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Toward creating a global map of drainage rate using satellite soil moisture data as the only input

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The parameterization of hydrological processes over large areas is extremely difficult. The large heterogeneities in soil surface conditions makes impracticable to obtain reliable estimates of soil hydraulic parameters for areas larger than few squared kilometers. However, the knowledge of these parameters on a global scale is essential for a number of hydrological and climatic applications. For instance, their use within SM2RAIN algorithm (Brocca et al., 2014) would allow to obtain a self-calibrated precipitation product based on soil moisture data and independent from any other data sources.

In this study, a new approach is suggested to estimate the coefficients of the drainage rate at satellite footprint scale (∼25 km) by using only satellite soil moisture data. To this end, discrete dry down events after rainfall are selected during the periods in which surface runoff and evapotranspiration rates are negligible compared to the drainage rate. Then, by exploiting the water balance equation, soil moisture recession curves are analyzed to derive the coefficients of a power law model of drainage rate. Scientific challenge here is the selection of dry down intervals, mainly because no ancillary data, like precipitation, is used to identify the drying periods.

In-situ soil moisture data from 10 sites across the world characterized by different soils, land uses and climatic regimes, and three satellite soil moisture datasets from the Advanced SCATterometer (ASCAT), the Soil Moisture Active Passive (SMAP) mission and the Soil moisture Ocean Salinity (SMOS) mission are considered as the soil moisture datasets. Finally, to validate the model results at satellite footprint, an indirect method is used to determine the correlation between model outputs and some relating parameters (e.g., soil texture, vegetation cover).

The preliminary results show that the model can capture the dynamic of drying process at point and satellite footprint scale. However, the drainage rates derived from satellite datasets are found to be higher than the ones from in-situ data and it can be attributed to soil moisture measurement depth.

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Toward creating a global map of drainage rate using satellite soil moisture data as the only input

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A. Introduction

- The parameterization of hydrological processes over large areas is extremely difficult.
- The large heterogeneities in the soil surface conditions makes impracticable to obtain reliable estimates of soil hydraulic parameters for areas larger than few squared kilometers.
- The knowledge of these parameters on a global scale is essential for a number of hydrological and climatic applications.
- The variation of soil moisture is highly correlated with the soil hydraulic properties spatially in soil with high permeability (Mohanty 2013)
- Remote sensing provides the unique opportunity to have global scale surface soil moisture measurement with good spatial (~20km) and temporal coverage (~daily) (Brocca et al. 2017)
- Different studies has been dedicated recently to measuring the drying rate from satellite soil moisture data indicating that the rate of drying observed by satellite is higher than the probe measurement (Rondinelli et al. 2015, Shellito et al. 2016)
- In another study by Koster et al. 2017, in order to forecast the soil moisture in time, a loss function is developed based on the SMAP soil moisture time series
- However, in most of these studies they are looking for the loss function that is combination of evapotranspiration and drainage (McColl et al. 2017), Hence having the estimate of the two process separately is not possible yet.

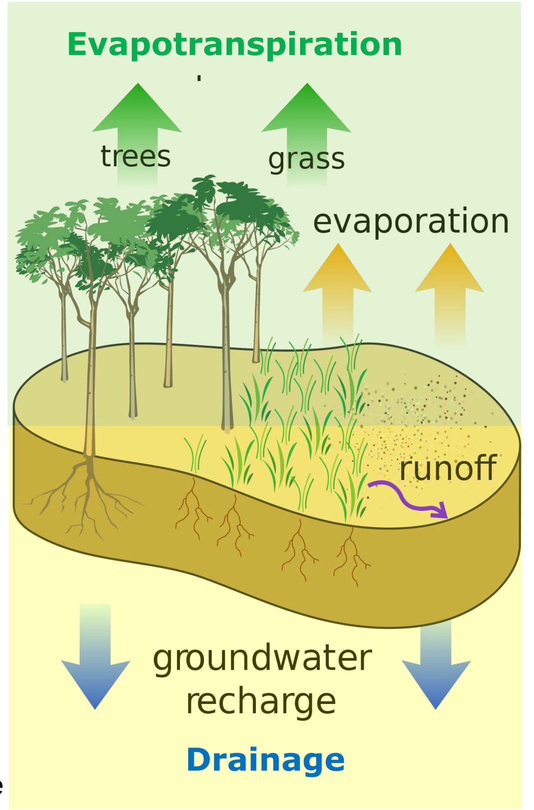

Figure 1– The process involved in the drying of the soil; Drainage and Evapotranspiration

The Challenge!

Is it possible to decouple the Drainage and Evapotranspiration, by analyzing dry downs after precipitation events?

The Study goals

- To develop a model to decouple the drainage and evapotranspiration by analyzing the soil moisture time series
- To test the model performance with in-situ soil moisture data and investigate the possible application to satellite soil moisture data

C. Methodology

C1. What is DfD?

DfD: Estimating drainage rate from Dry down in soil moisture

- DfD stands for the **Drainage from Dry down**
- Discrete dry down events after multiple rainfall events are selected during the periods in which surface runoff and evapotranspiration rates are negligible compared to the drainage rate
- The scatter plot of soil moisture variation (ds/dt) against soil moisture (SM) is plotted for all dry downs in log-log scale and a line is fitted to the points
- Based on the water balance equation and assuming a power law model for drainage rate (Brocca et al. 2008), the drainage coefficients (a and b) are estimated
- one of the challenges in this approach is selection of right dry down events in which the drainage is the dominant process in the drying of the soil

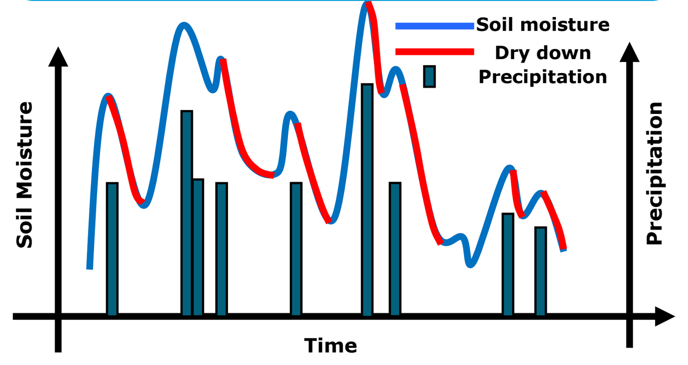

Figure2. The selection of dry down during the rainless period

$$\frac{ds}{dt} = P - ET - D$$

considering dry downs with P and ET = 0

$$Assuming: D = a \times S^b$$

$$ds/dt = -as^b$$

$$\log\left(-\frac{ds}{dt}\right) = \log(a) + b \times lnS$$

C2. DfD tuning in a Synthetic experiment

- To find the best selection criteria a synthetic experiment is devised
- In this experiment using a numerical model and assuming a soil type a synthetic soil moisture time series is generated (The inputs are precipitation (p) and air temperature (T))
- The ET can be added or removed when synthetic soil moisture data is generated to see the impact of ET on the drying process
- The selection of drying events plays an important role in decoupling of the process, the goal of synthetic study is to find the best criteria to select drainage-derived dry downs in different soil type and climate combinations.

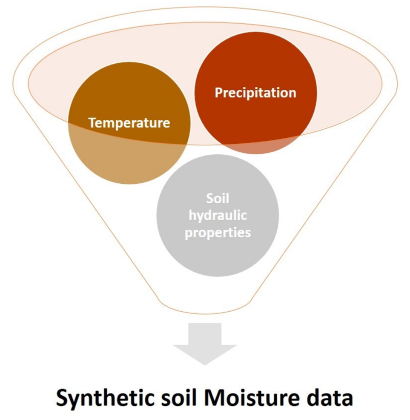

Figure.3-A water balance based numerical model is used to generate the soil moisture time series under more controlled situation the inputs are, Precipitation, Soil hydraulic properties and Temperature data

C3. Applying DfD to in-situ and Satellite data

- After finding the best selection criteria the DfD method is applied according to the flowchart in figure 4

C4. Developing the Self Calibrated SM2RAIN

What is SM2RAIN?

The SM2RAIN algorithm is based on the inversion of the soil water balance equation for retrieving rainfall from SM data. The soil is assumed to work as a natural rain gauge for measuring the amount of rainfall fallen into the ground

$$p(t) \cong Z\,ds(t)/dt + a\,s(t)^b$$

Estimating Precipitation Using DfD parameters

The SM2RAIN is run using three different sets of parameter:

1. a, b and Z are obtain through SM2RAIN calibration with precipitation(SM2R-Classic)
2. Z is fixed as the probe measuring depth and a and b are calibrated (SM2R-Zfixed)
3. Z is fixed a and b are obtained from DfD (SM2R-DfD)

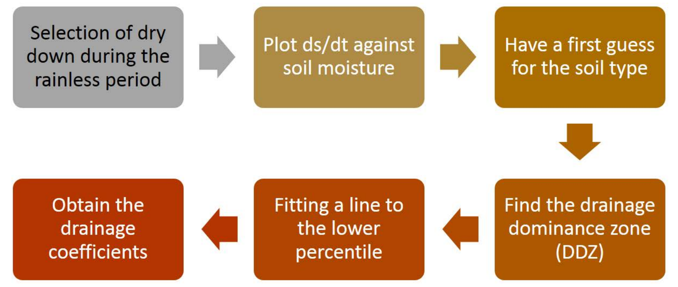

Figure 4– the DfD frame work for decoupling the drainage from Evapotranspiration from time series of the soil moisture

C5. Applying DfD to satellite data

- The DfD model is applied to the ASCAT daily soil moisture data at pixels located in the selected sites
- DfD is also applied to 24 hour aggregated in-situ data
- The result for same location are compared

D. dataset and the study Area

The DfD model (with the best criteria from the synthetic study is applied to in-situ soil moisture data from 7 sites across the world (figure.5)

Figure.5-The location and the of the in-situ sites used in this study

Station name	country	climate	Soil type
BIB	Luxemburg (Bibeschbach)	Humid temp	Loam
VOB	France (Valescure)	Humid temp	Sandy
RES	Italy (Ressi)	Humid temp	Sandy loam
BENIN	Central Benin	Sub-humid	Loam
NIGER	SW of Niger	Semi-arid	Sandy
AUS1	Australia (Yanco)	Semi-arid	Clayey
USA1	USA (Little Washita)	Sub-humid	Sandy
FRA1	France (Anduze)	Mediter-ranean	Loam

Figure.6- ASCAT soil moisture data is obtained for the same sites and the DfD is applied to obtain drainage at satellite foot print

D. Results

D1.Time aggregation in Ideal situation (No ET)

- The Soil moisture recession scatter plot is like a line when the drainage is the only process in drying of the soil (no-ET line)
- By aggregating in time the model is generally underestimating the rate of the drainage

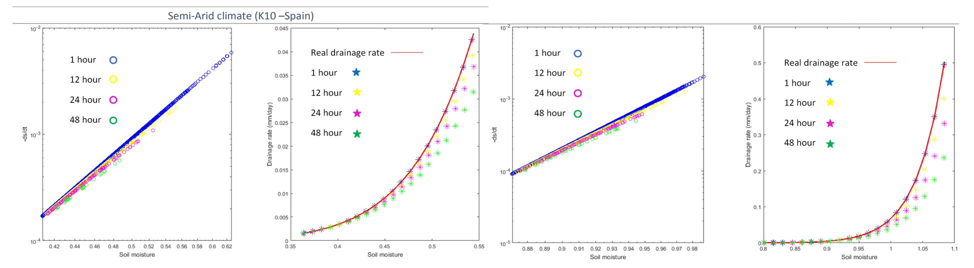

Figure 7-The impact of the aggregation in time in different soil type the left panel is for a sandy soil and the right panel is for a clayey soil, the synthetic soil moisture data are generated for a site in Spain with semi-arid climate (K10)

D2. impact of ET on (S—ds/dt) plot

- By adding ET, the drying rate will be raised above the No-ET line
- The shape of SM RSP is changing mainly based on the soil type
- The drainage can be seen in drying events close to saturation and in lower 5-10 percentile of SM RSP

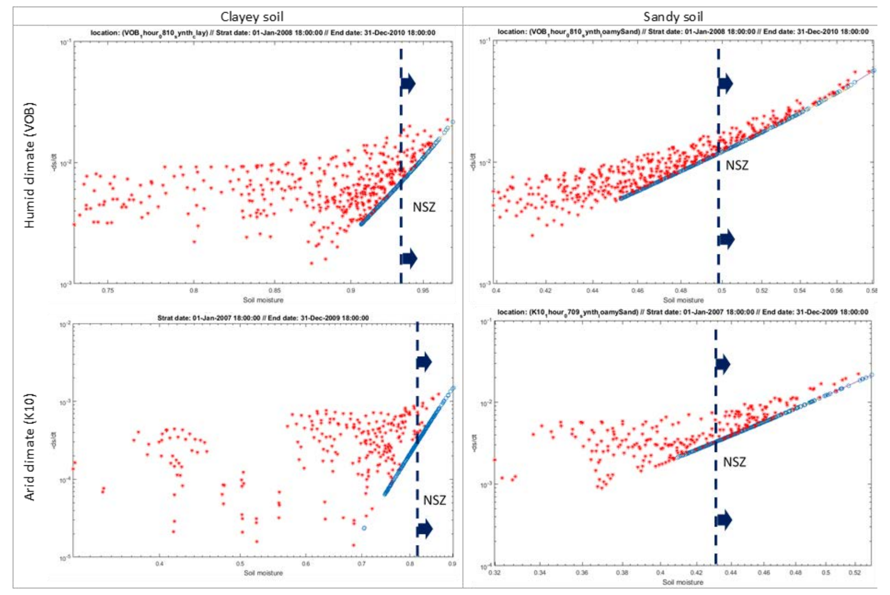

Figure8- the SM RSP obtained from DfD model at 2 sites with Humid (VOB-France) and Arid (K10 –Spain) climate and with two different soil type

D3. Validation through SM2RAIN

- Analysis of SM RSP for two sites indicate that the soil at the Australia site is fine and at RES site should be coarse texture
- Simulation of precipitation by SM2RAIN using DfD parameter indicates acceptable result at both site

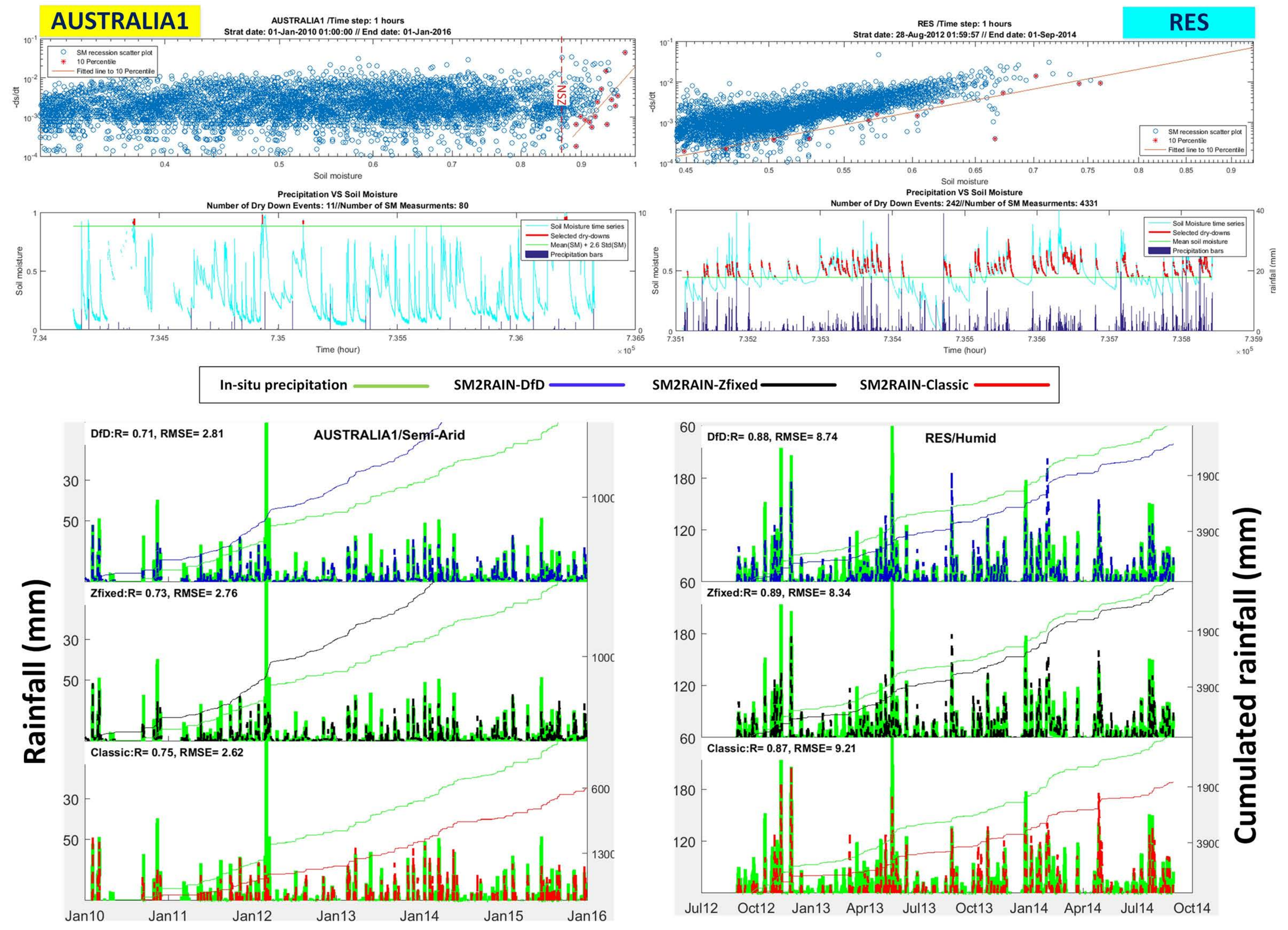

Figure.9. top panel, The SM RSP diagram for Australia and Ressi (northern Italy) that characterized by different soil type and climate, and simulation of rainfall by SM2RAIN using DfD (first row), SM2RAIN by fixing the Z parameter (middle row) and classical SM2RAIN

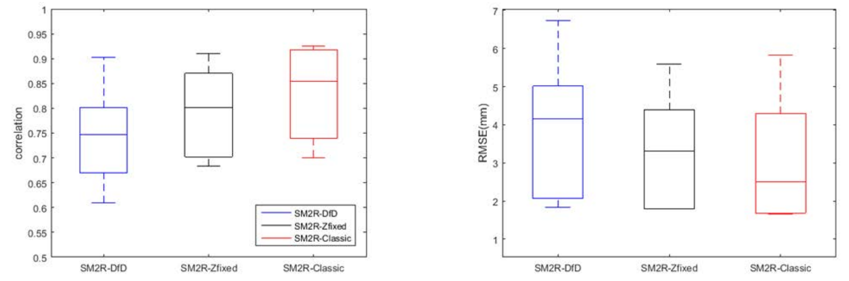

Figure 10. The box plot of RMSE and correlation of simulated precipitation by SM2R-DfD at 7 site across the world

D4. Applying DfD to satellite dataset

- The drainage rate in RESSI and AUSTRALIA1 is obtained by applying DfD to the ASCAT data
- The in-situ soil moisture data is also aggregated to daily time step
- The drainage rate obtained from satellite data is a bit higher in sandy soil and lower in clayey soil

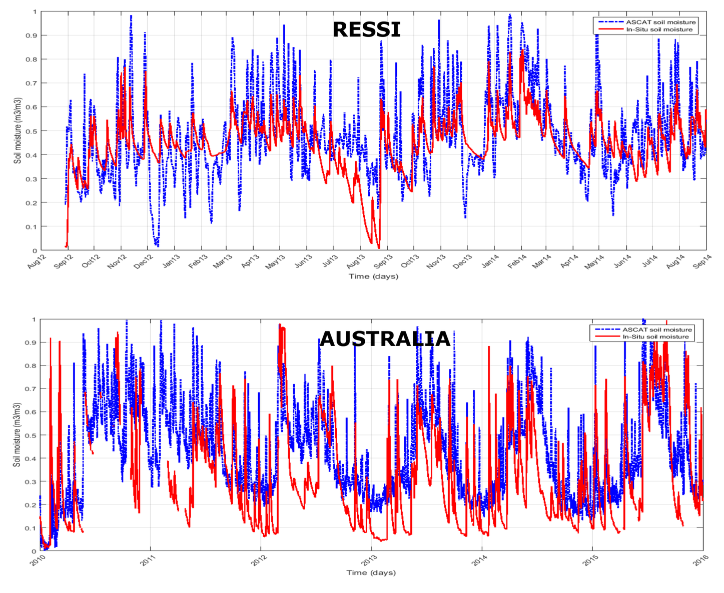

Figure 11. The in-situ and ASCAT soil moisture time series for Ressi (Northern Italy) with sandy soil and Humid climate (top panel) and AUSTRALIA1 (Yanco) with clayey soil and semi-Arid climate

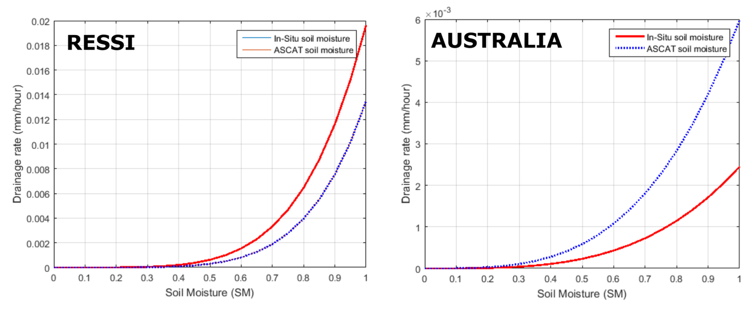

Figure 12. The drainage rate obtained from in-situ and satellite soil moisture time series using DfD at daily time steps

E. Conclusion

- We developed DfD (Drainage from Dry Down) model for estimating the drainage rate from the soil moisture time series
- DfD was successfully applied to synthetic and in-situ observation
- DfD is able to determine drainage coefficients that agree well with available soil hydraulic properties at the selected sites
- The application of DfD to SM2RAIN algorithm enables us to obtain a self-calibrated SM2RAIN that relies only on soil moisture observations for the estimation of rainfall (i.e. no need of rainfall data for calibration)
- DfD is also applied to satellite soil moisture data from ASCAT at the selected sites, the preliminary results indicate that in sandy soil the model overestimates and in clayey soil underestimates the drainage rate.

F. Future works

- Applying the model on a global scale using satellite soil moisture data and compare the result with the available world soil map
- Integrate the model with SM2RAIN to obtain a self-calibrated precipitation product based on soil moisture data and independent from any other data sources
- integrating the drainage coefficient from DfD into other hydrological models

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Sharif University of technology

Istituto di Ricerca per la Protezione Idrogeologica

SMOS+RAINFALL SMOS satellite capabilities

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