

**PROJECTS**

**CS02:** The CESAR

Observatory: climate monitoring and process studies

**CS03:** Representation of soil moisture and root water uptake in climate models

**CS04:** The regional climate impact of aerosols

**CS05:** Remote influences on European climate

**CS06:** Refinement and application of a regional atmospheric model for climate scenario calculations for Europe

**CS07:** Tailoring climate information for impact assessment

# Update on the KNMI Regional Climate Model RACMO

Regional Climate Models (RCM) are increasingly used for downscaling global climate model projections to refine spatial and temporal resolutions. The challenge is to develop modules that improve the representation of small-scale features in the Regional Climate Models.



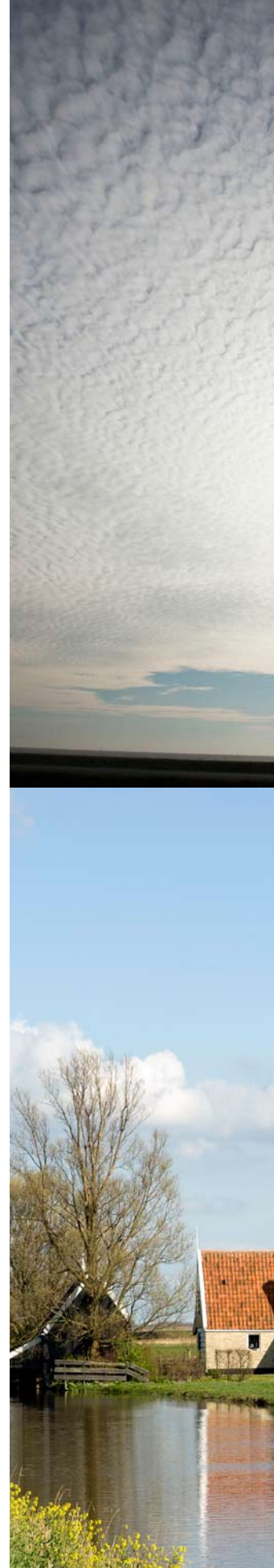
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**L**ARGE SCALE ATMOSPHERIC FEATURES such as weather systems or long-lasting episodes of excessive precipitation or drought are typically inherited from the lateral boundary conditions and reproduced fairly well by adequately configured RCMs. It is information on small-scale features such as intense precipitation events, gradients across coastlines and mountains, or conditions where the surface is strongly decoupled from the overlying atmosphere, where RCMs can add skill to the coarse scale climate projection<sup>[1]</sup>.

The modeling group at the Dutch KNMI institute has devoted more than a decade of research to building the Regional Atmospheric Climate Model (RACMO). This model is performing very well in European projects (PRUDENCE, ENSEMBLES), where RCMs are confronted with a range of observations<sup>[2]</sup>. It reproduces summertime precipitation and temperature variability very well and captures the main climatic gradients. There are, however, several areas that need improvement.

A systematic warm bias in high latitude winters persists, as well as a wet winter bias in mid-latitudes<sup>[3]</sup>, among other structural shortcomings. In addition, many improvements to components of the model have only been guided by empirical evidence, such as the deepening of the soil layer to mitigate a summer warm and dry bias<sup>[4]</sup>. Finally, some processes, which have a clear and important impact on the regional climate, such as direct and indirect effects of temporally variable aerosols, are lacking in the model.

Ongoing research activities continuously lead to further improvements of the model. This paper highlights a few developments that may lead to significant changes in future projections applied with the RACMO model. They cover the areas of coastal precipitation effects, land surface hydrology, turbulent mixing and aerosols.

### Coastal precipitation effects in summer and autumn

The temperature of the North Sea has a significant impact on the spatial distribution of precipitation in the Netherlands. During July 2006 the temperature in large parts of North-West Europe was more than 3K warmer than normal, and it was excessively dry in the Netherlands and surroundings. During August 2006 the atmospheric circulation changed and transported large amounts of moist air from the North Sea into the country, and record breaking precipitation events occurred in the coastal zone of the Netherlands. Partially in

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the context of climate change projections, it was found that in late summer and autumn the coastal precipitation increases at a rate of 14 % per degree temperature rise of the North Sea when cold and unstable air is transported from the North Sea. The temperature increase of the North Sea appears to exceed the global mean temperature rise during the past decades. This is associated to the observed increase in coastal precipitation relative to the main land area. High resolution RACMO simulations carried out for this 2006 episode<sup>[5]</sup> confirm the correlation between sea surface temperature and coastal precipitation (see figure 1). Coarse resolution simulations with low resolution sea surface temperatures (left panel) are unable to generate the strong precipitation gradient across the coastal area. The high resolution version of RACMO, however, shows a good simulation with realistic sea surface temperatures (right panel). Increased resolution, and inclusion of realistic sea surface temperature calculations are components of a future version of RACMO, which will lead to a better representation of important spatial features.

#### Land surface hydrology

In an earlier version of RACMO, used for early European climate integrations, a typical problem emerged: during summertime, continental areas in Eastern and Southeastern Europe showed a strong warm and dry bias, caused by a rapid depletion of the soil water reservoir and positive feedbacks reinforcing this dry-down. The cause of this bias is probably a mixture of coarse resolution, errors in the representation of land surface and precipitation processes, and a soil water reservoir that is too shallow. This latter feature was corrected for by extending the soil depth arbitrarily, indeed leading to a better summer climate over continental Europe<sup>[6]</sup>. However, the procedure followed was not very satisfying, as no clear physical evidence was given to support the increase in soil depth.

In a later evaluation study, Wipfler et al<sup>[7]</sup> used a mix of satellite observations and model versions to identify an optimal and realistic configuration of the soil-root system. Straight incorporation of soil depth data from an external source (FAO) did not lead to an improved model performance, as this soil depth data generally showed shallower root zones than already present in RACMO, thus reinforcing the bias problem. Apparently additional processes are in place that constrain the hydrological cycle in that area.



### Example: Evaporation in the Danube Region

Comparison with remotely sensed evaporation data covering a major part of the Hungarian Danube region revealed an interesting feature (figure 2): large areas are shown where the annual evaporation exceeds the annual precipitation amount, pointing at non-local sources of water. These areas include major irrigation fields bordering the Danube river, and the large Lake Balaton, both not represented well in the RACMO model. Inclusion of these processes in future versions of RACMO are underway, and will probably lead to improved representation of continental scale hydrological processes.

### Turbulent mixing

Near surface temperatures are highly controlled by turbulent mixing of air in the lowest atmospheric layers. Turbulent mixing, in turn, is very efficient when the air is heated from below, such as during summer days with fair weather conditions. But for cases where the surface is cooler than the atmosphere, such as nighttime or (high latitude) winter conditions, turbulence is very inefficient and strong vertical temperature gradients can occur. It is under these conditions that large systematic (positive) biases occur in the modeled temperature in many model configurations, including the older versions of RACMO. To complicate the picture further, mixing also occurs under conditions of small-scale organized convection: parcels heated from below (or cooled from above) tend to rise (or sink) in organized cells, leading to for instance scattered clouds in areas with rising air and clear skies in the areas with descending air in between. In many models including RACMO the effect of small-scale organized convection is represented in a separate module using a so-called mass-flux approach.

### DualM-TKE formulation

A suite of alternative formulations in the representation of mixing have been examined using the RACMO model. The optimal configuration is attained with the so-called “dualM-TKE” formulation (see figure 3). In this representation mixing by turbulence and mixing by organized convection are integrated into a single module rather than treated separately. The integration of turbulence and convection and the inclusion of an equation for the Turbulent Kinetic Energy (TKE) enhances the synergy and robustness of the model formulation. The new module leads to a significant improvement of temperature under conditions which are typically difficult to represent: nocturnal

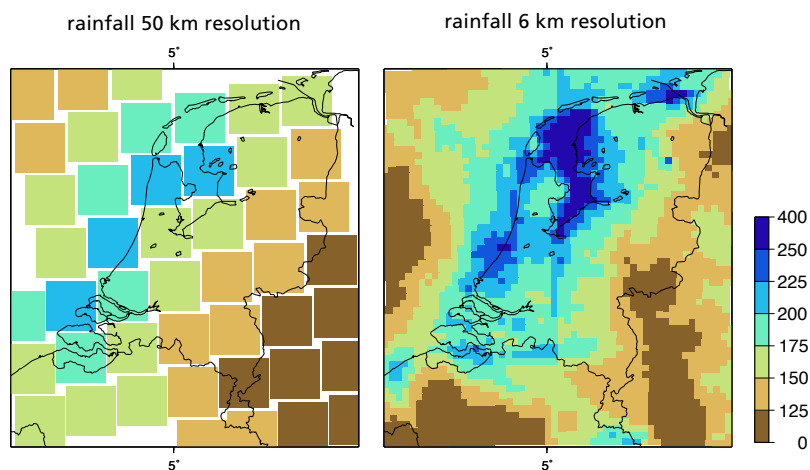


FIGURE 1: RACMO calculations of monthly rainfall in August 2006. Left panel: simulation at 50 km resolution forced with low resolution North Sea surface temperatures. Right panel: 6km resolution simulation with high resolution satellite inferred sea surface temperatures (Lenderink et al, 2009).

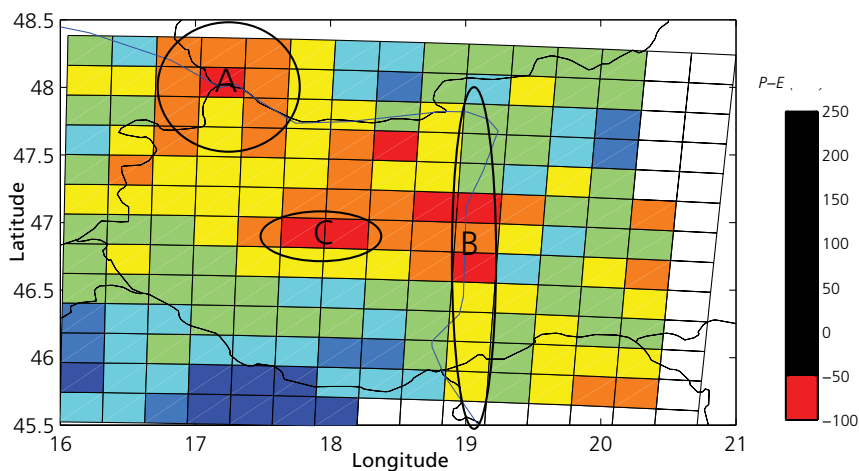


FIGURE 2: Annual balance of precipitation (P) minus evaporation (E) for the Hungarian Danube area. Both P and E are estimated from satellite data. Negative values of P-E (dark blue shading) denote non-local water sources to sustain evaporation. Regions A and B are irrigation areas, and C is Lake Balaton.



and/or (high latitude) cold season temperatures have a much smaller systematic positive bias. Also this change will significantly increase the realism of projected temperature changes in future model simulations.

### Aerosols

The representation of direct and indirect effects of aerosols is a very active field of research. Direct effects of aerosols include changes in the reflection of shortwave radiation by changes in the aerosol composition of the clear sky atmosphere, thereby affecting the surface energy balance. The indirect aerosol effects refer to the interaction between aerosols and clouds. They include the increase of the number of particles that allow cloud water droplets to be formed by condensation, the so-called Cloud Condensation Nuclei (CCN). Changes in cloud droplet size and number considerably alter the reflection of shortwave radiation and, to a lesser extent, the cloud emissivity affecting the longwave radiation (Figure 4). In

addition, the onset of precipitation and the lifetime of clouds depends on CCN, causing another indirect effect of aerosols.

In the reference version of RACMO the effects of aerosols and CCN are implemented in a very indirect way. Cloud formation processes and atmospheric reflection properties are “tuned” to account for aerosol effects, and the spatial distribution of aerosols is typically prescribed and does not respond to temporal or spatial changes in aerosol emissions or chemical processes in the atmosphere that change the aerosol distribution. A chain of research activities is currently underway to implement aerosols in a much more interactive way, by coupling aerosol distributions generated by an offline chemistry/transport model (LOTOS) to the actual cloud and radiation modules in RACMO. This coupling is both scientifically and technically very complex. Scientifically, because a lack of observations and basic understanding of the relevant processes makes it difficult to constrain

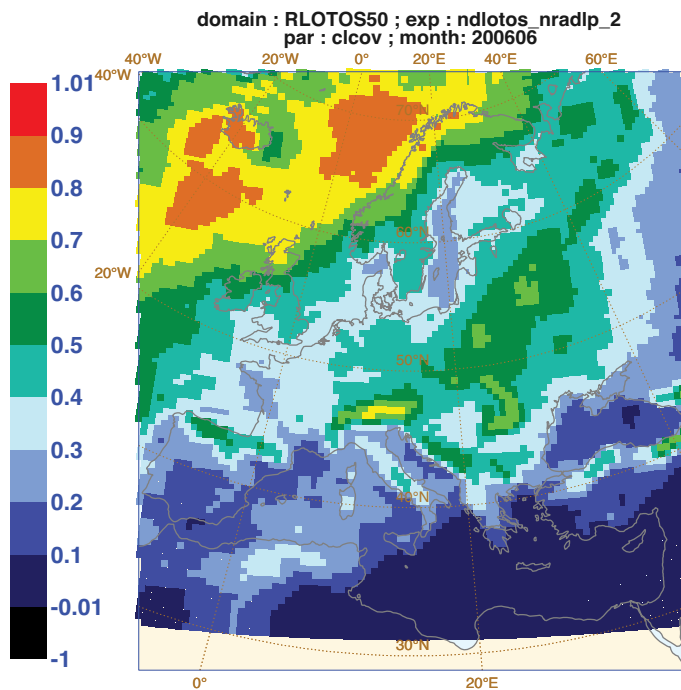


FIGURE 4: Radiative response of RACMO to aerosol field distributions generated by the LOTOS model relative to a result obtained with a “fixed” aerosol distribution. Left panel shows mean monthly cloud cover for June 2006, center panel shows the response in short wave radiation at the surface (LOTOS aerosol minus fixed aerosol), right panel shows response in daily mean 2-meter temperature.

model behavior within the range of related observations. Technically, because separate model codes to trace aerosols and to calculate atmospheric dynamics need to exchange relevant information at an agreed frequency, spatial domain and variable type. A fully coupled aerosol/RCM system is not yet operational at KNMI, but important progress is made here.

### Conclusions

Global and regional climate models, such as the KNMI RACMO model, are continuously in development. The development is guided by an increasing availability of relevant observations, which are used to both detect areas where improvements are needed, and to provide high-level input to the changed modules. The improvements listed in this paper illustrate this continuous cycle of model improvements, and provide an outlook to future model versions that are increasingly capable of representing the important processes governing our climate system.

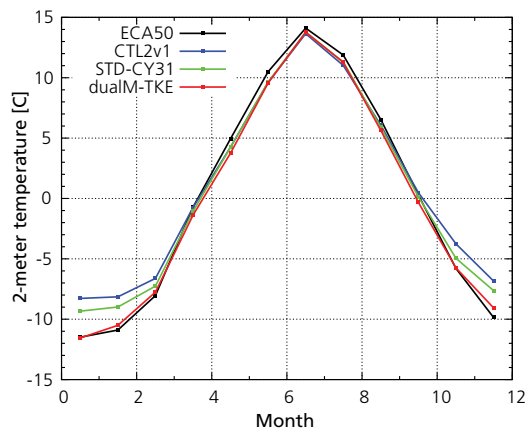
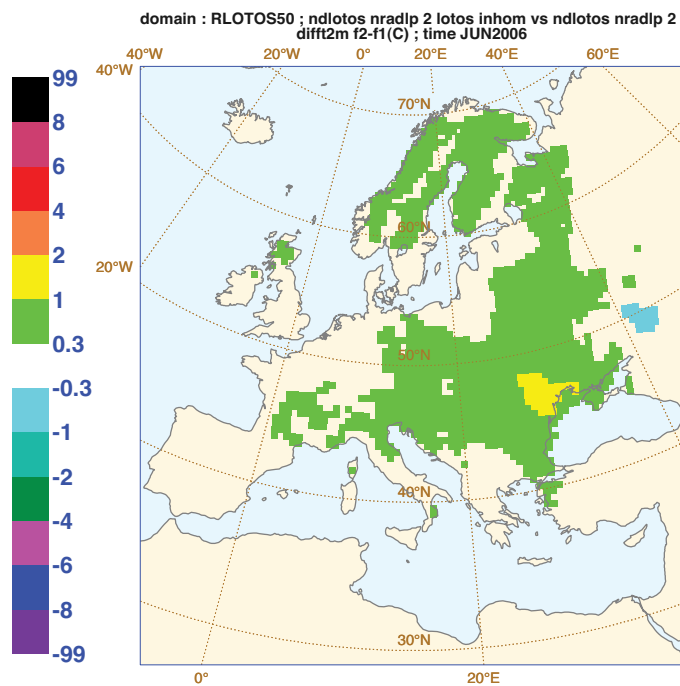
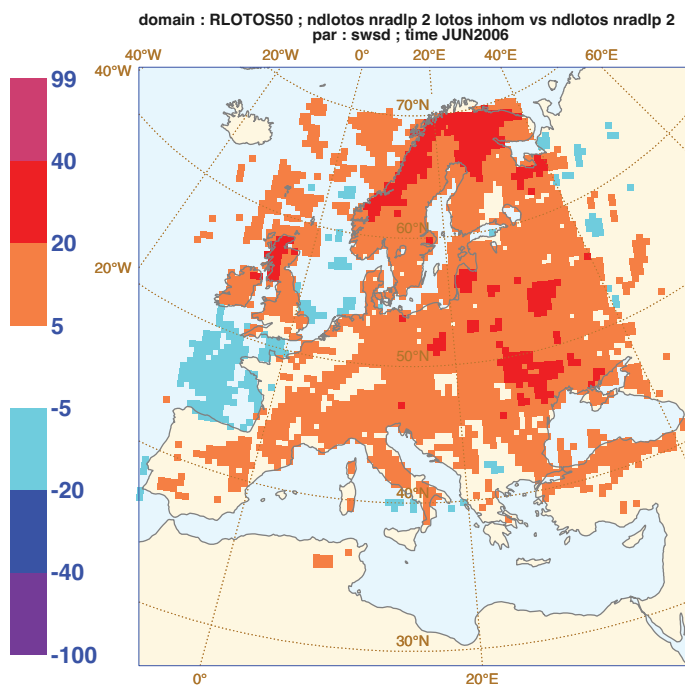


FIGURE 3: Mean annual cycle of 2m temperature in Northern Scandinavia during a 7 year period (2000 – 2006). Shown are observations (ECA50, in black), the current control version (blue), the new version without TKE mixing (green) and the version with the dualM-TKE mixing (red). During summertime the difference between the model versions and observations is very small. During wintertime, the systematic positive bias in the old and current RACMO versions is entirely removed by using the dualM-TKE formulation.



Despite continuous improvements of our climate models, there are fundamental limitations of the predictability of the climate system. Even with “perfect” models, natural variability and unknown evolution of the driving forces will inevitably lead to “imperfect” forecasts. The popular phrase “Model outcome should be used and interpreted with care” is not only a reflection of scientists’ modesty when their limited expert knowledge about the climate system is considered. It also refers to the need to interpret model results with a proper understanding of the fundamental limitations of predictability. Model results perfectly serve the need for credible and realistic outlooks towards how our future (regional) climate might look like, feeding our imagination that is necessary to take adequate measures. Better models will be better capable of providing these future snapshots. Thus, investing in model improvement remains a wise thing to do.

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