International Journal of Engineering Research
Volume No.7, Issue Special 4, pp : 409-412
ISSN:2319-6890 (online),2347-5013(print)
9,10 March 2018

Evaluation and Analysis of the Projected Pathway of Global Warming Targets Matter

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***Abstract**: Since the 'Paris agreement' in 2015 there has been much focus on what a +1.5 °C or +2 °C warmer world would look like. Since the focus lies on policy relevant global warming targets, or specific warming levels (SWLs), rather than a specific point in time, projections are pooled together to form SWL ensembles based on the target temperature rather than emission scenario. This study uses an ensemble of CMIP5 global model projections to analyse how well SWL ensembles represent the stabilized climate of global warming targets. The results show that the SWL ensembles exhibit significant trends that reflect the transient nature of the RCP scenarios. These trends have clear effect on the timing and clustering of monthly cold and hot extremes, even though the effect on the temperature of the extreme months is less visible. In many regions there is a link between choice of RCP scenario used in the SWL ensemble and climate change signal in the highest monthly temperatures. In other regions there is no such clear-cut link. From this we conclude that comprehensive analyses of what prospects the different global warming targets bring about will require stabilization scenarios. Awaiting such targeted scenarios we suggest that prudent use of SWL scenarios, taking their characteristics and limitations into account, may serve as reasonable proxies in many situations.*
Keywords : RCP

Introduction

At the Cancun Climate Change Conference in 2010 the parties agreed to 'commit to a maximum temperature rise of 2 degrees Celsius above pre-industrial levels, and to consider lowering that maximum to 1.5 degrees in the near future' [1]. In the celebrated Paris Agreement the parties agreed to the even more ambitious aim to keep 'a global temperature rise this century well below 2 degrees Celsius above pre-industrial levels'. The purpose of these limits is to avoid 'dangerous' climate change, even though there is no clear scientific evidence supporting this. Rather, it is clear that even an increase of 2 degrees may lead to significant impacts, but also that the differences between 1.5 and 2 degrees are important [2]. Instead of scientifically based limits the 1.5 and 2 degree targets should be seen as political choices balancing climate impact and what is realistic and tolerable [2].

Since the Paris Agreement there is substantial interest in exploring what a 1.5 or 2 degree warmer world would look like. This new interest has shifted the perspective on how we look at climate change; from temperature increase at a specific point in time to the climatic conditions associated with some specific temperature increase regardless of when this point is reached. We call these specific warming levels (SWLs). By definition the average global mean temperature at a SWL will be the same in all projections independent of choice of model, scenario etc. Therefore it is common practice, and seen as an advantage, to increase the ensemble size by lumping together all available projections reaching the desired SWLs. This approach also reduces the model uncertainty due to different climate sensitivities in the models. Depending on their climate sensitivity different climate models will reach a SWL at different pace. The difference in time when 2 degree warming is reached (SWL2) may be as large as 50 years .This also means that it can be questioned what a SWL climate actually represents if different and possibly incommensurate emissions scenarios are used to form the SWL ensemble. If the warming trend is strong in a projection it may lead to a different climate compared to a projection with a weak warming trend. Furthermore, the lead time to when the SWL epoch occurs is shorter in the former case than in the latter case.[3]

If global warming is to be limited below 2 °C it will not be achieved by following the pathway of e.g. Representative Concentration Pathway 8.5 (RCP8.5) since the climate according to RCP8.5 will continue to warm after SWL2 occurs. This means that studies of SWL2 using RCP8.5 risk overestimating the climate change until SWL2, especially when it comes to extremes. The only RCP scenario that will not lead to a warming more than 2 °C is RCP2.6 .This may seem obvious, but this is not normally how SWLs are treated. This paper investigates how the choice of emission scenarios affects the simulated temperature climate at different SWLs [4].

DATA and METHOD

This study uses data from global climate models (GCMs) within the Climate Model Intercomparison Project Phase 5. All data from realization r1i1p1 of scenarios RCP2.6, RCP4.5, RCP8.5 available via the Earth System Grid Foundation (ESGF) was used. Models were only included in the analyses if projections for all three RCP scenarios were available. Data from 26 models met these criteria (supplementary table S1). To facilitate the ensemble analyses all data were interpolated onto a 1° × 1° latitude/longitude grid [5].

A specific warming level (SWL) is based on the annual global mean surface temperature (GMST); e.g. SWL2 occurs when the annual GMST reaches a warming of 2 °C compared to pre-industrial levels. The timing of a SWL is defined as the first 30 year period when the 30 year average annual

International Journal of Engineering Research ISSN:2319-6890 (online),2347-5013(print)
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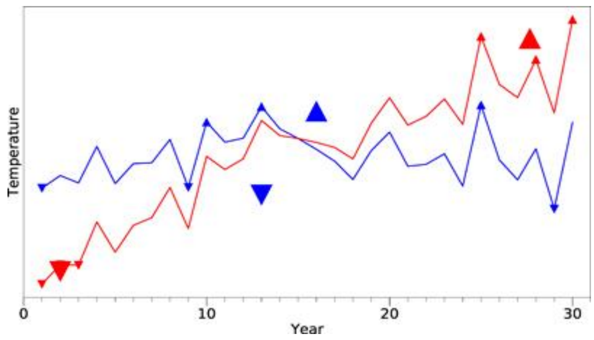
GMST reaches the SWL. The SWLs studied are SWL1.5, SWL2 and SWL4; corresponding to a warming of 1.5 °C, 2 °C and 4 °C. The timing of the SWLs is calculated individually for each projection. Under RCP2.6 19 of the 26 projections reach SWL1.5, but only nine of these continue to reach SWL2 making results based on the latter less reliable. As expected no RCP2.6 projection reaches SWL4. Under RCP4.5 all 26 projections reach SWL1.5 and 24 continue to SWL2. However, only two of them reach SWL4, and at a very late stage why they will not be analysed further. Under RCP8.5 all 26 projections reach both SWL1.5 and SWL2, and 20 continue to reach SWL4 [6].



"**Figure 1.** Schematic of the influence of a trend during a 30 year SWL epoch on the timing and average of temperature extremes. Blue (red) line is synthetic data without (with) a trend added. Small triangles pointing downward (upwards) indicate low (high) extremes, and the large triangles indicate the mean across the three individual points".

The reasons for a projection not reaching a SWL is either that the simulation was discontinued or that the climate stabilises so that the SWL would never be reached, or at least not within a foreseeable future, i.e. before year 2300. Based on the temperature trends towards the end of the projections it is possible to make a rough estimate of when it would reach a SWL. Under RCP2.6 only one projection might reach SWL2 within the 22nd century, the remaining projections are more or less stabilized and would require several hundreds or even thousands of years to reach SWL2. Of the two projections that do not reach SWL2 under RCP4.5 one might have done so around the middle of the 22nd century had the simulation been continued. This is late compared to when the other projections reach SWL2, which in most cases is in the beginning of the 21st century, and it can be argued that also this projection has approximately stabilised on a level below SWL2. All RCP4.5 projections would require hundreds or even thousands of years to reach SWL4. Finally, under RCP8.5 the six projections that do not reach SWL4 would likely have done so in the beginning of the 22nd century had the simulations been continued after year 2100 [7].

To investigate to what extent the climates during the SWL epochs represent stabilized climates and whether the choice of RCP has an impact on this we focus on analyzing the presence of a trend in annual mean temperature during the SWL epoch, and whether this has any impact on the distribution of cold and hot months. A way to assess the effect of the different trends is to look at the difference in timing of the coldest and warmest summer or winter months during the 30 year SWL epoch (figure 1). In theory, under a climate without a trend the coldest/warmest months should be randomly distributed over the 30 year epoch and there should be no systematic difference in expected timing. In reality it is not necessarily that simple since natural decadal variations can be large [8]. The temperature difference between the cold and the warm months depends on the inter-annual variability. In a climate with a warming trend, on the other hand, the coldest months are more likely to appear in the beginning of the period and the warmest months at the end of the period, and the temperature span should include the additional effect of the warming trend. To quantify these aspects of the climate we devise four simple metrics all calculated for each grid-point and 30 year epoch separately: (i) slope of annual mean temperature, (ii) difference in timing of the three coolest and the three hottest months present in the time-series of annually warmest months, (iii) average temperature span between the same three coolest and hottest months, and (iv) the climate change signal of the average of the same three hottest months relative the recent climate period of 1970–2000. These metrics are meant to answer the following specific questions: (i) Is there a trend during the 30 year epoch, and if so does it vary with RCP and SWL? (ii) Does a trend have any influence on how the coldest/warmest months are distributed in time during the epoch? iii) Does a trend have any influence on the temperature span of the annually hottest month, and thus on the temperature of the most extreme months? iv) Do the simulated climates change signal of the extreme months vary with RCP and SWL?

The temperature trend during the 30 year epoch is calculated as follows. Annual temperature fields from each member belonging to a specific SWL/RCP ensemble are pooled together and the ensemble slope of temperature in each gridpoint is calculated by linear regression. In this way we focus on the impact of the long-term trend and filter out interannual and decadal variability as well as the impact of any specific model [9].

The timing and temperature difference of the coolest/warmest months in a season within a 30 year epoch is calculated as follows. From each projection in an SWL/RCP ensemble the annually warmest months are selected. From this time series the three coolest and hottest months are identified and their mean temperature and timing (i.e. year of occurrence) is calculated. Then the temperature difference and difference in timing between the coolest and hottest months is calculated and finally averaged across all projections

RESULTS

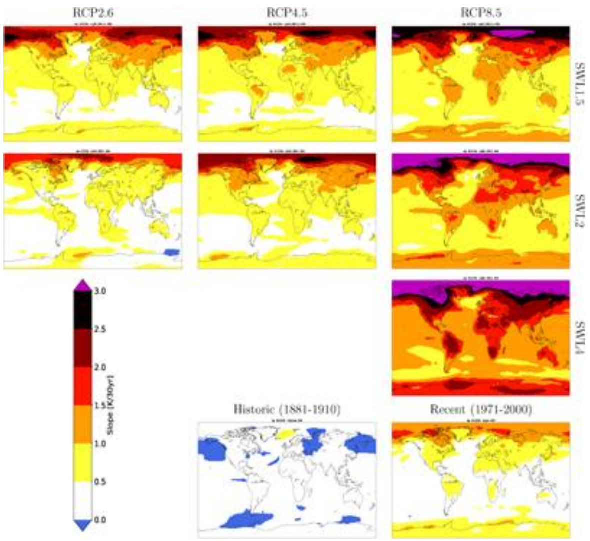
Figure 2 shows the ensemble slope of temperature in all grid points. In supplementary figure S1 the statistical significance of the slope is shown in the same fashion.

The historical period almost show no trends, only a small part of the Arctic Ocean shows a slope larger than 0.5 K/30 yr (figure 2, bottom centre). This general lack of significant

ISSN:2319-6890 (online),2347-5013(print)
9,10 March 2018

trends suggests that for the ensemble of projections used in this study the historic period 1880–1910 is a reasonable approximation of pre-industrial climate free of any major anthropogenic influence.

The recent period (figure 2, bottom right) shows some significant warming trends, which is strongest over land areas and over the Arctic. The Arctic and the northern parts of North America and Eurasia show slopes of more than 1.0 K/30 yr. This resembles the observed warming pattern [10]. Low slope values are seen in all ocean areas and statistically insignificance is particularly obvious in the Antarctic Ocean and North Atlantic as well as in several of the major areas of ocean upwelling .



“**Figure 2.** Maps of the ensemble mean of the linear trend (slope) in annual temperature for the different SWL/RCP epochs and the historic and recent periods. The associated statistical significance is shown in supplementary figure S1”.

For SWL1.5 the patterns (figure 2 first row) are similar but more pronounced compared to the recent period. RCP2.6 shows slopes of at least 0.5 K/30 yr almost in all land areas, and most of the northern hemisphere oceans. There is a clear transition towards more pronounced slopes going from RCP2.6 to RCP8.5. The slopes according to RCP4.5 is somewhere in the middle of RCP2.6 and RCP8.5. For RCP8.5 the slopes are statistically highly significant (supplementary figure S1) except ocean areas in the vicinity of Antarctica, as well as in an North Atlantic area south of Greenland consistent with the slowdown of the Atlantic meridional overturning circulation in the 20th century.

For SWL2 (figure2, second row) the RCP2.6 slopes are generally weaker and statistically less significant compared to the corresponding SWL1.5 results. We interpret this as an effect of the smaller ensemble of projections, nine members compared to 19 members for SWL1.5. Slopes according to RCP4.5 are similar, but slightly weaker, than at SWL1.5. In RCP4.5 SWL2 begins in about half of the projections around year 2030 or later when emissions are starting to decline and the temperatures are starting to stabilize. Still, a clear trend remains; the statistical significance is about the same as for SWL1.5. For RCP8.5 on the other hand the trends are clearly stronger at SWL2 compared to SWL1.5. The trends are statistically highly significant almost everywhere under RCP8.5, but show low statistical significance over Antarctica and the Southern Ocean under RCP4.5 [11].

At SWL4 the overall spatial patterns in RCP8.5 is similar to SWL1.5 and SWL2, but the trends are even stronger and statistically highly significant.

DISCUSSION

In most studies using SWL ensembles, there are two underlying assumptions. (1) The choice of RCP scenario has no importance for the SWL climate. (2) A time period when a SWL is reached represents a stabilised climate with a certain average temperature, e.g. SWL2 represents a 2 °C warmer world. Both these assumptions are of course true for the average temperature; the average temperature at SWL2 *is* 2 °C warmer than in pre-industrial time. However, if something other than the average temperature is studied the assumptions may not be correct. The choice of RCP scenario governs the pathway to the SWL, in some scenarios the SWL is approached quickly with a steep temperature increase during the SWL epoch, whereas in others the SWL is approached more slowly with the modest trend within the SWL epoch [12].

From our analyses it is clear that SWL ensembles do not typically represent stabilized climate conditions. Already SWL1.5 according to RCP2.6—which is the combination of SWL and RCP that should show the smallest climate change—shows significant trends in most regions of the world. The trends get stronger and more significant with higher RCPs and higher SWLs [13, 19].

It can also be questioned if the SWL climates are representative of a climate stabilised at a certain warming. If the temperature reaches a SWL it will also pass that level according to the RCPs, with the possible exception of SWL2 in RCP2.6. Since the RCP scenarios describe the way *through* the SWLs and beyond, rather than the way *to* and after having reached a global warming target, there is a risk that the climate impact is overestimated or otherwise misrepresented [14-19].

CONCLUSIONS

In this study we have analysed how ensembles of projections based on different RCP scenarios agree in their representation of temperature extremes at three specific warming levels (SWL) relevant for the discussion of global warming targets. We summarize or findings in the following points:

- All ensembles representing a future SWL show a temperature trend (which was statistically highly significant with few exceptions). If we want to study the climate impact when the 1.5 °C or 2 °C 'targets' are met, and the difference in impact between these targets, this should be done with climate model simulations using emissions scenarios aiming to meet these targets and not just passing them. Such stabilisa-

 ISSN:2319-6890 (online),2347-5013(print)

tion scenarios could possibly also include overshoot scenarios where the temperature exceeds the target, but later fall below it.

- The impact of this trend during the SWL epoch is mixed. There is a clear tendency for cold extremes to cluster early in the period and warm extremes to cluster in the end of the period. In many regions, like West Africa, the different trends have an effect on the intensity of the climate change signal in the hottest months. In some regions, like North Europe, such an impact could not be seen.

References

i. *Collins M et al 2013 Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change ed T F Stocker, D Qin, G-K Plattner, M Tignor, S K Allen, J Boschung, A Nauels, Y Xia, V Bex and P M Midgley (Cambridge: Cambridge University Press) Long-term climate change: projections, commitments and irreversibility*

ii. *Flato G et al 2013 Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change ed T F Stocker, D Qin, G-K Plattner, M Tignor, S K Allen, J Boschung, A Nauels, Y Xia, V Bex and P M Midgley (Cambridge: Cambridge University Press) Evaluation of climate models*

iii. *Grillakis, M. G.; Koutroulis, A. G.; and Tsanis, I. K. The 2 °C global warming effect on summer European tourism through different indices. Int. J. Biometeorol. 2015,* ***60****, 1205–1215.*

iv. *Hartmann D L et al 2013 Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change ed T F Stocker, D Qin, G-K Plattner, M Tignor, S K Allen, J Boschung, A Nauels, Y Xia, V Bex and P M Midgley (Cambridge: Cambridge University Press) Observations: atmosphere and surface.*

v. *IPCC 2013 Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change ed G J van Oldenborgh, M Collins, J Arblaster, J H Christensen, J Marotzke, S B Power, M Rummukainen and T Zhou, T F Stocker, D Qin, G-K Plattner, M Tignor, S K Allen, J Boschung, A Nauels, Y Xia, V Bex and P M Midgley (Cambridge: Cambridge University Press) Annex I: atlas of global and regional climate projections*

vi. *Joshi, M.; Hawkins, E.; Sutton, R.; Lowe, J.; and Frame, D. Projections of when temperature change will exceed 2 °C above pre-industrial levels. Nat. Clim. Change. 2011,* ***1****, 407–412.*

vii. *Kay J E et al 2015 The community earth system model (CESM) large ensemble project: a community resource for studying climate change in the presence of internal climate variability Bull. Am. Meteorol. Soc.* ***96*** *1333–49*

viii. *Knutti, R.; Rogelj, J.; Sedláček, J., and Fischer, E. M. A scientific critique of the two-degree climate change target Nat. Geosci. 2016,* ***9****, 13–18.*

ix. *Koutroulis, A. G.; Grillakis, M. G.; Daliakopoulos, I. N.; Tsanis, I. K.; and Jacob D. Cross sectoral impacts on water availability at +2 °C and +3 °C for the east Mediterranean island states: the case of crete. J. Hydrol. 2016,* ***532****, 16–28.*

x. *Maule, C. F.; Mendlik, T.; and Christensen, O. B.; The effect of the pathway to a two degrees warmer world on the regional temperature change of Europe. Clim. Ser. 2016,* ***7****, 3–11.*

xi. *Rahmstorf, S.; Box, J. E.; Feulner, G.; Mann, M. E.; Robinson, A.; Rutherford, S.; and Schaffernicht, E. J.; Exceptional twentieth-century slowdown in Atlantic Ocean overturning circulation. Nat. Clim. Change. 2015,* ***5****, 475–480.*

xii. *Roudier, P.; Andersson, J. C. M.; Donnelly, C.; Feyen, L.; Greull, W.; and Ludwig, F. Projections of future floods and hydrological droughts in Europe under a +2 °C global warming. Clim. Change. 2016,* ***135****, 341–355.*

xiii. *Sanford, T.; Frumhoff, P. C.; Luers, A.; and Gulledge, J. The climate policy narrative for a dangerously warming world. Nat. Geosci. 2014,* ***4****, 164–166.*

xiv. *Schleussner C-F et al 2016 Differential climate impacts for policy-relevant limits to global warming: the case of 1.5 °C and 2 °C Earth Syst. Dyn.* ***7*** *327–51*

xv. *Taylor, K. E.; Stouffer, R. J.; and Meehl, G. A. An overview of CMIP5 and the experiment design Bull. Am. Meteorol. Soc. 2011,* ***93****, 485–498.*

xvi. *UNFCCC 2010 The Cancun Agreements. United Nations Framework Convention on Climate Change http://unfccc.int/meetings/cancunnov2010/meeting/6266.php*

xvii. *UNFCCC 2015 The Paris Agreement. United Nations Framework Convention on Climate Change http://unfccc.int/paris_agreement/items/9485.php*

xviii. *Vautard R et al 2014 The European climate under a 2 °C warming Environ. Res. Lett.* ***9*** *11*

xix. *van Vuuren, D. P.; den Elzen, M. G. J.; Lucas, P. L.; Eickhout, B.; Strengers, B. J.; van Ruijven, B.; Wonink, S.; and van Houdt, R. Stabilizing greenhouse gas concentrations at low levels: an assessment of reduction strategies and costs Clim. Change. 2007,* ***81****, 119–159.*

DOI : 10.5958/2319-6890.2018.00129.0