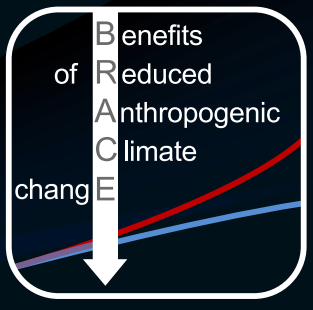
THE BRACE PROJECT

Decisions about responding to climate change attempt to balance the costs of reducing emissions with the benefits of lessening climate impacts on people and ecosystems. However, few studies have compared impacts across different future climate scenarios. As a result, we have an incomplete understanding of the benefits of emissions reductions.

The project on the Benefits of Reduced Anthropogenic Climate changE (BRACE) explored global and regional impacts of climate change that could be avoided in a future scenario with lower emissions due to moderate emissions reduction efforts relative to a future scenario with higher emissions. Because impacts depend on societal conditions in addition to the state of the climate, the study also evaluated these benefits for two different compatible societal futures. One assumed society followed an optimistic, low vulnerability development pathway, while the other assumed a pessimistic, high vulnerability future.

Led by researchers at the National Center for Atmospheric Research (NCAR), the BRACE project comprised research contributions from more than 50 authors from 18 institutions across 18 impact studies. Results of this project have been published in a special issue of Climatic Change (see http://www.cgd.ucar.edu/projects/chsp/brace-ccsi.html).

THE BENEFITS OF REDUCED ANTHROPOGENIC CLIMATE CHANGE



Climate scenarios

The BRACE project assesses the differences in impacts between two future climate scenarios: a higher emissions future with global average temperatures increasing about 3.7°C above pre-industrial levels toward the end of the century and a moderate emissions future with global average warming of about 2.5°C. These different scenarios are based on Representative Concentration Pathways (RCPs) 8.5 and 4.5, two future pathways of greenhouse gas emissions and atmospheric concentrations that were developed by the research community to help explore how climate might change under a range of possible future emissions. The names of these pathways (RCP 8.5 and 4.5) refer to the strength of the effect of greenhouse gases on the climate system by the end of the century (8.5 and 4.5 Watts per square meter, respectively).

Socioeconomic scenarios

The BRACE project also compares impacts according to two different Shared Socioeconomic Pathways (SSPs). The SSPs were developed by the research community to represent alternative futures of societal development in which the difficulty of responding to climate change varies widely. The BRACE project compared impacts under SSP3 versus SSP5. SSP3 is a scenario with slow development that poses high challenges for adaptation. SSP5 is a more optimistic scenario in which the world is less vulnerable to climate change and better able to adapt.

AVOIDED IMPACTS OF CLIMATE CHANGE ON EXTREME EVENTS (~2060-2080)

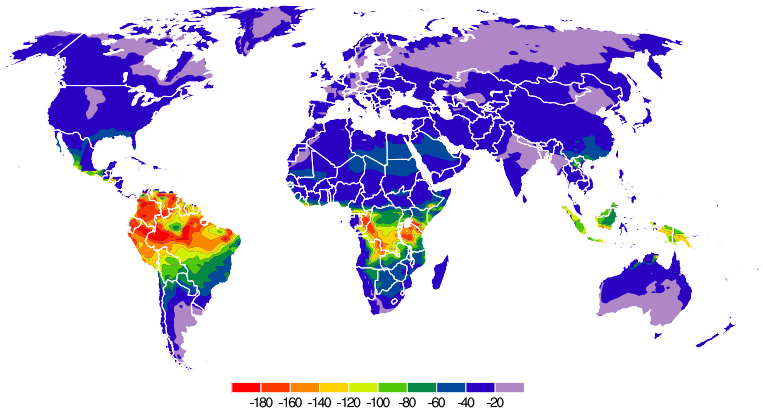
The BRACE project found substantial benefits to mitigation for extreme event outcomes under the moderate emissions scenario when compared to the high emissions scenario. These benefits were statistically significant in some regions as early as the 2020s and widespread by midcentury.

U.S.

- Heat wave days reduced by about half
- Daily extreme rainfall exceedance reduced by ~8%

GLOBAL

- 20-year heat event intensity reduced by at least 1°C over 94% of land and at least 2°C over 50% of land
- Area in which current 20-year heat events occur every year reduced by ~70%
- Likelihood of summer temperature warmer than historical record reduced by half
- Land area experiencing record heat reduced by one-third to one-half
- Increase in aridity reduced by about half



Difference in heat wave days per year in the moderate versus high emissions scenario

AVOIDED IMPACTS OF CLIMATE CHANGE ON HEALTH (~2060-2080)

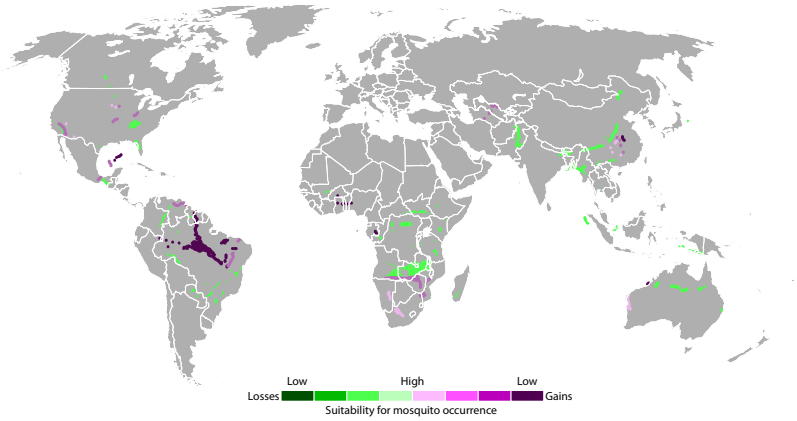
The BRACE project found moderate to substantial benefits to mitigation for health-related outcomes under the moderate emissions scenario when compared to the high emissions scenario. For some outcomes, socioeconomic drivers were found to strongly influence results.

U.S.

- High-mortality heat waves reduced by ~25%
- Population exposure to high-mortality heat waves reduced by about half in the absence of adaptation

GLOBAL

- Population exposure to heat waves reduced by about half
- Reduction of ~30% in number of humans experiencing increased exposure to dengue virus vector mosquito



Change in area of dengue virus mosquito vector occurrence in the moderate versus high emissions scenario

AVOIDED IMPACTS OF CLIMATE CHANGE ON AGRICULTURE (~2060-2080)

The BRACE project found mitigation had a modest benefit for agriculture under the moderate emissions scenario when compared to the high emissions scenario, but effects varied substantially by region, crop types, and assumptions about the effects of CO_2 fertilization. Crop yield and price outcomes were influenced more strongly by societal change than by climate change.

GLOBAL

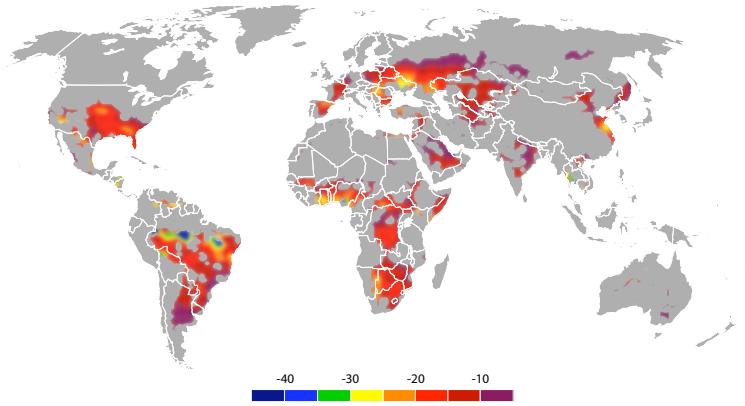
Without CO_2 fertilization effects

- Crop price increases reduced by one quarter to one half
- Empirically estimated declines in maize and wheat yields reduced by ~40%
- Crop exposure to extreme heat reduced by about a third

With CO_2 fertilization effects

- Small effects of mitigation on regional crop prices
- Decline in maize yields reduced by half*
- Decline in wheat yields similar in both scenarios
- Negative benefits of mitigation on wheat yields*

*Different results are possible depending on the model used and assumptions about the effects of CO_2 fertilization.



Difference in number of days >35°C as a percentage of maize growing season in the moderate versus high emissions scenario

AVOIDED IMPACTS OF CLIMATE CHANGE ON TROPICAL CYCLONES (~2060-2080)

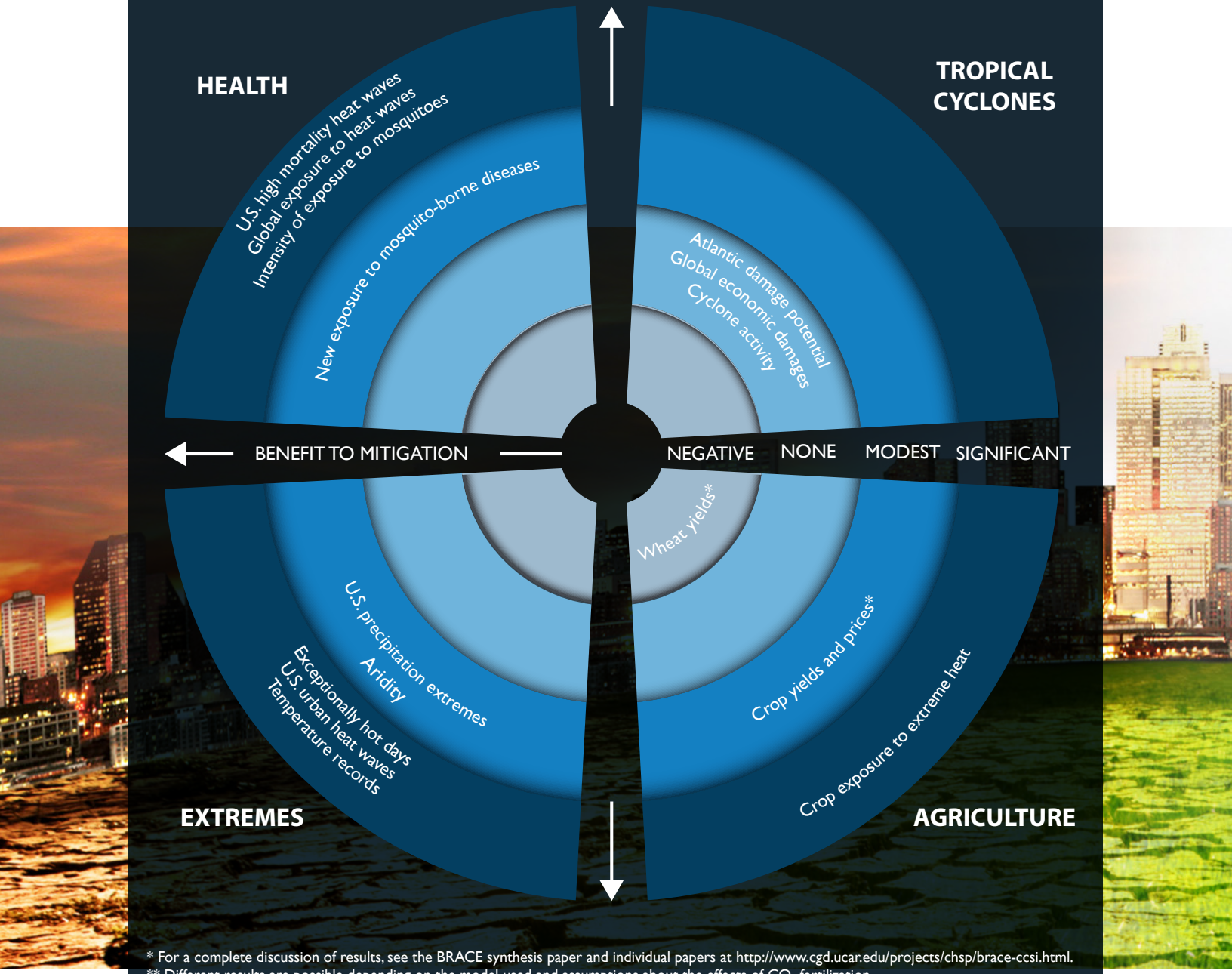
The BRACE project results showed no statistically distinguishable differences in tropical cyclone activity and damage between the moderate emissions scenario and the high emissions scenario, so no firm conclusion about the benefits of mitigation could be drawn. Economic damage results were more strongly influenced by assumptions about population and income growth than climate change.

- Both scenarios indicated declines in overall tropical cyclone activity but increases in the strongest storms, relative to present
- Both scenarios indicated declines in Atlantic tropical cyclone damage potential
- Both scenarios showed increases in global economic damage from tropical cyclones

Maps are based on the following papers from the Climatic Change special issue:
Extremes - Oleson et al., 2015; Health - Monaghan et al., 2016; and Agriculture - Tebaldi and Lobell, 2015.

BRACE conclusions should be interpreted in the context of a number of limitations of the individual studies and of the project design as a whole. BRACE studies primarily used ensembles from NCAR's Community Earth System Model (CESM), and in those cases conclusions should only be drawn for that model. In addition, no study can reasonably include all relevant determinants of risk, so results cannot be assumed to represent all possible risks from climate change under RCPs 4.5 and 8.5.

BRACE Results: RCP 4.5 versus 8.5



* For a complete discussion of results, see the BRACE synthesis paper and individual papers at http://www.cgd.ucar.edu/projects/chsp/brace-ccsi.html.
** Different results are possible depending on the model used and assumptions about the effects of CO_2 fertilization.

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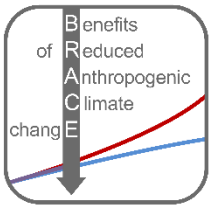
BRACE Key Messages



Understanding and quantifying the difference in climate-related risks between alternative levels of future climate change are critical to informing climate change policies, such as mitigation and adaptation.

The project on the Benefits of Reduced Anthropogenic Climate change (BRACE) explored global and regional impacts of climate change that could be avoided in a future scenario with lower emissions due to moderate emissions reduction efforts relative to a future scenario with higher emissions.

Because impacts depend on societal conditions in addition to the state of the climate, BRACE studies also evaluated the benefits of mitigation for two different societal futures. For several impacts, the effect on outcomes of alternative future societal development pathways was substantially larger than the effect of the two climate scenarios.

The BRACE project found substantial benefits to mitigation for extreme event outcomes under the lower emissions scenario when compared to the higher emissions scenario. These benefits were statistically significant in some regions as early as the 2020s and widespread by midcentury.

The project found moderate to substantial benefits to mitigation for health-related outcomes under the lower emissions scenario. For some outcomes, socioeconomic drivers were found to strongly influence results.

The project found mitigation had a modest benefit for agriculture under the lower emissions scenario, but effects varied substantially by region, crop types, and assumptions about the effects of CO2 fertilization. Crop yield and price outcomes were influenced more strongly by societal change than by climate change.

Results showed no statistically distinguishable differences in tropical cyclone activity and damage between the lower emissions scenario and the higher emissions scenario, so no firm conclusion about the benefits of mitigation could be drawn. Economic damage results were more strongly influenced by assumptions about population and income growth than climate change.

BRACE conclusions should be interpreted in the context of a number of limitations of the individual studies and of the project design as a whole. BRACE studies primarily used ensembles from NCAR's Community Earth System Model (CESM), and in those cases conclusions should only be drawn for that model. In addition, no study can reasonably include all relevant determinants of risk, so results cannot be assumed to represent all possible risks from climate change under RCPs 4.5 and 8.5.

BRACE | Climatic Change Special Issue

A special issue of *Climatic Change*, edited by Brian O'Neill and Andrew Gettelman from NCAR, has been published and features papers and results from the Benefits of Reduced Anthropogenic Climate changE (BRACE) project. View linked articles in the table of contents below, or read more about the background and rationale for BRACE.

Table of Contents

Methodological Issues

Climate Extremes

Health

11. Jones, B. et al. Population exposure to heat-related extremes: Demographic change vs climate change. Climatic Change, submitted.
12. Anderson, G.B., Oleson, K.W., Jones, B., Peng, R.D., 2016. Classifying heatwaves: developing health-based models to predict high-mortality versus moderate United States heatwaves. Climatic Change. DOI: 10.1007/s10584-016-1776-0.
13. Anderson, G.B., Oleson, K.W., Jones, B., Peng, R.D., 2016. Projected trends in high-mortality heatwaves under different scenarios of climate, population, and adaptation in 82 US communities. Climatic Change. DOI: 10.1007/s10584-016-1779-x.
14. Marsha, A., Sain, S. R., Heaton, M. J., Monaghan, A. J., Wilhelmi, O. V., 2016. Influences of climatic and population changes on heat-related mortality in Houston, Texas, USA. Climatic Change. DOI: 10.1007/s10584-016-1775-1.
15. Monaghan, A.J., Sampson, K.M., Steinhoff, D.F., Ernst, K.C., Ebi, K.L., Jones, B., Hayden, M.H., 2016. The potential impacts of 21st century climatic and population changes on human exposure to the virus vector mosquito Aedes aegypti. Climatic Change 1-14. DOI:10.1007/s10584-016-1679-0.

Agriculture and Land Use

16. 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 1–15. DOI:10.1007/s10584-016-1654-9.
17. Ren, X., Weitzel, M., O'Neill, B.C., Lawrence, P., Meiyappan, P., Levis, S., Balistreri, E.J., and Dalton M., 2016. Avoided economic impacts of climate change on agriculture: Integrating a land surface model (CLM) with a global economic model (iPETS). Climatic Change. 1-15. DOI: 10.1007/s10584-016-1791-1.
18. Tebaldi, C., Lobell, D., 2015. Estimated impacts of emission reductions on wheat and maize crops. Climatic Change 1–13. DOI:10.1007/s10584-015-1537-5.

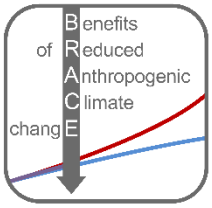
Tropical Cyclones

19. Bacmeister, J., Reed, K.A., Hannay, C., Lawrence, P., Bates, S., Truesdale, J.E., Rosenbloom, N., Levy, M., 2016. Projected changes in tropical cyclone activity under future warming scenarios using a high-resolution climate model. Climatic Change. DOI: 10.1007/s10584-016-1750-x.
20. Done, J.M., PaiMazumder, D., Towler, E., Kishtawal, C.M., 2015. Estimating impacts of North Atlantic tropical cyclones using an index of damage potential. Climatic Change 1–13. DOI:10.1007/s10584-015-1513-0.
21. Gettelman A., Bresch D.N., Chen C.C., Truesdale J.E., Bacmeister J.T., 2017. Projections of future tropical cyclone damage with a high-resolution global climate model. Climatic Change. DOI: 10.1007/s10584-017-1902-7.

BRACE Studies Submitted to Other Journals

22. Hu, A., Bates, S. Avoided Sea Level Rise from thermal expansion for RCP4.5 versus RCP8.5. In preparation.
23. Towler, E., H. Lazrus, and D. Pai Mazumder, 2017: Characterizing drought risks and implications for water management under climate change. NCAR Technical Note NCAR/TN-533+STR, 25 pp, doi:10.5065/D6HD7T3N.

BRACE Contact Information



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Additional BRACE Resources

BRACE Highlights Brochure

Results from the BRACE brochure were summarized in a four-page brochure. View the BRACE highlights brochure to learn more about the BRACE project.

BRACE in the News

NASA data shows this May is hottest ever

High chance every summer will mark new record heat

Consequences of Climate Change: Expect Record-High Hot Summers in 50 Years

Future summers are going to be even hotter

Brace for warmest ever summers across the globe in 50 years

Boulder researcher sees frequent severe heat waves later in century

Searing Heat Waves Detailed in Study of Future Climate

Scientists conclude greenhouse gas reduction will decrease summer heat

BRACE Activities

BRACE authors have given talks and posters at numerous venues. A video of an NCAR seminar presentation by Brian O'Neill on the BRACE project is also available to watch.

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