Dynamic Global Vegetation Model ORCHIDEE

Simulates the Energy, Water and Carbon balance
Land component of the IPSL Earth System Model
Terrestrial Biosphere (ORCHIDEE)

Atmosphere
Prescribed or Modeled (LMDZ GCM)

- temperature, winds, precipitation, pressure, radiation, humidity
- CO₂ concentration

- sensible and latent heat fluxes, albedo
- CO₂ flux, roughness
- surface temperature

Energy and Water Balances, options Photosynthesis, Routing (SECHIBA)
Δt = 30/15 min

- GPP, soil profiles of temperature and water
- LAI, albedo, roughness

Vegetation and Soil Carbon Cycle (STOMATE)
Δt = 1 day

- NPP, biomass, litterfall...
- vegetation types

Vegetation distribution
Prescribed or Modeled (LPJ DGVM)
Dt = 1 year

Krinner et al., 2005
Why using ORCHIDEE

Climate impact & feedbacks: Energy & Water balances
- Impact of surface heterogeneity
- Global climate impact
- Regional climate impact
- Climate Change and Fires
- Climate extremes impact

Climate impact & feedbacks: Agrosystems
- Regional impacts
- Land sharing mitigation potential
- Food supply

Attribution of global changes (GHG balances, run-off…)
- Carbon sink attribution (climate, N cycle, land use, forest management, fire)
- Change in run-off

Tipping Points
- Boreal regions: Permafrost melting…
- Amazon: possible die back
More than 20 years of development

Model

SECHIBA → ORCHIDEE

Carbon Cycle (STOMATE)

Dynamic Veg. (LPJ)

Carbon Cycle

Dynamic Veg. (LPJ)

+ New hydrology

+ River routing

+ Forest management

+ Crops module

+ Permafrost

+ Nitrogen Cycle

Towards a single shared tool

80s

(Laval et al., 1981)

(Ducoudré et al., 1993)

(Viovy et al., 1997)

(Polcher et al., 1998)

(Krinner et al., 2005)

90s

Small group btw LMD/LSCE (5-10)

2000

Increasing number of developers & users (15-25)

2009

Specific “Project Group” across IPSL & few other labs.

Few Scientists at LMD (3-4)

LMD → LMD/LSCE organization
More than 20 permanents, Few laboratories

LSCE – Paris (Biogeochemistry and Biophysics): 10 permanents
P. Ciais, A. Cozic, N. De Noblet, J. Lathière, S. Luyssaert, F. Maignan,
C. Ottlé, P. Peylin, N. Viovy, N. Vuichard ; 10-15 Post-Doc / PhD

IPSL (Engineering) : M.A. Foujols, J. Ghattas

LMD – Paris (Energy and Water balance):
F. Chéruy, J. Polcher, C. Risi ; 2-3 Post-Doc / PhD

SISYPHE – Paris (Water cycle):
A. Ducharne + 2 Post-doc / PhD

LGGE - Grenoble (High latitude processes):
G. Krinner ; 3 Post-doc / PhD

University of Peking – China (Biogeochemical cycle):
S. Piao; 5 Post-doc / PhD

University of Antwerp / Ghent – Belgium (Biogeochemical cycle):
I. Jansen, H. Verbeeck ; 3 Post-doc / PhD
Main features of ORCHIDEE

- Vegetation defined as Plant Functional Types (13 currently)
  A mosaic of vegetation in each grid cell

- A “big leaf approach”
  - One Energy budget for the whole grid box
  - Fully implicit coupling with the Atmospheric LMDz model
  - Coupled with snow & soil energy budget

- Soil energy and hydrology
  - Solve the Heat Diffusion Equation ; 7 layers ; up to 5.5m
  - Fully coupled with the calculation of surface temperature
  - “New” 11-layers soil hydrology scheme

- Photosynthesis / Phenology
  - Farquhar & Ball and Berry model
  - Computation a several levels (light decrease) ➔ integration
Surface description: a tile approach

- A mosaic of vegetation
- 13 different Plant functional types
Hydrological Processes in ORCHIDEE

- Partition of throughfall between infiltration and runoff
- Water fluxes in soils (soil moisture and drainage)
- Routing of runoff into river discharge
- Human pressures, e.g. irrigation
- Interactions with floodplains (fluxes and storage)
- Wetlands
- Snow pack processes
- Permafrost (freeze/thaw in the soil)
- Interactions with groundwater tables (fluxes and storage)
“Slow biogeochemical” Processes

- Phenology - Budburst based on GDD, soil water...
- Senescence: Based on Leaf age, Temp...
- Carbon Allocation:
  - 8 pools of living biomass
  - 4 litter pools and 3 soil carbon pools (CENTURY)
- Autotrophic respiration: Maintenance & Growth
- Heterotrophic Respiration
- Fire module (SPITFIRE)
- Turnover : death of plants, etc.
Recent improvements of ORCHIDEE

- Generalization of PFT concept (number not limited)
- A 11-layer hydrological scheme
- Scientific documentation
Two versions of the soil hydrology

**Choisnel = ORC2**

*Ducoudré et al., 1993; de Rosnay et al. 1998*

- Conceptual description of soil moisture storage
- 2-m soil and 2-layers
- Top layer can vanish
- Constant available water holding capacity (between FC and WP)
- Runoff when saturation
- No drainage from the soil
- We just diagnose a drainage as 95% of runoff for the routing scheme

**CWRR = ORC11**

*de Rosnay et al., 2002; d’Orgeval et al., 2008*

- Physically-based description of soil water fluxes using Richards equation
- 2-m soil and 11-layers
- Formulation of Fokker-Planck
- Hydraulic properties based on van Genuchten-Mualem formulation
- Related parameter based on texture (fine, medium, coarse)
- Surface runoff = P – Esol – Infiltration
- Free drainage at the bottom
Test over the Amazon: 2 versus 11 layers

Reconstruction of varying water stocks

Larger amplitude of storing/releasing water in ORC-11LAY is more realistic.
Comparison with SMOS: soil moisture evolution

Guadalquivir area:
lon: -6:-4, lat: 37.2:38.

3 days average to reduce instrument noise

- The ERA-Interim rainfall forcing ORCHIDEE is rather good.
- The general annual cycle is rather well captured.
- The amplitude of the response to the rainfall events is more spiked in SMOS than the 0-5cm layer in ORCHIDEE.
Recent developments to be merged

- High latitudes processes

- Nitrogen cycling

- A Forest Management Module
Climatic specificities of high latitudes and specific processes

~ 55% of NH land surface area is subject to seasonal freezing with snow cover periods.

~ 25% of NH land surface area is underlain by permafrost.
High latitude Processes

- Permafrost & Climate change (soil heating)
- Wetlands hydrology ➞ CH4 emissions
- Snow: Adaptation of ISBA-ES + Soil freezing
Change in Northern Hemisphere spring LAI

A) Detection

LAI trend (1982-2002)

B) Attribution

Factors:
Temperature is dominant > CO2 > Precipitation

Piao et al., GRL, 2006
Nitrogen Cycling in ORCHIDEE

Carbon cycle:
- Atm CO₂
  - photosynthesis
  - litterfall & mortality
  - decomposition
  - respiration

Nitrogen cycle:
- Plant
  - assimilation
  - denitrification
  - N deposition
  - N fixation
  - mineralization
  - N leaching
- Litter / CWD
- Soil Mineral N
- Soil Organic Matter
Nitrogen Cycling in ORCHIDEE

Sensitivity to elevated CO$_2$ (Duke forest: *Pinus taeda*)

- CO$_2$ enrichment since 1997 in 3 paired rings
- Control: ambient (~365 ppmv)
- Elevated: ambient + 200 (~565 ppmv)
- Age related decline in NPP
- Age related limitation of LAI
- Age related allocation between stem and roots
- Branch mortality
- Coarse woody litter compartment
- Individual growth of trees
- Generic management
Simulation of carbone fluxes for UE 25

Uptake

Release

Net uptake

Source: Luyssaert et al., 2010; Bellassen et al., in prep
Current developments

**Integration within 2-3 years**

- New multi-layers energy budget
- New radiative transfer scheme
- New plant functional types (PFTs)
- Coupling surface and ground water hydrology
- Coupling with WRF atmospheric model
- Isotopic module for Water and Carbon isotopes
- Vegetation and chemistry: coupling INCA-ORC
Mid term improvement (1-2 yr)

**New energy budget**

- Closed canopy (1.9.6)
- Prescribed radiation scheme $f$(LAI)
- Big-leaf energy budget (implicit)
- Prescribed snow albedo $f$(snow age)

- Open canopy (under development)
- Two way radiation scheme $f$(canopy)
- Multi-layer energy budget (implicit)
- Snow under the canopy $f$(snow age)

**New C allocation scheme**
How does forest management affect:
- the surface albedo?
- subsequently the climate?
Interactions between the terrestrial biosphere and the atmospheric chemical composition
Coupling INCA and ORCHIDEE

**Biogenic Compounds:**
- VOCs (80%)
- NOx (10%)

**Deposition at the surface:**
- O3: 25% of photochemical production
- Strongly linked to vegetation type

**GLOBAL CHANGES ???**
- Climate, land-use, chemistry, etc.

**Terrestrial biosphere**

**Atmospheric Chemical Composition**
- Ozone, OH, aerosols, GES lifetime

**HIGH REACTIVITY**
- HIGH REACTIVITY
- SIGNIFICANT SINK
- IMPACT ON ECOSYSTEMS (pollution)