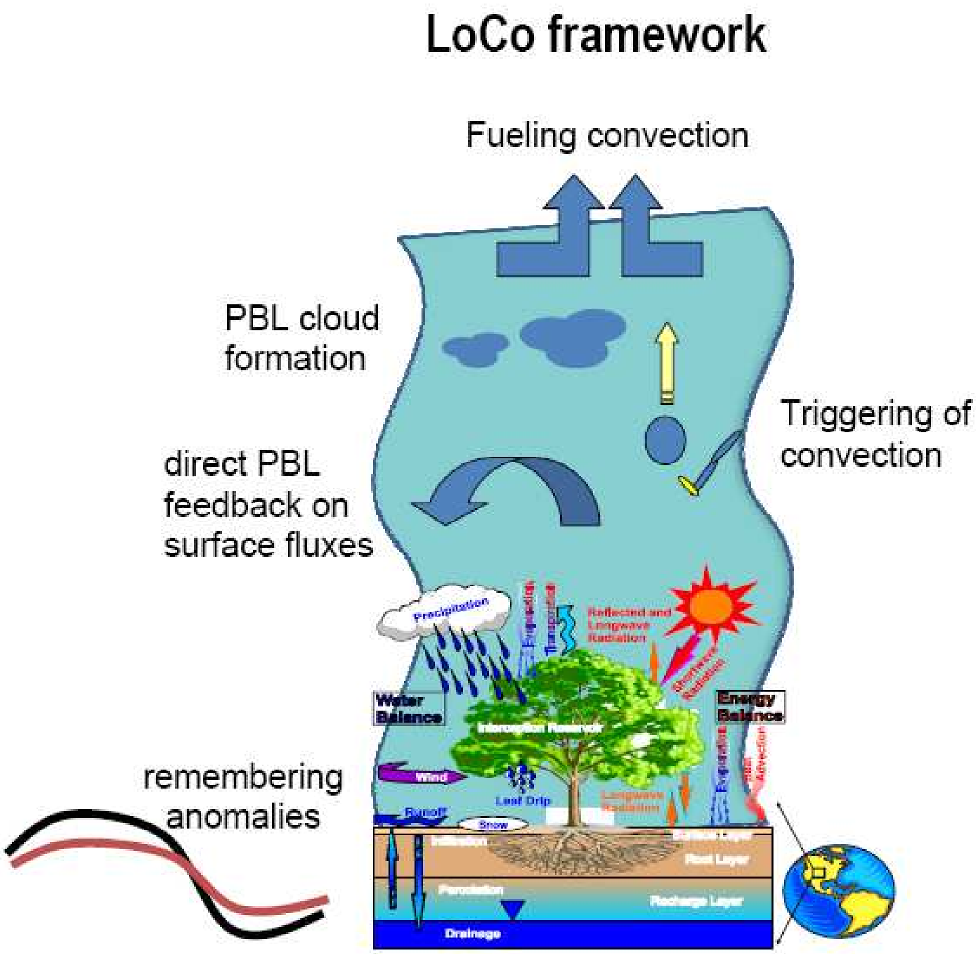
Technical Report No. 15

Methodology for atmospheric analysis and feedback correction



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Objective of this report

This report aims to define the analysis needed to quantify the atmospheric corrections required for off-line hydrological modelling. It is part of the WATCH WorkBlock 5, workpackages 5.1 and 5.2 and parts of 5.3.

Overview

The main objective of Workblock 5 is to provide a global and regional analysis of feedbacks between the land surface and climate system using a fusion of models and data. It is known that the land has an impact on the weather and climate. The rain that falls, the clouds that form above us, the wind patterns and the temperatures and humidity of the air around us, are to some extent affected by the roughness, the albedo and the wetness of the land below us. It is important to quantify this feedback loop, so that the forecast models and the climate prediction models can correctly predict the right meteorology.

Feedbacks between the land and the atmosphere are less important for the hydrological community, as it is assumed they are given the correct meteorology, either from observations or from meteorological models. The feedbacks are included in the information given to them. However, there is a case when this feedback loop may be important. If the hydrological model is attempting to understand the impact of a change in the land state, then the interaction with the atmosphere may need to be considered. For instance, if a Water Resource researcher wished to address the impact of doubling the extent of an irrigation scheme, they might need to include the impact that such an increase in wet soil might have on the clouds, rain, humidity and temperature of the region. If they ignore it, then the meteorological driving force of evaporative demand or the incoming precipitation may be wrong and lead to an inconsistent estimate of the impact that such an irrigation scheme might have on the region's water resources. This feedback will be quantified for WATCH. The method is outlined below.

For the purposes of the work being proposed here, it is important to define the scope carefully since the subject of 'land-atmosphere feedbacks' encompasses a huge area of concern: from carbon emission of wetlands to meteorological blocking highs causing seasonal droughts. So, the method defined here addresses the issue of land-atmosphere feedbacks as they relate to the necessary measures required by an off-line hydrological model to account for significant changes to their meteorological driving data as a result of the imposed changes to the land state. The change of land state could be irrigation (as outlined above) or a land-use change: from grass or trees to crops, or from one crop type to another e.g. a food crop to a fuel crop. In this study, we are only considering the water and energy implications of such a change. The issue of biogeochemical feedbacks will not be included here.

Ecosystem feedbacks.

In addition to the land-atmosphere feedback, WATCH also aims to quantify processes that are yet included in off-line hydrological models that may impact the region's water resources. Two examples are being studied: the impact of increased CO_2 on the water use efficiency of vegetation will be assessed, in relation to the impact it has on water resources (PIK and UKMO, 5.2.1). The other example is the impact that complex snow processes have on runoff production (CEH, 5.2.2). Both of these examples do not affect the driving data, so the result of these studies will be to advise the WATCH modelling community when and where these processes have to be included in order to correctly model the regions water resources.

Feedbacks from the land onto the driving data

There are two main changes to the driving data that could occur as a result of a change in the land state: the change in precipitation and the change in the evaporative demand. The former is a tricky thing to predict. For instance, often changes in cloud cover and air temperature and humidity are affected by forces outside the immediate area, or are changing due to local but complex processes such as mesoscale circulations, lateral but local meteorological dynamics or convective processes. The physics involved and the scale and complexity of the processes means that complex numerical atmospheric models are often necessary to quantify the process. A series of numerical model experiments are planned under WATCH WB5. These are outlined below. In addition, a simple, analytical model can be used to look at the triggering of convective precipitation. Use of such a model will be used to supplement the numerical model-based studies.

The impact on the evaporative demand, however, is sometimes amenable to a simpler solution: the way that the shallow cloud cover and the temperature and humidity near to the surface respond to the land surface over the course of a day can be quantified by studying the processes that affect the development of the Planetary Boundary Layer (PBL) over a day.

A method of combining the information from numerical experiments that have already been run, or that are being run in the WATCH WB5 programme, and a site-specific, analytical solution to the local, one-dimensional feedbacks (outlined below) is proposed in this study for a comprehensive analysis of feedbacks in the climate system and how they need to be included in hydrological models.

Feedback on rainfall.

From a Meteorologists point of view, feedbacks are a very important phenomenon. Rainfall, in particular, is a key result of a weather prediction model and anything that influences it will be well researched. Meteorologists have found that the best way to get an answer to the question of whether a particular change in the land state will produce a change in the precipitation is to use a Numerical Weather Prediction model: current examples used widely are Large Eddy Simulation models, a Regional Climate Model or a Global Climate Model – the choice of which would depend on the scale of the change being studied. For instance, LUCID is a new international research programme which will use several GCM models in an experiment designed to look at the impact of current land cover (as opposed to a land cover assuming no humans ever lived) on our current regional patterns of weather. WATCH will take part in this project and the results will be available to the WATCH community (CEH 5.3.3). The results will be used to assess how much of the modelled change in river flow is due to the change in evaporation characteristics, and how much due to the change in the driving data (precipitation and evaporative demand). In this way, WB5 will use the results from LUCID to identify where and by how much an off-line hydrological model would have to nudge their driving data if they wish to conduct a land-cover change experiment.

Another example is the GLACE experiment, reported in Koster et al (2004), which used several GCMs to identify the locations where a change in soil moisture alters the precipitation fields, when averaged over one season. The models agreed that the Southern Great Plains in the US and the Sahelian region in Africa and North India were all areas which showed a significant control of the rainfall from the soil moisture. The results from these model runs can be used explicitly to nudge the driving data for hydrological models (5.1, VUA & CEH). Data is being collated within WATCH WB5 to check these model results, which may shift the location of the feedback hotspot (VUA, 5.1). Result from these exercises in affirming the location and strength of the hotspots will be used in WATCH.

A PBL model which identifies the likelihood of convective precipitation being triggered, has been developed by Findell and Eltahir (2003a and 2003b). This model has been demonstrated (WUR 5.1) to work being initialised by profiles from ERA40. It can therefore be used to supplement the feedbacks hotspots map for WATCH.

Changing evaporative demand in response to land surface.
There are two important processes that interact with the moist-physics processes in the atmosphere to produce land-atmosphere feedbacks. One is the response of the evaporation to a change in soil moisture which is a non-linear, ‘threshold’ type function. It is the nature of this non-linear behaviour of the control of the soil moisture on the evaporation to have two ‘attractors’, the wet and the dry.

The other process that is important is the behaviour of the saturated humidity curve with temperature. In the Clasius-Clayperon curve, the saturated humidity increases exponentially with temperature. The consequence is that as a surface dries out and the air temperature rises, the evaporative demand increases non-linearly; not just as a result of the drier air but as a result of the warmer air. The next questions then are: how much? When? Where does this positive feedback come into play? Do we need a full 3-D GCM to calculate it? The answer is that sometimes a GCM will be necessary if the drying is at such a large scale that it alters the large-scale climate through changes in pressure and so on. But there are local changes that can be quantified without such an expensive tool.

Shuttleworth (2008) used the outputs from McNaughtan and Spriggs (1989) PBL model to quantify how the evaporative demand increases with decreasing soil moisture as the actual evaporation goes down. He demonstrated that the gradient of the demand increases faster than the gradient of the actual evaporation. This method will be used in WATCH as the first estimate of the PBL feedback on the land surface in terms of the evaporative demand (5.1, CEH). An effective Preistley Taylor coefficient can be calculated to increase the potential evaporation in arid zones.

The second estimate will be to use a PBL model (either analytical or numerical, Ek and Holtslag, 2004) which includes the processes of cloud formation. The model will be conditioned (initialised) by background profiles of temperature and humidity to diagnose changes in the driving data (air temperature, humidity and in coming radiation) caused by local influence of the land surface (5.1 CEH). For the 20th century, profiles will be taken from ERA40 (WUR, 5.1), and for the 21st century, they will be taken from the GCM output (WUR 5.1).

Overview

A combined GLASS-LoCo/WATCH workshop in July 2008 identified a series of diagnostics that could be used to quantify the strength of the land-atmosphere feedbacks (Hurk, vd and Blyth, 2008: See this link for presentations etc http://www.knmi.nl/~hurkvd/LoCo_workshop_2008.html). It is proposed that a series of global maps will be produced which show where the different mechanisms for the feedbacks are strongest; the soil moisture to evaporation link, the evaporation to air temperature and humidity link the link between the growth of the planetary boundary layer and the development of shallow clouds and the link between soil state and the possible triggering of convective storms. WATCH will contribute to this study using a combination of EO data from VUA and ERA40 analysis to identify where there are strong links between soil moisture and air temperature (CEH, 5.1).

These maps will be used in the WATCH WB5 to improve our driving data nudging scheme, in particular the location of where it is required. The series of nested analyses of the feedbacks strengths and methods to quantify the result, using output from numerical experiments and site-specific analytical models will allow WB5 to address the issue of the impact of land-change on the driving data for use by off-line hydrological models (VUA and CEH, 5.1).

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