Crop Monitoring as an
E-agricultural tool in
Developing Countries

SEVENTH FRAMEWORK PROGRAMME

E-AGRI
E-Agriculture

EVALUATION REPORT ON RICE SIMULATION ON LARGE AREA

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Author(s):Roberto Confalonieri, Caterina Francone, Valentina Pagani, Wang Zhiming
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Signatures

Author(s) : Roberto Confalonieri
Caterina Francone
Valentina Pagani
Wang Zhiming

Reviewer(s) :Qinghan Dong

Approver(s) :

Issuing authority :

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EXECUTIVE SUMMARY

This report presents the results of the evaluation of the spatially distributed simulations of rice growth and development in the Jiangsu province performed with the multi-model approach (i.e., the WARM, CropSyst, and WOFOST models). Parameters used for the three models are those calibrated and evaluated for E-AGRI deliverable D32.3.
The values of final aboveground biomass and maximum leaf area index simulated by the three models are analysed. Results of the simulations performed by WARM, CropSyst and WOFOST in the hottest and coldest years of the available time series (i.e., from 1989 to 2010) are shown as examples. The spatial patterns of biomass and leaf area index changed substantially in the two years, although the three models differed on this aspect.

1. Introduction

Among the advanced functionalities implemented in BioMA, one of the most relevant is that its structure, based on multi-approach components for the simulation of biophysical processes, allows for running multi-model simulations. This increases the capability of the modelling system to capture the peculiarities related to specific locations or seasons. This is due to the different approaches adopted by the different models to reproduce crop growth and development under conditions defined by the environment explored and – in general – by the different factors modulating or limiting crops' productivity.

The crop models currently implemented in BioMA, via the CropML (Crop Model Library) component, are WARM (Confalonieri et al., 2009a), CropSyst (Stöckle et al., 2003), and WOFOST (Van Keulen and Wolf, 1986). These models greatly differ for the approaches used to reproduce light interception, biomass accumulation, assimilates partitioning, and leaf area evolution. Moreover, they proved to differ also in terms of complexity (Confalonieri et al., 2009), robustness (Confalonieri et al., 2010) and plasticity (Confalonieri et al., 2012).

2. Materials and methods

2.1. Large scale rice simulation in Jiangsu

Simulations were performed on each Jiangsu grid cell where rice is grown according to the mask received by JAAS. The resolution of the cell (25 × 25 km) is derived from the resolution of the primary model input, i.e., the meteorological data. The next subsections report a description of the three models – useful to discuss results – and of the database used to run the simulations.

2.1.1. The crop models

The spatially distributed rice simulations were performed by using the WARM (Confalonieri et al., 2009a), CropSyst (Stöckle et al., 2003), and WOFOST (Van Keulen and Wolf, 1986) models. WARM (Water Accounting Rice Model) is a model specific for rice simulations, and it is operationally used by the European Commission for rice yield forecasts. The other herbaceous species are simulated – within the European Commission MARS Crop Yield Forecasting System (http://mars.jrc.it/) – using WOFOST. CropSyst has been used in many studies worldwide for evaluating the impact of management and climatic scenarios for a variety of crops. The three models differ for the approaches used to reproduce the different processes related to crop growth and development, for the amount of data needed for their use, and for their behaviour, being characterized by different degrees of complexity.
The three models simulate crop development as a function of the thermal time accumulated, with options to account for photoperiod. CropSyst has an option to account also for vernalization (not used for rice), whereas WARM accounts for the floodwater effects on temperature through the micrometeorological model TRIS.
WARM simulates net photosynthesis using a radiation use efficiency (RUE) approach, with RUE varying to account for thermal limitation to photosynthesis, saturation of the enzymatic chains, and senescence. Photosynthates are daily partitioned to leaves, stems and panicles. LAI is computed multiplying the leaves biomass by the specific leaf area, with the latter varying according to the development stage. Development stages are standardized by converting growing degrees days into a numerical code, in turn used to

synchronise the simulation of the different processes. Effects of diseases and abiotic damages on crop growth can be simulated.

Concerning daily biomass accumulation, CropSyst is based on the Tanner and Sinclair (1983) relationship between aboveground biomass (AGB), potential transpiration, vapour pressure deficit (VPD) and a VPD-corrected transpiration use efficiency (TUE_{VPD}). The instability of the Tanner and Sinclair equation for low values of VPD leads to the adoption of a temperature-limited RUE approach when these conditions occur. CropSyst simulates leaf area development as a function of AGB, a constant specific leaf area and an empirical coefficient, without the simulation of dynamic AGB partitioning to the different plant organs.

WOFOST is the most sophisticated in reproducing the biophysical processes involved with crop growth, calculating gross photosynthesis, growth (during photosynthates partitioning to plant organs) and maintenance respirations. Partitioning of assimilates is thus driven by growth respiration, development-specific partitioning factors and efficiencies of assimilates conversion into the different organs. Leaf area expansion is calculated as a function of temperature for leaf area index (LAI) lower than one, and derived from specific leaf area and development stage elsewhere. WOFOST has a three-layer canopy representation, with a spherical leaf angle distribution and LAI split among the layers using a Gaussian integration. Leaves death is simulated by WARM and CropSyst as driven by senescence, with WOFOST reproducing this process also as a function of leaves self-shading.

2.1.2. Database structure

Meteorological inputs

The meteorological dataset is retrieved from the Era-Interim reanalysis database of the European Centre for Medium-Range Weather Forecasts (ECMWF)[1] with 25 × 25 km grid resolution from 1989 to 2010. The meteorological data obtained from ECMWF database are:

- daily minimum and maximum temperature;
- daily minimum and maximum relative humidity;
- daily global solar radiation;
- daily horizontal wind speed.

[1] http://www.ecmwf.int/products/data/archive/descriptions/ei/index.html

In the Jiangsu province, rice is grown under flooded conditions, thus water stress does not influence crop growth and development. For this reason, the main meteorological variables which control plant growth and development are temperature and solar radiation.

The studied area is not so extended and a period of five months (i.e., the rice growing season) was considered, thus meteorological data were not highly variable from 1989 to 2010. For this reason, we decided to show and discuss here only the results of spatially distributed simulations for WARM, WOFOST and CropSyst only in the coldest and hottest years within the 1989-2010 period. Different agro-climatic indices reported in literature are based on the use of thermal sums derived from daily mean air temperature (e.g., Barnett et al., 2006), thus, for the selection of the hottest and coldest years, degree days accumulated during the rice growing period (i.e., from June to October) were calculated. This analysis showed that 1999 and 2006 were the coldest and the hottest year of the time series, respectively. The difference in the degree days accumulated from rice sowing to maturity between the two years was about 144 °C.

Model parameters

The complete list of the values of calibrated parameters for WARM, WOFOST and CropSyst is detailed in the version 2.0 of deliverable D32.3 (appendix tables). These values were obtained by using the 2011 and 2012 field observations, collected at nine sites in the regions of Yangzhou, Taizhou and Huaian, located at the central-west part of the Jiangsu province.

Management parameters

According to field experiments used for model calibrations, the principal rice growing season was from June to October, thus the sowing date was set to the 1st of June in all the grid cells where simulations were performed.

The crop mask (1 × 1 km resolution) was provided by the Jiangsu Academy of Agricultural Science and it is represented in Figure 1. As the figure shows, rice is mostly cultivated in the central and northern part of Jiangsu, although rice is cultivated practically in the entire Province.

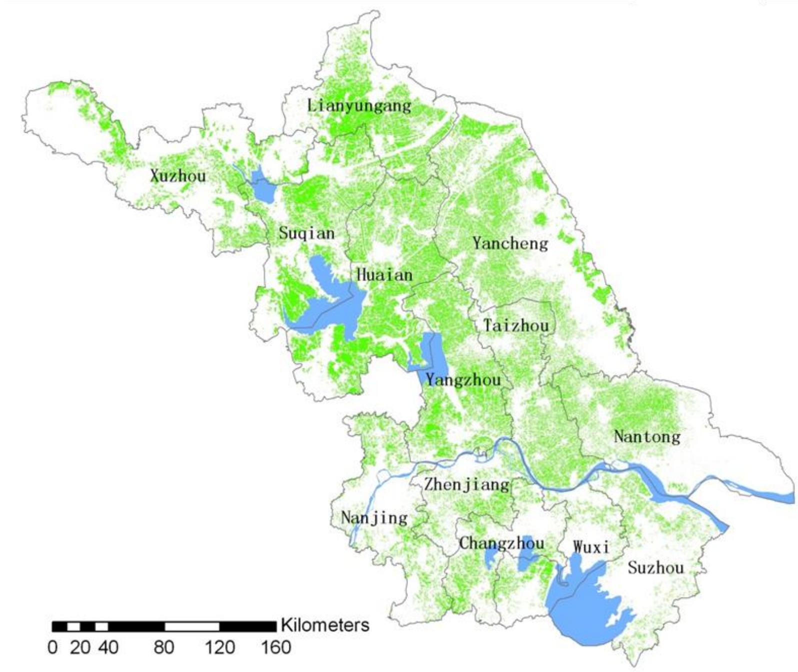

Figure 1 Crop mask of rice (green areas) in the Jiangsu province

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3. Results and Discussion

Figure 2a and 2b show the values of rice aboveground biomass (AGB) at physiological maturity simulated by WARM for the 1999 and 2006 season, respectively, in the Jiangsu province. The AGB at physiological maturity is chosen since it can be considered as a synthetic representation of the culmination of all the biophysical processes involved with crop growth and development.

In 1999 the AGB pattern shows higher values at the north of the province and lower at the southern part, except for cells alongshore, which are characterized by high AGB values (Figure 2a). The decreasing north-south gradient simulated by WARM is marked; indeed, the figure shows a difference of about 6000 kg ha^{-1} between the maximum and the minimum value of AGB. The main factor explaining this trend is radiation, whose values are higher in the northern areas (Figure 3), thus leading to a higher potential for photosynthesis.

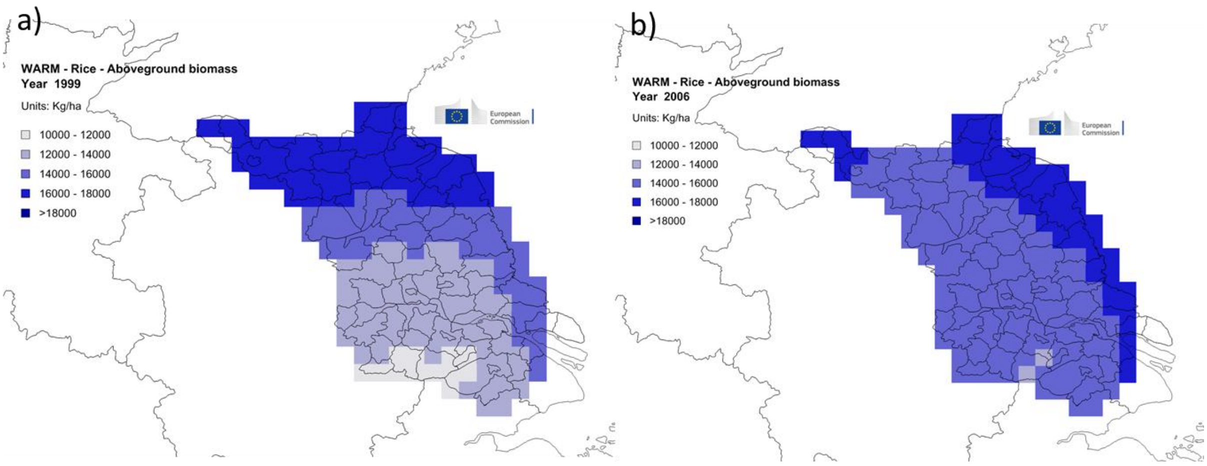

Figure 2 Maximum value of aboveground biomass simulated by WARM in: a) 1999 growing season; b) 2006 growing season. Grid cell resolution is about 25×25 km.

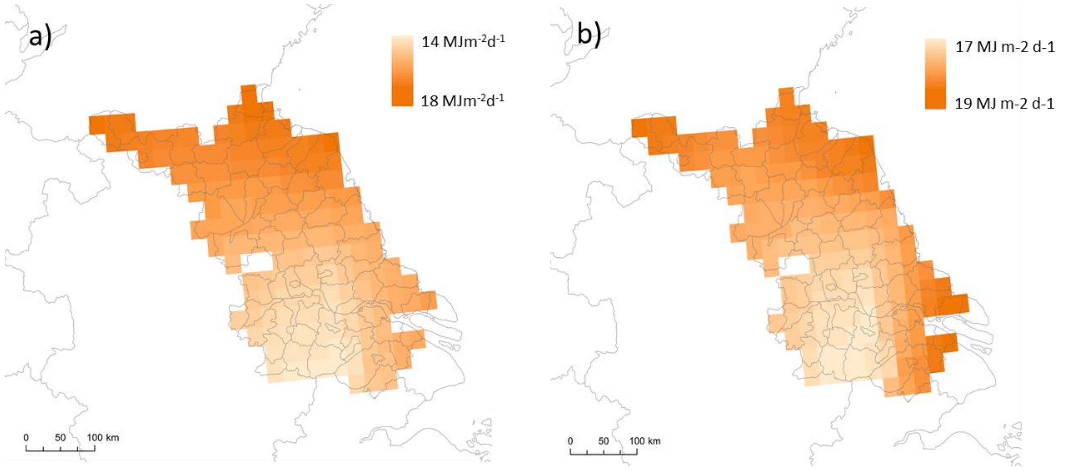

Figure 3 Daily global solar radiation averaged from: a) June to October 1999; b) June to October 2006

In Figure 4, the results of the spatial analysis of 1999 temperature data are presented:

a) daily maximum temperature averaged from June to October;
b) daily minimum temperature averaged from June to October;
c) maximum value reached by maximum daily temperature from June to October;
d) minimum value reached by minimum daily temperature from June to October.

1999 was the coldest year in the time series analyzed: the daily maximum temperature averaged in the rice growing period ranged from 24°C to 28 °C, whereas the maximum value recorded was 37°C at the north-western and south-eastern part of the province. Daily minimum temperature ranged from 18°C to 21°C, with a minimum value of 1°C at the north-east of Jiangsu.

In case daily air temperature was lower or higher than the optimum one (which, in the calibration activity, was set to 29°C), WARM simulated a thermal limitation which cause a decreasing of AGB accumulation. In 1999 high and low temperatures did not have a relevant effect on AGB accumulation; indeed, AGB trend did not follow the temperature gradient.

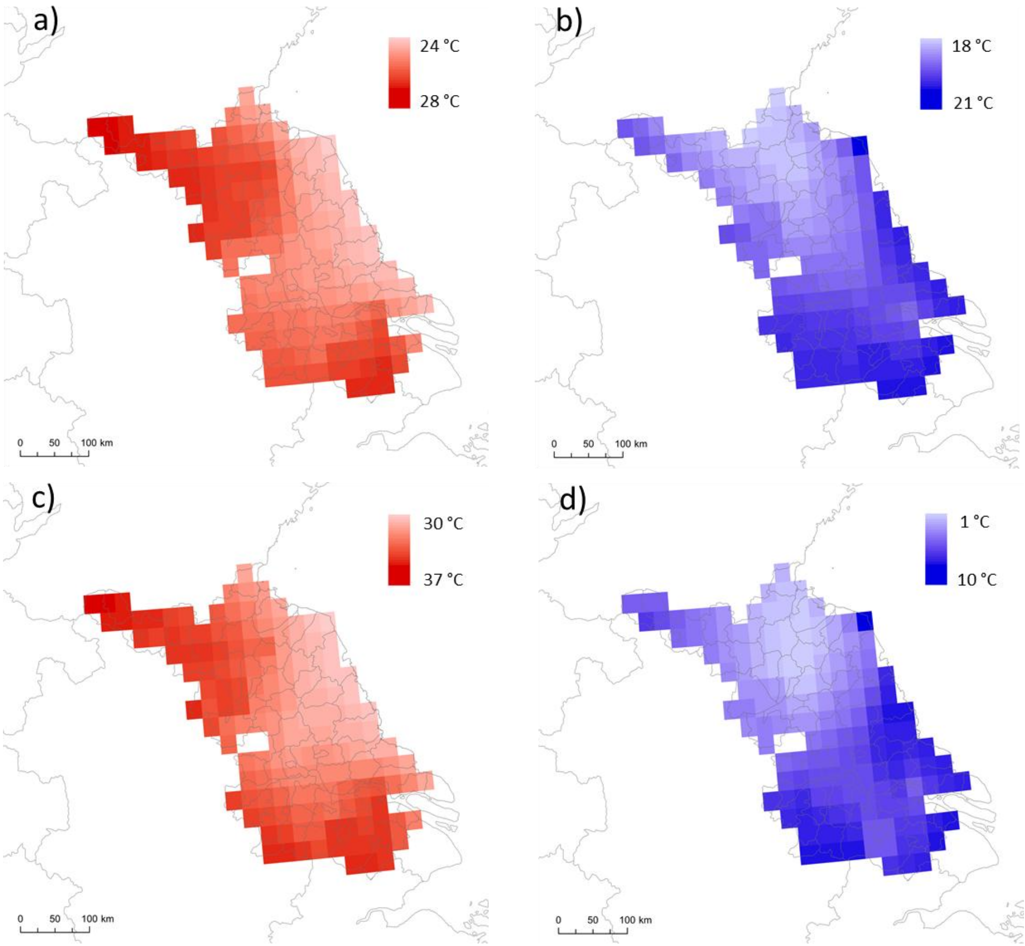

Figure 4 Daily maximum (a) and minimum (b) temperature averaged out from June to October 1999. Maximum value reached by daily maximum temperature (c) and minimum value reached by daily minimum temperature (d) from June to October 1999.

In 2006, the pattern shown is characterized by higher AGB values alongshore and lower in the continental part of the province (Figure 2b). In 2006, in fact, the simulated gradient is not so marked: the figure shows that only two AGB classes were simulated, 14000-16000 and 16000-18000 at western and eastern part of the Jiangsu province, respectively.
Also in this case, the AGB spatial trend followed the distribution of radiation values (Figure 3b). The minimum value of radiation in 2006 was 17 MJ m^{-2}, whereas in 1999 was 14 MJ m^{-2}, and this explains why – in the hottest year – the low AGB values simulated for 1999 were never reached. Solar radiation averaged during the rice growing period reached high values in all the northern cells, whereas only alongshore areas were characterized by the highest values of AGB. This was probably due to a thermal limitation in the AGB

accumulation simulated by WARM: temperatures were almost 2 °C higher in 2006 than in 1999 (Figure 5), and in the northern cells the maximum temperature reached during the rice growing period was about 39°C.

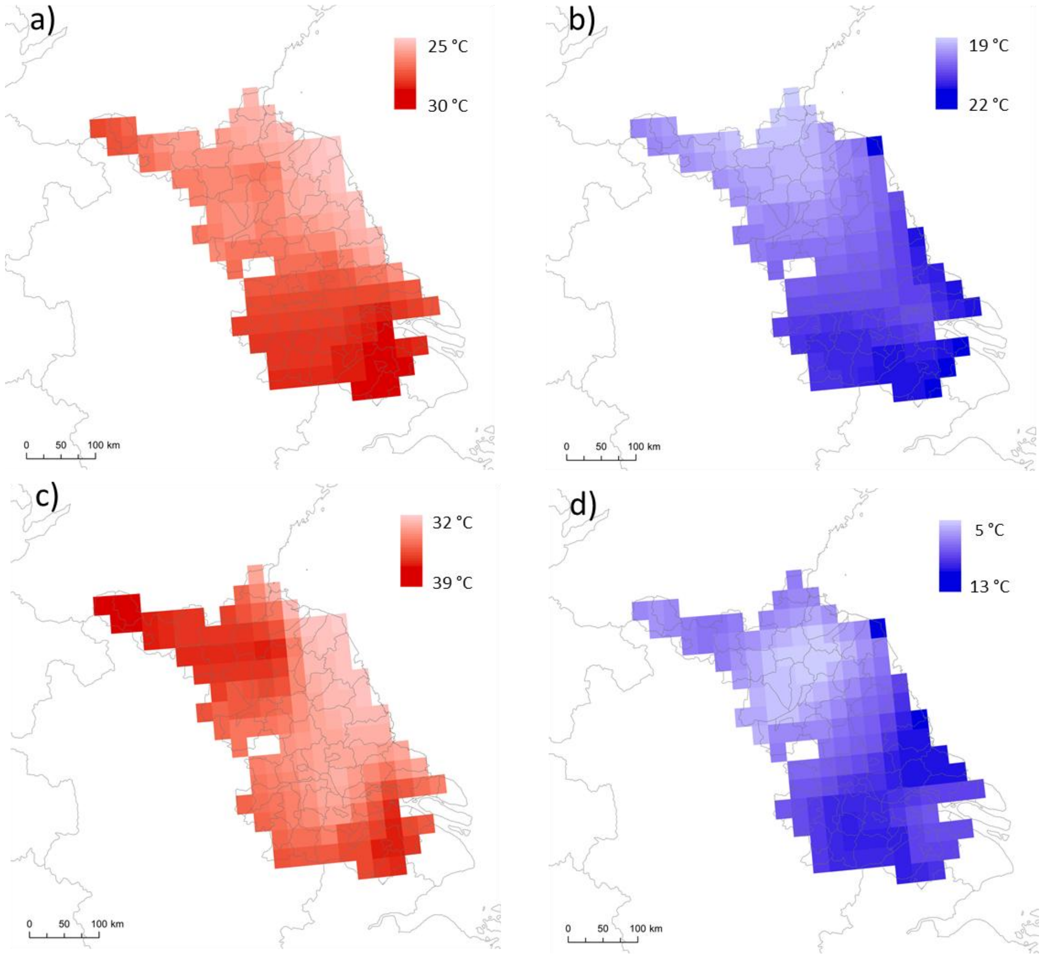

Figure 5 Daily maximum (a) and minimum (b) temperature averaged out from June to October 2006. Maximum value reached by daily maximum temperature (c) and minimum value reached by daily minimum temperature (d) from June to October 2006.

Figure 6a and 6b show the values of maximum leaf area index (LAI) simulated by WARM in the 1999 and 2006 seasons, respectively. The trend followed was the same simulated for AGB in the two years. In 1999 the values of LAI ranged from 6 $m^2 m^{-2}$ at the southern part of the province to values higher than 9 $m^2 m^{-2}$ at the northern part; whereas in 2006, which was hotter, the minimum value of LAI was 7.5 $m^2 m^{-2}$.

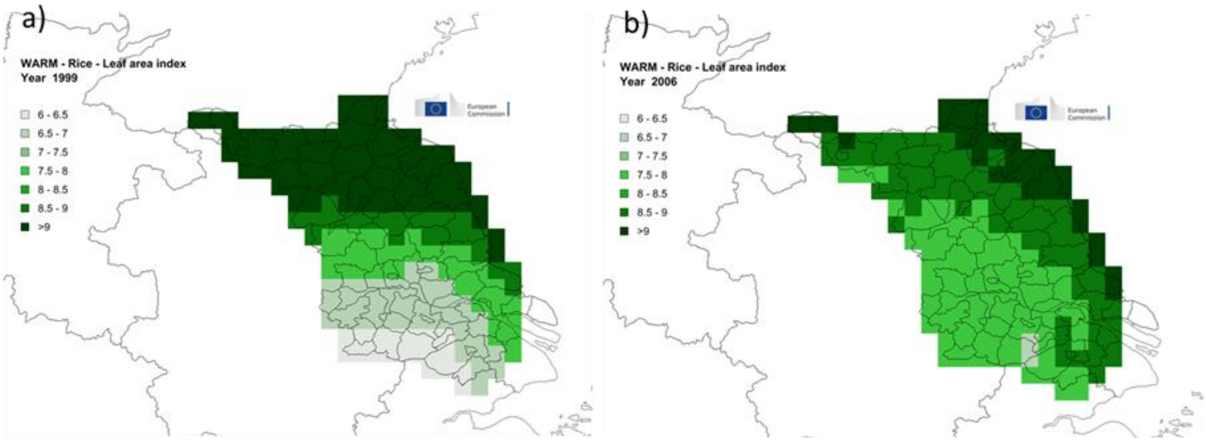

Figure 6 Maximum value of leaf area index simulated by WARM in: a) 1999 growing season; b) 2006 growing season

Results simulated by CropSyst (Figure 7a and 7b) present a spatial pattern similar to the one discussed for WARM, although, for CropSyst, the north-south gradient in 1999 appears less marked (Figure 7a). The AGB values simulated by CropSyst were higher than those simulated by WARM: AGB ranged from 14000 kg ha^{-1} to values higher than 18000 kg ha^{-1}. In 2006 CropSyst, contrarily to WARM, simulated high AGB values in all the northern cells and this is likely due to the lower CropSyst sensitivity to high temperature, like those experienced by the crop in the northern part of Jiangsu (Figure 5c). The lower sensitivity of CropSyst to thermal limitation to photosynthesis when temperatures are high is explained by the fact that the response function to temperature adopted by this model is a linear one, assuming values from 0 (base temperature) to 1 (optimum temperature), without a decreasing phase for high temperature values. Moreover, thermal limitation to photosynthesis are explicitly accounted by the model only in one of the two approaches used each day (the minimum is than selected) to simulate biomass accumulation, i.e., the radiation use efficiency one. This means that – when the VPD-corrected transpiration use efficiency approach is selected (i.e., when transpiration is low or for high VPD values) – the model is less sensitive to temperature, and high biomass accumulation rates are simulated even in case of temperature out of the range the crop is adapted to.

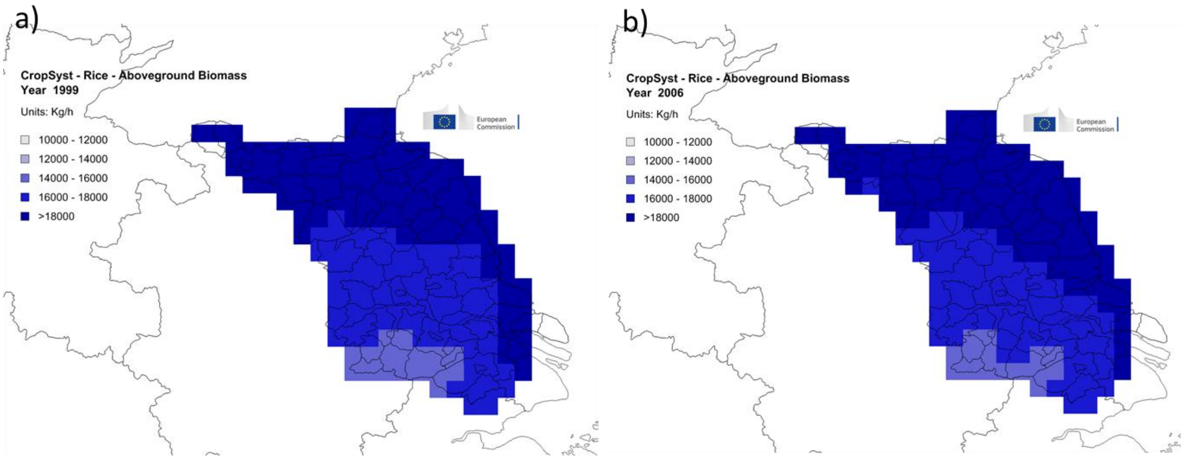

Figure 7 Maximum value of aboveground biomass simulated by CropSyst in: a) 1999 growing season; b) 2006 growing season. Grid cell resolution is about 25×25 km.

The trend of maximum LAI simulated by CropSyst is less marked than the one simulated by WARM, as shown in Figure 8a and 8b. Moreover, LAI values were always higher than 8 m^2 m^{-2} in all the units, and reached the highest values at the northern part of Jiangsu in 1999 and alongshore in 2006.

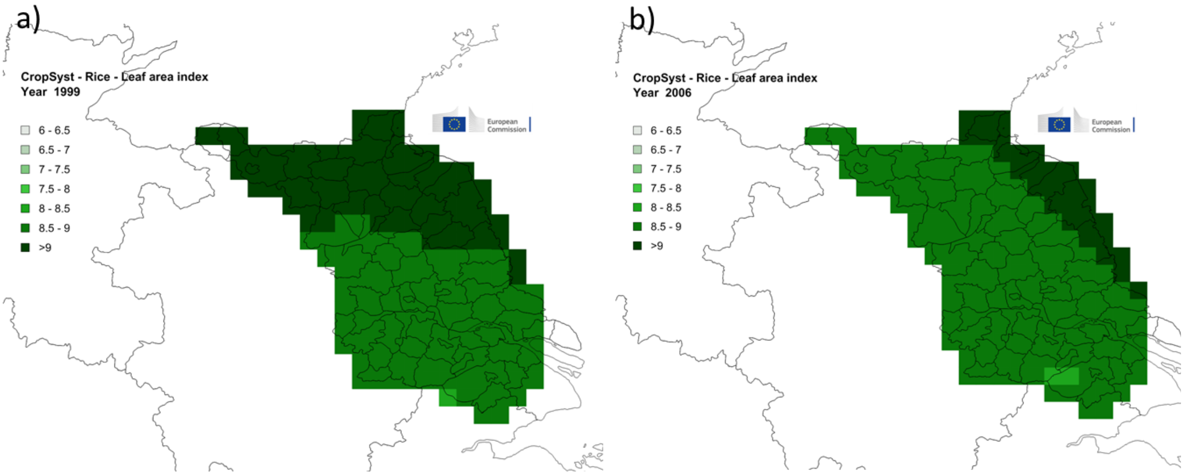

Figure 8 Maximum value of leaf area index simulated by CropSyst in: a) 1999 growing season; b) 2006 growing season

WOFOST results for 1999 (Figure 9a) present the same north-south pattern already discussed for the other two models. The values of AGB were lower than those simulated by WARM and CropSyst: the minimum AGB value was 10000 kg ha^{-1} and the maximum was 16000 kg ha^{-1}. WARM and CropSyst simulated an east-west pattern in 2006, whereas WOFOST simulated a north-south trend, with values of biomass similar to those obtained in 1999 (Figure 9b). The response to high temperature is opposite than CropSyst response: the accumulation of biomass simulated by WOFOST is reduced with temperature higher than the optimum one (at the extreme north and south-west of Jiangsu) and for this aspect WOFOST is similar to WARM. The sensitivity to high temperatures is even higher than the one of the WARM model because the response function to temperature is used to modulate gross photosynthesis, but it also influences respiration, which is a process not simulated by net-photosynthesis models like WARM and CropSyst.

This double limitation to daily biomass accumulation for high temperatures (temperature limitation affects both gross photosynthesis and respiration) explains some differences in the AGB patterns simulated by WARM and WOFOST. In particular at the extreme north-west part of Jiangsu, where the maximum temperature during the rice growing period reached the highest values both in 1999 and 2006, WOFOST simulated a decline of AGB accumulation, not shown in the WARM results. At the southern part of the province, where maximum temperature averaged from June to October reached high values in 2006, the area characterized by the lowest values of AGB (i.e., 10000 kg ha^{-1}) simulated by WOFOST is larger than the one obtained with WARM.

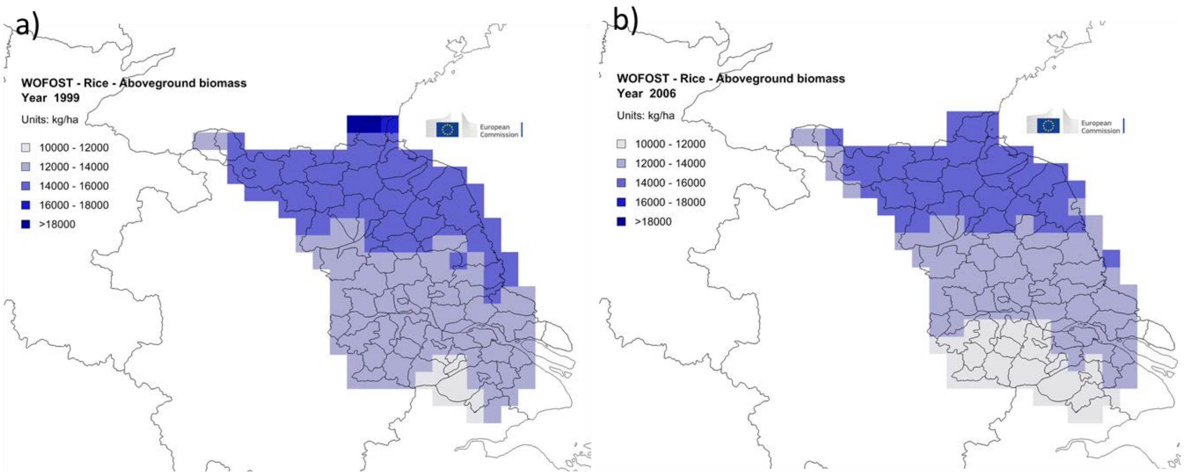

Figure 9 Maximum value of aboveground biomass simulated by WOFOST in: a) 1999

growing season; b) 2006 growing season. Grid cell resolution is about 25×25 km

LAI pattern simulated by WOFOST in 1999 is highly marked, like the trend simulated by WARM, with a minimum value of 6.5-7 m^2 m^{-2} at the southern part of the province and values higher than 9 m^2 m^{-2} in all the northern cells. In 2006, the lowest values of LAI were simulated in a wider southern area compared to 1999, like for AGB values. In northern cells, LAI simulated in 1999 was higher than the one simulated in 2006, but this did not influence the accumulation of biomass, which was the same in the two years. This is explained by the fact that – for high values of LAI – the interception of solar radiation does not increase substantially.

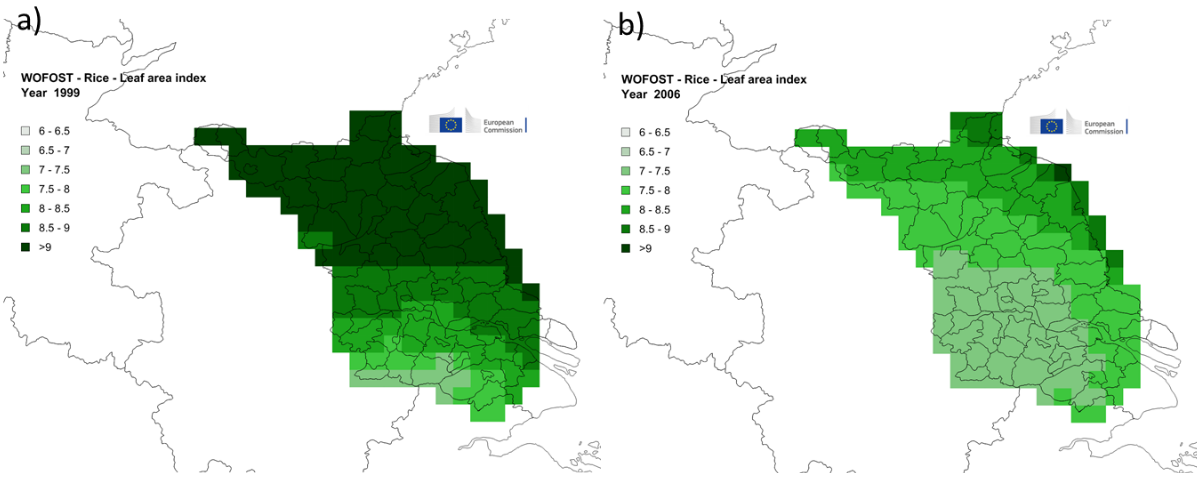

Figure 10 Maximum value of leaf area index simulated by WOFOST in: a) 1999 growing season; b) 2006 growing season

4. Conclusions

The results of the spatially distributed simulations of rice growth and development in the Jiangsu province, performed using WARM, CropSyst and WOFOST, demonstrate the importance of the multi-model approach proposed in E-AGRI-WP3.

The different approaches for aboveground biomass accumulation implemented in the three models actually lead to heterogeneous results when the models are applied to all the study area, although more similar results were obtained during calibration on data collected in the experimental stations. The spatial variability of the aboveground biomass and leaf area index outputs was mainly driven by global solar radiation and maximum and minimum temperature patterns, with differences on spatial distribution of the outputs due to the three different approaches used to reproduce photosynthesis.

WARM resulted the model that simulated the most marked gradient of AGB and LAI. CropSyst simulated the highest values of AGB and WOFOST the lowest ones. The simulated outputs clearly reflected the different response of the three models to high temperatures: WARM and WOFOST simulates a thermal limitation when daily temperatures are higher than the optimum one, thus AGB accumulation decreases when these conditions occur. This was here obtained especially for 2006, which was the hottest year among those analyzed.

Aboveground biomass and leaf area index values simulated by the three models presented a general north-south gradient. This is a demonstration that at the north of Jiangsu the weather conditions are more favourable to rice development; indeed, as rice mask shows (Figure 1), the crop is mainly cultivated at the northern and central part of the province.

5. References

Barnett, C., J. Hossel, M. Perry, C. Procter, and G. Hughes. 2006. A handbook of climate trends across Scotland. Scotland and Northern Ireland Forum for Environmental Research, SNIFFER Project CC03, Edinburgh, United Kingdom.

Confalonieri, R., Acutis, M., Bellocchi, G., Donatelli, M., 2009. Multi-metric evaluation of the models WARM, CropSyst, and WOFOST for rice. Ecological Modelling, 220, 1395-1410.

Confalonieri, R., Rosenmund, A.S., Baruth, B., 2009a. An improved model to simulate rice yield. Agronomy for Sustainable Development, 29, 463-474.

Confalonieri, R., Bregaglio, S., Acutis, M., 2010. A proposal of an indicator for quantifying model robustness based on the relationship between variability of errors and of explored conditions. Ecological Modelling, 221, 960-964.

Confalonieri, R., Bregaglio, S., Acutis, M., 2012. Quantifying plasticity in simulation models. Ecological Modelling, 225, 159-166.

Stöckle, C.O., Donatelli, M.,Nelson, R., 2003. CropSyst, a cropping systems simulation model. Eur. J. Agron. 18, 289–307.

Tanner, C.B., Sinclair, T.R., 1983. Efficient water use in crop production: research or re-search? In: Taylor, H.M., Jordan, W.R., Sinclair, T.R. (Eds.) Limitations to efficient water use in crop production. Amer. Soc. Agron., Madison, WI

Van Keulen, H., Wolf, J., 1986. Modelling of agricultural production: weather soils and crops. Simulation Monographs, Pudoc, Wageningen, The Netherlands, pp. 479