Soil moisture–precipitation feedback experiments over the Netherlands with AROME

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Abstract

This report is a contribution to the Knowledge for Climate Research Programme (KvK) under Theme 6. We have applied the climate version, HCLIM, of the meso-scale modelling system HARMONIE to study soil moisture–precipitation feedback mechanisms over the Netherlands. The studied time period, May 10–15 1999, represents a consecutive number of days with afternoon rain showers. By perturbing the soil moisture in a number of model experiments we have related changes in simulated precipitation to changes in simulated evapotranspiration. The resulting evaporation to precipitation ratio is comparable to another study for the same region but it is also shown that the results are sensitive for the size and location of the chosen area.

1 Introduction

By far the most popular variables requested from climate model simulations are precipitation and near-surface air temperature. More emphasis is nowadays towards the extremes of these variables and not only on their mean value characteristics. Thus, the challenge for the climate modelling community is to keep on quantifying the uncertainty in climate scenarios in general while at the same time quantifying the contribution of small-scaled extreme events. The general uncertainty is tackled by the use of multi-model ensembles. To statistically cover the uncertainty range, a large amount of simulations is required which means that climate models cannot be too expensive (too high in resolution). Given today's computer resources, most climate models are therefore not suitable to quantify extreme event characteristics, especially not for precipitation, since they operate on scales usually larger than 10 km. Explicit simulation of extreme precipitation events requires yet an order of magnitude higher resolution.

The Numerical Weather Prediction (NWP) community, running limited area models, does apply models on the kilometer scale today. One such community is HIRLAM in which KNMI and SMHI are members. HIRLAM applies the meso-scale modelling system HARMONIE which represents a suite of physical parametrization packages that are developed to be applicable to different resolutions. For this study we make use of two HARMONIE packages, the ALARO package for boundary conditions and the AROME package for the actual simulations.

Under Theme 6, project 1, in the Knowledge for Climate Research Programme (KvK), we look into how the HARMONIE system can be used to study relevant processes over the Netherlands. For these studies we apply HARMONIE as a climate model meaning that no data assimilation is applied. As we are not dependent on data assimilation we have more freedom to activate physical processes that we find relevant for the study. But, it also means that we apply the HARMONIE system beyond normal NWP applications and therefore some efforts have been needed to modify and develop the HARMONIE system, e.g. related to updates of sea-surface temperature and physiographic information and related to not so well tested physics options. This climate version of HARMONIE is from here on called HCLIM.

In this specific study we do not really apply HCLIM in a classical multi-year climate mode since we concentrate on a very limited period of time, namely half a month. However, we do apply the climate version of HARMONIE which illustrates that the model system has reached a stage where it can be used for climate applications. Thus, the developments made benefit partners within HIRLAM, and outside, who want to apply HARMONIE for climate studies.

This case study has been inspired by work performed in the Netherlands by co-author Emma Daniels and by Hohenegger et al. (2009) on soil moisture–precipitation feedback. By changing the soil moisture conditions in a coupled land–atmosphere 3D model system we investigate the sensitivity in corresponding precipitation generation. Hohenegger et al. (2009) relate this sensitivity partly to model resolution over the European Alpine region, or more specifically to resolved or parameterised convection. They describe a number of triggering mechanisms where the resulting convection activity depends on positive or

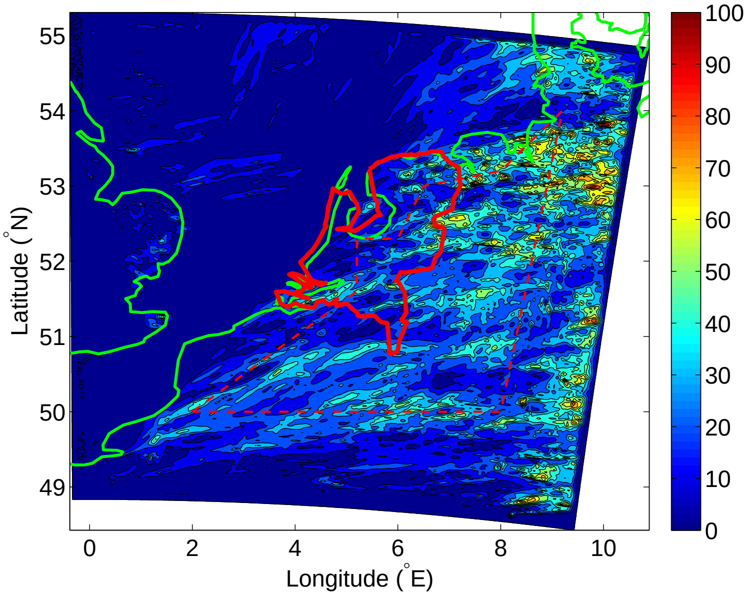

Figure 1: The model domain with accumulated precipitation (mm) over the period May 10 00Z – May 16 00Z. A rough coast line is indicated by green line and the Netherlands country border used for area averaging by red line.

negative soil moisture–precipitation feedbacks. They conclude that the feedback sign depends on if the convection is resolved or not but the results are also sensitive to how the convection is parameterised in the non-resolved case. We study a resolved convection case where the horizontal resolution is 2.5 km. The chosen period and region, May 10-15, 1999, over the Netherlands, has been investigated by Emma Daniels by applying the meso-scale model WRF (Weather Research and Forecasting). She has shown that this period is characterised by direct soil moisture–precipitation feedback where a combination of synoptic forcing and direct recycling of soil moisture contribute to the precipitation generation.

2 Method

2.1 Model setup

Simulations have been performed using the non-hydrostatic NWP and climate modelling system HARMONIE (version 37h1.2) with additional climate modifications, i.e. HCLIM. Depending on resolution and purpose HCLIM can be setup using different model components. In this study we run HCLIM with AROME atmospheric physics (Seity et al., 2011; Bubnová et al., 1995) at 2.5 km resolution for a 300x300 grid centred over the Netherlands (Figure 1). Boundary conditions at 12 km resolution were downscaled from ERA-Interim using HCLIM with ALARO atmospheric physics (Gerard et al., 2009; Gerard, 2007; Piriou et al., 2007).

The surface physics in both model setups is based on SURFEX (Masson et al., 2013). The

Table 1: List of simulations. One control simulation and four with perturbed soil moisture.

Acronym	Description
CTL	Control simulation.
DRY	Soil moisture decreased by 30% at 00Z May 10.
WET	Soil moisture increased by 30% at 00Z May 10.
WLT	Soil moisture kept constant at wilting point (θ_{wp}).
FCP	Soil moisture kept constant at field capacity (θ_{fc}).

SURFEX version used is 6.0 and namelist settings for SURFEX includes soil diffusion scheme with seven soil layers and one patch for nature.

2.2 Experiment

In total five simulations have been performed (Table 1). All simulations start at 00Z May 1, 1999, and last until 00Z May 16, 1999. The first part of these simulations will be treated as spinup period and we will concentrate the analysis on the later period May 10 00Z – May 16 00Z which is forced synoptically by a depression north of the Netherlands and is characterised as a convection dominated weather situation with afternoon rain showers.

Initial conditions for prognostic variables are from the same ALARO simulation as used for boundary conditions. In the control simulation the soil moisture, θ, evolve freely during the whole simulation while for all other simulations the soil moisture has been perturbed. For the DRY and WET simulations the soil moisture (PWG in in isba.F90) was modified by -30% and +30%, respectively, at 00Z May 10 for all grid points and for all soil layers. For the WLT and FCP simulations the soil moisture was forced to wilting point and field capacity, respectively, at the end of each time step. All output data is written with six hours interval.

3 Results

All results represent the time period May 10 00Z – May 16 00Z. Figure 2 shows the time evolution of the Soil Water Index, defined as

$$SWI = \frac{\theta - \theta_{wp}}{\theta_{fc} - \theta_{wp}}. \qquad (1)$$

In ISBA, θ can exceed θ_{fc} (i.e. $SWI > 1$) and fall below θ_{wp} (i.e. $SWI < 0$). As expected, an initially dry soil shows more variability in SWI with time during a rainy period than a soil that initially is already medium wet or really wet. The reason is that a larger fraction of any water that infiltrates into a wet soil will go to runoff and a smaller fraction will increase the soil moisture while for a dry soil the opposite occurs. Note that the WLT and

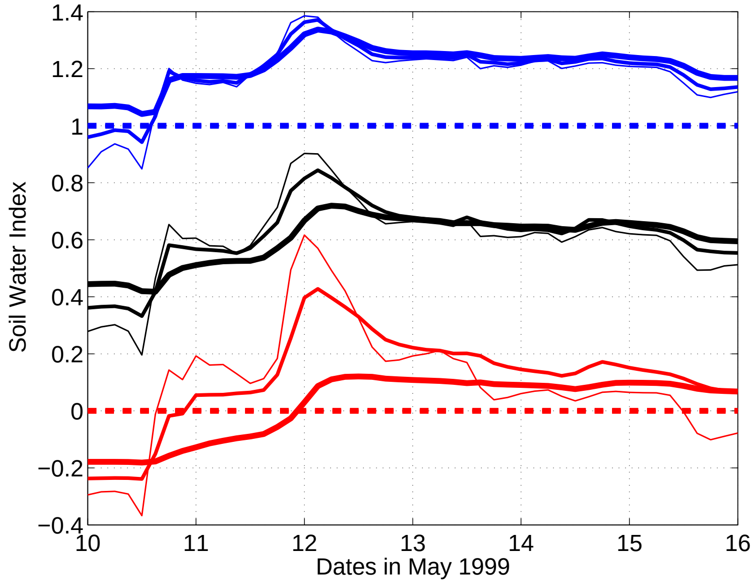

Figure 2: Soil Water Index for soil levels with mid depth at 1.5 cm (thin line), 13.5 cm (medium) and 46.5 cm (thick) averaged over the Netherlands in Figure 1 for CTL (black), DRY (solid red), WET (solid blue), WLT (dashed red) and FCP (dashed blue).

FCP simulations have wilting point and field capacity values prescribed for all individual layers.

The simulated precipitation, along with daily observed precipitation, is shown in Figure 3. In general AROME overestimates the precipitation for the period as a whole, although the main part of this overestimation is due to excess rainfall during May 11. May 10 and 14 on the other hand show very good agreement with observations. In a comparison with Figure 1 it becomes obvious that a more wet soil gives more precipitation. Thus, this period and region is characterised by a positive feedback between soil moisture and precipitation. Note also that the increase in accumulated precipitation from DRY to CTL simulations is larger than the increase from CTL to WET simulations although the corresponding increases in soil moisture at the end of the period are roughly the same. Results by Hohenegger et al. (2009) over the Alpine region based on simulations with similar model resolution gave a negative feedback between soil moisture and precipitation. However, their weather situation was characterised by a weaker synoptic-scale forcing where the convective activity was due to strong surface heating.

A thorough analysis of the soil moisture–precipitation feedback mechanisms would require a water budget analysis where all components of the water cycle can be examined. However, the present AROME setup does not allow such an analysis since only a limited number of water budget variables are available. For the same reason, Emma Daniels in her study used an alternative method where changes in precipitation between the different simulations are related to corresponding changes in evapotranspiration. The accumulated evapotranspiration is shown in Figure 4. As for precipitation, but here even more pronounced, the change from DRY to CTL is larger than the change from CTL to WET.

In Figure 5 the differences in precipitation and evapotranspiration with respect to the

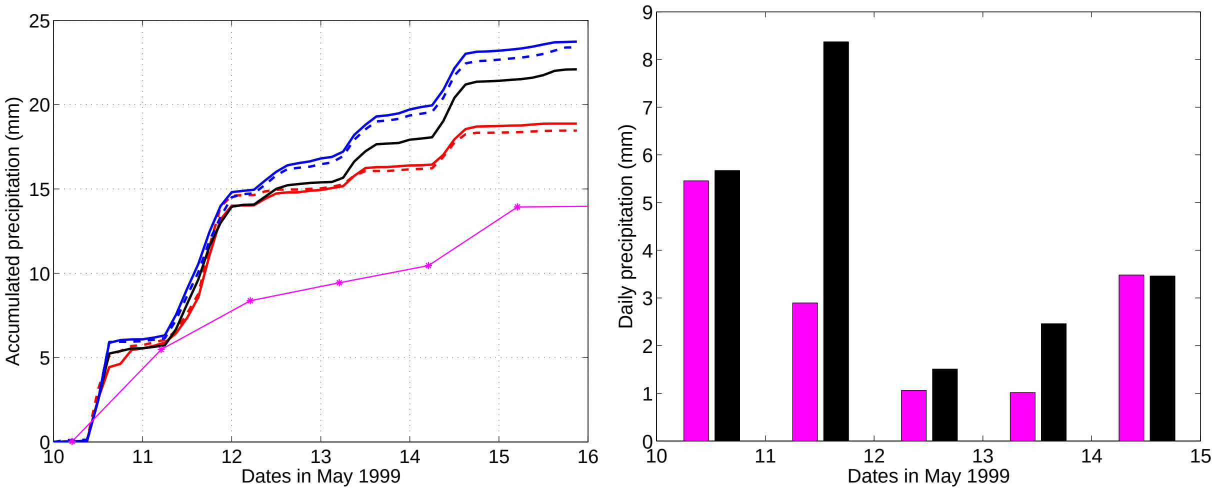

Figure 3: On the left accumulated simulated precipitation averaged over the Netherlands in Figure 1 for CTL (black), DRY (solid red), WET (solid blue), WLT (dashed red) and FCP (dashed blue). Accumulated observed daily precipitation (magenta). On the right daily CTL simulated precipitation (black) and corresponding observed precipitation (magenta) for hour interval 08Z-08Z.

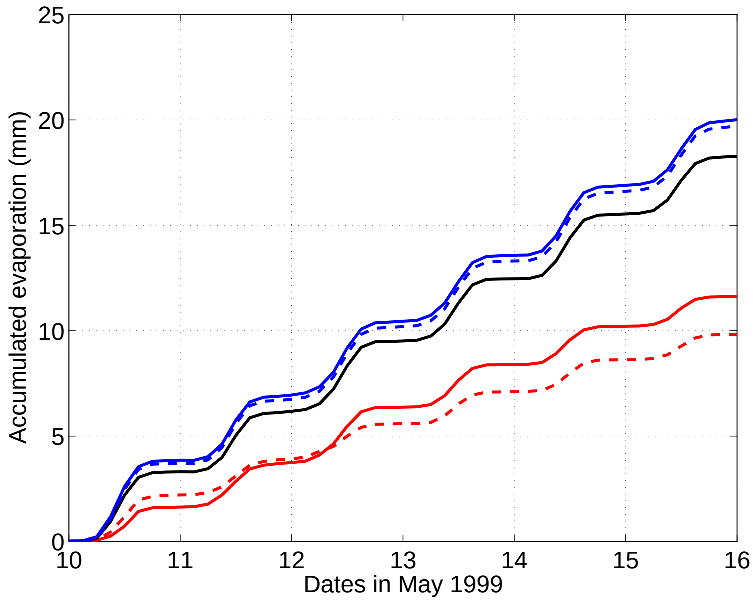

Figure 4: Accumulated evapotranspiration averaged over the Netherlands in Figure 1 for CTL (black), DRY (solid red), WET (solid blue), WLT (dashed red) and FCP (dashed blue).

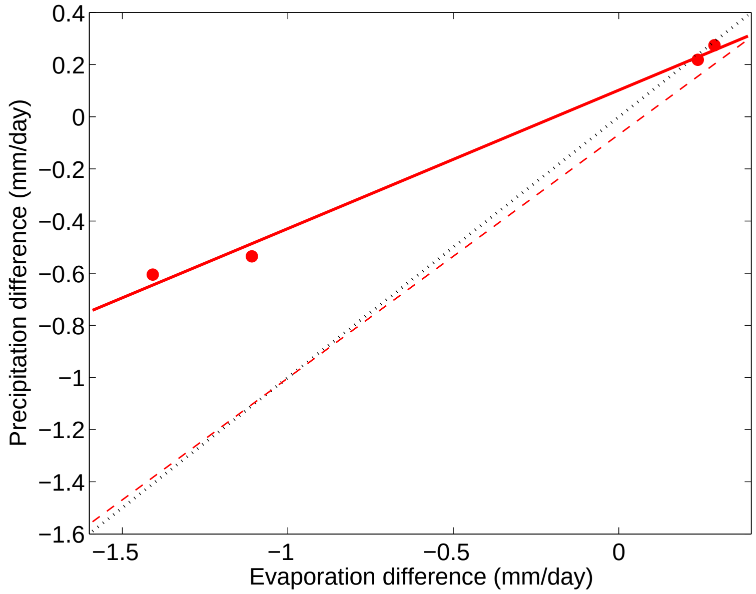

Figure 5: Red dots represent difference in precipitation versus difference in evapotranspiration between the perturbed simulations and the control simulation. Dotted line represents 100% and red solid line 53% ratio of evaporation to precipitation, respectively. The dashed red line corresponds to the red-dashed region in Figure 1 and an evaporation to precipitation ratio of 93%.

CTL simulation at the end of accumulated period are presented. A liner relationship between these differences appears where the slope of the linear regression represents the evaporation to precipitation ratio. The ratio over the area of the Netherlands becomes 53%. In the study by Emma Daniels et al., focusing on May 10–14, they reached a bit higher ratio of 67%. However, the ratio is very sensitive to the averaging area. A larger area, denoted by the red dashed line in Figure 1, gives an evaporation to precipitation ratio of 93% and other averaging areas tested, but not shown, give values also outside the range of values presented here, even $>$ 100%. Thus, as already indicated and now emphasized by these results, one has to look into the individual moisture budget components related to e.g. local and advective water vapor sources, respectively, to achieve a more correct picture of soil moisture–evapotranspiration–precipitation feedback mechanisms.

4 Remarks

This study has illustrated the how the climate version of HARMONIE, HCLIM, can be used as a tool to investigate and understand regional climate processes and feedback mechanisms. HCLIM represents a new generation of regional climate models with respect to resolution and physics since it can be applied on scales for which convection can be resolved. This is a very important, especially for studies related to extreme precipitation, since the quite large uncertainty represented by the parameterisation of convection in more coarse resolution setups is reduced. HARMONIE, including the atmospheric physics packages AROME and ALARO in combination with the surface physics package

SURFEX, is now used as official NWP model system in many European countries. Given its climate option, HCLIM, HARMONIE represents a powerful tool for high resolution NWP and climate studies over Europe and elsewhere.

Acknowledgments

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References

Bubnová, R., Hello, G., Bénard, P., Geleyn, J.-F., 1995. Integration of the fully elastic equations cast in the hydrostatic pressure terrain-following coordinate in the framework of the ARPEGE/Aladin NWP system. Monthly Weather Review 123, 515–535.

Gerard, L., 2007. An integrated package for subgrid convection, clouds and precipitation compatible with meso-gamma scales. Quarterly Journal of the Royal Meteorological Society 730, 711–730.

Gerard, L., Piriou, J.-M., Brožková, R., Geleyn, J.-F., Banciu, D., 2009. Cloud and precipitation parameterization in a meso-gamma-scale operational weather prediction model. Monthly Weather Review 137, 3960–3977, doi: 10.1175/2009MWR2750.1.

Hohenegger, C., Brockhaus, P., Bretherton, C. S., Schär, C., 2009. The soil moisture–precipitation feedback in simulations with explicit and parameterized convection. J. Climate 22, 5003–5020, doi: 10.1175/2009JCLI2604.1.

Masson, V., et al., 2013. The SURFEXv7.2 land and ocean surface platform for coupled or offline simulation of earth surface variables and fluxes. Geosci. Model Dev. 6, 929–960, doi: 10.5194/gmd-6-929-2013.

Piriou, J.-M., Redelsperger, J.-L., Geleyn, J.-F., Lafore, J.-P., Guichard, F., 2007. An approach for convective parameterization with memory: Separating microphysics and transport in grid-scale equations. J Atm. Sci. 64, 4127–4139, doi: 10.1175/2007JAS2144.1.

Seity, Y., Brousseau, P., Malardel, S., Hello, G., Bénard, P., Bouttier, F., Lac, C., Masson, V., 2011. The AROME-France convective-scale operational model. Monthly Weather Review 139, 976–991, doi: 10.1175/2010MWR3425.1.