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The relative importance of topography and land use on the Veluwe rainfall maximum in The Netherlands

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A majority of studies on feedbacks between land use/land cover change and climate focuses on the influence and/or impact of a land cover change on precipitation under various atmospheric conditions in different regions of the world. The basic mechanism behind changes in land use and its meteorological impacts is that a land cover or land use change modifies the surface roughness, the radiation balance and the subsequent partitioning of available energy over sensible and latent heat fluxes. Their relative importance may vary spatially and in time depending on the synoptic meteorological situation. Differences in the heat, moisture and momentum fluxes at the land surface interface lead to altered heat and moisture content of the atmospheric boundary layer (ABL). Changes in temperature and humidity in the ABL affect convective heating, total diabatic heating, subsidence and moisture convergence. The feedbacks between changes in land use and topography and their impacts on the regional scale will directly affect processes which drive and change mesoscale circulations.

Results from the EU funded EURuralis project shows that a change in land use is foreseen for the western part of mainland Europe as Eastern European countries are admitted to the EU market. It is expected that in the coming decades, besides an increase in urban areas, agricultural lands will be abandoned and replaced by forests. This land use change may have major impacts on the discharge regime of the main rivers adding to the first order consequences of global warming. In this study we will study feedbacks between the land surface and the atmosphere for an area in the central part of The Netherlands (Veluwe) to assess the possible effects on precipitation and evaporation of land use change in the Rhine river basin and the feedbacks involved.

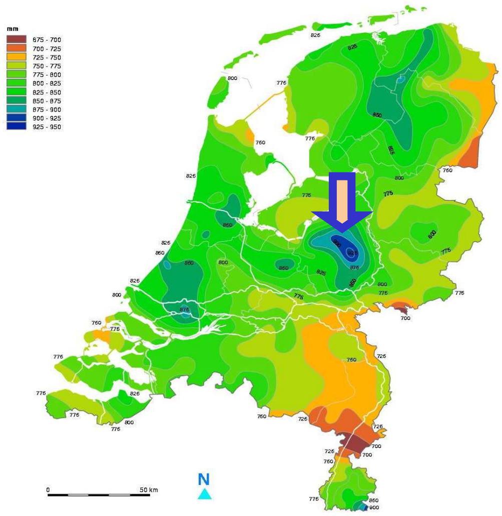

Figure 1: Yearly precipitation sum (mm) as a climatological mean (1971-2000). The arrow points to the Veluwe.

The Veluwe is a densely forested and elevated area of approximately 625 km2 with a maximum altitude of just over 100 meter in an otherwise flat surrounding. The area is covered with glacial deposits, but in the early 20th century it was decided that the area would be afforested to reduce wind erosion that was threatening the surrounding agricultural area. The Veluwe exhibits an average yearly precipitation sum which is 75-100 mm higher than the rest of the country, a difference of around 20 % per year (see figure 1, (Heijboer and Nellestijn 2002)). The distribution of rainfall throughout the year is reasonably uniform with an average monthly precipitation sum at the Veluwe of almost 70 mm. This precipitation maximum is thought to be orographic (topography) but could also be induced by the forest covering the area. To investigate the exact reason behind the precipitation maximum of the Veluwe we want to answer the following main question: What is the relative contribution of topography and of land cover to regional precipitation?

To analyse this the RAMS model (Regional Atmospheric Modelling System, (Pielke et al. 1992); (Cotton et al. 2003)) has been implemented for The Netherlands. The scenarios used in this study are highly idealized but are designed in such a way that the possible reasons behind the precipitation maximum will be unravelled. As we use scenarios which did not occur in past times, it is not possible to validate the outcomes of the scenario simulations of the model. However, the model will be validated using actual vegetation and topography in a control simulation.

To validate the results of the control simulation, surface observations from various Dutch observational stations are used. At these sites standard meteorological parameters are measured together with observations of exchange fluxes of radiation, heat, moisture and momentum. The main variable of interest in this extended abstract is: precipitation (mm).

Besides the aforementioned control simulation, the following scenarios are analyzed (Figure 2 + table 1):

- **NoForest (NF):** The dominant forest type (coniferous forest, dark green) has been replaced by grassland (light green) in a rectangular box around the Veluwe (upper panel in figure 2). This change leads to a change in aerodynamic roughness (z0) from 0.9 meter to 0.02 meter and a change in albedo from 0.10 to 0.20 [-]
- **NoTopo (NT):** The topography of the Veluwe has been brought back to sea level in a rectangular box around the Veluwe (lower panel in figure 2) reducing the maximum difference in topography from 100 meters to 1 meter
- **No Topo/No Forest (NTF):** Combination of the scenarios NoForest and NoTopo

Table 1: Configuration of the simulations. Land use and topography scenarios relate to the right hand figures of figure 1

Simulation	Land use	Topography
CTRL	Actual	Actual
NF	NoForest	Actual
NT	Actual	NoTopo
NTF	NoForest	NoTopo

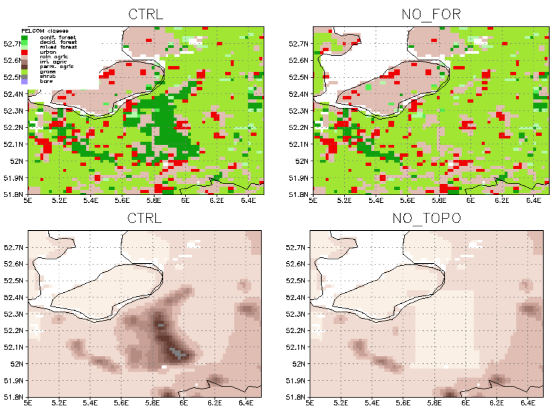

Figure 2: Graphical representation of the various scenarios used in the simulations. Top left: actual land use (CTRL); Bottom left: actual topography; top right: land use in the NF-and NTF-scenario; bottom right: topography in the NT- and NTF-scenario

All simulations (CTRL, NF, NT and NTF) are executed for the same time periods. These periods cover varying large scale atmospheric dynamics that are representative synoptic conditions of summer and winter months, with convective conditions prevailing under warm conditions. Winter precipitation is mostly part of a low pressure system with accompanying frontal precipitation under westerly conditions. The validation of the model looking at the precipitation in the winter simulation shows that the precipitation is simulated well (figure 3). The simulated precipitation expressed as the averaged accumulated sum, 105 mm, is close to the observed value of 110 mm. The observed temporal pattern is also closely resembled by the model. The observed peaks in daily precipitation are mostly captured by the model, except for 5 February (overestimation of 6.5 mm) and 25 February (underestimation of almost 9 mm). We conclude that these differences between model and observations are a direct result of the model displacing predicted areas of intensive precipitation rates by 20-30 km compared to the observations. In the summer simulation RAMS overestimates the rainfall by almost a factor 2.5 (simulated: 145 mm, observed: 60 mm). This difference is mainly due to the fact that the model overestimates rainfall rates at the end of the simulation when a persistent weather system is located above The Netherlands.

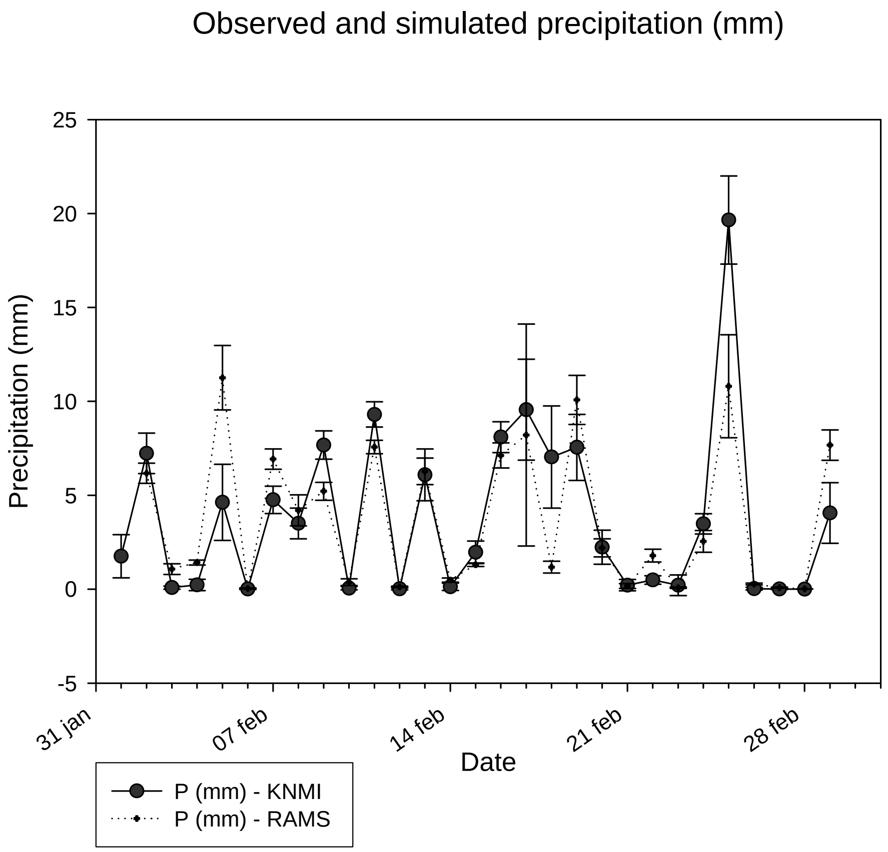

Figure 3: Time series of precipitation (mm) and accompanying error bars for WIN-CTRL (top) and SUM-CTRL (bottom). Solid line: observations KNMI; dotted line: RAMS

All simulations, tabulated before, use the same meteorological initial and boundary conditions. The analyses presented here will focus on the differences in simulated precipitation. Figure 4 shows the difference in accumulated precipitation between the scenarios and the control simulation. This figure shows that the change in precipitation in both NT-simulations is located close to the area where the topography has changed. The signal doesn't change too much between winter and summer simulation. In the NF-simulations the signal in change of precipitation is more diffuse. Due to the change in roughness length above the 'deforested' area a change in flow is observed. This change is apparent in the winter simulation where a band of heavy precipitation seems to be displaced to a more southerly position. This strong band of precipitation is part of a synoptic event which passes The Netherlands in the last week of the winter simulation.

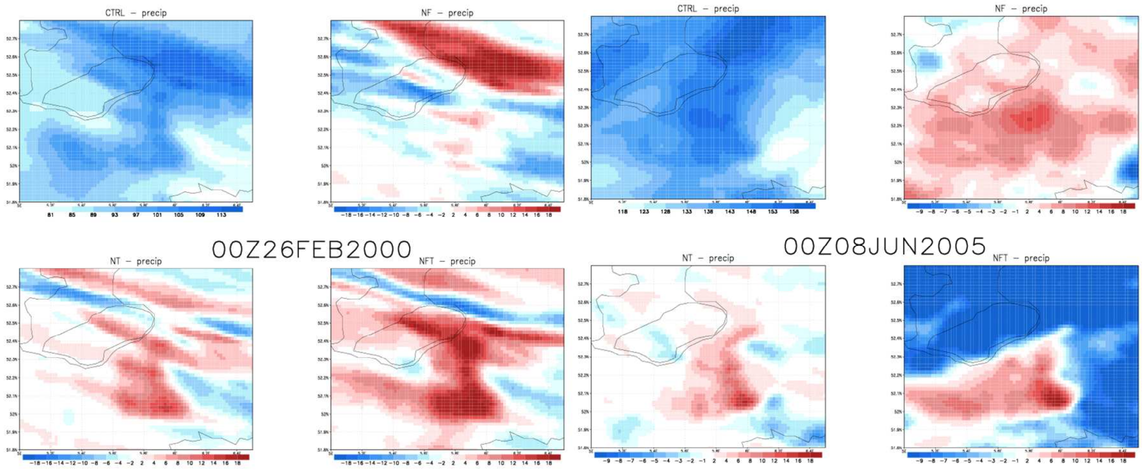

Figure 4: Left panel – results from the winter simulation, Right panel – results from the summer simulation. For both graphs: Top left graph: simulated cumulative precipitation (mm) at the end of the simulation; top right: difference between simulated precipitation between CTRL and NF (P_{CTRL}-P_{NF}); bottom left: difference between simulated precipitation between CTRL and NT (P_{CTRL}-P_{NT}); bottom right: difference between simulated precipitation between CTRL and NFT (P_{CTRL}-P_{NTF})

From the results we can conclude that the precipitation maximum observed at the Veluwe is not only orographically, but that the contribution of the forest to is not negligible and is of the same order of magnitude.

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