

# METEOROLOGICAL FORECASTS AND AGROMETEOROLOGICAL MODELS INTEGRATION: A NEW APPROACH CONCERNING EARLY WARNING FOR FOOD SECURITY IN THE SAHEL

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## ABSTRACT

Food security is still the main problem that Sahelian populations have to face. In the Sahel, agriculture is primarily based on rainfed crops and it is often structurally inadequate to manage the climatic variability. Latest Early Warning approaches insist on two action levels: prevision and prevention. In its biophysical aspect, prevision is mainly based on tools and models utilizing satellite data to monitor the growing season. Agrometeorological models have a central role in this chain because they transform meteorological data into levels of risk for agriculture. On the other hand, prevention, aiming to reduce the risks, is actually based on meteorological forecasts. Nowadays, quantitative meteorological forecasts allow early warning systems providing critical information to farmers, in order to reduce risks related to meteorological phenomena.

This paper presents the integration of meteorological forecasts with classical agrometeorological monitoring achieved by ZAR model. Input data are Rainfall Estimate provided by Meteosat Second Generation and forecasts from GFS (Global Operation Forecast) model, Precipitation at ground, at 7 days, downscaled at 8 kilometres. Such integration allows the production of information, as prevision of good conditions for sowing, of crops onset in sowed areas and of crop conditions during the growing period. ZAR is used by Agrhymet Regional Center for regional assessments and by National Meteorological Offices of Senegal, Mali, Burkina Faso and Niger for their early warning activities.

## RESUMÉ

La sécurité alimentaire reste un des problèmes majeurs pour les populations sahéliennes. L'agriculture sahélienne est basée principalement sur les cultures pluviales et elle n'est pas souvent en même de faire face aux aléas climatiques. Les dernières approches pour l'Alerte Précoce soulignent deux niveaux d'action: la prévision et la prévention. Sur le plan biophysique, la prévision est basée essentiellement sur des outils qui utilisent les données satellitales pour le suivi de la saison. Les modèles agro-météorologiques jouent un rôle central dans cette approche puisqu'ils transforment les données météorologiques en niveaux de risque pour l'agriculture. De l'autre côté, la prévention, finalisée à la réduction du risque, est actuellement basée sur les prévisions météorologiques. Grâce à celles là, les systèmes d'alerte précoce peuvent produire aujourd'hui, des informations essentielles pour les agriculteurs tout en permettant de réduire les risques liés aux phénomènes météorologiques.

Cet article présente l'intégration des prévisions météorologiques et du suivi agro météorologique classique atteint par le model ZAR. Les données en entrée sont les estimations de pluie fournies par Meteosat Second Generation et les prévisions provenant du modèle GFS (Global Operation Forecast), Précipitation au sol, à 7 jours, *downscaled* à 8 kilomètres de résolution. Cette intégration conduit à une production d'informations, comme la prévision de bonnes conditions pour les semis, de l'installation des cultures aux zones semées et des conditions des cultures pendant la saison agricole. Le ZAR est actuellement utilisé par le Centre Régional Agrhymet pour les estimations régionales et aussi par les Météorologies Nationales de Sénégal, Mali, Burkina Faso et Niger pour leurs activités d'alerte précoce.

## 1. INTRODUCTION

In the Sahelian region, food security is still the main problem that populations have to face. Since 1970 many Early Warning Systems have been developed in order to avoid major food crisis. The factors that mainly conditions food security in Sahelian Africa are the availability and the accessibility to the food. The first factor depends on a large extent on agricultural production, stocks and imports, the second on the regularity of grain supplies to the market and on the income of the population.

Early Warning Systems insist on two levels: prevision and prevention. In its biophysical aspect, prevision is mainly based on tools and models utilizing satellite data to monitor the growing season. This approach is centred on the identification of risks and the production of information within the time prescribed for decision-making (Vignaroli *et al.*, 2006). Agrometeorological models have a central role in this chain, because they are able to transform meteorological data into levels of risk for agriculture (Di Vecchia *et al.*, 2002). Meteorological satellites provide the basic data for many agrometeorological models. Considering the availability of food depends mostly on rainfed agriculture, agrometeorology is the critical sector for food security monitoring and the zones at food security risk are mainly those where there is a cereal production shortage in relation to the local demand.

Moreover, previous years have known the development, which is represented by the prevention. It summarizes a package of measures to be taken in order to avoid a negative event, removing or reducing the probability of occurrence.

In this context, the advices to farmers are a fundamental component of prevention allowing a better adaptation of traditional crop calendar to climatic variability. Today, the production of meteorological forecasts and the availability of dissemination infrastructures (Pérarnaud *et al.*, 2004) allow early warning systems providing critical information to farmers, so as to avoid risks related to meteorological phenomena (Ndiaye, 2004).

In this framework, AGRHYMET Regional Center and IBIMET-CNR in collaboration with WMO have improved the ZAR (Zones A Risque) model, in order to integrate classical agrometeorological models with meteorological forecasts. Input data are Rainfall Estimate data and Rainfall Forecasts. Meteosat Second Generation provides rainfall estimate. Forecasts come from GFS (Global Operation Forecast) model, Precipitation at ground, at 1° resolution for the following 180 hours from the running time. Such images are downscaled at 8 kilometres applying a downscaling technique, developed originally at Ibimet, which increases the resolution at ground to 0.08° using the rainfall spatial distribution coming from the MSG precipitation patterns.

The integration of rainfall estimation and forecast allows the production of information such as prevision of good conditions for sowing, of crops onset in sowed areas and of crop conditions during the growing period. Besides forecast analysis, ZAR uses algorithms for the estimation of crop onset, crop conditions and phenological phases in a settled time (Pini, 2005). Input data for those analyses are rainfall estimation, evapotranspiration, available soil moisture and agronomic data for the crops that ZAR simulates. Indeed, ZAR allows the user choosing between four different rainfed crops: millet, sorghum, cowpea and groundnut. ZAR is used by Agrhymet Regional Center for regional assessments and by National Meteorological Offices of Senegal, Mali, Burkina Faso and Niger for the seasonal monitoring.

The topics on which thorough reflections must be carried out are the reinforcement of the spatial and temporal scales of meteorological forecasting and the strengthening of the systems for information dissemination toward farmers.

## 2. METHODOLOGY

### 2.1 The study area

The Sahel covers the area between the Sahara and the Sudan, laying from Senegal to Chad, and receiving about 250-500 mm summer rainfall (Wezel and Rath, 2002) or, for other authors, 150-600 mm. (see Wickens, 1997). In spite of some local exceptions, it is characterized by semi-desert grassland, scrubs and wooded grasslands, in which Acacia species play a dominant role. Although the area has been inhabited since at least 9000 years ago, only in the recent decades the overexploitation of soils, closely linked to the

population increase, has led to soil exhaustion and to lower productivity, enhanced, furthermore, by limited rainfall which in consequence of global change is becoming more and more scarce and irregular. Climate change and overexploitation are leading to a quick and often irreversible degradation of natural resources. In this context, the ZAR is operational at regional level and locally in four of the nine CILSS (Comité permanent Inter-Etats de Lutte contre la Sécheresse au Sahel) countries: the Senegal, Mali, Burkina Faso and Niger.

Even if last years knew favourable rain seasons., in relatively extended areas severe droughts took place and consequently the crop production potential considerably has decreased.

The study area coincides with the agricultural zone: in the north this area is delimited by the isohyet 250 millimetres. Millet and sorghum are the most important food crops, representing respectively 43% and 24% of the total agricultural production (AGRHYMET, 2003).

In the northern part of the region, which is the most sensitive to climatic fluctuations, the most widespread crop is the short cycle millet, with a cycle length variable between 70 and 90 days, depending on the variety. Its water requirement ranging from 400 to 700 millimetres (Bacci L. *et al.*, 1992). In the zones with a short rain season, like those ones considered in this study, the sowing takes place during the onset of the rain season because first rains gave rise to a fast mineralization of the nitrogen pools of the soil (Bacci L. *et al.*, 1992).

After the sowing, germination and stem elongation lasts between 15 to 20 days (Bacci L. *et al.*, 1992). Notwithstanding the drought resistance of this crop, the seedling sensitivity to water stress is high: an interruption of the rainfall following the rain season onset can cause the death of the seedlings and consequently the failure of the sowing. Nevertheless, the re-sowing done late during the campaign might involve relevant losses in the production and, in the case of insufficient rainfall during the rest of the season, could be followed by the complete loss of the yield.

## 2.2 Input data

The model input data are Rainfall Estimate data and Rainfall Forecasts, evapotranspiration, available soil moisture and agronomic data for the crops that ZAR simulates.

**Rainfall estimates** are provided by Meteosat Second Generation. The METEOSAT-8 (MSG) images data acquisition every 15 minutes, allows the monitoring of precipitating cloud systems in a high temporal and spatial resolution (3x3km). To improve the monitoring of precipitation on African agricultural areas, a database of cumulated rainfall maps has been set up and disseminated free of charge online by IBIMET-CNR (IBIMET, 2005). The rainfall maps are obtained by means of a statistically blended technique (Turk *et al.*, 2000a; 2000b) that dynamically correlates brightness temperatures, as measured by geostationary sensors (i.e., METEOSAT-8) and instantaneous precipitation levels, as computed by MW passive radiometer (i.e., SSM/I) data (Ferraro and Marks, 1995; Ferraro, 1997) using a statistical correlation (Crosson *et al.*, 1996). This blended technique allows monitoring the precipitating cloud systems in a high/ temporal (every 15 minutes) and spatial resolution (3 km at nadir).

By applying the aforementioned statistical relationship between the rain-rate and brightness temperature to the newly incoming METEOSAT-8 images, the instantaneous rainfall maps are calibrated and then elaborated.

A future improvement in rainfall estimates will be the introduction of different rainfall measurements (raingauge data) to calibrate and validate the estimates from satellite observations.

Further than rainfall estimates produced by IBIMET, ZAR allows the use of FEWS RFE decadal images and METEOSAT 7 decadal images in a spatial resolution of 5 by 5 Km.

**Meteorological forecasts** used by ZAR come from GFS (Global Operation Forecast) model. The NCEP (National Centers for Environmental Prediction) of the NOAA makes a set of forecast products available four times a day.

Utilising GFS model, Precipitation at ground, average Temperature at ground and relative Humidity are forecasted at 1° resolution for the following 180 hours from the running time. The images by NCEP at 1° resolution are processed with downscaling procedures in order to supply coherence with other available data. Such downscaling technique is based on rainfall satellite estimates coming from MSG and SSM/I through the Turk *et al.* (2000a; 2000b) algorithm. To downscale the GFS rainfall, each day, the precipitation forecasts are collected for the following 72 hours and the satellite rainfall estimates for the previous 72 hours

(up-scaled to 0.1 degree of spatial resolution). By this way, GFS forecast information is integrated for the following three days with the more detailed spatial information given by satellite rainfall estimates in the previous 3 days (Guarnieri et al., 2006). The Comprehensive seven days Forecast downscaled at 8 km resolution is thus used by ZAR.

The model uses other agrometeorological data for the analysis. They are:

- PET (Potential Evapo-Transpiration ),
- Growing season average starting,
- Growing season average end,
- Available soil moisture,
- Considered crops agronomic data (phenological phases length and cultural coefficient - Kc)

### 2.3 The model

ZAR is composed by different modules (fig. 1) aiming:

- the monitoring of crop installation at 5 or 10 days periods;
- the monitoring of crop growth following the installation at 5 or 10 days periods;
- the sowing conditions forecast at 7 days;
- the forecast of crop conditions in the risky areas, at 7 days.

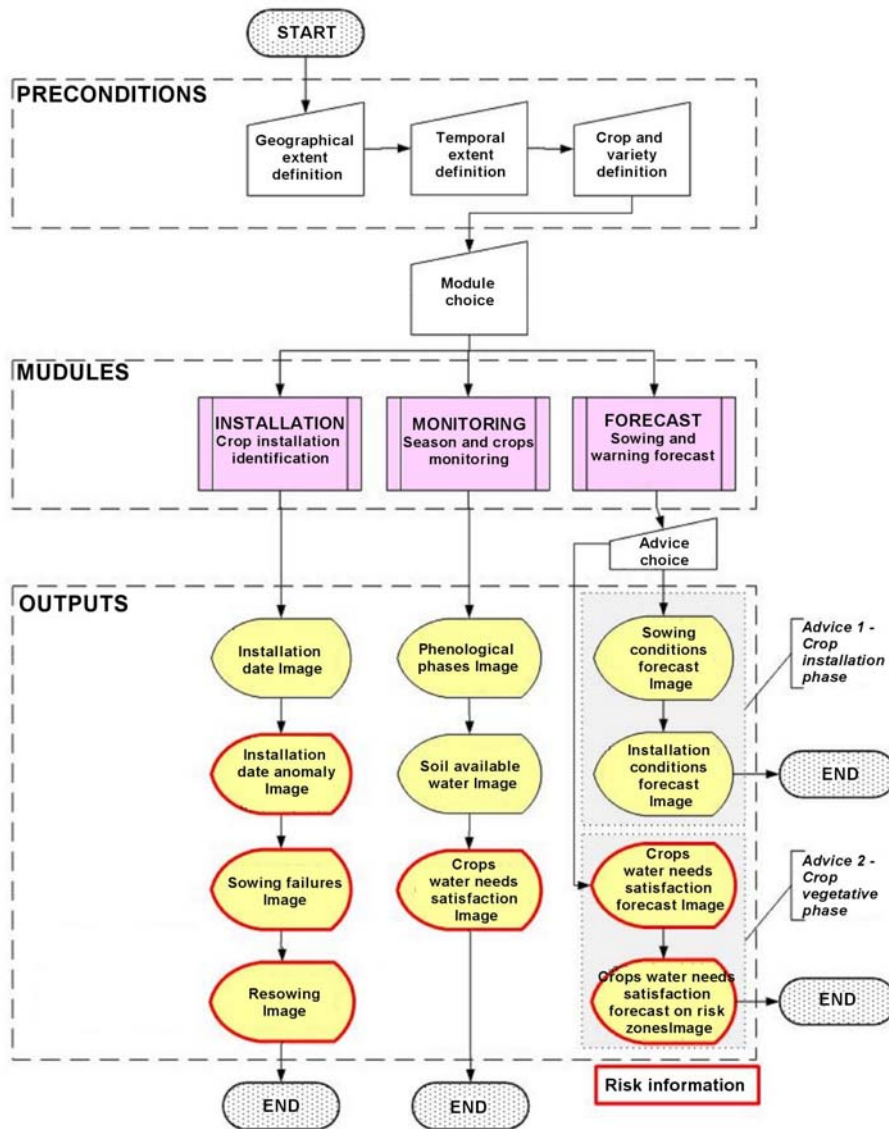


Figure 1, ZAR flow chart

ZAR allows the user personalizing different parameters:

- crops and varieties:
  - o pearl millet 85 days
  - o pearl millet 130 days
  - o cowpea 75 days
  - o groundnut 100 days
  - o groundnut 140 days
  - o sorghum 110 days
- sowing conditions (rain threshold and period)
- geographical extent of analysis area.

Starting from the decadal or pentadal rainfall estimates by the MSG images, the ZAR model identifies the zones where the crops have been established later than normally because of the late onset of the rain season or because of the first sowing failure. In these conditions it might happen the crops can not finish the growing cycle. In an agronomic point of view, this involves a reduction of the yields that can drive to a complete loss of agricultural production in those areas with a low agricultural suitability (Martini, 1994). During the crop cycle, ZAR assesses the satisfaction of crop water needs showing the stress areas.

Specifically for the forecast, ZAR integrates two modules operating during different periods of the growing season. The sowing condition forecast module produces information to be used by farmers for their sowing activities management. In particular, it can be used to plan of field preparation activities and to identify the best sowing period, aiming to reduce sowing failure risks.

The forecast of crop conditions module is used during the seasonal monitoring and it aims to forecast the crops conditions in those areas where stress conditions have been identified.

### 3. RESULTS

During the agricultural season, from the 1st decade of May to the 3rd decade of September, the model produces the following layers:

1. Installation module:
  - crop installation (areas where sowing and crop installation conditions occurred)
  - sowing failures (areas where sowing conditions occurred but not the installation conditions)
  - re-sowing (zones where, after a sowing failure, sowing conditions occurred again)
  - comparison between the actual and the average crop installation
  - comparison between the actual and the last year crop installation
2. The monitoring module:
  - phenological phases (for the areas where crop installation occurred: the actual crop phase)
  - crop water needs satisfaction (for the areas where crop installation occurred: the water stress level)
  - the soil available water (for the areas where crop installation occurred: the water actually available in the soil)
3. The forecast module:
  - sowing condition forecast (areas where forecasted rainfall will satisfy sowing conditions)
  - installation forecast (fig. 2) (for the areas where last decade rainfall estimation satisfy the sowing conditions and the forecasted rainfall will satisfy installation conditions)
  - crop water needs satisfaction forecast (for the areas where crop installation occurred, the forecasted water stress level)

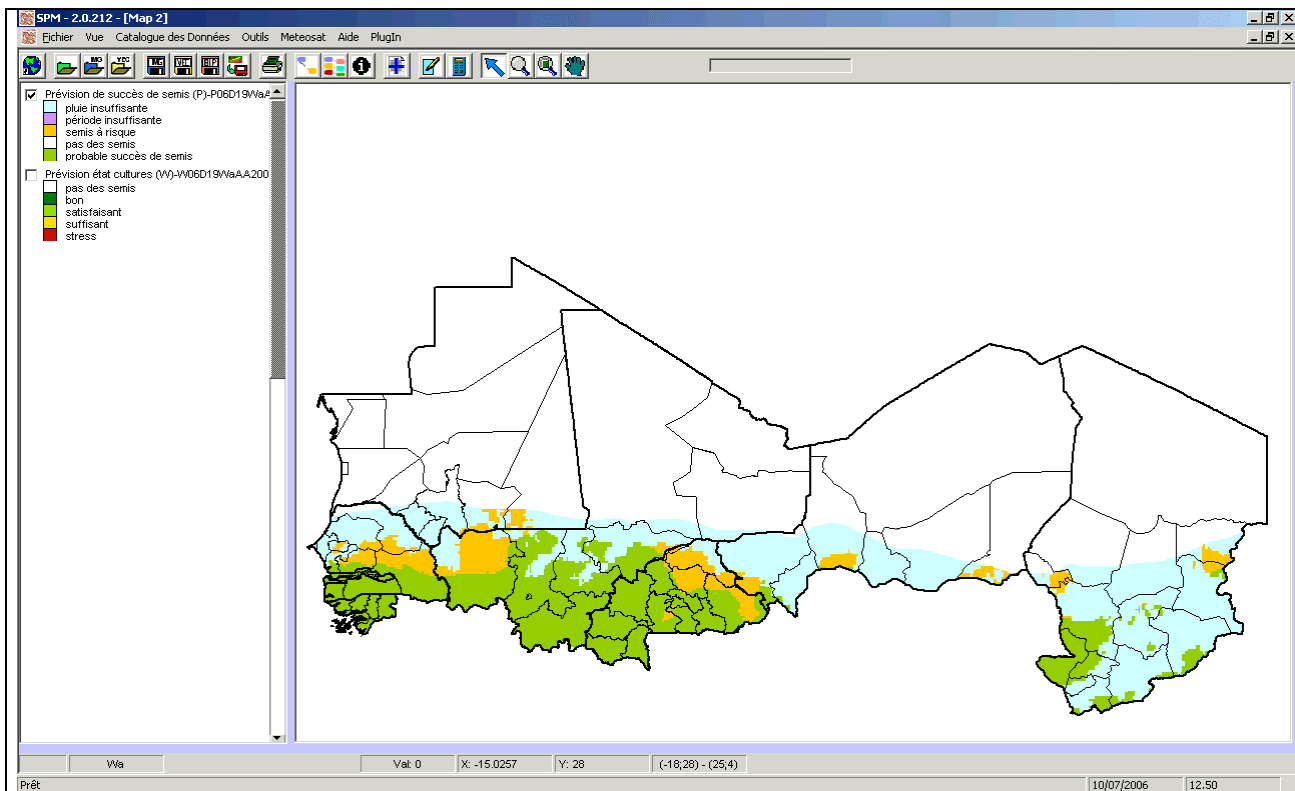


Figure 2, installation forecast for the 1<sup>st</sup> decade of July 2006 (forecast time 1<sup>st</sup> of July 2006)

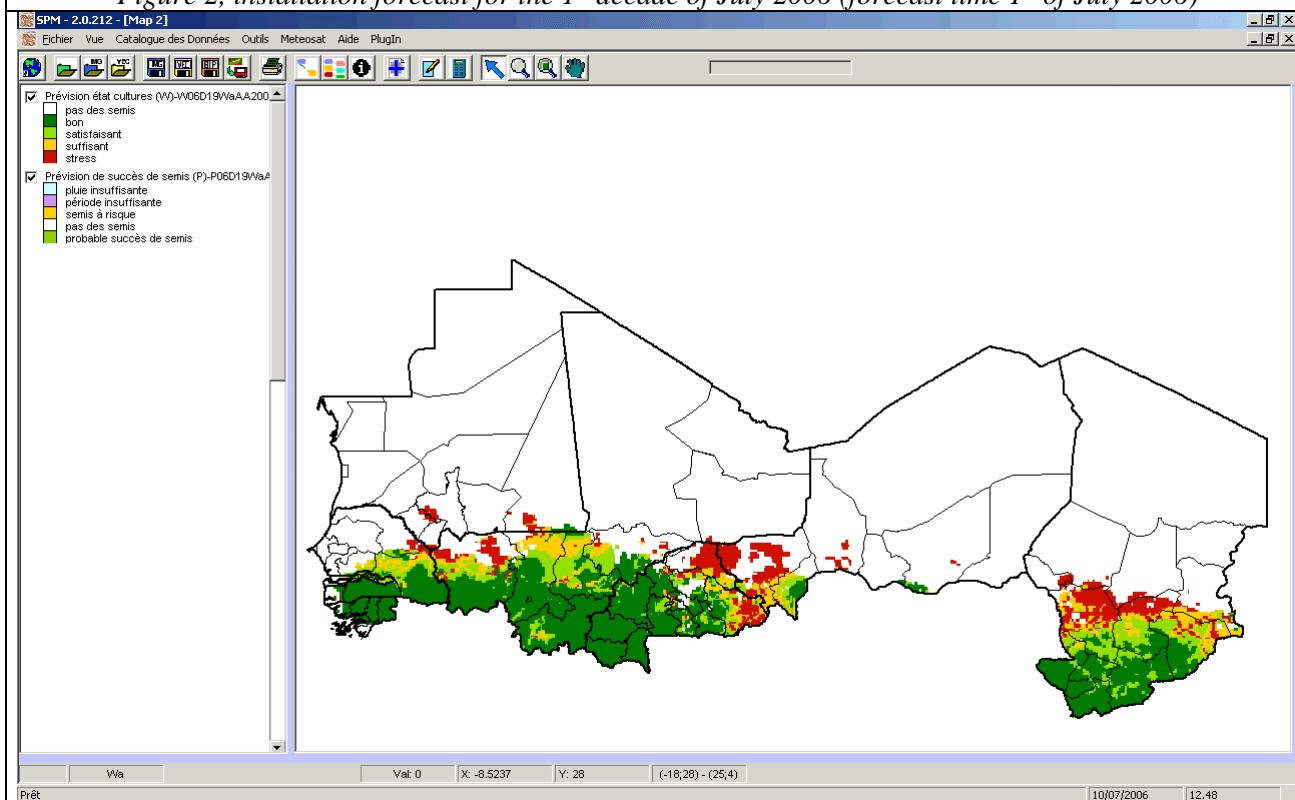


Figure 3, crop water needs satisfaction forecast for the 1<sup>st</sup> decade of July 2006 (forecast time 1<sup>st</sup> of July 2006)

#### 4. CONCLUSIONS

Given the absence of a dense rain gauge network in the Sahelian region, the rainfall estimated images are a precious source of data for decadal rainfall estimation. This information is essential to identify the risk zones for agricultural production and to monitor the agricultural campaign.

Rainfall forecasts, in synergy with rainfall estimates, add new value to agrometeorological modelling. The methodological approach proposed in this paper to detect risk zones for rainfed crops can be very useful both for the identification of zones with potential production shortage and for the reduction of agrometeorological risk through advises to farmers.

The integration of other sources of information, as NDVI images and field data, allows the improvement of the diagnosis about the crop establishment and production in the Sahelian environment. In effect ZAR is conceived as one of the tools identified by the “calendrier de prévision et gestion des crises alimentaires” (Vignaroli *et al.*, 2006) in order to satisfy information needs in terms of early warning according to different levels and geographical extensions of crises (Di Vecchia *et al.*, 2002, Vignaroli *et al.*, 2006). The CPC is a methodological environment which integrates cartographic, biophysical and socio-economic data, models and analysis in order to monitor factors affecting food security during the year and to evaluate the impact on population vulnerability caused by a natural or human extreme event.

In this context, two aspects must be carried out and they are the reinforcement of the spatial and temporal scales of meteorological forecasting and the strengthening of the systems for information dissemination toward farmers.

The reliability of rainfall forecast is the first critical point for the production of agrometeorological forecasts. Even if the GFS model has been conceived for continental scale, the downscaling of its products allows their utilisation at regional or national scale; but it should be incorrect to neglect the original resolution at 1 degree. Furthermore, the comprehensive seven days forecast allows producing advises, but the improvement of the temporal range would enable a better advises exploitation, leaving to farmers more time to make decision and to carry out field activities.

Past experiences showed in many Sahelian countries appropriated advises, allowing farmers to exploit agrometeorological information, contributed in increasing of crop productions. From 1983 to 2004, in Mali the « Projet Pilote d'Assistance Agro-météorologique aux Paysans » (AAMP, 2005), proved an increase of about 30% in cereal production. In Senegal, starting from 1992 to 1994, the “projet d'Assistance Météorologique à l'Agriculture au Sénégal » (AMAS) estimated an increase of 20% in cereal yields obtained using agrometeorological advises.

The Mali experience proved also the real effectiveness of the dissemination of information channels (rural radios and Ranet).

One of the main stakes is the appropriateness of agro meteorological advises, in terms of comprehensibility and suitability. Information should not upset traditional practices or agricultural calendars, rather than integrate them with new information otherwise not available for farmers.

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