SPOT VEGETATION CONTRIBUTION TO DESERT LOCUST HABITAT MONITORING

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Summary

The Desert Locust, scientifically known as *Schistocerca gregaria*, was first reported as a threat to humankind as the eighth biblical plague of Egypt and regular upsurges still occur. To prevent plagues, early detection and immediate control of locust populations are required. Continuous information about locust populations and ecological conditions, such as rain and vegetation, is needed. Ground data collection is limited and expensive. Satellite imagery offers a synoptic overview of potential rainfall and vegetation development over desert locust habitats. In the framework of an EU/JRC–FAO agreement and financial support of the EU, SPOT VEGETATION imagery was made available to FAO. Introduction into the operational activities of the locust forecasters at FAO Rome was undertaken under a SSTC funded project. A reliable NDVI threshold to visualise the distinction between bare soil and sparse vegetation was established on S10 products and a positive relation of S10-NDVI with sparse plant cover was confirmed. Analysis was undertaken for the detection of soil moisture using SPOT SWIR band on S1 data. After a rain event, a significant drop in reflectance of the SWIR band was identified compared to other channels, but more work is needed to confirm this trend.

Introduction

The Desert Locust, *Schistocerca gregaria*, is a common threat to agriculture, subsistence farming and vulnerable pastures, which are indispensable for life to the people resisting hardship in desert and semi-desert areas of northern Africa, the Middle East and south-west Asia. Ensuring food security through technology transfer to improve or optimise farm practices and to increase food production can only be at its maximum efficiency when safekeeping of the existing food crops is well established. Integrated Pest Management and protection against migrant pests plays a crucial role in this process. Control of the migrant Desert Locust is an important part of the general effort ensuring food security. To further improve the combating of locust pests in general, and to improve its routine global monitoring and forecasting activities for its member countries, FAO is implementing a regional Emergency Prevention programme, EMPRES. One aspect of the programme focuses on increasing early warning capabilities and potential in view of optimising routine monitoring of the locust situation. Integration of various data sources, such as field information, meteorological data and satellite remote sensing products, can improve the efficiency of field surveys, the planning of control and the containment of locust plagues in general.

The current research (*) is executed in a partnership between the Université Catholique de Louvain-La-Neuve (UCL), the Joint Research Centre of the EU at Ispra (JRC) and the Food and Agriculture Organization of the United Nations (FAO), combining the required complementary technical and application based experiences. The objectives of the research are: (i) detection of soil humidity; (ii) improvement of the measurement of vegetation growth; (iii) transformation of data for fast delivery

Locust Management

Preventive control of localized Desert Locust outbreaks, defined as a sudden increase in populations exhibiting or beginning to exhibit gregarious behaviour, is the corner stone of the current adopted strategy in containing the migrant Desert Locust pest (FAO report on the DLCC, 1999). Efficient early detection and control of these outbreaks ensures not only overall success, but also reduces costs, scale and environmental hazards of chemical control. An accepted level of early detection can be achieved by routine monitoring of locust habitats and by forecasting where and how populations might develop. In view of the migrant character of the pest, this is needed at both national and global levels, covering the entire recession area (Plate 1).

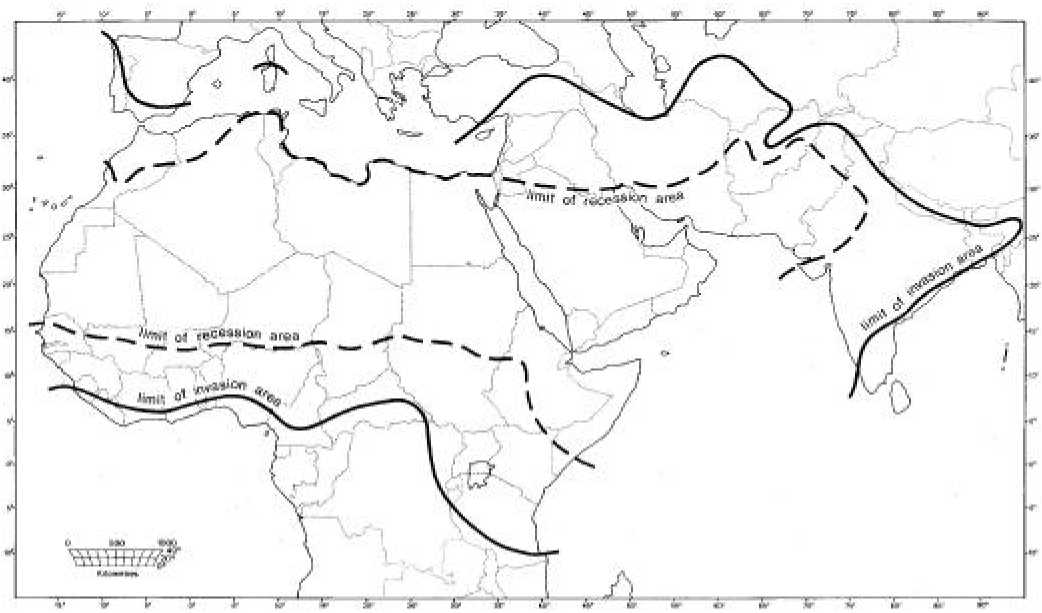


Plate 1. Distribution of the Desert Locust

National Plant Protection Services organise field surveys to obtain an idea of the locust populations and the condition of the locust habitats in terms of soil moisture and vegetation. Worthwhile targets, large enough populations of hoppers or adult insects, are controlled. Otherwise, population or significant humidity and vegetation information is assessed for further monitoring. Information is communicated by radio to the national centre, where it is interpreted. FAO, with financial support of the Belgian Co-operation Agency and in collaboration with the Natural Resources Institute (NRI, University of Greenwich) developed a GIS application called RAMSES, currently installed in two countries, to allow full digital manipulation of these data in a spatial context. (FAO/GCP/INT/596/BEL, 1998; Cherlet M.R., 1996)

Information is regularly sent every ten days or several times per month by e-mail to the FAO in Rome where a global situation assessment and forecast is made (http://www.fao.org/NEWS/GLOBAL/locusts/locuhome.HTM). At FAO the country data is evaluated together with meteorological information and low resolution satellite information using a GIS application, called SWARMS, designed for managing global datasets. A FAO locust situation and forecast bulletin is then prepared monthly. If the locust situation is critical, intermediate warning bulletins are issued. The monthly bulletin, electronically distributed, gives affected countries timely information on the situation in neighbouring countries or regions in order to plan their survey and control operations. The bulletin is also directed to the donor community in view of policy decision making for country support or emergency interventions. It is of further use to the scientific community.

SPOT VGT in Locust Management

The highly required field surveys, however, are expensive, cover small areas and cannot be frequent. Vast expanses have to be covered "blindly" and the erratic and unpredictable nature of meteorological events means that not all favourable conditions can be detected. Rainfall being the first indicator of potentially good habitat conditions, Meteosat-based Cold Cloud Duration and rainfall estimates (Snijders, 1991) were applied but results are still not adequate over desert areas. Falling back to the secondary effects of rainfall, soil moisture and vegetation, both crucial for locust development, NOAA AVHRR data were introduced to FAO by the FAO ARTEMIS system in view of obtaining frequent synoptic overviews of the vegetation situation over the recession area (Cherlet M.R. & Hielkema J.U. 1989). Some methods to increase the reliability of the NOAA NDVI were developed (Cherlet M.R. & al., 1991; Cherlet M.R. & Di Gregorio A., 1993), but results for detecting very sparse vegetation remained limited conditioned by the poor NOAA AVHRR image positioning, poor calibration and high sensitivity of the NDVI-MVC compositing technique to directional perturbing factors. Furthermore, the delivery delays and discontinued spatial cover made fully operational use of NOAA data difficult. Through its design and distribution policy (http://spot4.cnes.fr/spot4_gb/index.htm), SPOT VEGETATION now offers an immediate advantage on these shortcomings, although the operational experience up to date concerning the timely delivery is not satisfactory. For locust work, delays can be only in the order of three to four days for vegetation monitoring; for soil moisture monitoring delays can only be two days or less.

Operational Integration

In response to the immediate operational needs, the integration of the SPOT VGT data into the routine work in Rome was based on the experience with the NOAA data. Interpretation improvements were empirically established. The first step was to allow the locust forecaster easy and quick access to the imagery, which for the first time in history, routinely covered the complete recession area on a regular basis. The FAO software WINDISP (http://www.fao.org/WAICENT/faoinfo/economic/giews/english/windisp/windisp.htm) was used to create quick access projects for viewing country specific information. A first, albeit still rough, user product was designed to highlight the areas of significant vegetation development and/or change. In analogy to the approach of Hielkema (Hielkema, 1981), the number of pixels above a certain threshold on a half-degree grid basis are calculated and represented. Plate 2 shows this controlled way of re-sampling, allowing quick and easy overview. of the situation and the difference images give a first indication of change. . After this screening, the forecaster can "zoom" in to full resolution.

Related to this product and to the correct interpreting of the imagery for sparse vegetation in general, it is crucial to establish a reliable NDVI, or similar vegetation index, value threshold, which significantly indicates the transition of dominant soil reflectance into a dominant vegetation reflectance. Convergence of two quick empirical methods allowed definition of this threshold reasonably adequate for immediate operational use. At this stage of the project, only standard NDVI S10 products were used “as they are”.

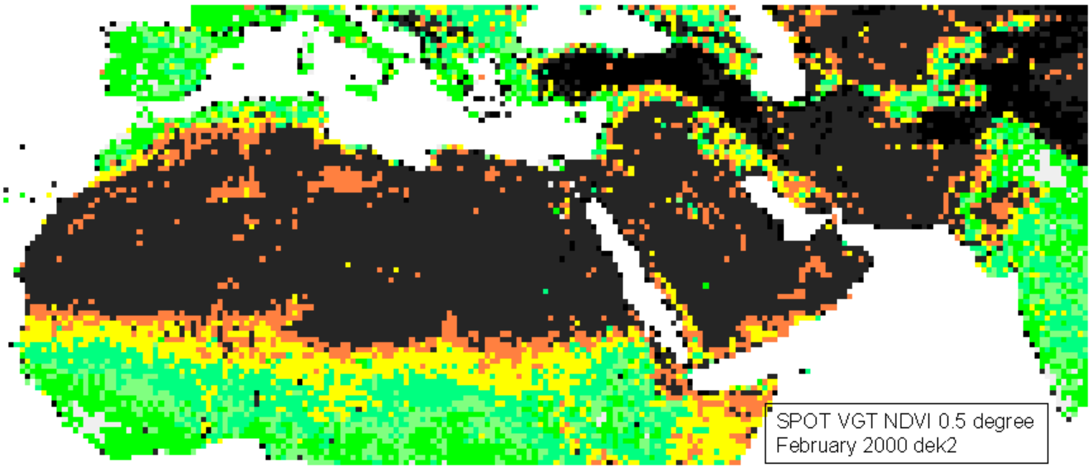


Plate 2 preliminary controlled re-sampling as overview product
(Brown: 5%> VI 0.14 ; Yellow: 5-30%>VI 0.14 ; LGreen: 30-85%>VI 0.14 ; DGreen >85% >VI 0.14)

SPOT VGT S10 NDVI Analysis

Temporal NDVI profiles

Firstly, area clustering and time series analysis indicated the general trends and level for thresholding. Plates 3 and 4 show time series for some areas of interest. For both areas, the oscillations around NDVI 0.1 during the first 6 to 7 decades (June-July 1999) are considered to be mainly due to background noise, “soil” reflectance fluctuations due to different sun intensities, atmospheric conditions and bi-directional effects. No meteorological events could cause plant-growing conditions during this period. Rain reported from mid July through August 1999 for both areas and the observable increase in NDVI value, suggest that green biomass starts to be significantly present from decade 8 and 9 (Aug). In Mali, plate 3, the main vegetation type was known and superimposition of the phenology curve of the dominant vegetation type, *Tribulus terrestris spp*., seems to confirm this trend. An NDVI value between 0.11 and 0.12 would distinguish between soil and vegetation in that area. Plate 4 for Sudan, shows the same pattern, but NDVI values have to be higher than 0.13 or 0.14 to separate them from the yet un-defined fluctuations earlier in the season.

Results of the simulated value ranges (plate 5) for single bands and NDVI, together with the operational time series indicate that an increase in NDVI value of at least 0.01 is needed to conclude that ‘something happened’. Plate 5 shows the simulated NDVI values for the Top Of Atmosphere (TOA) and Top Of Canopy (TOC) over a year period (Defourny P. & Schouppe M., 1996 to 1998; Wasseige de, et al., 2000). The TOC in black represents a fixed target, equal to a Sahara environment at 23 – 30 degrees N latitude. The variations in values illustrate the noise of the signal when using a stable target. Three main cycles can be observed: (I) seasonal cycle due to changes is solar angle; (ii) a 26 days cycle due to the satellite orbit effects and (iii) a 5 days cycle due to shifts in viewing angle from vertical zenith. Introduction of other effects such as the 30 years averaged aerosol thickness didn’t influence the actual reflectance or NDVI.

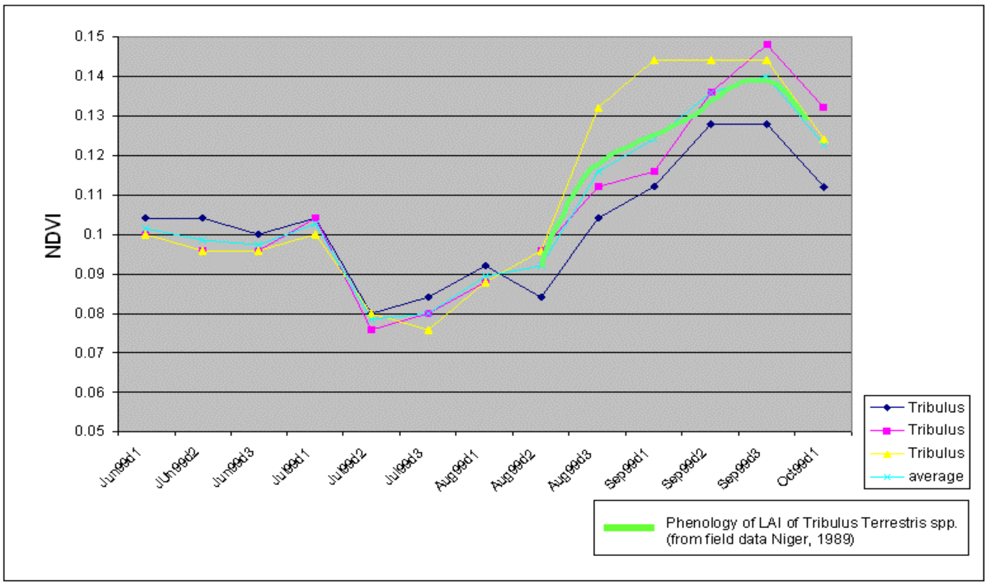


Plate 3 time series of SPOT VGT S10 NDVI for *Tribulus spp*.
Ajar plain, Adrar Mali (around 0.83E,18.67N)

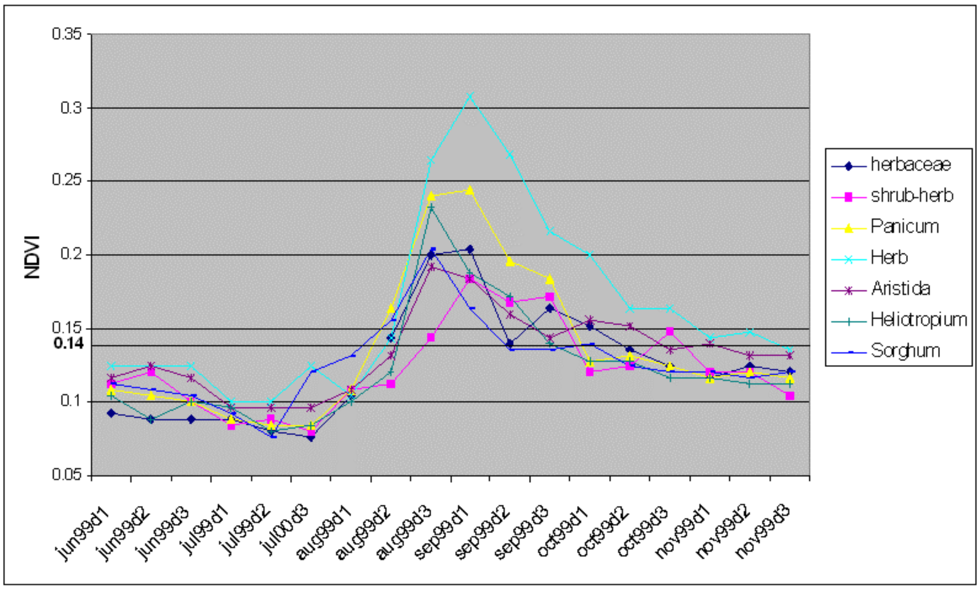


Plate 4 time series of SPOT VGT S10 NDVI for locust habitats in Sudan (around 35E,17N)

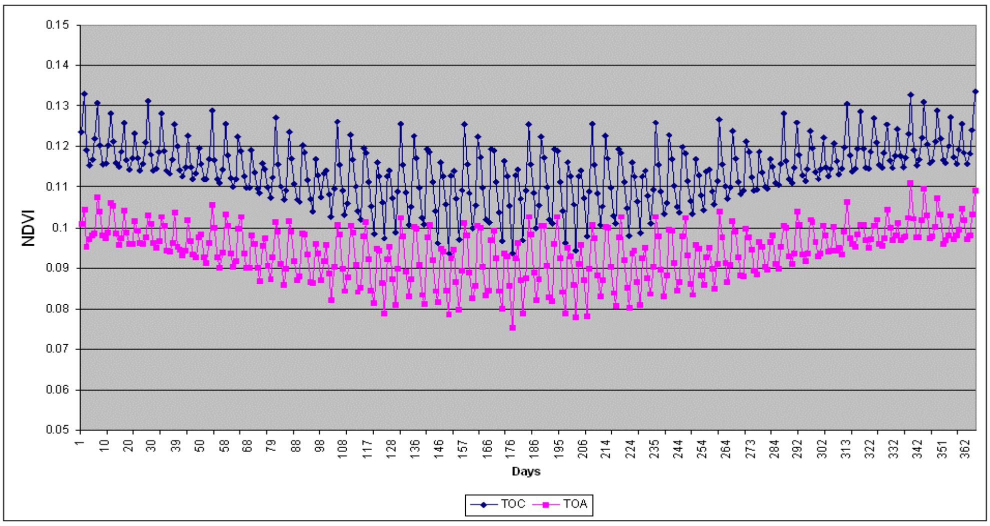


Plate 5 yearly simulated NDVI for Top Of Canopy (TOC) and Top Of Atmosphere (TOA)

Field data collections for these specific areas were requested from FAO in Mali and to the national teams of Sudan, Mauritania and Eritrea. Data on plant cover, species, soil and humidity were collected on requested and random GPS locations. This evidence suggested that a NDVI threshold of 0.14 is an acceptable threshold to be applied uniformly over the image. Most homogeneous events are picked up. Areas with very low vegetation cover of low LAI plants, such as the example in plate 3, or areas where zones of vegetation are too small and intersected, although favourable for locusts, are partly missed with such a threshold. In Sudan e.g. some GPS locations report 30% (which is still appreciable) cover of green vegetation and only show an NDVI of 0.076 : far below the 0.14 threshold, this may be due to the type of vegetation (low LAI) or the structure of the cover (spotty, rather than homogeneous). But a too low threshold set to include such low NDVI would seriously over-estimate vegetation in other areas. At this stage not enough background information is available to allow for habitat specific thresholds on S10 NDVI. Furthermore, relative indices and thresholds will be looked at.

On the temporal profiles, plates 3 and 4, a sudden drop in NDVI values can be observed during the 10-day period after which the first rains were reported. During the next ten days, the NDVI values increase again. Some hypotheses, such as cloud presence, atmospheric or ground effect, dry vegetation decomposition and impact of soil humidity on bi-directional reflectance, will have to be analysed on S1 single channel imagery. If this effect is found to be independent from general noise, it could be very valuable to include in the algorithm of a final user product.

NDVI related to Plant Cover

An average correlation between plant cover and NDVI was found to be 0.65. In general, a high plant cover yields a predictable high correlation, while the lower covers are more prone to wrong estimation with regard to the cover itself but also, as shown in the above example, to the potential development of the locust. Plate 6 shows the evolution of the SPOT VGT NDVI related to ground coverage of senescent vegetation in Sudan. The NDVI values show a clear positive relationship with the vegetation cover. The standard deviation shown for each of the coverage classes seems to increase with cover. This could be explained by the different phenological stages of the vegetation when cover is more abundant and which accounts for important variations in LAI resulting in different reflectance behaviour. A distinctive difference in NDVI values between the high and medium-low coverage (classes 1 – 2) suggests existence of a threshold of minimum percentage of actual vegetation cover needed to result in a distinct "green –biomass-NDVI" value.

Considering that, for plate 6, the phenological stage at the time of observation was senescent and that the data extraction is based on SPOT VGT S10 maximum composites, the same vegetation at maximum reflectance could have been actually more green. This would indicate a bias towards higher NDVI's for all the cover classes. However, because the bias applies to all the cover classes, this observation does not invalidate the above positive relationship between cover and NDVI which was moreover observed with a dataset of green vegetation, see plate 7. A steady decrease in NDVI with less cover (from class 1 to 3) and less decrease towards class 4 can be noticed. We want to note here that, up to date, the available data sets needed to be analysed separately as they are very heterogeneous, diverse, very often not complete and collected by many different observers. Sets of accompanying photos will be used trying to cross calibrate the field estimates.

Further on plate 7, we can observe a systematic lower NDVI value for all coverage classes during the 3rd 10-day period of February 2000, the time of the actual field observation, than compared with the 2nd 10-day period. During the 3rd 10-day period the vegetation was observed close to maturation, hence values should be higher or very close to those of the 2nd 10-day period. The explanation apparent to date is that the effect is caused by presence of considerable thick aerosols due to continued sand storms at the end of February 2000, causing increased scattering.

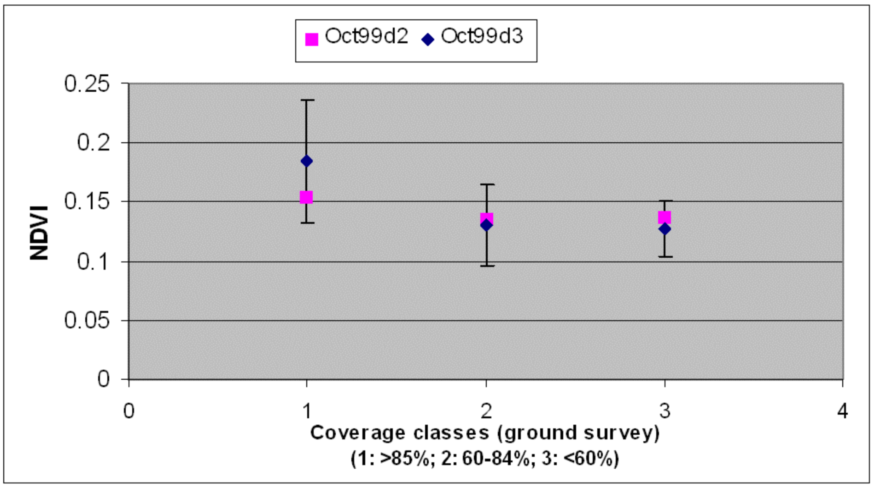


Plate 6 SPOT VGT S10 NDVI values related to ground cover (dry&drying vegetation) in desert area in Sudan

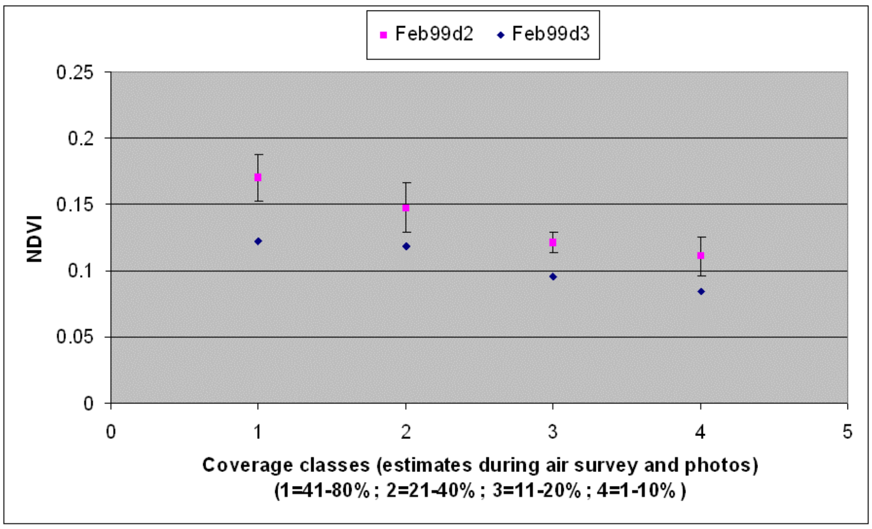


Plate 7 SPOT VGT S10 NDVI values related to ground cover (green vegetation) in desert areas in Mauritania

To the contrary, other, yet undetermined, factors influence NDVI values to result in relatively high values without presence of significant vegetation on the ground. Time series of the rocky outcrop, Jebel Elba in South-Western Egypt, scores considerable NDVI values from end November 1999 onwards. While in February 2000 during field observation no significant vegetation was reported.

Further analysis is needed to see how to take into account the effect of soil reflectance and bi-directional effects in a manner that remains compatible with the operational constraints of the EMPRES project. The hypothesis to be verified is whether it is possible further to lower the threshold at which growth of very sparse vegetation can be detected with full confidence, whether habitat specific threshold should be established or if a change threshold would be more indicative.

SPOT VGT SWIR Analysis for detection of soil humidity

Over the whole of the recession area, 45 weather stations reported rain during the period 21/10/99 till 20/11/99, for which also SPOT VGT S1 imagery was available. Based on this data only stations which reported rain during several consecutive days were selected. This was done assuming that surface humidity should be more apparent. Out of 45 only 9 stations were finally used in the analysis: 5 in Morocco, 2 in Algeria and 2 in Sudan. Not all are very representative for key breeding areas, but are in the arid belt. During this exercise it became clear that available rainfall data is on the one hand very sparse and on the other hand not of very reliable quality. Daily rainfall data traditionally covers the period from mid-night to mid-night. As the SPOT VEGETATION has a pass over time at about 10:30 hrs, the daily data was recalculated from mid-day to mid-day to improve correlation with the satellite measure. In this way, the SPOT VGT observation relates effectively with events that potentially happen during the 24 hours preceding satellite pass over.

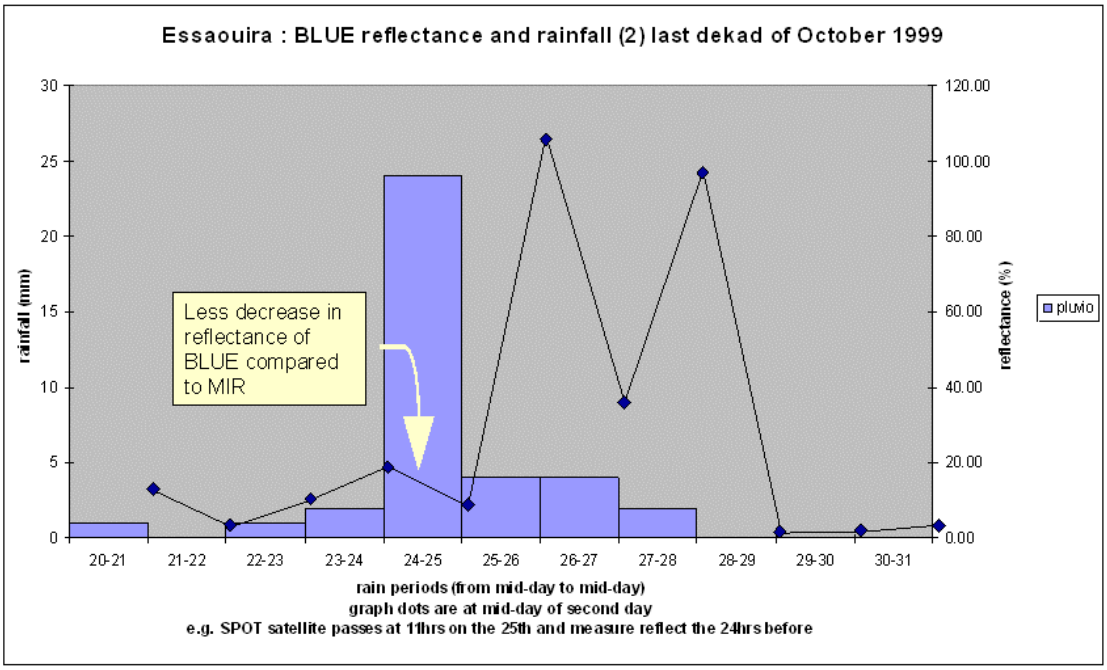
Extraction of band reflectance, based on S1 products, was performed only for the last 10-day period of October and the second of November 1999. No rain was reported during the other 10-day periods for which S1 products are available. Mean and standard deviation were extracted for each of the 4 channels using a 3x3 window around the geographic location of the stations. The response of the single bands to the rainfall events was evaluated by simply superposing the spectral profile of daily reflectance values and the daily rainfall data.

Related to the detection of the reaction of the SWIR to rain events, it became clear that the obvious cloud cover can persist during days, obstructing clear surface measures needed before and after the rain event. Cloud cover at satellite over pass results of course in very high reflectance values in all channels. However some quick dissolving clouds could give some possibilities of pure measures. In Agadir e.g. after a cloudy day on the 28th of October with, however, only 2mm reported rainfall, the next day appears clear on the image. The SWIR reflectance decreased by 25% on the 29th of October. Caution is needed though as this decrease, which in fact reached 90% in some other channels, might be the consequence caused by the disappearing of the clouds rather than an effect of marginally increased soil moisture.

From the dataset, only one clear and significant situation was found where before and after a relative important rain event, the sky was reportedly clear of clouds at satellite over pass. Plates 8 and 9 show the profiles for the Essaouira rain station in Morocco. Like the previous example, Agadir, reflectance in all bands drastically decrease just after the rain event. The

SWIR profile shows a much more remarkable fall of 75% relative to a 50% decrease of reflectance in the other bands. Based on the location of the station, east of the Atlas mountains, the importance of the rainfall, 25mm, and the obvious clear sky at satellite pass-over the day after the rain, we can assume that the significant drop in SWIR reflectance to be strongly related to the increase in surface moisture caused by the observed rain event. The drastic increase of reflectance in all bands the following three days is due to renewed cloud presence. Interesting to note is that at the end of the 10-day period the level of reflectance is at the lowest. It can be assumed that this is related to soil moisture accumulated after a few consecutive rain days. This is, however, unconfirmed until now.

At this time in the project, the given example is the only one identified and it is of course premature to generalise the observed effect in reflectance variation. It is even more premature to try to define a threshold of SWIR sensitivity to increased soil moisture. However, this hopeful example stimulates further research in this sense and databases will have to be expanded and scrutinised. On the other hand the difficulties encountered to find (cloud-free) data to work with puts in question the operational use of such approach. Hence, it is planned to look further at deviation and variations in time series of SWIR reflectance in relation to, yet to be established, longer-term dry season reflectance.



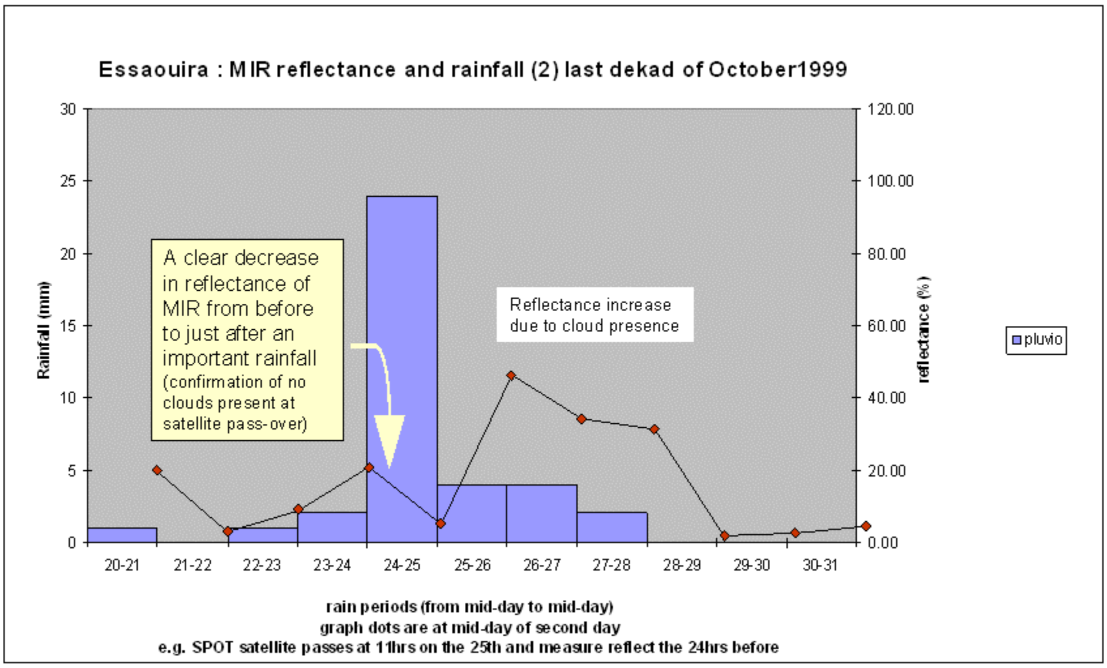


Plate 8 & 9 Reflectance profiles of SPOT bands related to rainfall during the last 10-day period of October 1999 for the station Essaouira in Morocco

Conclusions and perspectives

SPOT VEGETATION data has been successfully introduced into the operational activities of the Desert Locust Control Group in FAO, through agreements between JRC/EU and FAO. Within FAO data is made available through the ARTEMIS system. SPOT VGT S10 NDVI imagery is cut into a window presenting the complete Desert Locust recession area. Controlled re-sampling seems to be a valid approach helping the non-technical user in evaluating quickly large datasets. An interactive application will be developed to handle SPOT VGT data.

A threshold to distinguish bare soil from sparse vegetation, applicable over the whole window has been defined. Based on time series analysis and field verification, a generalised NDVI threshold at value 0.14 was defined for immediate operational use. This still leaves uncertainties in vegetation detection. A good correlation between NDVI, plant cover and phenology was found. After satisfying immediate operational needs based on existing S10 products, further work is to be undertaken to optimize the NDVI threshold or to apply different methods or vegetation indices to reliably estimate desert vegetation based on SPOT VGT. Proposals for new operational SPOT VGT user products might result from this research.

Signal noise related to satellite and sensor behaviour was identified as a disturbing factor. Bi-directional and compositing strategies, cloud and exceptional aerosols were found to influence the data, making user products less reliable. Collaboration with other research groups can improve on these problems.

Detection of soil moisture using the SPOT SWIR channel proved promising but difficult in terms of finding adequate data for verification and correlation with rainfall events. Apart from the research, this puts in question the operational use of the SWIR band for determining soil moisture changes immediately after rain events. It is therefor planned to undertake detailed statistical analysis on time series in relation with long term dry averages.

(*) **Acknowledgements**
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