NOAA/AVHRR Data for Crop Monitoring at a Regional Level: Possibilities and Limits in the European Context

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ABSTRACT

Crop monitoring with NOAA-AVHRR has been studied extensively over the last years, mainly in the large agricultural production areas with large fields and extensive cropping systems. Our first results, obtained from 1983 in the South of France, confirmed the usefulness of Normalized Difference Vegetation Index (NDVI) and surface temperatures (Ts) measurement with NOAA for a qualitative assessment of status of annual crops, in relation with the main land-use. However, several factors appeared as limiting for a more precise assessment:

- the problems associated with the physics of the measurement (angle of view, cloud detection, atmospheric corrections);
- these related to the small size of European fields, leading to the quasi systematic concept of mixed pixel associated to NOAA-AVHRR resolution (1 km²);
- the intensive level of production for most crops, making the assessment of biomass insufficient for a proper quantitative yield estimation.

The study supported by the JRC Ispra, within the frame of the “E.E.C. Pilot Project on remote sensing applied to agricultural forecasts”, for the years 87 to 90 aimed at the definition of possible methodologies based upon the complementary analysis of NDVI and Ts time profiles, for a quantitative assessment of regional yields. The paper presents the main results obtained and analyzes the progress in dealing with each of the three limiting factors above-defined and the main lines of research for coming years, identified from the main problems still unsolved.

INTRODUCTION

NOAA-AVHRR has been extensively used these last ten years for monitoring vegetation and assessing crop yield (cereals and pastures) in large areas, mainly Africa (for early warning purposes) (Tucker et al., 1984 ; Tucker et al., 1986 ; Johnson et al., 1987 ; Le Comte, 1989 ; Seguin et al., 1989 ; Prince, 1991 ; Hutchinson, 1991), but also Asia (Malingreau, 1986) or America (Boatwright and Whitehead, 1986 ; Gallo and Flesch, 1989 ; Philipson and Teng, 1988).

The application to cereal production in the European context is more difficult, for two reasons:

- the small size of fields (about 1ha typically), compared to the large dimensions in the extensive conditions of main cereal producers (USA and Canada, the past USSR, Australia, Argentina...),
- the high yields (between 5 and 10 t/ha), resulting from an intensive production with modern cultivars, high level of fertilizer inputs and pest control and a reduced sensitivity to weather fluctuations. Mean variations in yield generally stay below 10%, and classical statistical services (already existing) in each country provide estimates with a precision of the order of 5%.

With this background, it is clear that NOAA-AVHRR cannot be used, at the present time, for improving yield forecasting in Europe. But it appears feasible to consider it for alarm, in complement to information from the agrometeorological network, and for the detection and mapping of local climatic events wich may significantly depress yields in a given region.

The objective of this paper is to assess the possibilities and limits of these applications by a presentation of the studies performed for more than ten years in our laboratory on this subject, especially the last developments within the “EEC Pilot Project on the Application of Remote Sensing to Agricultural Statistics”.

1. THE PRELIMINARY STUDIES

1.1. First experiments with TIROS-N (thermal IR bands)

Our interest for NOAA meteorological satellites started with the field of thermal infrared and the derivation of
surface temperature as an indicator of evapotranspiration and soil moisture (Reiniger and Seguin, 1986). The analysis of HCMM (Heat Capacity Mapping Mission) data between 1978 and 1980 (with a 500 m resolution), was supported by an experimental site in La Crau (between Marseille and Avignon), and more precisely the contrast between a dry zone (dead native grass in Summer) and patches of irrigated pastures (Seguin et al., 1982). These sites were large enough (between 20 and 100 km$^2$) to allow the measurement of surface temperature differences between them from satellite thermal IR, not only with HCMM for some dates, but also with a meteorological satellite named TIROS-N on a regular daily basis (fig. 1).

1.2. Preliminary analyses with NOAA (1983)

This experiment allowed us to appreciate the great advantage of regular monitoring with the polar orbiter satellites NOAA, (which followed TIROS-N after 1979), in comparison to land observation satellites like LANDSAT or SPOT. It explains why, as early as 1983, when AVHRR data became available in France, we started a program using both NDVI and Ts as indicators of crop situation. The first analysis of temporal evolution of NDVI and (Ts-Ta) (difference between Ts and the ground maximum air temperature) for dry and irrigated Crau confirmed the correct assessment by NOAA of the contrast in terms of biomass and water stress (fig. 2).

However, the limited number of dates processed in 1983 was unsufficient for a real purpose of crop monitoring. We passed then to a second phase involving more selected data during the agricultural cropping season.

2. MULTITEMPORAL ANALYSIS ON SMALL AGRICULTURAL ZONES

About 40 dates per year (March-October) were selected on the basis of clear sky conditions in the lower Rhone Valley for the years 1984 to 1987.

Data from NOAA-AVHRR were received at CMS (Centre de Météorologie Spatiale) Lannion and processed in LERTS (Laboratoire d’Etudes et de Recherches en Télédétection Spatiale) Toulouse by Y. Kerr. Temporal evolutions of NDVI and (Ts-Ta) were extracted for small agricultural areas in the regions of Crau and Camargue in the Rhone delta. These areas of 4 to 30 km$^2$ were chosen in order to ensure the highest homogeneity in land use with dominant cultures. From the published results (Lagouarde et al., 1986a; Lagouarde et al., 1986b), we may extract the main following features:

- in spite of the limitation at some periods (like spring) by the cloud coverage, this selection of dates allowed a good characterization of the evolution of biomass by NDVI and of the water availability by (Ts-Ta) along the season (fig. 3 for the case of dry and irrigated Crau);
- both curves displayed noticeable fluctuations. NDVI values are greatly influenced by the angle of view by NOAA and by atmospheric conditions (water vapour and aerosols), whilst (Ts-Ta) is dependent upon the micro climatic conditions (especially the wind velocity).

For the second parameter, these fluctuations can be damped by considering the cumulative values of $\Sigma (TS - Ta)$, more directly related to the level of actual evapotranspiration ET at the agrometeorological time scale of water balance (typically 5 to 10 days). The case of NDVI is more difficult: the progress of studies allow to now well understand the effect of the various involved parameters, but methods for routine corrections are still

![Fig. 1 - Temporal evolution of differences in surface temperature from TIROS N between the dry Crau and 3 zones of irrigated Crau (from Seguin et al., 1982).](image-url)
Fig. 2 - NDVI and $T_s$ values from NOAA-AVHRR in 1983 (13 dates) for dry and irrigated Crau.

Incomplete (especially as regards the aerosols). So that only mathematical processes of the temporal curves may improve the signal, as we will see later.

- in spite of these fluctuations, NDVI temporal curves well describe the main features of existing crops and especially the contrast between permanent productions like pastures, winter crops (wheat) and summer crops (like corn or rice) (fig. 4);

In the case of mixed systems, the curve also exhibits a mixed feature, expressing the respective weight of the contributing components (fig. 5).

- even with a collocation error as low as 1-2 pixels, the analysis of small zones (4 km$^2$), which would ensure a better homogeneity of land use and dominant crops, is unrealistic, because small errors in this localization induce their own fluctuations: the comparison of two spatial scales for a dominant corn area displays higher (purer) NDVI values for some dates at the small scale of 4 km$^2$, but also a less stable temporal curve than 25 km$^2$ (fig. 6).

With these first elements, it was possible to consider a more operational phase, with an optimal data set (1 scene/day) used for an attempt of crop monitoring on a regional basis with NOAA data.
3. REGIONAL CROP MONITORING IN RELATION WITH AGRICULTURAL STATISTICS

3.1. The context of the study

The EEC Pilot Project for the Application of Remote Sensing to Agricultural Statistics coordinated by the JRC in Ispra (Italy) was initiated in 1988 with the aim of improving the collection of statistical information and agricultural forecasts over Europe (Meyer-Roux, 1990). The Action 2 is specifically designed for the application of meteorological satellites to vegetation monitoring and the identification of yield indicators.

Within the frame of this action, our research has been extended to several agricultural regions of France (Bassin of Paris and Southwest especially), with the objective of assessing to which extent pluriannual series of NOAA-AVHRR may be used to detect the main weather effects upon agricultural crop production at the scale of administrative units ("cants" and "departments", with typical scales of $10^2$ and $10^3$ to $10^4$ km$^2$ respectively). Our project associated us with LERTS Toulouse, as previously, and was reinforced by CEMAGREF (Centre National du Ma-chinisme Agricole, du génie Rural des Eaux et des Forêts) in Montpellier (see Kerdiles et al., 1991).
NOAA data were acquired each day in CMS Lannion and converted to composite scenes on a 5 day basis with the maximum NDVI value for each pixel. The three years 1988, 1989 and 1990 were used for this study. It is interesting to note that of the last two years were affected by a severe summer drought.

3.2. Main results

Even with the improved processing, fluctuations still appeared in NDVI curves. However, the larger number of dates allowed to set up an algorithm for filtering (eventually completed by a smoothing procedure) (fig. 7), so that the temporal curves may be used for an automatic assessment of the main land use classes at NOAA scale (Louahala et al., 1991). Filtered curves effectively display very characteristic shapes for each “canton”, in relation with the dominant crop production (fig. 8).

The obtained curves of NDVI and $\Sigma(Ts-Ta)$ clearly detect, for a large number of “cantons” the effect of drought conditions in 1989 (starting at the end of May, day 150) affecting summer crops, as it appears in fig. 9 (canton of Villefranche de Lauragais, near Toulouse, 159 km$^2$).

$\Sigma(Ts-Ta)$ values may be converted, using a simplified linear relationship (see Seguin et al., 1991 for details) to ET values by using the equation:

$$ET = Rn - a\Sigma(Ts-Ta)$$  \hspace{1cm} (1)

which relates ET values to net radiation Rn values, with $a = 0.30$ mm/day/$^\circ$C. Resulting ET for a large homogeneous zone of pastures (marais de Brouage, 140 km$^2$ near the atlantic ocean in the “Charentes” region) clearly depict the drop (from 6 mm/day to 1 mm/day) during the summer of 89, contrasting with values staying larger than 4 mm/day in 90 (fig. 10). These computations are in good

Fig. 7 - The effect of filtering and smoothing on a NDVI curve (from Louahala et al., 1991).

Fig. 8 - NDVI in 1988 for two “cantons” with dominant crops [ ] winter cereals (filled squares) [ ] irrigated corn (empty squares).

Fig. 9 - The effect of summer 89 drought on NDVI (a) and $\Sigma(Ts-Ta)$ (b) curves for the Villefranche de Lauragais canton (159 km$^2$).
agreement with a reduction of grossly 40% in the grass production (3t/ha in 89 against 5t/ha in 88).

This type of quantitative agreement is however limited to a small number of administrative units with significantly dominant crops. Generally, there is only a qualitative correspondence between satellite data and reported yields (for instance, NDVI lower and Σ(Ts-Ta)) larger in 89). But more precise quantitative relations are impossible to establish, because of the mixing of crops with different calendars and different background vegetation which prevent to attribute to each of them (or at least to each main group) their own characteristic temporal curves of NDVI and Σ(Ts-Ta). Sometimes also, the situation is complicated by pests and diseases severely affecting yield without reducing biomass and then NDVI.

CONCLUSION

We can conclude that NOAA data can hardly be used, at the present stage, for a proper quantitative assessment of yield at the regional level in the agricultural context of France.

But they are of a high informative value for an early detection of alarms (mainly in relation with droughts, but also with any climatic event like frost or hail) at a regional level and quick mapping of affected zones, with an assessment of the degree of severity in general terms.

For a more quantitative assessment, basic tools exist for biomass estimation at the pixel size : the estimation (by NDVI) of the efficiency of PAR interception on one hand, the assessment of water stress by Σ(Ts-Ta) on the other hand. However, two main obstacles limit the access to yield and then define the research to develop in this context:

1. the mixed nature of pixels at 1 km² scale. Approaches to retrieve the informations pertaining to each crop group, by combination with SPOT data became recently available (Fischer et al., 1991); useful information will also be delivered, in the future, by active microwave measurements from SAR data (especially for soil moisture);

2. the poor significance of biomass for yield in the European agricultural context. The solution here seems to rely on the combination with agrometeorological models, which incorporate informations on the farming techniques (Seguin, 1992).

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