Towards implementation of the "Local-Coupled" GLASS theme

Bart vd Hurk (KNMI), Christa Peters-Lidard (NASA) and Paul Dirmeyer (COLA),
August 2004

Introduction

More than two years ago, a workshop held in De Bilt was devoted to the discussion and design of an experiment plan addressing the so-called "local land-atmosphere coupling" (or LoCo) theme of GLASS. Rationale behind this theme that in many experiments devoted to calibration of land surface schemes or finding optimal states of the land surface via data assimilation, land-atmosphere coupling (abbreviated as LAC hereafter) is usually neglected since the atmosphere is a prescribed forcing to these experiments (the PILPS-set-up). However, intuition and practical evidence have shown that this lack of feedback affects the result, leaving us with models and surface states that possibly have systematic errors in their calibration or absolute state values. Examples are problematic assimilation of snow in cases where the assumed atmospheric temperature differs from the actual temperature and snow melt processes may cause erratic states (Houser et al, 2002), sensitivity of nocturnal boundary layer development to subtle land surface parameterizations affecting skin temperature (Steeneveld et al, 2004), deep boundary layers over BOREAS during Spring (Betts et al, 2001), and suspiciously high snow sublimation rates in the PILPS2E experiment leading to alterations to various participating land surface models (Bowling et al, 2003). In systems where a land-atmosphere coupling is included (e.g. data assimilation using atmospheric screen level quantities), the strength of the feedback may have a strong impact on the results. Spurious soil moisture data assimilation increments were diagnosed from forecast errors of near surface humidity in Mediterranean areas (Van den Hurk et al, 2004), and the annual cycle of soil water in ERA40 over Europe is clearly suppressed (Seneviratne et al, 2004). Many more examples can probably be given.

The workshop report (Van den Hurk et al, 2002) includes a proposal for a three-stage experimental plan to systematically exploit this complex field of (local) LAC. In stage 1 an inventory of models, areas and periods is made where LAC significantly alters the sensitivity of the calculated fluxes to perturbations in the forcing. Both uncoupled and coupled experiments must be carried out, where precipitation and radiation are provided as external input and the coupling only affects the turbulent exchange. Boundary conditions for an atmospheric single column model should be provided from time series from a high resolution (limited area) model. It is assumed that a coupled system is more robust and less sensitive to forcing perturbations, but the increased number of degrees of freedom may also well give rise to unexpected amplifications of the sensitivities. In a second stage, the nature of the LAC should be diagnosed further by coupling various surface schemes to a single boundary layer model (facilitated via the ALMA interface) or vice versa, and thus identify model components that play an important role in LAC. Stage 3 addresses the impact of LAC on data assimilation results, by comparing coupled and uncoupled simulations with and without data assimilated into it. Subject of research is the degree to which LAC alters the effectiveness of data assimilation, or, in other words, whether the size of the increments is different for both configurations.

Interaction with GABLS

The LoCo theme has clear interfaces with the GEWEX Atmospheric Boundary Layer Studies (GABLS) research theme. So far, it has executed a single-column and LES-model intercomparison for a stable boundary layer case study. An important conclusion from this intercomparison was an immense sensitivity of the development of the nocturnal boundary layer to the surface boundary condition (surface temperature). In many operational models frequent extreme nocturnal cooling is pragmatically avoided by enhancing the supply of heat by turbulent mixing, but the formulation of the land surface model (e.g. spatial resolution in the soil; calibration of heat exchange coefficients) may well be held responsible for this apparent deficiency (Steeneveld et al, 2004). For the near future, a further model intercomparison using actual field data is being developed in GABLS, where a specific 3-day episode during CASES has been identified as a suitable data set (Holtslag, priv.comm.). The primary goal of this intercomparison is to highlight the role of LAC in the development of stable boundary layers, eventually to come up with realistic solutions to the problem of unrealistic nocturnal temperature drift. The model intercomparison should include a suite of land surface modules coupled to single-column or LES-models.

Implementation of the LoCo-experiment

The GEWEX newsletter paper on the De Bilt workshop ended with an open call for interested parties to play a role in the experimental set-up. Similar to well-working teams like PILPS, GLACE, GSWP, ALMA and other internationally organized initiatives, a "LoCo" team should be established to draft an experimental design, call for participants and coordinate analysis and publication of results. Owing to the fairly complex nature of the problem and owing to the well-known limitations of available time and resources, a coordination panel and detailed experimental plan has not yet been established.

But alike the history of PILPS, GLACE, etc the LoCo-team and experiment should evolve from evidence of its significance. That is, a start should be made and the results from this first set of experiments should define the agenda for future developments. Drafting a complete experimental design in which all three stages are included in a mature way has been demonstrated to be too ambitious at the present state-of-the-art, so a more pragmatic approach is warranted. Let us start with throwing up a proposal for three studies (one for each phase), to be completed with new studies as time evolves and success is demonstrated.

Phase 1: LAC during CASES

A suitable candidate to start the implementation of the LoCo-experiment is the CASES case study adopted by GABLS. The three-day time period has been selected in order to comprise three different regimes of nocturnal boundary layers: one night dominated by turbulent exchange, one night with little turbulence and major radiative control, and one night with clearly observed intermittent turbulent behavior. However, the experiment should comprise the full diurnal cycle, to include an analysis of model behaviour during daytime as well. Being a Phase 1 study, no efforts should yet be spent to defining a

uniform model for the atmospheric column, but the GABLS LES simulations should be used as later boundary condition for the participating atmospheric column models.

Each participating model should be able to run in three modes: land surface only, atmosphere only, and coupled (very much alike the work by Ek and Holtslag, 2004, who elaborated the Cabauw site). In each mode, perturbations to external forcings or initial conditions that affect the surface energy fluxes (radiation, soil moisture and/or precipitation, soil temperature) are applied and the response to these perturbations is evaluated for each mode. Similar to the GLACE framework, a coupling parameter Ω must be defined that measures this response as function of the perturbation, and allows mutual intercomparison of model systems and/or modes of operation. The null-hypothesis is that Ω is similar for the coupled and uncoupled modes, implying that running in PILPS-mode gives the same fluxes as when coupled models would have been used. It should be explored whether definitions of Ω could be formulated that can also be extracted from the available observations, but probably a 3-day simulation period is too short to find clear response indicators like ∂evap/∂soilmoisture. This lack of observational guidance gives the experiment a synthetic flavour, but it may highlight important coupling properties of individual modeling systems.

In this stage, no direct merge with GABLS is yet foreseen; it is just anticipated to use the CASES observations and atmospheric boundary conditions that are also used in GABLS. The main task of the GLASS panel is to put together a team that prepares the experimental infrastructure and calls for participants.

The major disadvantages of the CASES dataset are that (a) the experiment was focused on nocturnal boundary layers and the availability and/or quality of (profile) data during daytime is not certain; (b) the period is very short in comparison to the PILPS experiments, where effects of ignoring coupling may well mainly affect parameters that are effective on much longer (seasonal) time scales, as outlined above, and (c) the site may be not too exciting in terms of hydrology or meteorology (probably no precipitation, little variability in daytime forcings).

Phase 2: LAC investigated with a common boundary layer model
The same experiment as described for phase 1 could be repeated with a land surface schemes coupled to a uniform atmospheric host model. In practice, this is very similar to the GABLS goal to eventually couple a suite of land surface models to a common LES, albeit that for our purpose the analysis should extend also to the daytime conditions. Again, it is the purpose of this study to assess whether Ω is sensitive to the mode of operation, but it allows to focus on land surface components that may be most sensitive to the effect of the coupling.

It is probably the most pragmatic to initiate this phase by joining the GABLS experiment. The main task of the GLASS panel is to search for partners in the land surface modeling community to participate in the GABLS case study, and probably to provide a co-PI for this particular experiment.

When successful, phases 1 and 2 should be succeeded by similar studies carried out over different sites, to span a wide range of climate regimes and land surface characteristics. Potential candidates are Cabauw, Boreas, LBA and probably others.

Phase 3: Analysis of soil moisture analyses
In the European ELDAS project, 3 different institutes operating different land surface schemes carried out a soil moisture data assimilation experiment over Europe during a single growing season. At ECMWF the system was set-up in a single column modeling framework, which enables a rapid and efficient examination of the results for a wide range of locations spread across Europe. Since in the very near future their land surface module will be coupled to the atmosphere in a way that is fully compliant with the ALMA interface standards, any surface scheme that uses this interface can effectively be coupled to the atmospheric model and be used in a similar data assimilation experiment. An outstanding problem of the ECMWF soil moisture assimilation problem is the fact that large non-systematic increments are applied during the summer season that unrealistically dampen the annual cycle of the soil water, also in ERA40. By exchanging land surface modules or components that affect the degree to which data assimilation increments are exchanged with the atmosphere, the origin of this problem could be tracked. The null-hypothesis is that changing the land surface parameterization will reduce the data assimilation increments to purely random corrections of small size to repair errors in precipitation and radiative boundary conditions. If this is not the case, the data assimilation increments compensate for systematic errors in the atmospheric response to surface fluxes, like an overactive boundary layer ventilation removing too much water from the air mass close to the surface, or misrepresentations of lateral or vertical transport of moisture in general.

An experiment like this is may be less suitable for execution in a large modeling community, owing to the relatively heavy infrastructural requirements. However, it is fairly likely that a limited number of participants can be found that are interested in joining the experiment to begin with. The way forward should be to continue the analysis work that is currently taking place for ELDAS with the ECMWF land surface scheme and probably one or two other schemes that could be coupled to the same, atmospheric model, and conclude from the findings of this work whether extension with more surface schemes is desirable. In the meanwhile, technical issues and issues related to code availability must be resolved prior to opening the experiment to the public.

Conclusion
While for the “Local Uncoupled”, “Global Uncoupled” and “Global Coupled” GLASS themes considerable progress has been reached, the “LoCo”-theme is waiting for initiatives to design and launch an experiment plan. This initiative should be both appealing to a wider community and modest in order to be achievable. The above mentioned ideas are supposed to trigger the discussion during the 2004 Kyoto GLASS-panel meeting, where new ideas or suggestions for implementation should be generated.

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