GFDL CLIMATE MODELING RESEARCH HIGHLIGHTS

The National Oceanic and Atmospheric Administration (NOAA)
Geophysical Fluid Dynamics Laboratory (GFDL) - Princeton, NJ

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THE SHRINKING ARCTIC ICE CAP

Satellite observations show that Arctic sea ice extent has declined over the past three decades [*e.g.*, NOAA magazine, 2006]. Global climate model experiments, such as those conducted at NOAA's Geophysical Fluid Dynamics Laboratory (GFDL), project this downward trend to continue and perhaps accelerate during the 21st century.

The Arctic is a region that is projected to warm at about twice the rate of the global average [Winton, 2006a] - a phenomenon sometimes referred to as "Arctic amplification". As Arctic temperatures rise, sea ice melts—a change that in turn affects other aspects of global climate.

While beyond the scope of GFDL's climate model simulations, other research suggests that Arctic sea ice changes can impact a broad range of factors — from altering key elements of the Arctic biosphere (plants and animals, marine and terrestrial, including polar bears and fish), to opening polar shipping routes, to shifting commercial fishing patterns, etc.

► An Ice-Free Arctic in Summer?

The three panels to the right are snapshots of how late summer Northern Hemisphere sea ice concentrations vary in time in a GFDL CM2.1 climate model simulation. The figures depict sea ice concentration - a measure of how much of the ocean area is covered by sea ice, and the climate model variable that is most similar to what a satellite observes.

By the late 21st century, the GFDL computer model experiments project that the Arctic becomes almost ice free during the late-summer. But during the long Arctic winters (not shown) the sea ice grows back, though thinner than is simulated for the 20th century.

The rate at which the modeled 21st century Arctic warming and sea ice melting occurs is rapid compared to that seen in historical observations. Abrupt Arctic changes are of particular concern for human and ecosystem adaptations and are a subject of much current research [Winton, 2006b].

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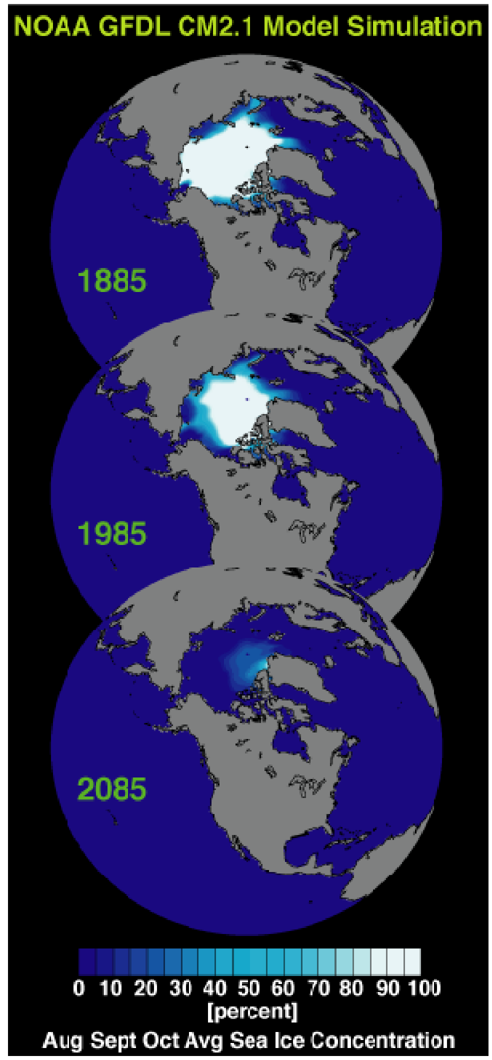

[Above] Sea ice concentrations simulated by GFDL's CM2.1 global coupled climate model averaged over August, September and October (the months when Arctic sea ice concentrations generally are at a minimum). Three years (1885, 1985 & 2085) are shown to illustrate the model-simulated trend. A dramatic reduction of summertime sea ice is projected, with the rate of decrease being greatest during the 21st century portion. The colors range from dark blue (ice-free) to white (100% sea ice covered).

TAKE HOME POINTS

- Arctic sea ice is projected to decline dramatically over the 21st century, with little late summer sea ice remaining by the year 2100.
- The simulated 21st century Arctic sea ice decline is not smooth, but contains periods of large and small changes.
- The Arctic region responds sensitively to past and future global climate forcings, such as changes in atmospheric greenhouse gas levels. Its surface air temperature is projected to warm at a rate about twice as fast as the global average.

From the IPCC* Summary For Policymakers...

"Sea ice is projected to shrink in both the Arctic and Antarctic ... In some projections, Arctic late-summer sea ice disappears almost entirely by the latter part of the 21st century.

"Average Arctic temperatures increased at almost twice the global average rate in the past 100 years."

*Reference: Intergovernmental Panel on Climate Change (IPCC) WG1 Fourth Assessment Report, Climate Change 2007: The Physical Science Basis, Summary For Policymakers.
Available online at www.ipcc.ch

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Research Highlights, Graphics & Animations
www.gfdl.noaa.gov/research/climate

The modeled summertime Arctic sea ice extent (the size of the area covered by sea ice) does not vary smoothly in time, as there is a good deal of year-to-year variability superimposed on the downward trend. This can be seen in the graph to the right and also in animations found at www.gfdl.noaa.gov/research/climate/highlights. By the end of the 21st century, the modeled summer sea ice extent usually is less than 20% of the that simulated for 1981 to 2000.

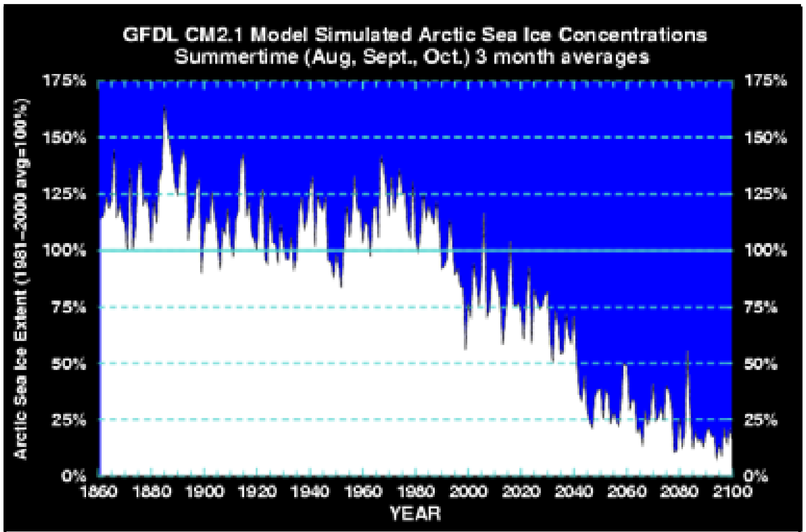
The Arctic sea ice results shown here are not unique to the GFDL climate model. Generally similar results are produced by computer models developed at several other international climate modeling centers. Though some uncertainties in model projections of future climate remain, results such as these, taken together with observations that document late 20th century Arctic sea ice shrinkage, make the Arctic a region that will continue to be studied and watched closely, as atmospheric greenhouse gas levels increase.

► Climate implications of shrinking summer sea ice

Melting sea ice can influence the climate through a process known as the ice-albedo feedback. Much of the sunlight reflected by sea ice returns to space and is unavailable to heat the climate system. As the sea ice melts, the surface darkens and absorbs more of this energy. This, in turn, can lead to greater melting. This is referred to as a "positive feedback loop" because an initial change (sea ice melting) triggers other responses in the system that eventually act to enhance the original change (inducing more sea ice melting).

At GFDL, research has focused on the role of the ice-albedo feedback in the enhancing simulated Arctic warming and on the potential for this positive feedback loop to lead to abrupt changes [Winton, 2006a]. A somewhat complex picture has emerged that shows the ice-albedo feedback as a contributor, but not necessarily the dominant factor in determining why modeled Arctic surface air temperatures warm roughly twice as fast as the global average. It also has been found that, for the range of temperature increases likely to occur in the 21st century, the Arctic ice-albedo feedback adjusts smoothly as the model's ice declines, by reducing the ice-cover at progressively earlier times in the sunlit season. This smooth adjustment maintains a fairly constant amplification of Arctic temperature change relative to global average warming.

The details of how Arctic feedback processes act in climate models at various modeling centers differ, and so analysis and computer model development work continues in order to better understand and to reduce uncertainties in Arctic climate change simulations.



[Above] Summertime Arctic-wide sea ice extent simulated by the GFDL CM2.1 model for the historical period 1860 to 2000 and projected for the 21st century following the SRES A1B emissions scenario. Sea ice extent values are normalized (scaled) so that the average for years 1981 to 2000 is equal to 100%. Totally ice free summer conditions would equal 0%.

► Some Related References

Delworth, *et al.*, (2006): GFDL's CM2 global coupled climate models - Part 1: Formulation and simulation characteristics, *Journal of Climate*, Vol. 19, No. 5, pages 643-674. [LINK]

Knutson, *et al.*, (2006): Assessment of Twentieth Century Regional Surface Temperature Trends using the GFDL CM2 Coupled Models, *Journal of Climate*, Vol. 19, No. 9, pages 1624-1651. [LINK]

NOAA Magazine, (2006): New data show downward trend in arctic sea ice, online release date: Nov. 20, 2006. [LINK]

Parkinson, et al., (2006): Evaluation of the simulation of the annual cycle of Arctic and Antarctic sea ice coverages by 11 major global climate models, Journal of Geophysical Research, Vol. 111, C07012, doi:10.1029/2005JC003408.

Winton, (2006a): Amplified Arctic climate change: What does surface albedo feedback have to do with it? *Geophysical Research Letters*, Vol. 33, L03701, doi:10.1029/2005GL025244. [LINK]

Winton, (2006b): Does the Arctic sea ice have a tipping point?, *Geophysical Research Letters*, Vol. 33, L23504, doi:10.1029/2006GL028017. [LINK]

For more GFDL CM2.1 references, see http://nomads.gfdl.noaa.gov/CM2.X/references

For more information on this topic, including high resolution graphics and animations, please see "THE SHRINKING ARCTIC ICE CAP" links at http://www.gfdl.noaa.gov/research/climate/highlights

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About GFDL

Located in Princeton, New Jersey, the Geophysical Fluid Dynamics Laboratory (GFDL) develops and uses mathematical models and computer simulations to improve our understanding and predictions of the behavior of the atmosphere, the oceans, and climate. Over its 50-year history, GFDL has set the agenda for much of the world's research on the modeling of global climate change and has played a significant role in the World Meteorological Organization and Intergovernmental Panel on Climate Change (IPCC) assessments, as well as the US Climate Change Research Program (US CCSP).

The multi-year effort that culminated in the GFDL CM2.1 global climate model used in the research presented here was truly a lab-wide endeavor, and one that supports the National Oceanographic and Atmospheric Administration's (NOAA's) strategic goal to "*Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond.*"

For more background information about GFDL, see...
http://www.research.noaa.gov/organization/backgrounders06/gfdl.html

Supplementary Information

Some Fine Print:

More About These GFDL Climate Model Experiments

The Geophysical Fluid Dynamic Laboratory's GFDL CM2.1 coupled model used to conduct the simulations is representative of the state-of-the-art in global climate modeling [Delworth et al. (2006)]. This model became GFDL's workhorse model for studies of decadal to century time scale climate variability and change in 2004 and likely will remain a key tool in climate change studies for a few years. The GFDL CM2.1 computer model of the Earth's global climate system contains atmosphere, ocean, land, and sea ice components that interact with one another and respond to changes in climate forcings[1]. The sea ice component has state-of-the-art treatments of sea ice growth, melt, and motion [Winton (2000)].

Regarding the climate forcing scenarios used in the model simulation shown here, for the years prior to 2000, the model includes most of the major climate forcing factors that were observed to change in the real world (e.g., changes in seven atmospheric greenhouse gas levels, volcanic aerosols, black and organic carbon aerosols, tropospheric sulfate aerosols, ozone, solar irradiance, and land surface changes). Run in this manner, the GFDL CM2.1 model has been shown to be credible at reproducing the decade to decade variations in global mean surface air temperature observed during the 20th century, though it tends to exhibit somewhat less warming than was observed in the high northern latitudes [Knutson et al. (2006)]. The CM2.1 model simulated Arctic sea ice extent is close to the observed on an annual mean basis, but it somewhat underestimates the summer extent [Delworth et al. (2006), Parkinson et al. (2006)].

To explore a range of "If ... Then" future scenarios, several different 21st century emissions scenarios have been used at GFDL and other climate research centers. In the CM2.1 figures displayed here, we show results from what is known as the SRES A1B emissions scenario - one with a mid-level increase in 21st century greenhouse gas levels [IPCC (2000)]. We display results from the A1B scenario not because it is considered any more or less likely to resemble the emissions scenario that actually will occur in the coming decades, but rather because, even as a "middle of the road" emissions scenario, the model's summertime Arctic sea ice extent exhibits a fairly dramatic climate change response that is clearly visible in the graphics.

Of course, some uncertainties in model projections of future climate remain and stem from the fact that we do not know how the atmosphere's composition will change in the future and because the models themselves are imperfect.

The GFDL climate model simulations considered in the 2005 Arctic Climate Impact Assessment Report [ACIA (2005)] were not a product of the GFDL CM2.1 model, but rather were from a previous generation of global coupled climate model know as GFDL R30. The ACIA report includes discussion of potential biological and societal impacts of Arctic climate change that go beyond the scope of the physical climate system simulated in GFDL CM2.1 model.

The model experiments from which the figures on these pages were derived have been documented in peer-reviewed scientific journals (see references below). However, the specific CM2.1 sea ice concentration figures presented here have not appeared in the peer reviewed literature.

Model output files from the experiments shown here can be freely downloaded from the GFDL Data Portal (nomads.gfdl.noaa.gov).

References:

⌂ symbols identify papers available for viewing online from the GFDL Online Bibliography web page: http://www.gfdl.noaa.gov/reference/bibliography/

○ symbols indicate non-GFDL references.

○ ACIA (Arctic Climate Impact Assessment) (2005): Arctic Climate Impact Assessment—Scientific Report. Cambridge Univ. Press, U.K. (http://www.acia.uaf.edu/pages/scientific.html)

⌂ Delworth, *et al.,* (2006): GFDL's CM2 global coupled climate models - Part 1: Formulation and simulation characteristics, *Journal of Climate*, Vol. 19, No. 5, pages 643-674.

○ IPCC (Intergovernmental Panel on Climate Change) (2000): Special Report on Emission Scenarios. Cambridge University Press, U.K. (http://www.grida.no/climate/ipcc/emission/)

○ IPCC (Intergovernmental Panel on Climate Change) (2007): Climate Change 2007: The Physical Science Basis, Summary for Policymakers. (published online 2 Feb 2007 at http://www.ipcc.ch/)

⌂ Knutson, *et al.,* (2006): Assessment of Twentieth Century Regional Surface Temperature Trends using the GFDL CM2 Coupled Models, *Journal of Climate*, Vol. 19, No. 9, pages 1624-1651.

○ NOAA Magazine, (2006): , New Data Show Downward Trend In Arctic Sea Ice, online release date: Nov. 20, 2006. (http://www.noaanews.noaa.gov/stories2006/s2744.htm)

○ Parkinson, et al., (2006): Evaluation of the simulation of the annual cycle of Arctic and Antarctic sea ice coverages by 11 major global climate models, *Journal of Geophysical Research*, Vol. 111, C07012, doi:10.1029/2005JC003408.

⌂ Winton, (2000): A reformulated three-layer sea ice model. *Journal of Atmospheric & Oceanic Technology*, Vol. 17, No 4, pages 525-531.

⌂ Winton, (2006a): Amplified Arctic climate change: What does surface albedo feedback have to do with it? *Geophysical Research Letters*, Vol. 33, L03701, doi:10.1029/2005GL025244.

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For more GFDL Climate Research Highlights, see http://www.gfdl.noaa.gov/research/climate/highlights/

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[1] A climate forcing (or more properly, a radiative forcing) is the result of a process that directly changes the energy balance of the climate system by affecting the balance between incoming solar radiation and outgoing longwave and shortwave radiation. It does not include the effects of feedbacks. A positive forcing tends to warm the surface of the Earth and a negative forcing tends to cool the surface. Forcing agents, such as greenhouse gases, aerosols, and surface albedo changes, are those things that cause variations in radiative forcings.

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