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METEOROLOGY

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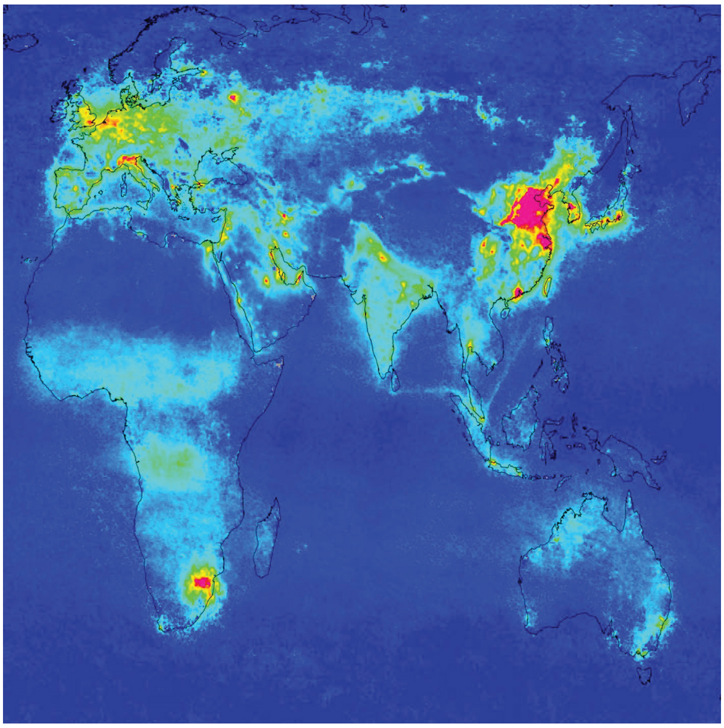

NO2 pollution map courtesy of KNM/IASB/ESA

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iCOLT – Seasonal forecasts of crop irrigation needs at ARPA-SIMC

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Every year, ARPA-SIMC, the Hydro-Meteo-Climate Service of the Environmental Agency of Emilia-Romagna provides a probabilistic assessment of potential irrigation demand of crops for the plain area of Emilia-Romagna (Northern Italy) and for each of the eight reclamation and irrigation consortia (hereafter referred to as 'consortia'), as shown in Figure 1. This is carried out using the iCOLT system (irrigazione e Classificazione delle cOLture in atto tramite Telerilevamento – irrigation and classification of current crops by remote sensing) which integrates satellite data, seasonal weather forecasts and water balance predictions.

An early assessment of the irrigation water need is of great importance, especially in a region like Emilia-Romagna that is located in the Northern Mediterranean area and exposed to water scarcity in summer. In recent years, the region has faced several droughts combined with very large summer temperature anomalies. This led to major problems in water management, which needs to balance the demands from civil, agricultural and industrial activities. In particular, the whole of Northern Italy was affected by an intense precipitation deficit, extending from September 2011 to September 2012, and by intense heat-waves. These conditions led to dramatic consequences for agriculture, especially in those Italian regions where water scarcity made it impossible to irrigate crops.

- The production was reduced by 20% for tomatoes, between 30% and 50% for corn (whose quality was also lower due to very high temperatures), by 40% for soya-beans, by 25% for rice and between 10% and 20% for sunflower seeds.
- Reductions in production were recorded for peaches (between 10% and 25%), pears (about 40%) and apples (about 20%).

The iCOLT system takes advantage of the ECMWF facilities made available as part of the Special Project SPIT-SPIA, aimed at producing seasonal predictions for Italian agriculture. It was mostly developed in the framework of the Italian national project Agroscenari, which is concerned with evaluating the impact of climate change on agriculture and devising specific adaptation strategies. The system has been operational at ARPA-SIMC since 2010, with the results made available via the agency's official website. It is an example of a climate service for agriculture, with specific application in the field of water management at regional and irrigation consortium scales. In the following, we give a description of the system, of its workflow in operational conditions, and of the results obtained for the summers of 2011, 2012 and 2013.

The iCOLT system has recently been officially recognized by the regional authorities of Emilia-Romagna as a strategic adaptation tool, amongst others, to address growing uncertainties in water availability for agriculture due to climate change.

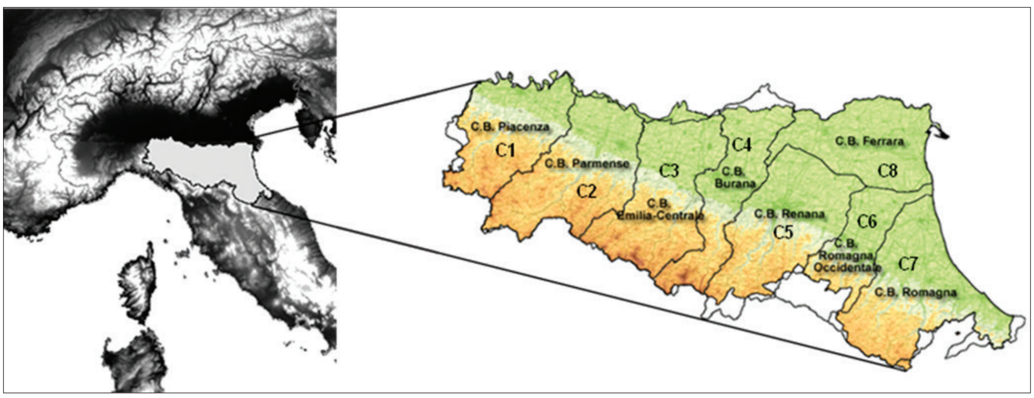

Figure 1 Emilia-Romagna region and the eight consortia.

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The operational system

Figure 2 shows the iCOLT operational workflow producing seasonal predictions of summer irrigation water need for Emilia-Romagna. The operational process spans two years.

- The process starts in mid-October of year one with the acquisition of the first satellite image of the region.
- By April of the following year, all satellite images have been acquired and the information on crop distribution can be classified (*Spisni et al*., 2010).
- By the third week of May, the calibrated probabilistic seasonal predictions for Emilia-Romagna are made available and the seasonal predictions of water irrigation need can be generated.
- At the end of summer, meteorological observations are used to estimate the actual irrigation needs using the CRITERIA water balance model (Controllo Riserve Idriche Territoriali per la Riduzione dell'Impatto Ambientale – Local water resource monitoring to reduce the environmental impact) developed by ARPA-SIMC (see, for example, *Marletto et al*., 2007).

Wherever possible, forecast results are also verified using observed irrigation data. Each element of this workflow will now be described in detail.

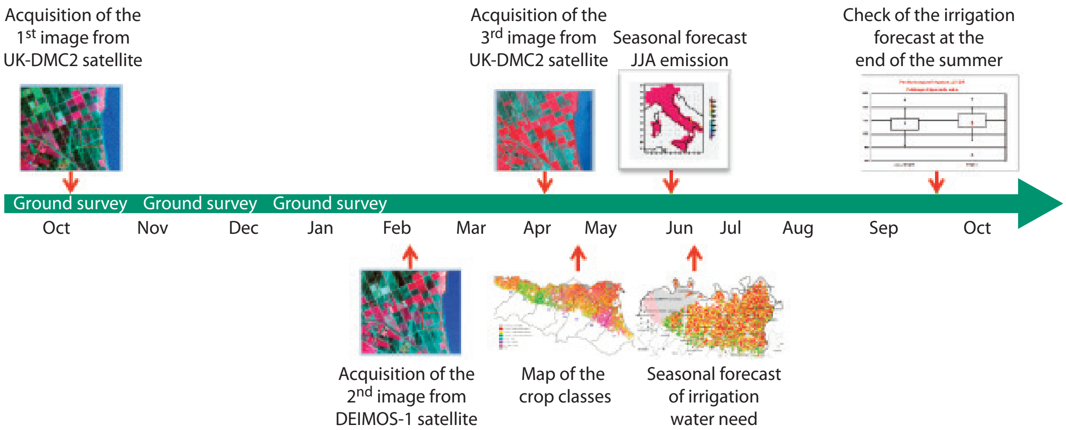

Figure 2 The iCOLT system workflow.

Crop classification and mapping with remote sensing

The first step of the iColt system consists of the classification of current agricultural crops on the whole regional plain (about 1,180,000 hectare). The classification is based on field surveys and on the analysis of visible and near infrared satellite images taken in October, February and April. The three temporal windows for the satellite images are chosen to enhance the differences between the phenological stages of crop macro-classes. In any particular year, the satellite data sources used depend upon availability and image quality. As an example, for 2013, the three images were taken on 16 October 2012 (satellite UK-DMC2), 8 February 2013 (satellite DEIMOS-1) and 18 April 2013 (satellite UK-DMC2).

Crops are grouped into five macro-classes: summer herbaceous, winter herbaceous, multiannual fodder crops, fruit orchards and vines, and rice paddies. The results are available by the end of April each year.

Seasonal forecasts

ARPA-SIMC has been producing local probabilistic seasonal forecasts since 2007 by calibrating the operational multi-model ensemble global seasonal predictions to the local climate. The multi-model ensemble is produced at ECMWF by the EUROSIP system (see Box A and *Pavan & Doblas-Reyes*, 2013). The final predictions are made available on a 35 km regular latitude-longitude grid covering the whole of Italy. These predictions represent the contribution of ARPA-SIMC to the Task Team on Monthly and Seasonal Predictions created by the Italian National Civil Protection Agency. This Task Team gives technical support to decision making at national level concerning water management, health care and wild fires prevention.

Summer seasonal forecasts for the June to August are issued in mid-May. Calibrated ensemble predictions of seasonal anomalies are produced for several variables needed as input of the weather generator scheme. These variables are:

Seasonally cumulated precipitation, wet day frequency and wet-wet frequency (i.e. the frequency of occurrence of a wet day after another wet day).

Minimum and maximum seasonal averaged temperature and the average difference in maximum temperature between dry and wet days.

A weather generator produces time series of daily precipitation and minimum and maximum temperature data that are statistically compatible with the seasonal anomalies given as input (*Tomei et al*., 2010). These synthetic daily time series are finally fed into the CRITERIA water balance model (see Box B for more information). Moreover, ARPA-SIMC has developed an empirical equation to assess the current value of the depth of the shallow water table using temperature and precipitation observations (*Tomei et al*., 2010). Seasonal forecasts of these two variables also allow the production of probabilistic seasonal predictions of water table level, a crucial source of water for the crops located in the Emilia-Romagna plain.

EUROSIP

A

The EUROSIP multi-model seasonal forecasting system consists of a number of independent coupled seasonal forecasting systems integrated into a common framework. From September 2012, the system included forecasts from ECMWF, the Met Office, Météo-France and NCEP (National Centers for Environmental Prediction). The reason for using a multi-model forecasting system is that research has shown that in most cases the multi-model combination is better than the best single model.

Data from all component models is archived at ECMWF, and can be accessed subject to the terms of the policy EUROSIP data.

ECMWF produces a number of multi-model products that are created from the integrated output of the component models. They are officially referred to as 'EUROSIP products'. Most of these products are provided in graphical form only, although also some numerical data are made available. These multi-model products can be accessed just like any other ECMWF product.

Data from the individual models is also archived at ECMWF, but the data can only be accessed subject to specific terms in the EUROSIP data policy.

For more information go to: http://www.ecmwf.int/products/forecasts/seasonal/documentation/eurosip/ch3.html

Results

Figure 3 presents, for each consortium, the time series of the box plots for the probabilistic seasonal predictions of irrigation need anomaly for the last three summers. Climatological values of the irrigation need and validation data are estimated using the CRITERIA water balance model forced by meteorological observations over the period 1991 to present. The irrigation need anomalies are computed by subtracting the climatological values from those predicted values. It should be noted that these results are obtained in forecast mode, so that the reference period includes only data preceding the forecast season.

For each consortium**,** at least two out of three forecasts are able to capture the sign of the observed anomaly and in some cases the forecast also gives a correct indication of the intensity. Furthermore, in some cases, the system captures differences in irrigation needs between consortia within the region. The particularly good skill of these predictions exceeded the expectations, since the products are obtained using probabilistic seasonal forecasts which do not have a high skill over Southern Europe (*Pavan & Doblas-Reyes*, 2013). It is possible that the ability of the system to capture the observed interannual variability is linked to the strong dependence of the water table level on the meteorological conditions that occurred over the preceding few months. As a consequence, a good estimate of the initial conditions of this quantity may have a positive impact on the final product, thereby improving the overall skill of the system.

In 2012, Emilia-Romagna suffered from an intense drought that substantially lowered the water table level, while in 2013 the opposite took place. These conditions favoured irrigation needs being higher than their climatic values in 2012, but lower in 2013. Furthermore, in these two years, although the meteorological seasonal predictions could not capture the exact intensity of the climate anomaly, they reproduced its general characteristics and made at least a partial contribution to the overall good performance of the system.

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The CRITERIA model

B

The The water balance model CRITERIA describes the dynamics of water in agricultural soils. In the iCOLT system it makes use of:

- Observed (until May) and predicted (for the rest of summer) daily data: namely minimum and maximum temperatures, precipitation, and water table depth.
- Yearly regional crop type maps derived from remote sensing classification.
- Static soil type data taken from the official Emilia-Romagna soil atlas.

CRITERIA is based on the approach of Driessen & Konijn (1992), though it has been improved by assuming a multi-layered soil and explicitly computing approximate values of daily evaporation, transpiration, water flows between layers, deep drainage, runoff and subsurface runoff. Crop development and the dynamics of related processes (e.g. those associated with the leaf area index and the rooting depth) are simulated in CRITERIA by means of empirical equations based on degree-day sums.

To assess the crop water demand, the irrigation process is controlled by a number of parameters, including the irrigation season duration, irrigation shift minimum period, maximum volume for a single irrigation, crop coefficients reached by the crop in the maximum development, crop sensitivity values to the water stress and, if applicable, percentage of controlled stress.

The ability of the system to capture differences between water irrigation needs between consortia might be linked to (a) a correct evaluation of the initial conditions of the local water table level and (b) the good quality of the evaluation of the geographical distribution of different crop macro-classes since each of them is characterized by different water needs.

Table 1 is based on data for summer 2013 and presents one of the typical operational products of iCOLT that provides an assessment of crop water needs at regional and local level to water management authorities. The table shows the median, the 25th percentile and the 75th percentile of the probabilistic seasonal predictions of irrigation (466 million cubic metres) for each consortium and for the region as a whole, together with the estimated irrigation need. These last values are obtained by the end of the season by running the CRITERIA water balance model forced with meteorological observations. Actual observed data are currently being collected, but, as for now, are not yet available for all consortia. The table shows that there is a difference of about 20% between the median of the probabilistic forecast and the estimated values of water irrigation needs.

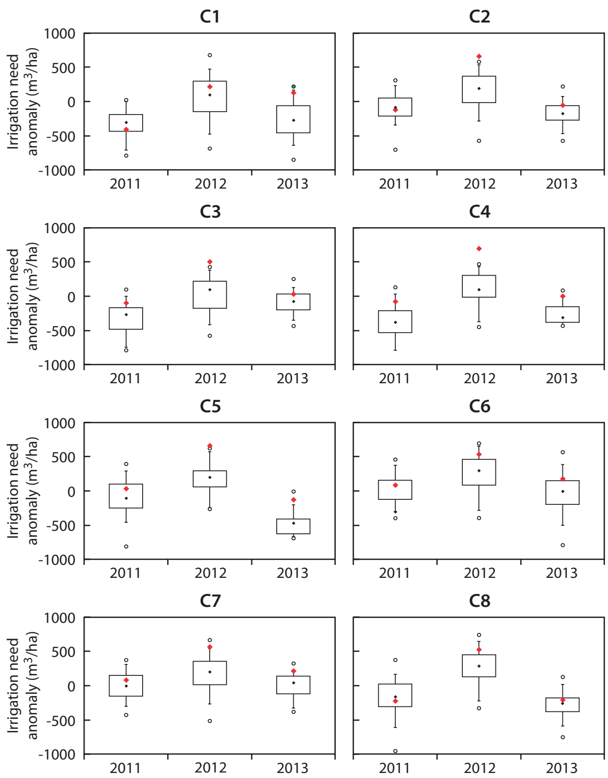

Figure 3 The panels refer to each Emilia-Romagna consortium and show the box plot for the probabilistic seasonal predictions of irrigation need anomaly (in m^3/ha) obtained using the iCOLT system for the years 2011, 2012 and 2013. Climatological values and validation values (red dots) are estimated using the CRITERIA water balance model forced with meteorological observations. Boxes cover from the 25th to the 75th percentiles, whiskers extend to the 5th and 95th percentiles while extreme values are indicated by black dots. Red, solid dots indicate the observed values.

Current performance and future developments

The iCOLT system is used operationally at ARPA-SIMC to provide information about seasonal probabilistic irrigation needs over the plains of Emilia-Romagna. The system combines information on land use (obtained from high-resolution satellite data), meteorological observations (provided by the local regional meteorological office), and probabilistic seasonal predictions (obtained by calibrating the operational EUROSIP multi-model seasonal forecasts over the regional climate).

The results for the last three seasons indicate that this product has a relatively good skill. In particular, at least two out of three probabilistic predictions for each consortium are able to capture the sign of the observed anomaly, if not its amplitude. Furthermore, to some degree, the dependence of the predictions on the geographical position of each consortium is similar to that observed.

Consortium	25^{th} Percentile	Median	75^{th} Percentile	Estimate
C1	50.0	63.1	78.2	92.0
C2	27.3	35.5	44.2	44.7
C3	26.2	36.8	46.6	48.7
C4	5.2	11.4	26.6	42.3
C5	6.7	21.1	28.4	56.1
C6	83.9	97.0	110.7	108.1
C7	59.7	71.6	80.9	80.3
C8	102.3	129.6	147.4	156.6
TOTAL	**361.2**	**466.0**	**563.0**	**628.8**

Table 1 Summer (June to August) 2013 predicted and estimated irrigation water needs (millions of cubic metres) for each consortium. The table reports the median and the 25^{th} and 75^{th} percentiles of the predicted values and the estimate of the irrigation need obtained from the CRITERIA model forced with meteorological observations.

With regard to the ability of the system:

On the one hand it can capture the interannual variability which seems to be partly due to the dependence of the predictions on the soil water table level at the beginning of the prediction season. The calibrated probabilistic seasonal prediction skill in the last three years was possibly higher than the average, contributing to the overall good performance of the system.

On the other hand it can capture differences in irrigation need between consortia. This might be due partly to the differences in initial condition of soil water table level and partly to a good evaluation of the geographical distribution of crop classes, characterized by different water needs.

These promising results prompt the continuation of the current provisional operational practice for the next few years and a more thorough study of seasonal irrigation water need predictions over a longer period to evaluate their actual skill. Particular attention will be paid to the evaluation of the dependence of the quality of the final product on the various components of the system. The study will also cover a comparison between observed irrigation data and estimated data obtained by forcing the CRITERIA water balance model with meteorological observations.

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Further information (in Italian)

CRITERIA model: http://www.tinyurl.com/criteriamodel

Seasonal forecasts: http://www.arpa.emr.it/sim/?previsioni/lungo_termine

iColt reports and results: http://www.arpa.emr.it/sim/?telerilevamento/colt

Agroscenari project: http://www.agroscenari.it

Further reading

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