January sea ice trends during the period of three IWC IDCR/SOWER circumpolar surveys (1978-2004)

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ABSTRACT

Trends of sea ice in the period of IWC IDCR/SOWER circumpolar surveys from CPI to CPIII (1978-2004) are fundamental information to understand the year-to-year sea ice variability. The trends of *sea-ice-extent* (*sea-ice-field*) in the IWC management areas were estimated by Murase and Shimada (2004) but the temporal coverage was limited to 2002. Rest of two years (2003 and 2004) are included in this paper. In addition, trends of *sea-ice-area-in-the-sea-ice-field* and *open-sea-area-in-the-sea-ice-field* are also considered in this paper. The trends in each IWC management area, western and eastern half of each IWC management area (e.g. Area I West and East) and each 10° degree longitudinal sector are investigated in this paper. Region specific year-to-year sea ice variabilities were detected. The variabilities were not consistent even in same management area. For example, differences of *open-sea-area-in-the-sea-ice-field* in two 10° degree longitudinal sectors in Area V (170°E-180° and 180°-170°W) between CPII and CPIII were large in comparison with rest of Area V. *Open-sea-area-in-the-sea-ice-field* in these sectors in CPIII were larger than CPII. Number of Antarctic minke whales in *sea-ice-field* is expected to be large if *open-sea-area-in-the-sea-ice-field* is large. Region specific investigation is required to understand the effect of sea ice on abundance estimation of Antarctic minke whales.

INTRODUCTION

The International Whaling Commission (IWC) has conducted the Antarctic minke whale (*Balaenoptera bonaerensis*) abundance assessment cruises since 1978/79 in the Antarctic in austral summer. The names of the cruises were firstly the International Decade of Cetacean Research programme (IDCR, from 1978/79 to 1995/96) and then the Southern Ocean Whale and Ecosystem Research programme (SOWER, from 1996/97 to 2009/2010). Matsuoka, *et al.* (2003) presented an extensive review of these cruises. These cruises covered three circumpolar surveys for the purpose of comprehensive assessments: 1978/79-1983/84 (first circumpolar, CPI), 1984/85-1990/91 (second circumpolar, CPII) and 1991/92-2003/04 (third circumpolar, CPIII). A noticeable abundance decline from CPII to the CPIII using the IWC standard abundance estimation method (Branch, 2006) has raised questions whether the decline is true or apparent. Discussion on reasons for the difference between the estimates between CPII and CPIII is ongoing in the Scientific Committee of IWC (IWC/SC). One of the reasons identified in IWC/SC is change in the location of the ice-edge and the proportion of animals south of the ice-edge (IWC, 2003a).

Several studies suggested that area of sea ice in the Antarctic showed area specific year-to-year variations (Zwally, *et al.*, 2002; Cavalieri, *et al.*, 2003; Cavalieri and Parkinson, 2008). Understanding of the sea ice variability specific to each IWC management area is fundamental information to see the effect of it on abundance estimation of Antarctic minke whales. IWC established six areas in the Antarctic for management of large whales: Area I (120°W-60°W), Area II (60°W-0°), Area III (0°-70°E), Area IV (70°E-130°E), Area V (130°E-170°W) and Area VI (170°W-120°W) (Donovan, 1991). Although Murase and Shimada (2004) investigated the January yearly trend of *sea ice extent* in each IWC management area, their analysis was limited to 2002.

Moreover, they only used *sea-ice-extent* (*sea-ice-field*). Recent discussion in IWC/SC more focused on sea ice and abundance of Antarctic minke whales at regional scale (e.g. each 10 longitudinal sector). In addition, it was acknowledged that *open-sea-area-in-the-sea-ice-field* is important to estimate abundance of Antarctic minke whales. This paper presents the results of investigation on January sea ice trends during the period of three IWC IDCR/SOWER circumpolar surveys (1978-2004). Trends of *sea-ice-extent* (*sea-ice-field*), *sea-ice-area-in-the-sea-ice-field* and *open-sea-area-in-the-sea-ice-field* in each IWC management area, western and eastern half of each IWC management area (e.g. Area I West and East) and each 10° degree longitudinal sector are investigated in this paper. .

MATERIALS AND METHODS

Satellite derived daily sea ice data, *Bootstrap Sea Ice Concentrations from Nimbus-7 SMMR and DMSP SSM/I* (Comiso, 1999) from 1978 to 2004 was used in the analysis. The data was provided by *the National Snow and Ice Data Center* (NSIDC, US). Sea ice observation using the satellite passive microwave sensors was started with the launch of *Scanning Multichannel Microwave Radiometer* (SMMR) on Nimbus-7 in 1978. The sensor was changed to Special Sensor Microwave/Imager (SSM/I) in 1987 and the data collection is still on going. The data were collected every other day for the SMMR whereas those were collected every day for the SSM/I. Sea ice concentration is expressed as percentage of area covered by sea ice in every 25km^2 × 25 km^2 grid cell. Sea ice concentrations more than 15% was commonly used in the sea ice trend analysis (Bjøgo, *et al.*, 1997; Hanna, 2001; Zwally, *et al.*, 2002). Therefore, grid cells with more than 15% sea ice concentrations were used in this analysis. The original data was in the NSIDC polar stereographic projection and it was converted to the polar stereographic Zenithal equal area projection. Monthly mean data in January were calculated by using daily data for each year. January anomalies of *sea-ice-extent* (*sea-ice-field*), *sea-ice-area-in-the-sea-ice-field* and *open-sea-area-in-the-sea-ice-field* was calculated. Their anomalies were calculated as average values from 1978 to 2004 minus observed values for each year. Definitions of *sea-ice-extent* (*sea-ice-field*), *sea-ice-area-in-the-sea-ice-field* and *open-sea-area-in-the-sea-ice-field* are summarized in Fig. 1. *Polynya* is not considered in this paper because automatic detection of *polynya* is technically difficult. The anomalies were calculated in each IWC management area, western and eastern half of each IWC management area (e.g. Area I West and East) and each 10° degree longitudinal sector.

RESULTS AND DISCUSSION

As an example of yearly variations of sea ice, anomalies of *open-sea-area-in-the-sea-ice-field* in the IWC management areas in January are shown in Fig. 2. Each management area showed area specific yearly variation. Large difference of *open-sea-area-in-the-sea-ice-field* between CPII and CPIII was observed in Area V (130°E-170°W). The difference was pronounced in East (165°E-170°W) in comparison with West (130°E-165°E) (Fig. 3). Sea ice conditions in East affected the change in *open-sea-area-in-the-sea-ice-field* in Area V. Likewise, contribution of some 10° degree longitudinal sectors affected the trends in West/East of Area V (Fig. 4). Differences of *open-sea-area-in-the-sea-ice-field* between CPII and CPIII in two 10° degree longitudinal sectors in Area V (170°E-180° and 180°-170°W) were large. *Open-sea-area-in-the-sea-ice-field* in these sectors in CPIII were larger than CPII. Number of Antarctic minke whales in *sea-ice-field* is expected to be large if *open-sea-area-in-the-sea-ice-field* is large. It was demonstrated that abundance of Antarctic minke whales in Area V was low when *sea-ice-extent* (*sea-ice-field*) was large (Matsuoka *et al.*, 2009). Number of Antarctic minke whales in *sea-ice-field* could relate to *open-sea-area-in-the-sea-ice-field*. Region specific year-to-year sea ice variabilities were also detected in other management areas (see Figs. in Appendix). The results of this paper suggested that region specific investigation is required to understand the effect of sea ice on abundance estimation of Antarctic minke whales. Development of such database is critically important to account the effect. *Polynya* (number of grid cells containing less than 15 % sea ice concentrations in the south of sea ice edge observed by IDCR/SOWER vessels) was not considered in this analysis because automatic detection of *polynya* is technically difficult. However, *polynya* is considered as one of the important habitat of Antarctic minke whales, area of *polynya* should be calculated in each surveyed year in addition to *open-sea-area-in-the-sea-ice-field.*

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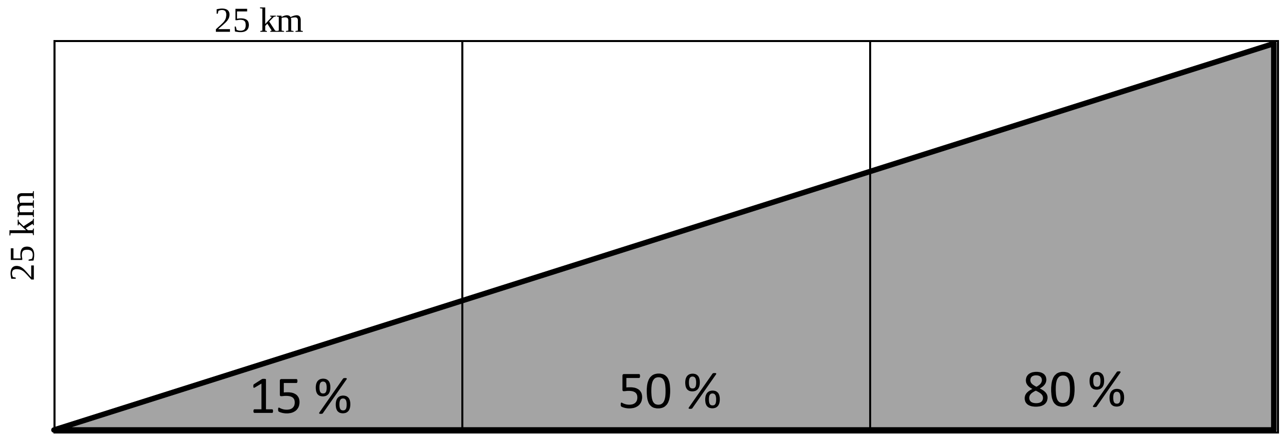


Fig. 1. Schematic diagram of relationship between *sea-ice-concentration*, *sea-ice-extent* (*sea-ice-field*), *sea-ice-area-in-the-sea-ice-field* and *open-sea-area-in-the-sea-ice-field*. Grey area shows sea ice concentrations in 25 ×25 km grid cells. Spatial resolution of satellite data "*Bootstrap Sea Ice Concentrations from Nimbus-7 SMMR and DMSP SSM/I*" is 25 ×25 km grid cell. Definitions of *sea-ice-concentration*, *sea-ice-extent* (*sea-ice-field*), *sea-ice-area-in-the-sea-ice-field* and *open-sea-area-in-the-sea-ice-field* are as follows.

Sea-ice-concentration

Sea ice concentration in each 25×25 km grid cell (625km^2) in %. In the diagram, the sea ice concentrations are 15, 50 and 80 % from left to right.

Sea-ice-extent (*sea-ice-field*)

Number of grid cells containing more than 15 % sea ice concentrations. In the diagram, the sea ice extent is 625km^2 × 3. *Sea-ice-field* is used as an alternative definition of *sea-ice-extent* in this paper.

Sea-ice-area-in-the-sea-ice-field

Area covered by sea ice in each 25 ×25 km grid cell in *sea-ice-field* (grey area in the diagram). In the diagram, the sea ice extent is 625km^2×0.15+625km^2×0. 5+625km^2×0.8.

Open-sea-area-in-the-sea-ice-field

Sea ice free area in each 25 ×25 km grid cell (white area in the diagram). In the diagram, the sea ice free area in the sea ice field is 625km^2×0.85+625km^2×0. 5+ 625km^2×0.2.

Polynya

Number of grid cells containing less than 15 % sea ice concentrations in the south of sea ice edge. The ice edge is defined by a level of ice cover that prevents the survey from being conducted at normal survey speed (11.5 knots) (IWC, 2003b). Because automatic detection of polynya is technically difficult, polynya is not considered in this paper.

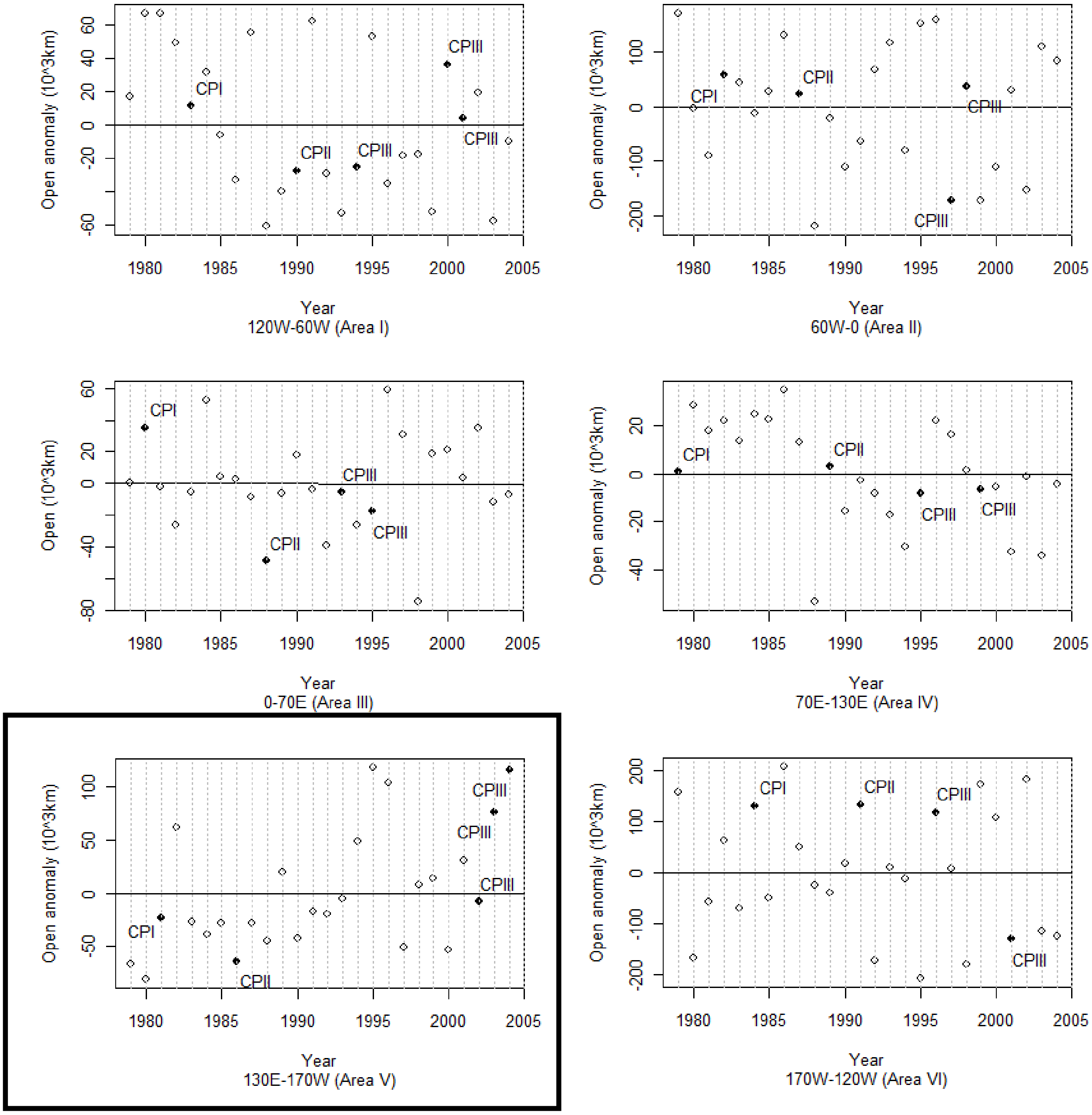


Fig. 2. Anomaly of *open-sea-area-in-the-sea-ice-field* in January from 1978 to 2004 in each IWC management area (I-VI).

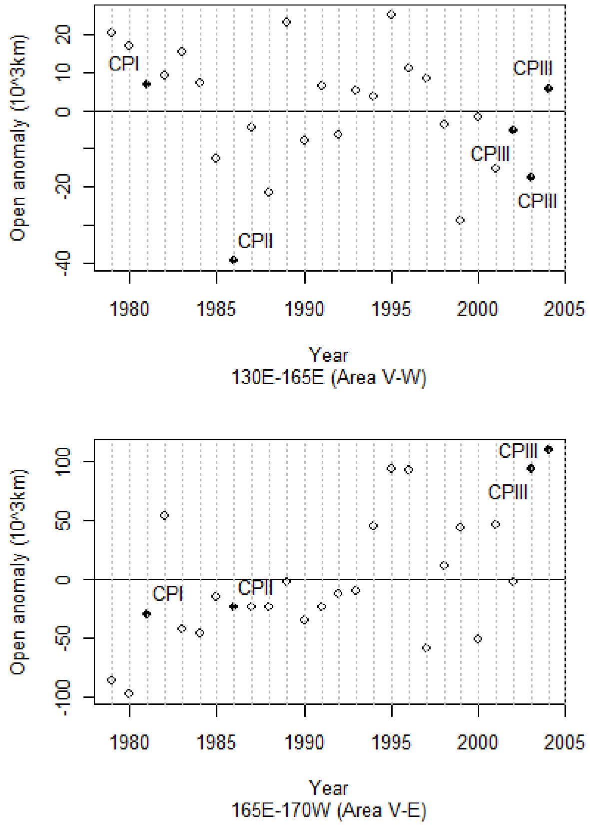


Fig. 3. Anomaly of *open-sea-area-in-the-sea-ice-field* in January from 1978 to 2004 in West (130°E-165°E) and East (165°E-170°W) of Area V.

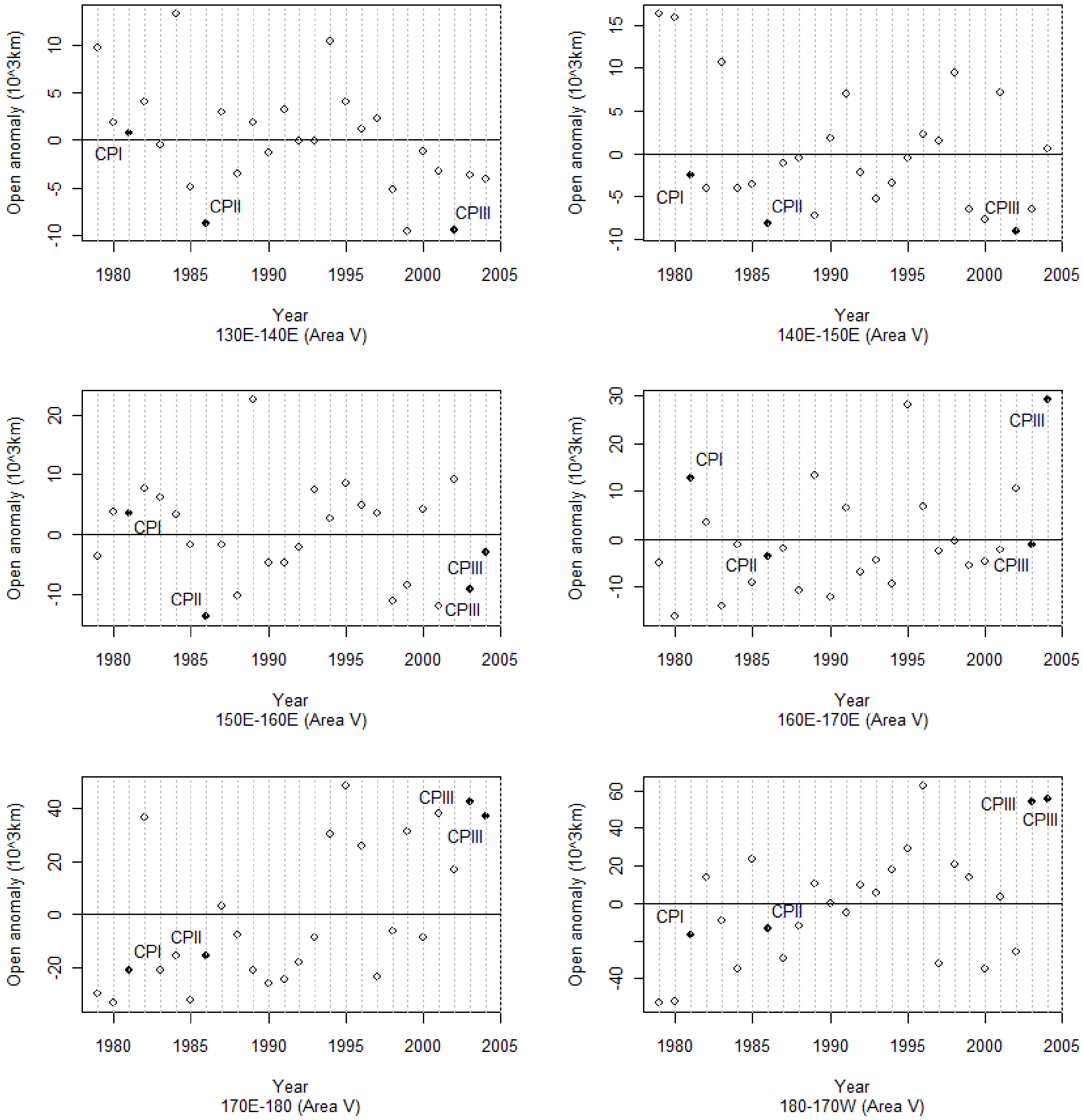


Fig. 4. Anomaly of *open-sea-area-in-the-sea-ice-field* in January from 1978 to 2004 in each 10º longitudinal sector in Area V.

APPENDIX

Fig. E-1 ~ 9. Anomaly of *sea-ice-extent* (*sea-ice-field*) in January from 1978 to 2004 in each IWC management area, western and eastern half of each IWC management area and each 10° degree longitudinal sector.

Fig. A-1 ~ 9. Anomaly of *sea-ice-area-in-the-sea-ice-field* in January from 1978 to 2004 in each IWC management area, western and eastern half of each IWC management area and each 10° degree longitudinal sector.

Fig. O-1 ~ 9. Anomaly of *open-sea-area-in-the-sea-ice-field* in January from 1978 to 2004 in each IWC management area, western and eastern half of each IWC management area and each 10° degree longitudinal sector.

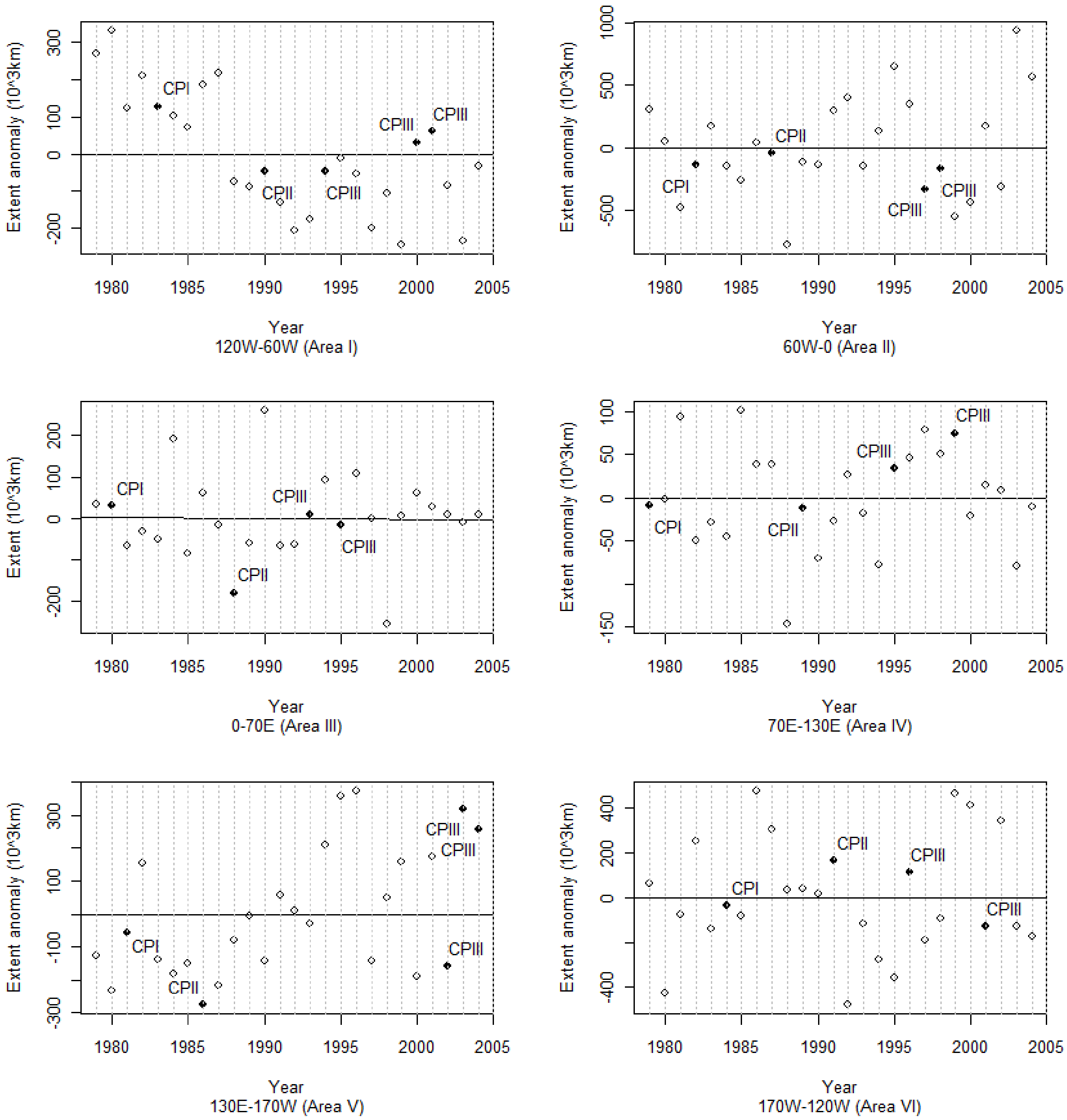


Fig. E-1. Anomaly of *sea-ice-extent* (*sea-ice-field*) in January from 1978 to 2004 in each IWC management area (I-VI).

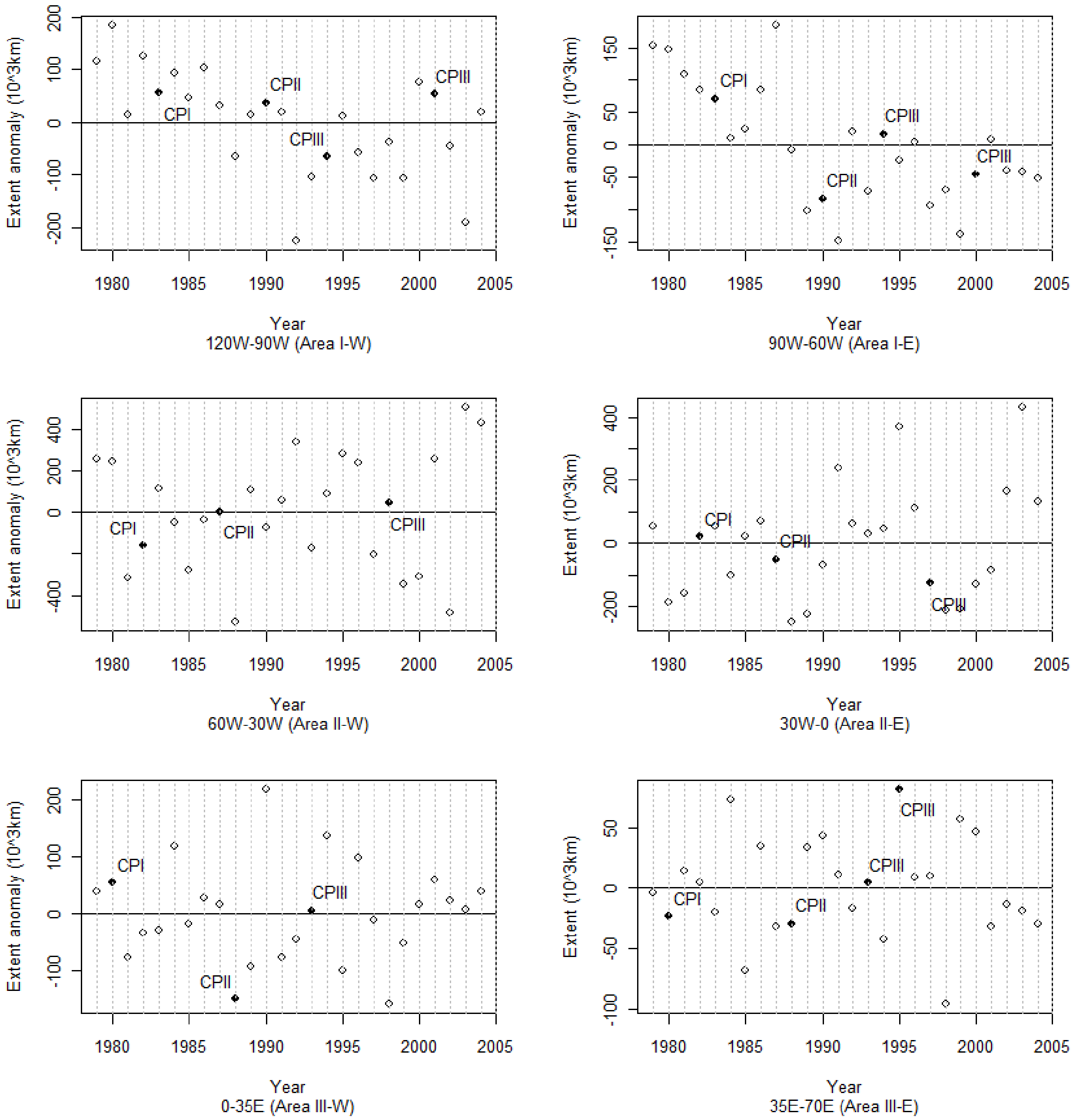


Fig. E-2. Anomaly of *sea-ice-extent* (*sea-ice-field*) in January from 1978 to 2004 in each IWC management area (I-III). Each area is divided into two: West (W) and East (E).

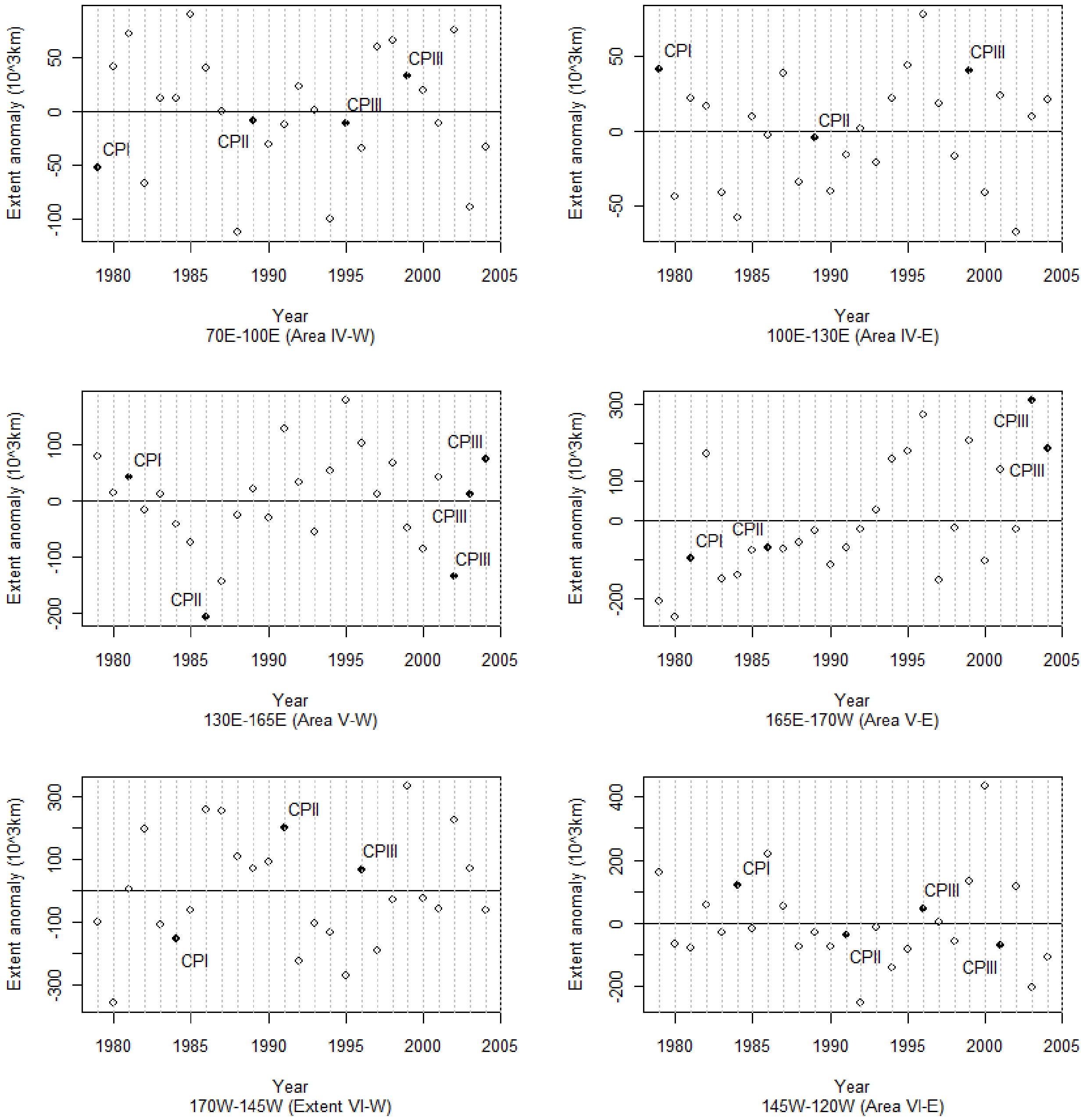


Fig. E-3. Anomaly of *sea-ice-extent* (*sea-ice-field*) in January from 1978 to 2004 in each IWC management area (IV-VI). Each area is divided into two: West (W) and East (E).

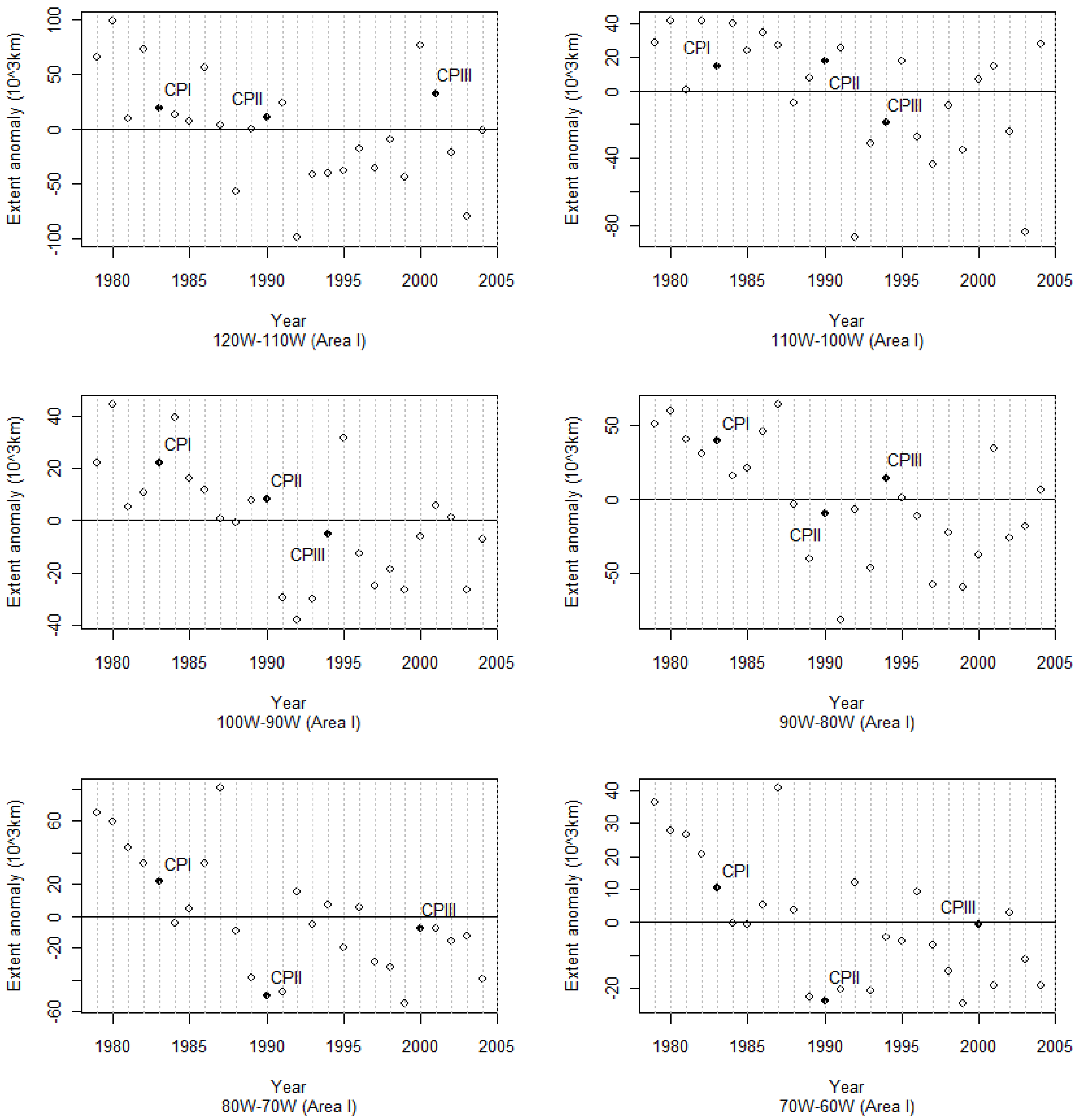


Fig. E-4. Anomaly of *sea-ice-extent* (*sea-ice-field*) in January from 1978 to 2004 in each 10º longitudinal sector in Area I.

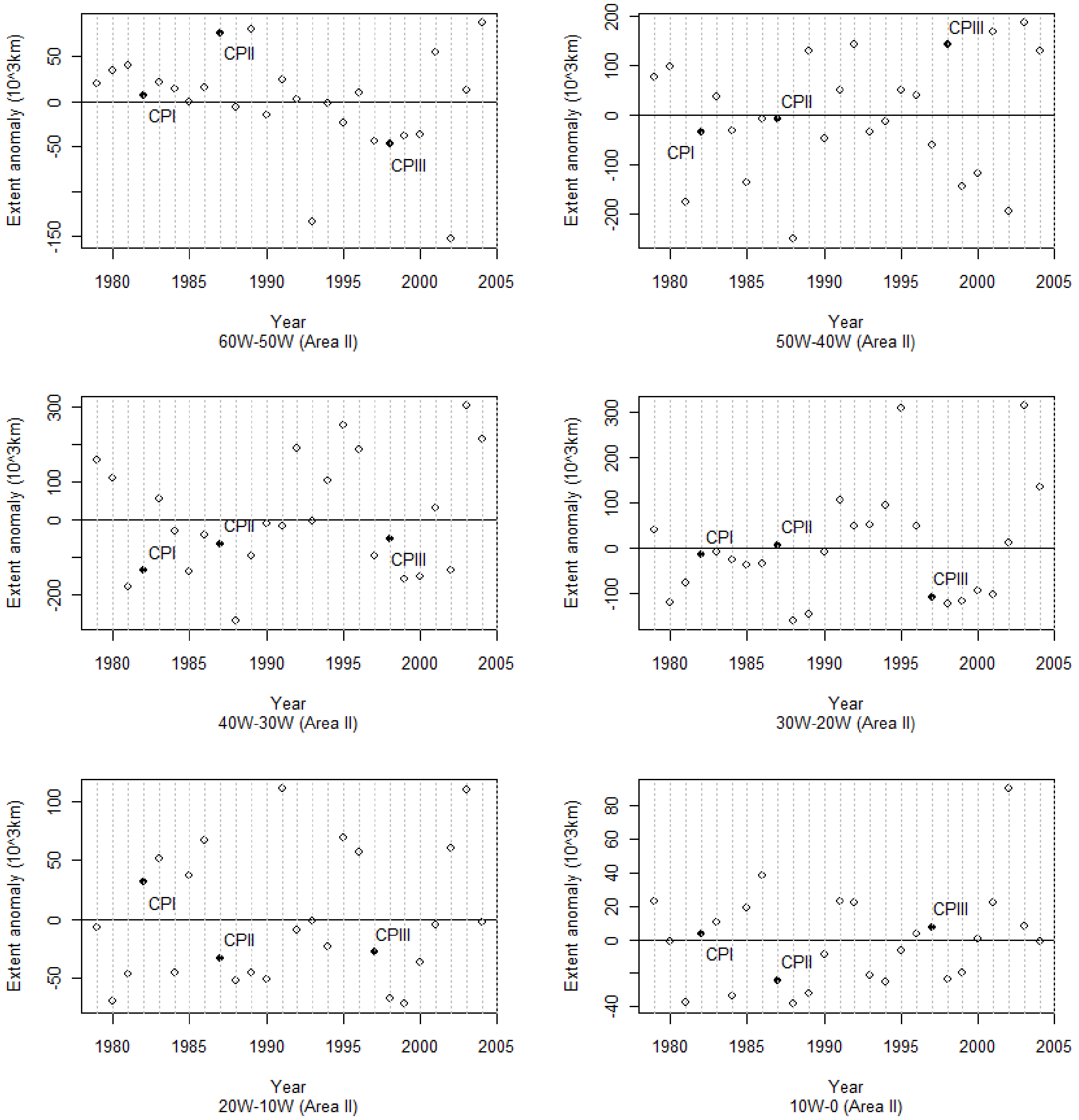


Fig. E-5. Anomaly of *sea-ice-extent* (*sea-ice-field*) in January from 1978 to 2004 in each 10º longitudinal sector in Area II.

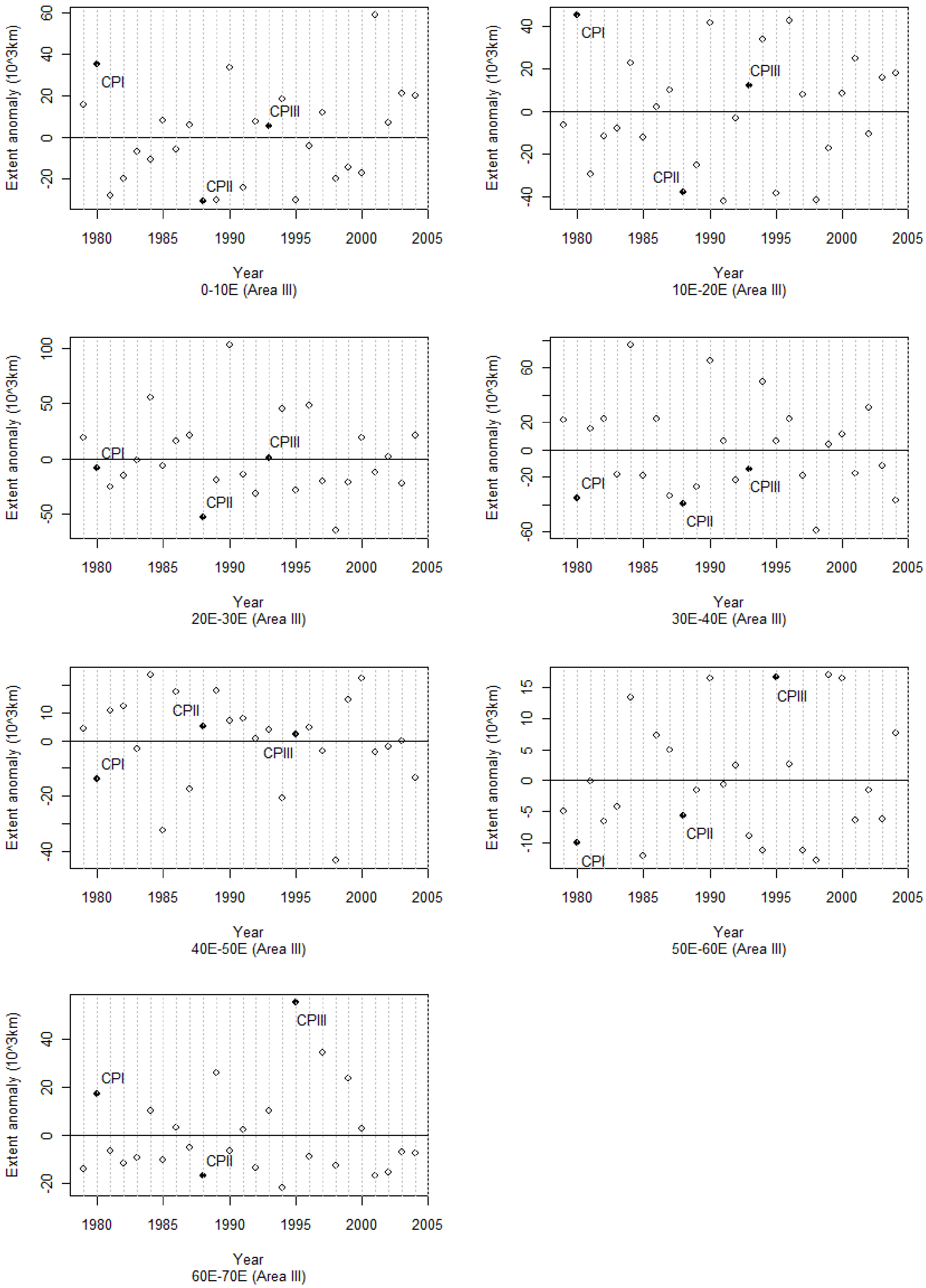


Fig. E-6. Anomaly of *sea-ice-extent* (*sea-ice-field*) in January from 1978 to 2004 in each 10º longitudinal sector in Area III.

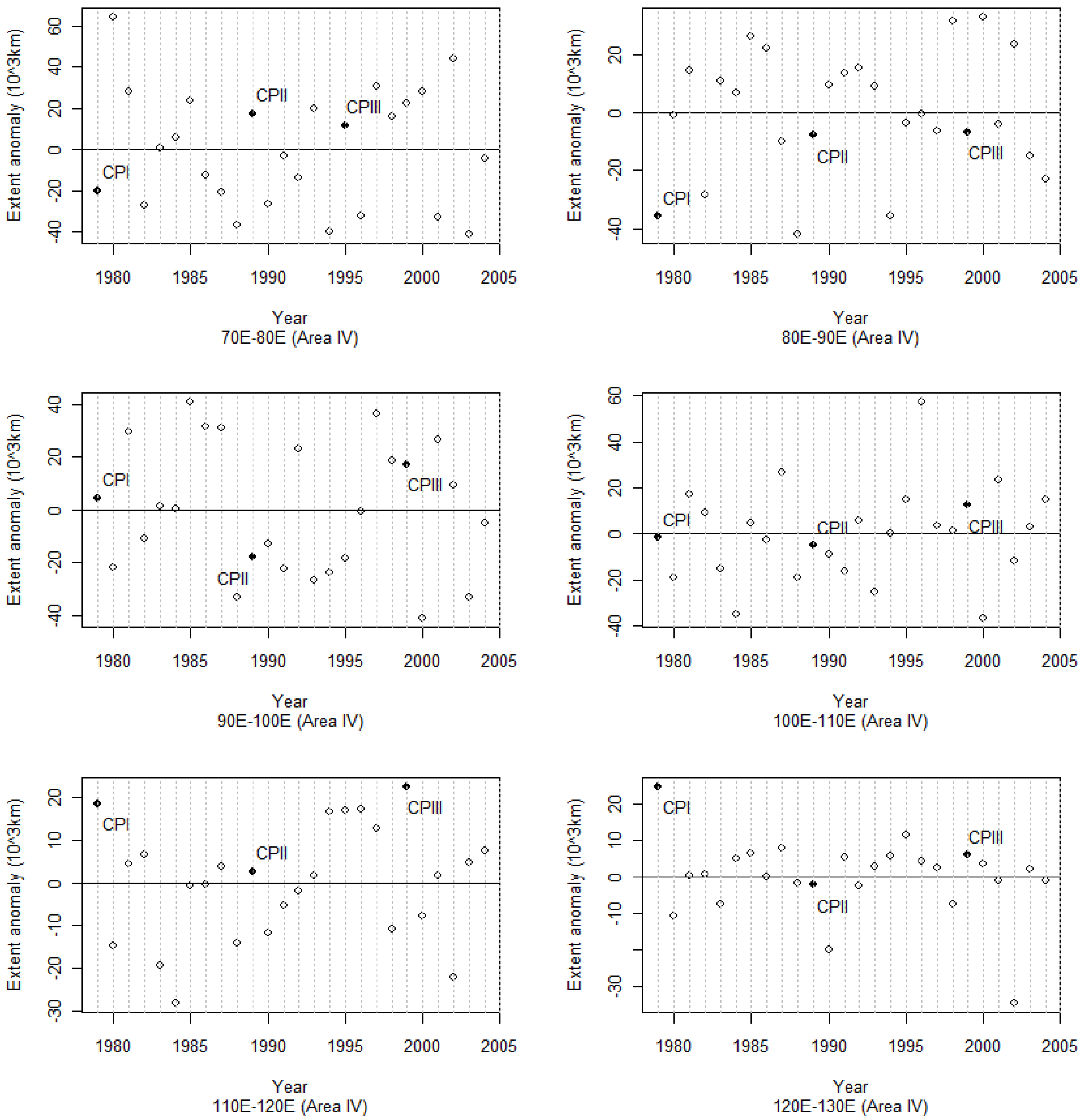


Fig. E-7. Anomaly of *sea-ice-extent* (*sea-ice-field*) in January from 1978 to 2004 in each 10º longitudinal sector in Area IV.

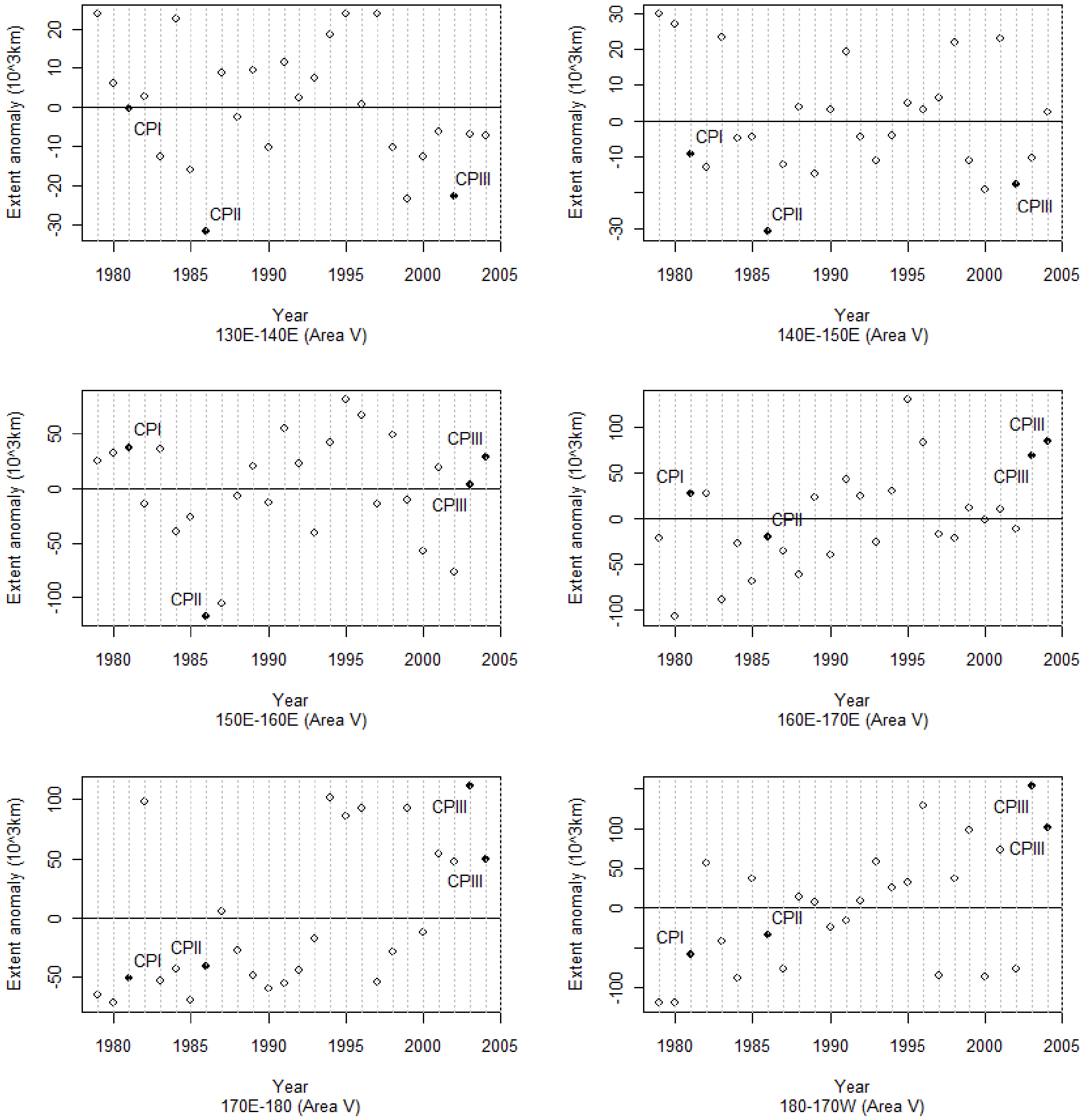


Fig. E-8. Anomaly of *sea-ice-extent* (*sea-ice-field*) in January from 1978 to 2004 in each 10º longitudinal sector in Area V.

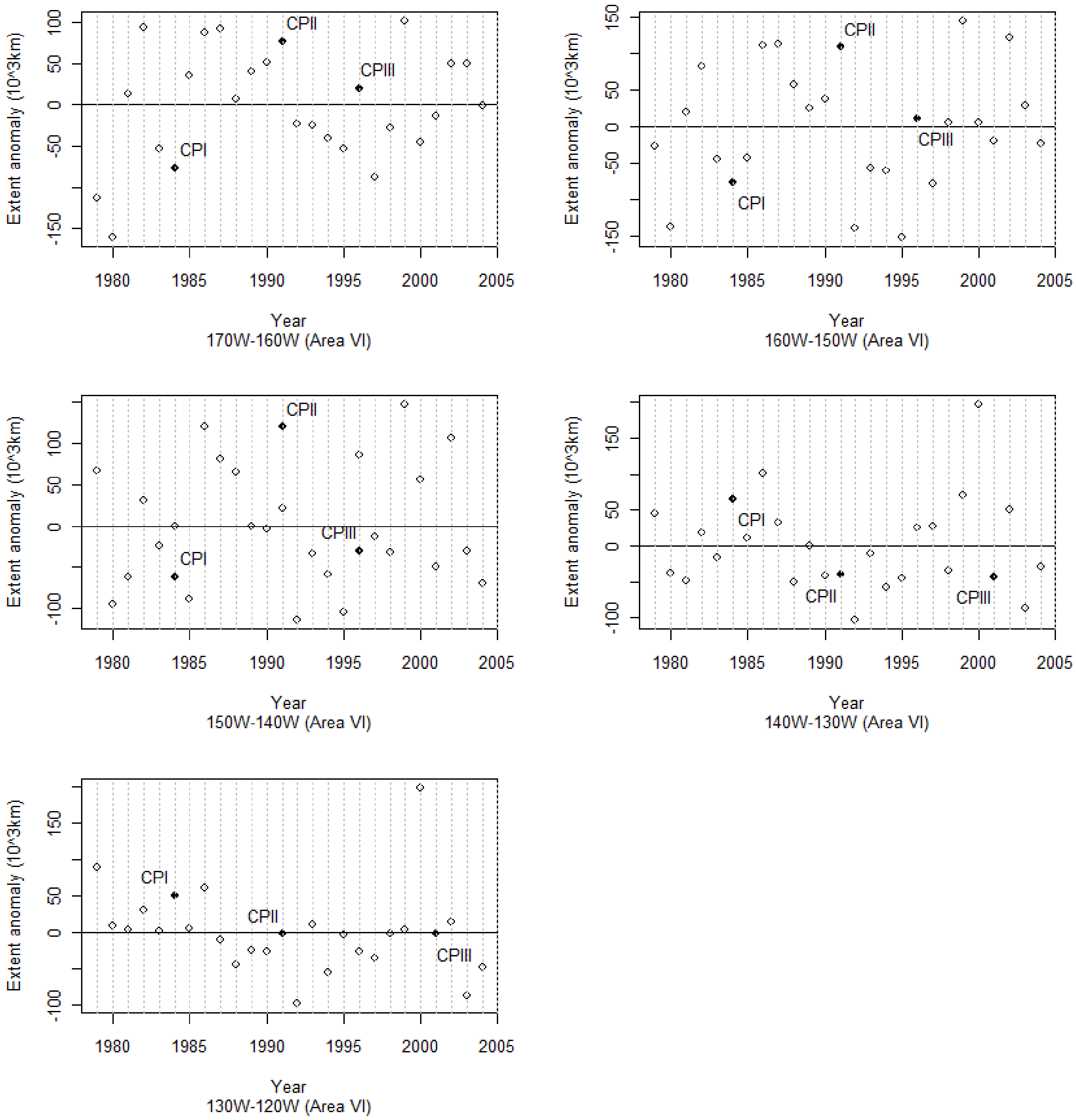


Fig. E-9. Anomaly of *sea-ice-extent* (*sea-ice-field*) in January from 1978 to 2004 in each 10º longitudinal sector in Area VI.

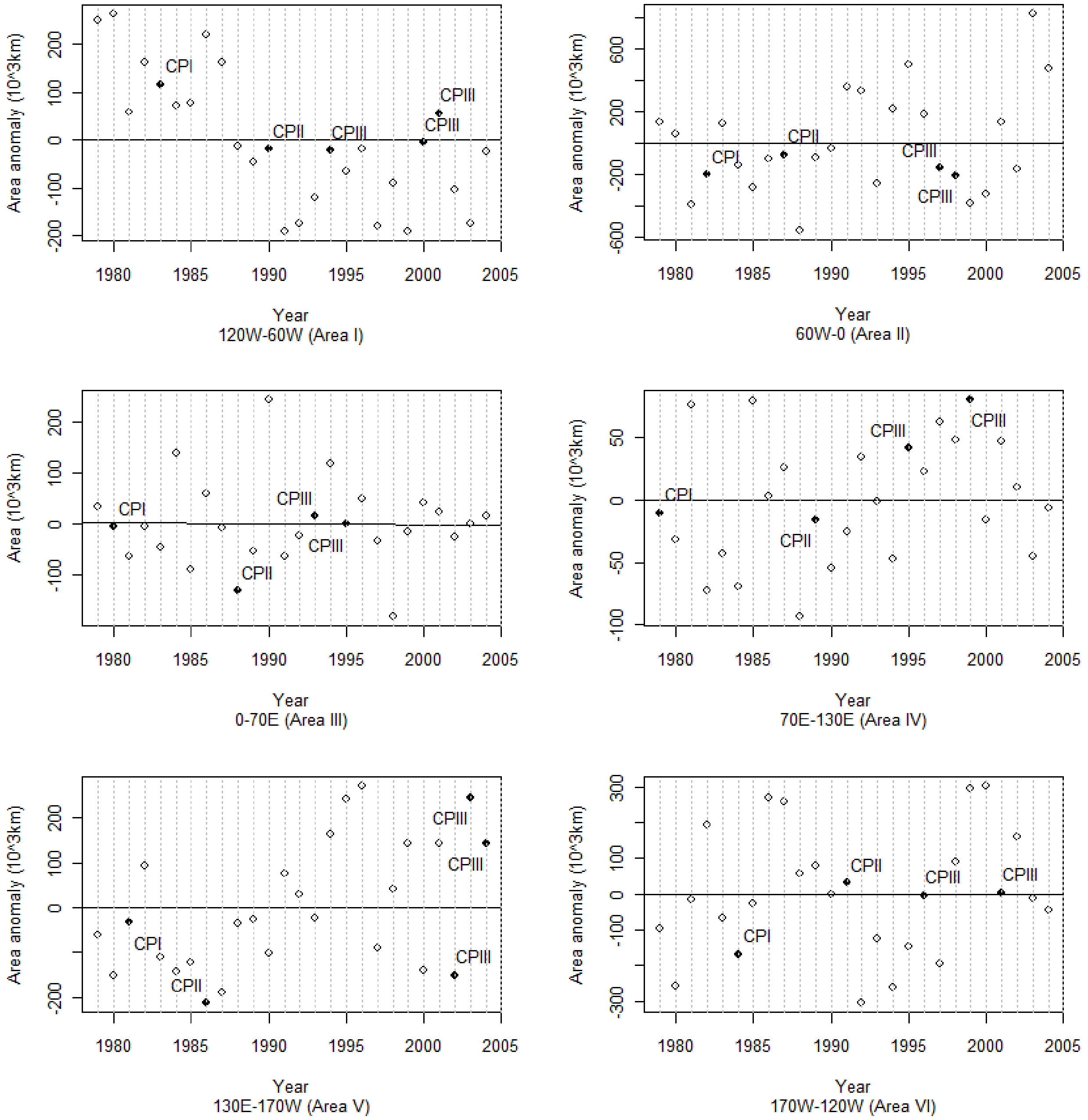


Fig. A-1. Anomaly of *sea-ice-area-in-the-sea-ice-field* in January from 1978 to 2004 in each IWC management area (I-VI).

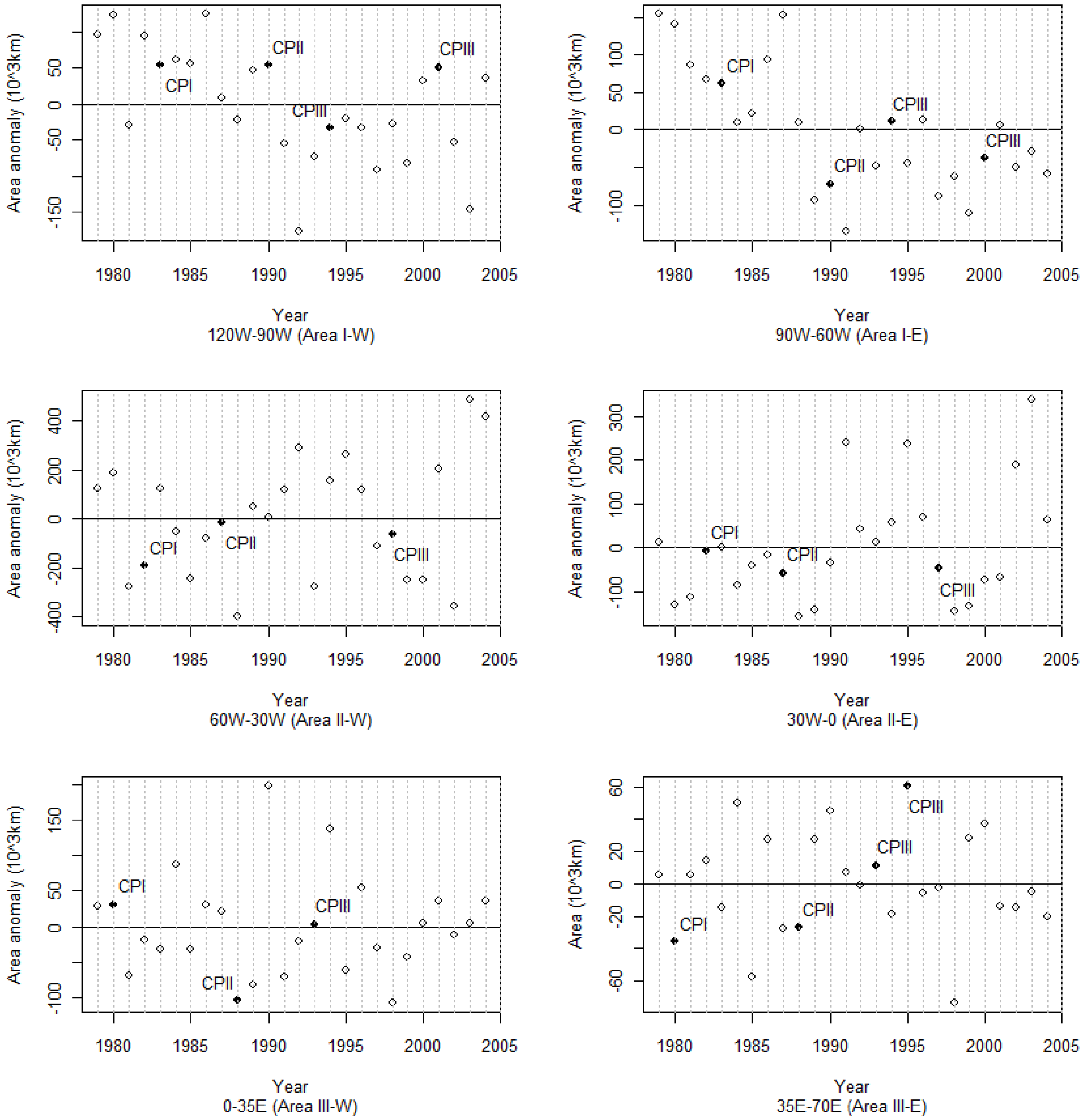


Fig. A-2. Anomaly of *sea-ice-area-in-the-sea-ice-field* in January from 1978 to 2004 in each IWC management area (I-III). Each area is divided into two: West (W) and East (E).

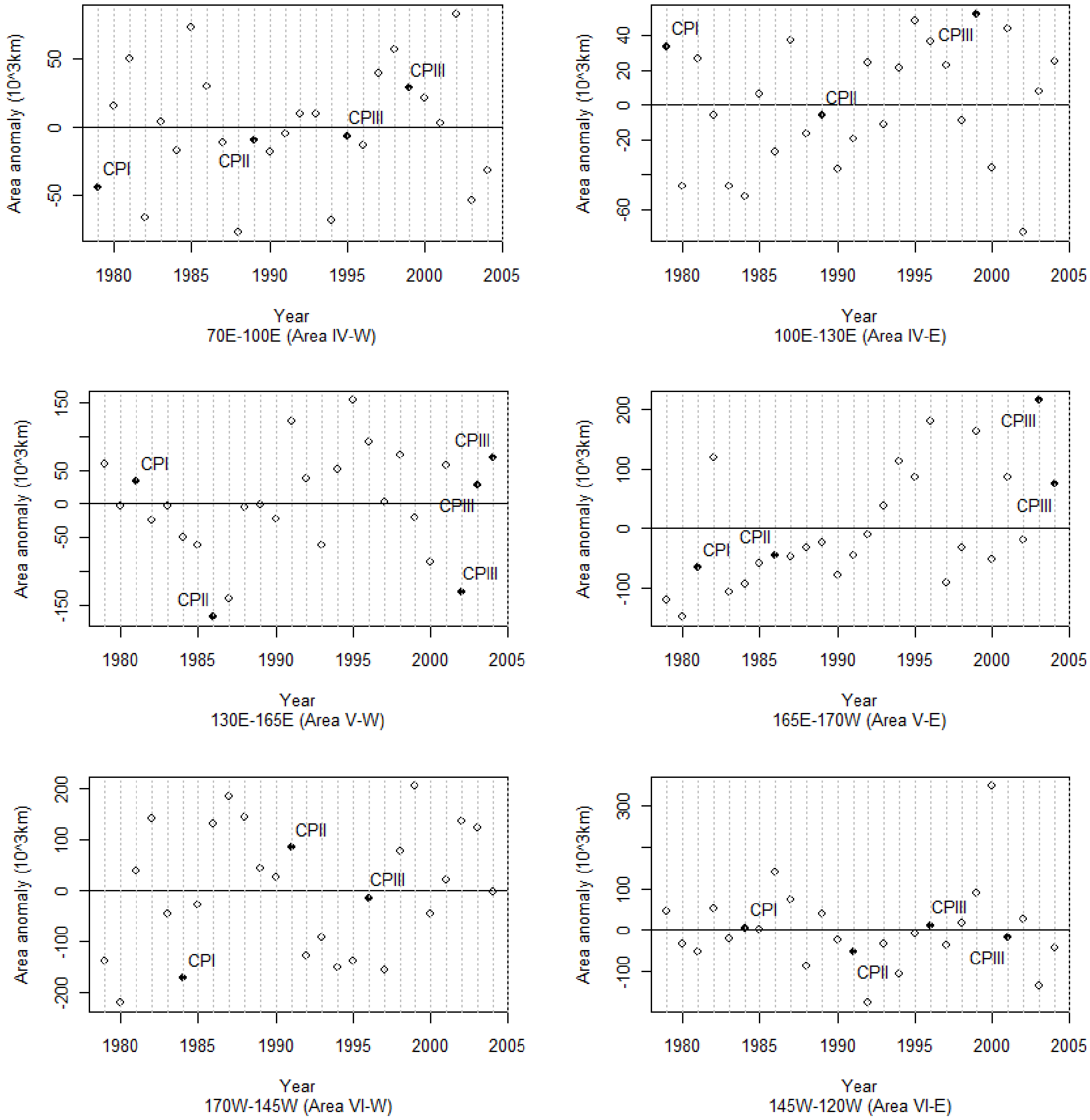


Fig. A-3. Anomaly of *sea-ice-area-in-the-sea-ice-field* in January from 1978 to 2004 in each IWC management area (IV-VI). Each area is divided into two: West (W) and East (E).

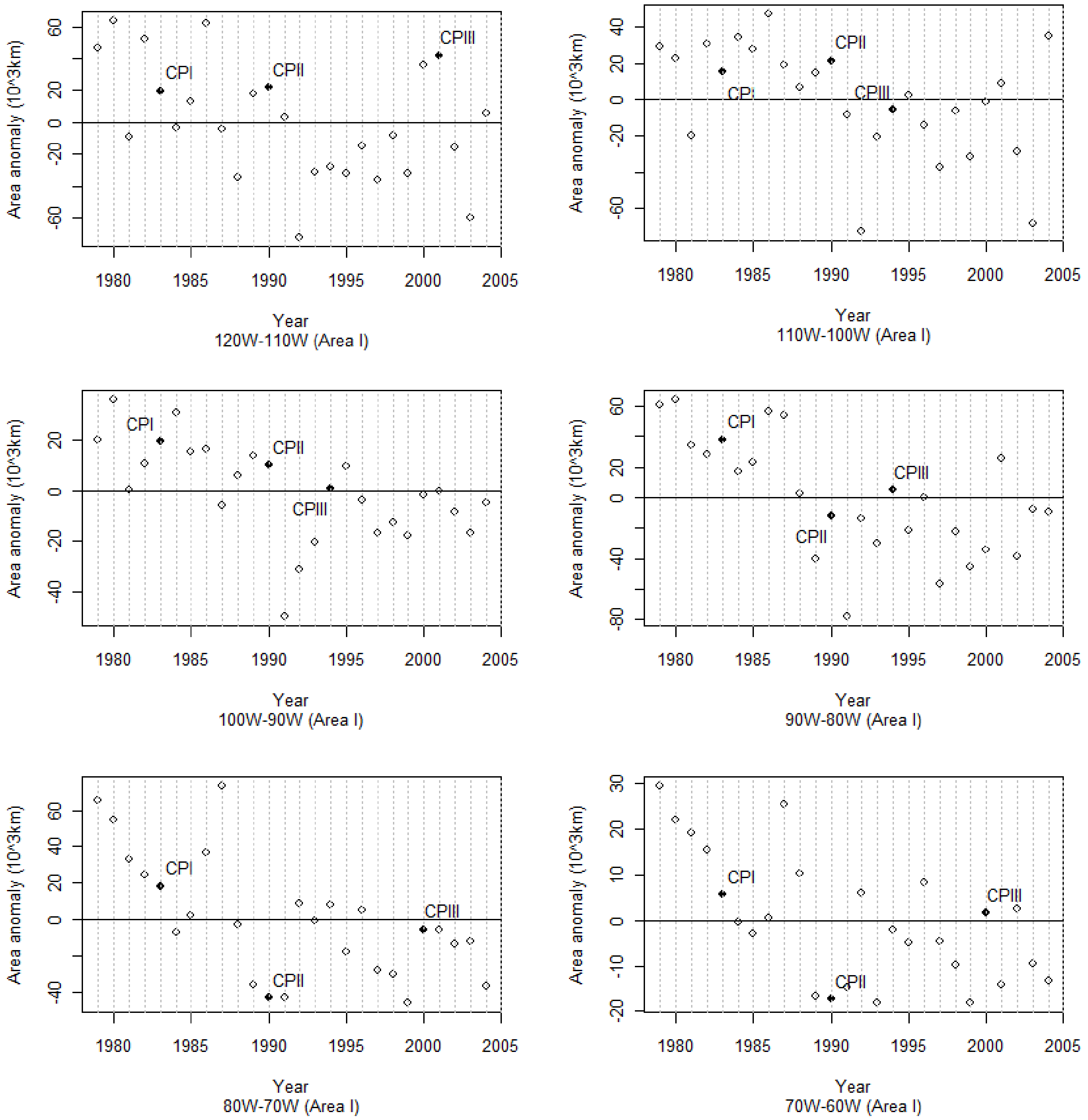


Fig. A-4. Anomaly of *sea-ice-area-in-the-sea-ice-field* in January from 1978 to 2004 in ach 10º longitudinal sector in Area I.

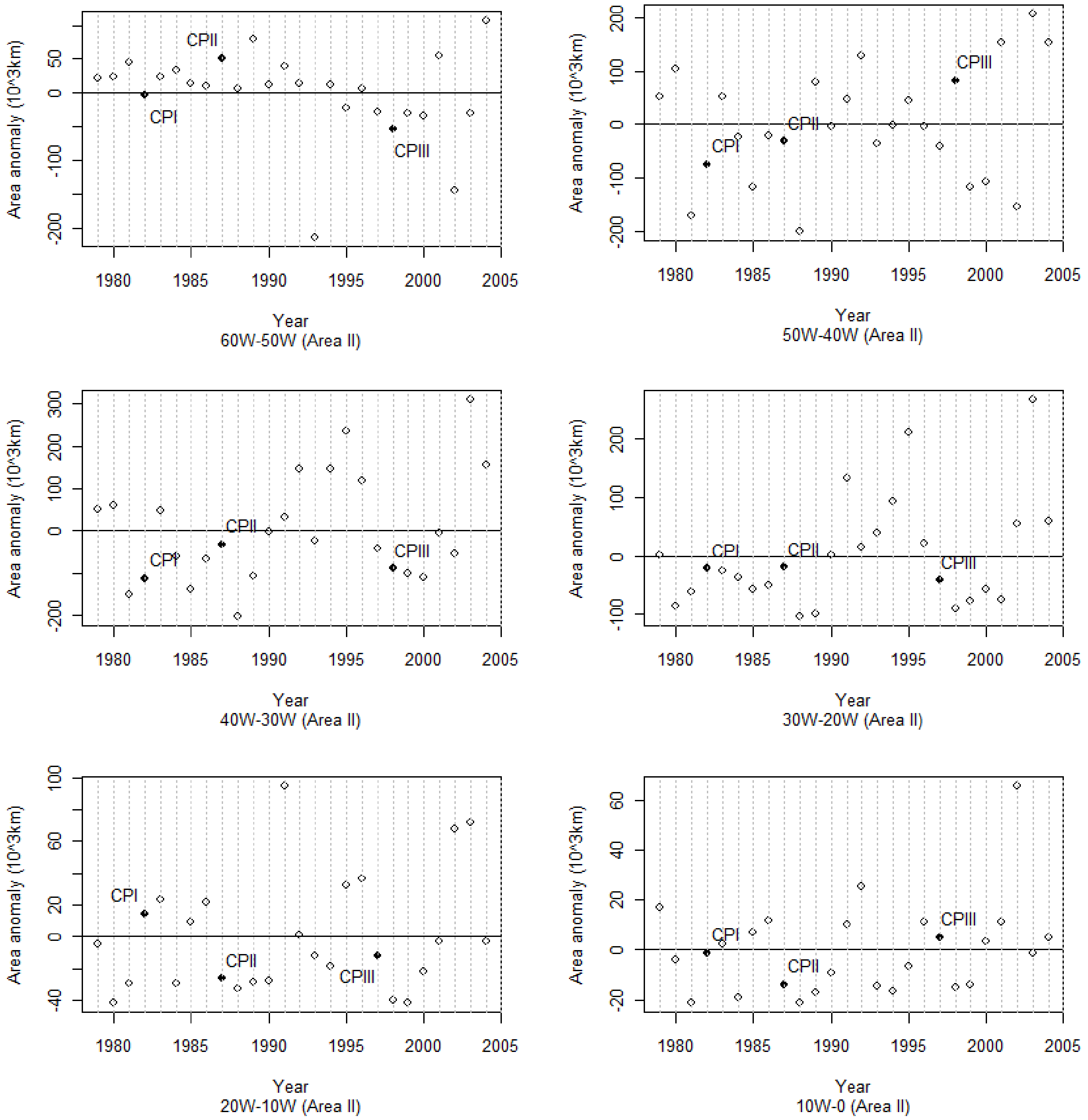


Fig. A-5. Anomaly of *sea-ice-area-in-the-sea-ice-field* in January from 1978 to 2004 in each 10º longitudinal sector in Area II.

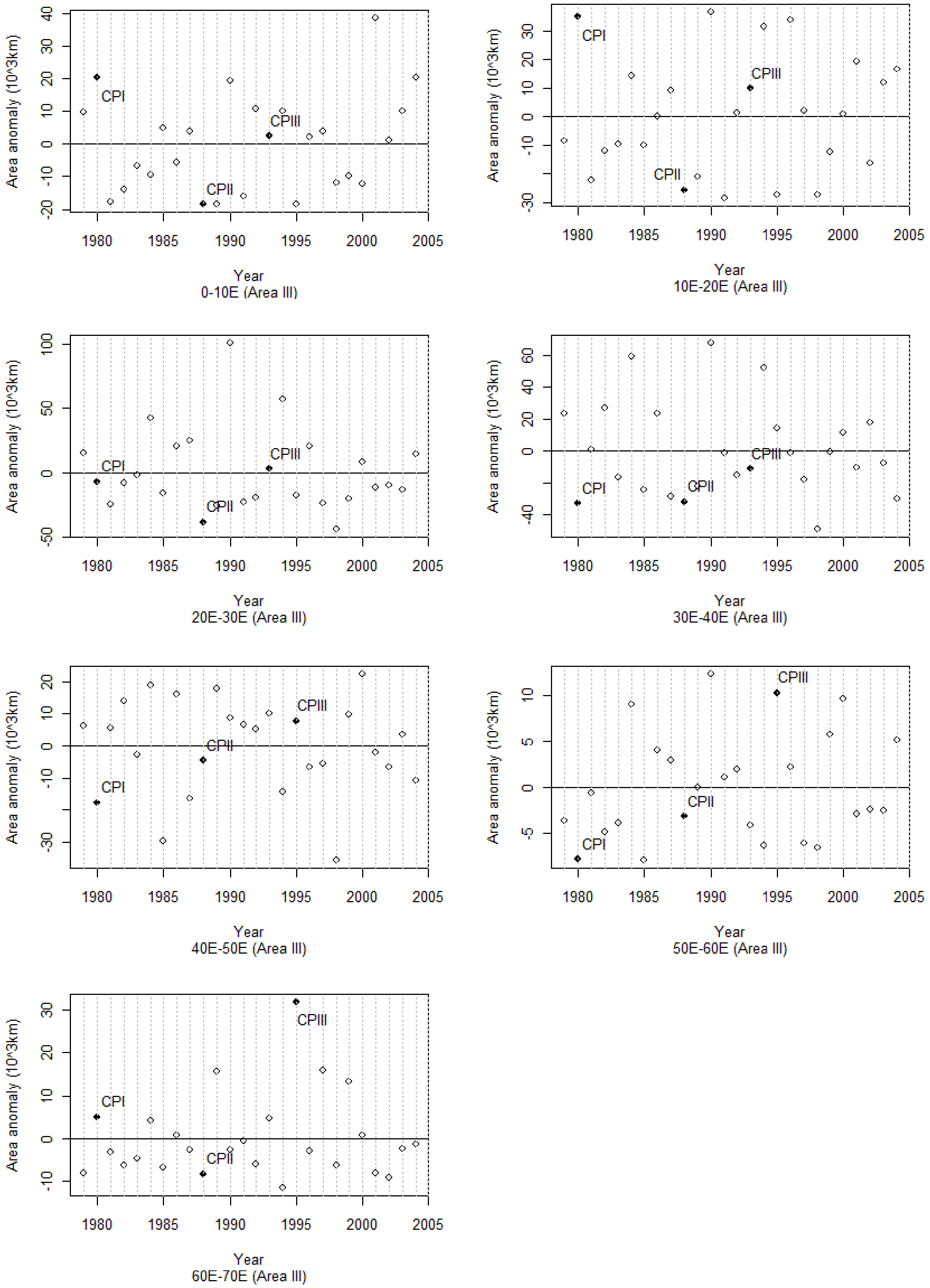


Fig. A-6. Anomaly of *sea-ice-area-in-the-sea-ice-field* in January from 1978 to 2004 in each 10º longitudinal sector in Area III.

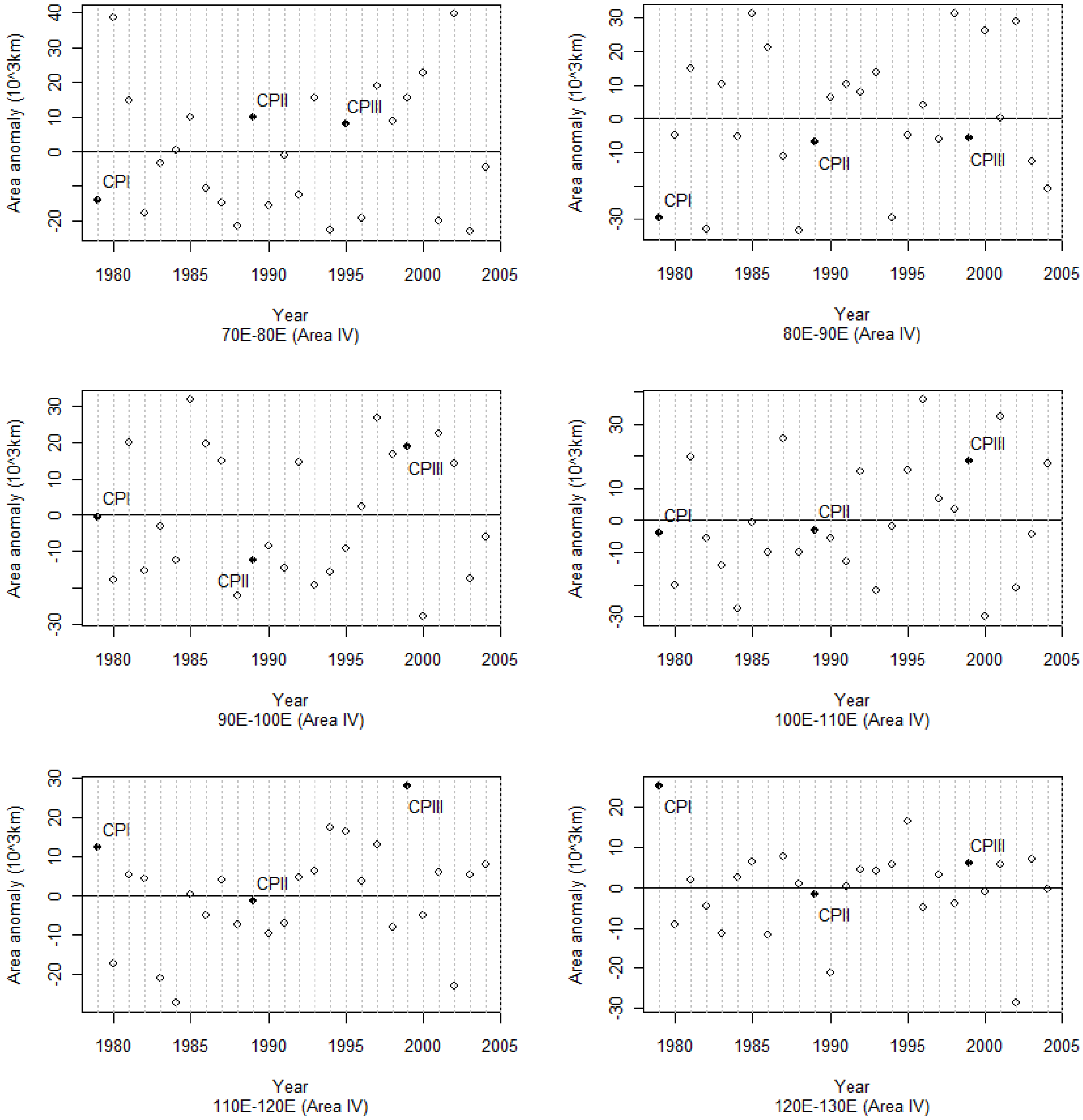


Fig. A-7. Anomaly of *sea-ice-area-in-the-sea-ice-field* in January from 1978 to 2004 in each 10º longitudinal sector in Area IV.

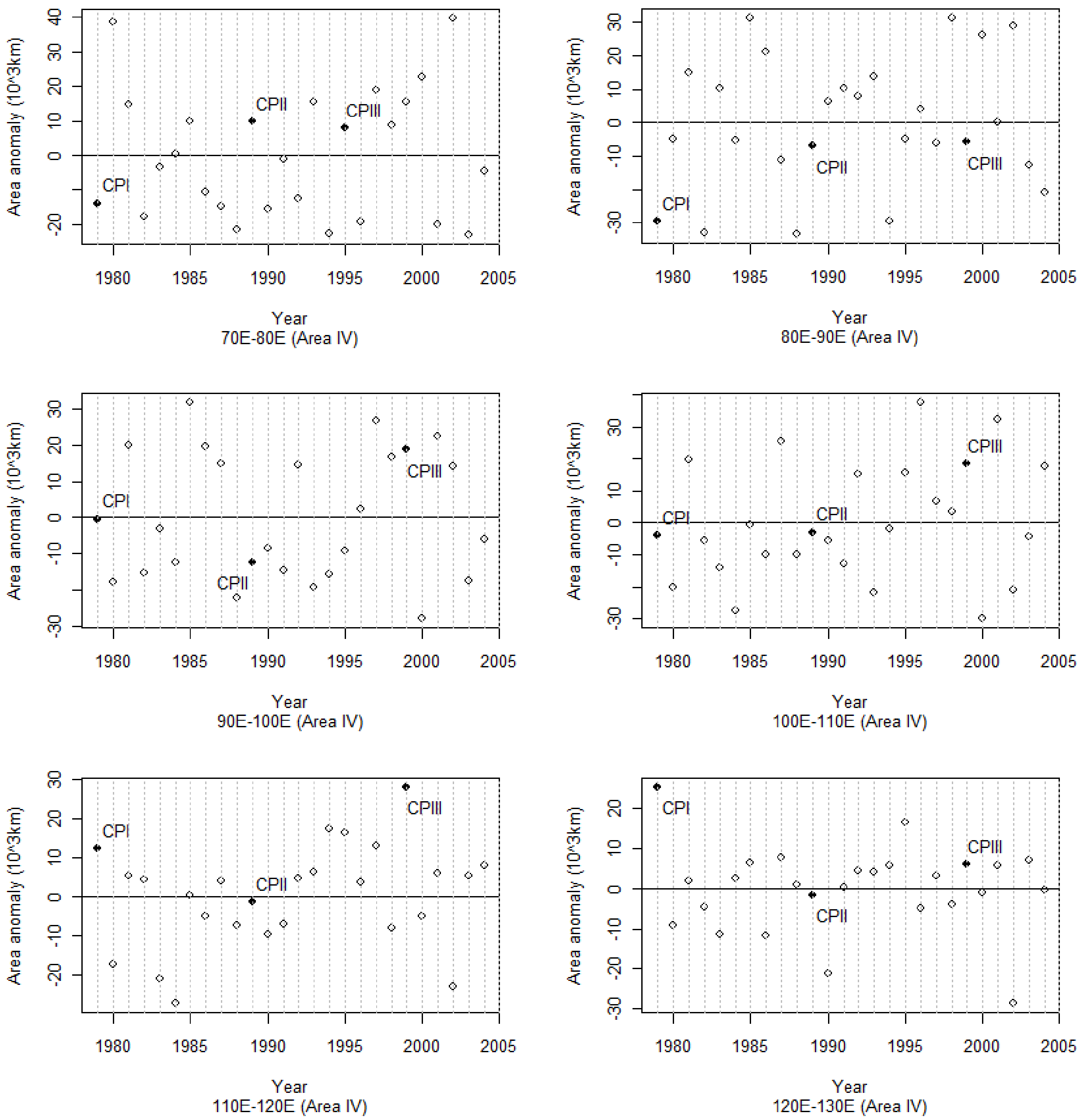


Fig. A-8. Anomaly of *sea-ice-area-in-the-sea-ice-field* in January from 1978 to 2004 in each 10º longitudinal sector in Area V.

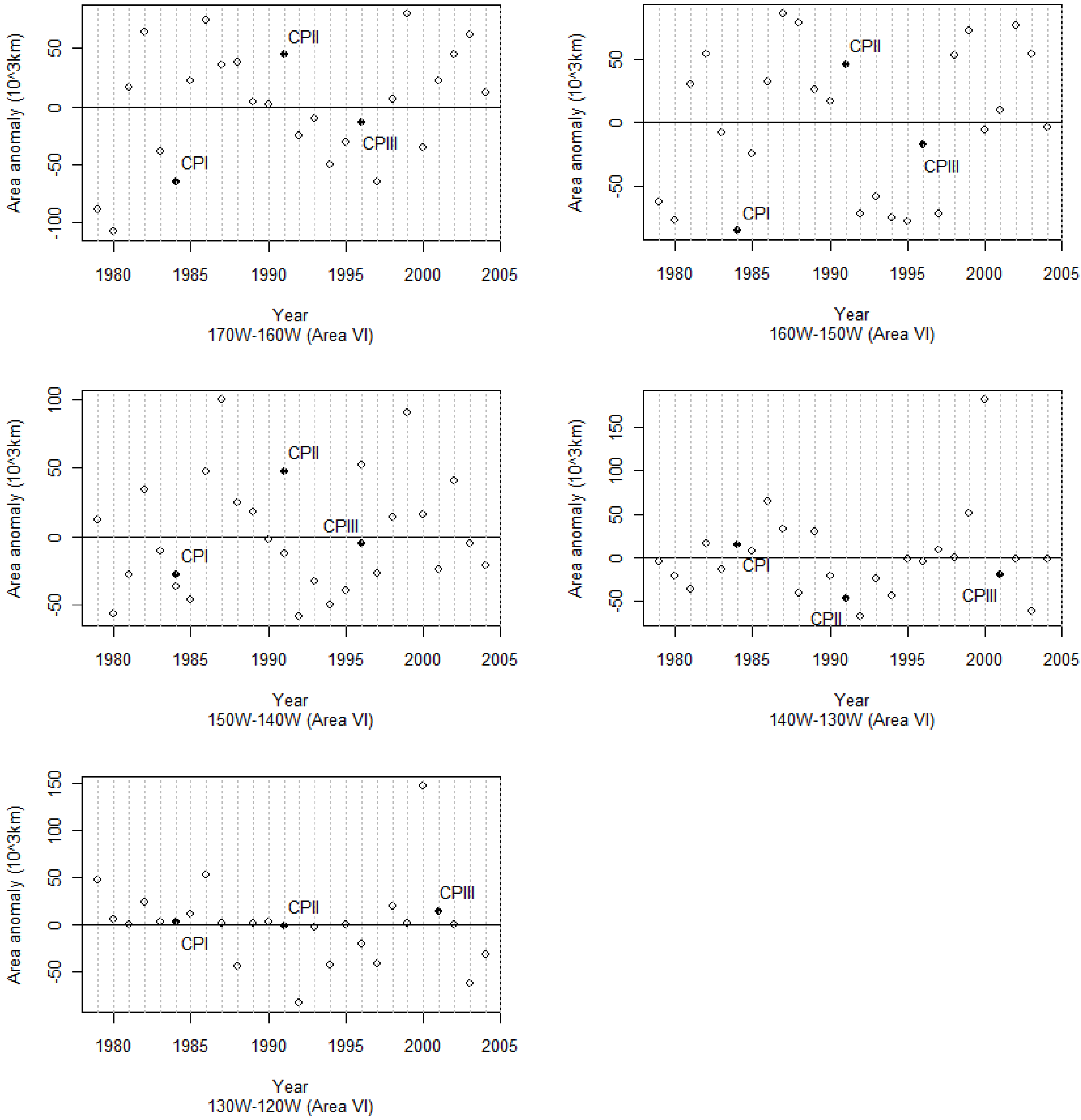


Fig. A-9. Anomaly of *sea-ice-area-in-the-sea-ice-field* in January from 1978 to 2004 in each 10º longitudinal sector in Area VI.

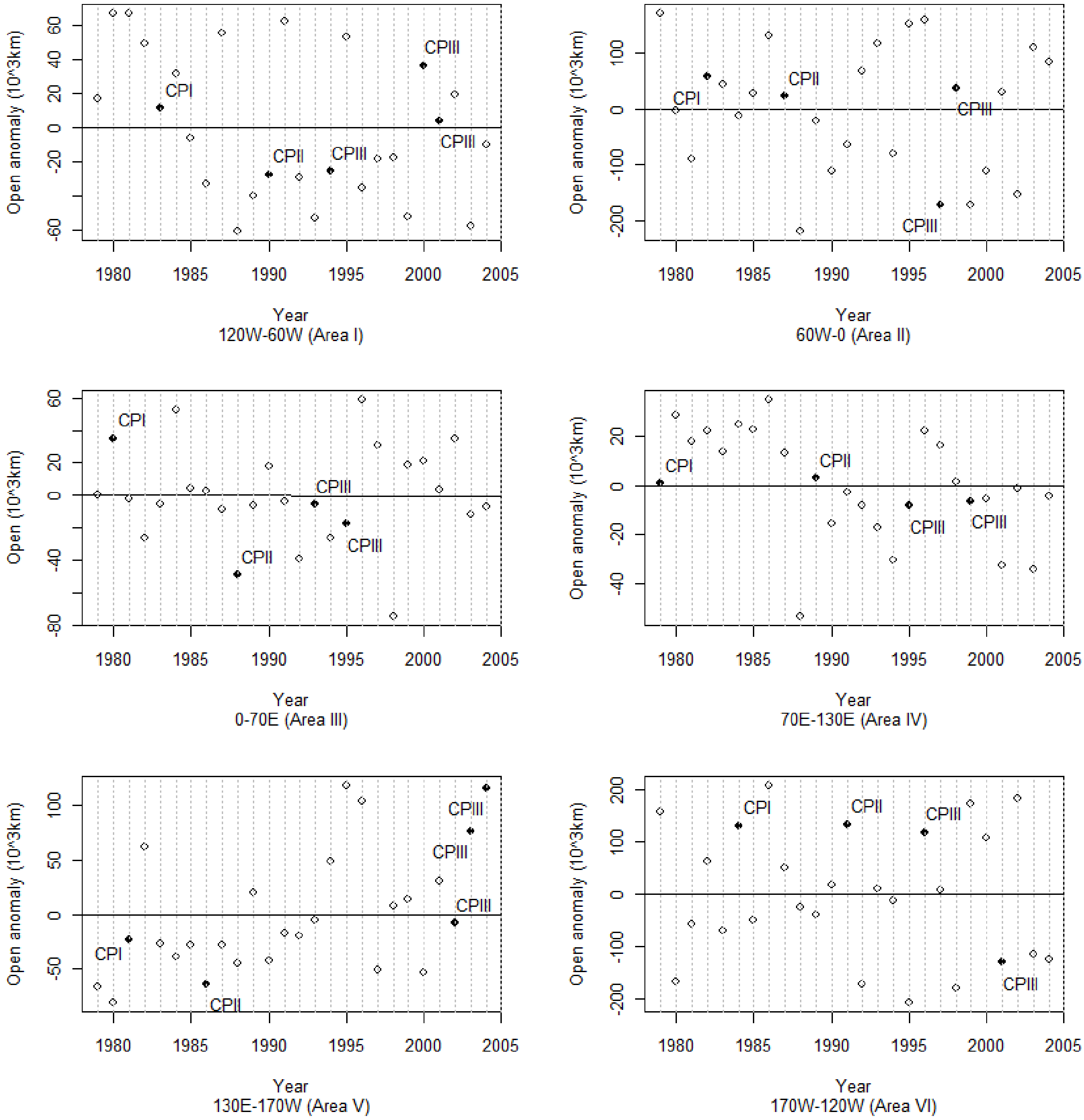


Fig. O-1. Anomaly of *open-sea-area-in-the-sea-ice-field* in January from 1978 to 2004 in each 10º longitudinal sector in each IWC management area (I-VI).

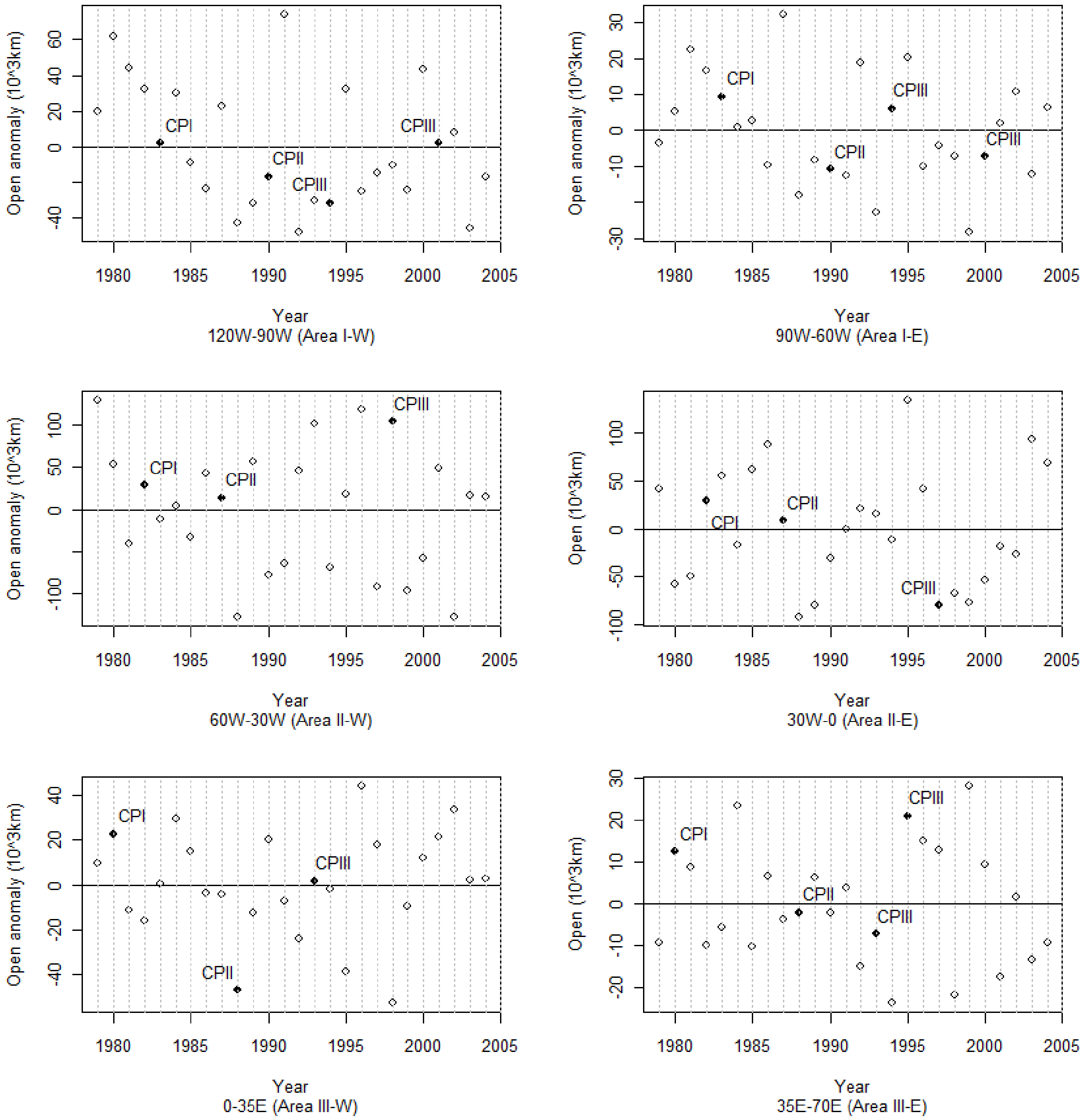


Fig. O-2. Anomaly of *open-sea-area-in-the-sea-ice-field* in January from 1978 to 2004 in each IWC management area (I-III). Each area is divided into two: West (W) and East (E).

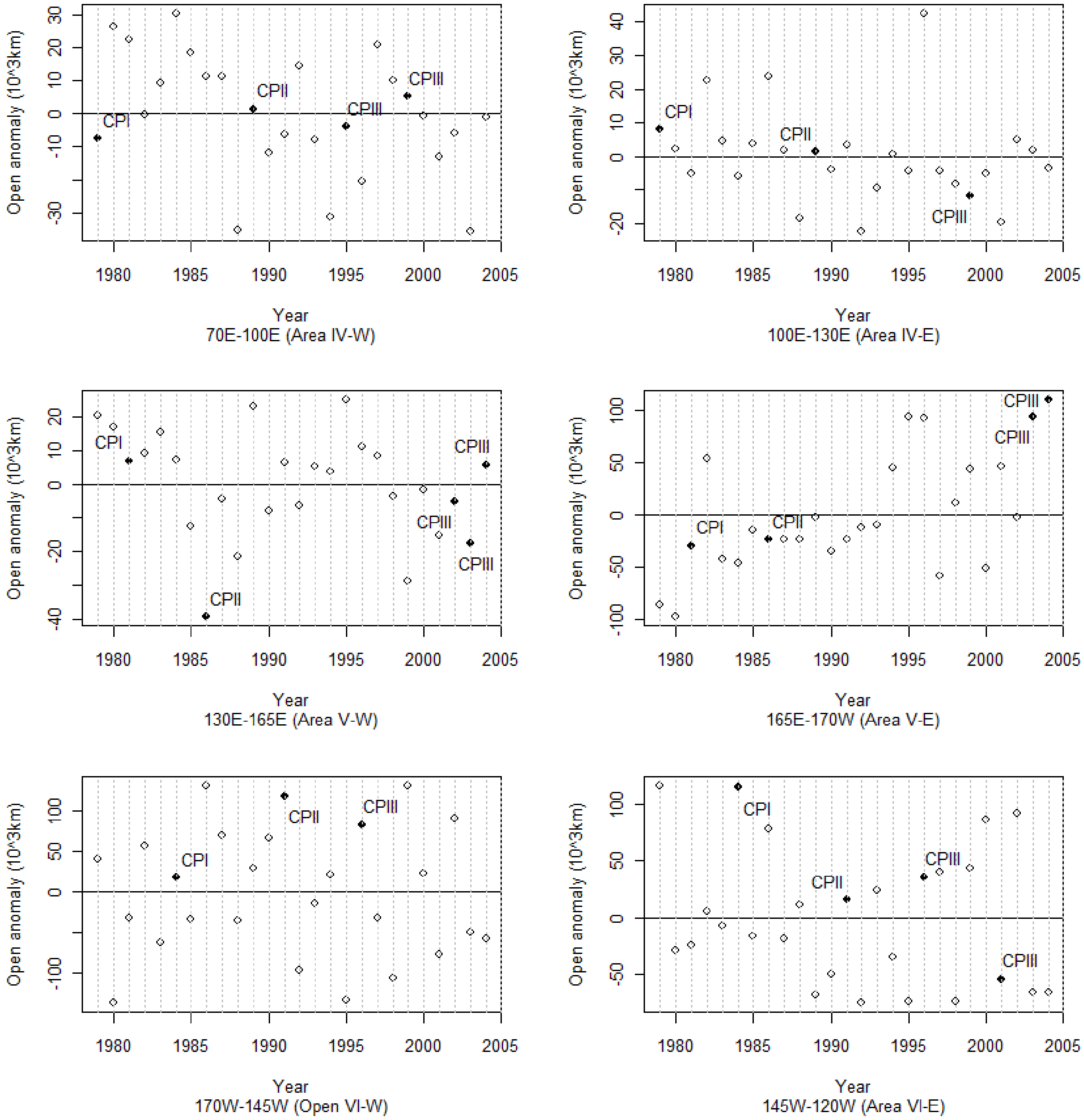


Fig. O-3. Anomaly of *open-sea-area-in-the-sea-ice-field* in January from 1978 to 2004 in each IWC management area (IV-VI). Each area is divided into two: West (W) and East (E).

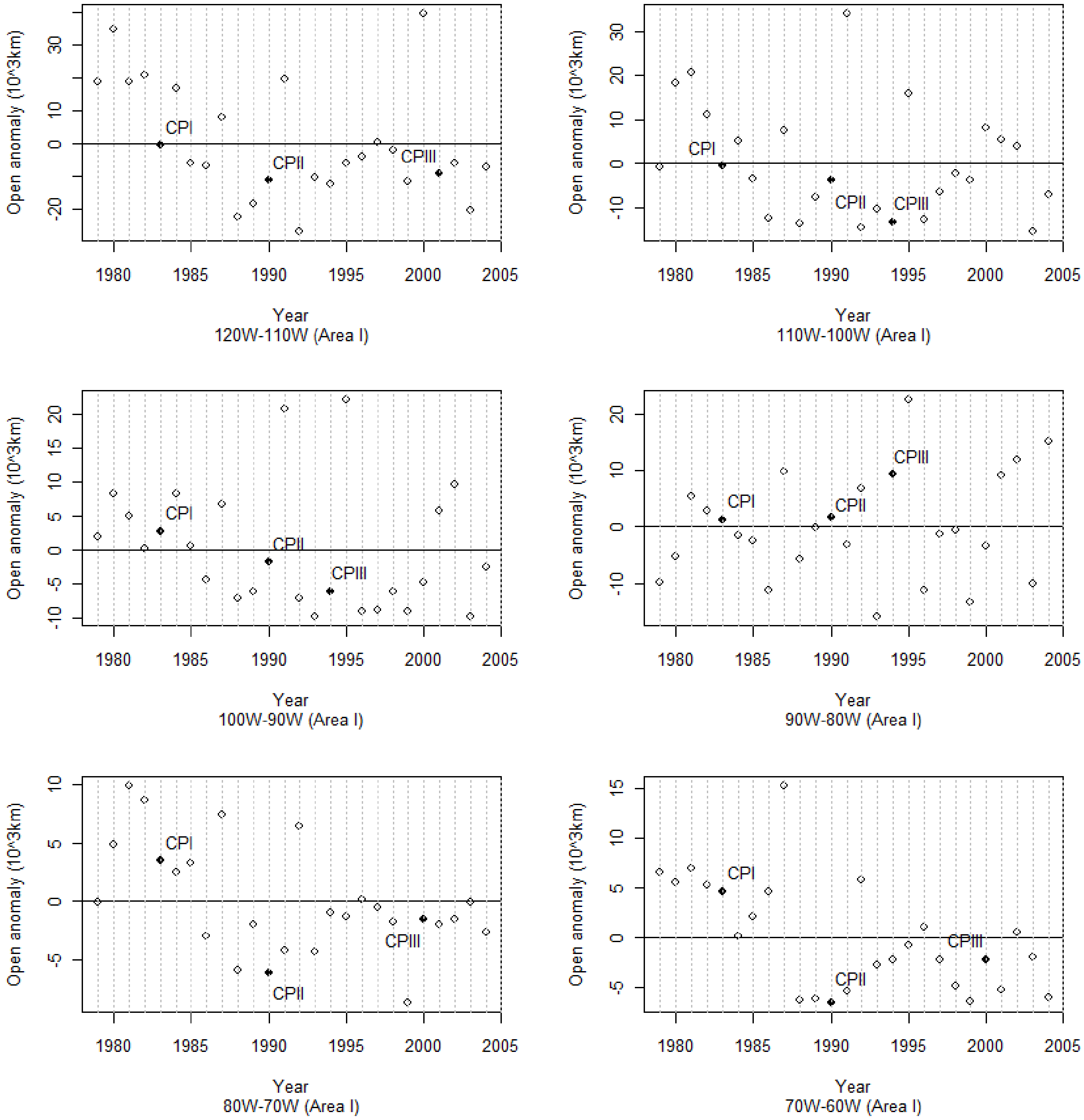


Fig. O-4. Anomaly of *open-sea-area-in-the-sea-ice-field* in January from 1978 to 2004 in each 10º longitudinal sector in Area I.

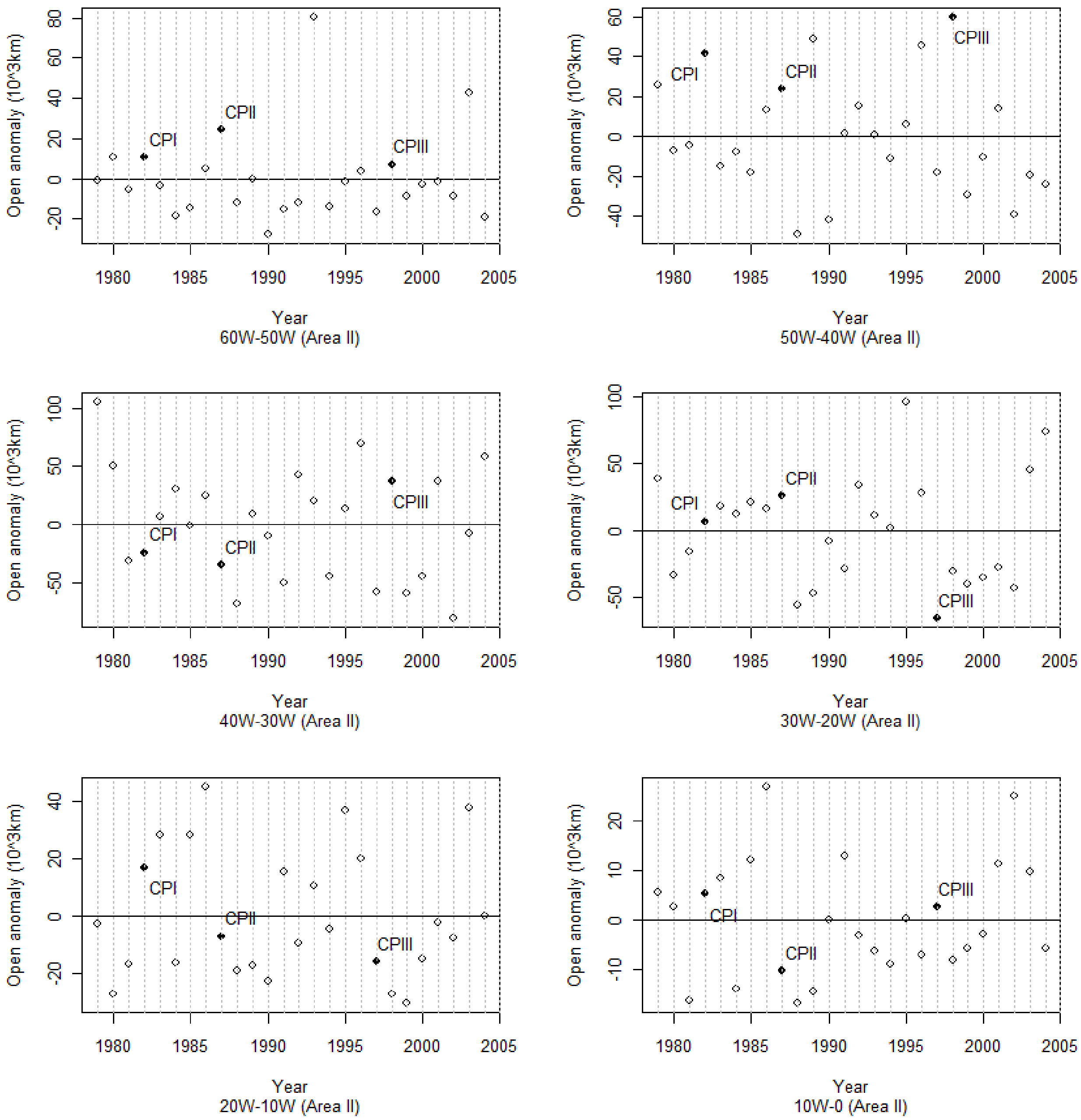
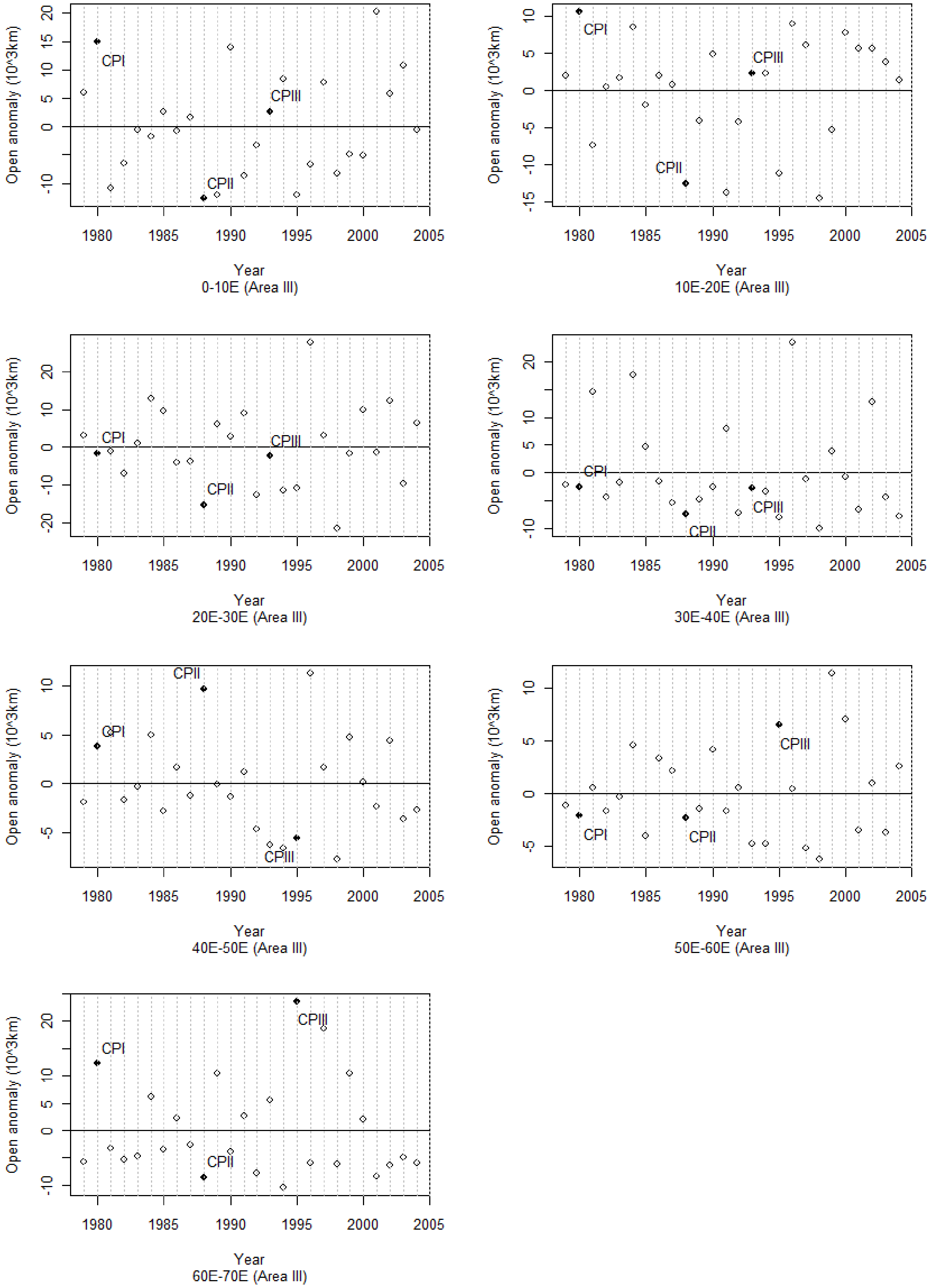


Fig. O-5. Anomaly of *open-sea-area-in-the-sea-ice-field* in January from 1978 to 2004 in each 10º longitudinal sector in Area II.



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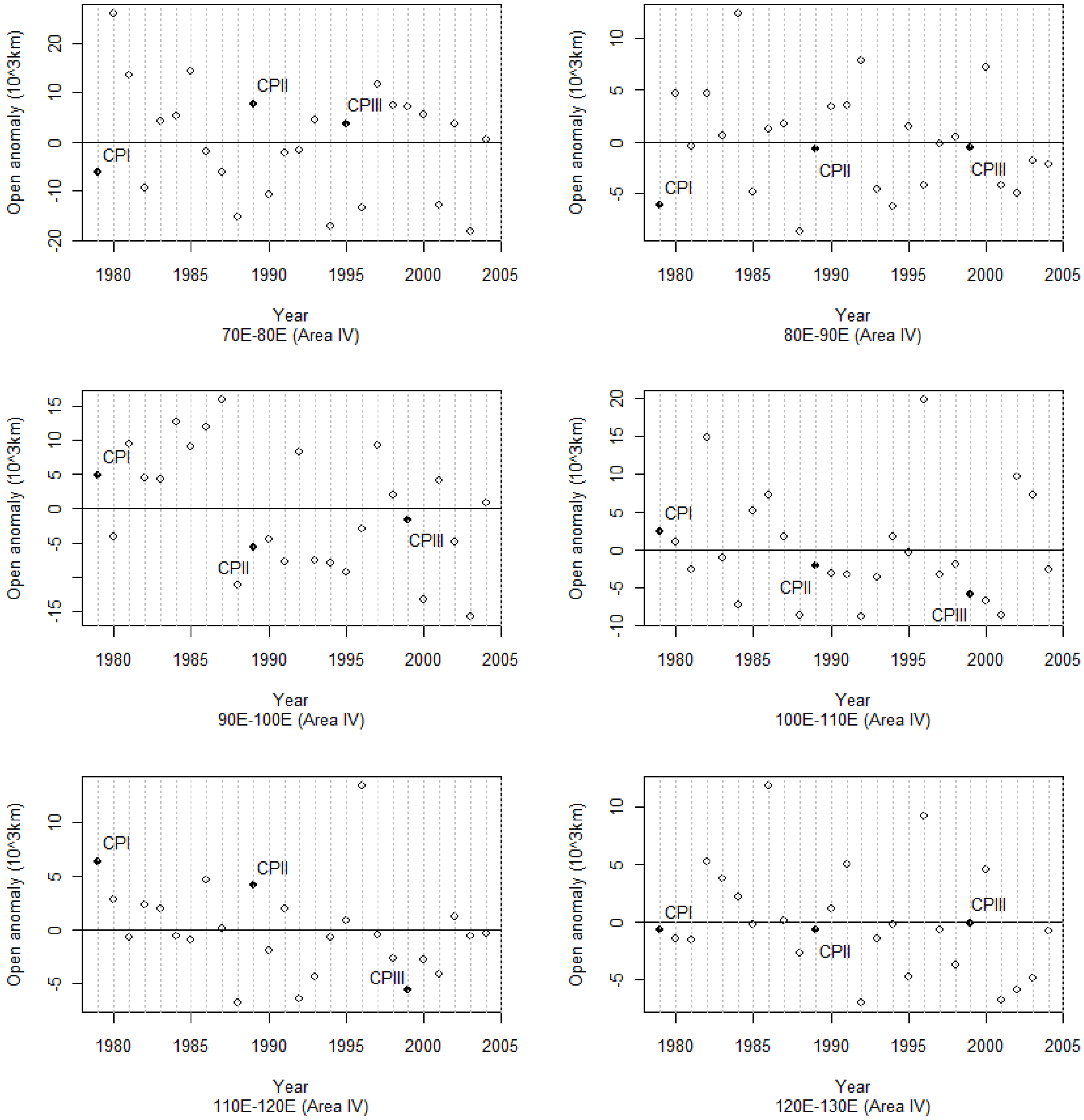

Fig. O-7. Anomaly of *open-sea-area-in-the-sea-ice-field* in January from 1978 to 2004 in each 10º longitudinal sector in Area IV.

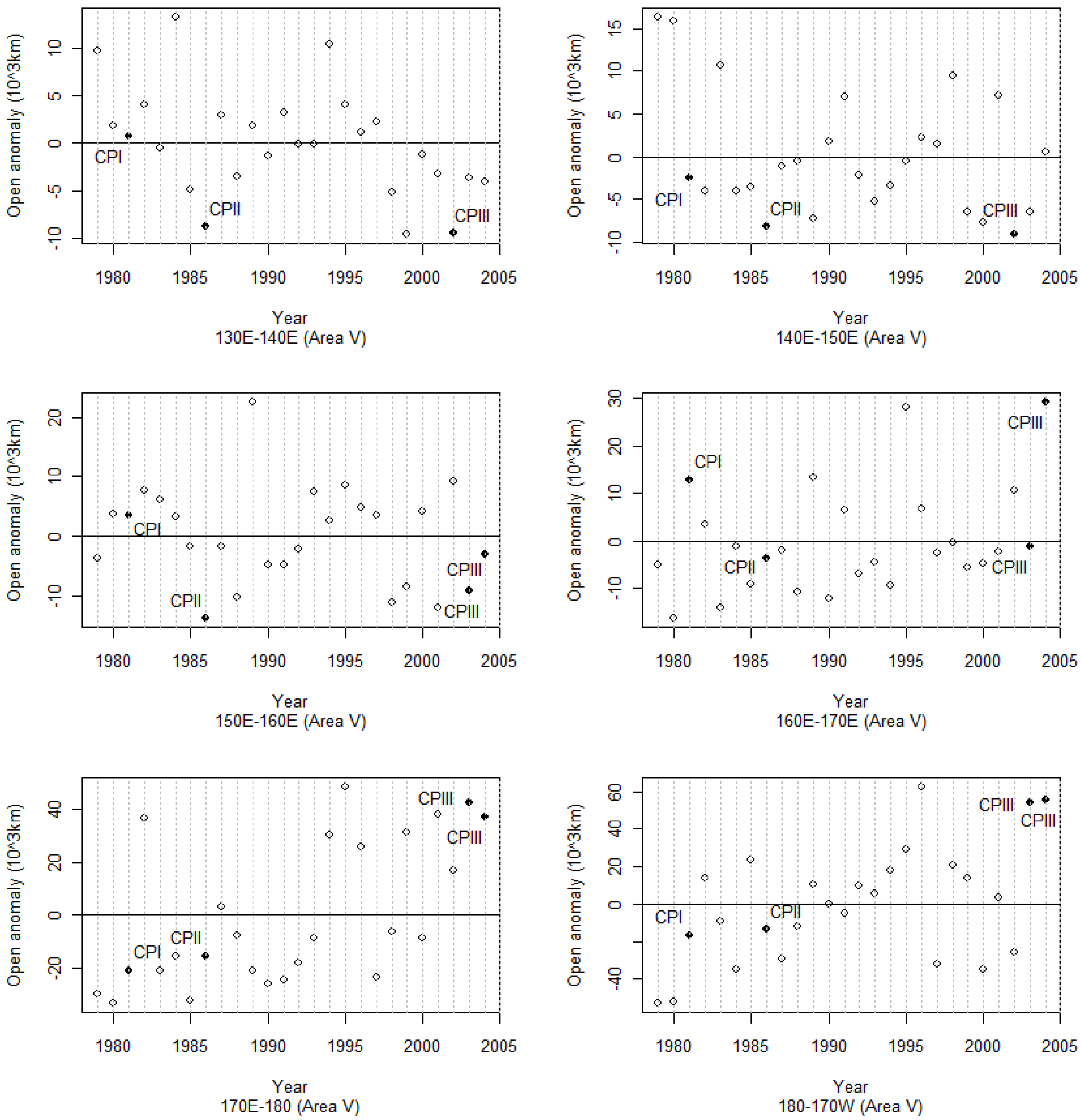

Fig. O-8. Anomaly of *open-sea-area-in-the-sea-ice-field* in January from 1978 to 2004 in each 10º longitudinal sector in Area V.

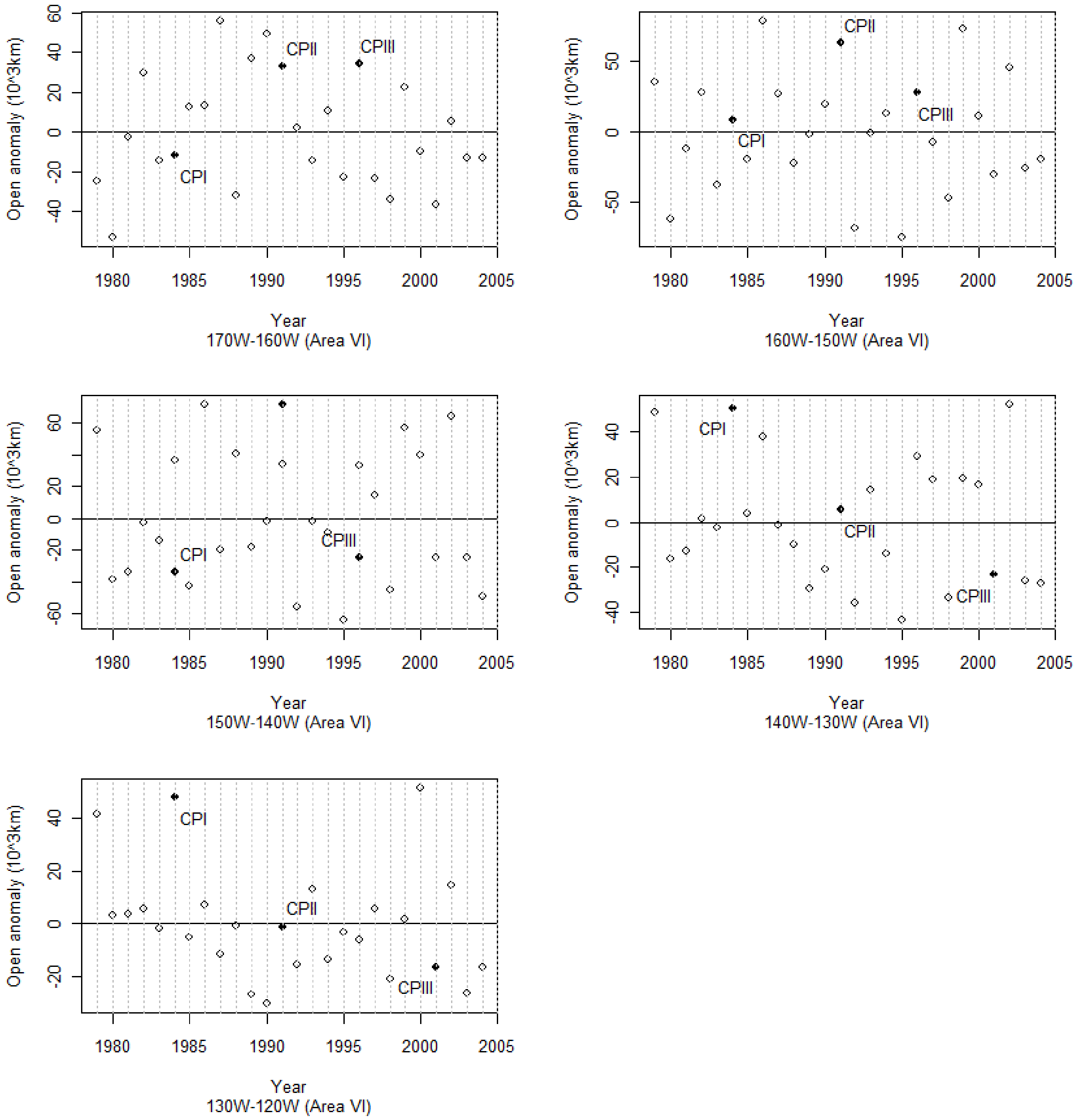

Fig. O-9. Anomaly of *open-sea-area-in-the-sea-ice-field* in January from 1978 to 2004 in each 10º longitudinal sector in Area VI.