OPEN SOURCE GEOPROCESSING TOOLS AND METEOROLOGICAL SATELLITE DATA FOR CROP RISK ZONES MONITORING IN SUB-SAHARAN AFRICA

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ABSTRACT

In Sub-Saharan Africa analysis tools and models based on meteorological satellites data have been developed within different national and international cooperation initiatives, with the aim of allowing a better monitoring of the cropping season. In most cases, the software was a stand-alone application and the upgrade, in terms of analysis functions, database and hardware maintenance, was difficult for National Meteorological Services (NMSs) in charge of the agro-hydro-meteorological monitoring. The web based solution proposed in this work intends to improve and ensure the sustainability of applications so to support national Early Warning Systems (EWSs) for food security. The Crop Risk Zones (CRZ) model for Niger and Mali, integrated in a web-based open source framework, has been implemented using PL/pgSQL & PostGIS functions to process different meteorological data set: a) the rainfall precipitation forecast images from Global Forecast System (GFS) b) the Climate Prediction Center (CPC) Rainfall Estimator (RFE) for Africa c) MSG images from EUMETSAT Earth Observation Portal d) the MOD 16 Global Terrestrial Evapotranspiration Data Set.

Restful Web Services uploads raster images into the PostGIS spatial database for PostgreSQL and PL/pgSQL functions were employed to run CRZ model to identify for the main crops of the Region, the installation phases, the crops phenological phases and risk production zones images. This model is focused on the early identification of risks and the production of information for food security within the time prescribed for decision-making.

The challenge and the objective of this work is to set up an open access monitoring system, based on meteorological open data providers, targeting NMSs and any other local decision makers for drought risk reduction and resilience improvement.

INTRODUCTION

Agriculture in the Sub-Saharan Africa is characterized by traditional techniques and it is strongly dependent on climatic conditions and rainfall, whose variability has a strong impact on people's livelihood and community socio-economic development.
In general, low rainfall during the growing season can bring to lower crop yields and, sometimes, to food crises (Sultan et al., 2005). Crop yields may suffer significantly with either a late onset or early cessation of the rainy season, as well as with a high frequency of damaging dry spells (Mugalavai et al., 2008).
For the most important Sahelian rainfed crops, the early identification of crop risk zones is essential to intercept agricultural drought phenomena, detecting seeding delay and failure, and monitoring crops water conditions in each growth stage (Bacci et al. 2009).
Since the early '90s, crop monitoring analysis tools and simulation models based on meteorological satellite data (Samba, A., 1998; CNR-IBIMET, 2006; Traore et al., 2010) have been developed within different international cooperation programmes to allow monitoring of the cropping season in CILSS (Permanent Interstates Committee for Drought Control in the Sahel) countries. Usually, software was a stand-alone application, transferred to National Meteorological Services (NMSs) but without continuous user support and

updates. Furthermore, the scarcity of economic resources for hardware and software maintenance, besides the availability of timely meteorological data, led to the failure of regular drought monitoring activities carried out by National Early Warning System (EWSs) for food security.

This paper presents the "4Crop" web application, an open source solution to meet the needs of a long-term sustainability of operational tools for drought risk identification and forecast, and balance the lack of sufficient and timely acquisition of ground data using meteorological satellite open data set. This web application is based on Crop Risk Zone (CRZ) model, the updated version of "Zone à Risque (ZAR) model" (CNR-IBIMET, 2006) distributed as stand-alone software over the NMSs of CILSS countries in the framework of AP3A (Early Warning and Agricultural Production Forecast, 1995-2001) and SVS (Vulnerability Monitoring in the Sahel, 2002-2008) Projects, funded by Italian Cooperation and implemented with World Meteorological Organization and the AGRHYMET Regional Center in Niger.

The challenge of "4Crop" web application is to give open access to CRZ model output and results. The goal is to support Sub-Saharan EWSs and any other local users in decision making and foster drought risk reduction and resilience in food security; in order to avoid language barrier, that could prevent a wider use of the web application, 4Crop is available in French, the official language of the target countries. Moreover, the approach here proposed is meant to encourage the integration and sharing of interoperable and open source solutions so to contribute to the setting up of distributed climate services in developing countries.

METHODOLOGY

The CRZ model for crop risk zones monitoring in Sub-Saharan Africa (Vignaroli et al. 2016) runs 2 different modes:

- diagnostic mode: drought monitoring during the agropastoral campaign, allowing NMSs to identify agricultural drought risk areas and to support decision making at local and national level in agricultural drought management. This type of early warning information empowers National EWSs decision making, as it is an input to estimate the nutritional food insecurity, so to better identify potentially vulnerable populations and assess food crises risks within the 'Harmonized Framework" put in place by CILSS with EU, FAO and WFP.
- predictive mode for "advisory-support" activities to farmers carried out by the Agricultural Extension Services, who are in charge for the implementation of the most appropriate strategies to minimize drought risk on crops (i.e. identification of the optimal period of sowing, choice of varieties based on the expected length of the growing season, adoption of suitable cultural practices for soil water management) and to build farmers resilience.

The model is composed by different modules (Figure 1): crop installation monitoring (at 5 or 10 days periods), crop growth following the installation phase (at 5 or 10 days periods), sowing conditions forecast (at 7 days) and forecast of crop conditions in the risk areas (at 7 days).

The most important model data input are:

- Cumulated Rainfall Estimate Images (5 – 10 dd)
- Cumulated Precipitation Forecast (180 h)
- Monthly PET (Potential Evapo-Transpiration)
- Average start of growing season (last 10 years or more)
- Average end of growing season (last 10 years or more)
- Available soil moisture

- Phenological phases' length and cultural coefficient – Kc (FAO) for each simulated crop.

The model allows users to customize some parameters: crops and varieties, sowing conditions (rain threshold and period) and geographical extent of analysis area. At present the model has been tested on the following four crops: pearl millet (85 days and 130 days), cowpea (75 days), groundnut (100 days and 140 days), sorghum (110 days).

Meteorological satellite data set and download chains

Due to the lack of a dense weather station network in Africa and of the availability and consistency of long-term rainfall data for the Sahelian Region, satellite-derived open data set have been used as input data for the model. Global Forecast System (GFS) is the reference data source for forecast images, the Climate Prediction Center (CPC) Rainfall Estimator (RFE) for daily Rainfall Estimates over the African continent and/or the historical series of satellite rainfall estimates data, derived from MSG images provided by EUMETSAT Earth Observation Portal.
Furthermore monthly average Potential Evapotranspiration gridded data required by the CRZ model have been downloaded from MOD 16 Global Terrestrial Evapotranspiration Data Set.
Data download chains have been implemented for each data set to store row data in GeoTiff and NetCDF-CF OGC standard, so to establish an automatic procedures that provide the input data for the monitoring of the cropping season for the CRZ model.
At the end of the download procedures, the JAX-WS Restful Service is called to upload the raster images in PostgreSQL & Post GIS database to feed CRZ model .

Open Source geoprocessing tools for CRZ model implementation

The CRZ model has been developed using PL/pgSQL - SQL Procedural Language for PostgreSQL database system and PostGIS library built-in PostgreSQL. Each module (Figure 1) is composed by a main PL/pgSQL function, performing initialization process, and by an iteration of functions for crop simulation processes. The CRZ modules work on input raster data stored previously into the Geodatabase.
For example in the "Installation module" the initialization process extracts the input data from Geodb (daily RE, daily PET images, end season and the average sowing date images) and sets the parameters defined by the user. The ST_Clip function cuts the input images with country's boundaries so time and resource consuming are optimized for the following processing phases. The ST_Union function, in this initialization process, generates the RE and PET dekadal and pentadal input images. Within this module the iteration of functions generate module output (crop installation, sowing failures, etc.). ST_MapAlgebra, as callback function, perform pixel-by-pixel operations over raster images defined by CRZ model algorithm.
At the end of iteration cycles of each module, the main PL/PgSQL function stores the results into the Geodabase with all metadata information related to the model run.
Finally a JAX-WS, using the PostGIS predefined functions ST_asraster, ST_colormap, ST_asPNG, ST_asGDALraster, publishes classified output images on 4Crop web Interface.

User Centered Approach for "4Crop" web application

Fore the implementation of the 4Crop web application, the definition of user requirements has been carried out through a User Consultation Process (UCP), involving the technical staff of Niger and Mali National Meteorological Services. In the first phase of 4Crop web

development, the operators/users have been interviewed in order to understand their specific needs in terms of usage, information products (maps and report), and also to assess the usability needs in view of their previous experience on the software "Zone à Risque (ZAR) model". The interviews allowed to better focus user requirements, particularly for what concerns User Interface (UI) development. In the second phase the UI was shared with the users, through a web platform (InVisio), to have their feedbacks and further suggestions.

RESULTS AND DISCUSSIONS

4Crop French version web application (Figure 2), targeting Niger and Mali National Meteorological Services, is implemented on a coherent Open Source web-based Spatial Data Infrastructure to treat all input and output data in an interoperable, platform-independent and uniform way. It utilizes CRZ model to evaluate impacts due to drought stress during the whole crop growth cycle over large areas, providing farmers with information to implement appropriate and timely response strategies to minimize risk exposure.
During the cropping season, from the 1st decade of May to the 3rd decade of September, the CRZ model produces the following outputs:
1. Installation module (Figure 3):
   - 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 (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).

The 4Crop overall approach, including the UCP, could represent an enabling factor to allow a switch from generic advice to precision information, so to improve planning, decision-making process and response measures, within various stakeholders. As a matter of fact the web application increases the accessibility of accurate drought risk information for different stakeholders; it provides specific advices for end users at different decision-making levels, bridging the gap between available technology and local users' needs.
Finally, especially in developing countries, open source solutions can play an important contribution for capacity building in local Institutions, which are the main actors in planning and implementation of prevention and response policies to potential food crisis.

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REFERENCES

Bacci M., Di Vecchia A., Genesio L., Tarchiani V., Vignaroli P., 2009. Identification et Suivi des Zones à Risque agro-météorologique au Sahel. In Changements Globaux et Dèveloppement Durable en Afrique,volume 3. Rome, Aracne Editrice. ISBN 978-88- 548-2980- 0

CNR-IBIMET, 2006. SPM Suivi des pluies par Meteosat & ZAR Modèle Zone à Risque. Version 2.0. Centre Regional AGRHYMET. ISBN 88-900502-1-7.

Mugalavai E.M., Kipkorir E.C., Raes D., Rao M.S., 2008. Analysis of rainfall onset, cessation and length of growing season for western Kenya. Agricultural and forest meteorology 148: 1123-1135.

Samba, A. 1998. Les logiciels DHC de Diagnostic Hydrique des Cultures. Prévision des rendements du mil en zones soudano-sahéliennes de l'Afrique de l'Ouest. Sécheresse 9(4): 281-288 pp.

Traore,S.B., Alhassane, A.,Muller, B.,Kouressy, M.,Somé, L.,Sultan, B.,Oettli, P., Siéné Laopé, A.C.,Sangaré, S.,Vaksmann, M.,Diop, M.,Dingkhun, M.,Baron,C., 2010. Characterizing and modelling the diversity of cropping situations under climatic constraints in West Africa. Atmos. Sci. Lett.12,89–95, http://dx.doi. org/10.1002/asl.295.

Vignaroli, P. , Rocchi, R., De Filippis, T., Tarchiani, V., Bacci, M., Toscano, P., Pasqui, M., Rapisardi, E., 2016. The Crop Risk Zones Monitoring System for resilience to drought in the Sahel. In Geophysical Research Abstracts Vol. 18, EGU2016-16616-3, 2016. EGU General Assembly 2016.

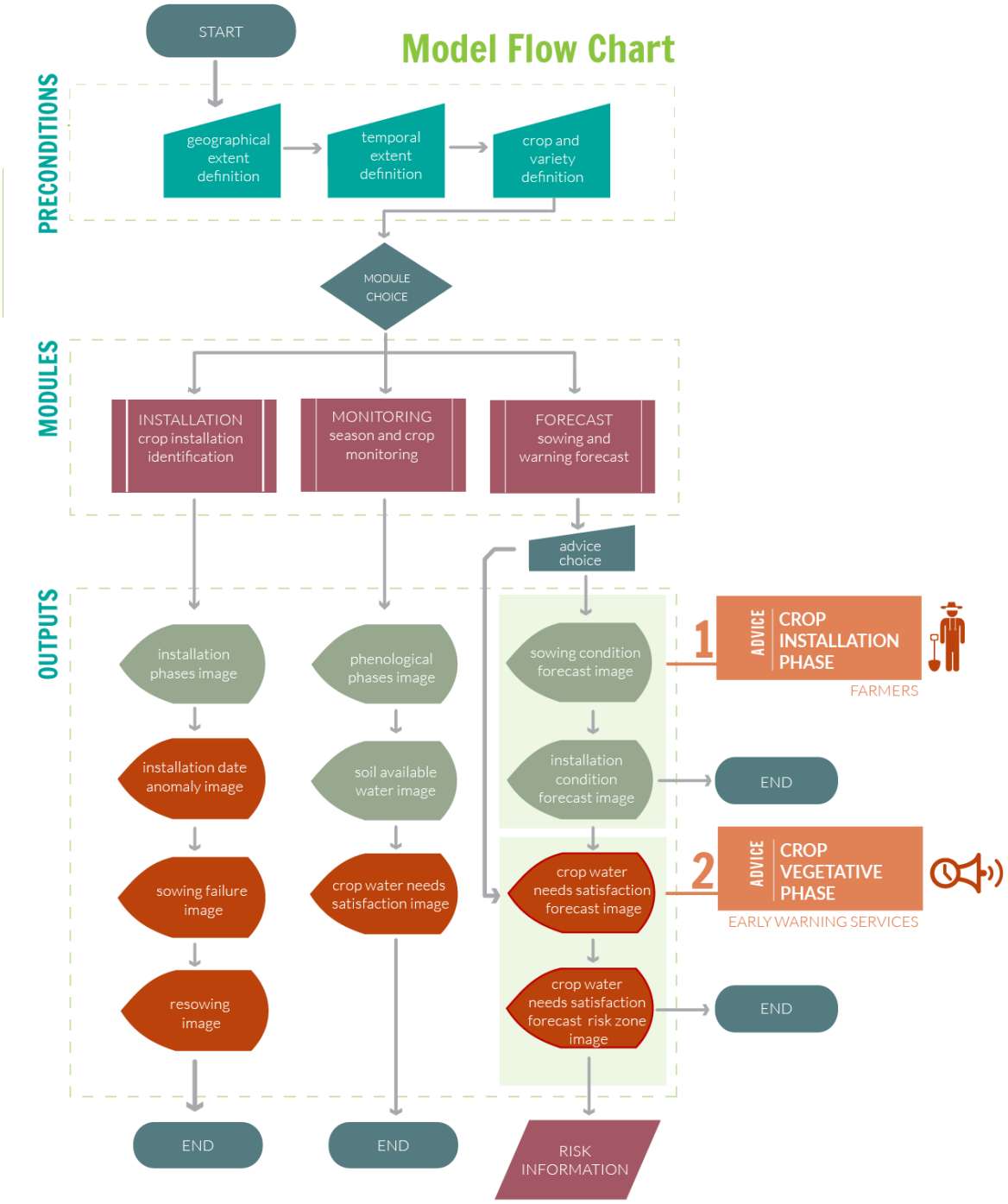

Figure 1 – Crop Risk Zone model Flow Chart

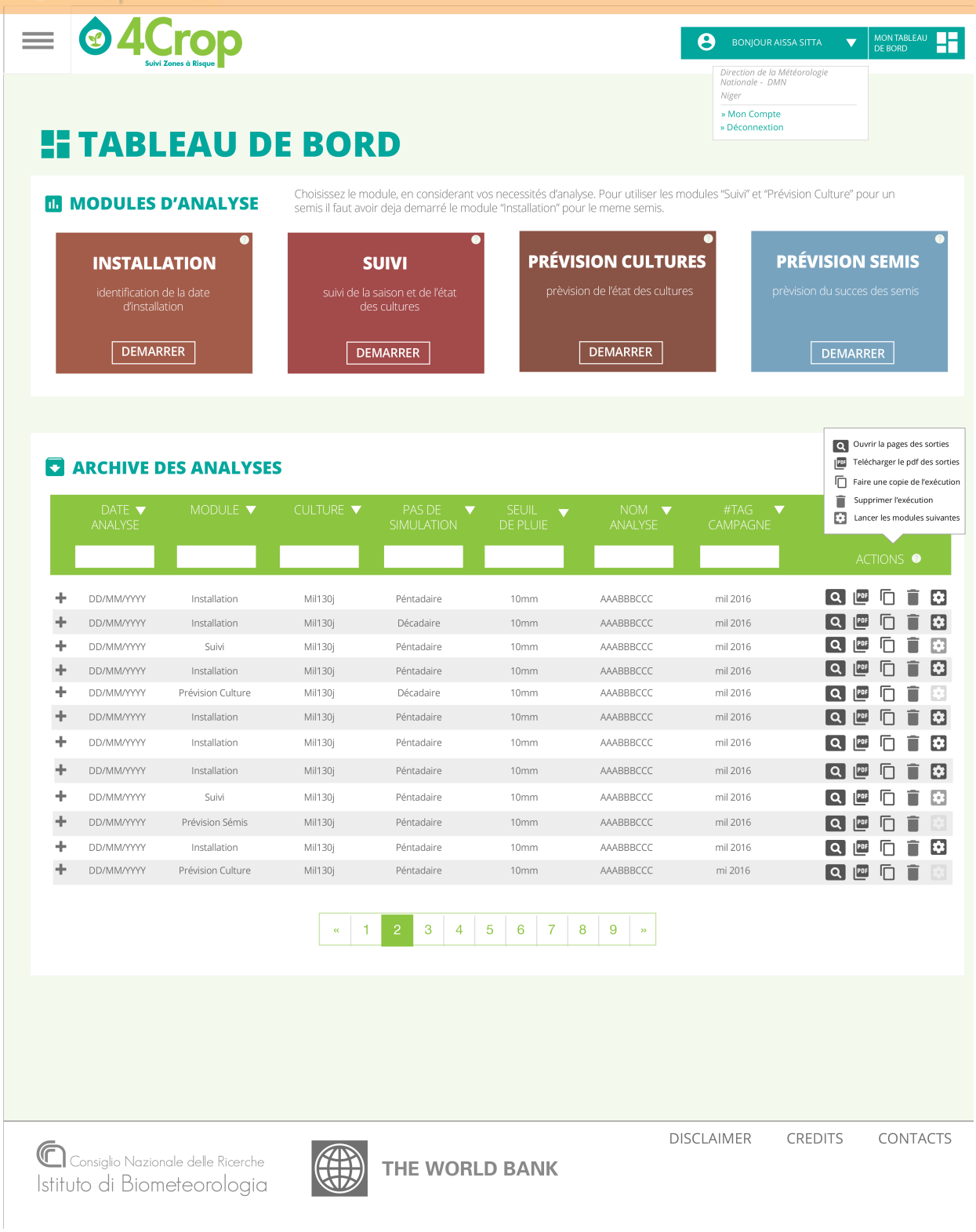

Figure 2 - 4Crop Web Application interface

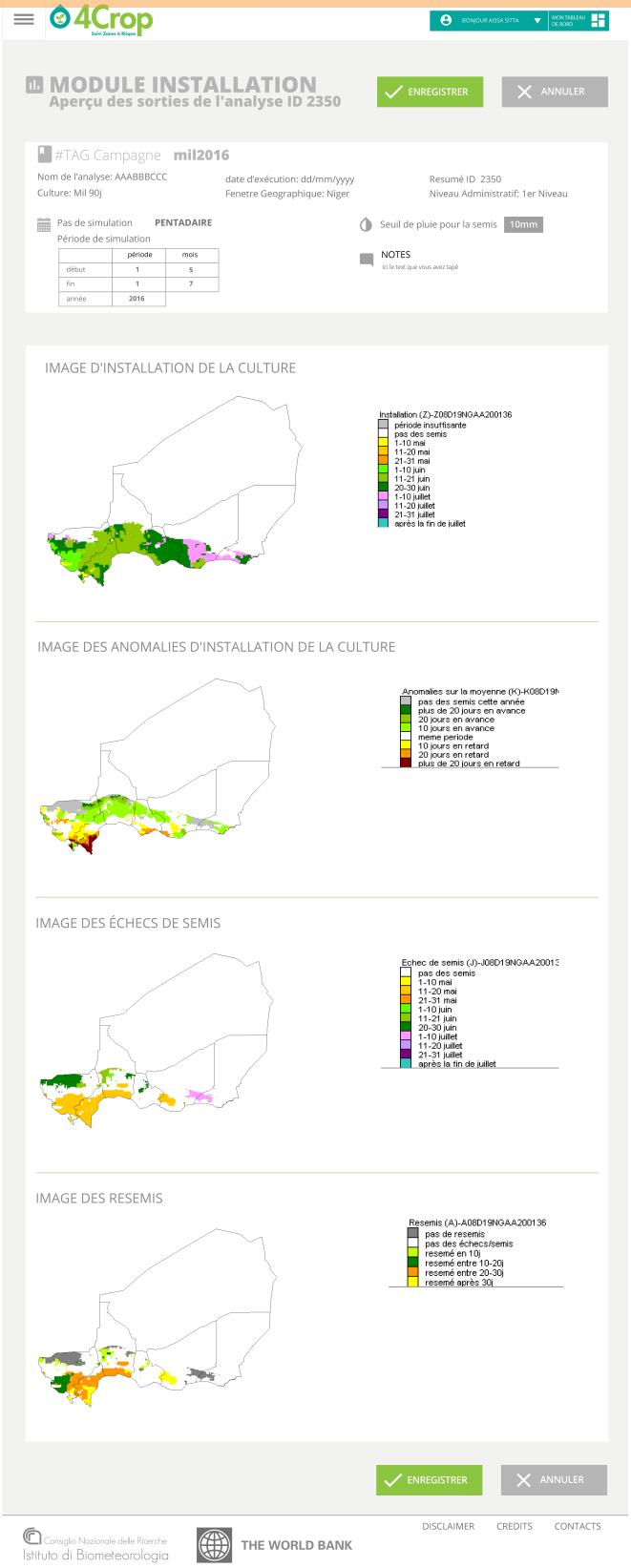

Figure 3 - CRZ Installation Module: output for Niger

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