A Model Assessment of Satellite Observed Trends in Polar Sea Ice Extents

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Abstract

For more than three decades now, satellite passive microwave observations have been used to monitor polar sea ice. Here we utilize sea ice extent trends determined from primarily satellite data for both the Northern and Southern Hemispheres for the period 1972(73)-2004 and compare them with results from simulations by eleven climate models. In the Northern Hemisphere, observations show a statistically significant decrease of sea ice extent and an acceleration of sea ice retreat during the past three decades. However, from the modeled natural variability of sea ice extents in control simulations, we conclude that the acceleration is not statistically significant and should not be extrapolated into the future. Observations and model simulations show that the time scale of climate variability in sea ice extent in the Southern Hemisphere is much larger than in the Northern Hemisphere and that the Southern Hemisphere sea ice extent trends are not statistically significant.

Popular Summary

Long-term sea ice trends in both polar regions observed over the last three decades with satellite passive microwave radiometers have received much attention recently by the scientific community as well as by the press. For the purpose of putting these trends into a broader statistical context and for understanding their climatic significance, we compared them with results from simulations by eleven climate models. In the Northern Hemisphere, observations show a statistically significant decrease of sea ice extent and an acceleration of sea ice retreat during the past three decades. However, from the modeled natural variability of sea ice extents in control simulations, we conclude that the acceleration is not statistically significant and should not be extrapolated into the future. In the Southern Hemisphere the sea ice extent trends are not statistically significant.

Significant Findings

In the Northern Hemisphere, satellite observations show a statistically significant decrease in sea ice extent and an acceleration of sea ice retreat during the past three decades, whereas for the Southern Hemisphere the observed positive trend is not significant. However, from a comparison of modeled natural variability of sea ice extents from control simulations of eleven climate models, we conclude that the acceleration in the Northern Hemisphere is not statistically significant and should not be extrapolated into the future. In the Southern Hemisphere the observed trend over this period remains statistically insignificant.

Abstract

For more than three decades now, satellite passive microwave observations have been used to monitor polar sea ice. Here we utilize sea ice extent trends determined from primarily satellite data for both the Northern and Southern Hemispheres for the period 1972(73)-2004 and compare them with results from simulations by eleven climate models. In the Northern Hemisphere, observations show a statistically significant decrease of sea ice extent and an acceleration of sea ice retreat during the past three decades. However, from the modeled natural variability of sea ice extents in control simulations, we conclude that the acceleration is not statistically significant and should not be extrapolated into the future. Observations and model simulations show that the time scale of climate variability in sea ice extent in the Southern Hemisphere is much larger than in the Northern Hemisphere and that the Southern Hemisphere sea ice extent trends are not statistically significant.

1. Introduction

In an earlier attempt to use climate models to assess and interpret the observed contemporary trend in Northern Hemisphere sea ice extents, *Vinnikov et al.* [1999] were limited by the brevity of the available satellite record, less than two decades, and by having simulations from only two climate models available at that time. Two new factors move us to update the *Vinnikov et al.* [1999] assessment now. The first one is that *Cavalieri et al.* [2003] extended the records of sea ice extents back to 1972-1973, using Nimbus 5 Electrically Scanning Microwave Radiometer (ESMR) [Zwally et al., 1983; Parkinson et al., 1987] and U.S. National Ice Center (NIC) data [*Dedrick et al.*, 2001], appending to the satellite multichannel passive-microwave data record that began with

the Nimbus 7 Scanning Multichannel Microwave Radiometer (SMMR)[Gloersen et al., 1992] in 1978 and has continued since 1987 with the Defense Meteorological Satellite Program Special Sensor Microwave Imager (SSMI) [Cavalieri et al., 1999]. After updating, the length of the homogeneous time series of monthly mean sea ice extents for the Arctic and Antarctic regions exceeded three decades. The other factor is that 20th century climate changes have been recently simulated using mostly the same external forcing by several climate modeling centers around the world for the Fourth Intergovernmental Panel on Climate Change (IPCC) Climate Change Assessment [*IPCC AR4*, 2004]. The results of these simulations are available through the Program for Climate Model Diagnostics and Intercomparison (PCMDI) at Lawrence Livermore National Laboratory, USA [*AchutaRao et al.*, 2004].

The time series of satellite observed monthly sea ice extents for the north and south polar regions [*Cavalieri et al.*, 2003] has been updated through 2004, and this extended data set is used in this analysis. Taking into account the known physics of microwave radiation, radiometer specifications, and sea ice retrieval algorithms, we estimate that an appropriate model correspondence with the observed ice extents, defined as the integrated area with ice concentration of at least 15%, is the simulated area with ice thickness greater than 6 cm and ice concentration greater or equal to 15%. This criterion has been used for calculating simulated sea ice extents from climate model outputs, which include ice thickness and ice concentration as the two main sea ice outputs. To determine the simulated Northern Hemisphere sea ice extent for 1972-2004 and the simulated Southern Hemisphere sea ice extents for 1973-2004, for each of the selected models we used the "20th Century simulation (20C3M)" run1 and the first few years of

the "Future climate simulations: scenario SRES A2" run1, which is a continuation of 20C3M run1. Up through 2004, SRES A2 scenario does not differ from other forcing scenarios for future climate simulations. We also used the multi-centennial "Pre-Industrial control runs (PICTRL)" of the same models to asses natural climate variability in model simulated sea ice extents. The sea ice simulation data came from the following eleven climate models: (1) UKMO-HadCM3, from the United Kingdom Met Office Hadley Centre: (2) UKMO-HadGEM1, also from the United Kingdom Met Office Hadley Centre; (3) ECHAM5/MPI-OM, from the European Centre for Medium Range Weather Forecasts Hamburg Model, Germany; (4) CGCM3.1 (T-47), from Canadian Centre for Climate Modeling and Analysis; (5) CSIRO-Mk3.0, from the Commonwealth Scientific and Industrial Research Organization, Australia; (6) MIROC3.2 (medres), Model for Interdisciplinary Research on Climate, Japan; (7) BCCR-BCM2.0, from Bjerknes Centre for Climate Research, Norway; (8) GISS-ER, from the NASA Goddard Institute for Space Studies, USA; (9) IPSL-CM4, from Institute Pierre Simon Laplace, France; (10) INM-CM3.0, from Institute of Numerical Mathematics, Russian Academy of Science, Russia; (11) GFDL-CM2.1, from the NOAA Geophysical Fluid Dynamics Laboratory, USA. *Parkinson et al.* [2005], using the same satellite observed data for 1979-2004 have shown that the majority of these models realistically simulate at least key aspects of the seasonal cycle and geographical patterns of sea ice in Northern and Southern Hemispheres.

2. Trends in observed and model simulated sea ice extents

Satellite observed annual mean sea ice extents in the Northern and Southern Hemispheres are shown in Figure 1. *Cavalieri et al.* [1997] reported hemispheric asymmetry in global sea ice changes during 1978-1996 including opposing trend lines. With the extended record, the two hemispheres continue to behave differently, but it is no longer the case that the sign of the trend in the two cases differs. Sea ice in the Northern Hemisphere continues, with the extended record, to have a negative trend, with a mean rate of $-0.32 \cdot 10^6 \text{km}^2/10$ yr, and we can also see an acceleration in the rate of ice retreat, approximately equal to $-0.16 \cdot 10^6 \text{ km}^2/(10\text{yr})^2$. Sea ice in the Southern Hemisphere no longer has a positive trend, once the data from the early and mid-1970s are included. The best approximation for the Southern Hemisphere required a 3rd degree polynomial, and even then the coefficients are not statistically significant. A linear least squares fit line for the Southern Hemisphere ice, 1973-2004, has the same negative sign as in Northern Hemisphere but it is much smaller in magnitude and is not statistically significant. The multi-year averages, standard deviations, trends and standard errors of trends in the observed data and in model simulated contemporary climate change are given in Table 1 and will be discussed in the next section.

The seasonal cycles of linear trends by month for 33 years of satellite microwave observations, 1972-2004, in the Northern Hemisphere (thick lines) and for 32 years, 1973-2004, in the Southern Hemisphere (thin lines) are shown in Figure 2. Vertical bars display standard errors of the trend estimates. The observed sea ice extents do not differ noticeably compared to earlier published estimates for a shorter period [*Cavalieri et al.*, 2003]. The corresponding seasonal cycles of trends in the model simulated sea ice extents for the same time interval are also shown in Figure 2.

3. Model assessment of observed trends

Comparing the climate model simulations to the observations:

(1)   Satellite observed annual mean multi-year averages for 33-32 years of sea ice extents (α) are almost equal in both hemispheres ($11\text{-}12 \cdot 10^6$ km^2). The majority of the models agree that annual average sea ice extents in the two hemispheres do not differ significantly for present-day climate.

(2)   The observed standard deviation of detrended annual mean sea ice extents (σ) in the Northern Hemisphere ($0.16 \cdot 10^6$ km^2) is much smaller than in the Southern hemisphere ($0.38\ 10^6$ km^2).   All the models agree with the larger interannual variability of sea ice extents in the Southern versus Northern Hemisphere, but the observed variability is at the low end of variability in model simulations. More representative estimates of modeled natural variability of sea ice extents $<\sigma>$ were obtained from multi-centennial control simulations of the preindustrial climate than for the 33/32-year observation period. These estimates were calculated by averaging variances of detrended ice extents computed in moving windows of length 33-32 years and suggest that the years of observation, 1972-2004, may represent a period of relatively low interannual variability of sea ice extents in the Northern Hemisphere.

(3)   The observed decreasing trend in Northern Hemisphere sea ice extents, $\beta\approx-0.3 \cdot 10^6$km^2, is statistically significant based on the error statistics σ_β and $\sigma_{<\beta>}$ for sea ice extents from most of the models. Observed sea ice retreat in the Southern Hemisphere is much weaker and statistically not significant, but it is reproduced in simulations of 8 of the 11 climate models.

(4)   Acceleration in the rate of sea ice retreat observed in the Northern Hemisphere is statistically significant according to calculations based on the observed data by themselves. But, none of the simulations from the 11 climate models obtain a statistically significant acceleration. Clearly, acceleration is necessary at some point in order to transition from a stationary sea ice regime, as seems to have existed in the Northern Hemisphere ice cover in the first half of the 20th century [*Vinnikov et al.*, 1999], to the current retreating sea ice cover.

(5)   As can be seen in Figure 2, sea ice retreat in the Northern Hemisphere is almost constant during all months of the year and does not have a statistically significant seasonal cycle. The 1973-2004 trend in the Southern Hemisphere is also negative, but it is much smaller compared to same trend in Northern Hemisphere and statistically insignificant at each month of the year. The modeled Northern Hemisphere trend is larger than the observed trend in some models, smaller than the observed trend in other models, but only one of the models does not reproduce a 1972-2004 Northern Hemisphere sea ice retreat. Most of the models, like the observations, show an absence of a prominent seasonal cycle in the trend values.

4. Concluding remarks

We have attempted to place more than three decades of satellite observed polar sea ice variations into a broader statistical context by comparing them with sea ice simulations from eleven state-of-the-art climate models. The simulations were used both for the time period of satellite observations (1972/73-2004) and for multi-centennial control runs of pre-industrial climate. Our results are based on only a single model simulation for each of the models, not more than one sample from a variety of possible

realizations that can be obtained using each model. Only the main components of external forcing in these model simulations are the same. On the other hand, the minor components of external forcing are not sufficiently different to explain the differences of statistics obtained from the models. Initial states of the climate system are quite different as are the sensitivities of each model. As a result, the models demonstrate a wide range of variations in simulated sea ice extents. Nevertheless, the climate model simulations provide strong statistical support to the conclusion that the satellite observed retreat in Northern Hemisphere sea ice extents is indeed a real climate change and that the retreat is a response to changes in the observed external forcing of the global climate system.

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Figure captions

Figure 1. Satellite observed annual mean sea ice extents in the Northern and Southern Hemispheres and polynomial approximations of climatic trends.

Figure 2. Seasonal cycle in observed and model simulated trends in Northern (thick lines) and Southern Hemisphere (thin lines) sea ice extents. Vertical bars show standard errors of trend estimates.

Table 1. Multi-year average (α), standard deviation (σ), mean linear trend (β), and acceleration of the trend (γ) in observed and model simulated time series of annual mean ice extents estimated for 33-32 years of satellite observation; σ_β and σ_γ are standard errors of β and γ estimated from the same data; $<\sigma>$, $\sigma_{<\beta>}$ and $\sigma_{<\gamma>}$ are standard deviation of detrended ice extents, trends β and accelerations γ, estimated in moving windows (33 and 32 years) in control model simulations. Standard errors $\sigma_{<\beta>}$ and $\sigma_{<\gamma>}$, estimated from multi-centennial control simulations, are more accurate and should be used if available.

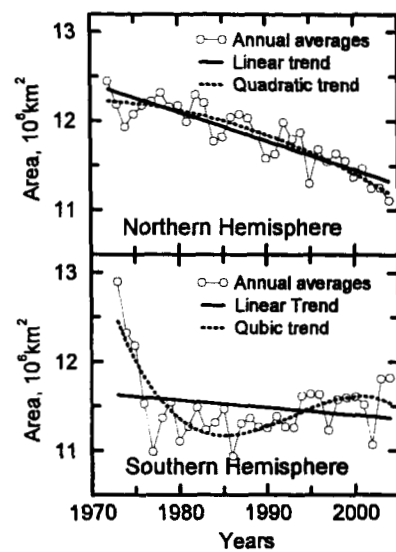|	Northern hemisphere, 33 yrs, 1972-2004									Southern hemisphere, 32 yrs, 1973-2004					
	Average & Standard Deviation, 10^6 km^2			Linear trend, 10^6 km^2/10 yr			Acceleration, 10^6 km^2/(10 yr)^2			Average & Standard Deviation, 10^6 km^2			Linear trend, 10^6 km^2/10 yr		
	α	σ	$<\sigma>$	β	σ_β	$\sigma_{<\beta>}$	γ	σ_γ	$\sigma_{<\gamma>}$	α	σ	$<\sigma>$	β	σ_β	$\sigma_{<\beta>}$
Observed	11.84	0.16		-0.32	0.03		-0.16	0.06		11.50	0.38		-0.08	0.07	
HadCM3	12.23	0.27	0.35	-0.31	0.05	0.14	-0.17	0.11	0.28	11.66	0.53	0.56	-0.28	0.10	0.13
HadGEM1	13.25	0.27	0.28	-0.51	0.05	0.17	-0.40	0.09	0.26	14.62	0.33	0.47	-0.33	0.06	0.09
ECHAM5	12.11	0.22	n/a	0.05	0.04	n/a	-0.12	0.09	n/a	10.51	0.77	n/a	-0.43	0.15	n/a
CGCM3	11.60	0.15	0.22	-0.14	0.03	0.10	0.16	0.06	0.20	15.34	0.67	0.64	-0.23	0.13	0.15
CSIRO-MK3	14.19	0.32	0.30	-0.14	0.06	0.17	-0.06	0.14	0.39	12.52	0.39	0.44	0.03	0.07	0.17
MIROC3	12.52	0.24	0.26	-0.34	0.04	0.10	0.05	0.10	0.23	7.71	0.46	0.40	0.42	0.09	0.18
BCCR-BCM2	13.55	0.24	0.27	-0.08	0.04	0.14	-0.26	0.09	0.27	9.12	0.50	0.43	0.17	0.04	0.24
GISS-ER	14.78	0.18	0.14	-0.06	0.03	0.06	-0.31	0.06	0.12	9.46	0.42	0.50	-0.33	0.08	0.20
IPCL-CM4	9.72	0.28	0.30	-0.39	0.05	0.14	-0.26	0.11	0.28	3.09	0.39	0.44	-0.16	0.08	0.17
INM-CM3	9.94	0.32	0.35	-0.22	0.06	0.09	-0.04	0.14	0.21	13.41	0.50	0.48	-0.45	0.10	0.27
GFDL-CM2.1	12.36	0.40	0.36	-0.47	0.07	0.20	-0.52	0.14	0.38	8.03	0.74	0.51	-0.48	0.14	0.32

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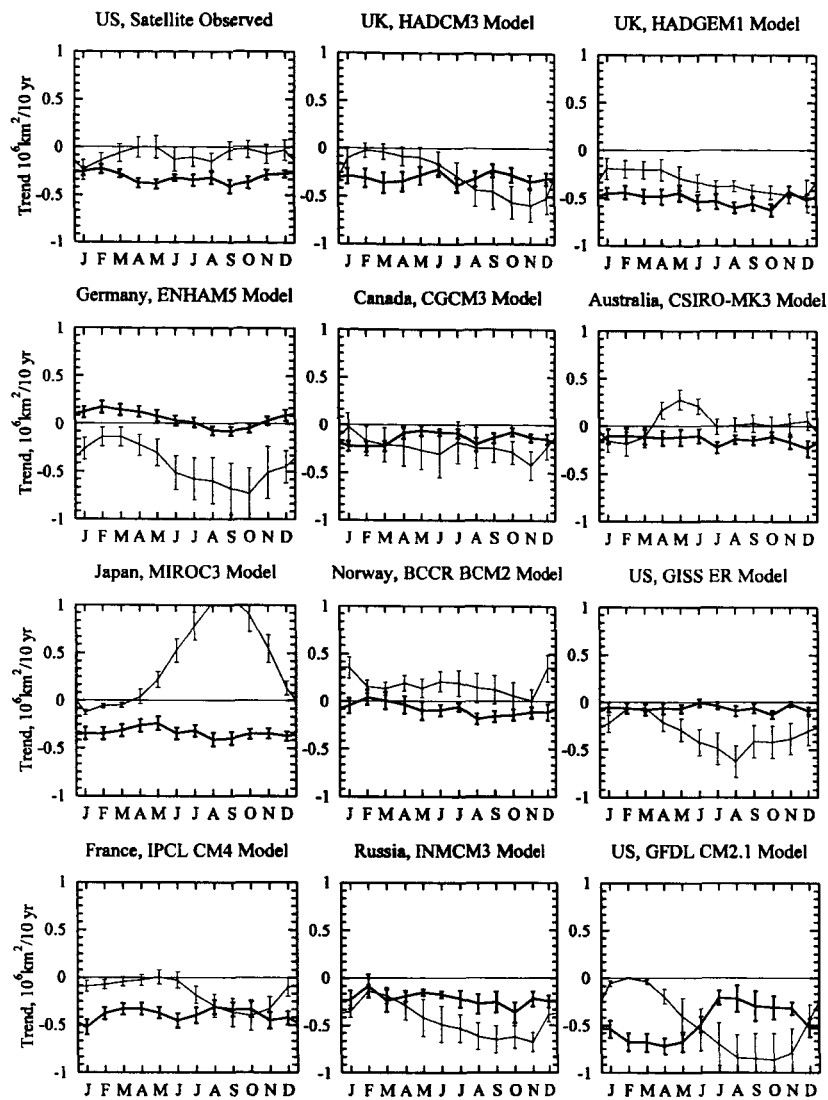
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