From Ecological Models to Modelling Platforms: Bridging Science, Scientific Programming, and Web Application Development

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Introduction

The recent decades have witnessed a boom of environmental measurements and huge data collections on the Internet as part of large-scale research networks (Schimel *et al*. 2019, Reichstein *et al*. 2019, Farley *et al.* 2018). Although ecological models play a critical role in studying and simulating the key processes and integrated ecosystem responses (Hanson and Walker 2020, Medlyn *et al*. 2015, Fisher *et al*. 2014), they are lagging in their ability to fully benefit from available diverse, large data compendiums (Fer *et al*. 2020, Rineau *et al*. 2019, Dietze *et al*. 2018). On the other hand, the rapid development of new information technologies for internet programming provides an opportunity to overcome this situation by shifting to more comprehensive multifunctional modelling platforms by bridging advanced scientific theories, quantitative modelling, and web application development.

Objectives and Hypotheses

To serve the above need, we introduce the online modelling platform **DIMONA** (**D**ynamic **I**ntegrated **M**odel for **O**rganism–e**N**vironment **A**nalysis) that nests coupled ecohydrological and biogeochemical modules (that could also be used as separate models) and searching algorithms to explore any coordinates in the world for weather, soil, and hydrology records (Figs. 1, 2, 3, 7). Our main objective is to demonstrate how such a new-generation online modelling platform as DIMONA can be used for multiple research purposes, including modelling, data collection, and advanced real-time simulations of current plant and ecosystem productivities coupled to hydrology, soil properties and nutrients.

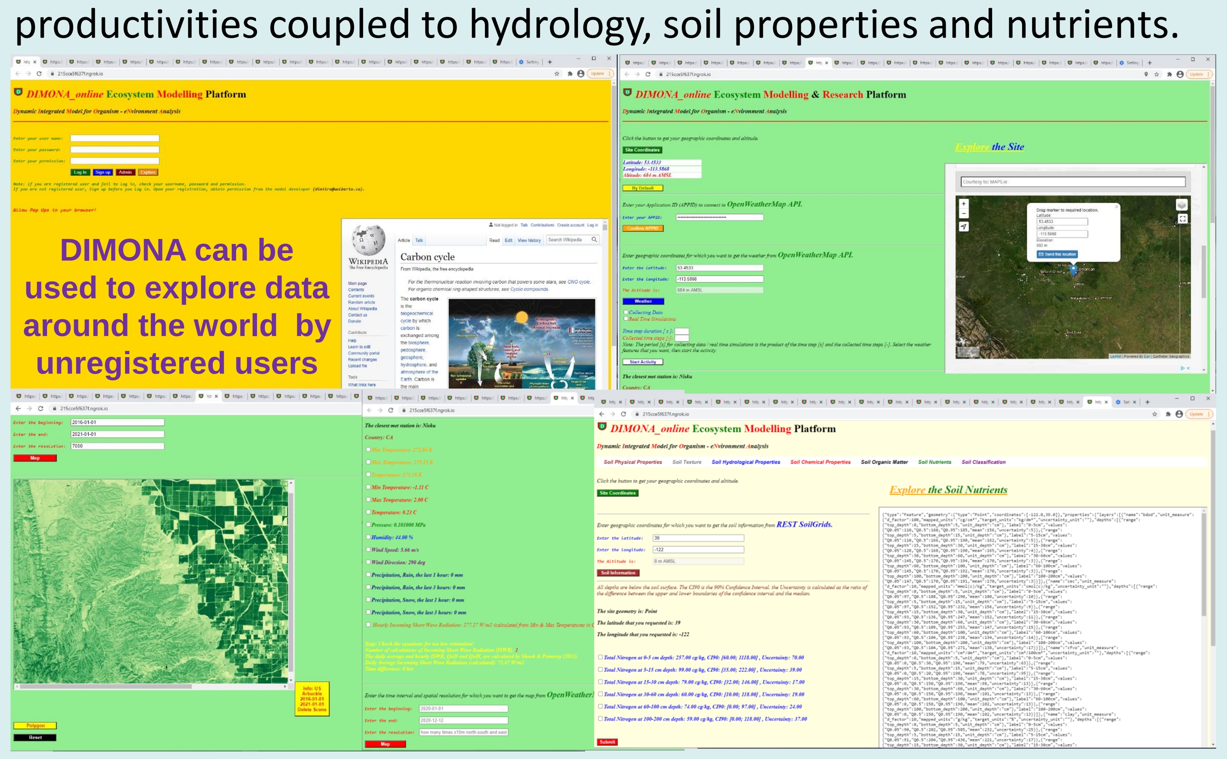


Fig. 1. DIMONA online modelling platform, key features to explore data without personal account

Methods

The Modelling Platform. The scientific code of DIMONA is written in C++ programming language and can be run on a desktop as well. The web application code for the front-end (the website interface in the browser) is written in HTML5, CSS3, and JavaScript/jQuery. The web application code for the back-end (the server and the database, currently Apache) is written in PHP7 and MySQL for signup, login and identification, and run setup including managing personal user accounts and folders, storing and sharing users' files, model input and output, running C++ model executables. DIMONA is used for multiple purposes here, i.e. data exploring (no personal account needed) (Fig. 1), classic process-based modelling (personal account needed) (Figs. 2, 4, 5, 6), and/or real-time simulations with or without data collection (personal account needed) (Figs. 3, 7).

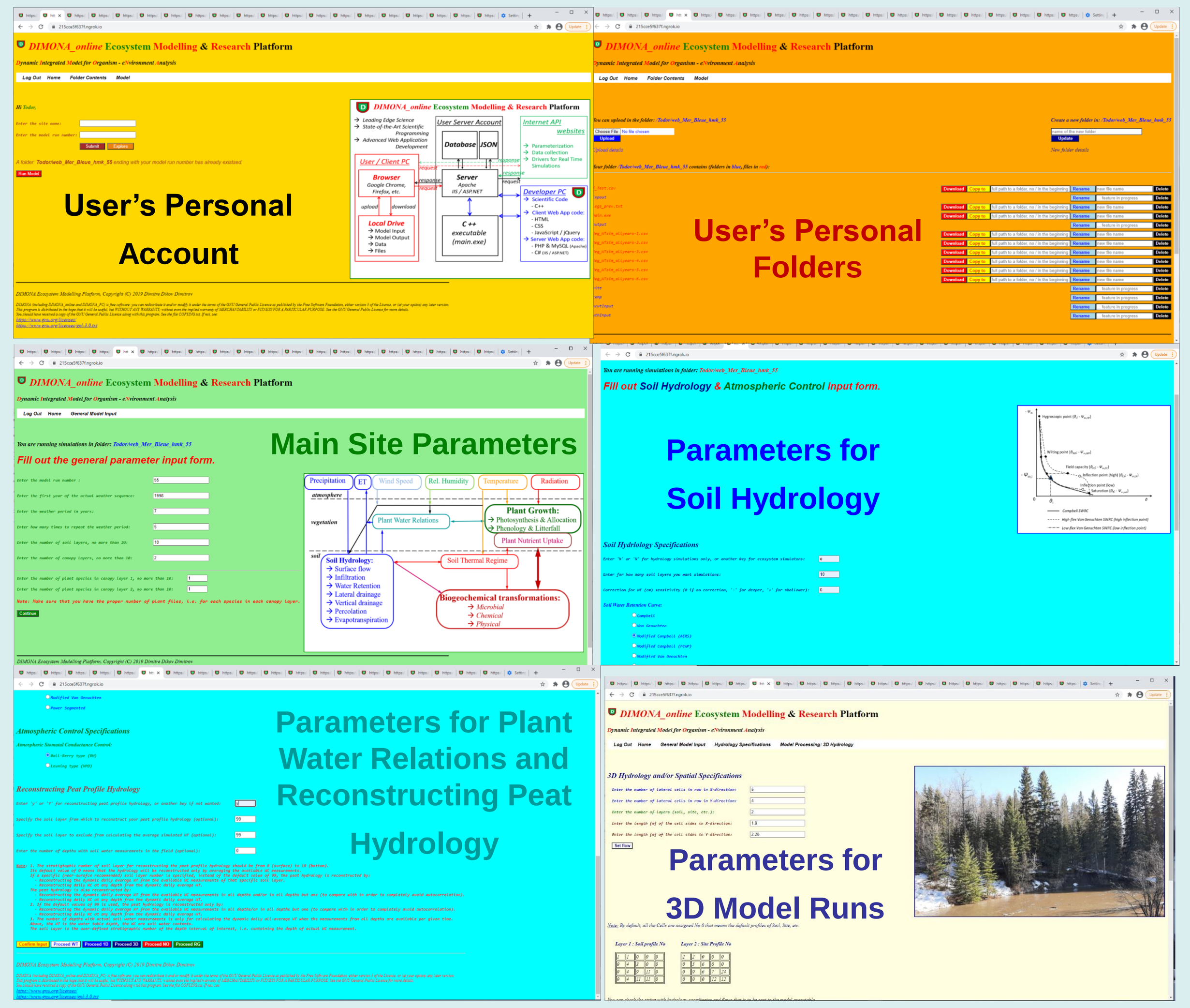


Fig. 2. DIMONA online modelling platform, process-based modelling with ***personal account***

DIMONA simulates climate-driven, environmentally constrained coupled ecohydrological and biogeochemical processes, including plant C fixation, photosynthate allocation, nutrient (N, P) uptake and assimilation, plant growth, litterfall and mortality, ecosystem productivity and biomass stocks, at various spatial and temporal scales. The model output is constrained by site observations, landscape aggregations, and big data on the internet. DIMONA allows to test different equations for the same hydrological and plant processes. Simulations at hourly and less than hourly (munities) time steps enable modelling of the explicit diurnal cycle of photosynthesis. A novel hydrological module for organic soils has been recently developed for DIMONA to simplify the dynamic modelling of soil water contents (θ) at any depth from observed water table (WT) depth, and reversely, for modelling of dynamic WT depth from measured θ (Dimitrov and Lafleur 2020).

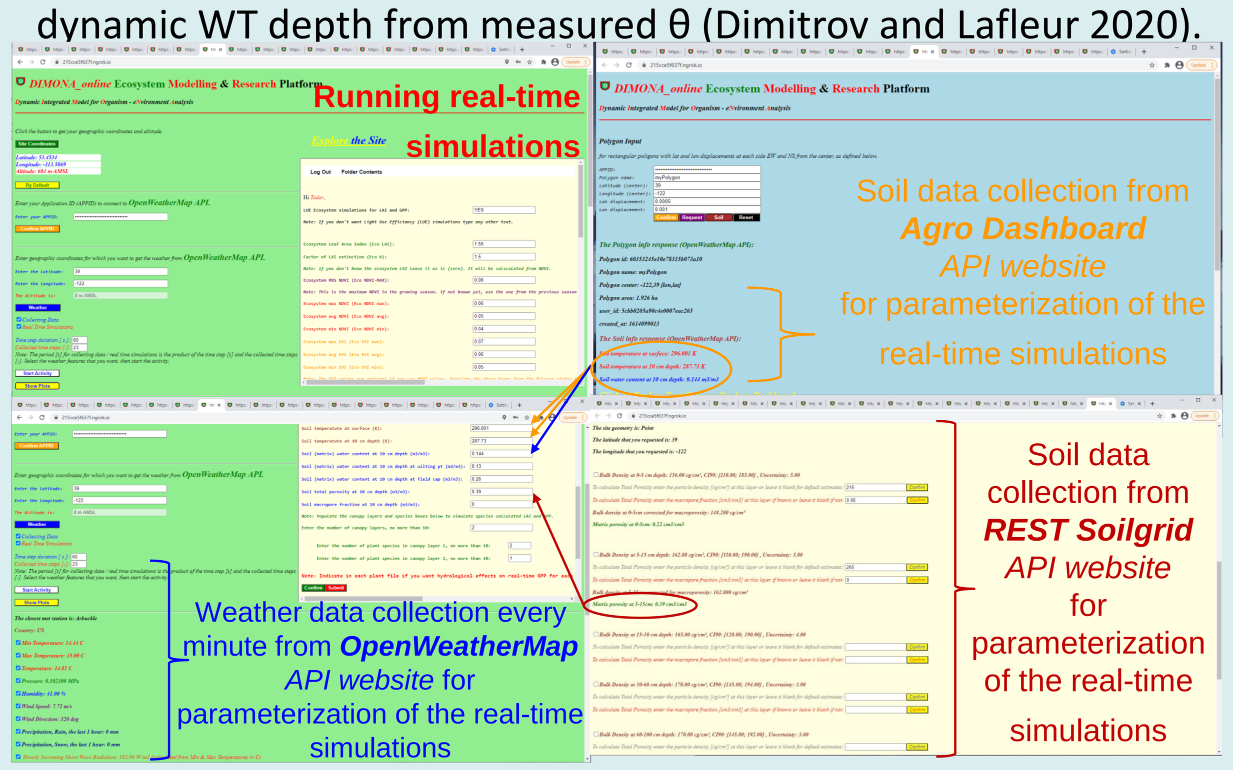
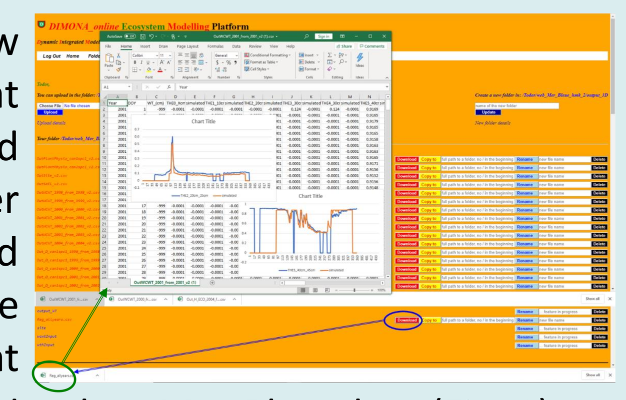


Fig. 3. DIMONA online modelling platform, real-time simulations with ***personal account***

Test Sites. Mer Bleue bog, located near Ottawa, (Ontario, Canada), is covered by moss and small shrubs, with peat depth of 4-5 m (Lafleur et al. 2005a,b, 2003, Frolking *et al.* 2002). The other site is located at 39N 122W, nearby Sacramento (California, USA), with hypothetical cover of ericaceous shrubs.

The Model Experiment. To demonstrate the potential of DIMONA for classic process-based modelling (Fig. 2) at hourly and daily time steps, we compared: (i) simulated θ at various depths with the measured θ (TDR); (ii) simulated WT depth with the observed piezometric one; and (iii) simulated ecosystem GPP and NPP with observations at Mer Bleue bog. To demonstrate the potential of DIMONA for advanced real time simulations at a minute time step, we modelled the photosynthesis of hypothetical ericaceous shrubs nearby Sacramento, every minute over a 20-minute time period at sunrise on February 23, 2021, under ambient and unlimiting soil hydrology. The simulations were driven by current weather data at the site reported by OpenWeatherMap API website, and collected and utilized by DIMONA every 60 sec, and parameterized by soil properties reported at the same site by REST Soilgrid and Agro Dashboard API websites, and collected by DIMONA (Fig. 3, 7).

Results and Discussion



DIMONA captured well the low water-holding capacity of peat at 20 and 30 cm in hummocks, and at 3 and 15 cm in hollows of Mer Bleue bog. DIMONA modelled well the dynamics of WT in the zone of intense WT fluctuations at 40 cm and deep drying at 50 cm depth at Mer Bleue bog (Fig. 4).

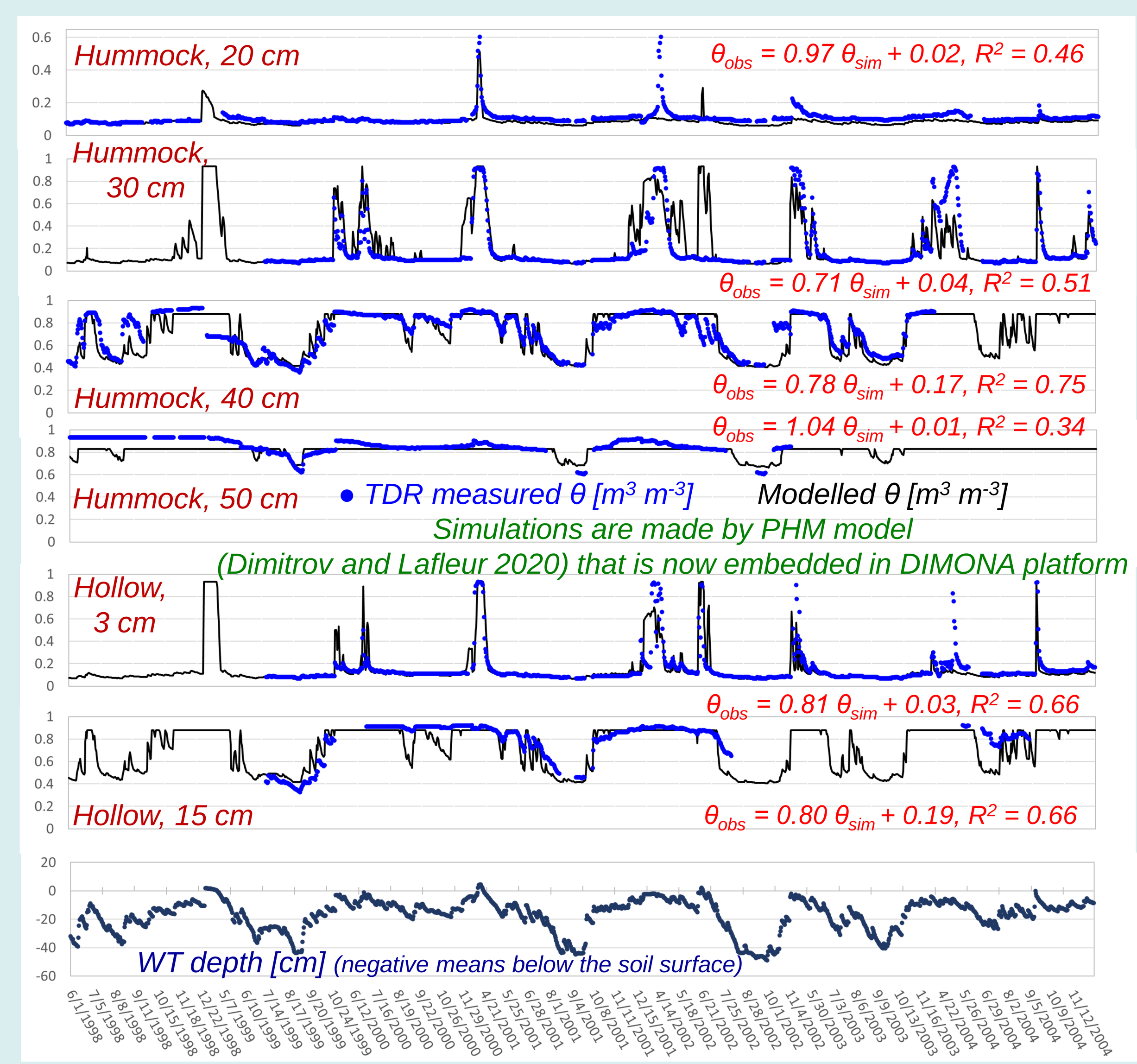


Fig. 4. Simulated θ at various depths and microtopographic positions at Mer Bleue bog.

Also, DIMONA managed to simulate the dynamics of WT depth from the available TDR measured θ at various depths in hummocks and hollows during 1998 – 2004 period at Mer Bleue bog (Fig. 5).

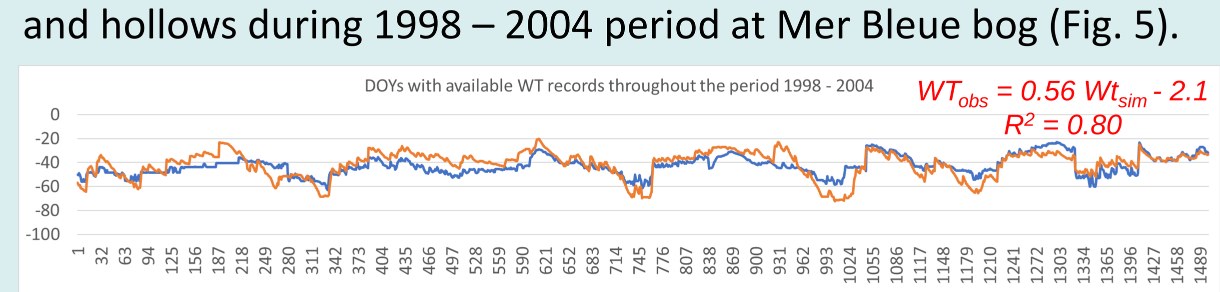


Fig. 5. Simulated WT depth below the hummock surface from θ at various depths at Mer Bleue.

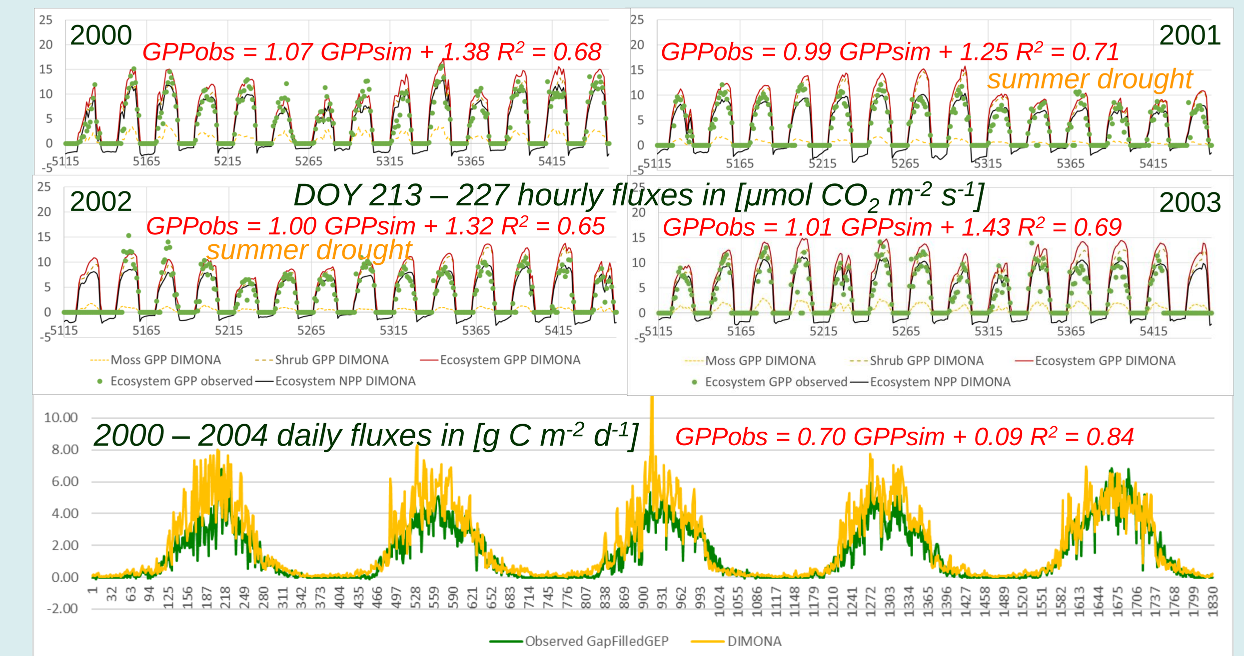


Fig. 6. Simulated hourly and daily course of GPP and NPP vs observed GPP at Mer Bleue bog.

Consistent with observations, soil water status affected plant and ecosystem gross primary productivity (GPP) and net primary productivity (NPP) in the model; NPP = GPP – Ra (autotrophic respiration). Compared to the wet years 2000, 2003, 2004 progressive summer droughts in dry 2001 and 2002 resulted in lower moss productivities due to lower moss water status, while the vascular productivities remained relatively unaffected with remaining soil moisture in deeper peat layers that provided the necessary plant water status in the field and in the model (Fig. 6).

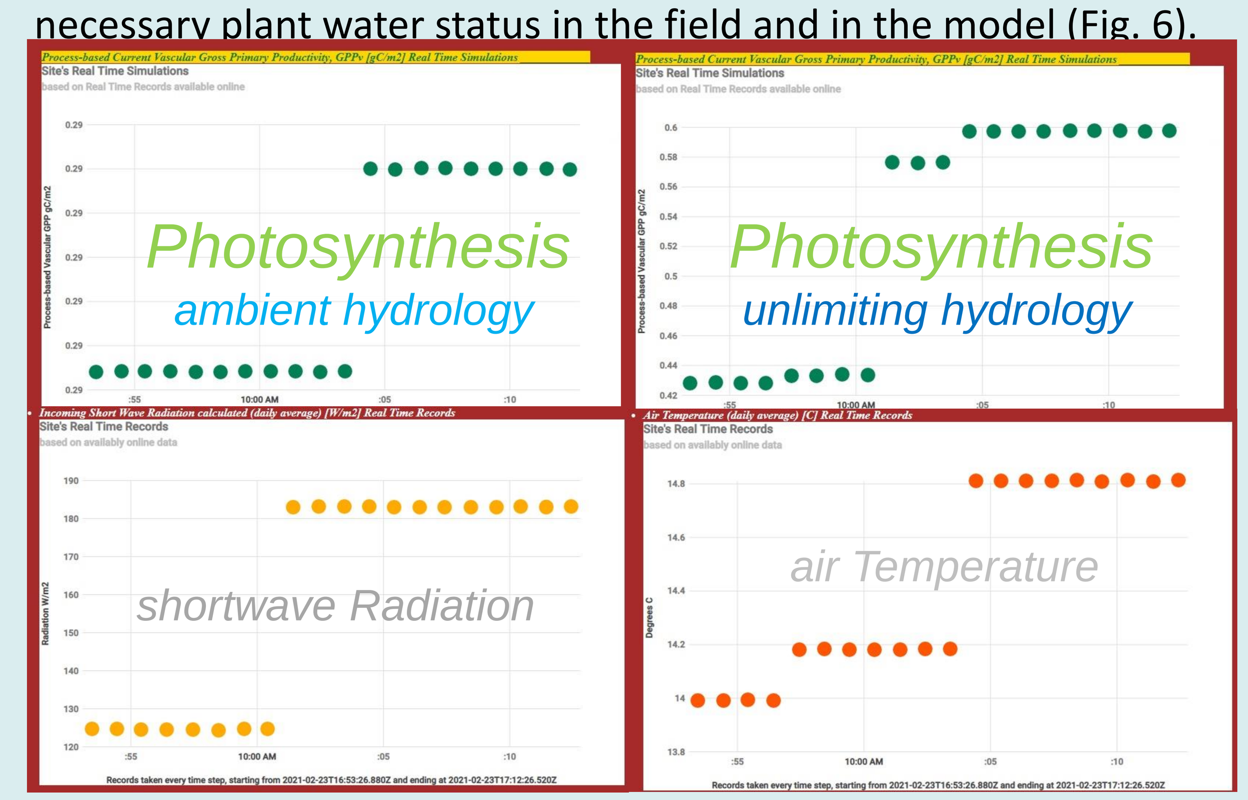


Fig. 7. Simulated photosynthesis [μmol CO_2 m^{-2} s^{-1}] every minute over 20 minutes, Sacramento.

In the morning of Feb 23, 2021, DIMONA reproduced the shrub photosynthesis nearby Sacramento every minute over a 20-minute period (Fig. 7). Low air temperature (T_{air}) and incoming shortwave radiation (R_s) this time of the year reported by OpenWeatherMap API website, resulted in low photosynthesis rates of both shrubs under ambient and unlimiting soil hydrology, parameterized by REST Soilgrid and Agro Dashboard API websites (Figs. 3, 7). However, the rapidly increasing T_{air} and R_s, at sunrise and the corresponding photosynthesis rates were captured by DIMONA at a minute time step, as well as the ~ two-fold lower photosynthesis under ambient hydrology compared to the one under unlimiting hydrology (Fig. 7).

Conclusion

Bridging science, scientific and internet programming brings a new perspective to future development of the ecological modelling.

Acknowledgements

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