

USE OF REMOTE SENSING FOR CROP YIELD AND AREA ESTIMATES IN THE SOUTHERN OF BRAZIL

D. C. Fontana^{a,*}, R. W. Melo^a, A.P. L. Wagner^b, E. Weber^b, A. Gusso^b

^a UFRGS Faculdade de Agronomia, 15.100 Porto Alegre, Brasil - (dfontana@ufrgs.br; melo_rw@yahoo.com.br)

^b UFRGS Centro Estadual de Pesquisas em Sensoriamento Remoto e Meteorologia, 15.044 Porto Alegre, Brasil
(anaplw@yahoo.com.br; Anibal.Gusso@ufrgs.br; eweber@portoweb.com.br)

Commission VIII, WG VIII/10

KEY WORDS: Agriculture, developing countries, mapping, modelling, satellite

ABSTRACT:

The purpose of this paper is to describe the main actions undertaken by the Federal University of Rio Grande do Sul (UFRGS-Universidade Federal do Rio Grande do Sul) in activities related to crop monitoring and forecasting in Rio Grande do Sul State, the most southern state in Brazil. First the importance of agricultural activity is placed in the context of the state, showing grain production data. A short description of UFRGS and the group of researchers is also presented. Then several actions developed by the University to monitor crops and forecast harvests are presented, by discussing the methodology and main results of project GeoSafras (GeoHarvests). This is a multi-institutional nationwide project coordinated by the National Supply Company (CONAB-Companhia Nacional de Abastecimento). From the methodological standpoint, the project uses a set of techniques and methods, some already tested and others under development, in the fields of remote sensing, geoprocessing and agrometeorology. In this paper as an illustration, some results are presented using soybean crop. Finally, a report is made on actions in cooperation with Joint Research Centre (JRC), the results of which were presented at a JRC workshop in Montevideo, comparing ECMWF (European Center for Medium range Weather Forecasting) simulated data to observed data at several surface meteorological stations, as well as, evaluating the use of simulated data in the soybean yield model in Rio Grande do Sul State.

1. BRAZILIAN AGRICULTURAL CONTEXT

Brazil is one of the main grain producers and exporters in the world, and agribusiness is crucially important for the economy of the country. Regionally, Rio Grande do Sul, the most southern state of the country, is the third largest grain producer among the Brazilian states. In the last 5 years the average contribution of Rio Grande do Sul has been about 17% of the national harvest. The largest volumes of grain in the state are soybean (6025579.8 t), rice (5576242.6 t), maize (4064680.8 t) and wheat (1609823.8 t) (IBGE, 2006).

Since the agricultural industry has produced the main trade balance surplus in Brazil, in the last few years, government actions are required for effective control of imports and exports of agricultural products, both as regards the trade balance and adequate supply for the domestic market.

Surveys of Brazilian harvests have traditionally been performed using shire information obtained in a subjective survey system, based on the opinion of technical and economic agents involved in the sector.

Recently, the National Company for Supply (CONAB – Companhia Nacional de Abastecimento – <http://www.conab.gov.br>), the institution responsible for generating national agricultural estimates, proposed a project to revitalize the institution by improving the system of estimating areas and agricultural yields in Brazil. The work has been developed using a multi-institutional network to developing objective methods that can be absorbed by the institution and implemented operationally. This project is called GeoSafras (GeoHarvests).

2. MAIN CROP MONITORING AND FORECASTING ACTIONS AT UFRGS

2.1 Background

The research group on harvest monitoring and forecasting at Federal University of Rio Grande do Sul State (UFRGS – Universidade Federal do Rio Grande do Sul <http://www.ufrgs.br>) is currently participating in the GeoSafras project, proposing methodological developments and tests that can be passed on to CONAB and incorporated to the crop monitoring and forecasting program in Brazil.

UFRGS, located in Porto Alegre, capital of the state of Rio Grande do Sul, is a century-old institution. Courses of study in all fields of knowledge at all levels, from Basic Education to Post-Graduate studies are taught at the University. Currently, the University has 355 research groups. One of the outstanding groups researches crop monitoring and forecasting. These researchers are located at the Faculty of Agronomy (<http://www.ufrgs.br/agronomia>) and at the State Center of Research on Remote Sensing and Meteorology (CEPSRM-Centro Estadual de Pesquisas em Sensoriamento Remoto e Meteorologia – <http://www.ufrgs.br/srm>).

Nowadays, the team working on this line of research includes permanent UFRGS staff (Denise Cybis Fontana, Jorge Ducati, Mônica Kreling, Moacir A Berlatto, Homero Bergamaschi and Laurindo Guasselli), and FEPAGRO staff (Ronaldo Matzenauer and Jaime Maluf), masters scholarship students (Eliana V. Klering and Amanda H. Junges), scientific initiation students (Ana Paula A. Cordeiro, Fernando T. Machado, Laurie F. Cunha, Lucas S. Borne and Márcia dos Santos), technical development people (Ricardo W. Melo, Anibal Gusso and Gilca

* Corresponding author.

M. Alves) and consultants (Ana Paula L. Wagner and Eliseu Weber).

Joint CONAB-UFRGS activities began during the 1998/99 crop yield, in a pilot experiment in the state of Rio Grande do Sul, using only a Landsat scene covering part of the northwest of the state. In 1999/2000 the work were repeated but the coverage area was greatly increased, now to approximately 50% of the soybean-cultivated area in Brazil (Fontana et al., 2000). Despite promising results, work was interrupted, and it was only from the 2003/2004 crop onwards that the partnership was established again. During the period of the interruption, three workshops were held, which made it possible to prepare a new institutional arrangement for cooperation, in which a group of research institutions from several Brazilian states participated, working in an integrated manner. Among the participating institutions were UNICAMP, INPE, INMET, EMBRAPA, IBGE, and others.

At UFRGS GeoSafras-related work is oriented towards the three segments that constitute a crop forecasting program: estimates of cultivated area, estimates of yield and monitoring during the crop development period. A few of the experiments developed with soybean crops in the state of Rio Grande do Sul will be described in this document.

2.2 Methodology

Methodologically, the actions present a set of techniques and methods, some of them already tested and others still under development, in remote sensing, geoprocessing and agrometeorology.

With remote sensing, the land surface characteristics can be measured based on high-altitude sensing devices, on board airplanes or satellite. Satellite images, in particular, have allowed increasingly detailed studies on a regional scale, due to the possibility of viewing the same territory at regular time intervals. This characteristic shows its potential to follow the changes that occur on the earth surface over time. Furthermore, the images allow measuring the characteristics of the surface in different bands, both in the visible and in the infra-red region. Analysis of these bands allows mapping the different types of land cover, including agricultural crops. Using geoprocessing, it is possible to locate geographically and quantify the cultivated areas, integrating regional or national information. In agrometeorology models are already available to quantify the plant-climate relationship by using data from surface meteorological stations together with satellite images to forecast yield.

2.3 Main results of project GeoSafras-UFRGS

A methodological possibility that has been tested at GeoSafras is the combined use of medium and low spatial resolution sensors. The sensors with medium spatial resolution can contribute detailed information in certain areas, while the lower spatial resolution sensors can help generalize information. We have worked with the three main crops in the Rio Grande do Sul State, that are: soybean, rice and wheat. As an illustration, some results are presented in this paper using soybean.

2.3.1 Landsat/TM – for crop area mapping: Most of the work done with medium resolution sensors in Brazil has used Landsat/TM satellite images. The results accumulated by the group at UFRGS using these images to estimate the area planted with soybean during several crops years have proved promising, revealing high accuracy when evaluated based on field data (Motta, 2002; Weber et al., 2005). However, despite

the high concordance between the results of image classification and ground control, in many cases considerable discrepancies were found between area estimates obtained at a municipal level from images and estimates supplied by CONAB and also by Brazilian Institute of Geography and Statistics (Instituto Nacional de Geografia e Estatística – IBGE). For all the years studied, despite the good results obtained with several classification methodologies, the greatest challenge was to render actions that could supply the information needed for large regions operational, in a timely manner compatible with the schedule of official surveys. One of the greatest obstacles in this sense is always how long it takes to obtain the Landsat/TM images, which has delayed the beginning of their processing and, consequently, obtaining results. The mapping of the 2005/06 crop is shown in Figure 1, making it clear that most of the soybean cultivated in Rio Grande do Sul is concentrated in the center-north region of the state.

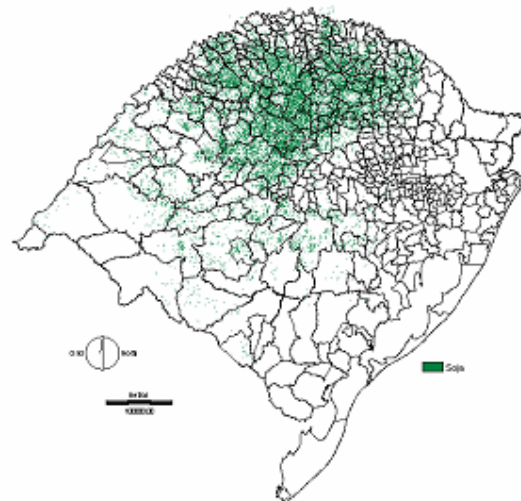


Figure 1. Soybean cultivated area in Rio Grande do Sul State, mapped using 11 Landsat-TM images, during 2005/06 crop year.

2.3.2 Terra/MODIS – for crop area mapping: As to the low resolution sensors, the initial attempts to estimate the crop area with low spatial resolution images were performed using AVHRR/NOAA images. Despite the feasibility of using these images in monitoring programs, the study performed by Motta et al. (2003) showed that the potential of using these images to make inferences about the cultivated areas had to be further evaluated because of the 1 km spatial resolution at the nadir. Later, MODIS/TERRA images began to be used. These images have a spatial resolution of 250m and a temporal resolution of 16 days, adequate for this type of study. In this case, the studies to determine the crop area were performed by analyzing the time variations of the vegetation index. Throughout the growing season, the crops present a time variation different from the other types of ground cover. At the beginning of the cycle, during the crop implantation phase, the vegetation index values are low, increasing as crop growth and development occurs, and diminishing again at the end of the cycle as the plants become senescent. During the 2004/05 and 2005/06 harvests, tests of the use of MODIS/TERRA images were made to map soybean in Rio Grande do Sul State. At both harvests, two methods were tested, based on the use of the Normalized Difference

Vegetation Index (NDVI): one tries to individualize the soybean areas using an image of difference and another uses reclassification through an NDVI threshold in two periods and then cross-matches binary images. In both techniques, images of contrasting periods are used in terms of NDVI, one for the phase during which the crop is planted, and the other when the crop is fully developed. In these two methodologies, the analyses were also based on field data recorded by GPS in several crops. The results obtained have been very promising and the data obtained for the 2005/06 harvest are shown in Figure 2. A more detailed analysis of the results obtained is ongoing with a view to applying it to other crops and in other regions, especially concerning the practicality, low cost and easy data generation.

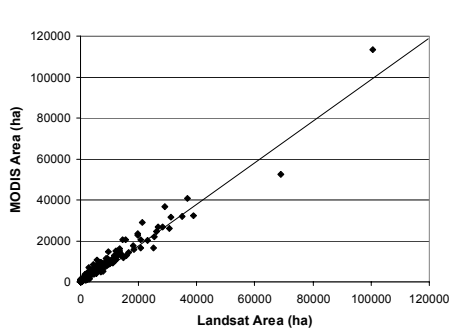


Figure 2. Comparison between soybean area from Landsat and MODIS images, using just counties 100% covered by images without clouds, in Rio Grande do Sul State during 2006/06 crop year.

2.3.3 NOAA/AVHRR – for monitoring and yield estimates: Another low spatial resolution sensor used lately by the UFRGS group is the AVHRR/NOAA images, now for monitoring and yield estimates. Yield, defined as grain production per unit of area, is a result of the complex interaction between soil conditions (physical and chemical conditions), management (cultivar, spacing,...), and the meteorological conditions (water, thermal,...). On the other hand, modelling the environment may be conceived as the simplified representation of the relationship between the crop and the environment. Agrometeorological model characteristics are accuracy, objectivity, easy implementation and low costs. They can be used to predict plant behaviour, if a given condition exists in crop forecasting programs. This type of modeling is based on establishing growth and development relations for the vegetation, with variables describing the meteorological conditions during the cycle. The functions consider the differences in crop sensitivity to stresses throughout the cycle, the so-called “critical periods”. In Rio Grande do Sul a few previous studies, such as those performed by Berlato (1987) and Fontana et al. (2001), proposed the use of soybean yield prediction models (similar to others non-irrigated spring-summer crops), and the independent variable to be used was some expression of water availability. In these models different weights are assigned to the different stages of crop development, according to the relative sensitivity of the plant to the water deficit. Later, Melo et al. (2003) added a spectral term to the agrometeorological model. The hypothesis to introduce remote sensing techniques is based on the fact that plant growth and development may be monitored by orbital remote sensors,

that the remote measurement of the biomass may be a complementary estimator of grain yield, and, finally, that measurement from satellites allows improved detailing of spatial variations of yield. The spectral term is given by the Maximum Value Composites (MVC) of the Normalized Difference Vegetation Index (NDVI), obtained from satellite images with low spatial resolution but high temporal resolution, as in AVHRR/NOAA. In the case of these types of models, the agrometeorological term covers the thermal and water conditions, while the spectral term introduces into the model other factors that determine growth and are not taken into account in the agrometeorological term, such as differences in management practices, cultivars and other stresses. The results of applying this model for the last 4 crops is shown in Figure 3. It is found that the estimates accompany the tendencies of the official statistics (IBGE), although with less sensitivity, ie, the estimated yields are below those observed in the high yield years and above those of low yield. It is thus found that the model proposed can potentially be used at a regional level, fulfilling the demand of agencies in charge of official crop surveys in Brazil. For monitoring activities, AVHRR/NOAA images have been tested with success for Rio Grande do Sul conditions (Fontana et al., 2002) These images are available at CEPSSM web site (www.ufrgs.br/srm).

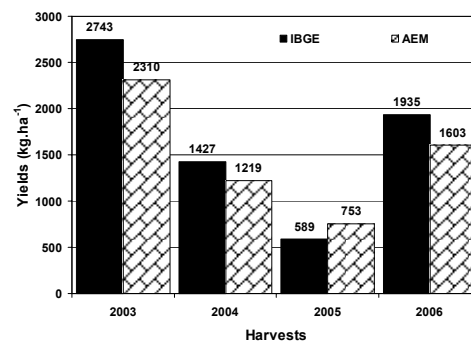


Figure 3. Soybean yield by IBGE and estimated by the agrometeorological-spectral model (ASM) for the last four harvests in Rio Grande do Sul State.

3. ACTIONS IN COLLABORATION WITH THE JRC

During the International Workshop of Crop Monitoring and Forecast, held in Montevideo, October 9-11, 2006, a few results of work done in cooperation between AGRIFSH/MARS-FOOD and UFRGS were presented (Melo e Fontana, 2006). In this study, meteorological data simulated by the JRC and measured at meteorological stations during the January 2003-December 2005 period were used.

The data simulated, all of them for 10 days, were obtained from the website of JRC (JRC, 2006) in the form of GeoTIFF images of maximum, minimum and mean temperature, rainfall and evapotranspiration. The meteorological data from 17 surface stations located in the state of Rio Grande do Sul were obtained from the observation networks of the 8th District of the National Institute of Meteorology - 8° DISME/INMET – 8° Distrito do Instituto Nacional de Meteorologia) and from the State Foundation of Agricultural and Livestock Research of the Department of Science and Technology (FEPAGRO/SCT - Fundação Estadual de Pesquisa Agropecuária da Secretaria de Ciência e Tecnologia).

The results showed that the maximum temperature data simulated overestimated by 5.2°C, on average, the data observed at the meteorological stations, while the minimum temperature data presented a mean underestimate of 4.9°C. The mean temperature data simulated presented a slight tendency to underestimate, and were very close to the 1:1 line, with a standard deviation of 1.1°C (Figure 4).

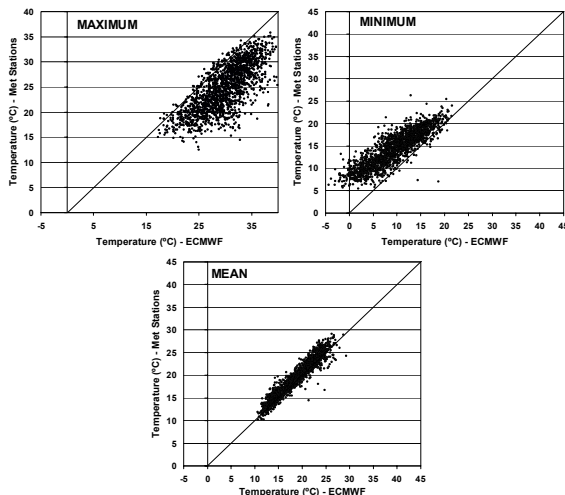


Figure 4. Maximum, minimum and Mean Temperature measured (Met Stations) and estimated by ECMWF in the Rio Grande do Sul state.

On the other hand, the rainfall data presented a wide dispersion compared with the data observed at the surface meteorological stations (Figure 5). Part of the dispersion may be due to the fact that analysis was performed comparing data collected at an observation point (meteorological station) and mean data from a grid generated by the JRC model. Analyzing the evapotranspiration data simulated by JRC, a slight tendency to underestimate small values and overestimate values with a greater magnitude, compared with the values calculated based on the meteorological data was observed at the surface stations (Figure 5).

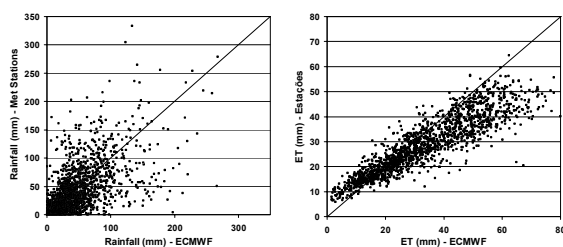


Figure 5. Rainfall and Evapotranspiration (ET) measured (Met Stations) and estimated by ECMWF.

In the follow up of this paper, the performance of the agrometeorological-spectral model to estimate soybean yield was evaluated, for the region with the highest soybean production in the state of Rio Grande do Sul, using data from surface meteorological stations and data simulated by ECMWF. The study showed that the meteorological simulated data may be used as an alternative source of data to calculate the

estimated soybean yields in the region with the highest production in the Rio Grande do Sul State (Figure 6).

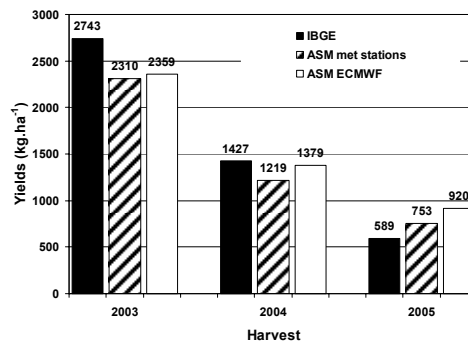


Figure 6. Soybean yield by IBGE and estimated by the agrometeorological-spectral model (ASM) using data from meteorological stations and by ECMWF simulations.

4. FINAL CONSIDERATIONS.

The partnership between UFRGS and CONAB, established through the GeoSafras project, has provided an excellent environment to exchange experiences between the two institutions, as well as with the other partner institutions. Besides testing and developing techniques and methods, the vocation of the University is to train human resources, providing trained professionals who may be taken on by the institutions responsible for obtaining information on agricultural crops. On the other hand, in this partnership, CONAB and UFRGS has an opportunity to perform research on an applied topic, which has led to establishing and maintaining this research group.

The methods developed at GeoSafras project fulfilling the demands by objectivity, accuracy, low costs and practicality of the estimations. Of course, the methods need of continued improvement especially for crop area and yield forecasting, what justifies founding allocation. Finally, according to the UFRGS researchers, the experience exchanges are welcome.

References

- Berlato, M. A. 1987. *Modelo de relação entre o rendimento de grãos e soja e o déficit hídrico para o Estado do Rio Grande do Sul*. 103f. Thesis (Meteorology) – Curso de Pós-Graduação em Meteorologia, Instituto Nacional de Pesquisas Espaciais.
- Fontana, D. C. et al. 2001. Modelo de estimativa de rendimento de soja no Estado do Rio Grande do Sul, *Pesquisa Agropecuária Brasileira*, 26(3), pp. 399-403.
- Fontana, D. C., Weber, E., Ducati, J., Figueiredo, D. C., Berlato, M. A., Bergamaschi, H., 2000. A case study for crop monitoring and harvest forecast in south Brazil. In: *28th International Symposium on Remote Sensing of Environment*, Cape Town, South Africa. p.91 – 94.
- Fontana, D.C., Weber, E., Ducati, J., Berlato, M. A., Guasselli, L.A., Gusso, A. 2002. Monitoramento da cultura da soja no centro-sul do Brasil durante La Niña 1998/200. *Revista Brasileira de Agrometeorologia*, 10(2), pp.343-251.

IBGE – INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. 2005. Available at <http://www.ibge.gob.br>. Accessed in: 30 may 2006.

JRC. Joint Research Centre Simulated Meteorological Data. 2006. Available at: <http://agrifish.jrc.it/marsfood/ecmwf.htm>. Accessed in: 23 May 2006.

Melo, R. W., Fontana, D. C. 2006. Avaliação de dados meteorológicos disponíveis no website do Joint Research Center In: *II International workshop on crop monitoring and forecasting in South America*, Montevideo, Uruguay. Vol.1. p.1– 7.

Melo, R. W., Fontana, D. C., Berlato, M. A. 2003. Modelo agrometeorológico-espectral de estimativa de rendimento da soja para o estado do Rio Grande do Sul In: *XI Simpósio Brasileiro de Sensoriamento Remoto*, Belo Horizonte, Brasil. p.173 – 179.

Motta, J. L. G., Fontana, D. C., Weber, 2003. E. Análise da evolução temporal o NDVI/NOAA em região de soja no Rio Grande do Sul In: *XI Simpósio Brasileiro de Sensoriamento Remoto*, Belo Horizonte, Brazil. p.97 – 204.

Motta, J.L.G. 2002. *Subsídios à previsão de safra de soja no Rio Grande do Sul usando técnicas de sensoriamento remoto*. Thesis (Remote Sensing) - Universidade Federal do Rio Grande do Sul.

Weber, E., Fontana, D. C., Ducati, J., Silva, T. R., Saraiva, T. S., Freitas, L. A. S. 2005. Comparação entre resultados de classificação de imagens Landsat e CBERS para estimativa de área cultivada com soja no planalto do Rio Grande do Sul In: *XII Simpósio Brasileiro de Sensoriamento Remoto*. Goiânia. São José dos Campos, Brasil: Vol.1. p.321 – 328.

Acknowledgements

The authors thank CONAB and UNPD for founding the GeoSafras project, CNPq for the scholarships and JRC for the opportunity to participate in the event.