Climatic Change (2018) 146:277–285
https://doi.org/10.1007/s10584-017-2136-4

An introduction to the special issue on the Benefits of Reduced Anthropogenic Climate changE (BRACE)

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Received: 25 August 2017 / Accepted: 23 December 2017 / Published online: 22 January 2018

The scientific literature on climate change impacts is large and diverse, as is appropriate for such a wide-ranging and multi-faceted field. Climate change affects many sectors of human activity, over a range of time and geographic scales, through multiple channels: economic, ecological, and social. Research on climate impacts therefore spans many disciplines and methods. The topic can be approached by asking questions from the perspective of policy, governance, economics, demographics, technological change, climate hazards, or other factors.

The diversity of the literature is a strength in generating a multi-dimensional understanding of the potential effects climate change may have on society. It is a challenge, however, in drawing conclusions about how sensitive impacts might be to climate change itself. For example, the Intergovernmental Panel on Climate Change (IPCC) Working Group II, in its most recent assessment report (Intergovernmental Panel on Climate Change 2014), aimed to synthesize knowledge by expressing judgments about risks at two levels of warming (relative to pre-industrial): 2 and 4 °C. This effort faced many challenges in drawing conclusions across a literature that was not developed explicitly to compare effects across levels of climate change. Another WGII approach to synthesizing and communicating risks, the Reasons for Concern framework (Oppenheimer et al. 2014; Smith et al. 2001), similarly aims to characterize risk as a function of different levels of global mean temperature change, for five broad risk categories. It also faces a number of challenges in drawing on the literature to inform judgments of risk levels and in accounting for other dimensions of the problem, particularly the vulnerability of affected populations (O'Neill et al. 2017a).

Yet understanding how risk changes with different levels of climate change is central to an informed response to the issue. Mitigation to reduce the anticipated level of climate change is motivated primarily by the assumption that it will generate benefits in terms of reduced climate

This article is part of a Special Issue on "Benefits of Reduced Anthropogenic Climate changE (BRACE)" edited by Brian O'Neill and Andrew Gettelman

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change impacts. A well-developed literature exists on the costs of mitigation (Clarke et al. 2014), founded on a long history of organized model comparison studies (for example, Kriegler et al. 2014). But for climate change impacts, controlled modeling studies of the consequences of alternative climate futures are less common (Huber et al. 2014).

BRACE, and studies like it (Arnell et al. 2013; EPA 2015; Houser et al. 2015; Warszawski et al. 2014), are aimed at furthering our understanding of how impacts vary across levels of climate change by carrying out a consistent set of impact analyses within a single experimental design. The BRACE project was coordinated at the National Center for Atmospheric Research (NCAR) and involved the participation of over 50 scientists from 18 institutions. This special issue reports the results of the study in the form of 20 papers covering physical impacts on the climate system (with a focus on extreme events), impacts to health, agriculture, and coastal regions (from tropical cyclones), and methodological issues related to climate model emulation. It includes a synthesis paper (O'Neill et al. 2017b) that describes the study design and modeling framework, synthesizes results, and discusses limitations and future directions. Here, we provide a brief summary of the project design, expanding on its relation to the scenario literature, and an overview of the papers included in the issue. While we leave the discussion of results mainly to the synthesis paper, we extend it here to include some additional detail on the relationship between BRACE results and those from other avoided impact studies, and emphasize future research needs.

1 The BRACE project framework

The BRACE experimental design compares impacts of various types across two scenarios of future greenhouse gas concentrations, Representative Concentration Pathways (RCPs) 8.5 and 4.5, based on an enemble of climate outcomes simulated with a single model: the Community Earth System Model (CESM) version 1.1. Most BRACE studies draw on a 30-member initial condition ensemble of RCP8.5 (Kay et al. 2015), referred to as the CESM Large Ensemble (CESM-LE), and a new 15-member ensemble of RCP4.5 (the CESM Medium Ensemble, CESM-ME) developed for the BRACE study (Sanderson et al. 2015). The two scenarios lead to an increase in global mean temperature of about 3.7 and 2.5 °C relative to pre-industrial, respectively, by 2060–2080. The initial condition ensembles allow the project to characterize more precisely extreme events associated with these scenarios, and to better distinguish forced responses from internal variability.

Impact assessments in BRACE focus on changes to the physical climate system and to biophysical and societal impacts related to agriculture, health, and coastal regions. Since impacts depend on assumptions about future societal conditions as well as future climate change, societal impact studies employ future socioeconomic conditions based on Shared Socioeconomic Pathways (SSPs) 3 (Regional Rivalry) and 5 (Fossil-fueled Development). These two SSPs offer contrasting visions of future vulnerability to climate impacts (O'Neill et al. 2015), and are consistent with the emissions and concentrations assumed in the two RCPs, as we discuss below.

By being structured around two RCPs and two consistent SSPs, the BRACE study represents a contribution to integrated assessments based on the so-called new scenario framework (van Vuuren et al. 2014). The RCPs and SSPs were designed to provide alternative climate and societal futures (respectively) that could be combined to investigate how impacts and mitigation or adaptation responses might vary depending on future climate or societal conditions. BRACE focuses on a subset of possible RCP-SSP combinations that explores these sensitivities. RCPs with lower forcing and less climate change than those used here could have been chosen. For example, RCP2.6 leads to about 2 °C of future warming, consistent with one of the long-term climate targets in the Paris Agreement. Indeed, understanding risk reduction that would result from deeper emission reductions than those represented in BRACE is also important, and an extension of the project, BRACE 1.5 (http://www.cgd.ucar.edu/projects/chsp/brace1.5.html), is currently underway that will examine impacts associated with climate scenarios that stabilize at either 2 or 1.5 °C of warming, as generated with CESM (Sanderson et al. 2017).

However, the choice of RCPs 8.5 and 4.5 has a number of benefits. RCP8.5 assumes no emission mitigation is undertaken and provides a scenario representative of high forcing pathways in the literature, useful for characterizing potentially high risk outcomes. RCP4.5 assumes moderate emission reduction takes place which, while not sufficient to achieve the targets in the Paris Agreement, may be more consistent with current emission trajectories and policy commitments. These two RCPs are also included in one recent avoided impact study for the USA (Houser et al. 2015); another (EPA 2015) used a reference scenario similar to RCP8.5 paired with a lower mitigation scenario. In addition, these two RCPs are the focus of the current US National Climate Assessment. BRACE results can therefore contribute to literature and assessment using these scenarios.

In combining RCPs with SSPs, care must be taken to ensure that they are consistent with each other; that is, that the socioeconomic conditions assumed in the SSPs could plausibly lead to the emission and concentration pathways assumed in the RCPs. In the case of RCP4.5, this is straightforward. Emission scenarios based on the SSPs show that in all cases, baseline scenarios that assume no mitigation produce emissions that lead to more than 4.5 W/m2 of forcing in 2100 (Riahi et al. 2017). Therefore, for all SSPs, assumptions about emission mitigation can be added to produce scenarios that are consistent with RCP4.5.

However, for RCP8.5, the situation is more complicated. Current emission scenarios indicate that all but one of the SSPs (SSP5) fail to produce emissions that grow rapidly enough over time to reach 8.5 W/m2 of forcing by the end of the century (Riahi et al. 2017). This would suggest that the BRACE pairing of SSP3 with RCP8.5 is inconsistent. The limitation of only using SSP5, and no other SSP, in combination with RCP8.5 is a real obstacle to impact studies. SSP5 assumes very rapid economic and human development, producing optimistic outcomes in terms of reduced vulnerability to climate change. Therefore, this limitation prevents exploration of futures with both substantial climate change (as assumed in RCP8.5) and high societal vulnerability, as for example in a pessimistic societal development scenario like SSP3.

The BRACE project therefore developed a variant of SSP3 that assumes somewhat higher economic growth rates than in its original incarnation, sufficient to drive energy demand and greenhouse gas emissions to levels consistent with RCP8.5, but still low enough to keep the scenario relatively pessimistic in terms of economic and human development outcomes. This higher growth variant of SSP3 (SSP3-HG) (Ren et al. 2016) could be considered for use in other impact studies facing the same limitation of the current set of SSPs and RCPs. It would also be possible to develop other high-emission variants of SSP3, for example, by assuming carbon subsidies are implemented.

2 The BRACE special issue

The special issue begins by examining broad features of climate system outcomes associated with the two RCPs, and means for emulating them. Sanderson et al. (2015) present the CESM-

ME simulations and compare key features with results from the CESM-LE, showing differences in mean temperature and precipitation as well as in measures of extremes at the monthly time scale. Two papers then use the two ensembles to demonstrate successful approaches to emulating CESM outcomes for mean seasonal temperature and its variability (Alexeeff et al. 2016) and extreme precipitation (Fix et al. 2016) using statistical models. Such emulation approaches can facilitate the production of climate information for use in avoided impact studies.

A group of five papers focuses on differences between RCPs in extreme events. Tebaldi and Wehner (2016) examine differences in daily temperature extremes, while Lehner et al. (2016) assess differences in record-setting seasonal temperatures. Oleson et al. (2015) investigate multi-day heat (or cold) wave outcomes, distinguishing in particular between those occurring in urban versus rural areas. Xu et al. (2015) test the sensitivity of heat extremes to aerosols by producing a third CESM ensemble that replicates the CESM-LE but with fixed aerosol concentrations. Lin et al. (2015) use the same ensemble to look at the relative influence on aridity of greenhouse gases and aerosols.

Another five papers investigate avoided health impacts between scenarios. Jones et al. (2018) and Monaghan et al. (2015) model future population exposure to health risks, in the first case to rural and urban heat waves, and in the second case to the virus vector mosquito *Aedes aegypti*, which can transmit the viruses responsible for dengue fever, Zika, chikungunya, and yellow fever. Anderson et al. (2016a, b) go beyond exposure to model the occurrence of "high mortality" heat waves in the USA—those anticipated to lead to a more than 20% increase in mortality rates. Marsha et al. (2016) focus on a single US city (Houston) in more detail, modeling potential future heat-related mortality under both scenarios.

In the agriculture area, Levis et al. (2016) use a new version of the Community Land Model (the land surface component of CESM) that includes a number of explicit crop types to examine climate effects on potential yield and crop water demand across scenarios. Tebaldi and Lobell (2015) take another approach to estimating potential yield effects, developing an empirically based statistical model for global yield and using it to project future impacts. Ren et al. (2016) build on the CLM results, using a global integrated assessment model to investigate the consequences of these potential yield effects for the agricultural economy.

For tropical cyclones, Bacmeister et al. (2016) carry out high-resolution time-slice experiments with the Community Atmosphere Model (the atmospheric component of CESM) to simulate future tropical cyclone activity under both scenarios. Gettelman et al. (2017) combine these projections with the projected economic value of coastal assets to estimate cyclone-related damages. Done et al. (2015) take a different approach, developing and applying an index of cyclone damage that is based on large-scale features of climate to project potential impacts.

O'Neill et al. (2017b) synthesize the wide range of results produced by the BRACE papers. As a high level summary, the project finds that in many cases, the impacts avoided by following RCP4.5 rather than 8.5 are substantial, particularly for extreme events. In some other cases, the conclusions are more nuanced. The magnitude or even sign of the avoided impacts can depend on model assumptions, as is the case most prominently for assumptions related to the CO_2 fertilization effect on crop yields. In other cases, such as for some health-related outcomes, avoided impacts are relatively modest and are more sensitive to assumptions about societal conditions than to climate change. And in some cases, particularly related to tropical cyclones, natural variability makes it difficult to draw robust conclusions about the effect of reduced climate change.

3 Discussion, caveats, and future needs

The results of the BRACE study are broadly consistent with other avoided impact studies. We take as representative points of comparison two studies of US impacts, the Climate Change Impacts and Risk Analysis project (CIRA; EPA 2015) and the American Climate Prospectus (ACP; Houser et al. 2015 and see also Hsiang et al. 2017), and two global studies, the Inter-sectoral Impact Model Intercomparison Project (ISIMIP; Warszawski et al. 2014) and the closely related Agricultural Model Intercomparison and Improvement Project (AgMIP; Nelson et al. 2014; Rosenzweig et al. 2014). Although most have results for RCPs 8.5 and 4.5 (and in some cases, additional climate scenarios), these studies are not perfectly comparable to BRACE. CIRA and ACP focus on the USA only, while most of the BRACE studies were global in extent (with US results not always broken out). CIRA uses a mitigation scenario that is lower than RCP4.5. ACP estimated impacts of future climate on current socioeconomic conditions, without using scenarios of future societal development. The first round of ISIMIP assessments focused largely on biophysical impacts rather than societal impacts, and AgMIP is of course limited to the agricultural sector. Some other projects, such as AVOID (Arnell et al. 2013), are similar to BRACE in spirit but focus on different scenarios and/or sectors, and therefore have little overlap in results.

Nonetheless, some limited comparison is instructive. The BRACE conclusion that RCP4.5 would lead to substantial reductions in extreme heat events and in associated mortality impacts (which were evaluated for the USA only) is broadly consistent with other studies, although metrics of outcomes differ to some extent across studies. BRACE found that population exposure (in the USA and globally) to extreme heat events would be reduced by half in RCP4.5 in the 2061–2080 time period, and the frequency of potentially high-mortality heat waves in the USA would be reduced by a third. The ACP found a reduction by two-thirds in the frequency of 1-in-20-year temperature-related mortality events (Houser et al. 2015, Fig. 8.4; reduction from more than six to less than two heat- or cold-related mortality events over the 2060–2080 time period), and a similarly large reduction in overall temperature-related mortality (Houser et al. 2015, Fig. 8.3, for the 2080–2099 time period), a broader measure than the focus on high mortality events in BRACE. The CIRA project found a more than 40% reduction in US heat-related mortality. ISIMIP did not address this impact in its first round of analysis (where the focus was on malaria), although has work underway in a new round to examine it (Frieler et al. 2016).

For agriculture, BRACE found relatively modest effects, with mitigation to RCP4.5 increasing potential global crop yields about 5% in the absence of CO_2 fertilization, and reducing them by about the same amount when CO_2 fertilization is included. Results for the USA were slightly larger at approximately +/−10%, without/with CO_2 fertilization. The effect of mitigation on crop price impacts was somewhat larger in magnitude. The ACP projects somewhat larger benefits in the USA of mitigation, finding that, without CO_2 fertilization, the median loss in production declines from −40 to −14% when moving from RCP8.5 to RCP4.5 in the 2080–2099 period (Houser et al. 2015, Fig. 6.6). Like BRACE, it finds that including CO_2 fertilization can produce increases in projected yield in both scenarios; e.g., the likely range of effects on production in RCP8.5 is −42 to +12% by the end of the century. The CIRA project finds more consistently beneficial consequences to mitigation, with RCP4.5 leading to increased yields for all crops (relative to RCP8.5) of roughly 5–20% in the 2060–80 period, accounting for CO_2 fertilization, and declines in crop prices of 2–8%. BRACE global results fall within the range of the multi-model comparison carried out in AgMIP, both for potential yield and crop price effects (Ren et al. 2016).

For tropical cyclone damages, BRACE found that globally, overall cyclone activity declined in both RCPs, but the frequency of the most intense storms increased, leading to an increase in economic damages to coastal assets. However, results varied regionally, and the opposite held for the USA: changes in tropical cyclone activity led to a decrease in damages, although total damages still increased over time due to increased coastal development. The ACP and CIRA project estimates are not strictly comparable in that they include the effects of both sea level rise and coastal storms (whereas BRACE does not include sea level rise effects). However, the ACP distinguished the effects of these two drivers, finding that, based on projections of increasing tropical cyclone activity from Emanuel (2013) and Knutson et al. (2013), tropical cyclones would exacerbate the coastal impacts of sea level rise by a factor of 2–3 in 2080–2099 (Houser et al. 2015, Fig. 11.19 and associated text). The CIRA study finds very small benefits of mitigation to coastal property, and does not present results separately for storm changes versus sea level rise.

As pointed to in O'Neill et al. (2017b), there are a number of limitations to the BRACE study. Accounting for uncertainty is a key limitation. While the approach of relying on single-model initial condition ensembles of climate simulations has some benefits related to extreme events and natural variability, it also has the drawback of not incorporating structural uncertainty in the climate model. Other avoided impact studies have taken different approaches to this issue. The first phase of CIRA, for example, used a single climate model, but because it was somewhat simpler than a full earth system model, it was possible to introduce uncertainty in the model's climate sensitivity and carry out multiple simulations (Monier et al. 2015). CIRA also included uncertainty in spatial patterns of climate change by using a pattern scaling approach based on multiple climate models. This approach introduces parameter uncertainty, and some structural uncertainty, into climate outcomes. Other projects, such as ISIMIP, use a small multi-model ensemble of climate simulations. This approach has the benefit of capturing some structural uncertainty in the model, but selection of a set of models that spans a wide range of uncertainty in key, impact-relevant variables, for multiple regions, can be difficult. Climate model emulation, as explored in Alexeeff et al. (2016) and Fix et al. (2016) in the BRACE project, may offer a way forward in more fully capturing climate model uncertainty in a computationally tractable manner.

The BRACE project accounts for uncertainty in future societal conditions by estimating a number of impacts under two alternative SSPs. This distinguishes BRACE from other projects that do not vary future societal conditions (e.g., CIRA) or that estimate impacts assuming current socioeconomic conditions (e.g., ACP). However, future work could further consider uncertainty in societal conditions by accounting for the time at which a particular level of climate change is experienced. Societal conditions in the same SSP but earlier or later in the century can differ widely, and could also substantially affect results.

An additional key uncertainty only partly accounted for is in the impact models. For example, two separate estimates of climate effects on potential yield are made in BRACE, with both a process-based and a statistical model, but only one set of these results is used in the analysis of economic consequences for agriculture. The economic impact study is itself carried out with a single economic model. CIRA takes a similarly single-impact-model approach, while ISIMIP is designed specifically to estimate uncertainty across models.

In addition, similar to other avoided impact projects, BRACE has treated impacts in a sector-by-sector manner, and does not account for inter-sectoral interactions. For example, yield impacts assumed that wherever crops are specified to be irrigated, sufficient water exists for irrigation. Climate impacts on water available for irrigation, or on water-using sectors such as energy production, do not affect impacts on agriculture. In future work, it will be important to take at least the largest of such potential interactions into account.

Finally, only limited adaptation was accounted for in BRACE impact studies. Anderson et al. (2016b) test the sensitivity of heat-related mortality to adaptation, but no explicit adaptation options are modeled. Rather, the study quantifies the consequences of generic adaptation actions that lessen vulnerability at a hypothetical pace over time. Future work that tested whether specific options could achieve such reductions in vulnerability would improve on this approach. As another example, Ren et al. (2016) quantify economic impacts on agriculture in a model that incorporates some autonomous adaptation measures. For example, the agriculture industry, when faced with less productive land due to the effects of climate change, responds endogenously by shifting inputs to production among land, labor, capital, energy, and material inputs. This response can lessen the costs of climate change impacts on the agriculture sector. However, the study does not explicitly quantify the magnitude of this adaptive response, nor does it account for other potentially important types of adaptation such as crop-switching. Thus, the avoided impact results in this study can be viewed as conservative with respect to adaptation.

Given these caveats, the BRACE results—like any single impact study or project—cannot be taken as a definitive statement on the avoided impacts likely to result from emission reductions that would reduce warming from more than 3.5 to around 2.5 °C. Nonetheless, when considered as part of the broader and accumulating literature on avoided impacts, these results add to our understanding of the potential benefits of reduced climate change. Heat-related impact reduction is the most robust avoided impact. Societal conditions that affect the vulnerability of the population stand out as a key determinant of risk reduction, potentially informing efforts to integrate vulnerability into frameworks for characterizing climate risk (O'Neill et al. 2017a). We hope that lessons from the study can stimulate more and better future work on avoided impacts.

References

Alexeeff SE, Nychka D, Sain SR, Tebaldi C (2016) Emulating mean patterns and variability of temperature across and within scenarios in anthropogenic climate change experiments. Clim Chang. (this issue). https://doi.org/10.1007/s10584-016-1809-8

Anderson GB, Oleson KW, Jones B, Peng RD (2016a) Classifying heatwaves: developing health-based models to predict high-mortality versus moderate United States heatwaves. Clim Chang. (this issue). https://doi.org/10.1007/s10584-016-1776-0

Anderson GB, Oleson KW, Jones B, Peng RD (2016b) Projected trends in high-mortality heatwaves under different scenarios of climate, population, and adaptation in 82 US communities. Clim Chang. (this issue). https://doi.org/10.1007/s10584-016-1779-x

Arnell NW, Lowe J, Brown S, Gosling S, Gottschalk P, Hinkel J, Lloyd-Hughes B, Nicholls R, Osborn T, Osborne TM (2013) A global assessment of the effects of climate policy on the impacts of climate change. Nat Clim Chang 3:512–519

Bacmeister JT, Reed KA, Hannay C, Lawrence P, Bates S, Truesdale JE, Rosenbloom N, Levy M (2016) Projected changes in tropical cyclone activity under future warming scenarios using a high-resolution climate model. Clim Chang. (this issue). https://doi.org/10.1007/s10584-016-1750-x

Clarke L, Jiang K, Akimoto K, Babiker M, Blanford G, Fisher-Vanden K, Hourcade JC, Krey V, Kriegler E, Löschel A, McCollum D, Paltsev S, Rose S, Shukla PR, Tavoni M, van der Zwaan B, van Vuuren DP (2014) Assessing transformation pathways. In Edenhofer O, Pichs-Madruga R, Sokona Y, Farahani E, Kadner S, Seyboth K, Adler A, Baum I, Brunner S, Eickemeier P, Kriemann B, Savolainen J, Schlömer S, von

Stechow C, Zwickel T, Minx JC (eds.) Climate change 2014: mitigation of climate change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge and New York

Done JM, PaiMazumder D, Towler E, Kishtawal CM (2015) Estimating impacts of North Atlantic tropical cyclones using an index of damage potential. Clim Chang. (this issue). https://doi.org/10.1007/s10584-015-1513-0

Emanuel KA (2013) Downscaling CMIP5 climate models shows increased tropical cyclone activity over the 21st century. Proc Natl Acad Sci 110:12219–12224

EPA (2015) Climate change in the USA: benefits of global action. United States Environmental Protection Agency, Office of Atmospheric Programs, Washington, DC, p 93

Fix MJ, Cooley D, Sain SR, Tebaldi C (2016) A comparison of US precipitation extremes under RCP8. 5 and RCP4. 5 with an application of pattern scaling. Climatic Change. (this issue). https://doi.org/10.1007/s10584-016-1656-7

Frieler K, Betts R, Burke E, Ciais P, Denvil S, Deryng D, Ebi K, Eddy T, Emanuel K, Elliott J, Galbraith E, Gosling SN, Halladay K, Hattermann F, Hickler T, Hinkel J, Huber V, Jones C, Krysanova V, Lange S, Lotze HK, Lotze-Campen H, Mengel M, Mouratiadou I, Müller Schmied H, Ostberg S, Piontek F, Popp A, CPO R, Schewe J, Stevanovic M, Suzuki T, Thonicke K, Tian H, Tittensor DP, Vautard R, van Vliet M, Warszawski L, Zhao F (2016) Assessing the impacts of 1.5 °C global warming—simulation protocol of the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP2b). Geosci Model Dev Discuss 2016:1–59

Gettelman A, Bresh D, Chen CC, Truesdale JE, Bacmeister JT (2017) Projections of future tropical cyclone damage with a high resolution global climate model. Clim Chang. (this issue). https://doi.org/10.1007/s10584-017-1902-7

Houser T, Hsiang S, Kopp R, Larsen K (2015) Economic risks of climate change: an American prospectus. Columbia University Press, Columbia

Hsiang S, Kopp R, Jina A, Rising J, Delgado M, Mohan S, Rasmussen D, Muir-Wood R, Wilson P, Oppenheimer M (2017) Estimating economic damage from climate change in the United States. Science 356:1362–1369

Huber V, Schellnhuber H, Arnell N, Frieler K, Friend A, Gerten D, Haddeland I, Kabat P, Lotze-Campen H, Lucht W (2014) Climate impact research: beyond patchwork. Earth Syst Dyn 5:399

Intergovernmental Panel on Climate Change (2014) Summary for policymakers. In: Field CB, Barros VR, Dokken DJ, Mach KJ, Mastrandrea MD, Bilir TE, Chatterjee M, Ebi KL, Estrada YO, Genova RC, Girma B, Kissel ES, Levy AN, MacCracken S, Mastrandrea PR, White LL (eds) Climate change 2014: impacts, adaptation, and vulnerability. Part a: global and sectoral aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp 1–32

Jones B, Tebaldi C, O'Neill BC, Oleson K, Gao J (2018) Avoiding population exposure to heat-related extremes: demographic change vs climate change. Clim Chang. (this issue). https://doi.org/10.1007/s10584-017-2133-7

Kay J, Deser C, Phillips A, Mai A, Hannay C, Strand G, Arblaster J, Bates S, Danabasoglu G, Edwards J (2015) The Community Earth System Model (CESM) large ensemble project: a community resource for studying climate change in the presence of internal climate variability. B Am Meteorol Soc 96:1333–1349

Knutson TR, Sirutis JJ, Vecchi GA, Garner S, Zhao M, Kim H-S, Bender M, Tuleya RE, Held IM, Villarini G (2013) Dynamical downscaling projections of twenty-first-century Atlantic hurricane activity: CMIP3 and CMIP5 model-based scenarios. J Clim 26:6591–6617

Kriegler E, Weyant JP, Blanford GJ, Krey V, Clarke L, Edmonds J, Fawcett A, Luderer G, Riahi K, Richels R (2014) The role of technology for achieving climate policy objectives: overview of the EMF 27 study on global technology and climate policy strategies. Clim Chang 123:353–367

Lehner F, Deser C, Sanderson BM (2016) Future risk of record-breaking summer temperatures and its mitigation. Clim Chang. (this issue). https://doi.org/10.1007/s10584-016-1616-2

Levis S, Badger A, Drewniak B, Nevison C, Ren X (2016) CLMcrop yields and water requirements: avoided impacts by choosing RCP 4.5 over 8.5. Climatic Change. (this issue). https://doi.org/10.1007/s10584-016-1654-9

Lin L, Gettelman A, Fu Q, Xu Y (2015) Simulated differences in 21st century aridity due to different scenarios of greenhouse gases and aerosols. Clim Chang. (this issue). https://doi.org/10.1007/s10584-016-1615-3

Marsha A, Sain S, Heaton M, Monaghan A, Wilhelmi O (2016) Influences of climatic and population changes on heat-related mortality in Houston, Texas, USA. Clim Chang. (this issue). https://doi.org/10.1007/s10584-016-1775-1

Monaghan AJ, Sampson K, Steinhoff D, Ernst K, Ebi K, Jones B, Hayden M (2015) The potential impacts of 21st century climatic and population changes on human exposure to the virus vector mosquito Aedes aegypti. Clim Chang. (this issue). https://doi.org/10.1007/s10584-016-1679-0

Monier E, Gao X, Scott JR, Sokolov AP, Schlosser CA (2015) A framework for modeling uncertainty in regional climate change. Clim Chang 131:51–66

Nelson GC, Valin H, Sands RD, Havlík P, Ahammad H, Deryng D, Elliott J, Fujimori S, Hasegawa T, Heyhoe E (2014) Climate change effects on agriculture: economic responses to biophysical shocks. Proc Natl Acad Sci 111:3274–3279

O'Neill BC, Kriegler E, Ebi KL, Kemp-Benedict E, Riahi K, Rothman DS, van Ruijven BJ, van Vuuren DP, Birkmann J, Kok K (2015) The roads ahead: narratives for shared socioeconomic pathways describing world futures in the 21st century. Global Environmental Change

O'Neill BC, Oppenheimer M, Warren R, Hallegatte S, Kopp RE, Poertner HO, Scholes R, Birkmann J, Foden W, Licker R, Mach KJ, Marbaix P, Mastrandrea MD, Price J, Takahashi K, van Ypersele J-P, Yohe G (2017a) IPCC reasons for concern regarding climate change risks. Nat Clim Chang 7:28–37

O'Neill BC, Done JM, Gettelman A, Lawrence P, Lehner F, Lamarque J-F, Lin L, Monaghan AJ, Oleson K, Ren X, Sanderson BM, Tebaldi C, Weitzel M, Xu Y, Anderson B, Fix MJ, Levis S (2017b) The Benefits of Reduced Anthropogenic Climate changE (BRACE): a synthesis. Clim Chang. (this issue). https://doi.org/10.1007/s10584-017-2009-x

Oleson K, Anderson G, Jones B, McGinnis S, Sanderson B (2015) Avoided climate impacts of urban and rural heat and cold waves over the US using large climate model ensembles for RCP8. 5 and RCP4. 5. Clim Chang. (this issue). https://doi.org/10.1007/s10584-015-1504-1

Oppenheimer M, Campos M, Warren R, Birkmann J, Luber G, O'Neill B, Takahashi K (2014) Emergent risks and key vulnerabilities. In: Field CB, Barros VR, Dokken DJ, Mach KJ, Mastrandrea MD, Bilir TE, Chatterjee M, Ebi KL, Estrada YO, Genova RC, Girma B, Kissel ES, Levy AN, MacCracken S, Mastrandrea PR, White LL (eds) Climate change 2014: impacts, adaptation, and vulnerability. Part a: global and sectoral aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp 1039–1099

Ren X, Weitzel M, O'Neill BC, Lawrence P, Meiyappan P, Levis S, Balistreri EJ, Dalton M (2016) Avoided economic impacts of climate change on agriculture: integrating a land surface model (CLM) with a global economic model (iPETS). Clim Chang. (this issue). https://doi.org/10.1007/s10584-016-1791-1

Riahi K, van Vuuren DP, Kriegler E, Edmonds J, O'Neill BC, Fujimori S, Bauer N, Calvin K, Dellink R, Fricko O, Lutz W, Popp A, Cuaresma JC, Samir KC, Leimbach M, Jiang L, Kram T, Rao S, Emmerling J, Ebi K, Hasegawa T, Havlik P, Humpenoeder F, da Silva LA, Smith S, Stehfest E, Bosetti V, Eom J, Gernaat D, Masui T, Rogelj J, Strefler J, Drouet L, Krey V, Luderer G, Harmsen M, Takahashi K, Baumstark L, Doelman JC, Kainuma M, Klimont Z, Marangoni G, Lotze-Campen H, Obersteiner M, Tabeau A, Tavoni M (2017) The shared socioeconomic pathways and their energy, land use, and greenhouse gas emissions implications: an overview. Glob Environ Chang Hum Policy Dimens 42:153–168

Rosenzweig C, Elliott J, Deryng D, Ruane AC, Müller C, Arneth A, Boote KJ, Folberth C, Glotter M, Khabarov N (2014) Assessing agricultural risks of climate change in the 21st century in a global gridded crop model intercomparison. Proc Natl Acad Sci 111:3268–3273

Sanderson BM, Oleson KW, Strand WG, Lehner F, O'Neill BC (2015) A new ensemble of GCM simulations to assess avoided impacts in a climate mitigation scenario. Clim Chang. (this issue). https://doi.org/10.1007/s10584-015-1567-z

Sanderson BM, Xu Y, Tebaldi C, Wehner M, O'Neill B, Jahn A, Pendergrass AG, Lehner F, Strand WG, Lin L (2017) Community climate simulations to assess avoided impacts in 1.5 and 2 °C futures. Earth Syst Dynam 8:827

Smith JB, Schellnhuber H-J, Mirza MMQ, Fankhauser S, Leemans R, Lin E, Ogallo L, Pittock B, Richels R, Rosenzweig C, Safriel U, Tol RSJ, Weyant J, Yohe G (2001) Vulnerability to climate change and reasons for concern: a synthesis. in McCarthy JJ, Canziani OF, Leary NA, Dokken DJ, White KS (eds.) Climate change 2001: impacts, adaptation, and vulnerability. Cambridge University Press, Cambridge, pp. 913–967

Tebaldi C, Lobell D (2015) Estimated impacts of emission reductions on wheat and maize crops. Clim Chang. (this issue). https://doi.org/10.1007/s10584-015-1537-5

Tebaldi C, Wehner MF (2016) Benefits of mitigation for future heat extremes under RCP4. 5 compared to RCP8. 5. Climatic Change. (this issue). https://doi.org/10.1007/s10584-016-1605-5

van Vuuren DP, Kriegler E, O'Neill BC, Ebi KL, Riahi K, Carter TR, Edmonds J, Hallegatte S, Kram T, Mathur R, Winkler H (2014) A new scenario framework for climate change research: scenario matrix architecture. Clim Chang 122:373–386

Warszawski L, Frieler K, Huber V, Piontek F, Serdeczny O, Schewe J (2014) The inter-sectoral impact model intercomparison project (ISI–MIP): project framework. Proc Natl Acad Sci 111:3228–3232

Xu Y, Lamarque J-F, Sanderson BM (2015) The importance of aerosol scenarios in projections of future heat extremes. Clim Chang. (this issue). https://doi.org/10.1007/s10584-015-1565-1