SPECIAL PROJECT PROGRESS REPORT

All the following mandatory information needs to be provided. The length should *reflect the complexity and duration* of the project.

Reporting year	2018
Project Title:	Small-scale severe weather events: Downscaling using Harmonie
Computer Project Account:	spnlster
Principal Investigator(s):	Andreas Sterl
Affiliation:	KNMI (Royal Netherlands Meteorological Institute) P.O. Box 201 3730 AE De Bilt Netherlands
Name of ECMWF scientist(s) collaborating to the project (if applicable)	n/a
Start date of the project:	13 April 2016
Expected end date:	31 December 2019

Computer resources allocated/used for the current year and the previous one

(if applicable)

Please answer for all project resources

		Previous year		**Current year**	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	25000000	25000000	25000000	25000000
Data storage capacity	(Gbytes)	15,000	0	15,000	0

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 (10 lines max)

For 2018 a run with boundaries from a CMIP6 run with EC-Earth for the present climate was planned. However, due to various delays such a run could not be performed in 2018. In order not to delay the project further, it was decided to revert to an existing CMIP5 run with EC-Earth. This implies that also the run for a future climate has to be made with boundaries from the CMIP5 version of EC-Earth. That run has already been performed in the first months of this year (2019).

Summary of plans for the continuation of the project (10 lines max)

The runs planned for this project have been finished. We are now working on their analysis.

List of publications/reports from the project with complete references

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

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

Summary of results

If submitted **during the first project year**, please summarise the results achieved during the period from the project start to June of the current year. A few paragraphs might be sufficient. If submitted **during the second project year**, this summary should be more detailed and cover the period from the project start. The length, at most 8 pages, should reflect the complexity of the project. Alternatively, it could be replaced by a short summary plus an existing scientific report on the project attached to this document. If submitted **during the third project year**, please summarise the results achieved during the period from July of the previous year to June of the current year. A few paragraphs might be sufficient.

Experiments
The aim of this project is to dynamically downscale climate model output using the non-hydrostatic Harmonie Climate (HCLIM). The model has a horizontal resolution of 2.5 km, and the model domain covers western Europe (e.g., see Fig. 1 in [2]).

The project comprises of three runs of 10 years duration that differ in their boundary conditions

1. boundary conditions from ERA-Interim, period 2000-2009
2. boundary conditions from EC-Earth, present climate (1995-2005)
3. boundary conditions from EC-Earth, future climate (2089-2099) under RCP8.5

The first two runs serve to establish the quality of the EC-Earth driven run, and the third provides the climate-change signal. The third run has just been finished. Its analysis is under way.

Assessment of EC-Earth driven run
Last year we reported about the comparison of temperature and precipitation between observations and the ERA-Interim driven run (see [1]). Overall, the model appeares to be too wet and slightly too cold. The precipitation bias is largest in mountainous regions and modest (<10%) in the Netherlands and surrounding areas, where the model even has a dry bias in summer.

Run 2 (present climate, EC-Earth driven) provides the baseline against which the climate-change signal (run 3) is determined. A comparison between this run and run 1 (see [2]) shows the bias introduced by using a climate model (EC-Earth) rather than a reanalysis product (ERA-Interim) as the boundary condition. Harmonie inherits the cold bias of EC-Earth and is much too cold ([2], Figs. 1+2). The cold bias is lowest in winter. The EC-Earth driven run experiences no extra precipitation bias as compared to the ERA-Interim driven one ([2], Figs. 3+4).

Extreme precipitation events
An important reason to use a convection permitting model like Harmonie is its supposed ability to better model high-precipitation events that typically occur on small spatial scales during intense convection. A comparison between radar observations of precipitation and Harmonie output demonstrates the ability of the model to reach high precipitation intensities (see [2], Figs. 5-8, lower panels). The PDF of hourly rain fall from Harmonie compares much better with the observed PDF than does the PDF from RACMO, especially in summer. There is a clear advantage of using a convection permitting model when investigating extreme rainfall events. At the same time, the ERA-interim driven run is in much better agreement with the observations than the EC-Earth driven one, especially in summer. This is a logical consequence of the fact that the latter is too cold.

Diurnal cycle of precipitation
Convection needs enough heating to occur. Therefore, it has a pronounced diurnal cycle which peaks in the late afternoon, causing a corresponding diurnal cycle in precipitation. This cycle is absent in RACMO, but clearly emerges in Harmonie (see [2], Figs. 5-8, upper panels), where it has the right phase and amplitude. Again, the ERA-Interim forced run provides better results than the EC-Earth forced one, and again the difference between the two is largest in summer.

Climate change signal
The difference between runs 3 and 2 represents the climate change signal. As the run has just been finished, only a first simple difference plots have been produced so far. A thorough analysis is underway. One of the simple plots is reproduced in Fig. 1, which shows relative differences in mean and maximum (monthly maximum of hourly precipitation) precipitation for DJF and JJA. Both mean and maximum precipitation increase in the future run in winter (DJF), while precipitation decreases in summer (JJA). The latter signal is clear for the mean, but very noisy for the maxima, where some areas show an increase and others a decrease, without a clear spatial pattern. Probably 10 year is too short a period to reliably detect changes in maximum precipitation.

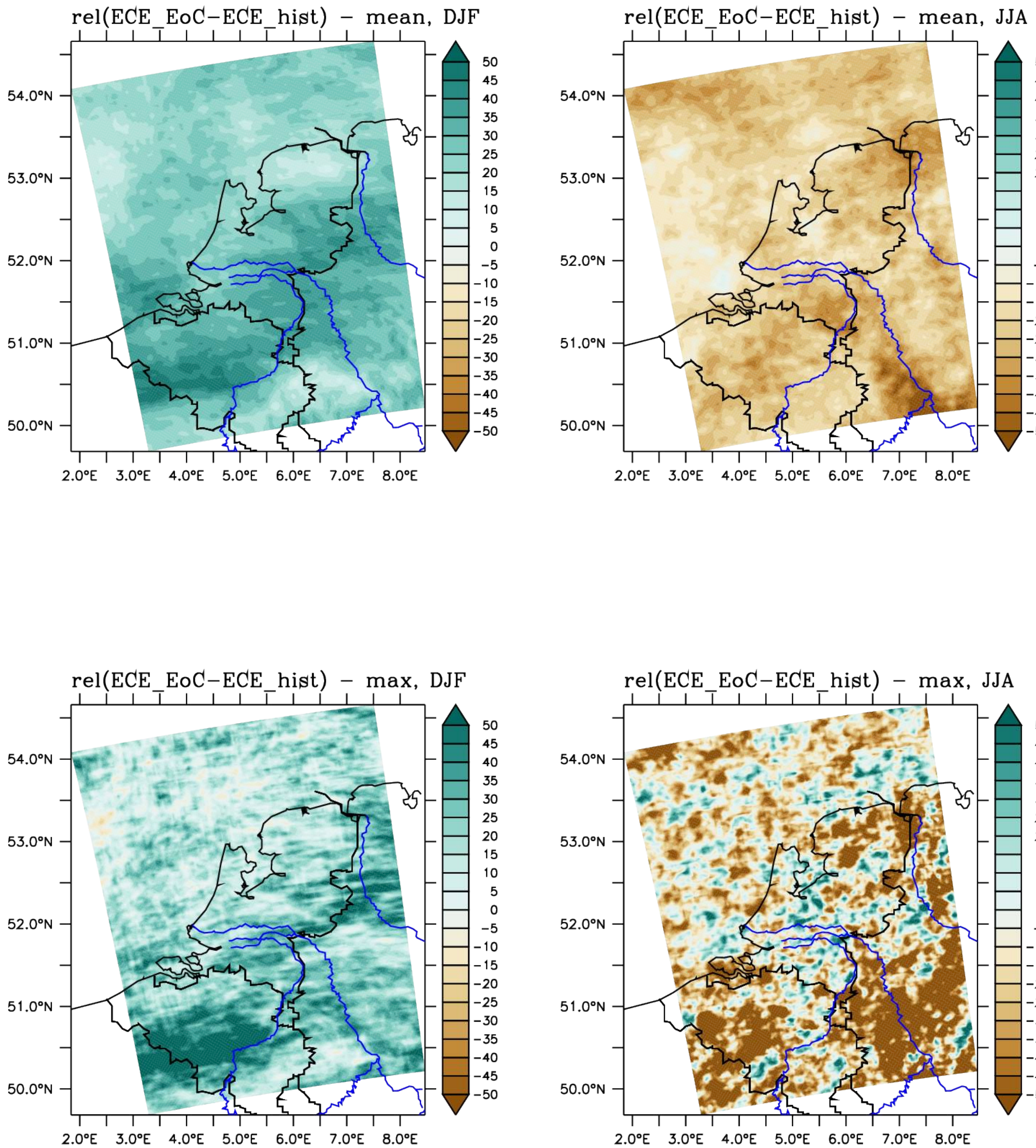

Figure 1: Relative precipitation difference (in percent) between 2089-2099 (RCP8.5) and 1995-2005 for DJF (left) and JJA (right). The upper row is for mean precipitation, the lower for season-averaged monthly maximum hourly precipitation.

Appendix (next page)

Evaluation of high resolution climate simulations with Harmonie over Europe (Hylke de Vries, Bert van Ulft, Erik van Meijgaard, Geert Lenderink, Andreas Sterl; KNMI, De Bilt, Netherlands, June 06, 2019)

Evaluation of high resolution climate simulations with Harmonie over Europe

Hylke de Vries, Bert van Ulft, Erik van Meijgaard, Geert Lenderink, Andreas Sterl
Royal Neteherlands Meteorological Institute, KNMI

Version: June 6, 2019

We report on the performance of the convection-permitting model Harmonie over Europe. Two decade-long simulations of the current climate are compared. In the first simulation, Harmonie is driven by ERA-Interim for the period 1999-2009. In the second simulation, obtained for the period 1996-2005, Harmonie is driven by by the global climate model EC-Earth. The reason for using a slightly different period, is that in this way we could contribute with our simulations to the collective experiment CORDEX-FPS described in Coppola et al (2018). In both simulations, the regional climate model RACMO2 (resolution 0.11 degree) is used as an intermediate model. Temperature and precipitation are compared to E-OBS, and a more detailed analysis is given of precipitation over the Netherlands. Especially intense precipitation associated with summer convection is a key variable where added value is expected compared to the coarser resolution models. A third and fourth simulation of a future warmer climate are under way.

1 Introduction

Regional climate studies often aim to assess the current state of the local climate, to understand aspects of its variability, and to identify differences between the local and larger-scale or global response to the increase of greenhouse gases. The regional climate model (RCM) plays an essential role in this research area. Since it can be run at much higher spatial resolution than the global climate models (GCM) in which it is nested, it resolves the dynamics and physical processes at much finer scale. These fine scales are relevant and responsible for most of the high-impact weather. The latest generation of these regional climate models solves runs with non-hydrostatic dynamics at resolutions of 1-3km. Because these models operate in the spatial domain where large-scale convection is resolved explicitly, they are referred to as the convection-permitting regional climate models (CPRCMs). Harmonie is such a non-hydrostatic CPRCM that operates at 2.5km resolution. Although deep convection is explicitly resolved, shallow-convection is still parameterised, like various other subgrid processes. The climate version of Harmonie used in this project is referred to as HCLIM38-AROME, because of the AROME-physics package that has been used. It is described in more detail in Belusic and et al. (submitted) and first results of a model intercomparison of CPRCMs that includes HCLIM38-AROME can be found in Coppola et al (2018).

2 Data and methods

Two Harmonie runs are compared, one (evaluation, labelled EVAL) run for the period 1999-2009, which is forced by ERA-Interim/RACMO2, and one (current, labelled HIST) climate run for the period 1996-2005, which is driven by EC-Earth/RACMO2. Model output of temperature and precipitation are compared against E-OBS (Haylock et al, 2008) over the period 1999-2009. Over the Netherlands, we perform a more detailed analysis of the precipitation distribution, by comparing it to a gridded radar product (Overeem et al, 2009). A similar comparison has been carried out in Belusic and et al. (submitted).

Nesting within RACMO2 There are at least two reasons for using an RCM in between GCM or reanalysis and the CPRCM. The first and primary reason is to improve the performance of Harmonie, by smoothing the transition from coarse GCM or reanalysis to the fine-scale CPRCM. Without the intermediate nest the southern and western parts of the domain were found to be much too dry, with too little precipitation. Including the nesting substantially alleviated this issue. A second reason is that RCMs that run at O(10-15km) resolution are currently still the main working horse for conducting regional climate studies. By nesting Harmonie in RACMO2, we can therefore directly assess whether there is any ”added value” in the use of very high resolution. Regarding the future climate response, the high resolution models can also be used to examine whether 'surprises' occur, in the sense of a (e.g. scaling) response that differs substantially between RCM and CPRCM. An example of a recent study where HCLIM is used in a climate-change context is Lenderink et al (2019).

Selection of driving GCM member For the GCM-forced simulation, a choice had to be made which EC-Earth simulation to use. This is relevant because the period under consideration is not very long (only a decade), implying that internal variability is still relevant. As options for boundary conditions, we could in principle take any member from an existing 16-member initial-condition ensemble generated by EC-Earth, that had already been downscaled with RACMO2. In this selection procedure, the following pragmatic approach has been taken: We chose the ensemble-member that was relatively ”close” to the ensemble mean of that period (For the future simulation we have used the same approach). The definition of ”close” was based on ranking of (a) the circulation frequencies obtained from a cluster analysis of the mslp-patterns over Europe, (b) an analysis of the precipitation distribution over the Netherlands, and (c) of the mean absolute difference in precipitation over Europe, compared to the ensemble mean.

Metrics Maps of a few basic statistics (seasonal averages and standard deviation) are computed for temperature and precipitation, similar to results shown in a previous progress report (Sterl and et al., 2018). One of the primary reasons for using Harmonie is to be able to capture small-scale phenomena such as for example intense summer convection. Both the timing and the intensity of the maximum rainfall are important and of high impact in terms of their relation to extreme weather. For this reason, we also present results of hourly rainfall accumulations. More specifically, for this part of the evaluation we compare the output of HCLIM (2.5km) and RACMO2 (0.11 degree) against hourly accumulated radar data over the Netherlands. This radar data has a resolution of 2.4km. In order to compare the model performances at this high spatial resolution, the data of both HCLIM and RACMO2 are interpolated to the radar grid using nearest-neighbor mapping. The statistics of two types of hourly precipitation are compared. First we look at the time-series of the hourly spatial precipitation maxima found within the entire Netherlands. We call this the hourly ”FLDMAX” statistics. This analysis therefore focuses on essentially the grid-scale performance of the model. Secondly we study the other end, the so-called ”FLDMEAN” statistics. In this latter approach, we study the area-average precipitation, again considering the entire analysis domain (Netherlands). Confidence interval estimation is performed using bootstrapping. This bootstrapping is implemented as sampling with replacement from the hourly data. The resulting estimate is slightly over-confident as it ignores any time-correlation in the hourly precipitation data. For the FLDMAX approach this is not important, but for the FLDMEAN approach, an alternative, based on daily sampling leads to slightly wider confidence bounds.

3 Results

First we discuss the climatology of temperature and precipitation. This is followed by a more detailed analysis of the precipitation distribution over the Netherlands. Compared to the previous report, we focus on the difference between the EC-Earth forced run and the one forced by ERA-Interim.

Climatology of temperature and precipitation Figure 1 shows the winter mean, minimum and maximum 2m-temperature averages and their differences with respect to observations. The bottom row shows the multi-year seasonal average of monthly-standard deviation of daily-mean temperature (a measure of the variability on daily time-scale). As already discussed in the previous report, the ERA-Interim forced HCLIM run (and also in the intermediate model RACMO2) is slightly too cold compared to E-OBS, mountainous regions in particular (Sterl and et al., 2018). Over the low-lying areas, the negative bias is about 1 degree. Both min and max temperatures are too cold, yet the typical temperature variability is rather good (bottom panels). This negative bias is larger in the EC-Earth forced run. Despite the increased bias the variability is comparable to the

ERA-Interim forced run. In the other seasons the bias is even worse, as the EC-Earth forced run is now clearly much colder than the ERA-Interim forced run (Fig. 2 shows the summer). Summer, spring and autumn all experience a negative bias of several degrees. To large extent this bias is inherited from EC-Earth which also is too cold. Temperature variability remains good, suggesting that for applications a simple bias-correction could be considered.

For precipitation the same matrix-approach is used (Fig.3-4). Here we measure the variability on the daily time-scale using the monthly standard deviation of daily precipitation sums. Given the rather large temperature differences it is remarkable that both HCLIM runs produce a similar bias pattern with respect to the observations. In winter, the EC-Earth forced run is somewhat wetter over France and drier over the Eastern part of the domain. The summer patterns are however quite similar.

Distribution and daily cycle of precipitation over the Netherlands For the Netherlands we have compared the hourly precipitation to radar. Data has first been converted to the 2.4x2.4 km radar grid using nearest neighbour interpolation. As outlined in section 2 we study statistics of hourly FLDMAX (the spatial maximum value) and FLDMEAN (the spatial average value) precipitation. The top row in Figure 5 shows for each hour of the day during the summer half year (SUM6, April-September) the 90th and 99th percentile as well as the average FLDMAX precipitation, for the radar product and the model simulations. The orange line indicates the hourly precipitation obtained with RACMO2 in the ERA-Interim forced run. It is clear that the HCLIM runs are very close to the observations. Timing and amplitude in both HCLIM runs are almost perfect. There is unambiguous added value of the CPRCM compared to the RCM at this (hourly) time-scale and (grid) spatial scale. The RCM is neither able to reach the intensities, nor shows signs of a diurnal cycle. These results are comparable to those reported in Belusic and et al. (submitted). That paper also presented a comparison to rain gauges over Germany, where a similar added value is shown. The bottom panel shows the hourly FLDMAX distribution. This panel confirms the superiority of the CPRCM at the grid scale, but also shows the rather good correspondence between radar and the ERA-Interim forced run (denoted hclim). The EC-Earth forced run (hclim_hist) is close, but seems unable to reach the highest percentiles.

Figure 6 shows the same panels, but obtained for the FLDMEAN approach. Here we aggregated the hourly data first to the size of the Netherlands, prior to computing the distribution. Obtained precipitation values are obviously much smaller compared to FLDMAX and also the amplitude of the diurnal cycle is much smaller. Both HCLIM runs again agree very well with each other as well as to the radar product in terms of their diurnal cycle and distribution, but now also the RCM produces results in the same range. It is hard to identify added value at this spatial scale.

In the winter half year (October-March) the amplitude of the diurnal cycle in FLDMAX precipitation is almost absent (Fig 7). Because of the almost complete absence of convection, there is no preference in winter times for precipitation to occur in the late afternoon. The CPRCM and RCM difference in FLDMAX intensities remains however as in summer, with the RCM being unable to reach high intensities. There is little difference between the EC-Earth forced run and the run forced by ERA-Interim.

References

Belusic D, et al (submitted) HCLIM38: A flexible regional climate model applicable for different climate zones from coarse to convection permitting scales. GMD

Coppola E, Sobolowski S, Pichelli E, Raffaele F, Ahrens B, Anders I, Ban N, Bastin S, Belda M, Belusic D, Caldas-Alvarez A, Cardoso RM, Davolio S, Dobler A, Fernandez J, Fita L, Fumiere Q, Giorgi F, Goergen K, Güttler I, Halenka T, Heinzeller D, Hodnebrog Ø, Jacob D, Kartsios S, Katragkou E, Kendon E, Khodayar S, Kunstmann H, Knist S, Lavín-Gullón A, Lind P, Lorenz T, Maraun D, Marelle L, van Meijgaard E, Milovac J, Myhre G, Panitz HJ, Piazza M, Raffa M, Raub T, Rockel B, Schär C, Sieck K, Soares PMM, Somot S, Srnec L, Stocchi P, Tölle MH, Truhetz H, Vautard R, de Vries H, Warrach-Sagi K (2018) A first-of-its-kind multi-model convection permitting ensemble for investigating convective phenomena over europe and the mediterranean. Climate Dynamics DOI 10.1007/s00382-018-4521-8, URL https://doi.org/10.1007/s00382-018-4521-8

Haylock M, Hofstra N, Klein Tank A, Klok E, Jones P, New M (2008) A European daily high-resolution gridded dataset of surface temperature and precipitation. J Geophys Res 113:D20,119, DOI 10.1029/2008JD10201

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Overeem A, Holleman I, Buishand A (2009) Derivation of a 10-year radar-based climatology of rainfall. Journal of Applied Meteorology and Climatology 48(7):1448–1463

Sterl A, et al (2018) Small-scale severe weather events: Downscaling using Harmonie. ECMWF Special Projects. Progress report.

List of Figures

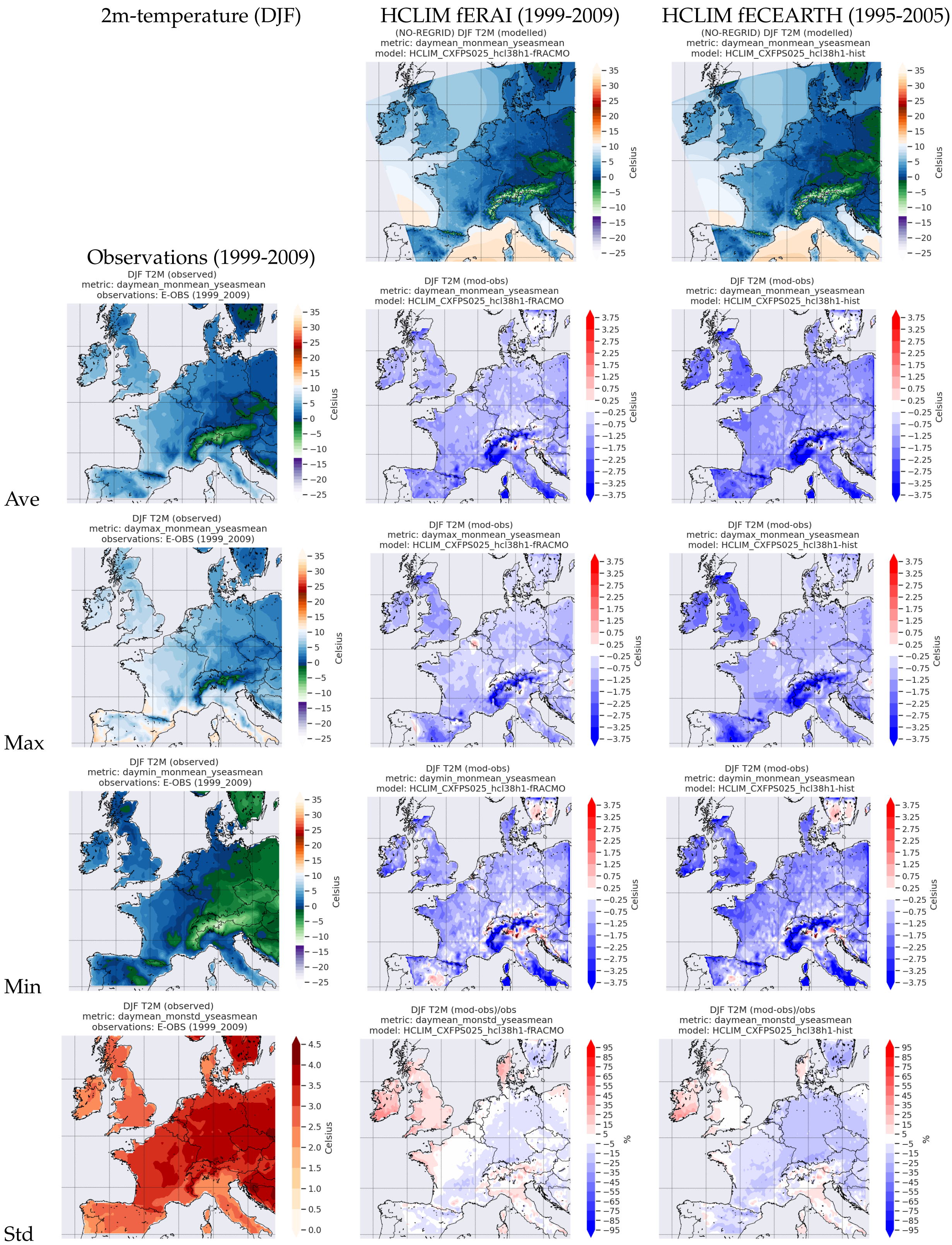

Figure 1: ***DJF T2M***. *Top row: Model native-grid seasonal averages. Left: HCLIM run forced by ERA-Interim; right: HCLIM run forced by EC-Earth. Left column: Observations top-bottom: daymean, daymax, daymin and monthly sd based on daily mean. The remaining panels show the model-obs absolute and relative differences for the fields on the left. Temperature is corrected for height-differences using adiabatic lapse rate.*

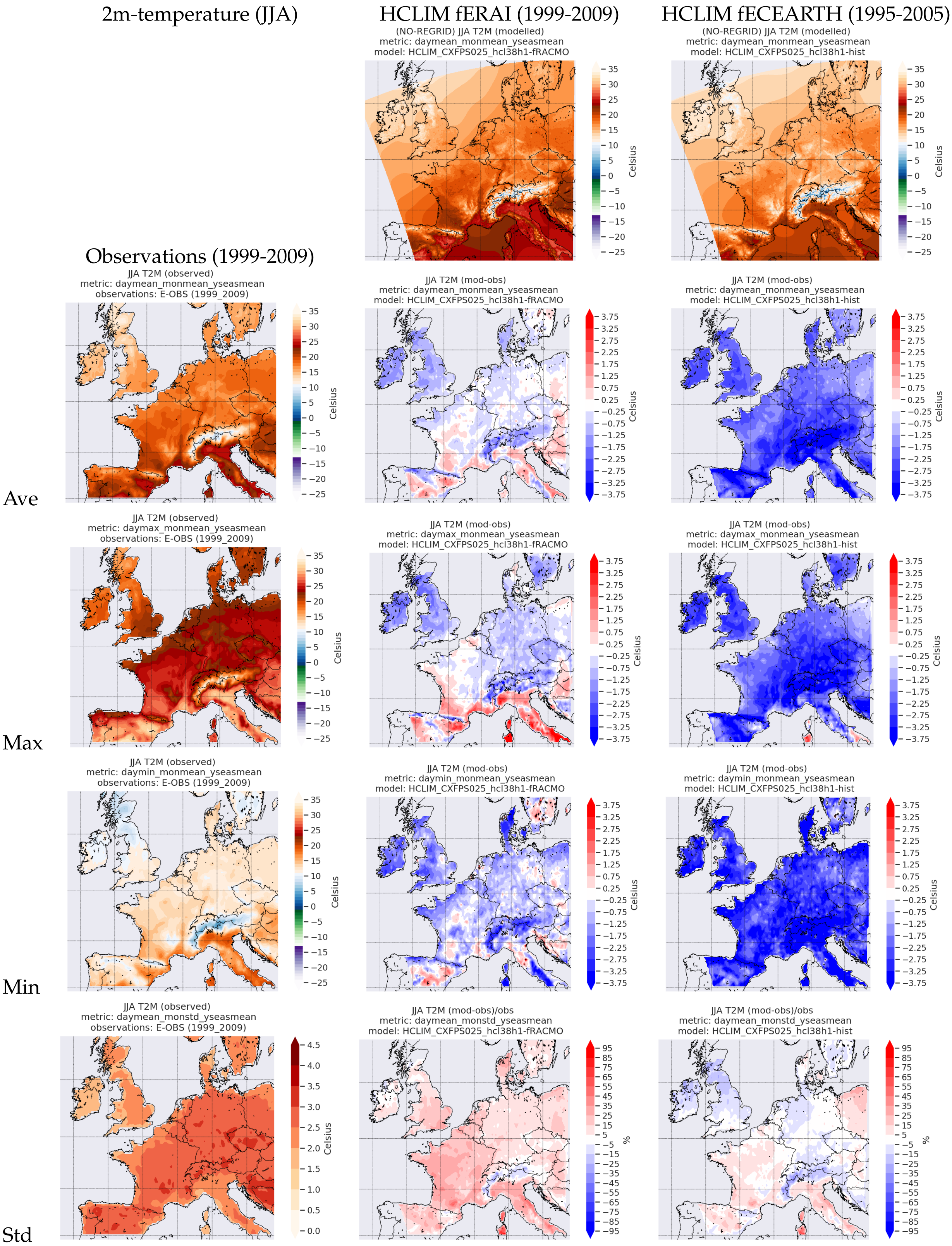

Figure 2: ***JJA T2M***. *Top row: Model native-grid seasonal averages. Left: HCLIM run forced by ERA-Interim; right: HCLIM run forced by EC-Earth. Left column: Observations top-bottom: daymean, daymax, daymin and monthly sd based on daily mean. The remaining panels show the model-obs absolute and relative differences for the fields on the left. Temperature is corrected for height-differences using adiabatic lapse rate.*

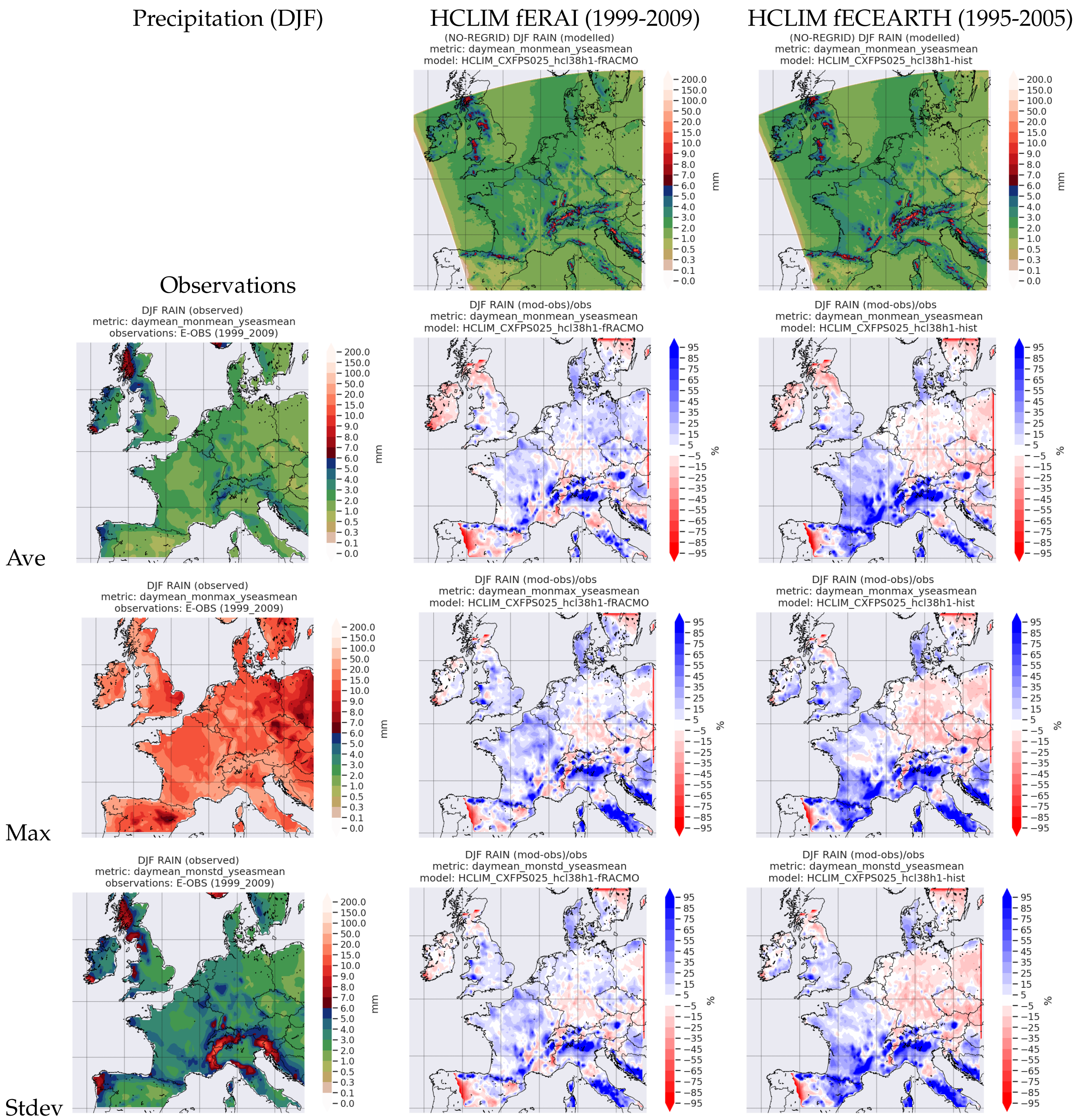

Figure 3: ***DJF RAIN***. *Top row: Model native-grid seasonal averages. Left: HCLIM run forced by ERA-Interim; right: HCLIM run forced by EC-Earth. Left column: Observations top-bottom: daysum, monmax and monthly sd based on daily sum. The remaining panels show the model-obs absolute and relative differences for the fields on the left.*

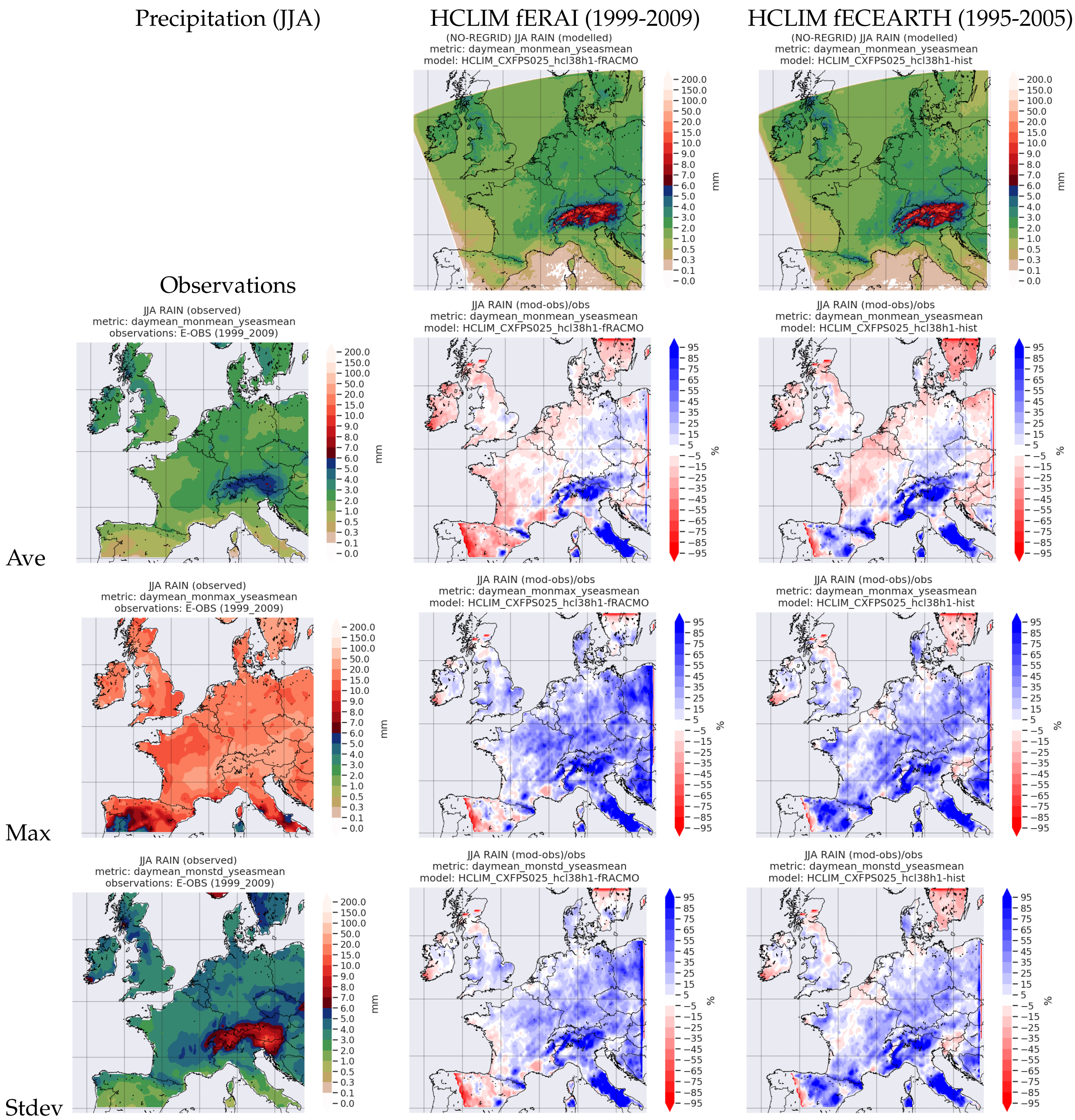

Figure 4: ***JJA RAIN***. *Top row: Model native-grid seasonal averages. Left: HCLIM run forced by ERA-Interim; right: HCLIM run forced by EC-Earth. Left column: Observations top-bottom: daysum, monmax and monthly sd based on daily sum. The remaining panels show the model-obs absolute and relative differences for the fields on the left.*

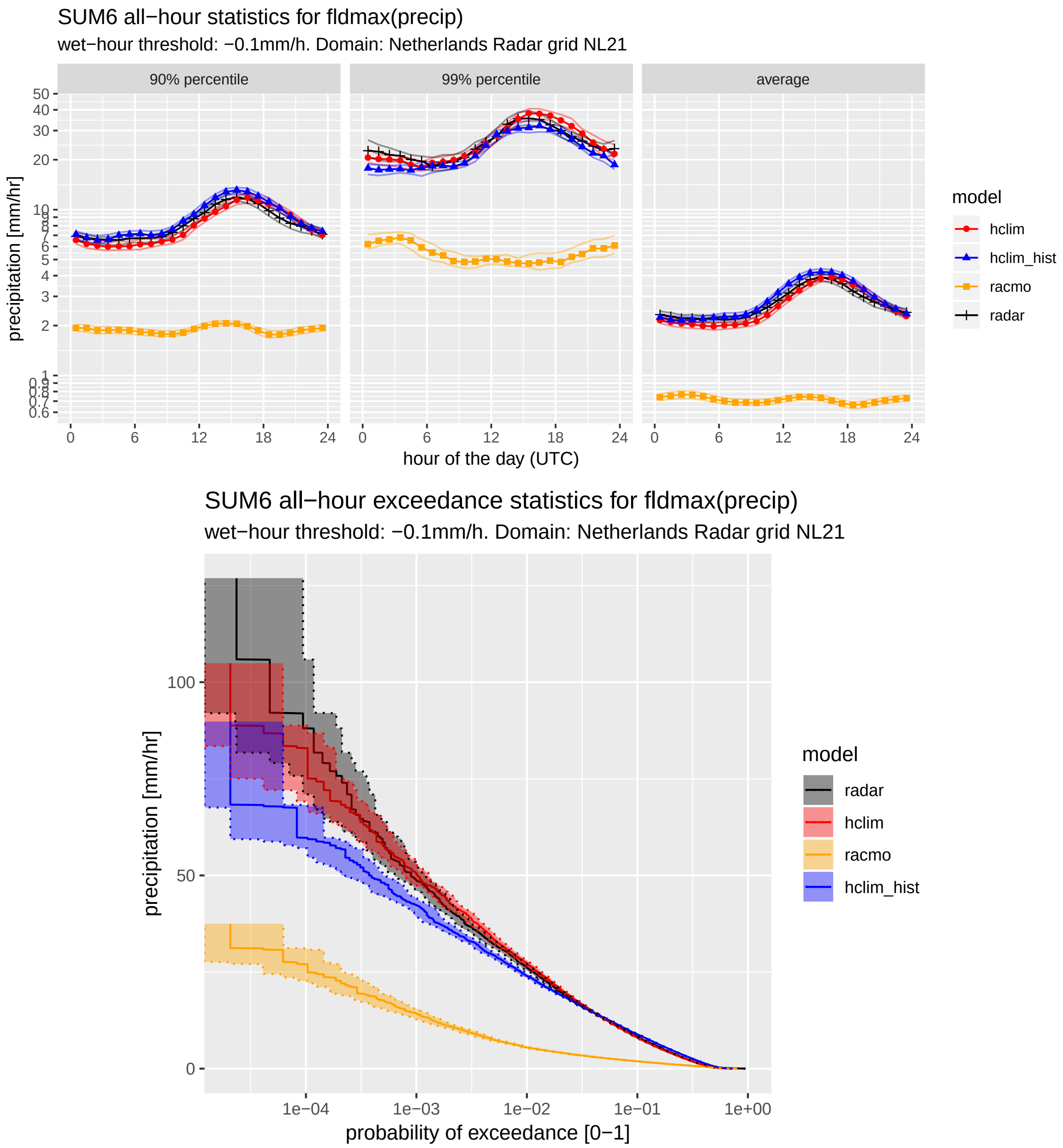

Figure 5: ***Summer FLDMAX precipitation over the Netherlands***. *Top: diurnal cycle of two percentiles and the average FLDMAX. Bottom-row. Exceedance frequencies. Color labeling: Radar (black); ERA-Interim forced HCLIM run (red, hclim) and the corresponding RACMO2 run (racmo, orange); EC-Earth forced HCLIM run (bluem hclim_hist).*

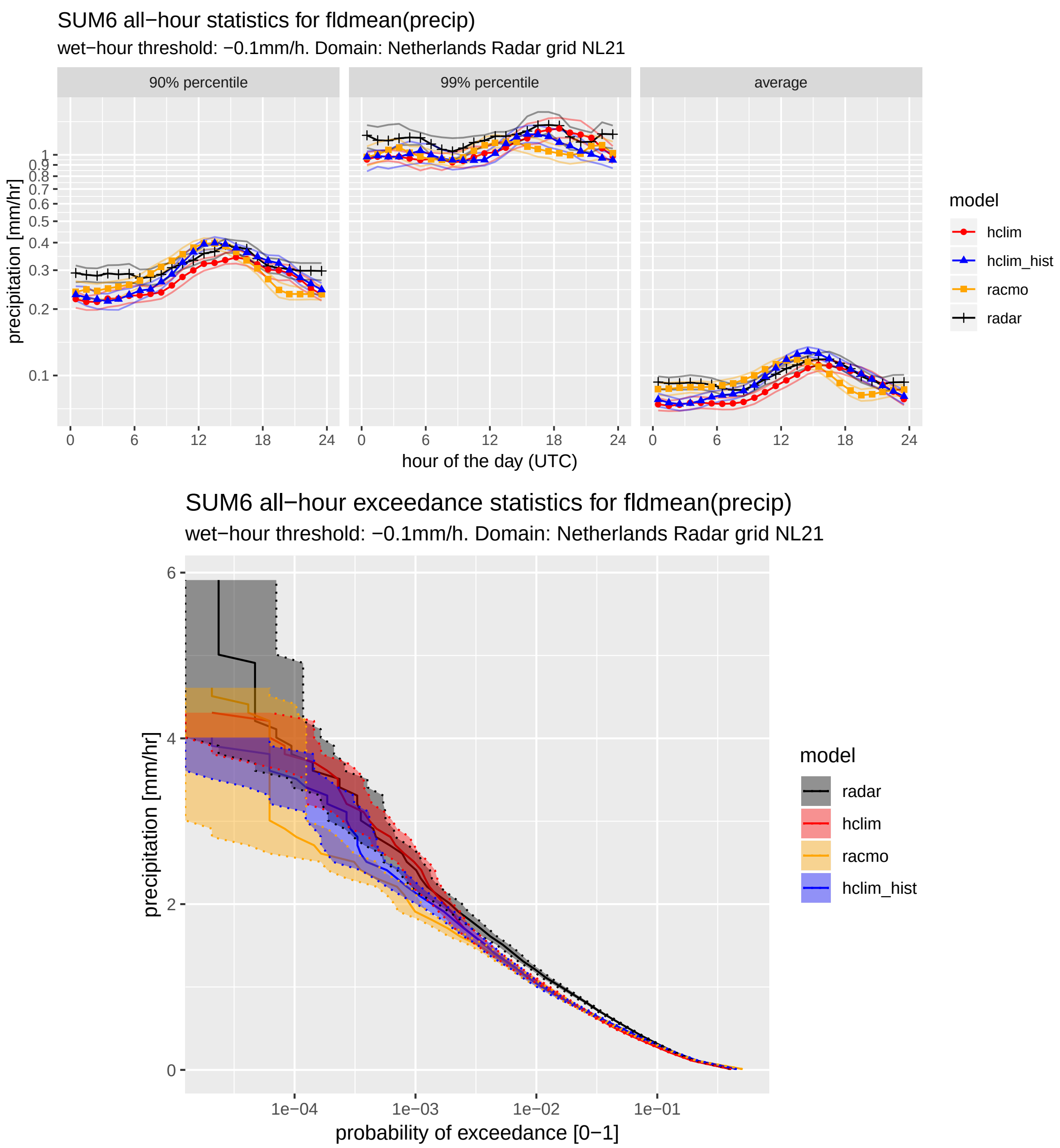

Figure 6: ***Summer FLDMEAN precipitation over the Netherlands***. *Further as in Fig 5.*

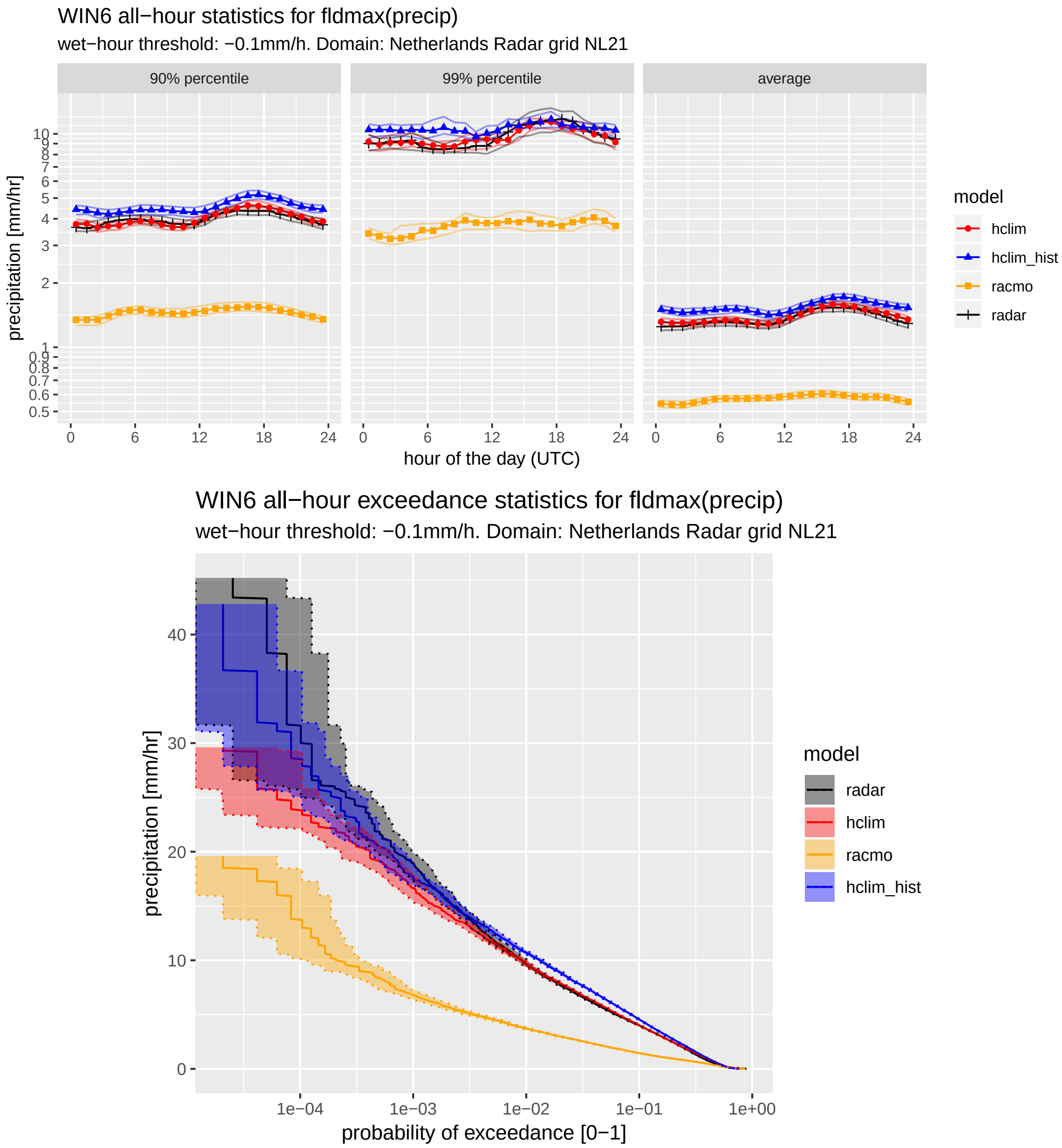

Figure 7: ***Winter FLDMAX precipitation over the Netherlands***. *Further as in Fig 5.*

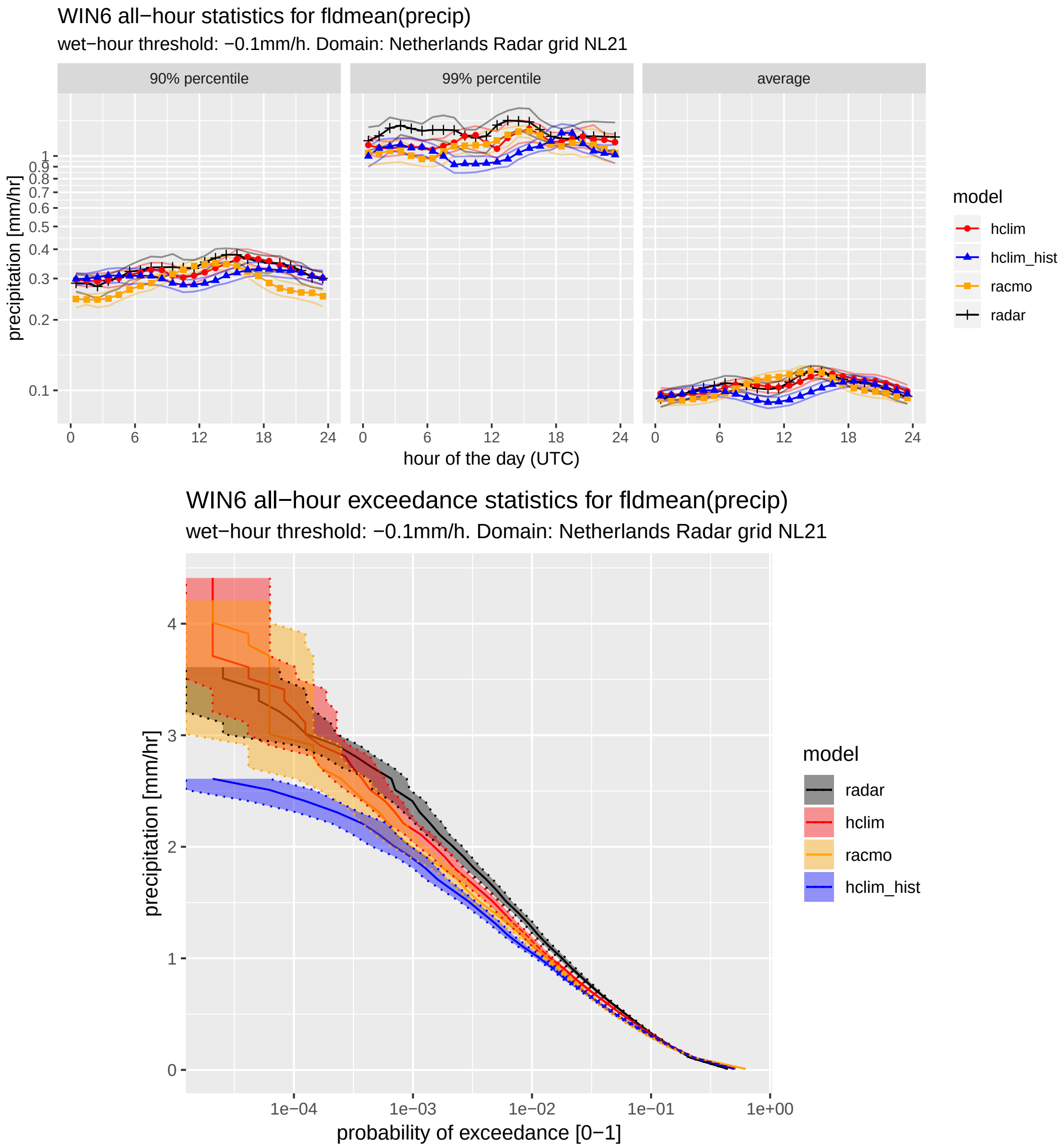

Figure 8: ***Winter FLDMEAN precipitation over the Netherlands***. *Further as in Fig 5.*