMOS-IC, ASCAT 498 and ERA5, are efficient to estimate the initial soil moisture conditions in an event-based hydrological 499 model, that could improve the forecasting capability in data-scare environments.

500

This study also showed that the hourly temporal resolution for soil moisture may provide a better estimate of the initial soil moisture conditions for both basins. Indeed, the use of hourly in-situ soil moisture measurements and ERA5 provided better performance to estimate the initial condition of the hydrological model. These results indicate that the temporal variability of soil moisture in these semiarid basins under high evapotranspiration rates can be very important causing a quick decay of soil

506 moisture following a rainfall event. For this type of basin or others under even more arid conditions, the 507 use of soil moisture products with an hourly temporal resolution could be required to estimate with accuracy the soil moisture content prior to flood events. This constitute a research challenge to monitor 508 509 soil moisture at the sub-daily timescale without ground measurements, since most remote sensing 510 products at present are not available at the hourly time step. As shown by this study, atmospheric 511 reanalysis coupled with a land surface model, such as ERA5, could provide a valuable alternative, in 512 particular since the resolution of these products is constantly improving along with a more realistic 513 representation of water balance.

514

For the catchment that is the most influenced by agricultural activities, the Issyl basin located nearby 515 516 Marrakech, the water uptake for irrigation made difficult the validation of the hydrological model. The 517 model overestimates runoff for some flood events, since the water uptake during floods from the river 518 channel by small artisanal structures is not monitored and thus cannot be represented in the hydrological 519 model. This example shows the difficulty in the implementation of a flood forecasting system in such basin without a good knowledge on the human influences on river discharge. This situation is not a 520 521 particular case but deemed common in semi-arid areas where rivers with a high risk of flooding are also 522 a substantial water resource for agriculture. Therefore, as shown by our results, a hydrological model 523 that is not accounting for water use and irrigation may not be efficient at reproducing flood events in an 524 operational context. The resolution of this issue would require the development of an irrigation 525 monitoring system, that would need intensive field surveys and mapping but also the agreement of the 526 local farmers that benefit from this system.

527

528 This study is a first step towards the development of operational flood forecasting systems in semi-arid North Africa basins highly impacted by floods. Indeed, the evaluation of the most suitable satellite or 529 reanalysis products to estimate soil moisture for the monitoring of the basin saturation conditions before 530 floods is a necessary first step prior to implement flood warning systems based on rainfall and soil 531 moisture thresholds or coupled hydro-meteorological modeling (Javelle et al., 2016; Norbiato et al., 532 2008). Three important aspects that should be addressed in further research aiming at developing a flood 533 534 forecasting system are: (1) the application of assimilation methods to correct the initial soil moisture 535 condition of the basin and to increase the latency of soil moisture by using the observed discharge before 536 the flood event (Coustau et al., 2013). However, the application of assimilation methods is limited in the basins where the hydrometric data is not continuous. (2) Joint assimilation of soil moisture and snow 537 538 cover in order to better predict floods in the mountainous basins (Baba et al., 2018; Koster et al., 2010). 539 (3) The selection of soil moisture data based on the latency of soil moisture products. For instance, the ERA5 reanalysis is available within 5-days latency when ASCAT or SMOS satellite products could be 540 available with 3-hours latency. With the issue of the latency to obtain some products, it should be noted 541 542 also that the mismatch of spatial resolution between large scale remote sensing products and very local

small-scale applications could be an additional issue. Prior to these developments, this type of evaluation should be generalized in Morocco and other sites in North Africa where soil moisture measurements are available, for the development of reliable flood forecasting systems using the outputs of meteorological

546 547 models.

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551

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561

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839 TABLES

841 Table 1: Stations with observed precipitation and river discharge

Catchment	Catchment Gauges Code Altitude [m] Source		Туре	Time step	Period			
	Asni	PR1	1170	LMI TREMA				
	Imskerbour	PR2	1416	416 LMI TREMA				
	Matate	PR3	1753	ABHT				
	Oukaimeden	PR4	3239	LMI TREMA	Р	30min	2008-2016	
Rheraya	Tachedert	PR5	2336	LMI TREMA				
	Tamatarte	PR6	1906	ABHT				
	Armed	SMPR7	2030	ABHT				
	Neltner	PR8	3177	LMI TREMA				
	Tahnaout	QR	990	ABHT	Discharge	10min	2014	
Issyl	Ait Bouzguia	PQI1	623		Precipitation and discharge	10 minutes	2010-2015	
	Ouaguejdit	PI2	1039		Precipitation			

Table 2: Characteristics of the selected flood events.

			Rheraya	
	Max Discharge [m ³ /s]	Volume [10 ³ m ³]	Precipitation Volume [10 ³ m ³]	Runoff Coefficient [%]
23/01/2014	17.1	459.2	2749.5	16.7
29/01/2014	39.7	602.8	2632.5	22.9
10/02/2014	19.2	543.2	2904.7	18.7
11/03/2014	19	557	1633.5	34.1
21/04/2014	38.2	1070	5431.5	19.7
21/09/2014	24.4	440.6	3363.8	13.1
05/11/2014	46.5	1027	5737.5	17.9
09/11/2014	42.2	869.3	4575.2	19
22/11/2014	99.5	3868.9	17586	22
28/11/2014	76.4	3797.2	11940.8	31.8
-			Issyl	
25/03/2011	63.8	385.28	27520	1.4
03/04/2011	16.6	550.656	30592	1.8
29/04/2011	19.7	246.4	11200	2.2
02/05/2011	17.1	303.36	10112	3.0
16/05/2011	45.8	361.12	9760	3.7
19/05/2011	27.6	315.392	7168	4.4
06/06/2011	18.3	212.352	5056	4.2
02/04/2012	16.8	216.576	18048	1.2
05/04/2012	20	543.744	7552	7.2
28/09/2012	22.7	126.72	7040	1.8
05/04/2013	15.4	365.376	16608	2.2
28/11/2014	37.2	489.6	28800	1.7
25/03/2015	16.2	767.424	18272	4.2

Table 3: Summary of the soil moisture products considered

Product	Туре	Temporal resolution	Spatial resolution	Source
ASCAT	Active	1 to 2 observations per day	12.5 km (H115)	EUMETSAT project (http://hsaf.meteoam.it/)
SMOS	Passive	1 observation per 2/3 days	25 km (EASEv2)	CATDS, (https://www.catds.fr/)
SMOS-IC	Passive	Daily	25 km (EASEv2)	Wigneron et al., 2007
ESA-CCI	Combined	Daily	25km	http://www.esa-soilmoisture-cci.org/
ERA5	Reanalysis	Hourly	31 km	Copernicus Climate Change Service (C3S), 2017

868 Table 4: Percentage of missing values for the different soil moisture pro	moisture products
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			Percentage of missing values								
		In-Situ	ASCAT	SMOS	SMOS-IC	ESA-CCI	ERA5				
	Rheraya	12%	0%	18.70%	6.82%	46%	0%				
	Issyl	-	0%	17.19%	9.10%	2.20%	0%				
869											
870											
871	Table 5: 1	Results of the	e correlation a	nalysis betwe	en the different s	oil moisture data	ı, in-situ				
872	measuren	nents and SN	1A model out	puts (significa	nt correlations a	re represented in	ı bold)				

		Winter	Spring	Summer	Fall
			Rhe	eraya	
In-situ	SMA A=8mm	0.82	0.83	0.67	0.75
	In-situ	0.47	-0.03	0.18	0.70
ASCAT	SMA A=8mm	Winter Spring Summer I A=8mm 0.82 0.83 0.67 0 n-situ 0.47 -0.03 0.18 0 A=8mm 0.32 0.09 0.54 0 n-situ 0.01 0.68 0.61 0 n-situ 0.01 0.68 0.61 0 A=8mm -0.09 0.75 0.58 0 n-situ 0.80 0.68 0.45 0 n-situ 0.80 0.72 0.62 0 n-situ 0.12 0.28 0.41 0 A=8mm 0.15 0.30 0.67 0 n-situ 0.74 0.73 0.04 0 A=8mm 0.43 0.47 0.34 0 A=8mm 0.41 0.52 0.59 0 A=8mm 0.41 0.52 0.59 0 A=30mm 0.85 0.81 0.56 0 <t< td=""><td>0.65</td></t<>	0.65		
	In-situ	0.01	0.68	0.61	0.16
SMOS	SMA A=8mm	Winter Spring Sur A=8mm 0.82 0.83 0 -situ 0.47 -0.03 0 A=8mm 0.32 0.09 0 -situ 0.01 0.68 0 -situ 0.01 0.68 0 A=8mm -0.09 0.75 0 -situ 0.80 0.68 0 A=8mm 0.12 0.28 0 -situ 0.12 0.28 0 -situ 0.15 0.30 0 -situ 0.74 0.73 0 -situ 0.74 0.73 0 -situ 0.43 0.47 0 -situ 0.43 0.47 0 A=8mm 0.41 0.52 0 -situ 0.43 0.47 0 A=30mm 0.85 0.81 0 0.70 0.89 0 0 0.70 0.89 0<	0.58	0.54	
SMOS IC	In-situ	0.80	0.68	0.61 0.58 0.45 0.62 0.41 0.67 0.04	0.85
SMOS-IC	SMA A=8mm	0.80	0.72	0.62	0.57
ESACCI	In-situ	0.12	0.28	0.41	0.60
	SMA A=8mm	0.15	0.30	0.67	0.51
	In-situ	0.74	0.73	0.04	0.73
EKAS	SMA A=8mm	0.86	0.74 0.73 0. 0.86 0.76 0. 0.43 0.47 0	0.54	0.65
Maar	In-situ	0.43	0.47	0.34	0.61
Mean	SMA A=8mm	0.41	0.52	0.59	0.58
			Is	syl	
ASCAT		0.77	0.86	0.70	0.90
SMOS		0.39	0.76	0.47	0.74
SMOS-IC	SMA A=30mm	0.85	0.81	0.56	0.93
ESACCI		0.70	0.89	0.77	0.89
ERA5		0.88	0.82	0.70	0.88
Mean	SMA A=30mm	0.72	0.83	0.64	0.87

Table 6: Calibration results of SCS-CN model, S is the potential maximum soil moisture retention,

882 BIAS_Q is the difference between the observed and calibrated peak discharge of the event, BIAS_V is

883	the difference between the observed and calibrated volume of the event.

	Rł	leraya					Issyl		
Events	S[mm]	Ns	BIASQ	BIASv	Events	S[mm]	Ne	BIASQ	BIASv
Livents	Stum	145	[%]	[%]	Livents	S[mm]	145	[%]	[%]
23/01/2014	19.1	-0.58	1.18	-5.76	25/03/2011	679.8	0,83	29,94	-13,5
29/01/2014	24.5	0.87	6.43	29.14	03/04/2011	730.5	0,02	-12,05	27,93
10/02/2014	34.6	0.71	-4.00	2.85	29/04/2011	218.1	0,83	0	10,36
11/03/2014	9.5	0.61	-17.39	2.57	02/05/2011	113	0,91	-0,58	44,39
21/04/2014	55.8	0.73	6.41	2.30	16/05/2011	176.5	0,61	17,69	-26,31
21/09/2014	34.6	0.77	27.08	-6.87	19/05/2011	136.7	0,87	1,09	9,64
05/11/2014	39.6	0.97	15.38	0.88	06/06/2011	108.8	0,75	0	-5,38
09/11/2014	40.7	0.83	6.30	-0.32	02/04/2012	440.3	0,56	0	15,26
22/11/2014	43.1	0.78	-5.06	2.38	05/04/2012	125.1	0,56	13,5	-1,91
28/11/2014	71.6	0.97	3.66	-6.22	28/09/2012	159.7	0,11	32,16	23,41
					05/04/2013	388.2	0,90	6,49	-4,16
					28/11/2014	254	0,74	1,88	0,71
					25/03/2015	356.6	0,89	0	12,32
Mean		0.67	4.00	2.09	Mean		0,66	6,93	7,14
Median		0.77	4.98	1.59	Median		0,75	1,09	9,64

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886 Table 7: Correlation between the different soil moisture products and the S parameter of the SCS-

887 CN hydrological model

		Rheraya	Issyl		
	S	Number of events	S	Number of events	
In-situ [Daily]	-0.71	8	-	-	
In-situ [Hourly]	-0.83	8	-	-	
SMA A=8mm	-0.32	10	-	-	
SMA A=30mm	0.02	10	-0.69	13	
ASCAT	-0.55	10	-0,29	13	
ESA-CCI	-0,29	8	-0.66	11	
SMOS	0.12	6	-0,59	6	
SMOS-IC	-0.81	10	-0.34	13	
ERA5 [Daily]	-0.46	10	-0.37	13	
ERA5 [Hourly]	-0.80	10	-0.63	13	

889 Table 8: Performance of the SCS-CN model in term of Nash Coefficients for the Rheraya and Issyl events,

890 using the daily or hourly time steps for the different soil moisture products.

					Daily			Hourly	
	ASCAT	ESA-CCI	SMOS	SMOS- IC	ERA5	In- situ	SMA 30mm	ERA5	In-situ
-					F	RHERAY	YA		
Min	-0.15	-	-	-0.04	-0.73	-1.88	-	-0.01	0.15
Mean	0.48	-	-	0.58	0.45	0.25	-	0.64	0.54
Median	0.57	-	-	0.63	0.66	0.49	-	0.73	0.61
Max	0.85	-	-	0.84	0.82	0.83	-	0.81	0.71
Min		560/1	1028			188 Y L	06.08	_	
	-	-30041	-1938	-	-	-	-90.08	114.60	-
Mean	-	-14138	-324	-	-	-	-24.77	-16.74	-
Vledian	-	-254	-1.80	-	-	-	-2.46	-0.85	-
Max	-	-2.10	-0.52	-	-	-	-0./8	0.83	-

913 FIGURES

914



916 Figure 1: Location of Rheraya and Issyl basins, the seguias network, the agricultural parcels and the

- 917 hydro-meteorological network PR: Rainfall station in Rheraya, SMPR: Soil moisture measurement+
- 918 Rainfall station in Rheraya, PQI: Rainfall and discharge station in Issyl, QR: Discharge station in
- 919 Rheraya.
- 920
- 921



923 Figure 2: Comparison between measurements of soil moisture (5cm depth) and different products of soil

924 moisture (Rheraya basin).925

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928 Figure 3: Relationship between S/A and observed soil moisture data between 08/04/2013 and 31/12/2016

929 for different values of A (Rheraya basin).



932 Figure 4: Relationship between different products of soil moisture with SMA outputs between 08/04/2013

933 and 31/12/2016 over the Rheraya basin.



Figure 5: Relationship between the different products of soil moisture and SMA outputs for
 A=30mm between 18/10/2010 and 20/08/2015 in the Issyl basin



Figure 6: Validation results of flood events simulated for the Rheraya using different soil moisture
products with a daily time step. The observed hydrographs (*Q*_{obs}) are compared to the simulated
hydrographs using ASCAT, SMOS-IC, ERA5 and in situ data.



Figure 7: Validation of the flood events simulated for the Rheraya using ERA5 and in situ soil moisture at
the hourly time step.



Figure 8: Validation result of flood events for the Issyl using ERA5 with hourly time step