Mini-project

Atmospheric boundary layer dynamics and surface-atmosphere coupling over continental surfaces

M2 MOCIS : Numerical Modeling course

Picture of the Great plains at Case-99 site, Kansas

1. Context:

Earth's climate and its evolution are determined by interactions between the ocean, the atmosphere, ice caps, and land surfaces under the external solar forcing and the atmospheric composition. Numerical models need to couple all these components of the system when they are used for running climate projections to anticipate the impacts of climate change. In particular, the land surface-atmosphere interactions strongly modulate the regional climate. They rely on complex overlaps of multiple land-atmosphere feedback processes and depend on the representation of the interactions between the soil moisture and the boundary layer through the partition of the available energy at the surface in sensible and latent heat, the impact on radiation, the representation of convection and its sensitivity to sub-grid scale heterogeneities, the representation of soil moisture, and the possible interplay with the atmospheric circulation . The complexity and the variety of processes involved make the land-atmosphere interactions one of the key sources of uncertainty in climate change simulations at regional scale.

The aim of this mini-projet is to decipher the main physical mechanisms and feedbacks that drive the atmospheric boundary layer dynamics and the surface-atmosphere couplings over the continents. For this purpose, you will perform an ensemble of sensitivity tests on numerical simulations performed with the last version of LMDZ coupled with a simplified soil model.

2. Soil model and key physical parameters for the surface-atmosphere coupling

Simplified model for continental surfaces:

An important difference between continents and oceans is the availability of water for evaporation.

In the IPSL climate model, the turbulent flows at the surface (latent and sensible) are computed by the continental surface model (ORCHIDEE), here we will use a simplified scheme (bucket). Evaporation is calculated as potential evaporation multiplied by an aridity coefficient, beta, which is a simple function of the water content in the soil (the bucket) qsol. One can plot beta as a function of the water in the soil.

beta = MIN(2.0*qsol/mx_eau_sol, 1.0) (ici, mx_eau_sol=150mm).

Thus the beta parameter controls the evaporative capacity of the soil, and thus plays an important role in the sensible/latent partitioning of turbulent surface flux.

Surface roughness:

A surface will be rougher if it has larger protrusions. For example, the boreal forest or a megalopolis will have a greater roughness length than the tundra, deciduous forests will be less rough in winter than in early summer.

Roughness length is a parameter related to the effect of surface roughness on turbulence. For the quantity of movement, this length is representative of the obstacles on which the pressure couples are exerted, it is related to the height of the obstacles. It is more related to molecular conduction for water and energy flows.

Thus the roughness length impacts the energy, moisture and momentum transfer between the surface and the atmosphere.

Thermal Inertia :

The heat transfer in the soil is parameterized according to a diffusive process (Fick's law). When LMDZ is not coupled to ORCHIDEE, heat transfer is handled by the routine soil.F90 and soil properties are assumed to be homogeneous so that the transfer equation can be simplified and solved along a vertical axis, each level of which corresponds to a multiple of the diurnal cycle (Hourdin 1992). Thus formulated, the model depends on only one physical quantity, the soil thermal inertia I, which is equal to the square root of the product of the soil thermal capacity and its thermal conductivity. It is this parameter that first controls the "damping" of the diurnal cycle (and thus its amplitude) by heat diffusion towards the lower layers. The thermal inertia of the soil can be changed in .def (parameter inertia_soil, default value = 2000 J m^{-2} K^{-1} $s^{-0.5}$ corresponds to a very moist soil). Note that in this simplified version the thermal inertia is independent of soil moisture.

Albedo

Albedo is a crucial parameter for the surface energy balance because it determines the amount of solar radiation absorbed by the soil. In 1D, the albedo is controlled by the parameter "albedo" in .def while in 3D, albedo maps are read during pre-processing.

It should be noted that ground emissivity is also an important parameter for surface-atmosphere coupling since it controls the capacity of the ground to absorb/emit infrared radiation. Nevertheless, the current formulation of the LMDZ radiative code does not allow the treatment (in a physical and robust manner) of soils with emissivity different from 1.

3. Sensitivity tests on the 1D DICE Case

The first part of this project is to investigate the sensitivity of the representation of the different terms of the surface energy balance and of the dynamics of the atmospheric boundary layer on the 1D DICE case (dice_bucket).
The DICE (Diurnal land-atmosphere Coupling Experiment) consists in simulating 3 diurnal cycles of the atmospheric boundary layer over the american Great Plains at Case-99 site, Kansas (see picture).
You may want to comment on:
-> the relative contributions of the different terms of the surface energy budget at different times of the day;
-> what drives the amplitude of the diurnal cycle and the stability of the boundary layer;
-> which mechanisms govern the near-surface humidity and temperature;
-> the sensitivity to the vertical resolution (79-level grid versus 90-level grid)
-> how the near-surface climate and the boundary-layer would change over a wetter/drier soil and/or over a higher vegetation?

4. Continental climate sensitivity to the surface-atmosphere coupling in 3D simulations

In a second step, you will determine to what extent the conclusions you drew on a simplified 1D set-up can be extended to 3D simulations. You can choose to (slightly) refine the grid over a particular continental region and assess the sensitivity of its near-surface climate to pre-identified key parameters. You can also propose and test relevant parameterization adaptation or improvements, like the inclusion of a humidity dependency of the soil thermal inertia.

5. References

Ait-Mesbah et al. 2015 The role of thermal inertia in the representation of mean and diurnal range of surface temperature in semiarid and arid regions https://doi.org/10.1002/2015GL06555

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