DIurnal land/atmosphere Coupling Experiment (DICE)

Motivation

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 modelled, 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 PBL 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. PBL 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 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 but with relatively little attention played to the role of the surface in constraining the surface fluxes. Another key aim of this project, then, is to bring these two communities together to bring their combined expertise to bear on this coupled problem.

Within the experiment proposed here, we suggest a simple methodology for assessing the impact of land/atmosphere feedbacks 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 (19 UTC, 2pm local time) of October 23rd 1999 to the 26th. 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. Further details of the forcing for the single column models are given below.

This project will be split into the three stages below. Operational model settings (or default settings for non-operational models) should be used for all of the stages, but additional development versions of the models can be submitted if desired. Similarly operational vertical resolution (in atmosphere and soil) and timestep should be used but higher resolution sensitivity tests are welcome.

Stage 1:

(a): The land surface models will be run using observed atmospheric forcing at a reference height. Ideally this would be high enough so that the 2 m screen level temperature and humidity, and the 10 m wind speed could be evaluated. However, data at the site were only from a 55 m tower (which is likely to be above the surface layer during stable conditions) or from 2 m screen level for temperature and humidity and 10 m for wind. So the surface schemes should be run with both the 55 m forcing and the 2 m screen level plus 10 m forcing, so that consistencies and differences can be assessed. The temporal resolution for both forcing datasets is 10 minutes. The resultant surface fluxes and 2 m screen level data derived by the models will be compared to the observed values to provide an initial assessment of the model performance.

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

Stage 2:

Each modelling group will run their land surface and single column models coupled for the 3 day period to include the land/atmosphere feedbacks. The initial soil conditions will be taken from the spin-up run in stage 1a. The modelled atmospheric profiles of temperature, humidity and wind will be 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) can then be 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) will be used as an ensemble of "surrogate observations". Each member of this ensemble will be 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 can then be 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 bottom model level atmospheric temperature, humidity and wind, along with the downward components of shortwave and longwave radiation, and the precipitation and surface pressure, derived by each of the boundary layer models used in stage 1(b) will be used as an ensemble of "surrogate observations". Each member of this ensemble will be 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 can then be 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.

Initial conditions for land surface schemes.

To initialize the deep soil temperature and moisture, the land surface models should be spun-up. Sensitivity runs with the JULES land surface model have shown that if the soil moisture is initially set to saturated conditions, then the soil moisture and temperatures can be spun-up using a 10 year forcing dataset. However, starting from a dry soil state takes longer (15 – 20 years).

So an approximately 10 year forcing dataset, at 3 hour temporal resolution, has been created. The land surface models should use linear interpolation to get higher temporal forcing as required. This forcing dataset uses values from the WATCH forcing dataset for the period of 1990 – 1998. It then uses data from the Smileyberg site as forcing for the last year, ending with the first day of the experiment. However the models should only be run to 19 UTC on this final day of spin-up forcing. Any gaps in the data from the final year have been filled with values from the WATCH forcing dataset.

In summary, the spin-up dataset should be used to initialize the land surface model soil temperatures and moistures, with the soil moisture set to saturation at the start. The spin-up forcing dataset has a total of 3583 days, at 3 hourly temporal resolution, but the model run should be stopped at 19 UTC on the final day.

Initial conditions and forcing for the Single Column Models (SCM)

Initial conditions for 19 UTC on Oct 23rd 1999 and forcing for the single column models are contained in the netcdf format driver file with the variable name and units used given in brackets below.

(a) Initial conditions for the atmosphere

- “height” is in metres above ground level up to 40km
- potential temperature (“theta”, K), defined relative to a reference pressure of 1000 hPa
- specific humidity (“qv”, kg/kg)
- horizontal wind components (“u”, “v”, m/s)
- pressure (“pf”, Pa)
- ozone mixing ratio (“o3mmr”)
- surface pressure (“psurf”, Pa)

(b) surface flux forcing

In stage 1 the SCM are forced at the surface by observed fluxes and stresses. It is anticipated that all models will already be able to run with observed surface sensible and latent heat fluxes. Specifying observed surface stress may be new to many models. Running boundary layer models with observed surface scalar fluxes and observed winds gives problems (Basu et al., 2008) due to the bimodal solution during zero flux conditions (i.e., a zero temperature gradient in neutral conditions, or a suppression of turbulence in very stable conditions). Hence it is important to specify the observed surface stresses directly. The observed friction velocity, u_*, is supplied and the stress components should be oriented with the model’s level 1 wind. However we recognize that this may be technically challenging and so alternatively the observed u_* can be combined with the model’s (interactive) level 1 windspeed, V, to calculate the surface drag coefficient as:

$$c_D^{\,1/2}=u_*/V$$

Tests in the Met Office SCM find the subsequent implicitly calculated surface stress still matches the observed u_* pretty well.

To generate the upward surface LW radiative flux, either the observed flux itself can be used or else the observed skin temperature. Similarly for the reflected SW flux, either the observed flux can be used or an albedo of 0.22

Forcing is provided every half hour and liner interpolation should be used for intermediate timesteps.

In summary, then the driver file contains the following surface data required to drive the SCM in stage (1):

- “time” is in seconds after 19 UTC on Oct 23rd 1999
- surface sensible heat flux (”shf”, W/m2)
- surface latent heat flux (“lhf”, W/m2)
- surface friction velocity (“ustar”, m/s)
- surface skin temperature (“Tg”, K), potentially used to generate upward LW flux

- upward LW flux from the surface (“lwup”, W/m2, positive upwards)
- upward SW flux from the surface (“swup”, W/m2, positive upwards)

(c) large-scale atmospheric forcing

All stages of the SCM simulations require the following large-scale forcing, as contained in the driver file, to maintain the local atmospheric profiles close to the observed sondes. Note that both a time-varying (vertically uniform) geostrophic wind and time and height varying horizontal advection increments are applied to the momentum fields.

- time-height varying temperature advection (“hadvT”, K/day)
- time-height varying moisture advection (“hadvq”, kg/kg/day)
- time-height varying zonal momentum advection (“hadvu”, m/s/day)
- time-height varying meridional momentum advection (“hadvv”, m/s/day)
- time-varying zonal geostrophic wind (“Ug”, m/s)
- time-varying meridional geostrophic wind (“Vg”, m/s)
- time-height varying vertical velocity (“w”, m/s), or pressure velocity (“omega”, Pa/s)

Full details of the derivation of this forcing are given in the accompanying document.

Output

The complete list of requested output is given in the accompanying document. The SCM diagnostics are very similar to those in GABLS3, but additional output to force the land surface models in stage 3 will also be required. These should be at 10 minute temporal resolution and include the downward components of shortwave and longwave radiation at the surface, rainfall, first model level temperature, humidity and wind, and surface pressure. The land surface diagnostics should follow the standard ALMA convention, but also include the 2 m screen level temperature and humidity and the 10 m wind speed.

Timescales

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, Exeter

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