



Climate system response to external forcings and climate change projections in CCSM4

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CESM Climate Variability and Change Working Group,
NCAR Climate Change Prediction Group,
Supported by DOE through the UCAR-DOE Cooperative Agreement



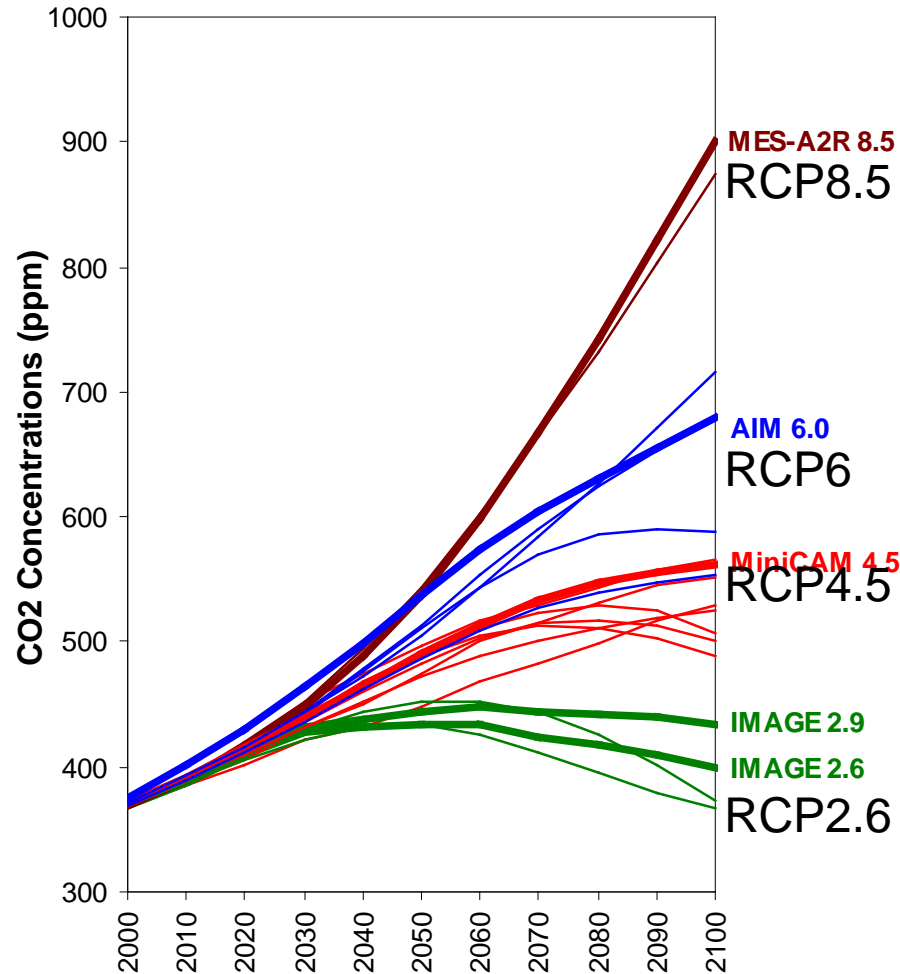
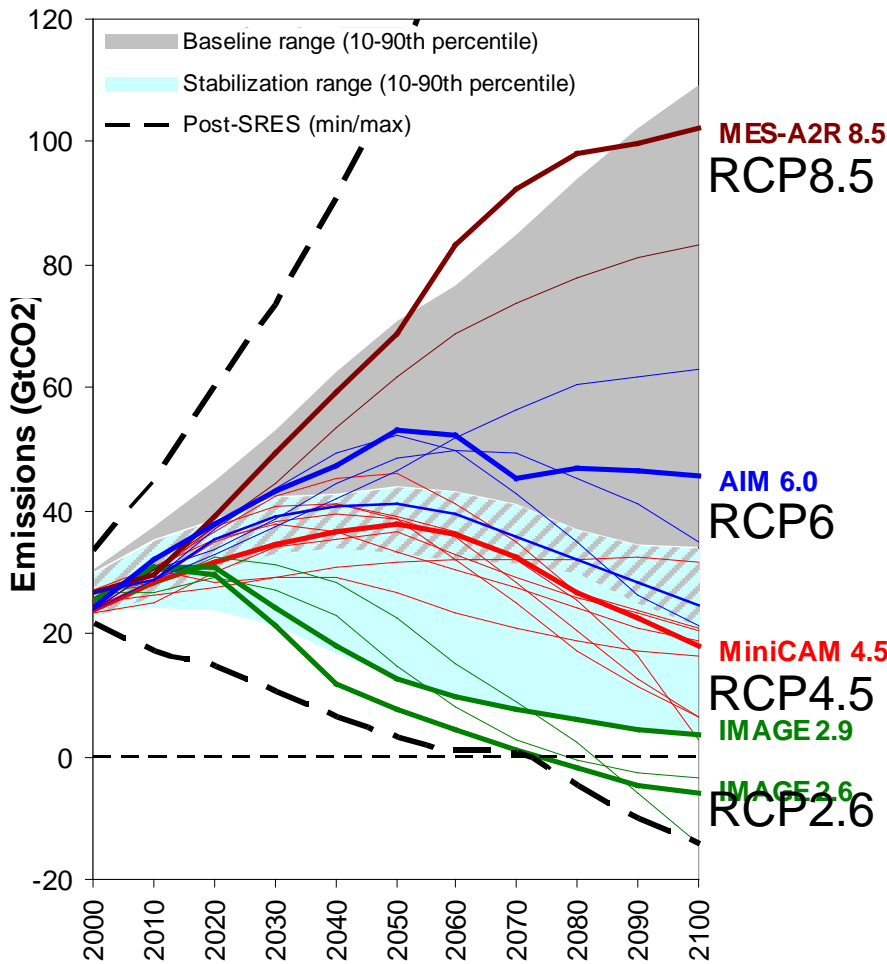
The IPCC AR4 in 2007 saw the end of the past 20 years of non-mitigation scenarios run in global climate models

Climate change science is now focusing on mitigation/adaptation

New mitigation scenarios target certain levels of climate change that require policy actions, including energy policy related to the DOE mission

With different mitigation choices, what is the remaining time-evolving regional climate change to which human societies will have to adapt?

New mitigation scenarios: representative concentration pathways (RCPs)





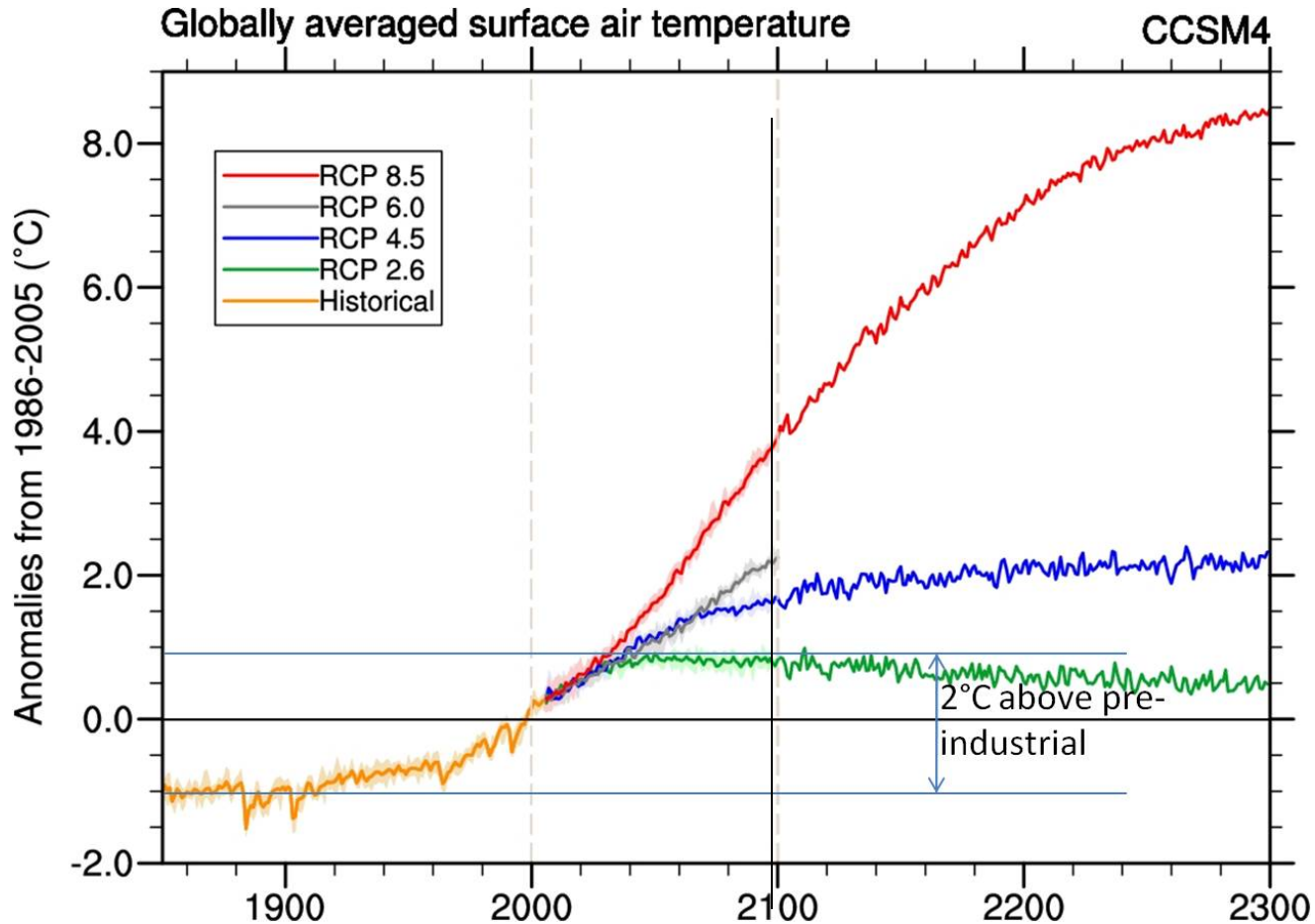
One way to achieve negative CO₂ emissions in RCP2.6 by around 2070 in terms of the energy policy contribution (in addition to economic and demographic considerations):

--by 2070, about 45% fossil fuel with carbon capture and storage (CCS),
20% fossil fuel without CCS,
and 35% renewables (some of that includes biomass and CCS as well) and nuclear.

In contrast, RCP8.5 with little mitigation implies, by 2070, 80% fossil fuels without CCS, no fossil fuel with CCS, and 20% renewables and nuclear

(van Vuuren et al., 2011, *Clim. Change*)

Results from CMIP5 experiments with CCSM4 at NCAR



(Meehl, G.A., W.M. Washington, J.M. Arblaster, A. Hu, H. Teng, C. Tebaldi, B. Sanderson, J.F. Lamarque, A. Conley, W.G. Strand, and J.B. White III, 2011: Climate system response to external forcings and climate change projections in CCSM4. *J. Climate*, accepted.)

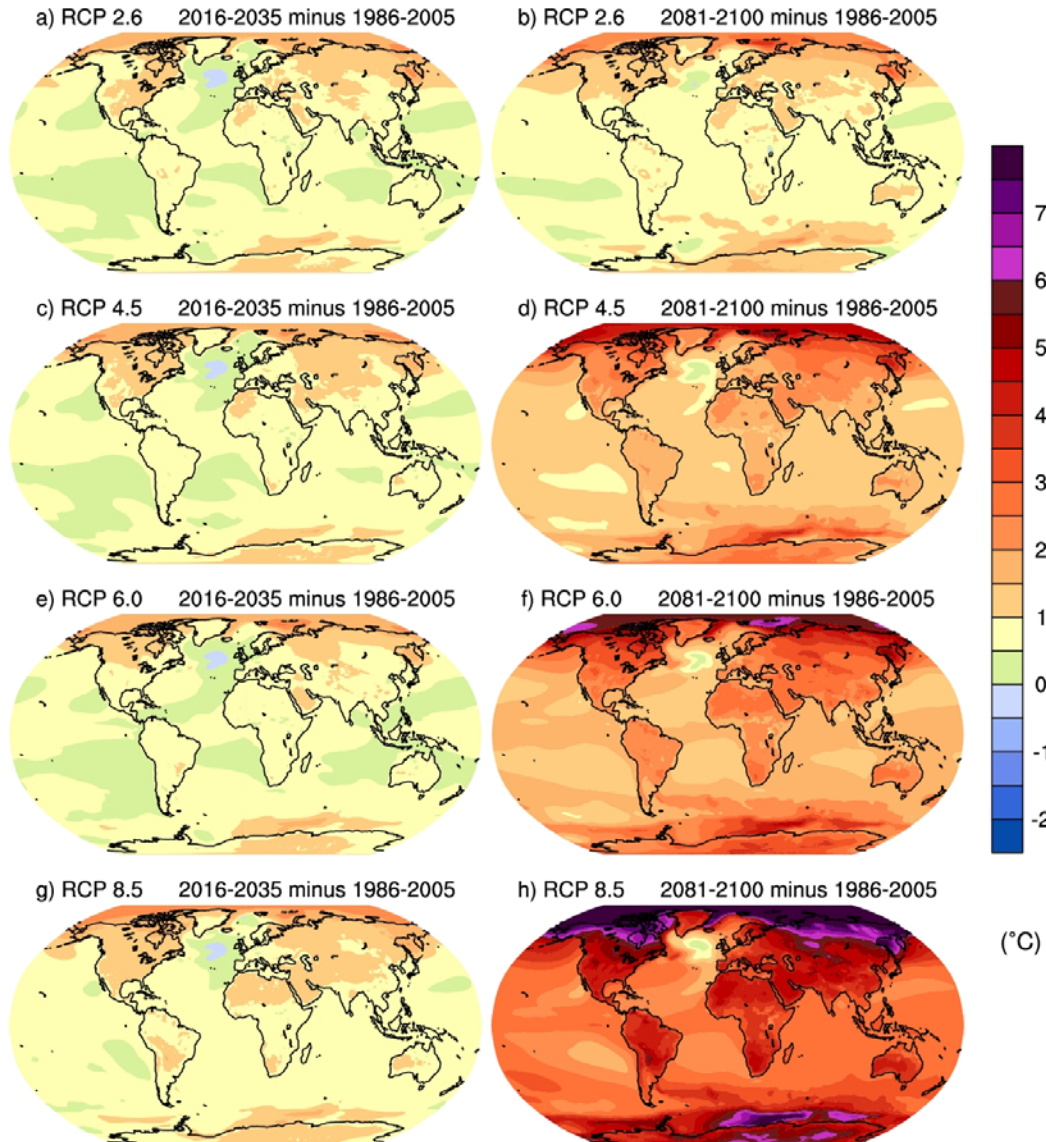


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CCSM4 surface air temperature changes



Warming in the near-term (2016-2035, left column) is similar no matter what scenario is followed—near term climate change is an adaptation problem

Magnitude of the warming later in the century (2081-2100, right column) depends a lot on what scenario is followed—the mitigation path we follow makes a big difference after mid-century

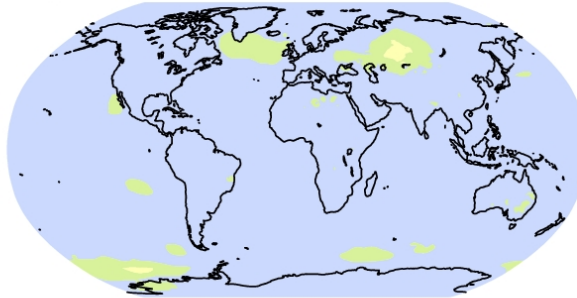
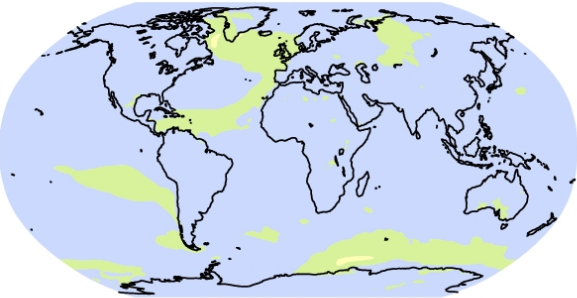
22nd century

23rd century

CCSM4 surface air temperature changes

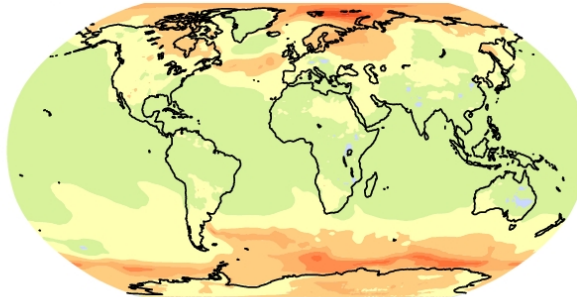
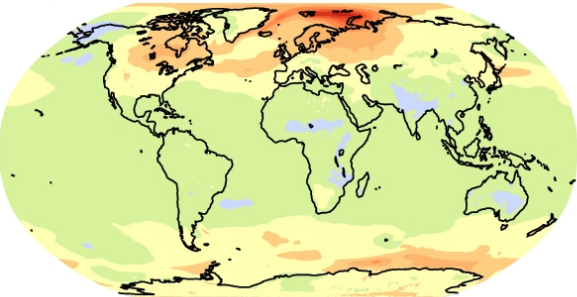
a) RCP 2.6 2181-2200 minus 2081-2100

b) RCP 2.6 2281-2230 minus 2081-2100



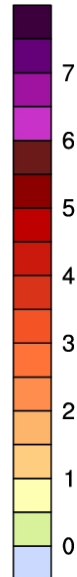
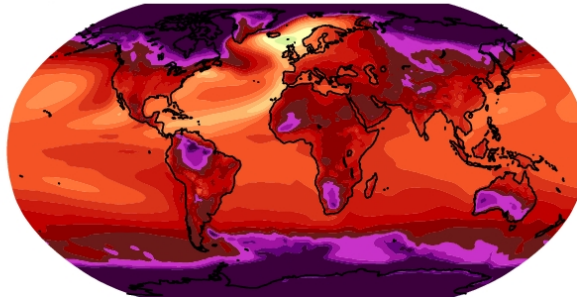
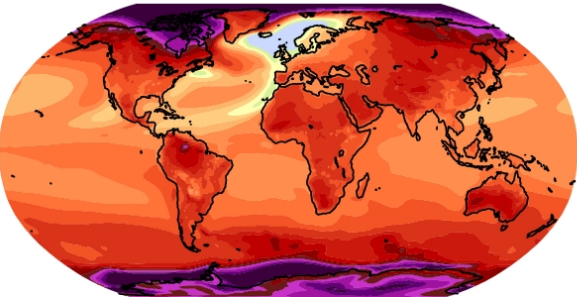
c) RCP 4.5 2181-2200 minus 2081-2100

d) RCP 4.5 2281-2230 minus 2081-2100



e) RCP 8.5 2181-2200 minus 2081-2100

f) RCP 8.5 2281-2230 minus 2081-2100



(°C)

Climate change doesn't stop at 2100

Aggressive mitigation in RCP2.6 produces **global cooling** after 2100 (top)

little mitigation in RCP8.5 results in ongoing large warming to 2300 (bottom)

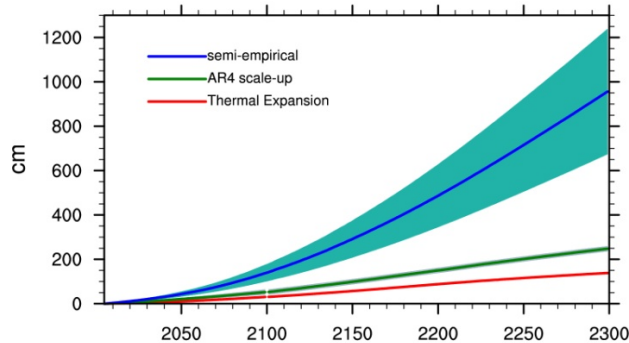


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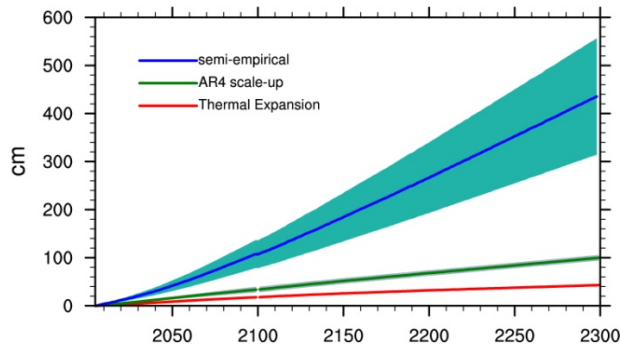


Global Sea Level Anomaly (rcp8.5)



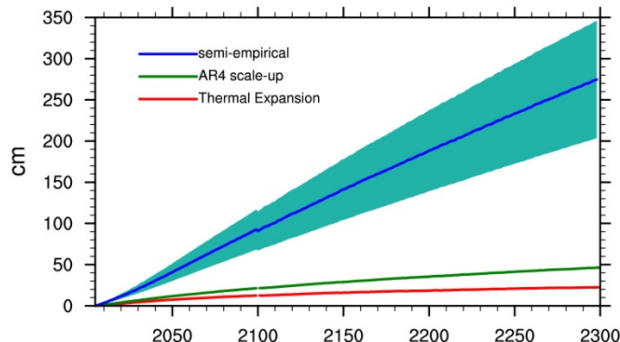
As temperatures stabilize, and even decrease after 2100 in the low RCP2.6 scenario, sea level would continue to rise due to climate change commitment.

Global Sea Level Anomaly (rcp4.5)



With aggressive mitigation scenarios, global temperatures can be stabilized, and though sea level rise cannot be stopped, it can be slowed down.

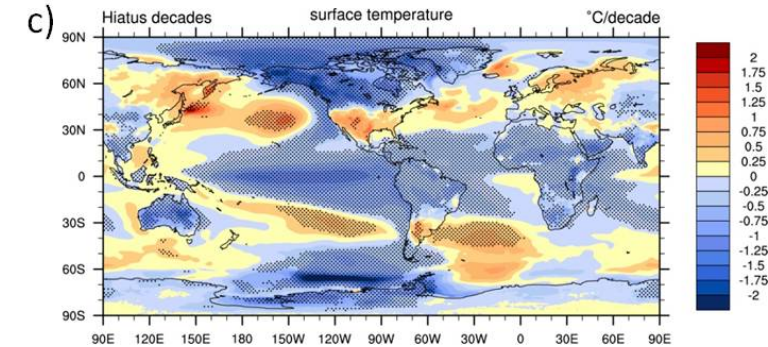
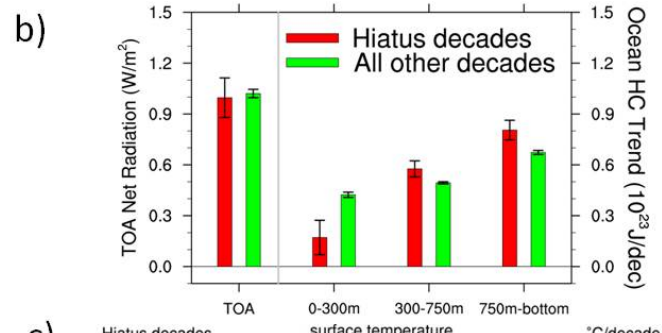
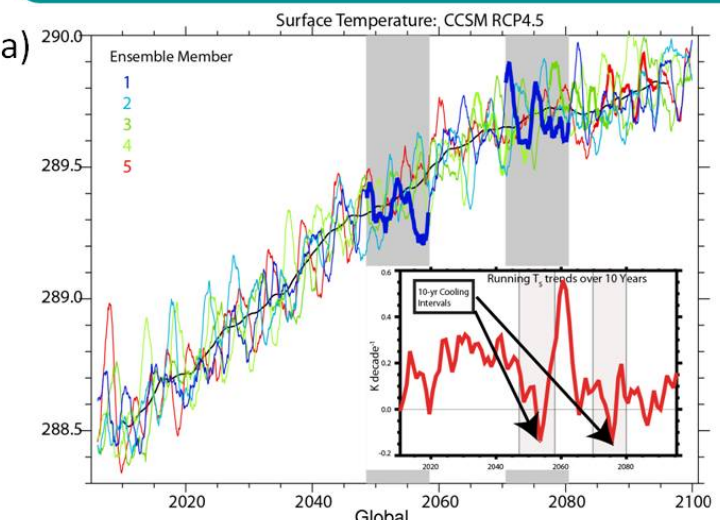
Global Sea Level Anomaly (rcp2.6)



bottom red line: thermal expansion from CCSM4

middle green line: scaled-up ice sheet discharge example from IPCC AR4 added to thermal expansion from CCSM4

top blue line: semi-empirical sea level rise, after Vermeer and Rahmstorf, 2009



There are some decades when there is a hiatus of global warming

Q: Where does the heat go when the surface temperature trend is flat for a decade or so?

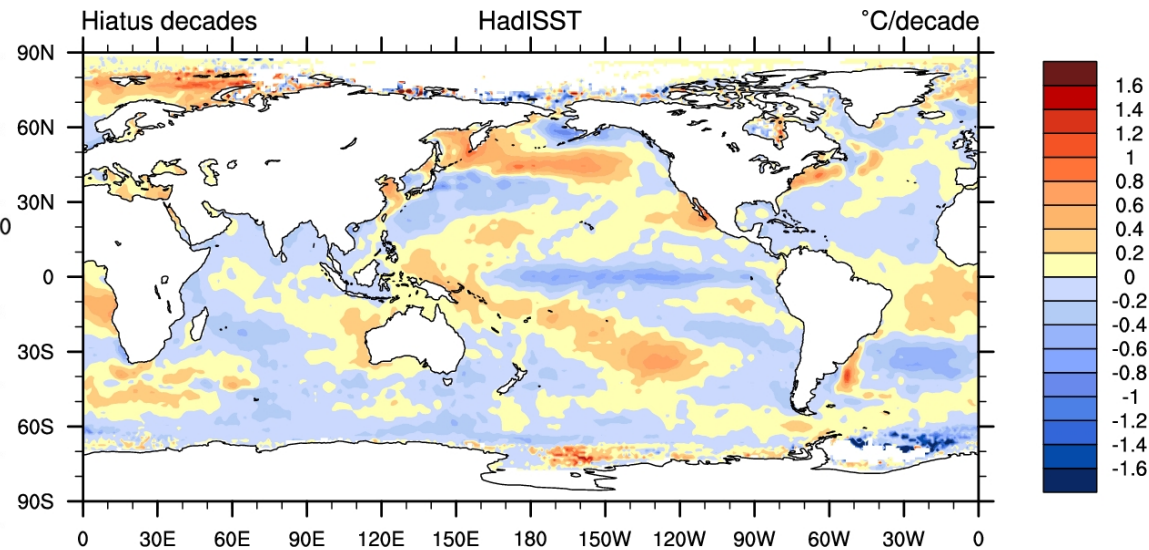
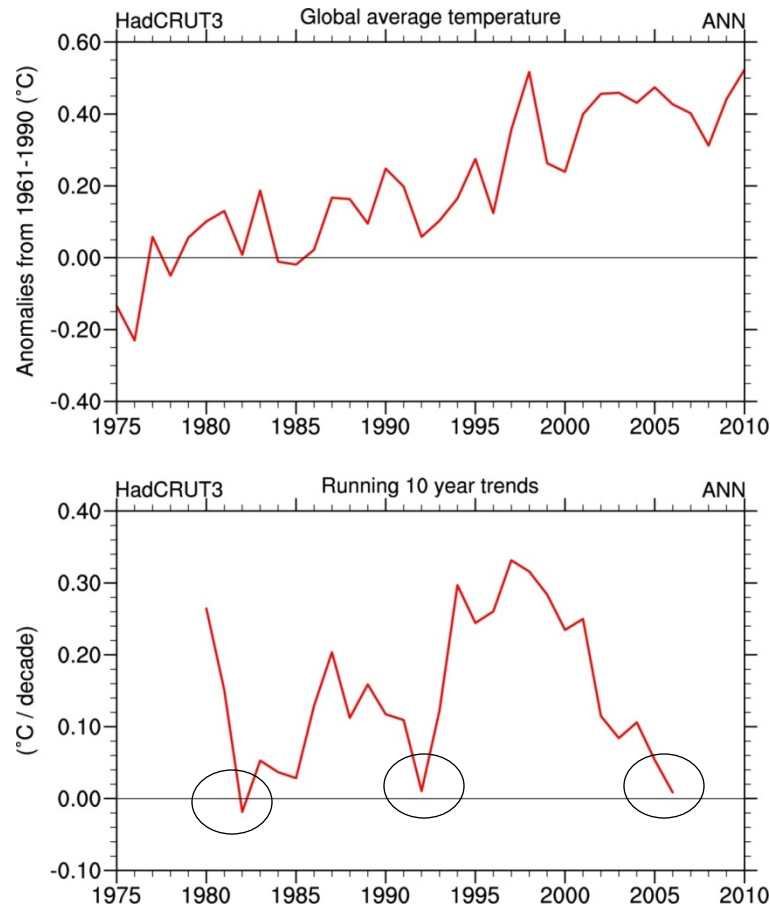
A: The deep ocean

with a La Niña-like SST pattern, increased heat convergence in the subtropical oceans, weakened MOC and Antarctic Bottom Water formation

A hiatus period: relatively common, consistent with our physical picture of how the climate system works, does not invalidate our basic understanding of greenhouse-gas-induced warming or the models used to simulate such warming.

(Meehl, G.A., J.M. Arblaster, J. Fasullo, A. Hu, and K.E. Trenberth, 2011: Model-based evidence of deep ocean heat uptake during surface temperature hiatus periods. *Nature Climate Change*, doi:10.1038/NCLIMATE1229)

A composite of three recent hiatus periods from observations also shows a La Niña-like SST anomaly pattern, suggesting similar processes to those in the model are at work



(Meehl, G.A., J.M. Arblaster, J. Fasullo, A. Hu, and K.E. Trenberth, 2011: Model-based evidence of deep ocean heat uptake during surface temperature hiatus periods. *Nature Climate Change*, doi:10.1038/NCLIMATE1229)



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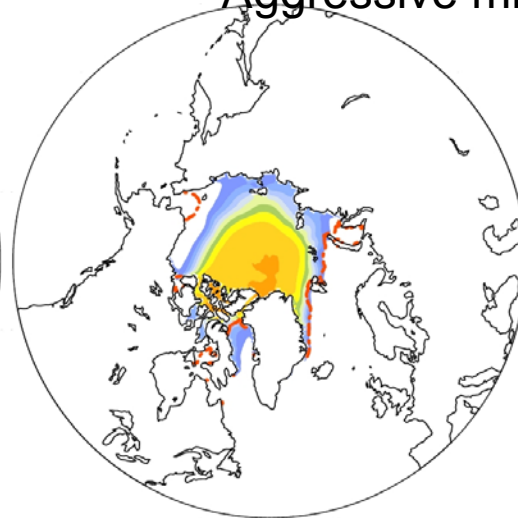
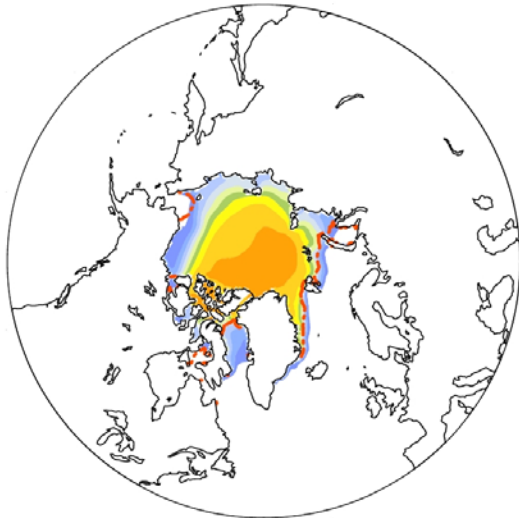
Summary

1. Analysis of CCSM4 simulations with aggressive mitigation in RCP2.6 (compared to little mitigation in RCP8.5) shows warming below 2°C relative to pre-industrial with ongoing global cooling to 2300, though sea level would continue to rise due to climate change commitment
2. Choice of scenario doesn't have a big impact on near-term climate change, but makes a lot of difference for longer term climate change; energy policy choices we make now will have a dramatic impact after mid-century
3. Internally generated decadal timescale variability produces periods of ten years or so of little globally averaged surface warming trend naturally, with the heat going into the deeper ocean layers; such hiatus periods are common and do not invalidate our understanding of climate change or climate models

a) 20C3M 1986-2005

b) RCP 2.6 2080-2099

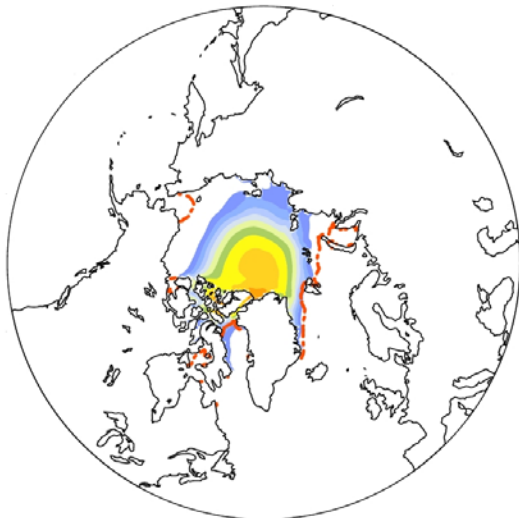
Aggressive mitigation



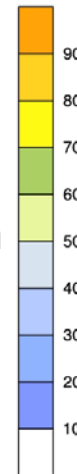
c) RCP 4.5 2080-2099

d) RCP 8.5 2080-2099

Little mitigation



ASO %

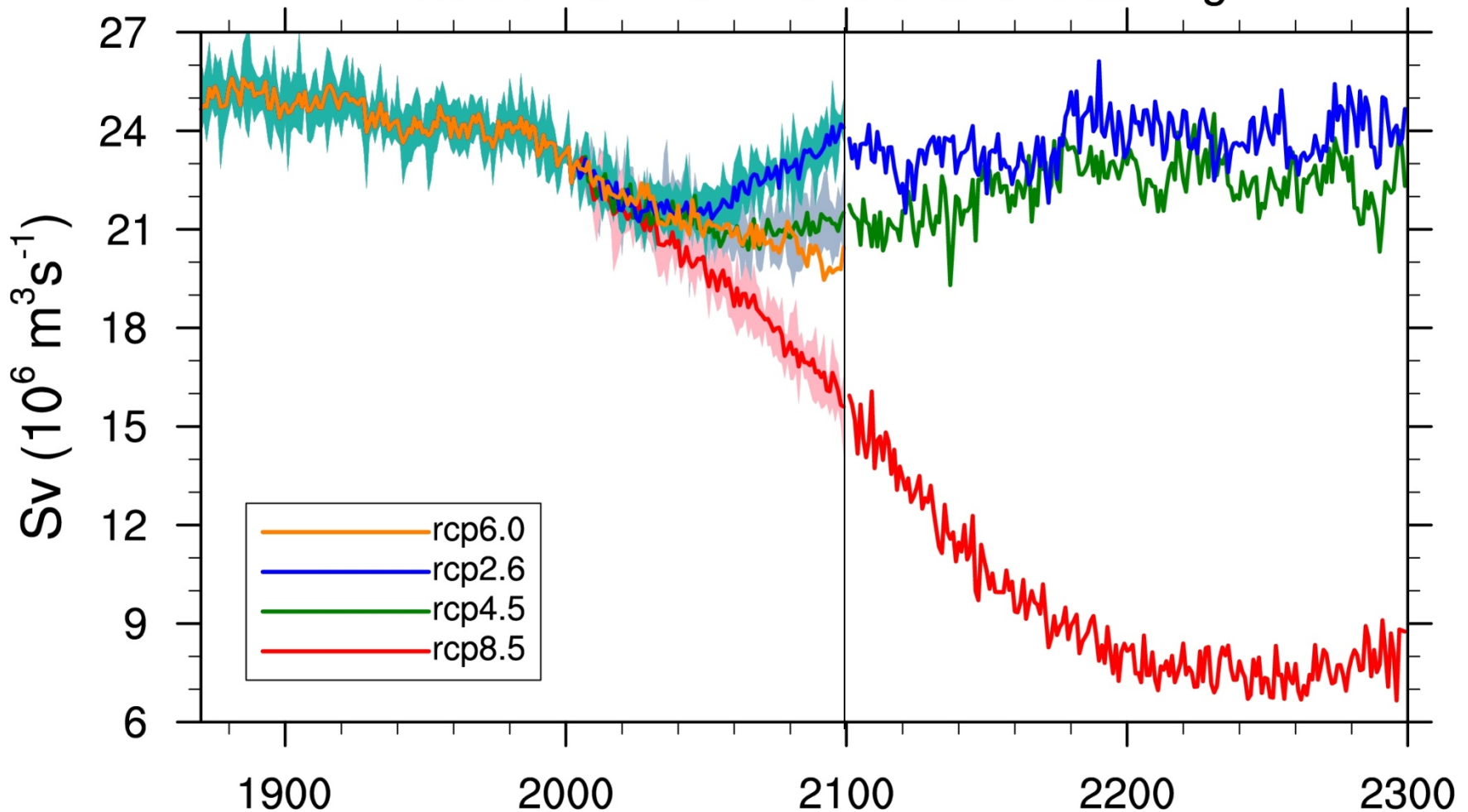


What difference can mitigation make for adaptation?

Much more Arctic sea ice would be retained with aggressive mitigation in RCP2.6, particularly in summer, compare to little summer sea ice with little mitigation in RCP8.5

Atlantic MOC stabilizes with more aggressive mitigation, and nearly goes away with little mitigation

Atlantic Maximum Meridional Overturning





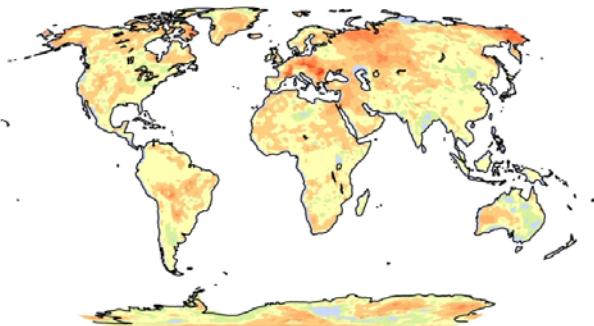
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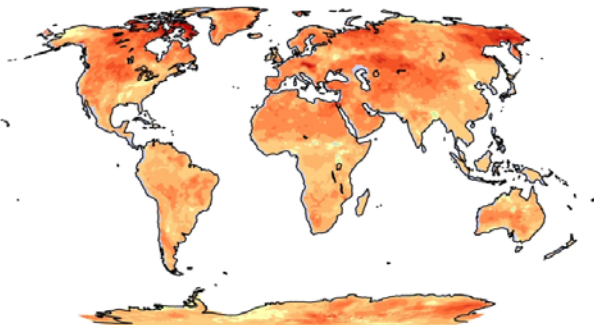


CCSM4 heat wave intensity changes

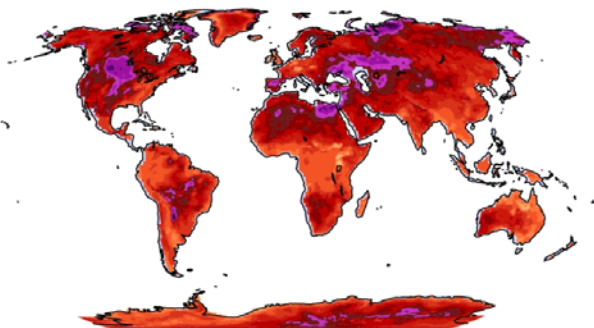
a) RCP 2.6 2081-2100 minus 1986-2005



b) RCP 4.5 2081-2100 minus 1986-2005



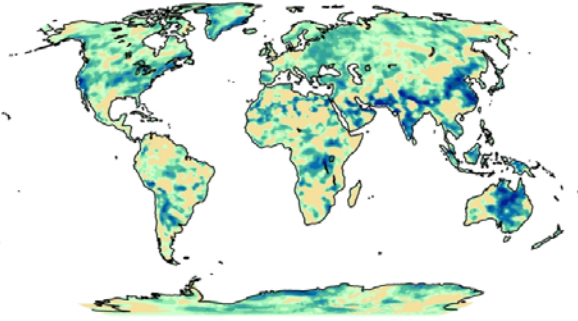
c) RCP 8.5 2081-2200 minus 1986-2005



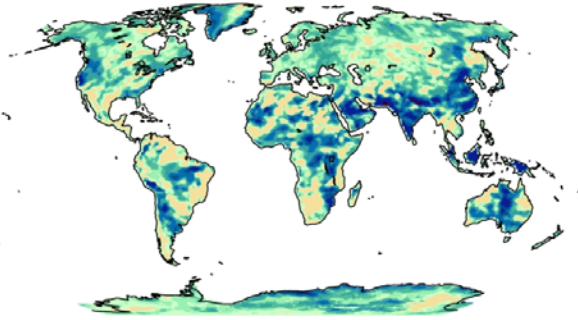
(°C)

CCSM4 precipitation intensity changes

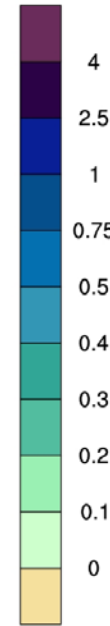
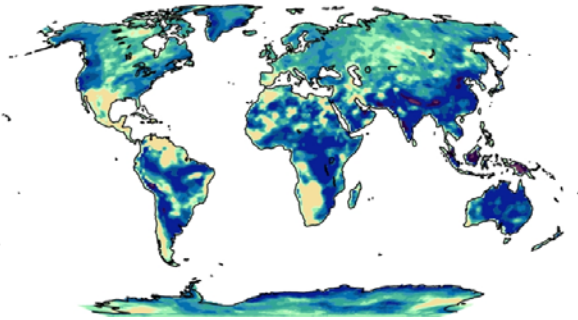
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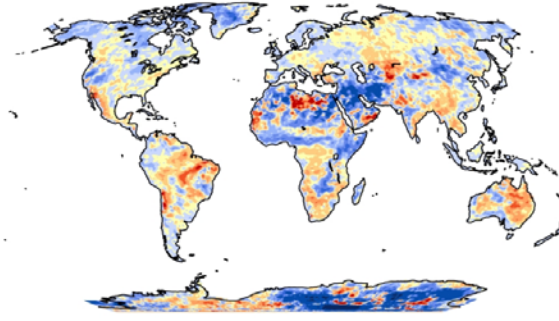
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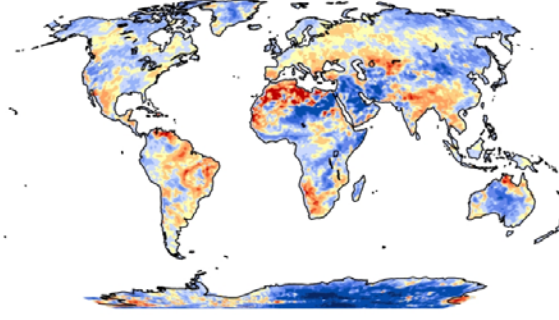
(mm day⁻¹)

CCSM4 consecutive dry days changes

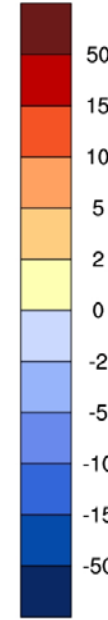
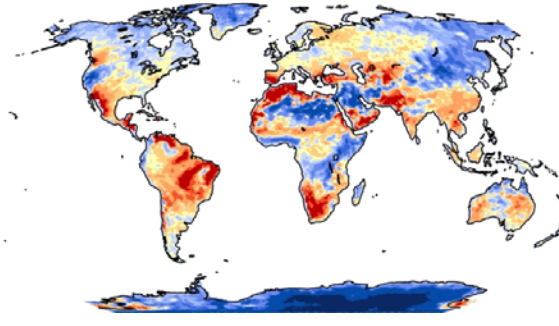
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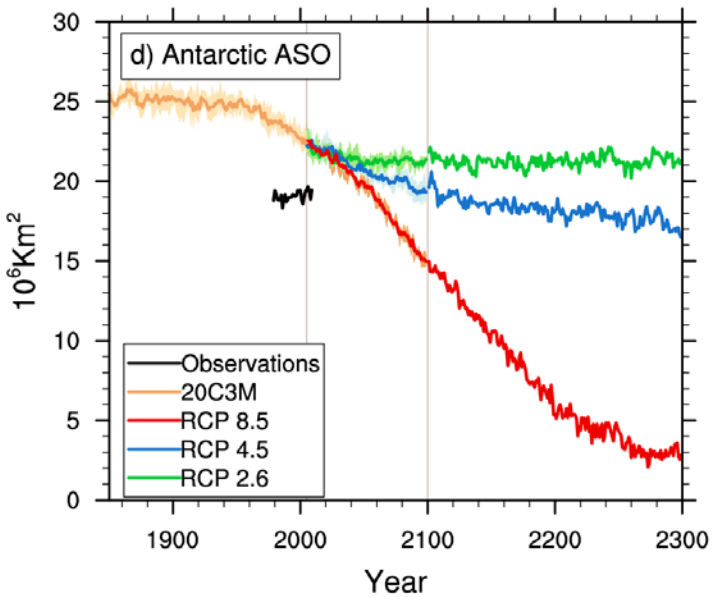
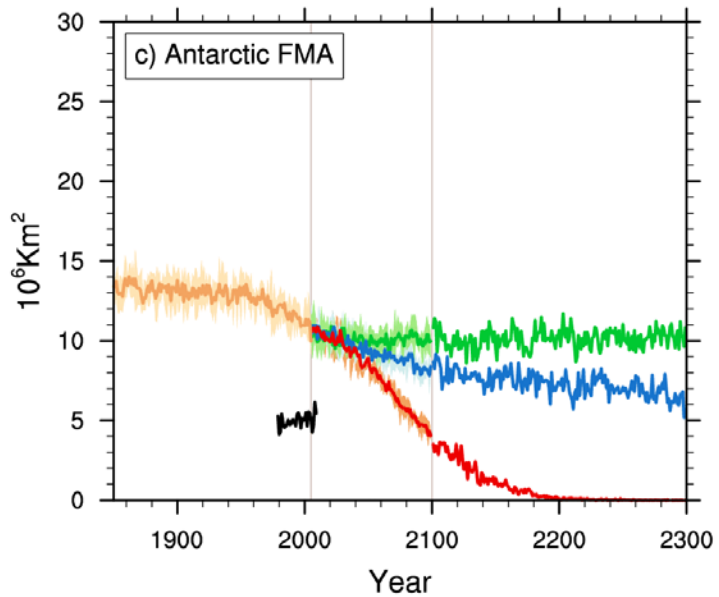
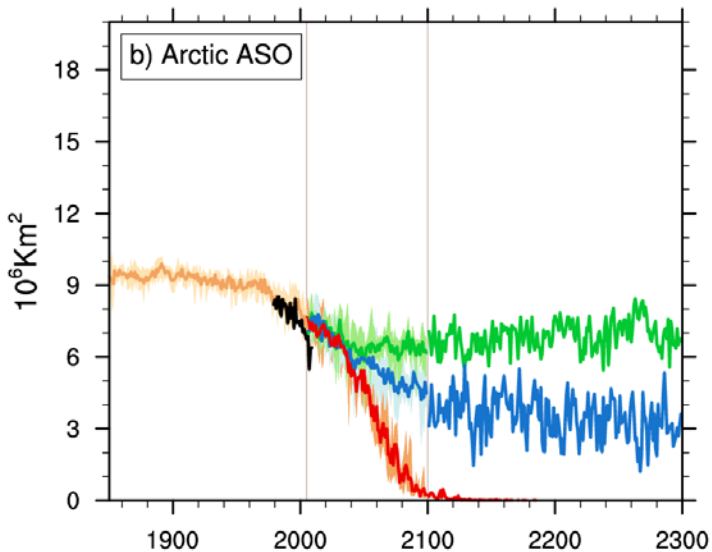
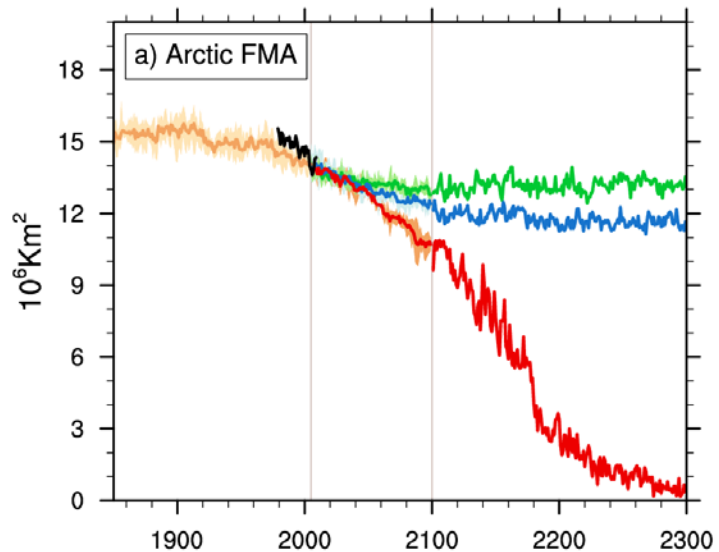


(days per year)

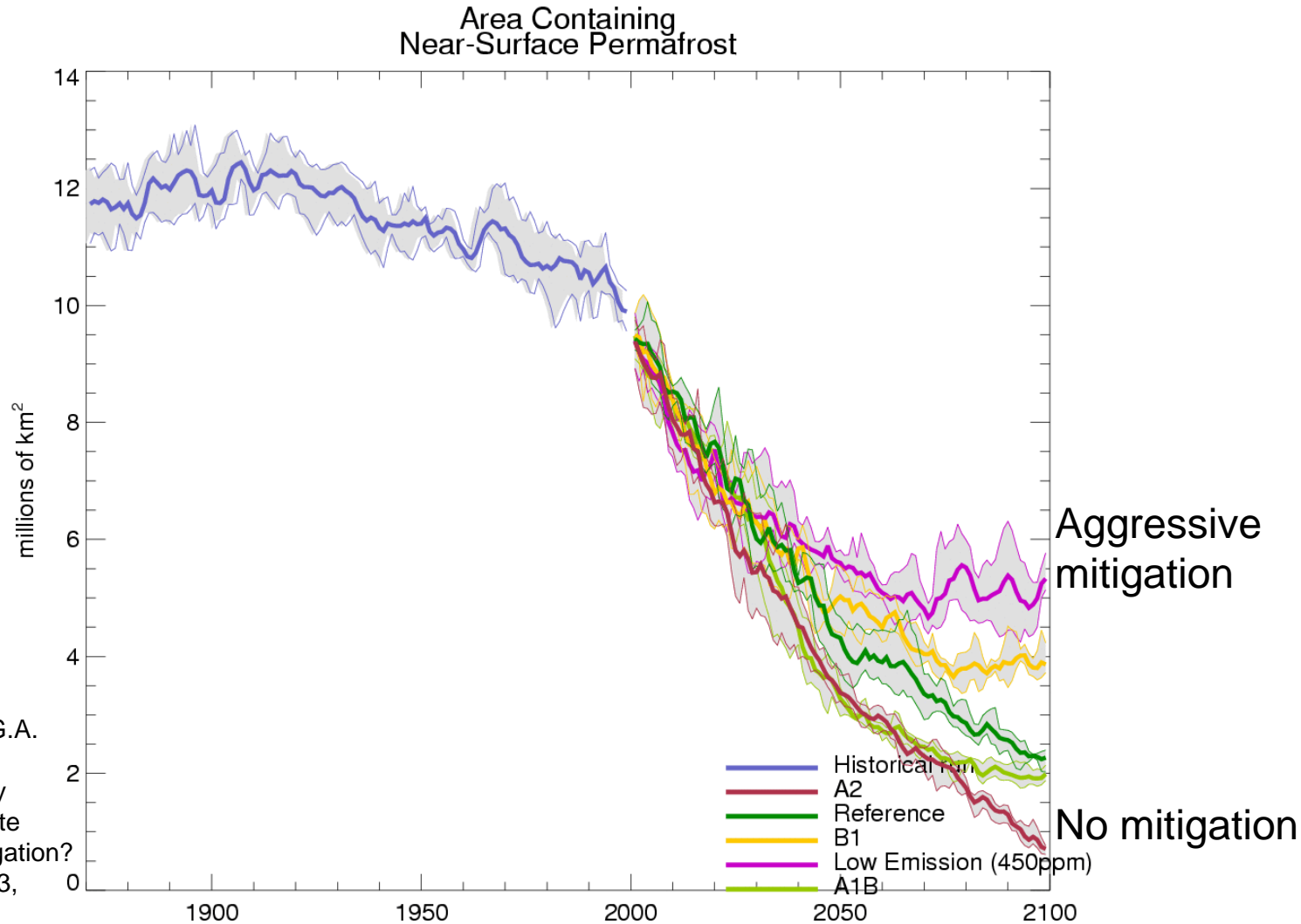


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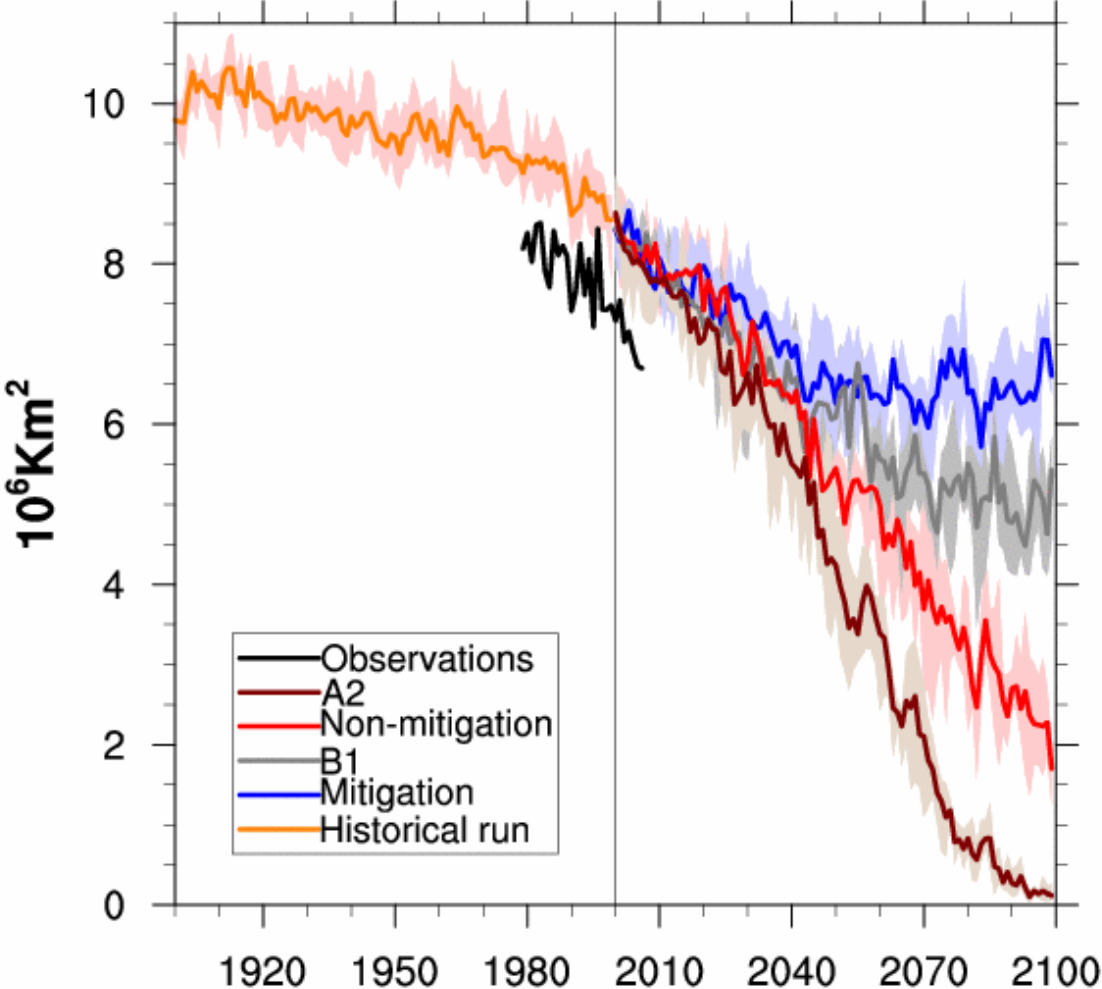


Mitigation could make a difference for reducing possible amplifying feedbacks (e.g. retaining more permafrost would keep more CO₂ and methane in the ground and out of the air where it would cause more warming)



(Washington, W.M., R. Knutti, G.A. Meehl, H. Teng, C. Tebaldi, D. Lawrence, L. Buja, and W. Gary Strand, 2009: How much climate change can be avoided by mitigation? *Geophys. Res. Lett.*, **36**, L08703, doi:10.1029/2008GL037074.)

ASO sea-ice extent





The Cooperative Agreement provides unique contributions to DOE-funded climate research

1. The Cooperative Agreement supports the Community Earth System Model (CESM) Climate Variability and Change Working Group (CCWG) through the Climate Change Prediction Group (CCP) at NCAR
2. The CCWG, with support from DOE as noted above, performs the climate change simulations with CCSM/CESM (e.g. CMIP5 for assessment in the IPCC Fifth Assessment Report, U.S. National Assessment, etc.)
3. The CCP group performs diagnoses of the climate change simulations (with the CESM suite of experiments and compared to larger multi-model datasets such as CMIP5) to expand the frontiers of our knowledge of climate variability and change, and to inform energy policy issues relevant to climate change adaptation/mitigation that are part of DOE's mission
4. The CCP group performs additional unique sensitivity experiments with CCSM/CESM to diagnose processes and mechanisms of climate variability and change, e.g. single forcing simulations to assess which forcing is causing changes to the climate system, or unique sensitivity experiments XXXXX



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Summary

Unique contributions of the UCAR/DOE Cooperative Agreement include support of the CESM Climate Variability and Change Working Group and its DOE-funded scientists at NCAR who not only run the CCSM/CESM CMIP5 climate change simulations for assessment in the IPCC AR5, but also diagnose the model runs and perform additional sensitivity experiments by expand our knowledge of climate variability and change relevant to energy policy that is an important element of DOE's mission

1. Analysis of CCSM4 simulations with aggressive mitigation in RCP2.6 (compared to little mitigation in RCP8.5) shows warming below 2°C relative to pre-industrial, with retention of most of the Arctic sea ice, though sea level would continue to rise due to climate change commitment
2. Choice of scenario doesn't have a big impact on near-term climate change, but makes a lot of difference for longer term climate change; energy policy choices we make now will have a dramatic impact after mid-century
3. Internally generated decadal timescale variability produces periods of ten years or so of little globally averaged surface warming trend naturally, with the heat going into the deeper ocean layers; such hiatus periods are common and do not invalidate our understanding of climate change or climate models



CMIP5 results from CCSM4: Contributions from the UCAR/DOE Cooperative Agreement support to the CESM Climate Variability and Change Working Group

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