ORCHIDEE-STICS MODEL FOR BETTER REPRESENTING CROPS INTO TERRESTRIAL ECOSYSTEM MODELS: VALIDATION AND APPLICATIONS

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Introduction

Croplands presently cover ≈ 15% of the land's surface. Crop functioning and land management imply different soil-vegetation-atmosphere flux timing and amplitude as well as soil and surface properties. Thus there is a need to account for agro-ecosystem specificities and their effect on the carbon, water and energy budgets for improving the understanding of the role of agriculture in the Earth-system. A new generation of global biosphere models now aims at including those crop specificities to quantify their biophysical (surface roughness, conductance and reflectivity) or biogeochemical (greenhouse gas emission/sequestration from vegetation and soil) effects. We describe here one of those models named ORCHIDEE-STICS, and detail some of the evaluation studies that have been performed up to now. Last, we present two 'valorization' studies using ORCHIDEE-STICS.

Methods

ORCHIDEE is a spatially explicit ecosystem model which evolved from a Soil-Vegetation-Atmosphere-Transfer (SVAT) scheme, describing at a half-hourly time step water, energy and photosynthesis fluxes. The model now includes a full coupling between surface fluxes and ecosystem water and carbon pools. The dynamics of carbon within each ecosystem include allocation, mortality, litter and soil organic matter decomposition. As most terrestrial ecosystem models, ORCHIDEE relies on the Plant Functional Type (PFT) concept to describe the vegetation diversity. PFT are distinct homogeneous vegetation cover units ignoring differences between species while concentrating on structural and functional attributes. Two herbaceous C3 and C4 PFT are used in the standard version of ORCHIDEE to represent agriculture differing from natural grasses only by their higher carboxylation and Rubisco regeneration rates in an attempt to account for greater crop productivities. Within the ORCHIDEE-STICS model, key variables that cannot be realistically simulated by ORCHIDEE for crops (Leaf Area Index, vegetation height, and nitrogen and water limitation modulated by fertilization and irrigation) are provided by STICS and assimilated into ORCHIDEE at a daily time step for each grid point. Thus, we built an interface through which both models can exchange information across the whole grid simultaneously. This exchange is performed via a "client-server" protocol relying on the CORBA numerical technology (http://omniorb.sourceforge.net/). The coupled ORCHIDEE-STICS model presently considers C4 crops, winter-type C3 and spring-type C3 crops, respectively represented by the maize, winter wheat and soybean parameters of STICS.

Evaluation

On-site evaluation. Site-level simulations of ORCHIDEE-STICS driven by local forcing data have allowed a first step in model evaluation against eddy-covariance flux measurement over maize and wheat in the United-States and against biomass measurements in France (De Noblet-Ducoudré et al., 2004, Figure 1). These comparisons demonstrated overall good performances of ORCHIDEE-STICS in reproducing NEE and surface energy budget variations on daily to seasonal time scales. More recently, within the frame of the CarboEurope-IP project, in-depth on-site analysis has been performed for five maize (Li et al., submitted) and seven wheat sites across Europe.

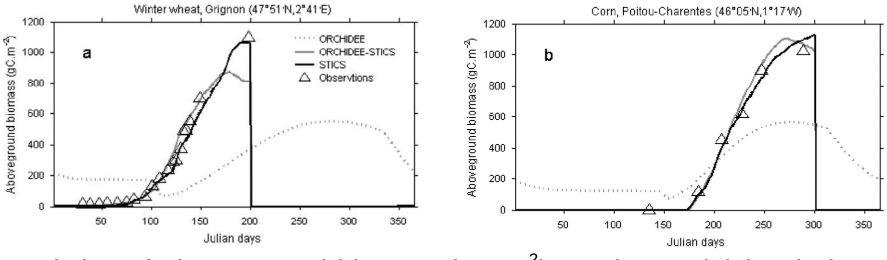

***Figure 1**: Time evolution of above-ground biomass (gC m^{-2}) as observed (triangles) and as simulated by ORCHIDEE (dotted grey line), STICS (black line) and ORCHIDEE-STICS (grey line) model for winter wheat (a) and maize crop (b).*

Regional scale evaluation. In order to quantify the improvement for LAI over Western Europe through the coupling of STICS with ORCHIDEE, we (Smith et al., in press) computed the Figure of Merit in Time (FMT) that gives a measure of the overlap between the integrals (area below each curve) of two times series, here the simulated (CROP or NoCROP) and observed (GIMMS) seasonal cycles of LAI (Figure 2). FMT was calculated on a monthly basis for the 1982-2002 mean simulated LAI cycles as compared with the observed cycle averaged over the same years. The FMT calculation indicates that the ORCHIDEE-STICS LAI is better in phase with the GIMMS LAI than the Standard ORCHIDEE LAI is. This improvement is generally proportional to the fractional coverage of croplands.

Applications

Carbon and water balance of European croplands over the 20th century

We (Gervois et al., 2008) assessed the effects of rising atmospheric CO2, changing climate, and farmers' practice on the carbon and water balance of European croplands during the 20th century. The enormous crop yield increase observed in all European regions (300–400% between 1950 and 2000), is found to be dominantly explained by improved practice and varieties selection, rather than by rising CO2 and changing climate. Agricultural soil carbon stocks in Europe are modeled to have decreased between 1950 and 1970, and since then to have increased again. Thus, the current stocks only differ by 1 ± 6 tC ha^{-1} from their 1900 value. Compensating effects of increasing yields on the one hand (increasing stocks) and of higher harvest index values and ploughing on the other hand (decreasing stocks) occur. The current cropland carbon balance is estimated to be a net sink of 0.16 ± 0.15 tC ha^{-1} a^{-1}. The annual water balance of cropland soils is influenced by increasing crop water use efficiency, one third of which is caused by rising CO2. However, increasing water use efficiency occurred mainly in spring and winter, when water is not limiting for plant growth, whereas no strong savings of soil water are achieved in summer through elevated CO2. Overall, trends in cultivation practices have caused a 3 times larger increase of water use efficiency than rising CO2.

Carbon sequestration due to the abandonment of agriculture in the former USSR since 1990

The end of the Soviet Union and the collapse of its agricultural structures in the early 1990's has induced the abandonment of a large croplands area, which have been recovered by herbaceous plants. This widespread unintended and abrupt land use change took place over 200,000 km^2, a large enough scale to impact the continental and global carbon budgets. The goal of this study is to estimate the net biome productivity (NBP) of the abandoned croplands and to assess the soil C storage dynamics due to recent land conversion. The soil C balance and its input (net primary productivity) and output (heterotrophic respiration) fluxes is simulated in a spatially explicit manner with the process-driven natural vegetation/crop model ORCHIDEE-STICS prescribed with successive area changes of abandoned croplands during the 1990s. We (Vuichard et al., 2008) estimate that regional agricultural abandonment is responsible of a cumulated carbon sink over 1991–2000 of 373 gC m 2, or 64 TgC over the domain considered, which defines a mean annual C sink of 46.7 gC m^{-2} a^{-1}. Agricultural practices during the former cultivation phase determine a legacy on the C sink following abandonment, which impacts by +37% to -25% according to the practice considered (no tillage, no fertilization, and export of some crop residues).

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