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Extending existing models to capture vegetation response to extreme weather events: the MODEXTREME project

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Abstract: Extreme weather events are combinations of meteorological drivers that exceed certain thresholds and occur with low frequency, negatively impacting human living conditions and economic systems including agriculture. The three-year European project MODEXTREME (started on November 1st, 2013) aims at improving the predictive capability of biophysical crop and grassland simulation models under extreme weather conditions (mainly high/low temperatures and water deficit/excess). Existing modelling solutions can be improved with re-usable software libraries to capture extreme weather impacts. Estimates from existing and new modelling solutions will be compared on a variety of datasets and evaluated with respect to medium-term trajectories of future climate (mid-21st century). This will be achieved via the multi-model platform for plant growth and development simulation BioMA (Biophysical Model Application) and will support short- and medium-term forecasts in Europe via the Monitoring Agricultural ResourceS (MARS) workflow of European Commission Joint Research Centre. Project results will also extend the toolbox for food security monitoring and early warning systems outside Europe (Argentina, Brazil, China, South Africa, and United States). This paper explores both conceptual and software challenges of the project.

***Keywords**:* BioMA modelling platform; Crop and grassland modelling; Extreme events; Food security; Software reuse

1 INTRODUCTION

Climate changes are negatively impacting food production while altering frequency and intensity of atmospheric extremes such as floods, droughts, severe heat and cold, and storms (Field et al., 2012). Water shortages are increasing in many parts of the world, including Southern Europe (Fereres et al., 2011) and an increased frequency of heat waves and precipitation extremes has caused widespread agricultural production losses in the last years (Coumou and Rahmstorf, 2012). Extreme events often occur with one another, and different plant stress factors (e.g. high temperature, evaporative demand) may simultaneously occur with different correlations between geographical areas. This generates an apparent complexity in the climate-forcing plant response relationships across a wide range of temporal and spatial scales (van Bussel, 2011; Lobell et al., 2013). It is known that many biological processes may undergo sudden shifts at given thresholds for temperature and precipitation (Hoffmann and Parsons, 1997). However, the mechanistic links between plant processes, and the relative role in these processes of extreme events, have been only fragmentarily documented and poorly described by crop and grassland models (Tubiello et al., 2007; Soussana et al., 2010; Snow et al., 2014). As a consequence, the extent of the inherent response of plant species and cultivars to extreme weather events remains an open field of research (Reyer et al., 2013).

The EU-FP7 project MODEXTREME (MODelling vegetation response to EXTREMe Events) has the goal of improving the analytical capabilities on the European and global agriculture facing extreme climatic events. This is done by improving the capability of biophysical models to simulate plant response to extremes in temperature (high and low) and precipitation (water deficit and excess). The primary focus is on the most important annual crops (wheat, maize, rapeseed, rice and soybean). Grasslands also receive attention because of their importance for forage production and the land area covered (about 40% of agricultural area in EU-27 countries, that is, 67 million hectares, Peyraud, 2013). The project also explores the impact on fruiting trees, evaluating the case of olives, considering the critical environments in which this extensively cultivated fruit crop is grown. Project actions focus on how new modelling solutions integrating the impact of extreme events will likely improve in-season forecasts within a frame of food security both within Europe and outside Europe. A further focus is the evaluation of improved modelling solutions for the assessment of projected climate change impacts.

2 RELEVANCE OF THE PROJECT

2.1. Modelling approaches to address the impact of extreme events on agricultural production

The project establishes a worldwide network for the review and formalization of physiological processes of a range of plant species and cultivars covering diverse geographic areas and climatic conditions, targeting the modelling of the impact of extreme weather events on yield. The fundamental aspects of plant physiology are addressed and made available in widely known modelling solutions, aiming at improved in-season forecasting systems of the most important commercial crops and grassland types. The project uses alternative state-of-the-art modelling solutions to gain insight on the value of different representations of the biophysical system, and to account for the epistemic uncertainty associated with different models. The project gathers plant and climate modelling scientists from across Europe and non-European countries. The expected outcome of the project is a rich set of processes and process-based models, in the form of engineered solutions to support the need of in-season agricultural yield monitoring and forecasts readily applicable in Europe (via MARS-Monitoring Agricultural ResourceS Unit Mission at the Joint Research Centre, http://mars.jrc.ec.europa.eu, Figure 1) but also transferable to countries in other continents.

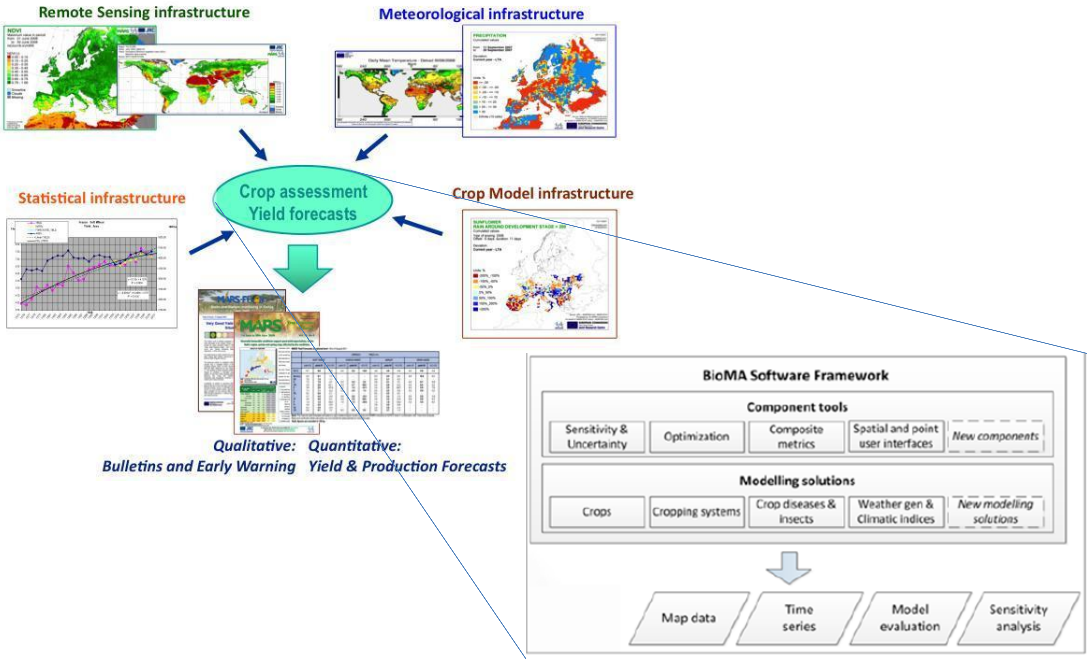

Figure 1. In-season agricultural yield monitoring and forecasting approach of MARS (Monitoring Agricultural ResourceS) Unit Mission. The modelling core is provided by the Joint Research Centre (JRC) application of the platform BioMA (Biophysical Model Applications)

The system is open to include modelling approaches for extreme events other than the ones which will be identified in MODEXTREME.

2.2. Modelling solutions into yield forecasting systems

The modelling solutions developed are distributed with documentation and training on the software used. Several actions are foreseen to specifically target MARS analysts, but also the scientific community. To assess how extreme events impact crop and grassland yields, the modelling platform BioMA (Biophysical Model Applications, http://bioma.jrc.ec.europa.eu; https://en.wikipedia.org/wiki/BioMA) is used. BioMA is the modelling core of the MARS forecasting system (Figure 1) used for scenario analysis, and its technology enables modellers to create new modelling solutions by assembling process-based models in a transparent way.

2.3. Yield forecasts, food security monitoring and early warning systems

Additionally, actions are planned to take the current institutional and food security context into account. At the level of software implementation, this is done by targeting an improvement of the performance of in-season crop and grassland yields modelling. On one hand, this has an impact on the monitoring and scenario analysis capabilities produced. On the other hand, it helps improving food security assessment (essentially food availability and the ability to obtain food over time). Through data and tool collection and integration, the project develops and evaluates methodologies for agricultural yield monitoring and forecast (starting on JRC-MARS experience) combining inputs from local groups of stakeholders with an analysis of relevant indicators and model outputs. Local stakeholders are invited to provide valuable open-ended comments on model-based results, under both historical conditions and conditions represented by climate projections, and to explore the possibility of local implementation of monitoring and forecasting systems. The role of FAO is to highlight interesting findings in each country and to present an overview of the capacity-building support.

3 SCIENTIFIC AND TECHNOLOGICAL METHODOLOGY

3.1. Process studies

The response of fundamental plant processes to climatic extremes is elucidated by quantifying the effect of a broad range of hydrological (water deficit and excess) and temperature extremes (heat waves and cold spells) on plant responses. The main paradigms are that a) these events affecting the progress of plant development (e.g. expansion of organs, flowering time) can be modelled in a relatively simple way (Tardieu et al., 2011), and b) combination of these events in models result in emergent properties that describe the complexity of species and varietal responses (Parent et al., 2010). This work is mainly carried out by analysing existing data from published and unpublished literature sources.

3.2. Creation of model objects

Model objects formalize and encapsulate basic plant responses to extreme events and extend modelling capabilities. They are created using the component-oriented paradigm, focusing on the reusability and transparency of model objects (Donatelli and Rizzoli, 2008). The architecture fosters extensibility by allowing the development of new modelling solutions, while also facilitating software deployment in different production environments. New modelling solutions are used via BioMA applications, but an intermediate step in their development within the project will allow for re-use in different platforms (e.g. RECORD, http://www4.inra.fr/record).

3.3. Evaluation of modelling solutions

New modelling solutions will allow modellers to simulate the impacts of extreme events via different crop and grassland models. Simulations will be run using re-implementations of widely known model packages (e.g. CropSyst, Stöckle et al., 2003; WOFOST, van Ittersum et al., 2003) as well as others under new development. The project proposes a science-stakeholder engagement process (Matthews et al., 2011) concerned with communicating the consequences of extreme weather events through analysis of historical datasets and projections of future impacts. This engagement strategy is facilitated by workshops where stakeholders from European and non-European countries deliberate on the response from alternative modelling solutions using outputs from regional climate models. The deliberative process with stakeholders is also intended to identify and refine modelling solutions that could serve as decision support for in-season forecasting efforts.

4 PROJECT CONSORTIUM

MODEXTREME relies on a European partnership including institutions from seven Member States of the European Union plus Switzerland and Ukraine (Figure 2, left). The expertise of Europe is compared to other areas of the world (Figure 2, right), where scientists have already been dealing with extreme conditions. All continents but Oceania are represented in the consortium. South America is represented by two countries (Argentine and Brazil).

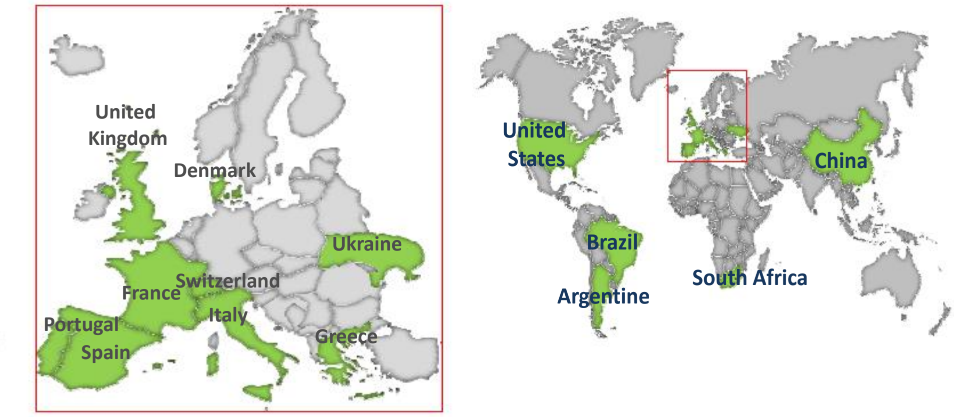

Figure 2. MODXTREME consortium in Europe (left) and beyond (right).

Globally, 18 organizations from 14 countries contribute to the project, including: a management consulting company (INRA-Transfert, France), a software enterprise (Softeco Sismat, Italy), an international organization (Food and Agricultural Organization of the United Nations, Italy), seven universities (University of Cordoba, Spain; University of Lisbon, Portugal; University of Milan, Italy; University of East Anglia, United Kingdom; University of Pretoria, South Africa; Democritus University of Thrace, Greece; Washington State University, United States), and eight research institutes (French National Institute of Agricultural Research; Agricultural Research Council of Italy; Agroscope Research Station, Switzerland; Danish Meteorological Institute; Ukranian Hydrometeorological Institute; Brazilian Agricultural Research Corporation; Argentinian National Agricultural Technology Institute; Chinese Academy of Agricultural Sciences).

5 PROJECT IMPLEMENTATION

MODEXTREME envisages three main avenues for model improvement with respect to extreme events. First, the collection of existing and development of novel formalisms that explicitly take into account non-linearities and discontinuities in the responses is extended to characterize genotypic differences using maize as a pilot example. Second, development, testing and application of process-based models are expanded via: creation of dedicated libraries of reusable model components; facilitation of the design and implementation of new, dedicated simulation models; use of resources from a variety of crop and grassland models; broadening of the deliberative process for model evaluation with social dialogue (science-stakeholders approach). A third avenue is the inter-comparison of alternate modelling solutions, based on experimental data from different agro-ecological areas in Europe and worldwide. The latter parallels (and will contribute to) other international efforts, such as the Agricultural Model Intercomparison and Improvement Project (AgMIP, http://www.agmip.org), in which a large part of the MODEXTREME consortium is also involved.

Figure 3 - which reflects the workpackage (WP) structure of the project - highlights the central role of the BioMA platform and its modelling solutions (WP2). They have the dynamic role of integrating knowledge from basic researches in agro-ecology (WP1) and climatology (WP3), and provide the context for knowledge transfer, first to answer the societal question of improving food security (WP4), and ultimately to support institutional policy-making mainly at the level of Directorate General Agriculture of the European Commission (WP5).

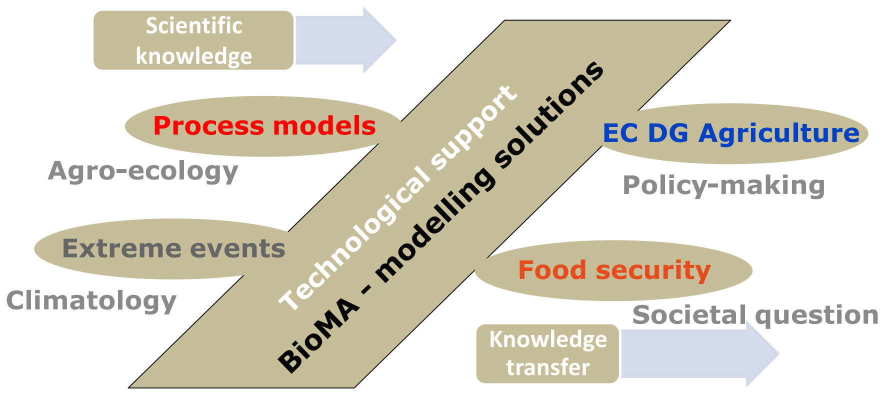

Figure 3. Rationale of the project.

Interdependencies and relations between WPs are in Figure 4, which also include dissemination (WP6) and management and coordination (WP7).

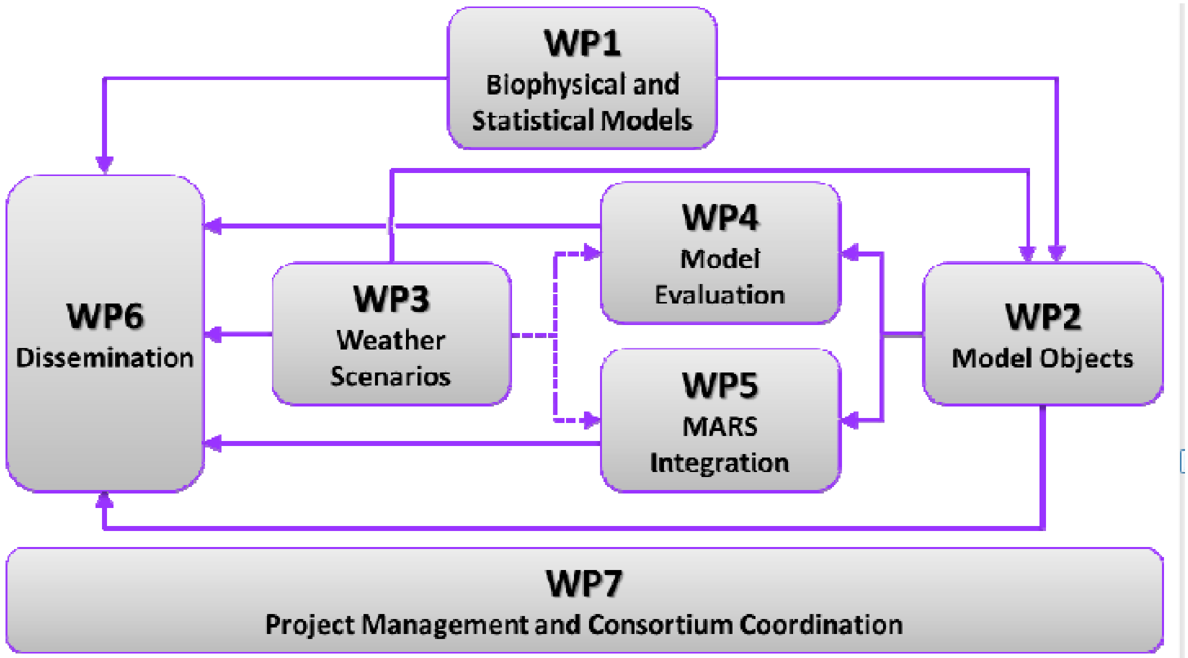

Figure 4. WP interdependencies and information flow.

6 CONCLUDING STATEMENTS

Food security is decreasing in the context of the inter-linked food and economic crisis, and a number of studies (e.g. Paillard et al., 2011; Beddington et al., 2012) have indicated the need for increasing research efforts in the area of agriculture and climate change. They include the improvement of modelling capabilities to better assess the impacts on agricultural production of extreme weather events, which are of increasing concern for food security (Battisti and Naylor, 2009; Long and Ort, 2010). Improving the representation of the impact of extreme weather events in simulation models of crop and grassland systems is among the issues meriting attention in today's research in agriculture and food security.

Food security underpins MODEXTREME. The purpose of the project is not to run integrated evaluations of agricultural production systems in far-reaching scenarios. Rather, it is meant to deliver tools that can be used to evaluate food security concerns, incorporating the broad spectrum of climatic conditions and reference datasets provided by non-European partners and enlisting FAO's global reach. Process-based simulation models are widely accepted as necessary tools for assessing crop and grassland yield potentials at point, regional and continental scales, and are used by decision-makers for short-term income calculations and policy development. In this perspective, the project undertakes the food security issue, as threatened by extreme weather events, by focusing on the potential added value of improved simulation tools of crop and grassland performances. Interaction with stakeholders is central to verify that new simulation tools will add value as compared to existing approaches.

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