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Analysis of C-band scatterometer moisture estimations derived over a semi-arid region

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Abstract

Spatial and temporal variations of soil moisture strongly affect flooding, erosion, solute transport and vegetation productivity. Their characterization offers numerous possibilities for the improvement of our understanding of complex land surface-atmosphere interactions. In this paper, soil moisture dynamics at the soil's surface (the first centimetres) and in its root-zone (at depths down to 1m), are investigated using 25×25 km^2 scale data (ASCAT/METOP scatterometer), for a semi-arid region of North Africa. Our study highlights the quality of the surface and root-zone soil moisture products, derived from ASCAT scatterometer data recorded over a two year period. Surface soil moisture tends to be highly variable, because it is strongly influenced by atmospheric conditions (rain, evaporation). On the other hand, root-zone moisture is considerably less variable. A statistical drought-monitoring index, referred to as the 'Moisture Anomaly Index', is derived from ASCAT and ERS time series. This index was tested with ERS and ASCAT products during the 1991-2010 study period. A strong correlation is found between the proposed index and the SPI precipitation index.

Key words: ASCAT/METOP, radar, surface moisture, root zone moisture, drought.

I. Introduction

Soil moisture corresponds to the water held in the pores of the unsaturated zone. It is one of the most important soil variables, in terms of its influence on climatology, hydrology and ecology [1-2]. The surface and root-zone soil moisture contents regulate the water and energy budgets at the soil-vegetation-atmosphere interface. Moisture content is also an important parameter in watershed modelling, since it partially controls the partitioning of rainfall, infiltration and surface runoff, and thus the hydrodynamics of a river's flow at its outlet [3]. In the last 10 years, large-scale intensive droughts have been observed on all continents, and have affected vast areas of land. The accompanying high economic and social costs have led to an increase in the attention paid to droughts [4]. Several studies have been carried out, establishing a direct link between water content in the soil profile and drought, in an effort to improve our understanding of the processes involved in the latter [5]. Various different indices have been developed to quantify droughts. The most commonly used drought indices are based on precipitation measurements: the Palmer Drought Severity Index (PDSI; [6]), the Rainfall Anomaly Index (RAI; [7]), the decile method [8], the National Rainfall Index (NRI; [9]), the Standardized Precipitation Index (SPI; [10-11]). Concerning drought indices based on soil moisture estimations, only a limited number of studies have been made, e.g. the drought index called Soil Moisture Drought Index (SMDI), proposed by [12].

Despite the key role of soil moisture as shown in the last section, this parameter is difficult to accurately evaluate, due to its strong spatial and temporal variability, resulting primarily from the local topography, and variations in soil type and land use [13-14]. [15] reviewed several studies dealing with soil moisture variability. [16] postulated that fields maintain spatial patterns of soil moisture over time. If such patterns are maintained, then it should be possible to minimize the number of observations, with no significant loss of information. [13] and [17-18] demonstrated that a small number of temporally stable sites can provide a good representation of the mean soil moisture within small watersheds. However, these studies examined the temporal stability of near-surface soil moisture only.

There are three alternative sources which can be used to estimate soil moisture dynamics over large areas: the first of these is based on hydrological modelling, the second makes use of satellite observations, and the third relies on representative Catchment Average Soil Moisture Monitoring sites. Land surface models can synthesize spatially distributed rainfall, land use, soil, and topographic maps to generate surface soil moisture predictions over large spatial areas. However, models are also frequently affected by errors due to the simplifications or assumptions they make, e.g. they can be affected by: rainfall, soil texture, model calibration and parameter identification [19].

Considerable efforts have been made over the past 3 decades, to develop remote sensing techniques for the characterization of the spatial and temporal variability of soil moisture over large regions**.** In particular, active and passive microwave techniques, as well as interpretation tools, have been developed [20]. The effectiveness of low-resolution space-borne scatterometers (active microwave) for land surface characterization has been demonstrated by a large number of studies related to the study of soil moisture [21-24]. Various studies [25-30] have been made, with the aim of allowing soil moisture to be operationally monitored from space, in order to improve hydrological and surface model simulations. ASCAT/METOP moisture estimations have been validated at different sites; in particular for temperate sites in Europe [29-30], showing that assimilation on process models can make a strong contribution. For semi-arid and arid regions, the validation of these scatterometer products has been proposed for a very limited number of studies [24].

The aim of the present paper is firstly to propose a validation of ASCAT/METOP soil moisture products, over a semi-arid region and then to consider the use of ERS and ASCAT moisture products for drought monitoring. Section 2 describes the studied site and the database we used. Section 3 presents our validation of ASCAT/METOP products. Section 4 presents the Moisture Anomaly Index, based on ERS and ASCAT time series recorded during the period from 1991-2010. Finally, our conclusions are presented in Section5.

II. Studied site and database

A. Studied site

The Kairouan plain [31] is situated in central Tunisia (9°30'E-10°15'E, 35°N, 35°45'N) (Fig. 1). The climate in this region is semi-arid, with an average annual rainfall of approximately 300 mm per year, characterised by a rainy season lasting from October to May, with the two rainiest months being October and March. As is generally the case in semi-arid areas, the rainfall patterns in this area are highly variable in time and space. The mean temperature in Kairouan City is 19.2 °C (minimum of 10.7 °C in January and maximum of 28.6 °C in August). The mean annual potential evapotranspiration (Penman) is close to 1600 mm. The landscape is mainly flat. The vegetation in this area is dominated by agriculture. The crops are various and their rotation is typical of semi-arid regions. Figure 1 shows the site land-cover map, produced from SPOT satellite high resolution data. Three land cover classes are dominant over the region of interest: (i) Pasture cover: a mixed shrub-land cover, typical of semi-arid regions in North Africa. (ii) Annual agriculture: mainly winter wheat and barley. These crops are sown around mid-November, and are harvested in late May or early June. (iii) Olive trees: they correspond to the most common class of land use in the studied area. There is a inter-tree spacing of approximately 20m, and the resulting land coverage is quite low (about 5%).

The mountainous areas in the western part of the Kairouan plain are excluded from the area proposed for ASCAT data validation. Concerning the soil, an intensive ground campaign has shown that its mean texture comprises 45% sand, 32% clay and 23% loam. The highest sand percentages are observed in non-irrigated olive groves, which are particularly well adapted to sandy soil.

B. Ground soil moisture measurements

In our study, we use data from two thetaprobe stations separated by a distance of approximately 10 km as illustrated in figure 1. For each permanent thetaprobe measurement, the volumetric soil moisture is measured every 6 h, from the surface down to a depth of 120 cm (a total 5 probes were used for each station, at five different depths: 5, 20, 40, 80 and 120 cm). The deeper the probes, the smoother the recorded response. At the first two depths, the soil moisture is found to react quickly to rainfall. At greater depths, the soil moisture has only small variations. The surface soil moisture data corresponds to the average moisture recorded by the two probes inserted at a depth of 5 cm. The root-zone soil moisture data is obtained by averaging the values measured by the probes installed between the depths of 5 cm and 120 cm. Thetaprobe calibrations are realized at installation phase using different gravimetric measurement.

Figure 2 illustrates the moisture measurements recorded during the study period at different soil depths with the precipitation records. We observe particularly a high variation of surface soil moisture (5cm depth) due to precipitation events and high evaporation level. We note the absence of measurements from the end of May 2009 to the beginning of October 2009. We stopped measurements during this period.

C. ASCAT/METOP products

The ASCAT scatterometer radar is one of the 12 instruments carried by ESA's METOP-A satellite (launched in 2006), and operates in the C - band (5.3 GHz), in the vertical polarization. Over land, the measured radar backscattering coefficient depends on the soil moisture, surface roughness, vegetation characteristics and the incidence angle of the transmitted radar beam. The soil moisture data is retrieved from the backscattering coefficient, using a change detection method developed at the Institute of Photogrammetry and Remote Sensing (IPF), Vienna University of Technology (TU - Wien), and described by [22], [32-34]. This method has been applied with success over different climatic regions, the Canadian Prairies [32], the Iberian Peninsula [35], Western Africa [36], and France [23], [37-38]. The relative soil moisture data, ranging between 0% and 100%, are derived by scaling the normalized backscattering coefficients σ° at forty degree incidence angle between the lowest/highest values corresponding to the driest/wettest soil conditions [39]. The derived soil moisture product, expressed in relative units and referred to as 'surface soil moisture' (*ms*), represents the water content in the first 5 cm of the soil and ranges between the extremes corresponding to totally dry conditions, and a totally saturated water capacity. The spatial resolution is defined by cells of approximately 50 km, with a grid spacing of 25 km, and the temporal resolution of the data varies between approximately two and three measurements per week. ASCAT/METOP crossing times are at approximately 9:30 local time for the descending overpass and 21:00 for the ascending overpass.

In order to compare surface soil moisture (m_s) with ground measurements, m_s products were converted to physical units of m^3m^{-3} by using the 90% confidence interval of a Gaussian distribution [37] equal to $\mu \pm 1.65*\sigma$, where μ and σ are respectively the mean and the standard deviation of the thetaprobe ground data:

$$\theta(t) = m_s(t) * (\theta_{max} - \theta_{min}) + \theta_{min} \quad (1)$$

where θ(t) is the surface soil moisture content at a time t [m^3m^{-3}], $m_s(t)$ is the ASCAT scatterometer surface soil moisture [-] at a time t, θ_{max} is the maximum wetness value [m^3m^{-3}] equal to ($\mu + 1.65 * \sigma$) and θ_{min} is the minimum wetness value [m^3m^{-3}] equal to ($\mu - 1.65 * \sigma$).

The Soil Water Index data (SWI) was derived from m_s using, Eq. 2, and represents the root-zone soil moisture content in the first meter of the soil in relative units ranging between wilting point and field capacity [21].

$$SWI(t) = \frac{\sum_i m_s(t_i) e^{-(t-t_i)/T}}{\sum_i e^{-(t-t_i)/T}} \qquad for \qquad t_i \le t \tag{2}$$

where m_s is the surface soil moisture estimate from the ASCAT scatterometer at time t_i. The parameter T, called the characteristic time length, represents the time scale of soil moisture variations in units of time. T equal to 20 days has shown the best fit to ground measurements.

In order to compare root-zone soil moisture from ASCAT scatterometer (SWI) with thetaprobe measurements, SWI products were converted to physical units (m^3m^{-3}) by using wilting point and field capacity values, Eq. 3:

$$\theta(t) = SWI(t) * (\theta_{\max_p} - \theta_{\min_p}) + \theta_{\min_p} \tag{3}$$

$\theta_{\min_p}$ is the minimum wetness value of soil profile and $\theta_{\max_p}$ is the maximum wetness value of soil profile. They are estimated from ground continuous soil moisture measurements. They are respectively equal to $0.1m^3/m^3$ and $0.35\ m^3/m^3$.

III. Discussion of the quality of ASCAT products

A. Comparison with ground measurements

Because of the limited number of ground stations used in our study, we compared mean ground measurements and ASCAT products estimated for each day for just one 25×25 km^2 pixel (ASCAT scatterometer), corresponding to site1 illustrated in figure 1, between January 2009 and December 2010. This 'reference' pixel is a completely flat area, with a high percentage of dispersed vegetation. In our comparison, we consider the mean measurements provided by the two ground stations.

These two measurements reveal a very small difference (with an R^2 correlation coefficient between measurements equal to 0.32, and an rms equal to 0.06 m^3 m^{-3}), due to the homogeneity of precipitation over the studied area. The surface soil moisture (at a depth of 5 cm) derived from radar data is well correlated with the *in-situ* measurements, as shown in Fig. 3. The statistical outcome of our comparison between ground-truth measurements and satellite products is moderate (RMSE 0.043 m^3 m^{-3}, low bias 0.018 m^3 m^{-3}, and R^2 of 0.5), due to the high variability of the moisture in the five first centimetres of soil [40]. However, significant differences are found in the rate at which the soil moisture decreases after rainfall events. In particular, the ASCAT products indicate a more rapid decrease in moisture than that shown by the ground-truth measurements. This is probably due to the effective penetration depth of the ASCAT radar, which is theoretically smaller than the value of 5 cm used for the ground-truth measurements [41]. The root-zone soil moisture results are shown in Fig. 4-a. Over the two year study period, the decreasing and increasing soil moisture trends retrieved by the ASCAT scatterometer are generally coherent to those determined from the ground-truth measurements, but with different intensities, with a RMSE of 0.039 m^3 m^{-3}, a low bias equal to 0.02 m^3 m^{-3}, and R^2 of 0.65 (Fig4-a). Fig4-b illustrates a comparison between root-zone estimated soil moistures with ground measurements. Each point corresponds to mean values for one decade. In the case of high moisture levels, the satellite product leads to underestimated values. It is likely that the main cause of this discrepancy is the rapid decrease in surface soil moisture estimation after rainfall events, particularly in the case of torrential rain, which can produce a strong increase in root zone soil moisture.

B. Comparison with ASAR/ENVISAT products

The second type of validation of ASCAT products, established for the Kairouan site, was based on comparisons with ASAR/ENVISAT soil surface moisture products recorded during the 2009 and 2010 seasons [31]. The moisture estimation is proposed for two types of vegetation cover, which represent a high combined percentage of land use. The first mapping process is dedicated solely to the monitoring of moisture variability over areas in the "non irrigated olive tree" class of land use. The approach we have developed is based on a simple linear relationship between soil moisture and the backscattered radar signal, normalised to a reference incidence angle. The second process is proposed over wheat fields. A semi-empirical model, based on the water-cloud model for vegetation correction, is used to retrieve soil moisture from the radar signal. This analysis is based on a large database, including both ENVISAT / ASAR and simultaneously acquired ground-truth measurements (moisture, vegetation, roughness), during the 2008–2009 vegetation cycle [31]. Table 1 illustrates details of ASAR/ENVISAT images acquisitions.

28 mapping dates are proposed during the 2009 and 2010 rainy seasons, for the studied site. As shown in Fig. 5, despite the low numbers of dates (only 17) for which both types of satellite measurement were recorded approximately in the same time (in ascendant or ascendant orbits), we observe a strong degree of correlation between the ASAR and ASCAT scatterometer data, with the differences corresponding to an RME error of only 0.032 m^3m^{-3}. These comparisons are made over two ASCAT product grids, corresponding to site2 illustrated in figure 1. We consider this area in order to do comparison principally over olive groves (about 80% of land cover), characterised by a high percent of bare soil without any irrigation.

For each grid (25 x 25 km^2), we compute the mean value of the soil moisture derived from ENVISAT / ASAR map products**.** The spatial variances of the ASAR estimations, based on the scale of the ASCAT grid, are also illustrated with bar errors in Fig. 5. Spatial variations in soil moisture are related mainly to variations in rainfall and vegetation cover over the ASCAT grid.

C. Correlation with Rainfall

Fig. 3 provides a time series comparison of surface soil moisture and rainfall. The latter is given by the mean value of measurements taken from different rain gauge stations on the Chebika and Houarab sites. It can be seen that although the rainfall and estimated ASCAT soil moisture values are not directly comparable, the surface soil moisture peaks occur after rainfall events during the rainy season. For the studied sites, we computed that 70% of ASCAT volumetric moisture values exceeding 15% correspond to rainfall events, which occurred on the two preceding days. Similarly, 90% of ASCAT soil moisture values lower than 5% corresponds to an absence of rainfall during the five preceding days. These results show that there is a good degree of correlation between rainfall and variations in soil moisture. For the root zone soil moisture, a more quantitative analysis is proposed in section IV, using the SPI precipitation index.

D. Limitations of the proposed products

Despite the satisfactory results achieved with various validation approaches, we observed some limitations in the retrieval of ground-truth measurements, particularly after a rainfall event. As described in section III-A, this effect is closely related to the combined influences of the soil moisture gradient, for the first five centimetres below the surface, and the effective radar penetration depth, which is theoretically less than 5 cm for medium and high moistures. Fig. 6 illustrates the soil moisture ground gravimetric measurements obtained over the studied site on 12 different dates, with more than twenty samples for each date, for the three depths: 1 cm, 2 cm and 5 cm. Measurements were realized in five different test fields, with three to five measurements for each depth, for each field. It can be clearly seen that the soil moisture increases with depth. The difference in volumetric moisture between the value for the first centimetre and the mean value taken over 5 cm could be greater than $0.1 m^3 m^{-3}$. [40-41] have theoretically demonstrated the influence of this moisture profile variability on the strength of the backscattered signal, and therefore on the estimation of soil moisture. For this reason, ground measurements made with 5 cm profiles can be significantly different to values derived from remotely sensed (satellite) estimations.

This limitation is generally less problematic in humid regions [37-38]. In fact, soil moisture variations as a function of depth are not generally as significant in humid regions as in arid or semi-arid regions. It is very difficult to propose a modified form of the Wagner algorithm to improve soil moisture estimations, because of the extremely challenging requirement of determining the soil's exact moisture profile in the first centimetre, since this is a temporally variable function of precipitation, atmospheric conditions and soil texture.

Despite these limitations, the retrieved accuracies are satisfactory and the ASCAT products can be used in semi-arid regions, which suffer considerably from frequent drought events. As discussed in the introduction, soil moisture and precipitation could be key parameters for the analysis of such drought events. In the future, they could be used for the forecasting of drought periods.

IV- Moisture Anomaly Index

In the previous section, it is shown that differences between dry and wet periods can be clearly detected through the use of *SWI* index time series. In this section, we propose a simple new index, which can provide a quantitative representation of drought intensity, and the significance of a drought period, based on the water content profile. We thus propose a new index based on statistics derived from *SWI* time series retrieved from ASCAT and ERS scatterometer products covering the period (1991-2010). This index, referred to as the 'Moisture Anomaly Index' (*MAI*), is written:

$$MAI_i = \frac{SWI_i - (SWI_i)_{mean}}{\sigma_i} \quad (3)$$

Where SWI_i is the *SWI* estimate for the i^{th} month (or generally a period of one, two, or three months), $(SWI_i)_{mean}$ is the mean value of the *SWI* during month (a period) *i*, derived from the previously described 20 years of *SWI* time series data from ERS and ASCAT scatterometers, and σ_i corresponds to the standard deviation of the *SWI* values estimated for month *i*, over the same 20 year period.

When the *MAI* is greater than zero, a high *SWI* value is indicated, corresponding to a wet profile and the absence of drought.

When the *MAI* is negative, a low *SWI* value, which is probably the result of drought or a period with a lack of precipitation, is indicated.

The *MAI* is calculated over the site 1. **Approximately three *SWI* satellite observations are proposed per month. Therefore, a new *MAI* could be proposed every decade.** In order to validate the proposed index, we studied the correlation of the *MAI* with the *SPI* precipitation index estimated **from two rain gauge measurements**, (for periods of computation of one, two and three months). The strongest correlation is found for 3 months period.

Fig. 7 shows, together with the 3months-*SPI* precipitation index, the 3months-*MAI* index for each month from December to April, during the 20 processed years recorded in our database. For example for December, computations of *SPI* and *AMI* are realized with data acquired in October, November and December. The *MAI* index can be seen to range, according to the month of the year, between approximately -1.5 and 2.5. As an example, during the month of February the proposed index ranges between a minimum of -1.66 in 2010, the driest year, and a maximum of 1.93 in 1992. In general, limited periods of drought or a lack of precipitation, lasting for a period of several weeks, were observed every year. This leads to a local decrease in the *MAI* index. A strong correlation can be observed between the *MAI* and the precipitation index, *SPI*. A strong decrease in the precipitation index is generally associated with a negative *MAI* index. This can be seen for example in 1995 and 2006, for almost all months. On the other hand, in several different cases a strong increase in the *SPI* index leads to a positive *MAI* index, as can be seen for example in the month of December 1993. However, in some cases we observe a certain degree of contradictory behaviour, as can be seen in 2007. Analysis of these occurrences shows that they may be explained by three factors:

- firstly, there are limitations in the method used for soil moisture profile estimation: in some cases we did not have access to surface moisture estimations during, and for a period of two days following, a strong precipitation event, and the influence of this event was thus neglected in the moisture profile computation. This is the case of March 2007, when 38 mm of precipitation was recorded in just one day without moisture estimation.
- secondly, the studied site being characterised by a small number of precipitation events, associated with a very high rate of evaporation, many minor events have a negligible effect on the moisture profile.
- thirdly, it is possible that in some cases a single rain gauge may record a very localized precipitation event, which has only a limited effect on the scatterometer estimations averaged over 25 x 25 km^2 pixels.

Although the MAI could be complementary to the use of precipitation indices, it can not replace the latter because, as described above, divergent results are found in some cases. The coherence between the two types of index would certainly be improved if soil moisture values were available on a daily basis.

The *MAI* to *SPI* precipitation index correlation coefficient is provided in Table 1. In general, these two indices are strongly correlated, particularly for rainy months (R2=0.68 for January, R2=0.83 for February and R2=0.63 for March). This result demonstrates the robustness of the proposed index, based on *SWI* products.

V. Conclusion

The aim of this paper was firstly to validate ASCAT soil moisture products over a semi-arid region, the semi-arid Kairouan Plain site. The statistical results of our study reveal a good degree of coherence between ground-truth measurements and remotely observed moisture products, with an *rms* error equal to 0.043m^3m^{-3} for surface moisture, and 0.039 m^3m^{-3} for root-zone moisture. A good agreement is found between ASCAT and ASAR estimations, with an *rms* error equal to 0.032 m^3m^{-3}. The differences in temporal variations, between the surface and root-zone moisture values, are explained by the fact that the surface soil moisture is affected, more strongly than the root-zone soil moisture, by the ambient atmospheric conditions. The results of our ASCAT product validation are encouraging, and other researcher workers could consider using this data for the purposes of validation, calibration or input generation (e.g. assimilation scheme) in their models, as an alternative to *in-situ* observations. In order to analyse the contribution of soil moisture products, we propose a simple Moisture Anomaly Index, which can provide a quantitative visualization of drought periods. This index is compared with and validated, using the SPI precipitation index. A high degree of correlation is observed between the two indices. However, some differences are observed in various cases, which could be related to the frequency of soil moisture estimations, the methodology used for soil moisture profile estimations, the characteristics of the semi-arid climate (limited precipitation events, high evaporation level), and the spatio-temporal scales at which the precipitation is measured and the moisture is estimated. Despite these limitations, the Moisture Anomaly Index could be a useful tool, complementary to the precipitation index, for the analysis of drought situations. This is **particularly the case in regions without rain gauge networks, and also in arid and semi-arid regions where a high precipitation record with a limited number of events could be in contradiction with water stock in soil**. The coherence between the two indices would certainly be improved if soil moisture estimations were available on a daily basis.

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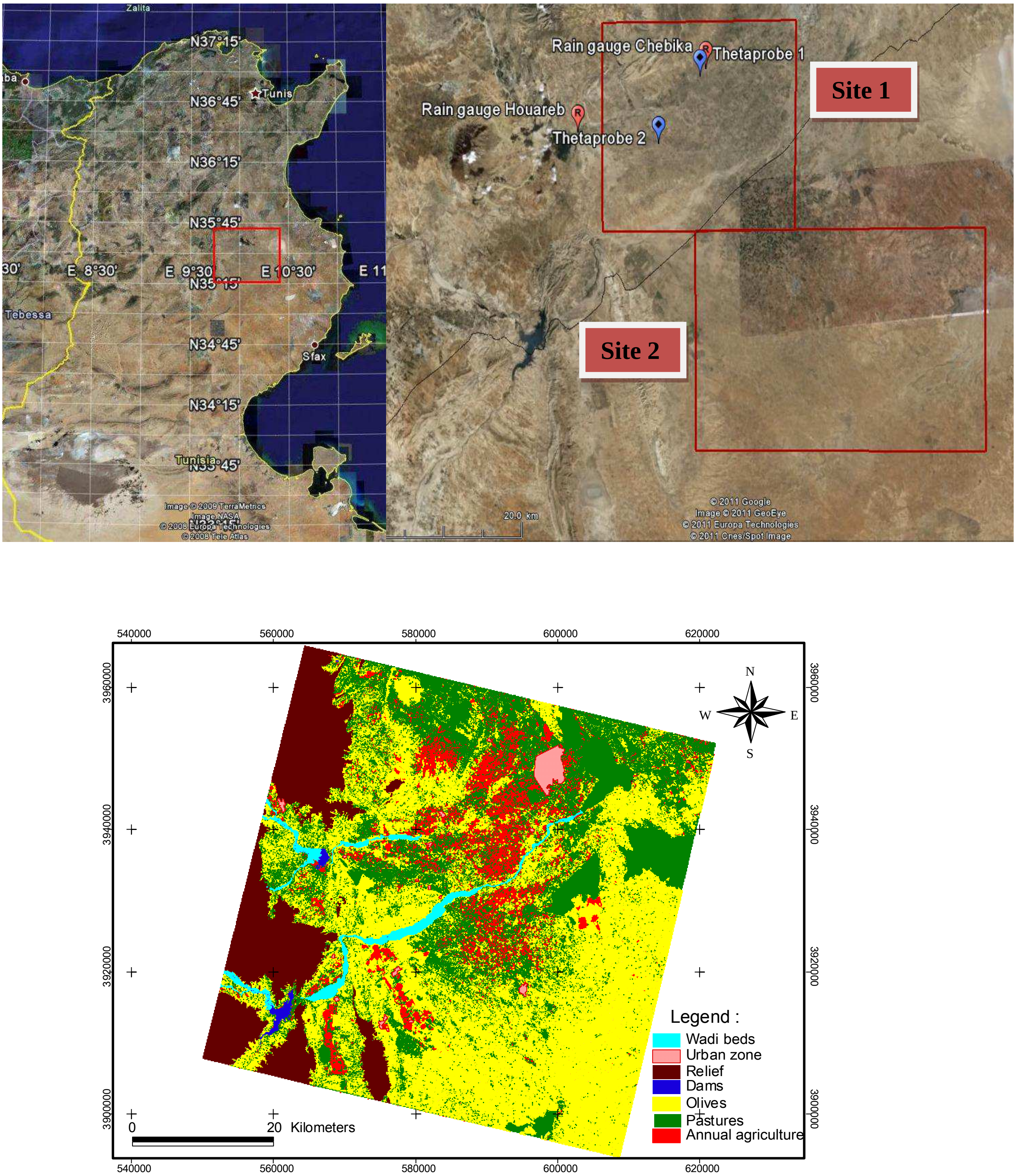

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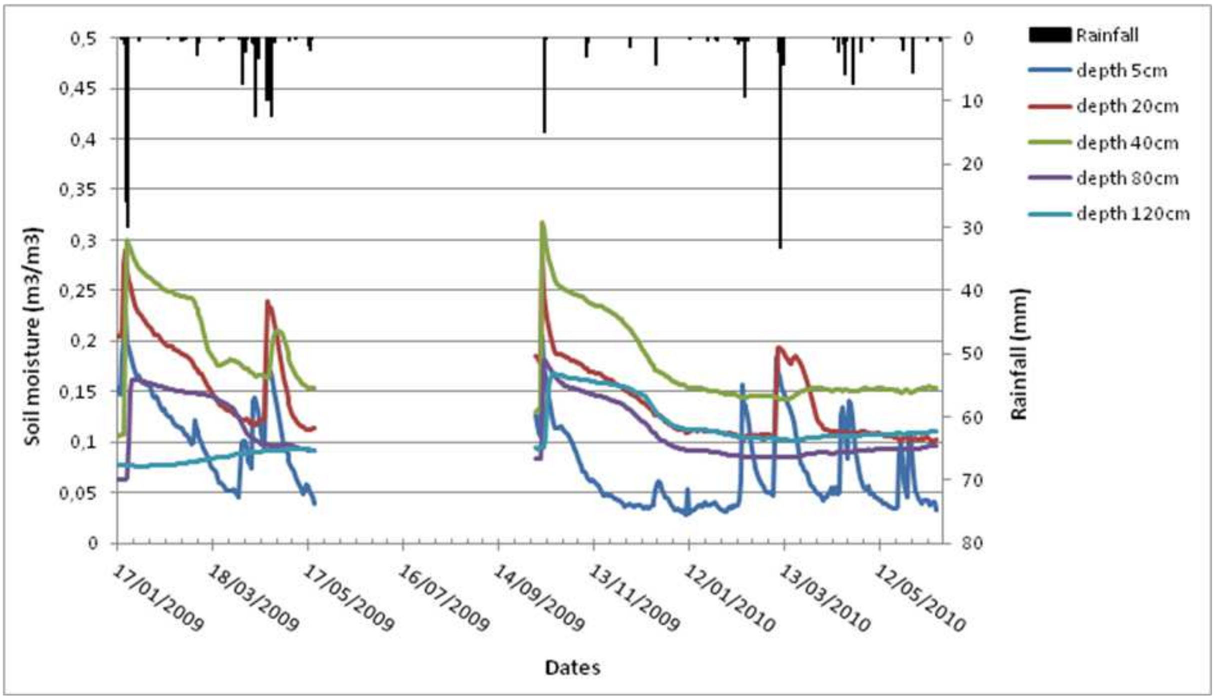

Figure 2: In situ soil moisture measurements recorded at different depths during the study period.

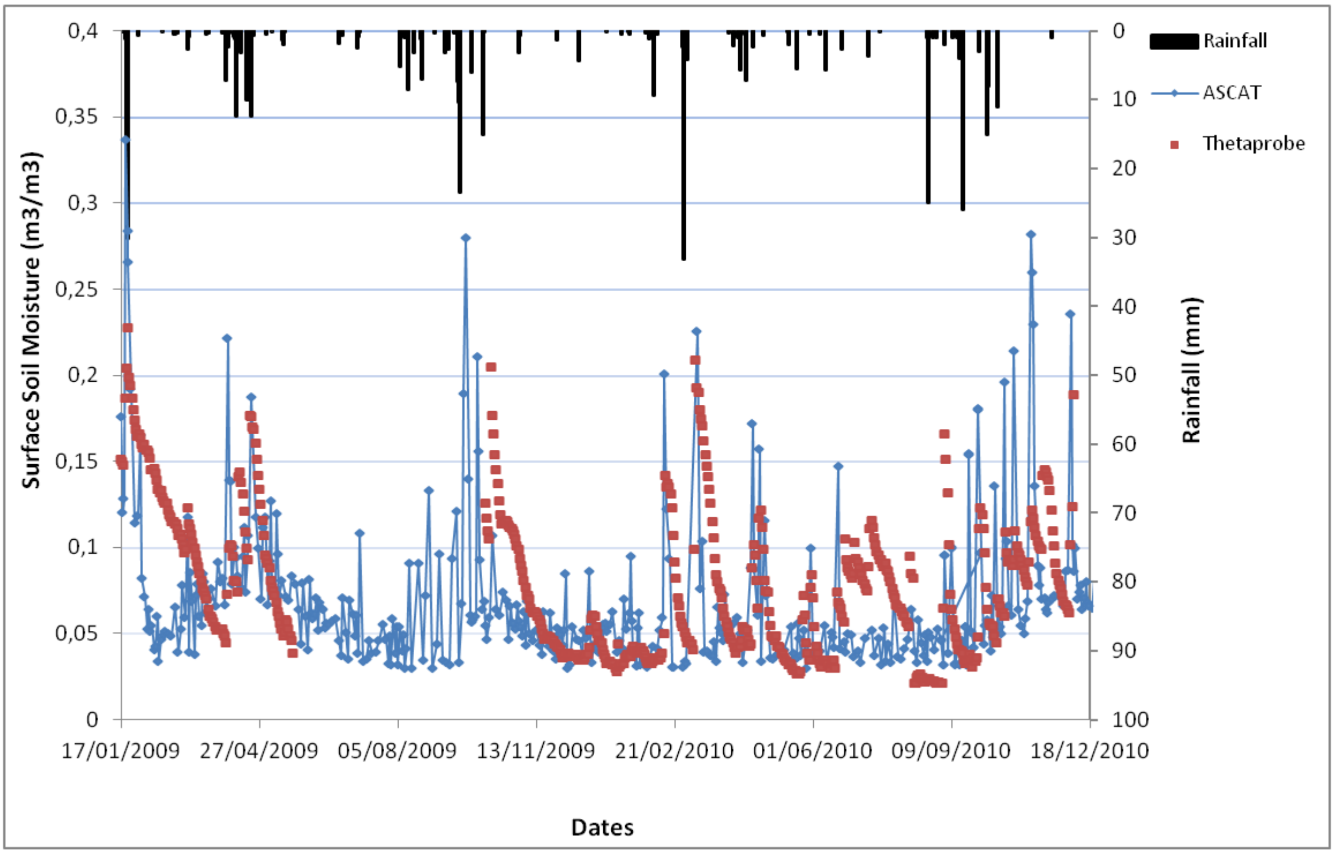

Figure3: Surface soil moisture measured with *in situ* with thetaprobes, and derived from ASCAT scatterometer, between January 2009 and December 2010.

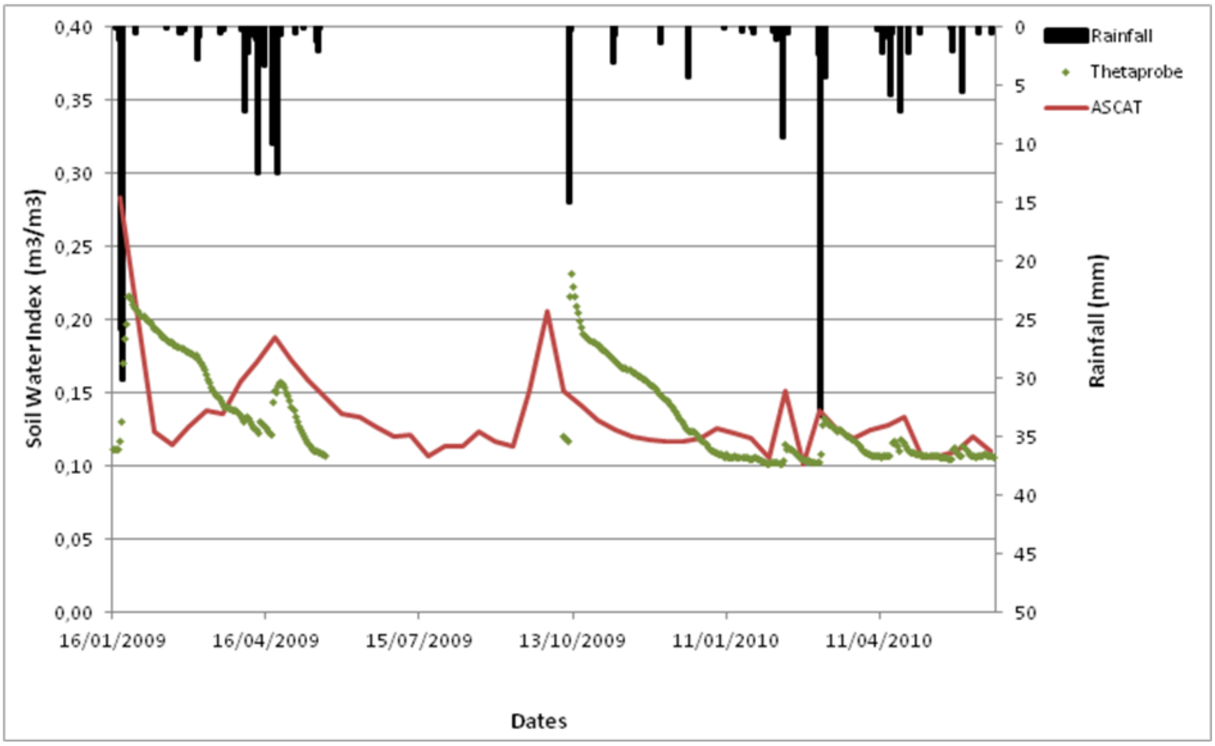

Figure 4a: Root-zone soil moisture measured *in situ* with thetaprobes, and derived from ASCAT scatterometer, between January 2009 and December 2010.

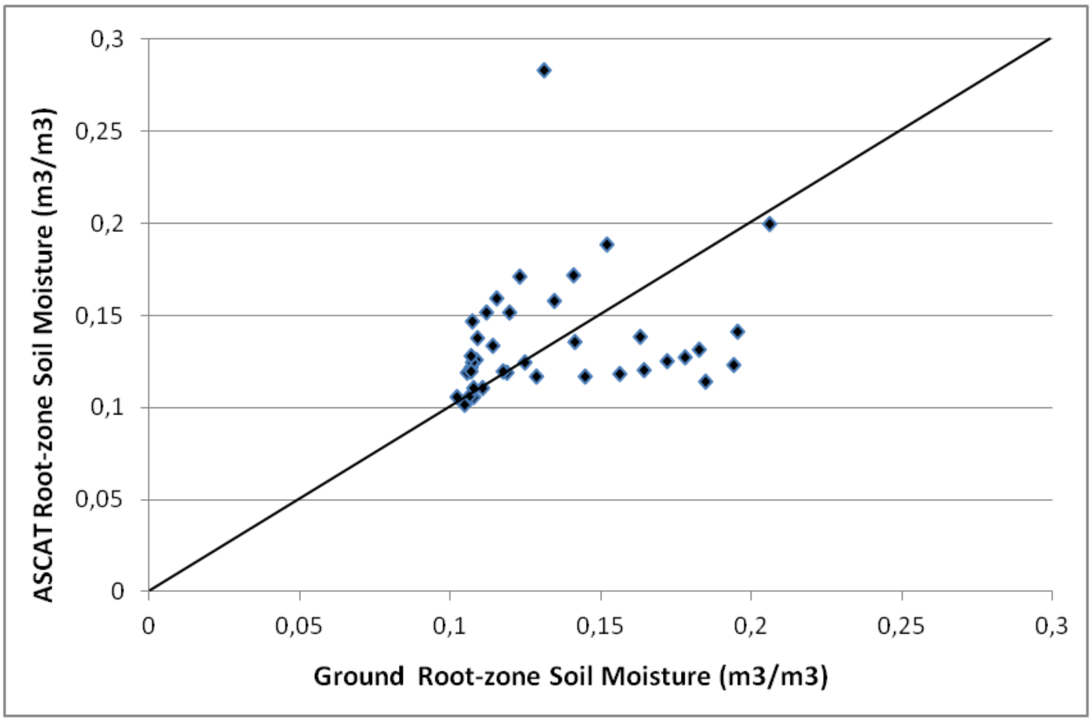

Figure 4b: Inter-comparison between the ASCAT root-zone soil moistures and in situ measurement values

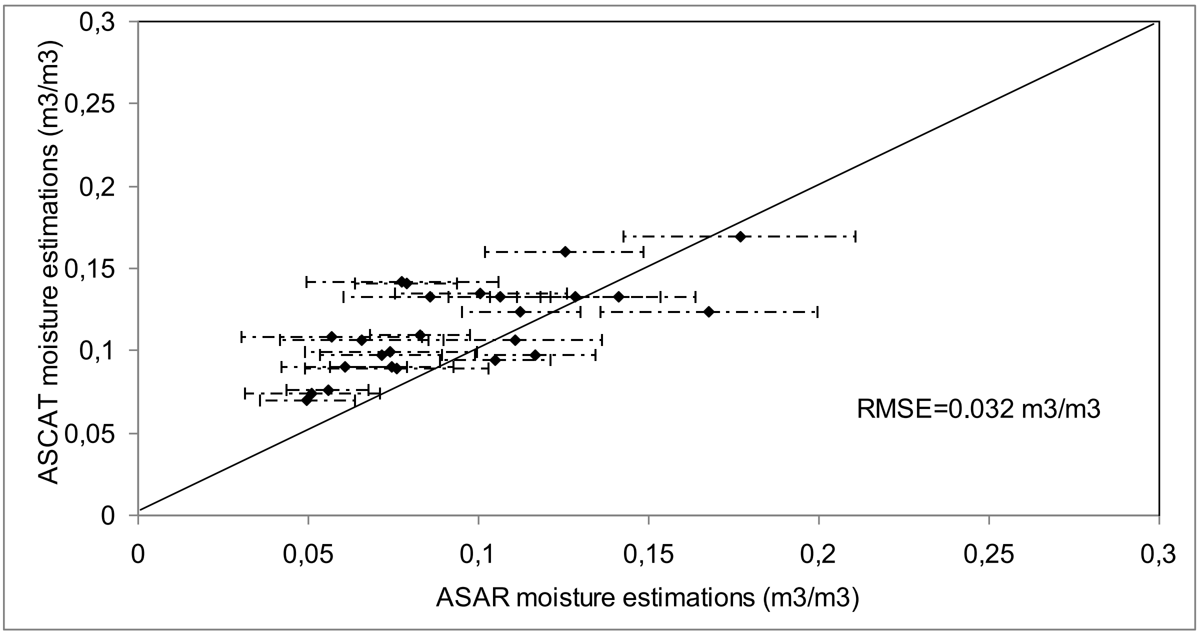

Figure5: Inter-comparison between the mean values of ASCAT and ASAR/ENVISAT surface soil moisture products, over two grids at the Kairouan site.

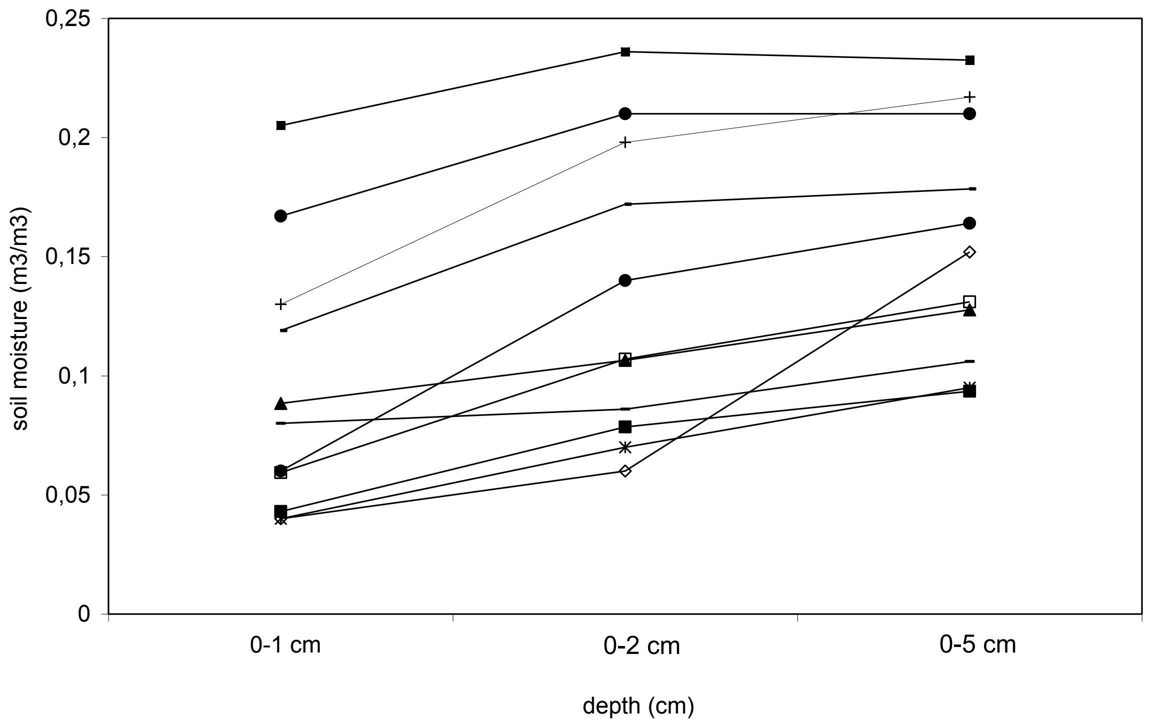

Figure 6: Illustration of soil moisture variation as a function of depth over studied site for different dates

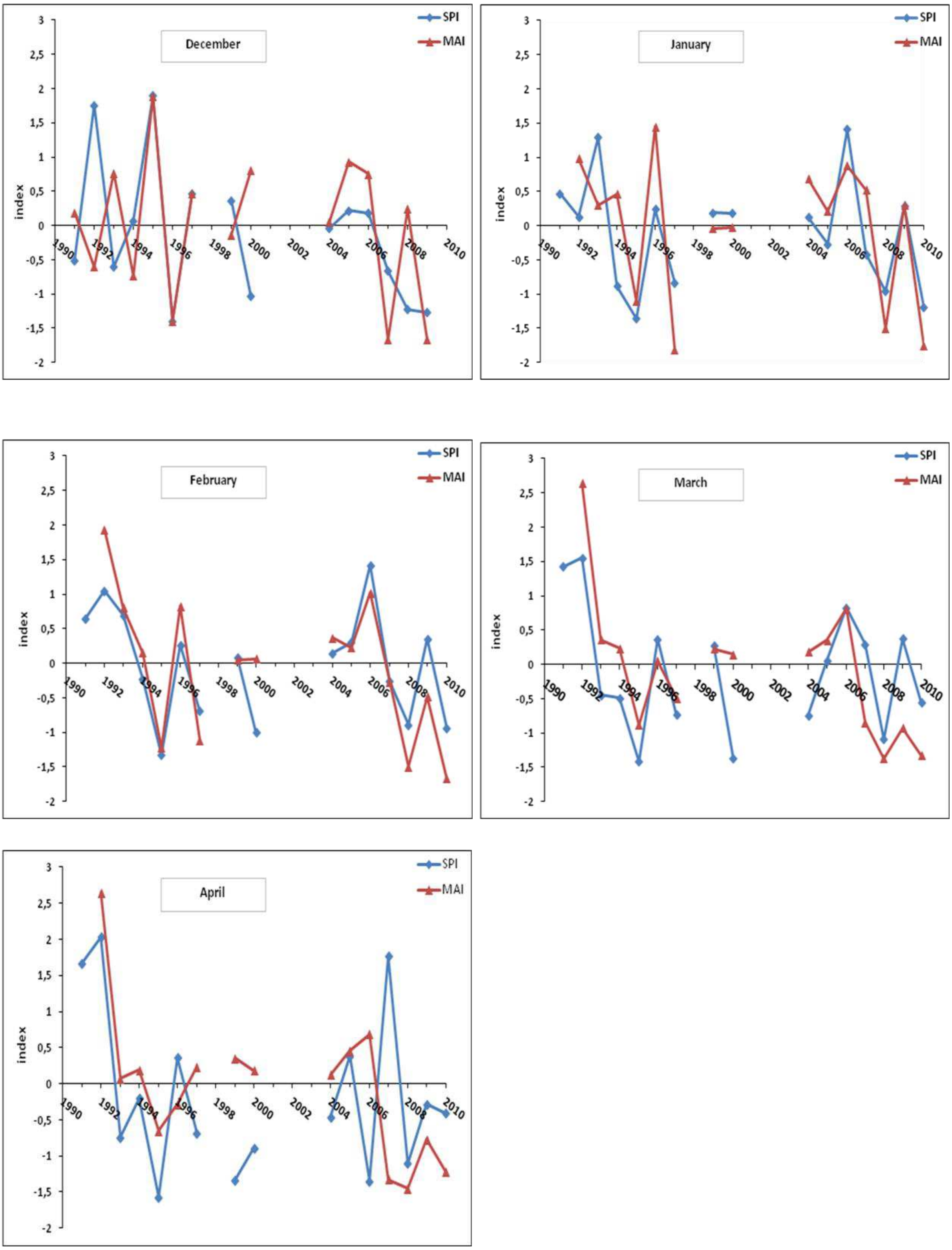

Figure 7: Variation of the *SPI* index and the *MAI* index for each month from December to April during the 20 proceeding years.

Date	Time	Beam mode	Incidence angle	Polarization	Orbit direction
19/01/2009	09:35:00	IS1	14.26	HH, VV	Descending
16/02/2009	21:08:47	IS2	18.62	HH, VV	Ascending
20/02/2009	09:29:21	IS3	25.69	HH, VV	Descending
07/03/2009	21:11:38	IS3	25.72	HH, VV	Ascending
08/03/2009	09:26:29	IS3	25.7	HH, VV	Descending
11/04/2009	21:11:36	IS3	25.72	HH, VV	Ascending
01/05/2009	09:29:20	IS3	25.72	HH, VV	Descending
16/05/2009	21:11:38	IS3	25.75	HH, VV	Ascending
20/05/2009	09:32:10	IS2	18.62	HH, VV	Descending
09/12/2009	21:05:51	IS1	14.27	HH, VV	Ascending
28/12/2009	21:08:44	IS2	20.24	HH, VV	Ascending
17/01/2010	09:26:25	IS3	26.64	HH, VV	Descending
20/01/2010	09:32:05	IS2	20.18	HH, VV	Descending
01/02/2010	21:08:43	IS2	20.247	HH, VV	Ascending
08/02/2010	09:34:55	IS1	14.25	HH, VV	Descending
17/02/2010	21:05:51	IS1	14.26	HH, VV	Ascending
20/02/2010	21:11:32	IS3	26.66	HH, VV	Ascending

Table 1: Illustration of ASAR/ENVISAT images details

Month	Correlation coefficient
oct	0,45
nov	0,31
dec	0,44
janv	0,68
fev	0,83
mars	0,62
avril	0,29

Table 2: Correlation coefficients between the *MAI* index et the *SPI* precipitation index