Correlation and Trend Studies of the Sea Ice Cover and Surface Temperatures in the Arctic

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ABSTRACT

Co-registered and continuous satellite data of sea ice concentrations and surface ice temperatures from 1981 to 1999 are analyzed to evaluate relationships between these two critical climate parameters and what they reveal in tandem about the changing Arctic environment. During the 18-year period, the actual Arctic ice area is shown to be declining at a rate of 3.1 ± 0.4 % decade^{-1} while the surface ice temperature has been increasing at 0.4 ± 0.2 K decade^{-1}. Yearly anomaly maps also show that the ice concentration anomalies are predominantly positive in the 1980s and negative in the 1990s while surface temperature anomalies were mainly negative in the 1980s and positive in the 1990s. The yearly ice concentration and surface temperature anomalies are shown to be highly correlated indicating a strong link especially in the seasonal region and around the periphery of the perennial ice cover. The surface temperature data are also especially useful in providing the real spatial scope of each warming (or cooling) phenomenon that usually extends beyond the boundaries of the sea ice cover. Studies of the temporal variability of the summer ice minimum also reveal that the perennial ice cover has been declining at the rate of 6.6% decade^{-1} while the summer surface ice temperature has been increasing at the rate of 1.3 K decade^{-1}. Moreover, high year-to-year fluctuations in the minimum ice cover in the1990s, may have caused reductions in average thickness of the Arctic sea ice cover.

Significant Findings:

The relationships between two critical climate parameters of the Arctic, namely ice concentration and surface temperatures, have been studied in tandem to evaluate what new information they could provide about the changing Arctic environment. During the 1981 to 1999 period, the actual Arctic ice area is shown to be declining at a rate of 3.1 ± 0.4 % decade^{-1} while the surface ice temperature has been increasing at 0.4 ± 0.2 K decade^{-1}. Yearly anomaly maps also show that the ice concentration anomalies are predominantly positive in the 1980s and negative in the 1990s while surface temperature anomalies were mainly negative in the 1980s and positive in the 1990s. The yearly ice concentration and surface temperature anomalies are shown to be highly correlated indicating a strong link, especially in the seasonal region and around the periphery of the perennial ice cover. The surface temperature data are also especially useful in providing the real spatial scope of each warming (or cooling) phenomenon that usually extends beyond the boundaries of the sea ice cover. Studies of the temporal variability of the summer ice minimum also reveal that the perennial ice cover has been declining at the rate of 6.6% decade^{-1} while the summer surface ice temperature has been increasing at the rate of 1.3 K decade^{-1}. This large rate of decrease in the relatively thick perennial ice cover causes overall decrease in thickness that is facilitated by high year-to-year fluctuation in the minimum ice cover in the1990s. The high fluctuation means increasing percentage of the relatively thin second year ice in the perennial ice cover and therefore decreasing overall thickness of the perennial ice cover.

Popular Summary:

During the last century, global temperatures have been increasing at the rate of about 0.5 K per decade. Such increases in temperature are expected to be amplified in the Arctic because of feedback effects between the ice surface and the atmosphere. Recent reports already show that the sea ice cover has been retreating by about 3% decade^{-1}, while submarine sonar data show a thinning by a few meters during the last few decades. The Arctic climate system is however complex and further studies are needed to better understand the changing Arctic environment.

We use co-registered and simultaneous satellite data sets of ice concentration and ice temperature to gain insight into the Arctic phenomenon. Our results, which cover a different period than those used in previous reports, show that the actual Arctic ice area has been declining at a rate of 3.1 ± 0.4 % decade^{-1} while the surface ice temperature has been increasing at the rate of 0.4 ± 0.2 K decade^{-1}. If these rates continue, the Arctic would look very different in the next century. What is even more impressive is the result from similar analysis of the perennial sea ice cover. This study shows that the perennial ice cover as observed during summer minimum has been declining at the rate of 6.6% decade^{-1} while the summer surface ice temperature has been increasing at the rate of 1.3 K decade^{-1}. The rate for perennial ice cover is about twice that of the total ice cover while the temperature increase for the same period is more than three times. The perennial ice cover is more difficult to melt than the seasonal ice cover because it consists mainly of multiyear ice which is much thicker (by a factor of 3 or more) than first year ice. A decreasing percentage of the perennial ice cover would already cause a decreasing thickness. In addition, high year-to-year fluctuations in the perennial ice cover is observed in the 1990s but not in the 1980s. A large year-to-year fluctuation, which is of the order of 1×10^6 to 2×10^6 km^2, means an increasing fraction of the relatively thinner second year ice cover which in turn favors a growing percentage of the thinner second year ice in the perennial ice cover. This will make the perennial ice cover even thinner.

Yearly anomaly maps were studied in detail and the results show that the ice concentration anomalies are predominantly positive in the 1980s and negative in the 1990s while surface temperature anomalies were mainly negative in the 1980s and positive in the 1990s. The spatial features of the anomalies are different from one year to another and events like the cooling due to the Pinatubo eruption, are reflected in the data. The yearly ice concentration and surface temperature anomalies are shown to be highly correlated indicating a strong link between these two variables, especially in the seasonal region and around the periphery of the perennial ice cover. The surface temperature data are also especially useful in providing the real spatial scope of each warming (or cooling) phenomenon that usually extends beyond the boundaries of the sea ice cover. This was especially true in 1998, which is regarded currently as the warmest year of the 19th century. The warming anomalies in 1998 were indeed unusual and extensive, but they were generally confined in the Beaufort Sea and North America while in Northern Russia and the Laptev Sea, a slight cooling was going on.

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year fluctuations in the minimum ice cover in the1990s, may have caused reductions in average thickness of the Arctic sea ice cover.

INTRODUCTION

The Arctic is a special region of interest because it is expected to provide early signals associated with a potential change in climate (Budyco, 1966; Manabe and others, 1992; Alley, 1996). Because of observed global warming especially in the second half of the 1990s (Jones and others, 1999), it is important to know how such increases in temperature are reflected in the Arctic. Recent reports already show that the sea ice cover has been retreating by about 3% decade^{-1} (Bjorgo and others, 1997; Parkinson and others, 1999), while submarine sonar data show a thinning by a few meters (Rothrock and others, 1999; Wadhams and Davis, 2000). The Arctic climate system is, however, a very complex system affected by periodic atmospheric phenomena, like the North Atlantic and Arctic Oscillation (Mysak, 1999), and unexpected changes in the dynamics of the ice cover. Accurate interpretation of observed Arctic changes thus requires a better understanding of Arctic processes.

The key objective of this study is to make simultaneous use of satellite sea ice concentration and surface temperature data to gain insight into the changing status of the Arctic climate. Co-registered data sets of these two geophysical variables are examined to obtain a better understanding of how the various components of the climate system interact with one another and how they act in-concert to influence the system. Previous studies on the variability and trends of the Arctic sea ice cover have been done using solely satellite passive microwave data or submarine sonar data. In this study, trends and spatial changes in the ice cover are analyzed in conjunction with trends and changes in surface temperatures. Anomalies in ice concentration and surface temperatures are examined on a year to year basis and relationships between these two variables are examined. The results are also used to evaluate observed changes in the Arctic, interpret trends in the total ice cover and its surface temperature, and better understand the status of the perennial sea ice cover.

VARIABILITY AND TREND OF THE SEA ICE COVER

Although the time series currently available for sea ice cover is slightly longer, the time period used in this study is from 1981 to 1999 since it is the period in which coincident and continuous infrared and passive microwave satellite data are available. The procedure for deriving ice concentration from satellite passive microwave data has been described in previous papers [Steffen and others, 1992] and will not be repeated here. The error associated with the ice concentration data is about 5 to 15% during dry surface conditions and gets higher when the surface gets wet as the snow melts in spring and when meltponds are formed over ice floes in the summer. In this study, the ice concentrations are derived using the Bootstrap Algorithm as described in Comiso and others (1997). The values and trends may therefore be slightly different from those reported elsewhere (Bjorgo and others 1997; Parkinson and others, 1999) even for identical periods.

Ice concentration maps are used to derive monthly ice extent, actual ice area, and average ice concentrations within the pact as done previously (Comiso and others, 1997; Parkinson and others, 1999). These are in turn used to calculate anomalies in monthly ice extent, actual ice area, and ice concentration by subtracting the 18 month climatological averages created for each of the 12 months of the year. The anomalies in ice extent, ice area and ice concentration for each month from August 1981 through July 1999, which are also used for trend studies, are shown in Figure 1. Yearly averages were also calculated for analysis of the yearly variability and associated trend. The yearly averaging was done from August of one year to July the following year to be able to compare yearly differences between different ice seasons as opposed to different annual averages that would start from the middle of one ice season to the middle of another.

The plot on ice extent anomalies (Figure 1a) show significant variability with a standard deviation of 0.33×10^6 km^2. Simple linear regression of the data yielded a trend of -275,940 ± 43,056 km^2 decade^{-1} or –2.23 ± 0.35% decade^{-1}. This is significantly less than –2.8%/decade reported previously by Parkinson and others (1999) but the latter was for a slightly different time period (i.e., 1978-1996). Also, a different ice data set was used (i.e., Team algorithm as described in Comiso and others, 1997) as indicated earlier. Anomalously low values occurred in 1989, 1990, 1993, 1995, and 1998 while an anomalously high value is apparent in 1996. The regression results from the yearly data yielded –2.24 ± 0.57% decade^{-1} which is almost the same as that from the monthly anomaly data but with higher error.

The variability in the anomalies in actual ice area (Figure 1b) is comparable to that of extent at 0.33×10^6 km^2. However, the trend in ice area is significantly larger at – 338,573 ± 40,353 km2 decade^{-1} or –3.12 ± 0.37% decade^{-1}. This is more comparable with previous reports for the 1979 to 1996 period. Again, the yearly averages yielded similar trends but larger error at –3.13 ± 0.56% decade^{-1}.

The difference between the ice extent trend and the ice area trend is basically caused by a net negative trend in ice concentration (Figure 1c) which is estimated at –0.94 ± 0.18%/decade. The change in the estimated ice concentration may not be all associated with a change in true ice concentration because it can be partly due to a change in the areal coverage in meltponding. The satellite sensor cannot distinguish between real open water and meltponded ice surfaces. Thus, a warming that leads to a corresponding increase in the extent of meltponding would cause a similar trend in ice concentration.

VARIABILITY AND TREND OF SURFACE TEMPERATURES

The procedure for deriving the surface temperature from satellite infrared data has been discussed elsewhere (Comiso, 2000). The error in the monthly data has been estimated to be less than 3 K as inferred from comparative analysis with in situ measurements. The precision of the geophysical products is likely better than the stated accuracy since the radiometer has an RMS error of less than 1K. Also, available situ measurements do not really provide the ideal validation data set since the temperatures are taken at a specific location and the instruments are sometimes affected by environmental factors such as snow and wind.

The monthly average anomalies in surface temperatures over sea ice, Greenland, and high latitude land areas from August 1981 through July 1999 are presented in Figures 2a, 2b, and 2c, respectively. The temperature anomalies over sea ice show significant interannual variations with standard deviation of about 1.3 K. The result of a linear regression on the monthly anomalies yielded a trend of 0.44 ± 0.17 K $decade^{-1}$ while the yearly averages for the same data set provided a trend of 0.44 ± 0.25 K $decade^{-1}$. The trend results from the monthly anomalies and yearly averages are consistent but the errors in the yearly averages are slightly higher than those of the monthly anomalies.

The monthly anomalies in temperature over Greenland (Figure 2b) are shown to have greater variability that those over sea ice. The standard deviation of this variability is greater at 2.1 K while the month to month change can be as large as 4K. The regression results show a negative trend of -0.15 ± 0.27 K decade^{-1} for the monthly anomaly data and -0.15 ± 0.48 K decade^{-1} for the yearly data. Although the trend is negative and different from those of the other study areas, the magnitude of the trend is small compared to the error and is not considered significant.

For land areas other than Greenland and >60° N, the anomalies are more variable than over sea ice but not as variable as Greenland. The trend in this data is highest among the three regions at 0.91 ± 0.20 K decade^{-1} for the monthly anomalies and 0.92 ± 0.24 K decade^{-1} for the yearly data. The higher trend over land (except Greenland) than over sea ice indicates that the former has been even more vulnerable to warming effects than the latter.

The warming trends derived from satellite data for sea ice and land are quite high compared to global averages derived from meteorological stations. The satellite data set, however, have been shown to be consistent with station data in the locations of the latter, and on a year to year basis. Also, there are areas, such as Greenland, that show cooling instead of warming. Although the record length is relatively short and accuracy of the data needs to be improved, the satellite data is for now the only data set that can provide good spatial coverage.

CORRELATION OF ICE CONCENTRATION AND SURFACE TEMPERATURE

To illustrate how the ice cover has been changing on a regional basis during the 1981 to 1999 period, anomalies in yearly ice concentrations are depicted in Figure 3 on a year-to-year basis. The anomaly maps are useful in that they readily provide specific spots where the Arctic ice cover has been increasing (grays, greens and blues) and where it is decreasing (oranges, purples, and reds). Highly anomalous regions for each year are thus easily identifiable. For reference, the 18-year average of ice concentrations (1981 to 1999 climatology) used to generate the anomaly maps is shown as the last image in Figure 3.

Generally, it is apparent that there is a predominance of anomalously high concentrations in the 1980s and anomalously low concentrations in the 1990s. It is thus not surprising that the trend analysis yielded negative results.

For comparative analysis, anomalies in surface temperatures are shown in Figure 4. In this case, increases are depicted in warm colors (oranges, reds, and purple, while decreases are represented of cool colors (greens, blues, and grays). The anomalously warm areas represented by warm colors are thus easy to compare with anomalously low ice concentrations (similar colors) and vice versa. The 18-year average surface temperature (climatology) is shown in the last image of Figure 4.

It is again apparent that there is a predominance of anomalously cold areas in the 1980s and a predominance of anomalously warm areas in the 1990s. This is consistent with Arctic warming as indicated previously and with the anomalies in the ice concentrations. But even in the 1980s, there were distinctly warm anomalies such as in Greenland in the 1981 to 82 season, Siberia in the 1983 to 1984 season and the Northern

Canada in the 1987 to 1988 season. Also, there were anomalously cold regions in the 1990s such as Northern Canada in the 1991 to 1992 season, Greenland in the 1992 to 1993 season, Canada in the 1993 to 1994 season and Russia in the 1998 to 1999 season.

A comparison of the anomalies in the Arctic sea ice region (Figure 3 versus Figure 4) show a strong coherence of ice concentration with surface temperature. The regions where ice anomalies were strongly positive are also regions where temperature anomalies that are strongly negative and vice versa. It is also apparent that we can learn a lot more from the temperature data than the ice concentration data because the study area is not confined to the sea ice regions. As indicated by the images, the temperature anomaly maps provide a more complete characterization of the scope of warming or cooling events in the Arctic. They show that a warming scenario, for example, is not just confined over the sea ice regions but considerably beyond these regions. A good example is the retreat in the sea ice cover in the Beaufort Sea during the 1997 to 1998 and 1998 to 1999 periods. While the retreat in the ice cover is substantial as has been quantified, the warming anomaly event in the region has a much wider scope and was even greater south of the Beaufort Sea. The temperature maps also show that during the same period, there was a cooling in Northern Russia.

The temperature anomaly maps also show some warming trends starting with the 1987 to 1988 ice season. The trend was interrupted by temporary cooling from 1991 through 1994. This cooling may have been the result of the Mount Pinatubo vocanic erruption in 1991. Also, while 1998 is considered the warmest year in the 19th century, it is apparent that there was a cooling in Northern Russia from 1997 through 1999.

The high coherence of the spatial features in the anomaly maps for the ice concentration compared to those of surface temperatures is intriguing. This was quantified by doing a regression analysis of the two variables on a pixel by pixel basis, using the 18 pairs of yearly anomaly maps. The results are shown in Figure 5 and expressed in terms of correlation coefficients on a pixel by pixel basis in the Arctic region. It is apparent from the color coded map that the region of highest negative correlation (pinks and purples) is the seasonal sea ice region. The correlation coefficiants are also very high around the periphery of the perennial ice region. In the Central Arctic, the correlation is poor as would be expected since the ice concentration in the region is always consistently high and changes very little although the surface temperature may change substantially. However, in some places, there are areas of positive correlation (greens) that may be significant. These are likely areas where spring melt causes ice emissivity to increase and therefore cause increases in the estimated ice concentration as the temperature increases. Overall, the result show that during warming, the area that is most affected is the seasonal region and the periphery of the perennial ice region. The effect on the latter can be profound as discussed in the next section.

VARIABILITY OF THE PERENNIAL ICE COVER

A study of the variability of the Arctic sea ice cover is not complete without the study of the variability of its perennial ice cover. We define perennial ice cover as that which survives the summer melt period and is composed mainly of thick multiyear ice floes. The perennial ice cover is an important climate parameter since it strongly influences the thickness distribution of the ice cover. Negative changes in multiyear ice cover have actually been reported (Johannessen and others, 1999). However, the data used for multiyear ice were inferred from the winter passive microwave data which has been reported previously to have large errors when compared with high resolution SAR data (Kwok et al., 1996).

The best way to quantify the state of the perennial ice cover is to monitor how the minimum ice extent and ice area have been changing from one year to another (Comiso, 1990). The minimum extent for the entire Arctic is not easy to estimate because ice minimum may occur during different times in different areas. This might be resolved by examining the time history of each pixel and find the yearly minimum in each pixel. However, such technique would be effective only if the ice pack is stationary and meltponding does not occur. Because the ice pack is constantly moving, such procedure will tend to choose ice pixels that may be temporarily displaced by open water because of wind. Also, meltponds have signatures similar to that of open water and the procedure would choose predominantly meltponded pixels that yields lower concentrations than the true ice concentration. The end results of such analysis would be difficult to interpret.

A good approximation to the extent of the perennial ice cover is the minimum extent during the summer/autumn period. Changes in pressure fields that tend to move the perennial ice cover around the Arctic region is not a problem since the entire region is considered. It is also encouraging that the day of minimum ice extent (or area) has also been found to occur at approximately the same time of the year (i.e., early September). Thus, the year-to-year difference in percentage contamination of the data by first year ice that formed during the summer is likely very small. A seven day running average of the daily extent or area is also used to improve the probability that the date chosen for each year is for the real minimum.

The ice extent and actual ice during summer minima from 1981 through 1999 are shown in Figure 6. The plots show changes in ice extent that are as large as a million km^2 from one year to the next. A large increase from one year to another usually mean a large increase in the area covered by second year ice cover since older ice types cannot increase area from one year to the next. Conversely, large decreases mean the decrease of all types of perennial ice cover that includes second year ice and the thicker and older ice types. An alternate yearly fluctuation of increases and decreases in areal coverage would thus mean the introduction of younger and thinner ice types. A repetition of this process would imply an overall thinning in the ice cover. Thus, even if the trend in areal extent is zero, the overall thickness of the ice cover could go down.

The plot in Figure 6 indeed show large yearly fluctuations in the extent and area during ice minimum in the 1990s while similar fluctuations is not apparent in the 1980s. The time of yearly fluctuation is from 1991 through 1997. The average fluctuation is about 10^6 km^2 but from 1995 to 1996, the ice extent increased by almost 2 x 10^6 km^2. We postulate that during the 6 year period, there was a significant thinning in the ice cover just on account of this phenomenon. The time period actually coincided with some of the submarine cruises during SICEX that yielded the data used for the detection of ice thinning by Rothrock and others (1999). If verified, this technique could be a powerful tool for thickness trend studies since it provides global and spatially detailed coverage.

In addition, trend analysis of the ice minimum data show large negative trends in both extent (-6.1 ± 3.0) and ice area (-6.5 ± 2.7%). This would mean a negative change in both area and thickness. It should be pointed out, as well, that a natural consequence of a thinning ice cover is also a reduction in surface area since under similar environmental conditions, it is the thinner ice type that gets melted first during the summer period.

The monthly averages in surface temperature during each September (when ice minima usually occurs) from 1981 to 1999 are also shown in Figure 6. The surface temperatures are taken only from areas with sea ice concentrations of 80% and higher. A higher concentration (than 80%) is not used as a cutoff because errors in concentration can be as large as 20% during this time period when the surface is meltponded and/or wet. Overall the time series shows a warming trend and the result of a regression analysis on the data yielded a rate of increase of 1.3 ± 0.5 K decade^{-1} during the 1981 to 1999 period. This rate of warming is quite high compared with those derived from the continuous data set of monthly anomalies or yearly averages (0.4 K decade^{-1}).

The yearly fluctuation is also very well correlated with those of the ice extent and ice area with correlation coefficient of about 0.65. Thus, when the temperature was abnormally high as in 1995, the ice extent and ice area were abnormally low, whereas, when the temperature was abnormally low, as in 1996, the ice extent and ice area were abnormally high. There are some exceptions, such as in 1987 to 88 and 1990 to 91 when warming is accompanied by increases in extent and ice area but this may simply be an indication that more complex processes sometimes affect the variability in the ice cover. It is useful to know that there is such a strong relationship between the two variables.

DISCUSSION AND CONCLUSIONS

Co-registered satellite ice concentration and surface temperature data for the period 1981 to 1999 have been assembled and analyzed. This study shows that the simultaneous observation of the two parameters provide many useful insights about the changing Arctic. Ice concentration data provide physical characterization of sea ice spatial distributions while surface temperature provide information about the thermal state of the ice surface. One or the other provides independent evaluation of the changing state of the Arctic but together they provide a characterization that is more complete than either one.

A general assessment from the monthly and yearly data shows that the ice cover has been declining at the rate of 2.3% decade^{-1} while the surface temperature was increasing at the rate of 0.4 K decade^{-1}. This is a smaller rate than the 2.8% decade^{-1} previously reported but the latter was done for a different 18 year period (1978 to 1996) and a different ice concentration algorithm was utilized to generate the ice data set.

The yearly anomalies in both ice concentration and temperature provide new insights into the changing Arctic ice environment. They provide year to year changes in good spatial detail of sea ice distributions and specific locations and magnitude of large positive and negative anomalies. It is apparent from the data that positive anomalies in ice concentrations are prominent in the 1980s while the reverse is true in the 1990s. This in itself is an indication that the ice cover has been declining. Similarly, negative anomalies in surface temperatures were dominant in the 1980s while positive anomalies were more frequent in the 1990s. This shows that while the ice cover is declining, the surface temperature is also on the rise indicating a close link of the two variables.

The yearly temperature maps are shown to provide useful information that is not available in the sea ice cover data. These maps show that in the Arctic there are large anomalies that extend beyond the sea ice margins. They allow quantification of the scope of these anomalies which are apparently driven by atmospheric patterns. The coherence of the spatial distribution of the anomalies of ice concentration and surface temperature is quite good and quantitative analysis show high negative correlation of the two variables especially in the seasonal ice regions where the anomalies are abnormally high. Also, it is apparent that there were some years when the anomaly patterns were exceptionally high, as in 1998, which is regarded as the warmest year in the 19^{th} century. It is shown that high positive anomalies are indeed evident in 1997-98 and 1998-99 ice seasons but the high positive values are confined primarily in Beaufort Sea and North America while slight cooling was going on in Russia and Kara Sea.

A key to an improved understanding of the current state of the Arctic ice cover is a good quantification of the variability of the perennial ice cover. This was derived from analysis of the extents and areas of the ice cover during summer minimum were. Results show a summer ice cover that has been declining at the rate of 6.5% $decade^{-1}$ while the average September surface temperature values were increasing at the rate of 1.3K $decade^{-1}$. The rate of decline in the perennial ice cover is double that of the rate of decrease in total sea ice cover. The rate of increase in surface temperature in September is also surprisingly high and more than double that for all seasons. These results are important since they pertain to that of the perennial ice cover which is directly connected to the ice thickness distribution. In addition, it is apparent that the minimum extent show higher yearly fluctuations in the 1990s than in the 1980s. Even without a trend, such phenomenon would cause a change is the overall composition of the difference ice types and favors increases in the fraction of the thinner and younger ice cover (e.g., second year ice), compared with the older and thicker ice types. The large decrease in the areal coverage of the perennial ice cover may thus be accompanied by a decrease in thickness as well.

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LIST OF FIGURES

1. (a) Trends in sea ice extent from 1981 through 1999 using monthly anomalies and yearly averages; (b) trends in actual ice area using monthly anomalies and yearly averages; and (c) trends in ice concentration using monthly anomalies and yearly averages. Yearly averages are from August to July the following year.
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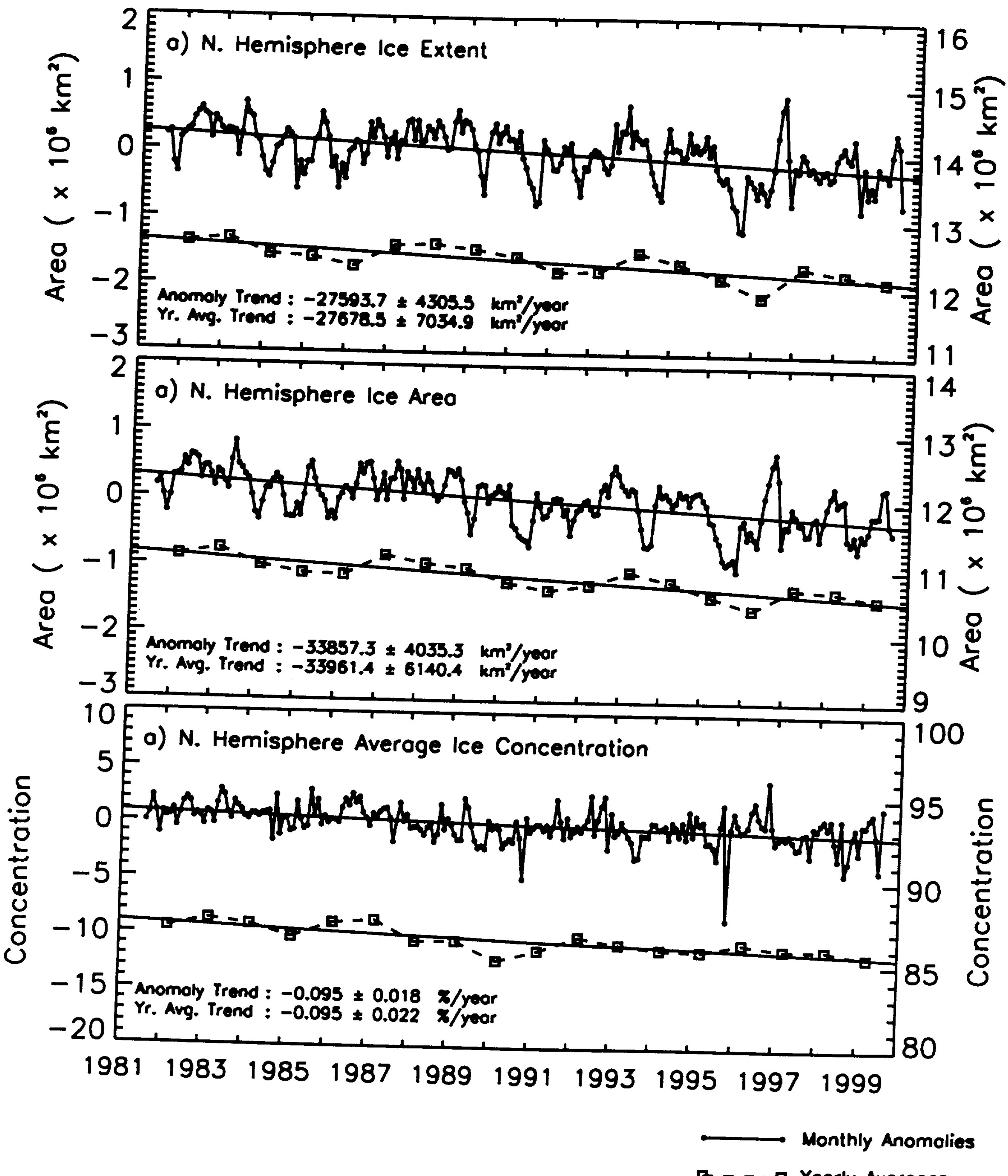
a) N. Hemisphere Ice Extent
Anomaly Trend : −27593.7 ± 4305.5 km²/year
Yr. Avg. Trend : −27678.5 ± 7034.9 km²/year
a) N. Hemisphere Ice Area
Anomaly Trend : −33857.3 ± 4035.3 km²/year
Yr. Avg. Trend : −33961.4 ± 6140.4 km²/year
a) N. Hemisphere Average Ice Concentration
Anomaly Trend : −0.095 ± 0.018 %/year
Yr. Avg. Trend : −0.095 ± 0.022 %/year
Area (x 10⁶ km²)
Concentration
1981 1983 1985 1987 1989 1991 1993 1995 1997 1999
Monthly Anomalies
Yearly Averages

Fig. 1

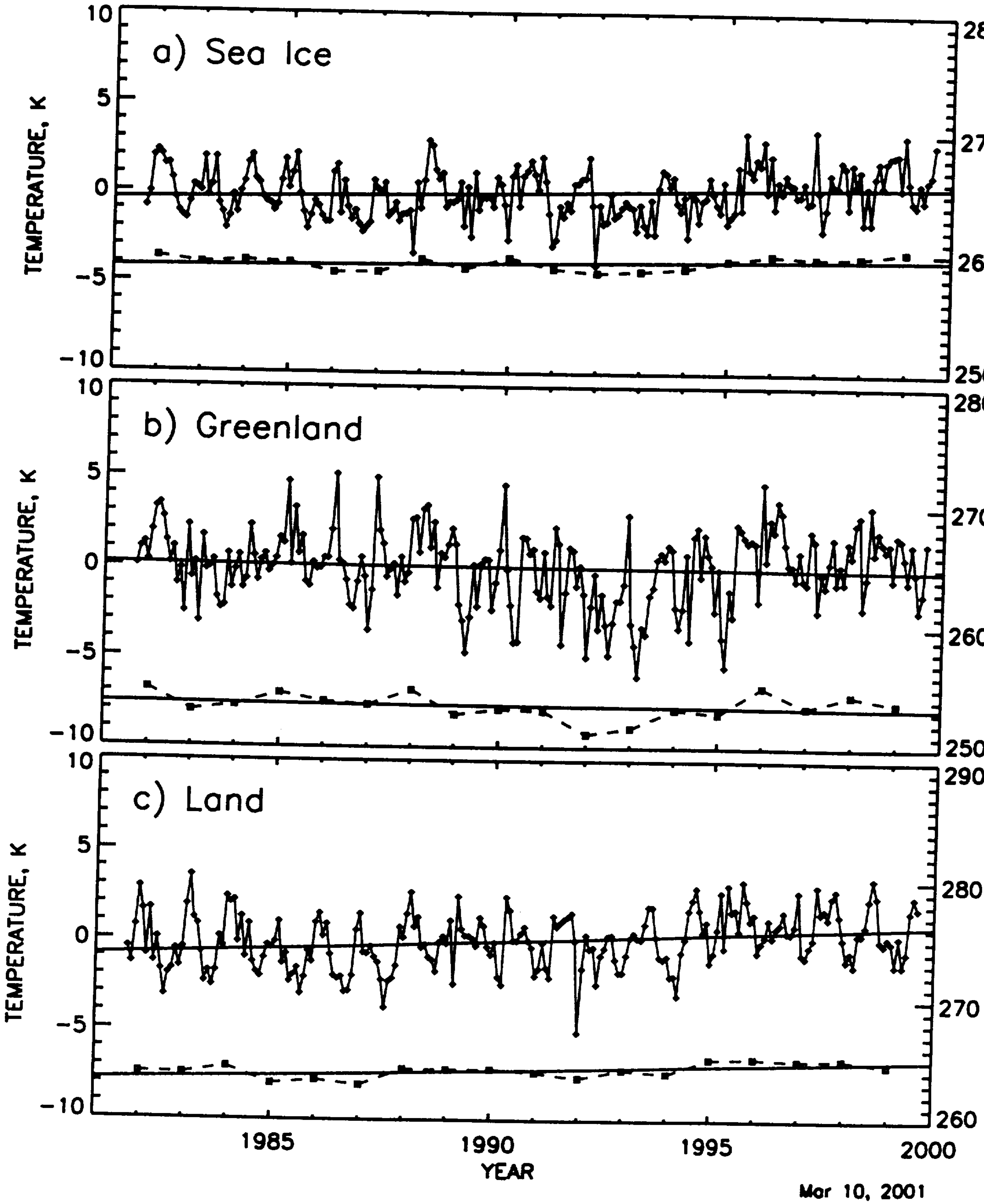
a) Sea Ice
b) Greenland
c) Land
TEMPERATURE, K
TEMPERATURE, K
10
5
0
-5
-10
280
270
260
250
290
1985
1990
1995
2000
YEAR
Mar 10, 2001

Fig. 2

Yearly Ice Concentration Anomalies (August–July)

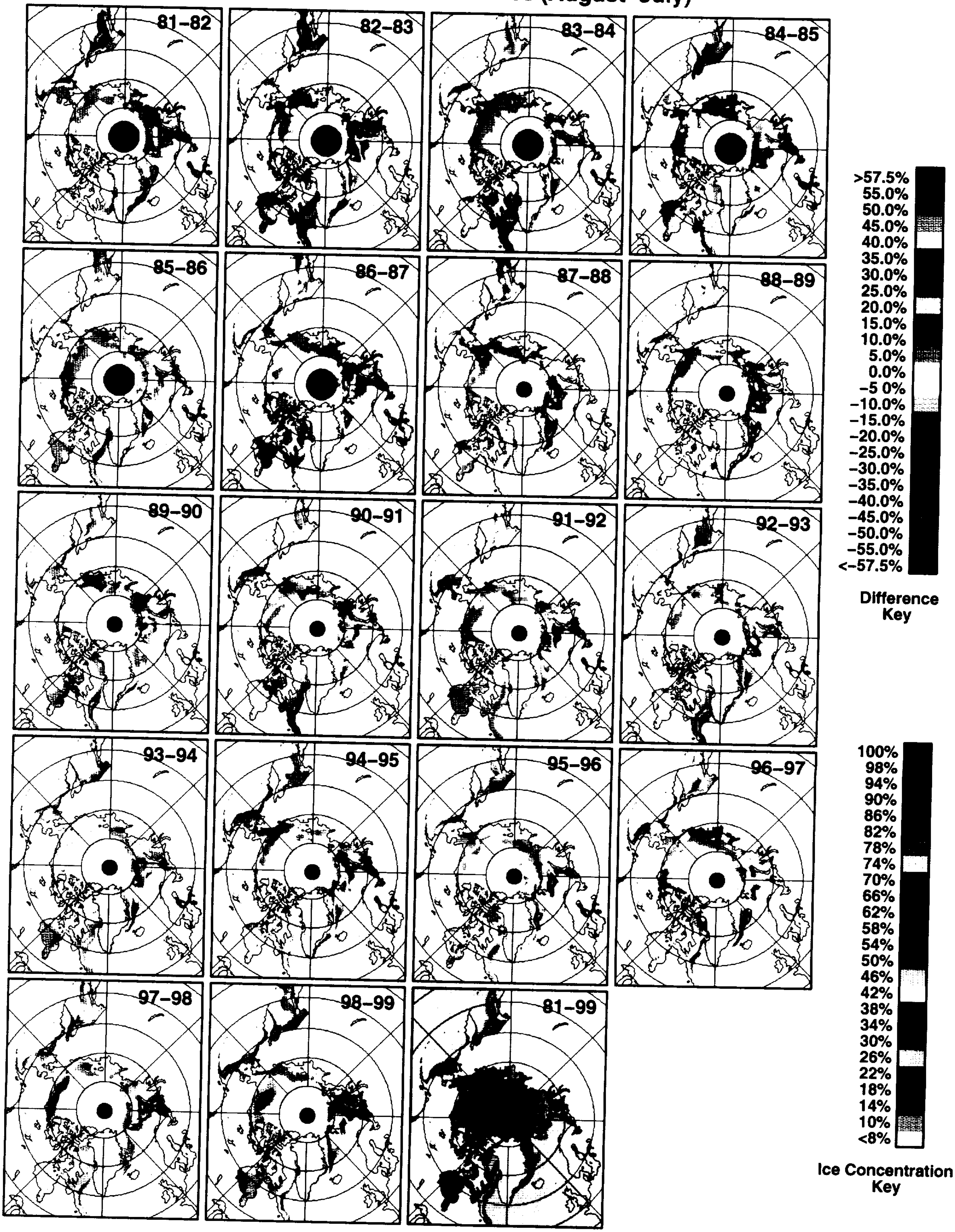

Fig 3

Yearly Surface Temperature Anomalies (August–July)

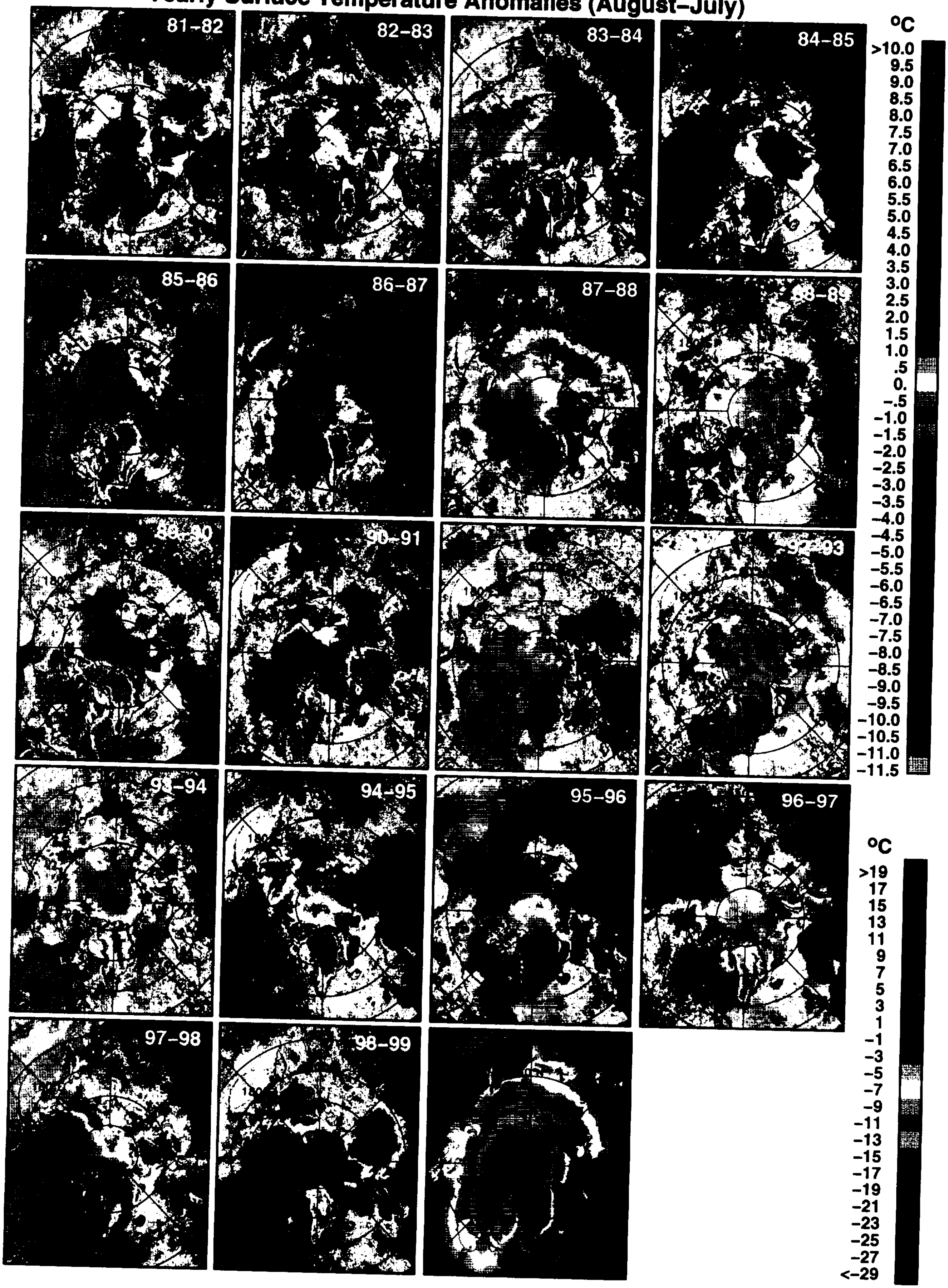

Fig 4

Correlation Coefficients: Surface Temperture vs Ice Concentration

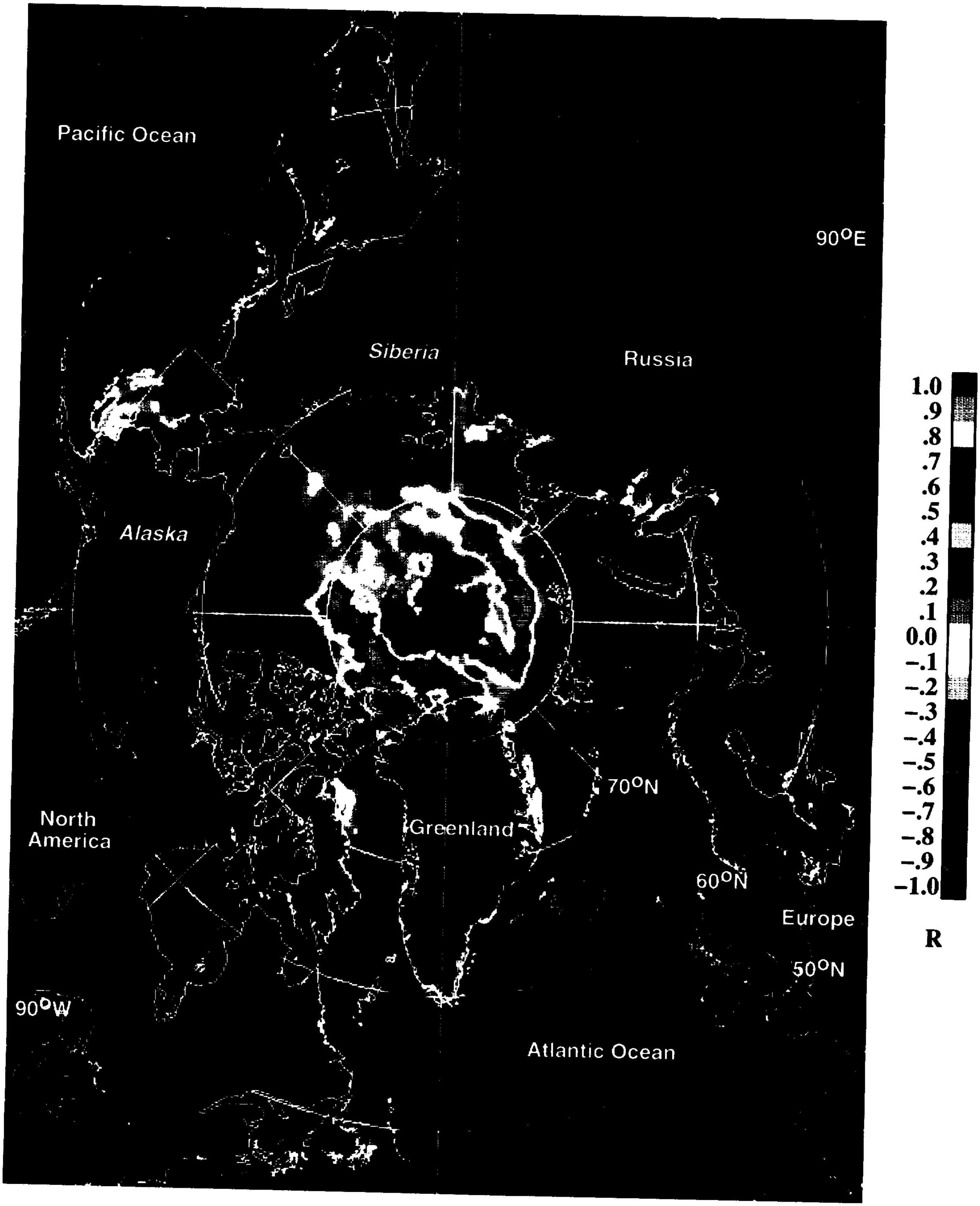

Fig 5

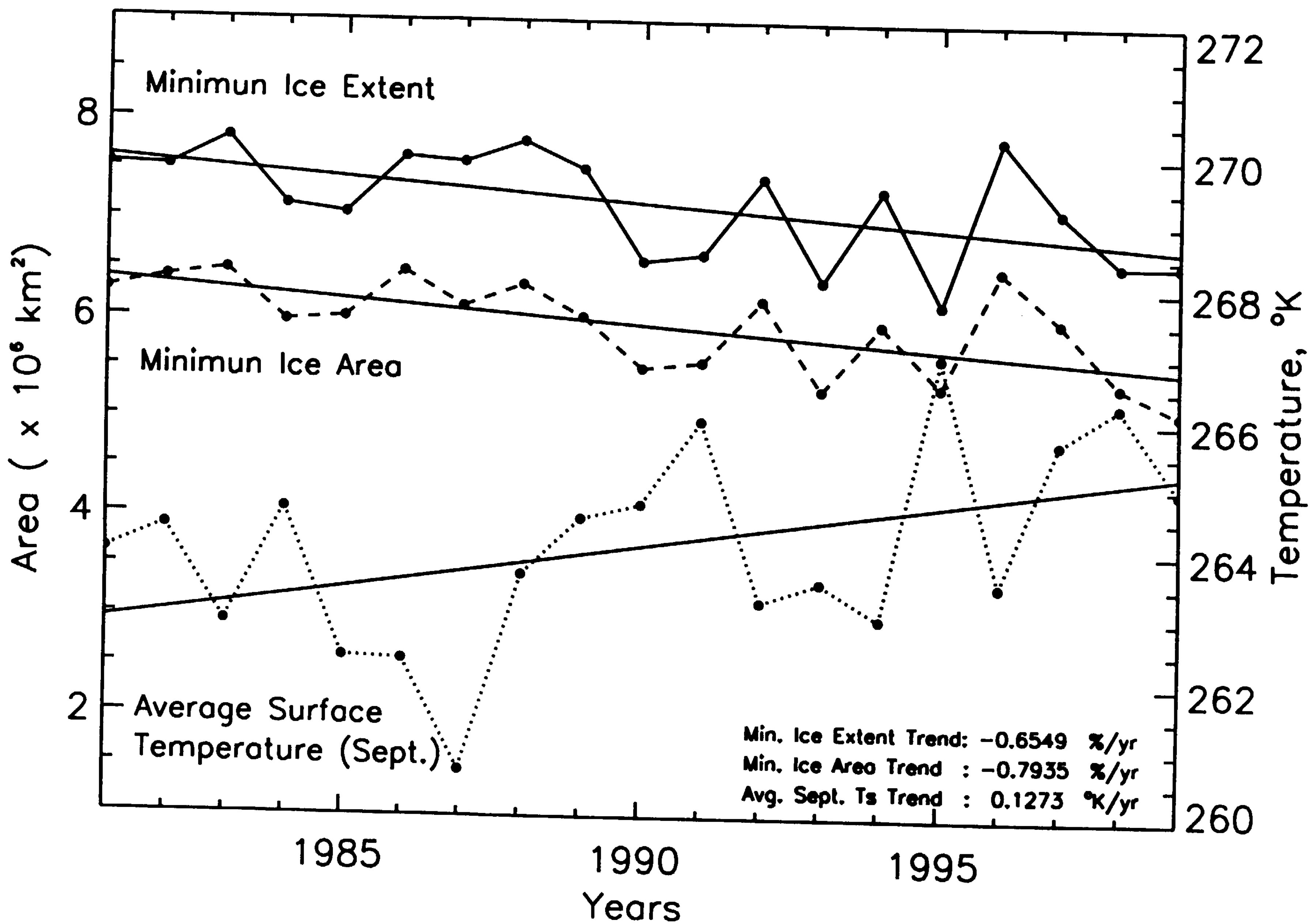
Minimun Ice Extent
Minimun Ice Area
Average Surface
Temperature (Sept.)
Min. Ice Extent Trend: −0.6549 %/yr
Min. Ice Area Trend : −0.7935 %/yr
Avg. Sept. Ts Trend : 0.1273 °K/yr
Area (x 10⁶ km²)
Temperature, °K
Years
1985
1990
1995
2
4
6
8
260
262
264
266
268
270
272

Fig 6