Abstract

Agriculture is a basic ingredient for building economy of a society and its production is therefore required to be considered and optimized. Moreover, Increase in the requirement for long-term and environment related use of natural resources along with a price effective and limiting use of fertilizers and pesticides oblige the engagement of modern technologies in agriculture.

In this research, the backscatter signatures of TerraSAR-X images from different crops, keeping mainly the impact of the temperature and precipitation under consideration, were evaluated. This is done by using TerraSAR-X images along with GIS information like fields spatial geometry including ground surveys. The sample data of three years (2010-2012) for crop seasons (April-October) on monthly basis for the test site is taken. The SAR backscatter signatures from Mössingen farmlands in Baden-Württemberg, are observed from 373 fields consisting of seven major crop types. In this study the correlation between SAR images and the farmlands conditions’ change, particularly in accordance with daily heat accumulations, is also investigated and a comparison of the three years’ SAR backscatter signatures is made for each crop type.

From the literature, it was found that Growing Degree Days (GDD) could be proved to be the best suitable parameter for finding the influence of daily temperatures on crops and hence on the TerraSAR-X backscatter. It is found that the SAR backscatter from farmlands depends upon the acquisition time during the crop season. It varies with the variant development stages of crop pants and local temperatures directly impact the crops development.

Introduction

The electromagnetic response of the different parts of a crop cover not only depends on the wavelength used for observation, but it also varies because of the season, angle of incidence of the sensor, crop’s features, illumination intensity, meteorological phenomenon and topography among other external factors. In this regard, Pinter et al. (2003) concluded that a significant challenge for agricultural remote sensing applications is to make the spectral signals originating with a plant response to be isolated to a
specific stress from signals associated with normal plant biomass or the background noise that is introduced by exogenous non-plant factor.

In fact, there are a number of types of remote sensing data available for crops’ monitoring. In this perspective, optical remote sensing data is among the most used. Many relevant applications of this type of data for several sensors have been reported to have noteworthy achievements due to the results reached from the physical understanding of the crops’ responses for optical bands (Ding and Chen, 2012). Nevertheless, due to the necessity of the daylight for illuminating the objects, the use of this kind of data is limited. It is hard to provide data on a regular basis using optical images because of cloud cover.

Another source of remote sensing data are the microwave sensors, that have a great capability to penetrate clouds and to some extend rain, and is the best possibility to operate in a wider range of weather conditions (Liu and Wu, 2001). In contrast to optical remote sensing sensors, microwave sensors are independent of sun illumination; therefore, having the capability of operating both day and night.

There are two ways to get microwave remote sensing data: using active sensors and using passive sensors. The active sensors are preferred on passive sensors due to the fact that these have perhaps higher resolution than passive sensors (Lu et al., 2008). Though the microwaves have a great capability to penetrate the clouds, the Real Aperture Radar (RAR) has a detriment that the azimuth resolution of images is not sufficiently good. Therefore, for radar images with better resolution one needs to combine both the radar technology and signal processing into the so-called Synthetic Aperture Radar (SAR) which is a common active sensor for microwave (Paul, 1997).

In comparison to the optical remote sensing, the SAR images for monitoring the vegetation are still not extensively applied for educational as well as industrial objects. Therefore, some related acquaintance about the impact of the vegetation conditions on the backscatter is required for using the SAR images to manage and monitor the agriculture resources (Nieuwenhuis and Kramer, 1996, Blumberg, 2007).

As global warming influences the whole world, Baden-Württemberg cannot be considered different. In this region, there are different situations of climate in terms of precipitation and temperature as compared to rest of the world which directly influence farmer’s activities in the fields with respect to seeding and harvesting time. Even a small increase in monthly temperature can cause whole crops to wither or be entirely destroyed. The overall worldwide temperature has been raised by 0.6 °C during the last 50 years. Climate change affects all the sectors of life. For instance, it affects the water balance and agriculture in such a way that there is lower groundwater level in summer whereas an even wetter winter than before, resulting in a possible decline in the agricultural production of wheat while more corn is produced. This shows a possibility of a warmer climate in future (LUBW, 2010). Furthermore, as the Baden-Württemberg has regions with different altitude and terrain characteristics like the Black Forest and Swabian Alps, the phenological stages of crops are different in various parts of the state. For this reason, the use of temperature interpolations, for getting precise local temperatures from the weather stations’ temperature measurements becomes complicated and hence not very expedient.
Aim and Objectives

The main aim of this study is to:

1. Compare the backscatter values with the fields’ ground truth information.
2. Find some meteorological approaches for the analysis of crop morphology.

In the current study, the analysis of backscatter values from TerraSAR-X remote sensing images is pursued. The backscatter signatures of different crops were derived for three years on a monthly basis and the correlation between these SAR images and the changes in farmlands conditions, particularly in accordance with heat accumulations, is investigated and a comparison of the three years’ SAR backscatter signatures is completed for various crops.

The specific objectives are to:

1. Organize some of the important crop types which are common in all the selected years.
2. Generate backscatter signatures for all the fields in groups of crop cultures within the test site.
3. Elaborate the behavior of different crop cultures according to their specific backscatter values.
4. Establish some techniques to incorporate the daily mean temperatures for the calculation of amount of heat used by the plant for its growth.
5. Find the effect of daily heat accumulations and precipitation on the SAR backscatter values from different crops.
6. Interpolate the average air temperature in order to get good estimation of the heat accumulations on local scale within the test site.

Study Area

The study area is located in the area of Burladingen near-Albstadt in the German state Baden Württemberg (BW). At a distance of about 75 km from Stuttgart, this area is sited near-Mössingen in the district of Tübingen. The extent of the scene acquired by TerraSAR-X is quite larger as compared to the concerned test site. The approximate coordinates of SAR scene, starting from upper-left corner in clockwise direction, are 48°31’55”N 8°49’33”E, 48°28’31”N 9°15’42”E, 48°17’21”N 9°11’54”E, 48°20’41”N 8°46’15”E. The area covered by the SAR-images has elevation values ranging from ~380m to ~880m but the concerned test site area has an estimated average elevation of 800 meters (© Google Earth 2011).
Figure 1: Spatial Location of the SAR Cover (Imagery)

Figure 2: Locations of the Observed Fields (Imagery)
Methodology

The data preparation in this study includes the meteorological data management, SAR images unzipping and their clipping processes. The data preprocessing of the SAR data includes the radiometric calibration and vector data projection system transformation. The complete radiometric calibration process can be divided into four parts as follows.

1. Extraction of the local incidence angle
2. Calculation of the beta naught
3. Calculation of the sigma naught
4. Calculation of the gamma naught

The SAR data post processing techniques which are used in this study are SAR data and GIS data processing and calculation of Growing Degree Days (GDD) for each crop type. The maximum and minimum centigrade temperatures and the base temperatures in centigrade for each crop culture were added in excel columns which were then manipulated according to the formula in equation 1.

\[
GDD = \frac{T_{\text{max}} + T_{\text{min}}}{2} - T_{\text{base}} \quad (1)
\]
If \( T_{average} = \frac{T_{max} + T_{min}}{2} < T_{base} \) then GDD = 0

Where, \( T_{max} \) and \( T_{min} \) are the daily maximum and minimum temperatures respectively and \( T_{base} \) is the base temperature which is different for different crops. This is a critical temperature at or below which the growth of the crop is stopped (Gordon and Bootsma, 1993).

These GDDs were calculated and saved in the corresponding excel column for the complete three years (from Jan. 01, 2010 till Dec. 31, 2012). These calculated degree days were then accumulated for whole of the years. This was executed in a way that every day’s accumulation was an integration of all the GDDs from Jan. 01 till the date.

**Formulation of Results**

Excel tables for different years were generated for all the available crop types that incorporated the means against the corresponding months along with the identity number of the fields. For instance data in table 1 represents an example of Rye 2012 where MM stands for mean of all the means from every month.

*Table 1: Excel Table for Means of Backscatter (\( \gamma^0 \)) from Rye Fields in 2012*

<table>
<thead>
<tr>
<th>IDNEW</th>
<th>Apr_12</th>
<th>May_12</th>
<th>Jun_12</th>
<th>Jul_12a</th>
<th>Jul_12b</th>
<th>Aug_12</th>
<th>Sep_12</th>
<th>Oct_12</th>
</tr>
</thead>
</table>

For further analyses, the means for each crop have been plotted using the plot option in MS Excel. The MM which is a so called reference backscatter signature is shown red within the backscatter signatures of all the fields. An example of Rye 2012 is shown in figure 4 in which x-axis contains time (acquisition basis) and on y-axis, there exists backscatter or gamma naught.
The tables and plots for all the available crops were generated in the same way. The means of means for each crop type have been plotted separately for all the three years 2010, 2011 and 2012. An example of Rye (figure 5) is presented here underneath.

\textit{Figure 5: Multiannual Means of Means (MM) from }$\gamma^0$\textit{ of Rye Fields}

The day by day growing degree days' (GDDs) accumulation was calculated and then plotted for all the three years for the different crops present in the study area. The critical temperature used for calculating the GDDs for most of the crops is 4.44 °C whereas a base temperature of 10 °C is used for the
corn only. The analyses of all the available crops have been completed for every year and every group based on seasonal or early or late development. The backscatter means of means (MM) and GDDs’ accumulations for all the three years have been plotted within a single frame in order to compare backscatter from crops and heat accumulation on multiannual bases. An example of Rye is presented in figure 6 under.

Crops’ Monitoring

There were total seven crop types that existed within the current test site in all the three years 2010, 2011 and 2012. The means of SAR backscatter from the concerned crops were plotted and analyzed for these three years separately. In order to compare SAR backscatter from these crops and heat accumulation on multiannual scale, the backscatter means of means (MM) and GDD accumulations for all the three years have been plotted within a single frame. These seven crop types that are listed below have been studied in detail.

1. Barley
2. Wheat
3. Rye
4. Corn
5. Red Clover
6. Ryegrass
7. Rapeseed

For the analysis of SAR backscatter from all the fields, these fields were separated into different groups for every crop type according to their year of existence and seasonal seeding. The SAR backscatter for all these fields, even within one group, shows variations depending upon their different growth and development rates. This is due to the fact that the rate of development and dry matter accumulation depends upon a number of environmental aspects including the amount of temperature, light, carbon dioxide, humidity and soil moisture and leaf water prestige over a wide optimal temperature range. Furthermore, SAR backscatter also varies with variation in the dielectric constant (soil moisture and leaf water) and other conditions within the fields. For instance, saturated soil is a strong reflector whereas dry soil has low radar reflectivity which results a decrease in the backscatter (Walker, 2014). Hence SAR backscatters from different fields with different growth and development rate is resulted to be differentiated but not truly explainable within a short information spectrum like the contemporary studies have. For example, there used the temperature and precipitation (prior to SAR acquisition time) values measured by a nearest available weather station with an analogous height and at this weather station, no rain was observed prior to SAR acquisition time which does not guarantee the unavailability of rain and/or dew in the test site region.
Multiannual Comparison of Rye

In figure 6, plots of $\gamma^0$ means of means (MM) and GDD accumulations for Rye are given for the comparative analysis of different years. The x-axis contains the typical date and there are two y-axes, one is the primary y-axis which contains the calculated GDD accumulation and the other is the secondary y-axis which is showing the values of backscatter, the so called gamma naught. For the purpose of quantitative comparison between different years, only those values of both y-axes have been plotted which correspond to TerraSAR-X acquisition dates and trend lines (in MS Excel) have been used for identifying the relative shifts of $\gamma^0$ (MM) between the different years. Obviously, there are shifts that can be explained by considering them along the two axes, the x-axis and the y-axis. Along y-axis amplitude of $\gamma^0$ changes which depends upon the individual fields’ parameters like dielectric constant (soil moisture or leaf water status), rows’ spacing (soil impact) and other fields. Likewise, there is a shift in the monthly trends of $\gamma^0$. This so-called x-shift is due to a shift in the development stages which is directly related to GDD. Hence in figure 6, when there are more spaces between the two years’ plots of GDD accumulation on a particular SAR acquisition date, more x-shift is observed between these years’ corresponding backscatter trends. There is a clear shift between the backscatter signatures of 2010, 2011 and 2012. This x-shift is due to the fact that 2011 was a warmer year as compared to 2010 and 2012 which can be seen by observing the GDD plots of the corresponding years in figure 6. So it can be concluded that due to the least warmth comparatively, the development in the year of 2010 was late as compared to 2012 which has even slower development rate than that of 2011 only in the 1st half of the cultivation time because latter in August and September, these two years became equally warmed.

![Figure 6: Comparison of Three Years’ $\gamma^0$ from Winter Rye and GDD Accumulations for Rye with 4.44 °C as $T_{\text{base}}$](image)
Conclusions and Recommendations

In this study, the TerraSAR-X backscatter signatures of different crop types were generated for the investigation of the crops conditions which has a direct correlation with the backscatter. Reference curves showing means of means (MM) for each crop type suggest roughly the changes of the backscatter signatures with respect to the time. The following points are concluded by exploiting the available resources.

1. The backscatter signatures imply the phenology stages, meaning every acquired backscatter value implies some particular level of growth and development of the crop plant.

2. GDD is a direct measure for the development rate of the crop which influences the corresponding backscatter values. This is also the idea behind its use in the current study instead of exploiting some other approach that incorporates the temperature values e.g. the accumulation of daily mean temperatures only.

3. The GDD approach is exploitable in different environments and geographical locations if the local temperature information is available.

4. Any ordinary temperature interpolation was not very useful due to the complex weather conditions in the vicinity of the test site which has Swabian Alps on one side whereas Black Forest on the other. So it was decided to use temperature and precipitation (prior to SAR acquisition time) values measured by a nearest available weather station with a similar height.

5. The accuracy of the implied results can be increased by using optimized temperature interpolations to get more precise local temperatures from the weather stations’ temperature measurements. Similarly there is a need for finding some method for estimating the occurrence of precipitation and dew (dew point temperature) on local level more precisely. In this way the moisture present on the surface of the leaves during the acquisition time can be estimated.

References


