Managing climate- and weather-related risks to improve agricultural decision making

FINAL REPORT

June 2014

Introduction

As articulated in our second report, provided in February of 2013, the main objective of the INMET – IICA – IRI project is to establish crop production forecasts. To advance this, we have engaged in three primary activities, including advancing multi-model seasonal climate prediction, developing a system for improved crop monitoring, and improving crop yield prediction. These three activities, conducted between August of 2013 and February of 2014, are described below.

1. Multi-model seasonal climate prediction

During 2013, Anthony Barnston of IRI and Caio Coelho of CPTEC (INMET) collaborated on the subject of the design and implementation of a mult-imodel seasonal climate prediction system, whose main products include:

1) a map showing the probabilities of the three tercile-based categories for precipitation and temperature;
2) a map showing the single deterministic forecast anomaly value; and
3) data of the probability of exceeding any value of precipitation or temperature.

The third product has the flexibility to allow users to view the part of the forecast probability distribution that matters most to them, in place of the more traditional tercile-based probabilities.

An important part of this effort is the way that the predictions of different dynamical and statistical models are brought together into a single final multi-model prediction. Questions such as whether to use skill-based model weighting came to the forefront in discussing this issue.

Coelho and Barnston communicated about the development of the above-described prediction system during the middle and latter part of 2013, exchanged figures and equations, and Coelho intended to write a journal article describing the new method. A complete outline of the proposed paper was written, but to date this paper has not yet been written due to lack of time at CPTEC.

In December 2013, Barnston was invited to attend a drought and climate prediction meeting in Fortaleza to be held in January 2014. The meeting was organized by Eduardo Martins (president of FUNCEME) and Divino Moura of INMET. The purpose of the meeting was to discuss best practices in developing seasonal forecast methodologies in Brazil and abroad, and also to launch a new Drought Outlook for the northeastern states of Brazil.

Barnston gave a presentation describing in detail the seasonal climate prediction methods used at NOAA/CPC and at Columbia/IRI, to help Brazil identify the differences and consider which elements of each system might apply most to their own prediction situation. Barnston emphasized the advantages of the use of science-based, objective systems as opposed to more intuitive, humanly determined forecast systems (e.g. developing probabilities coming from a consensus of forecasters). He noted that the latter approach often involves considerable subjectivity, and has been shown to have poorer performance than objectively based systems in one or more studies.

2. Crop monitoring

As a means to explore new methodologies for crop monitoring, a Maproom was designed to display the information used by CONAB for this activity. In comparison to tools that are currently in use, the Maproom can be tailored with shared data and information generated by CONAB or other Brazil institutions to improve the crop monitoring activities.

In this case, a summer crop mask was applied to NDVI to select only NDVI pixels that are actually summer crop fields. This being a proof-of-concept activity, the mask used is the one for summer 2009-2010 and is applied constantly across all years. However, a dynamic mask changing with time could be applied as well. Actual yield observations from IBGE website are also displayed.

Yield data in the IBGE web site stops in 2011, but the technical capacities were generated to automatically download updated IBGE data that would, in turn, automatically update the Maproom. MODIS data that currently serve for other projects is in the process of being updated.

The Maproom is operational and can be found on a demonstration website here:
http://iri.columbia.edu/~remic/proto/maproom/Agriculture/Crop_Monitoring/Brazil_NDVI.html

Maprooms are a technology developed by the IRI to advance the dissemination of added-value climate and environmental information to address specific real-world problems. Among other things, maprooms facilitate the exchange of information between stakeholders through the webpage directly. For instance, some parts of this report were generated by sharing the Maproom page with the Evernote application, which allows for editing and exporting to Microsoft Word.

2.1 NDVI Crop Monitoring

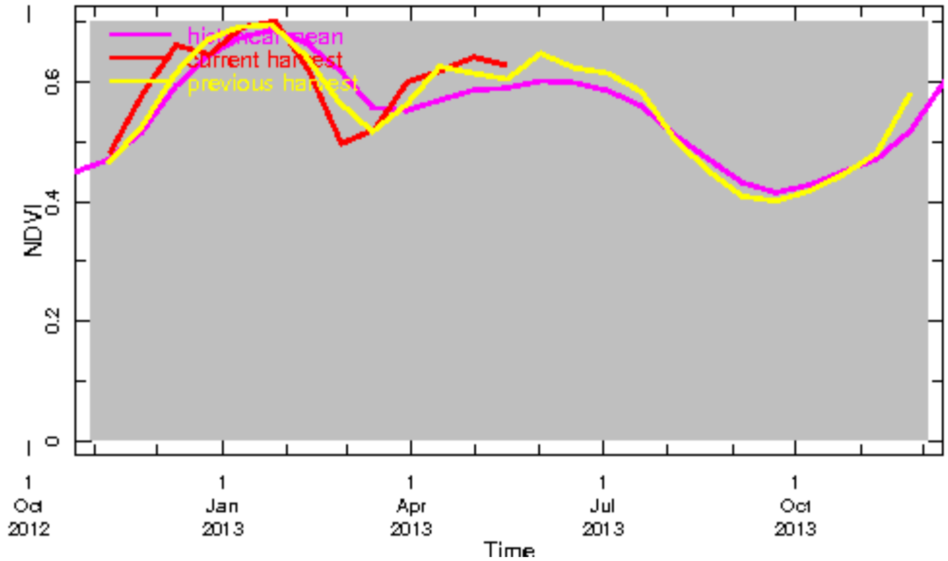
The Moderate Resolution Imaging Spectrometer (MODIS) Crop Monitoring allows for maps of estimated vegetation to be produced using the Normalized Difference Vegetation Index (NDVI). A crop mask is applied on NDVI to better monitor crop development.

NDVI is used as a proxy for crop status and, given its 16-day time resolution, as a monitoring tool for crop growth. The map shows anomalies in NDVI as percent of the 14-year mean for a selected 16-day period. It gives at a glance an idea of whether crop status is above or below the historical mean. The boundaries shown in the map are Meso-regions, a unit that the Brazilian Institute of Statistics (IBGE) uses for mapping regional crop production data (aggregating Municipios of different States). Clicking on a Meso-Region will reveal local information in the form of two graphs and one table. The table indicates the relative difference in percentage between the selected (by default current) 12-month period and the previous 12-month period, as well as the historical mean 12-month period. This is meant to indicate potential penalties in crop growth.

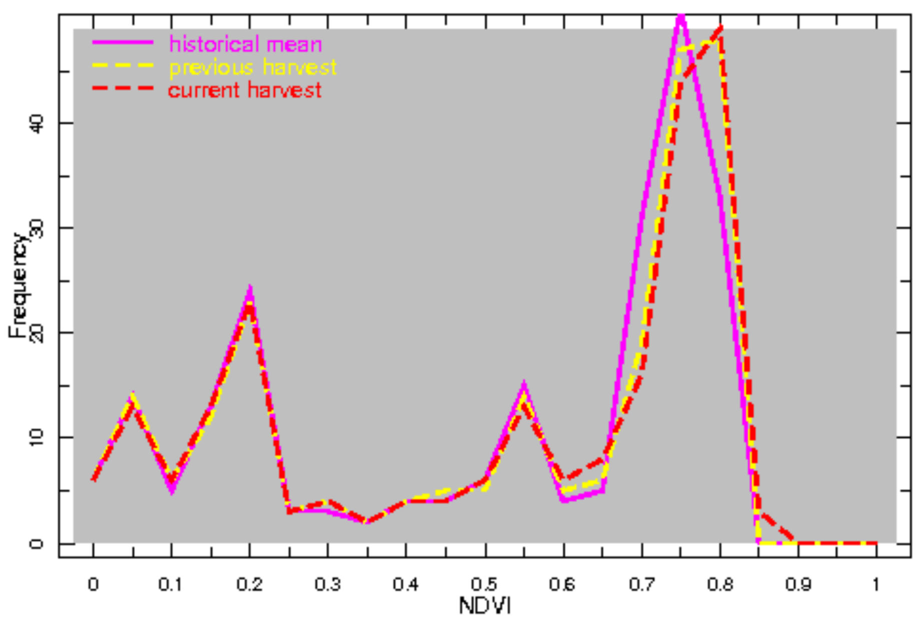
The graph shows December-February NDVI anomalies relative to the historical mean along with observed annual yields (from IBGE) expressed as year-to-year differences (i.e., difference between the annual yield and the yield of the previous year). The year-to-year differences applied on yield allows to remove a positive trend that is often found in yield data due to improvements in production technology and that is rarely the result of changes in environmental factors. The position of a yield data point is centered in the month of January of the year it reports, January being roughly the middle of the growing season across Brazil for Milho and Soja. Therefore this doesn't necessarily reflect the season when the harvest is actually made. This should be an indicator of how NDVI can be a good proxy for yield and therefore crop development.

Study region:

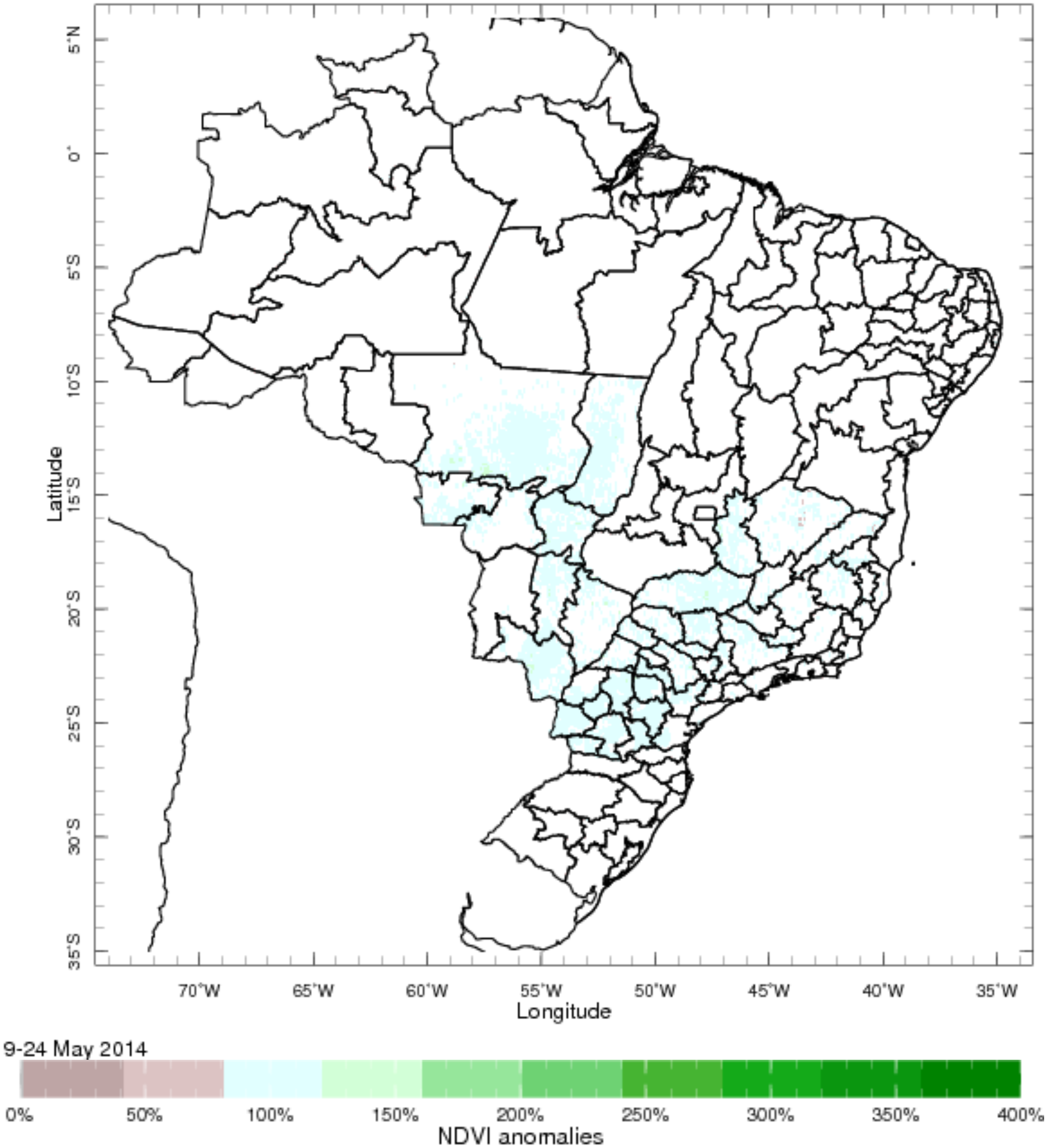
Observations for **NORTE CENTRAL PARANAENSE**



a) 16-day estimates of NDVI for the selected meso-region selected for a period of 12 months centered on the 16-day period selected (red), overlaid with the historical mean (magenta) of the same 12-month period and with the previous year (yellow) 12-month period. Time axis represents the previous 12-month time. This is meant to be an indicator of the temporal evolution of crop development.



b) Spatial distribution of 16 day estimates of NDVI for the selected meso-region for the selected 16-day period (red), overlaid with the historical distribution of the mean (magenta) of that selected 16-day period and with the distribution of that selected 16-day period during the previous year (yellow). This is meant to be an indicator of the anomalies of crop development.

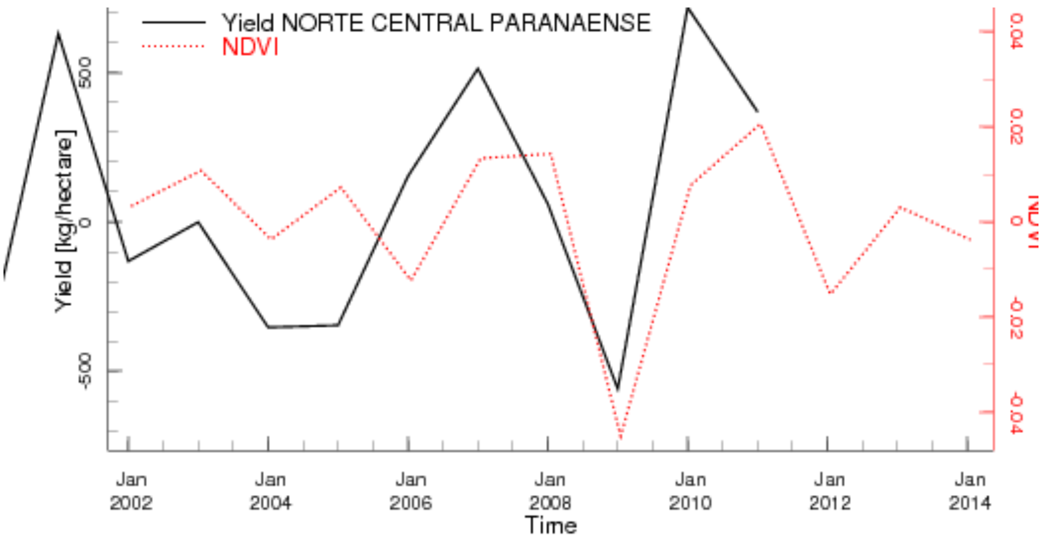


5°N
0°
5°S
10°S
15°S
20°S
25°S
30°S
35°S
Latitude
70°W
65°W
60°W
55°W
50°W
45°W
40°W
35°W
Longitude
9-24 May 2014
0%
50%
100%
150%
200%
250%
300%
350%
400%
NDVI anomalies

Relative Crop Development Penalties

16-day period	Difference with previous year	Difference with average year
31 Oct 2012 - 15 Nov 2012	4.0%	2.0%
16 Nov 2012 - 1 Dec 2012	10.0%	12.0%
2-17 Dec 2012	7.0%	11.0%
18-31 Dec 2012	-3.0%	1.0%
1-16 Jan 2013	-1.0%	3.0%
17 Jan 2013 - 1 Feb 2013	1.0%	2.0%
2-17 Feb 2013	-3.0%	-6.0%
18 Feb 2013 - 5 Mar 2013	-11.0%	-20.0%
6-21 Mar 2013	1.0%	-8.0%
22 Mar 2013 - 6 Apr 2013	6.0%	9.0%
7-22 Apr 2013	-1.0%	10.0%
23 Apr 2013 - 8 May 2013	4.0%	10.0%
9-24 May 2013	4.0%	7.0%
25 May 2013 - 9 Jun 2013	NaN%	NaN%
10-25 Jun 2013	NaN%	NaN%
26 Jun 2013 - 11 Jul 2013	NaN%	NaN%
12-27 Jul 2013	NaN%	NaN%
28 Jul 2013 - 12 Aug 2013	NaN%	NaN%
13-28 Aug 2013	NaN%	NaN%
29 Aug 2013 - 13 Sep 2013	NaN%	NaN%
14-29 Sep 2013	NaN%	NaN%
30 Sep 2013 - 15 Oct 2013	NaN%	NaN%
16-31 Oct 2013	NaN%	NaN%
1-16 Nov 2013	NaN%	NaN%
17 Nov 2013 - 2 Dec 2013	NaN%	NaN%

Actual Yield vs. NDVI Comparison



Lavoura Soja MesoRegion NORTE CENTRAL PARANAENSE

3. Crop yield prediction

3.1 Development and improvement of stand-alone models and tools for crop yield prediction

The team used two approaches to develop crop yield forecasts: one based on correlations between available soil water content at flowering and harvested yield, and another one based on linking seasonal rainfall forecasts with crop simulation models.

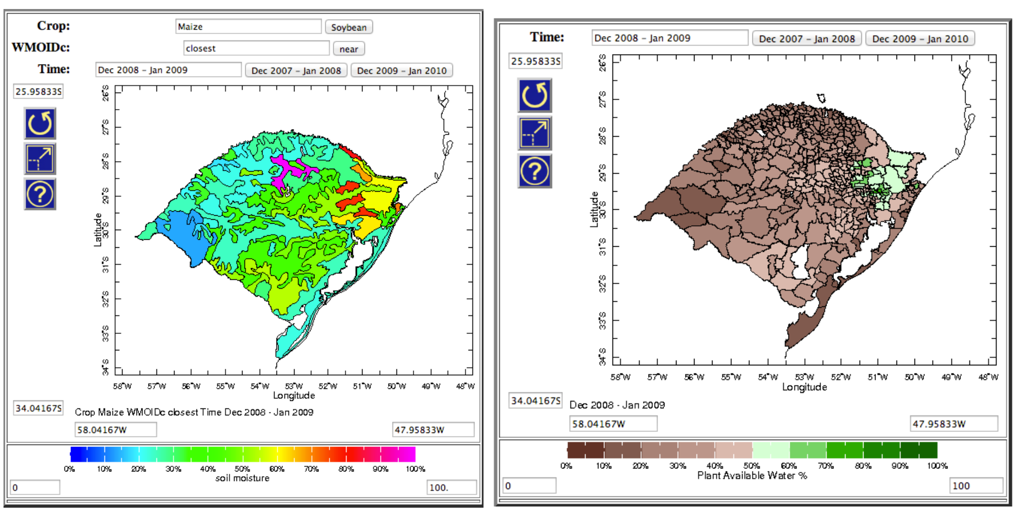
3.1.1. Stand-alone water balance model

We first used a simplified soil map to assign water holding capacity to the different soil types of Rio Grande do Sul (Figure 1). However, since the crop yield data are published by municipio, we expressed the soil water balances by municipio (Figure 2).

Figure 3.1: Simplified soil map used to estimate soil water balances

Figure 3.2: Soil water balance by soil type and by municipio

(a) By soil type (b) By municipio



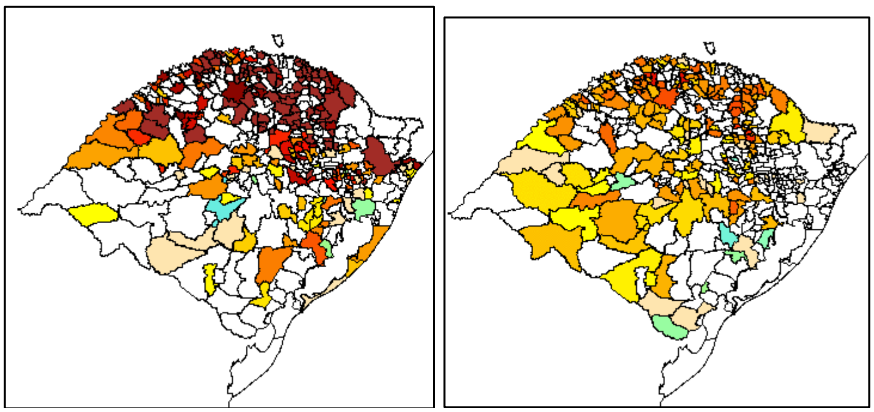
We developed a polygon-based water balance model (H20_Balance_Polygon_V01a) to calculate the components of the water balance of a soil polygon in a study region. At a given climate, agronomic and environmental conditions, the model calculates daily crop evapotranspiration, soil moisture (hence available water) and net water loss (runoff and percolation) then outputs them as individual text files that are in GIS-ready format so that it can be easily shown in maps.

The model is written in Fortran language hence it can be easily compiled/built and ported to different operating systems. Based on the request of INMET, the stand-alone water balance model was updated to be able to distinguish data from an automatic weather station and that of a synoptic station when reading the input files because of the different units of measurement used in solar radiation. Lag correlation analysis between the water balance components and crop yields can be done to develop a simple statistical crop yield prediction model.

We then developed maps of the municipios with more than 20% of their area planted to maize or soybeans (Figure 3)

Figure 3.3: Examples of maps showing municipios with 20% of their area planted to maize and soybeans

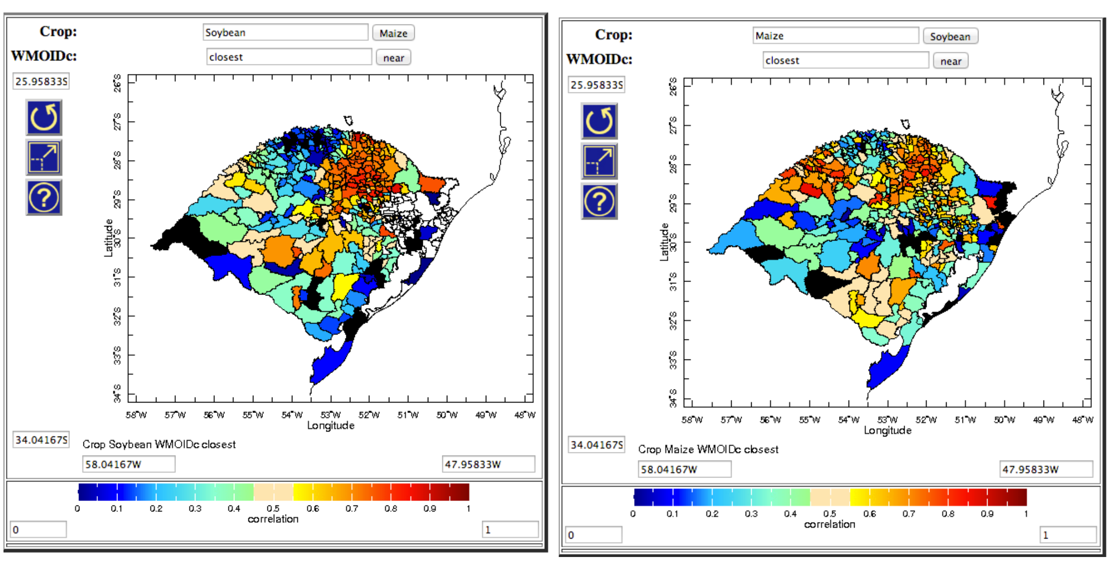
(a) Maize (b) Soybeans



Finally we calculated the correlation between plant available water in the soils in different trimesters and the obtained crop yields (maize and soybeans). The best correlations for both crops was found with availabel water in December-January (Figure 4)

Figure 3.4: Example of correlation between available water at flowering and crop yield.

(a) Soybeans (b) Maize



3.2 Linking tools for climate and crop models

The second approach we explored for crop yield prediction is by using crop simulation models and seasonal climate forecasts. Here, we developed two frameworks for linking probabilistic tercile-based climate forecasts with the crop models: a non-parametric resampling technique and by using a weather generator.

3.3 Forecast re-sampler

The forecast re-sampler (FResampler1) creates weather realizations of the tercile-based seasonal climate forecasts. This is done by sampling long-term climate data based on the probabilities of rainfall of being below-normal, near-normal and above-normal of that season. It samples with replacement blocks of weather data that contain solar radiation, maximum and minimum temperature and rainfall hence preserving the covariance between rainfall and other weather parameters. To complete the sequence of weather data for the full growing season, the tool attaches the remaining data from the sampled year until the time of harvest (and going back from the start of that year if needed).

After some discussions with INMET, however, the tool was updated to use weather data from the succeeding year of the sampled year instead of going back from the beginning of that sampled year to generate data sequence for seasons e.g., DJF, JFM, etc., which is common for summer crops sown in Sept-to-Nov in the southern hemisphere. Those weather realizations are then linked with the crop models to generate crop yield predictions (Figure 3.5). The advantage of this approach is that it uses the distribution (tercile-based) of the climate forecasts in generating daily realizations of that forecasts. Based on sensitivity analysis, the number of samples used is found to be critical for approximating the theoretical distribution of the seasonal rainfall based on the probabilistic climate forecasts. The tool is also written in Fortran.

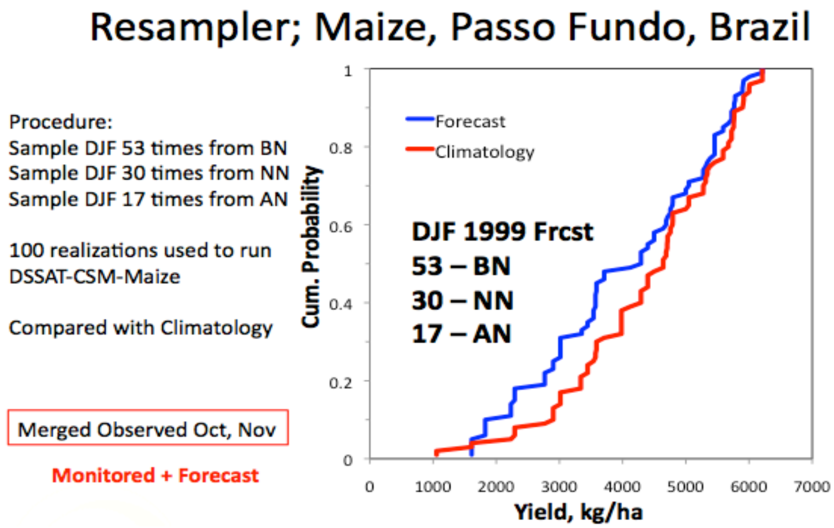
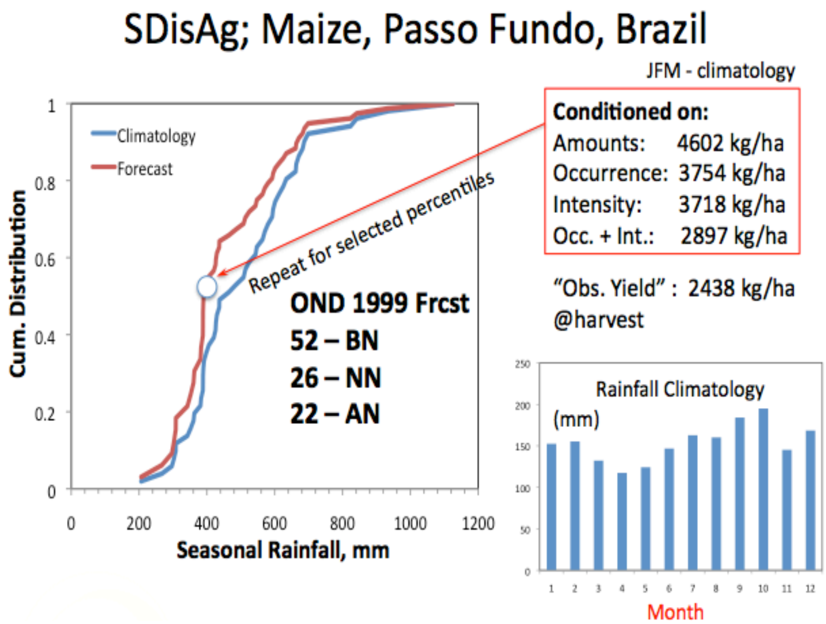


Fig. 3.5 Sample results of Reampler linked with DSSAT-CSM Maize for predicting yield given a probabilistic tercile-based seasonal rainfall forecast.

3.4 Stochastic disaggregation

Another approach for linking seasonal climate forecasts with a crop model is by a weather generator. The 'conditional' weather generator is designed to disaggregate monthly rainfall into daily realizations. The challenge here is how to translate the tercile-based probabilities of the seasonal climate forecast into monthly rainfall amounts. A framework was developed to solving this problem. First, we generate the climatological distribution of rainfall for that season. Then, we shift this rainfall distribution by applying the tercile-based forecast probabilities of rainfall for that season. This is done for each tercile category, respectively.

The adjusted seasonal rainfall distribution is the 'continuous' equivalence of the tercile-based seasonal rainfall forecast. This can then be disaggregated into monthly values (per percentile) by using the fractions of monthly rainfall within the considered season; these fractions are derived from climatology. For the stochastic disaggregation, generating other weather variables e.g., minimum and maximum temperature and solar radiation are based from climatology. However, the tool is able to disaggregate monthly values of these weather variables if given. It can also generate daily realizations of rainfall based on information from rainfall frequency and intensity. The generated weather realizations are then linked to the crop models to generate crop yield forecasts (Figure 3.6). This procedure however should be done per percentile of seasonal rainfall forecast distribution to generate a distribution of crop yields.



FigSample results of SDisAg linked with DSSAT-CSM Maize for predicting yield given a probabilistic tercile-based seasonal rainfall forecast.

3.5 Capacity building

A 5-day training/workshop of the stand-alone models and tools was conducted in August 2013 at INMET. Lectures also included how to integrate remote sensing with crop models, concepts and how to use DSSAT and AQUACROP models. Hands-on exercises on the soil water balance model, and the linking tools were conducted. In the hands-on exercises, we used actual NMME hindcasts developed for Rio Grande del Sur. After the workshop, INMET requested us to prepare a User Guide for the stand-alone tools. This was prepared and submitted to INMET.

3.6 Link to the models, linking tools and user guide

http://iri.columbia.edu/~ines/INMET