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PREDICTION OF SUMMER CENTRAL ENGLAND TEMPERATURE FROM PRECEDING NORTH ATLANTIC WINTER SEA SURFACE TEMPERATURE.

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ABSTRACT

A potentially useful predictive relationship has been found between the North Atlantic Sea Surface Temperature anomaly (SSTA) pattern in winter and the subsequent summer (July-August) Central England Temperature (CET) in England. This relationship can be seen in timewise correlation maps between CET and gridded SSTA. The SSTA pattern which correlates well with CET can be represented by an eigenvector. A regression equation was then established to predict subsequent summer CET from the strength of the eigenvector, which produced correlation skill of about 0.5 at a lead time of 4 months.

1.INTRODUCTION

The United Kingdom (UK) has had some notable warm summers in recent years prompting the question: Are these summers predictable? Empirical techniques using global scale patterns of historical sea surface temperature anomalies (SSTA) have been successfully used to predict seasonal rainfall in NE Brazil, tropical NW Africa and E Africa (Folland *et al.*, 1991, Ward and Folland, 1991, Ward *et al.*, 1993, Mutai *et al.*, 1996). The problem of predicting UK climate is much more difficult than that of predicting rainfall in these tropical regions. The UK is adjacent to the Atlantic Ocean and the Eurasian land mass and is affected by many different air mass types and synoptic scale variability, unlike the tropical regions mentioned above. Hence we should expect lower skill than that achieved by the tropical forecasts.

In this paper predictions of July-August Central England Temperature (CET) from SSTA are discussed. Central

England Temperature is a homogenised temperature series from 1659 to date first put together by Manley,(1974) and updated by Parker *et al.*,(1992). July-August CET is a good indicator of the nature of British summers because July and August are the peak summer months in the UK and persistence in CET between these months is high. The correlation (r) between July and August values for the period 1896-1995 is 0.53 compared with persistence between June and July (r(1896-1995)= 0.17) or August and September (r(1896-1995)= 0.35).

A number of experimental seasonal forecasts of UK summer temperature and rainfall were made in the 1970s by the UK Meteorological Office, based mainly on a selection of rules derived from past data linking UK summer temperatures and rainfall with spring Sea Level Pressure (SLP) indices from around the extra-tropical northern hemisphere (Murray, 1972, Ratcliffe and Collison, 1969) and with UK temperatures and rainfall for preceding months (Murray, 1968). Predictions using these methods were not particularly successful (Murray, 1977) and were discontinued in 1980. Barnston (1994) found evidence of predictability of seasonal temperature anomalies in Europe using canonical correlation analysis (CCA), though when the CCA forecasts are tested using independent data, correlation skill is less than 0.2. Plaut et al. (1995) suggested that CET may be predictable from the historical record of CET using Singular Spectrum Analysis but this technique only predicts a low frequency component of CET and was shown by Allen and Smith (1996) to have no useful skill.

Murray and Ratcliffe (1968) and Ratcliffe (1973,1977) linked three anomalous UK summers with north Atlantic and north Pacific SSTA. Folland *et al.* (1986) found significant correlations between southern hemisphere with north Indian Ocean minus rest of northern hemisphere July-September SST and July-August sea level pressure at 55°N 5°W (r (1901-84)=0.53). Since then a globally complete ice and sea surface temperature (GISST) dataset has been constructed (Parker *et al.*, 1995). This data is a considerable improvement on what was available in the 1970s so the problem of seasonal forecasting is being looked at again using the GISST data. There is the added benefit of an extra 20 years of good quality historical data now available.

In section 2 the identification from correlation maps of a North Atlantic SSTA pattern as a good CET predictor is described. Section 3 describes the use of an eigenvector to represent the predictor pattern. Assessments of predictions of CET for past years are discussed in section 4, some possible explanations for high skill scores are investigated in section 5 and some related prediction possibilities are discussed in section 6.

2.CORRELATIONS BETWEEN GLOBE-WIDE SST AND CET

July-August CET was correlated with 10°x10° latitude x longitude square averages of simultaneous SSTA worldwide (fig 1). Correlations were evaluated over a number of periods between 1871 and 1994 to test for sample dependency. Correlations over two periods, 1971-1994 and 1871-1994 are shown. Using the shorter period reduces error due to climate change or poor data, while using the longer period provides a larger sample.

For all periods assessed, the correlations are strongest in the N Atlantic as might be expected as the N Atlantic is the source of most of the UK's weather. Notable are the positive correlations adjacent to and to the SW of the UK, the negative correlations SE of Greenland and the positive correlations off the E coast of the USA. Note also the negative correlations in the eastern Mediterranean. Significant correlations are found in this area whether calculated over 1871-1994, 1941-94 or 1971-94. Elsewhere the correlations are weaker and more period dependent.

Figure 2 shows correlations between July-August CET and SSTA for the preceding months (June, May and April). The wave train like pattern of correlations referred to above in the N Atlantic is clearly visible whatever month's SSTA is used. Elsewhere correlations change with the SST month and years analysed. The N Atlantic wave train like pattern is also clearly visible when the preceding winter's SSTA (January-February) is correlated with the summer (July-Aug) CET (fig. 3). Whether calculated over 1871-1994 or 1971-1994, the extent and strength of the correlations with the winter SSTA is as great as with most of the spring SSTA and nearly as great as when simultaneous summer SSTA is used. Hence this pattern is potentially a useful long lead predictor of summer CET.

The wave train like pattern of correlations is positioned such that the negative correlations SE of Greenland may be related to flow around the Icelandic low pressure centre and the positive correlations to the SW of the UK may be related to flow around the Azores high, hence this wave train like pattern is probably related to the North Atlantic Oscillation (NAO) (Lamb,1987). The NAO is an index of the difference between SLP in the Azores and Iceland regions and is related to zonal wind strength in the mid-latitude N Atlantic. Further evidence for this link can be seen in the correlations between preceding winter (Jan-Feb) SLP and summer CET (fig. 4). Correlations between Iceland region SLP and CET are about -0.3 while correlations between Azores region SLP and CET are about +0.3.

There is some evidence of relationships between CET and SSTA beyond the N Atlantic but with the number of areas with significant correlations over 1971-1994 only just above the chance level, prediction skill from beyond the N Atlantic is likely to be only marginal. Previous studies eg. Ratcliffe and Murray (1970) and Palmer and Sun (1985) have detected predictability from NW Atlantic SST. Hence from now on this paper concentrates on the N Atlantic.

3.EIGENVECTORS OF N ATLANTIC SST

The next problem is to determine if the wave train of correlations can be represented by one or more indices. Calculating eigenvectors to represent the SSTA patterns has previously proved successful with the Hadley Centre forecasts of NW African and NE Brazil rainfall (Ward *et al.*, 1993). Eigenvectors represent the strongest patterns of variability in the data and are calculated independently of any predictand variable, unlike for example a pattern of correlations. Eigenvectors were calculated using 10°x10° GISST SSTA averages for winters (January-February) from 1901-90 between 40° and 70°N and between 80°W and 30°E. This domain covers most of the 10°x10° areas in the north Atlantic where winter SSTA is correlated with summer CET and minimizes areas with low correlation. Figure 5 shows eigenvectors 1 to 4 which explain 29%, 20%, 12% and 9% of the total variance respectively. Eigenvector 1 has a clear resemblance to the wave train patterns in the correlation maps (figs. 2,3) and hence the Time Series of Eigenvector 1 (TSE1) should be a good predictor of summer CET.

Eigenvector 1, like the correlation weights, is related to the NAO. The TSE1 is significantly correlated (r=0.44) with an NAO time series based on the difference in SLP between Stykisholmur in Iceland and Ponta Delgada in the Azores (fig. 6).

4.PREDICTIONS OF JULY-AUGUST CET

The 1871-1995 TSE1 in fig.5 was plotted against CET (fig 7). The correlation of 0.44 over the period 1871-1995 is significant at the 99% level. For 1971-1995 the correlation rises to 0.55. For comparison, correlations of 0.7 are typical for the tropical seasonal rainfall forecasts which have a shorter lead time.

An initial assessment of the TSE1 as a predictor of CET was carried out by calculating a linear regression equation minimizing root mean square error over the period 1871-1970 and testing it over the period 1971-95 (fig.8.1). As there is only one predictor, the correlation between the regression forecasts and observed is the same as the correlation between the TSE1 and observed. The variance of the forecasts is a quarter of the variance of the observations however. The forecasts were also assessed using a Linear Error in Probability Space (LEPS) score (Potts *et al.*, 1996) which takes account of biases in variance and means unlike correlation. Like correlation, LEPS scores are on a scale from -1 to 1 with perfect forecasts scoring 1, perfectly wrong forecasts scoring -1 and chance predictions scoring 0. The LEPS score of 0.11 is low given the correlation, reflecting the difference between forecast and observed variance. The low forecast variance is largely due to the low correlation (0.26) between the TSE1 and CET over the 1871-1970 training period.

The variance of regression forecasts can be made equal to the variance of the observations by using inflated regression (cf. Ward and Folland, 1991 page 725) when the standard linear regression equation "$\mathbf{Y=aX+b}$" is replaced by "$\mathbf{Y=aX/r+b}$" where $\mathbf{r}$ is the correlation between $\mathbf{X}$ and $\mathbf{Y}$ calculated using the same data as used to determine $\mathbf{a}$ and $\mathbf{b}$. The values of $\mathbf{a}$ and $\mathbf{b}$ are the same for inflated regression as for standard linear regression because the independent variable $\mathbf{X}$ was defined to have zero mean. Figure 8.2 shows 1971-1995 forecasts using inflated regression; the Standard Deviations (SD) of the forecast and observed temperatures are both 1.2°C. The Root Mean Squared Error (RMSE) of the forecasts is 1.3°C which is somewhat less than chance (1.4 x SD when the SDs of forecasts and observations are equal or 1.7°C in this case). The LEPS score of 0.21 is an improvement on the ordinary regression. For comparison, LEPS skill of the best empirical NE Brazil seasonal rainfall forecasts (0.5) is about 0.2 below the best correlation scores (0.7).

Forecasts can also be evaluated in terms of categories. The 1971-1995 temperature observations were split into 5 equiprobable categories called quints. Quint 1 represents the coldest 20% of years during this period and Quint

2 the next 20% etc. Table 1 shows a contingency table of forecast v observed quints of CET. These scores are better than chance when only 5 summers would be correctly predicted or persistence when only 3 summers are correctly predicted. These categorical forecasts can be assessed using the Folland-Painting score (FP Score)(Folland *et al.*, 1986). This measure is used regularly to assess 30 day forecasts issued by the UK Meteorological Office (Harrison, 1995). The FP score takes account of all the frequencies in the contingency table and is calculated as a percentage where 100% represents all perfect forecasts, 0%=chance and -100%=all worst possible forecasts. The FP score for the 1971-95 forecasts in table 1 is 26%. This compares well with the 30 day forecasts of temperature for 10 UK regions which over the past 4 summers had an average FP score of about 15% (Harrison, personal com.) and with persistence which has an FP score of 8%.

The forecasts for 1971-95 have a "warm" bias, quints 1 and 2 are forecast only once each while quint 5 is forecast 10 times. CET has been 0.6°C warmer on average during 1971-1995 than during the previous 100 years (fig 7). While it was correct to predict warmer CET during 1971-1995 relative to 1871-1990, the warming was over predicted by about 0.7°C . The skill in predicting this warming can be seen by using quints calculated over the training period, 1871-1970 (Table 2). The number of successful forecasts goes up to 11 and FP skill up to 34% but 9 of the correct forecasts are for the warmest quint.

This prediction scheme was also assessed over a longer period (1946-95) using the jackknife technique. The jackknife technique involves forecasts being made for each year using a regression equation compiled using the remaining years. The year being forecast is excluded from the regression equation to make the forecasts independent. The subsequent two years are also excluded as these may be related to the forecast year through persistence. Since the same years are used to calculate and test the regression equations, the interdecadal or longer period variation in CET which affected the 1971-95 forecasts should only have a minimal impact here. Figure 9 shows the 1946-1995 jackknife forecasts plotted against observed CET. The correlation of 0.49 is less than for the 25 year period but is still significant at the 99% level. RMSE was equal to SD of the forecasts and of the observations at 1.1°C. The ratio of RMSE to SD is slightly lower for this period compared with 1971-1995 indicating better skill for 1946-95. The LEPS score was 0.28.

TABLE 1 Contingency table based on forecast and observed temperature 1971-1995 using 1971-1995 Quints

	Observed Quint				
Forecast Quint	Q1 (cold)	Q2	Q3	Q4	Q5 (warm)
Q1 (cold)	0	1	0	0	0
Q2	0	0	1	0	0
Q3	2	3	2	0	0
Q4	1	1	0	3	1
Q5 (warm)	2	0	2	2	4

TABLE 2 Contingency table based on forecast and observed temperature 1971-1995 using 1871-1970 quints

	Observed Quint				
Forecast Quint	Q1 (cold)	Q2	Q3	Q4	Q5 (warm)
Q1 (cold)	0	0	1	0	0
Q2	0	0	0	1	0
Q3	0	1	2	0	0
Q4	1	2	1	0	0
Q5 (warm)	0	4	1	2	9

TABLE 3 Contingency table based on forecast and observed temperature 1946-1995 using 1871-1970 quints

	Observed Quint				
Forecast Quint	Q1 (cold)	Q2	Q3	Q4	Q5 (warm)
Q1 (cold)	3	0	2	0	0
Q2	1	2	4	1	1
Q3	1	4	4	1	3
Q4	1	2	1	1	2
Q5 (warm)	1	3	2	2	8

TABLE 4 Contingency table based on persisted (from last summer) and observed temperature 1946-1995 using 1871-1970 quints

	Observed Quint				
Forecast Quint	Q1 (cold)	Q2	Q3	Q4	Q5 (warm)
Q1 (cold)	2	0	3	1	1
Q2	2	1	2	1	5
Q3	2	4	2	3	2
Q4	0	3	2	0	1
Q5 (warm)	1	3	4	0	5

Table 3 is a repeat of table 2 but for the 50 Jack-Knife forecasts. The 1871-1970 based quints were again used for consistency. The distribution of summer temperatures over 1946-1995 was not very different to 1871-1970. For comparison, results using persistence for the same period are given in table 4.

Again the skill is again higher than expected by chance or from persistence of the previous year's CET anomaly. The correct quint was predicted 18 times compared with a chance figure of 10 and a persistence score of 10 (table 4). The FP score was 26%, the same as for the 1971-1995 forecasts. Using testing period (1946-1995) quints did not change skill much (17 correct forecasts and FP score of 24.5%) reflecting less different quint boundaries. The persistence FP score was -1%.

5.EXPLAINING THE PREDICTABILITY

High skill scores from empirical prediction can often be the result of trend in the data or the persistence of the anomalies used to make the prediction. All the assessments here were made using Jackknife forecasts for 1946-1995 unless specified otherwise.

The contribution of trend to the skill was investigated using optimal climate normals (OCN) (Huang et al., 1996) and by repeating the predictions using high pass filtered SST predictor time series. OCN involves assessing persistence skill by using average JA CET for a set of **n** years prior to the forecast year as the prediction. An assessment was made using every value of **n** between 1 and 15. These assessments are likely to show skill if there is significant trend or long term persistence in the data. None of these OCN assessments revealed any significant predictability however suggesting that the contribution to predictability from trend in CET is insignificant.

A second check for trend was made by assessing forecasts with trend removed from the predictor so trend cannot contribute to skill. The 1946-95 jackknife assessments were repeated with the predictor SST index substituted with the high pass (<10 years) filtered component of the index; the filtering having been done using a Kalman filter. The resulting correlation skill was a little lower (r=0.42) than that obtained with unfiltered data but still significant at the 99% level.

The level of predictability from January-February SSTA is not sustained when later (March-April-May-June-July) SSTA are used (fig 10). Correlation skill only rises again when July-August SSTA (simultaneous to CET being predicted) are used. A similar dip in skill occurs with the independent predictions for 1971-95. The explanation for this dip in skill is not known. The wave train like predictor SSTA pattern is very persistent between JF and April-May as shown by the correlation of 0.8 between the TSE1 for JF and April-May (fig. 11) over 1946-1995. There is less persistence into later months; the correlation between JA and JF TSE1 is 0.4 which is slightly less than the correlation between the JF TSE1 and JA CET. These results indicate that the CET prediction skill from JF SSTA could partly be explained by persistence of SSTA. The predictability may also be related to evolution of both atmospheric and oceanic anomalies between JF and JA leading to a situation in JA which effects temperature over Central England. The evolving SSTA pattern may be masked by changes in SST during the spring (March-June) : Small variations in the relationships between JA CET and SSTA can be seen in fig. 2. Some of the SSTA linked to CET are located near Greenland in areas affected by sea ice in winter. The interannual variability discussed here may well be related to variations in ocean circulation and sea ice such as those discussed by Mysak and Power (1992). The retreat of sea ice in Spring may weaken the link between sea ice related anomalies and SSTA.

6. OTHER FORECASTING POSSIBILITIES

The fact that the SST Eigenvector 1 pattern was related to NAO begged the question: Could a better forecast be produced using an SLP based NAO index. To check this the Jackknife test described above was repeated on the same 50 years but with the SSTA eigenvector time series substituted with the NAO series plotted in figure 6; the difference in SLP between Stykisholmur in Iceland and Ponta Delgada in the Azores. The correlation was just 0.19, compared with 0.47 using SSTA, so clearly NAO is not a better predictor.

It may also be possible to use the SST eigenvector to predict England and Wales Rainfall (EWR) like CET. EWR (Gregory *et al.*, 1991) is a long homogenized series like CET. The negative correlation between rainfall and temperature in summer is well known so some skill in predicting rainfall is likely. When predictions of EWR for 1946-95 were assessed using the Jackknife technique however, the correlation skill (r=0.32) was found to be much lower than for temperature forecasts and insignificant at the 95% level (fig. 12). Independent forecasts for 1971-95 were also much less skilful than the temperature forecasts. This may be because rainfall is more influenced by less predictable small scale variability such as thunderstorms especially in summer.

7. FORECAST OF CET FOR JULY-AUGUST 1996

A real-time forecast of CET for July-August 1996 CET was calculated by updating the North Atlantic eigenvector time series using SST for January and February 1996 and feeding the 1996 value into the inflated regression equation used to predict 1971-1995 temperatures. The forecast of 15.4°C was about 0.6° below the 1946-95 average and 3.5° below the record value obtained in 1995. The standard error of the forecast was calculated over 1971-1995 to be 1.2°C.

The observed value was 16.5°C. The 1.1°C difference between forecast and observed was slightly less than 1 standard error.

8.CONCLUSIONS AND RECOMMENDATIONS

Evidence was found of useful predictability of recent central England summer temperature from the previous winter N Atlantic sea temperature. This predictability has been particularly good in recent years when there have been more mild westerly winters and more warm summers than usual. Correlation Skill compares favourably with the skill of 1 month long-range weather forecasts of the UK (Harrison, 1995) but not so well with the skill in predicting seasonal rainfall in tropical regions like the Sahel or NE Brazil (Ward , 1993).

The long lead time is remarkable and further investigation to determine the mechanism is required. A possible mechanism is that the JF SSTA is part of a coupled evolutionary process in the atmosphere and ocean and perhaps sea ice leading to conditions in JA which affect CET.

Little evidence was found of relationships between SST in other parts of the world and CET. However, the predictability of other UK climate variables from a north Atlantic SST index such as used here to predict CET should be investigated.

ACKNOWLEDGEMENTS

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Figure 1.1; Correlation map between July–August CET and July–August GISST 1971–1994

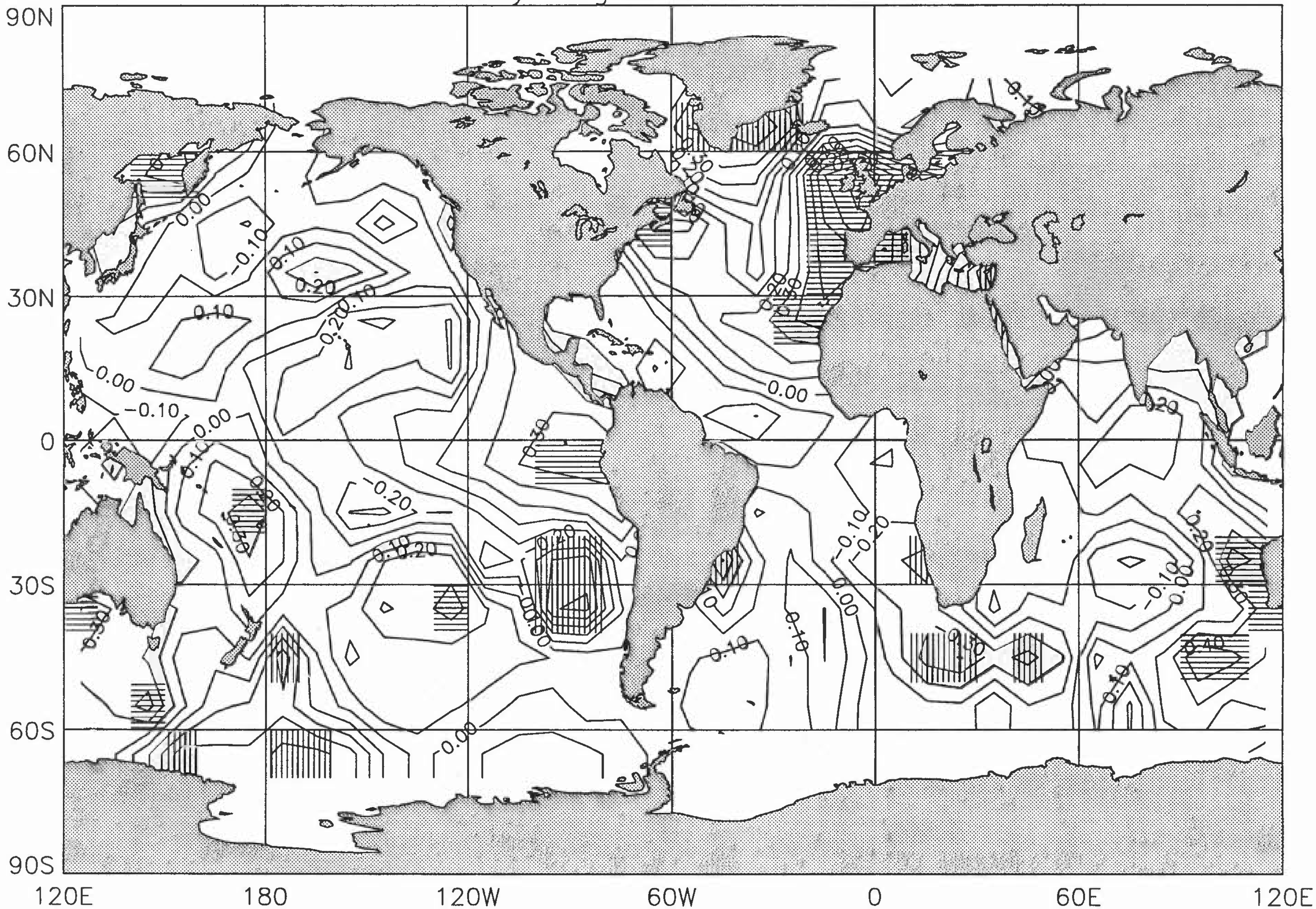


Figure 1.2; Correlation map between July–August CET and July–August GISST 1871–1994

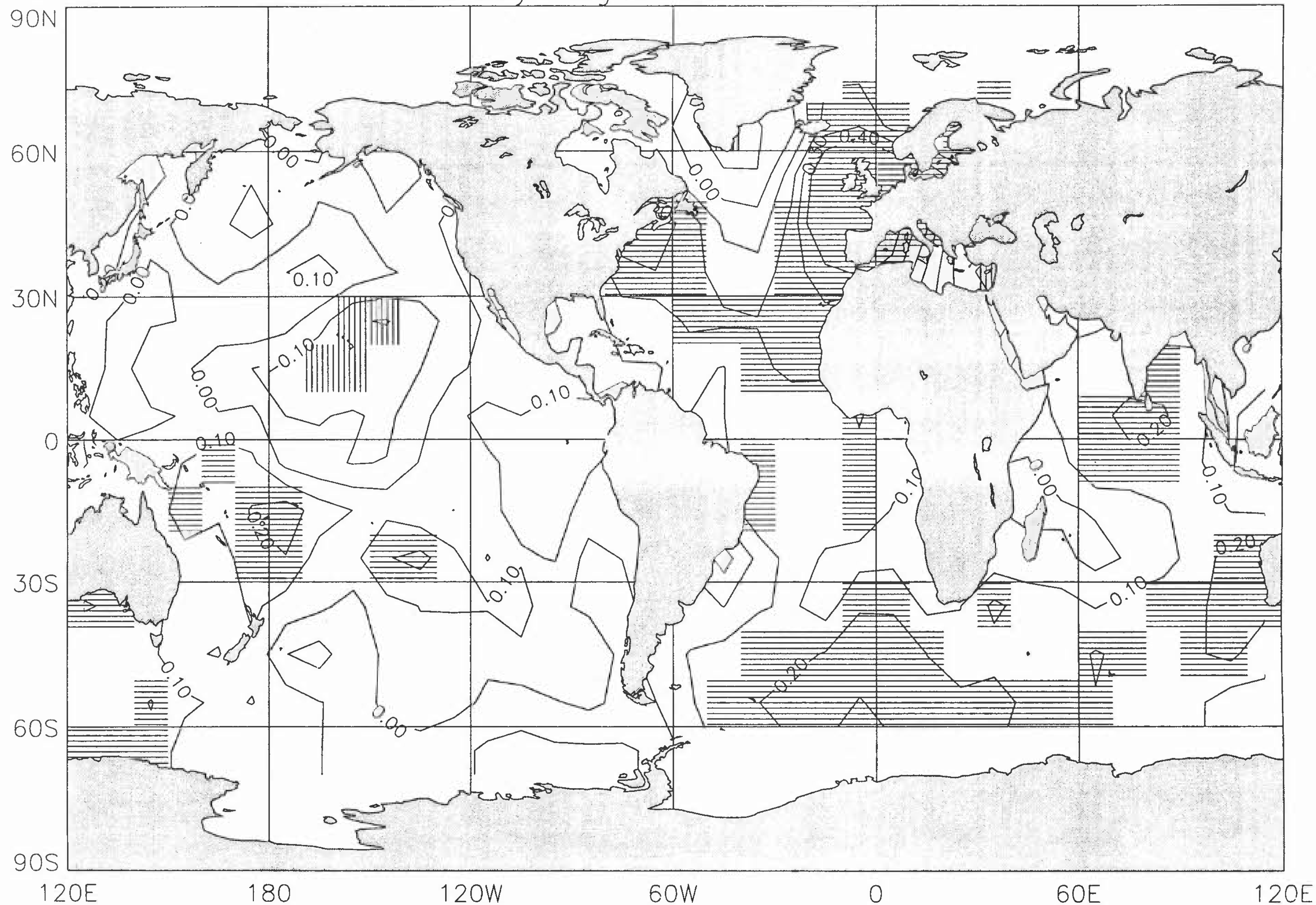


Figure 2.1; Correlation map between July–August CET and June GISST 1871–1994

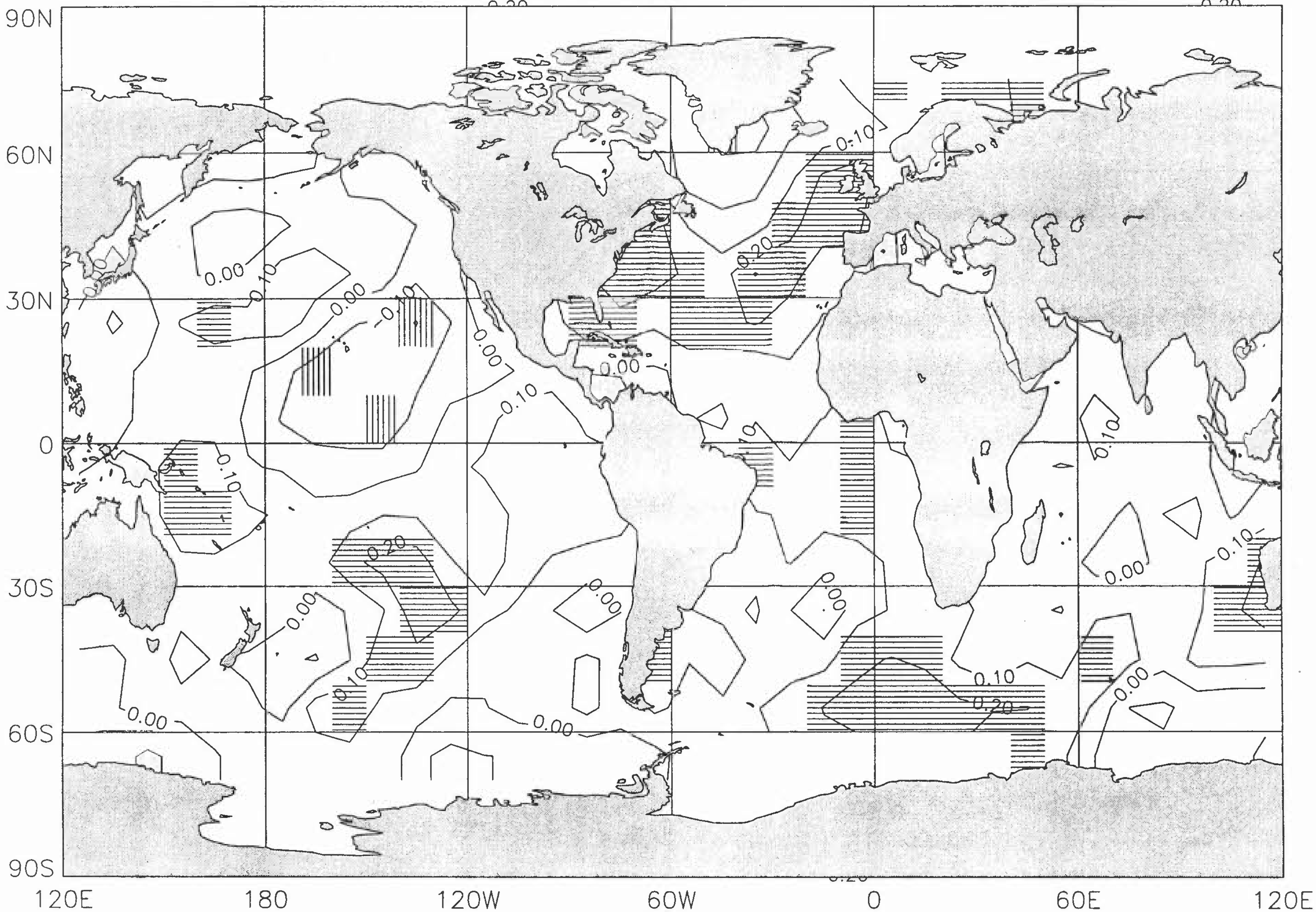


Figure 2.2; Correlation map between July–August CET and May GISST 1871–1994

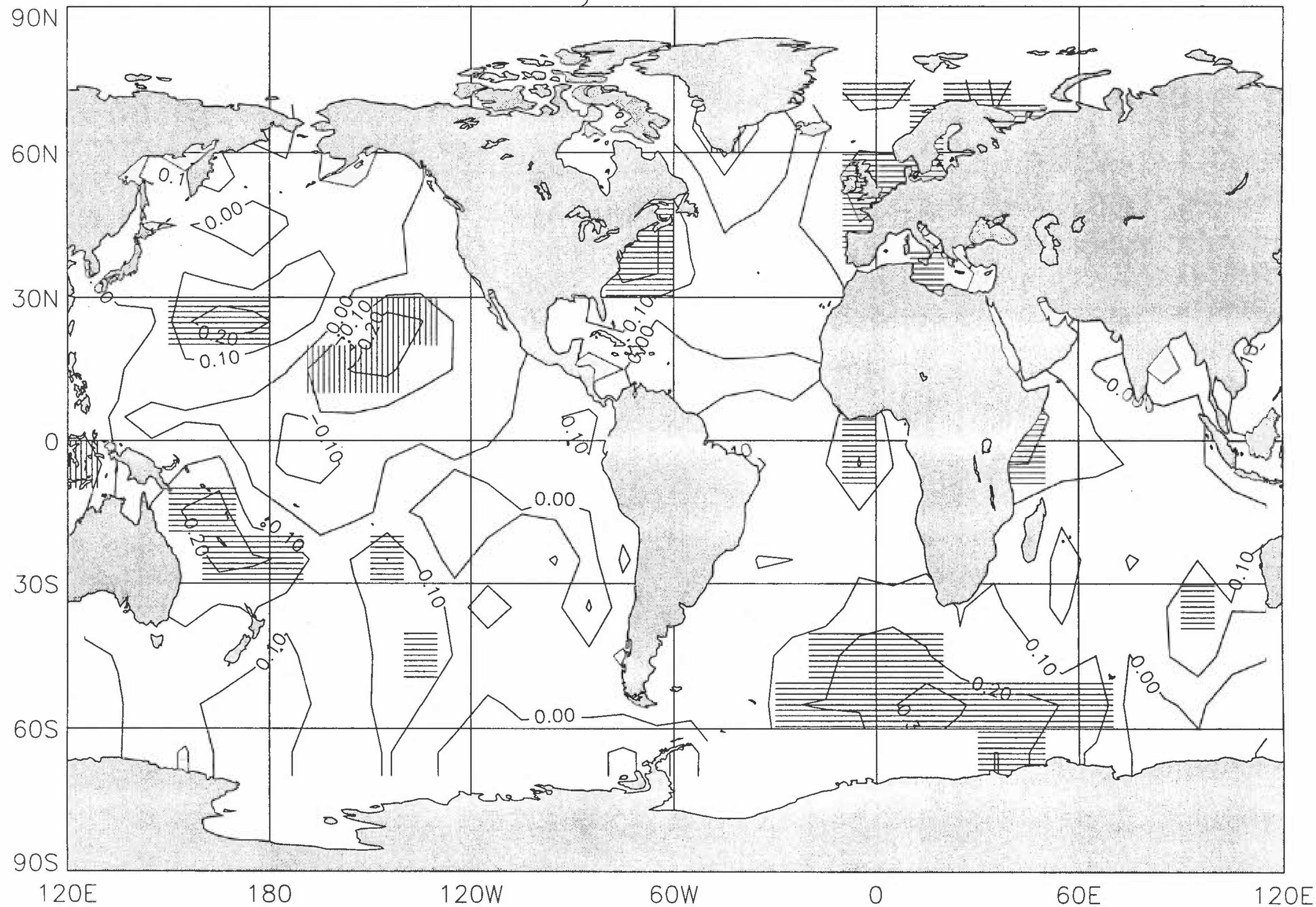


Figure 2.3; Correlation map between July–August CET and April GISST 1871–1994

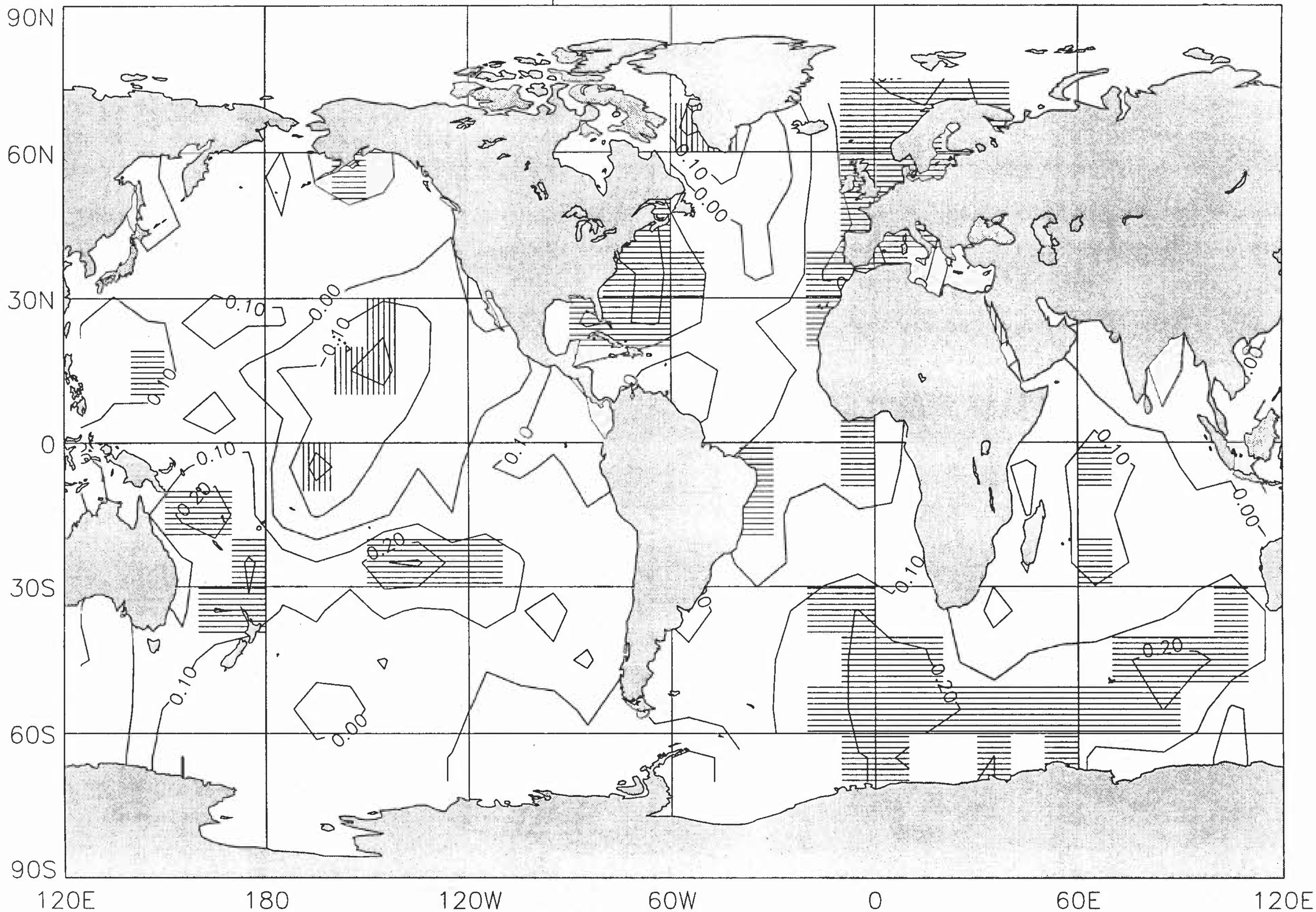


Figure 3.1; Correlation map between July–August CET and January–February GISST 1871–1994

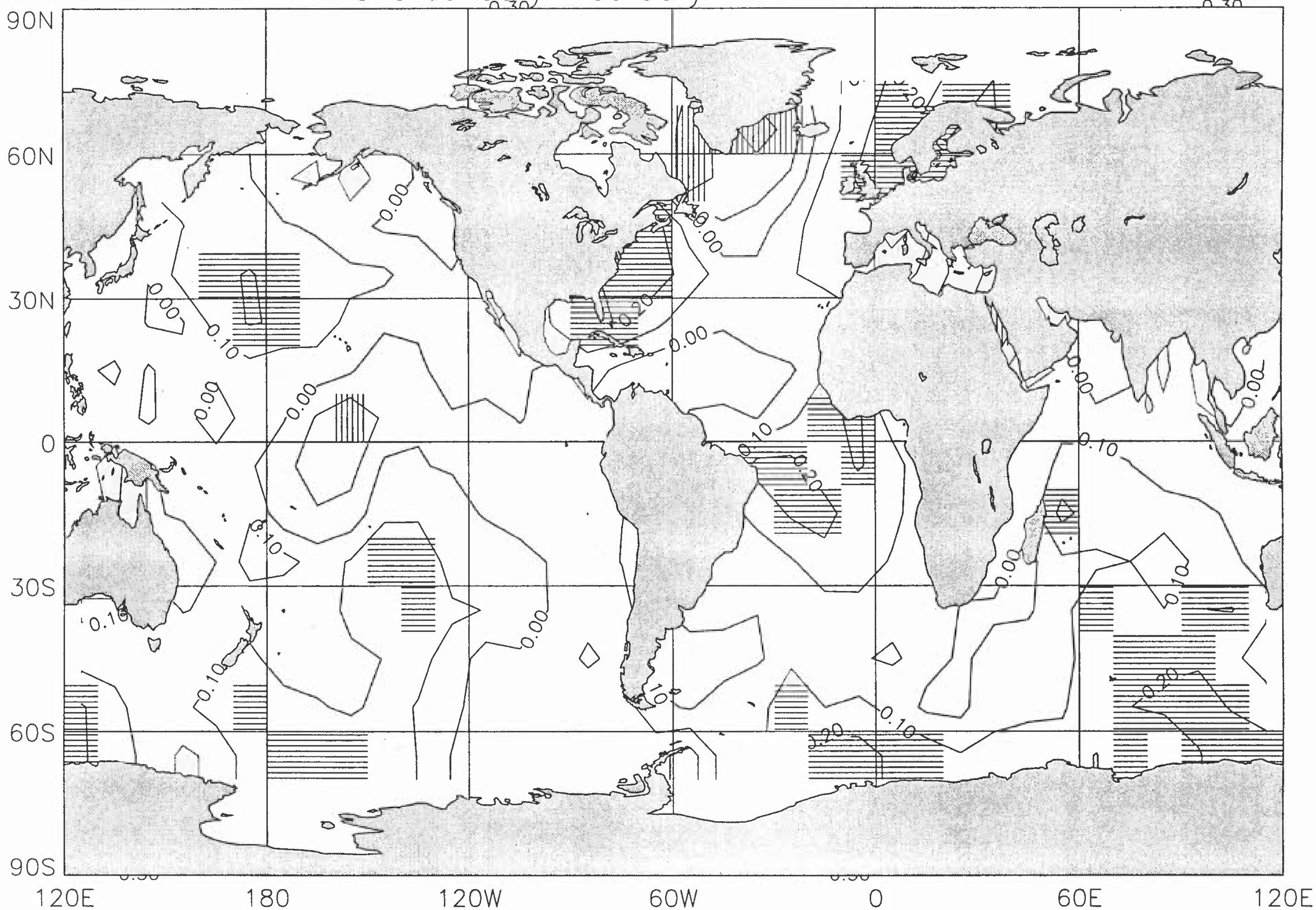


Figure 3.2; Correlation map between July-August CET and January-February GISST 1971-1994

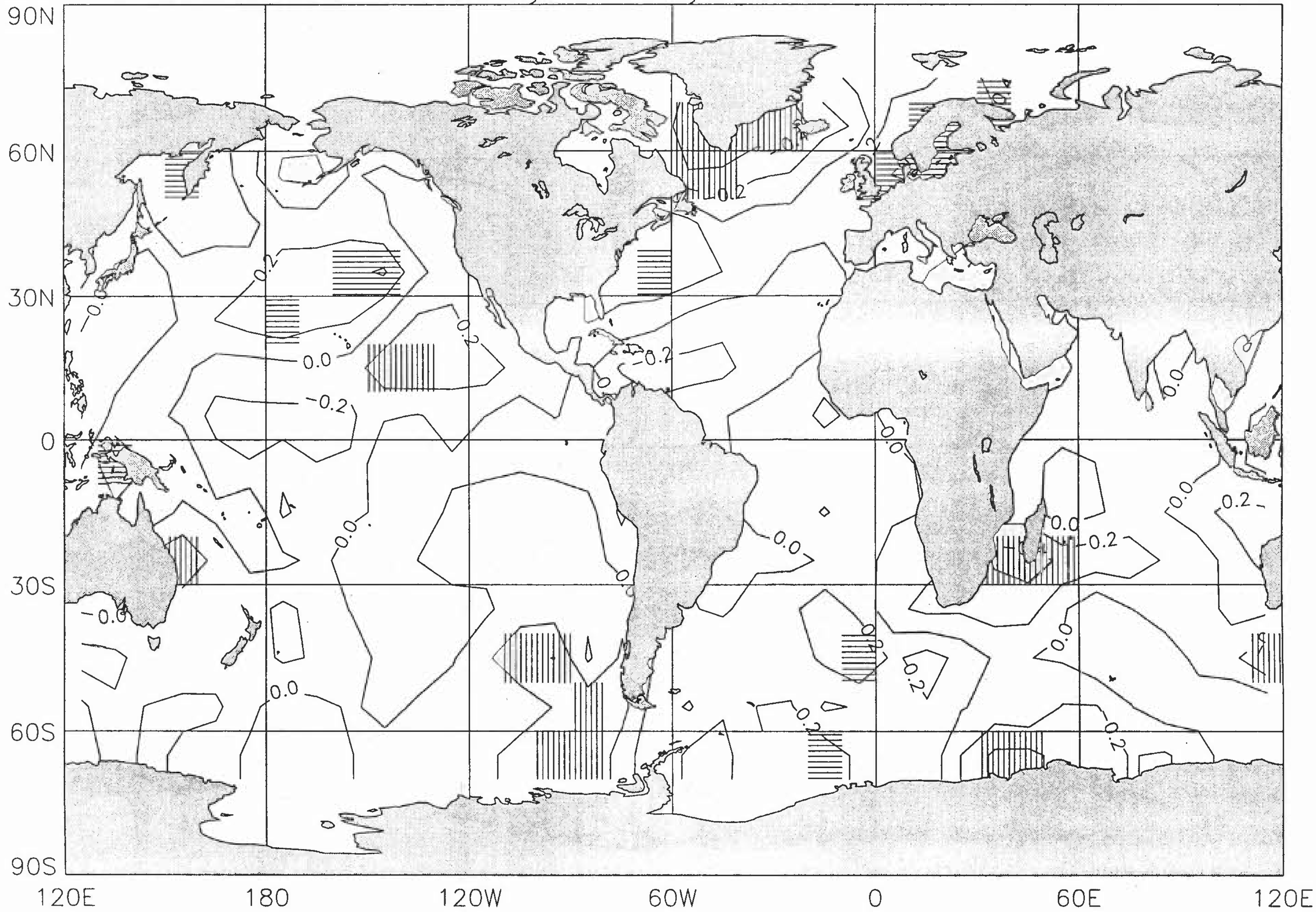


Figure 4; Correlation map between July–August CET and January–February SLP, 1971–1994

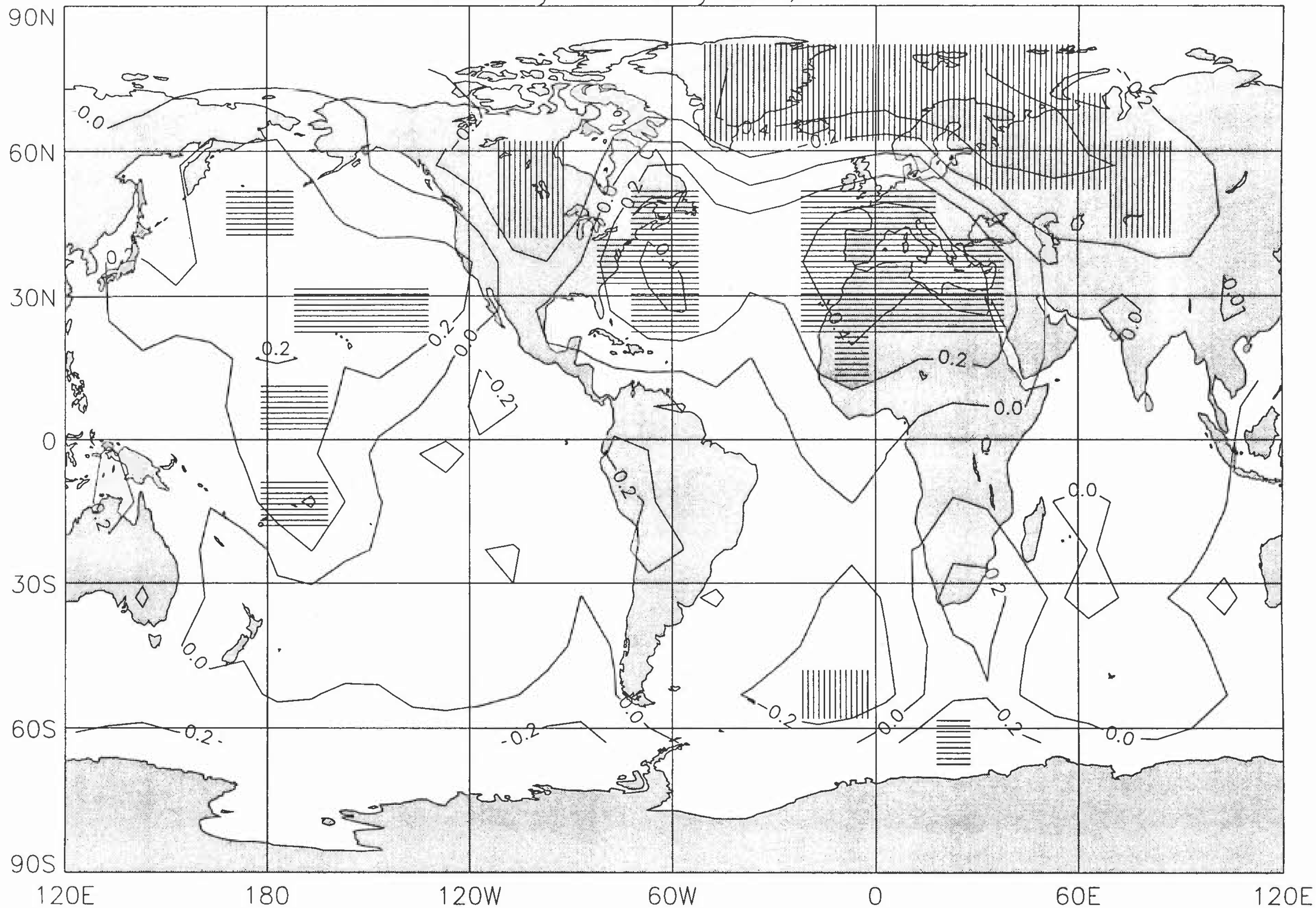


Figure 5; 1901–90 Atlantic 40–70N GISST Eigenvectors

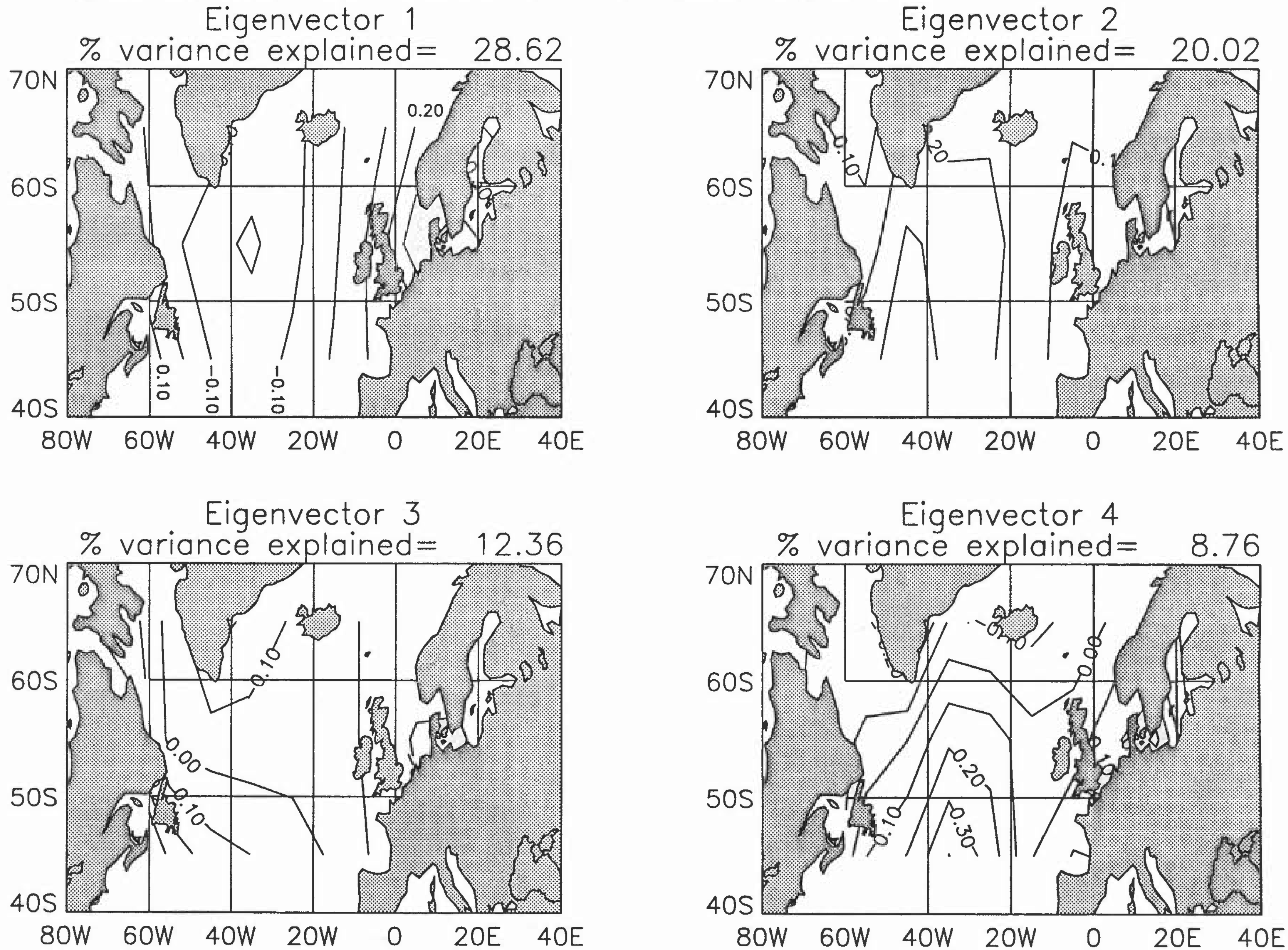
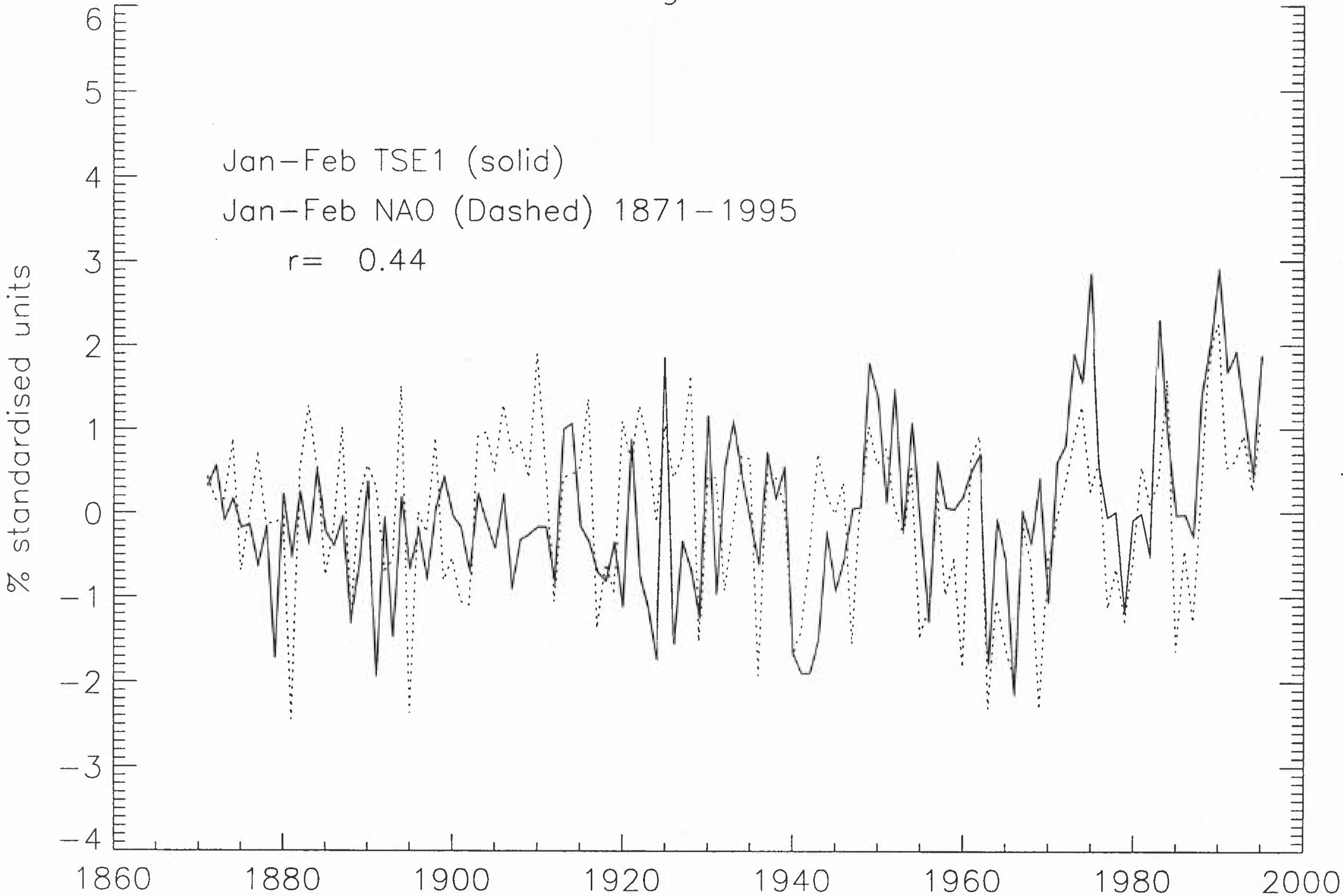


Figure 6



Jan–Feb TSE1 (solid)
Jan–Feb NAO (Dashed) 1871–1995
r= 0.44
% standardised units
6
5
4
3
2
1
0
−1
−2
−3
−4
1860
1880
1900
1920
1940
1960
1980
2000

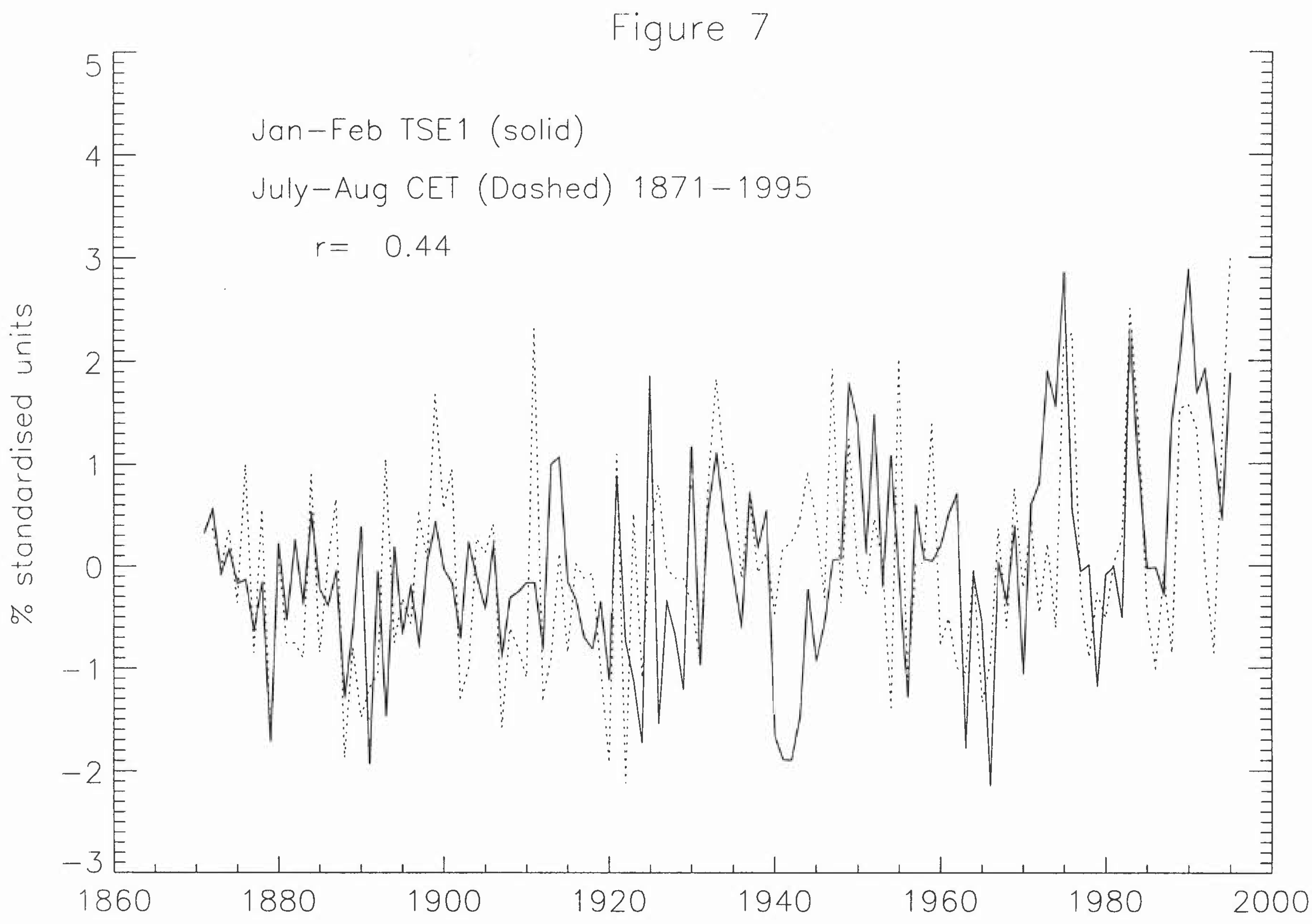


Figure 7
Jan-Feb TSE1 (solid)
July-Aug CET (Dashed) 1871-1995
r= 0.44
% standardised units
5
4
3
2
1
0
-1
-2
-3
1860
1880
1900
1920
1940
1960
1980
2000

Figure 8.1

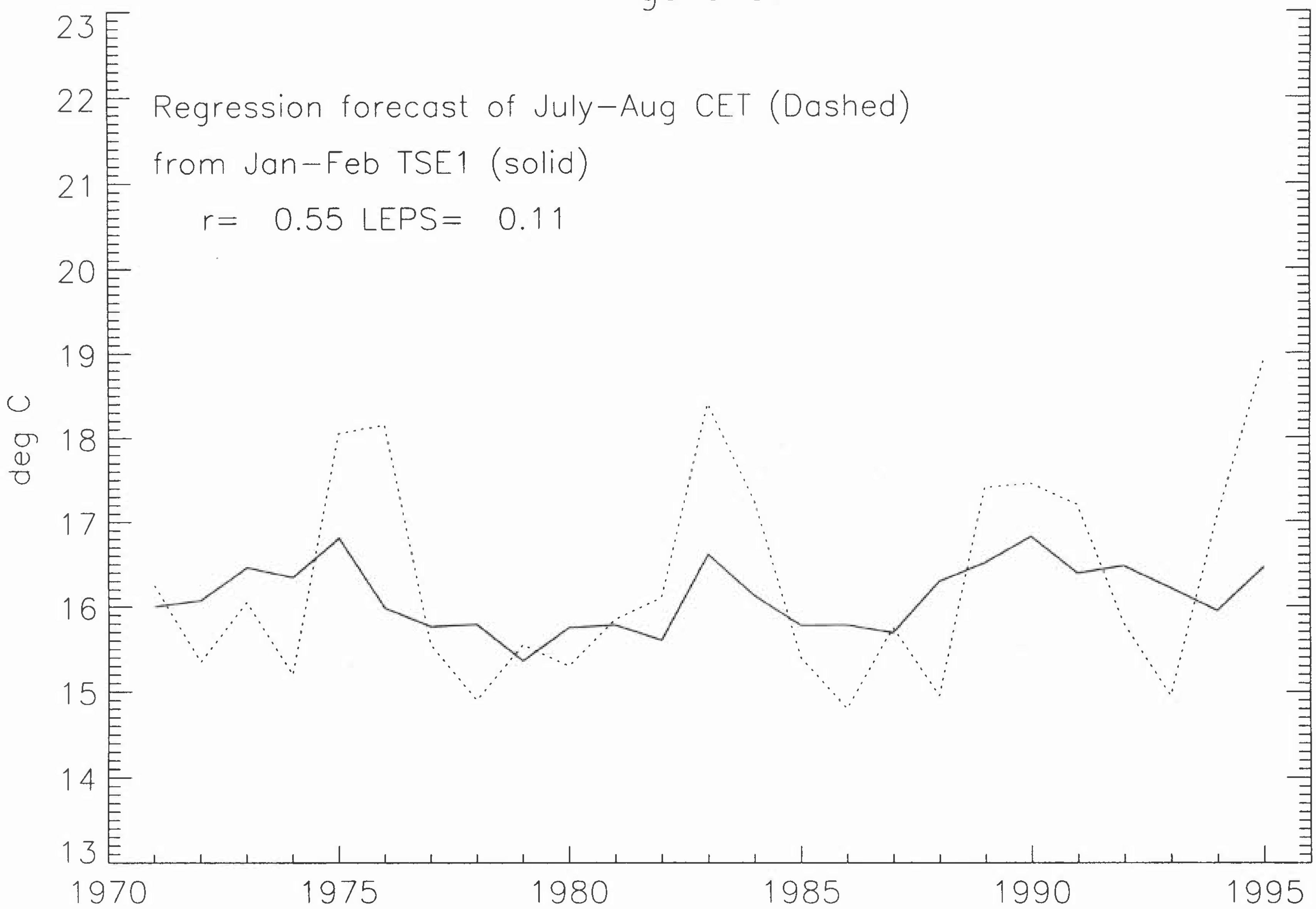
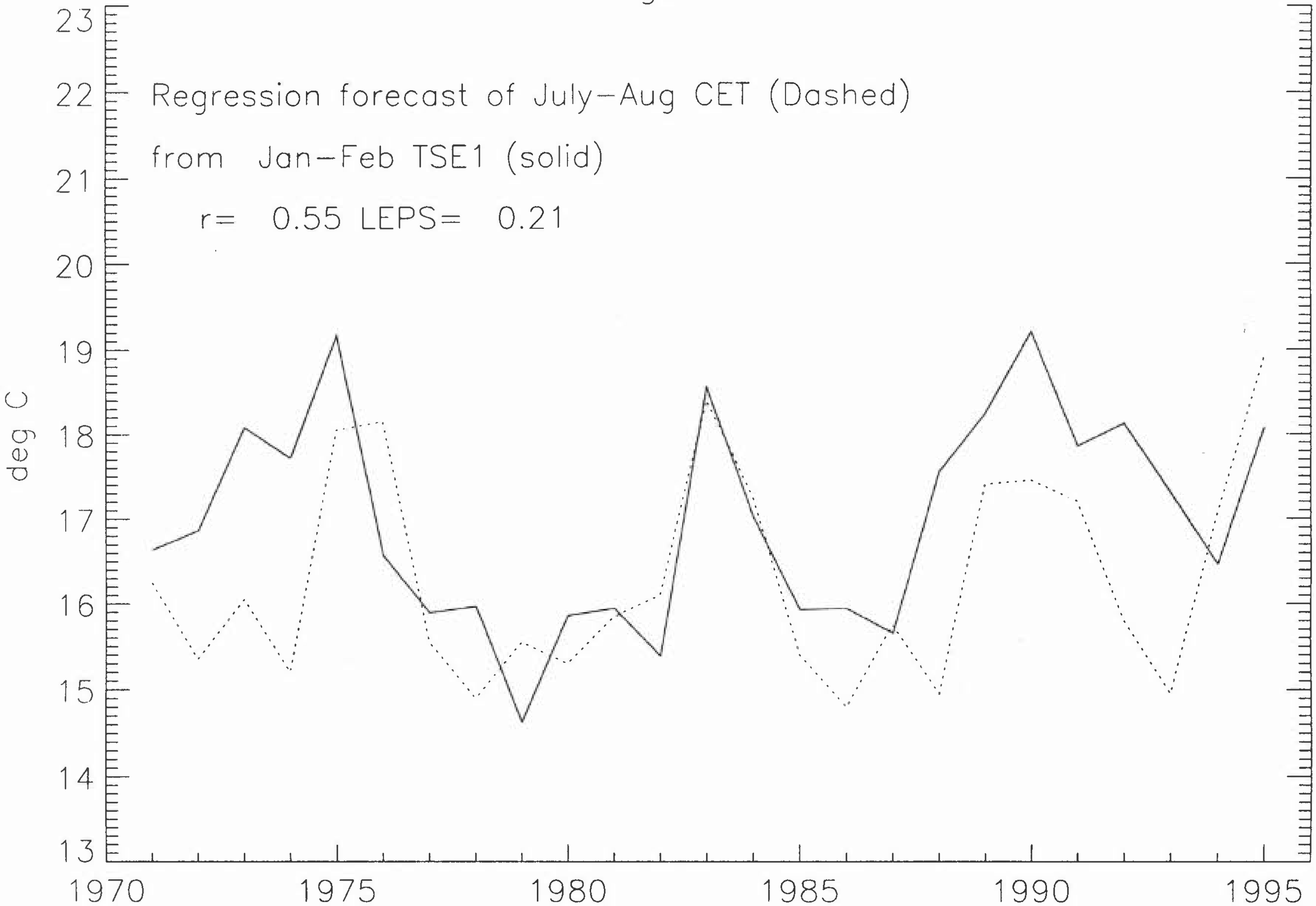

Regression forecast of July–Aug CET (Dashed)
from Jan–Feb TSE1 (solid)
r= 0.55 LEPS= 0.11
deg C
23
22
21
20
19
18
17
16
15
14
13
1970
1975
1980
1985
1990
1995

Figure 8.2



Regression forecast of July-Aug CET (Dashed)
from Jan-Feb TSE1 (solid)
r= 0.55 LEPS= 0.21
deg C
23
22
21
20
19
18
17
16
15
14
13
1970
1975
1980
1985
1990
1995

Figure 9

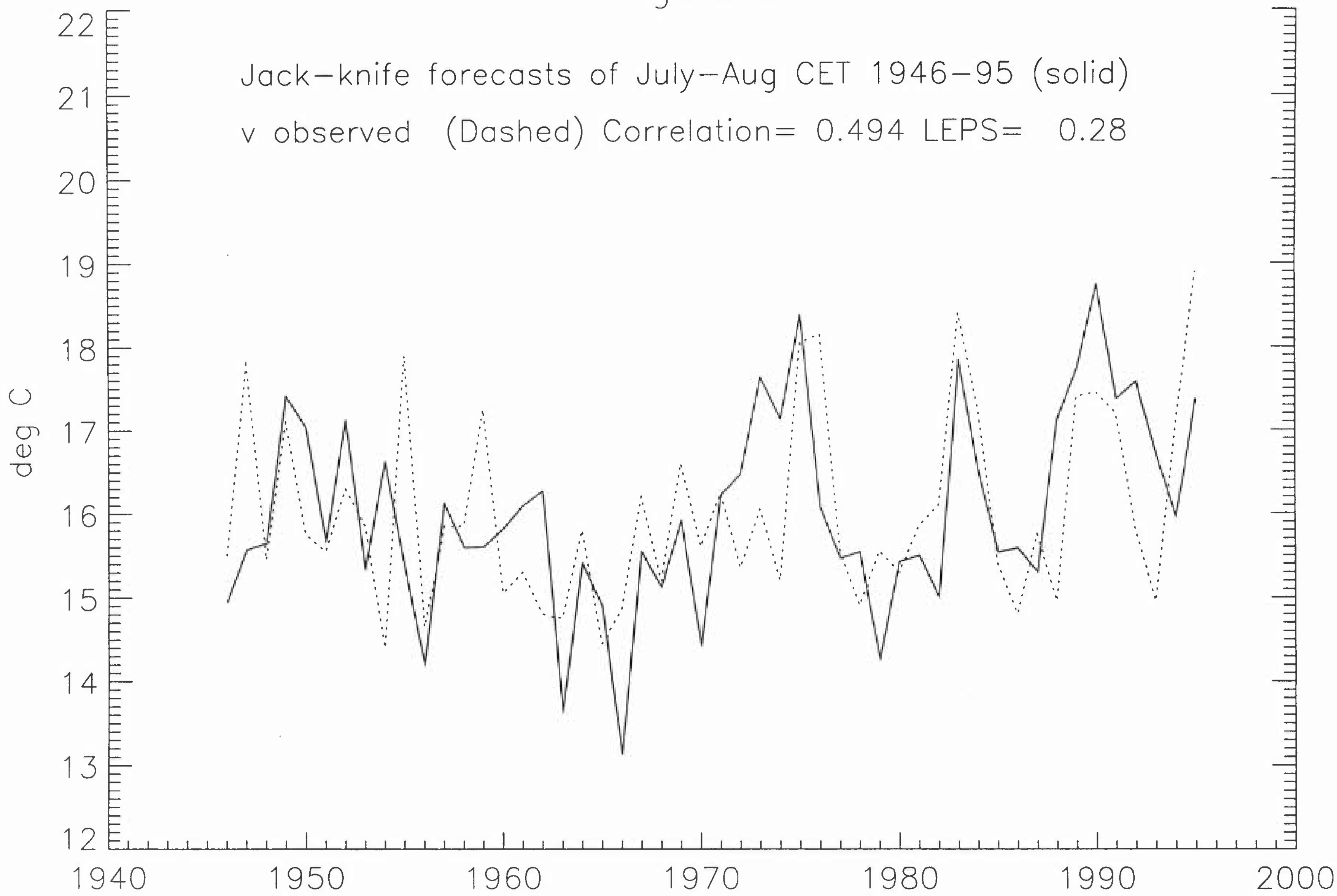
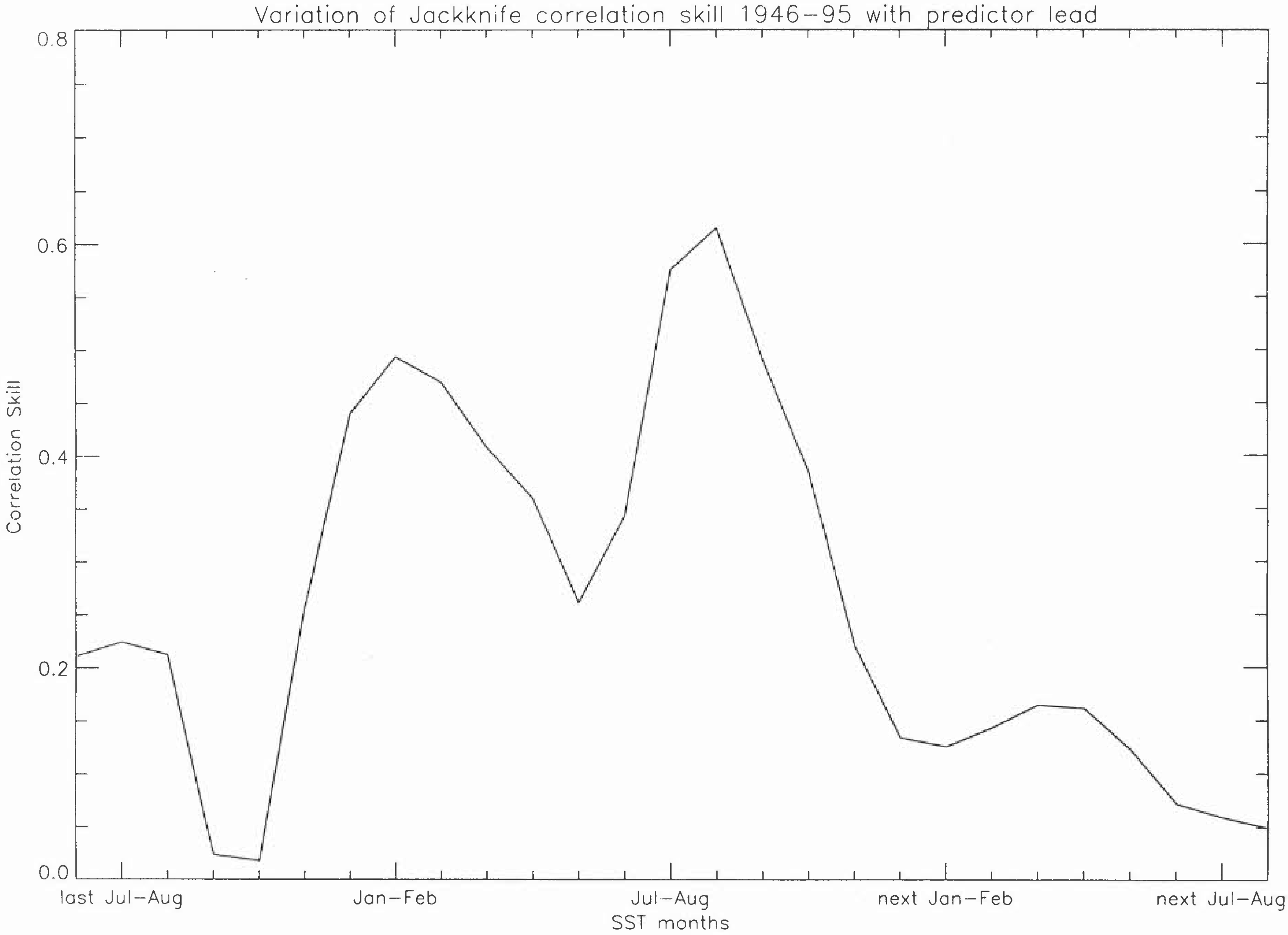

Jack-knife forecasts of July-Aug CET 1946-95 (solid)
v observed (Dashed) Correlation= 0.494 LEPS= 0.28
deg C
22
21
20
19
18
17
16
15
14
13
12
1940
1950
1960
1970
1980
1990
2000

Figure 10;



Variation of Jackknife correlation skill 1946–95 with predictor lead
0.8
0.6
0.4
0.2
0.0
Correlation Skill
last Jul–Aug
Jan–Feb
Jul–Aug
next Jan–Feb
next Jul–Aug
SST months

Figure 11;

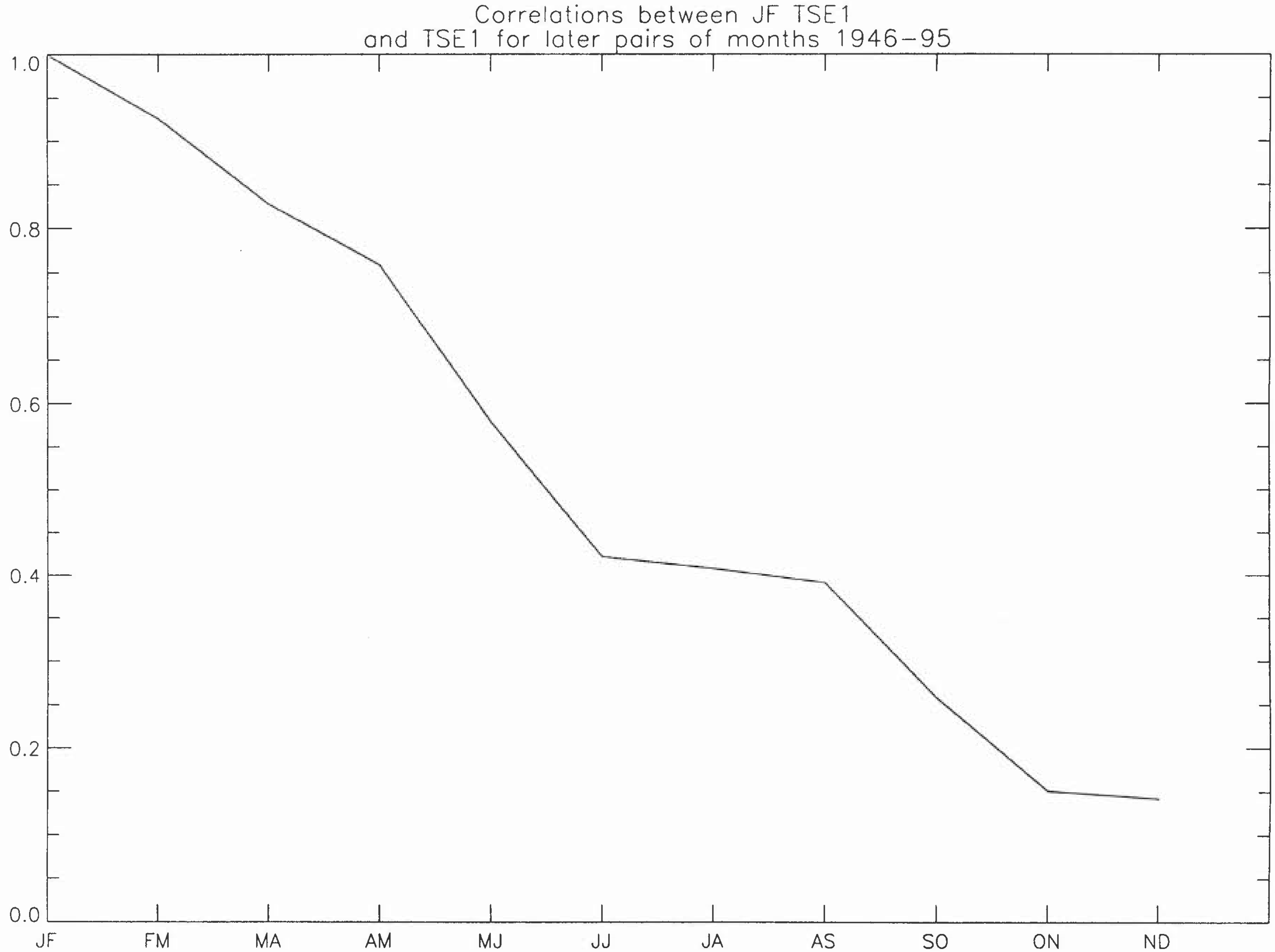
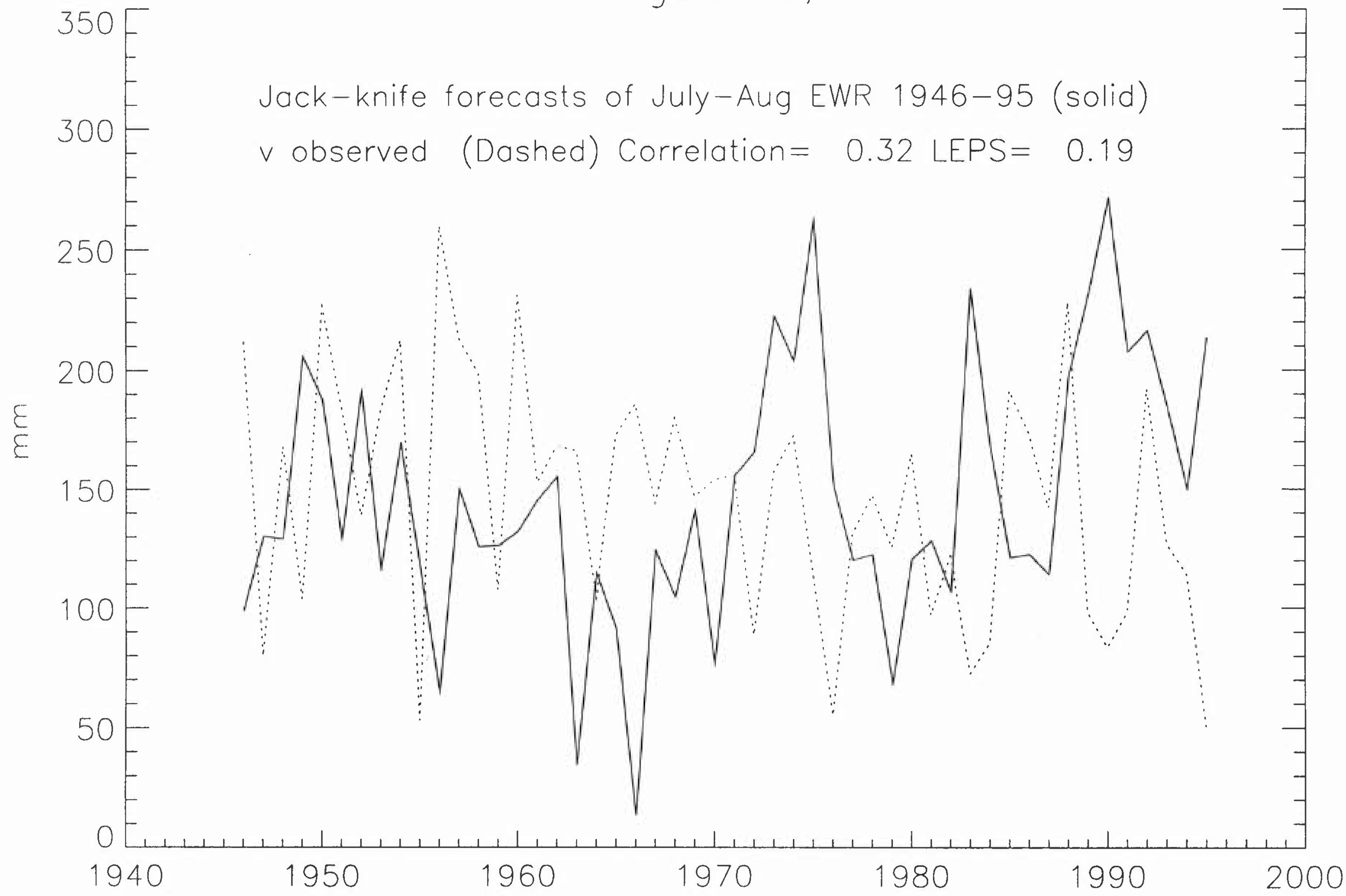

Correlations between JF TSE1
and TSE1 for later pairs of months 1946-95
1.0
0.8
0.6
0.4
0.2
0.0
JF
FM
MA
AM
MJ
JJ
JA
AS
SO
ON
ND

Figure 12;



Jack-knife forecasts of July-Aug EWR 1946-95 (solid)
v observed (Dashed) Correlation= 0.32 LEPS= 0.19
mm
350
300
250
200
150
100
50
0
1940
1950
1960
1970
1980
1990
2000