Northern Hemisphere Sea Ice Extent

Vinnikov *et al*. (*1*) strongly suggested that the observed downward trend in Northern Hemisphere sea ice extent from 1953 to 1998 relates to anthropogenic global warming. Their conclusion was based on the supposed low probability ($P < 0.1\%$) that a trend of the observed magnitude results from natural climate variability, with P estimated by sampling the simulated ice extent in a 5000-year control experiment using the climate model of the Geophysical Fluid Dynamics Laboratory (GFDL). The natural variability of sea ice extent was characterized by its standard deviation, σ: For detrended observations from 1953 to 1998, $\sigma = 240{,}000$ km^2; for the GFDL model, $\sigma = 250{,}000$ km^2. Vinnikov *et al*. took the small difference between these standard deviations as evidence that the model realistically simulates natural variability of sea ice extent.

Unfortunately, Vinnikov *et al*. did not account for what appears to be a spurious feature of the simulated sea ice: The GFDL model produces sea ice thicknesses that alternate between positive and negative values at many adjacent grid cells between 45°N and 80°N. Some climate models can produce such patterns through numerical operations. Time series of annual mean ice concentrations at adjacent grid cells in the North Atlantic (Fig. 1) illustrate this effect. Because Vinnikov *et al*. assigned an ice concentration only to those grid cells in which the ice thickness exceeded +2 cm, they excluded the negative ice concentrations in neighboring cells that cancel much of the variability. The cancellation is nearly complete over eight adjacent grid cells (Fig. 1B). If the negative ice concentrations are added back and the GFDL model's sea ice extent is recalculated, the mean is 9% lower and $\sigma = 160{,}000$ km^2 (*2*), about one-third smaller than the standard deviation calculated by Vinnikov *et al*. (*1*). This recalculation weakens their claim that the natural variability implicit in the model is realistic.

The match between the simulated variability and observations depends on the analysis and interpretation of the observations. After removing the linear trend from 1953 to 1998, Vinnikov *et al*. (*1*) estimated that the observed $\sigma = 240{,}000$ km^2, thereby identifying all of the trend with nonnatural (anthropogenic) effects. At the other extreme, if it is hypothesized that all of the linear trend is natural (nonanthropogenic), then the observed $\sigma = 350{,}000$ km^2, more than twice that of the model. This hypothesis deserves consideration, because the linear trend of the observations for the half century before the model period, from 1900 to 1952, amounts to +130,000 km^2 per decade [figure 2 of (*1*)]. Admittedly, this earlier trend depends sensitively on a handful of data points near the beginning and end dates of the period. The extent to which the model underestimates natural variability is likewise uncertain, because it is unknown how much of the trend can be attributed to natural variability, how much to anthropogenic forcing, and how much to observation errors. Our analysis does not show that the recent downward trend in Northern Hemisphere sea ice extent is due to natural variability. Nevertheless, it does raise questions as to whether the variability calculated in the GFDL climate model can serve as a basis for concluding that the observed downward trend in sea ice extent from 1953 to 1998 is related to anthropogenic warming.

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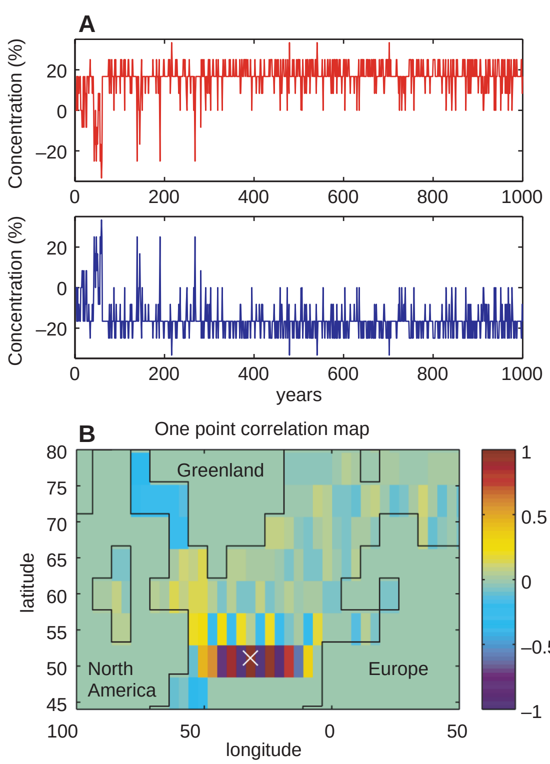

Fig. 1. (**A**) Time series of the annual mean sea ice concentration for the GFDL model at two adjacent points in the North Atlantic. Red time series shows values for grid cell labeled "X" in (B); blue time series shows values for cell immediately adjacent and east of that cell. Vertical axis gives percentage of grid cell with sea ice coverage averaged from monthly values that are either 100, 0, or −100%, depending on whether the monthly mean ice thickness is greater than +2 cm, between −2 and 2 cm, or less than −2 cm. Horizontal axis gives year of model run. (**B**) Map of correlation between red curve in (A) and the annual mean ice concentration at all other grid cells in the North Atlantic.

References and Notes

1. K. Y. Vinnikov *et al*., *Science* **286**, 1934 (1999).
2. The mean of σ for 46-year intervals is given to eliminate biases associated with differing lengths of modeled and observed time series.

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Response: Vinnikov *et al*. (*1*) showed that the large observed downward trend of Northern Hemisphere sea ice extent during the past half century is greater than would be expected from natural climate variability, and suggested that the trend was likely caused in part by anthropogenic global warming. We reached this conclusion by comparing the observations with simulations of natural variability and of anthropogenic climate change (forced by observed greenhouse gases and tropospheric aerosols) from two different climate models: one from the GFDL and one from the Hadley Centre. Moritz and Bitz claim that the method used for computation of sea ice in the GFDL model is erroneous, in view of negative values of sea ice, and also question the removal of the linear trend from the 1953-to-1998 climate change record to compare observed natural variability of sea ice with that implicit in the long GFDL control run.

On the first point, Moritz and Bitz have misinterpreted the workings of the GFDL sea ice model. The negative values arise from the spatial polar filter, used to control spurious numerical waves that are generated because of the convergence of the meridians. Before the ice thicknesses are passed to the model's atmospheric component, the negative values are eliminated using a thermodynamic balance between the sea ice and the oceanic mixed layer. This balance eliminates the negative ice by taking heat and water from the mixed layer and assures that the sea surface temperatures are set to freezing where ice exists. The negative values do not affect the surface fluxes or surface albedos in any way. Therefore, canceling the positive values with the negative ones, as Moritz and Bitz attempt, has no physical basis.

The spatial polar filter is successfully used in weather-forecasting models as well as for climate simulations. Moreover, the Hadley Centre model, on which our analysis was also based, uses a different filtering technique that produces no negative sea ice values. Our analysis uses only positive sea ice values from the gridpoint ocean model and never considers the artificial values considered by Moritz and Bitz. We did not exclude any gridpoints with negative sea ice amounts in our analysis, because there are none.

Our 2-cm cutoff for model sea ice thickness, also mentioned by Moritz and Bitz, was arbitrarily chosen so that the area mean sea ice extent in the model is similar to the observed. Its choice has nothing to do with variability of the sea ice extent. A nonzero value for this cutoff is necessary because the model does not simulate sea ice concentration, because we use monthly time averages and not daily values in our analysis, and because of sampling and measurement uncertainties in the observations as well as the model. As it turns out, the 2-cm cutoff corresponds approximately to the sensitivity of microwave satellite radiometers to detect sea ice. Obviously, the cutoff choice affects the calculated ice extents; however, our conclusions would not change using other values near 2 cm.

The arguments of Moritz and Bitz on their second main point—whether removing the linear trend in observations from 1953 to 1998 is appropriate—depend heavily on the record from 1900 to 1952, before the period examined by Vinnikov *et al*. (*1*). That earlier record cannot be used to extract sea ice variability from the observations, however, because the observations before 1950 are very inhomogeneous (which, indeed, is why we did not use those data in our analysis). Meanwhile, we have examined the interannual variability of Northern Hemisphere sea ice extent during the second half of the 20th century in both the GFDL and Hadley Centre models. That variability can be decomposed into two parts: natural climate variability and external anthropogenic forcing, or global warming. Each of these components is responsible for approximately half of the variance estimated from the modeled variation in sea ice extent for 1953-to-1998. We analyzed each of these components in the observed data separately and found the same trend and the same natural variability. Obviously, we would prefer to have longer observed periods with good-quality data to estimate trends, but they are not available.

Using the 5000-year GFDL control run, we found that the mean interannual standard deviation of detrended Northern Hemisphere sea ice for 46-year intervals is 220,000 ± 35,000 km^2 (±1 standard deviation). This is very close to both the observed 1953-to-1998 detrended value of 235,000 km^2 and to the detrended 1953-to-1998 GFDL transient run value of 200,000 km^2. This suggests that both climate models realistically reproduce an important aspect of observed natural interannual variability of sea ice extent. Moritz and Bitz claim that the observed trend may be interpreted as part of natural climate variability, but model experiments tell us that this is not the case. The Hadley Centre model produces the same results with respect to sea ice variability and sea ice trend as does the GFDL model. The model simulations look remarkably like the observations when forced with observed radiative forcing.

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1. K. Y. Vinnikov *et al*., *Science* **286**, 1934 (1999).

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