LATE REQUEST FOR A SPECIAL PROJECT 2018–2020

MEMBER STATE: Germany

This form needs to be submitted via the relevant National Meteorological Service.

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Project Title: Extreme Weather and the Midlatitude Response to Recent Decadal Warming in OpenIFS

If this is a continuation of an existing project, please state the computer project account assigned previously.	**SP** ________________	
Starting year: (A project can have a duration of up to 3 years, agreed at the beginning of the project.)	2018	
Would you accept support for 1 year only, if necessary?	YES [X]	NO [ ]

Computer resources required for the years: (To make changes to an existing project please submit an amended version of the original form.)		**2018**	**2019**	**2020**
High Performance Computing Facility	(SBU)	10 Million	0	0
Accumulated data storage (total archive volume)[2]	(GB)	15 000	0	0

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[1] The Principal Investigator will act as contact person for this Special Project and, in particular, will be asked to register the project, provide an annual progress report of the project's activities, etc.

[2] If e.g. you archive x GB in year one and y GB in year two and don't delete anything you need to request x + y GB for the second project year.

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Extended abstract

All Special Project requests should provide an abstract/project description including a scientific plan, a justification of the computer resources requested and the technical characteristics of the code to be used.

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Extreme Weather and the Midlatitude Response to Recent Decadal Warming in OpenIFS

Joakim Kjellsson & Mojib Latif
GEOMAR Kiel, Germany

November 23, 2017

Short summary

- Assess the sensitivity of extreme weather events and the midlatitude atmospheric circulation to recent decadal warming and horizontal resolution in the OpenIFS model.
- Understand and quantify model biases that arise due to insufficient horizontal resolution.
- Outcomes will guide the development of a new high-resolution coupled climate model at GEOMAR, but will also be beneficial for other modelling groups.

Overview

Our knowledge of climate change and climate variability in the 21st century largely relies on predictions using climate models. The climate-model simulations in the CMIP5 archive can generally reproduce the observed large-scale flow and low-frequency variability, but do not have fine enough horizontal or vertical resolution to resolve mesoscale flows ($\sim 10-100$km) and their associated variations, e.g. oceanic eddies or tropical cyclones. It is well established that increasing the horizontal resolution of the atmosphere model reduces biases and improves the simulation of e.g. precipitation (Wehner et al., 2014), development of extreme storms (Wedi et al., 2012), tropical atmosphere-ocean interactions (Harlaß et al., 2017), and tropical storms (Atlas et al., 2005). We will study extreme weather events and the Northern and Southern midlatitude circulation in the OpenIFS model, using a suite of experiments at T255, T511 and T1023 spectral truncation. The aim is to understand how extreme weather responds to decadal warming, as well as what horizontal resolution is sufficient to reproduce the observed response, and what biases may arise from insufficient horizontal resolution.

This project runs in parallel with a project on the impacts of horizontal resolution in OpenIFS at the HLRN high-performance cluster in Hannover & Berlin, Germany. Current developments of a high-resolution climate model, FOCI, based on OpenIFS and NEMO, will be guided by the results of this project. The results of this project will be beneficial for other climate-modelling groups as well, e.g. EC-Earth and FESOM2, which are coupling with OpenIFS.

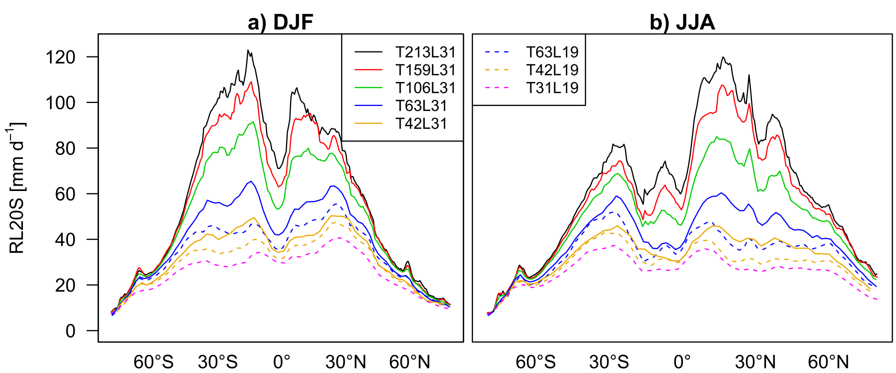

Figure 1: Zonal mean of 20-year return values of winter precipitation. Extreme precipitation events become more extreme with higher resolution of the atmosphere model. Taken from Volosciuk et al. (2015).

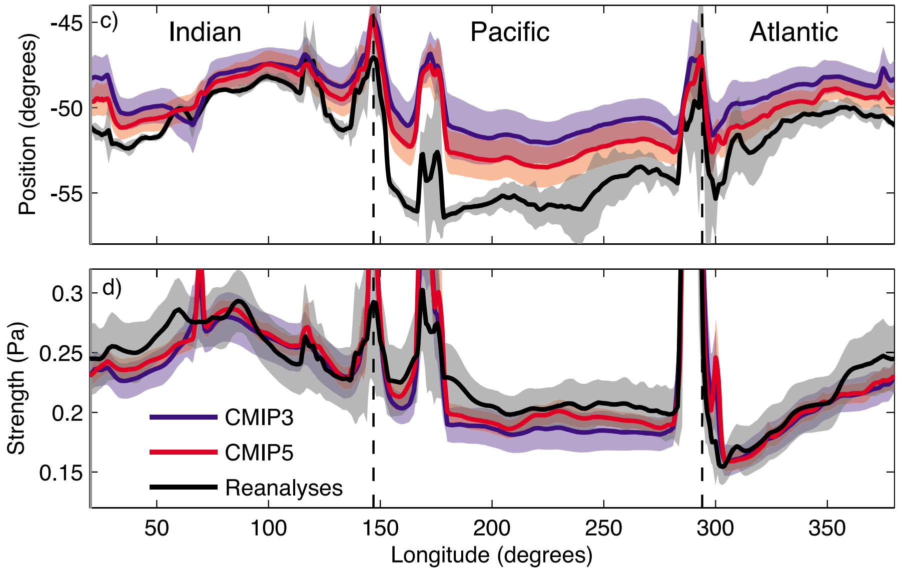

Figure 2: Position (top) and strength (bottom) of the westerlies over the Southern Ocean in reanalysis, CMIP3 and CMIP5 data. The jets are too far north and too strong in the CMIP3 and CMIP5 models. Taken from Swart and Fyfe (2012).

Specific examples

Extreme weather

Extreme weather events, e.g. tropical storms, heat waves, or heavy-precipitation, are events of large socio-economic impacts. Studies applying theory and a few climate models suggest that most extreme weather events will become more intense during the 21st century in response to global warming, and also that these events can only be represented in atmosphere models which resolve the mesoscale ($10 - 100$ km), which is not the case for the climate models used in the latest IPCC report (AR5). Previous studies (Wehner et al., 2014; Frei et al., 2006; Volosciuk et al., 2015) have shown that the intensity of e.g. extreme precipitation events is sensitive to the horizontal resolution of the atmospheric model (Fig. 1). However, few studies have used horizontal resolutions finer than $\sim 0.5°$ (~ 50 km). Here, we will study how the horizontal resolution of an atmosphere model impacts its ability to simulate the frequency and intensity of extreme weather events as well as their recent trends. Our main focus will be on heavy precipitation, strong winds and heat waves. We will use a horizontal resolution (T1023L91) that is higher than any previous studies which address extreme events globally. By using OpenIFS we will use a model that has already been well tuned to present-day climate, thereby increasing the realism of our simulations. While it is not a focus in this project, the model output may be used later to investigate tropical storms as well. Further, the model output may also be of interest to other research groups.

Midlatitude atmospheric circulation and trends

It has been proposed that the sea-ice loss and enhanced surface warming in the Arctic region, which weakens the meridional temperature gradient and slows down the Rossby-wave propagation in the Northern Hemisphere (NH) midlatitudes, could result in more persistent extreme weather events, e.g. cold spells and droughts (Francis and Vavrus, 2012). While Arctic surface warming can alter the NH midlatitude jet stream, it is unclear if it has done so recently (Barnes and Screen, 2015). Experiments with climate models have shown that the response of the Northern midlatitude atmospheric circulation to Arctic warming is highly dependent on the air-sea interactions (Deser et al., 2015), which in turn are sensitive to the horizontal resolution of the atmosphere and ocean models (Roberts et al., 2016). Using the OpenIFS model at varying horizontal resolution, we will investigate if the link between the Arctic warming and trends in midlatitude extreme weather is sensitive to the horizontal resolution of the atmosphere model.

We will also study the atmospheric circulation over the Southern Ocean. The Southern Ocean and the North Atlantic are the only regions with oceanic deep-water formation, e.g. where the atmosphere is effectively in contact with the deep ocean. Climate models generally struggle to reproduce the correct properties of the surface waters in regions of deep-water formation, but Stössel et al. (2015) reduced biases by increasing the horizontal resolution of the atmosphere model. We will investigate how the surface climate over the Southern Ocean changes when horizontal resolution is increased. Furthermore, a common bias in climate models in the

Table 1: Details and costs of model experiment to be carried out.

Parameter	**T255**	**T511**	**T1023**
Spectral truncation	T255	T511	T1023
Cluster used	HLRN	HLRN	ECMWF
Horizontal grid resolution	$\sim 0.7°$	$\sim 0.35°$	$\sim 0.18°$
Vertical levels	91	91	91
Time step [min]	45	15	10
Simulated years	1982-2016	1982-2016	1982-1987 / 2011-2016
Ensemble members	3	3	1
Est. cost [SBU/sim.year]	N/A	N/A	1 million
Est. total cost [SBU]	N/A	N/A	10 million
Est. total output (6-hourly) [Tb]	9	38	15

CMIP5 archive is that the westerlies over the Southern Ocean are too strong and located too far north (Fig. 2), and wind variability is too zonal (Schroeter et al., 2017). In the Northern Hemisphere, Hourdin et al. (2013) showed that increasing the horizontal resolution leads to more realistic midlatitude westerlies, suggesting similar improvements may be attainable for the Southern Hemisphere, and Jung et al. (2012) noticed changes to the Amundsen Sea Low as horizontal resolution was increased from T159 to T511 and further to T1279.

Model experiments

This project runs in parallel with another project at the North-German HLRN cluster[1]. At HLRN, we will run ensembles of global simulations using the OpenIFS model at T255L91 and T511L91 resolution, focusing on the atmospheric response to the horizontal and temporal resolution of the lower boundary condition, which we will vary between 1° and 0.25° horizontal resolution and daily to monthly temporal resolution. Previous results showed a rather strong sensitivity to both the temporal and horizontal resolution of the surface forcing (Zhou et al., 2015). The HLRN clusters comprise in total two Cray XC30 and two Cray XC40 systems (all with support for hyperthreading), and OpenIFS has been successfully installed and tested on all.

We propose to run two 5-year simulations of the global atmosphere of 1982-1987 and 2011-2016 (10 years total) with specified observed surface forcing using OpenIFS at T1023/N512 horizontal resolution with 91 vertical levels. Combining the T1023L91 simulation with the results from the simulations at T255L91 and T511L91 resolution (carried out at HLRN, Germany) we will study the impact of horizontal resolution on the atmospheric general circulation, extreme weather events, and the atmospheric response to changes in SSTs and sea ice cover from the period 1982-1987 to 2011-2016. We will use the NOAA High Resolution (0.25°) data set of sea-surface temperature and sea ice cover as lower boundary condition, which is available from 1982-2016. Details of the model experiments are given in Table 1.

Since extreme precipitation events are short-lived ($\sim$ 1 hour), we will store precipitation variables with hourly frequency. We will also store horizontal velocities, temperature and specific humidity on all model levels with 6-hourly frequency to properly capture midlatitude storms. Storing 6-hourly data will also allow us to use the output in possible future projects, e.g. tracking paths and intensities of tropical storms. Table 1 shows the estimated total output of 6-hourly data from the OpenIFS experiments. End storage will be on the local tape storage shared between GEOMAR and Christian-Albrechts Universität (CAU) in Kiel.

Outcomes

The key outcome of this project is to understand to what extent coarser-resolution models are able to capture the frequency and intensity of extreme weather events as well as trends in the midlatitude circulation, and what biases may arise from using insufficient horizontal resolution. As many state-of-the-art climate models will soon employ atmospheric models of $\sim 0.5 - 1°$ horizontal resolution, it is important to understand to what extent such models capture the frequency and intensity of extreme weather events, as well as air-sea fluxes in the polar regions, and transports of heat and water. Awareness of these biases is crucial for our confidence in climate model projections of future climates. Currently, OpenIFS is being applied as the atmosphere component in climate models at GEOMAR, Alfred-Wegner Institute (AWI), and the EC-Earth consortium. Understanding how horizontal resolution impacts the simulated climate as well as its variations and extremes will guide the decision on what horizontal resolution is necessary in future high-resolution climate simulations, and ultimately

[1]Project no. shk00018, lead by Prof. Dr. Mojib Latif, GEOMAR

improve predictions of future climates and extreme events.

All output from the global simulations with OpenIFS will be stored and made available upon request to anyone who wishes to use it for research or teaching purposes. The model output may be used by BSc or MSc courses on atmosphere modelling in Kiel or other places, or students who wish to pursue a MSc project on e.g. the impacts of horizontal resolution on various atmospheric phenomena. The data may also be used for future research projects on how horizontal resolution impacts the model's ability to simulate e.g. quasi-biennial oscillation (QBO, cf. Hertwig et al. (2015)), tropical storms (cf. Atlas et al. (2005)), mesoscale energy spectra (e.g. Augier and Lindborg (2013)), or atmospheric air-mass transformations in the thermodynamical framework of Kjellsson et al. (2014) or Laliberté et al. (2015).

Project members

Dr. Joakim Kjellsson (Principal Investigator)
Dr. Joakim Kjellsson was awarded his PhD at Stockholm University in 2014, in which he studied how the global atmospheric circulation varies during ENSO phases and how it will change with global warming. He has experience in ocean and atmosphere modelling and was part of the pilot testing of OpenIFS in 2013. He has worked on how the kinetic energy budget in the ocean and air-sea exchanges of momentum depend on the horizontal resolution in ocean models, and is now working on coupling the OpenIFS model into the FOCI climate model at GEOMAR.

Prof. Dr. Mojib Latif
Prof. Dr. Mojib Latif leads the Marine Meteorology unit and the Ocean Circulation and Climate Dynamics division at GEOMAR Kiel. He has a long history of studying climate variability on timescales ranging from monthly, through decadal, to centennial and millennial timescales, as well studying air-sea interactions in the tropical regions. The Marine Meterology unit at GEOMAR has a strong focus on modelling air-sea interactions to understand the atmospheric and oceanic role in climate variability on a wide range of timescales, e.g. the Madden Julian Oscillation (MJO), the North Atlantic Oscillation (NAO), the El Niño/Southern Oscillation (ENSO), the Atlantic Multidecadal Variability (AMV) or the Pacific Decadal Variability (PDV), as well as the climate response to (natural and anthropogenic) external forcing.

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