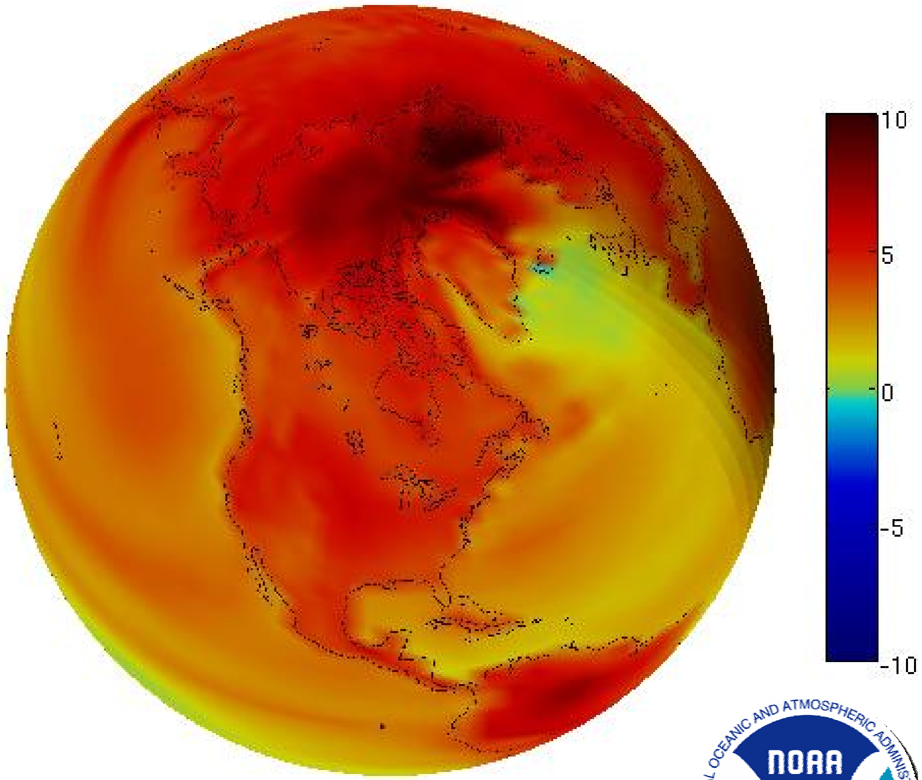
50^{th} Anniversary CO2 Record Symposium

Session 2: Assessing Impacts and Urgency

The Possibility of Large Temperature Increases With CO2 Doubling



Alexander E. MacDonald

DAA, NOAA OAR LCI

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November 28, 2007

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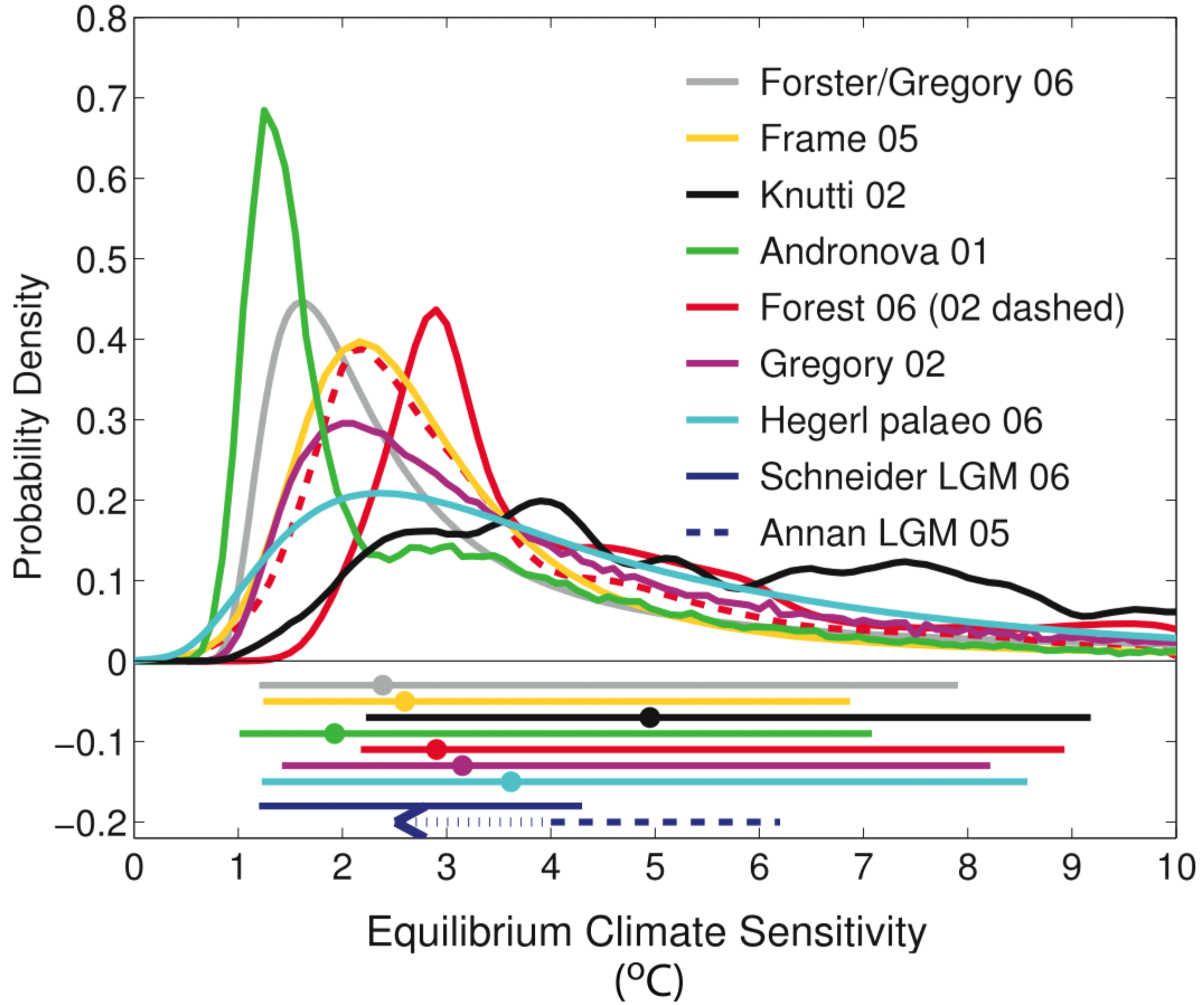

.gure 9.20

Climate models run with different parameterizations show the possibility of very large temperature changes.

What is the probability of very large increases of earth's average temperature for a doubling of CO2?

Why Is Climate Sensitivity So Unpredictable?

Gerard H. Roe* and Marcia B. Baker

Uncertainties in projections of future climate change have not lessened substantially in past decades. Both models and observations yield broad probability distributions for long-term increases in global mean temperature expected from the doubling of atmospheric carbon dioxide, with small but finite probabilities of very large increases. We show that the shape of these probability distributions is an inevitable and general consequence of the nature of the climate system, and we derive a simple analytic form for the shape that fits recent published distributions very well. We show that the breadth of the distribution and, in particular, the probability of large temperature increases are relatively insensitive to decreases in uncertainties associated with the underlying climate processes.

The envelope of uncertainty in climate projections has not narrowed appreciably over the past 30 years, despite tremendous increases in computing power, in observations, and in the number of scientists studying the problem (*1*). This suggests that efforts to reduce uncertainty in climate projections have been impeded either by fundamental gaps in our understanding of the climate system or by some feature (which itself might be well understood) of the system's underlying nature. The resolution of this dilemma has important implications for climate research and policy.

We investigate a standard metric of climate change: Climate sensitivity is defined as the equilibrium change in global and annual mean surface air temperature, ΔT, due to an increment in downward radiative flux, ΔR_f, that would result from sustained doubling of atmospheric CO_2 over its preindustrial value ($2 \times CO_2$). It is a particularly relevant metric for current discussions of industrial emissions scenarios leading to the stabilization of CO_2 levels above preindustrial values (*2*). Studies based on observations, energy balance models, temperature reconstructions, and global climate models (GCMs) (*3*–*13*) have found that the probability density distribution of ΔT is peaked in the range $2.0°C \le \Delta T \le 4.5°C$, with a long tail of small but finite probabilities of very large temperature increases. It is important to ask what determines this shape and, in particular, the high ΔT tail, and to what extent we can decrease the distribution width.

Climate consists of a set of highly coupled, tightly interacting physical processes. Understanding these physical processes is a massive task that will always be subject to uncertainty. How do the uncertainties in the physical processes translate into an uncertainty in climate sensitivity? Explanations for the range of predictions of ΔT, summarized in (*14*), have focused on (i) uncertainties in our understand-

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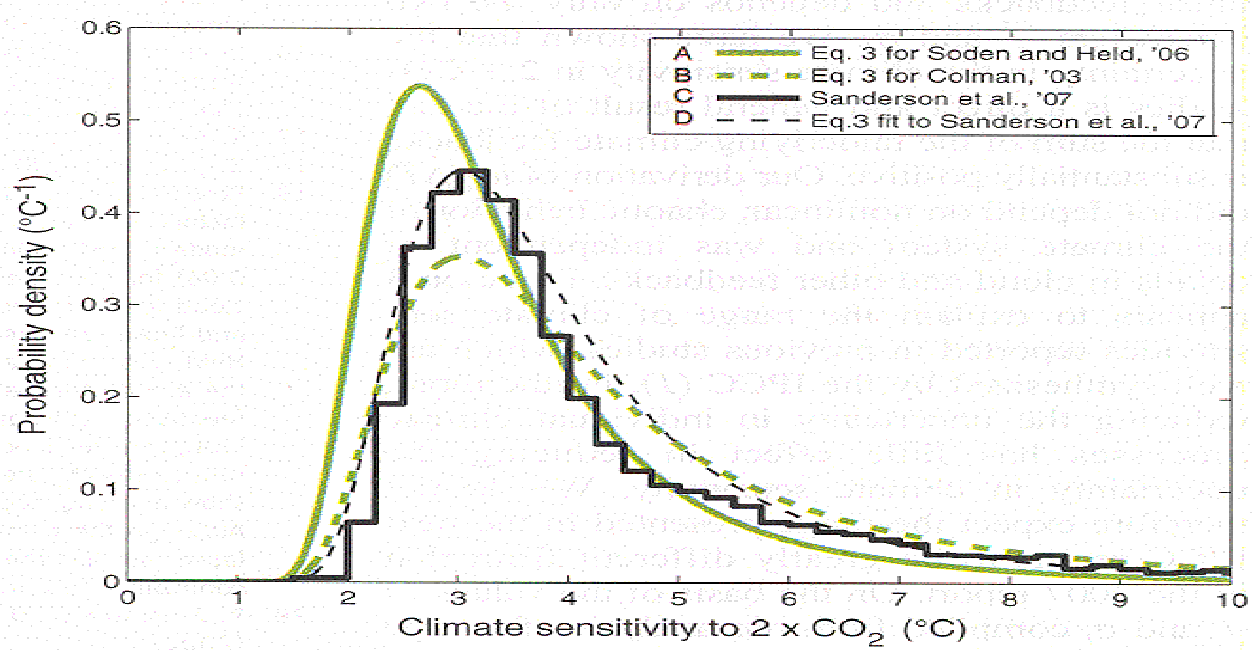
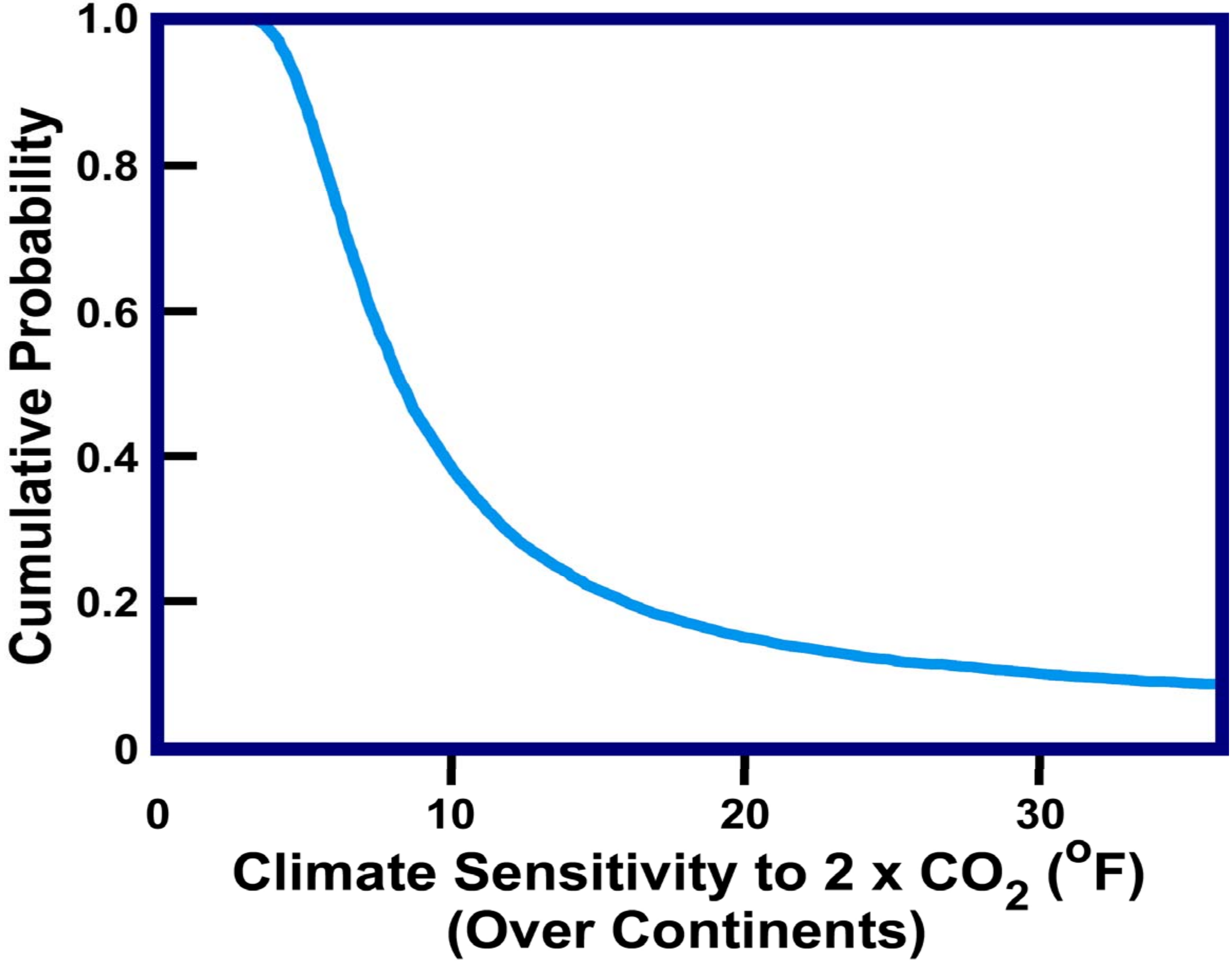




Adapted from Roe and Baker, 2007, SCIENCE, Fig. 2C, p 630.

Main Points

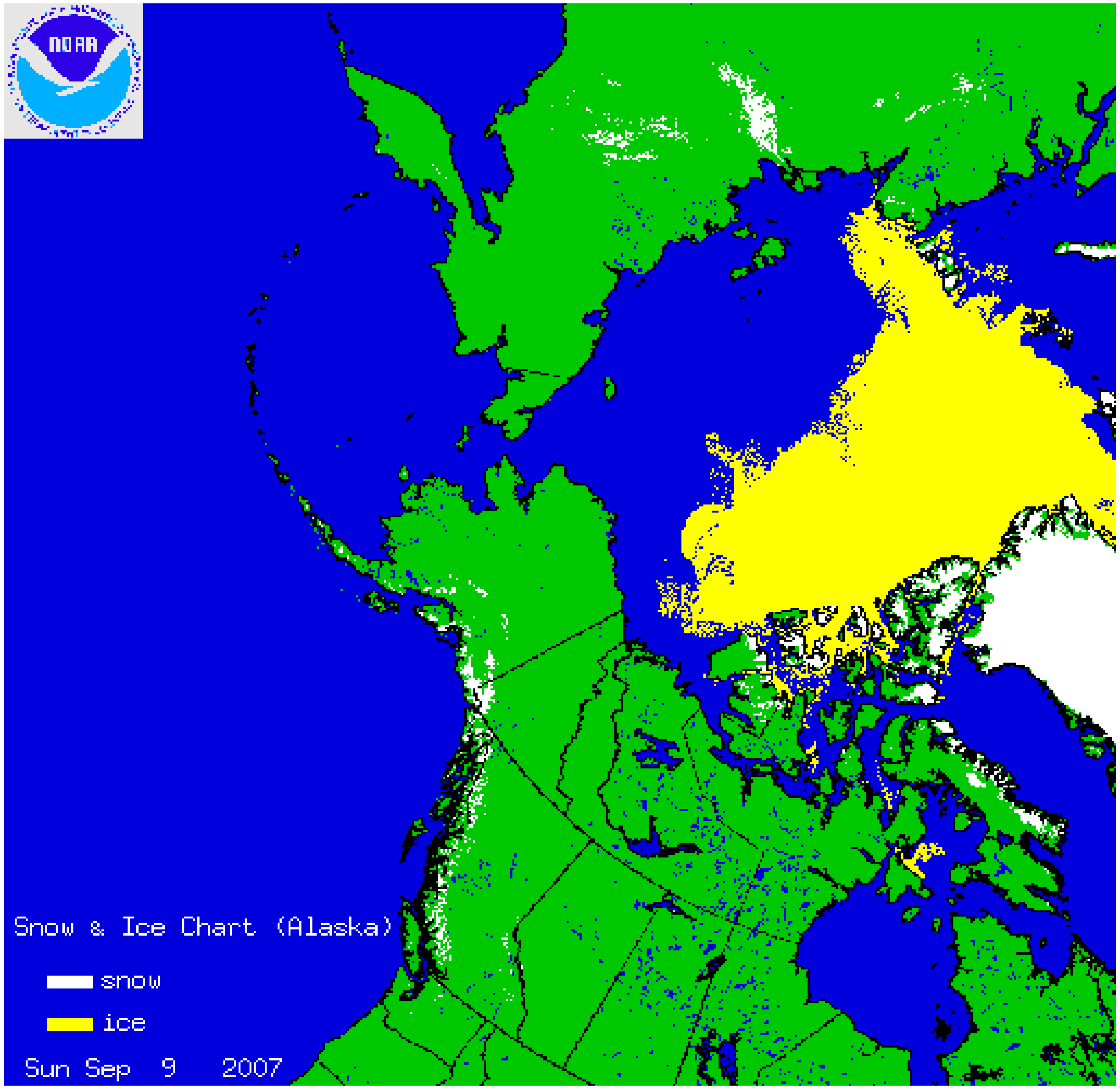
- New evidence suggests the earth's climate system has the potential for large increases in global temperature for CO_2 doubling.

- By **reducing uncertainty in feedback**, we can determine the danger of overwhelming temperature change.

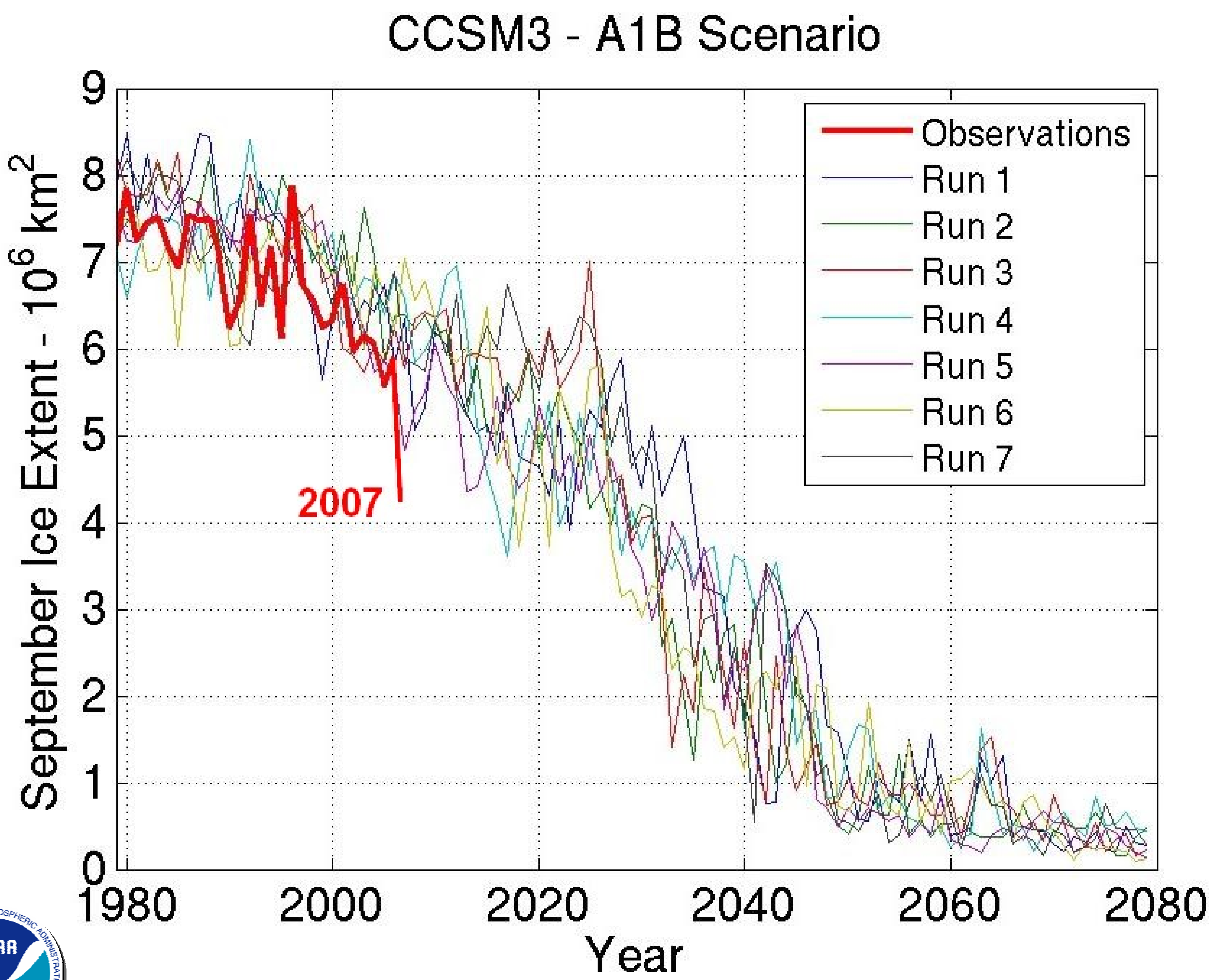
Climate Feedbacks

- Ice/albedo
- Water vapor
- Carbon release from high latitudes
- Clouds
- Aerosols (Negative)
- etc.

Feedback: Ice/Albedo



The 2007 loss of Arctic ocean ice indicates that the ice/albedo feedback has been underestimated.


CCSM3 - A1B Scenario
September Ice Extent - 10^6 km^2
Year
Observations
Run 1
Run 2
Run 3
Run 4
Run 5
Run 6
Run 7
2007
0
1
2
3
4
5
6
7
8
9
1980
2000
2020
2040
2060
2080

Feedback: High latitude carbon release

"About 500 Gt C remain preserved in the Yedoma ice-complex in northeast Siberia."

(If it) "warms more more rapidly in the future, (it) could again become a **powerful positive feedback** . . ."

Thermokarst Lakes as a Source of Atmospheric CH_4 During the Last Deglaciation

K. M. Walter,[1,2*] M. E. Edwards,[3,4] G. Grosse,[5] S. A. Zimov,[6] F. S. Chapin III[7]

Polar ice-core records suggest that an arctic or boreal source was responsible for more than 30% of the large increase in global atmospheric methane (CH_4) concentration during deglacial climate warming; however, specific sources of that CH_4 are still debated. Here we present an estimate of past CH_4 flux during deglaciation from bubbling from thermokarst (thaw) lakes. Based on high rates of CH_4 bubbling from contemporary arctic thermokarst lakes, high CH_4 production potentials of organic matter from Pleistocene-aged frozen sediments, and estimates of the changing extent of these deposits as thermokarst lakes developed during deglaciation, we find that CH_4 bubbling from newly forming thermokarst lakes comprised 33 to 87% of the high-latitude increase in atmospheric methane concentration and, in turn, contributed to the climate warming at the Pleistocene-Holocene transition.

Methane is an important greenhouse gas, whose sources to the atmosphere during the last deglaciation have yet to be reconciled with geological and paleoecological evidence. In northern high latitudes, ice-core records show that abrupt (decadal-scale) increases in temperature and precipitation were followed by a slower (100- to 300-year) rise in atmospheric methane concentration (AMC) (*1–3*), likely reflecting a lag in the terrestrial ecosystem response to rapid climate change. Values of the interpolar methane gradient, an indicator of the latitudinal distribution of CH_4 sources computed from the difference in CH_4 concentration between ice cores from Greenland and Antarctica, suggest that a new arctic/boreal source contributed substantial amounts of CH_4 from 14 thousand calendar years before present (kyr B.P.) through the Younger Dryas (YD) (~13 to 11.5 kyr B.P.) and accounted for >30% (30 to 40 Tg CH_4 year^{-1}) of the rapid rise of CH_4 emissions (83 to 99 Tg CH_4 year^{-1}) during the early Holocene (11.5 to 9.5 kyr B.P.) (*1–5*).

Two main hypotheses have been advanced to explain millennial-scale variations in AMC: a catastrophic release of methane hydrates in seafloor sediments ["clathrate gun hypothesis" (*6*)] and an increased CH_4 emission from northern wetlands in response to climate warming [wetland hypothesis (*7–9*)]. Reservations remain in the literature about attributing early Holocene CH_4 to a single source (*3, 4, 10–12*). Recent evidence of widespread northern peatland formation during the early Holocene suggests that wetlands may have contributed 4 to 9 Tg CH_4 year^{-1} (*8, 9*). There is a marked paucity of peatland initiation dates for the vast region of north Asia that was not ice-covered during the Last Glacial Maximum (LGM) (*9*). It was in the lowland areas of this region that an extensive initiation of deep "thermokarst" lakes occurred at the beginning of the last deglaciation [(*13–15*) and table S1] and may have been a source of atmospheric CH_4 at that time (*16*). When ice-rich frozen ground thaws, the loss of volume from melting ice creates depressions in the land surface: a process called thermokarst (*13*). Ponding of water in depressions creates thermokarst lakes, which may expand as a result of both thermal and mechanical erosion over time scales of decades to centuries (*13*).

We develop this third alternative hypothesis (thermokarst-lake hypothesis): CH_4 ebullition (bubbling) from newly formed thermokarst lakes occurred extensively across large unglaciated regions in northern high latitudes, particularly in Siberia, as the climate became warmer and wetter. Thermokarst-lake CH_4 emissions are distinct from those of wetlands because thermokarst lakes are a distinctive ecosystem type (*13*) not typically included in wetland emission estimates (*17*) and because ebullition, which dominates CH_4 emissions from thermokarst lakes, is a substantially larger source of CH_4 than previous-

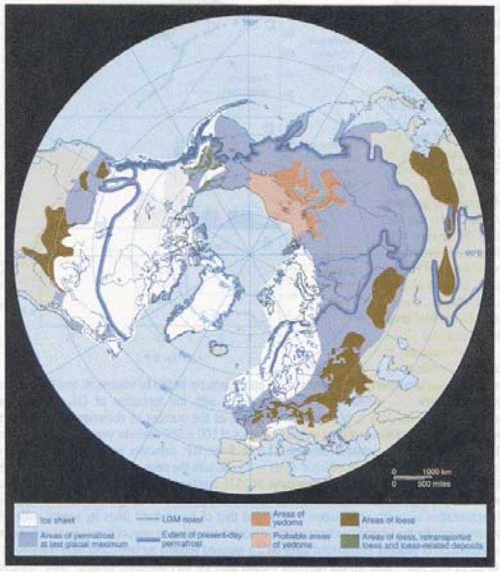


Fig. 1. Current and probable LGM regions of loess, loess-related deposits, and yedoma mapped in relation to the modern and LGM distribution of permafrost. Information sources are provided in the SOM text. Modern and LGM coasts are shown, the latter approximated from the modern 120-m isobath (*30*). The map indicates that considerable areas of loess would have been frozen at the LGM and subsequently thawed, and yedoma would have extended northward on the exposed Siberian shelf.

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Main Points

- New evidence suggests the earth's climate system has the potential for large increases in global temperature for CO_2 doubling.

- By reducing uncertainty in feedback, we can determine the danger of overwhelming temperature change.

- We need a "Manhattan Project" to quantify climate feedbacks, and determine the "acceptable" level of CO_2 stabilization.

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