Palmer LTER: Potential Ecological Impacts from Variations in Polar Climate

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1. Abstract

- Polar regions are unique in that sea ice, a dominant and distinguishing characteristic of Southern Ocean marine ecology, forms a range of habitats for animals as well as extensive and varied surfaces for algal and microbial populations.

- The Palmer Long Term Ecological Research (PAL) program focuses on understanding the ecological role of sea ice with the primary objective being to gain a general understanding of the physical and climatic controls on interannual sea ice variability, the effects of this variability on trophic interactions, and the biogeochemical consequences thereof.

- Climate research to date shows that the western Antarctic Peninsula (WAP) region has experienced a statistically significant warming trend during the past half century, and as determined from satellite passive microwave data during the past two decades air temperatures and sea ice extent are strongly anti-correlated.

- The variability in both air temperature and sea ice extent in the WAP region has been shown to be influenced by contrasting maritime (warm and moist) and continental (cold and dry) climate regimes. The more recent years have seen an increasing maritime influence in the WAP region, with corresponding effects on the marine ecosystem.

- As part of the PAL program, the ecological influence of these trends and variability is being studied, and effects have already been demonstrated at all trophic levels.

2. PAL Original Hypotheses

The central null hypothesis and several alternate hypotheses, that together comprise our integrated, transdisciplinary research prospectus, are presented below.

H_0: Neither the presence nor the extent of annual sea ice in the PAL study area influences ecosystem structure and dynamics.

H_{A1}: Interannual variations in ice dynamics are a quasi-predictable manifestation of ocean and atmospheric circulation processes which influence the extent of CDW upwelling onto the continental shelf. The presence of this warm, salt water mass affects the heat and salt budgets of the region and hence controls ice dynamics.

H_{A2}: Primary and secondary production are enhanced during high ice years, causing a general intensification of biogeochemical cycling rates and particle export processes.

H_{A3}: Increased food production and under-ice refuge during sequential above normal sea ice years promotes optimal recruitment and growth of krill and, in subsequent years (1-2 yr lag), a greater breeding success and survival of apex predators (e.g., Adelie penguins).

H_{A4}: The exchange of carbon dioxide between the atmosphere and the surface ocean is influenced by ice dynamics, CDW upwelling, primary and secondary production rates and organic particle sedimentation. The WAP region may be an important, albeit temporally-variable, source/sink term in global carbon budgets.

3. PAL PI’s and Components

Karen Baker (UCSD) - data management

Bill Fraser (Montana State U) - apex predators

David Karl (U Hawaii) - microbial ecology

Doug Martinson (LDEO) - modeling

Langdon Quetin (UCSB) - secondary production

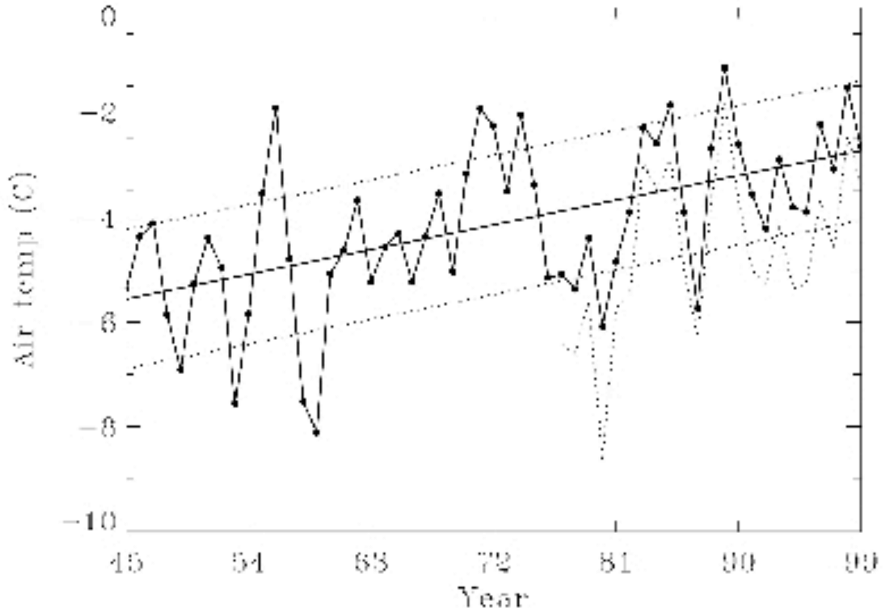
Robin Ross (UCSB) - secondary production

Ray Smith (UCSB) - bio-optical modeling, remote sensing

Maria Vernet (UCSD) - primary production

4. Surface Air Temperature

Figure 1

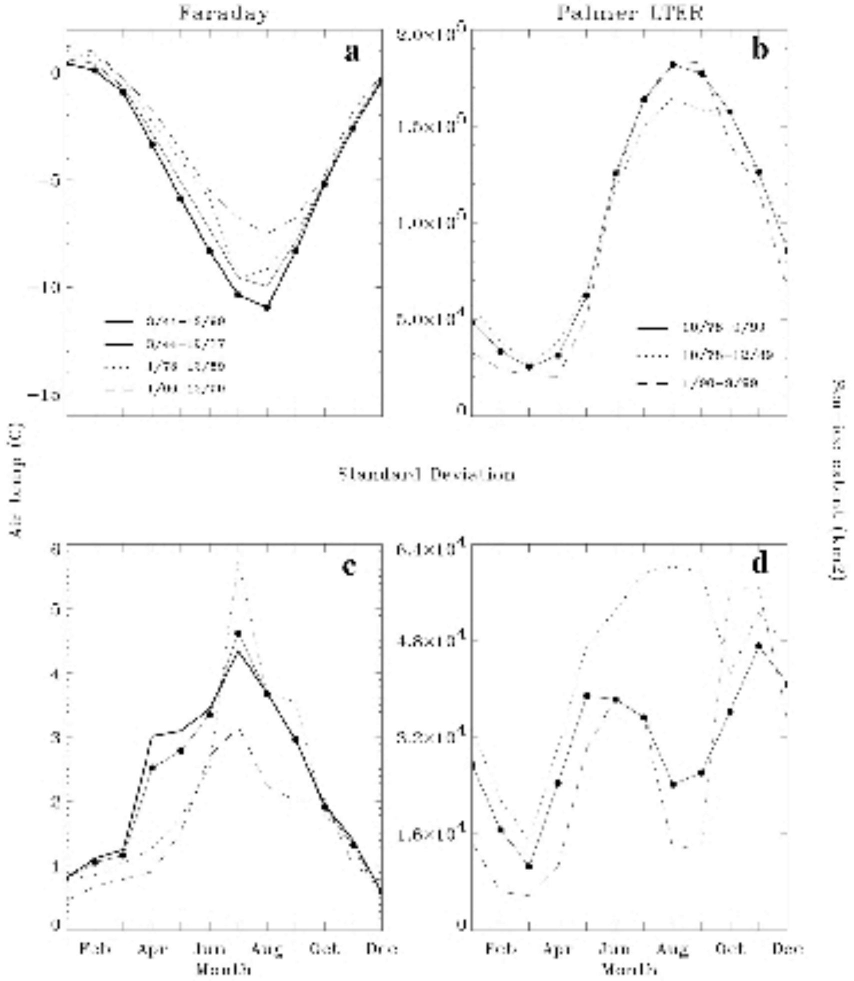


Air temperature data from Faraday/Vernadsky and Rothera Stations were kindly supplied by the British Antarctic Survey.

Figure 1 shows the Faraday annual average air temperatures from 1945 to 1999 (N=55). The dotted curve is Rothera air temperature for comparison. The solid straight line is the least-squares regression with a gradient of 0.052C/year, and the dotted lines indicate ±1 standard deviation from this line. Even after penalizing for serial correlation (N*=28.9), the warming trend over this period is significant at greater than the 99% confidence level.

5. Air/Ice Seasonal Variability

Figure 2



Figures 2a and 2**b** show annual curves of (**a**) monthly mean air temperatures for Faraday and (**b**) monthly mean sea ice extent for the Palmer LTER (i.e., WAP) region, respectively. Each annual curve includes a different time period (see legends).

Figures 2c and **2d** show the standard deviations of the monthly means shown in 2a and 2b, respectively.

6. Sea Ice vs Air Temp & SOI

Figure 3

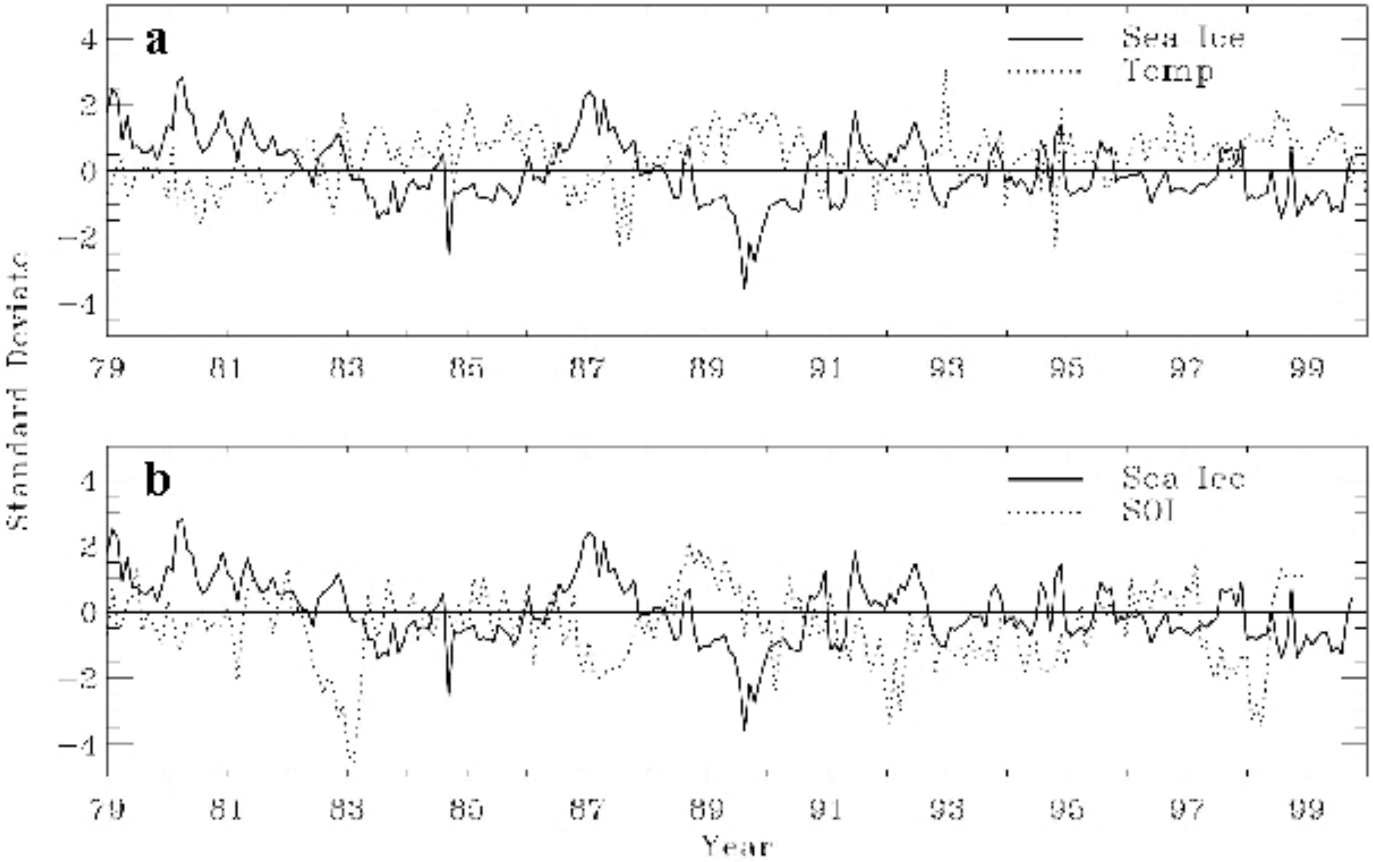


Figure 3 shows that sea ice extent is anti-correlated with both air temperature (**a**) and the Southern Oscillation Index (**b**). The data were smoothed by a five month running mean.

7. Annual/Seasonal Trends

Figure 4

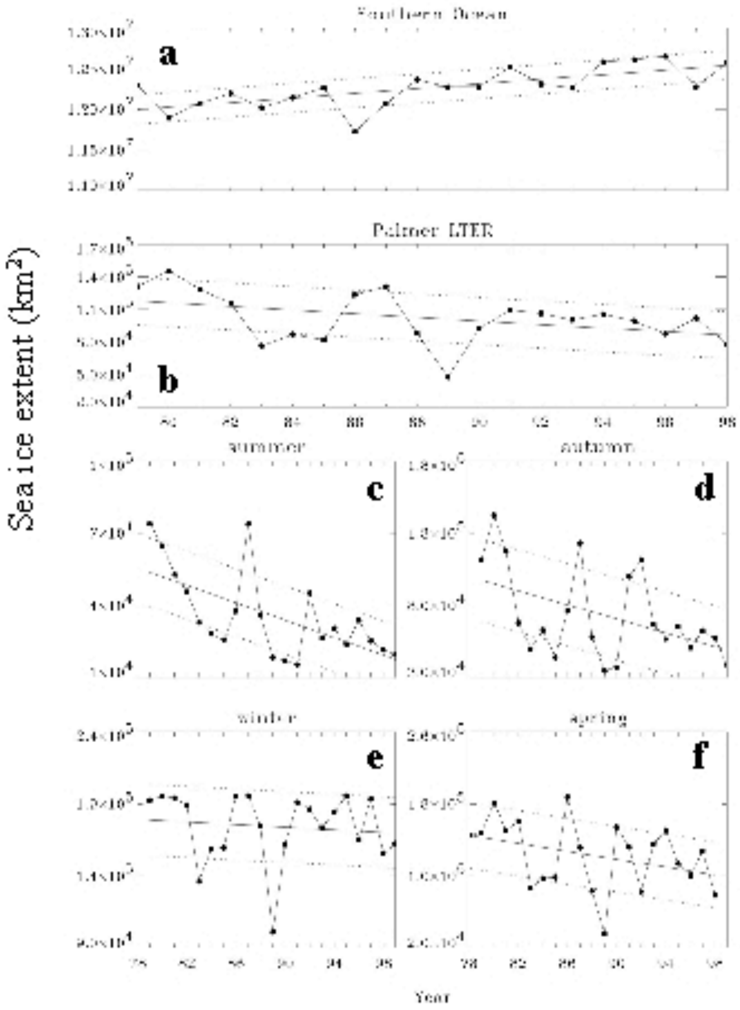


Figure 4 shows mean annual sea ice extent for the Southern Ocean (**a**) and the LTER region (**b**). Mean annual sea ice extent for the Palmer LTER region for summer (**c**), autumn (**d**), winter (**e**) and spring (**f**) are shown to illustrate that the annual trend in the WAP region is mostly due to the decreasing sea ice trend during summer.

8. Daily Variability

Figure 5a

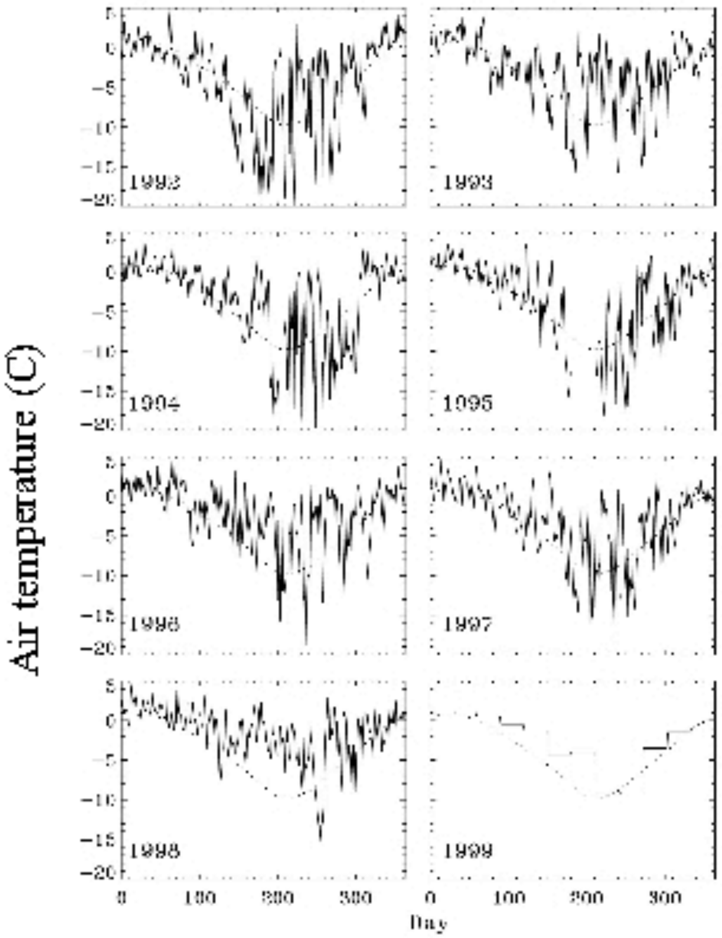


Figure 5b

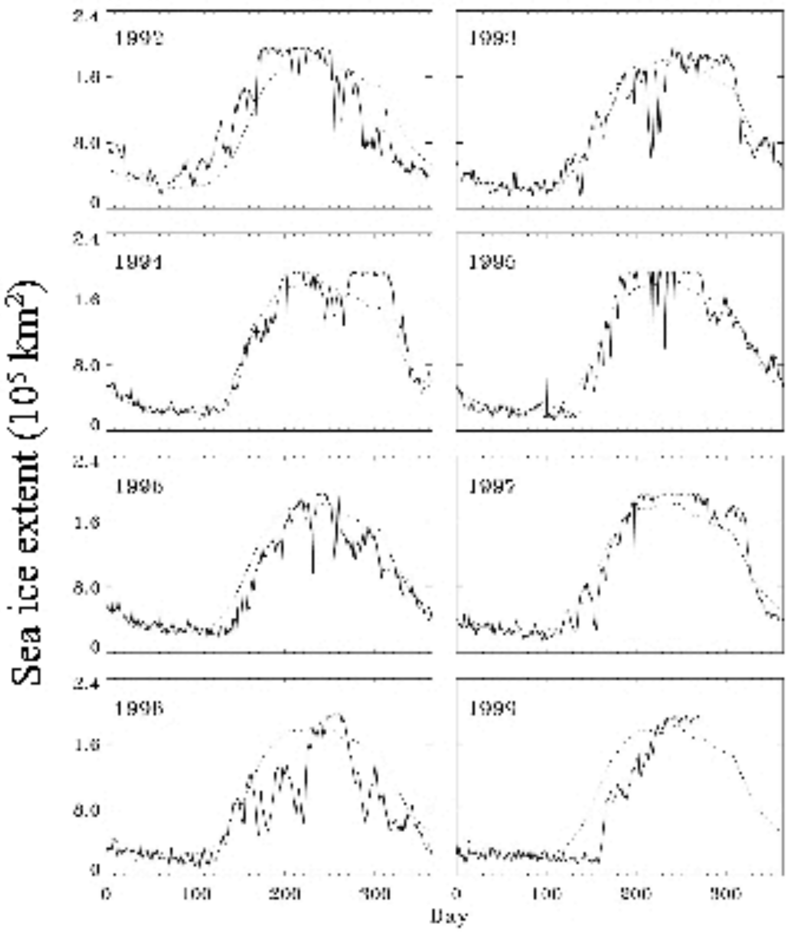
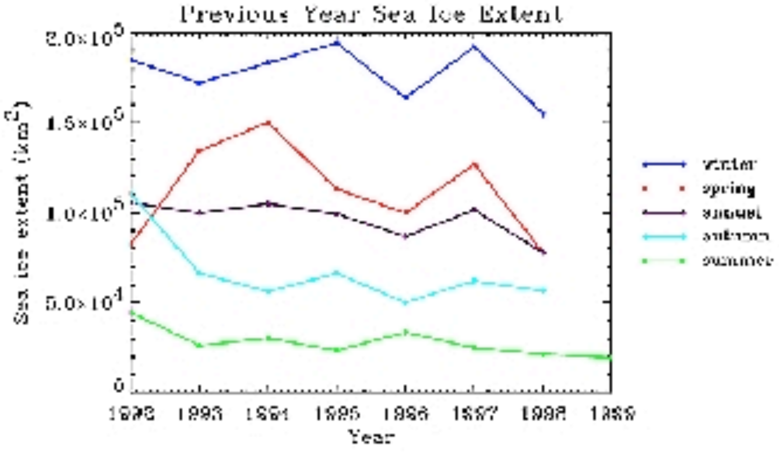


Figure 5 shows the annual curves of daily temperature (**a**) and sea ice extent (**b**) for the period 1990 through 1999. Thin dashed line gives the monthly mean for these data for the period of the satellite microwave data (10/78-9/99).

9. Ice-Ecosystem Connections



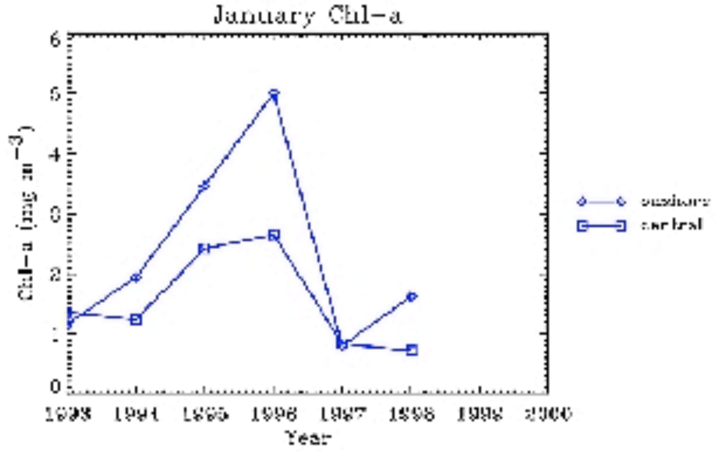
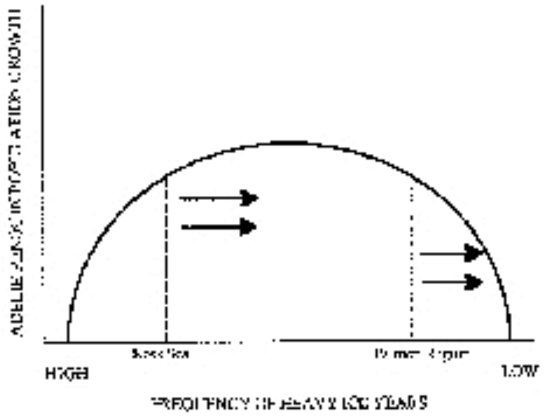


Table 1. January chlorophyll biomass from 1993 to 1998 in various sectors of the Palmer LTER grid in relation to mean sea ice extent during the previous winter and spring. The central and southern areas of the LTER grid include the mean of transect lines 500 and 600, and 200 and 300, respectively (see Figure 1). The onshore and offshore areas of the LTER grid include the mean of the innermost station (nearest the coast) and outermost station (furthest from the coast), respectively, of all transect lines. The rank of each variable is given in parenthesis to assist in cross-comparisons.

Year	Chlorophyll (mg/m^2) in four sectors of the LTER grid				Sea ice extent (km^2) during the previous	
	central	southern	onshore	offshore	winter	spring
1993	1.36 (3)	0.59 (5)	1.15 (5)	0.36 (5)	184,888 (3)	82,174 (6)
1994	1.23 (4)	1.39 (1)	1.94 (3)	0.85 (1)	172,297 (5)	131,273 (2)
1995	2.42 (2)	1.07 (2)	3.46 (2)	0.56 (2)	183,118 (4)	150,220 (1)
1996	2.65 (1)	0.87 (3)	5.02 (1)	0.44 (3)	194,320 (1)	113,664 (4)
1997	0.83 (6)	0.46 (6)	0.80 (6)	0.11 (6)	163,807 (6)	99,912 (5)
1998	0.72 (5)	0.68 (4)	1.62 (4)	0.41 (4)	192,157 (2)	126,866 (3)



10. WAP Climate

- The last two decades (1980-90's) were warmer than the previous several decades (**Fig 1**), and the largest temperature changes occurred in winter (JJA), in contrast to relatively little change in spring (SOND) (**Fig 2a**).
- The later advance and earlier retreat of sea ice in the 1990's (**Fig 2b**) translates into a shorter sea ice season (~2 weeks) during the 1990's as compared with the 1980's.
- There is significantly less variation in Faraday air temperatures during the 1990's compared to either the 1980's or the earlier decades (**Fig 2c**); this indicates an increased maritime influence in the WAP area.
- Sea ice extent in the WAP region is anti-correlated with both Faraday air temperature and the Southern Oscillation Index (**Fig 3**); these data support the idea that the linkage between sea ice and cyclonic activity is varying on global scales.
- The Southern Ocean as a whole shows a slightly increasing trend in sea ice extent (**Fig 4**), whereas in the WAP region there is a decreasing trend, particularly in summer sea ice extent, which is consistent with the increased maritime influence in the WAP area.
- During the decade of the 1990's, sea ice extent anomalies in the WAP region have generally been lower, and their timing more seasonally erratic, than in the earlier decade (**Fig 4**).
- The last two winter seasons in the WAP have been distinguished by above average temperatures from January to July with corresponding low sea ice (**Fig 5**); in both seasons the sea ice advance was late (August).

11. Discussion

- King and Harangozo (1998) have discussed the trends in climate change in the WAP and identified two possible factors as causes for the interannual variability in the temperature record: atmospheric-ice-ocean interactions, and variability in maritime versus continental control on climate.

- The increased maritime influence during recent decades is clear from the data, whereas the mechanisms underlying atmospheric-ice-ocean interactions and the causative factors involved remain to be elucidated.

- The life histories of various polar marine species are synchronized with the seasonality of sea ice (e.g. Smith and others, 1995). Sea ice is responding to climate change and this physical forcing on the biological community is evident (REF?).

- Furthermore, sea ice is a complex habitat, exhibiting various physiochemical and biological characteristics, and sea ice biological communities respond to distinct microenvironments and go through various stages of succession during the growth, evolution and decay of sea ice (e.g. Dieckmann and others, 1990).

- With respect to these various sea ice habitats, here is preliminary evidence that the dynamical process by frazil-pancake formation as described by Ukita & others (2000) may form a distinct habitat not previously described.

12. Summary

- Air temperatures within the WAP show a statistically significant warming trend which has persisted throughout the 1990's. However, during the 1990's the variance of wintertime temperatures has decreased and the persistence is less as compared with the 1980's.

- Increased air temperatures within the WAP are statistically linked to a decrease in sea ice extent and, as with temperature, the persistence of the 1980's has given way to less variance in the 1990's.

- These observations suggest that the balance between contrasting maritime and continental climatic regimes within the WAP region have moved toward increased maritime influence during the 1990's. These changes are related to an increase in cyclonic activity and increased boundary-layer winds flowing from the northwest with associated warm and moist air advection into the region.

- The consequences of these changes on sea ice growth processes and the evolution of the sea-ice cover may be profound for the marine ecology of the region.

- The ecological impact of sea ice is a complex space-time matrix of biology and physical forcing. Indexes have been developed which provide a general methodology for quantitatively linking variability in sea ice coverage to variability in marine ecosystems.

13. References

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