A new community experiment to understand land/atmosphere coupling processes

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Motivation

The Diurnal land/atmosphere Coupling Experiment (DICE) is a first attempt to identify the interactions and feedbacks between the land surface and the atmospheric boundary layer. There are many interactions which act on the local scale and vary in their complexity, as seen in the simplified schematic in Fig. 1. However, the implications of these interactions are not well known in general and are often poorly represented in numerical models.

The GLACE experiment (Koster et al, 2006, Guo et al., 2006) identified regions of the world (known as the land surface hot spots) where there is a high coupling strength between soil moisture and precipitation, i.e., between the land surface and the atmosphere. However, this community experiment also highlighted large differences in the coupling strength between the various models, even in the hot spot regions. In reality there is only one value for this coupling strength, so this experiment has highlighted our limited knowledge of what this coupling strength should actually be.

Subsequent research looking into the physical mechanisms for the coupling strength of various models (e.g., Lawrence and Slingo, 2005, Comer and Best, 2012) has shown that it is the interaction between atmospheric parametrisations that determine the land/atmosphere coupling strength rather than the interactions between the land and the atmospheric boundary layer. However, more work is required to fully understand the implications of this.

The timescales for variations in the soil moisture at deep layers are of the order of months to years. This means that such variations could be critical for constraining the evolution of seasonal to decadal predictions. However, if the coupling between the land and the atmosphere is not correctly modeled, then such seasonal predictions may not be correctly constrained, leading to a reduced quality for these valuable predictions.

In addition, land atmosphere interactions play a critical role in determining the near surface atmospheric states of temperature and humidity throughout the diurnal cycle, but in particular during the stable nocturnal boundary layer. During these conditions, subtle interactions between the land and the atmospheric boundary layer can have significant impacts on the evolution of the near surface and potentially lead to large errors in a prediction. It is unclear from current research whether these model deficiencies result from the land surface scheme, the stable boundary layer scheme or the interactions between them. Likewise, the daytime diurnal cycle of surface fluxes and evaporative fraction is tightly coupled to the convective boundary layer heat and moisture budget, driven principally by the feedback of entrainment, and studies (Santanello et al. 2011, 2013) have shown that the influence of the land vs. boundary layer as such depends on the regime of interest (e.g. dry vs. wet).

It is difficult to isolate and identify issues related to either the land surface or atmospheric boundary layer schemes within any particular model in general, due to the complexities of the schemes and the resulting large observational data requirements. As such, little progress has been made over the last decade with regards to understanding land/atmosphere feedbacks. The Global Land Atmosphere

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System Study (GLASS) panel within Global Energy and Water EXchanges (GEWEX) has had an activity on local coupling (LoCo) between the land and atmosphere for many years, and while development of an array of diagnostic approaches has been fruitful, progress on a systematic, community-wide experiment (such as GLACE or PILPS) has been slow due to the complexities described above. In parallel, the Global Atmospheric Boundary Layer Studies (GABLS, now part of the GEWEX Global Atmospheric System Studies, GASS) community has been evaluating the performance of atmospheric boundary layer models through several intercomparison studies (e.g., Cuxart et al 2006, Svensson et al 2011) but with relatively little attention played to the role of the surface in constraining the surface fluxes. Another key aim of the DICE project, then, is to link these two communities together to bring their combined expertise to bear on this coupled problem.

Within the DICE experiment, a simple methodology for assessing the impact of land/atmosphere feedbacks is proposed by first assessing the individual components constrained by observational data and then identifying changes due to coupling. This is the first step towards understanding the true observed physical feedbacks whilst understanding the impact of parametrisation interactions.

Project outline

The project will use data from the CASES-99 field experiment in Kansas (latitude 37.65 N, longitude 263.265 E), for the 3 days from the afternoon of October 23rd 1999 to the 26^{th}. A good feature of the days chosen is they give clear skies throughout and three nights of varying character: intermittent turbulence, continuous turbulence and very stable, respectively. Data from this experiment have already been used by the GABLS boundary layer community to assess their models (Svensson et al (2011)). However, within the current project protocol, the boundary layer models (single-column models) will be designed to use observed surface fluxes as their bottom boundary condition, rather than the specified land surface temperatures used in the previous experiment. This enables a clean split between the land surface schemes and the atmospheric boundary layer schemes.

The project design splits into the three stages, illustrated in Fig.2:

Stage 1:

(a): The land surface models are run using observed atmospheric forcing at a reference height, following the protocol used for many of the PILPS experiments (e.g., Henderson-Sellers et al. 1993, 2003, Irranejad et al. 2003). The resultant surface fluxes and 2 m screen level data derived by the models is then compared to the observed values to provide an initial assessment of the model performance.

(b): Similarly, the single column models are run using the observed surface fluxes as a bottom boundary condition and the large-scale atmospheric forcing provided. The resultant wind, temperature and humidity profiles are then compared to the observed atmospheric data to provide an initial assessment of the models

Stage 2:

Each modelling group runs their land surface and single column models coupled to include the land/atmosphere feedbacks. The modelled atmospheric profiles of temperature, humidity and wind are compared to observations, along with the surface fluxes of momentum, heat and moisture, the screen level temperature and humidity and the 10m wind speed. Differences between the results from the coupled run and those from the two model components driven by the observed data (in stage 1) are assessed to investigate the impact of the coupling through feedback processes.

Stage 3:

(a): The set of surface fluxes derived by each of the land surface models used in stage 1(a) is used as an ensemble of "surrogate observations". Each member of this ensemble is used by the boundary layer models, analogous to stage 1(b), to create an ensemble of atmospheric profiles for each boundary layer model. The spread of the ensemble of boundary layer profiles is then compared between the boundary layer models to identify which models have the largest spread and which have the smallest spread. The models with the largest spread are the ones that are most sensitive to the surface fluxes, whereas the modes with the smallest spread are the ones that are least sensitive to the surface fluxes. Further analysis could then be undertaken to identify the processes responsible for the atmospheric sensitivities to the surface fluxes.

(b): The set of atmospheric data, derived by each of the boundary layer models used in stage 1(b) is used as an ensemble of "surrogate observations". Each member of this ensemble is used to force the land surface models, analogous to stage 1(a), to create an ensemble of surface fluxes, screen level temperature and humidity, and 10m wind speed for each land surface model. The spread of the ensemble of surface fluxes and screen level variables is then compared between the land surface models to identify which models have the largest spread and which have the smallest spread. The models with the largest spread are the ones that are most sensitive to the atmospheric forcing, whereas the modes with the smallest spread are the ones that are least sensitive to the atmospheric forcing. Further analysis could then be undertaken to identify the processes responsible for the land surface sensitivities to the atmospheric conditions.

A challenging timescale has been set for the DICE experiment, with initial results being shared during a workshop in the fall. This timescales for each part of the experiment are as follows:

- April 2013: Observational data released to participants
- June 2013: Results returned from stage 1
- June 2013: Results returned from stage 2
- Aug 2013: Results returned from stage 3
- 14 – 16 Oct: Workshop on initial results from the experiment hosted by the UK Met Office

Further details of the experiment, along with the observational data and how to take part, can be found on the project website: http://appconv.metoffice.com/dice/dice.html

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Figures

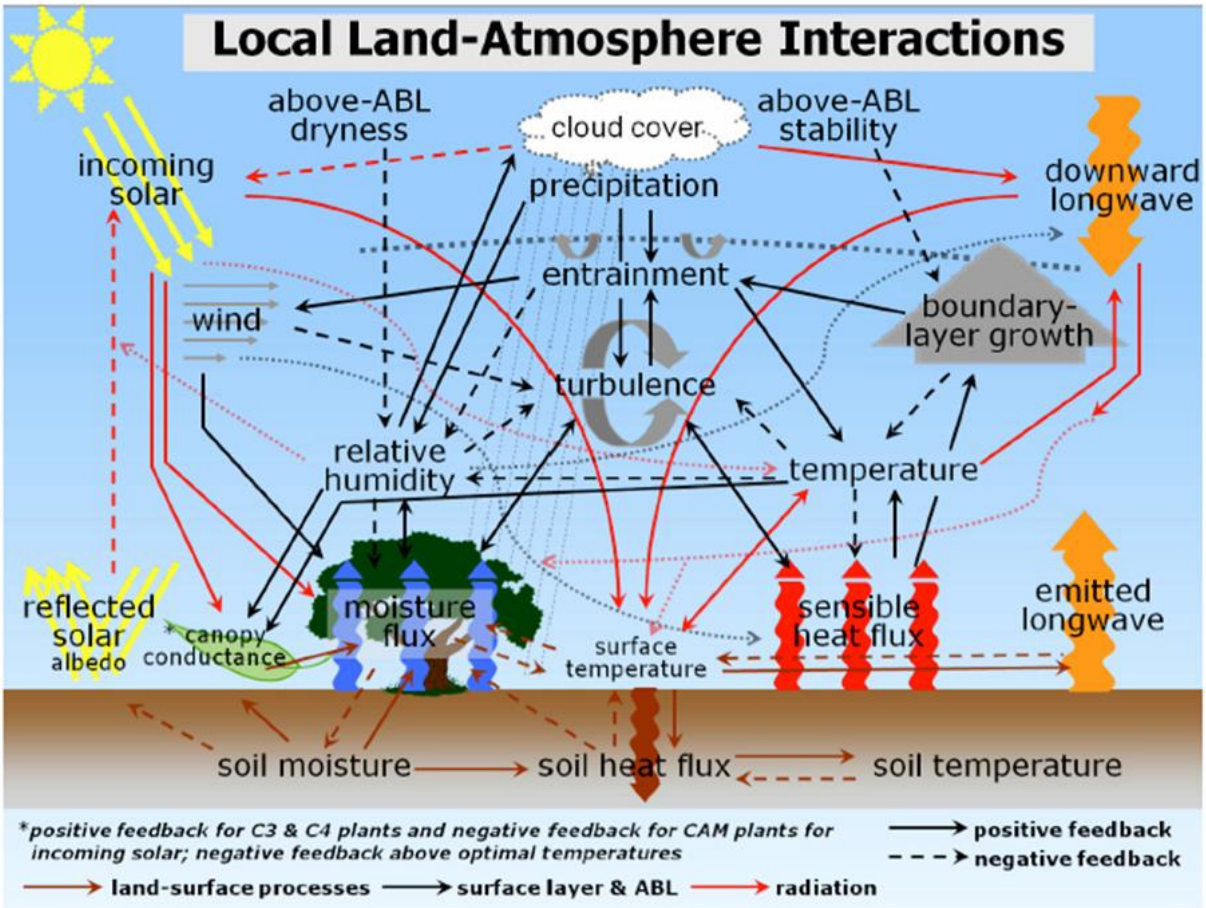

Figure 1: Schematic of the complex interactions between the land surface, atmospheric boundary layer, and radiation via many variables. Adapted from Ek and Holtslag (2004), courtesy of Mike Ek.

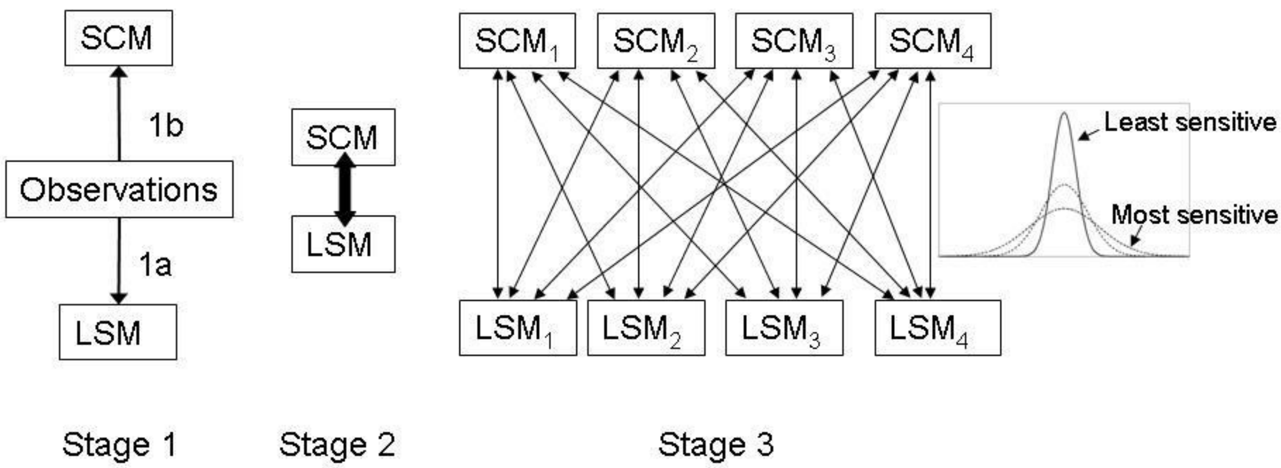

Figure 2: schematic illustrating the three stages of the project