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LONG-TERM VARIATION OF ANTARCTIC SEA ICE AND ITS PREDICTION POSSIBILITY

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Abstract: The SIGRID Antarctic sea ice data (1973-1989) and the satellite microwave radiation data of SMMR and SSM/I (1978-1995) are used in this paper. Through assimilation-processing, these data sets are combined into a single time series data set (1973-1995). The maximum entropy spectrum analysis method is used to analyze the long-term variation periods of Antarctic sea ice; and the interrelationship between sea ice and ENSO events is examined. Based on these analyses results, the prediction possibility of Antarctic sea ice is studied, and forecasting regression equations of long-term variation trend of Antarctic sea ice are established to predict the long-term forecasting of sea ice.

1. Introduction

As a heat sink, Antarctic sea ice plays an important role in global climate change. Since NOAA and Nimbus series satellite began taking Antarctic sea ice data and microwave radiation data in 1972, studies of Antarctic sea ice variation and its impact on global climate have become available. Recent data analysis of anomalies in sea level pressure, meridian wind stress, sea surface temperature, sea ice extent, sea surface height and wind stress curl indicate that these anomalies propagate eastward over the Southern Ocean. This system of coupled anomalies is called the Antarctic Circumpolar Wave (WHITE and PETERSON, 1996; JACOB and MITCHELL, 1996). WHITE and PETERSON (1996) mentioned that the initiation of the Antarctic Circumpolar Wave is probably associated with El Nino activity. XIE *et al.* (1993, 1995) and ZOU *et al.* (1996a) studied the variation features of Antarctic sea ice and its relationship with Arctic sea ice and with El Nino and the Southern Oscillation (ENSO). Following these studies, in this paper, the variation periods of Antarctic sea ice and their relationship with ENSO and global climate change are analyzed further. These research results are used to study prediction possibility and to establish forecasting equations applying to the long-term prediction of Antarctic sea ice.

2. Data

The SIGRID sea ice data (1973-1989) provided by U.S. National Ice Center (NIC) and sea ice data induced from the satellite microwave radiation data (1978-1994) provided by the U.S. National Snow-Ice Data Center (NSIDC) are used in this paper. The former ended in 1989 while the latter started from 1978. Both series are very short and cover the same time period, 1978-1989. We used assimilation-processing to combine several years of sea ice data into a multi-year time series (ZOU *et al*., 1996b). In the same period, 1978-1989, the sea ice area value of SIGRID data was rather smaller than introduced from radiation data, so a correcting parameter value is calculated. Both series are combined as a single continuous data series of Antarctic sea ice in 1973-1994. This is very useful to study the long-term variation of sea ice.

In this paper, we use the 1973-94 data set with the corrected SIGRID data in 1973-November, 1978 and the microwave data in December, 1978-1994. Antarctic sea ice variation is analyzed for five regions as follows: Region I (0°-120°E), the eastern Antarctic sea ice facing the South Indian Ocean; Region II (120°E-120°W), the western South Pacific limits, mainly the Ross Sea; Region III (120°W-60°W), the eastern South Pacific limits, mainly the Amundsen Sea-Bellingshausen Sea; Region IV (60°W-0°), the South Atlantic limits, mainly the Weddell Sea; and Region V, the whole of the Antarctic sea ice.

3. Long-term Variation of Antarctic Sea Ice

The variation curves of monthly mean net sea ice area anomaly of the Antarctic sea ice regions are studied (see figures in XIE *et al*., 1995; ZOU *et al*., 1996a) with some main results as follows.

The general variation trends of Regions I and II are roughly similar with very obvious interannual change. There was more sea ice in middle 1970s, and less ice from the end of the 1970s to the beginning of the 1980s. After that, there was variation about a normal value.

In Region III, the phase change was opposite to that in Region II. It attained a maximum in 1977-78, and a minimum in 1983-84. In general, there was more ice in the middle-later 1970s and less or normal in the early 1980s.

Region IV is very different from Region III. It showed a maximum in 1973 and a minimum in 1977. It steadily varied about the normal in the 1980s and increased again in the 1990s.

Region V, the whole of Antarctic sea ice, is the synthetic result of the four sub-Regions mentioned above. The whole of Antarctic sea ice showed a maximum in 1973 and attained a minimum in 1977-80. Then it increased slowly but below the normal value until 1988. After that, sea ice increased to above the normal in the 1990s.

We try to study the inter-decade variation of Antarctic sea ice. Because our data start

Table 1. Total of yearly-mean of net sea ice area (10^5 km^2) in two 10-years periods and their difference.

Sea ice region	S_1	S_2	S_2-S_1
Region I	25.91	25.24	−0.67
Region II	29.48	29.01	−0.47
Region III	10.59	9.02	−1.57
Region IV	26.80	28.50	+1.70
Region V	92.77	91.75	−1.02

S_1 : Total of yearly-mean sea ice area in 1973-1982.
S_2 : Total of yearly-mean sea ice area in 1983-1992.

from 1973, we calculate the decade-total sea ice value for 1973–82 and 1983–92 and obtain the difference between two decades as shown in Table 1. It can be seen that, excepting Region IV (the Weddell Sea Region) with a positive difference value of sea ice, the other four Regions show negative values. It means that, sea ice was less in later 10-years. For the whole Antarctic, the total sea ice area decreased about 1.024×10^5 km^2. This must have a very important impact on global climate change.

4. Relationship between Antarctic Sea Ice and ENSO Events

By use of the maximum entropy spectrum analysis method, the variation periods of Antarctic sea ice are calculated as shown in Table 2.

Table 2. Variation periods (months) of the Antarctic sea ice.

Sea ice region	Principal period	Sub-period		
I	80	48		18.5
II	80			21.5
III	120	48	26.7	20
IV	60		26	20
V	60			21

Five elements of ENSO events are sea surface temperature anomaly (SSTA) of the four Nino regions: (Nino 1+2 (10°S-0°, 70°W-90°W), Nino 3 (5°S-5°N, 90°W-150°W), Nino 4 (5°S-5°N, 150°W-160°E), and Nino West (0°-10°N, 150°E-130°E)) and SOI (the southern oscillation index). By use of the Antarctic sea ice data in 1973–1993 and ENSO data in 1964–1995, the running cross correlation coefficients between them are calculated with fixed sample length of 132 months. All the correlation coefficient series show a very significant periodic variation. As an example, the correlation coefficient curves between sea ice of Region I and five elements of ENSO events with both 96 months lead and lag are shown in Fig. 1.

Figure 1 shows a very significant periodic change of correlation coefficient between SSTA-SOI and sea ice of Region I, the eastern Antarctic sea ice with the period of 40–50 months. This is just the variation period of SSTA of Nino 1+2, Nino 3 and Nino 4 and also corresponds to the first sub-period of sea ice of Region I of 48 months. This means that, if two elements have the same or a similar variation period, their correlation coefficient would be resonant in the same period. In other words, they would be best correlated in this period. This is especially true when SSTA leads sea ice. It can be seen from Fig. 1 that, two strong positive correlation stages appear in SSTA of three Nino Regions in 85–72 and 40–18 months prior to sea ice in Region I, and there is a weak positive stage at 10–30 months lag. Two strong negative correlation stages appear in SSTA at 65–42 months and $+6\sim-6$ months prior to sea ice.

The correlation variation between sea ice of Region I and SOI is just opposite to the variation mentioned above. The correlation variation between sea ice of Region I and SSTA of Nino West is the same as SOI but not too significant.

Figure 2 shows a very interesting and very good correlation between SSTA of Nino

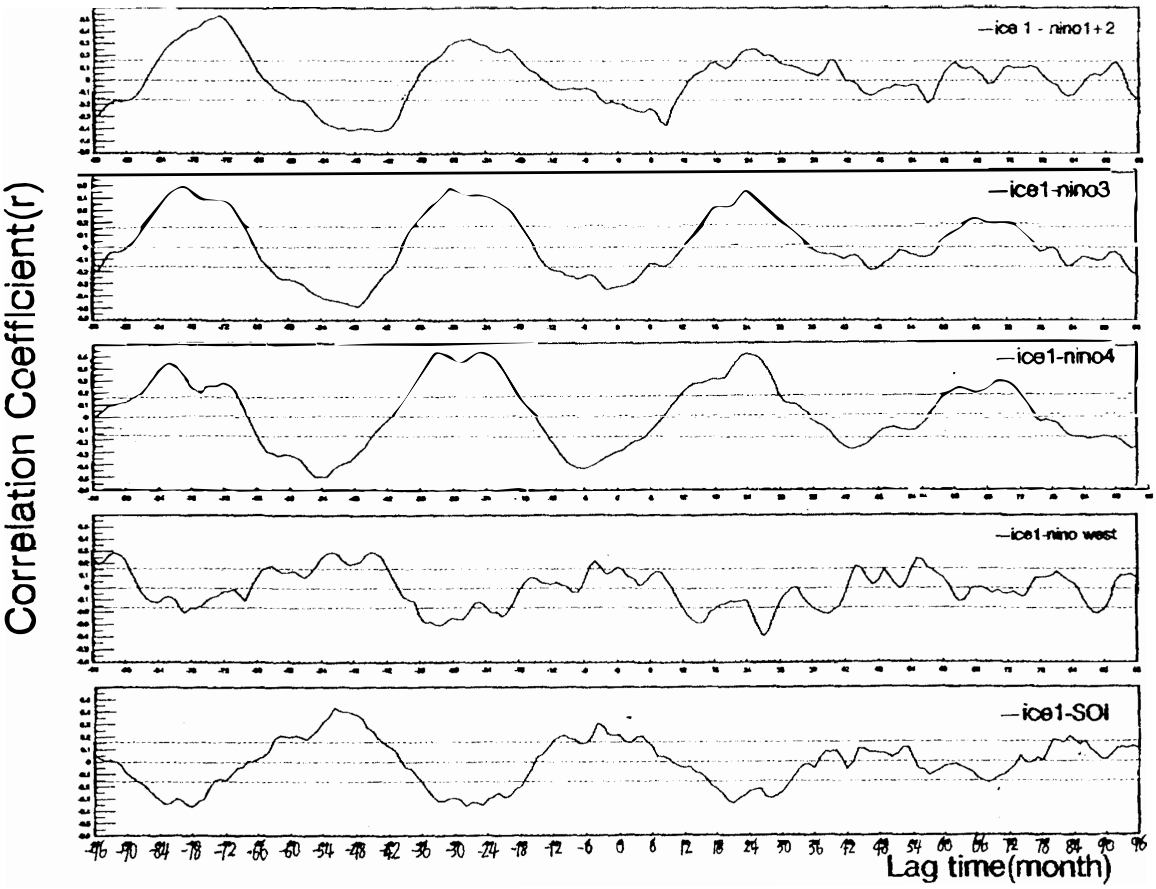

Fig. 1. Correlation coefficient curves between Antarctic sea ice of Region I and five elements of ENSO events.

4 region and sea ice of Region II. In a strong sine-type wave of the quasi-11 year period for sea ice in 90 months lead to 36 months lag to SSTA, the maximum negative correlation coefficient of -0.58 appears in SSTA after 2 months lag with a significance level $>99.99\%$. This is similar to the contemporary negative correlation between sea ice in Region II and SSTA of Nino 3. This means that, SSTA of Nino 3 and Nino 4 (160°E-90°W, the central-eastern equatorial Pacific) has an excellent correlation with sea ice in Region II (120°E-120°W) at almost the same longitude. We call this the Southern Oceanic Oscillation (SOO) (XIE *et al.*, 1995).

All these relationship explain that sea surface temperature anomaly (SSTA) of the eastern-central equatorial Pacific (the El Nino events) is closely related to variation of sea ice of the eastern Antarctic and the eastern South Pacific. And the former has important significance for prediction of the latter.

5. Prediction Possibility of the Antarctic Sea Ice

First, using the periodic change of sea ice itself and the accumulated sea ice anomaly curves, the long-term variation trend of sea ice can be extrapolated roughly. The details of this method are seen in XIE *et al.* (1993).

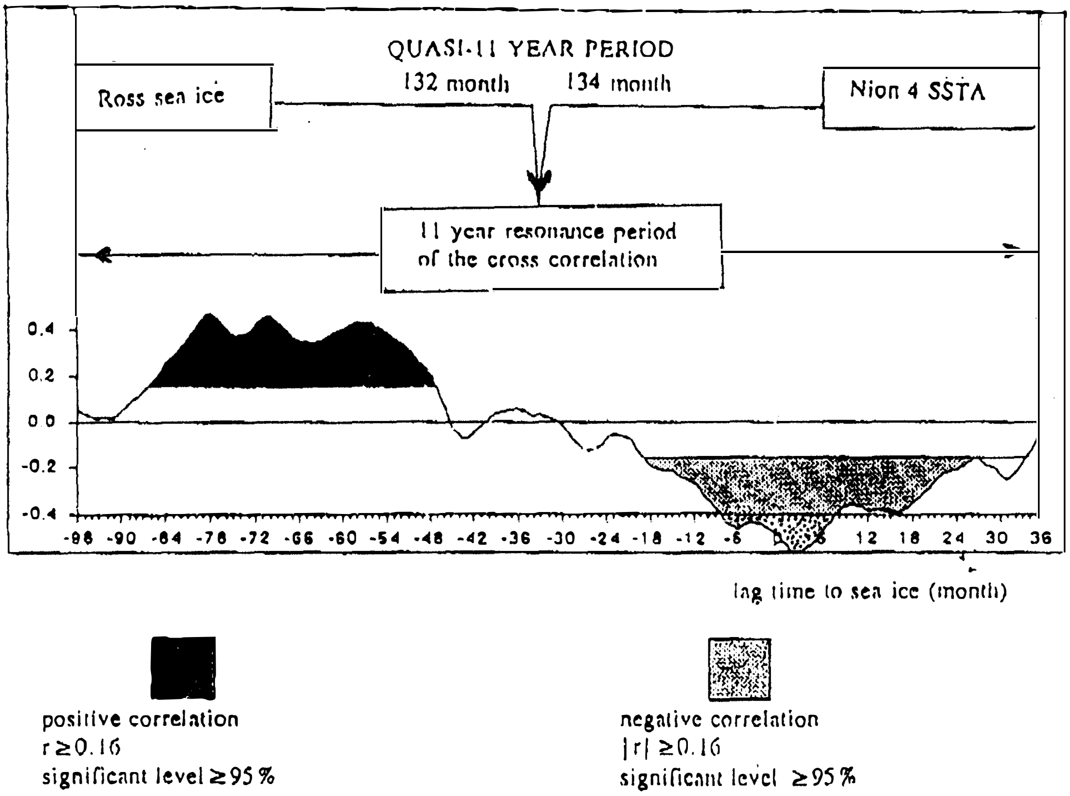

Fig. 2. A mechanism model chart of cross-correlation coefficient time series between SSTA of Nino 4 (5°S-5°N, 150° W-160°E) and sea ice in the Ross Sea area (120°E-120°W). The numerals on the abscissa are the number of months by which SSTA leads (−) or lags (+) sea ice.

Second using the physical elements of high correlation, the regression forecasting equations are established. It is known from analysis mentioned above that Antarctic sea ice and ENSO events are correlated with each other; moreover, the correlation is stronger and more significant when ENSO leads to sea ice. We select sea temperature anomalies of some grid points in the equatorial Pacific with higher correlation of significance level above 95% as forecasting factors. Using sunspot series as factors too, through the stepwise regression calculation, the forecasting models are established as follows:

Forecasting model of sea ice of Region I (multi-correlation coefficient=0.7).

$$\mathrm{Ice1} = -30558.5 + 122891.8 \times N_{3\text{-}203} + 121386.5 \times N_{2\text{-}148} + 79991.7 \times N_{2\text{-}73} - 74104.9 \times N_{2\text{-}181}.$$

Forecasting model for Region II (multi-correlation coefficient=0.7).

$$\mathrm{Ice2} = -91141.8 + 80.1 \times S_{383} - 97595.0 \times N_{2\text{-}111} - 77040.7 \times N_{3\text{-}54} + 76979.3 \times N_{3\text{-}129} - 221974.1 \times N_{4\text{-}161}.$$

Forecasting model for Region III (multi-correlation coefficient=0.67).

$$\mathrm{Ice3} = -130560.2 + 44641.1 \times N_{1\text{-}184} + 32961.5 \times N_{1\text{-}61} - 54586.6 \times N_{2\text{-}159} + 59.8 \times S_{44}.$$

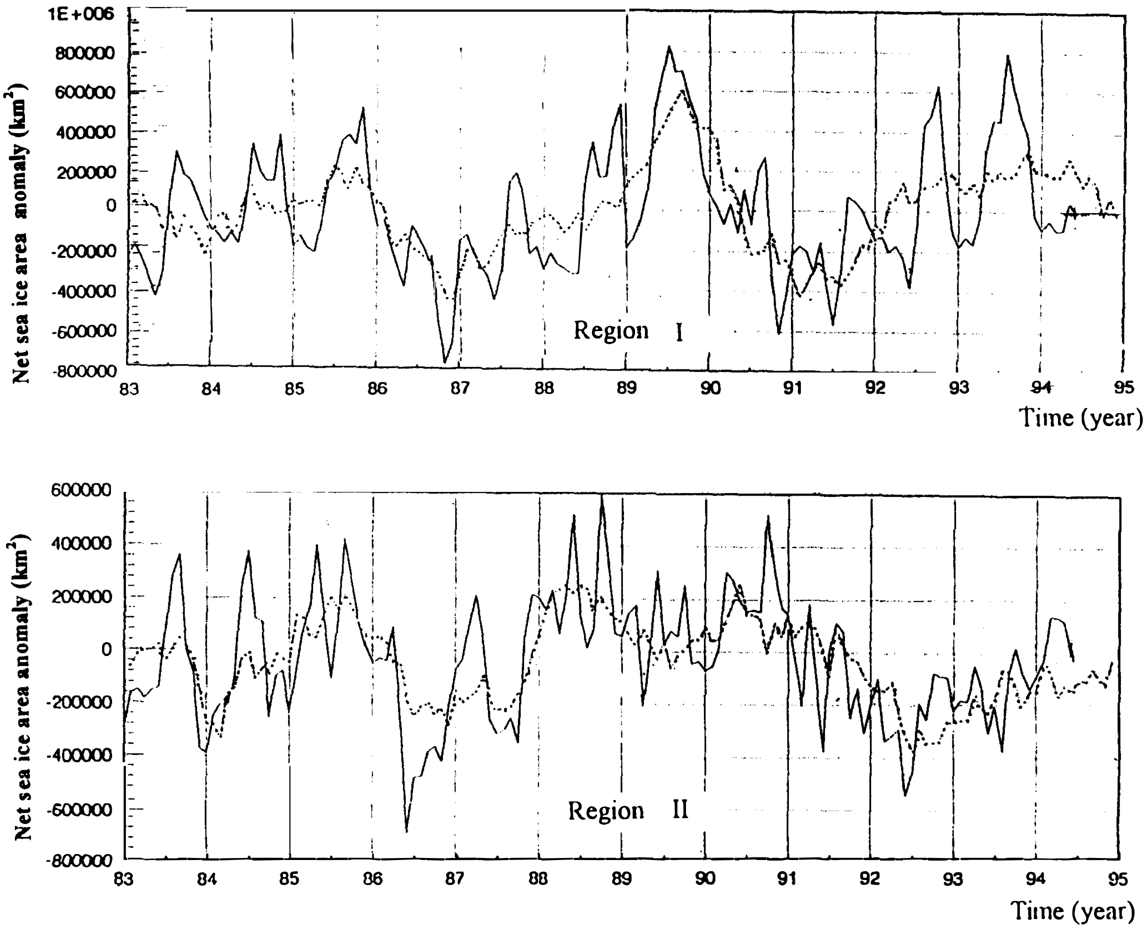

Fig. 3 Comparison between calculated value (dashed line) and observed value (solid line) in five Antarctic sea ice Regions. a. Region I (0-120E). b. Region II (120E-120W). c. Region III (120W-60W). d. Region IV (60W-0). e Region V, whole Antarctic.

Forecasting model for Region IV (multi-correlation coefficient=0.7).

$$Ice4 = 62821.0 + 102899.4 \times N_{1-120} - 111050.3 \times N_{2-195} - 96715.4 \times N_{3-28}.$$

Forecasting model for Region V (multi-correlation coefficient=0.75).

$$Ice5 = -275317.6 - 213354.5 \times N_{3-14} + 210696.3 \times N_{3-132} + 306576.3 \times N_{4-3} + 179.9 \times S_3.$$

Here, IceA is net sea ice area anomaly of Region A; N_{X-Y} is sea temperature anomaly of region Nino X, S_Y is sunspot number, Y is month number of ENSO prior to sea ice.

It can be seen that the multi-correlation coefficients after the fitting calculation are rather high, in the range 0.67-0.75. We use these forecasting models to calculate sea ice in January-December, 1994 and compare with the observed values in January-May, 1994 as shown in Fig. 3. Both the fitting calculation value (dashed line) and observed value (solid line) are roughly similar. The general trends were: mainly decreasing for Regions I and III, and mainly increasing for Regions II and IV; mainly increasing for the whole of

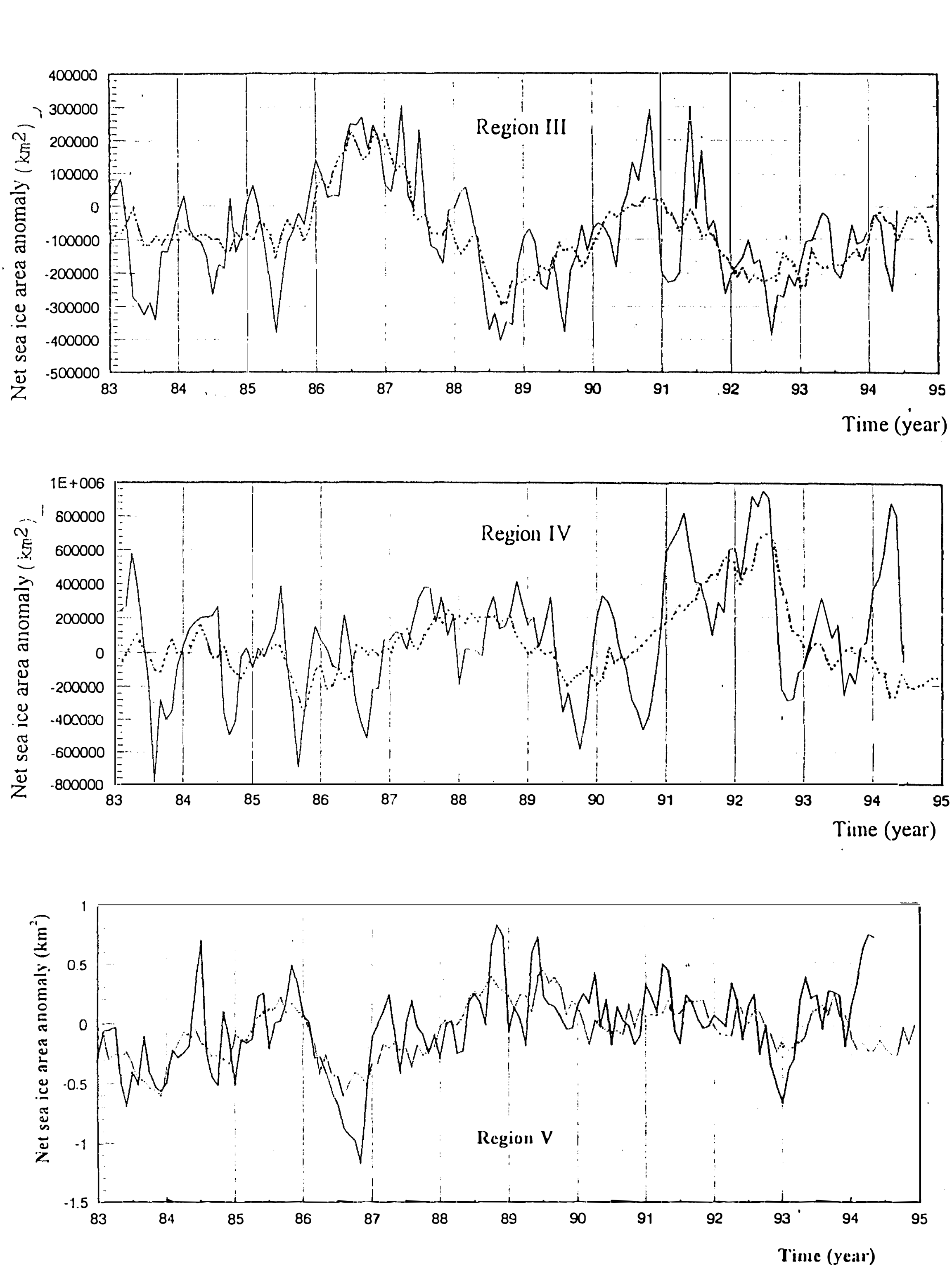

Fig. 3 (Continued).

Antarctic sea ice (Region V) in 1994. This is coincident with the result based on the extrapolation method.

All these forecasting models were applied for the annual prediction of sea ice in 1995.

6. Conclusions

Based on the analysis results, some conclusions are introduced as follows:

a) Both Antarctic sea ice and five elements of ENSO have a significant periodic variation.

b) If two series have the same or a similar variation period, their running cross correlation coefficient series would be resonate to produce a strong correlation wave. For example, sea ice of Regions I and III has the same first sub-period of 48 months; and SSTA of Nino 1+2 has a variation period of 43 months while Nino 3 and Nino 4 have a period of 48 months. As a result, a strong correlation oscillation period of about 40–50 months takes place.

c) The Antarctic sea ice of Regions I, II and III has a very strong periodic correlation oscillation with sea temperature of the eastern-central equatorial Pacific from SSTA with 96 months lead to 24 months lag of sea ice. The correlation is much stronger when SSTA leads than lags. So, this is useful for prediction of sea ice by using SSTA.

d) Based on the variation rule of sea ice itself, its interrelation with ENSO events, and the sunspot series as factors, the stepwise regression forecasting equations for Antarctic sea ice in the five Regions are established. Their multi-correlation coefficients are rather high, in the range 0.67–0.75, with a good result in experimental prediction of sea ice in 1994. This means that, a good possibility for the prediction of Antarctic sea ice exists.

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References

JACOB, G.A. and MITCHELL, J.L. (1996): Ocean circulation variation associated with Antarctic Circumpolar Wave. Geophys. Res. Lett., **23**, 2947–2950.

WHITE, W.B. and PETERSON, R.G. (1996): An Antarctic circumpolar wave in surface pressure, wind, temperature and sea ice extent. Nature, **380**, 699–702.

XIE, S., XUE, Z.H. *et al.* (1993): Antarctic sea ice and ENSO. Proc. of PACON Symp. 1993, 286–295 (in English).

XIE, S., BAO, C. *et al.* (1995): The southern oceanic oscillation. Sci. Bull., **40**(18), 1679–1681.

ZOU, B., XIE, S. and HAO, C. (1996a): Variation features of the Antarctic sea ice. to be published in "Interaction and Inter-Impact between the Antarctic and Global Climate Environment, 1996".

ZOU, B., XIE, S. and HAO, C. (1996b): Reprocessing of satellite microwave radiation data and its products. to be published in "Interaction and Inter-Impact between the Antarctic and Global Climate Environment, 1996".

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