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The effect of the pathway to a two degrees warmer world on the regional temperature change of Europe

Cathrine Fox Maule [a,*], Thomas Mendlik [b], Ole B. Christensen [a]

[a] Danish Meteorological Institute, Climate and Arctic Research, Lyngbyvej 100, DK-2100 Copenhagen Ø, Denmark
[b] Wegener Center for Climate and Global Change and Institute for Geophysics, Astrophysics and Meteorology, University of Graz, Austria

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ABSTRACT

The purpose of this study is to investigate if the pathway to reach a 2 degree warmer world influences the regional climate in Europe at the time of 2 degrees of global warming above the pre-industrial level. We have investigated this using climate change data from ensembles of both Global Climate Models and Regional Climate Models. We compare the change of regional temperature in Europe to the global temperature change for different emission scenarios, following the IPCC Representative Concentration Pathways (RCP), to see if the pathway has any influence. We find that there is a small but significant difference in the regional temperature change, but the effect is small compared to internal variability on the timescales involved in reaching +2 degrees for the investigated emission scenarios. From an adaptation point of view, reaching +2 degrees as slowly as possible will obviously allow for a longer time period to implement adaptation measures to mitigate the effect of climate change.

Practical implications

At the UNFCCC Conference of the Parties in Cancun (UNFCCC, 2010), the parties agreed to prevent the global warming from increasing above 2 degrees relative to the pre-industrial level. The changes in the regional climate at this level of warming and the related impacts on e.g. health, tourism (e.g. Grillakis et al., 2015, 2016), energy consumption/production, agriculture and floods and droughts (e.g. Roudier et al., 2016) have been the focus of the recent EU-FP7 project IMPACT2C. Some of the main results regarding what a 2 degrees warmer world looks like are available in the IMPACT2C Atlas on https://www.atlas.impact2c.eu/en/ and in the policy briefs as e.g. *Effects of 2 °C Warming – IMPACT2C modelling results: climate change and sea-level rise from a 2 °C climate* (Watkiss et al., 2015, but see also Watkiss et al., 2013). The abovementioned goal of the UNFCCC of a global warming limit of +2 degrees implicates that it is of no importance how fast we reach this threshold, but that only the value of the global warming is important. It is a known fact that this is not the case for sea level rise, where the pathway to reaching +2 degrees is important for the projected mean sea level. The present study investigates if another parameter, namely the local and regional temperature change over Europe in a 2 degrees warmer world, is dependent on how long time it takes to reach the +2 degrees. The time to reach +2 degrees is dependent on emission path; the higher the level of emissions, the faster +2 degrees will be reached. If the regional temperature change is dependent on emission path, the consequences of global warming cannot simply be described at general levels of global warming but would need extra information about the pathway taken, hence complicating intercomparisons of impacts calculations. The globe does not warm completely uniformly due to varying thermal inertia of the climate system e.g. caused by the oceans' slower heat uptake. Generally land areas warm faster than ocean areas (IPCC, 2013). The degree of pathway dependence on the regional temperature change over Europe is investigated in this study using the available ensembles of GCM simulations for various emission scenarios.

We use a multi-model ensemble of 120 GCM simulations from CMIP5, distributed on 22 different GCM's and three RCP scenarios (RCP2.6, RCP4.5 and RCP8.5), and for each simulation determine the time when the global temperature reach 2 degrees above the pre-industrial level for a 30 year period. For this period we then calculate the regional temperature change over Europe. Analyzing this set of time to reach +2 degrees and regional temperature change data, we find that the regional temperature change does depend on the time to reach +2 degrees with a factor of about $9 \cdot 10^{-3}$ °C/yr. I.e. that if the time to reach +2 degrees can be prolonged

* Corresponding author.
E-mail addresses: cam@dmi.dk (C.F. Maule), thomas.mendlik@uni-graz.at (T. Mendlik), obc@dmi.dk (O.B. Christensen).

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by about 15 years, the regional temperature change over Europe will be reduced with about 0.14 °C; prolonging the time by about 25 years will reduce the average warming over Europe by about 0.23 °C.

Therefore from an adaptation point of view prolonging the time before +2 degrees is reached will not only allow for more time for implementing appropriate adaptation measures for the +2 degrees changed climate, it will also mean that the regional temperature change over Europe will be lower when that global value is reached than if the +2 degrees is reached quickly. This is likely to mean that consequences of high-temperatures like e.g. heat waves probably would be less in a world which reaches the +2 degrees slowly than in a world where the +2 degrees is reached quickly. In short, the sooner emissions are lowered, the higher the mitigation effects on local and regional temperature changes in Europe will be for a given global warming target like the +2-degree goal.

1. Introduction

This study is part of the FP7 project IMPACT2C, which investigates the impacts of a global warming of 2 °C (hereafter +2C) over the pre-industrial level. To investigate the consequences of such a +2C warming, an ensemble of climate model simulations is used, but IMPACT2C takes a novel approach on how to analyze the ensemble: Traditionally, the research focus lies on a well-defined future time-slice (for example 2021–2050 or 2071–2100), where statistical properties of an ensemble of climate models are investigated. In contrast to that, in IMPACT2C, the fact that different climate models project different temperature changes with time was embraced, and the future time-slices considered are defined as the period when the individual climate simulations used reach +2C for a 30 year period. In short each GCM will be analyzed for a different future time slice, and all these possible climates of +2C have been compared and are considered equal members of a +2C ensemble (Vautard et al., 2014). One of the advantages of this approach is that ensemble sizes can be increased, as simulations from different scenarios can be lumped together.

The assumption that the climate in a +2C world is independent of how fast the +2C is reached is thus fundamental in the IMPACT2C project. It is therefore worthwhile testing if this hypothesis holds. The +2C time-slices are picked out of transient simulations and correspond to different radiative forcings, aerosol loads and CO_2 concentrations, and very different rates of change. In this work we want to discuss whether those +2C worlds also can be compared on a regional scale. In particular we want to check whether reaching +2C global temperature change later in time has any implications on regional temperature change.

Studies such as Matthews et al. (2012) have shown that global warming projected by GCMs for a given year can largely be associated with cumulative CO_2 emissions, being independent of the underlying emission scenario; see also IPCC (2013) Fig. SPM10, when the multi-model mean of a large ensemble of GCMs is considered. So in this case given a cumulative carbon emission budget, global temperature warming can be estimated regardless of the specified time-slice or emission scenario. This would legitimate the comparison between different time-slices of +2C worlds shaped by different scenarios at least on a global scale. However, the individual GCMs have different climate sensitivities and disagree on the amount of global warming for a given cumulative emission.

It is well known that several processes in the climate system involve inertia, which makes it relevant to study if the path taken to reach +2C affects the regional climate. A number of studies have investigated the effect of thermal inertia in the climate system. Many are based on idealized experiments with either a sudden complete cessation of carbon emissions, an abrupt increase, or a short large-amplitude emission pulse; the response of the climate system to the sudden changes in atmospheric CO_2 content is then analyzed. Using such an idealized experiment where the forcing was abruptly returned to pre-industrial levels Held et al. (2010) probed the fast and slow components of changes in the near surface air temperature due to changes in the forcing. They found different spatial patterns of the fast and slow components; with the fast component generally having above average warmings over the continents and in the Arctic, whereas the slow component has a more distinct latitudinal dependence with above average warming poleward of 40°N and 40°S and below average warming in between. The fast component reacts very quickly to changes in forcing, with a characteristic time scale of less than 5 years, while the slow components have a typical time scale of a few decades. Effects on this time scale are relevant to the present study.

Several studies have touched on the issue of regional temperature change compared to global temperature change. Gillett et al. (2011) found that regional temperatures change even when the global mean temperature remains almost constant, due to processes of different thermal inertia, based on an experiment investigating the effects of a complete cessation of CO_2 emissions using the Canadian Earth System Model, CanESM1. In a different study by Ishizaki et al. (2012) the temperature scaling pattern dependency on the RCPs was investigated based on an ensemble of MIROC5 (Watanabe et al., 2010) simulations. They found scenario dependence of the surface air temperature scaling pattern over Europe which was mainly due to sulfate aerosols (Mitchell et al., 1999; Ishizaki et al., 2012). These studies based on single-model experiments indicate that the regional temperature change over Europe is not determined solely by the global temperature change. Taking a multi-model approach, a recent study by Christensen et al. (2015) based on a large ensemble of transient RCM simulations primarily from the EU FP7 project ENSEMBLES data base (van der Linden and Mitchell, 2009), found that many regional average fields, including temperature, over Europe scale linearly with global warming. In this study we take a multi-model approach and search for the effect detected in the above-mentioned single-model experiments; the main question is, whether thermal inertia has a detectable effect on the time-scales at which +2C is reached for the current scenarios.

We have investigated the effect of the scenario on the European climate exemplified by temperature in a +2C world. The scenarios we have investigated are standard IPCC scenarios, the so-called Representative Concentration Pathways (RCPs) (van Vuuren et al., 2011). Fig. 1 shows the radiative forcing of the four RCP scenarios, RCP2.6, RCP4.5, RCP6.0 and RCP8.5. It is evident from the figure that until 2025–2030 the different RCPs follow each other very closely. Any effect of the scenario on the change in global mean temperature can obviously only be detected when the scenarios differ significantly with respect to radiative forcing. Recent analyses conclude that the maximum warming caused by pulse emissions of CO_2 manifest themselves about 10 years up to several centuries after the emission depending on the emission size (Ricke and Caldeira, 2014; Zickfeld and Herrington, 2015); one of the main reasons for this time lag is ocean thermal inertia. The time lag means that visible effects in global temperature will only be clear some time after the time when scenarios differ noticeably in forcing. We set 2040 as the limit after which we would expect to see differences in the regional temperature change.

A central part of the IMPACT2C project has been to evaluate the impact of +2C using a suite of impact models covering topics like sea level rise, crop models, hydrological and socio-economic

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