

An aerial photograph of a vast, textured sea ice field in shades of white, light blue, and dark blue. In the foreground, a curved, reddish-brown metal railing of a ship's deck is visible, suggesting the photo was taken from a vessel. The horizon is visible in the distance under a clear sky.

Antarctic Sea Ice variability in the Weddell, the Bellinghausen and the Amundsen Seas

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- **White and Peterson (1996)** Identify a coupled air-sea-ice pattern of interannual anomalies propagating eastward in a wave train with the circumpolar flow (wavenumber-2 pattern), with a periodicity of 4-5 years and taking 8-10 years to encircle the pole (propagation speed of $\sim 8 \text{ cm s}^{-1}$). Antarctic Circumpolar Wave.
- **Qiu et al. (1997)** used a coupled ocean-atmosphere model to show that a coupled instability of the system must be responsible for the generation of the ACW.
- **Christoph et al. (1998)** found a dominating zonal wave number 3 around the Antarctica in atmospheric and oceanic variables.
- **Cai et al. (1999)** also found a wave number of 3 and presented a possible mechanism for maintaining the modeled ACW through coupled air-sea interactions.
- **Baines et al. (2000)** and **Goodman et al. (1999)** using analytical models proposed the hypothesis that the ACW may be maintained by coupling between the extratropical ocean and the atmosphere and it can be considered as an unstable coupled air-sea mode.

- Cai et al. (2001) suggested the presence of both zonal wave numbers 2 and 3 in the ACW structure during the last two decades of the century.
- Venegas et al.(2001) suggested that sea ice variability in the Weddell Sea is dominated by quasi-quadrennial (3 to 4 year period) oscillations (QQ) that propagates eastward in the winter ice pack at a speed of $\sim 8 \text{ cm s}^{-1}$ coupled to atmospheric and oceanic fluctuations.
- Venegas et al. (2001) Found that this coupled mechanisms occur in other sectors of Antarctica (Ross, Amundsen, and Bellinghausen Seas)
- Yuan et al.(2001) found that the dominant interannual variance structure in the sea ice edge and surface air temperature fields are organized as a quasi-stationary wave which they call the “Antarctic Dipole” (ADP), characterized by a relationship between the ice and temperature anomalies in the central/eastern Pacific and Atlantic sectors of the Antarctic. It has the same wavelength as the ACW.

- **Simmonds et al.(1995) observed a strong relationship between ice extent in the southeast Indian Ocean in winter and the Southern Oscillation Index in the previous 12 months.**
- **Gloersen, P. (1995) said that sea ice fluctuations in Antarctica contain periodicities that are associated with ENSO events.**
- **Ledley et al.(1997) obtained significant correlations between the Ross sea ice concentrations and the ENSO cycles, with reduced sea ice concentrations in the Ross Sea during El Niño years.**
 - **Peterson et al (1998) suggested that the ACW has a major source in the western subtropical South Pacific Ocean due to the fact that ENSO signal is transferred through the atmosphere into the ocean, and it propagates in the ocean from the subtropics to the high latitudes.**
 - **Yuan et al. (2000) found that the sea ice edge anomalies in the Amundsen, Bellinghausen and Weddell Seas show the strongest polar links to extra polar climate.**

- **Kwork, R. and J. C. Comiso (2002) said that the Amudsen, Bellinghausen, and Weddell Sea sectors of the Antarctic polar ocean showed the strongest link to the Southern Oscillation and that in the ENSO warm episodes the ice cover of the Bellinghausen and Amudsen Seas experienced a significant retreat.**

- **Venegas (2003) suggested a possible mechanism behind the Antarctic Circumpolar Wave (ACW) interannual variability as a combination of two signals with different temporal and spatial characteristics, one of wave number 3 and a period of oscillation of 3.3 yr and a second with wave number 2 and a period of 5 yr which apparently is forced by the tropical ENSO phenomenon.**

• Most of the principal features of Antarctic sea ice that are presented in literature were performed in what is called S-mode with different tools (Empirical Orthogonal functions (EOF), Common Factor Analysis (CFA), Multi Taper Method-Singular Value Decomposition (MTM-SVD), Principal Component Analysis (PCA), among others) and their retained as a most the first two components of the climate behavior. Almost these are the most important features of sea-ice climate system; these are not the only ones.

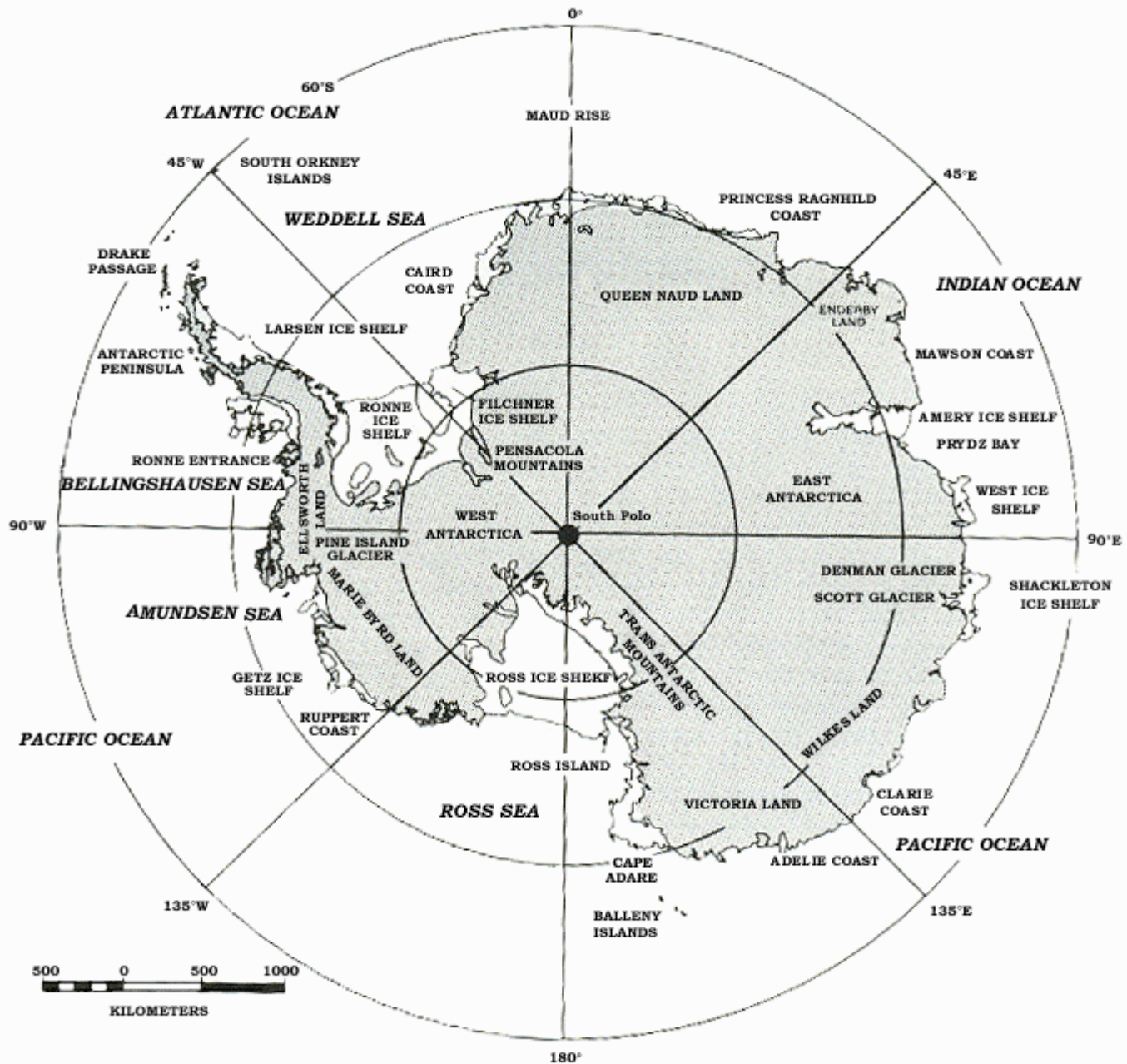
• The T-mode we will present here is a complement of S-mode analysis as it provides a form to really classify the ice field temporally. To investigate which are the main space patterns, when do they present and how they are coupled to different atmospheric variables is the principal goal of this presentation. For that reason we retained 6 Principal Component Scores that represent the most important features that characterized the 264 month of the record we used.

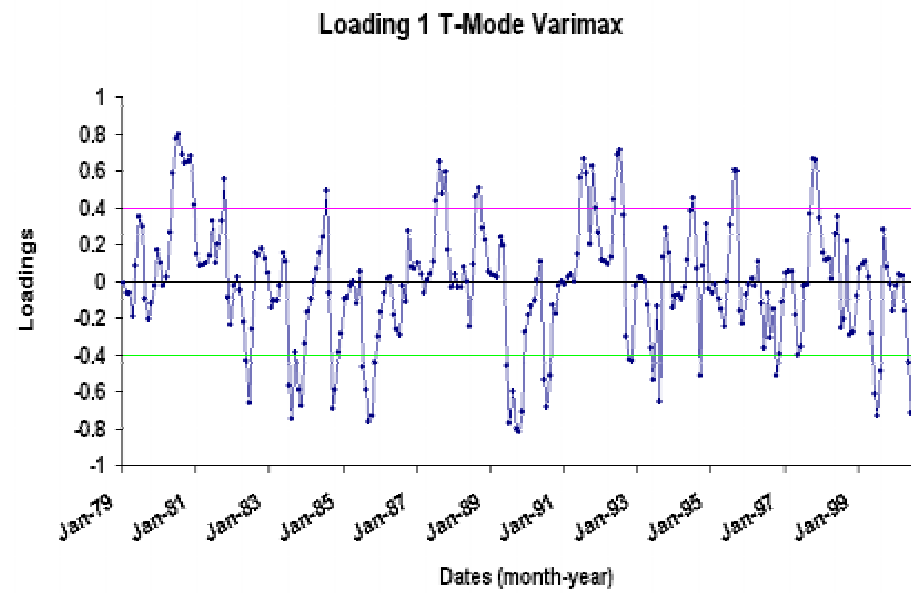
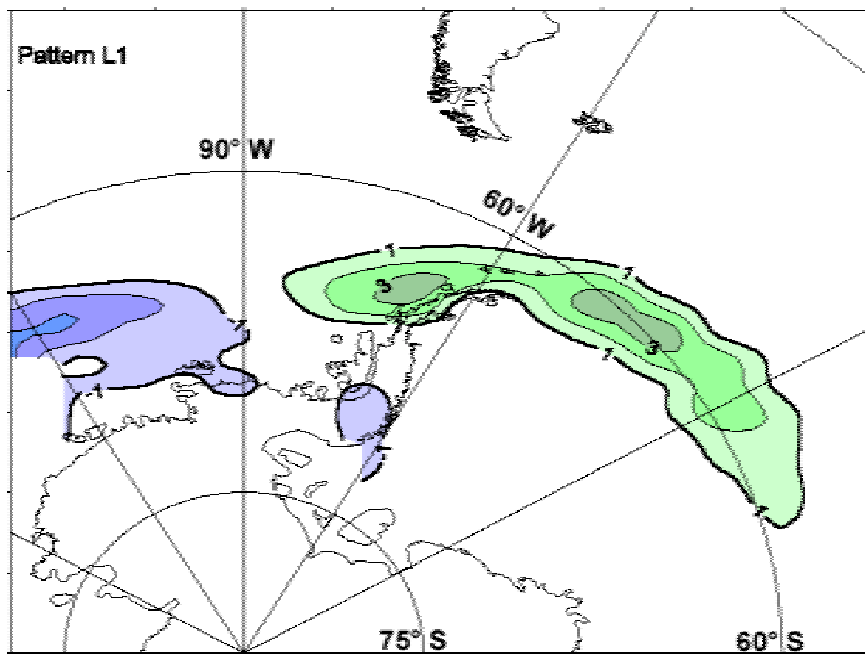
- **In T-mode, the statistical variables are the snapshots, or spatial fields at a given time of the physical variable under study. The domain is the time and the statistical observations are the different points in space included in the snapshot**
- **For that reason, the main spatial patterns of the sea-ice anomaly field are obtained. The associated time series (called PC loading time series) shows when the particular pattern is present and how significant its contribution is to the real field at a particular time.**
- **Concluding, the application of this mode permits the isolation of subsets of fields that have similar spatial variability.**

- The data set we used consists of NASA Goddard Space Flight Center (GSFC) sea ice concentration, in polar stereographic projection, derived from the Scanning Multichannel Microwave Radiometer (SMMR) and Special Sensor Microwave/Imager (SSM/I) data using the NASA Team algorithm.

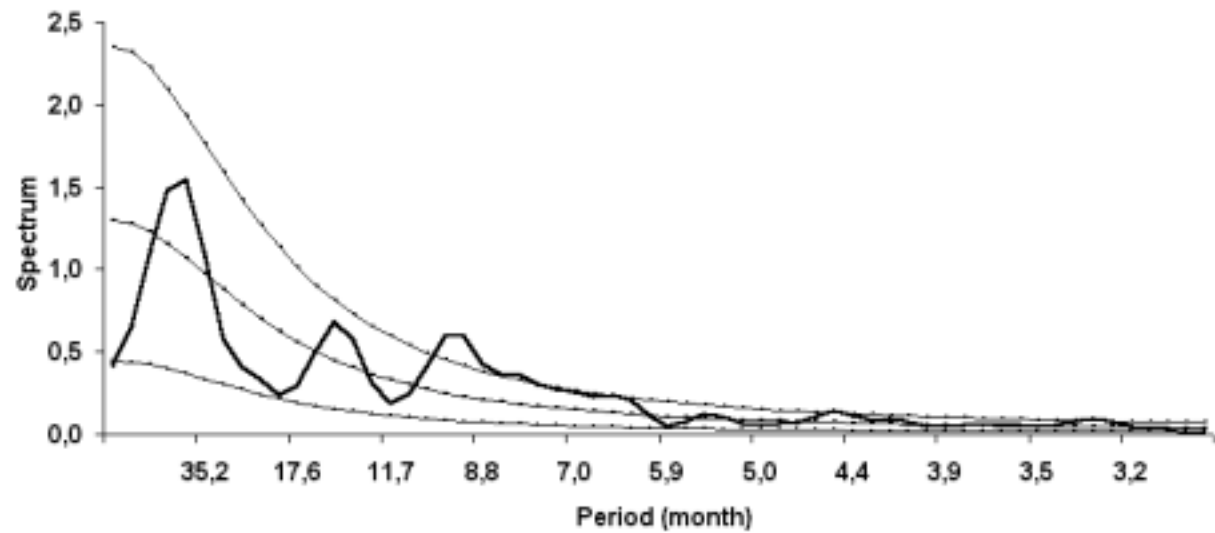
- These are monthly averaged sea ice concentrations derived from Nimbus-7 SMMR and DMSP-F8, -F11 and -F13 SSM/I daily brightness temperatures at a grid cell size of 25 x 25 km. The data set begins October 1978 and continues through December 2000.

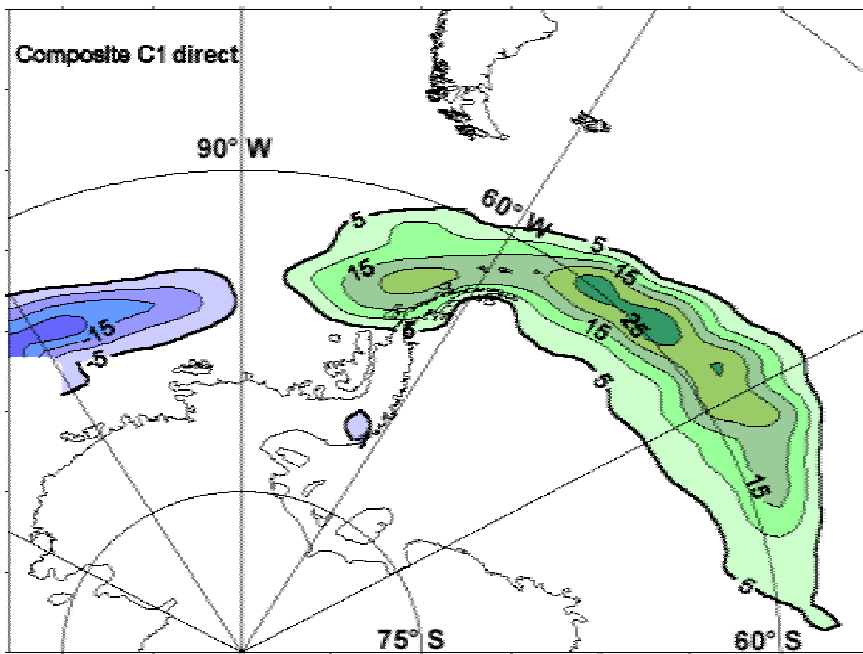
- We used monthly means of 850 hPa height, skin surface temperature, surface wind and 300 hPa winds from the National Centers for Environmental Prediction (NCEP) and National Center for Atmospheric Research (NCAR) Reanalysis Project .The reanalysis have an area of resolution of $2.5^{\circ} \times 2.5^{\circ}$. In our study we considered a record of 22 years from January 1979 to December 2000. The region of analysis is defined from 50° S to South Pole, and from 240° W to 360° W.



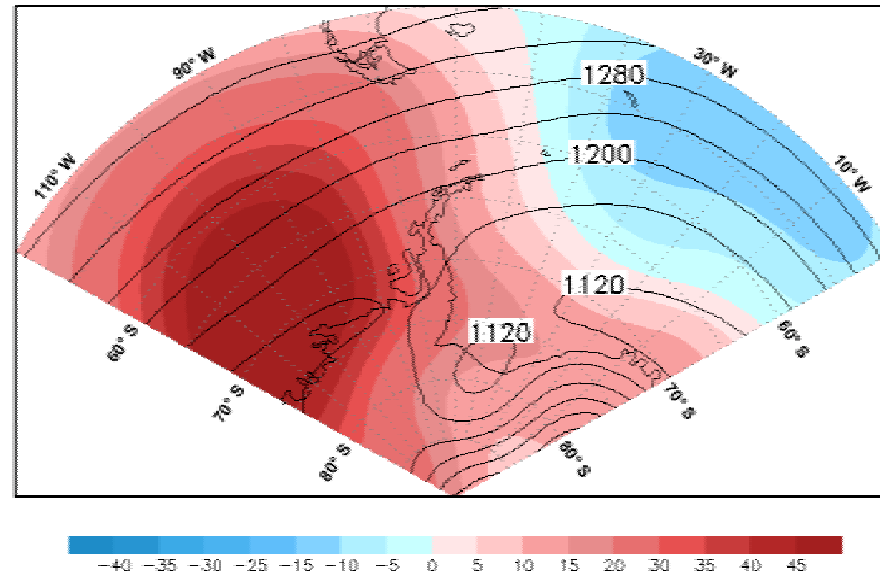


1st PC Score

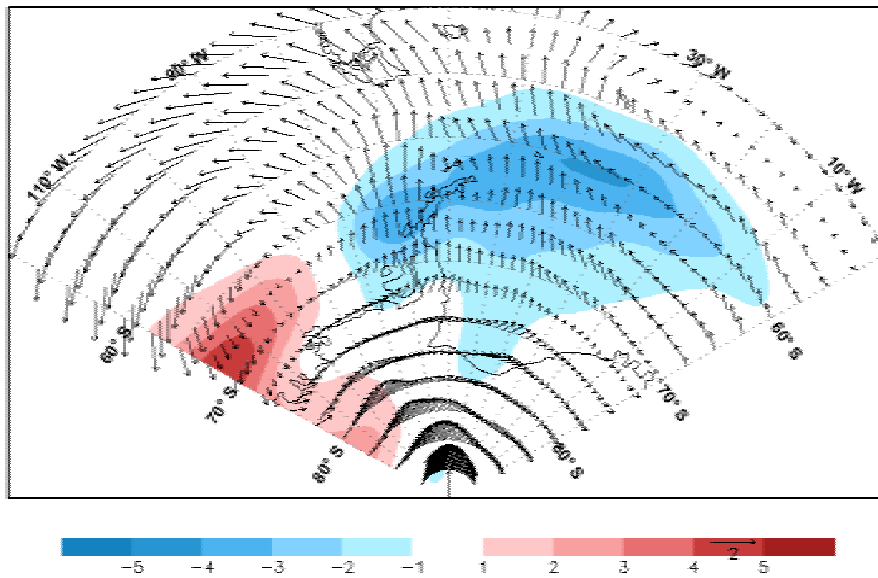




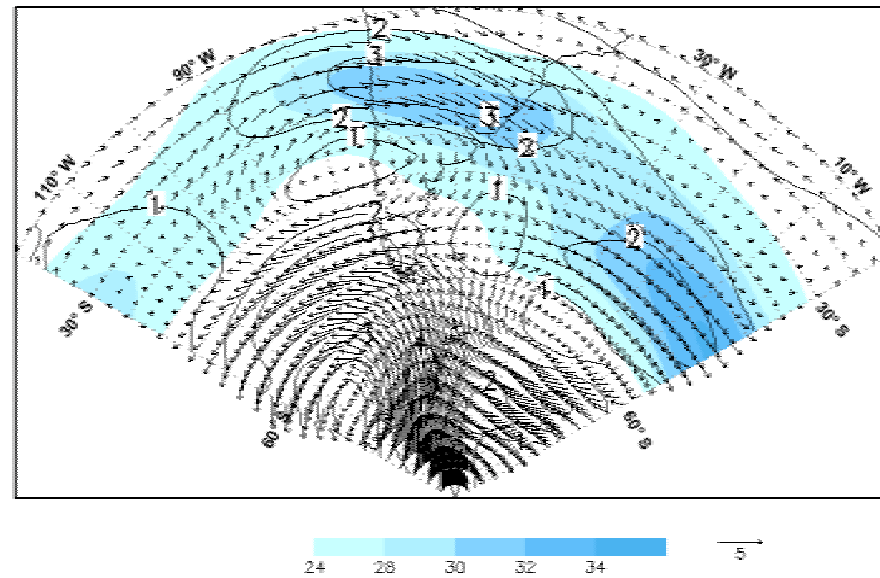
850 hPa Height and Height Anomalies PC Score 1 Direct



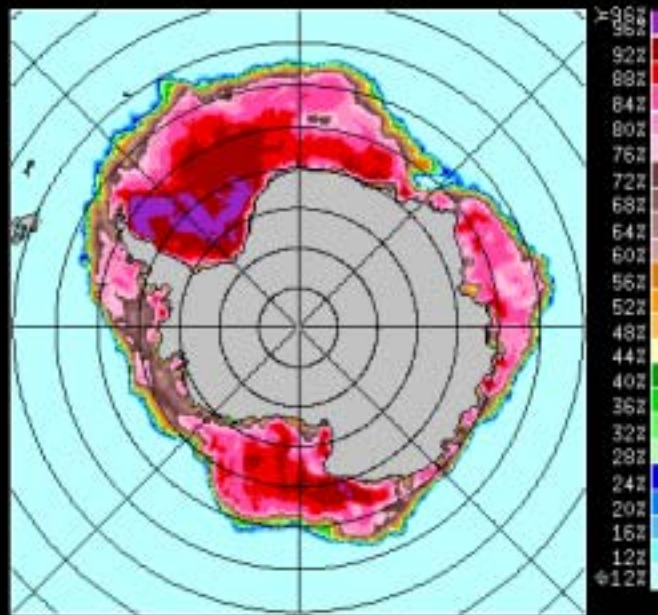
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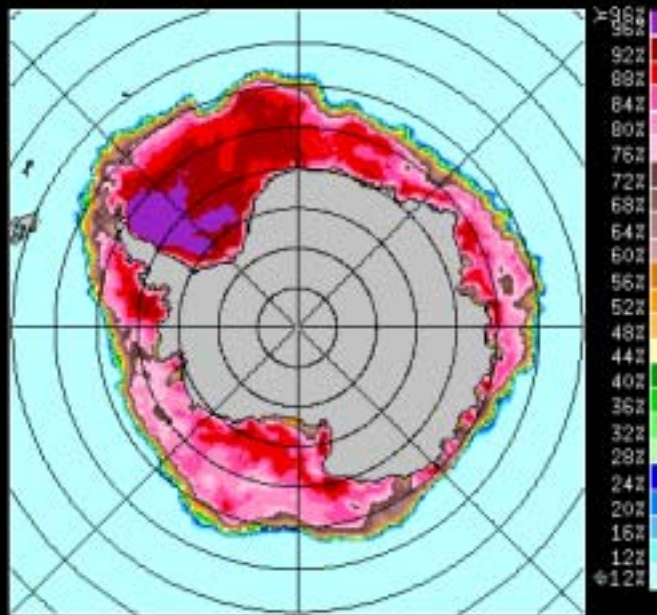
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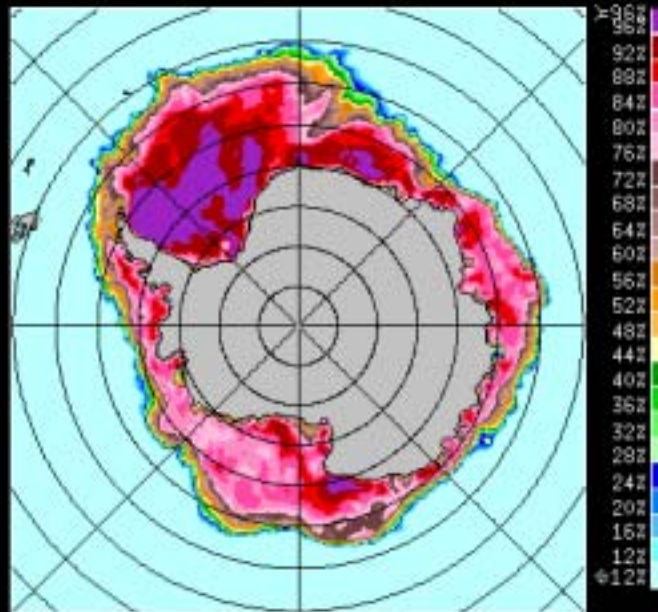
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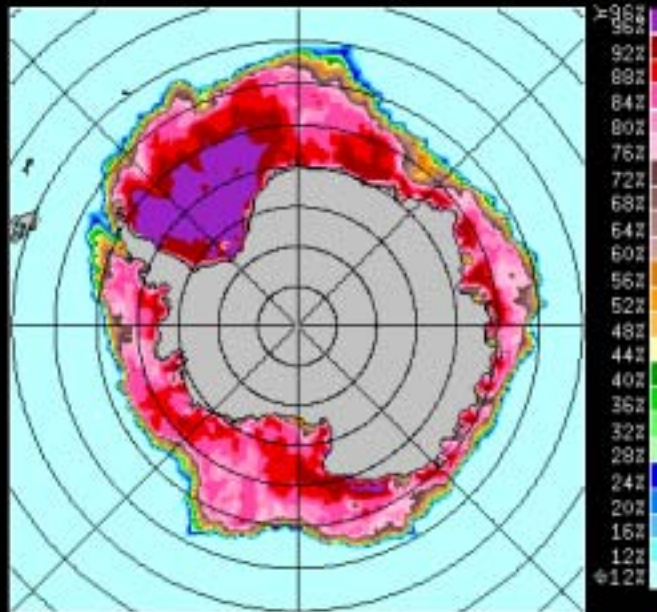
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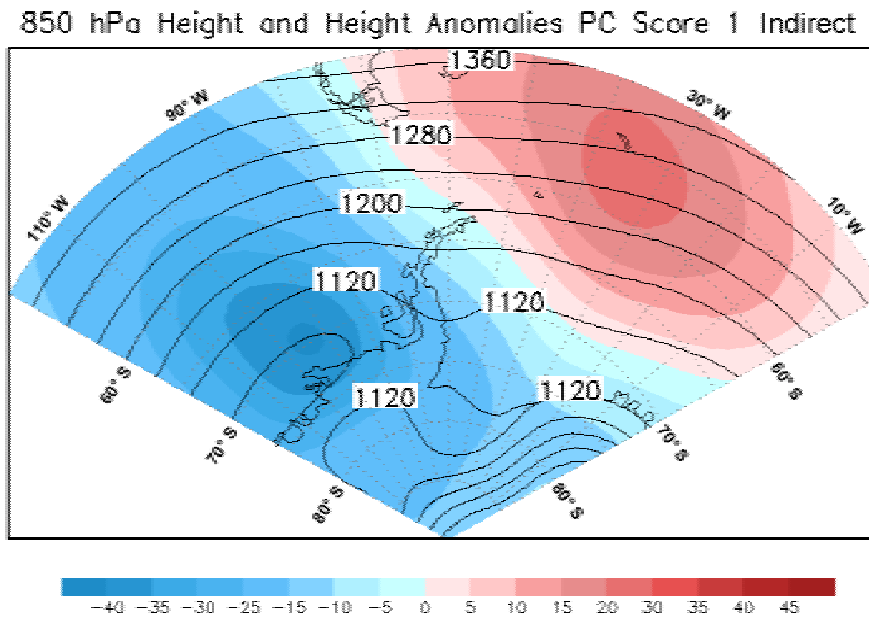
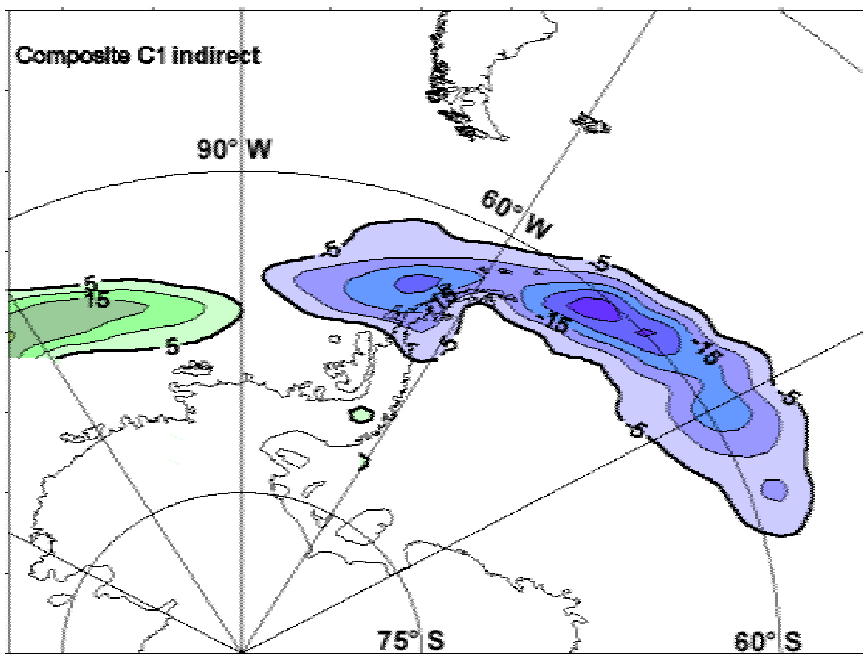


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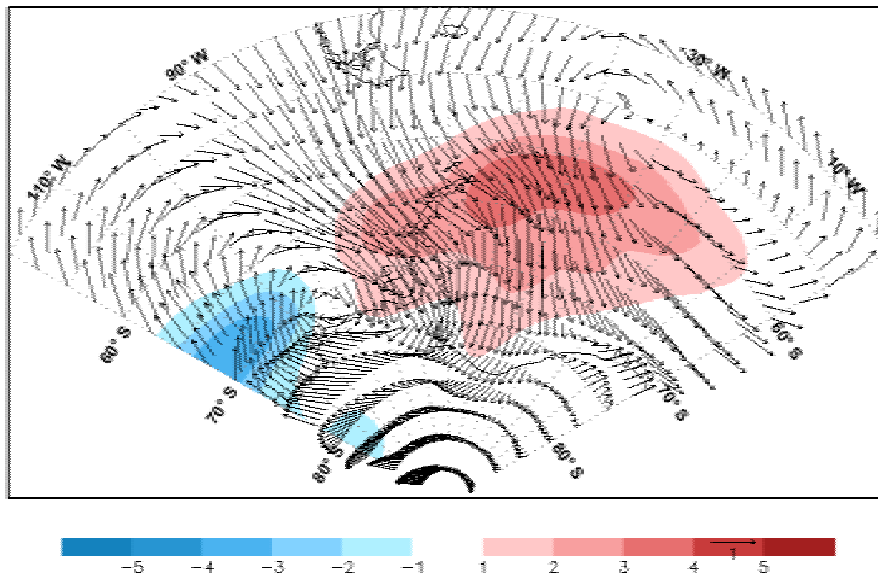


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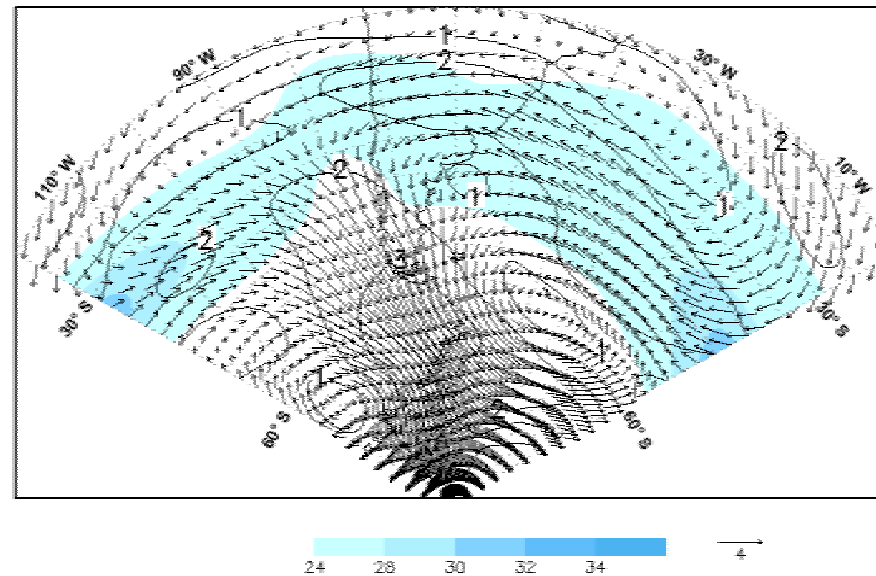




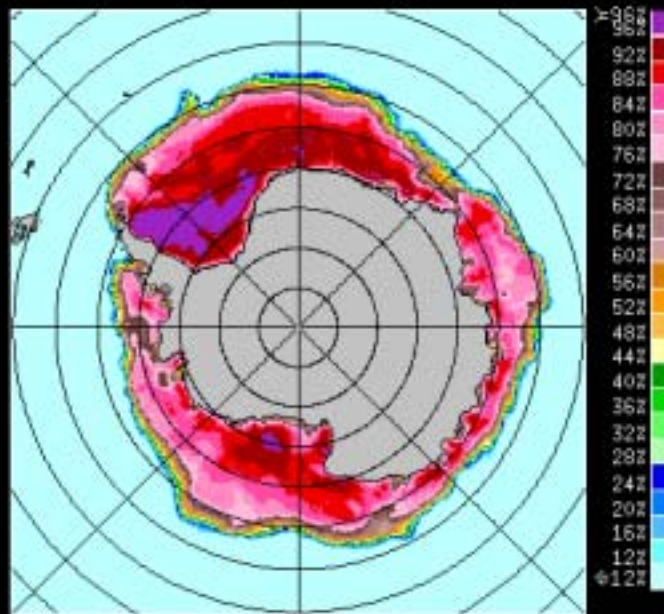
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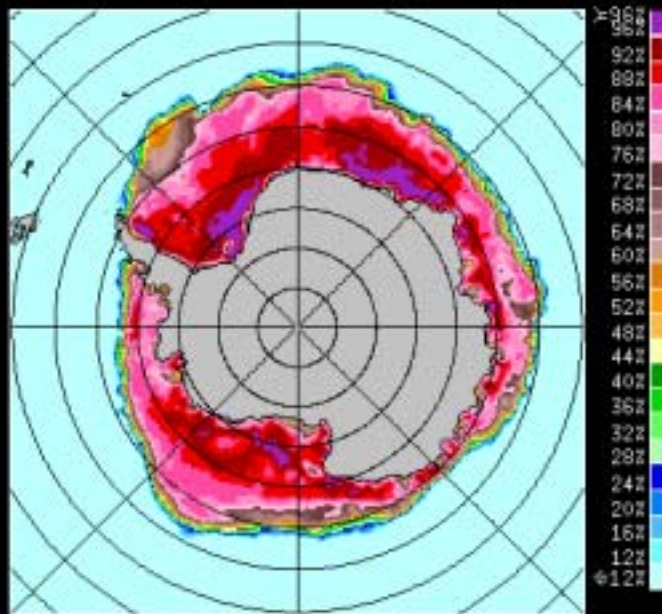
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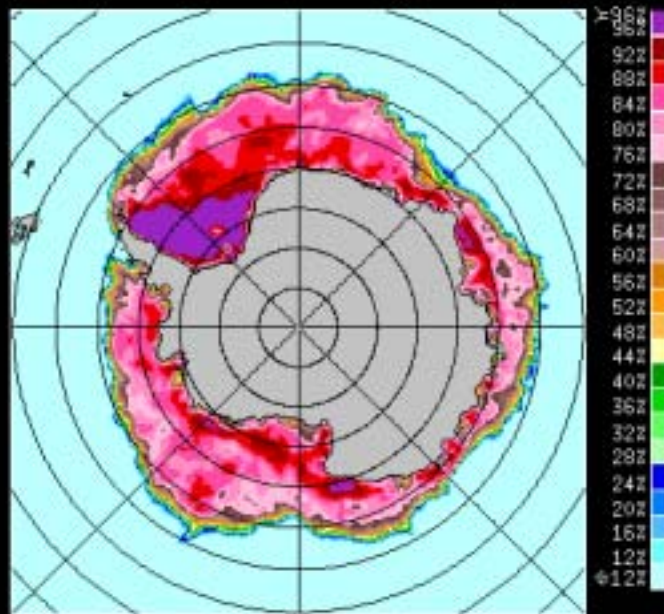
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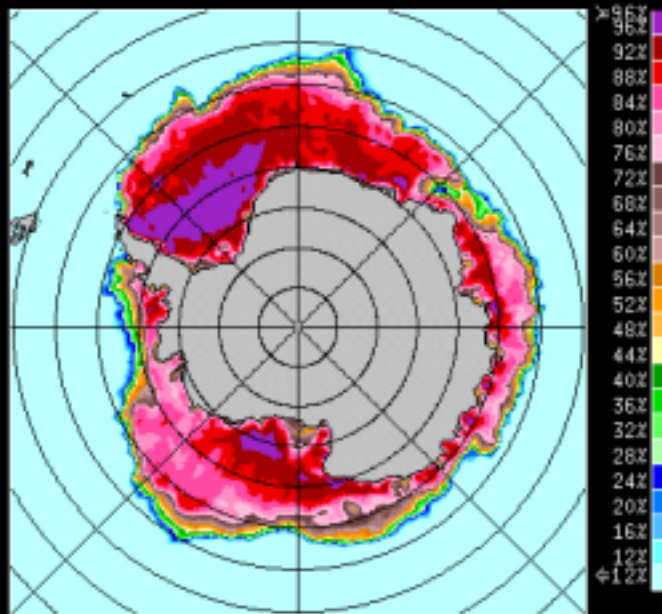
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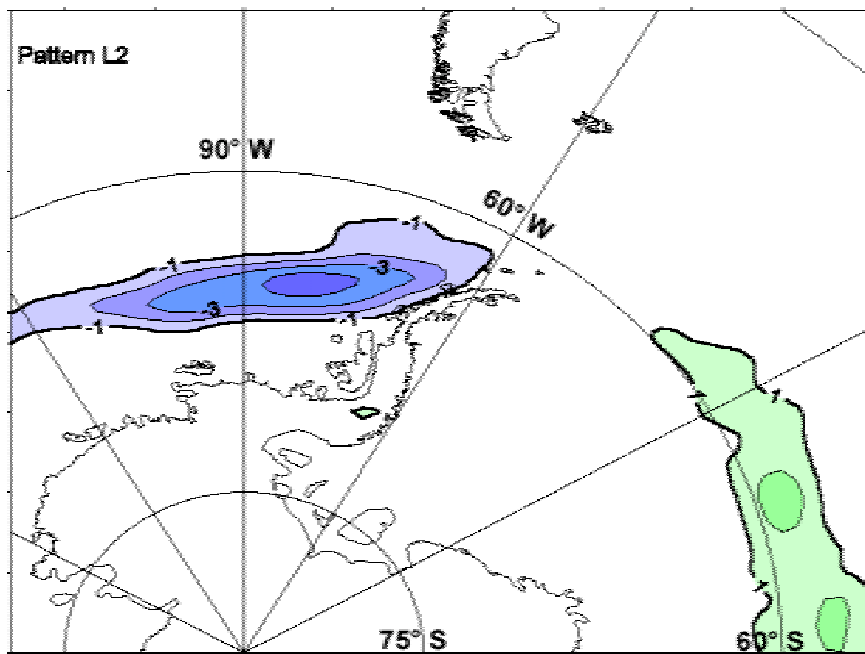


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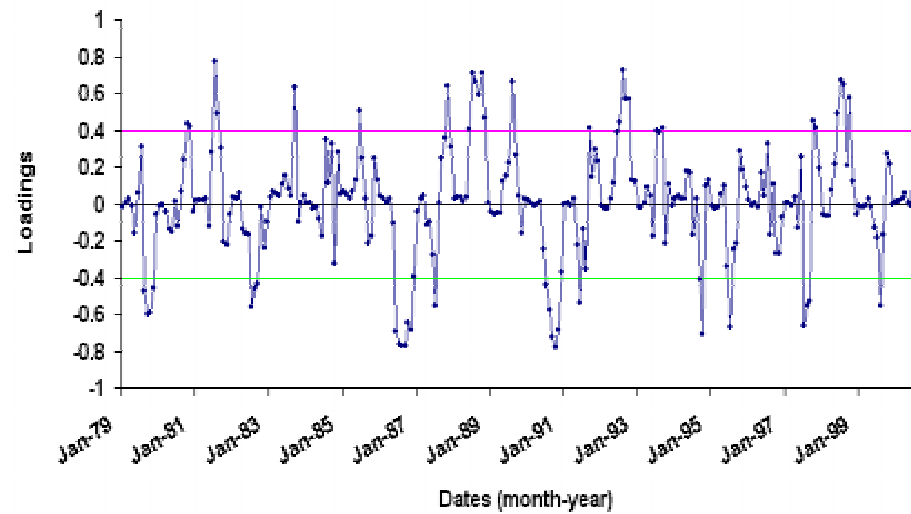


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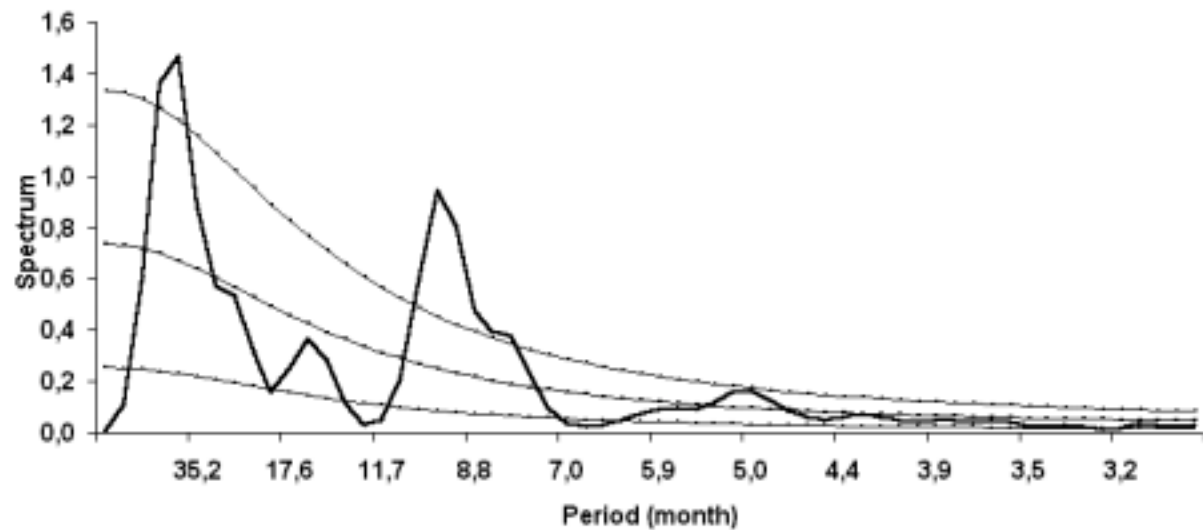


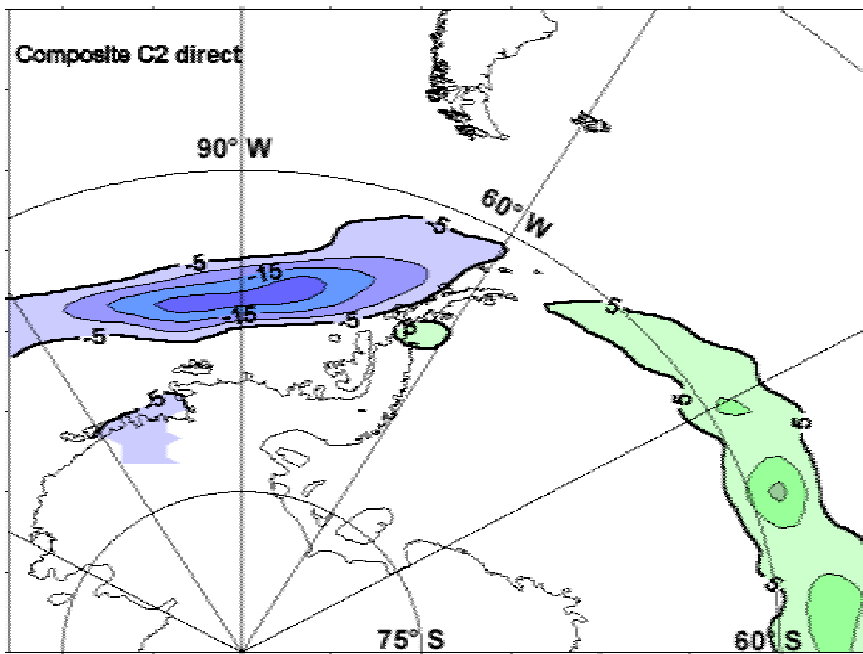


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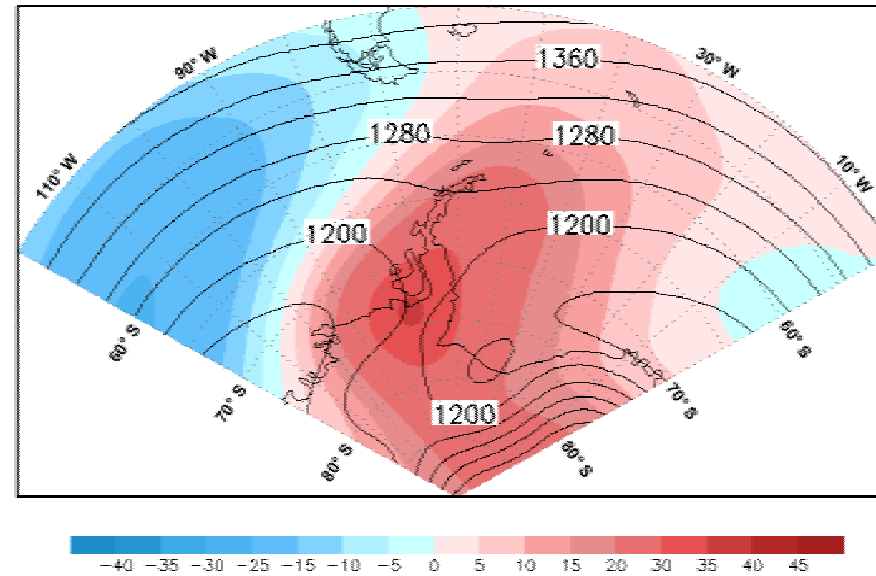


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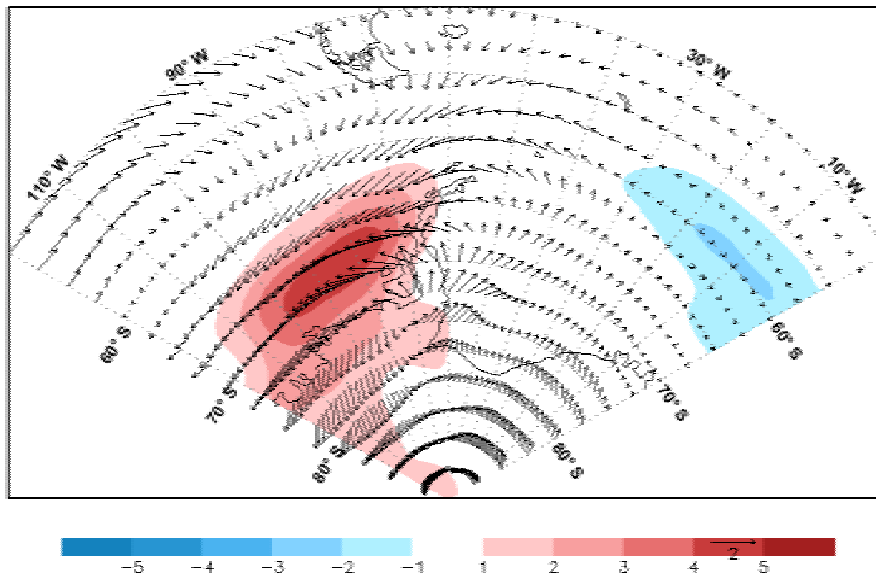




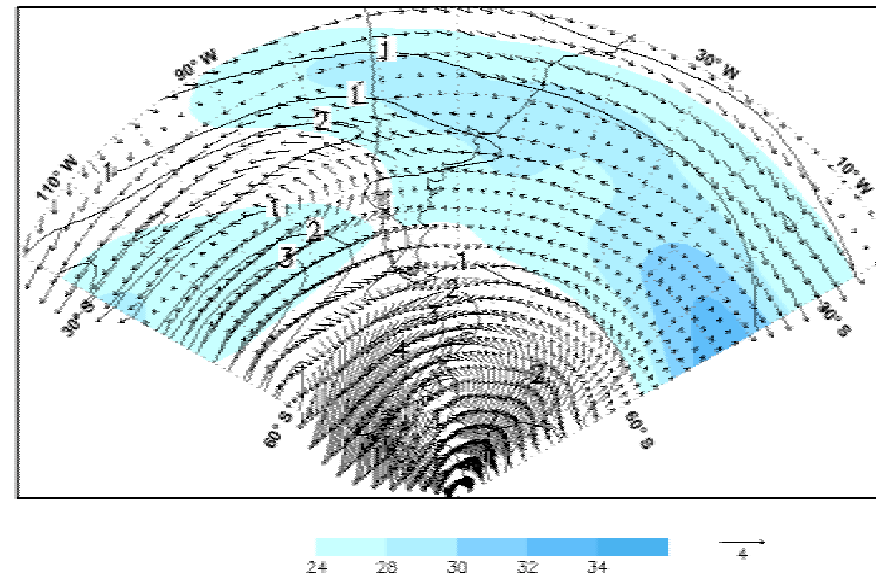
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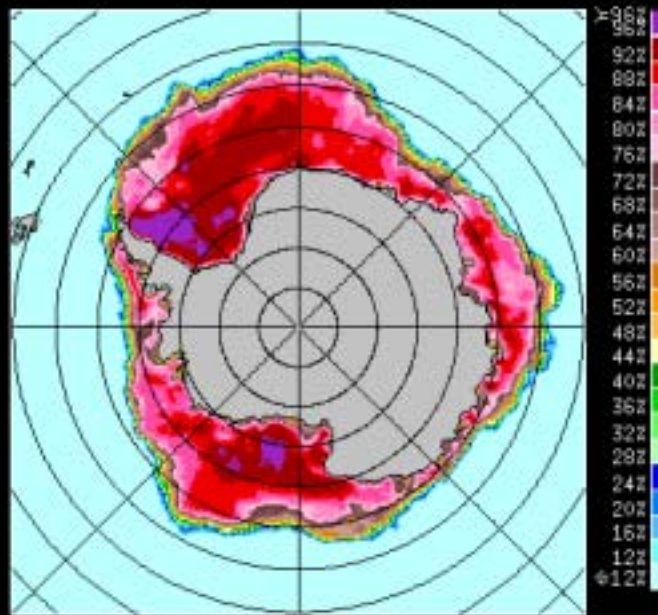
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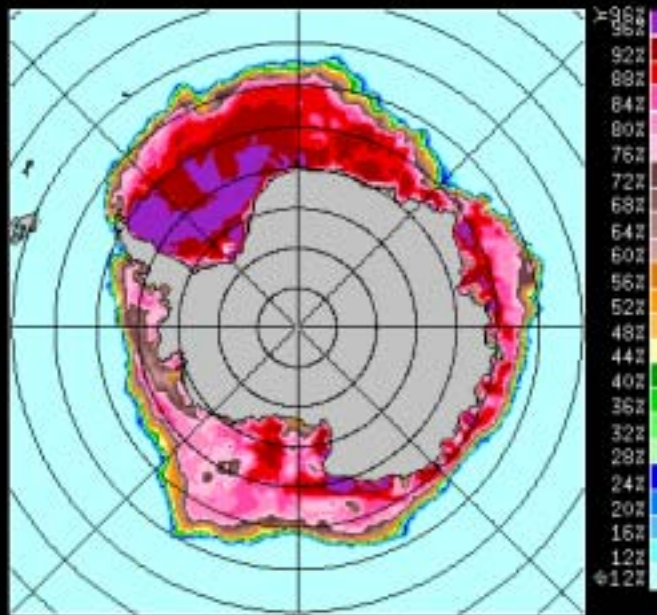
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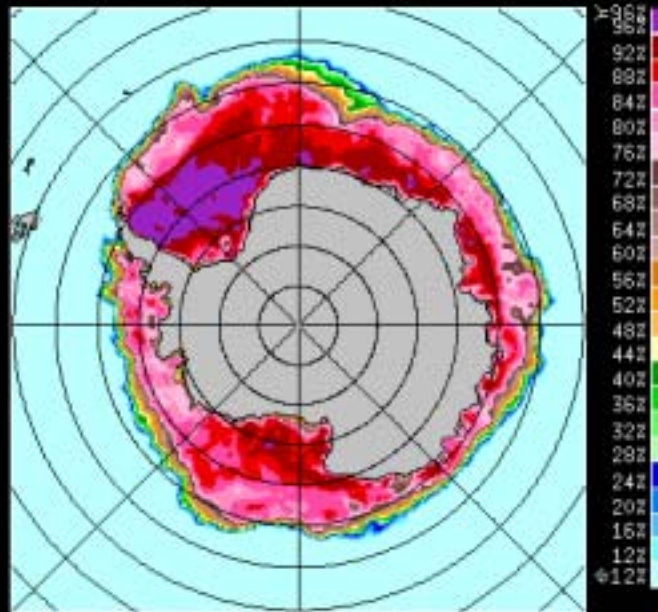
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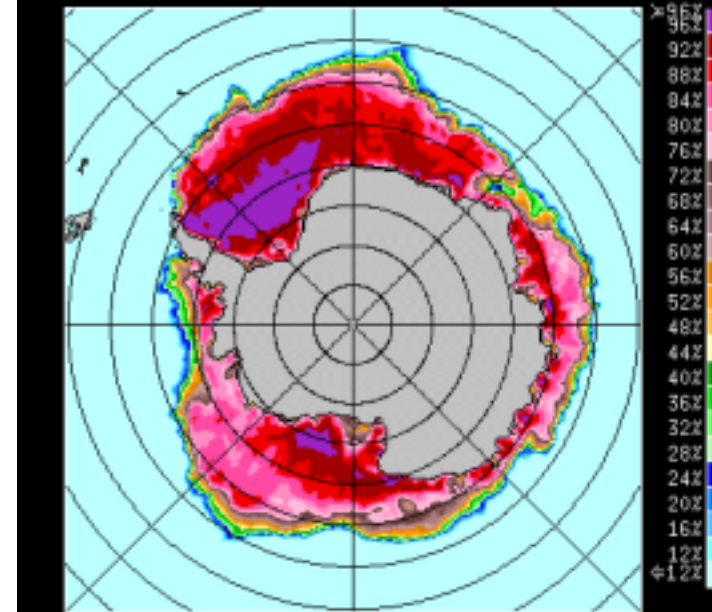
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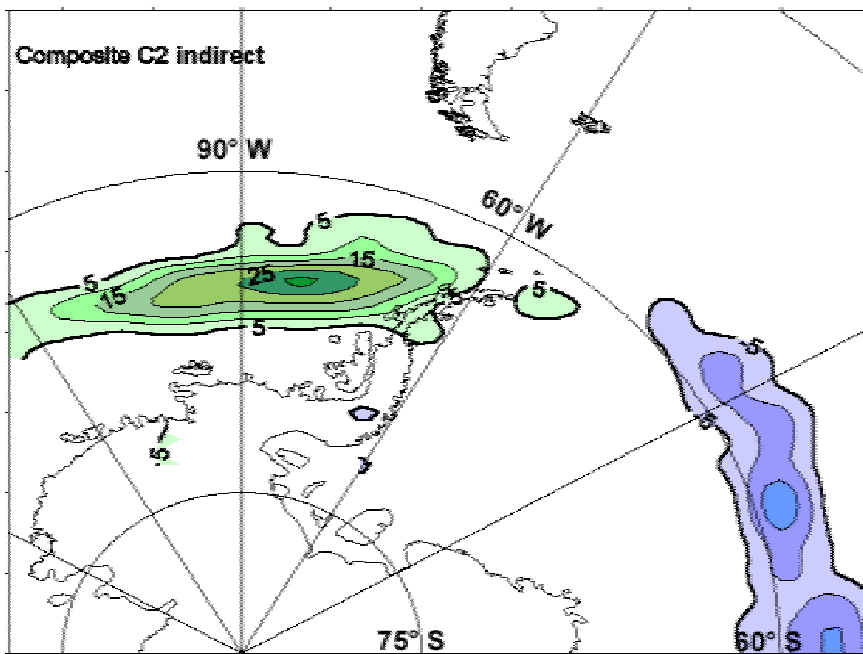


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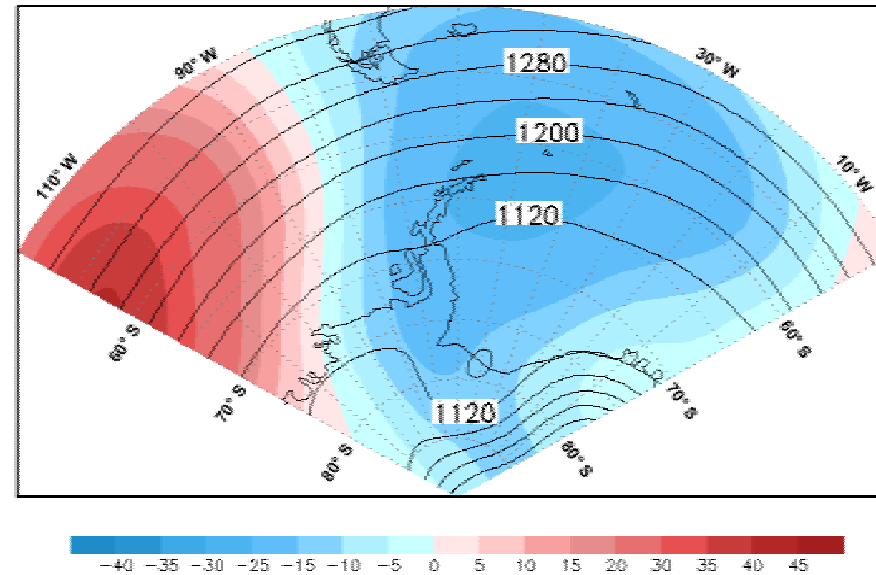


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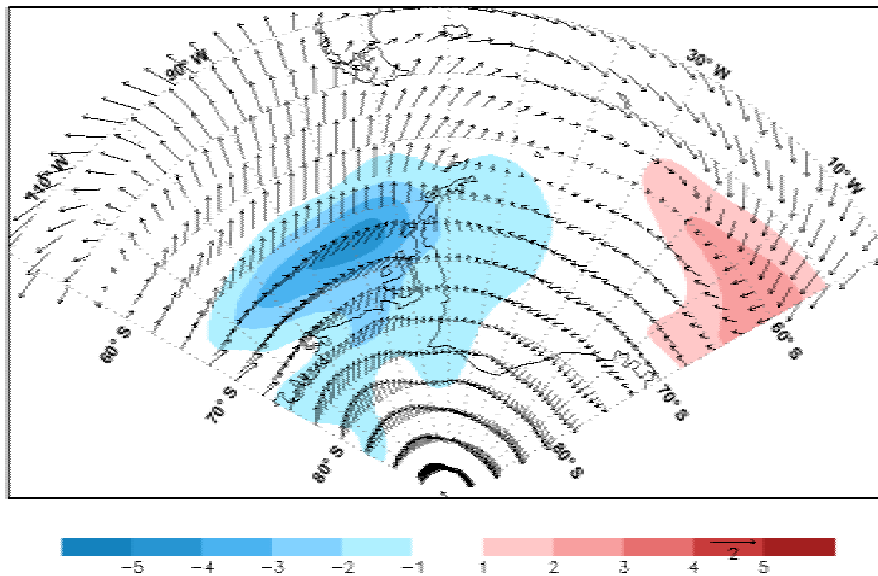




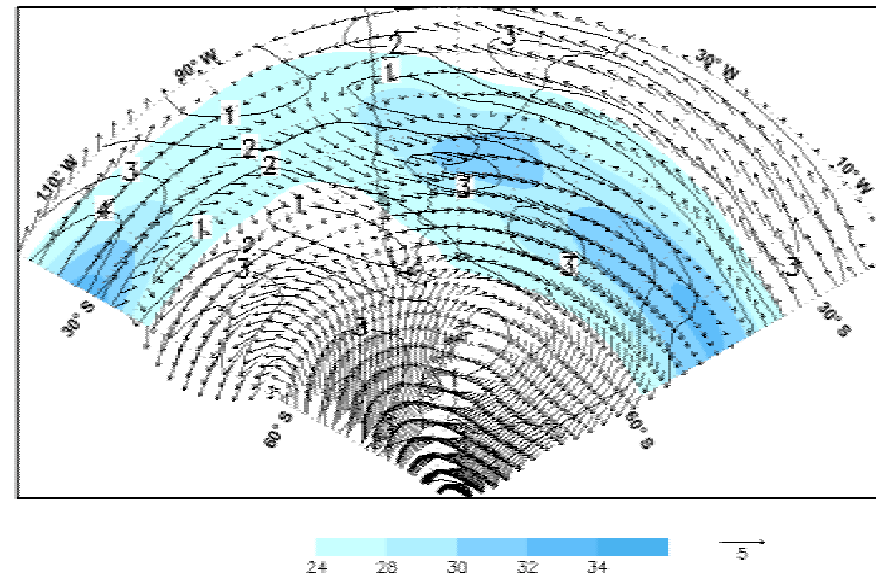
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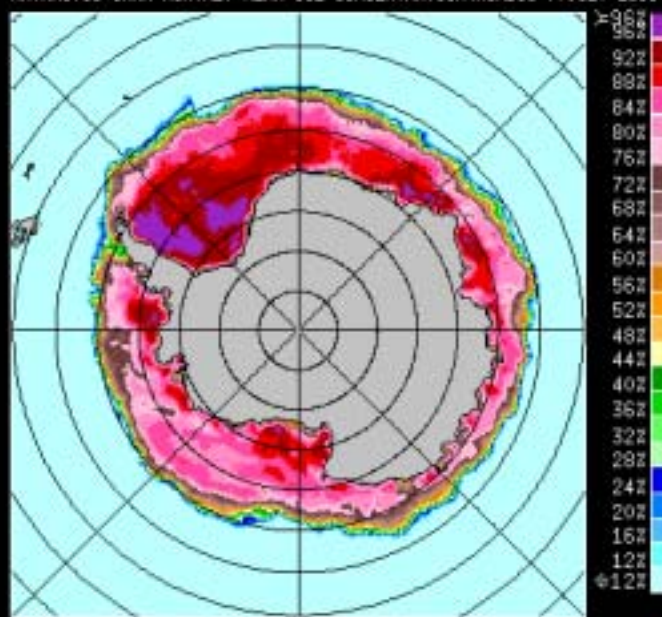
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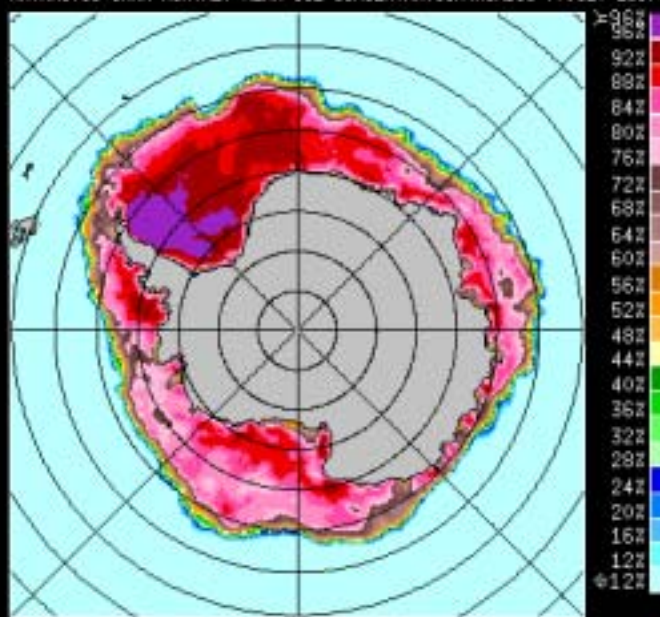
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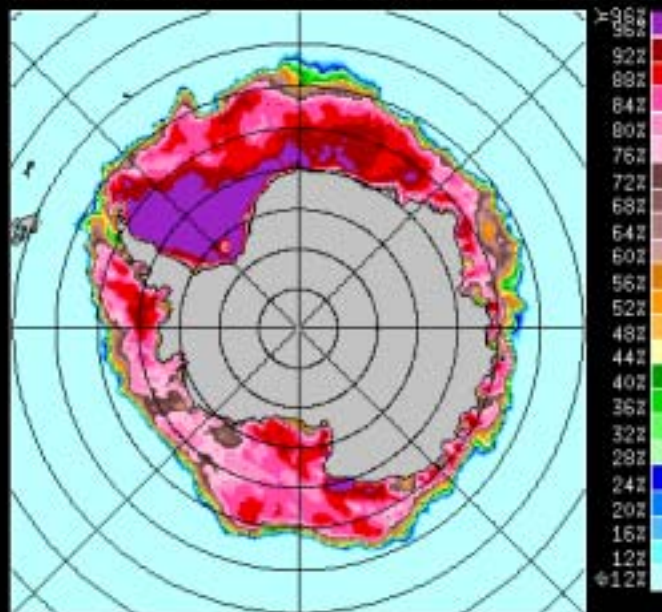
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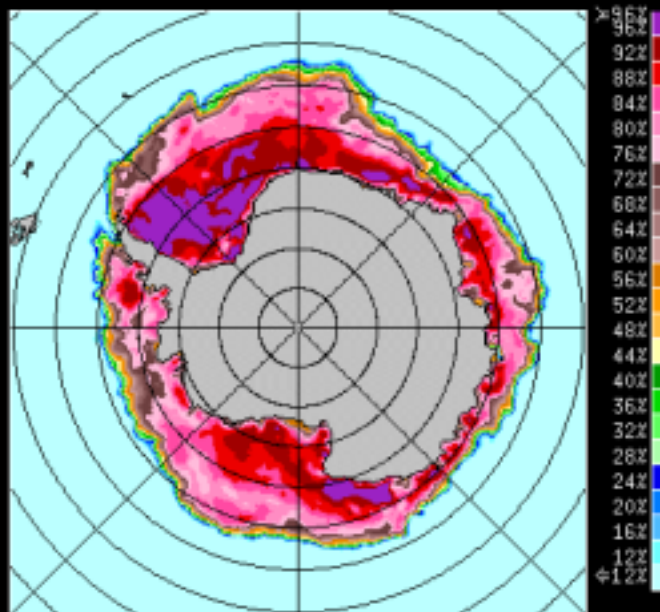
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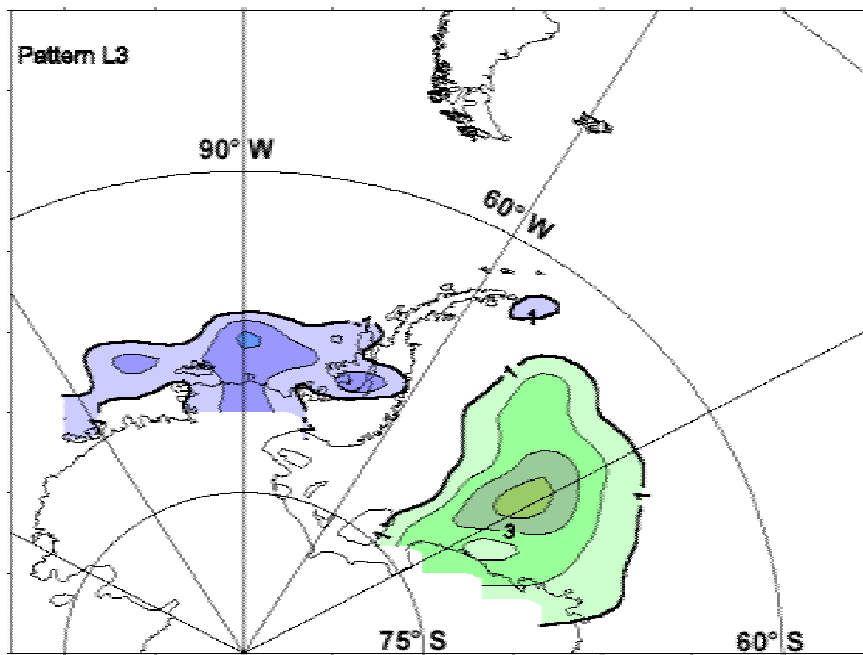


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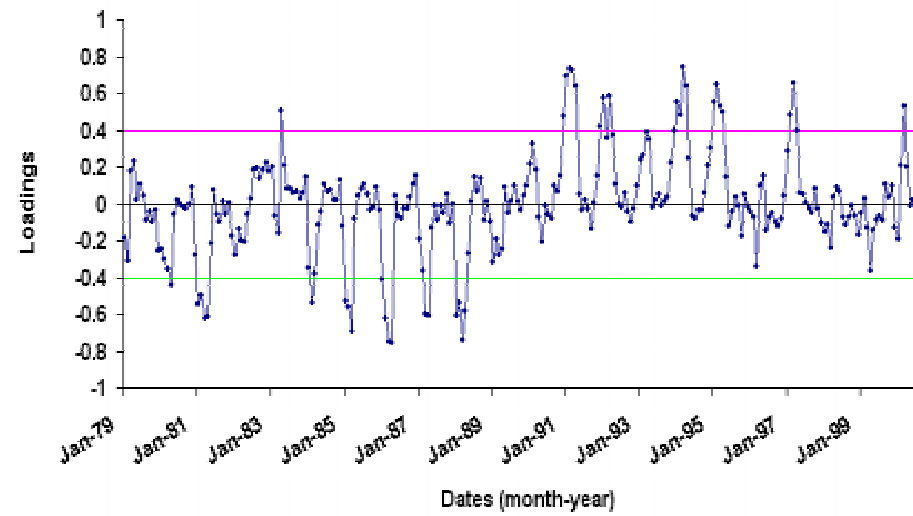


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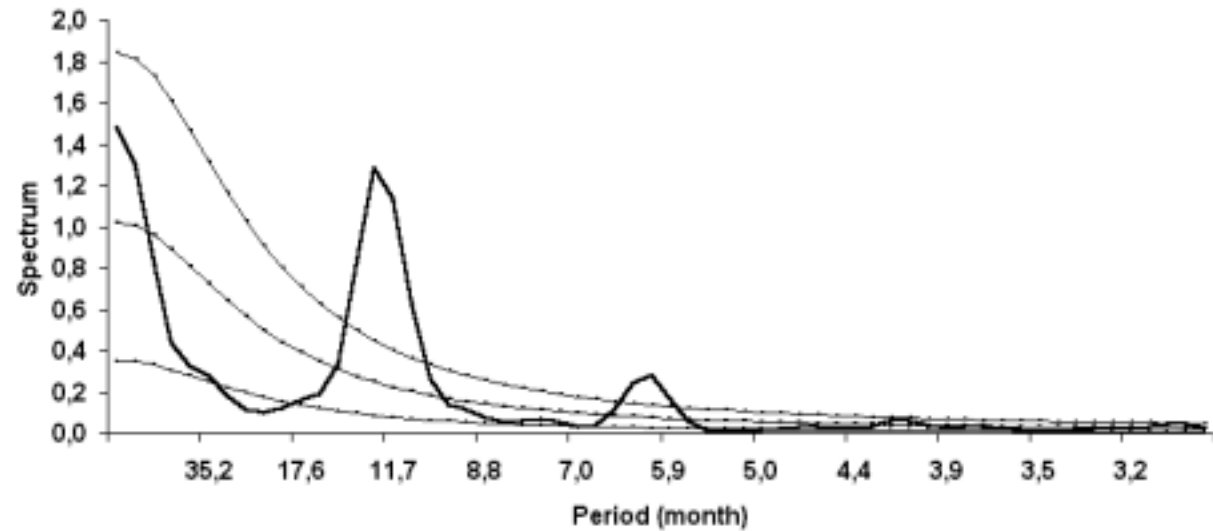


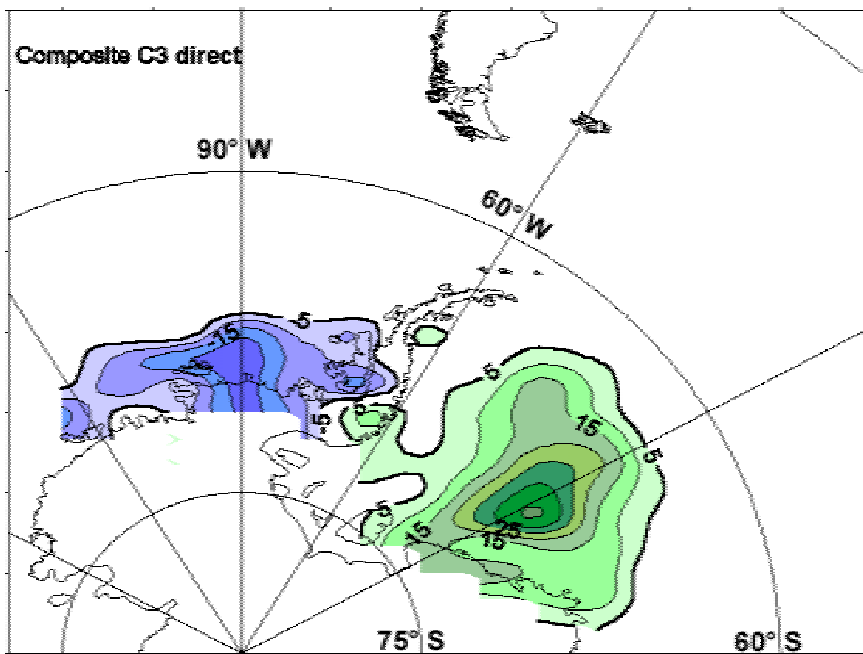


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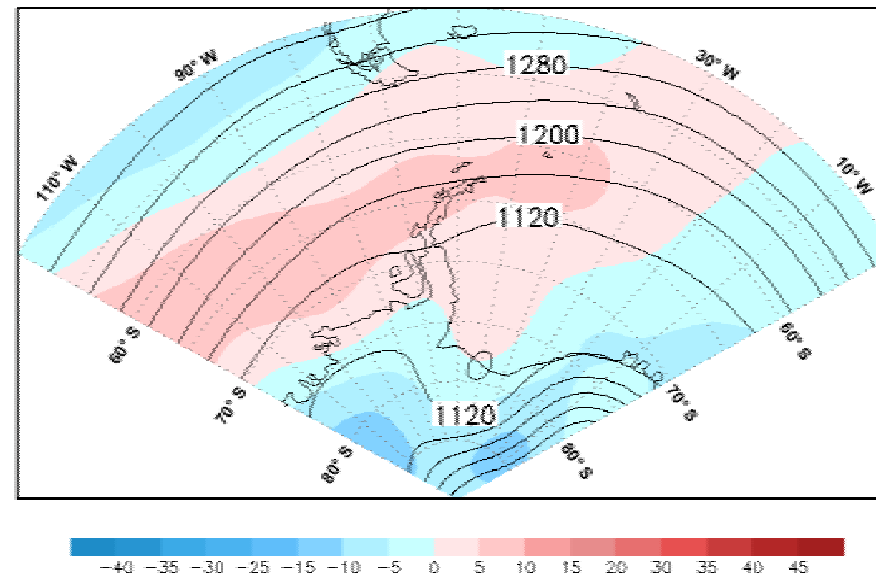


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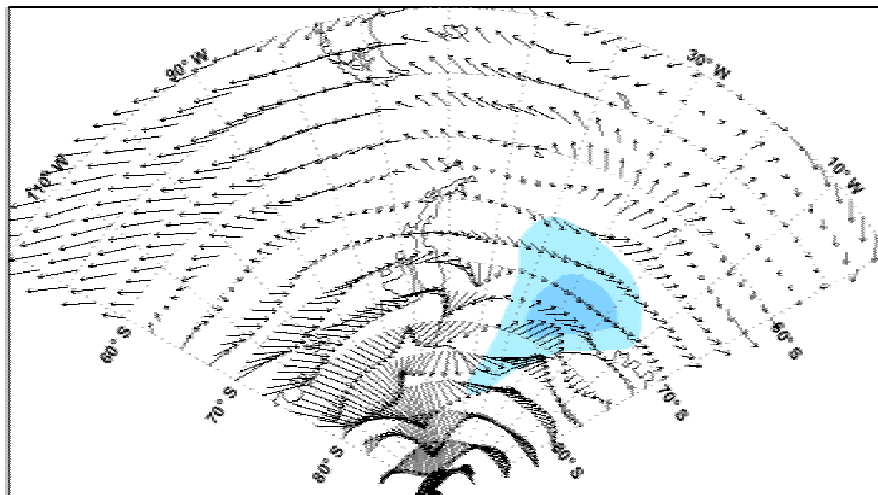




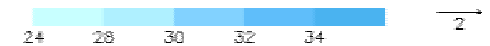
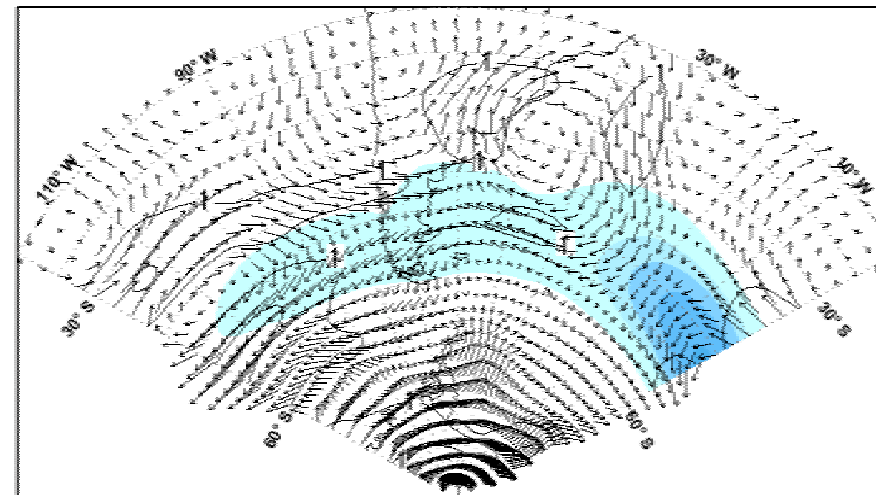
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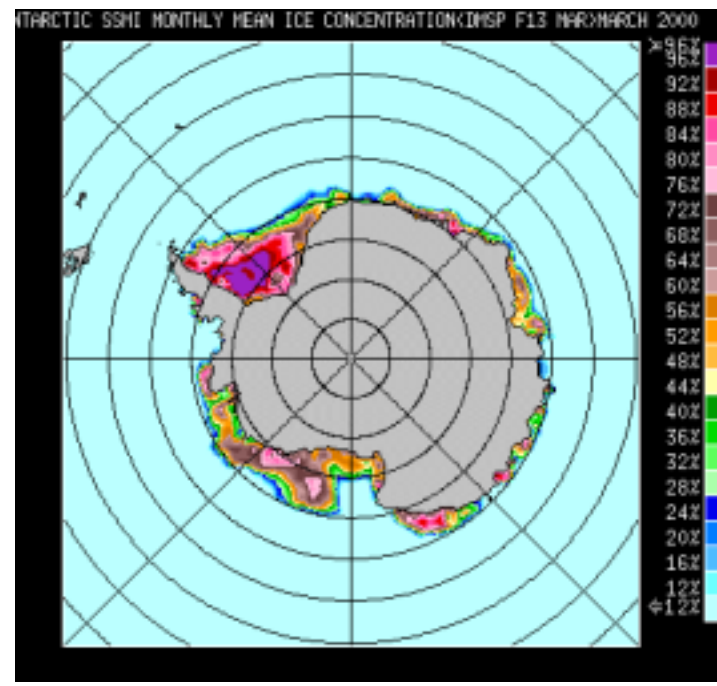
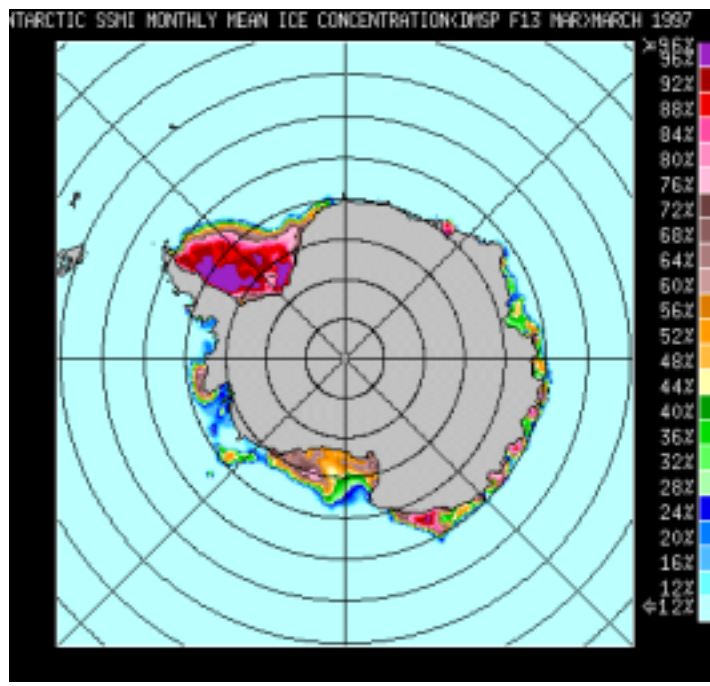
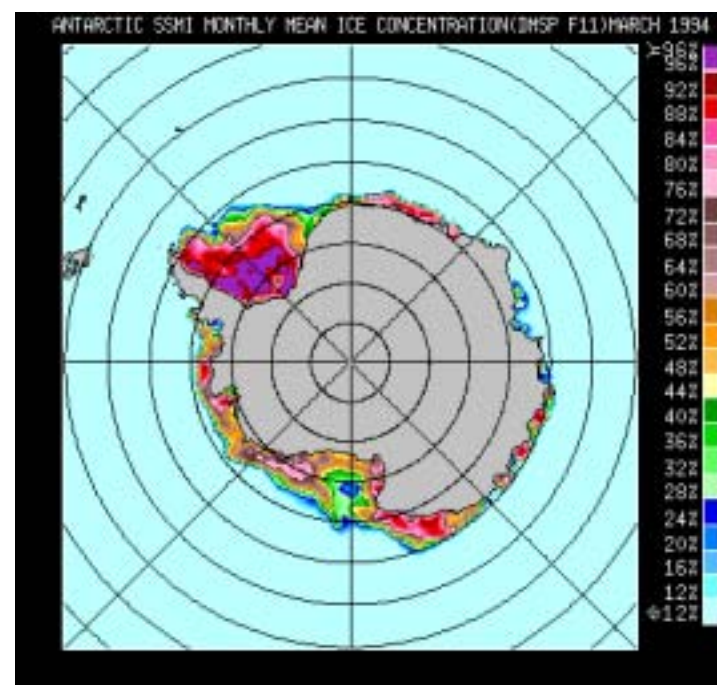
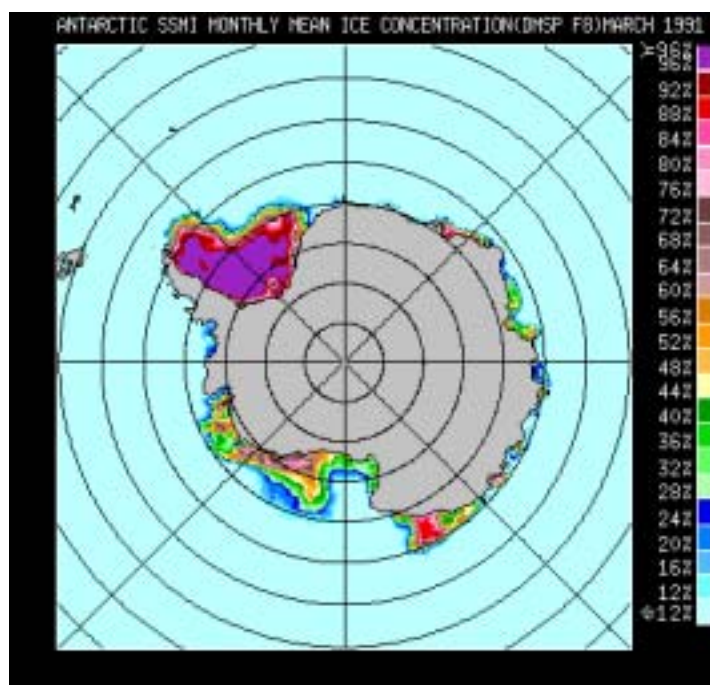


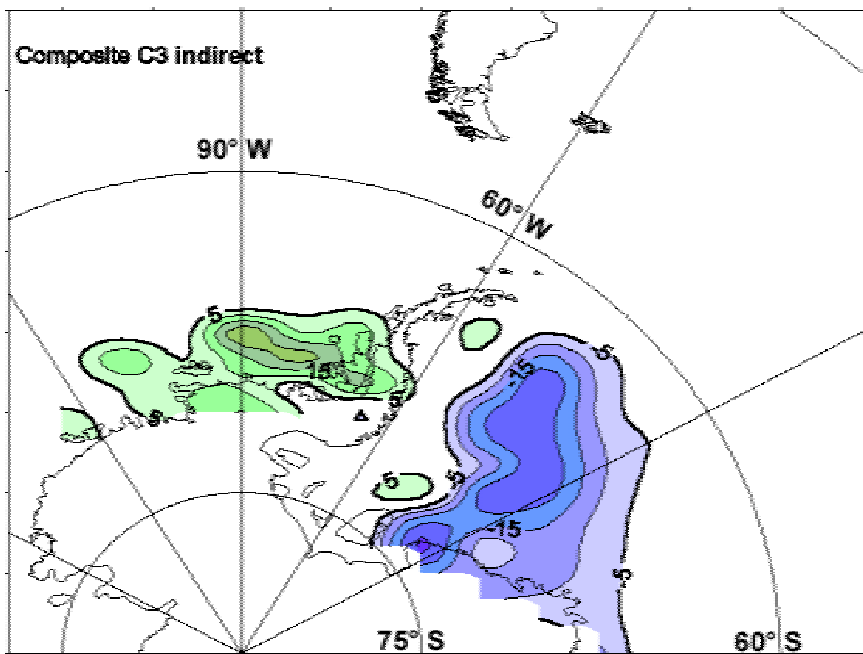
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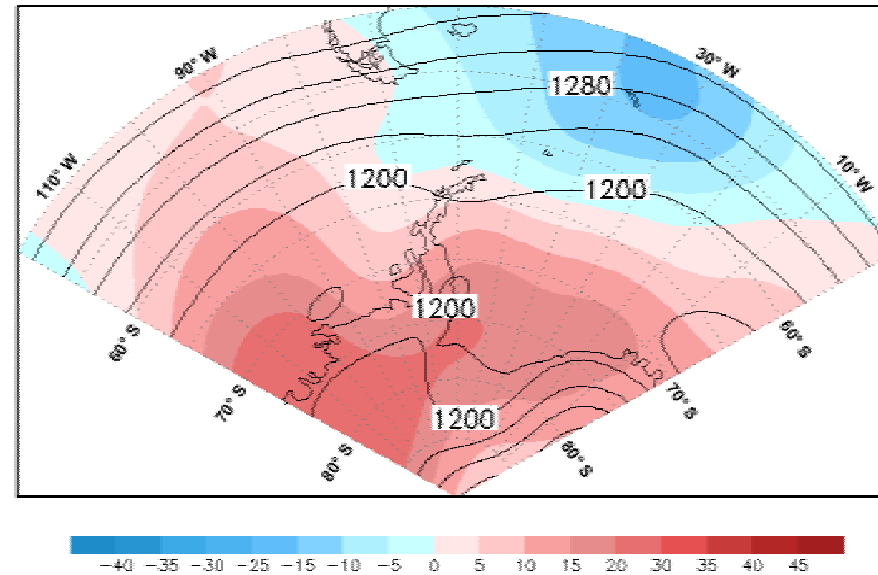
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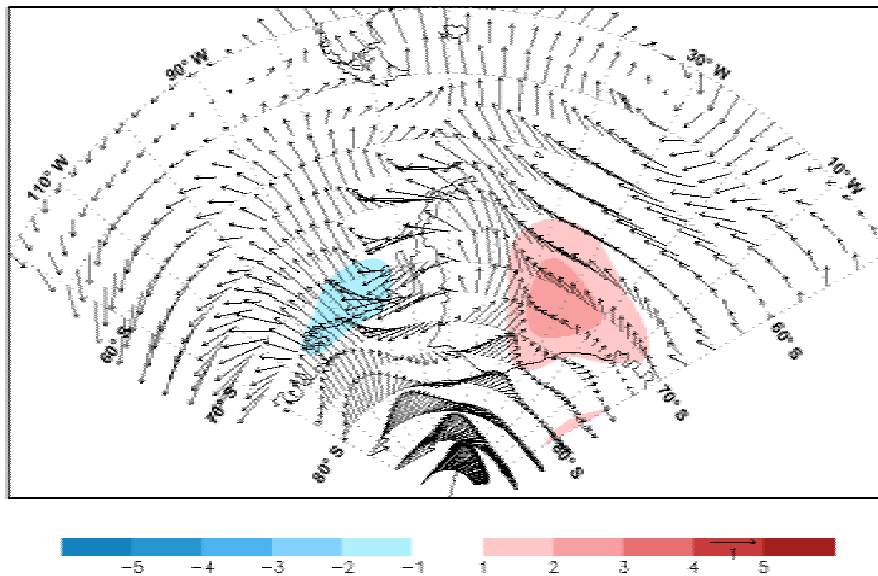




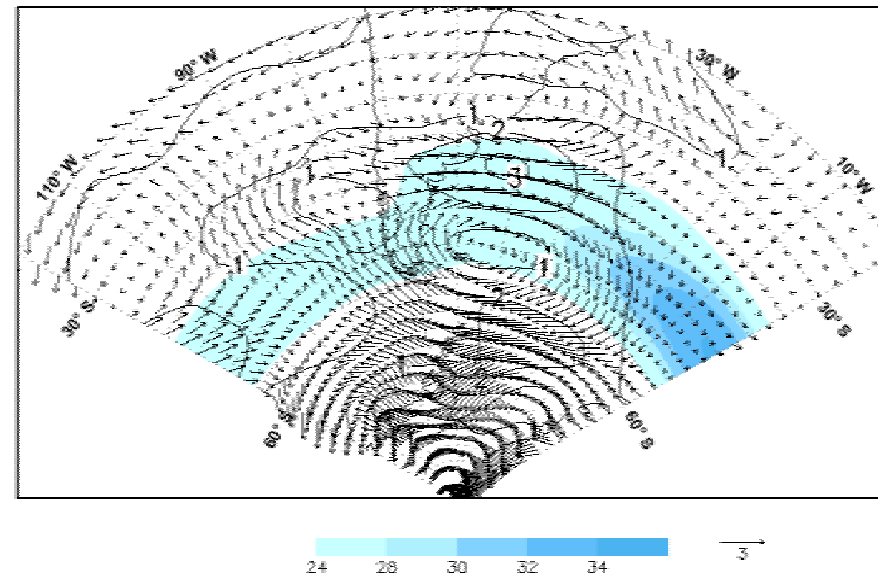
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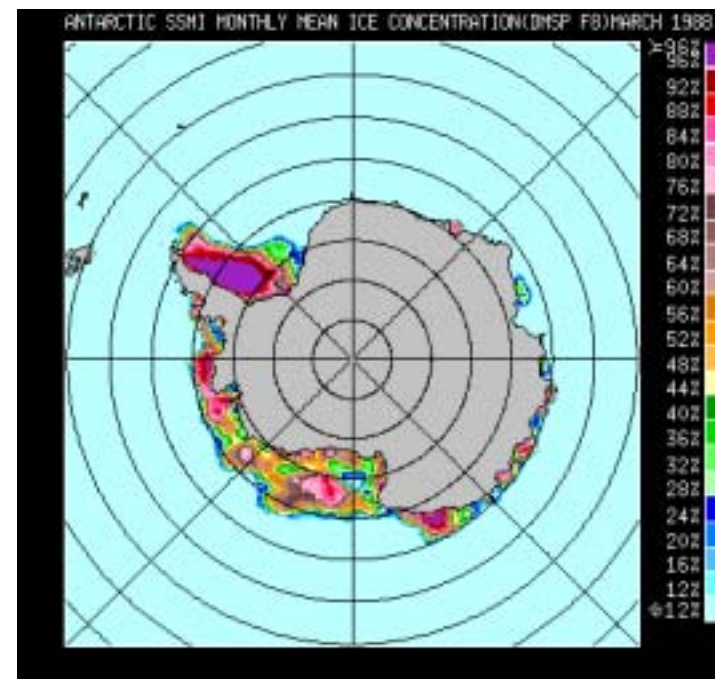
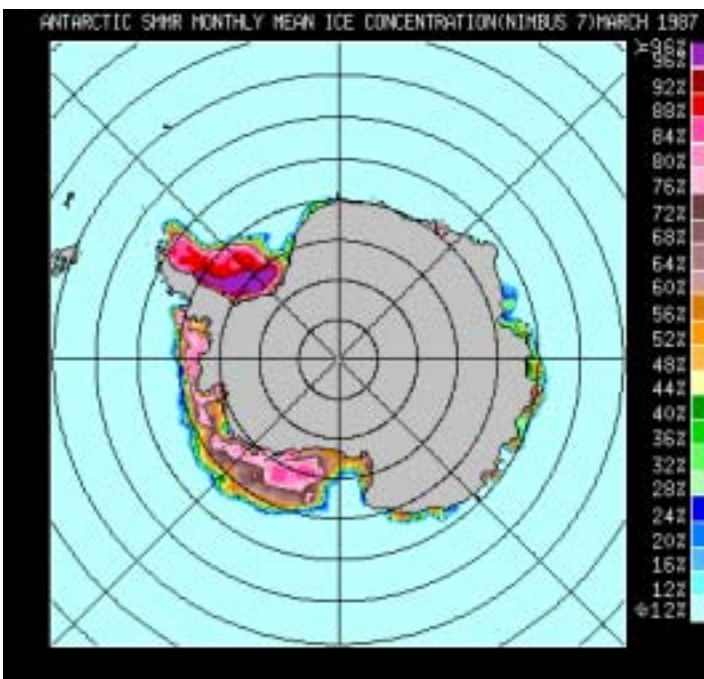
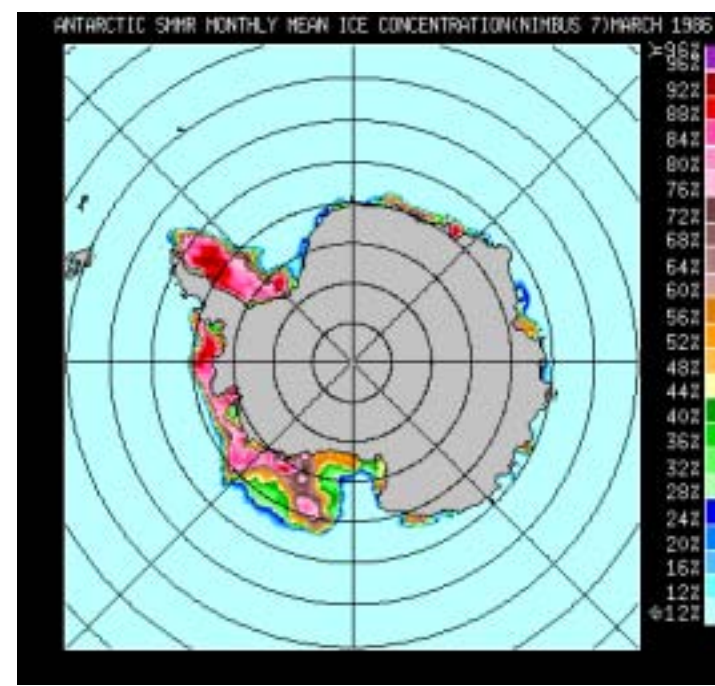
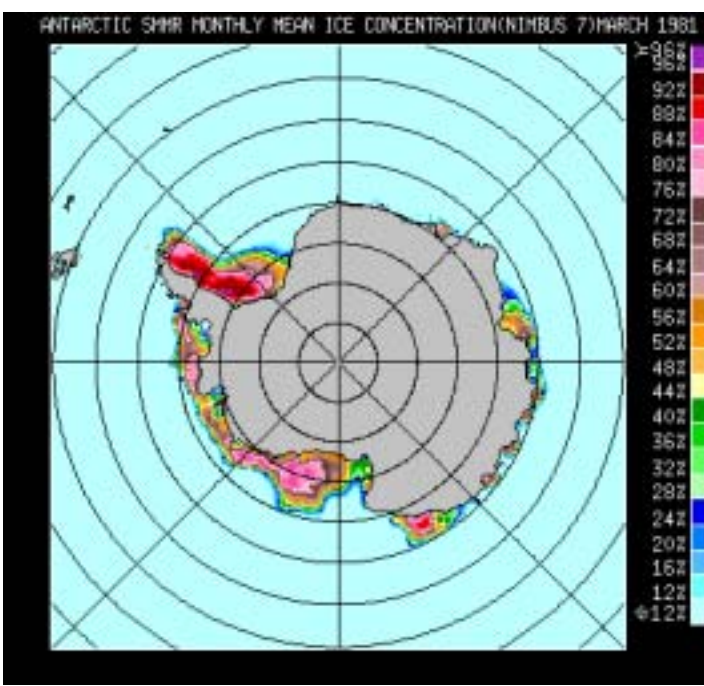


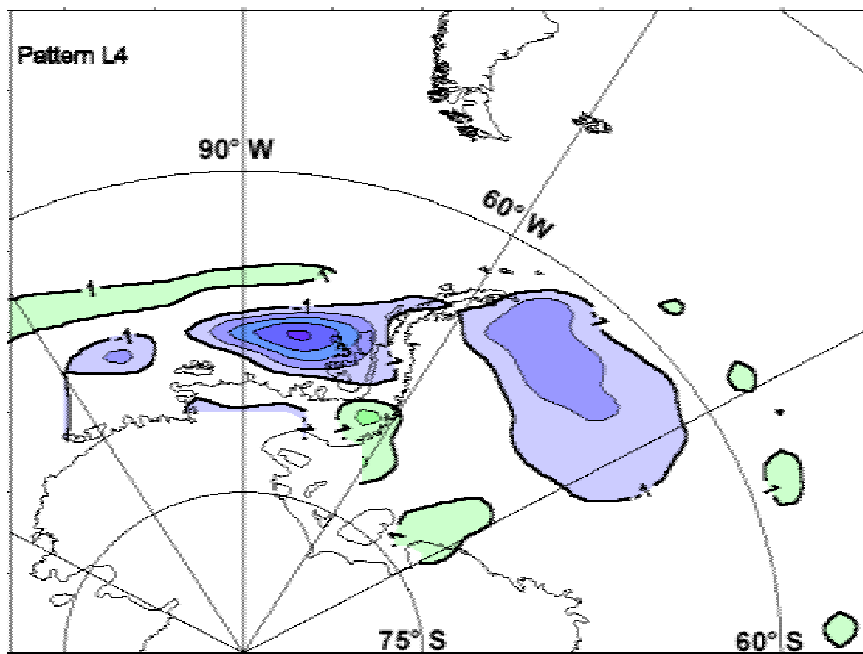
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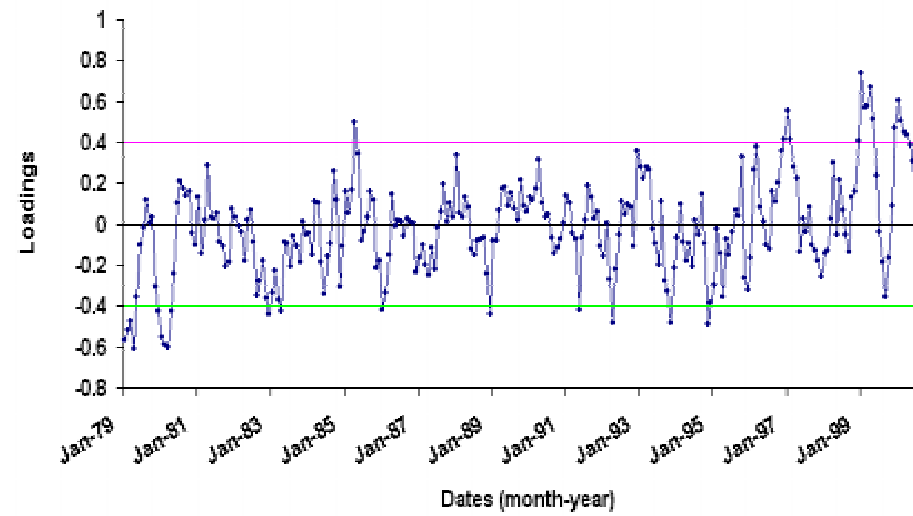
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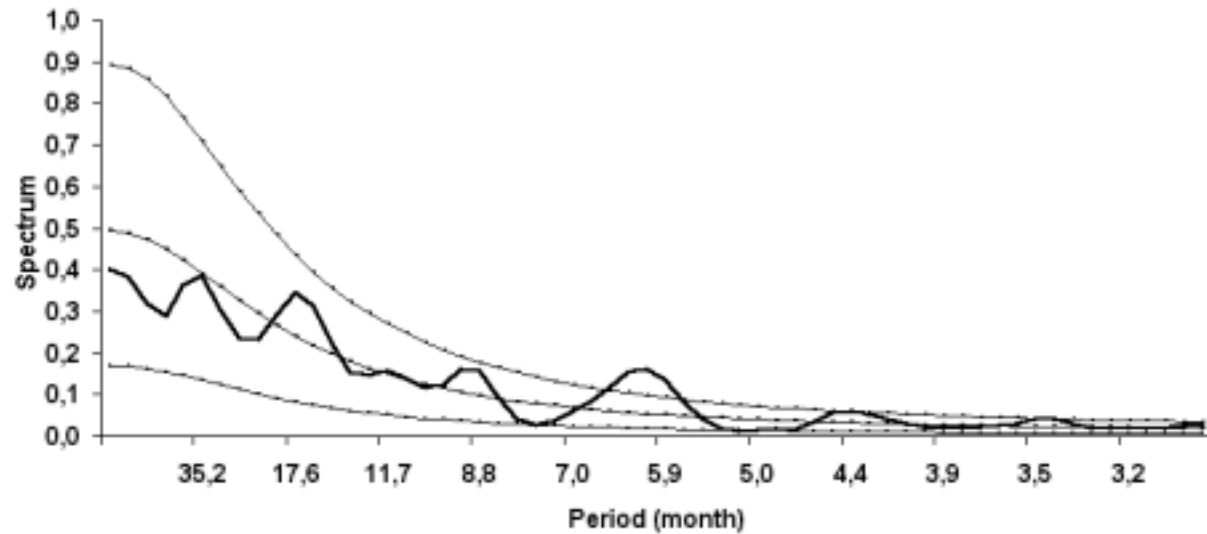


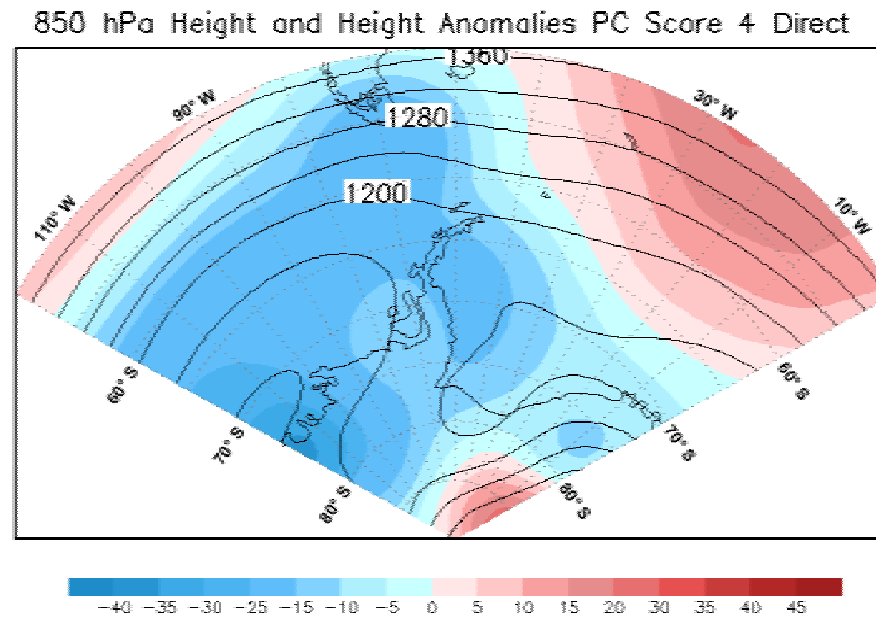
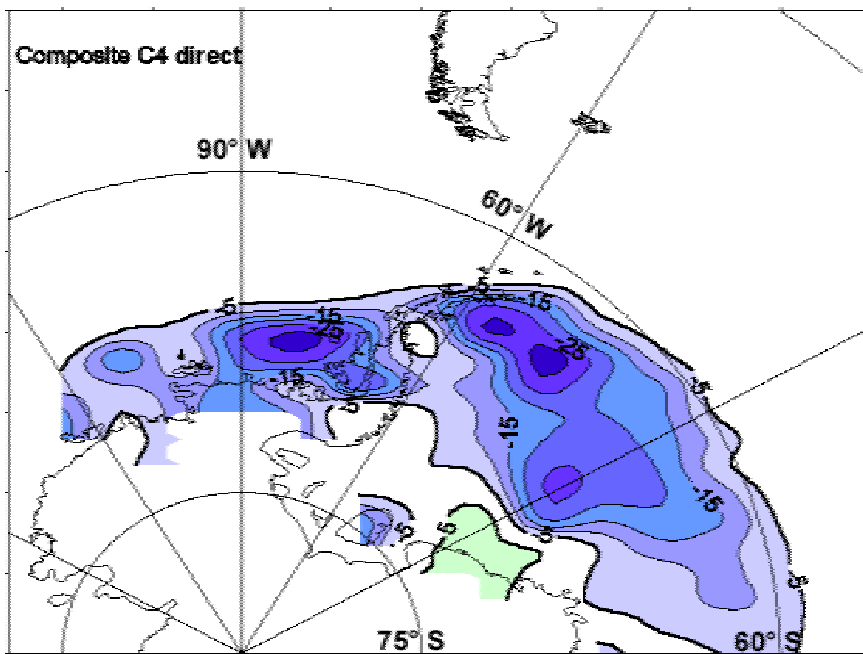


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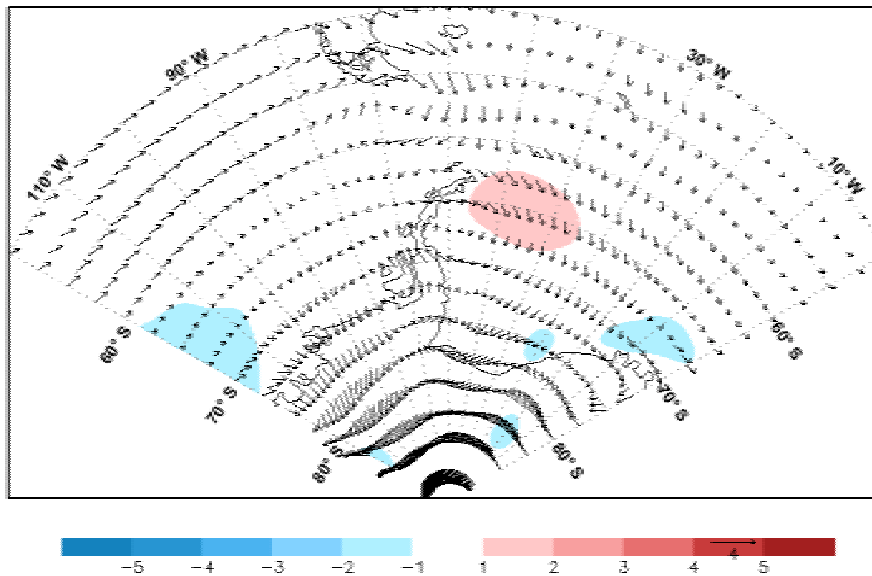


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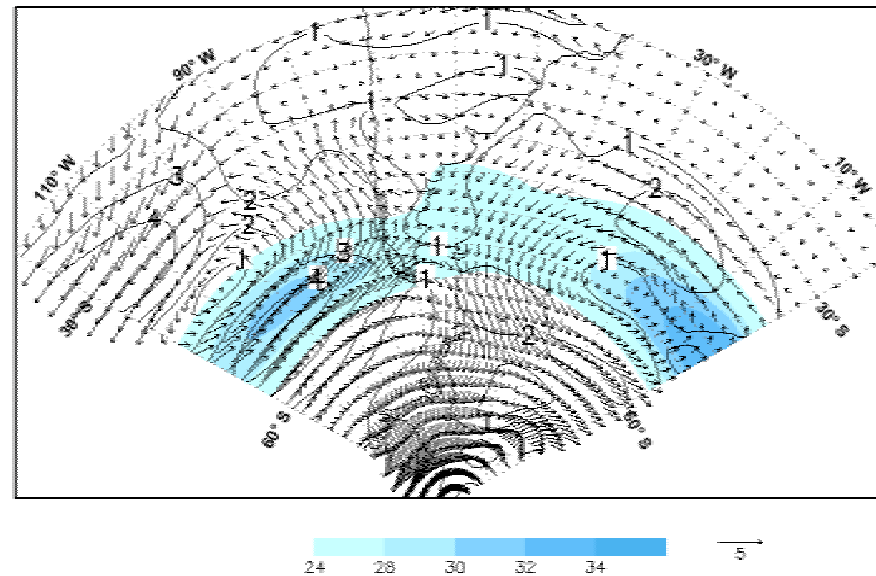


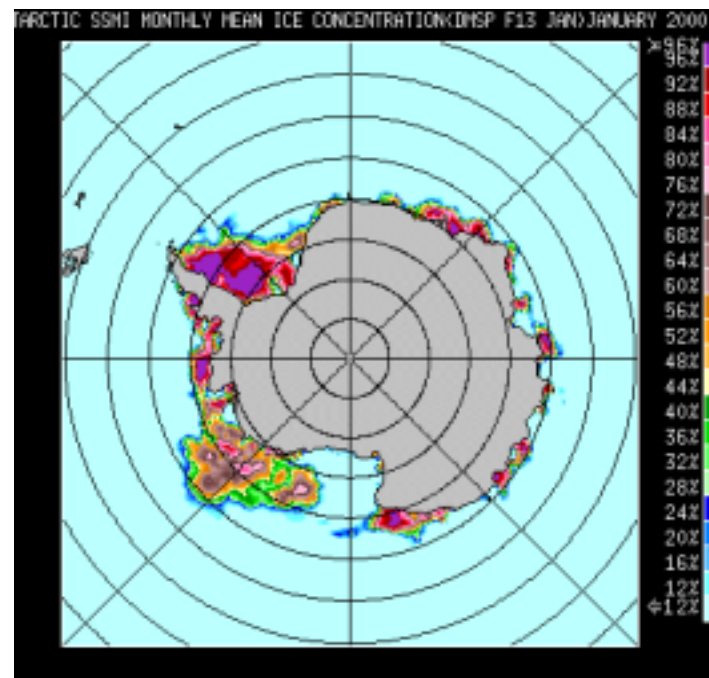
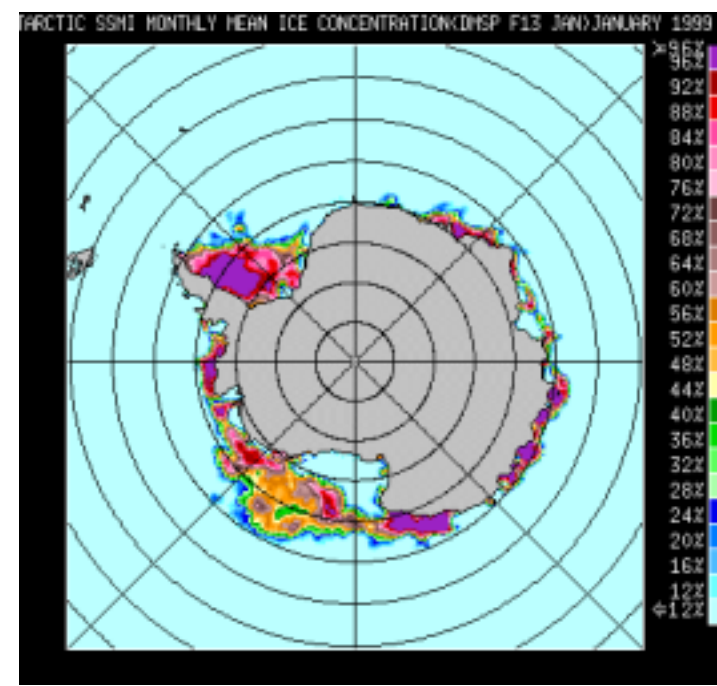
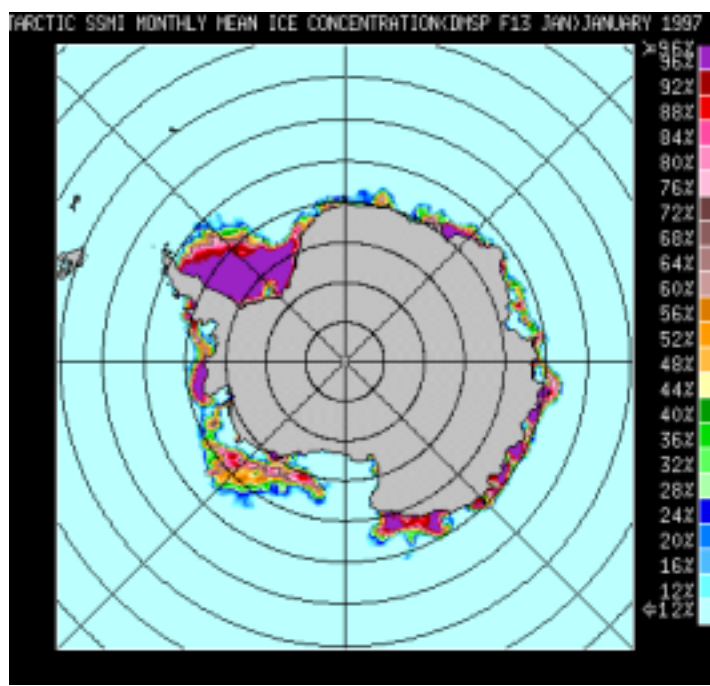


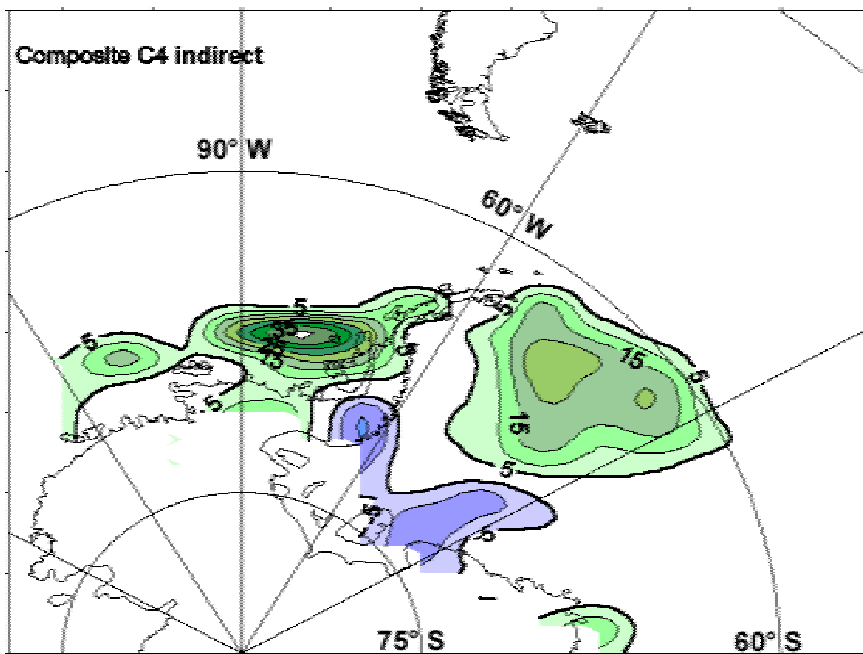
Surface Wind and Temperature Anomalies PC Score 4 Direct



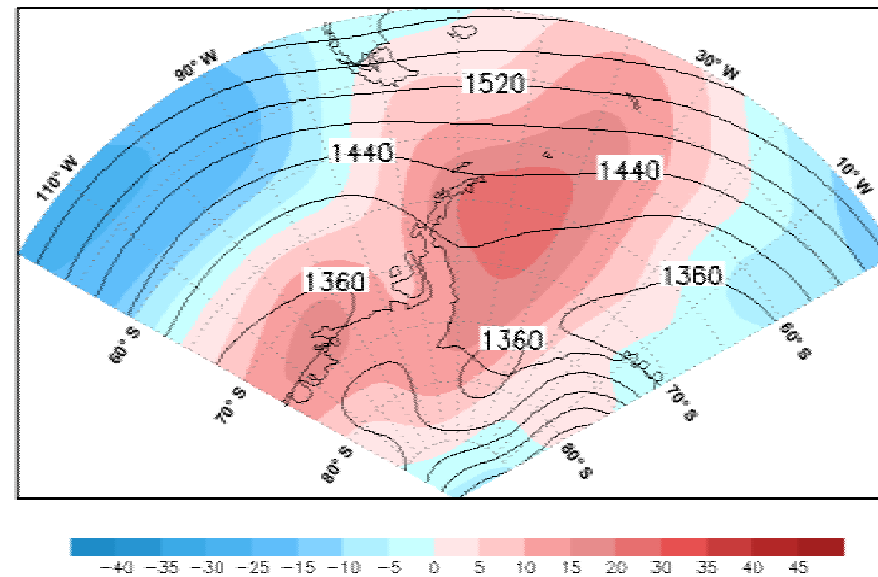
300 hPa Wind and Wind Anomalies PC Score 4 Direct



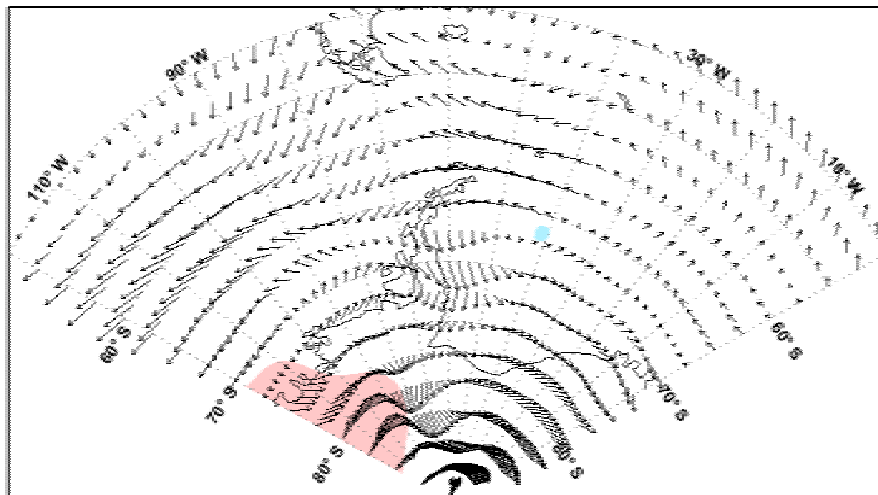




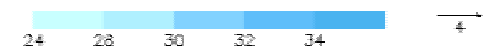
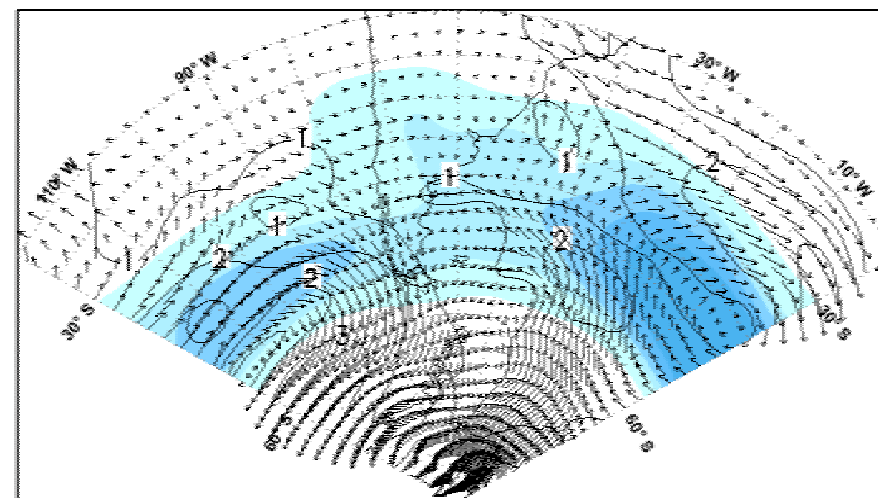
850 hPa Height and Height Anomalies PC Score 4 Indirect

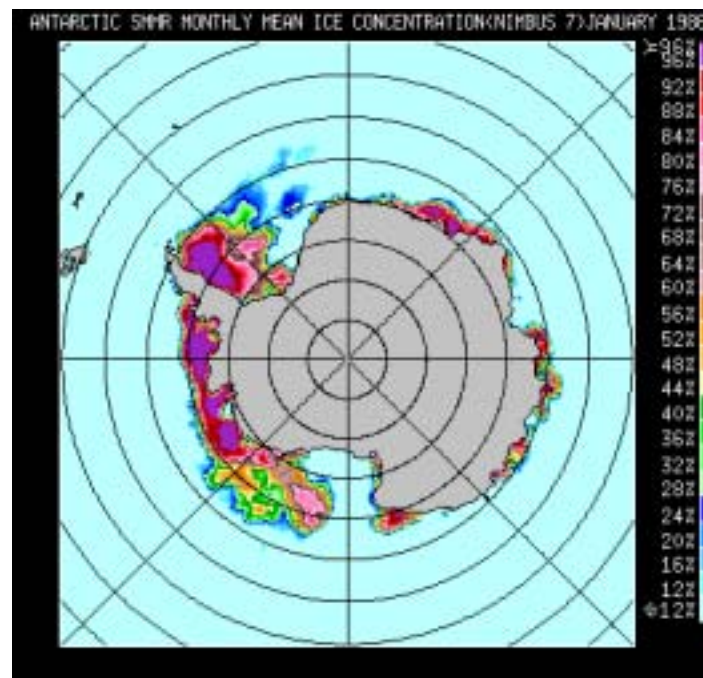
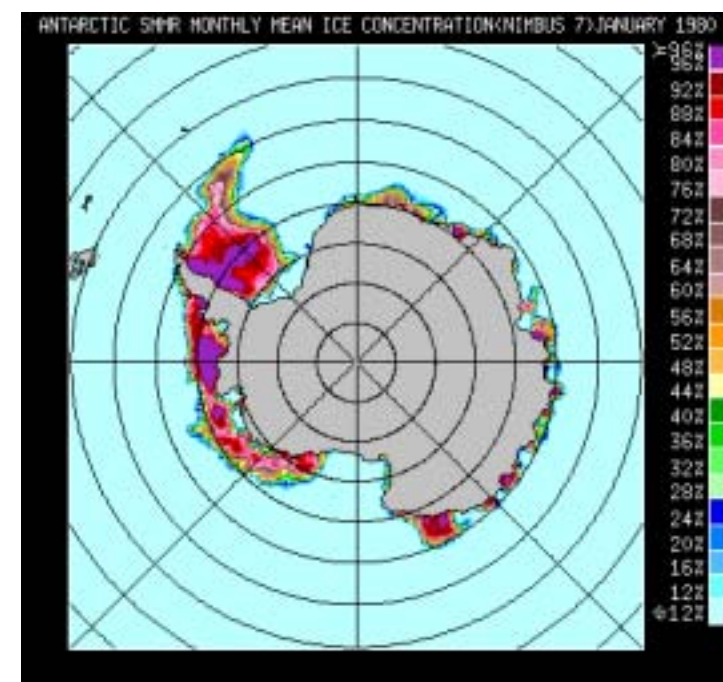
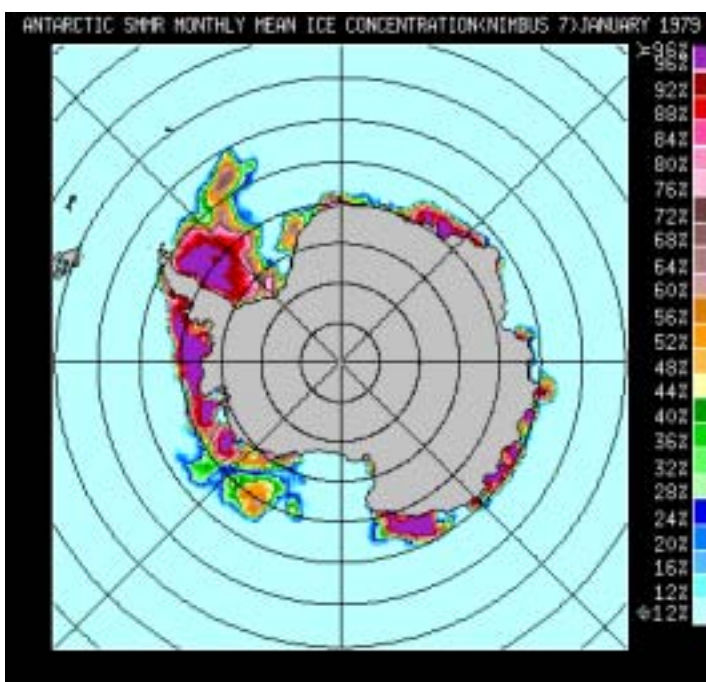


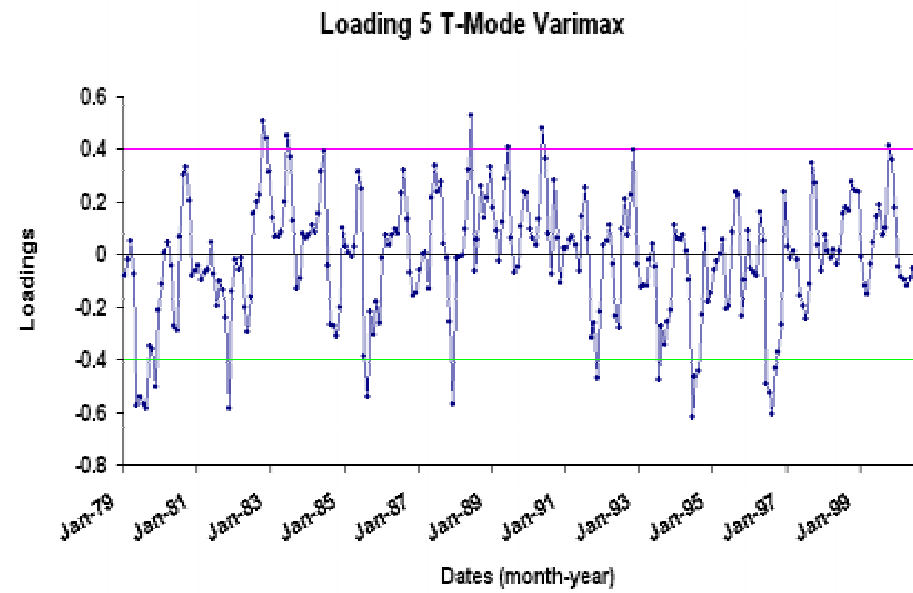
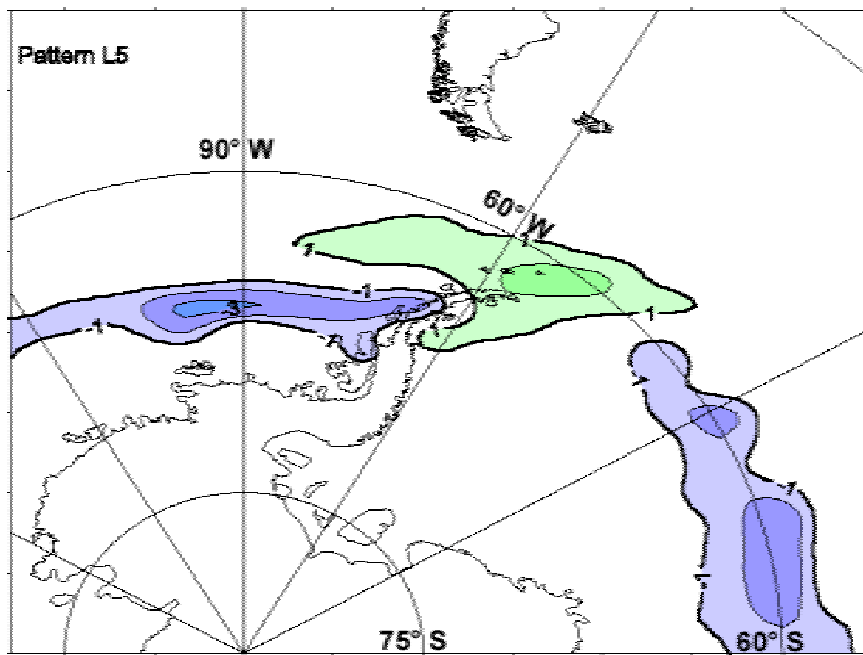
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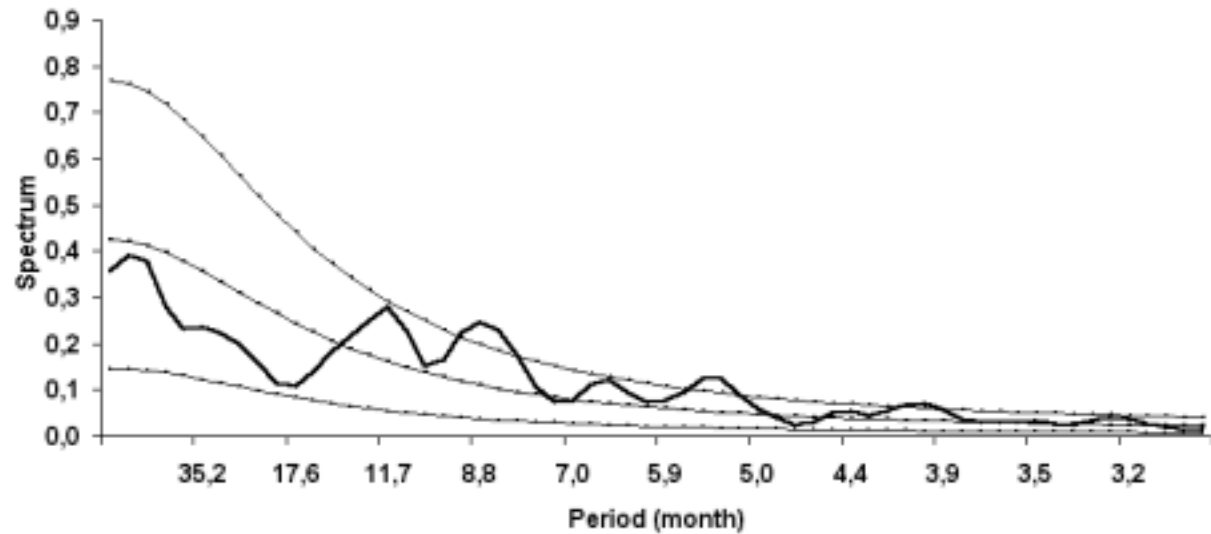
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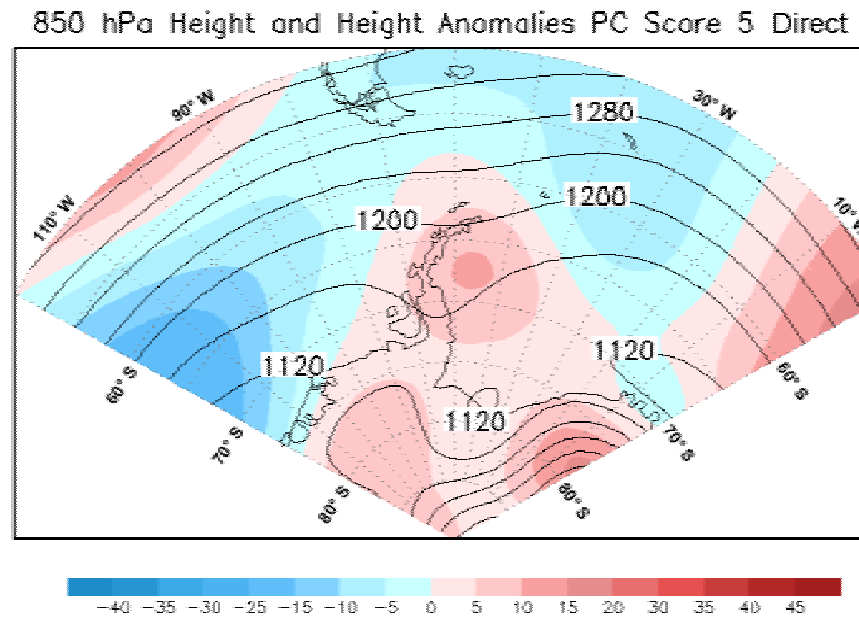
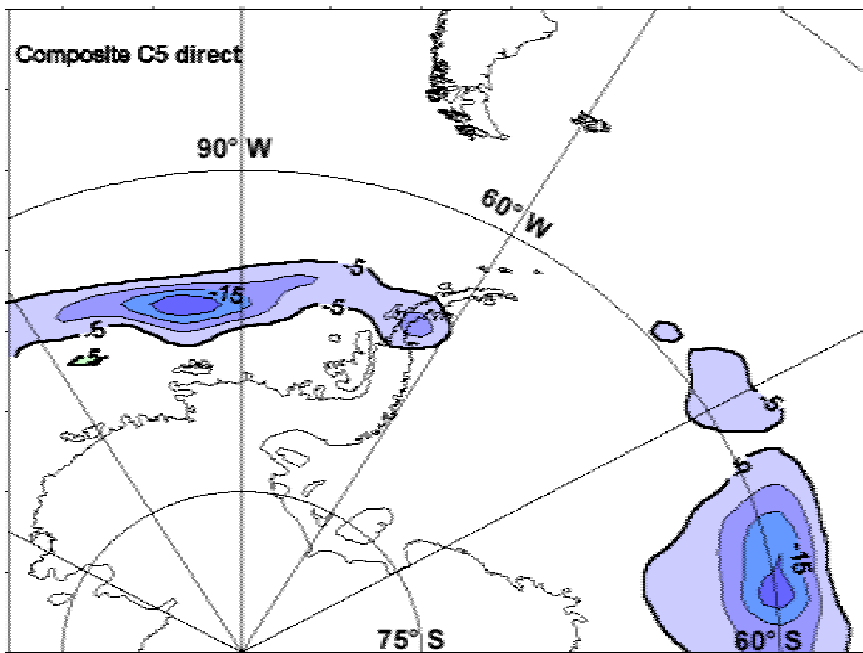




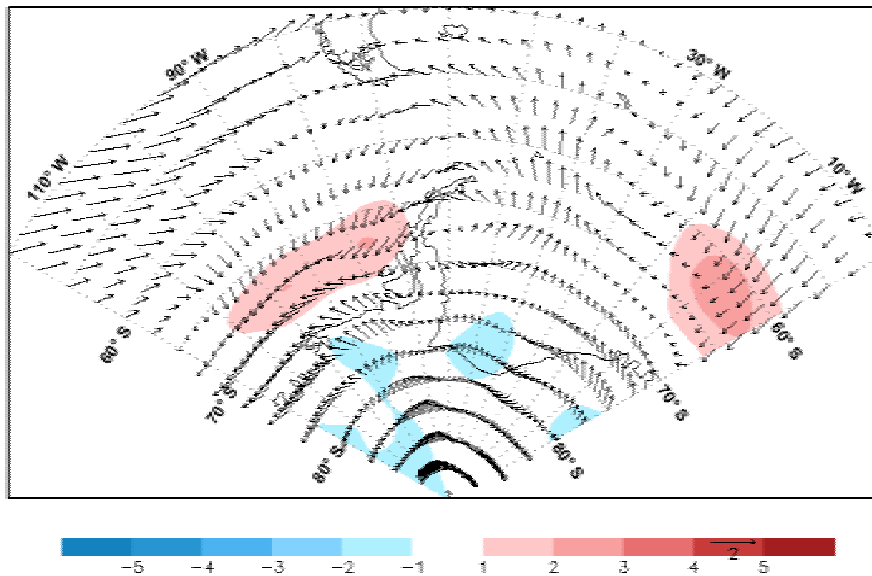


5th PC Score

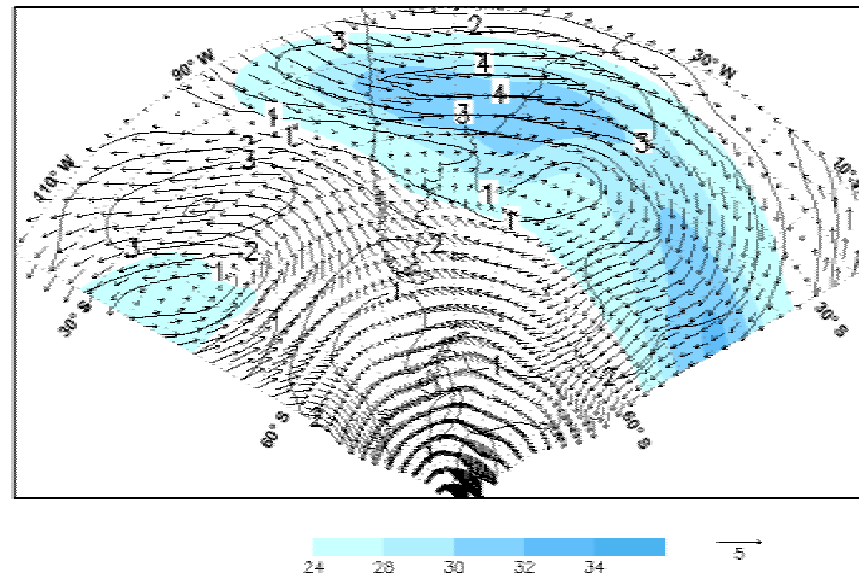




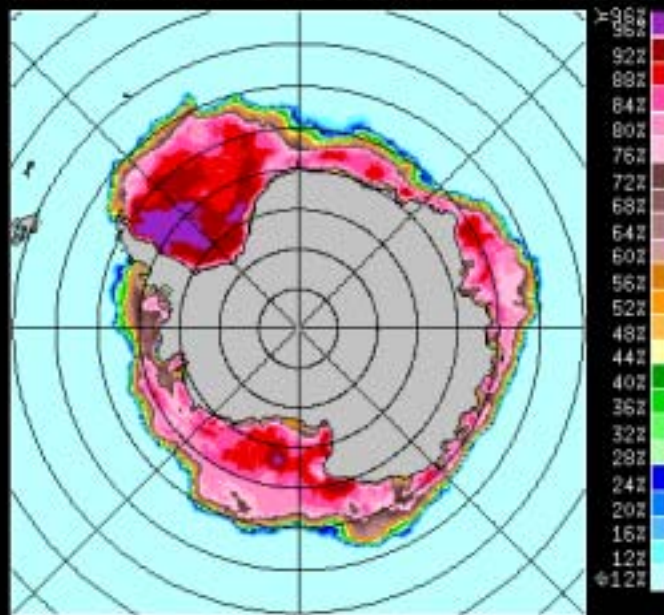
Surface Wind and Temperature Anomalies PC Score 5 Direct



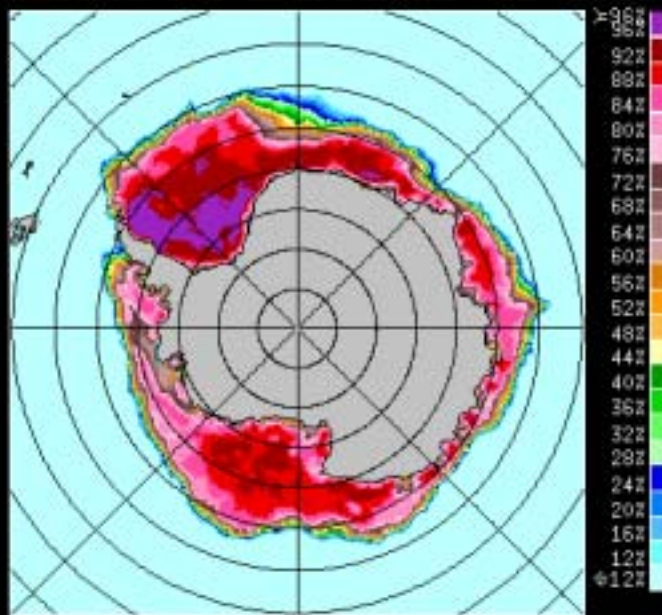
300 hPa Wind and Wind Anomalies PC Score 5 Direct



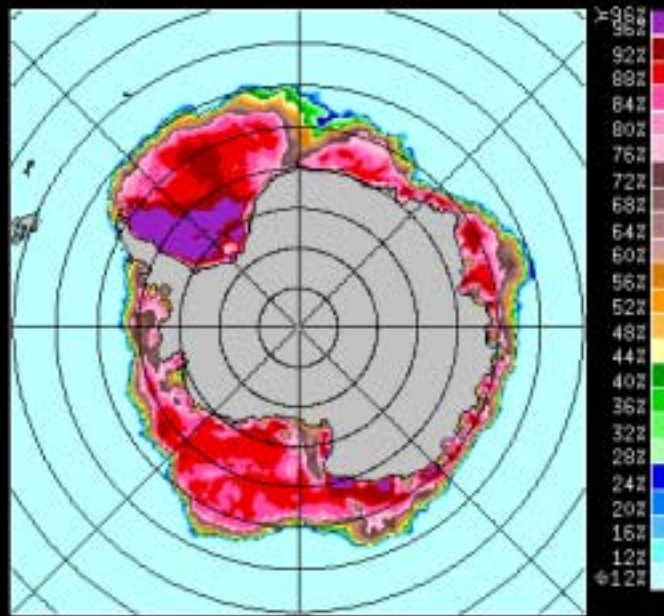
ANTARCTIC SSMR MONTHLY MEAN ICE CONCENTRATION(NIMBUS 7)JUNE 1983



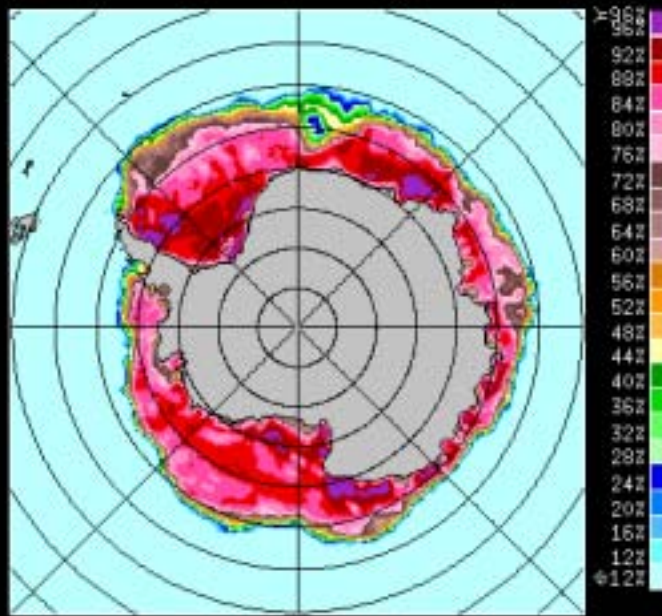
ANTARCTIC SSMR MONTHLY MEAN ICE CONCENTRATION(NIMBUS 7)JUNE 1984

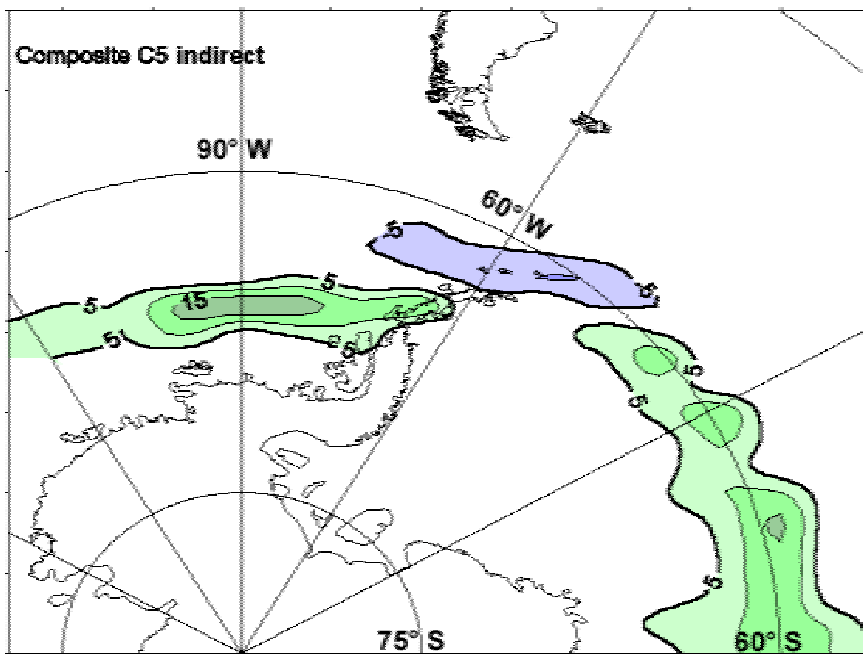


ANTARCTIC SSMI MONTHLY MEAN ICE CONCENTRATION(DMSP F8)JUNE 1983

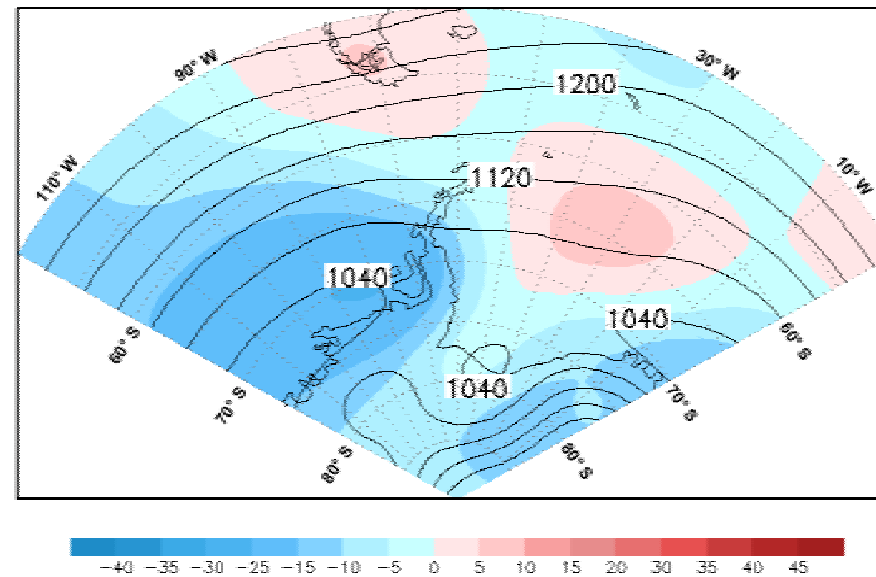


ANTARCTIC SSMI MONTHLY MEAN ICE CONCENTRATION(DMSP F8)JUNE 1984

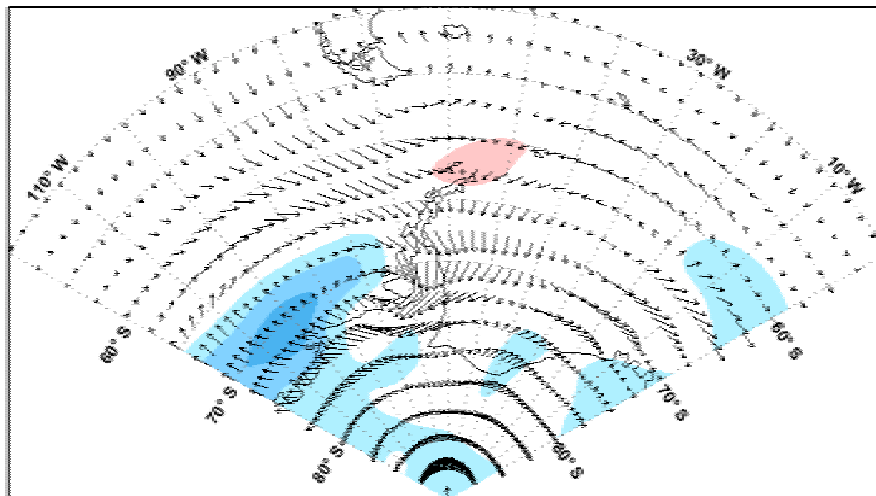




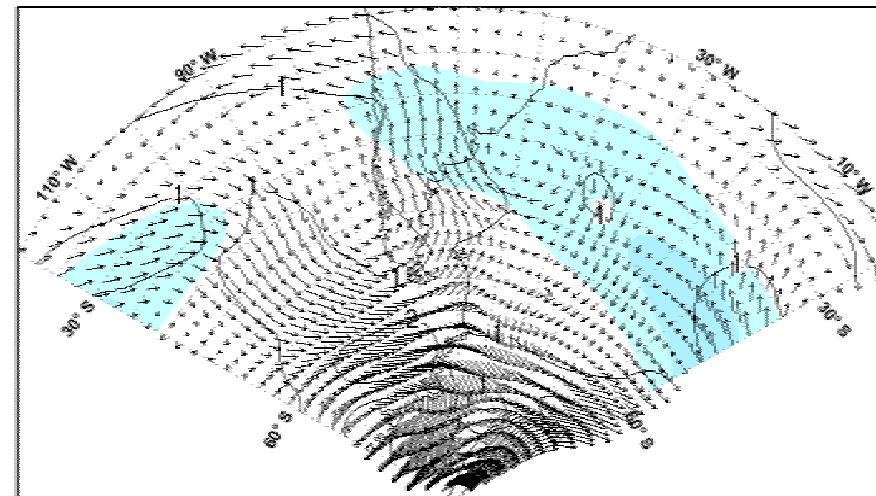
850 hPa Height and Height Anomalies PC Score 5 Indirect

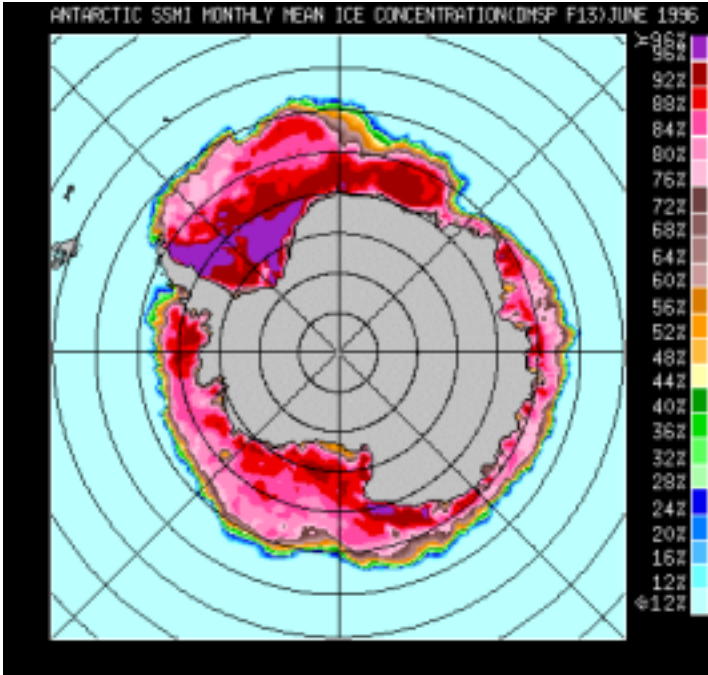
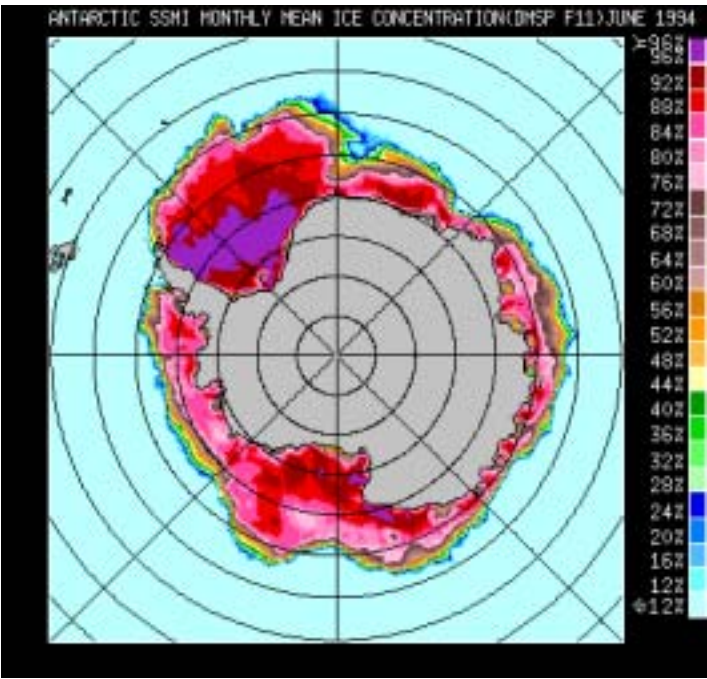
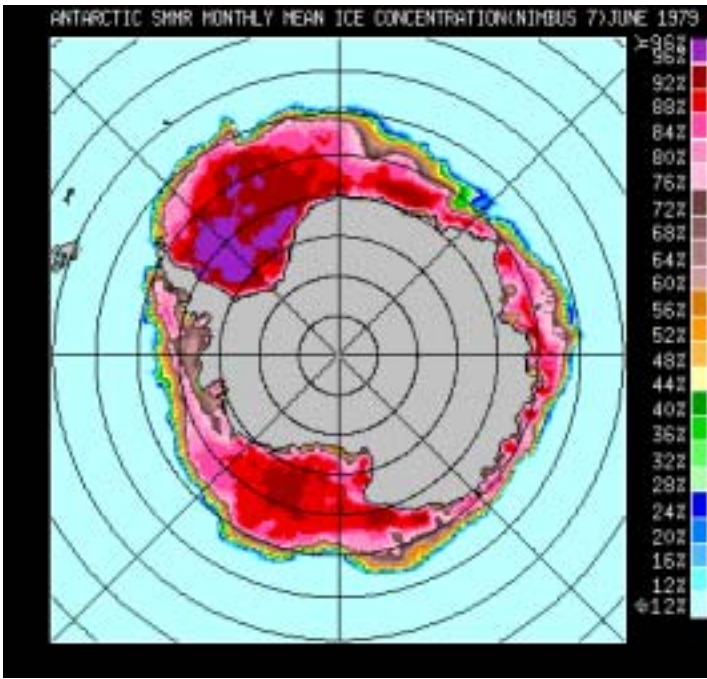


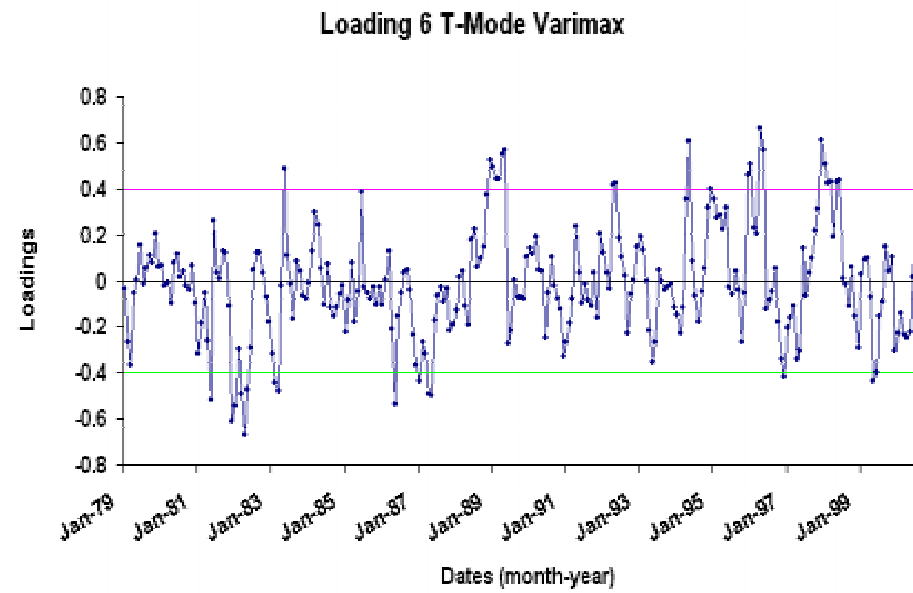
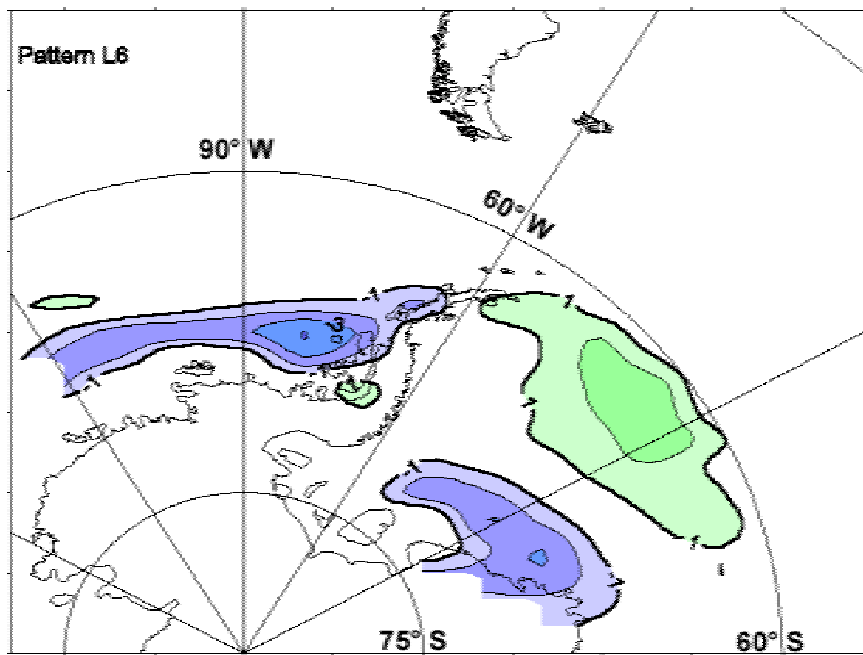
Surface Wind and Temperature Anomalies PC Score 5 Indirect



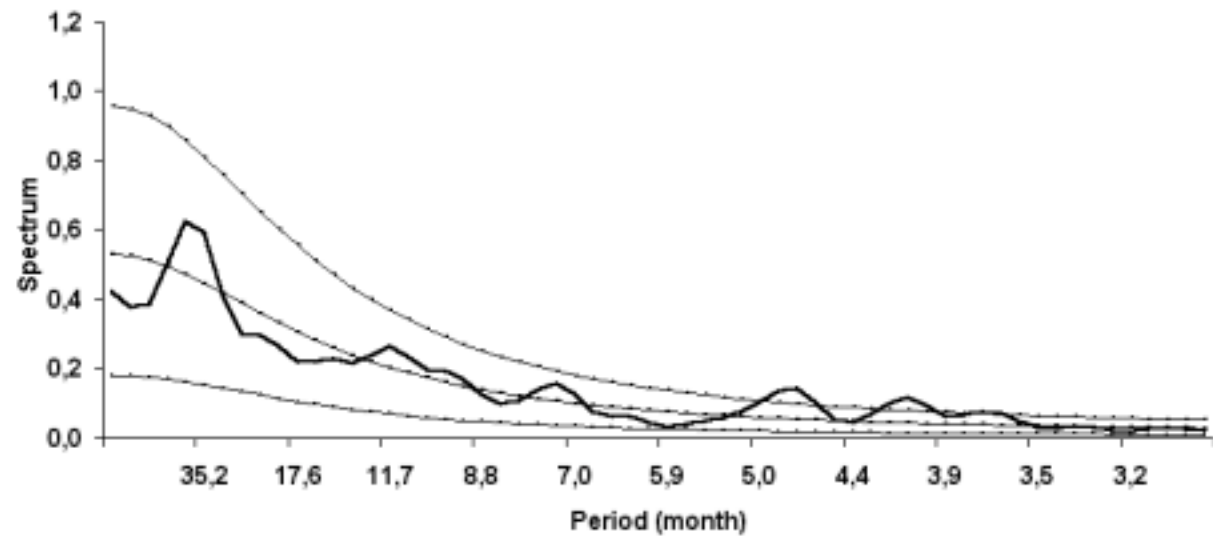
300 hPa Wind and Wind Anomalies PC Score 5 Indirect

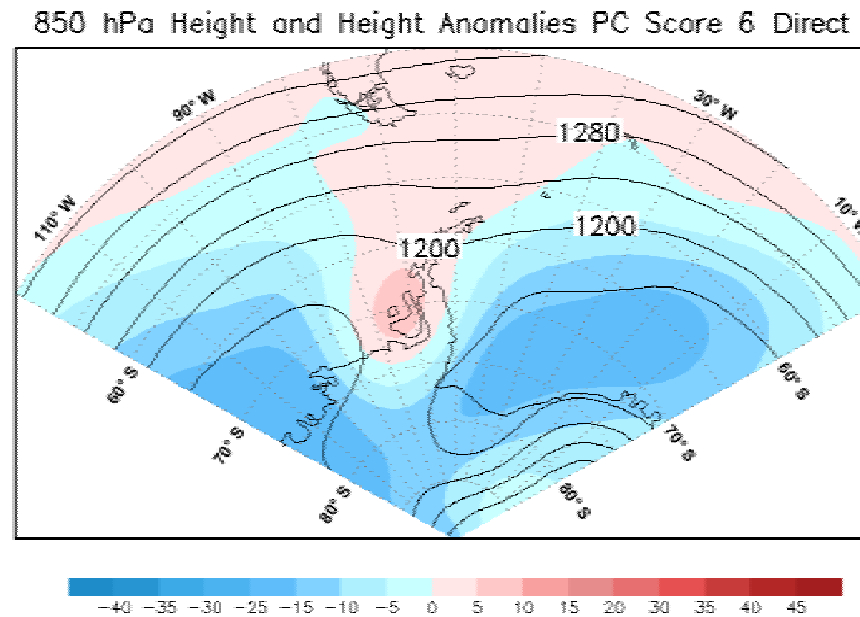
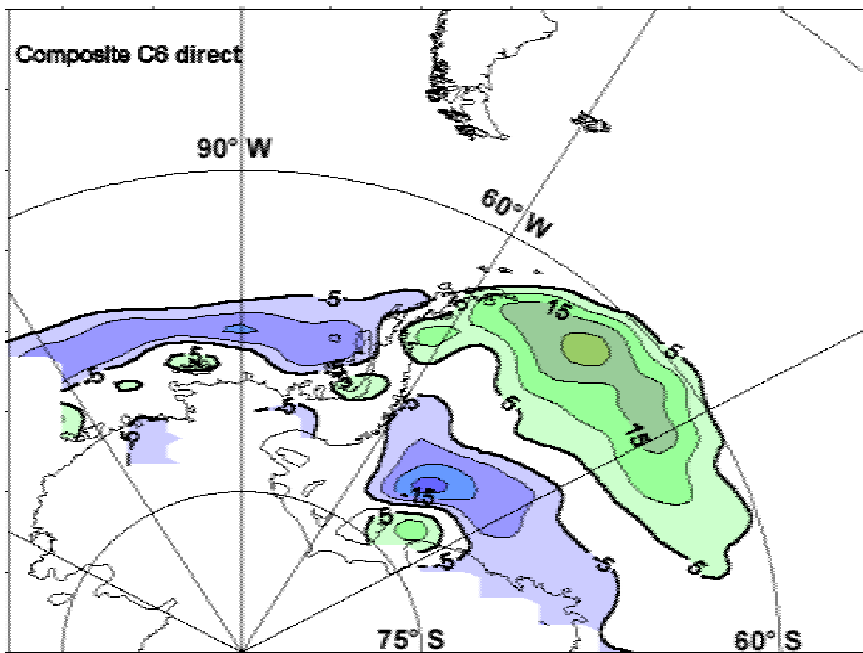




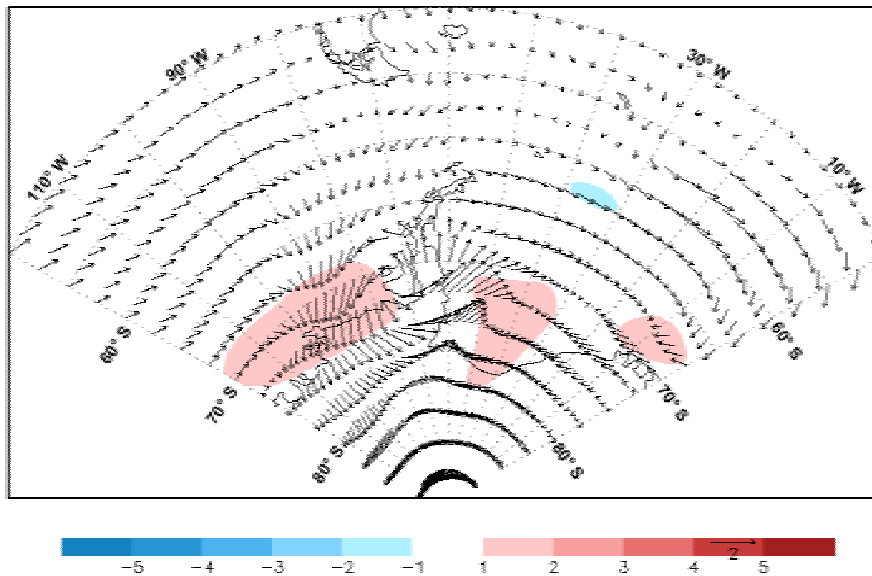


6th PC Score

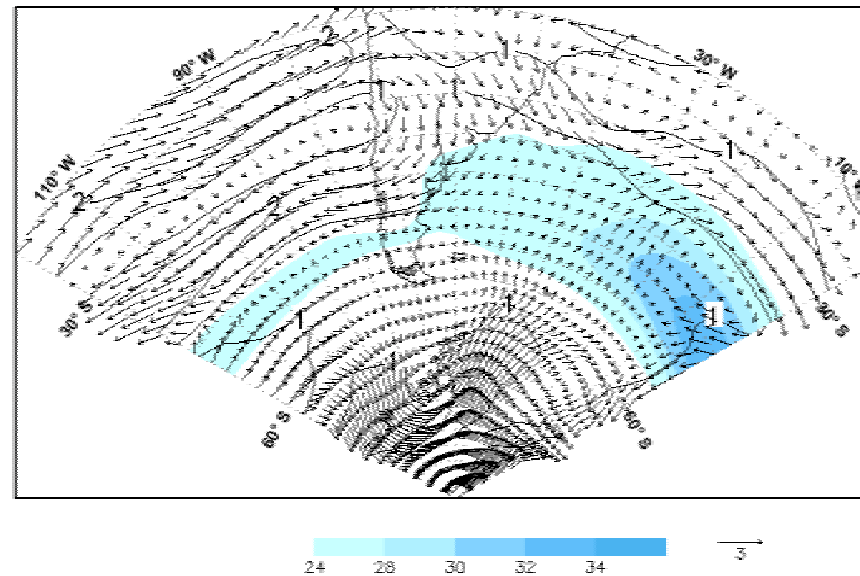




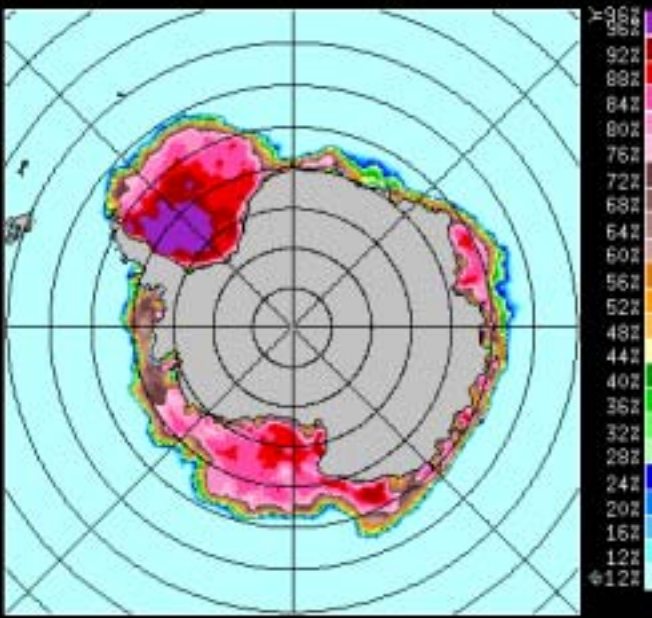
Surface Wind and Temperature Anomalies PC Score 6 Direct



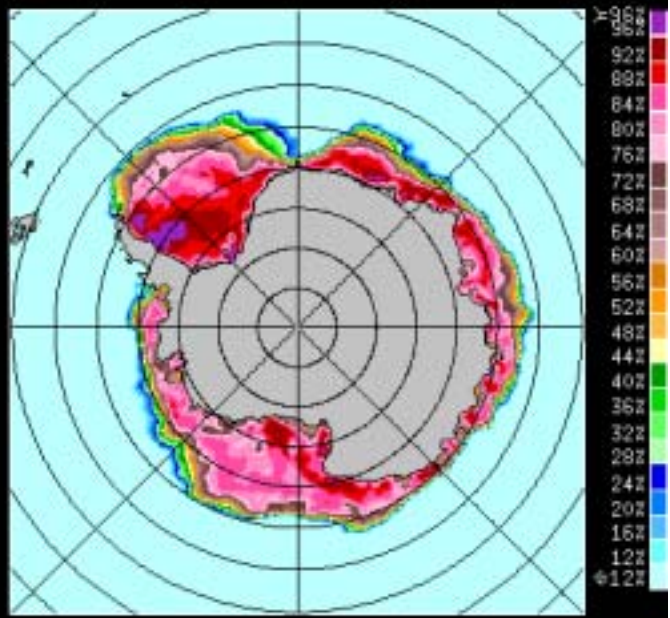
300 hPa Wind and Wind Anomalies PC Score 6 Direct



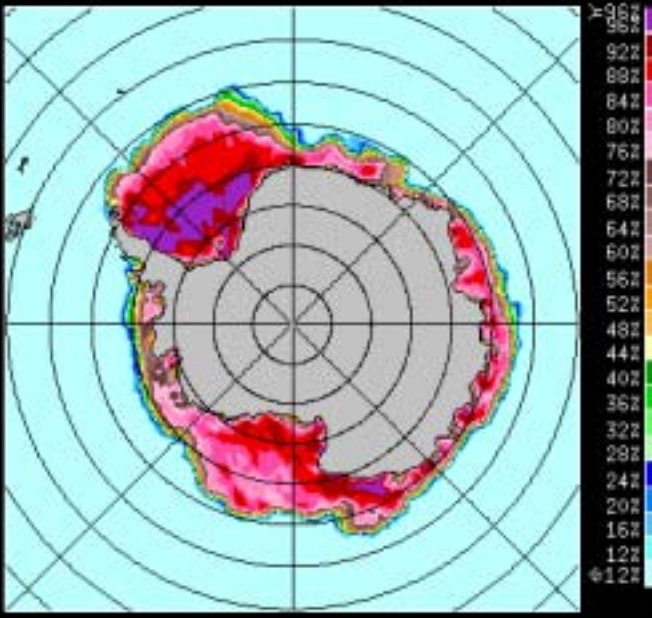
ANTARCTIC SSMR MONTHLY MEAN ICE CONCENTRATION(NIMBUS 7)MAY 1983



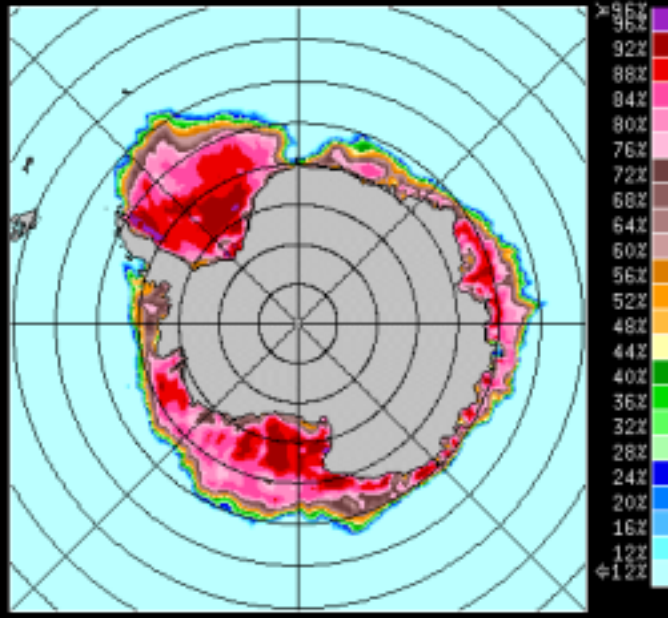
ANTARCTIC SSMI MONTHLY MEAN ICE CONCENTRATION(IMSP F8)MAY 1989

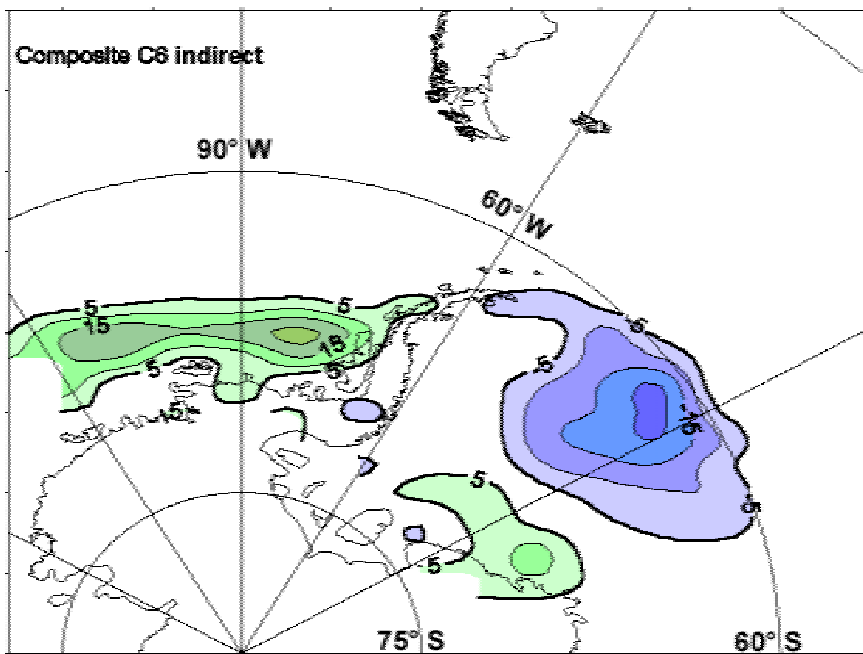


ANTARCTIC SSMI MONTHLY MEAN ICE CONCENTRATION(IMSP F11)MAY 1994

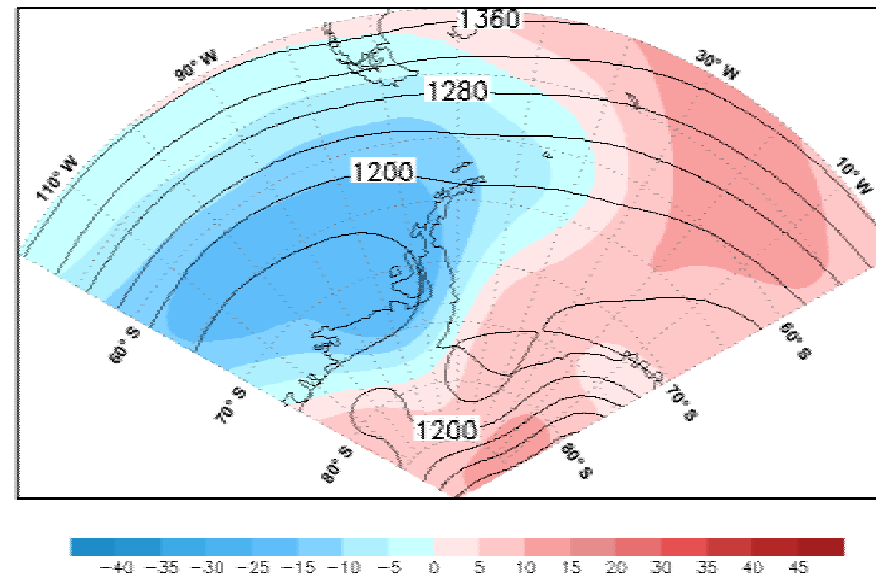


ANTARCTIC SSMI MONTHLY MEAN ICE CONCENTRATION(IMSP F13)MAY/MAY 1990

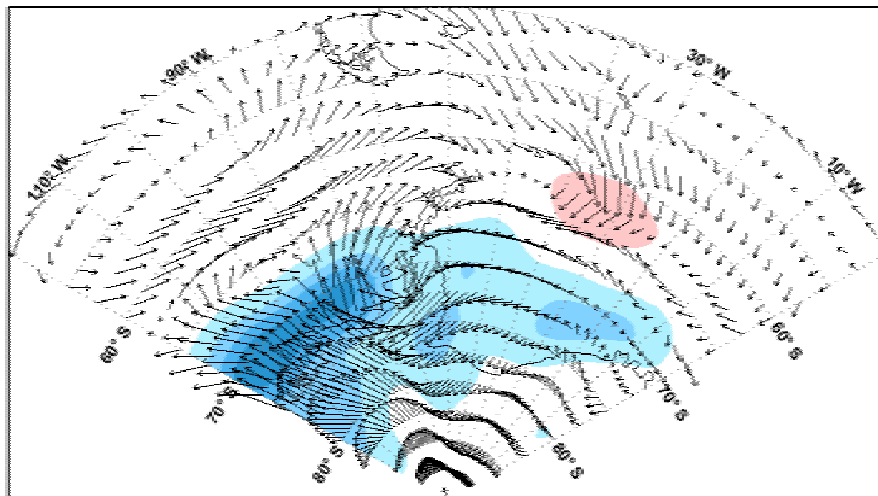




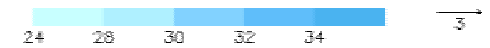
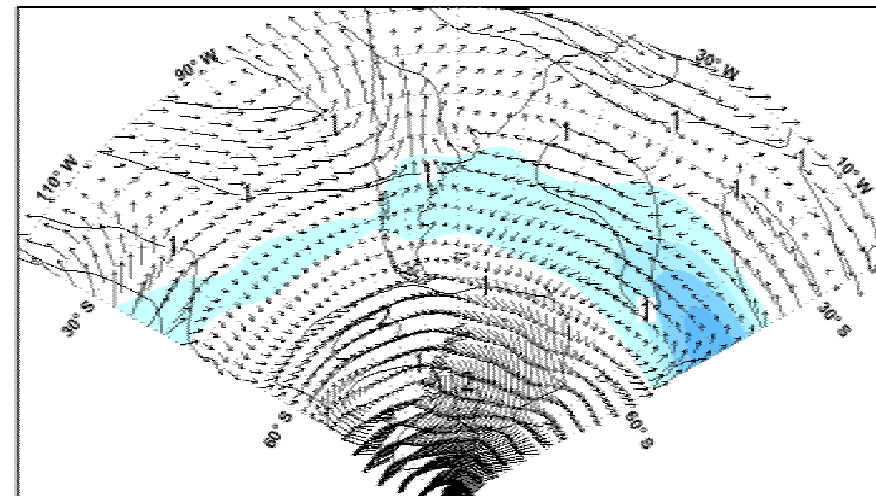
850 hPa Height and Height Anomalies PC Score 6 Indirect

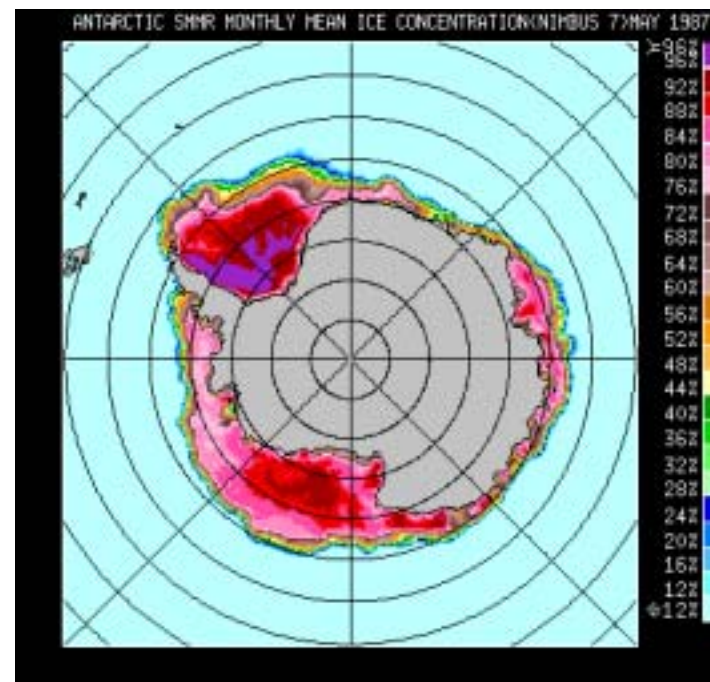
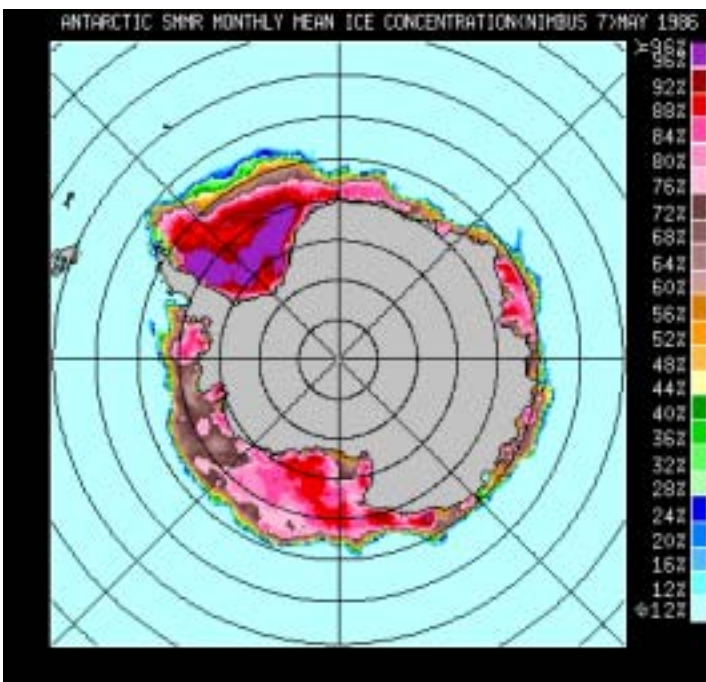
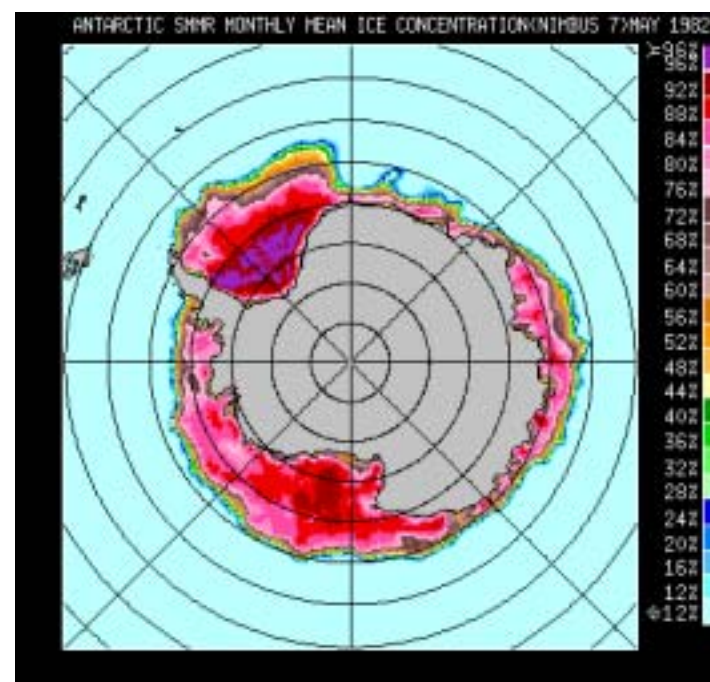
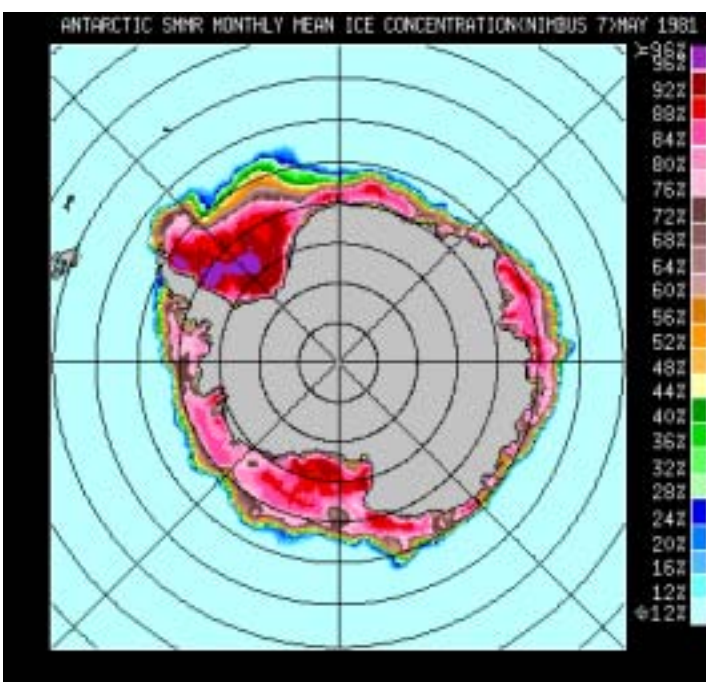


Surface Wind and Temperature Anomalies PC Score 6 Indirect



300 hPa Wind and Wind Anomalies PC Score 6 Indirect





	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
January	L4-	L4- (-)	L3-	L6-	(L4- L6-)	(L3-)	L3-	L4- L3-	L6-	L3-	L6+
February	L4-	L4- (-)	L3-	(L6-)	L6-	L3-	L3-	L3-	(L3-)	L3-	L6+
March	L4-	L4- (-)	L3-	L6-	L6-	(L3-)	L3-	L3-	L3-	L3-	L6+
April	L4-	L3- L4-	L3-	L6- (-)	L3+L4-	(L6+)	L4+	L3-	L3- L6-	L3-	L6+
May	L5-	L1+	L6-	L6- L1- (-)	L6+	(L5+)	(L4+L5+)	L6-	L6-	(L5+)	L6+
June	L5-	L1+	(L1+)	L1- (-)	L5+	L5+	L2+	L2-	(L5+)	L5+L2+	L1- L5-
July	L5-	L1+	L2+	L2-	L1-	L1+	L1-	L2- (-)	L2- L1+(+)	L2+(-)	L1-
August t	L5- L2-	L1+	L2+	L2-	L1-	(L5-)	L1- L5-	L2- (-)	L1+(+)	L2+L1+(-)	L2+L1-
September	L2-	L1+	(L1+)	L2-	L2+	L1-	L1-	L2- (-)	L1+(+)	L2+L1+(-)	L1-
October	L2-	L1+L2+	L1+	L5+(+)	L1- (-)	L1- (-)	L1-	L2-	L1+(+)	L2+(+)	L1-
November	L5- L2-	L1+L2+	L5-	L5+(+)	L1- (-)	L1- (-)	L1-	L2-	L2+	L2+(+)	L1-
December	L4-	L1+	L6-	L4- (+)	(L1-)(-)	(L1-)(-)	(L1-)	L2-	L5-	L6+L4- (+)	(L1-)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
January	(L3+)	L3+(-)	L3+(+)	(L4+)(-)	L3+	L3+	L6+(-)	L4+	L6+(+)	L4+(+)	L4+
February	(L3+)	L3+(-)	(L3+)(+)	(L3+)(-)	L3+	L3+	(L4+)(-)	L3+L4+	L6+(+)	L4+(+)	L4+
March	(L6+L3+)	L3+(-)	L3+(+)	L3+(-)	L3+	L3+	(L4+)(-)	L3+	L6+(+)	L4+(+)	L3+L4-
April	(L4+)	L3+(-)	L4- L6+(+)	(L3+)	L3+	L3+	L6+	L3+	(L4+)	L4+	L4+(+)
May	L5+	L4- (-)	L1+L6+(+)	(L1- L6-)	L6+	(L6+)	L6+	L1-	L6+	L4+L6-	L1- (-)
June	L1-	L1+L2- (-)	L1+(+)	L1-	L5-	(L2-)	L5-	(L1-)	L2+L6+	L1- L6-	L1- (-)
July	L1- L2- (-)	L1+	L1+L2+(-)	L5- L2+	L5- L1+	L2-	L5-	L2- (+)	L2+(-)	L1- (-)	L2+L1-
August t	L2- L1- (-)	L1+	L2+(-)	L1-	L5-	L1+	L5-	L2- (+)	L2+(-)	L2- L1+(-)	(L4- L1-)
September	L2- (-)	L2+	L2+(-)	L2+	L1- L2-	L1+	L5-	L2- (+)	(L1+L2+)	(L4-)(-)	(L6+L1-)
October	L2- (-)	L1+	L2+(-)	(L4-)(-)	L2-	(L4+)(-)	L1-	L1+L2+(+)	L2+	L5+	(L4-)
November	L2- (-)	L5- L1+	L1- L5+(+)	L4- (-)	L4-	(L4-)(-)	L1-	L1+L2+(+)	(L1- L4+)	(L5+)	L4+(+)
December	L3+(-)	L3+	(L4+)(-)	L3+(-)	L6+	L6+(-)	L4+L6-	L6+(+)	L4+	L4+	L4+(+)

- We described the strongest recurring spatial structure of the sea ice concentration anomalies, when do they present and how they are coupled to different atmospheric variables, using Principal Components Analysis.
- We have presented 6 PC scores rotated Varimax patterns, direct and inverse mode summing up 12 patterns that represent the most important spatial features that dominate sea ice variability in the Weddell, Amudsen and Bellinghausen Seas, and their associated circulation (height, temperature, and wind). These 12 patterns, or their combinations, describe completely the behavior of monthly means sea ice concentration anomalies. We can represent each month of the 22-year period under study with one pattern or a combination of two (Table 1).

- The strongest ice concentration anomaly pattern over 1979-2000 period is a dipole anomaly structure with the largest positive values located at 60° S in the Weddell Sea and the north extreme of Antarctic Peninsula over Bellinghausen Sea and negative values at 67° S corresponding to Amundsen Sea, modulated by a 9.8-month wave with a secondary peak 44-month.
- Another dipole anomaly structure, but in this case the largest values are negative and located at 65° S in the Bellinghausen Sea and the north extreme of Antarctic Peninsula and positive lesser values at 60° S in the Weddell Sea between 30° and 0° W, is represented by the second PC score. Both components correspond to winter and spring months (44-month wave).
- Another dipole anomaly structure, but in this case between the inside sector of the Weddell centered at 67° S, 30° W (most important anomaly), and the coastal area of Bellinghausen and Amudsen seas, is presented in summer and autumn months and was characterized by PC3 (~12-month wave modulated by a longer wave).

- The fourth principal component PC4 is characterized by both seas at both sides of Antarctic Peninsula with the same sign of anomaly and a very little center with opposite sign in the inside sector of the Weddell Sea (~6-month wave)
- Two negatives anomalies one over the Bellinghausen and Amudsen seas and the other over the Weddell between 0° and 40° W at 60° S, and a positive anomaly over the north of Antarctic Peninsula and it surrounding area, corresponding to the external region of the three seas were identified in PC5. This is a pattern of winter and spring months and it is not a bipolar structure (8.8-month wave)
- The last pattern we introduced (PC6) is a structure of anomalies that is present principally on summer and autumn months, but there exist some winter months also. It is a dipole anomaly structure at the Weddell, with positive values at the external region and negatives anomalies at the inside portion. It presents also a negative anomaly at the Bellinghausen-Amudsen seas that extent over Antarctic Peninsula (4.8-month wave).

- Patterns that can be modulated by the Antarctic Circumpolar Wave or the Quasiquadriennial wave are PC1 and PC2 that correspond to the behavior to winter and spring months over external regions of Bellinghausen, Amudsen and Weddell seas.
- Summer and autumn characteristics are modulated by an annual wave, a half-year wave, and a very long wave (10-years or more).
- As it can be seen the dipole mode between Bellinghausen and Weddell seas is not the only one feature present in sea ice concentration (e. i. patterns PC4 and PC5).
- We have not found any evidence of a straight connection between ENSO and the different patterns, but some of them are more present at one phase of the event than at the other (82-83, 87-88, 90 ENSO warm events with more Ice at A-B Seas)
- Principal Components Analysis has been useful for identifying unique patterns in the sea ice concentration anomaly and has allowed us to link these patterns with contemporary atmospheric circulation.

January 1979

