Planting date estimation in semi-arid environments based on Ku-band radar scatterometer data

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***Abstract*— A method to determine planting dates in semi arid regions is presented, based on K_u-band spaceborn scatterometer data. The planting date analysis was performed for Mali, a region with a broad range of vegetation cover with tropical forest in the south and desert in the north. The Ku-band data was acquired by the SeaWinds scatterometer onboard the QuikSCAT satellite during the time from January 2000 to December 2003. Climate data from meteorological stations was compared with scatterometer time series of data colocated from a circular area of a specific size. The comparison shows that the evolution of the backscatter signal is highly correlated with the vegetation cycle triggered in turn by the rain season. An accurate date for the onset of the growing season and therefore a basic planting date can be determined from noise-filtered backscatter time series using a simple threshold method. The temporal variations of the backscatter time series are mainly caused by vegetation growth and changes of surface soil moisture. An increased backscatter signal indicates therefore more and more sufficient growing conditions. For the estimation of the contribution of surface soil moisture, the backscatter was additionally compared with in-situ data from test sites within the Duero basin in Spain, covered by the soil moisture measurement network of the University of Salamanca. The comparison showed a significant influence of surface soil moisture on the microwave backscatter.**

I. Introduction

The planting date is defined as the moment, when a farmer put the seeds into the ground for growing. The individual farmer decides to plant based on the actual state and the history of the meteorological conditions, the state of the soil, the individual experience and economic situation.

Planting date studies neglect the impact of social state and social environment in most cases and concentrate on the analysis of the agrometerological parameter. The climatic and physical aspect, which allow plant growth and are necessary for a successful planting, will be short termed as growing conditions in the further text.

The growing conditions depend on a large number of different parameters and are especially influenced by the geographical position. While in humid regions the crucial factor is the incoming sun radiation and temperature [1], [2] , the crucial factor in semi arid regions is the plant available water [3], [4]. This study focuses on semi arid regions and the plant available water.

Variations of the radar scatterometer signal are mainly caused by changes of the dielectric properties of the scattering surface and by changes of the scattering mechanism as introduced by changes of surface roughness and contributions by volume scattering. The main reasons of these variations are changes of soil moisture and the growth of vegetation.

The high temporal sampling of the K_u-band scatterometer on the QuikSCAT platform, and reasonable resolution offers the potential to investigate daily differences of the dielectric properties of the earth surface. Vegetation growth and an increased surface soil moisture increase the backscatter from the surface. An increasing of the backscatter signal therefore indicates sufficient growing conditions.

II. Data

SeaWinds is a scanning dual spot beam scatterometer, launched in June 1999 aboard the QuikSCAT satellite [5]. Backscatter measurements are collected simultaneously at constant incidence angles of 46°, inner beam, and 54°, outer beam, with horizontal and vertical polarizations respectively, using a scanning dish antenna operating at 13.4 GHz (K_u-band). The antenna has a footprint size of roughly 25x25 km and scans over a swath of 1800 km, imaging thereby 90% of Earth's surface in one day.

The big advantage of SeaWinds compared to its predecessors is the extremely high temporal sampling rate. The sensor passes equatorial regions nearly every day. This temporal resolution allow accurate observation of the growing conditions.

SeaWinds datasets from January 2000 until December 2003 were used, based on the Level 2A product provided by NASA and Ifremer (French Research Institute for Exploitation of the Sea). Further information about the basic data processing is given in [6].

As a first processing step all singular σ^0 measurements with their footprint centre located within a radius of 12.5 km from the centre of the test area were extracted and collocated into two time series depending on their polarization i.e. inner- or outer beam [7]. For each beam the measurements of the individual orbits were averaged to a value representing the mean backscattering coefficient, σ^0 (Figure 1).

Different common methods for planting date estimation was used for the validation of the scatterometer algorithm. The data sets for these comparison studies include weather station data, satellite derived rainfall estimates (RFE) and normalised difference vegetation index (NDVI).

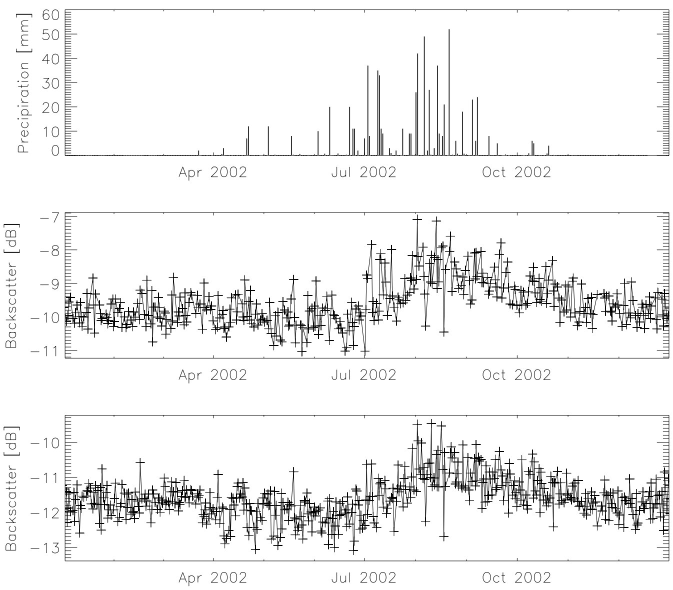


Fig. 1. Daily precipitation in mm, inner and outer beam backscattering coefficient in dezibel. The time series show the data of year 2002 for Bamako (Mali) at 7.95W, 12.53N.

In-situ soil moisture time series are obtained from the network of 23 time domain reflectometry (TDR) [8] soil moisture measurment stations that the University of Salamanca has set up in the area [9]. The time covered by this dataset is 1999-2003. For each station soil moisture values are recorded for the depth of 5 cm as well as an average value of the topmost 25 cm.

III. Algorithm

The backscatter time series of inner and outer beam in figure 1 shows a long-term increase of the backscatter during the rainy season and some peaks, which can be related to single rainfall events. This continuous increase of the backscatter signal is related to the rise of surface soil moisture and vegetation growth. The magnitude of the influence of soil moisture and vegetation changes on the backscatter signal at the K_u-band is not clear so far. However, the temporal development of the scatterometer signal is sufficient for the estimation of planting dates. Obviously, the increase of the signal indicates good growing conditions, independent if it is caused by a high soil moisture content or strong plant growth. The decrease of the backscatter signal at the end of the rainy season indicates the decrease of vegetation and the loss of soil moisture.

The time series shows a high temporal variation. For a clear identification of the onset of the long term increase of the signal, it is necessary to reduce these high variation caused by noise and detection of singular rainfall events. A simple moving average filter was applied to the time series with an characteristic time length of ten days.

The filtered backscatter signal allow a clear identification of the growing period. The onset of the continuous increase of

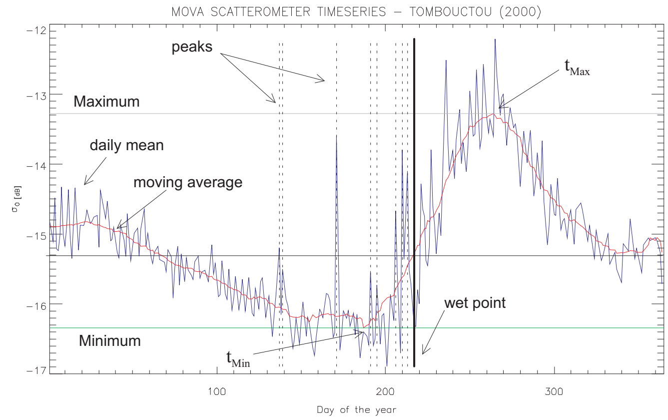


Fig. 2. Daily orbit raw values and moving average filtered of backscatter coefficient time series of the year 2000 at Tombouctou, Mali, (3W,16.71N). The figure shows additional the peak values and the wet point estimated by the scatterometer planting date algorithm.

the backscatter signal can be defined as the latest planting date in a first approach. In the subsequent text this point is referred to as the wet-point t_{wet}. Mathematically speaking, the time t_{wet} is defined as the moment, when the filtered backscatter time series exceeds a specified threshold value as illustrated in figure **??** and as defined by equation 1.

$$\overline{\sigma_0}(t_{wet}) \geq \overline{\sigma_0}(t_{min}) + f_0(\overline{\sigma_0}(t_{max}) - \overline{\sigma_0}(t_{min})) \quad (1)$$

At the dates t_{max} and t_{min} the moving average of the backscatter coefficient reaches its peak or its minimal value, respectively. f_0 defines the threshold value with respect to the difference between maximum and minimum filtered radar backscatter. The time t_{wet} indicates good growing conditions. The farmers will have planted at this moment in any case.

The farmer usually starts planting, when the soil stores enough water for the germination including reserve for short dry spells. Peaks in the raw scatterometer time series represent significant rain fall events shortly before the passing of the sensor. The behaviour of the farmer can be considered by the assumption, that peaks in the scatterometer time series within a certain time period $\Delta t_{Planting}$ before t_{wet} are potential planting dates. A peak at the time $t_{Peak,n}$ is defined as:

$$\sigma_{t_{Peak,n}} \geq \overline{\sigma_0}(t_{Peak,n}) + f_1 \Delta\overline{\sigma_0} \quad (2)$$

The parameter f_1 defines, by which factor the backscatter peak has to exceed the standard derivation with respect to the moving average at the same time. The farmer will plant his crop just after he observes a big rainfall event, if it is late enough in the year for continuous rainfalls. The planting will be successful, when the time difference between the planting and t_{wet} is not greater then $\Delta t_{Planting}$. The first scatterometer peak within the planting period $\Delta t_{Planting}$ offers a high opportunity for successful planting:

$$t_{Planting} = Minimum(t_{Peak,n}) \leq t_{Peak,n} \leq t_{wet} \quad (3)$$

with $t_{wet} - \Delta t_{Planting}$. Of course the individual parameters like $\Delta t_{Planting}$ could be adjusted for local conditions, crop and soil types. t_{wet} can be adjusted to crop types with different water demand by modifying the f_0 coefficient.

Compared to other algorithms, like the observation of station rainfall, the method is not affected by strong early rainfalls. The wet-point t_{wet} indicates a proceeding growing phase. The individual farmer should have planted his crop at this moment at the latest. Certainly the farmer will still plant before the estimated planting date, if the necessary rainfall events fail to appear for too long.

IV. ANALYSIS

A. Comparison with established methods

Unfortunately, there are no major studies on the quality of different planting date algorithms and the models representing these algorithms. All of them are consistent at first sight. They show a general trend of decreasing planting dates from South to North as expected due to the movement of the Inter Tropical Convergence Zone (ITCZ). The results of the different planting date estimation techniques vary around the planting periods, which are reported from ground observations.

The measurement at the weather stations in countries with poor infrastructure is irregular. Missing data limit the success of these methods in many cases. In the year 2000 only the weather station at Bamako, the capital city of Mali, provided sufficient data for planting date estimation. Only the satellite derived RFE and NDVI data sets were sufficient for a comparison analysis.

Figures 3(a) and 3(b) show a comparison between the radar scatterometer planting dates and planting dates estimated by the other data sets. The cross points of the plots indicate the wet point versus the planting date of the other methods and the diamonds mark the radar planting date. For the RFE the planting date was defined as the moment, when the rain rate exceeds 4 mm/day. The NDVI indicate the onset of the growing season, if it exceed his minimum value by over 10%.

The RFE derived planting dates are in good consistence with the scatterometer planting dates. The planting dates estimated from the NDVI data are over one week behind the scatterometer dates beside some cases, where the NDVI result in too early planting dates. The planting dates estimated with RFE and the scatterometer algorithm are in good agreement with crop report of the Food and Agriculture Organisation of the United Nations [10].

Figure 4 shows the south-north trend of the planting date and wet-point date estimated by the radar scatterometer. The movement of the Intertropical Convergence Zone causes this characteristic time change between the northern and southern parts of Mali.

B. Contribution of surface soil moisture

The raw backscatter coefficient time series indicate a high correlation with precipitation events for the soil moisture test side at the Duero basin. This fact exhibits points to a high sensitivity of the backscatter coefficient to the surface soil moisture content.

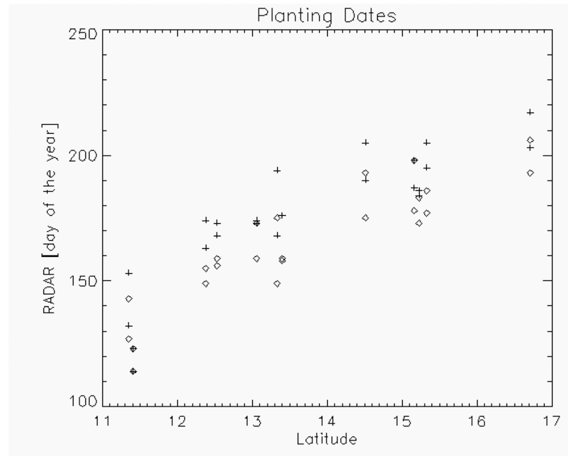


Fig. 4. North-south distribution of the radar scatterometer dates

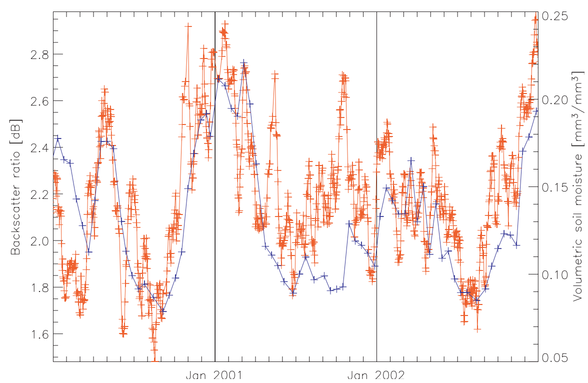


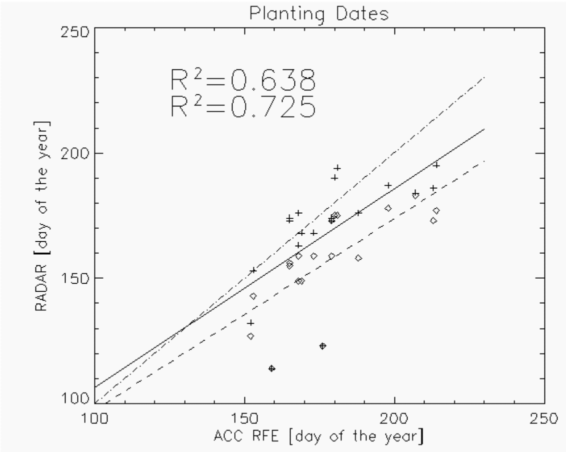
Fig. 5. Backscater beam ratio filtered with a moving average filter with a window size of ten days and volumetric soil moisture of the 5 cm top most soil layer. The test site is located near the Duero (Spain) at 41N and 5W.

The time series showed low response to vegetation dynamics. This unexpected result could be caused by the dominating agriculture. In the test area especially sun flowers and vineyards are the dominant cultivation.

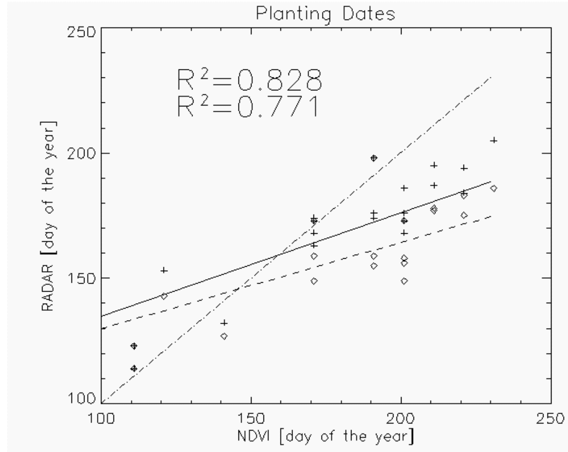
For the reduction of the seasonal trend on the SeaWinds backscatter in the further analysis the ratio between inner and outer beam was used. Previous studies [11] show a certain relationship between this SeaWinds beam ratio and surface soil moisture and reduce seasonal effect caused by vegetation.

Although the increase of signal during humid periods is present in the ratio time series, by combining the two beams a higher noise level is induced into the signal. It is necessary to use filtering techniques for a further analysis of the beam ratio series. For this study a basic moving average filter is used to reduce the noise level. In figure 5 a window size of 10 days was used for the filtering of the ratio time series.

In general both in-situ soil moisture nd the averaged ratio series show the same trend. Every peak in the soil moisture series correspond with a peak in the ratio series , but the ratio series is more dynamic. Some peaks in the ratio series are missing in the soil moisture series. The higher dynamic reflects the fact, that the backscatter interact with less then



(a) Planting date estimated by radar backscatter and RFE.



(b) Planting date estimated by radar backscatter and NDVI.

Fig. 3. For the study the planting dates at twelve different locations in Mali was estimated by the scatterometer algorithm for the year 2000-2002. Satellite derived rainfall estimates (RFE) was used for the validation because of unreliable weather station data in Mali.

one centimetre of the top most soil layer.

V. Conclusion

The differences between all planting date estimation methods make it difficult to draw a clear conclusion about the quality of the different approaches. It would be necessary to compare the techniques to extensive field measurements of planting date. Also precipitation, evapotranspiration and soil moisture data should be collected. However, the analyses lead to some important results. It became clear, that the deficiencies of ground measurements mainly caused by missing data are enormous. The weather station data are of limited significance, and it is impossible to make comparative long-term studies based on these data sets in Mali.

The NDVI only responds with a delay to changes of vegetation and soil moisture. Due to atmospheric influences like cloud coverage the NDVI can be used only with a reduced temporal resolution of around ten days. Nevertheless, long term NDVI data series exist and are widely used. The NDVI has been used for many years. In contrast to other remote sensing parameters it is very likely, that NDVI calculations will continue for the next years. The NDVI is adequate for long-term studies, where high temporal resolution is not required.

The newly developed radar scatterometer technique has proven its capability for planting date estimation. The high temporal resolution of the SeaWinds scatterometer permits a significant improvement in the estimation of planting dates. The backscatter signal has additional proven to be in good correlation with surface soil moisture and therefore is capable to indicate sufficient growing conditions even in the germination period.

Further research on planting date estimation has to focus on the spatial analysis of the data parallel to a validation in the field. The spatial patterns of planting date estimates should coincide with ground conditions. This would also improve the statistical relevance and provide a chance to continue with these analyses for more test sites and to continue the research for the proceeding years.

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