Process-based Crop Growth within the Land Surface Model JULES and Implications for Land-Atmosphere Exchange Processes

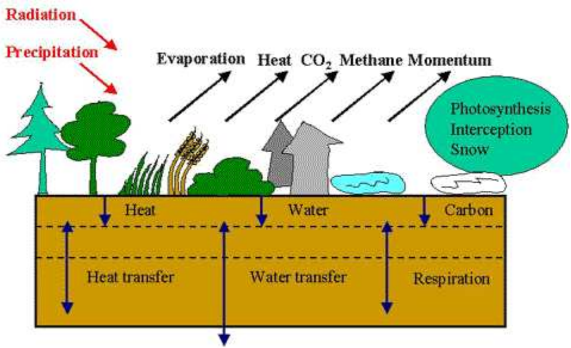
Catherine Van den Hoof[1,2] and Pier Luigi Vidale[1]

(1) Department of Meteorology, University of Reading, UK
(2) Belgian Nuclear Research Centre, Belgium

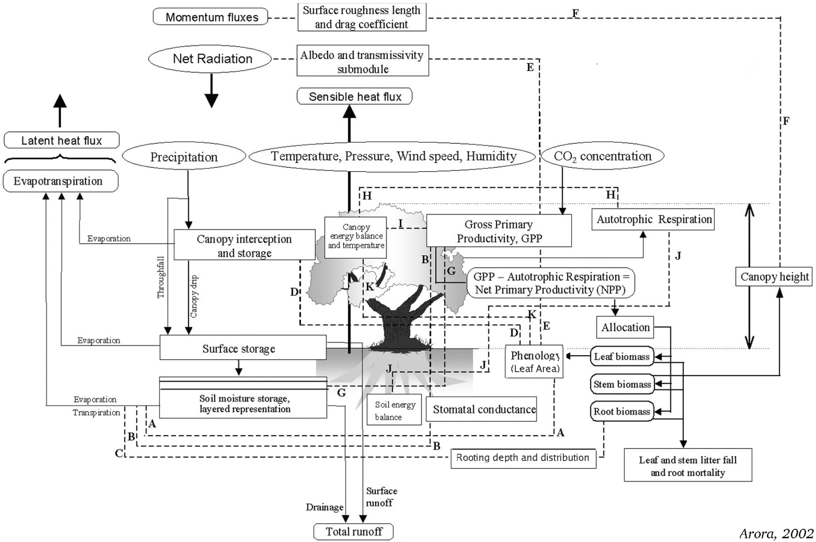
JULES Science Meeting
Edinburgh, UK
January 8 - 9, 2009

The Joint UK Land Environment Simulator (JULES)

JULES (Cox, 1999) represents land surface processes in natural ecosystems. It is a so called "third generation" land surface model (Sellers, 1997). The scheme includes the full hydrological cycle and vegetation effects on energy, water and carbon fluxes.



Soil-Vegetation-Atmosphere Interactions

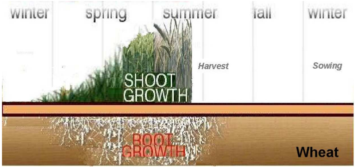


Arora, 2002

Differences between Natural Vegetation and Crops

Besides management practices, crops differ morphologically and physiologically from natural vegetation. Differences include:

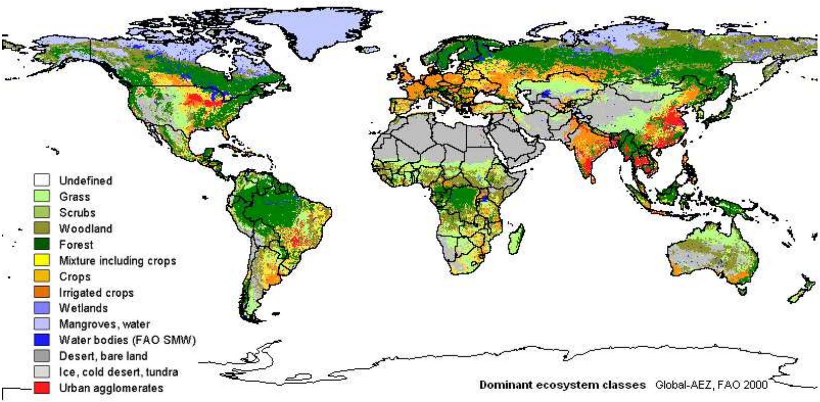
- Seasonal cycle and phenological development,
- Photosynthetic efficiency,
- Partitioning to yield.



These properties might affect the climate by modifying the energy, momentum and the hydrologic balance of the land surface.

Global Coverage of Agricultural Land

Around 11% of the land surface is used for crop production.



Why Dynamic Process-based Crop Growth?

- To be as realistic as possible
  - to understand the processes behind crop growth-atmosphere interactions,
  - to be usable in impact as well as in feedback studies.
- To be as generic as possible to minimise reparameterisation for wide range of
  - environmental conditions (i.e. climate change),
  - crop types (grouped in Crop Functional Types).
- To be consistent with representation of carbon and water fluxes within JULES for natural vegetation, to allow integrated studies.

Objective

What is the impact of crop growth and development on the surface exchange processes and what are the possible implications for crop production?

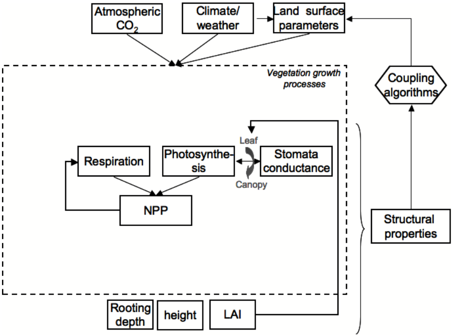
Method

- The sensitivity of the land surface to crops versus natural vegetation is evaluated by reparameterising a C3 grass into a crop.
- The sensitivity of the land surface, incl. crop, to dynamic versus static crop growth is evaluated by including a process-based crop growth module within JULES.

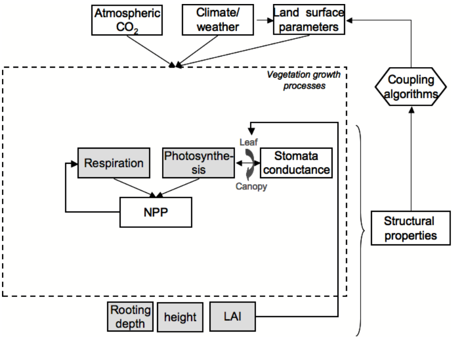
(Restricted to case study on wheat and fallow in France (1995).)

Reparameterising a Grass into a Crop Within JULES

JULES

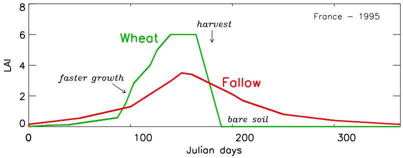


Reparameterising a Grass into a Crop Within JULES



JULES reparamterised for crops

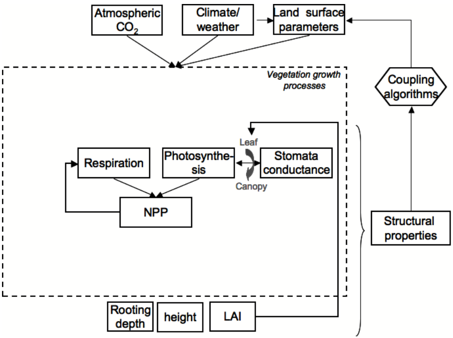
- Reparameterising the photosynthesis and respiration,
- Forcing with time series of LAI, height and rooting depth.



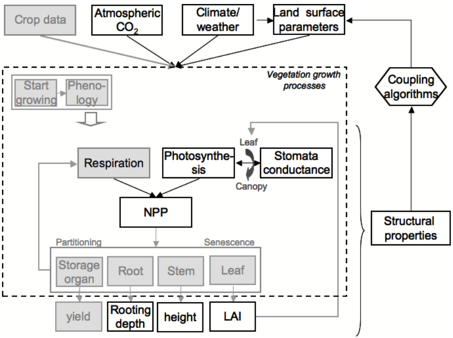
(Gervois, 2004; Calvet, 1999)

Process-based Crop Growth Module within JULES

JULES



Process-based Crop Growth Module within JULES



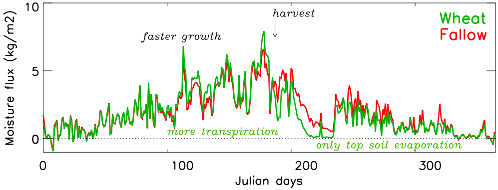
JULES -SUCROS

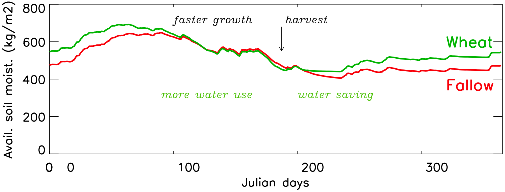
- Landsurface model JULES
- Crop module from SUCROS

  (Penning de Vries, 1982; Goudriaan and van Laar, 2002)

All vegetation types use a common photosynthesis-assimilation scheme, while specific modules are implemented for dynamic crop growth and development.

Impact of Crops vs. Natural Vegetation on Land Surface

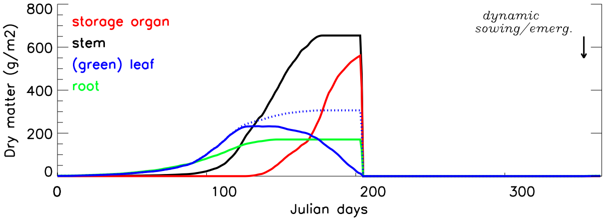




More water use during growing season and water savings after harvest.
The anomalies are the most significant, relative to the seasonal fluctuations, under water stress conditions and after harvest.

Dynamic Crop Growth and Development

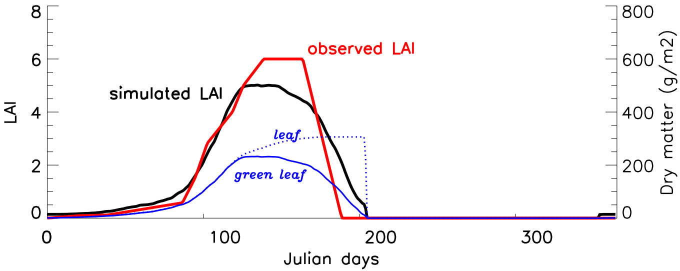
- Crop emergence after vernalisation period,
- Development rate is mainly determined by temperature,
- Growth rate is a function of phenological stage, partitioning of NPP to organs and environmental conditions.



Each timestep these prognostics are translated into biophysical parameters which then characterize the land surface and feed back on crop growth.

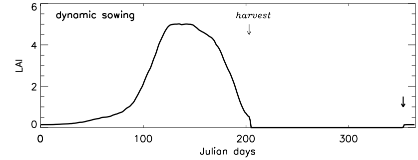
Observed vs. Simulated Leaf Area Index (LAI)

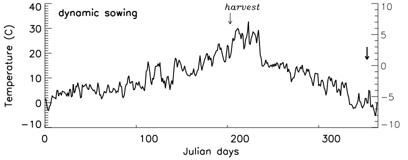
- Total DM → leaf DM → green leaf DM (senescence) → LAI

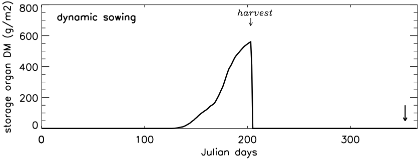


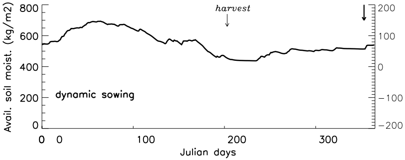
- Similar approach for height and rooting depth

Impact of Sowing Date

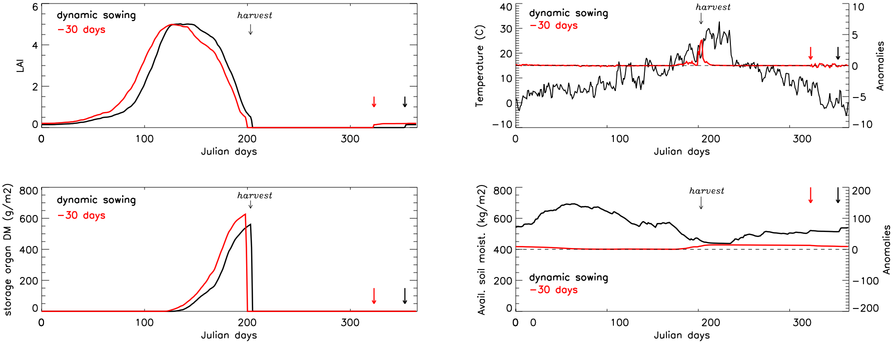






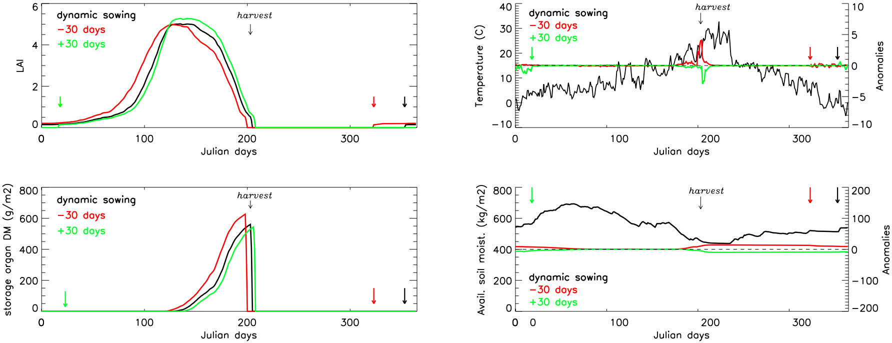


Impact of Sowing Date : 30 Days Earlier



- Lower temperature earlier in year explains slower development.
- Storage organ benefits from shift to less water stressed period.
- Harvest once evaporative demand becomes large.

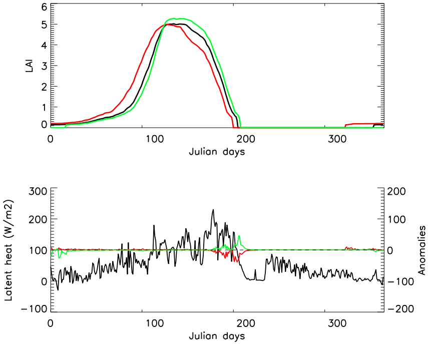
Impact of Sowing Date : 30 Days Earlier - 30 Days Later



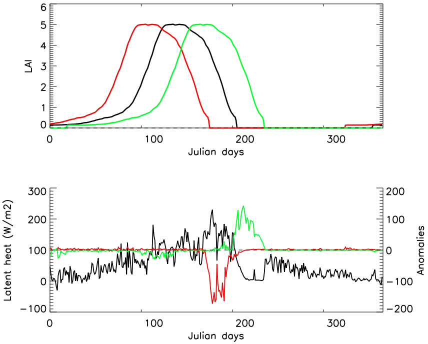
- The anomalies in fluxes are the most significant around harvest.
- Each organ responds according to conditions during development.
- Crops delay/accelerate their growth to mature at similar date.

Dynamic Versus Static Crop Growth

Dynamic



Static

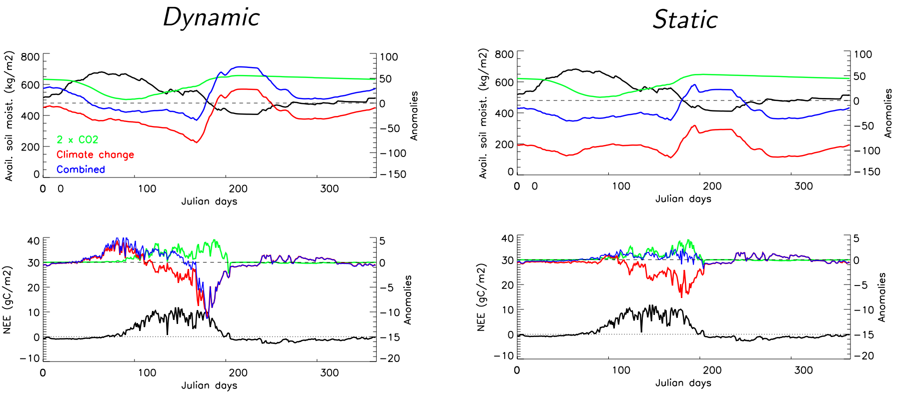


The impact on land surface and fluxes is less important for dynamic than for static crop growth since the crop adapts its growth to new environmental conditions.

A Growing Crop

under Changed Atmospheric Conditions

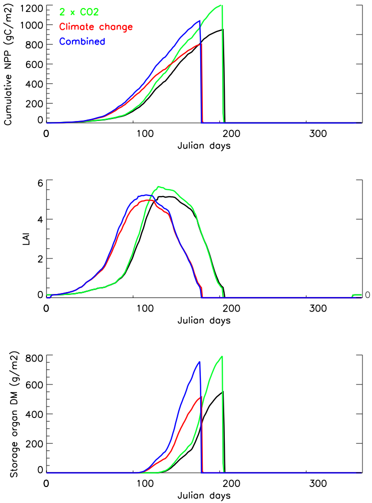
Impact on Surface and Fluxes



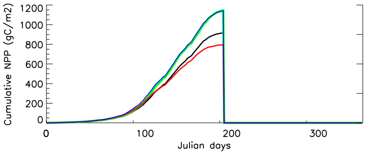
Under changed climate, the dynamic crop develops faster causing a shift in carbon flux. The moisture flux drops strongly since the crop is now harvested before the evaporative demand becomes very large.

Impact on Crop Growth and Production

Dynamic



Static



- Under changed climate, shorter season but less water stress for dynamic crop. Under doubled CO_2, higher CO_2-fertilisation due to interactive LAI.
- Under climate change, the CO_2 fertilisation is the most beneficial to storage organs.

Conclusion

- In JULES, the anomalies in fluxes and surface characteristics caused by substituting natural vegetation with crops are significant when compared to (observed) seasonal variability.
- A new crop growth model JULES-SUCROS has been constructed. This model is process-based and responds consistently to a variety of environmental forcings. It simulates well the seasonal cycle of a growing crop.
- Crop growth and organ development affect the surface exchange processes. This will likely feed back on the simulated surface climate when the model is coupled back to a GCM.
- Crops grow in symbiosis with their environment. The impact of climate change on the land surface might be overestimated when forcing the model with prescribed biophysical parameters.

Perspectives

- This modelling framework allows for further developments concerning management practices and environmental change studies.
- It contributes to the understanding of the effect of climate change on crop productivity, with emphasis on water availability and sustainability.
- Once coupled back to a GCM, the feedback of crop growth on the climate system will be investigated in depth.

However, to be fully operational, this model first needs to be tested for other sites and be parameterised, calibrated and validated for a wide range of environmental conditions and crop types.