A model assessment of satellite observed trends in polar sea ice extents

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[1] 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 satellite data for both the Northern and Southern Hemispheres for the period 1972(73)–2004, and assess and interpret them using results from simulations by eleven climate models. In the Northern Hemisphere (NH), 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. Most of the models, like the observations, show an absence of a prominent seasonal cycle in the trend values. Both observations and model simulations show that climate variability in sea ice extent in the Southern Hemisphere (SH) is much larger than in the NH and that the SH sea ice extent trends are not statistically significant. **Citation:** Vinnikov, K. Y., D. J. Cavalieri, and C. L. Parkinson (2006), A model assessment of satellite observed trends in polar sea ice extents, *Geophys. Res. Lett.*, *33*, L05704, doi:10.1029/2005GL025282.

1. Introduction

[2] In an earlier attempt to use climate models to assess and interpret the observed contemporary trend in Northern Hemisphere (NH) 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. Neither of those models was able to simulate realistically sea ice in the Southern Hemisphere (SH). Two new factors move us now to return to a model assessment of the observed climatic trends. The first factor is that *Cavalieri et al.* [2003] extended the *Parkinson et al.* [1999] records of sea ice extents back to 1972–1973 and forward to 2002. The second factor is that 20th century climate changes have recently been 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. The results of these simulations are available through the Program for Climate Model Diagnostics and Intercomparison (PCMDI) at Lawrence Livermore National Laboratory, USA.

[3] The time series of satellite observed monthly sea ice extents for the north and south polar regions [*Cavalieri et al.*, 2003] used in this analysis has been updated through 2004. 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 than 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 NH sea ice extents for 1972–2004 and the simulated SH 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. Through 2004, the 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 assess natural climate variability in model simulated sea ice extents. The sea ice simulation data came from the following eleven climate models: (1) UKMO-HadCM3 [*Gordon et al.*, 2000] and (2) UKMO-HadGEM1 [*Johns et al.*, 2005], both from the United Kingdom Met Office Hadley Centre; (3) ECHAM5/MPI-OM [*Marsland et al.*, 2003], from the Max Planck Institute for Meteorology, Hamburg, Germany; (4) CGCM3.1 (T-47) [*Kim et al.*, 2002], from the Canadian Centre for Climate Modeling and Analysis;

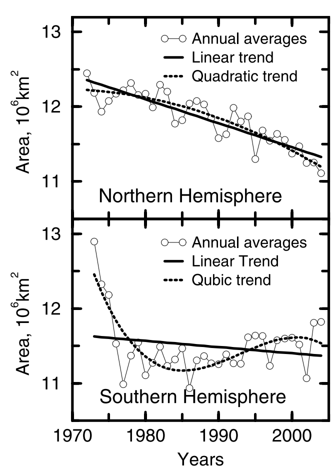

Figure 1. Satellite observed annual mean sea ice extents in the Northern and Southern Hemispheres and polynomial approximations of climatic trends.

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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[a]

		Northern Hemisphere, 33 yrs										Southern Hemisphere, 32 yrs						
		Average and Standard Deviation, 10^6 km^2			Linear Trend, 10^6 km^2/10 yr			Acceleration, 10^6 km^2/(10 yr)^2				Average and Standard Deviation, 10^6 km^2			Linear Trend 10^6 km^2/10 yr			
	Years, *N*	α	σ	⟨σ⟩	β	σ_β	$\sigma_{\langle\beta\rangle}$	γ	σ_γ	$\sigma_{\langle\gamma\rangle}$	%, *P*	α	σ	⟨σ⟩	β	σ_β	$\sigma_{\langle\beta\rangle}$	%, *P*
Observed	…	11.84	.16	…	−.32	.03	…	−.16	.06	…	…	11.50	.38	…	−.08	.07	…	…
HadCM3	340	12.23	.27	.35	−.31	.05	.14	−.17	.11	.28	0	11.66	.53	.56	−.28	.10	.13	28
HadGEM1	240	13.25	.27	.28	−.51	.05	.17	−.40	.09	.26	4	14.62	.33	.47	−.33	.06	.09	27
ECHAM5	n/a	12.11	.22	n/a	.05	.04	n/a	−.12	.09	n/a	n/a	10.51	.77	n/a	−.43	.15	n/a	n/a
CGCM3	500	11.60	.15	.22	−.14	.03	.10	.16	.06	.20	0	15.34	.67	.64	−.23	.13	.15	33
CSIRO-MK3	380	14.19	.32	.30	−.14	.06	.17	−.06	.14	.39	0	12.52	.39	.44	.03	.07	.17	15
MIROC3	500	12.52	.24	.26	−.34	.04	.10	.05	.10	.23	0	7.71	.46	.40	.42	.09	.18	38
BCCR-BCM2	250	13.55	.24	.27	−.08	.04	.14	−.26	.09	.27	2	9.12	.50	.43	.17	.04	.24	32
GISS-ER	500	14.78	.18	.14	−.06	.03	.06	−.31	.06	.12	0	9.46	.42	.50	−.33	.08	.20	45
IPSL-CM4	500	9.72	.28	.30	−.39	.05	.14	−.26	.11	.28	3	3.09	.39	.44	−.16	.08	.17	35
INM-CM3	330	9.94	.32	.35	−.22	.06	.09	−.04	.14	.21	0	13.41	.50	.48	−.45	.10	.27	40
GFDL-CM2.1	500	12.36	.40	.36	−.47	.07	.20	−.52	.14	.38	2	8.03	.74	.51	−.48	.14	.32	46

[a] σ_β and σ_γ are standard errors of β and γ estimated from the same data; ⟨σ⟩, $\sigma_{\langle\beta\rangle}$ and $\sigma_{\langle\gamma\rangle}$ 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 $\sigma_{\langle\beta\rangle}$ and $\sigma_{\langle\gamma\rangle}$, estimated from multi-centennial (*N*-years long) control simulations, are more accurate and should be used if available. ***P*** are occurrences of trends that exceed observed ones in the same moving windows expressed as a % of all the windows.

(5) CSIRO-Mk3.0 [*Gordon et al.*, 2002], from the Commonwealth Scientific and Industrial Research Organization, Australia; (6) MIROC3.2 (medres) [*Hasumi and Emori*, 2004], Model for Interdisciplinary Research on Climate, Japan; (7) BCCR-BCM2.0 [*Furevik et al.*, 2003], from the Bjerknes Centre for Climate Research, Norway; (8) GISS-ER [*Schmidt et al.*, 2005], from the NASA Goddard Institute for Space Studies, USA; (9) IPSL-CM4 [*Marti et al.*, 2005], from the Institute Pierre Simon Laplace, France; (10) INM-CM3.0 [*Diansky and Volodin*, 2002], from the Institute of Numerical Mathematics, Russian Academy of Science, Russia; (11) GFDL-CM2.1 [*Griffies et al.*, 2005], from the NOAA Geophysical Fluid Dynamics Laboratory, USA. C. L. Parkinson et al. (Evaluation of the simulation of annual cycle of Arctic and Antarctic sea ice coverages by eleven major global climate models, submitted to *Journal of Geophysical Research,* 2006), 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 both hemispheres.

4. Concluding Remarks

[13] 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, i.e., 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 statistical support to the conclusion that the satellite observed retreat in NH sea ice extents is a real climate change and that the retreat is a response to changes in the observed external forcing of the global climate system. An absence in the NH of a significant seasonal dependence of monthly trends, the acceleration of sea ice retreat, and the lack of a statistically significant trend observed in SH sea ice extent all deserve further investigation.