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METEOROLOGICAL OFFICE

The sensitivity of estimates of trends of global and hemispheric marine temperatures to limitations in geographical coverage

by

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THE SENSITIVITY OF ESTIMATES OF TRENDS OF GLOBAL AND HEMISPHERIC MARINE TEMPERATURES TO LIMITATIONS IN GEOGRAPHICAL COVERAGE

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1. INTRODUCTION

Justifiable concern has sometimes been expressed as to whether the global and hemispheric marine temperature anomaly time-series reported in eg Folland, Parker and Kates (1984) (FPK) are trustworthy, because of the limitations of the geographical coverage especially in the earlier years. The changes of data availability can be seen in FPK mainly in terms of total numbers of observations, but the decadal sea surface temperature (SST) anomaly fields presented in the Global Ocean Surface Temperature Atlas (GOSTA, Bottomley et al (1987)) clearly portray the gaps in spatial coverage in the earlier portions of the record. Before 1900 there were few data in the Pacific, and in the 1860's the observations were limited to the shipping routes from Western Europe to Brazil and, via the Cape of Good Hope, to Indonesia and Australia.

An experiment has therefore been carried out, to test the sensitivity of apparent global and hemispheric SST and night marine air temperature (NMAT) anomalies to artificial limitations of the geographical coverage to that actually available in early decades. Similar experiments, known as 'frozen grid' experiments, were carried out for land air temperatures by Jones et al (1986a, b): these authors found that the hemispheric anomalies on decadal time scales were insensitive to the artificial limitations of coverage, though the use of limited grids did, as expected, increase the interannual variability of the anomalies. The experiments reported in the present paper were designed to study the effects of changes of coverage on the perceived longer-term fluctuations and trends of marine temperature.

2. PROCEDURE

The marine temperature data are available as monthly anomalies relative to the GOSTA (mainly 1951-80) climatology for SST, and relative to 1951-80 for NMAT, for 5° latitude x longitude boxes. However, because of the persistence of SST anomalies (Newman and Storey (1985)) and to a lesser extent NMAT anomalies, the present work was carred out in terms of 3 month seasons (January to March etc). For a given 5° latitude x longitude box, the seasonal anomaly was defined as the average of the three constituent months, using as little as a single month if that was all that was available. Data with quality-control flags set (GOSTA (Bottomley et al (1987)); Parker (1984)) were included. The SST up to 1941 were corrected as in GOSTA using a model of an uninsulated canvas bucket assuming 4 minutes' total time for heat transfer. The NMAT data were also corrected as in GOSTA.

The frozen grids for each decade from 1861-70 up to 1951-60 were defined as those 5° latitude x longitude boxes with at least a specified percentage of seasons having an anomaly value as defined above. Initially the chosen criterion was 50%, giving the frozen grids shown (as maps of numbers of seasons having values) in Figures 1a to 10a for SST and in Figures 1b to 10b for NMAT. Because these grids include all areas with data coverage for the majority of seasons, they represent well the typical availability of data in each decade. Note the following features:

i. The coverage for 1861-70, although limited to the routes from Western Europe to Brazil and via the Cape of Good Hope to Indonesia and Australia, nevertheless includes much of the Atlantic and Indian Oceans.

ii. By 1871-80 the coverage in these oceans increased with the extension of data to North America and through the Suez Canal which opened in 1869, and there were a few routes represented in the Pacific.

iii. Coverage of the Pacific nevertheless remained poor until 1920.

iv. Coverage of SST only slightly exceeded that of NMAT (compare Figure 1a with Figure 1b etc). The restriction of data to night-time does not diminish the coverage substantially, because observations have generally been taken every 6 (or 4 or 3) hours on a continuous watch, so that a 5° latitude x longitude area, which takes of the order of 12 to 24 hours to cross, is generally sampled by night if it is sampled at all. The slight difference in coverage between SST and NMAT partly results, in fact, from the complete coverage of the GOSTA SST climatology as against the gaps in the NMAT climatology (illustrated by the climatology of air-sea temperature difference in Bottomley et al (1987)). The GOSTA SST climatology was made complete by using the climatology of Alexander and Mobley (1976) to fill in the gaps, particularly in the Southern Ocean. As a result, SST anomalies could be computed for locations where NMAT anomalies could not. A good example is the area west of Cape Horn from 1871 to 1930. This region was not well sampled after 1930, which is why it is missing from the 1951-80 NMAT climatology, and would have been missing from the SST climatology but for the use of earlier data by Alexander and Mobley, and their extrapolation to an assumed SST at the ice-edge.

In order to apply a severe test of the sensitivity of apparent global and hemispheric anomalies to the coverage of data, frozen grids were also formed for 1861-70 requiring at least 90% of seasons to have a value (Figures 11a, b). A less stringent test was also made, by reducing this criterion to 30% (Figures 11c, d).

When the frozen grids had been defined, 'global' and 'hemispheric' SST and NMAT anomalies were computed for each season from January-March 1956 to October-December 1985 for SST and 1981 for NMAT, using only the seasonal anomalies for the 5° latitude x longitude boxes included in the relevant frozen grid. The spatial averaging of boxes used a weighting for each box of cosine (latitude) multiplied by the proportion of ocean in the box. The seasonal time series thus computed were smoothed with a 41-term ($10^1/_4$ year) triangular filter and plotted, along with similarly-computed time-series using all available data for comparison.

3. RESULTS

Figure 12a compares the smoothed time-series of global SST obtained using frozen grids with the 50% criterion for 1901-10 and for 1861-70, with the corresponding curve based on all available data. The 1901-10 frozen grid gives a curve almost identical with that using all available data, and even use of the 1861-70 frozen grid does not result in deviations exceeding 0.1°C. The frozen grid for 1861-70 with the 90% criterion (Figure 11a) gives deviations (Figure 12b) which are hardly greater than with the 50% criterion. None of the frozen grids for other decades with the 50% criterion give deviations exceeding that for 1861-70, ie Figures 12a and 12b include the worst fits obtained for global SST. Use of the 30% criterion for 1861-70 gives a very slightly better fit than using the 50% criterion (Figures 12a, b).

Figures 12c and 12d correspond to Figures 12a and 12b but are for NMAT. The fits are nearly as good as for SST, even though they likewise include the worst fits obtained for global NMAT.

Figures 13 and 14 correspond to Figure 12 but are for the Northern and Southern Hemispheres respectively. The fits for SST remain very good for the 1861-70 frozen grid with the 50% criterion, and good when this criterion is tightened to 90%. The poorest fits are for Northern Hemisphere NMAT around 1880 using the 1861-70 frozen grids, and even in these cases the curves fit very well from 1890 to date (Figures 13c and d). Again the worst fits obtained are included in these diagrams, ie the 1871-80 etc frozen grids with the 50% criterion gave better fits. As before the 30% criterion for 1861-70 gives similar or very slightly better fits than the 50% criterion.

4. DISCUSSION

This experiment has shown empirically that estimates of trends of global and hemispheric marine temperatures are insensitive to the limitations in geographical coverage that have occurred since 1860. The reason appears to be that the climatic trends of SST and NMAT are coherent on a hemispheric scale. They are not completely coherent on a global scale, i.e. the hemispheres show somewhat differing trends (compare Figures 13a and 14a) but this characteristic does not degrade the results for the globe even for the 1861-70 frozen grids, because these grids encompass parts of each hemisphere (Figures 1a, 1b and 11a, 11b).

The considerable degree of coherence of the climatic trends on a hemispheric scale is illustrated in Figures 15a (SST) and 15b (NMAT) which compare the North Atlantic and North Pacific using all available data; and in Figures 16a (SST) and 16b (NMAT) which likewise compare the South Atlantic, South Pacific and South Indian Ocean. The poorest fits in Figures 13c and d correspond to a period when NMAT anomalies in the poorly sampled North Pacific differed markedly from those in the North Atlantic (Figure 15b). Apart from this instance, both SST and NMAT followed very similar trends in the North Atlantic and North Pacific. The coherence between the South Atlantic, South Pacific and South Indian Ocean is fairly good (Figures 16a, 16b): the results for the Southern Hemisphere (Figures 14a to d) have the advantage that both the South Atlantic and the South Indian Ocean were substantially sampled throughout the period (Figures 1 to 11). (The Mercator projections in these Figures over-emphasize the blank areas south of about 45°S).

Further evidence for the generally high coherence of the longer-term trends of SST comes from the pattern of the first covariance eigenvector of seasonal SST anomalies, defined using data for 1901-80 (Figure 17a). This eigenvector has the same sign throughout the world, and its coefficient (Figure 17b) has a correlation of 0.92 with the unsmoothed global seasonal SST anomaly time-series obtained using all available data for 1856-1986, which is dominated by long-term trends (see also FPK). None of these illustrations can strictly prove that the same coherence occurred in the mid-19th Century when there were no data in virtually the entire Pacific, but application of 'Occam's razor' makes this the most readily adopted hypothesis.

The results of this study increase the confidence that can be placed in estimates of global and hemispheric climate changes of marine temperatures. Shorter-term and smaller-scale fluctuations will, however, have been subject to greater sampling uncertainty, which can best be reduced by acquiring the additional data which probably reside in maritime archives around the world.

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Figure 1a.

NUMBER OF SEASONS WITH SST DATA (1 MONTH CAN CONSTITUTE A SEASON)

PERIOD 1861 TO 1870

MINIMUM % OF POSSIBLE SEASONS IF 5 DEG AREA IS TO BE PLOTTED HERE AND USED IN REGIONAL TIME SERIES: 50

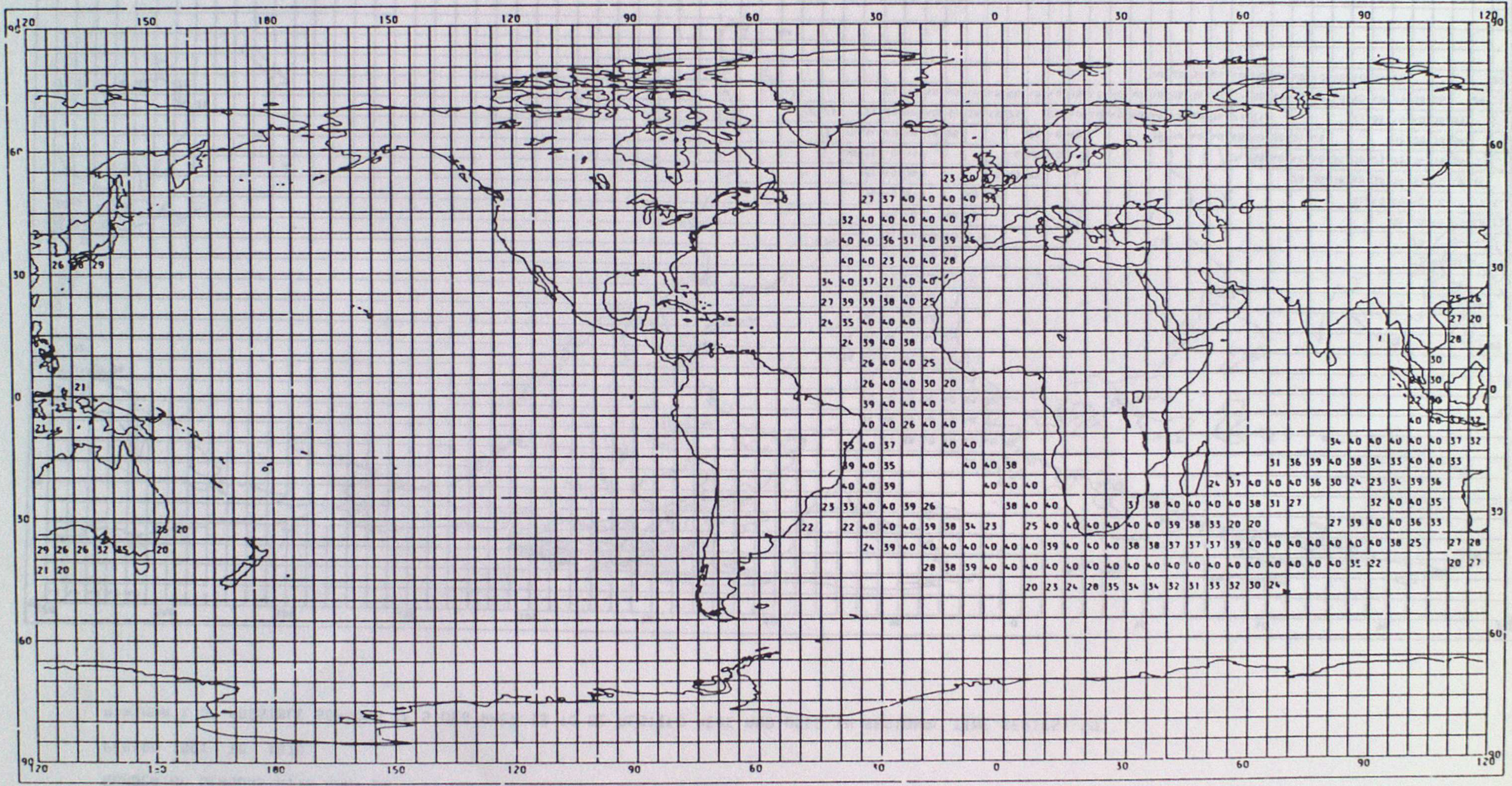


Figure 1b.

NUMBER OF SEASONS WITH NMAT DATA (1 MONTH CAN CONSTITUTE A SEASON)

PERIOD 1861 TO 1870

MINIMUM % OF POSSIBLE SEASONS IF 5 DEG AREA IS TO BE PLOTTED HERE AND USED IN REGIONAL TIME SERIES: 50

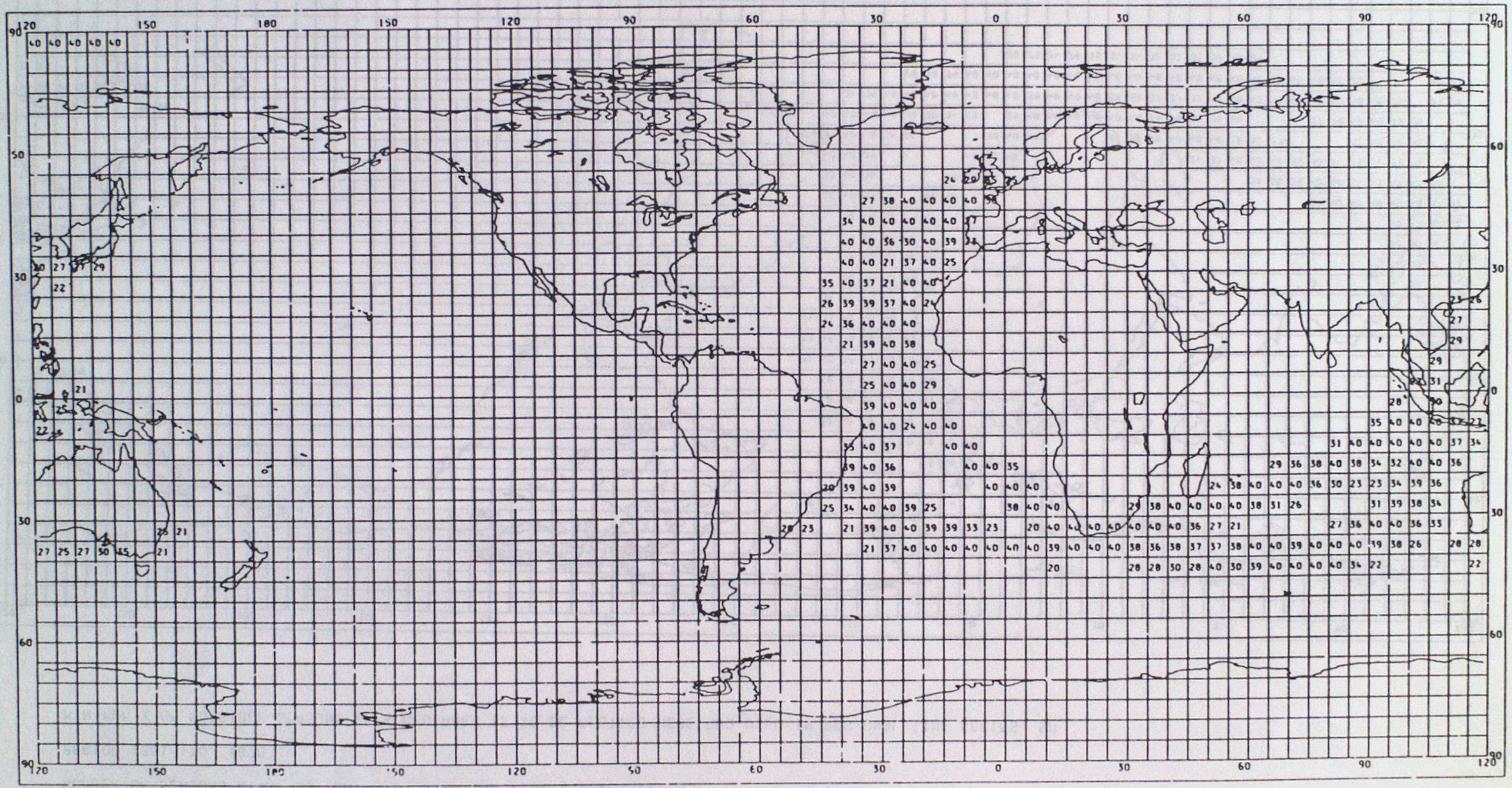


Figure 2a.

NUMBER OF SEASONS WITH SST DATA (1 MONTH CAN CONSTITUTE A SEASON)

PERIOD 1871 TO 1880

MINIMUM % OF POSSIBLE SEASONS IF 5 DEG AREA IS TO BE PLOTTED HERE AND USED IN REGIONAL TIME SERIES: 50

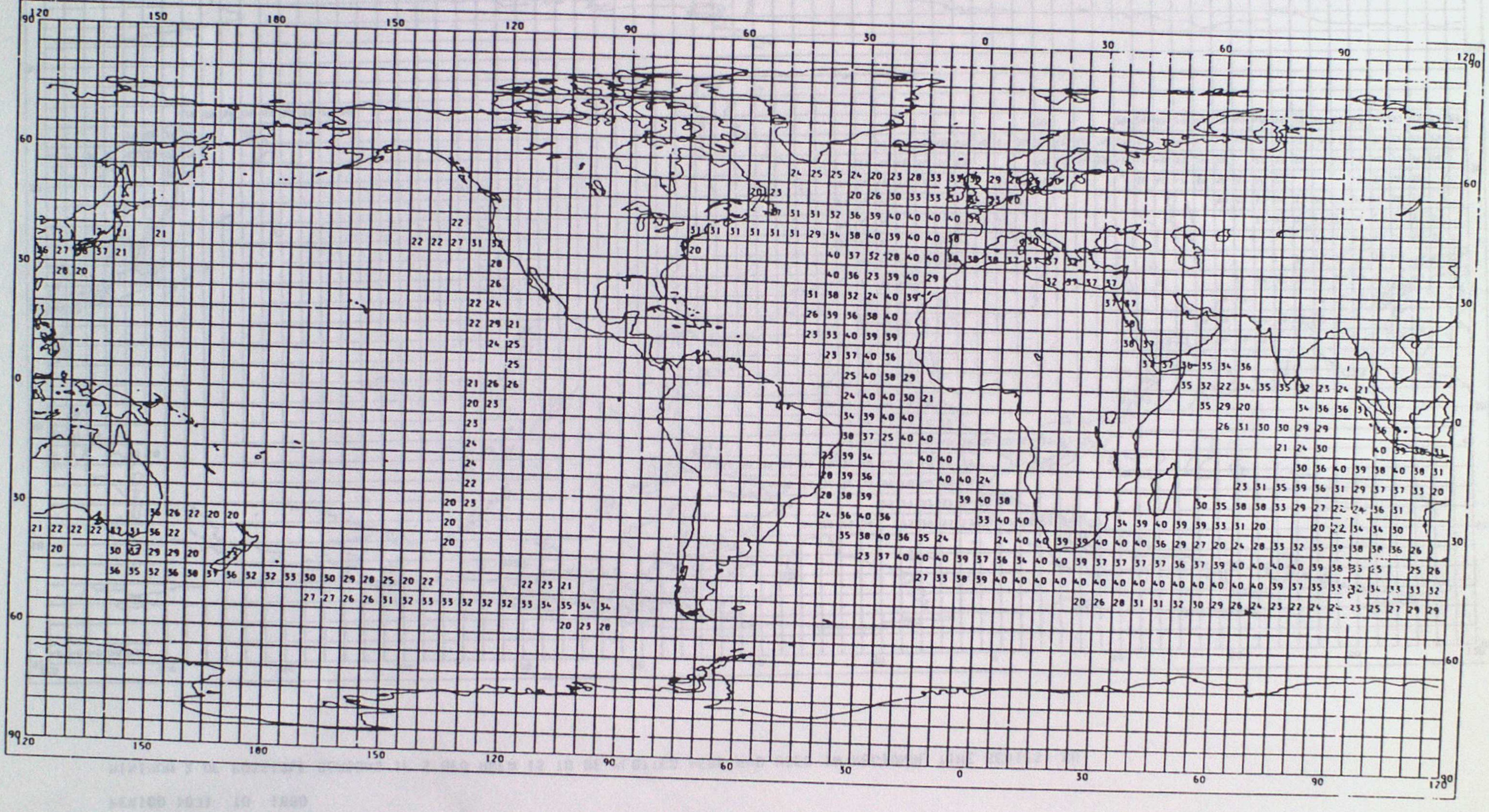


Figure 2b.

NUMBER OF SEASONS WITH NMAT DATA (1 MONTH CAN CONSTITUTE A SEASON)

PERIOD 1871 TO 1880

MINIMUM % OF POSSIBLE SEASONS IF 5 DEG AREA IS TO BE PLOTTED HERE AND USED IN REGIONAL TIME SERIES: 50

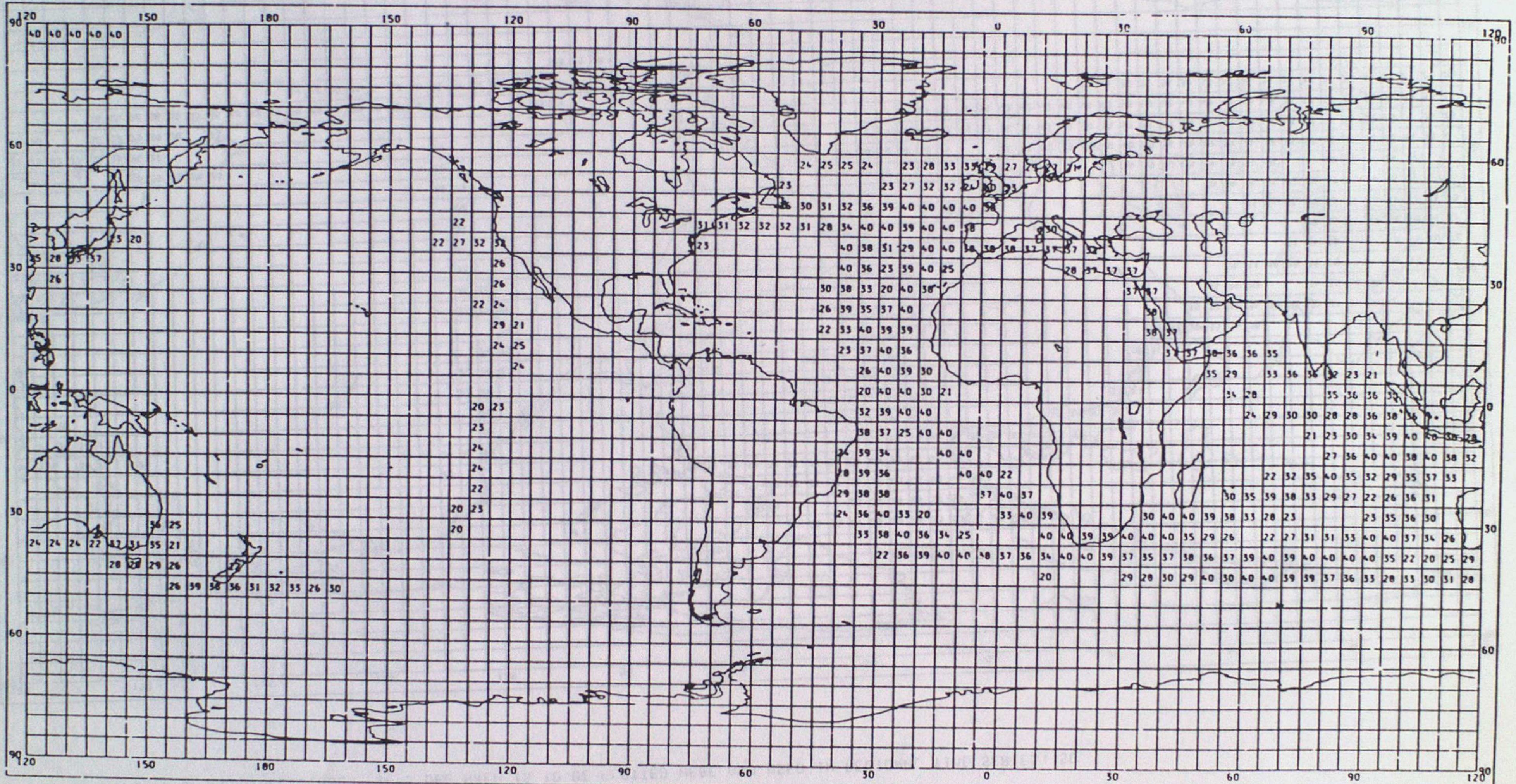


Figure 3a.

NUMBER OF SEASONS WITH SST DATA (1 MONTH CAN CONSTITUTE A SEASON)

PERIOD 1881 TO 1890

MINIMUM % OF POSSIBLE SEASONS IF 5 DEG AREA IS TO BE PLOTTED HERE AND USED IN REGIONAL TIME SERIES: 50

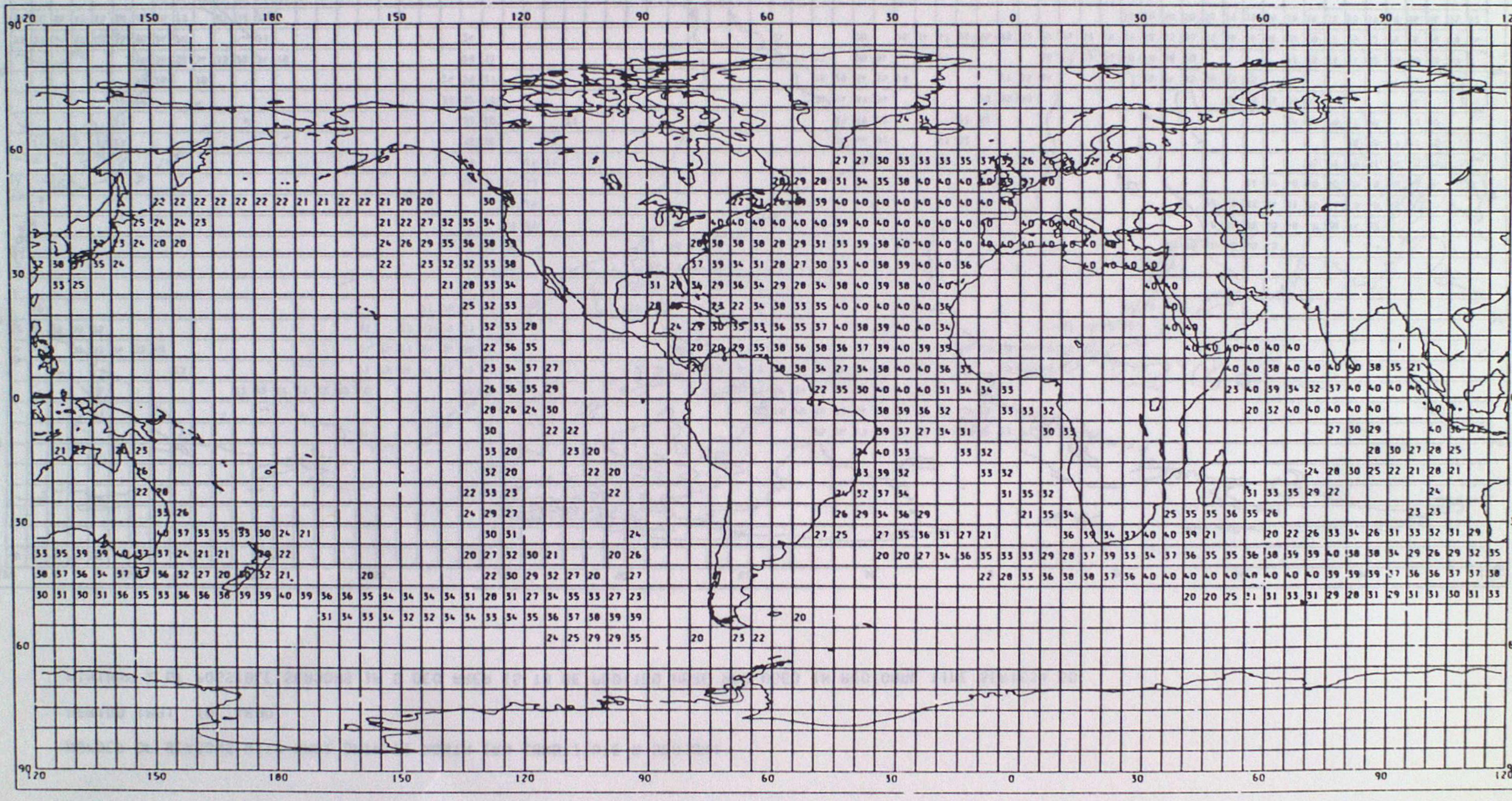


Figure 3b.

NUMBER OF SEASONS WITH NMAT DATA (1 MONTH CAN CONSTITUTE A SEASON)

PERIOD 1881 TO 1890

MINIMUM % OF POSSIBLE SEASONS IF 5 DEG AREA IS TO BE PLOTTED HERE AND USED IN REGIONAL TIME SERIES: 50

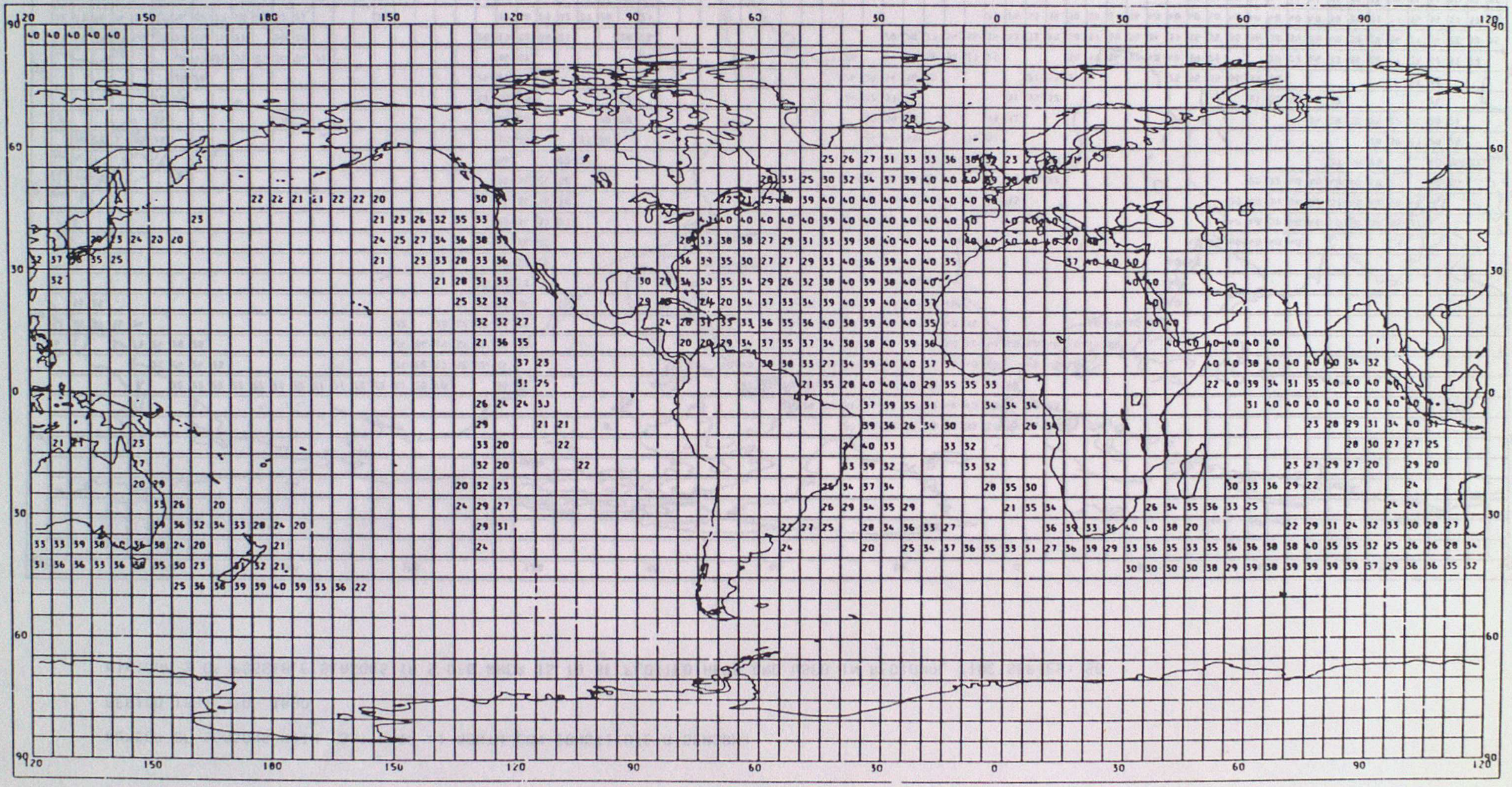


Figure 4a.

NUMBER OF SEASONS WITH SST DATA (1 MONTH CAN CONSTITUTE A SEASON)

PERIOD 1891 TO 1900

MINIMUM % OF POSSIBLE SEASONS IF 5 DEG AREA IS TO BE PLOTTED HERE AND USED IN REGIONAL TIME SERIES: 50

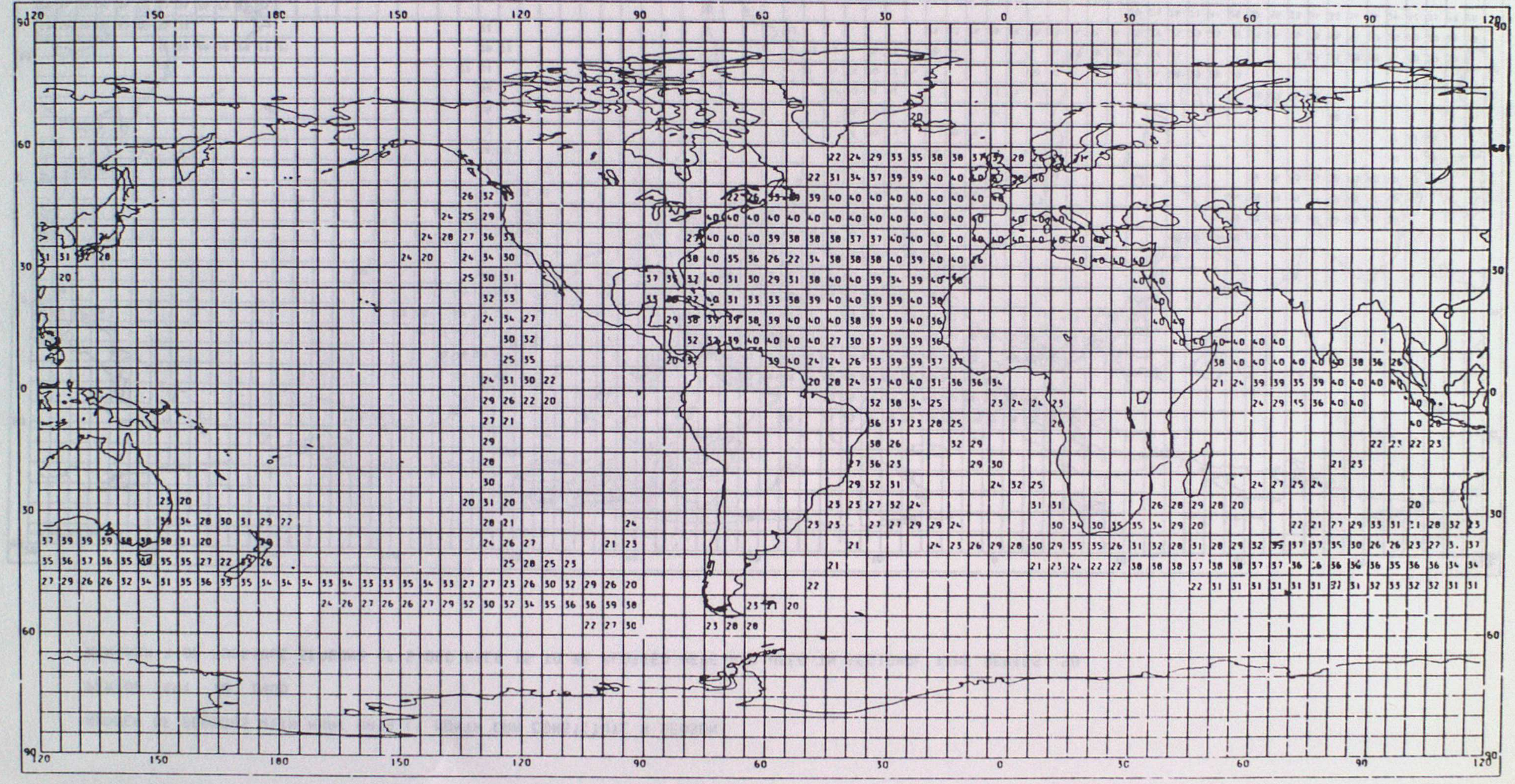


Figure 4b.

NUMBER OF SEASONS WITH NMAT DATA (1 MONTH CAN CONSTITUTE A SEASON)

PERIOD 1891 TO 1900

MINIMUM % OF POSSIBLE SEASONS IF 5 DEG AREA IS TO BE PLOTTED HERE AND USED IN REGIONAL TIME SERIES: 50

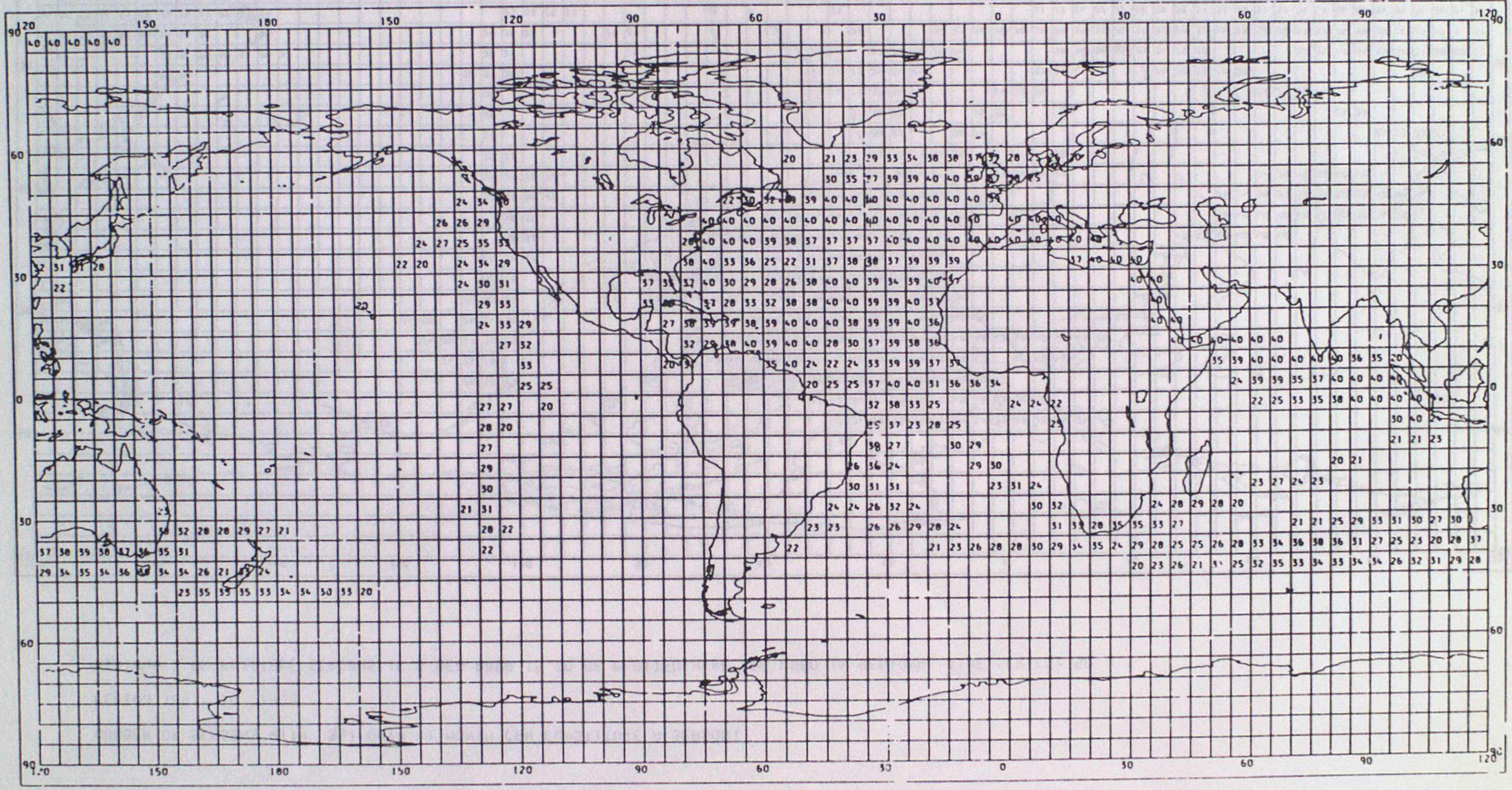


Figure 5a.

NUMBER OF SEASONS WITH SST DATA (1 MONTH CAN CONSTITUTE A SEASON)

PERIOD 1901 TO 1910

MINIMUM % OF POSSIBLE SEASONS IF 5 DEG AREA IS TO BE PLOTTED HERE AND USED IN REGIONAL TIME SERIES: 50

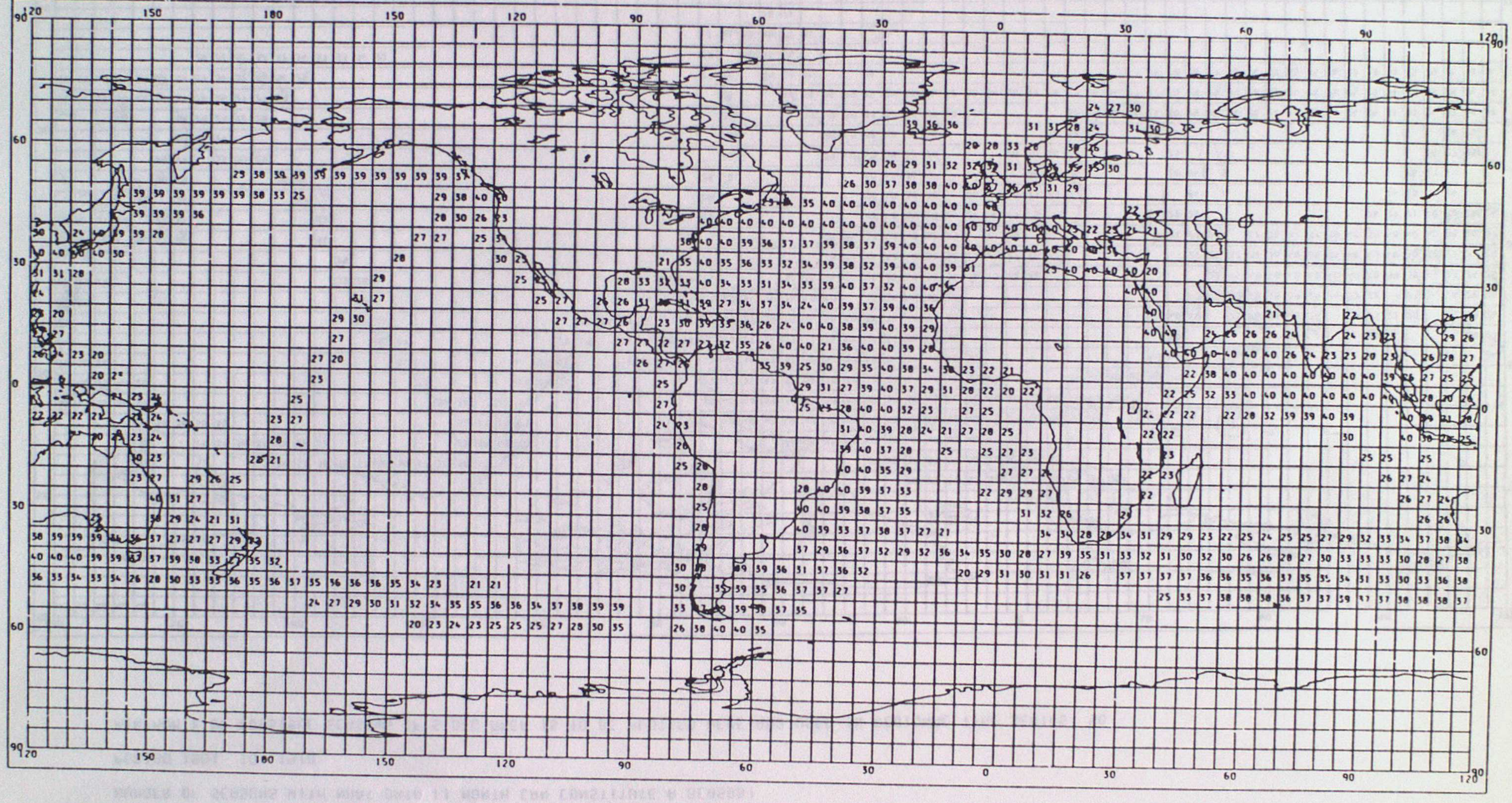


Figure 5b.

NUMBER OF SEASONS WITH NMAT DATA (1 MONTH CAN CONSTITUTE A SEASON)

PERIOD 1901 TO 1910

MINIMUM % OF POSSIBLE SEASONS IF 5 DEG AREA IS TO BE PLOTTED HERE AND USED IN REGIONAL TIME SERIES: 50

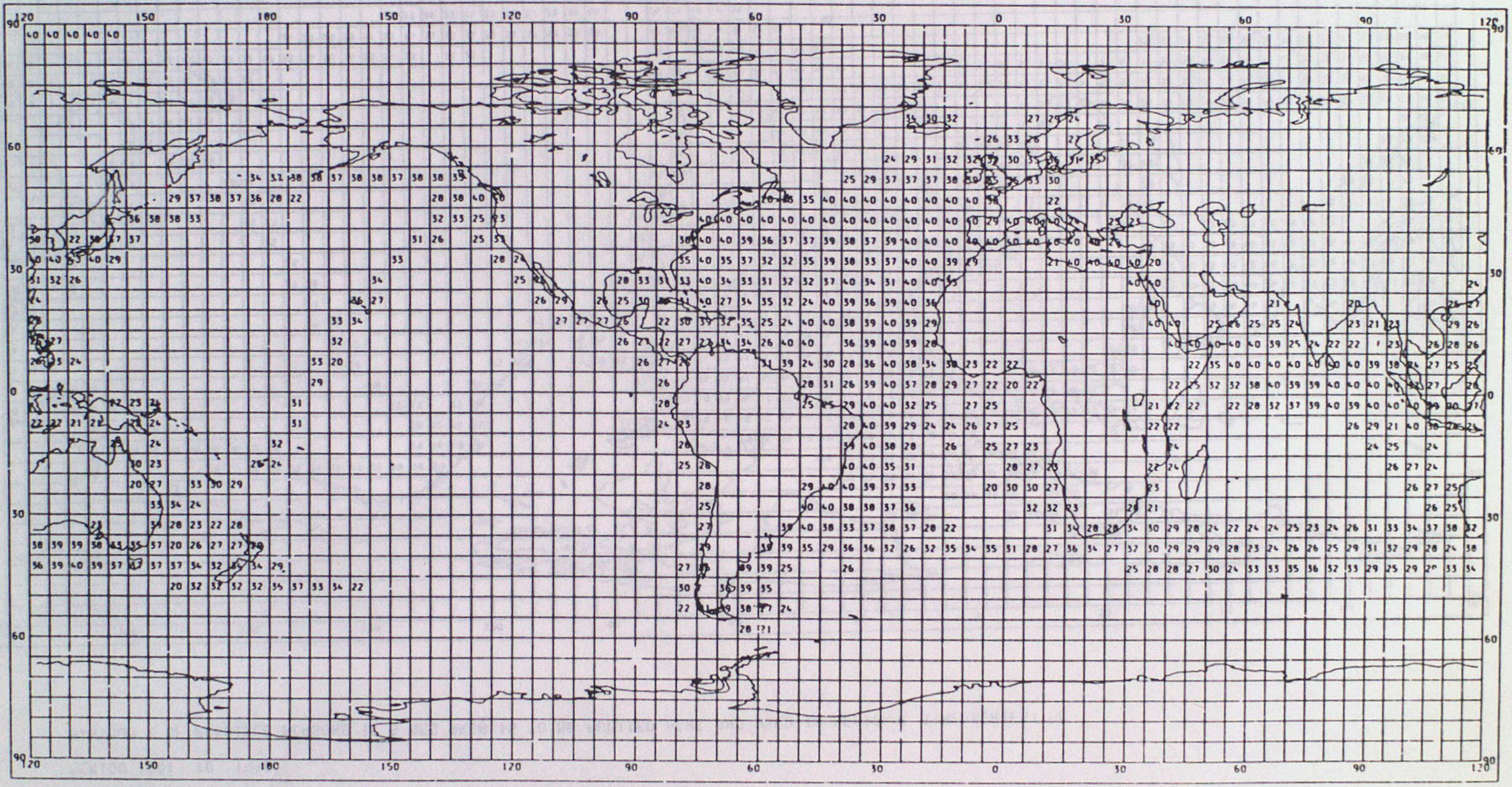


Figure 6a.

NUMBER OF SEASONS WITH SST DATA (1 MONTH CAN CONSTITUTE A SEASON)

PERIOD 1911 TO 1920

MINIMUM % OF POSSIBLE SEASONS IF 5 DEG AREA IS TO BE PLOTTED HERE AND USED IN REGIONAL TIME SERIES: 50

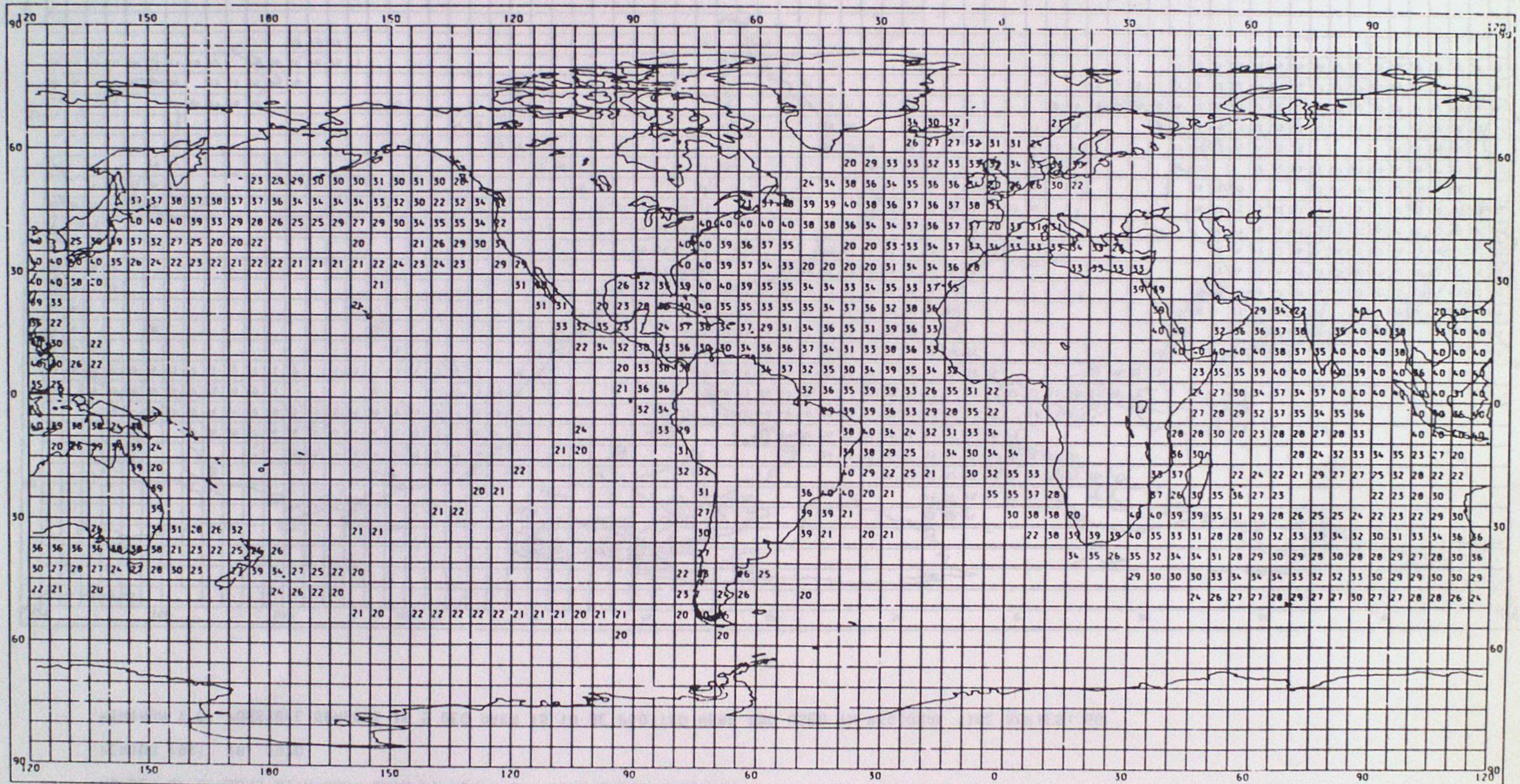


Figure 6b.

NUMBER OF SEASONS WITH NMAT DATA (1 MONTH CAN CONSTITUTE A SEASON)

PERIOD 1911 TO 1920

MINIMUM % OF POSSIBLE SEASONS IF 5 DEG AREA IS TO BE PLOTTED HERE AND USED IN REGIONAL TIME SERIES: 50

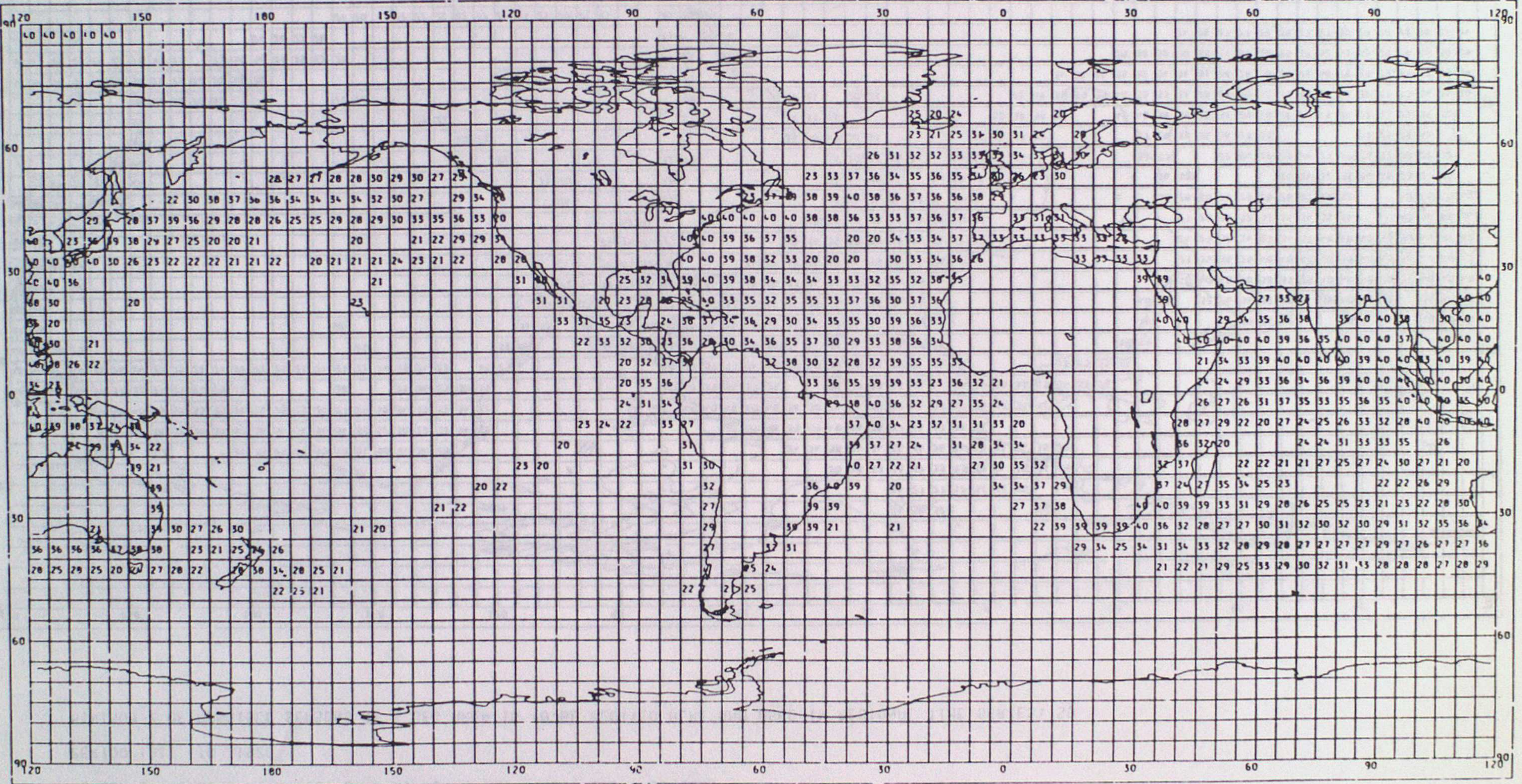


Figure 7a.

NUMBER OF SEASONS WITH SST DATA (1 MONTH CAN CONSTITUTE A SEASON)

PERIOD 1921 TO 1930

MINIMUM % OF POSSIBLE SEASONS IF 5 DEG AREA IS TO BE PLOTTED HERE AND USED IN REGIONAL TIME SERIES: 50

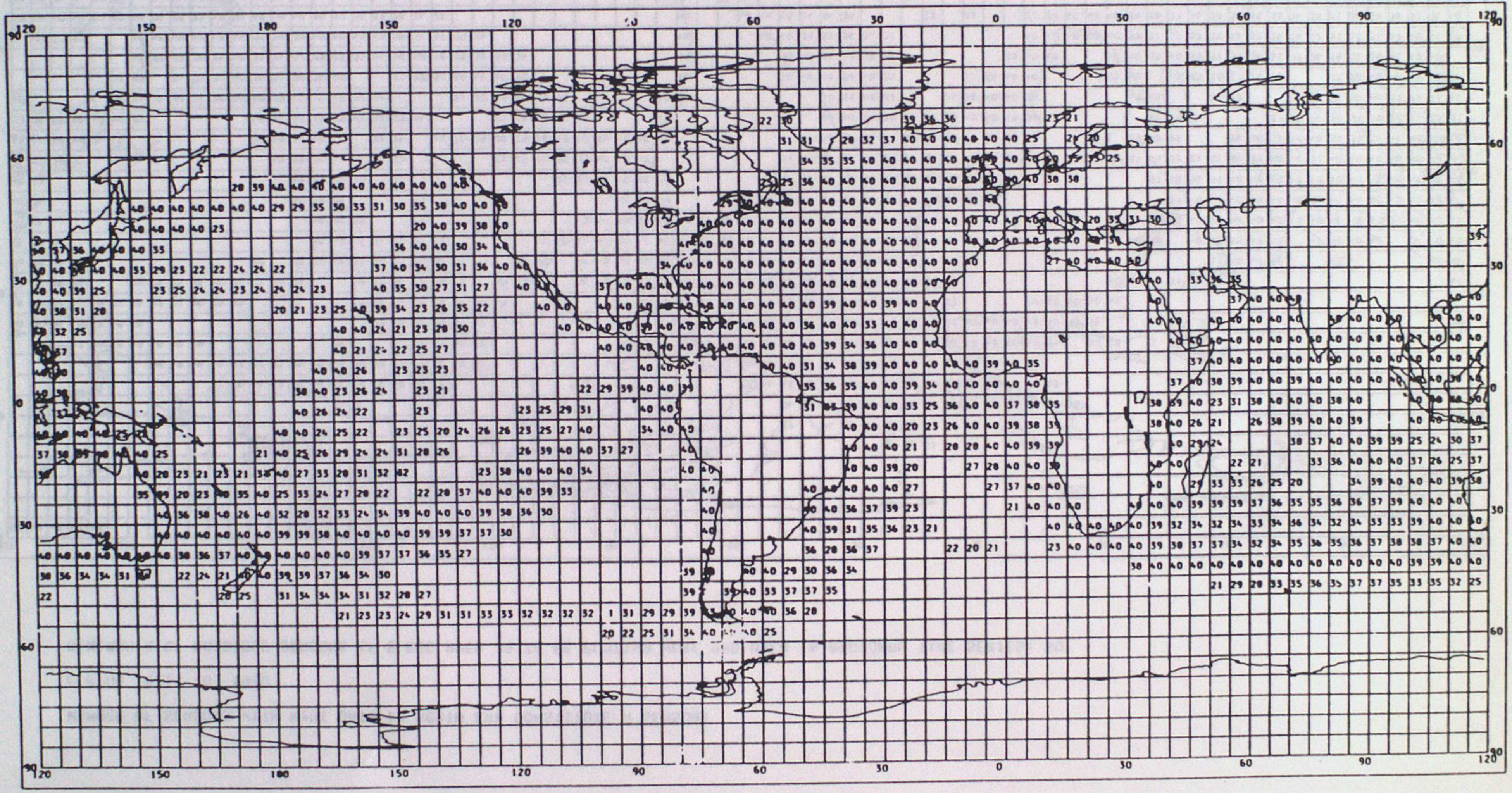


Figure 7b.

NUMBER OF SEASONS WITH NMAT DATA (1 MONTH CAN CONSTITUTE A SEASON)

PERIOD 1921 TO 1930

MINIMUM % OF POSSIBLE SEASONS IF 5 DEG AREA IS TO BE PLOTTED HERE AND USED IN REGIONAL TIME SERIES: 50

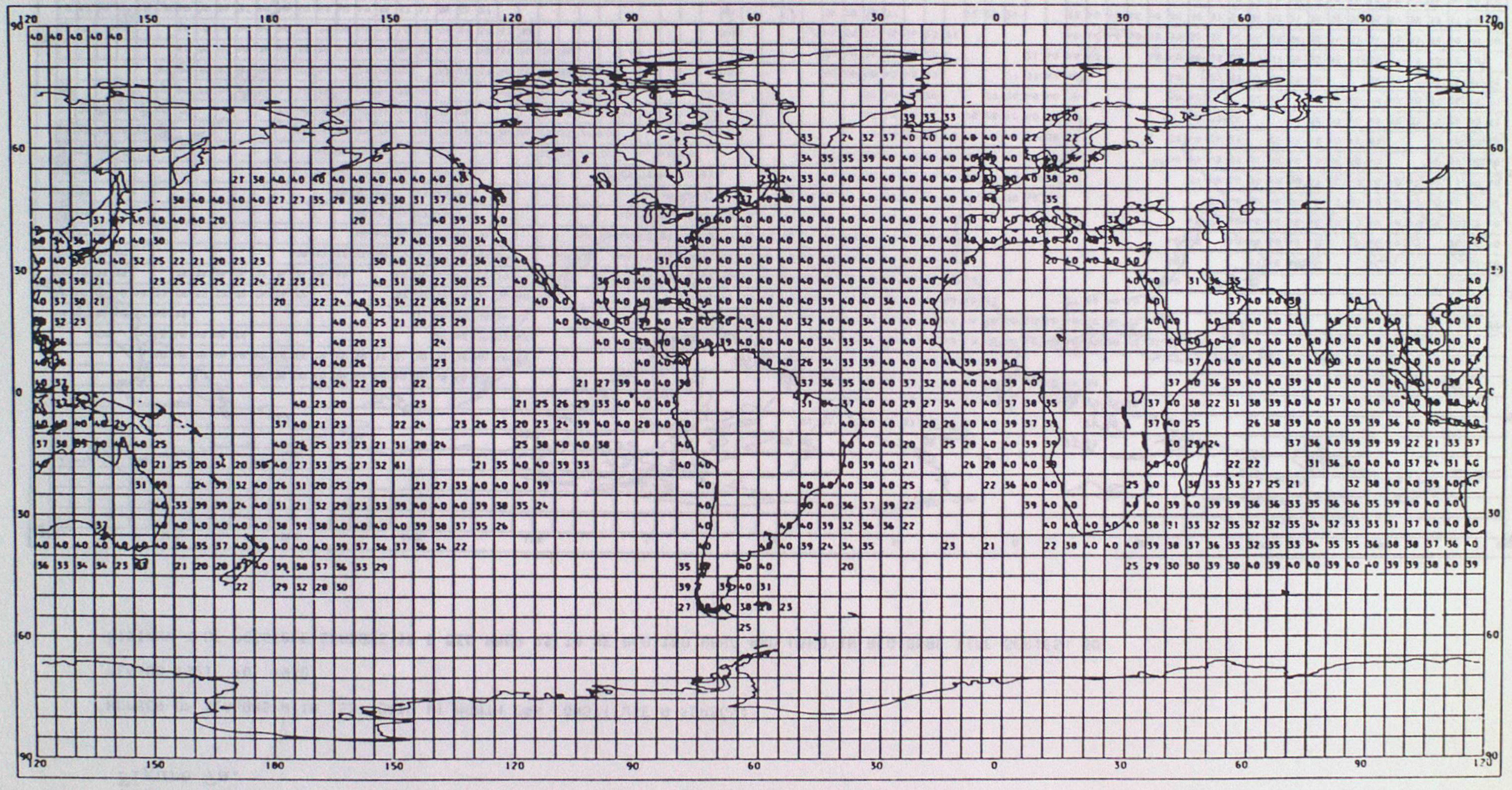


Figure 8a.

NUMBER OF SEASONS WITH SST DATA (1 MONTH CAN CONSTITUTE A SEASON)

PERIOD 1931 TO 1940

MINIMUM % OF POSSIBLE SEASONS IF 5 DEG AREA IS TO BE PLOTTED HERE AND USED IN REGIONAL TIME SERIES: 50

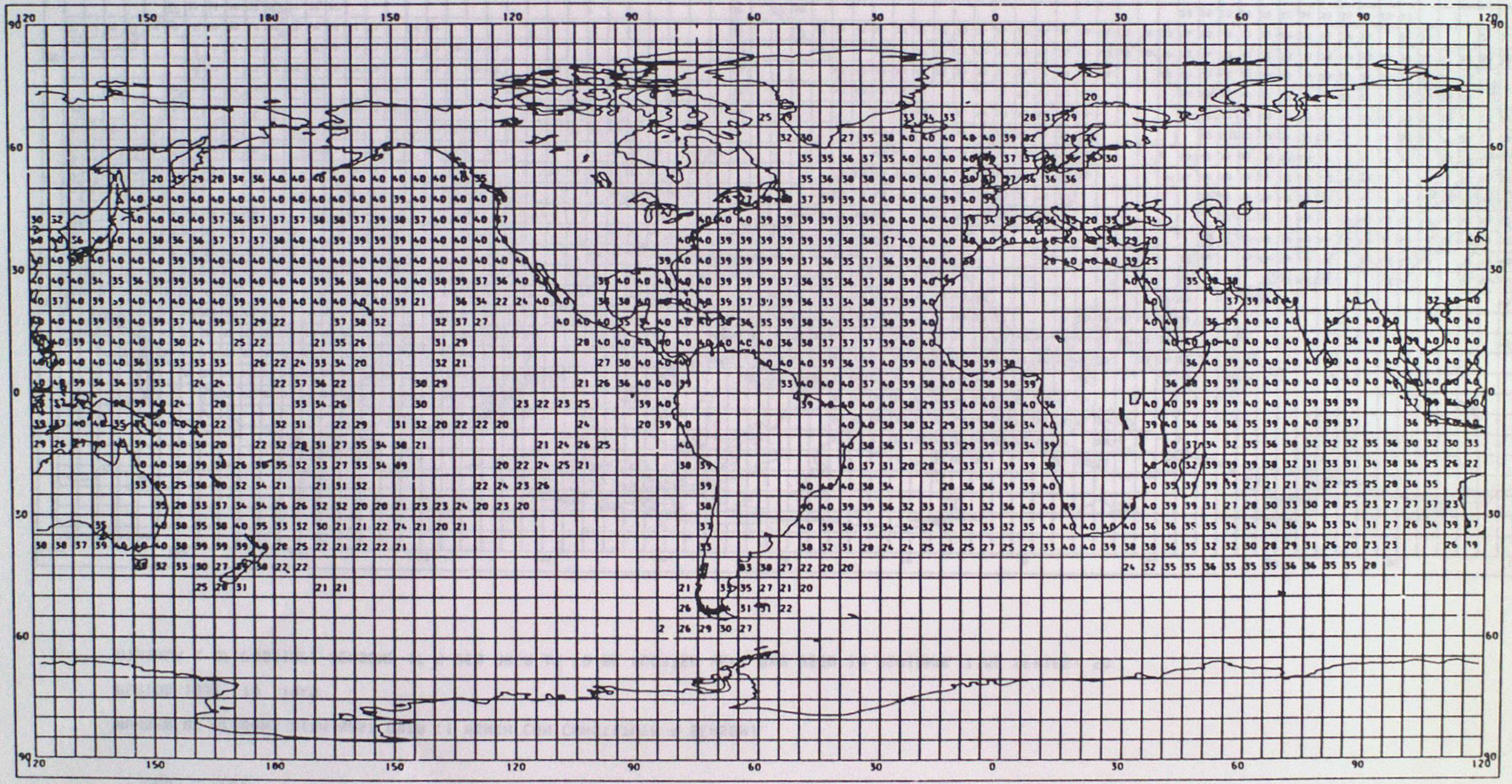


Figure 8b.

NUMBER OF SEASONS WITH NMAT DATA (1 MONTH CAN CONSTITUTE A SEASON)

PERIOD 1931 TO 1940

MINIMUM % OF POSSIBLE SEASONS IF 5 DEG AREA IS TO BE PLOTTED HERE AND USED IN REGIONAL TIME SERIES: 50

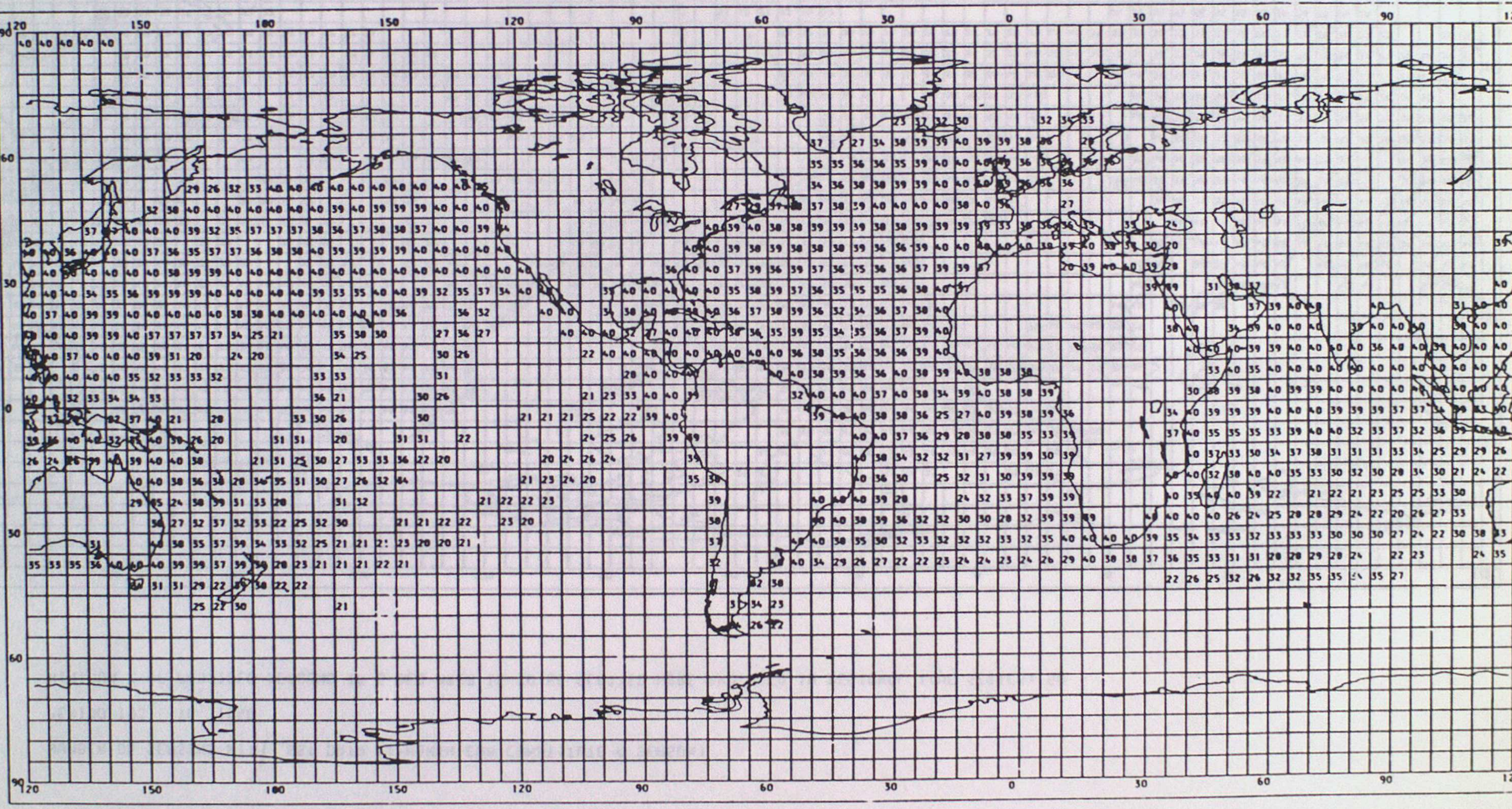


Figure 9a.

NUMBER OF SEASONS WITH SST DATA (1 MONTH CAN CONSTITUTE A SEASON)

PERIOD 1941 TO 1950

MINIMUM % OF POSSIBLE SEASONS IF 5 DEG AREA IS TO BE PLOTTED HERE AND USED IN REGIONAL TIME SERIES: 50

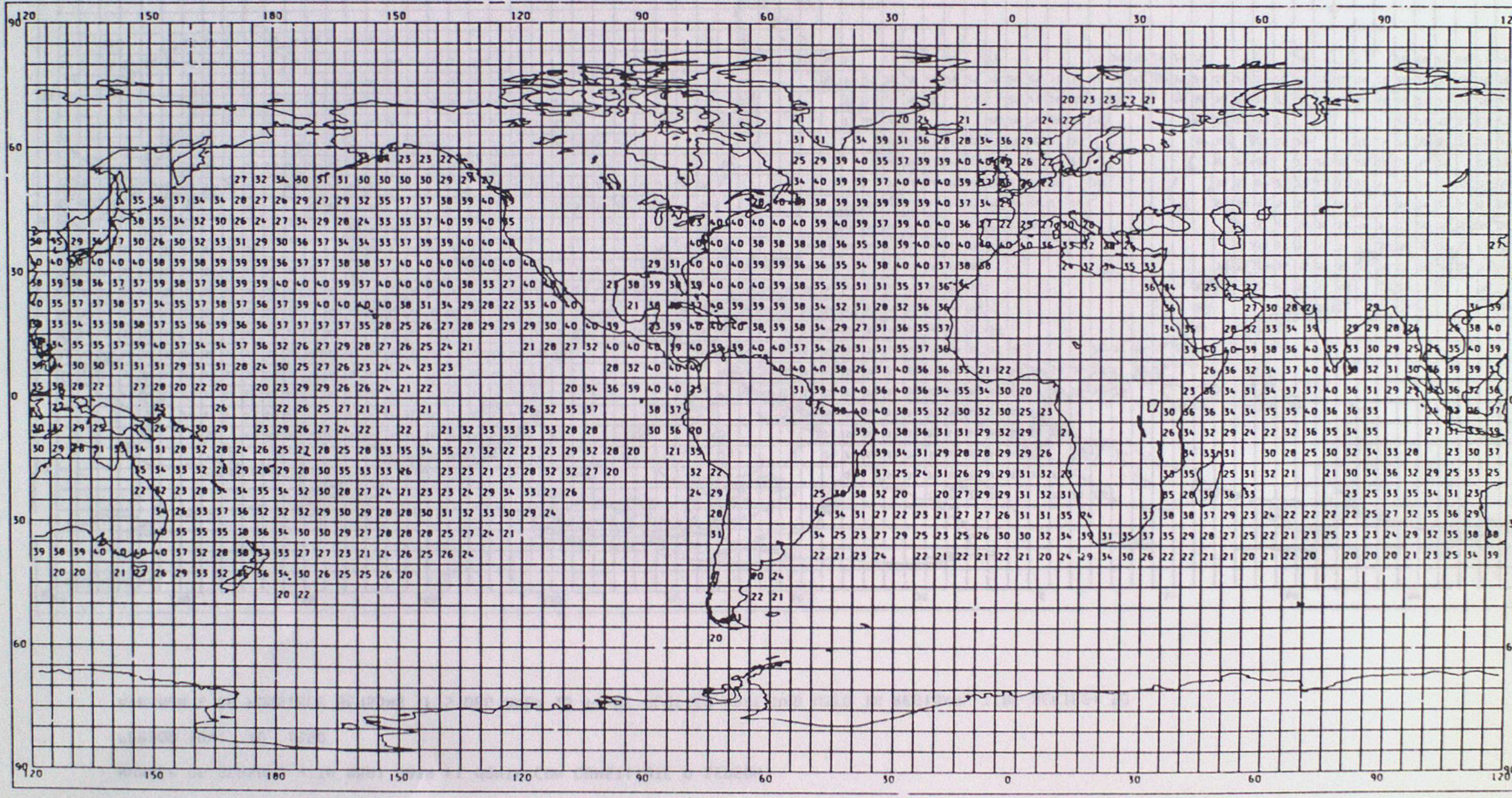


Figure 9b.

NUMBER OF SEASONS WITH NMAT DATA (1 MONTH CAN CONSTITUTE A SEASON)

PERIOD 1941 TO 1950

MINIMUM % OF POSSIBLE SEASONS IF 5 DEG AREA IS TO BE PLOTTED HERE AND USED IN REGIONAL TIME SERIES: 50

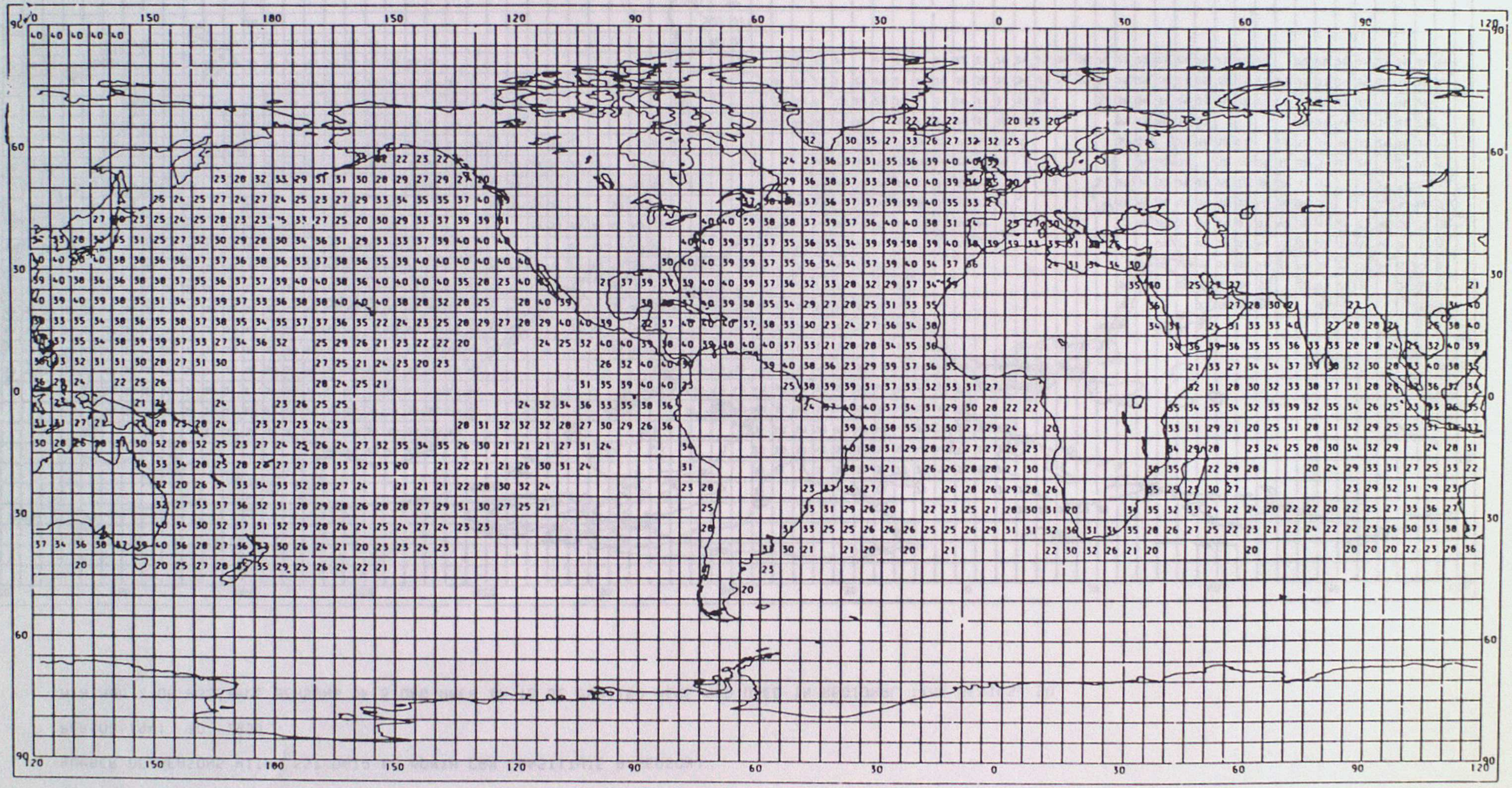


Figure 10a.

NUMBER OF SEASONS WITH SST DATA (1 MONTH CAN CONSTITUTE A SEASON)

PERIOD 1951 TO 1960

MINIMUM % OF POSSIBLE SEASONS IF 5 DEG AREA IS TO BE PLOTTED HERE AND USED IN REGIONAL TIME SERIES: 50

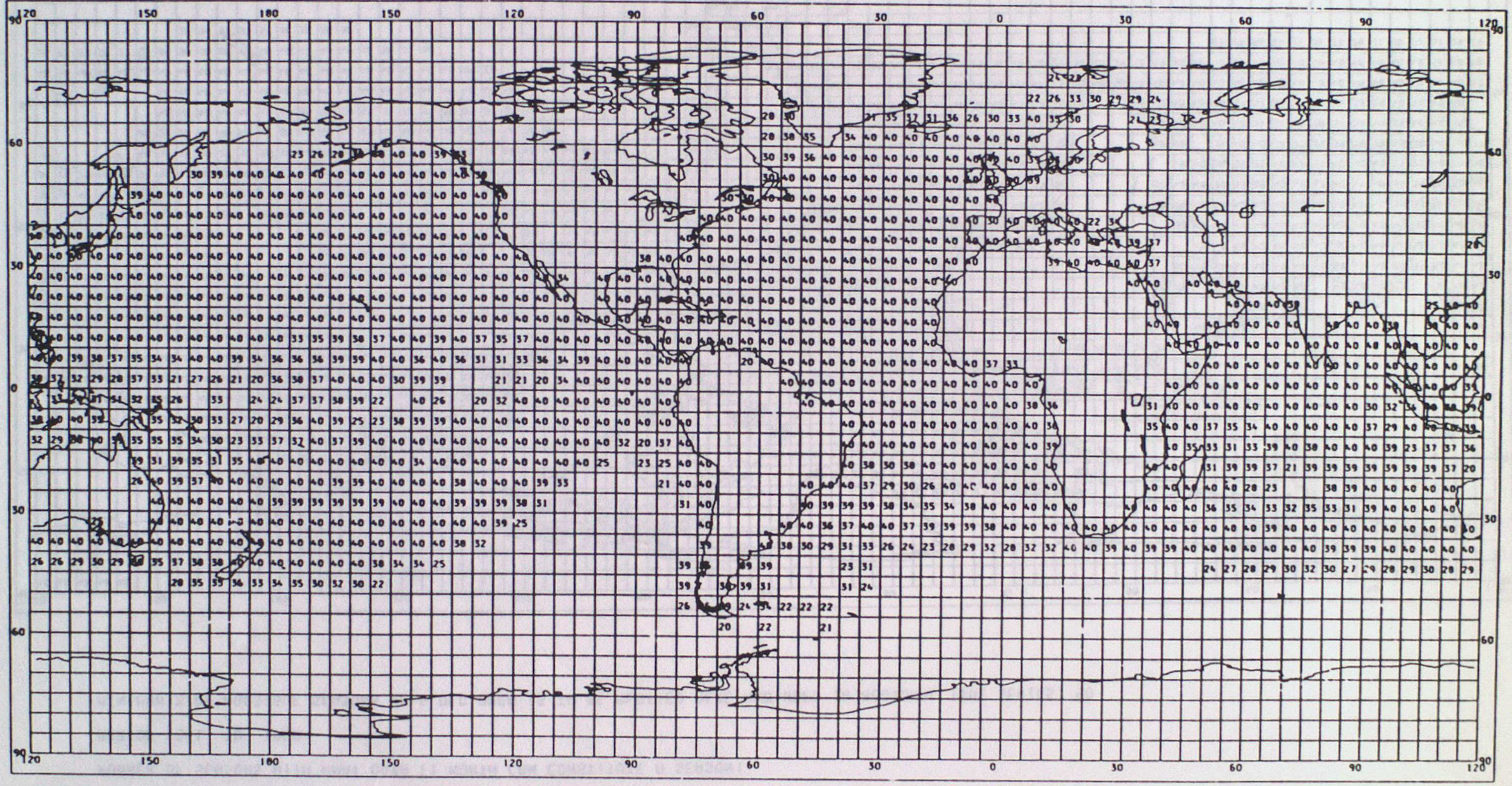


Figure 10b.

NUMBER OF SEASONS WITH NMAT DATA (1 MONTH CAN CONSTITUTE A SEASON)

PERIOD 1951 TO 1960

MINIMUM % OF POSSIBLE SEASONS IF 5 DEG AREA IS TO BE PLOTTED HERE AND USED IN REGIONAL TIME SERIES: 50

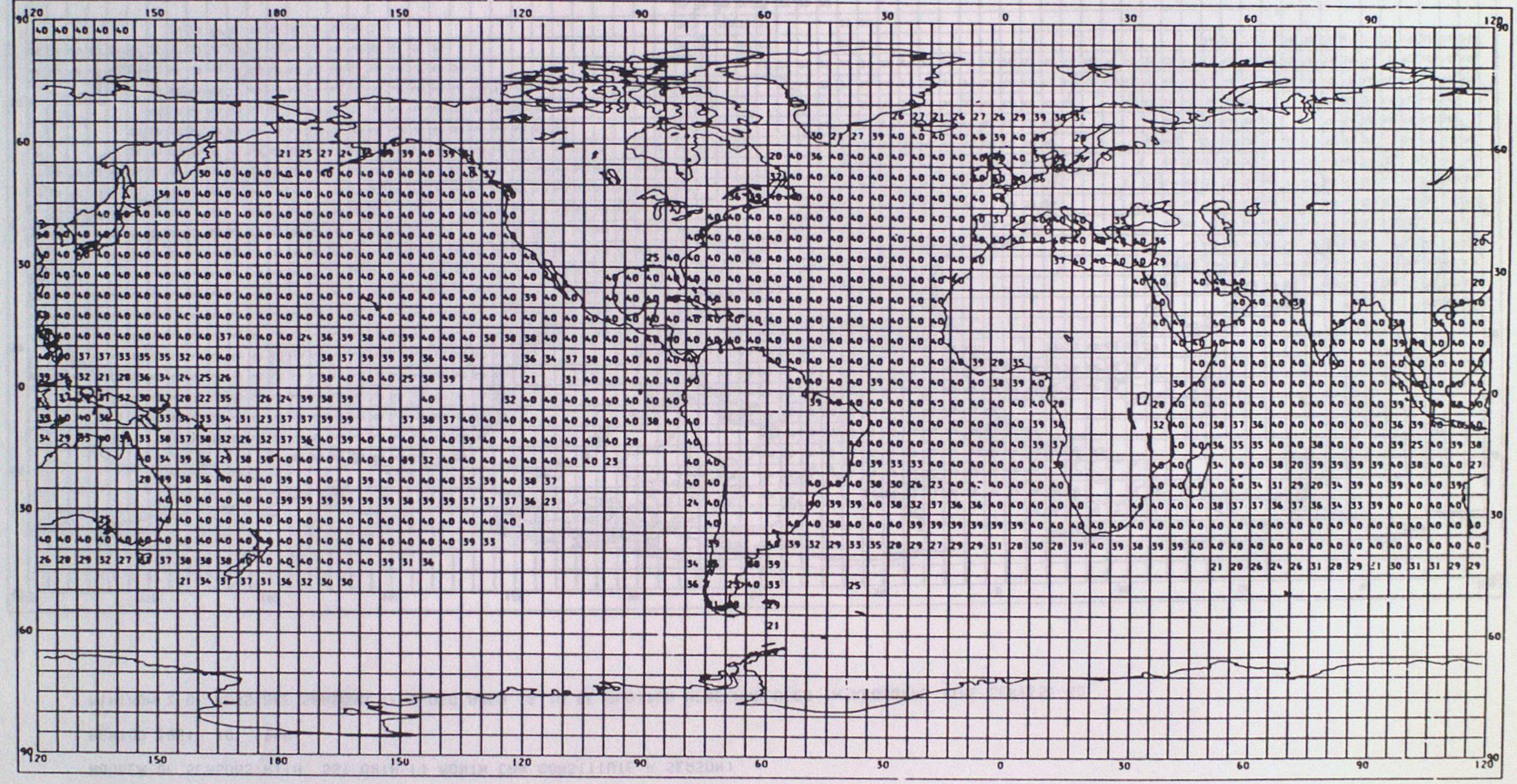


Figure 11a.

NUMBER OF SEASONS WITH SST DATA (1 MONTH CAN CONSTITUTE A SEASON)

PERIOD 1861 TO 1870

MINIMUM % OF POSSIBLE SEASONS IF 5 DEG AREA IS TO BE PLOTTED HERE AND USED IN REGIONAL TIME SERIES: 90

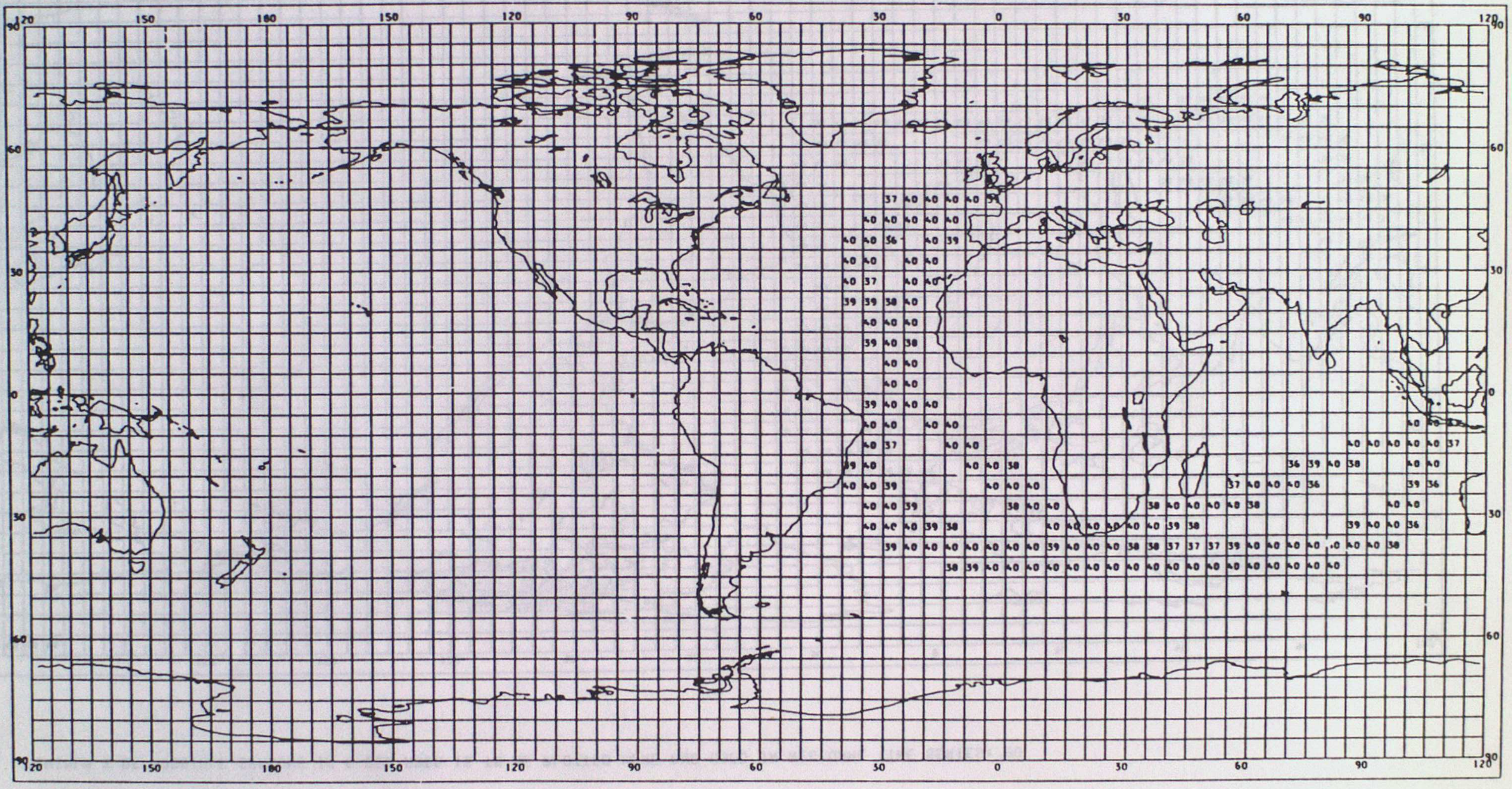


Figure 11b.

NUMBER OF SEASONS WITH NMAT DATA (1 MONTH CAN CONSTITUTE A SEASON)

PERIOD 1861 TO 1870

MINIMUM % OF POSSIBLE SEASONS IF 5 DEG AREA IS TO BE PLOTTED HERE AND USED IN REGIONAL TIME SERIES: 90

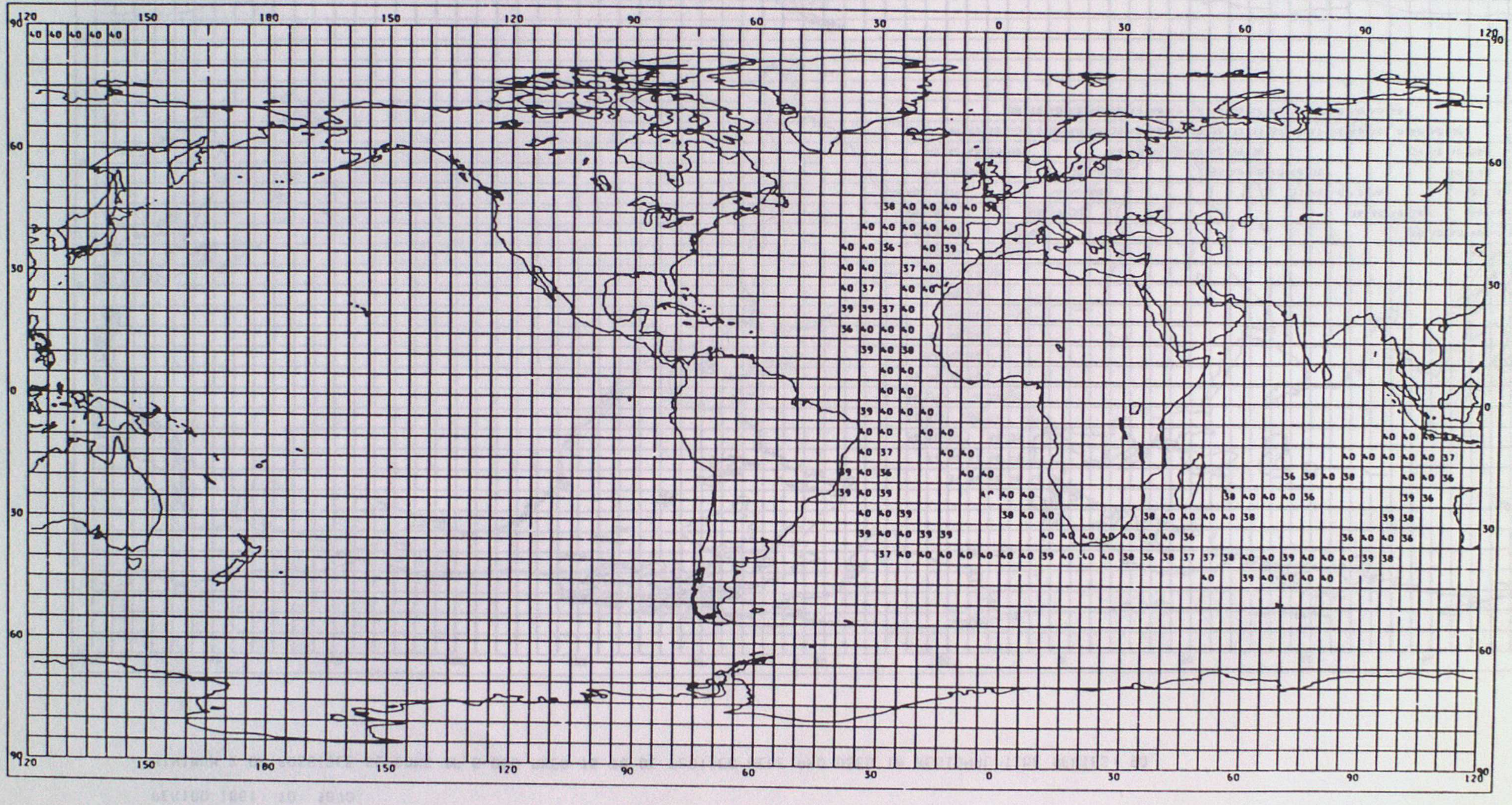


Figure 11c.

NUMBER OF SEASONS WITH NMAT DATA (1 MONTH CAN CONSTITUTE A SEASON)

PERIOD 1861 TO 1870

MINIMUM % OF POSSIBLE SEASONS IF 5 DEG AREA IS TO BE PLOTTED HERE AND USED IN REGIONAL TIME SERIES: 30

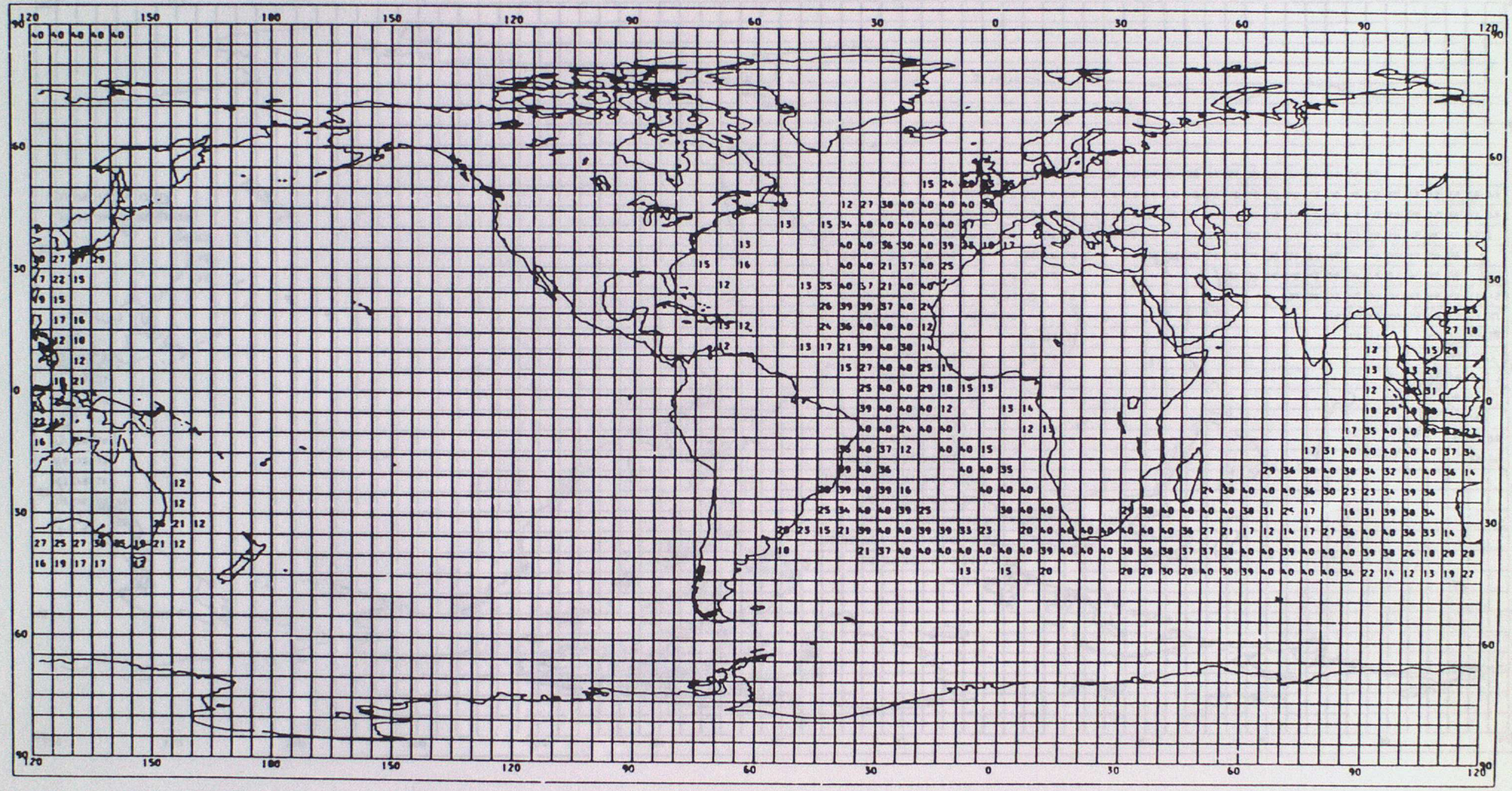
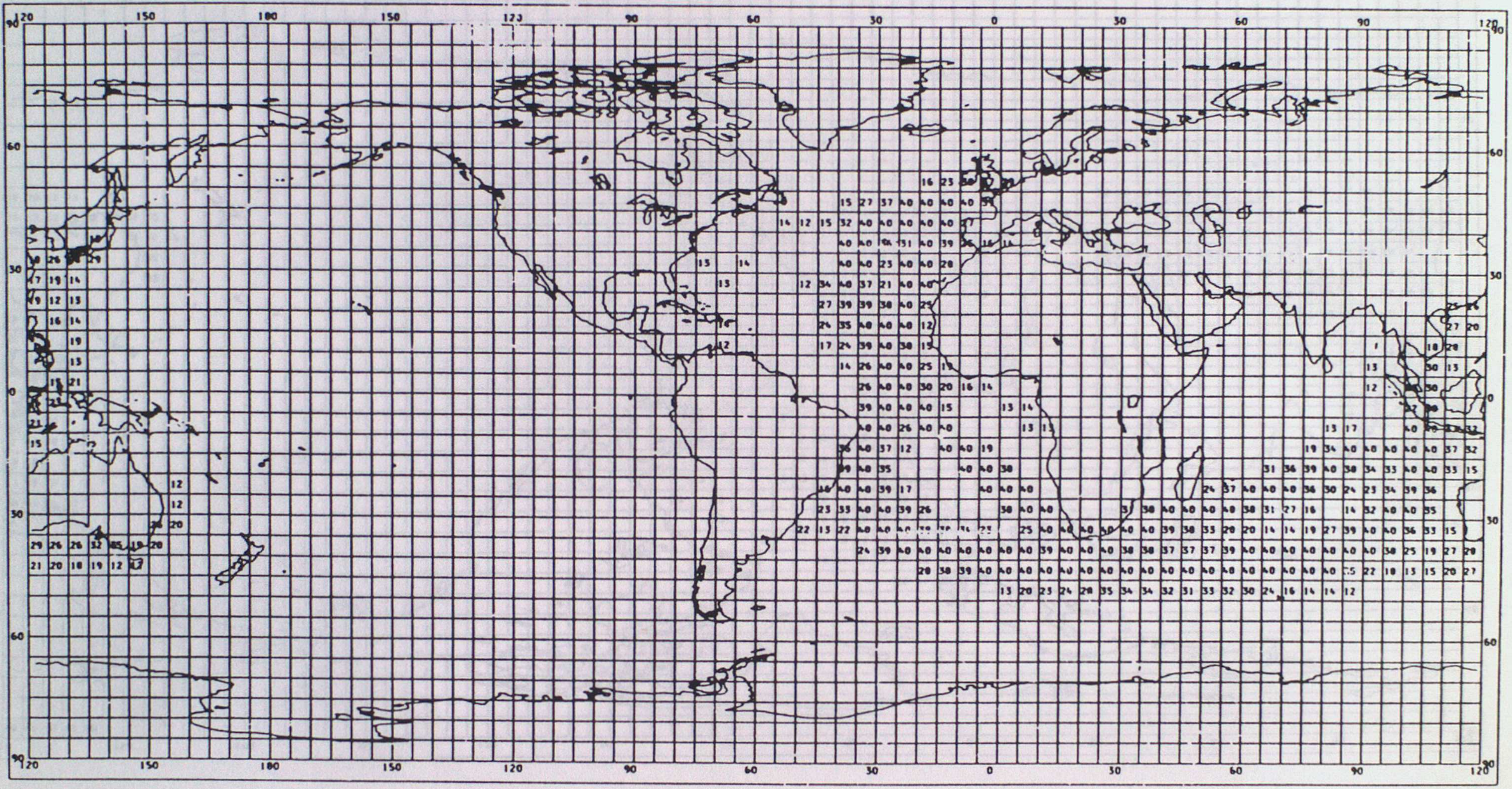


Figure 11d.

NUMBER OF SEASONS WITH SST DATA (1 MONTH CAN CONSTITUTE A SEASON)

PERIOD 1861 TO 1870

MINIMUM % OF POSSIBLE SEASONS IF 5 DEG AREA IS TO BE PLOTTED HERE AND USED IN REGIONAL TIME SERIES: 30



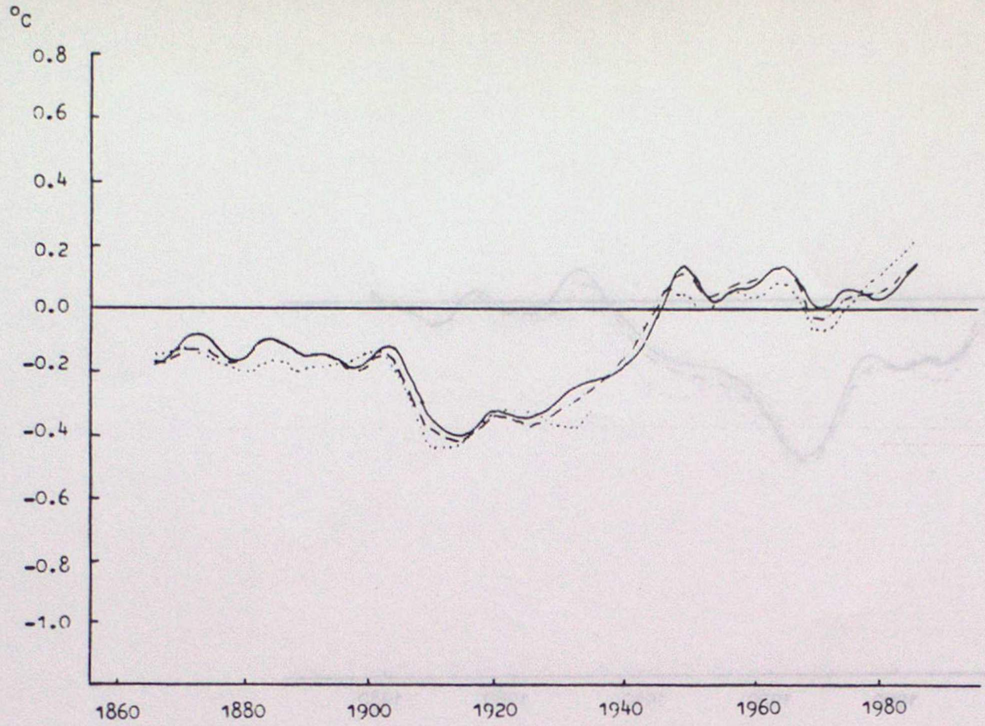


Figure 12a. Global SST w.r.t blended climatology. Plotting is at end date of 10.25 year triangular filter. Bucket-model corrections applied up to end of 1941.
—— Using all data.
----- Data restricted to 5 deg lat x long areas with at least 50% of seasons having data in 1901–1910.
..... Data restricted to 5 deg lat x long areas with at least 50% of seasons having data in 1861–1870.

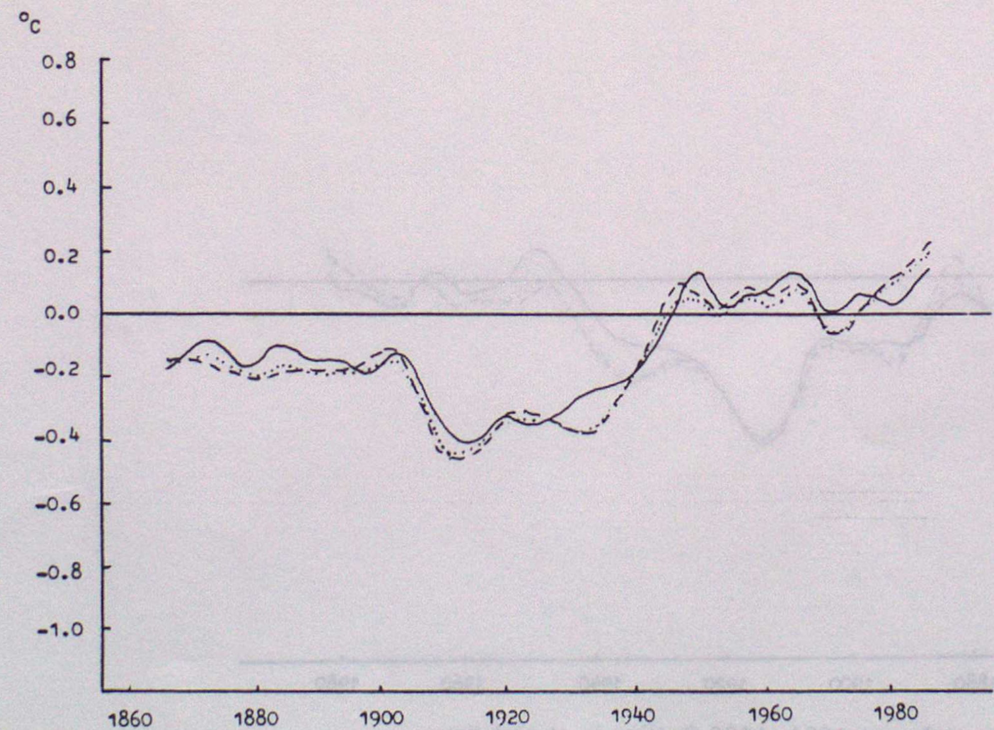


Figure 12b. Global SST w.r.t blended climatology. Plotting is at end date of 10.25 year triangular filter. Bucket-model corrections applied up to end of 1941.
—— Using all data.
----- Data restricted to 5 deg lat x long areas with at least 90% of seasons having data in 1861–1870.
...... Data restricted to 5 deg lat x long areas with at least 30% of seasons having data in 1861–70.

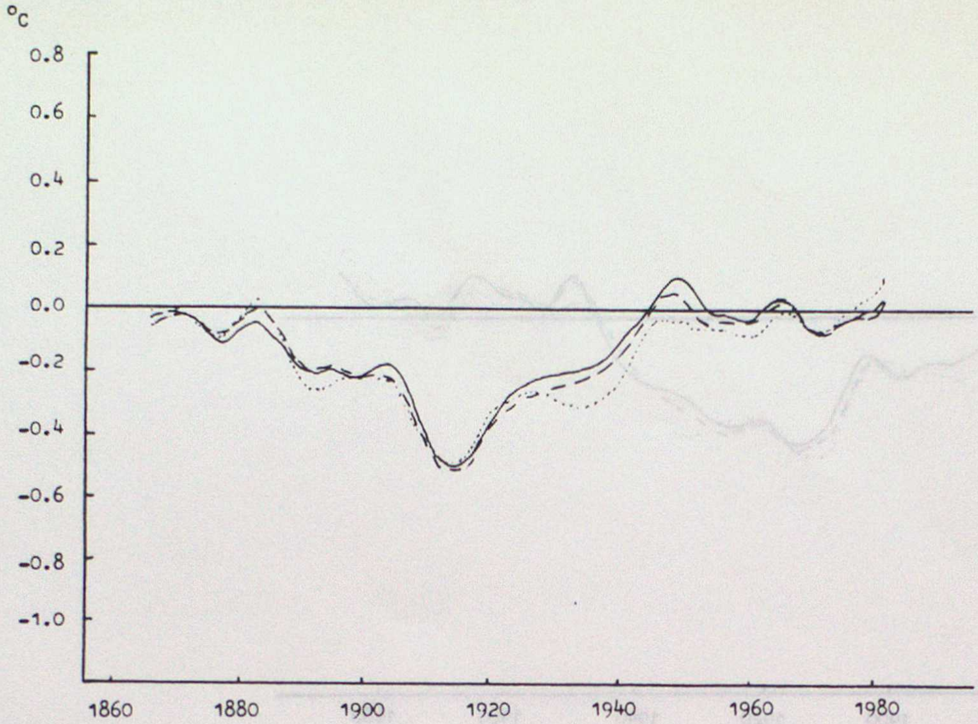


Figure 12c. Global night MAT w.r.t 1951–1980. Plotting is at end date of 10.25 year triangular filter. Instrumental corrections as in Global Ocean Surface Temperature Atlas.

——— Using all data.

– – – – – Data restricted to 5 deg lat x long areas with at least 50% of seasons having data in 1901–1910.

..... Data restricted to 5 deg lat x long areas with at least 50% of seasons having data in 1861–1870.

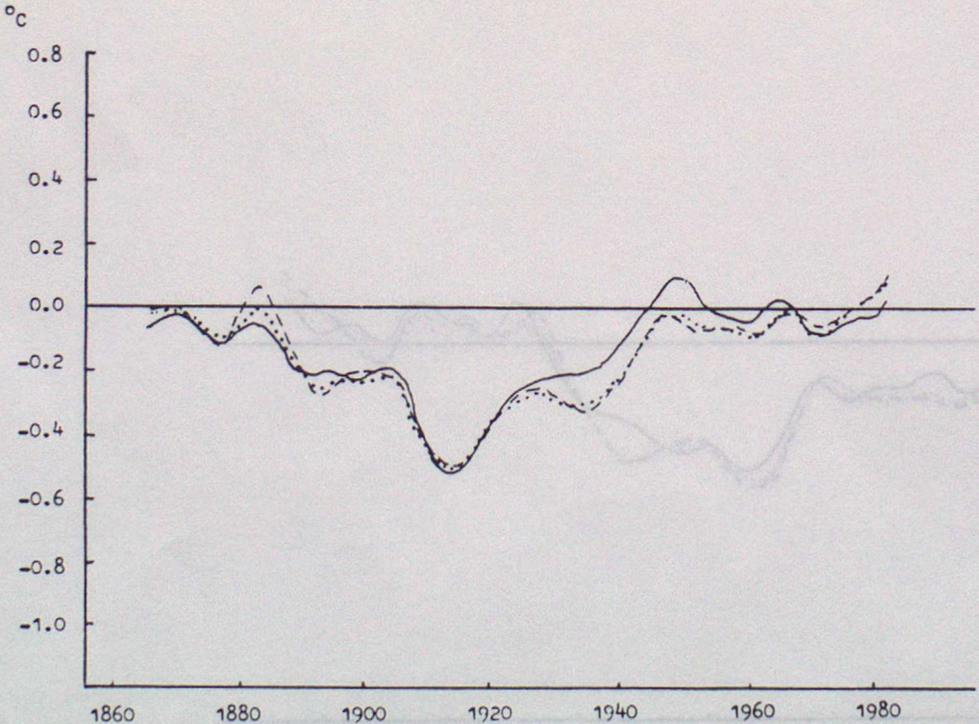


Figure 12d. Global night MAT w.r.t 1951–1980. Plotting is at end date of 10.25 year triangular filter. Instrumental corrections as in Global Ocean Surface Temperature Atlas.

——— Using all data.

– – – – – Data restricted to 5 deg lat x long areas with at least 90% of seasons having data in 1861–1870.

.... Data restricted to 5 deg lat x long areas with at least 30% of seasons having data in 1861–70.

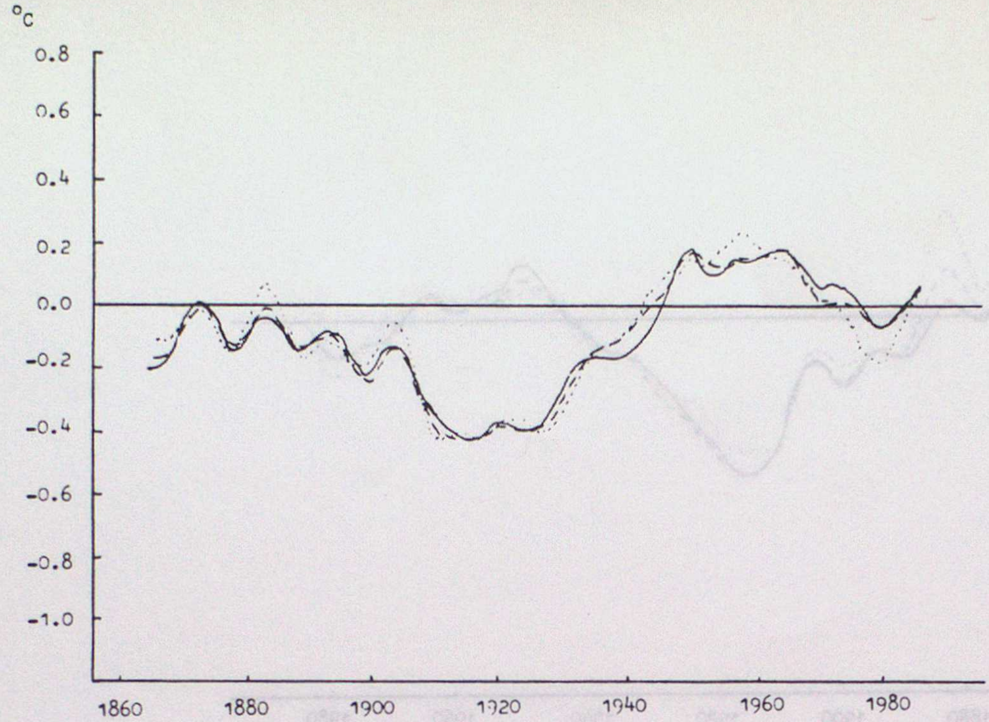


Figure 13a. N.Hemisphere SST w.r.t blended climatology.Plotting is at end date of 10.25 year triangular filter.Bucket-model corrections applied up to end of 1941.

——— Using all data.

- - - - - Data restricted to 5 deg lat x long areas with at least 50% of seasons having data in 1901-1910.

..... Data restricted to 5 deg lat x long areas with at least 50% of seasons having data in 1861-1870.

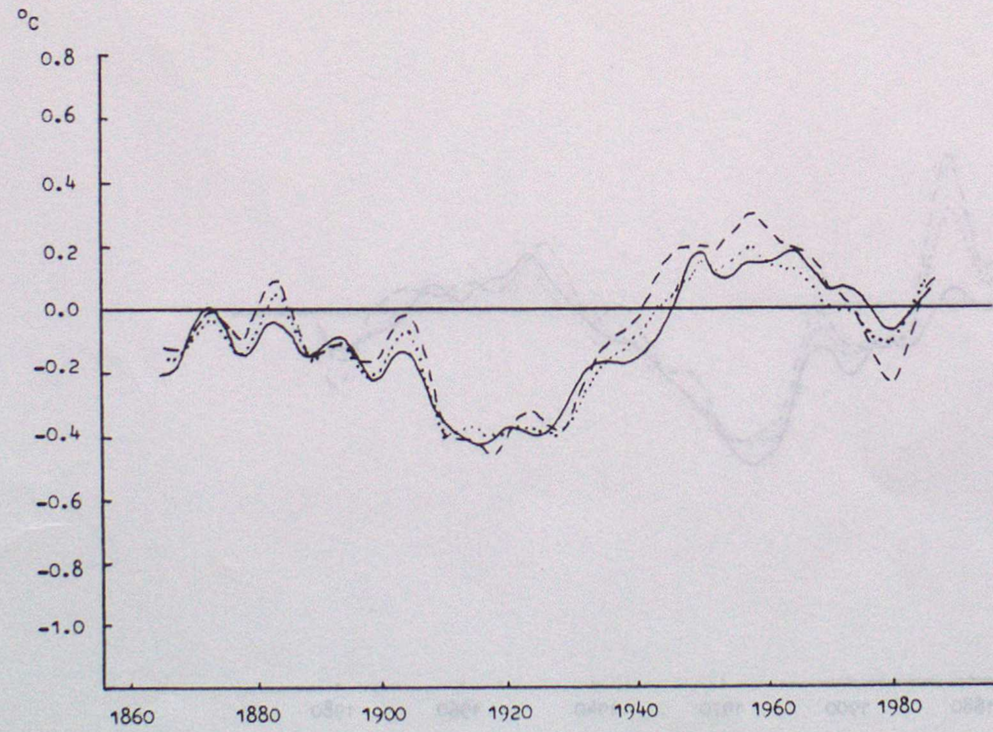


Figure 13b. N.Hemisphere SST w.r.t blended climatology.Plotting is at end date of 10.25 year triangular filter.Bucket-model corrections applied up to end of 1941.

——— Using all data.

- - - - - Data restricted to 5 deg lat x long areas with at least 90% of seasons having data in 1861-1870.

.... Data restricted to 5 deg lat x long areas with at least 30% of seasons having data in 1861-70.

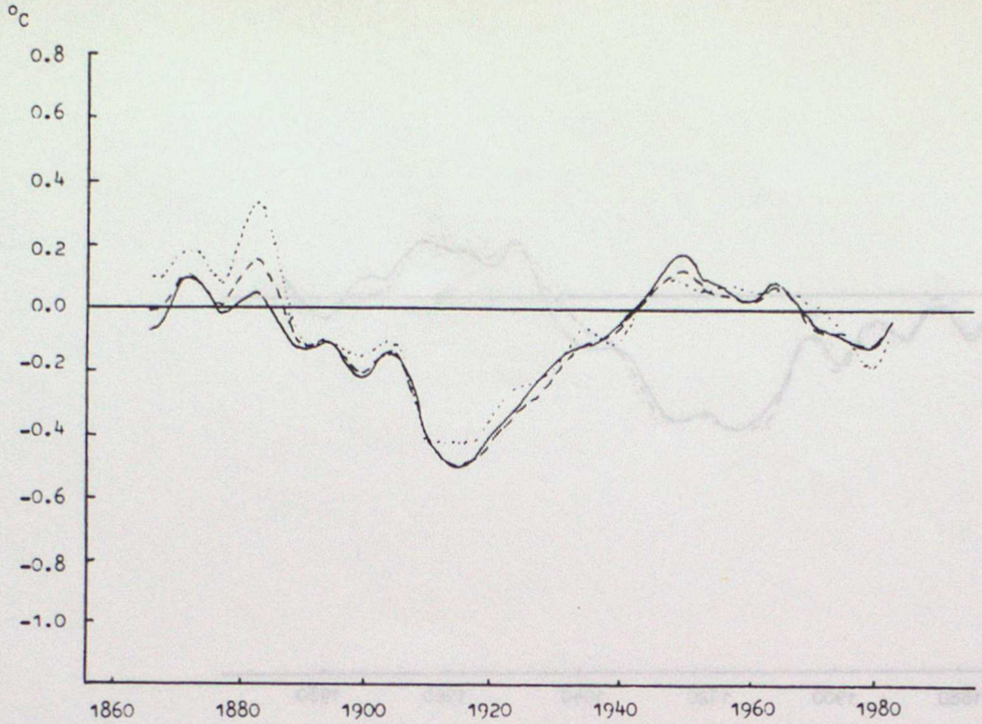


Figure 13c. N.Hemisphere night MAT w.r.t. 1951–1980.Plotting is at end date of 10.25 year triangular filter.Instrumental corrections as in Global Ocean Surface Temperature Atlas.

——— Using all data.

- - - - Data restricted to 5 deg lat x long areas with at least 50% of seasons having data in 1901–1910.

..... Data restricted to 5 deg lat x long areas with at least 50% of seasons having data in 1861–1870.

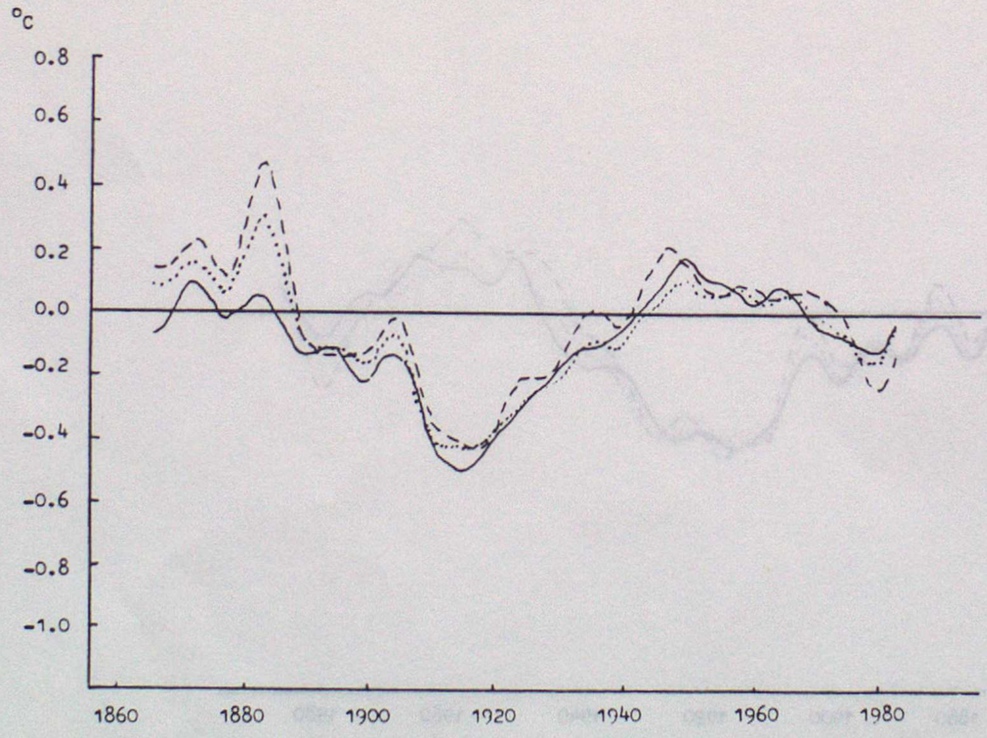


Figure 13d. N.Hemisphere night MAT w.r.t. 1951–1980.Plotting is at end date of 10.25 year triangular filter.Instrumental corrections as in Global Ocean Surface Temperature Atlas.

——— Using all data.

- - - - Data restricted to 5 deg lat x long areas with at least 90% of seasons having data in 1861–1870.

.... Data restricted to 5 deg lat x long areas with at least 30% of seasons having data in 1861–70.

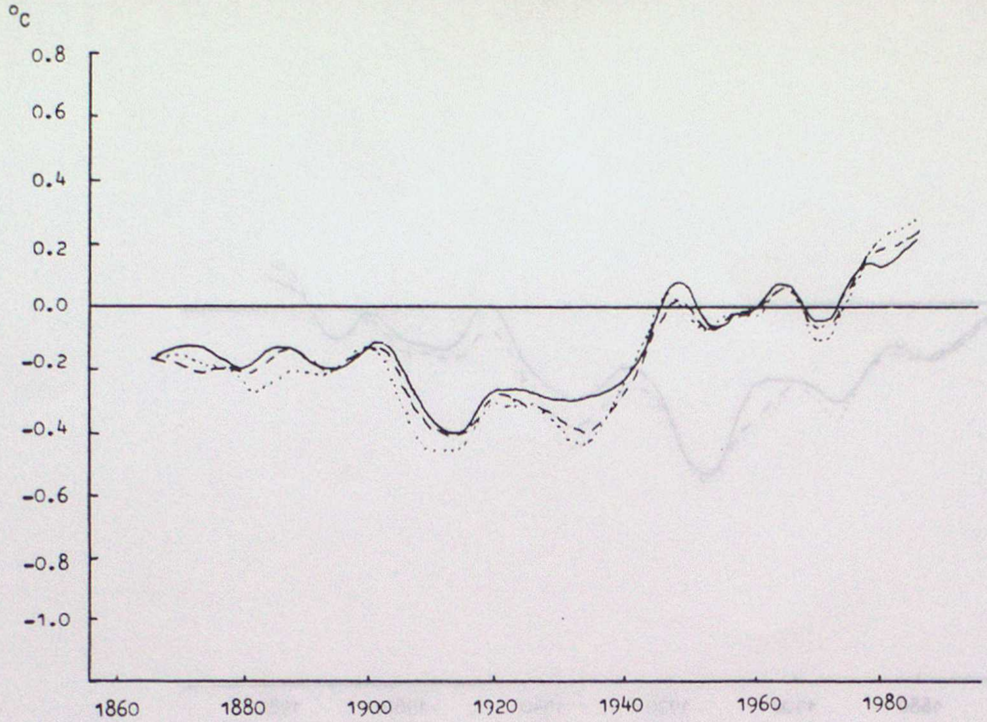


Figure 14a. S.Hemisphere SST w.r.t blended climatology.Plotting is at end date of 10.25 year triangular filter.Bucket-model corrections applied up to end of 1941.
—— Using all data.
- - - - - Data restricted to 5 deg lat x long areas with at least 50% of seasons having data in 1901–1910.
..... Data restricted to 5 deg lat x long areas with at least 50% of seasons having data in 1861–1870.

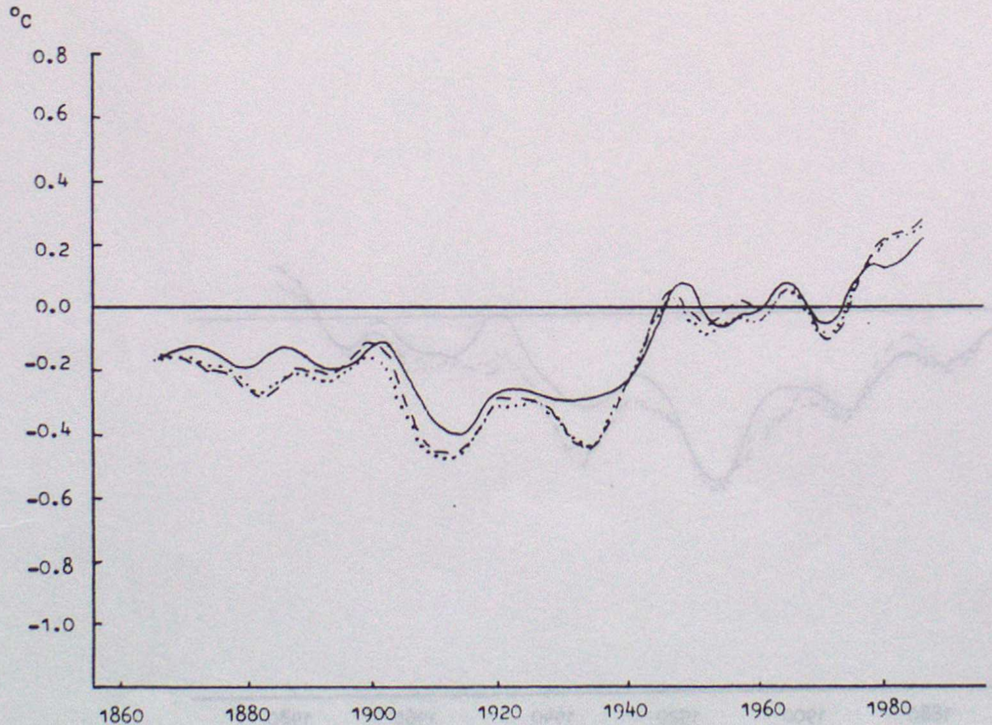


Figure 14b. S.Hemisphere SST w.r.t blended climatology.Plotting is at end date of 10.25 year triangular filter.Bucket-model corrections applied up to end of 1941.
—— Using all data.
- - - - - Data restricted to 5 deg lat x long areas with at least 90% of seasons having data in 1861–1870.
.... Data restricted to 5 deg lat x long areas with at least 30% of seasons having data in 1861–70.

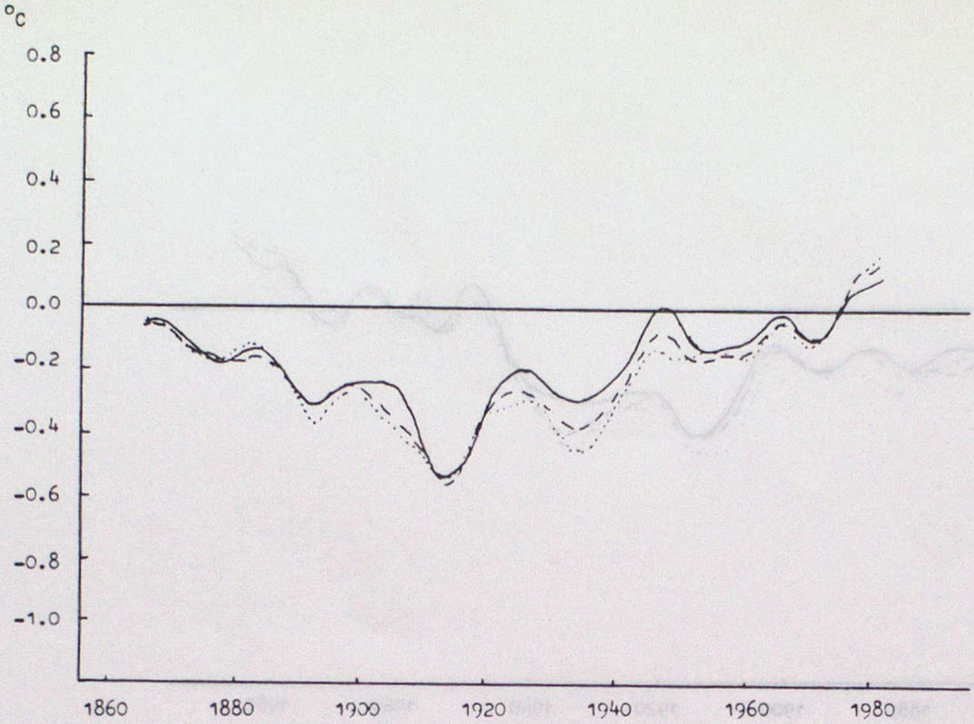


Figure 14c. S.Hemisphere night MAT w.r.t. 1951 - 1980.Plotting is at end date of 10.25 year triangular filter.Instrumental corrections as in Global Ocean Surface Temperature Atlas.

——— Using all data.

- - - - - Data restricted to 5 deg lat x long areas with at least 50% of seasons having data in 1901-1910.

..... Data restricted to 5 deg lat x long areas with at least 50% of seasons having data in 1861-1870.

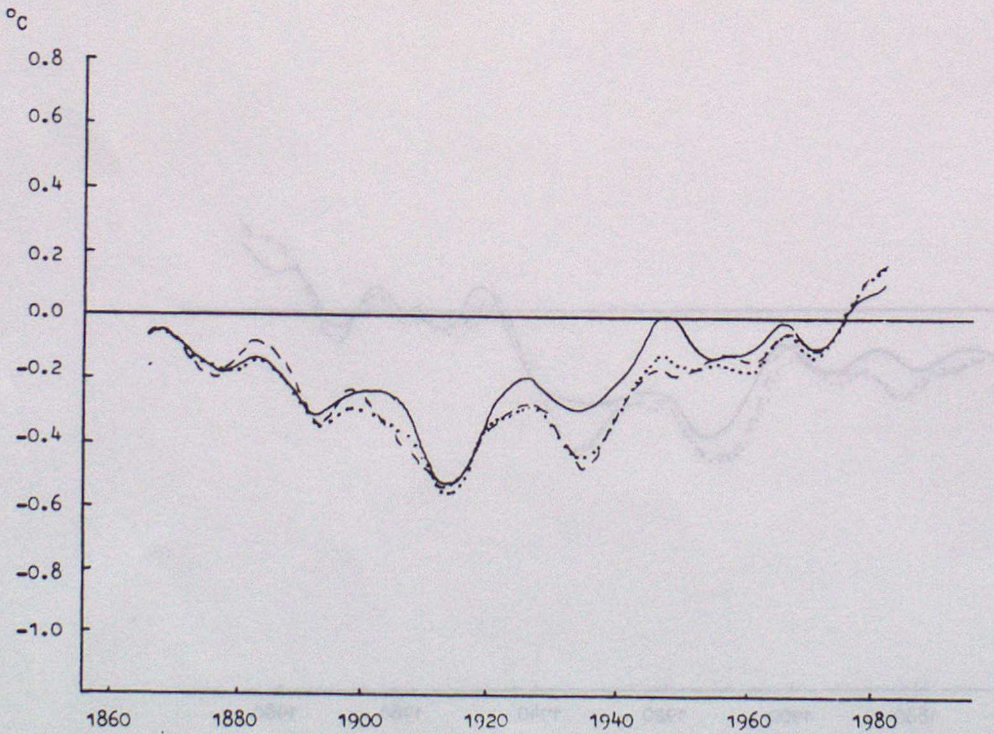


Figure 14d. S.Hemisphere night MAT w.r.t. 1951 - 1980.Plotting is at end date of 10.25 year triangular filter.Instrumental corrections as in Global Ocean Surface Temperature Atlas.

——— Using all data.

- - - - - Data restricted to 5 deg lat x long areas with at least 90% of seasons having data in 1861-1870.

.... Data restricted to 5 deg lat x long areas with at least 30% of seasons having data in 1861-70.

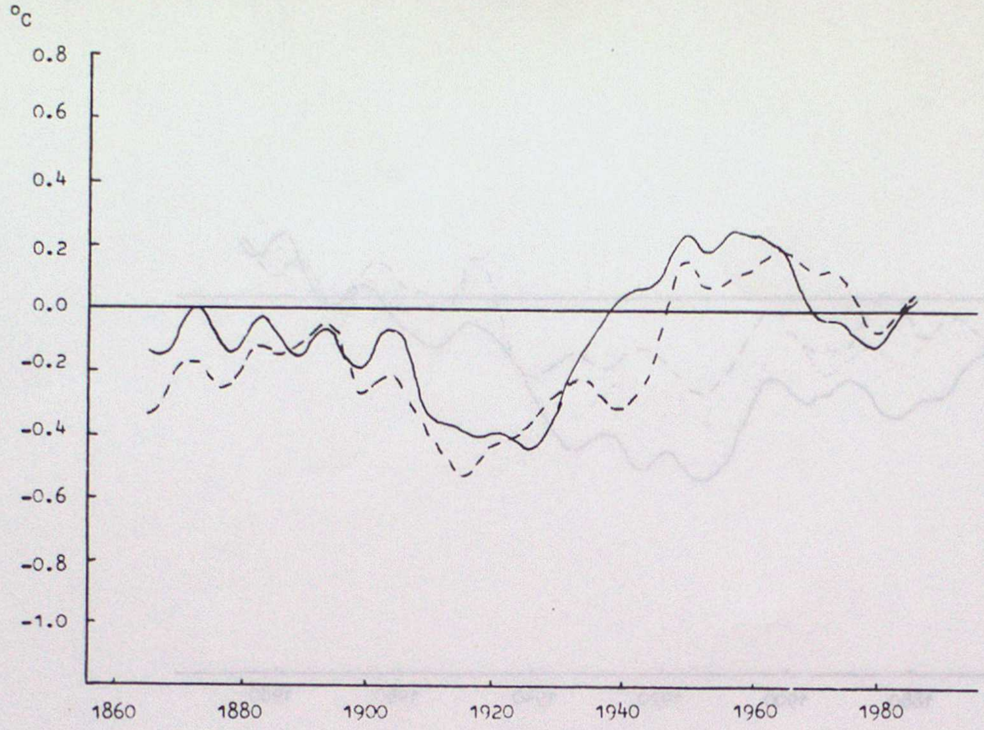


Figure 15a.
SST (w.r.t.blended climatology) for the N.Atlantic (———)
and for the N.Pacific (– – – –), using all data.
Plotting is at end date of 10.25 year triangular filter.
Bucket–model corrections applied up to the end of 1941.

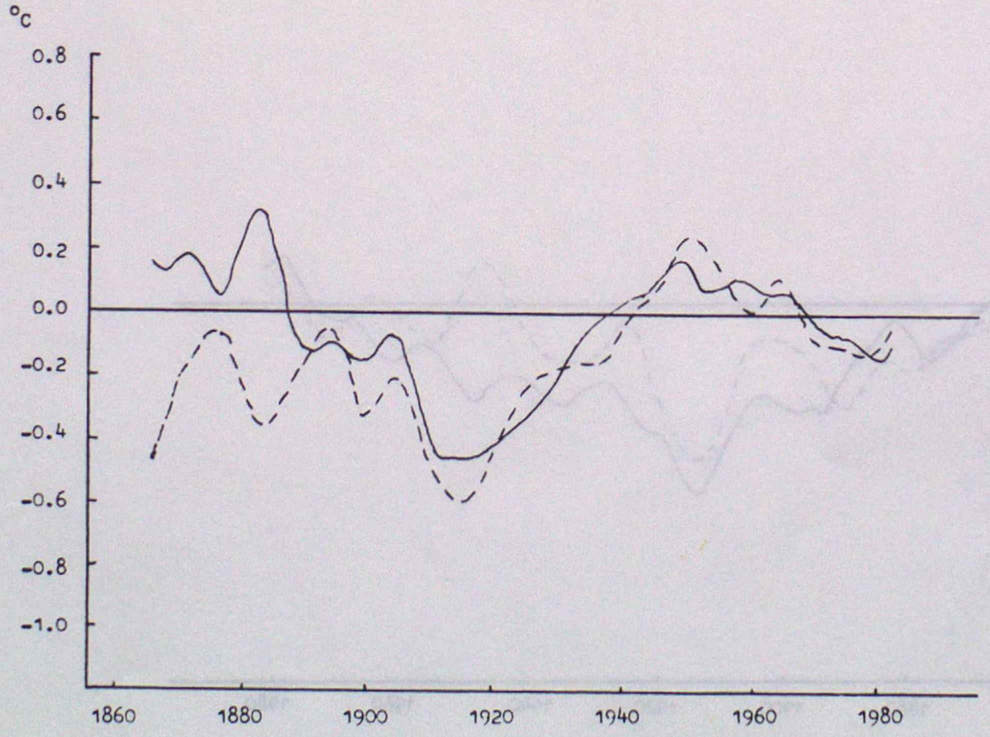


Figure 15b.
Night MAT (w.r.t. 1951–1980) for the N.Atlantic (———)
and for the N.Pacific (– – – –), using all data.
Plotting is at end date of 10.25 year triangular filter.
Instrumental corrections as in Global Ocean Surface Temperature Atlas.

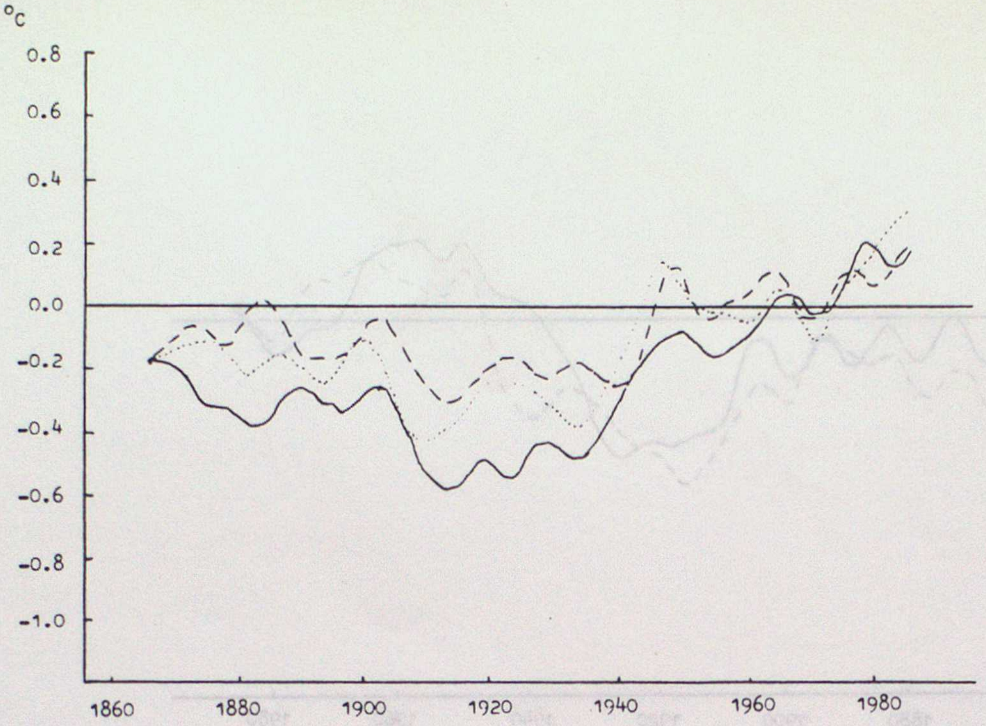


Figure 16a.
SST (w.r.t.blended climatology) for the S.Atlantic (———),
S.Pacific(– – – –)and for the S.Indian Ocean(.......) , using all data.
Plotting is at end date of 10.25 year triangular filter.
Bucket–model corrections applied up to the end of 1941.

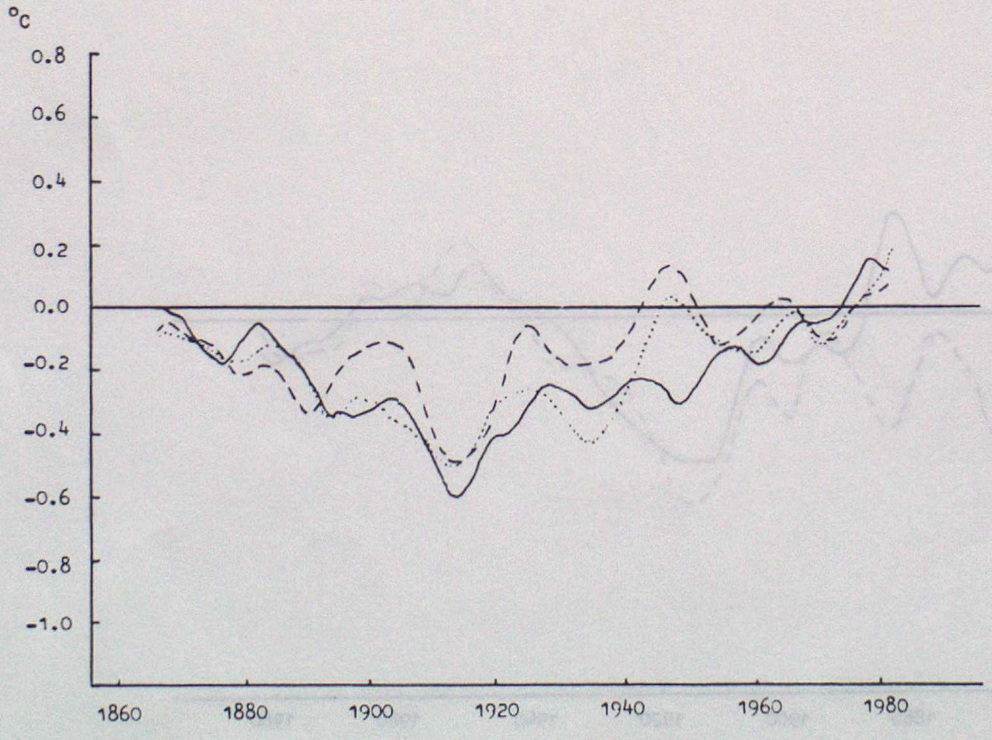


Figure 16b.
Night MAT (w.r.t. 1951–1980) for the S.Atlantic (———),
S.Pacific(– – – –)and for the S.Indian Ocean(.......) , using all data.
Plotting is at end date of 10.25 year triangular filter.
Instrumental corrections as in Global Ocean Surface Temperature Atlas.

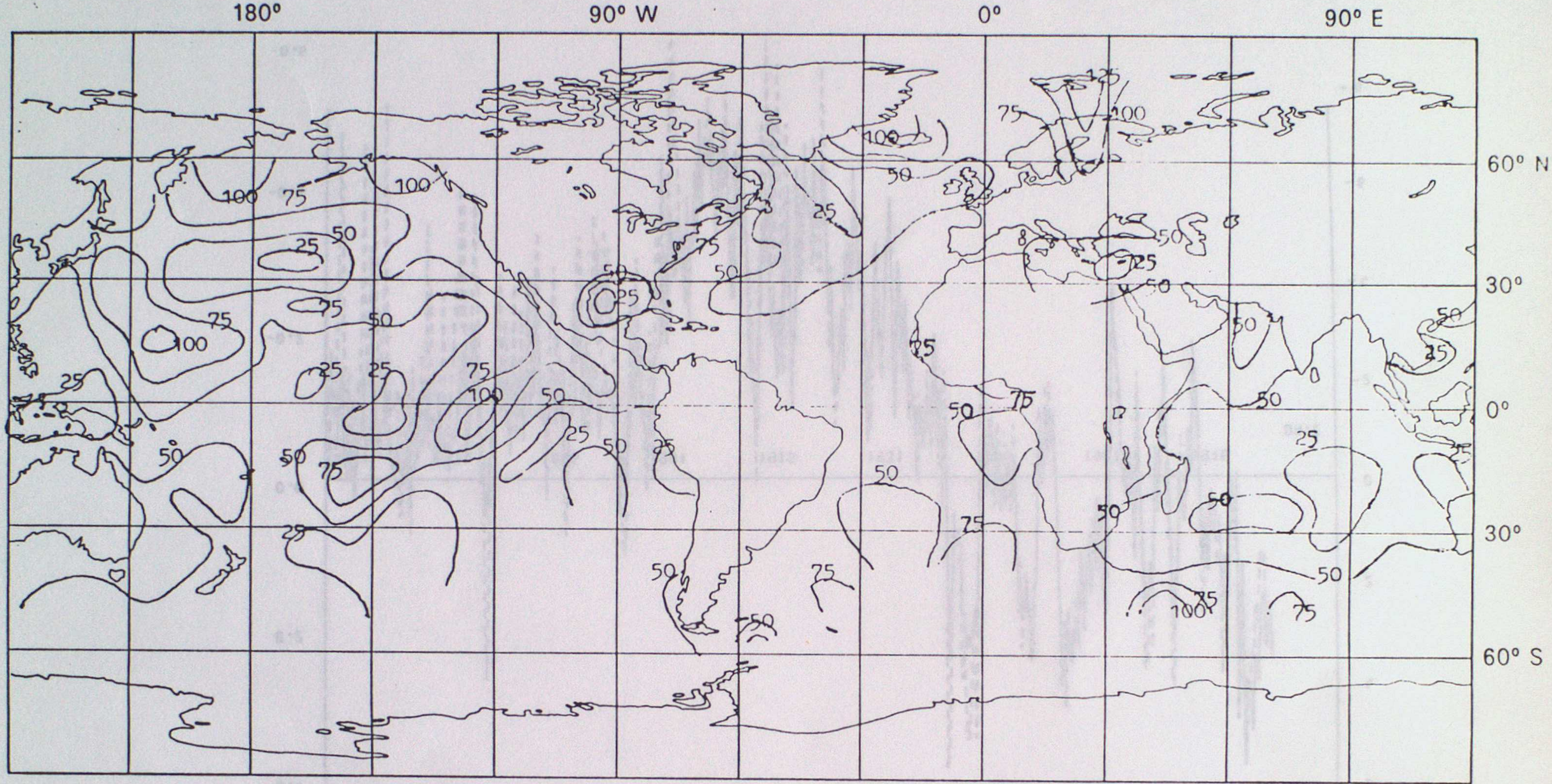
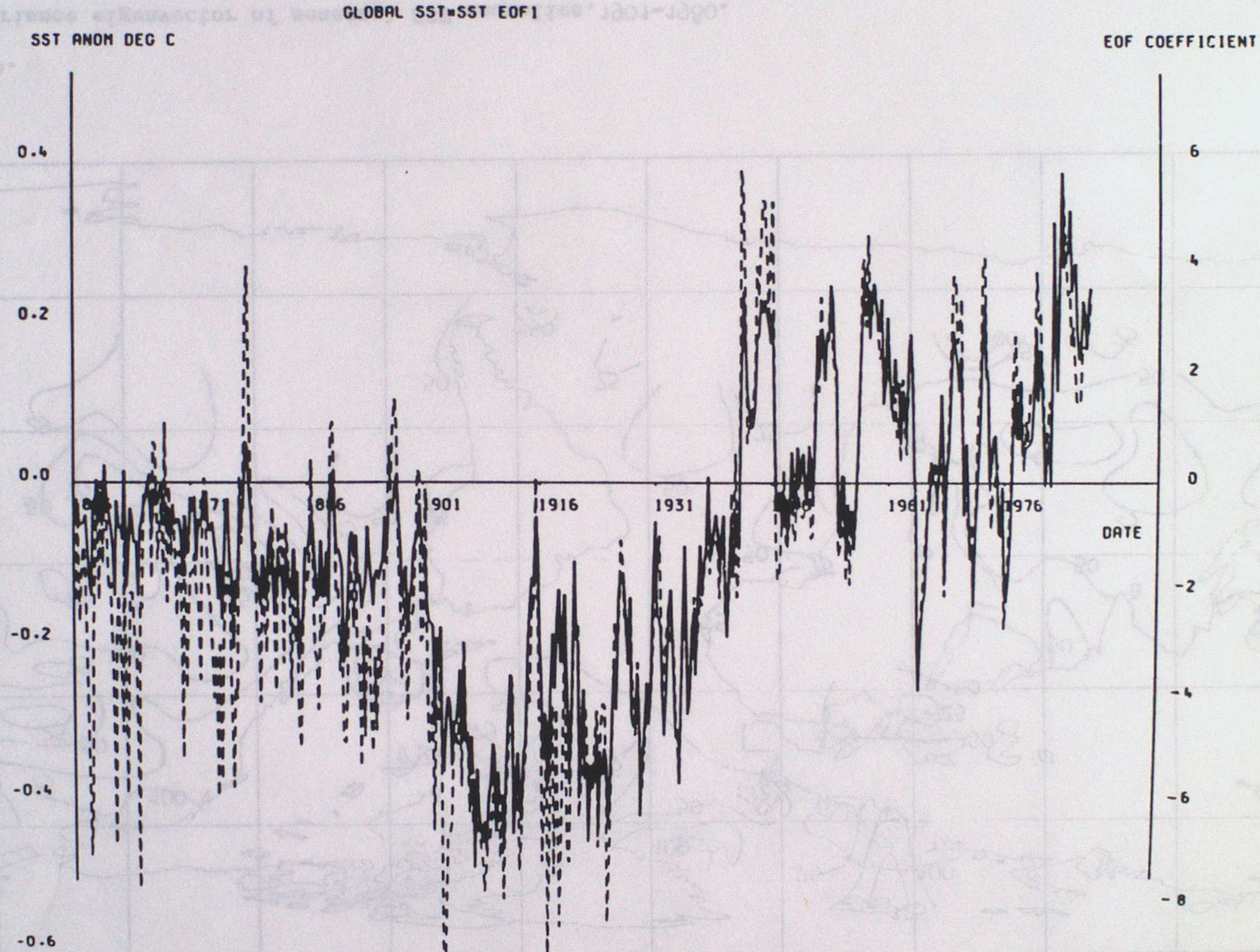


Figure 17a.

First covariance eigenvector of seasonal SST anomalies, 1901-1980.

Figure 17b. Global average SST anomaly (- - -) and the coefficient of the first 1901-80 covariance eigenvector of worldwide seasonal SST anomalies (———), 1856-1986



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