SPECIAL PROJECT
FINAL REPORT

All the following mandatory information needs to be provided.

Project Title:	Small-scale severe weather events: Downscaling using Harmonie
Computer Project Account:	SPNLSTER
Start Year - End Year :	2016 - 2019
Principal Investigator(s)	Andreas Sterl
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Other Researchers (Name/Affiliation):	Hylke de Vries (KNMI) Geert Lenderink (KNMI)

The following should cover the entire project duration.

Summary of project objectives

(10 lines max)

The non-hydrostatic Harmonie model is used in climate mode (HCLIM) to downscale climate model results. This offers the possibility to investigate the effect of climate change on small-scale phenomena like convective rainfall and wind gusts. This is not only relevant from a scientific point of view, but has many applications. For example, wind turbines suffer from night-time low level jets that are not represented well in current climate models, and convective events are only parameterized.

Summary of problems encountered

(If you encountered any problems of a more technical nature, please describe them here.)

No problems with the technical infrastructure at ECMWF.

One problem was a bug in HCLIM that requested a re-run. The necessary computing time was found on the regular KNMI budget.

Some problems occurred as driving data were not available in time. This could be solved by using an older set of data.

Experience with the Special Project framework

(Please let us know about your experience with administrative aspects like the application procedure, progress reporting etc.)

Application procedure and progress reporting were easy. Not burocratic. Both focus on the scientific aspect of the project, with minimal administrative burden.

Summary of results

(This section should comprise up to 10 pages, reflecting the complexity and duration of the project, and can be replaced by a short summary plus an existing scientific report on the project.)

Introduction

This section gives a short overview of results obtained using the HCLIM runs performed within this Special Prjocet. It mainly serves as a guide to the papers listed in the reference section. These papers superseede the internal reports (De Vries et al., 2018; De Vries et al., 2019) with preliminary results cited in earlier Progress Reports.
Most work has been done on prceipitation. Apart from that, the behaviour of soil moisture in the model has been assessed, and currently an investigation of wind gusts is being performed.

Model set-up and adjustments to plan

The original plan for the project was to perform three runs with the high-resolution, non-hydrostaic HARMONIE model in climate mode (HCLIM), one with boundaries from ERA-Interim, one with boundaries from the EC-Earth climate model for the same period as the ERA-Interim driven run, and one run with boundaries from EC-Earth in a future climate (2089-2099). The first run was intended to be compared with observations to establish the quality of the model. Ths second run was intended to show the difference between the ‘real’ climate and that of EC-Earth, and the third one to get the climate-change signal.

For EC-Earth, runs with the niewest version (v3), which is also used for the ongoing CMIP6 poject, were envisaged. However, development of EC-Earth.v3 took longer than anticipated, and we had to use existing runs from EC-Earth.v2 (the version used for CMIP5) instead. The disadvantage of using these runs is that they are too coold, with average temperatures in Europe being 1-2 K below the observed temperatures.

In the course of the project it became evident that an additional EC-Earth forced run for mid-century conditions would have added value for the characterisation of the cliamte-change signal. Such a run could not be perfomred withitn this Special Project, but could be realized in the framework of the H2020 EUCP project.

The first test runs were performed by driving HCLIM directly with boundaries from ERA-Interim of EC-Earth. Due to the large difference in resolution tis created some artifacts near the boundaries. We therefore resorted to a two-step coupling: the hydrostatic RCM RACMO was driven by ERA-Interim (EC-Earth), which in turn provided he boudnary conditions for HCLIM. RACMO has a horizondal resolution of ~11 km,, and its is run on a larger domain than HCLIM.

Precipitation

The runs have been performed with HARMONIE version 38h1.2, which was new at the time of beginning of this Special Project. The version came with several new parametrization options, which had to be tested first. Of special importance appeared to be a new scheme for shallow convection (called HARATU), which is based on the RACMO turbulence scheme.

Figure 1 shows comparisons of some model variables as obtained from different parametrization settings with measurements taken at the Cabauw meetoroloigcal tower. All four panels show that invoking the RACMO-based turbulence scheme has by far the largest impact. With the exception of near-surface temperature, this parametrization also leads to a better correspondence between model and observations. Partly baesd on these results, HARATU has become the default parametrisation for shallow convection in HARMONIE.

A thorough evaluation of HARMONIE in climate mode (HCLIM) has been performed by Belušsić et al. (2020). HCLIM is the same model code as used in our runs, but has been implemented for different areas by different researach groups. Belušsić et al. (2020) analyse runs performed for several regions. Besides our region covering north-western Europe, they also analyse configurations covering Greenland and East Africa. One of their main findings is that the use a a convection-permitting model like HCLIM drastically improves the intensity of sub-daily heavy precipitation.

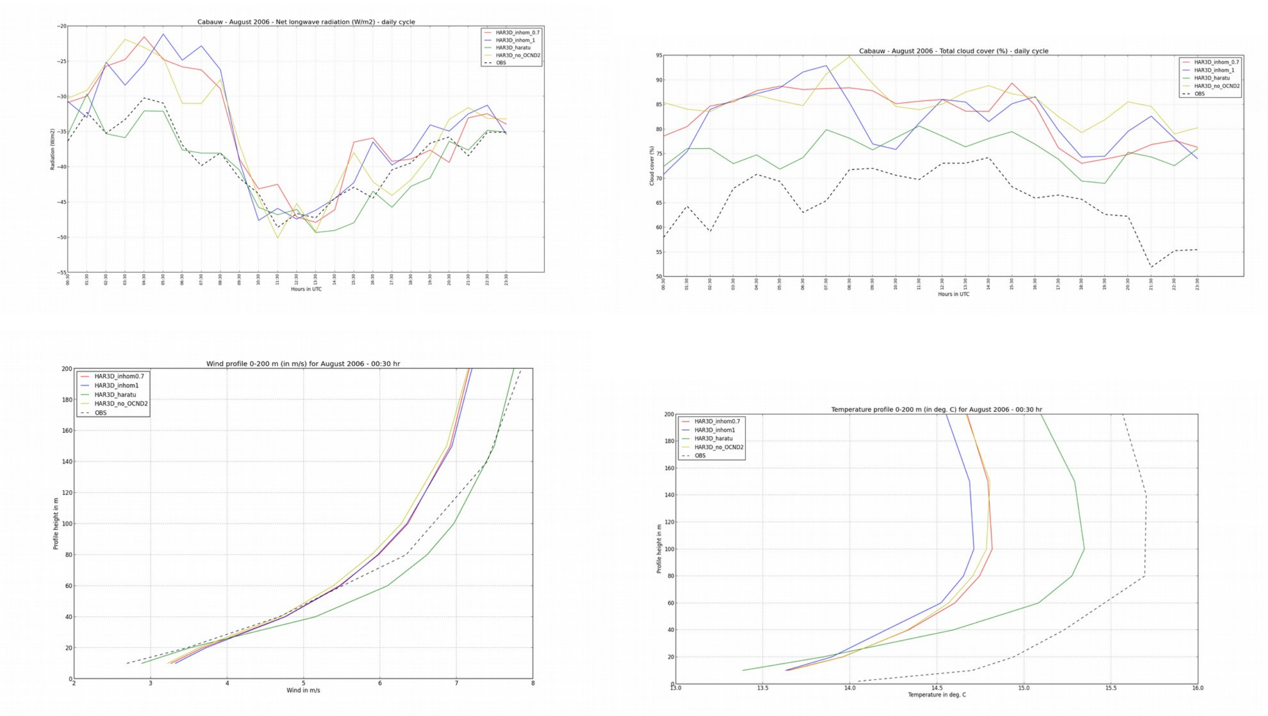

Figure 1: Comparison of model runs using different parametrization packages and observations from the Cabauw meteorological tower. Red and blue: default Harmonie with two different values (0.7 and 1) for the colud inhomogeneity factor (INHF), green: with HARATU, yellow: with old parametrization of ice clouds. Upper row:mean daily cycle of long wave radiation (left) and total cloud cover (right). Lower row: night-time vertical profiles of wind (left) and temperature (right).

This aspect is illustrated in Figure 2, where two statistics are studied for the Netherlands. The first is the hourly spatial precipitation maximum found within the Netherlands (FLDMAX statistic). The analysis focuses on model performance at the grid scale, and here we expect to find added value. Note that in this formulation the FLDMAX does not account for the spatial extent of the precipitation, nor does it account for the possible existence of several convective clusters at the same hour. The second statistic is called FLDMEAN, i.e. the hourly area-averaged precipitation. If a CPRCM (convection permitting regional climate model) outperforms its host model for the latter statistic, this is an example of upscale added value: the higher horizontal resolution also pays off at larger spatial scale. This is not guaranteed, especially not in winter, when precipitation is often caused by large-scale weather systems. Figure 2a shows that both the amount and the diurnal cycle of heavy precipitation are much better simulated by HCLIM (2.5 km resolution) than by RACMO (~11 km). Figure 2b and c show the precipitation distributions as exceedance plots. The exceedance plots are computed by simply ordering the FLDMAX or FLDMEAN data and inferring the empirical probability of a given value based on its order position. Not only at the grid scale (FLDMAX), but also at the largest spatial scale available (FLDMEAN, the Netherlands), HCLIM generally outperforms RACMO, especially for the larger precipitation amounts. Thus even at these spatial scales there is clear added value of the CPRCM. (Text adapted from Belušsić et al., 2020).

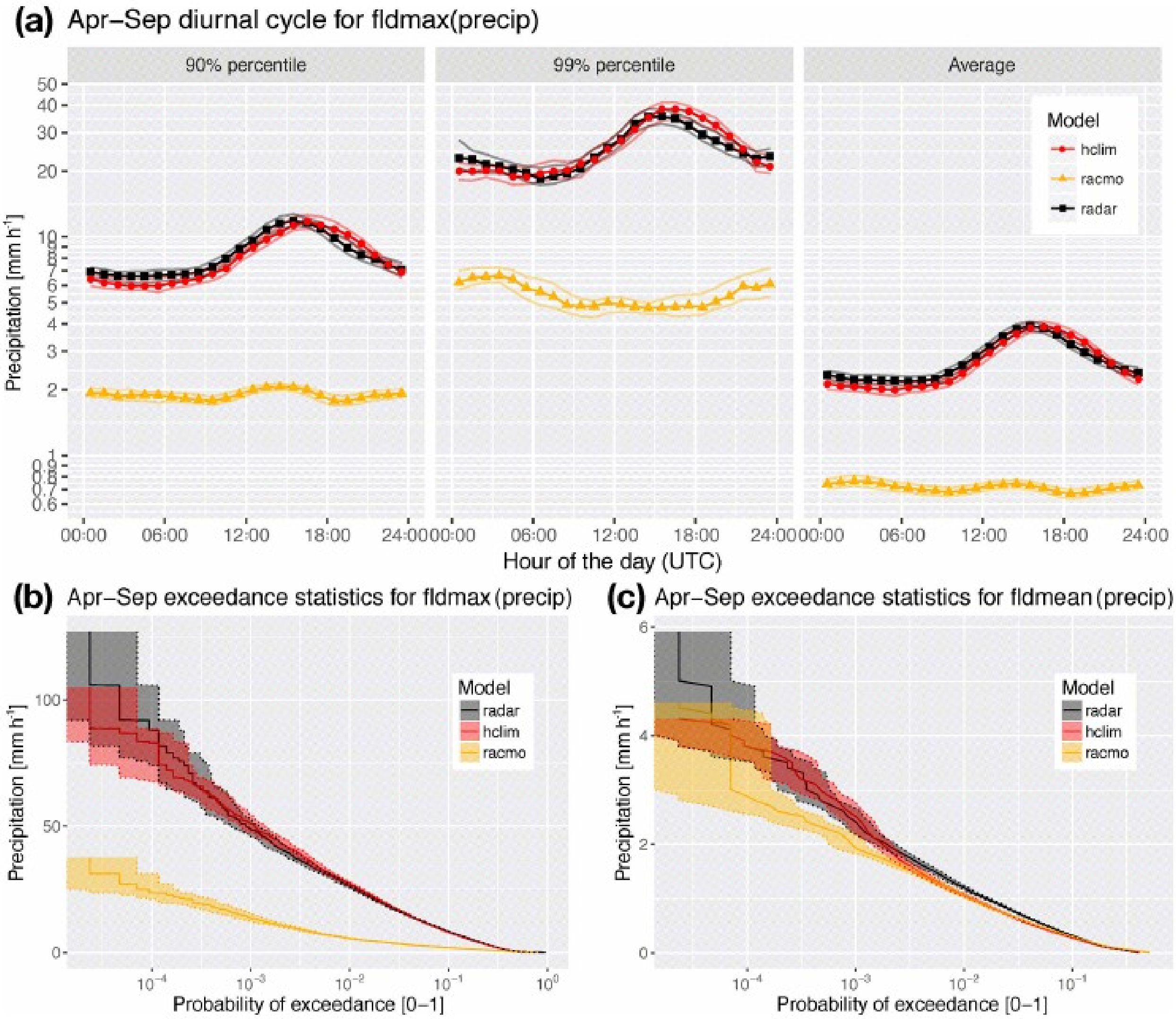

Figure 2: Diurnal cycle of two high percentiles (90th and 99th percentile) and the average of the FLDMAX hourly precipitation distribution (April–September) for radar, CPRCM and driving RCM. Probability of exceedance (April–September) for (b) the FLDMAX precipitation and (c) the FLDMEAN precipitation (note the difference in the vertical scale). Confidence levels (95 %) obtained using bootstrapping are indicated by shading. (Taken from Belušsić et al., 2020).

Ban et al. (2020) assess 22 different RCM-CPRCM combinations for their ability to reproduce the rainfall in the Alps region. Two of these combinations use HCLIM as the CPRCM, among them the run performed in this Special Project (denoted as KNMI in Figure 3). Ban et al. (2020) find that all models improve upon their driving model in representing rainfall over the Alps. Figure 3 shows a comparison of daily precipitation between RCM and CPRCM for the four seasons. In general, all CPRCMs improve upon their driving RCM, and the HCLIM runs are among the better ones. Ban et al. (2020) conclude:

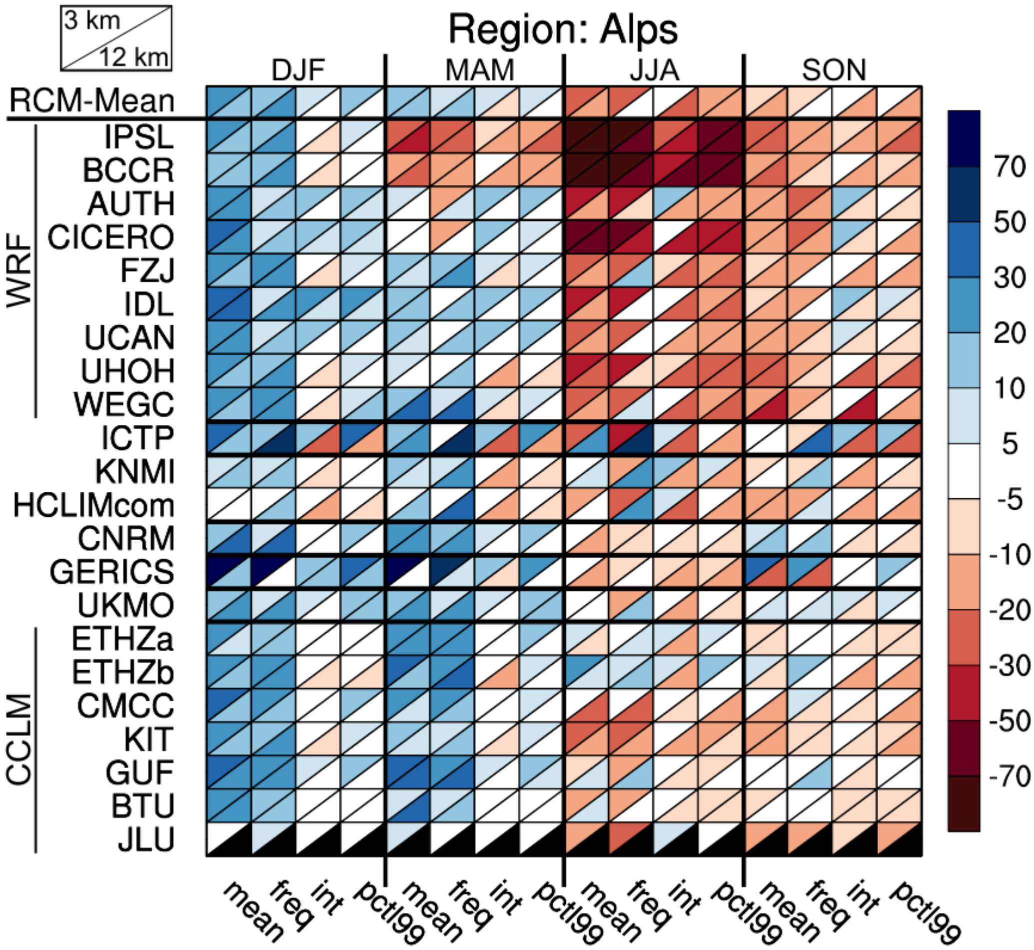

Figure 3: Relative bias of daily precipitation in four seasons (winter, spring, summer and autumn). Bias is calculated for each of the indices with regard to the APGD observations over the area of APGD observations. Each box represents the domain mean bias for 3 km (top triangle) and corresponding (driving) 12 km (bottom triangle) simulation. KNMI and HCLIMcom denote models that use HCLIM as the CPRCM. (Taken from Ban et al., 2020).

> In general, the spatial patterns of precipitation are represented quite well by the ensemble mean of km-scale simulations on both daily and hourly time scales. In many cases the representation is better than the ensemble-mean of the coarse resolution simulations. This is especially true in the summer season when the coarse resolution model overestimates the frequency and underestimates the intensity of both daily and hourly precipitation.
>
> The diurnal cycles of summer mean precipitation, wet-hour frequency and heavy precipitation are analyzed over three different regions - Switzerland, France and Italy. Over all three regions, the ensemble mean of km-scale simulations shows superior performance to the ensemble mean of coarse resolution simulations. It is clear that the longstanding problems of incorrect timing with too frequent and too weak precipitation is greatly improved by switching off the parameterization of convection. However, it must be noted that a large spread exists even within the km-scale ensemble and that there are many deficiencies in these modeling systems that need to be addressed.

Picelli et al. (2020) investigate the same models as Ban et al. (2020), but focus on the climate-change signal. Their mean finding is “The kilometer-scale ensemble refines and enhances the projected patterns of change from coarser resolution simulations and even modifies the sign of the daily precipitation intensity change and heavy precipitation over some regions. They also show a bigger amplitude of change for the diurnal cycle for mean, intensity, frequency and extreme and a larger positive change for high to extreme events for both daily and hourly precipitation distribution.”

Lenderink et al. (2020) investigate the scaling behaviour of precipitition. Their results confirm the earlier findings that heavy precipitation events increase faster with temperature than to be expected from thermodynamic changes alone. According to the Clausius-Clapeyron relation, the saturation vapour pressure increases with about 7%/K, so naively, one would expect a 7%/K increase in precipitation. However, heavy precipitation events appear to increase faster, with up to two times the Clausius-Clapeyron rate. The HCLIM runs confirm these earlier findings. At the same time they allow to investigate the impact of climate change on these scalings. Lenderink et al. (2020) find that for dewpoint temperatures above 15 °C the most extreme precipitation events experience the highest the rate of change. It appears that the strongest showers intensify with warming at the expense of small showers, and there is no unique change rate for all showers.

Soil Moisture

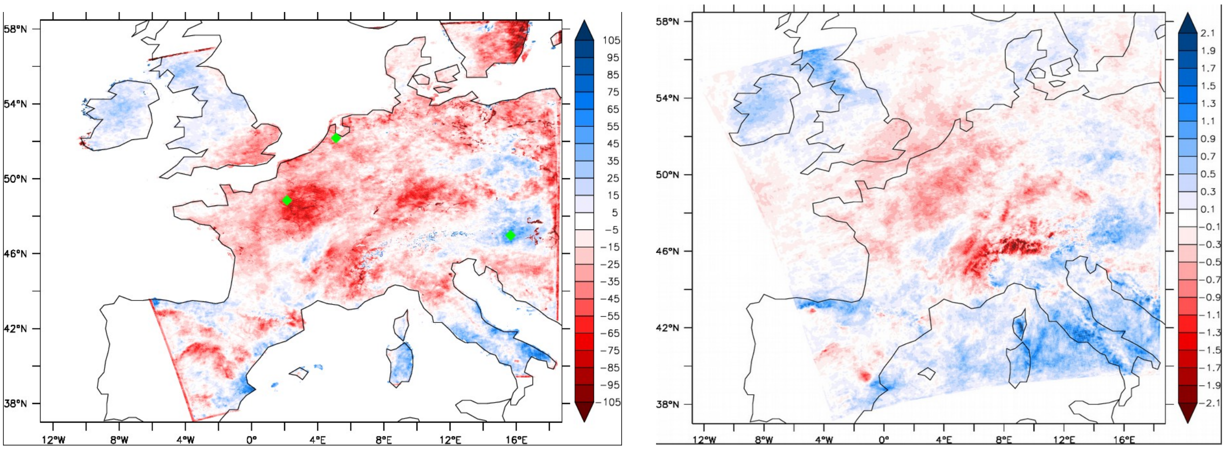

Figure 4: Linear trends in soil moisture (left, in kg m^{-2}/(10ys)) and precipitation (right, in mm d^{-1}/(10ys)). The green diamonds in the left panel denote the positions for which time series are shown in Fig. 5.

The left panel of Figure 4 shows the linear trend of total soil moisture content over the ten-year period of the ERA-Interim driven run. Large parts of continental north-western Europe get a bit drier, while southern Europe and the Brtish Isles get wetter. As Figure 5 shows, these trends are superimposed on a large interannual variability. The right panel of Figure 4 displays the linear trend of precipitation. Clearly, the large-scale patterns of soil-moisture change and precipitation change are similar. Therefore, the former can be explained by the latter, making us confident that the surface module of HCLIM works correctly and does not introduce artificial trends into the simulations.

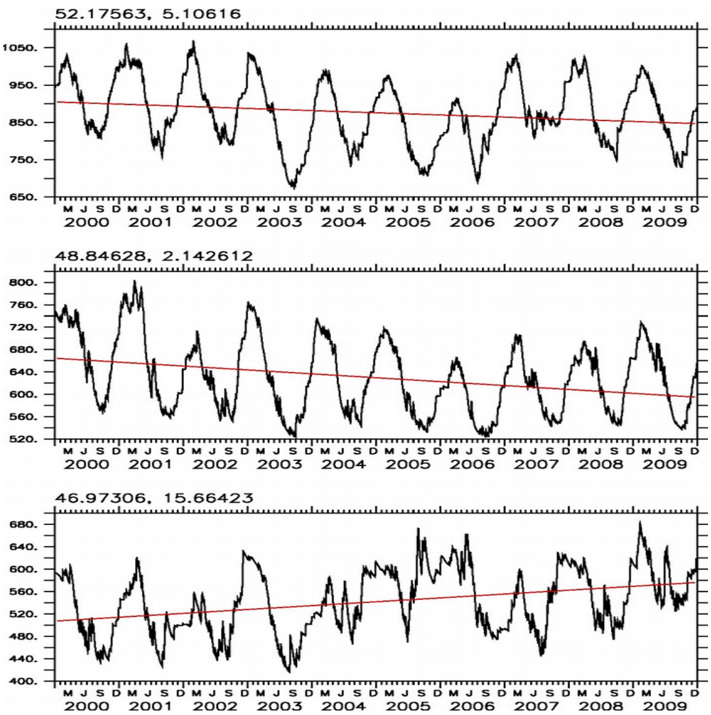

Figure 5: Time series of soil moisture at the three locations marked in Fig. 4. Monthly values in black, linear trend as a red line.

Results regarding wind gusts

Recently, we startet to investigate wind gusts in the HCLIM runs. Over land, wind gusts cause the largest wind related damage. The most severe wind gusts arer those associated with heavy convective events, and have to be parameterized even in HCLIM. A first result of that research is presented in Figure 6. Shown is the difference of the 50-year return wind gust derived from HCLIM output between the end of this century (2089-2099) and the present climate (1995-2005). Over the Netherlands, a clear increase of up to 10 m/s is visible.

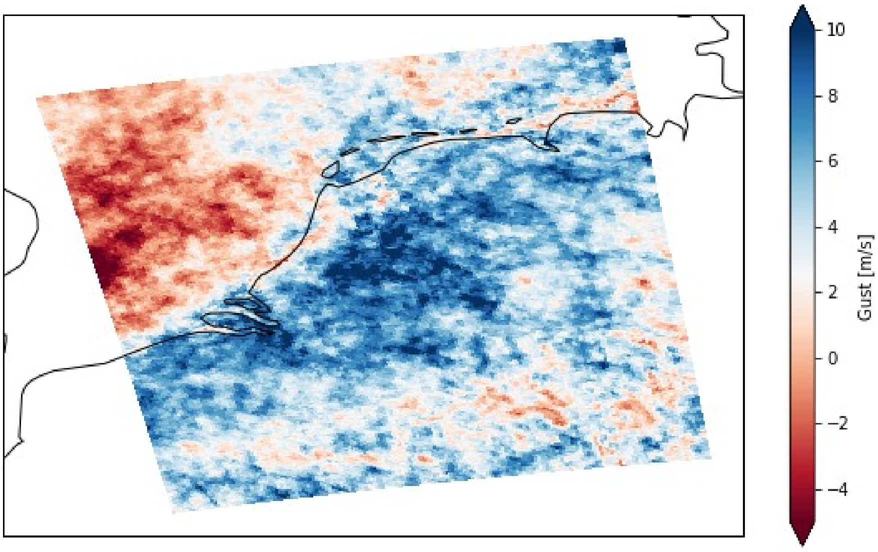

Figure 6: Change of 50-yr return value of wind gusts between the 2089-2099 run and the 1995-2005 run.

List of publications/reports from the project with complete references

Nikolina Ban, Erwan Brisson, Cecile Caillaud, Erika Coppola, Emanuela Pichelli, Stefan Sobolowski, Marianna Adinolfi, Bodo Ahrens, Ivonne Anders, Sophie Bastin, Danijel Belušić, Segolene Berthou, Rita M. Cardoso, Steven Chan, Ole Bøssing Christensen, Jesus Fernandez, Lluis Fita, Thomas Frisius, Klaus Goergen, Jan Erik Haugen, Oivind Hodnebrog, Stergios Kartsios, Eleni Katragkou, Elizabeth J. Kendon, Klaus Keuler, Alvaro Lavin-Gullon, Geert Lenderink, David Leutwyler, Torge Lorenz, Josipa Milovac, Hans-Juergen Panitz, Mario Raffa, Paola Mercogliano, Armelle Remedio, Christoph Schär, Pedro M.M Soares, Birthe Marie Steensen, Paolo Stocchi, Merja H. Tölle, Heimo Truhetz, Jesus Vergara-Temprado, Hylke de Vries, Kirsten Warrach-Sagi, Volker Wulfmeyer, Marjanne Zander (2020): The first multi-model ensemble of regional climate simulations at kilometer-scale resolution, Part I: Evaluation of precipitation, Clim. Dyn., under revision.

Belušić, D., de Vries, H., Dobler, A., Landgren, O., Lind, P., Lindstedt, D., Pedersen, R. A., Sánchez-Perrino, J. C., Toivonen, E., van Ulft, B., Wang, F., Andrae, U., Batrak, Y., Kjellström, E., Lenderink, G., Nikulin, G., Pietikäinen, J.-P., Rodríguez-Camino, E., Samuelsson, P., van Meijgaard, E., and Wu, M. (2020): HCLIM38: a flexible regional climate model applicable for different climate zones from coarse to convection-permitting scales, Geosci. Model Dev., 13, 1311–1333, https://doi.org/10.5194/gmd-13-1311-2020.

Hylke de Vries, Bert van Ulft, Erik van Meijgaard, Geert Lenderink and Andreas Sterl (2018): HCLIM38h1: A convection permitting climate model for Western Europe, KNMI, De Bilt, Netherlands, June 19, 2018 [*appendix to 2018 pprogress report*].

Hylke de Vries, Bert van Ulft, Erik van Meijgaard, Geert Lenderink, and Andreas Sterl (2019): Evaluation of high resolution climate simulations with Harmonie over Europe, KNMI, De Bilt, Netherlands, June 06, 2019 [*appendix to 2019 pprogress report*].

Geert Lenderink, Hylke de Vries, Hayley J. Fowler, Renaud Barbero, Bert van Ulft, Erik van Meijgaard (2020): Scaling and responses of extreme hourly precipitation in three climate experiments with a convection-permitting model, Phil. Trans. R. Soc. A., submitted.

Emanuela Pichelli, Erika Coppola, Stefan Sobolowski, Nikolina Ban, Filippo Giorgi, Paolo Stocchi, Antoinette Alias, Danijel Belušić, Segolene Berthou, Cecile Caillaud, Rita M. Cardoso, Steven Chan, Ole Bøssing Christensen, Andreas Dobler, Hylke de Vries, Klaus Goergen, Elizabeth J. Kendon, Klaus Keuler, Geert Lenderink, Torge Lorenz, Aditya N. Mishra, Hans-Juergen Panitz, Christoph Schär, Pedro M.M. Soares, Heimo Truhetz, Jesus Vergara-Temprado (2020): The first multi-model ensemble of regional climate simulations at kilometer-scale resolution, Part 2: future precipitation projections, Clim. Dyn, under revision.

Future plans

(Please let us know of any imminent plans regarding a continuation of this research activity, in particular if they are linked to another/new Special Project.)

- The results of the model simulation are still being analysed. Focus is on heavy precipitation and wind gusts.
- In collaboration with another project, an additional 10-year run for mid-century conditions has been performed.
- We do no thave immediate plans to apply for further special projects.