SPECIAL PROJECT FINAL REPORT

All the following mandatory information needs to be provided.

Project Title:	Extreme weather and the midlatitude response to recent decadal warming in OpenIFS
Computer Project Account:	spdekjel
Start Year - End Year :	2018 - 2018.
Principal Investigator(s)	Dr. Joakim Kjellsson
Affiliation/Address:	GEOMAR Düsternbrooker Weg 20 241 05 Kiel Germany
Other Researchers (Name/ Affiliation):	Prof. Dr. Mojib Latif, GEOMAR

The following should cover the entire project duration.

Summary of project objectives

(10 lines max)

Simulate the DJF season for the period 1982-1987 and 2012-2017. Study how wind storms and heavy precipitation events respond to the decadal warming between the two periods. Also compare high-resolution simulations with other low-resolution simulations to study the impact of model resolution on the simulated surface climate.

Summary of problems encountered

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

Initial technical problems, e.g. transferring data to/from ECMWF, compiling OpenIFS, and achieving acceptable model performance at ECMWF CCA cluster. We have overcome these problems now with the help from ECMWF helpdesk and OpenIFS team.

Experience with the Special Project framework

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

We have found the framework good, and have no negative remarks. The possibility to run OpenIFS at ECMWF where it has been tested before has been much easier than installing the model elsewhere.

Summary of results

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

Please see attached pdf file.

List of publications/reports from the project with complete references

Evaluation and testing of OpenIFS will be presented in the coming paper "Carver et al., The ECMWF OpenIFS numerical weather prediction model release cycle 40r1: description and use cases".
Analysis of changes in extreme precipitation was presented at the PalMod Open Science Conference and the EGU General Assembly.
A manuscript on the response of extreme precipitation to recent decadal warming in OpenIFS at varying horizontal resolution is currently being prepared.

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.)

Our results of changes in extreme DJF precipitation over Europe in OpenIFS were interesting, and we propose to extend this project in 2019-2020 to also simulate the JJAS season. We also wish to force OpenIFS with not just the observed changes in SST and sea ice but also changes from climate-model simulations of the late 21st century. Our proposed extension will therefore require a larger compute budget and run over a longer period of time.

Recent changes in precipitation, ECMWF report, June 2019

Joakim Kjellsson

June 2019

1 Project summary

The project set out with the objective to study how the midlatitude atmosphere and in particular weather extremes respond to surface change, and to what extent the response is dependent on model resolution. The simulations were partly carried out at the North-German supercomputer centre (HLRN) but we wished to push the model resolution towards that of operational forecasts which would not fit into our current compute budget. We therefore carried out experiments using a T1279 L137 configuration of the OpenIFS model at ECMWF CCA, simulating 10 winter periods (NDJF) to compare with the simulations of the same winters carried out using T159 L91, T255 L60 and T511 L91 configurations at HLRN.

2 Problems encountered

We encountered some technical problems when running the OpenIFS model. Firstly, we performed short test runs with both the Intel and Cray compilers and found that the Intel compilers, for some reason, resulted in a much slower model. Secondly, we struggled a bit with developing a proper script that runs the OpenIFS model, and the automatically restarts from the last

Table 1: Details of model configurations

Configuration	T159/L91	T511/L91	T1279/L137
Spectral truncation	T159	T511	T1279
Cluster used	HLRN	HLRN	ECMWF
Horizontal grid resolution	$\sim 1.125°$	$\sim 0.35°$	$\sim 0.14°$
Vertical levels	91	91	137
Time step [min]	60	15	10

time step, and post processes the output data. In the end, the model output was transferred to a cluster at Kiel University, Germany, where the post processing was done.

3 Experience with the project framework

We have found the special projects framework to work really well. The application procedure was relatively simple, although we would prefer to work with either online forms or Latex files rather than templates in MS Word. Technical support from ECMWF has been excellent and we also appreciate the monthly updates of the current budget.

4 Summary of results

We have investigated how extreme precipitation events are represented in climate models using the atmosphere model OpenIFS (Carver et al., 2018) at various horizontal resolutions. Intense precipitation events typically occur on sub-daily and sub-synoptic scales, and may therefore not be well represented in climate models using a horizontal resolution of ~ 100 km and daily-mean model output.

We ran a set of experiments with the OpenIFS model (Table 1) using T_L159 (typical climate-model resolution), T_L511 (typical high-resolution climate model or ensemble forecasts)[1] and T_L1279 (typical operational weather forecasts)[2] resolutions. To understand how precipitation has changed in the recent decades we simulated two time periods, 1982-1987 and 2012-2017, between which we have seen a global-mean surface warming of ~ 1 K. Only the highest-resolution simulations, T1279, which are the most expensive in terms of computation and storage, were carried out at the ECMWF HPC. To save computational cost, we only simulated the winter months, NDJF. All simulations used initial conditions and surface forcing data from prepIFS. Model output was stored every 6 hours.

Overall, the mean precipitation over Europe is well represented in OpenIFS, with relatively small biases which are reduced as horizontal resolution is increased beyond T159 (Fig. 1). Generally, the biases are smaller over land than over ocean. The most striking biases are over the North and Nordic Seas, and the T159 simulation also shows strong biases over the Scandinavian mountain regions. It is unclear what causes this bias.

While the mean precipitation in the simulations are comparable, we find significant differences in the 99th percentiles of precipitation, where T159 generally exhibits less intensity. We speculate that this is because the higher resolution simulations have deeper cyclones (Jung et al., 2012) and sharper horizontal gradients which can drive more intense precipitation events (Volosciuk et al., 2015). Regions of steep topography show more intense 99th percentile precipitation at higher resolution, which is to be expected as the topography slopes and vertical velocities can increase with increased horizontal resolution. Overall, increasing horizontal resolution leads to changes in the mean and 99th percentile precipitation of the same sign, suggesting that the precipitation distributions widen or narrow while retaining their overall shapes.

[1] T511L91 is the resolution of high-resolution runs with EC-Earth

[2] T1279 was the HRES resolution until 2016

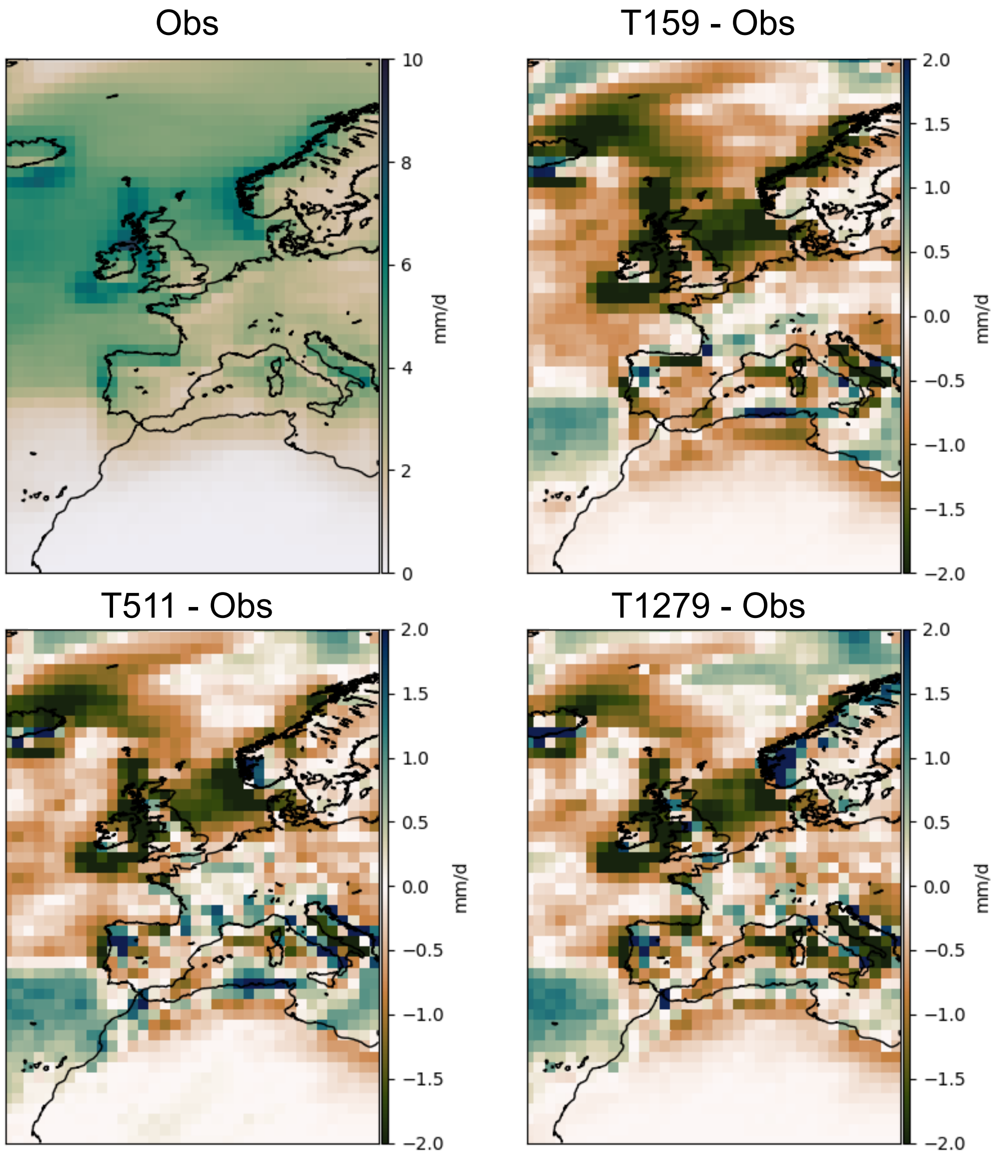

Figure 1: Bias in mean DJF precipitation in our T159, T511 and T1279 simulations as compared to GPCP observations.

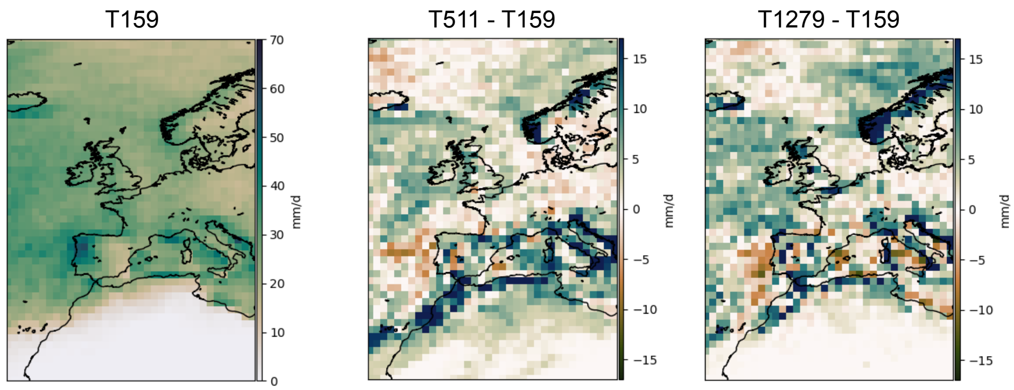

Figure 2: 99th percentile precipitation in winters 2012-2017 in T159, T511 and T1279 simulations. All data has been regridded to a N80 grid.

From the period 1982-1987 to 2012-2017, the global-mean surface temperature has increased by ~ 1 K, and by comparing the simulations of these two time periods we can estimate how surface warming impacts precipitation. Overall, the mean precipitation decreases over central Europe in the T159 simulation while the two higher resolution simulations show almost no change over this region (Fig. 3). Near the topography over the northern Iberian Peninsula, the precipitation increases in T511 and T1279 simulations but decreases in T159. Observations from the E-Obs dataset (not shown) confirm a recent increase in precipitation over this region, so this is a clear deficiency of the T159 simulation, likely due to inaccuracies in the representation of topography.

It should be noted that 1982-1987 was a period of relatively neutral NAO indices while 2012-2017 saw quite strong positive NAO indices. The simulated change in precipitation, i.e. overall wetter Northern Europe and drier Southern Europe, is associated with positive NAO. The surface warming between the two periods and the change in precipitation can thus not be directly linked to global warming since it is strongly affected by natural variability.

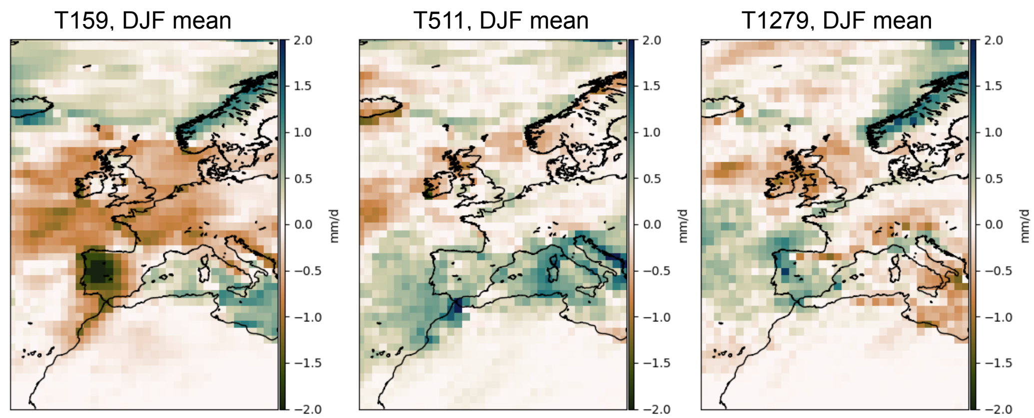

Figure 3: Difference in mean winter precipitation between 1982-1987 and 2012-2017 in our T159, T511 and T1279 simulations.

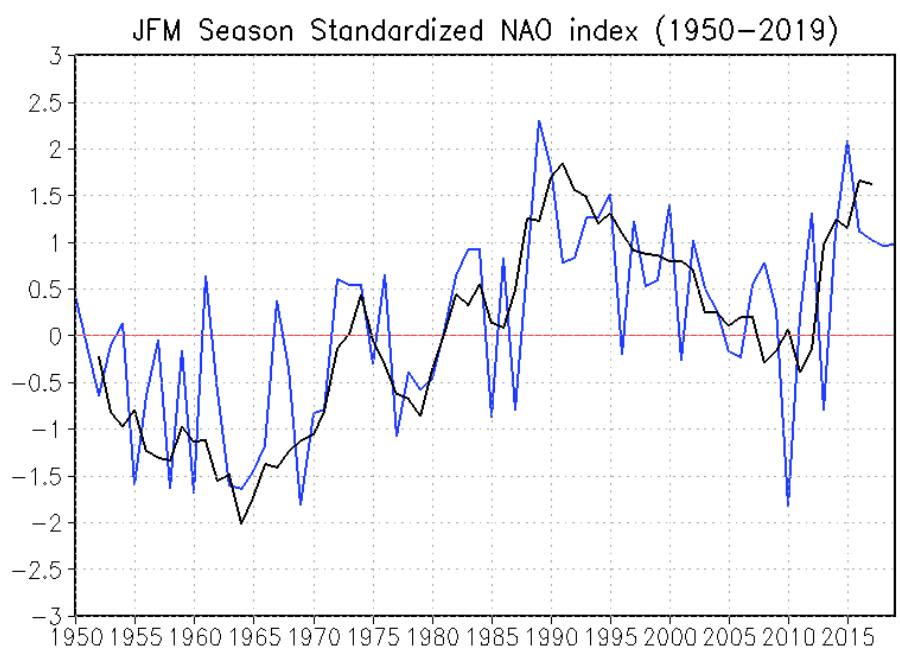

Figure 4: JFM NAO index from https://www.cpc.ncep.noaa.gov/products/precip/CWlink/pna/JFM_season_nao_index.shtml

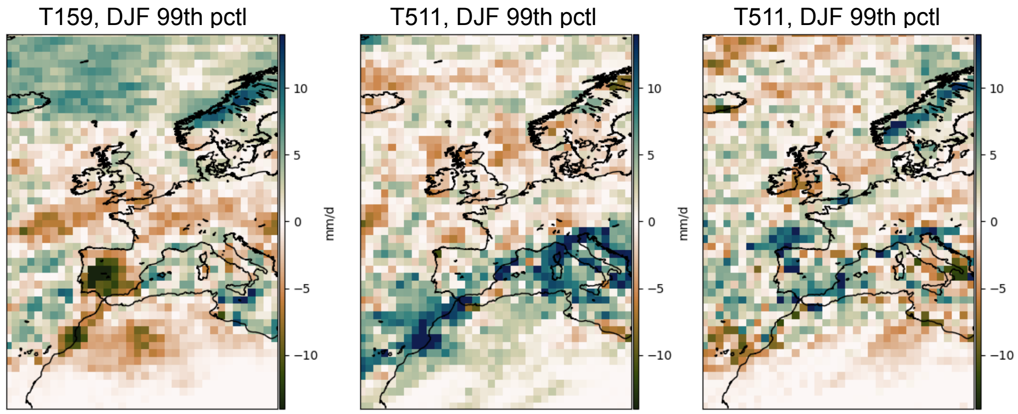

Figure 5: Same as Fig. 3, but for the 99th percentile of precipitation.

The response of the 99th percentile precipitation to recent warming is more noisy, but is generally of the same sign as the change in mean precipitation, indicating a widening of the precipitation distribution where the mean increases and a narrowing where it decreases.

It is unclear why the mean and 99th percentile of precipitation decreases over Scandinavia in the T511 simulation, while it increases in T159 and T1279 as well as in E-obs observations. We speculate that the synoptic-scale circulation is biased due to non-local biases which cause a shift in the storm tracks. Future work will explore this further.

Furthermore, we have studied the numerical performance and scalability of the OpenIFS model (Fig 6). We find that OpenIFS is a very scalable model, but that the sequential writing of model output to disk presents a bottleneck when saving variables on all model levels at a sub-daily frequency. This is likely the reason why the T1279 configuration does not scale as well as the T159 and T511 configurations.

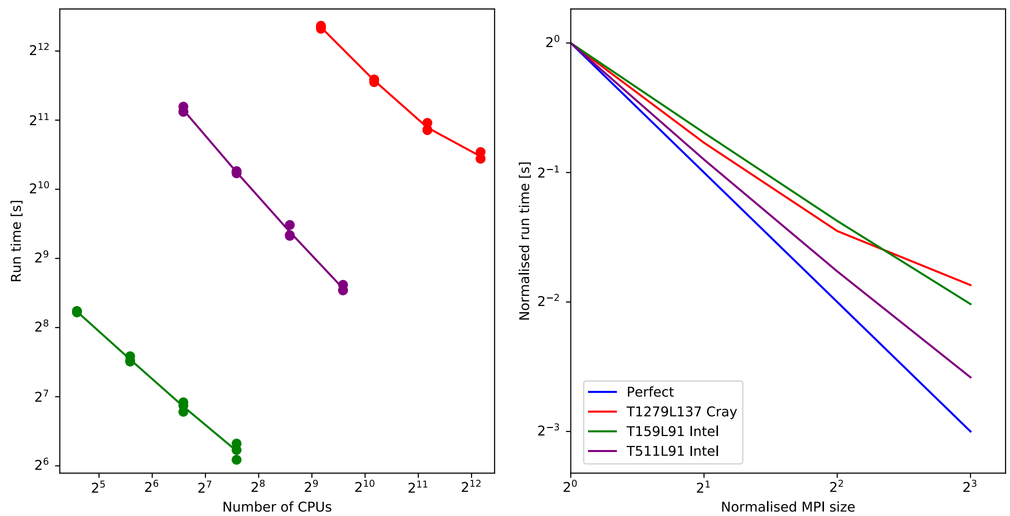

Figure 6: Number of MPI tasks and run time of 5-day forecasts with OpenIFS.

5 Publications from the project

- *Carver, G., and others (2019), The ECMWF OpenIFS numerical weather prediction model release cycle 40r1: description and use cases, manuscript in preparation.*
  This paper is a model description paper for OpenIFS CY40R1 where our performance tests are presented.

- *Kjellsson, J., Park, W. and Latif, M. (2019), Extreme weather events in high-resolution simulations with OpenIFS, manuscript in preparation.*
  Most of the results in this report are taken from this paper which is currently in preparation.

6 Future work

Future work includes further examining how weather extremes such as heavy precipitation and heat waves respond to various patterns of surface warming, in particular focusing on summer. This will be part of the special project SPDEKJEL in 2019-2020. We have also successfully performed simulations with OpenIFS T159L91 coupled to the NEMO ORCA05 ocean model via OASIS3-MCT3 and this coupled model also be used to study weather extremes and how they are impacted by air-sea interactions. In the near future, we will also upgrade our OpenIFS model to cycle 43, release 3, which includes several new features to improve the computational efficiency and accuracy of OpenIFS.

References

Carver, G., G. Szepszo, F. Vana, and J. Kjellsson, 2018: The ECMWF OpenIFS numerical weather prediction model release cycle 40r1: description and use cases (in prep.).

Jung, T., M. J. Miller, T. N. Palmer, P. Towers, N. Wedi, D. Achuthavarier, J. M. Adams, E. L. Altshuler, B. A. Cash, J. L. Kinter, L. Marx, C. Stan, and K. I. Hodges, 2012: High-resolution global climate simulations with the ECMWF model in project athena: Experimental design, model climate, and seasonal forecast skill. *Journal of Climate*, **25**, 3155–3172.

Volosciuk, C., D. Maraun, V. A. Semenov, and W. Park, 2015: Extreme precipitation in an atmosphere general circulation model: Impact of horizontal and vertical model resolutions. *Journal of Climate*, **28**(3), 1184–1205.