Modelling land-atmosphere interactions: Impact of near future land use and climate change over Western Europe

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Summary

Climate models simulate interactions between different drivers of the climate. One of them is the land surface which has been documented to have a vast influence on the regional climate. However, this driver and its influence on the climate is usually not well represented by the current regional climate models. The objective of this doctoral thesis is to demonstrate the importance of modelling **interactions between the land surface and the atmosphere** in Western Europe. This is relevant to reduce the uncertainty of a climate change projection. This in its turn is relevant for policy makers to develop adaptation and mitigation strategies to protect humans and their environment for climate change.

In this doctoral thesis two models have been coupled and applied for validation and projection purposes. The model that represented the atmosphere component is **ALARO-0**. This model is initially used at the Royal Meteorological Institute of Belgium for providing the weather forecasts. Since recently, this model is also used for regional climate modelling. The model that represented the land surface component within this thesis is **SURFEXv5**. This model is a result of combining schemes for distinct land surfaces such as urban and natural. The coupling of both models has already been done for numerical weather prediction applications and has illustrated a good performance. A similar setup was applied in this thesis for regional climate modelling.

The purpose of this doctoral thesis was twofold. Firstly, we validated the regional climate model ALARO coupled to SURFEX for the simulation of land-atmosphere interactions by (i) testing the added value of SURFEX, (ii) testing different initial conditions, (iii) illustrating the performance of the model for water vapour, and (iv) investigating the urban scale. Secondly, we applied ALARO-SURFEX for climate change projections for the next few decades (i.e. near future) under scenarios of greenhouse gas emissions and land surface changes. A specific feature of SURFEX is the representation of the land surface as a patchwork of natural, impervious and water surfaces. This is called the tiling approach. This is beneficial for the simulation of processes that occur at a scale smaller than the grid size of the model. Especially in Western Europe the land surface is composed of large heterogeneities.

The first part of the thesis focused on the validation of ALARO-SURFEX. The input for the model at regional scale came from a reanalysis that assimilates observations at the global scale. The method for using the information at global scale to drive a regional climate model is called downscaling. More specifically, the method applied is dynamical downscaling as we preserve the physical laws of the model. We presented the **added value of using SURFEX** with respect to the initial setup of the atmosphere model with a simple representation of the land surface. Both minimum and maximum temperatures in summer showed an improvement when using SURFEX, while precipitation was not very sensitive to the choice of the land surface modelling. These results contributed to the hypothesis that the detailed land surface representation in SURFEX has improved the performance of ALARO-0.

Now that the coupled model ALARO-SURFEX showed a good performance for the climate of Western Europe, it was of interest to select the best method for performing the simulations. This method should be carefully chosen to use the full potential of the improved land surface representation and related land-atmosphere interactions. We studied this by updating the **initial conditions** of the model with different frequencies. This process was done during the downscaling. The common method of downscaling is one with the initialisation at the start of the simulation for both the atmosphere and the land surface conditions. We compared this method with two alternative methods: (i) the initialisation at each day for both the atmosphere and the land surface, and (ii) the initialisation at each day for the atmosphere, but only once at the start of the simulation for the land surface. The two alternative simulations demonstrated a better performance of the model for temperature and precipitation in comparison to observations than the common method. The last method allowed for a full interaction between the land surface and the atmosphere.

Climate change projections usually focus on the change in temperature and precipitation. However, the atmospheric **water vapour** plays a key role in the feedback process of a changing climate. Therefore, a good simulation of the water vapour by climate models is crucial. The water vapour was well represented by the model on a yearly and seasonal basis, except for summer when it was too dry. This could be explained by the cold temperature bias of the model that resulted in a too low evaporation rate in summer. This phenomenan was less dominant in the other seasons, as the coupling between the temperature and the water vapour is strongest in summer. These results confirmed that the model well represented the interaction between the land and the atmosphere.

The land surface of Western Europe is covered with large urban surfaces that show distinct characteristics than natural surfaces. Fortunately, SURFEX has been developed with the detailed scheme for the **urban scale**. Furthermore, SURFEX could be used separately at a high resolution of 1 km without the coupling to the atmosphere model. Only the atmospheric parameters were used as input to drive SURFEX at a high resolution. This state of the art simulation illustrated an enhancement of the Urban Heat Island (UHI) during heat waves for Brussels. Although 1 km horizontal resolution was too coarse in terms of the urban microscale features, it was able to correctly simulate the nocturnal UHI in the city of Ghent. We concluded that the urban scheme within SURFEX was able to realistically represent the climate on the urban scale of Belgian cities.

The second part of this doctoral thesis focused on the use of ALARO-SURFEX for climate change projections under two scenarios of greenhouse gas emissions and one scenario of land use changes. The scenarios for **greenhouse gas emissions** were developed during the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) and are called Representative Concentration Pathways (RCPs). The climate change for the near future is particularly interesting for decision makers. Therefore, we investigated the changes in the mean temperature and precipitation and their extremes in the 30-yr period of 2006 to 2035 with respect to the 30-yr period of 1976 to 2005. Both temperature and precipitation were simulated to increase in the near future, though the changes were relatively small. In contrast to the mean change, the daily variability increased larger. This resulted in more extreme events such as heat waves and extreme precipitation events.

Although greenhouse gas emissions play an important role, there are other human sources for climate change. One of them is **changes to the land surface**. To study this we selected a scenario for the changes in land surface for the near future based on policy-related land use changes. The land conversions that received particular interest are already taking place in reality and will likely to continue in the future. The urbanisation effect was largest of the three selected land surface conversions in the present climate. Mainly minimum temperature was enhanced and extreme temperature because of an increase in impervious surfaces that resulted in a larger sensible heat flux. In the near future, the effect of the land surface changes on the near-surface parameters were more heterogeneous than the effect of the changes in greenhouse gas emissions. The urbanisation in Flanders was simulated to lead to a doubling of the temperature effect caused by greenhouse gas emissions. Moreover, heat waves were longer lasting and more intense because of the urbanisation in Flanders. On the other hand, afforestation helped to reduce the maximum temperatures.

We concluded that the ALARO-SURFEX model was able to **improve the regional climate** of Western Europe due to a more detailed representation of the land surface and its related interactions with the atmosphere. The model was also **applicable for projections** of the **near future** climate changes of both temperature and precipitation. Furthermore, SURFEX was reliable for representing the **urban characteristics** of Belgian cities. This gives the model great potential for providing relevant information that can be used as forcing for **impact studies** on for example heat stress in cities.