SURFACE SOIL MOISTURE ESTIMATION FROM SEVIRI DATA ONBOARD MSG SATELLITE

Wei Zhao [a,b,c], *Jelila Labed* [b], *Xiaoyu Zhang* [d], *Zhao-Liang Li* [a,b,*]

a. State Key Laboratory of Resources and Environment Information System, Institute of Geographical Sciences and Natural Resources Research, CAS, Beijing 100101, China;
b. LSIIT, UdS, CNRS; Bld Sebastien Brant, BP10413, 67412 Illkirch, France;
c. Graduate University of Chinese Academy of Sciences, Beijing, 100049, China
d. Shanxi university, Taiyuan 030006, China
* Authors to whom correspondence should be addressed: lizl@unistra.fr

ABSTRACT

Land surface temperature (LST) and vegetation index or Fraction of Vegetation Cover (FVC) triangle space in regional scale has been demonstrated to be an effective way to monitor surface soil moisture condition. In this study, LST mid-morning rising rate from geostationary satellite data is applied instead of LST in the triangle space. A new soil water dryness index (Temperature Rate Vegetation Dryness Index, TRVDI) is presented from the LST mid-morning rising rate – FVC space to reflect surface soil moisture condition. Regional TRVDI is calculated over a region of the Iberian Peninsula using MSG SEVIRI data recorded on July 2006. The validation was performed with AMSR-E soil moisture product and Anticipant Precipitation Index (API) for two meteorological stations in the area. Results indicate that TRVDI reflects the variation in soil moisture to some extent and is suitable to monitor regional surface soil moisture and temporal variation.

Index Terms—Soil moisture, MSG, Mid-morning temperature rising rate, Dryness index.

1. INTRODUCTION

Surface soil moisture is an important component for controlling surface energy partition and water vapor flux at the land surface/atmosphere interface. It is also one of the crucial parameters in hydrological process in the land surface. Consequently, accurate estimation of soil moisture is very useful in weather forecast modeling, climate modeling and global change study.

Monitoring soil moisture content from remote sensing technique using optical data goes back to 1970s, and it mainly relies on the magnitude of surface temperature change. It is a challenging problem due to the mutual interaction between soil, vegetation and atmosphere. Theoretically, soil moisture directly influences soil temperature by increasing the specific heat, thermal conductivity and thermal inertia of soils [1]. Thermal inertia derived from the change of soil surface temperature between day and night has been found to be highly correlated with the surface soil moisture content. However, it is only applicable in the regions with no or sparse vegetation cover. Vegetation and land surface temperature are both dependent on soil moisture. To retrieve soil moisture under vegetation cover, the temperature-vegetation index triangle method has been proposed [2]. Numerous studies have found that a scatter plot of remotely sensed surface temperature (Ts) and vegetation index or FVC often forms a triangular or a trapezoid shape if a full range of fractional vegetation cover and soil moisture contents exist in the study area [1]. Soil moisture can then be determined by analyzing the position of data distribution in surface temperature and vegetation index or FVC space, and it is a useful way to monitor regional soil moisture condition.

On the base of LST-vegetation index triangle space, LST mid-morning rising rate – FVC triangle space is presented, and Temperature Rate Vegetation Dryness Index (TRVDI) is developed in section 2. In section 3, MSG SEVIRI data and study region will be described. Section 4 illustrates regional TRVDI and its preliminary validation result with AMSR-E soil moisture data and also with Anticipant Precipitation Index (API) at two sites. Finally, a conclusion is drawn in section 5.

2. METHOD

2.1. LST mid-morning rising rate – FVC triangle space

Due to the sensitivity of LST to soil moisture, LST differs for vegetation and soil surface, and tends to be much larger for bare soil than for canopies. But LST estimation from thermal infrared data is greatly influenced by atmospheric effects like water absorption and by the emissivity and temperature separation. Moreover, instrument calibration also influences LST accuracy. Because of these, the errors in LST estimation can exceed several degrees. In the LST –

FVC space, the errors greatly change the point position. In order to minimize this effect, time-related changes in LST is a favorable way because LST variation is less sensible to estimation uncertainties and instrument calibration errors. Many studies show that mid-morning temperature rising rate is the most significant variable for soil moisture content retrieval [3-5]. Combined with vegetation index or FVC, LST mid-morning rising rate represents similar relationship like LST and vegetation index. For bare soil, LST mid-morning rising rate is primarily determined by soil moisture content. As vegetation cover increases, LST mid-morning rising rate decreases. A triangle space can be found in LST mid-morning rising rate and vegetation index or FVC scatterplot.

2.2 Temperature Rate Vegetation Dryness index, TRVDI

In the LST mid-morning rising rate – FVC space, the dry and wet edge representing the maximum and minimum rising rate can be depicted from the points' distribution. Under the assumption that soil moisture availability varies linearly from the dry edge to the wet edge, soil wetness index (Temperature Rate Vegetation Dryness index, TRVDI) is defined as:

$$TRVDI = \frac{RT_{\max(i)} - RT_{(i)}}{RT_{\max(i)} - RT_{\min}}$$

where RT(i) is the mid-morning rising rate of surface temperature for pixel *i*, RT_{min} is the minimum RT in the triangle that defines the wet edge, $RT_{max(i)}$ is the maximum RT for pixel *i* at FVC_i. (see Fig 1)

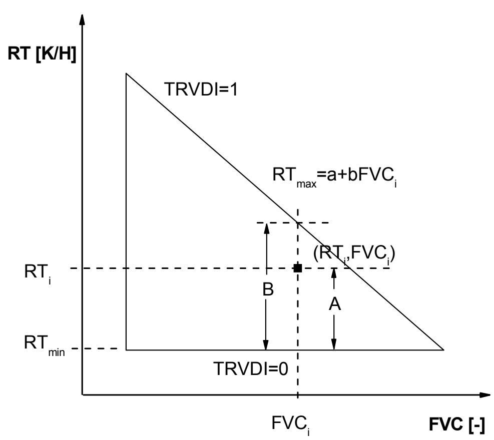

Fig. 1. Definition of the TRVDI. For a given pixel i ($NDVI_i$, RT_i), TRVDI is estimated to be the proportion between lines A and B

2.3 Antecedent Precipitation Index, API

The antecedent precipitation index (API) goes back to Kohler and Linsley [6]. It is a measure of soil moisture condition on the day and is considered as the best estimation of area-averaged soil moisture available on a routine basis over large areas. The API for day i is calculated from:

$$API_i = R_i + K * API_{i-1}$$

where R_i is the total precipitation for day i (mm) and K, the decay constant which generally varies with time due to the variation of surface potential evaporation, and in the summer time, it usually presents a low value compared to winter time. The application of API in practice suggests that K should lie between 0.80 and 0.98 [7]. In this study, K is simplified to be 0.80 in May and June..

3. STUDY AREA AND DATA

Our study area is located in the center part of Spain because of its clear sky condition compared with other European areas. Fig. 2 shows the study region bounded by the rectangle. The elevation in most of this region is more than 450 meters. For this study, regions with elevation between 450 and 900 meters are selected to minimize the effect of elevation changes to surface temperature change. The main land cover type in this region is woody savannas and croplands.

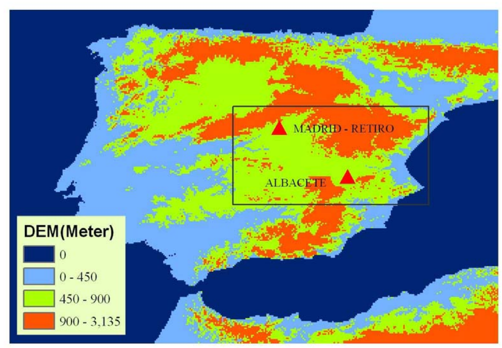

Fig. 2. Classification of DEM value in the study region. Two meteorological stations are marked by the red triangle.

As for satellite data, MSG-SEVIRI data is used. The MSG-SEVIRI sensor is a new type of geostationary satellites including 12 separate channels and 15 min temporal resolution. As for any geostationary satellite the compromise is the low spatial resolution of 4.8 km at nadir and large view angles. In this study, LST data and vegetation fraction cover data downloaded from Land Surface Analysis Satellite Applications Facility (https://landsaf.meteo.pt/) are used to derive LST mid-morning temperature rising rate and construct the triangle space.

For validation, the Advanced Microwave Scanning Radiometer — Earth Observing System (AMSR-E) instrument on the NASA Earth Observing System (EOS) Aqua satellite provides global passive microwave measurements of terrestrial, oceanic, and atmospheric variables for the investigation of water and energy cycles. Surface soil moisture (top 1cm) is also provided by the gridded Level-3 land surface product (AE_land3). This data is acquired from National Snow and Ice Data Center with Cylindrical Equal Area projection and pixel resolution of approximately 25km, the ascending daily soil moisture ($0.001 gcm^{-3}$) is used here. For field validation, daily precipitation data of the two meteorological stations within the study area is downloaded from European Climate Assessment & Dataset (http://eca.knmi.nl/), the station Madrid-Retiro and Albacete are marked in Fig.2 by the red triangle.

4. RESULTS

4.1 Mid-morning temperature rising rate – FVC space

Mid-morning temperature rising rate is calculated with MSG-SEVIRI LST for cloud free days in July. The temperature rising rate –FVC space is plotted in Fig.3. From the Temperature Rate – FVC scatter plot, it presents a triangle space. Temperature rate decreases when vegetation cover increases. The temperature rate changes from one value to others due to different environmental condition like atmospheric forcing besides surface soil moisture content. For dry and wet edge determinations, FVC is divided into many small ranges firstly, and maximum and minimum values of temperature rate are selected for each range. The dry edges are determined by the selected maximum temperature rate and the wet edges are retrieved from the mean value of minimum value under high FVC condition. The dry and wet edges are showed in Fig 3.

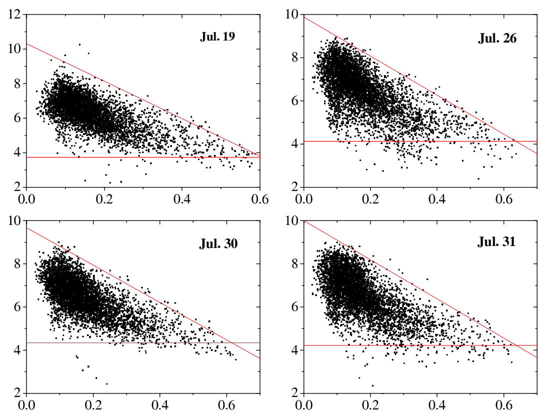

Fig. 3. Scatterplot of Vegetation Cover (x-axis) and Mid-morning temperature rising rate (y-axis, K/h) for cloud free days in July.

4.2 Validation of surface soil moisture estimates

4.2.1 TRVDI vs. AMSR-E soil moisture product

TRVDI is generated for each pixel and each day in the triangle space by extracting dry and wet edges. AMSR-E soil moisture data is then used to validate the correlation between TRVDI and surface soil moisture. Because the spatial resolution is different, one AMSR-E soil moisture pixel includes almost 25 TRVDI pixel, TRVDI should be integrated first. A look up table is constructed to connect each pixel in TRVDI product to AMSR-E soil moisture product, and new TRVDI value is generated for each AMSR-E soil moisture pixel by integrating all the TRVDI pixel value in this pixel. In this study, if there is more than eighty percent TRVDI pixel value available, the new TRVDI can be derived.

The integrated TRVDI values are then compared with soil moisture product. From the inspection of the scatter plots of cloud free days, TRVDI is negatively correlated with surface soil moisture to some extent. The linear fitted lines show some negative correlation with these two parameters. But for the correlation coefficient R-square, the value is around 0.1. It is a bit small and the distribution of scatter is too dispersed. In Fig.4, the soil moisture values vary from 90 to 140. The range is too small to present the regional spatial variation of soil moisture. Gruhier et al.[8] also have found that the AMSR-E soil moisture is not able to capture absolute soil moisture value, but it provides reliable information on surface soil moisture temporal variability, at seasonal and rainy event scale. Consequently, the relationship between TRVDI and AMSR-E soil moisture as displayed in Fig 4 is not clear and the uncertainty of soil moisture value may induce the low R-square in Fig.4.

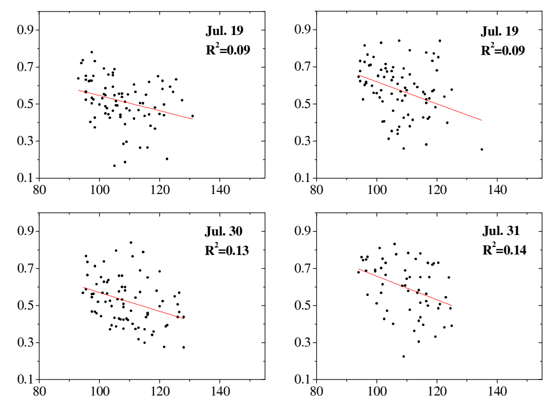

Fig. 4. Validation of TRVDI (y-axis) with AMSR-E surface soil moisture content (x-axis, $0.001 gcm^{-3}$) for cloud free days in July.

In addition to compare with the soil moisture value, we find Polarization Ratios (PR) derived from the AMSR-E data is mainly correlated to soil moisture and vegetation water content (VWC). PR can be derived by the difference between the vertical and horizontal brightness temperatures at a given frequency divided by their sum. The equation is given below:

$$PR = \frac{TB_v - TB_h}{TB_v + TB_h}$$

Gruhier et al. [8] have proved that PR provides better results than soil moisture product. To examine the sensitivity of TRVDI to PR, we compare TRVDI with PR value calculated from 36.8 GHz brightness temperature. Fig. 5 shows four days' scatter plot of TRVDI and PR. We find the R-square

are larger than that in Fig 4, and it infers that TRVDI can indicate spatial soil moisture and VWC condition.

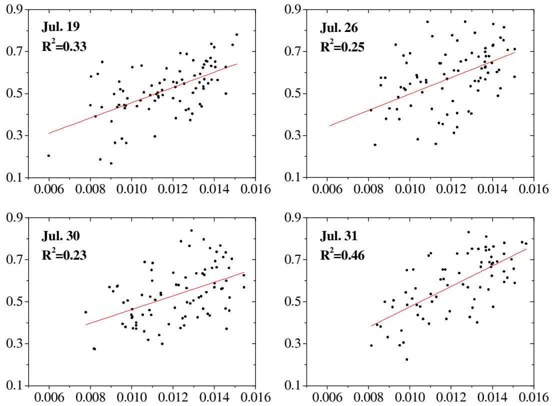

Fig. 5. Validation of TRVDI (y-axis) with AMSR-E PR for cloud free days in July.

4.2.2 TRVDI vs. API

For field validation, TRVDI is compared with the API of two meteorological stations mentioned above (Fig. 6). From the inspection of Fig 6, the API value increases with rainfall and decreases exponentially after precipitation. In Madrid – Retiro station, the TRVDI exhibits a high value before DOY 140 and decreases after two rainfall periods (DOY 139 to DOY 146 and DOY 160 to DOY 168). However, in Albacete station, the precipitation seems to have no significant influence to TRVDI. From the comparison of precipitation in two stations, the rainfall amount in Albacete is less than 10 mm. The small rainfall makes little change to surface soil moisture, thus dose not affect surface temperature too much. Consequently, the TRVDI changes little before and after rainfall in Alcacete. Generally, TRVDI can capture the soil moisture variation with rainfall. After rainfall, soil moisture increases with TRVDI dropping.

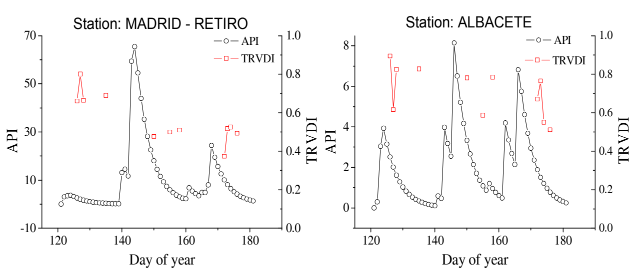

Fig.6. Temporal variation of TRVDI and API in two meteorological stations.

5. CONCLUSION

A new surface wetness index - TRVDI is proposed in this study based on MSG-SEVIRI satellite data. Regional TRVDI is derived from the mid-morning temperature rising rate and vegetation fraction cover triangle space using MSG-SEVIRI data. Preliminary validations are conducted at regional and field scales with AMSR-E soil moisture product and station API value respectively. It is proved that TRVDI is related to surface soil moisture condition, and TRVDI method is useful to monitor regional soil moisture condition. Besides soil moisture and vegetation cover, other environmental factors like atmospheric condition also influence the land surface temperature, further work will be conducted to explore this index.

6. ACKNOWLEDGEMENT

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