30-Year satellite record reveals contrasting Arctic and Antarctic decadal sea ice variability

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[1] A 30-year satellite record of sea ice extents derived mostly from satellite microwave radiometer observations reveals that the Arctic sea ice extent decreased by $0.30 \pm 0.03 \times 10^6$ km^2/10 yr from 1972 through 2002, but by $0.36 \pm 0.05 \times 10^6$km^2/10yr from 1979 through 2002, indicating an acceleration of 20% in the rate of decrease. In contrast, the Antarctic sea ice extent decreased dramatically over the period 1973–1977, then gradually increased. Over the full 30-year period, the Antarctic ice extent decreased by $0.15 \pm 0.08 \times 10^6$ km^2/10 yr. The trend reversal is attributed to a large positive anomaly in Antarctic sea ice extent in the early 1970's, an anomaly that apparently began in the late 1960's, as observed in early visible and infrared satellite images. *INDEX TERMS:* 4207 Oceanography: General: Arctic and Antarctic oceanography; 4275 Oceanography: General: Remote sensing and electromagnetic processes (0689); 4227 Oceanography: General: Diurnal, seasonal, and annual cycles. **Citation:** Cavalieri, D. J., C. L. Parkinson, and K. Y. Vinnikov, 30-Year satellite record reveals contrasting Arctic and Antarctic decadal sea ice variability, *Geophys. Res. Lett.*, *30*(18), 1970, doi:10.1029/2003GL018031, 2003.

1. Introduction

[2] Polar sea ice has undergone marked changes during the last two decades [*Bjørgo et al.*, 1997; *Parkinson et al.*, 1999; *Serreze et al.*, 2003; *Stammerjohn and Smith*, 1997; *Zwally et al.*, 2002], with a noted asymmetry between Arctic and Antarctic variabilities and trends [*Cavalieri et al.*, 1997]. The Arctic sea ice extent decreased by $0.329 \pm 0.061 \times 10^6$km^2/10yr over the period 1979–1999 [*Parkinson and Cavalieri*, 2002], whereas the Antarctic sea ice extent increased by $0.112 \pm 0.042 \times 10^6$km^2/10yr for 1979–1998 [*Zwally et al.*, 2002]. This hemispheric asymmetry is not inconsistent with some GCM simulations in which CO_2 concentrations were increased gradually [*Manabe et al.*, 1992; *Cavalieri et al.*, 1997].

[3] We have extended the analysis of Arctic and Antarctic sea ice variability from two to three decades (1973–2002) by bridging the gap between the Nimbus 7 data and the earlier Nimbus 5 satellite data record. The gap was bridged and the two satellite data records matched by using the National Ice Center (NIC) digital sea ice data set [*Dedrick et al.*, 2001]. Most of the recent satellite-based studies of sea ice variability have concentrated on the period since late 1978, when the Nimbus 7 satellite was launched.

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2. Sources of Data, Data Processing, and Matching Time Series

[4] The data sets used in compiling the three decade sea ice record include those from the Nimbus 5 Electrically Scanning Microwave Radiometer (ESMR) (December 1972–March 1977), the NIC (January 1972–December 1994 for the Arctic, January 1973–December 1994 for the Antarctic), and the combined Nimbus 7 Scanning Multichannel Microwave Radiometer (SMMR)/Defense Meteorological Satellite Program (DMSP) Special Sensor Microwave Imager (SSMI) (October 1978–December 2002). Previously, ice extents from the SMMR and three SSMI sensors were matched to provide a nearly continuous data set for 1978–1996 [*Cavalieri et al.*, 1999]. We have extended this time series through 2002 by using more recent SSMI data. The NIC ice extent data are used in this study to bridge the gap between the ESMR and SMMR/SSMI data. The need for matching satellite data records arises from differences in sensor operating frequency, incidence angle, footprint size, and local observation time. This necessitates either a period of overlap between the two sensors or a data record that bridges the gap and provides overlap with each of the separate data records.

[5] The daily ESMR brightness temperature data were mapped to the same polar stereographic grid used for the SMMR/SSMI 24-year (1979–2002) data set, then re-calibrated, cleaned by deleting bad data, and spatially interpolated for missing pixels. The brightness temperature maps were converted to sea ice concentration maps using a simple linear algorithm similar to the single-channel ESMR algorithms [*Parkinson et al.*, 1987; *Zwally et al.*, 1983a], with revised algorithm coefficents. As was done earlier for the SMMR/SSMI combined data set [*Cavalieri et al.*, 1999], the ice concentration maps were then subjected to a land spillover correction and SST filter to minimize weather contamination over open ocean areas before temporally interpolating for days of missing data. A 7-day moving average was applied to the ESMR ice concentration maps to reduce weather effects at the ice edge. Seven days is much shorter than the time scale of temporal autocorrelation of ice extents, which has been estimated to be about 50 days in both hemispheres [*Walsh and Johnson*, 1979; *Vinnikov et al.*, 2002]. Finally, sea ice extents were

calculated by summing the areas of all pixels with ice concentrations of at least 20%. The 20% cutoff, in contrast to the usual 15%, was used to eliminate additional spurious weather effects at the ice edge. The use of two ice-edge definitions (based on 20% for the ESMR data and 15% for the remaining ice extents) is resolved in the process of matching the different sea ice extent time series. Furthermore, *Parkinson et al.* [1999] show that sea ice trends are relatively insensitive to the choice of ice concentration cutoff over the range 15%–30%. Neither the 7-day moving average nor the increase to a 20% cutoff, for further weather clearing, was required for the SMMR/SSMI time series, because the SMMR and SSMI weather filters are based on the multichannel microwave data.

[6] Weekly Northern Hemisphere (NH) sea ice concentration files obtained from the NIC [*Dedrick et al.*, 2001] were mapped to the SSMI polar grid, and weekly ice extents were calculated by summing all pixels with ice concentrations of at least 15%. Because the updated weekly Southern Hemisphere (SH) ice concentration maps were not available from the NIC, we used the NIC weekly SH sea ice extent time series [*Ropelewski*, 1983], available from the NIC web site (http://www.natice.noaa.gov/PUB/Archive/antarctic/). The weekly NIC ice extents, which were interpreted as daily ice extents dated two days before the date of the ice chart's release, are used only as a means to bridge the gap between the two satellite data records. We did this to minimize the effect of inherent uncertainties in the NIC record [*Dedrick et al.*, 2001], including uncertainties resulting from nonuniform and different sources of data, and the subjective determination of sea ice extent by analysts. During the early part of the NIC record, significant areas of data represent interpolations or perceived climatological conditions, whereas in the late 1970's, ESMR and SMMR data were used by analysts to ''calibrate'' their estimates of ice concentration [*Dedrick et al.*, 2001]. For these reasons, we opted to maximize the use of the passive microwave satellite data and use the NIC data only to fill gaps in the satellite data record.

4. Conclusions

[13] Daily, monthly, and annual trends for three decades of Arctic and Antarctic sea ice extents have been generated utilizing a statistical technique that does not assume stationarity of the time series [*Vinnikov et al.*, 2002]. The resulting sea ice extent anomalies resemble anomalies for the period 1973–2000 published previously for the Antarctic (see Figure 2.16 in *IPCC* [2001]), but differ substantially from those published for the Arctic (see Figure 2.14 in *IPCC* [2001]), although both show negative overall trends. The reason for the Arctic differences during the early part of the period 1973–2000 is apparently the result of the *IPCC* [2001] study using different historical data sets in combination with the more current satellite sea ice data records. Additionally, there may have been differences in the method of data set blending, but this was not explained or referenced in *IPCC* [2001]. The time series presented in this paper are considered to be more consistent, because our primary source of data is satellite observations, using the blended ice extent data from NIC only to match the satellite time series and to fill gaps in the satellite records.

[14] The NH anomalies show a predominant period of 5 years, similar to what was reported by *Cavalieri et al.* [1997] for 1978–1996. This 5-year period falls within the broad spectral peak centered at 4.2 years obtained from an analysis of sea ice extent, area, and the Length of Day (LOD) index, used as a proxy for the El Nino/Southern Oscillation (ENSO) [*Gloersen*, 1995]. Regional Arctic sea ice variations result from atmospheric circulation changes and in particular from ENSO and North Atlantic Oscillation (NAO) events [*Deser et al.*, 2000; *Maslanik et al.*, 1996; *Mysak et al.*, 1996; *Parkinson*, 2000]. Patterns of Arctic surface air temperature changes and trends [*Rigor et al.*, 2000] are consistent with regional changes in sea ice extent [*Deser et al.*, 2000]. A dominant mode of Arctic variability is the Arctic Oscillation (AO), and its strong positive phase during the 1990s may account for much of the recent decrease in Arctic ice extent. The AO explains more than half of the surface air temperature trends over much of the Arctic [*Rigor et al.*, 2000].

[15] In contrast to the NH, the SH sea ice cover decreased dramatically over the period 1973–1977, then increased at an overall rate of $0.10 \pm 0.05 \times 10^6$ km^2/10yr from 1977 through 2002. This trend reversal results from the large positive anomaly in Antarctic sea ice extent observed in the early 1970's (Figure 1b). The decreasing positive anomaly from 1973 to 1976 (Figure 1b) is part of a longer period sea ice anomaly that began in the late 1960's and was observed in early visible and infrared satellite images [*Streten*, 1973; *Sissala et al.*, 1972; *Zwally et al.*, 1983b]. From 1968 to 1973 there was an increase in ice extent, preceding the 1973–1976 decrease (see Figure 5 in *Zwally et al.* [1983b]). The large positive sea ice extent anomaly in 1973 has been associated with a ''cold'' ENSO event [*Streten*, 1973; *Carleton*, 1989]. The fact that this short-term positive anomaly results in a negative trend for the 30-year period emphasizes the need for a longer time series extended back in time using, for instance, available visible and infrared satellite measurements.

[16] In addition to ENSO events, longer term atmospheric variations have been identified including appreciable changes in SH tropospheric circulation at middle and high latitudes since the 1970s [*Hurrell and Van Loon*, 1994]. These changes are also evident in the trend toward more positive SH annular mode indices over the last few decades [*Thompson and Wallace*, 2000], with the transition from mostly negative to mostly positive indices occurring during the 1970s. The more positive indices are associated with stronger westerlies and cooler temperatures over much of Antarctica [*Thompson and Solomon*, 2002]. Exactly how this trend is related, if at all, to the increase in sea ice extent since the 1970's remains to be determined.