

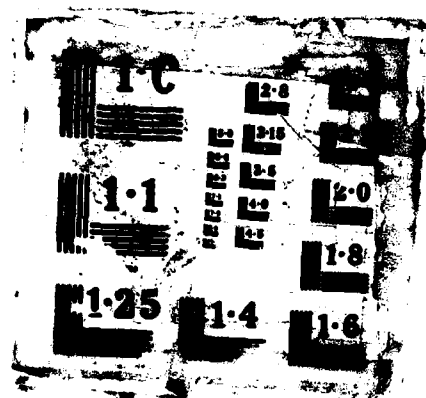
AD-A188 523

HOMOGENIZING SURFACE AND SATELLITE OBSERVATIONS OF  
CLOUD ASPECTS OF BIAS I. (U) LIVERPOOL UNIV (ENGLAND)  
DEPT OF GEOGRAPHY A HENDERSON-SELLERS ET AL. 18 NOV 87  
BOARD-IR-87-11 AFOSR-86-0299 F/G 4/2

1/2

UNCLASSIFIED

NL



**DTIC FILE COPY**

18 NOV 1987

Contract/Grant Number AFOSR-86-0299

**HOMOGENIZING SURFACE AND SATELLITE OBSERVATIONS OF CLOUD:  
ASPECTS OF BIAS IN SURFACE DATA**

A. Henderson-Sellers and A.H. Goodman  
Department of Geography  
University of Liverpool  
Liverpool, U.K.

**AD-A188 523**

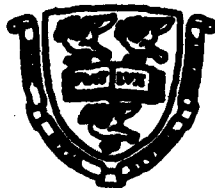
November 1987

Interim Scientific Report, 1 October 1986 - 30 September 1987

Approved for public release; distribution unlimited

Prepared for

**EUROPEAN OFFICE OF AEROSPACE RESEARCH AND DEVELOPMENT**  
London, England



**DTIC  
ELECTE  
DEC 22 1987**

**S D**

**QH**

**87 12 16 027**

AD-A188 523

| REPORT DOCUMENTATION PAGE                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                       | READ INSTRUCTIONS<br>BEFORE COMPLETING FORM                                     |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|---------------------------------------------------------------------------------|
| 1. Report Number<br><b>EOARD-TR-87-111</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | 2. Govt Accession No. | 3. Recipient's Catalog Number                                                   |
| 4. Title (and Subtitle)<br>Homogenizing surface and satellite observations of cloud: aspects of bias in surface data.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                       | 5. Type of Report & Period Covered<br>Interim, 1 October 86<br>30 September 87. |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                       | 6. Performing Org. Report Number                                                |
| 7. Author(s)<br>Ann Henderson-Sellers and Alan Goodman                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                       | 8. Contract or Grant Number<br>AFOSR-86-0299                                    |
| 9. Performing Organization Name and Address<br>Department of Geography,<br>University of Liverpool,<br>P.O. Box 147,<br>Liverpool, L69. 3BX.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                       | 10. Program Element, Project, Task<br>Area & Work Unit Numbers                  |
| 11. Controlling Office Name and Address<br>EOARD<br>223/231 Old Marylebone Road,<br>London, NW1, 5TH U.K.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                       | 12. Report Date<br>10 November 1987                                             |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                       | 13. Number of Pages<br>128                                                      |
| 14. Monitoring Agency Name and Address                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                       | 15.                                                                             |
| 16. & 17. Distribution Statement<br>Approved for public release; distribution unlimited.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                       |                                                                                 |
| 18. Supplementary Notes                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                       |                                                                                 |
| 19. Key Words<br>Bias, partial undercast, night-time bias of surface observers, okta observing scale.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                       |                                                                                 |
| 20. Abstract<br>A global, surface-observed cloud data set supplied by the U.S. Air Force for the months of July 1983 and January 1985 was investigated i) for evidence of night-detection bias in which observers may be repeatedly failing to discern the presence of cirrus and altostratus during darkness, ii) to assess the impact of the "partial undercast" bias and iii) to check for any significant bias effects arising from the definitions of 1 and 7 oktas cloud amount. Several well-spaced regions of the world were used as study areas in all 3 cases.<br><br>In case i) diurnal analyses of the frequency of occurrence of cirrus and altostratus were used to check for sunrise/sunset or daytime peaks which might have indicated anomalously high (low) values during daytime (night-time). Attention was particularly paid |                       |                                                                                 |

FORM 1473

A10



|                    |                      |
|--------------------|----------------------|
| By _____           |                      |
| Distribution/      |                      |
| Availability Codes |                      |
| Dist               | Avail and/or Special |
| A-1                |                      |

## 20. Abstract cont,d.....

to the  $10^{\circ} \times 20^{\circ}$  analysis region over Scandinavia where the large change in daylength between January and July would be expected to accentuate any bias present. Analysis within the study areas was repeated on small groups of stations within smaller areas to see whether the results were reproduced over smaller scales. It was found that the effects of bias may be stronger for small localities rather than over large areas. Only in the Scandinavian region was a significant diurnal variation identifiable for larger scales ( $10^{\circ} \times 20^{\circ}$ ). Supplementary diurnal analyses which may have helped to confirm any bias are included.

Partial undercast bias arises in situations in which upper cloud layers are present but are invisible to the observer as they do not encroach into any clear areas of the sky and therefore go unreported. In case ii) contingency probabilities which express the likelihood that given one cloud type another is present, were introduced in an attempt to confirm their potential use in such cases, as has been previously suggested. In the literature values of contingency probability for pairs of lower and upper cloud types have been shown to remain fairly steady over the range of partial undercast lower cloud amounts (i.e. 1-7 oktas). The results presented here showed a general decrease in contingency probability for increasing lower cloud amounts implying that the likelihood of the presence of upper clouds decreased as the lower cloud amount increased, a result inconsistent with previous assertions.

Possible biases arising out of the WMO definitions of 1 and 7 oktas were investigated with the aid of histograms showing the frequency with which each value on the okta scale is reported. Very low relative frequencies of 0:1 oktas indicate a situation in which the frequency of cloud amounts much less than 1 okta exceeds the frequency with which approximately 1 okta is actually present, causing an overestimate in the long term value of cloud amount. Such occurrences were found in several instances. Similarly very high relative frequencies of 7:8 oktas might suggest cases where the majority of 7 okta reports correspond to tiny gaps or suspected gaps in the cloud deck, causing an underestimate in the long term cloud amount. No instances of the latter were recorded.

The global data set was then used to construct a series of maps for the land and ocean describing the frequency of occurrence of cloud types, total and level cloud amounts and examples of contingency probabilities. The maps are presented and discussed in the context of their usefulness and in comparison to other data.

## **Contents**

|                                                                   | <i>Page</i> |
|-------------------------------------------------------------------|-------------|
| <b>1. Introduction</b>                                            | <b>3</b>    |
| <b>2. Analysis of January 1985 and July 1983</b>                  |             |
| <b>surface observations for evidence of bias</b>                  | <b>4</b>    |
| <b>2.1 Introduction</b>                                           | <b>4</b>    |
| <b>2.2 Data Source</b>                                            | <b>14</b>   |
| <b>2.3 Night Detection Bias</b>                                   | <b>14</b>   |
| <b>2.4 Discussion of Results</b>                                  | <b>17</b>   |
| <b>2.5 Other Methods of Detecting Nighttime Bias</b>              | <b>25</b>   |
| <b>2.6 The use of Contingency Probabilities for situations of</b> |             |
| <b>Partial Undercast Bias</b>                                     | <b>37</b>   |
| <b>2.7 Results</b>                                                | <b>41</b>   |
| <b>i) <math>L = St/Sc, U = Ac/As</math></b>                       | <b>41</b>   |
| <b>ii) <math>L = St/ScU = Ci/Cs/Cc</math></b>                     | <b>46</b>   |
| <b>2.8 1 and 7 okta bias</b>                                      | <b>53</b>   |
| <b>3. Global evaluation of surface cloud observations</b>         | <b>58</b>   |
| <b>3.1 Data</b>                                                   | <b>58</b>   |
| <b>3.2 Biases within the observations</b>                         | <b>59</b>   |
| <b>3.3 Analysis Procedure</b>                                     | <b>61</b>   |
| <b>i) Extraction of Required Information</b>                      | <b>61</b>   |
| <b>ii) Cloud Type Categories</b>                                  | <b>62</b>   |
| <b>iii) Cloud Amounts</b>                                         | <b>62</b>   |

|                                            |     |
|--------------------------------------------|-----|
| iv) Frequency of occurrence of cloud types | 64  |
| v) Exclusive Probability                   | 65  |
| vi) Contingency Probabilities              | 65  |
| 3.4 Map Format                             | 67  |
| 3.5 Discussion                             | 69  |
| 4. Summary and Conclusions                 | 123 |
| 5. Presentations and publications          | 124 |
| 6. References                              | 125 |

## **Abstract**

A global, surface-observed cloud data set supplied by the U.S. Air Force for the months of July 1983 and January 1985 was investigated i) for evidence of night-detection bias in which observers may be repeatedly failing to discern the presence of cirrus and altostratus during darkness, ii) to assess the impact of the "partial undercast" bias and iii) to check for any significant bias effects arising from the definitions of 1 and 7 oktas cloud amount. Several well-spaced regions of the world were used as study areas in all 3 cases.

In case i) diurnal analyses of the frequency of occurrence of cirrus and altostratus were used to check for sunrise/sunset or daytime peaks which might have indicated anomalously high (low) values during daytime (nighttime). Attention was particularly paid to the  $10^{\circ} \times 20^{\circ}$  analysis region over Scandinavia where the large change in daylength between January and July would be expected to accentuate any bias present. Analysis within the study areas was repeated on small groups of stations within smaller areas to see whether the results were reproduced over smaller scales. It was found that the effects of bias may be stronger for small localities rather than over large areas. Only in the Scandinavian region was a significant diurnal variation identifiable for larger scales ( $10^{\circ} \times 20^{\circ}$ ). Supplementary diurnal analyses which may have helped to confirm any bias are included.

Partial undercast bias arises in situations in which upper cloud layers are present but are invisible to the observer as they do not encroach into any clear areas of the sky and therefore go unreported. In case ii) contingency probabilities which express the likelihood that given one cloud type another is present, were introduced in an attempt to confirm their potential use in such cases, as has been previously suggested. In the literature values of contingency probability for pairs of lower and upper cloud types have been shown to remain fairly steady over the range of partial undercast lower cloud amounts (i.e. 1-7 oktas). The results presented here showed a general decrease in contingency probability for increasing lower cloud amounts implying that the

likelihood of the presence of upper clouds decreased as the lower cloud amount increased, a result inconsistent with previous assertions.

Possible biases arising out of the WMO definitions of 1 and 7 oktas were investigated with the aid of histograms showing the frequency with which each value on the okta scale is reported. Very low relative frequencies of 0:1 oktas indicate a situation in which the frequency of cloud amounts much less than 1 okta exceeds the frequency with which approximately 1 okta is actually present, causing an overestimate in the long term value of cloud amount. Such occurrences were found in several instances. Similarly very high relative frequencies of 7:8 oktas might suggest cases where the majority of 7 okta reports correspond to tiny gaps or suspected gaps in the cloud deck, causing an underestimate in the long term cloud amount. No instances of the latter were recorded.

The global data set was then used to construct a series of maps for the land and ocean describing the frequency of occurrence of cloud types, total and level cloud amounts and examples of contingency probabilities. The maps are presented and discussed in the context of their usefulness and in comparison to other data.

## 1. Introduction

The meteorological community is at present placing great emphasis on the analysis of clouds and their configurations from satellite imagery, much effort being devoted to the improvement of the accuracy and performance of retrieval algorithms (Rossow *et al.*, 1985; Arking and Childs, 1985; Chou *et al.*, 1986; Saunders and Kriebel, 1987; Coakley, 1987). The superior coverage afforded by satellites as compared to the uneven distribution of ground stations throughout the world and their scarcity over oceanic and polar regions is one of the chief causes of this trend. The satellite era now permits the remotely-sensed measurement of cloud optical parameters affecting the radiation budgets of the Earth and atmosphere to be achieved (e.g. Chahine, 1982) and methods for estimating cloud cover fraction from satellite radiance data are well documented in the literature (Reynolds and Vonder Haar, 1977; Coakley and Bretherton, 1982; Saunders, 1986), whilst schemes aiming to deduce the exact cloud types are now also developed (Desbois *et al.*, 1982; Liljas, 1984, 1986).

From a surface viewpoint reports of cloud type are still more reliable than those from above; the observer on the ground is that much closer to the clouds and is able to resolve individual clouds within his field of vision. Such data, describing the amount and type of cloud present, are still the only feasible means of validating and comparing remotely sensed cloud information (Henderson-Sellers *et al.*, 1987), also serving as sources of input and comparative data for the purposes of climate models. With the latter in mind, attention has been paid to evaluating global surface data not only in the form of amount climatologies (Berlyand and Strokina, 1980) but also in terms of the frequency of occurrence of the various cloud types, their individual amounts and the modes in which combinations of types occur together (Hahn *et al.*, 1982, 1984; Warren *et al.*, 1986, 1987). (A recent review of global cloud climatologies is given in Hughes (1984)). The International Satellite Cloud Climatology Project (ISCCP) will shortly be providing satellite retrievals against which comparative and validity exercises should take place whilst surface observations are already providing a major

component to the First ISCCP Regional Experiment (FIRE) (Cox *et al.*, 1987). With the above considerations in mind, particularly the likelihood of satellite-surface intercomparison, surface data for two separate months during ISCCP (July 1983 and January 1985) have been evaluated. Section 2 describes the analysis of this surface data set for the evidence of biases of different types and Section 3 describes a global scale evaluation of these surface observations of cloudiness. Section 4 contains a summary and conclusions and Section 5 a list of presentations and publications made this year.

## **2. Analysis of data set for evidence of bias**

### **2.1 Introduction**

Surface observations of clouds are routinely made worldwide either at land-based stations, on ships or from aircraft. In a typical case the observer records the total cloud amount present (also known as the skycover), i.e. the fraction of the celestial dome covered by cloud, along with each cloud type and the amount of each type. With a little experience estimating the skycover and identifying the cloud types visible is a relatively straightforward task. The ease with which a full description of the clouds can be given, however, depends on the types present and their relative configuration, as well as the experience, location and procedure adopted by the observer. Where the clouds exhibit vertical development the observer includes the sides as well as the bases of the clouds in his estimate of the total cloud amount (the skycover) (Figure 1) (Malberg, 1973), "overestimating" with respect to a satellite viewing the same area which would observe only the vertical projection of the clouds against the Earth (termed the earthcover). It is very important to recognise that surface observations made correctly are *not* overestimates; they are accurate reports of skycover. The terms over- and under-estimation enter descriptions, often inappropriately, when skycover and earthcover are compared without due evaluation of the definition of the terms.

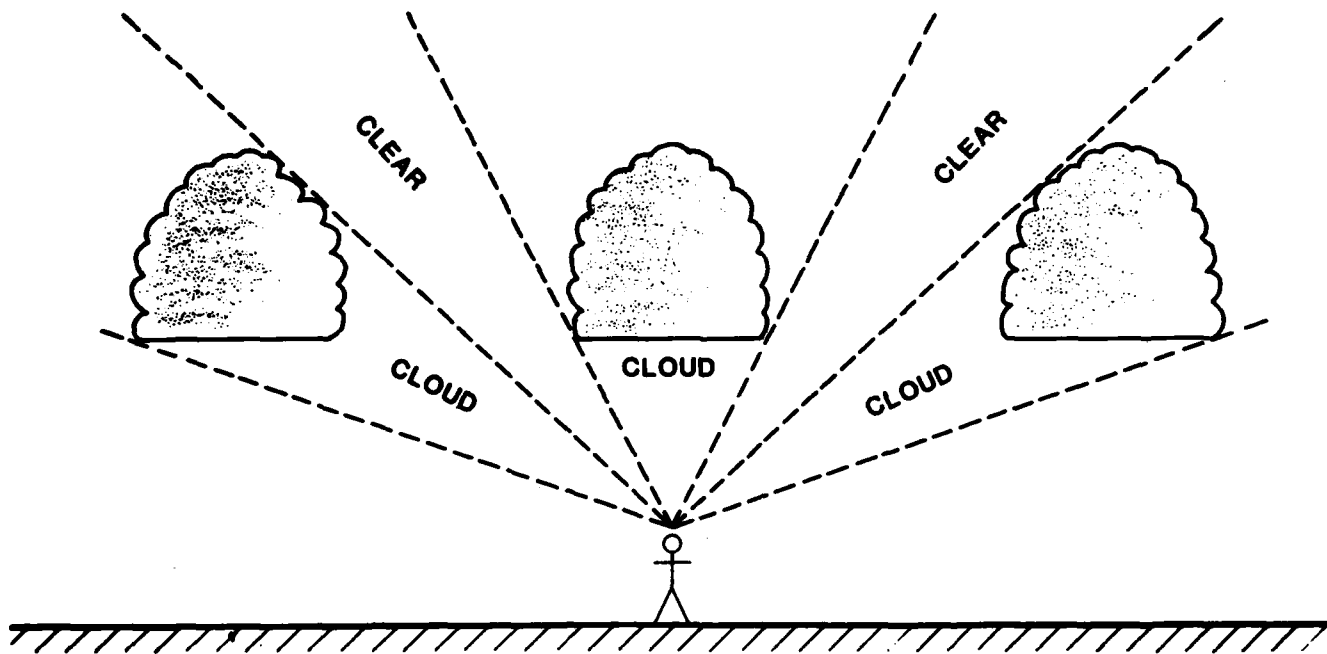


**Figure 1** Illustration of how an observer sees the sides as well as the bases of vertically-developed clouds (from Malberg, 1973).

Both surface and satellite observations may overestimate the cloud amount in situations when the clouds adopt regular arrays interspersed by small gaps as with stratocumulus and altocumulus. In such cases those gaps close to the horizon will not be detected. The quality of surface cloud observations is further affected by the fact that on many occasions the clouds comprise several types of differing amount and at various heights. In a multilayered situation the observer cannot always discern even the presence of middle or upper level clouds, let alone their amounts, due to obscuration by lower layers. Observations of clouds at night are especially difficult. The lack of illumination makes it hard for the observer to identify individual types (especially cirrus) and their respective amounts, even after he has accustomed his eye to the dim light.

The above points illustrate some of the problems encountered with surface-based cloud observations. In general, though, they provide relatively accurate estimates of low and total skycover and of cloud types. Prior to the advent of the satellite retrieval techniques they were the principal source of global cloud statistics and all cloud climatologies compiled in this period used ground-based reports (Brooks, 1927; London, 1957; Hastenrath and Lamb, 1977). Indeed, in the absence of a satellite-based global cloud climatology (Schiffer and Rossow, 1983), surface observations have often been deemed useful enough to be incorporated into climate models as both input and in validations. They also form a significant data component for the U.S. Air Force's nephanalysis (Fye, 1978; Henderson-Sellers and Hughes, 1985). Nevertheless, the potential biases inherent in such data require careful attention. Only recently, however, has this been forthcoming in the work of Hahn *et al.* (1982, 1984) and Warren *et al.* (1986), which introduced the concept of contingency probabilities as part of their overall description of the global cloud field as observed from the surface and whose work provided part of the motivation for this investigation. Nighttime bias, partial undercast bias and 1,7 okta bias were selected as study topics and the following sections detail the analysis of each type of bias.

**Table 1 Low level cloud classification ( $C_L$ ) as defined by WMO (from WMO, 1984)**

**$C_L$  — Clouds of the genera Stratocumulus, Stratus, Cumulus and Cumulonimbus**

| <b>Code</b> | <b>Technical specifications</b>                                                                                                                  | <b>Code</b> | <b>Non-technical specifications</b>                                                                                                                                                                                  |
|-------------|--------------------------------------------------------------------------------------------------------------------------------------------------|-------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 0           | No $C_L$ clouds                                                                                                                                  | 0           | No Stratocumulus, Stratus, Cumulus or Cumulonimbus                                                                                                                                                                   |
| 1           | Cumulus humilis or Cumulus fractus other than of bad weather,* or both                                                                           | 1           | Cumulus with little vertical extent and seemingly flattened, or ragged Cumulus other than of bad weather, * or both                                                                                                  |
| 2           | Cumulus mediocris or congestus, with or without Cumulus of species fractus or humilis or Stratocumulus, all having their bases at the same level | 2           | Cumulus of moderate or strong vertical extent, generally with protuberances in the form of domes or towers, either accompanied or not by other Cumulus or by Stratocumulus, all having their bases at the same level |
| 3           | Cumulonimbus calvus, with or without Cumulus, Stratocumulus or Stratus                                                                           | 3           | Cumulonimbus the summits of which, at least partially, lack sharp outlines, but are neither clearly fibrous (cirriform) nor in the form of an anvil; Cumulus, Stratocumulus or Stratus may also be present           |
| 4           | Stratocumulus cumulogenitus                                                                                                                      | 4           | Stratocumulus formed by the spreading out of Cumulus; Cumulus may also be present                                                                                                                                    |
| 5           | Stratocumulus other than Stratocumulus cumulogenitus                                                                                             | 5           | Stratocumulus not resulting from the spreading out of Cumulus                                                                                                                                                        |
| 6           | Stratus nebulosus or Stratus fractus other than of bad weather,* or both                                                                         | 6           | Stratus in a more or less continuous sheet or layer, or in ragged shreds, or both, but no Stratus fractus of bad weather*                                                                                            |
| 7           | Stratus fractus or Cumulus fractus of bad weather,* or both (pannus), usually below Altostratus or Nimbostratus                                  | 7           | Stratus fractus of bad weather* or Cumulus fractus of bad weather, or both (pannus), usually below Altostratus or Nimbostratus                                                                                       |
| 8           | Cumulus and Stratocumulus other than Stratocumulus cumulogenitus, with bases at different levels                                                 | 8           | Cumulus and Stratocumulus other than that formed from the spreading out of Cumulus; the base of the Cumulus is at a different level from that of the Stratocumulus                                                   |

- |                                                                                                                                        |                                                                                                                                                                                                                                           |
|----------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>9 Cumulonimbus capillatus (often with an anvil), with or without Cumulonimbus calvus, Cumulus, Stratocumulus, Stratus or pannus</p> | <p>9 Cumulonimbus, the upper part of which is clearly fibrous (cirriform), often in the form of an anvil; either accompanied or not by Cumulonimbus without anvil or fibrous upper part, by Cumulus, Stratocumulus, Stratus or pannus</p> |
| <p>/ C<sub>L</sub> clouds invisible owing to darkness, fog, blowing dust or sand, or other similar phenomena</p>                       | <p>/ Stratocumulus, Stratus, Cumulus and Cumulonimbus invisible owing to darkness, fog, blowing dust or sand, or other similar phenomena</p>                                                                                              |

\* "Bad weather" denotes the conditions which generally exist during precipitation and a short time before and after.

**Table 2 Middle level cloud classification ( $C_M$ ) as defined by WMO (from WMO, 1984)**

**$C_M$  — Clouds of the genera *Alto*cumulus, *Alto*stratus and *Nimbo*stratus**

| Code | Technical specifications                                                                                                                                                                                                       | Code | Non-technical specifications                                                                                                                                                                                                                                              |
|------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 0    | No $C_M$ clouds                                                                                                                                                                                                                | 0    | No <i>Alto</i> cumulus, <i>Alto</i> stratus or <i>Nimbo</i> stratus                                                                                                                                                                                                       |
| 1    | <i>Alto</i> stratus translucidus                                                                                                                                                                                               | 1    | <i>Alto</i> stratus, the greater part of which is semi-transparent; through this part the sun or moon may be weakly visible, as through ground glass                                                                                                                      |
| 2    | <i>Alto</i> stratus opacus or <i>Nimbo</i> stratus                                                                                                                                                                             | 2    | <i>Alto</i> stratus, the greater part of which is sufficiently dense to hide the sun or moon, or <i>Nimbo</i> stratus                                                                                                                                                     |
| 3    | <i>Alto</i> cumulus translucidus at a single level                                                                                                                                                                             | 3    | <i>Alto</i> cumulus, the greater part of which is semi-transparent; the various elements of the cloud change only slowly and are all at a single level                                                                                                                    |
| 4    | Patches (often lenticular) of <i>Alto</i> cumulus translucidus, continually changing and occurring at one or more levels                                                                                                       | 4    | Patches (often in the form of almonds or fishes) of <i>Alto</i> cumulus, the greater part of which is semi-transparent; the clouds occur at one or more levels and the elements are continually changing in appearance                                                    |
| 5    | <i>Alto</i> cumulus translucidus in bands, or one or more layers of <i>Alto</i> cumulus translucidus or opacus, progressively invading the sky; these <i>Alto</i> cumulus clouds generally thicken as a whole                  | 5    | Semi-transparent <i>Alto</i> cumulus in bands, or <i>Alto</i> cumulus, in one or more fairly continuous layer (semi-transparent or opaque), progressively invading the sky: these <i>Alto</i> cumulus clouds generally thicken as a whole                                 |
| 6    | <i>Alto</i> cumulus cumulogenitus (or cumulonimbogenitus)                                                                                                                                                                      | 6    | <i>Alto</i> cumulus resulting from the spreading out of <i>Cumulus</i> (or <i>Cumulonimbus</i> )                                                                                                                                                                          |
| 7    | <i>Alto</i> cumulus translucidus or opacus in two or more layers, or <i>Alto</i> cumulus opacus in a single layer, not progressively invading the sky, or <i>Alto</i> cumulus with <i>Alto</i> stratus or <i>Nimbo</i> stratus | 7    | <i>Alto</i> cumulus in two or more layers, usually opaque in places, and not progressively invading the sky; or opaque layer of <i>Alto</i> cumulus, not progressively invading the sky; or <i>Alto</i> cumulus together with <i>Alto</i> stratus or <i>Nimbo</i> stratus |

- |                                                                                                                                                                            |                                                                                                                                                                                                                                 |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>8    <b>Alto cumulus castellanus or floccus</b></p>                                                                                                                     | <p>8    <b>Alto cumulus with sproutings in the form of small towers or battlements, or Alto cumulus having the appearance of cumuliform tufts</b></p>                                                                           |
| <p>9    <b>Alto cumulus of a chaotic sky, generally at several levels</b></p>                                                                                              | <p>9    <b>Alto cumulus of a chaotic sky, generally at several levels</b></p>                                                                                                                                                   |
| <p>/    <b>C<sub>M</sub> clouds invisible owing to darkness, fog, blowing dust or sand, or other similar phenomena, or because of continuous layer of lower clouds</b></p> | <p>/    <b>Alto cumulus, Alto stratus and Nimbo stratus invisible owing to darkness, fog, blowing dust or sand, or other similar phenomena, or more often because of the presence of a continuous layer of lower clouds</b></p> |

**Table 3 High level cloud classification ( $C_H$ ) as defined by WMO (from WMO, 1984)**

$C_H$  — Clouds of the genera Cirrus, Cirrocumulus and Cirrostratus

| Code | Technical specifications                                                                                                                                                                                                                      | Code | Non-technical specifications                                                                                                                                                                                                                                                                                                                   |
|------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 0    | No $C_H$ clouds                                                                                                                                                                                                                               | 0    | No Cirrus, Cirrocumulus or Cirrostratus                                                                                                                                                                                                                                                                                                        |
| 1    | Cirrus fibratus, sometimes uncinus, not progressively invading the sky                                                                                                                                                                        | 1    | Cirrus in the form of filaments, strands or hooks, not progressively invading the sky                                                                                                                                                                                                                                                          |
| 2    | Cirrus spissatus, in patches or entangled sheaves, which usually do not increase and sometimes seem to be the remains of the upper part of a Cumulonimbus; or Cirrus castellanus or floccus                                                   | 2    | Dense Cirrus, in patches or entangled sheaves, which usually do not increase and sometimes seem to be the remains of the upper part of a Cumulonimbus; or Cirrus with sproutings in the form of small turrets or battlements, or Cirrus having the appearance of cumuliform tufts                                                              |
| 3    | Cirrus spissatus cumulonimbogenitus                                                                                                                                                                                                           | 3    | Dense Cirrus, often in the form of an anvil, being the remains of the upper parts of Cumulonimbus                                                                                                                                                                                                                                              |
| 4    | Cirrus uncinus or fibratus, or both, progressively invading the sky; they generally thicken as a whole                                                                                                                                        | 4    | Cirrus in the form of hooks or of filaments, or both, progressively invading the sky; they generally become denser as a whole                                                                                                                                                                                                                  |
| 5    | Cirrus (often in bands) and Cirrostratus, or Cirrostratus alone, progressively invading the sky; they generally thicken as a whole, but the continuous veil does not reach 45 degrees above the horizon                                       | 5    | Cirrus (often in bands converging towards one point or two opposite points of the horizon) and Cirrostratus, or Cirrostratus alone; in either case, they are progressively invading the sky, and generally growing denser as a whole, but the continuous veil does not reach 45 degrees above the horizon                                      |
| 6    | Cirrus (often in bands) and Cirrostratus, or Cirrostratus alone, progressively invading the sky; they generally thicken as a whole; the continuous veil extends more than 45 degrees above the horizon, without the sky being totally covered | 6    | Cirrus (often in bands converging towards one point or two opposite points of the horizon) and Cirrostratus, or Cirrostratus alone; in either case, they are progressively invading the sky, and generally growing denser as a whole; the continuous veil extends more than 45 degrees above the horizon without the sky being totally covered |

- |   |                                                                                                                                                   |   |                                                                                                                                                                                                       |
|---|---------------------------------------------------------------------------------------------------------------------------------------------------|---|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 7 | Cirrostratus covering the whole sky                                                                                                               | 7 | Veil of Cirrostratus covering the celestial dome                                                                                                                                                      |
| 8 | Cirrostratus not progressively invading the sky and not entirely covering it                                                                      | 8 | Cirrostratus not progressively invading the sky and not completely covering the celestial dome                                                                                                        |
| 9 | Cirrocumulus alone, or Cirrocumulus predominant among the $C_H$ clouds                                                                            | 9 | Cirrocumulus alone, or Cirrocumulus accompanied by Cirrus or Cirrostratus, or both, but Cirrocumulus is predominant                                                                                   |
| / | $C_H$ clouds invisible owing to darkness, fog, blowing dust or sand, or other similar phenomena, or because of a continuous layer of lower clouds | / | Cirrus, Cirrocumulus and Cirrostratus invisible owing to darkness, fog, blowing dust or sand, or other similar phenomena, or more often because of the presence of a continuous layer of lower clouds |

**Table 4 Categories of Observation Type in Data Set**

**a) Land**

- |       |                         |
|-------|-------------------------|
| i)    | Synoptic                |
| ii)   | Airways                 |
| iii)  | metar                   |
| iv)   | Synoptic-Airways merged |
| v)    | Synoptic-metar merged   |
| vi)   | Aero                    |
| vii)  | SMARS                   |
| viii) | Synoptic-Aero merged    |

**b) Sea**

- |    |          |
|----|----------|
| i) | Synoptic |
|----|----------|

## **2.2 Data Source**

The cloud data formed part of the global surface weather data set for the months of July 1983 and January 1985 and were obtained from the U.S. Defense Department via the Department of the Air Force. They include observations taken on land (from the World Meteorological Organisation (WMO) ground station network) and at sea. All ship-based observations are of the conventional synoptic type whilst those derived from land stations comprise several categories of report, depending upon source, predominantly synoptic but including such categories as airways and metar where the report has originated from airfields and is issued with respect to aircraft flight conditions. In some cases composite reports have been supplied by 'merging', for example an airway's report with the corresponding synoptic observation. The categories vary in the frequency and amount of data supplied but are given an equal weighting in the investigation. Maps showing the global distribution of the various types of report for both months can be found in Section 3. Table 4 lists each category.

All cloud observations are coded according to the WMO synoptic code (WMO, 1956, 1974, 1984, 1987) which assigns the clouds to three levels (low, middle and high) and a number in the range 0-9 for each level according to the type of cloud present (or absent) at that level. The code 255 refers to missing information about a cloud level, usually as a result of obscuration either by precipitation or by lower layers of cloud. The classification of cloud types for each level is given in Tables 1-3. Each report contains information on the total cloud amount and, where possible, on the amount of each type present.

## **2.3 Night Detection Bias**

It is a matter of synoptic experience that the observation of clouds during darkness is a harder task than during daylight hours. The presence of moonlight may alleviate the difficulties somewhat, frequently enabling the observer to detect altostratus and altocumulus but in the absence of this the

observing procedure becomes ever more subjective, particularly when dealing with cloud amount. Cirrus and altostratus are two of the types observers find hardest to detect at night particularly when they are present as part of a multilayered cloud scene and are partially obscured by lower layers. Even in the absence of other clouds the presence of thin cirrus by itself is hard to discern. Since cloud climatologies require nighttime observations in order to be fully representative it is possible that such bias, if repeated over a significant time period, would seriously reduce the quality of the climatology.

Riehl (1947), describing diurnal variations in cloudiness over the subtropical Atlantic, was probably the first to suggest a possible underestimate of cirrus by observers during nighttime. Normally this would be difficult to detect over the ocean because synoptic reports from ships are mostly received every 6 hours at 0, 6, 12 and 18 hours GMT which would provide insufficient diurnal sampling. Synoptic reports from land-based stations are, however, normally made every 3 hours GMT (some stations in the USAF data reported every hour) thus permitting at least preliminary investigations into the diurnal variation to be made.

Nocturnal bias has received scant attention since Riehl (Hahn *et al.*, 1984) and appears to have been passed over with little consideration. In an attempt to check for its presence or absence in the data available, the diurnal cycles of cirrus and altostratus were prepared for both July 1983 and January 1985 for all the stations residing within the shaded regions in Figure 2. The areas were selected so as to be spaced well apart and possibly to give some insight into global trends in observations. Although no information on the natural diurnal variation of cirrus and altostratus was available for comparison it was anticipated that anomalous peaks in the frequency of either cloud type either at sunrise/sunset or during the day would point towards some level of bias influencing the result. Apart from the central African region the study areas are in either the middle or higher latitudes of the northern hemisphere. Using data for both months provided the opportunity for determining whether the shorter daylength of winter would magnify any bias. All reporting hours

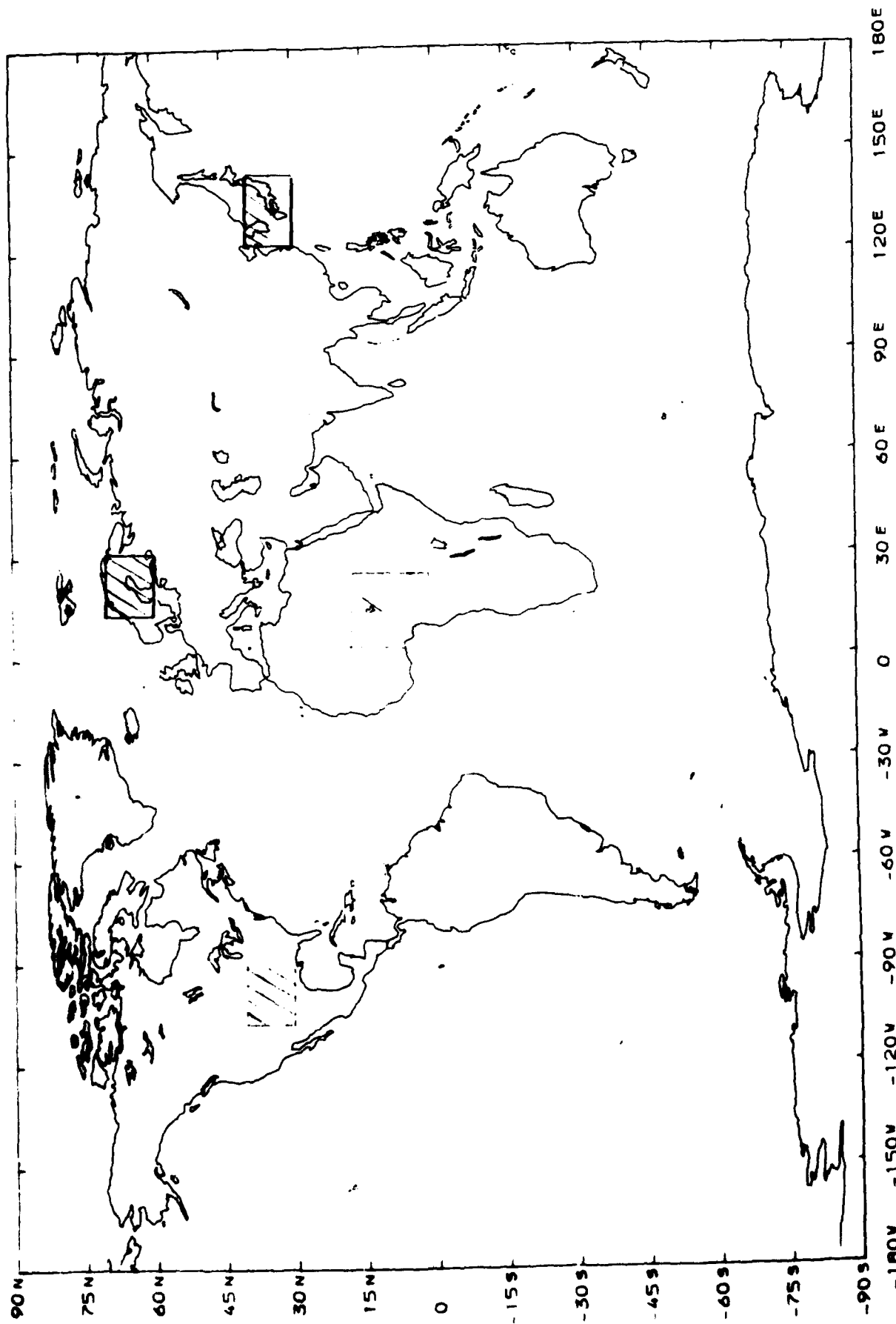


Figure 2 Analysis regions for night-detection bias investigation.

were adequately sampled (Table 5) except for Australasia which was thus removed from the list of analysis areas.

#### *2.4 Discussion of Results*

Figures 3 to 6 illustrate diurnal plots of the frequency of cirrus and altostratus at each of the eight standard synoptic reporting hours for July 1983 over each of the 4 study areas. In these diagrams the frequency of occurrence is determined by dividing the number of occasions the cloud type is observed by the number of times information about the appropriate cloud level was available, i.e. the level could be observed. These plots provide few initial clues as to the likelihood of nocturnal bias. Over eastern Asia and central Africa (Figures 3 and 4) small peaks of the order of 10% in the frequency of both cloud types are observed at 6 am local time but they are of similar magnitude to peaks observed at other times of the day, e.g. midnight. Over Scandinavia (Figure 5), only one small but very broad peak is discernible for each type whilst over the central United States (Figure 6) the peaks are again small and fairly regularly spaced.

Prior to comparing the January results with those for July, diurnal analyses were prepared for stations lying within  $1^{\circ} \times 2^{\circ}$  or  $2^{\circ} \times 2^{\circ}$  boxes of the selected areas, these boxes being spaced well apart within the parent study areas, to ascertain whether the results obtained on the larger scale were reproducible at much smaller scales (sometimes for single stations) and to check for any signs of bias which may have gone unnoticed when looking at the areas as a whole. The sampling criterion introduced required that at each of the eight observing hours there must be at least 30 individual reports.

The results over a small group of stations may be expected to exhibit more marked variability compared to the mean result for a larger number of stations. Figures 7 to 14 illustrate this clearly enough particularly in the American and Scandinavian examples (Figures 12, 13 and 14) where the mean pattern for the region as a whole is not preserved. The suggestion of bias is very strong in the example depicted in Figure 12 over northern Scandinavia. At this latitude darkness prevails for

**Table 5 Diurnal frequency of cloud reports**

| REGION       | MONTH & YEAR | HOUR |      |      |      |      |      |      |      |
|--------------|--------------|------|------|------|------|------|------|------|------|
|              |              | 00   | 03   | 06   | 09   | 12   | 15   | 18   | 21   |
| SCANDINAVIA  | JUL. 1983    | 2391 | 2766 | 3389 | 2872 | 3353 | 2858 | 3408 | 2077 |
|              | JAN. 1985    | 2890 | 3504 | 2966 | 3476 | 3051 | 3452 | 2236 | 2641 |
| CENTRAL      | JUL. 1983    | 884  | 716  | 1208 | 1072 | 1200 | 1073 | 1183 | 564  |
| AFRICA       | JAN. 1985    | 707  | 603  | 1028 | 782  | 989  | 764  | 1100 | 563  |
| AUSTRALASIA  | JUL. 1983    | 740  | 155  | 628  | 81   | 818  | 112  | 668  | 391  |
|              | JAN. 1985    | 600  | 354  | 909  | 151  | 425  | 213  | 806  | 25   |
| EASTERN ASIA | JUL. 1983    | 4061 | 2144 | 4044 | 2183 | 2973 | 2175 | 2589 | 2202 |
|              | JAN. 1985    | 3070 | 1885 | 3225 | 1851 | 2250 | 1616 | 1987 | 1769 |
| CENTRAL USA  | JUL. 1983    | 596  | 420  | 241  | 259  | 477  | 537  | 643  | 733  |
|              | JAN. 1985    | 504  | 323  | 244  | 238  | 254  | 485  | 494  | 535  |

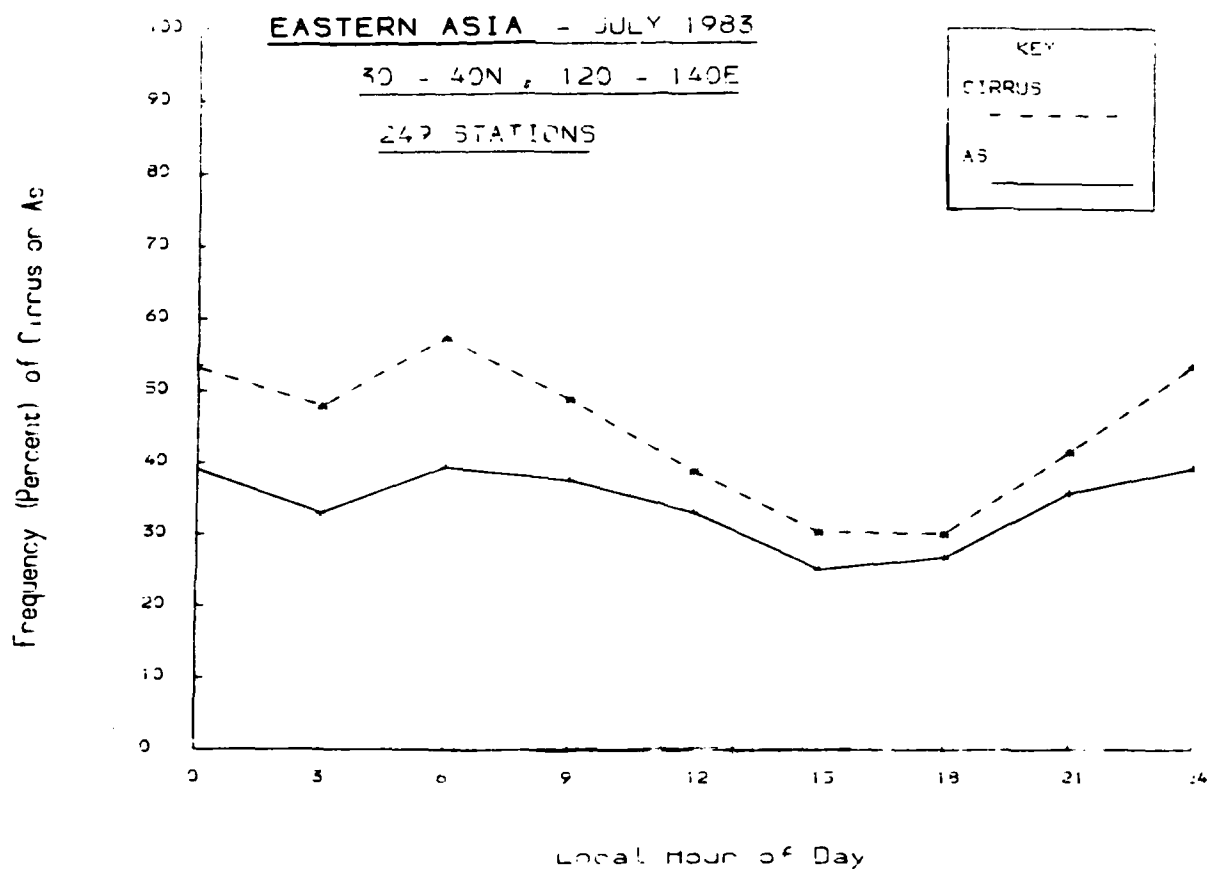


Figure 3 Diurnal variation of cirrus/altostratus over eastern Asia for July 1983.

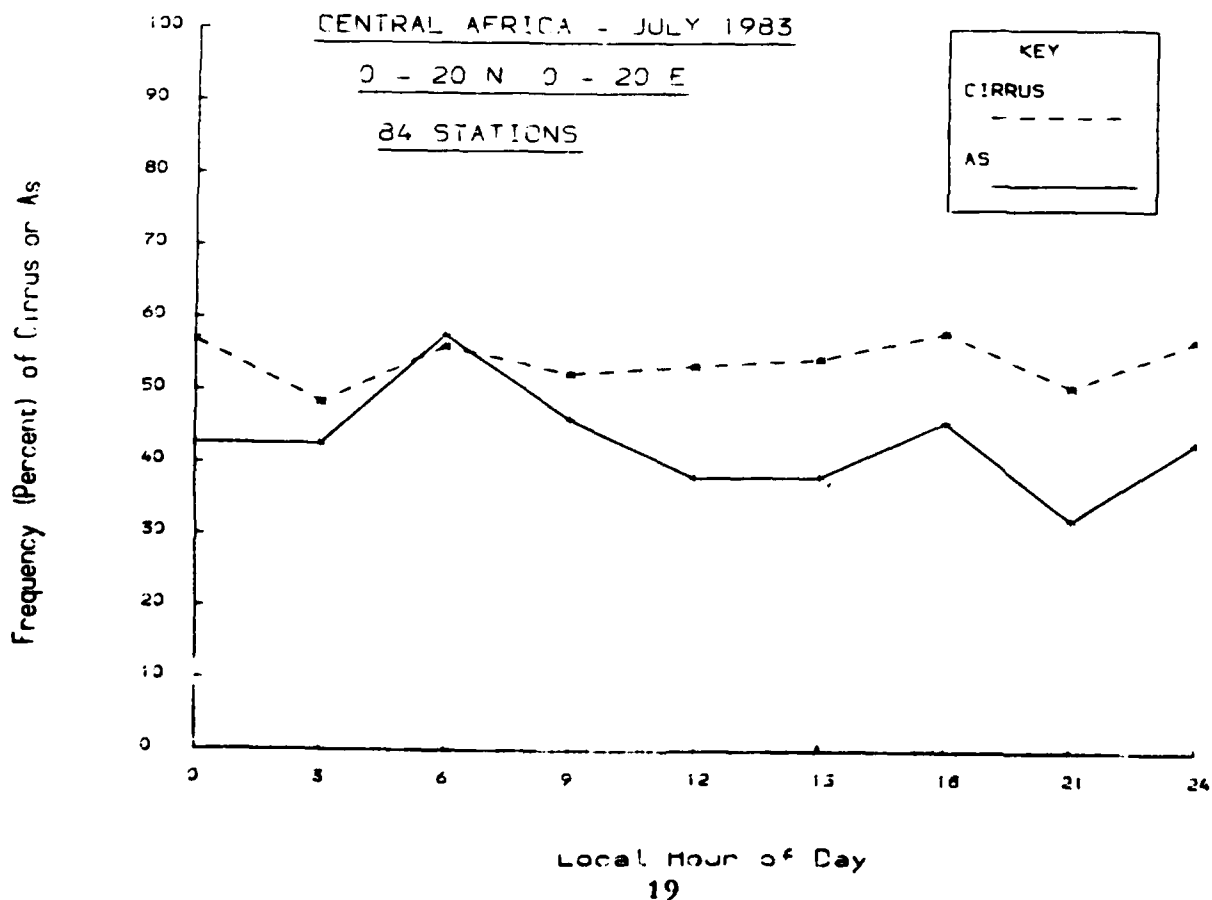


Figure 4 Diurnal variation of cirrus/altostratus over central Africa for July 1983.

Figure 5 Diurnal variation of cirrus/altostratus over Scandinavia for July 1983.

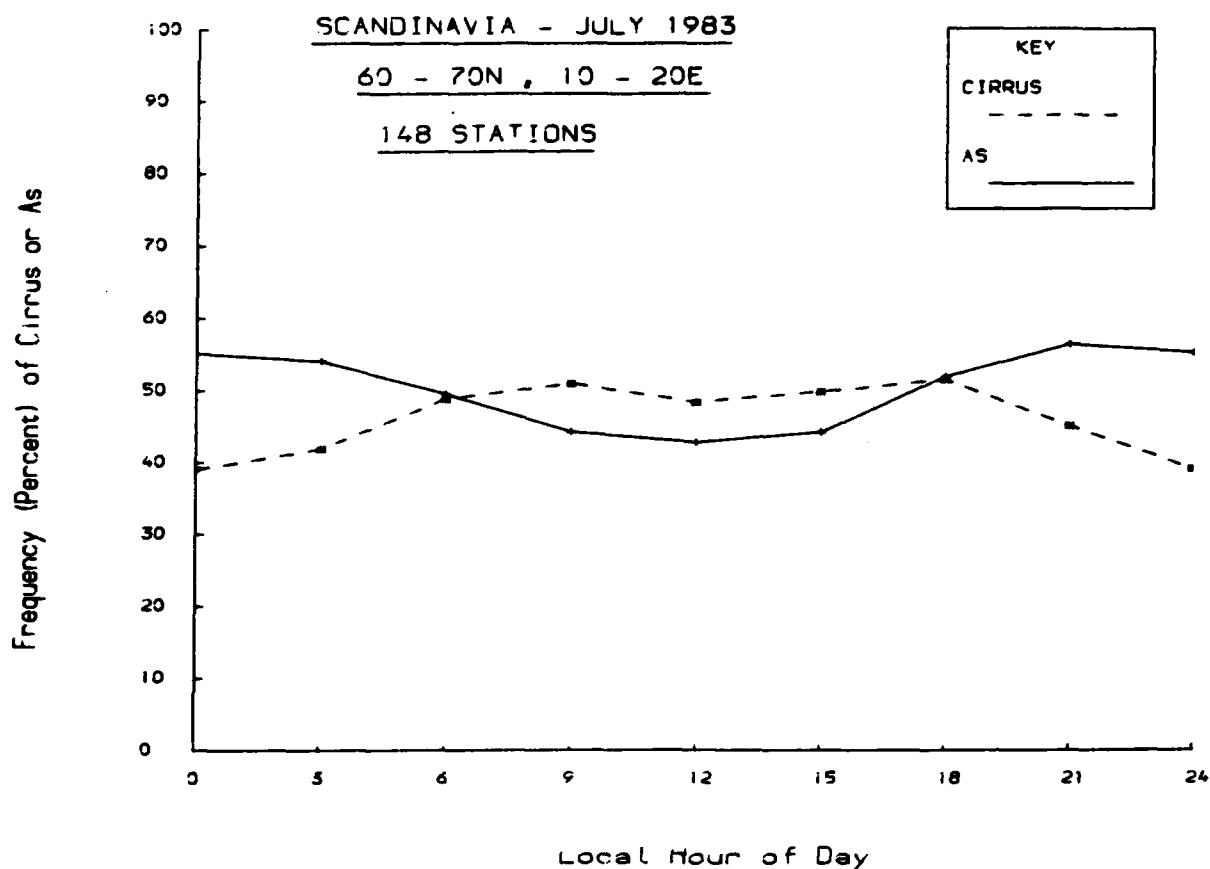


Figure 6 Diurnal variation of cirrus/altostratus over the central U.S.A for July 1983.

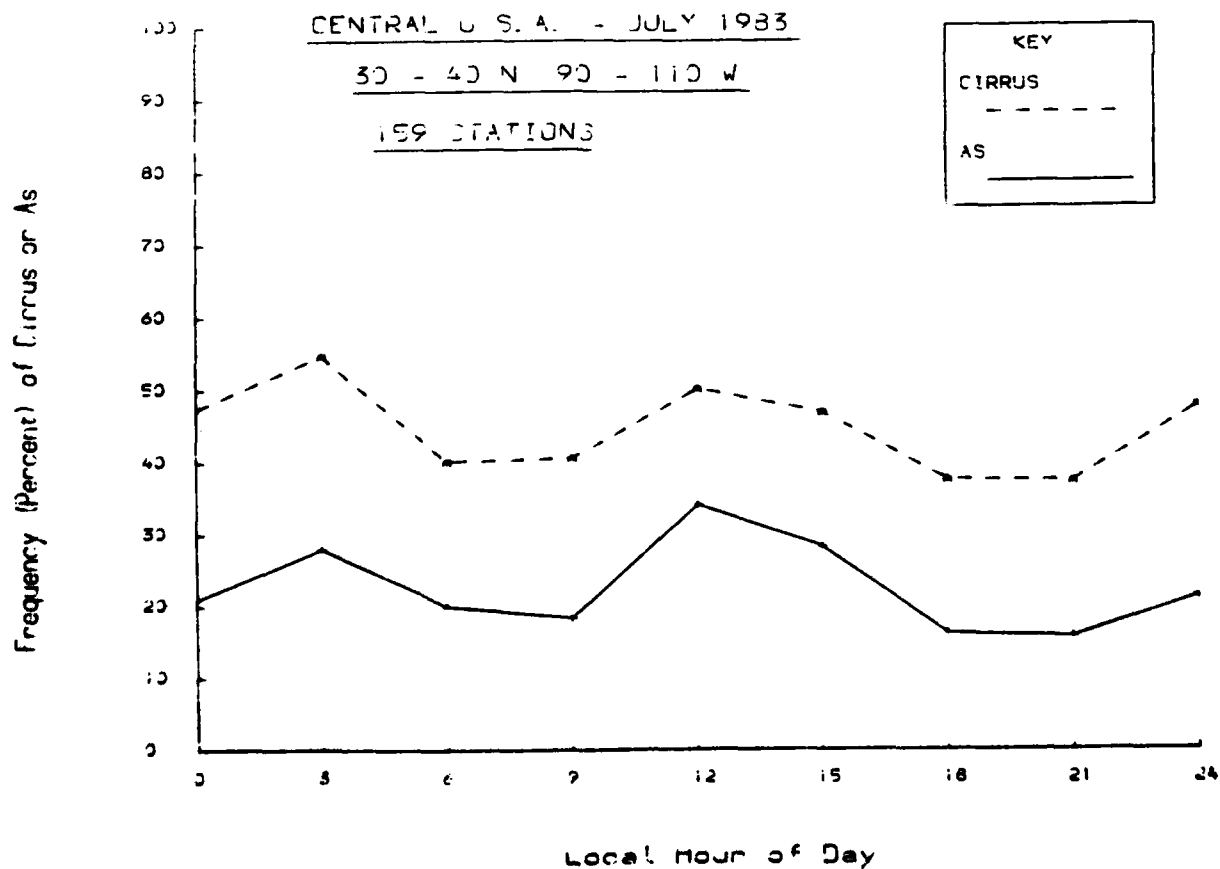


Figure 7 Diurnal variation of cirrus/altostratus over eastern Asia for the 6 stations within the region 34-35°N, 135-136°E for July 1983.

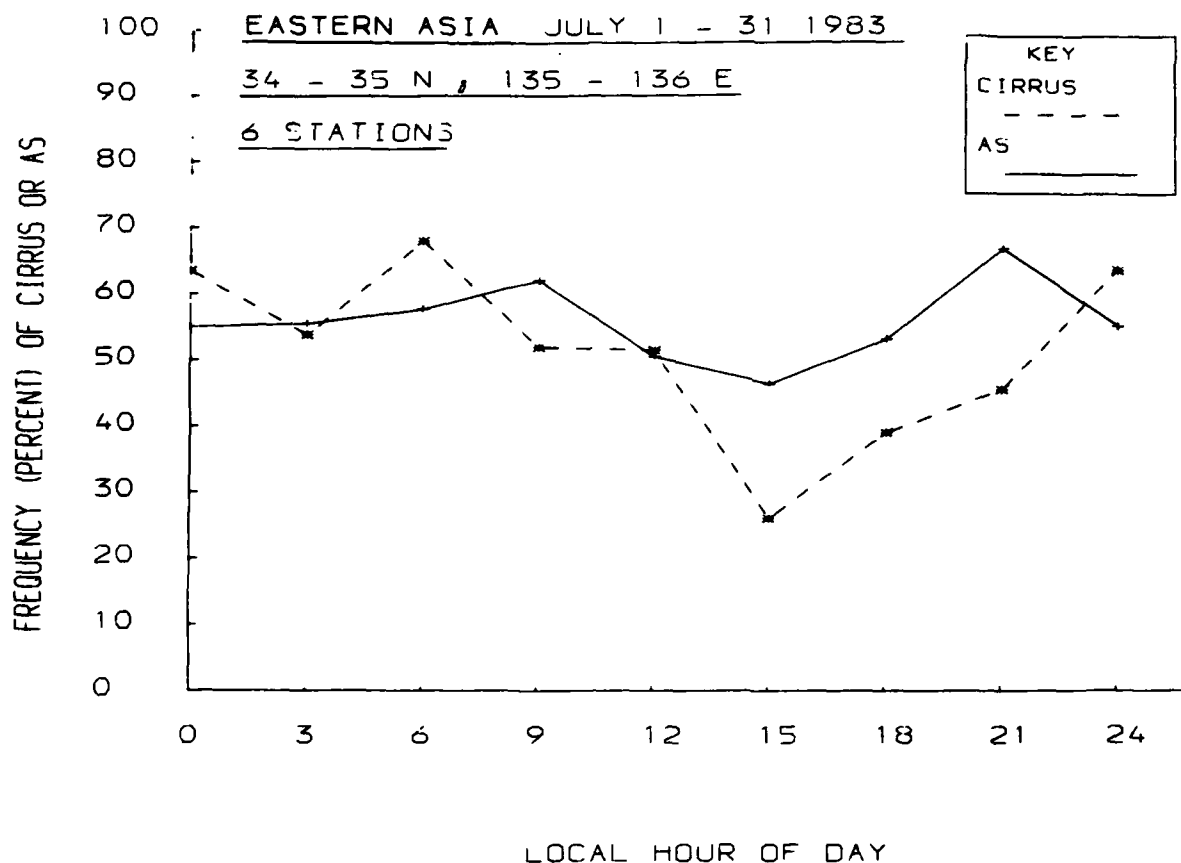
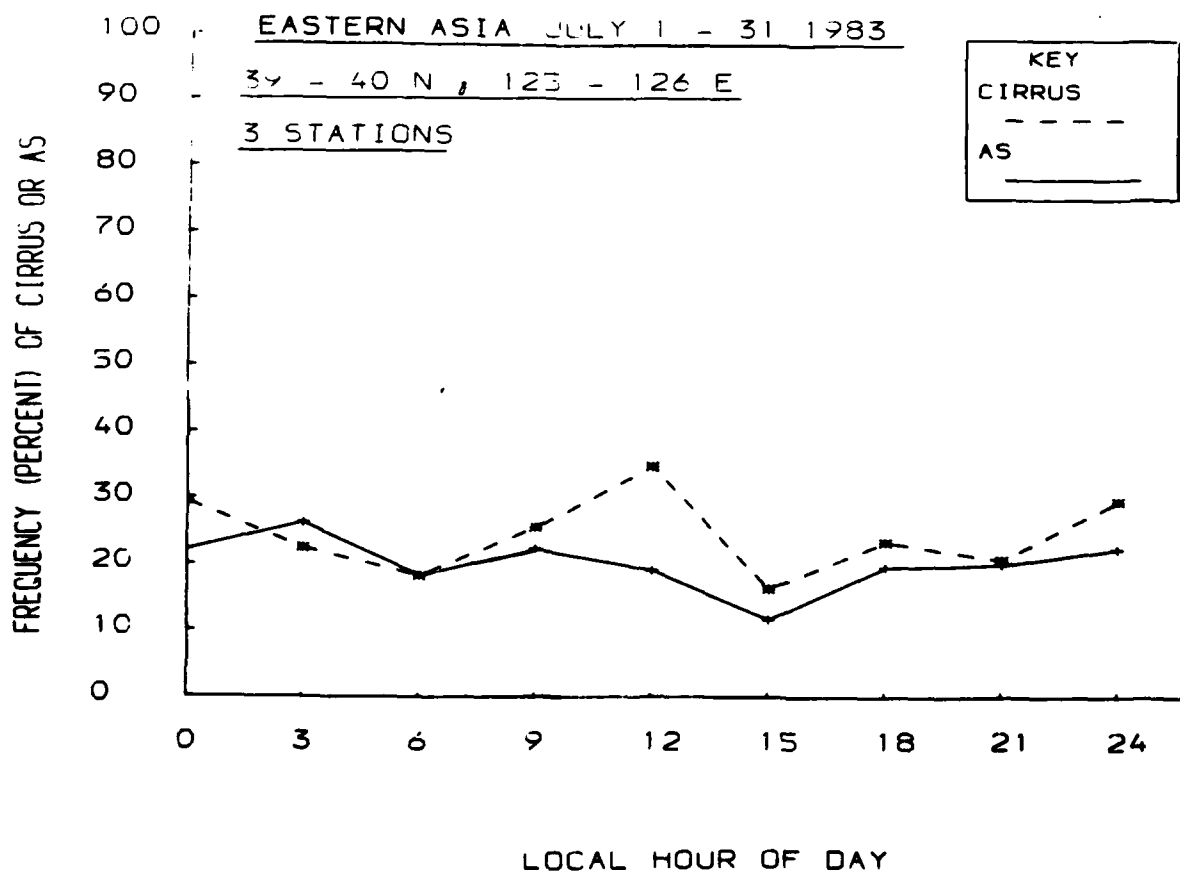


Figure 8 Diurnal variation of cirrus/altostratus over eastern Asia for the 3 stations within the region 39-40°N, 125-126°E for July 1983.



region 2-4°N, 11-12°E for July 1983.

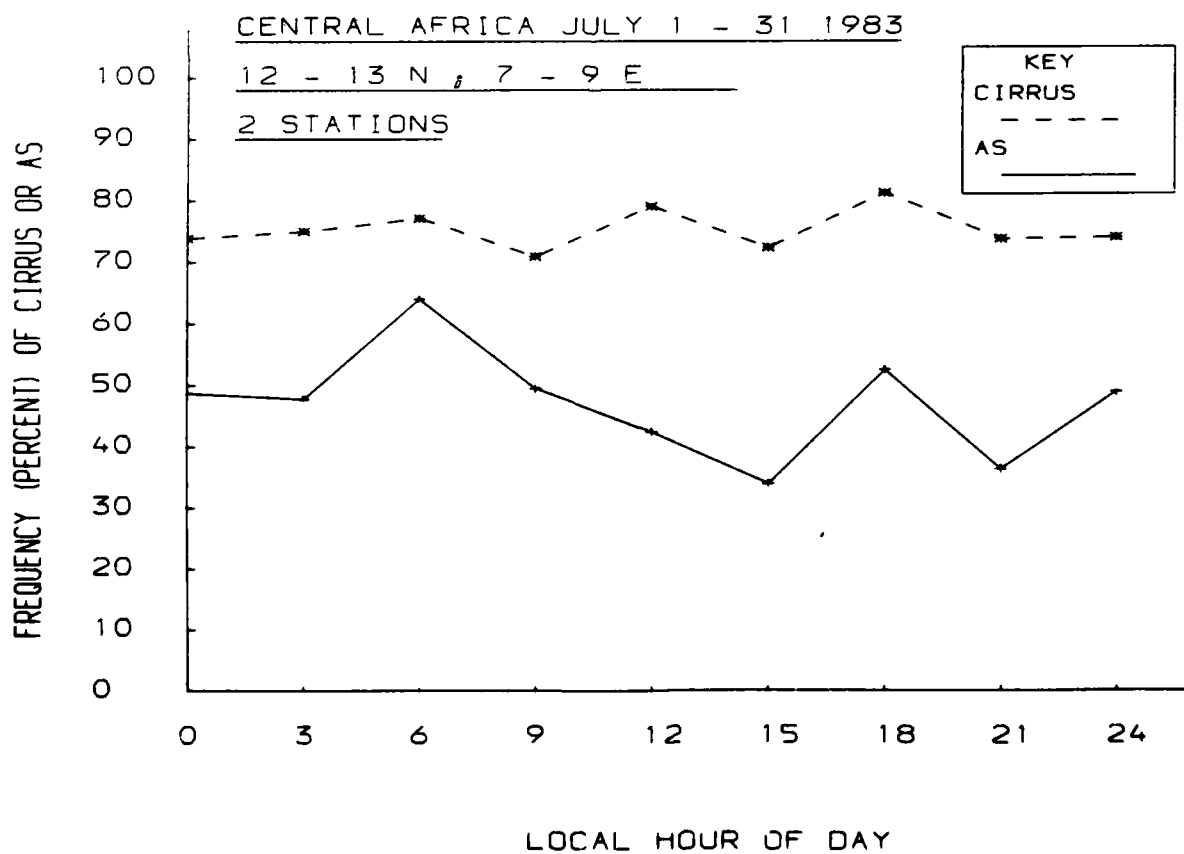
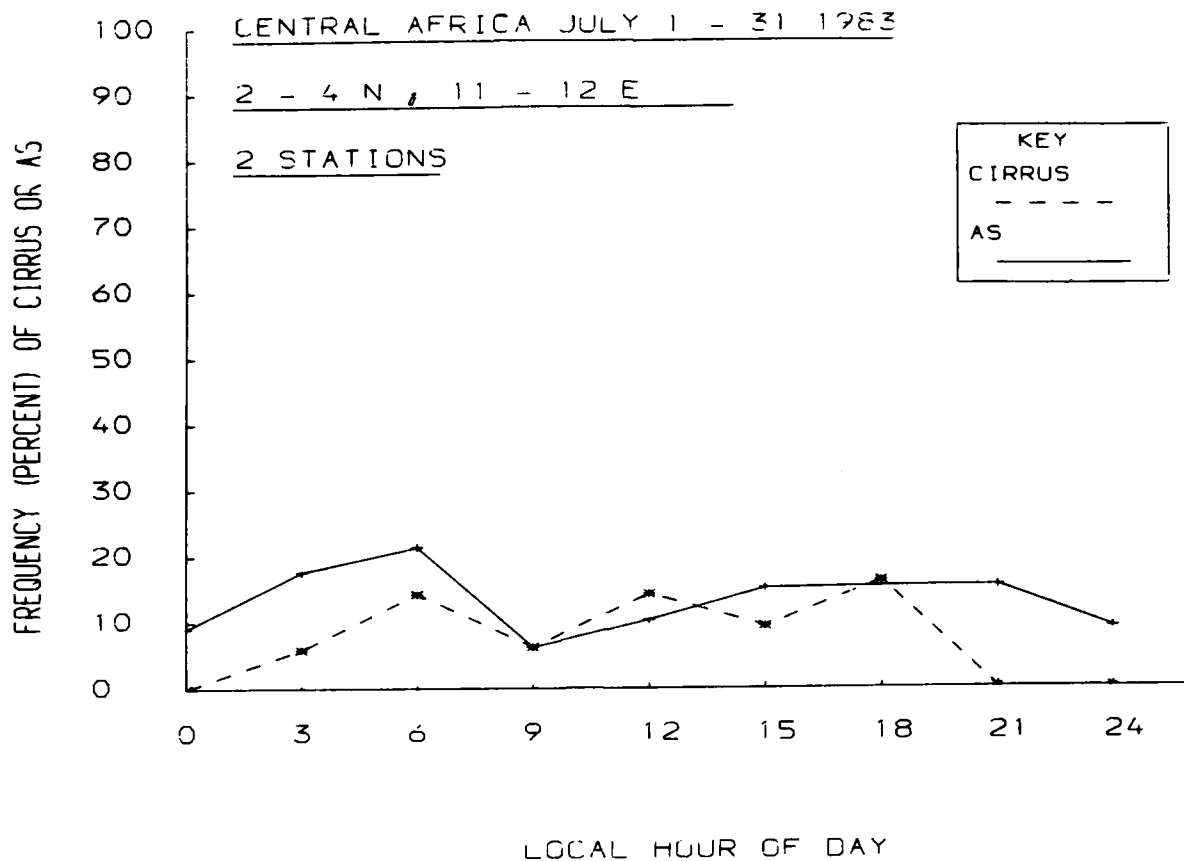


Figure 10 Diurnal variation of cirrus/altostratus over central Africa for the 2 stations within the region 12-13°N, 7-9°E for July 1983.

Figure 11 Diurnal variation of cirrus/altostratus over Scandinavia for the 1 Station situated at

69.44°N, 29.53°E for July 1983.

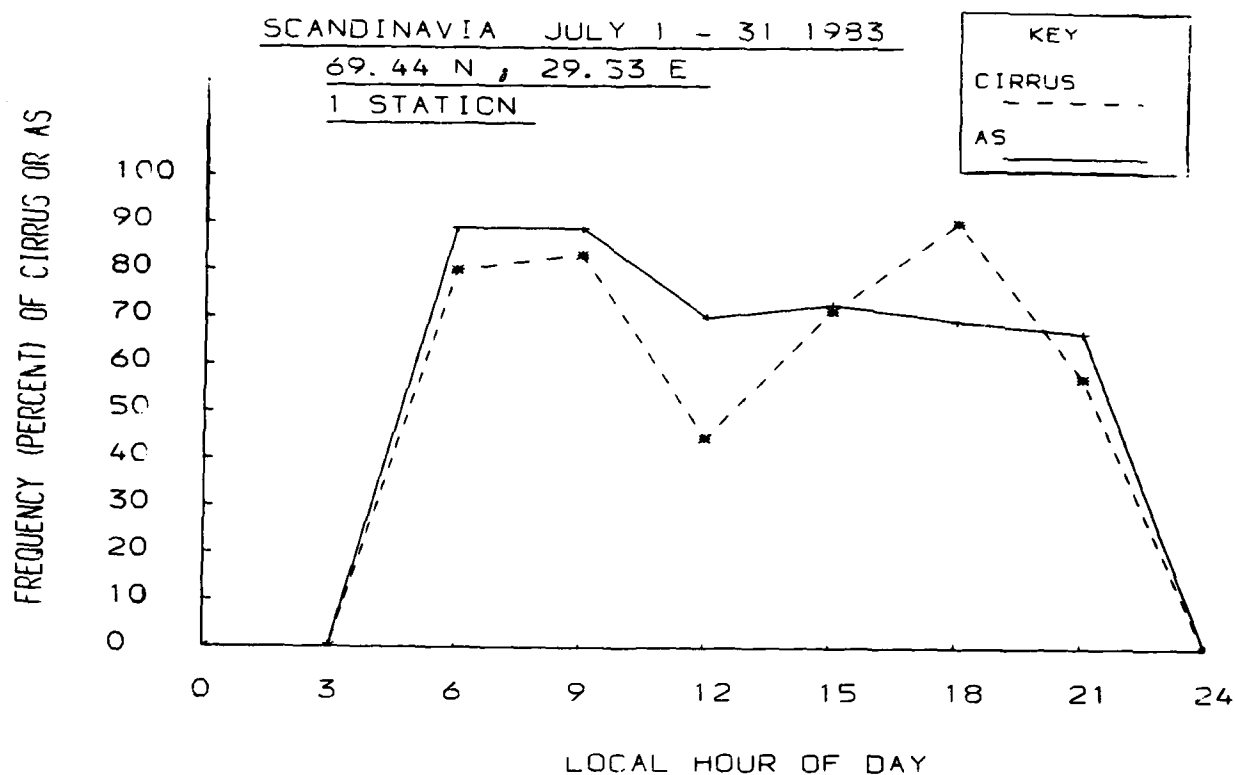


Figure 12 Diurnal variation of cirrus/altostratus over Scandinavia for the 5 stations within the region 60-62°N, 10-12°E for July 1983.

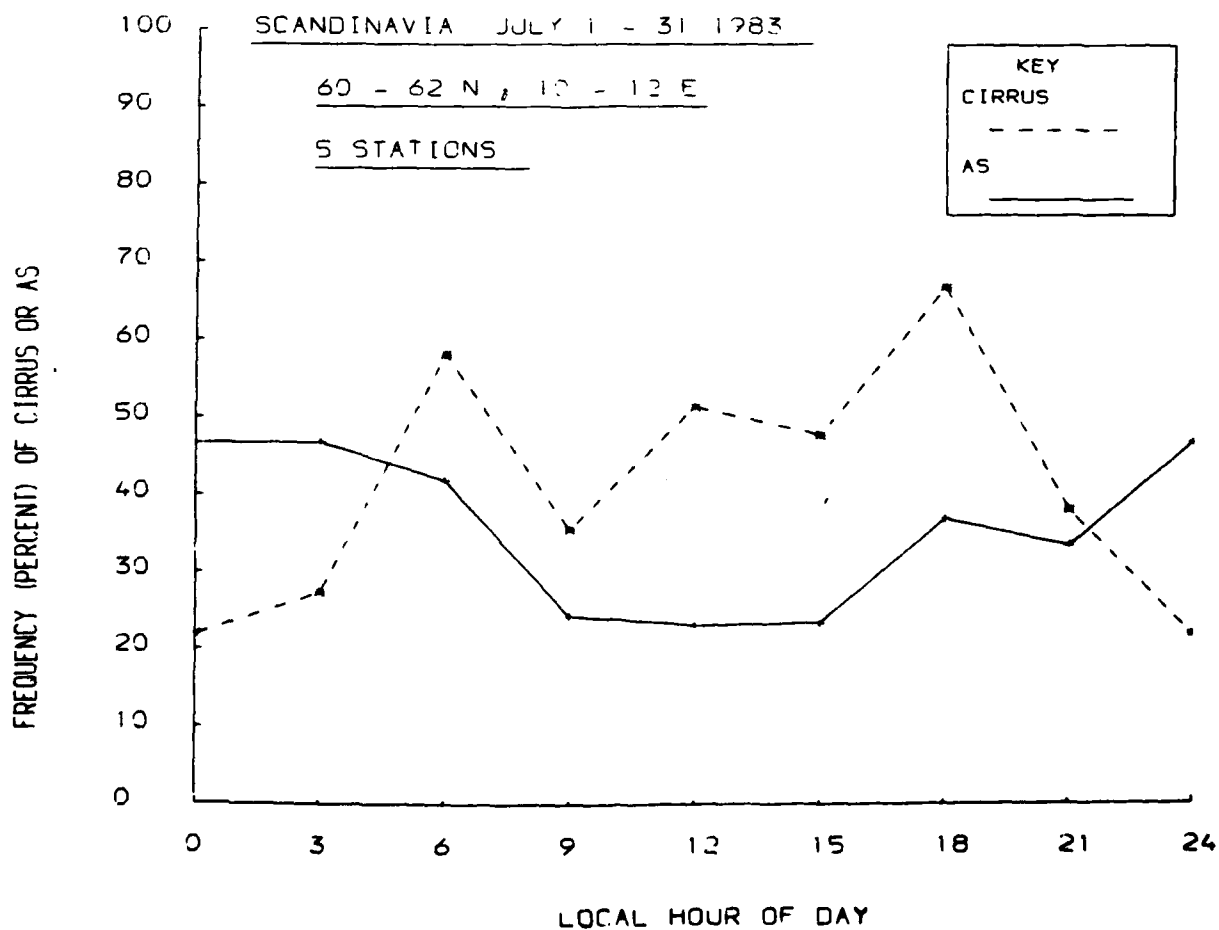


Figure 13 Diurnal variation of cirrus/altostratus over the central U.S.A for the 2 stations within the region 38-39°N, 104-105°W for July 1983.

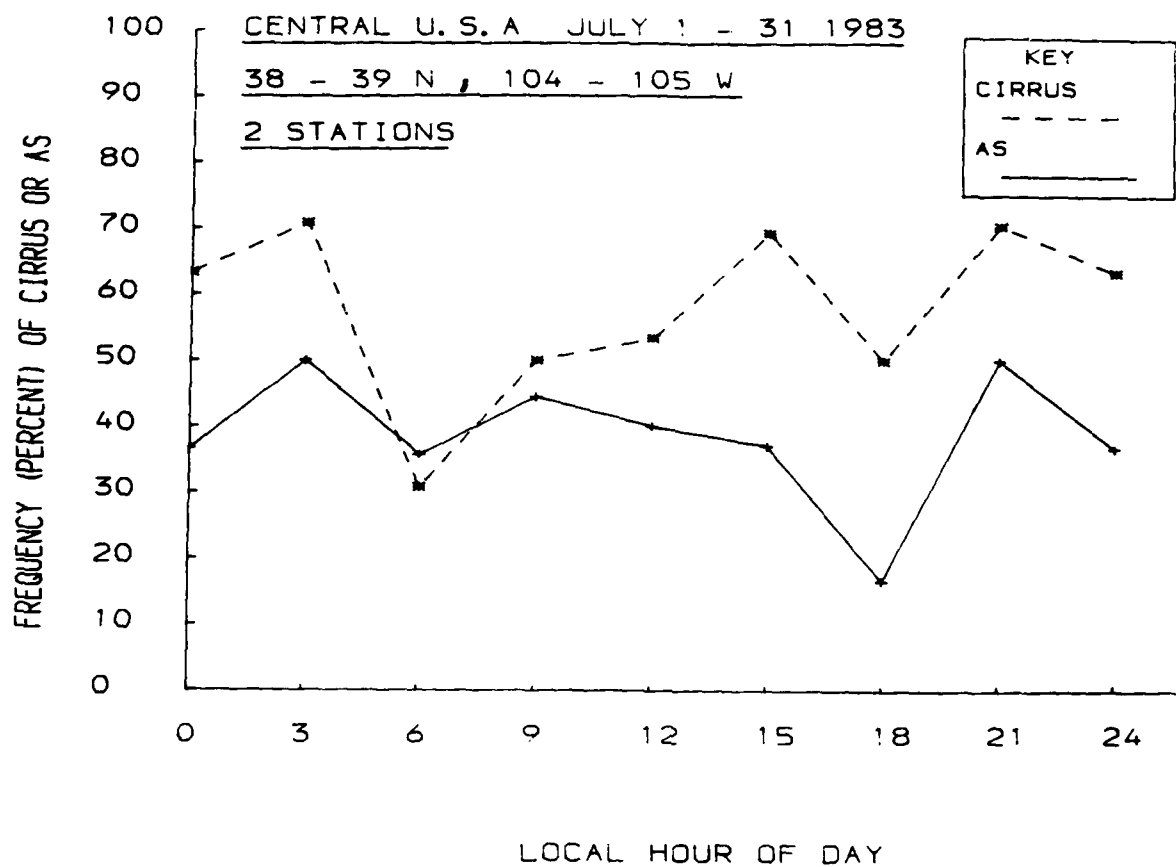
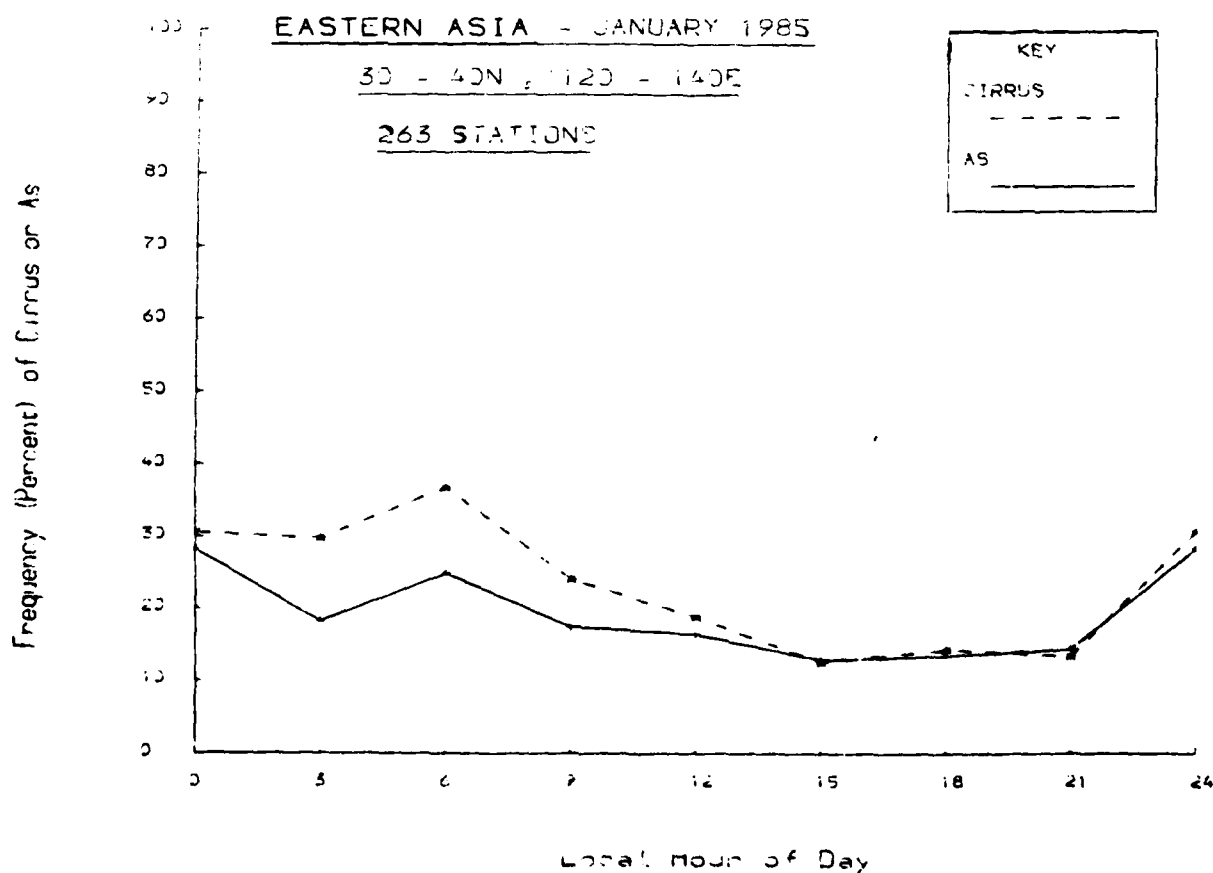


Figure 14 Diurnal variation of cirrus/altostratus over eastern Asia for January 1985.



only a couple of hours after midnight which correspond to the period of minimum frequency. The large rise in frequency between 3 am and 6 am and the corresponding fall from 9 pm to midnight are so large that it seems unlikely to be attributable entirely to natural variation. A smaller but still significant peak occurs at stations in the southern end of the Scandinavian region (Figure 13). Here the cirrus frequency increases by over 30% from 3 am to 6 am whilst the altostratus trace is similar to the larger scale plot, again suggesting that the influence of nighttime bias may be more noticeable at smaller scales.

The analyses for January 1985 are similar to those for July 1983, in that the results reveal little about bias effects, the cirrus curves exhibiting only small diurnal ranges (Figures 15 to 17). The exception is in Scandinavia (Figure 18) which shows pronounced peaks, particularly for cirrus, during the short period of daylight. Exactly how much of this variation could be accounted for by the observer's inability to detect nocturnal cirrus is not certain. The increase in cirrus/altostratus frequency between 6 am and 9 am is reflected in the local results in Figures 19 to 21 which all show well defined peaks at either 9 am or midday.

As with July the plots for local data show enhanced diurnal variability. The sharp peak found at the African station (Figure 22) depicts an increase in cirrus frequency of some 40% from darkness at 3 am to early morning at 6 am. Similar sharp peaks between 3 am and 6 am are found in eastern Asia (Figures 25 and 26) but in each case these are preceded by significant decreases in frequency between midnight and 3 am. In any event these changes are likely to be the result of natural changes, there being little or no daylight at 6 am over the region concerned.

### *2.5 Other Methods of Detecting Nighttime Bias*

Alternative methods by which nighttime bias might be detected were considered. Examination of diurnal analyses of middle or high cloud amount was one possibility. The likelihood exists that if night detection bias is seriously influencing surface observation, then the amounts of cirrus and altostratus are underestimated, whether the observer actually sees the cloud or not, for he is

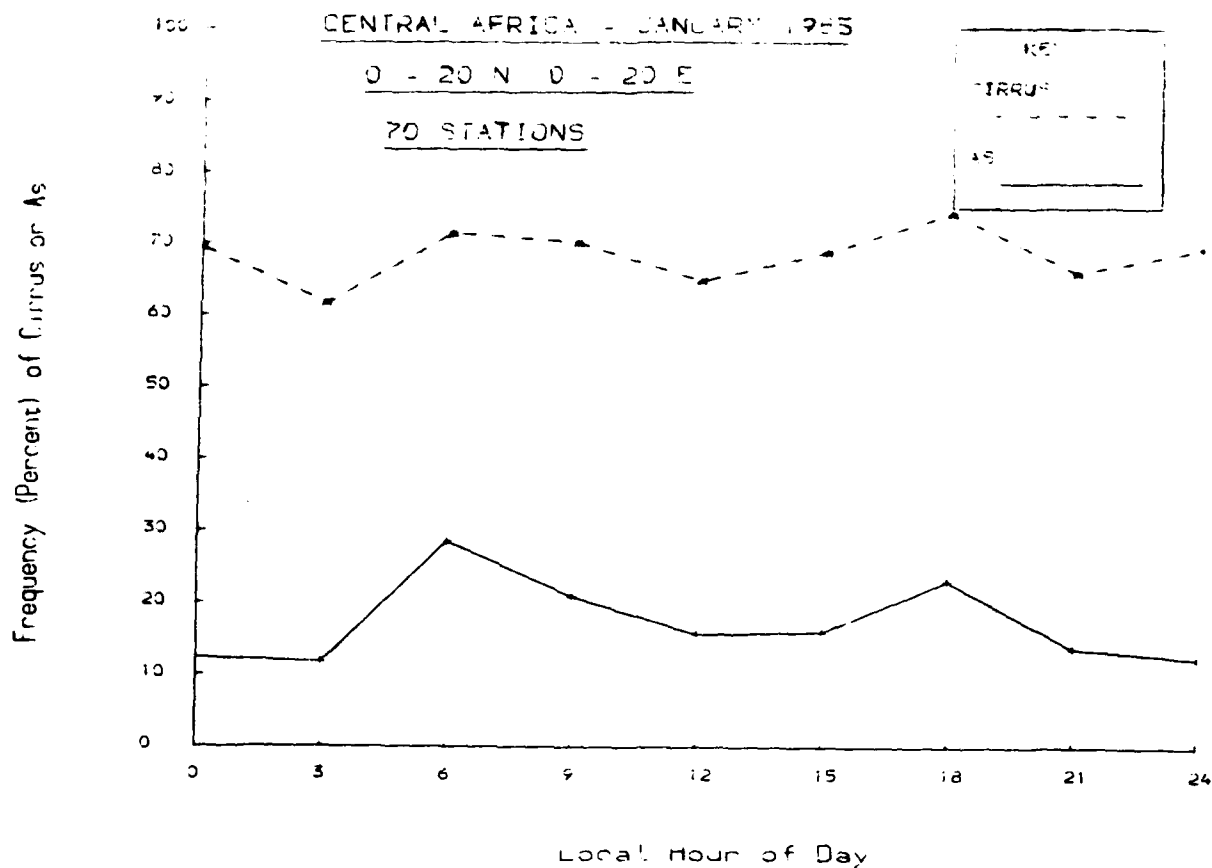


Figure 15 Diurnal variation of cirrus/altostratus over central Africa for January 1985.

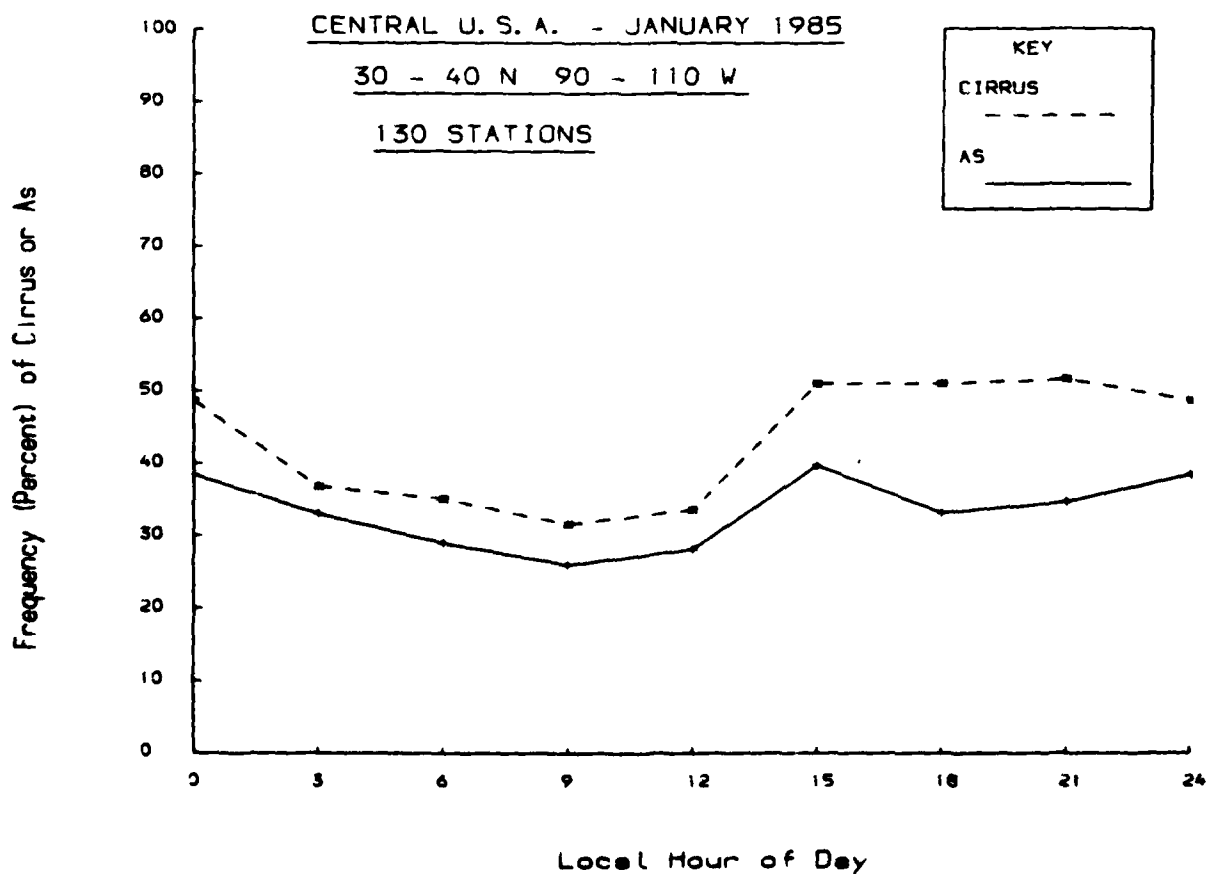


Figure 16 Diurnal variation of cirrus/altostratus over the central U.S.A for January 1985.

Figure 17 Diurnal variation of cirrus/altostratus over Scandinavia for January 1985.

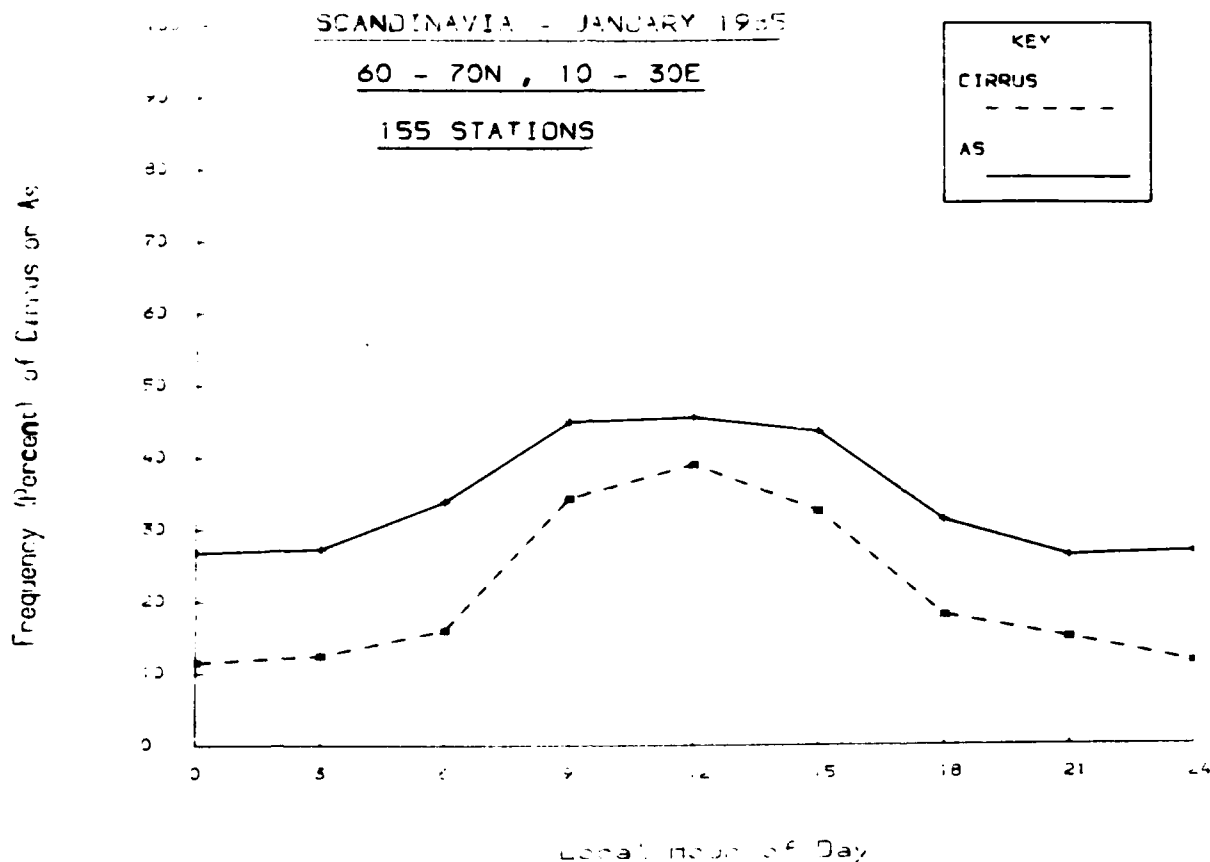


Figure 18 Diurnal variation of cirrus/altostratus over Scandinavia for the 2 stations within the region 68-70°N, 28-30°E for January 1985.

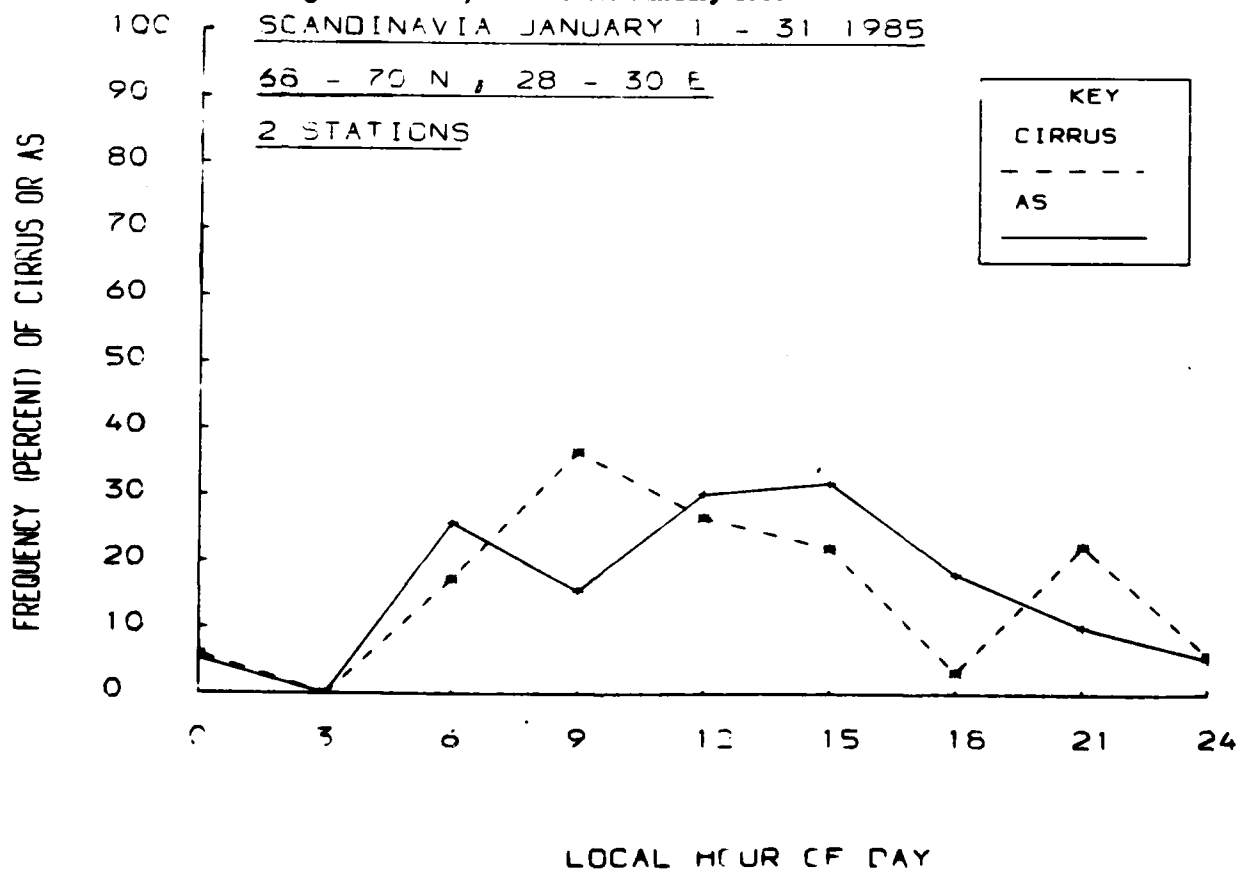


Figure 19 Diurnal variation of cirrus/altostratus over Scandinavia for the 4 stations within the region 60-62°N, 28-30°E for January 1985.

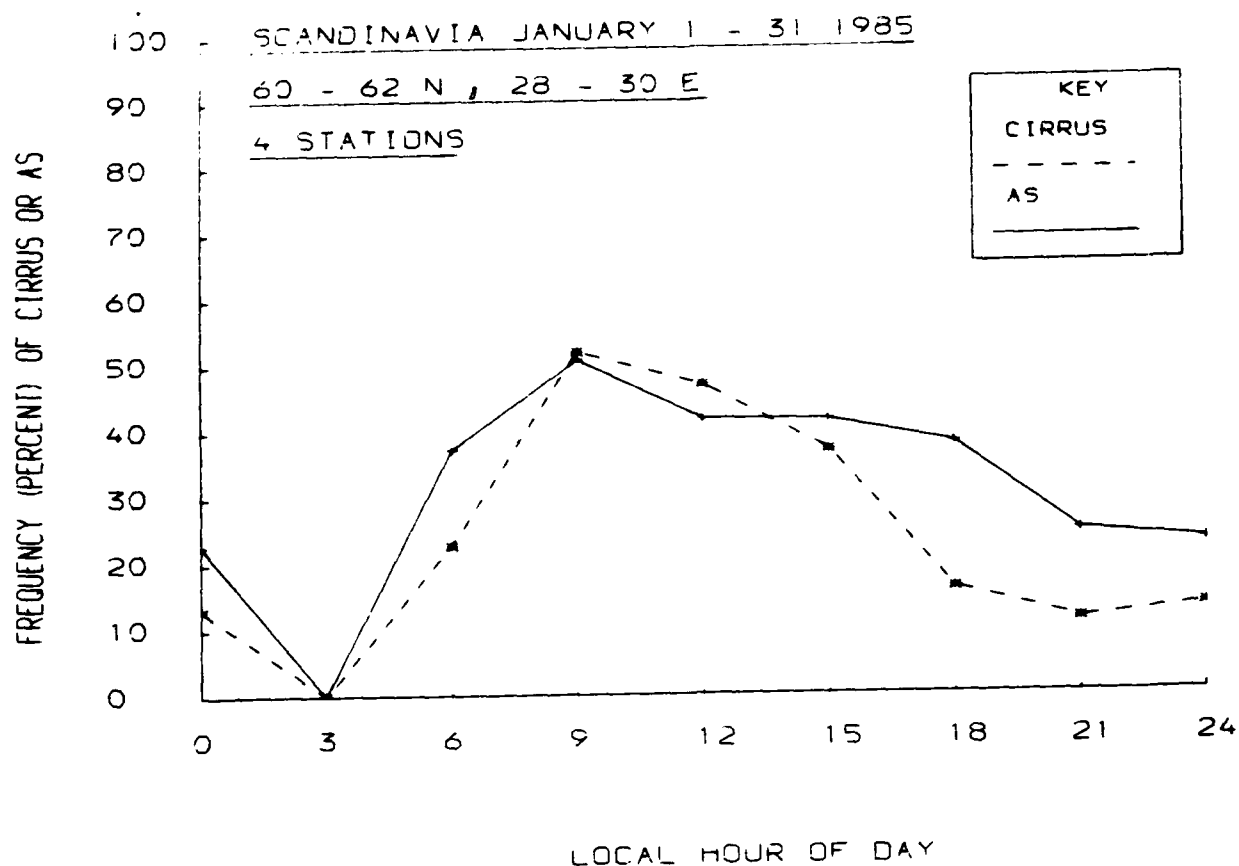
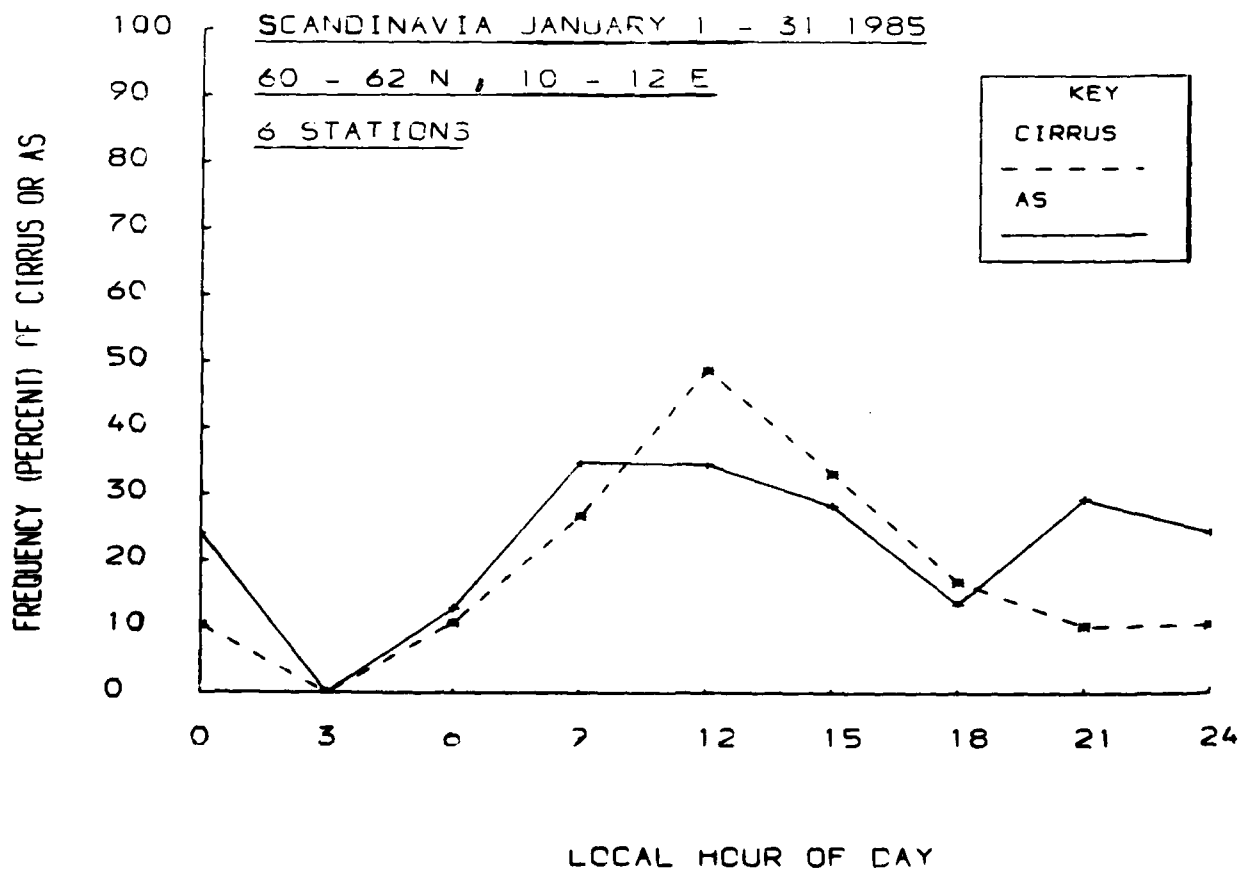


Figure 20 Diurnal variation of cirrus/altostratus over Scandinavia for the 6 stations within the region 60-62°N, 10-12°E for January 1985.



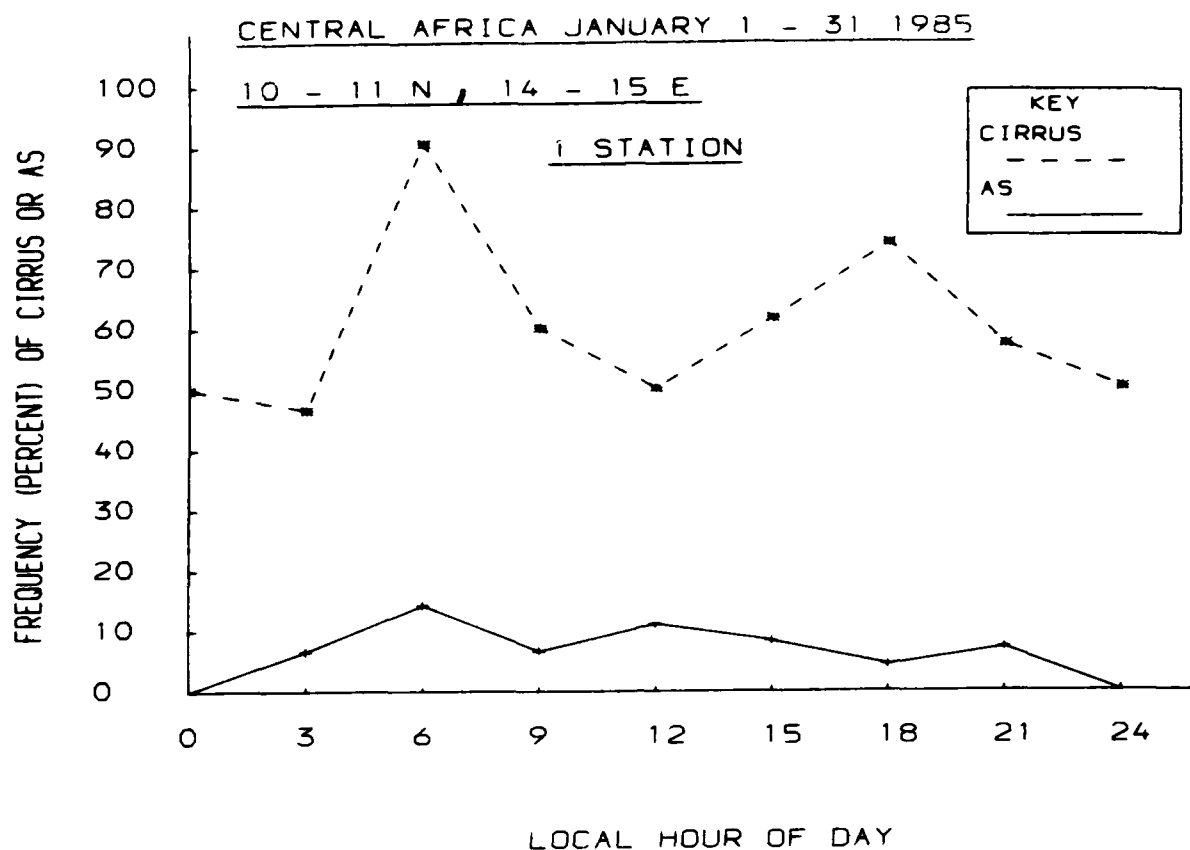


Figure 21 Diurnal variation of cirrus/altostratus over central Africa for the 2 stations within the region 2-4°N, 11-12°E for January 1985.

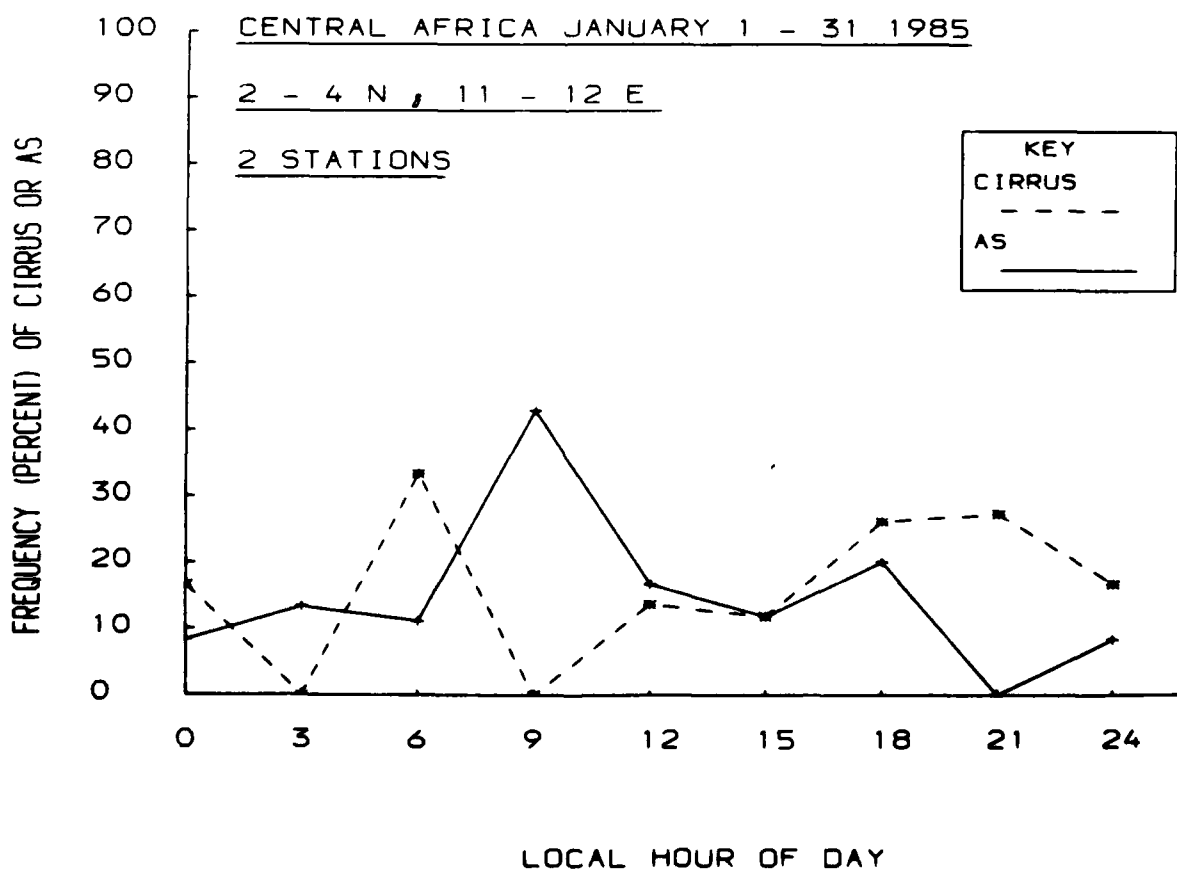


Figure 22 Diurnal variation of cirrus/altostratus over central Africa for the 1 station within the region 10-11°N 14-15°E for January 1985

the region 38-39°N, 93-95°W for January 1985.

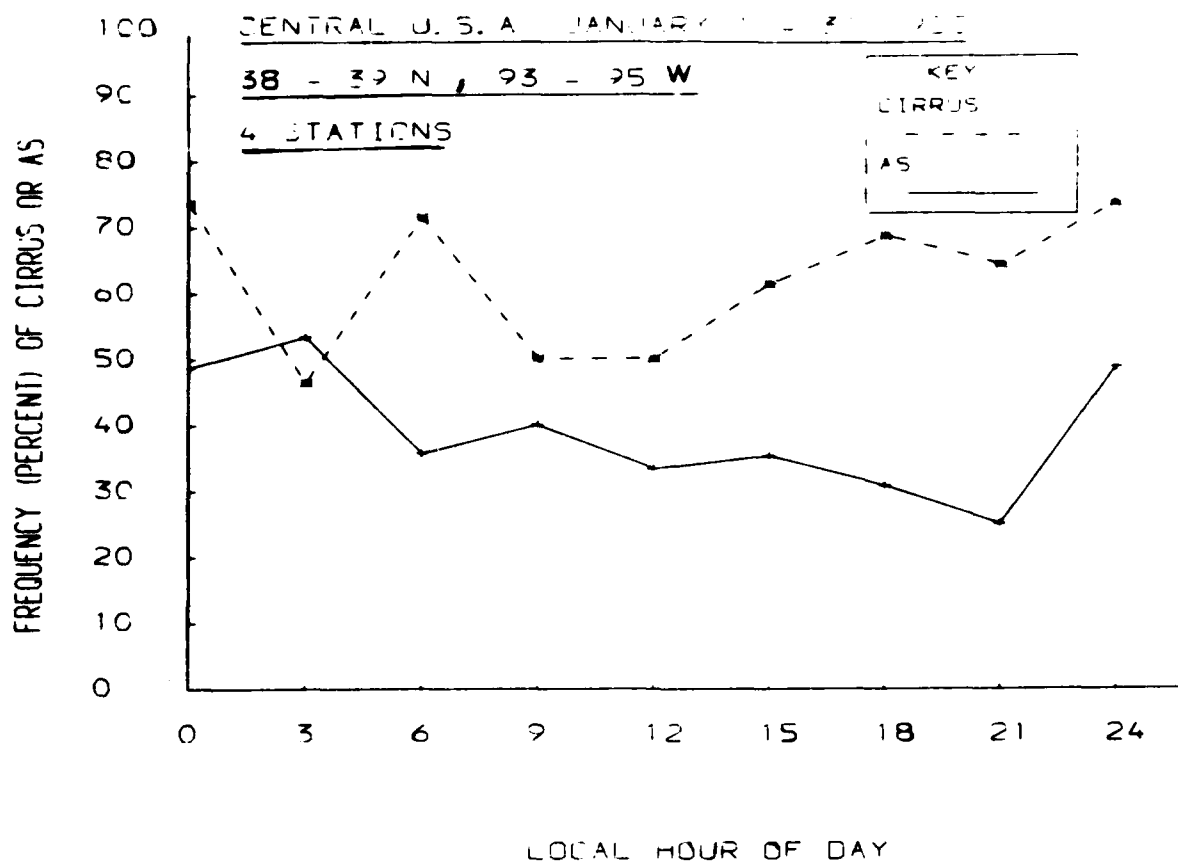


Figure 23 Diurnal variation of cirrus/altostratus over the central U.S.A for the 4 stations within the region 38-39°N, 104-105°W for January 1985.

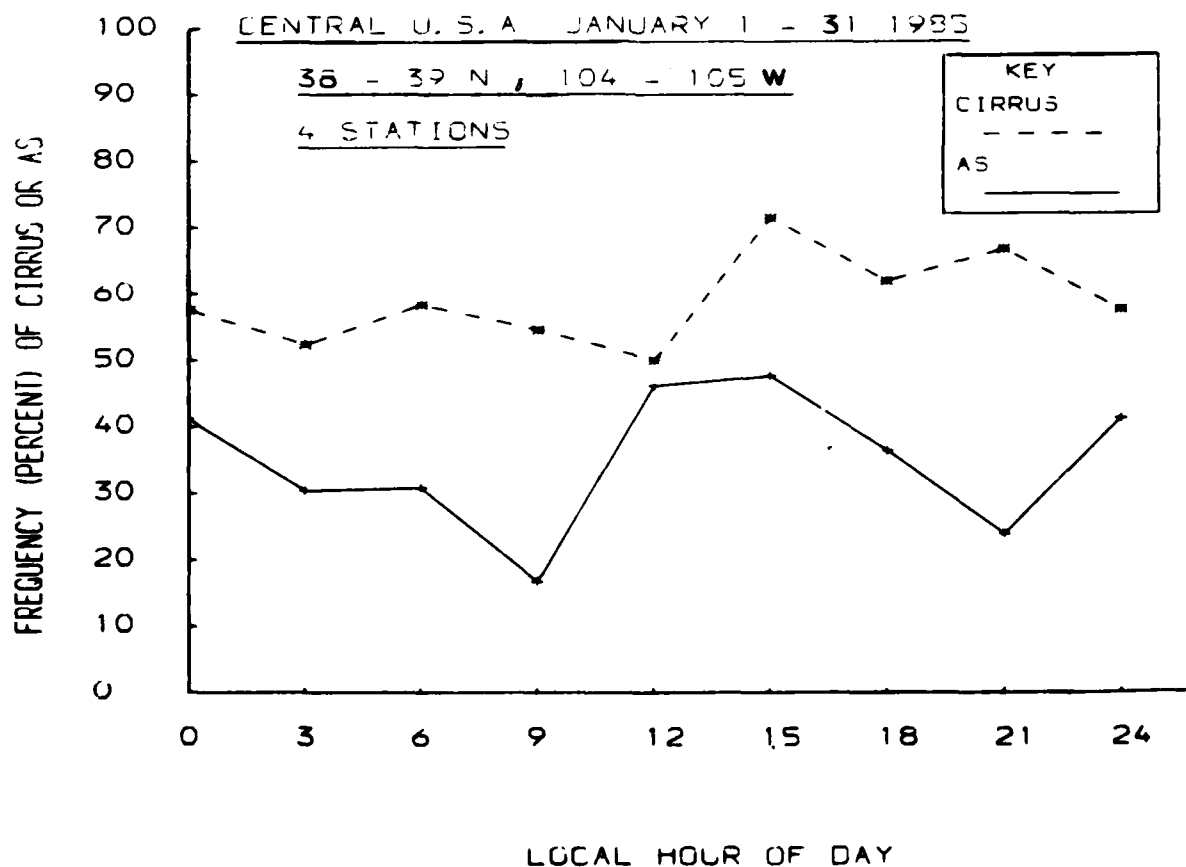


Figure 25 Diurnal variation of cirrus/altostratus over eastern Asia for the 2 stations within the region 31-33°N, 120-122°E for January 1985.

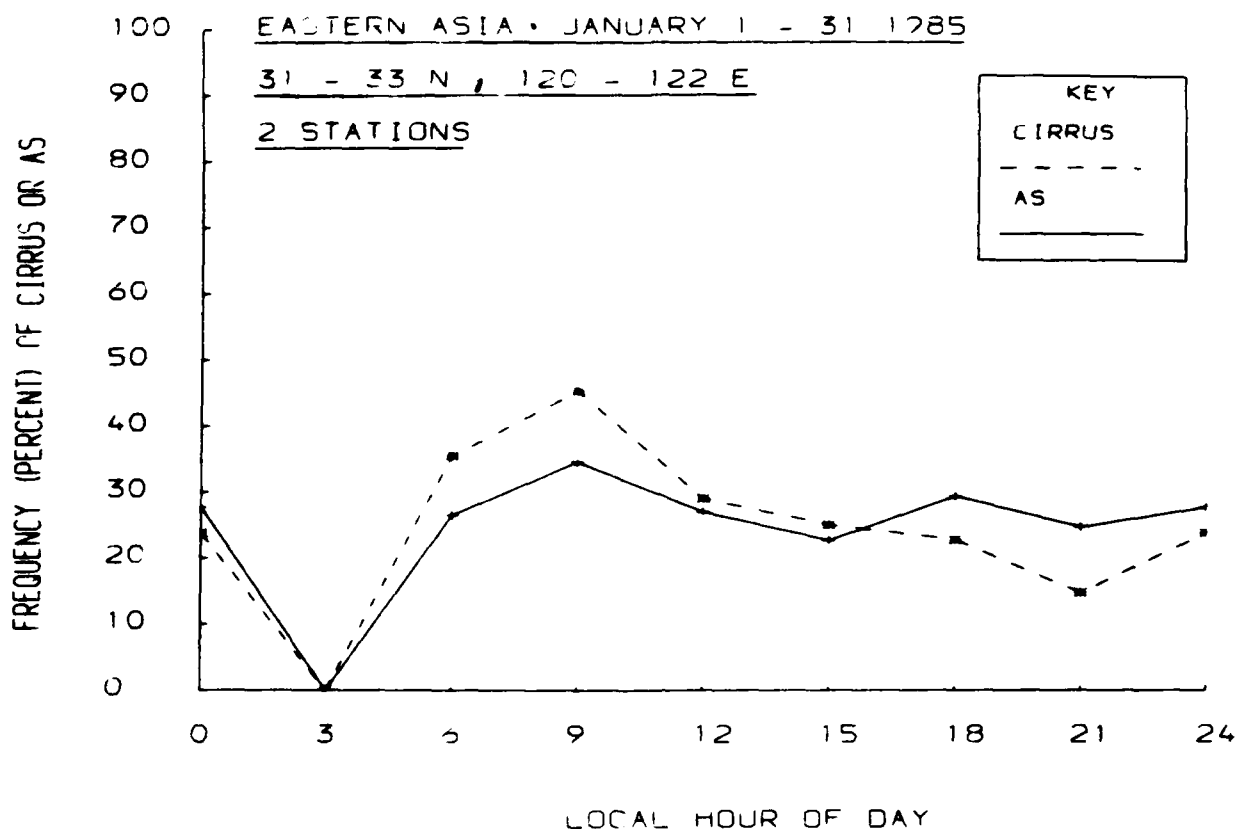
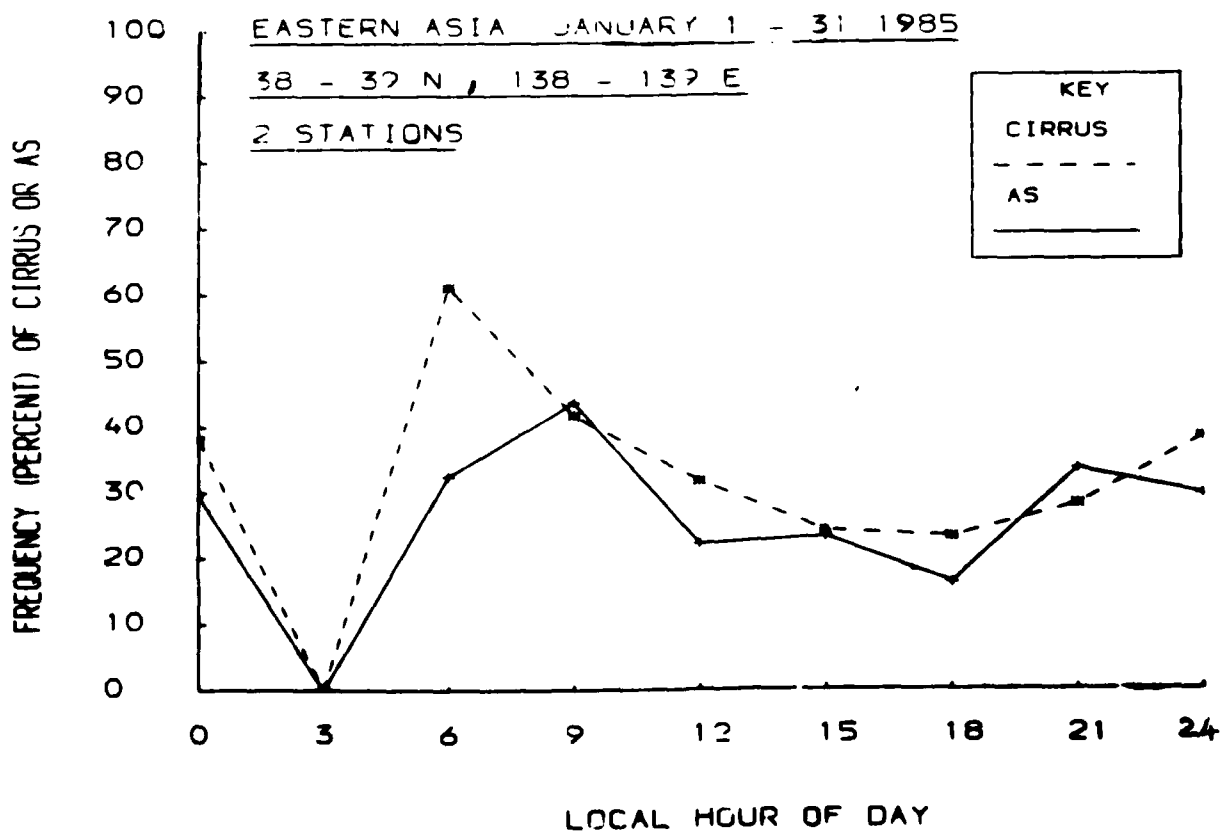


Figure 26 Diurnal variation of cirrus/altostratus over eastern Asia for the 2 stations within the region 38-39°N, 138-139°E for January 1985.



unlikely to detect all that is present. If a representative comparison could be made between long term climatological data and the data used in this exercise, then anomalously low values of the diurnal mean cirrus/altostratus amount during the day or at sunrise/sunset would indicate the likely presence of bias. Recent work by Warren *et al.* (1986) includes global maps of the mean cirrus amount for four consecutive 3-monthly periods for the years 1971-1981. The values are presented as both time-averaged amounts and mean amounts for all the occasions when cirrus was observed. Unfortunately, the maps were produced from data taken between 6-18 hours local time specifically to preclude observations in darkness, thus eliminating any nighttime bias contamination and rendering comparison here impossible.

Hahn *et al.* (1982, 1984), in producing their maps describing the global distribution of cloud type occurrence and the simultaneous occurrence of cloud type combinations, introduced the idea of contingency probabilities to express the likelihood that given the presence of one cloud type another type would be present. The exclusive probability was introduced as a modification of this idea, expressing the chance of a particular type being observed by itself. Recognition of clouds by an observer is naturally easiest when there is only one type present. Therefore the diurnal change of the exclusive probability for cirrus and altostratus was compiled for both months of data for the aforementioned areas in order to discern any distinguishing anomalies during the daylight hours suggestive of bias influence. These graphs are illustrated in Figures 27 to 34. The exclusive probabilities were determined only from reports containing information about all cloud levels, i.e. a report of stratus overcast would be discarded from the computations since all levels must be 'observable'.

The results illustrate a variety in the behaviour of the exclusive probabilities throughout the day but interpretation is made difficult by the lack of comparative data. In July over Africa and Scandinavia there is a pronounced drop from dawn to midday a result partially due to convection over the relatively warm land producing cumuliform cloud and reducing the chance of observing

Figure 27 Diurnal variation of the exclusive probabilities for cirrus and altostratus over Scandinavia for July 1983.

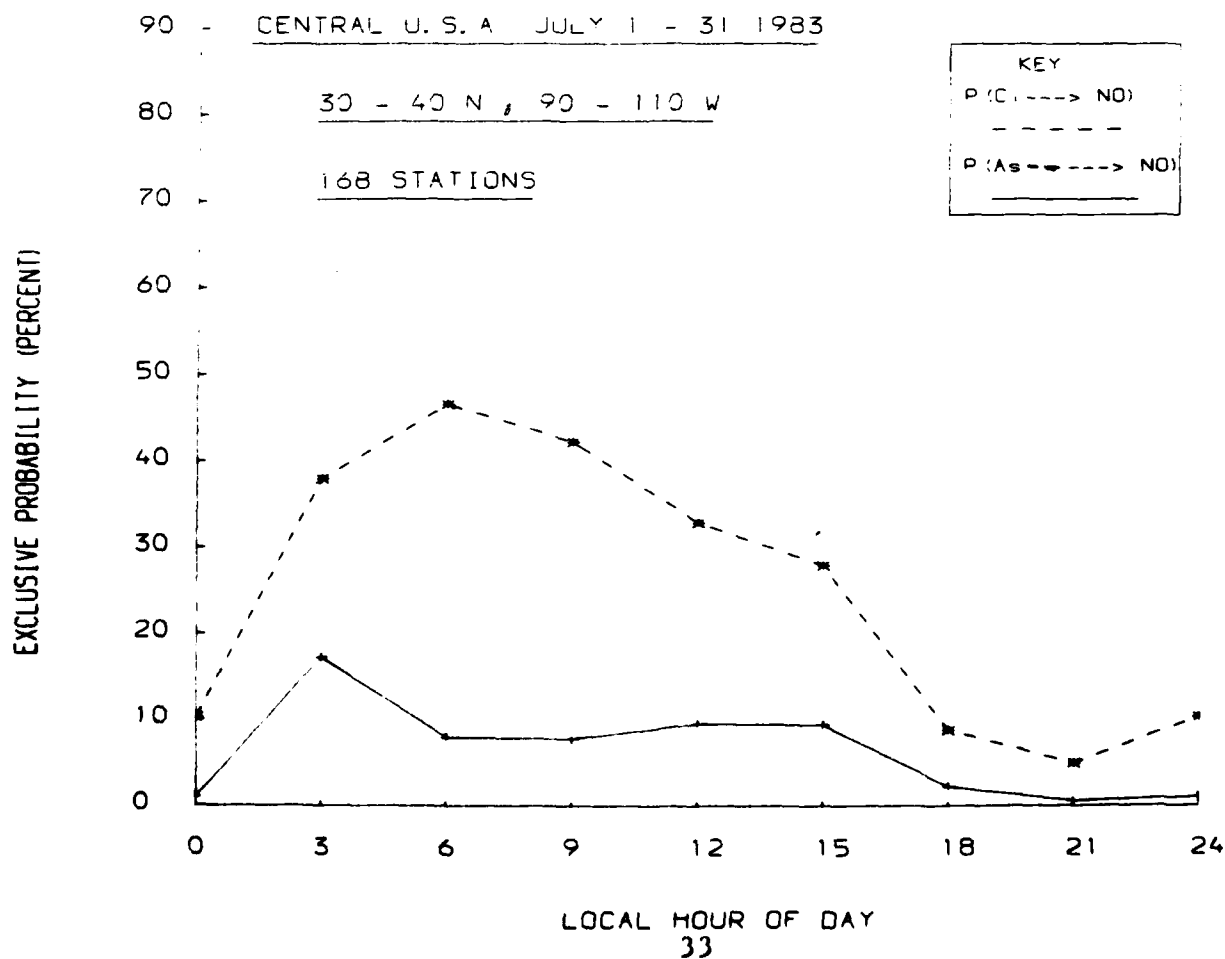
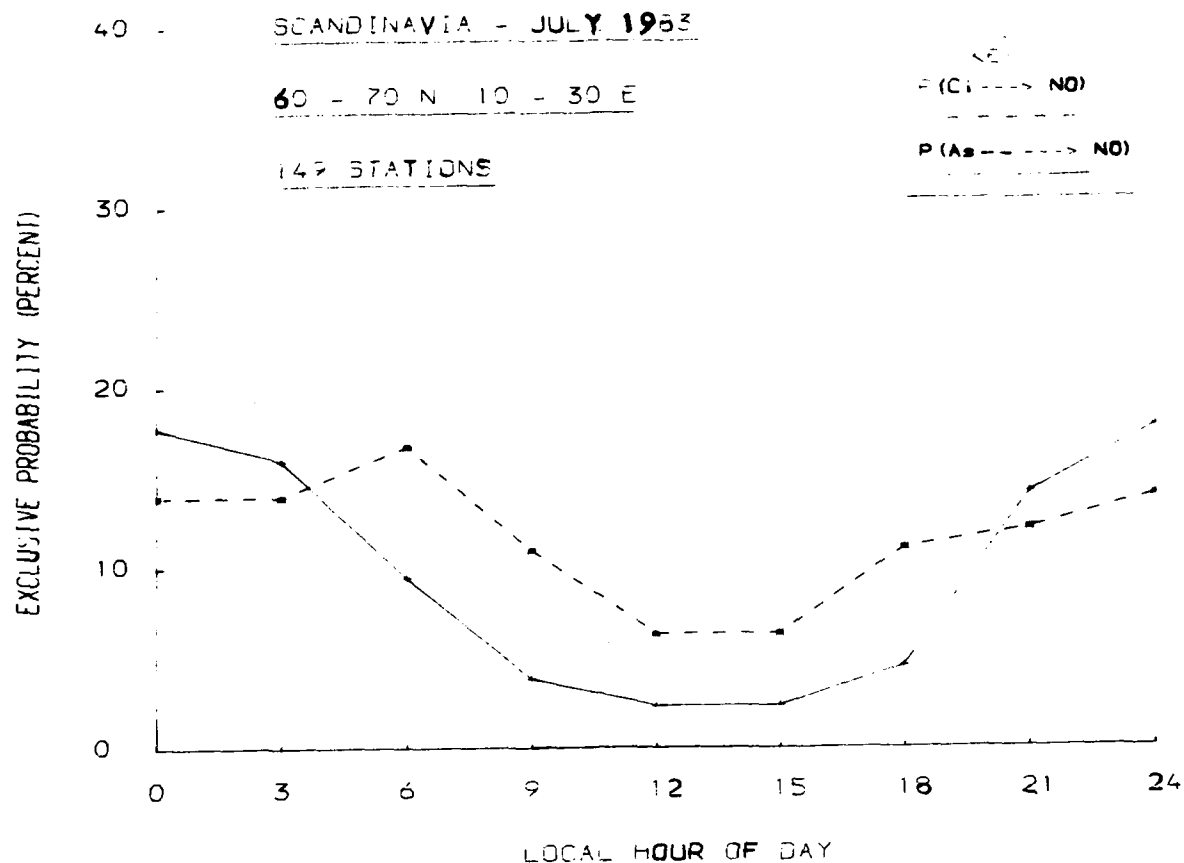


Figure 28 Diurnal variation of the exclusive probabilities for cirrus and altostratus over the central U.S.A for July 1983.

**Figure 29** Diurnal variation of the exclusive probabilities for cirrus and altostratus over central Africa for July 1983.

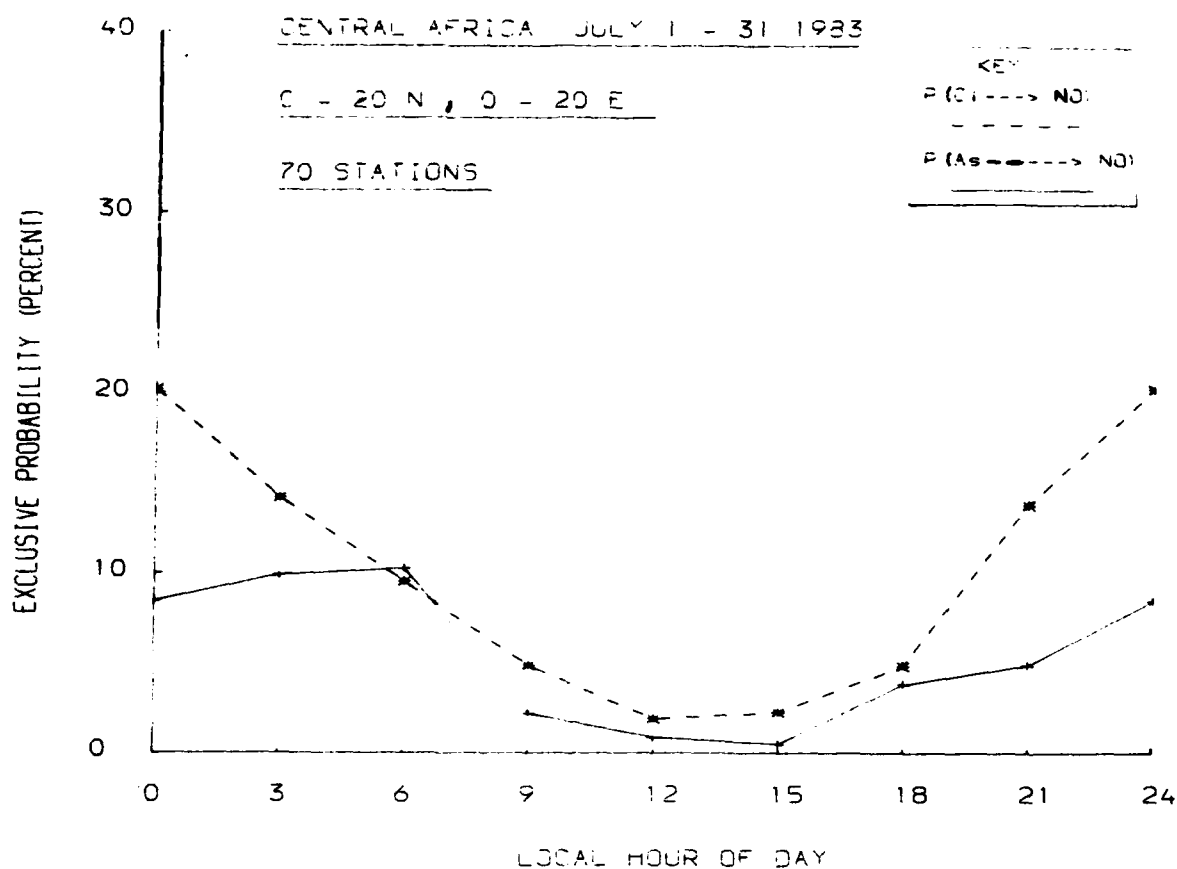
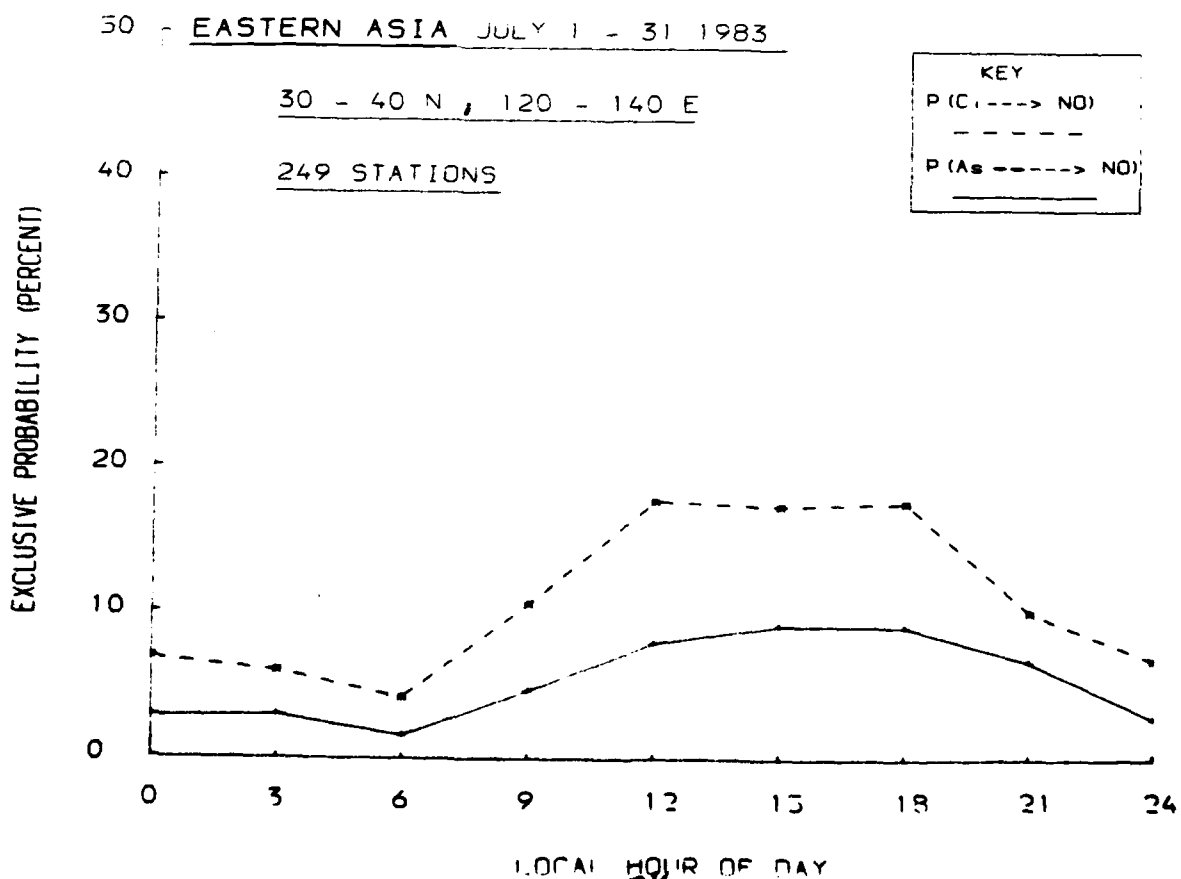


**Figure 30** Diurnal variation of the exclusive probabilities for cirrus and altostratus over eastern Asia for July 1983.



for January 1985.

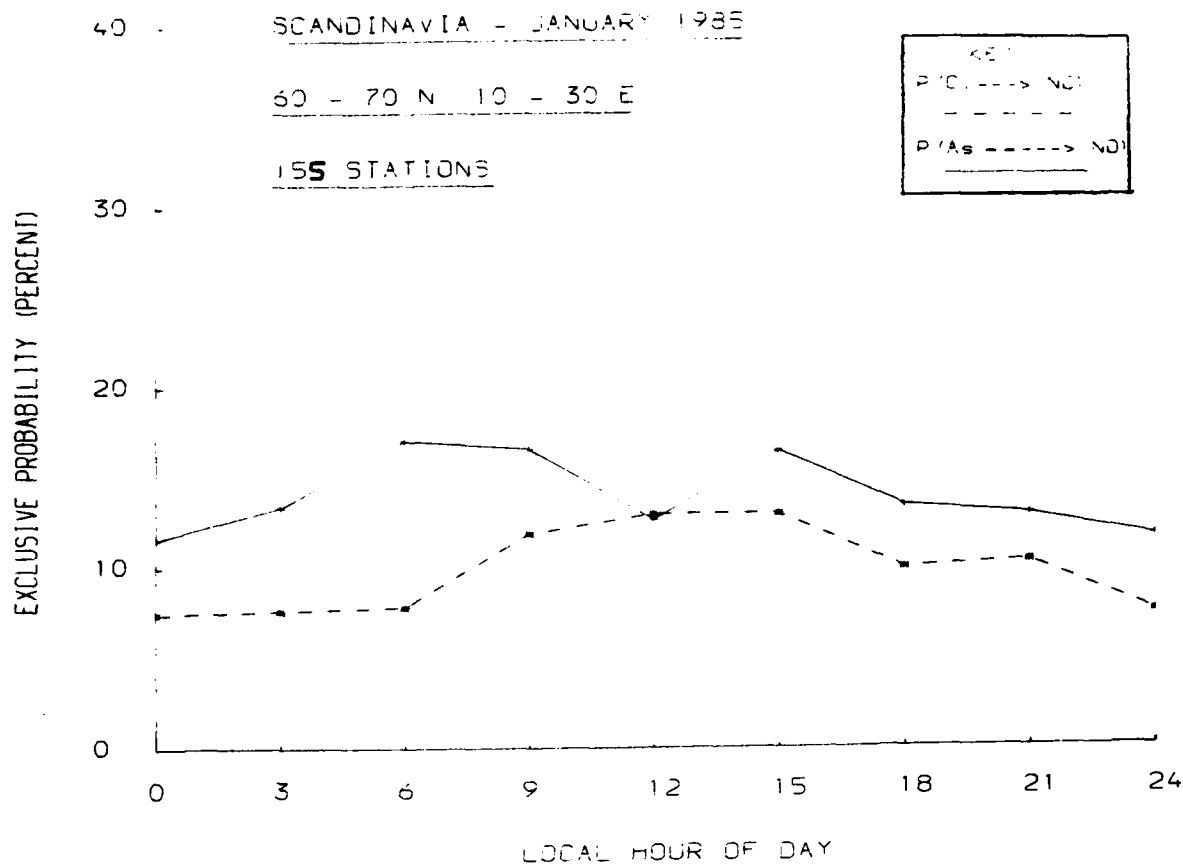


Figure 32 Diurnal variation of the exclusive probabilities for cirrus and altostratus over the central U.S.A for January 1985.

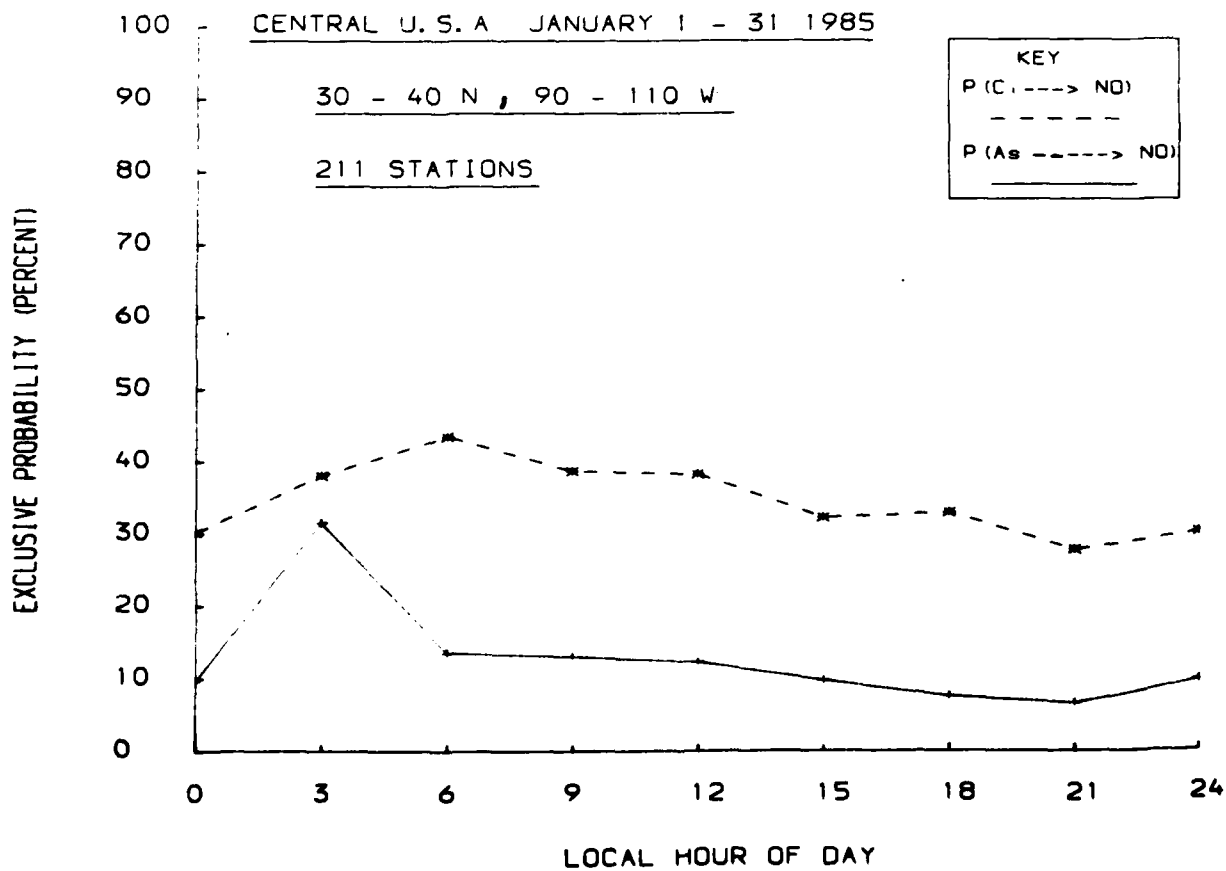


Figure 33 Diurnal variation of the exclusive probabilities for cirrus and altostratus over central Africa for January 1985

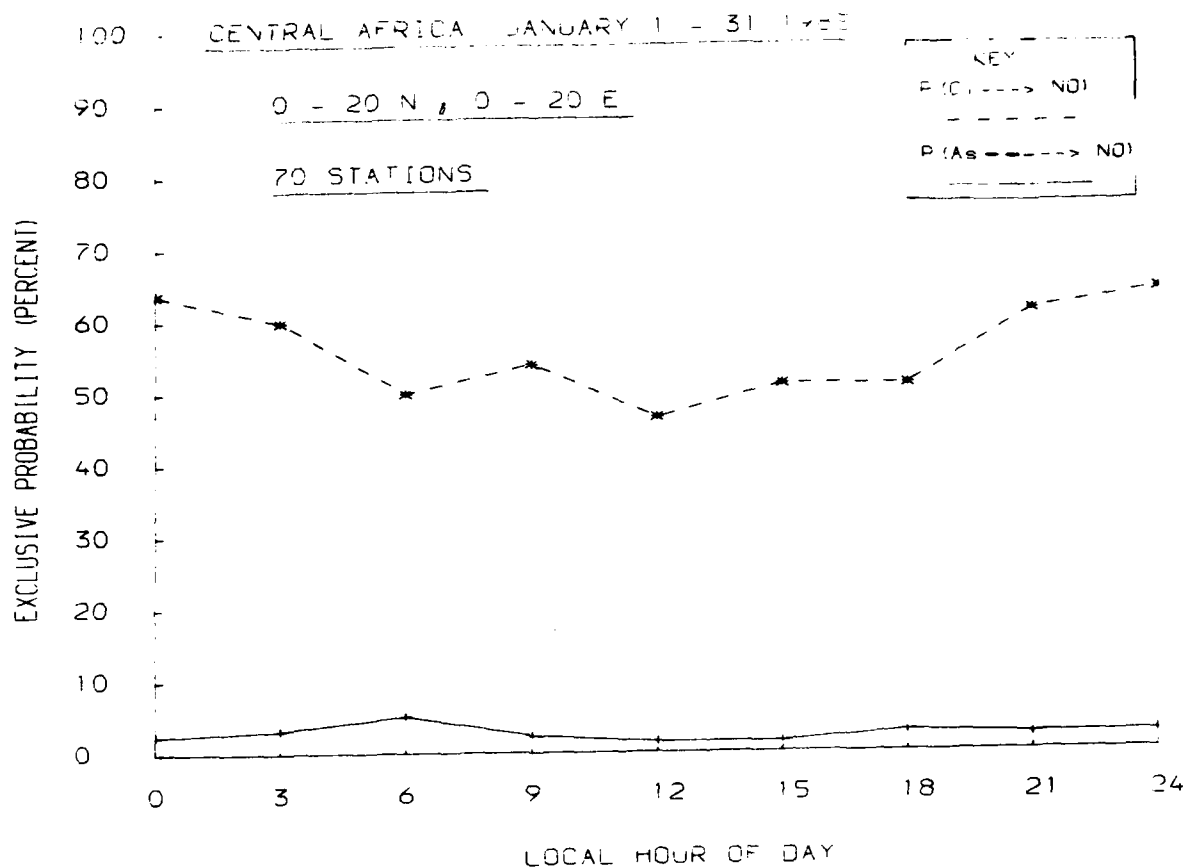
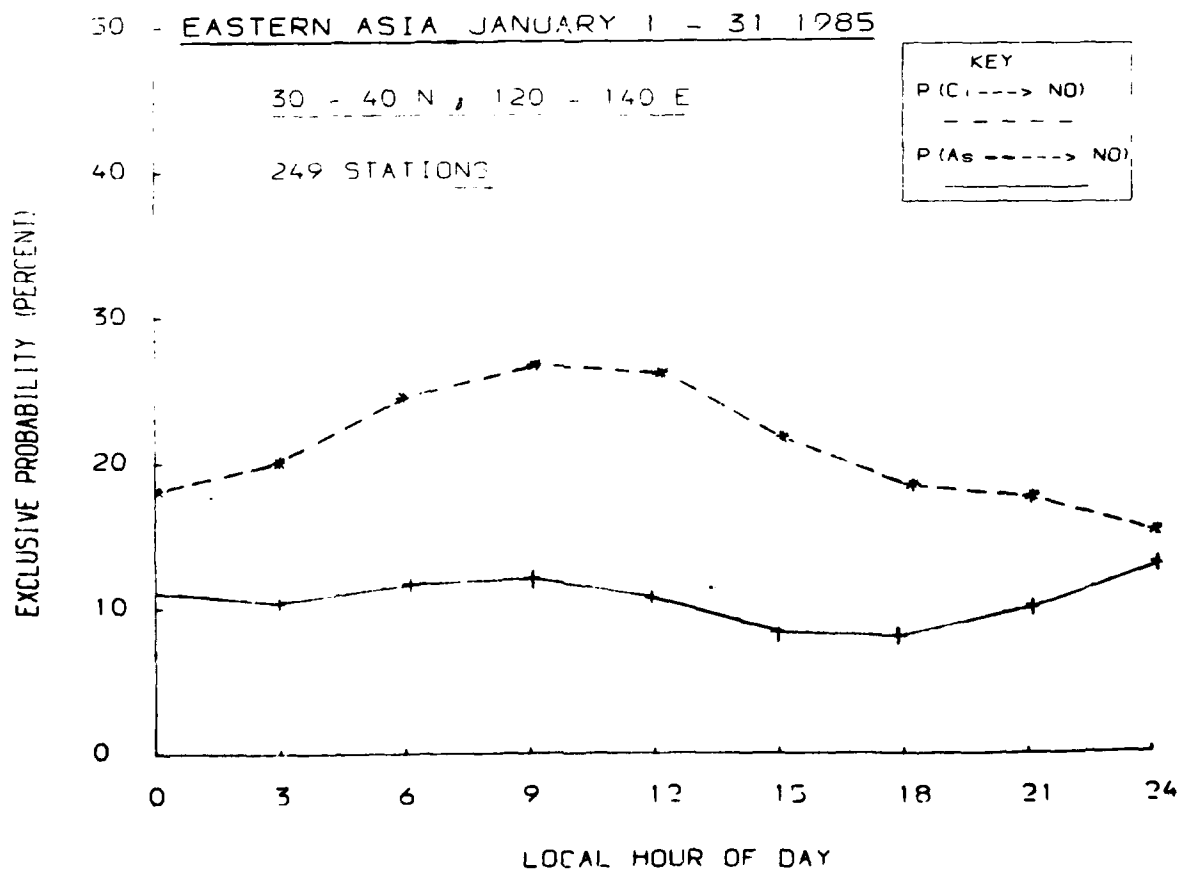


Figure 34 Diurnal variation of the exclusive probabilities for cirrus and altostratus over eastern Asia for January 1985



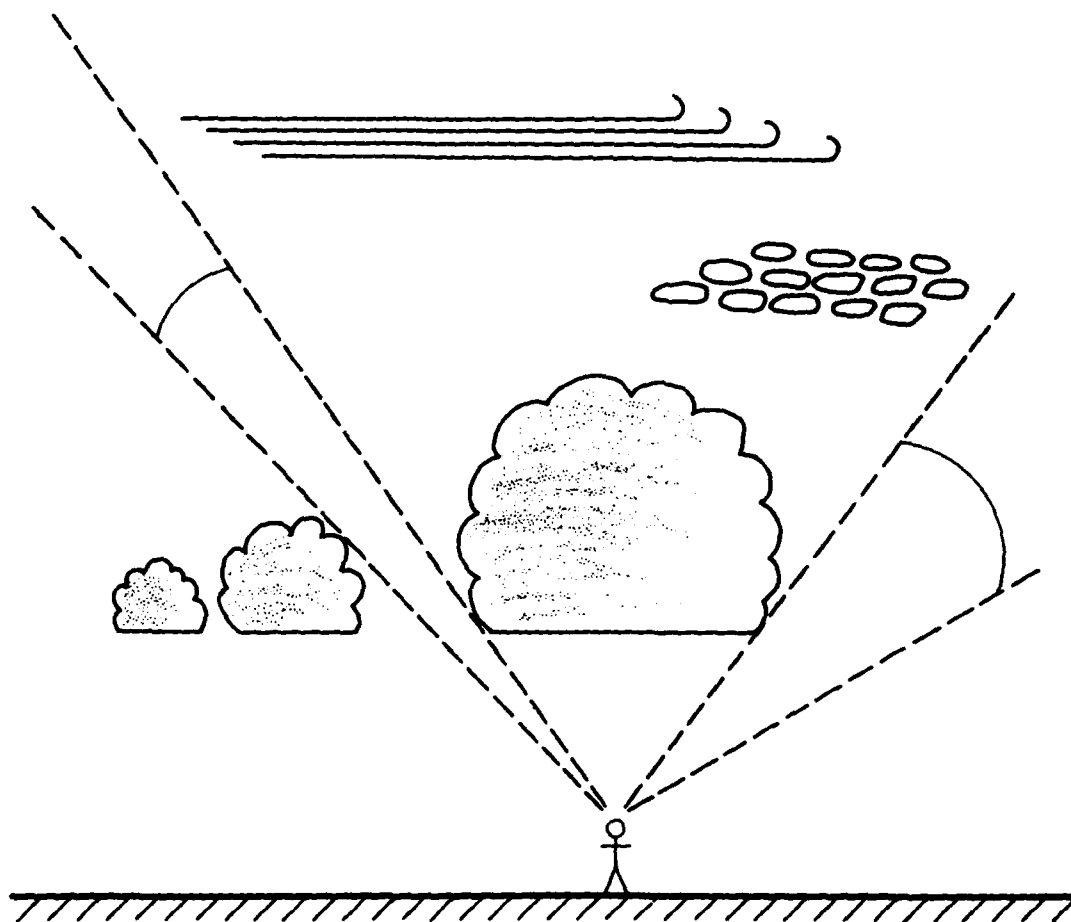
cirrus or altostratus by itself. Over the central U.S. much of the peak at 6 am is gained during darkness hours and is therefore probably not due to observer error. Over eastern Asia, however, in a region likely to experience convective cloud from the summer monsoon, the broad peak for cirrus is conspicuous although the rise it represents is only of the order of 10%. The data from January are of limited value although an interesting feature is how the shape of the curves over Scandinavia resembles the corresponding frequency curves. Here, however, the peaks are considerably smaller and consequently less significant.

Recent developments in satellite cloud retrieval permitted cirrus to be accurately detected during darkness (Inoue, 1985; Saunders, 1986; Saunders and Kriebel, 1987) from polar orbiting radiance data. Further insight into the impact of nocturnal bias may be possible from satellite/surface comparisons using these new algorithms.

#### *2.6 The Use of Contingency Probabilities for Situations of Partial Undercast Bias*

The term partial undercast bias (PUB) (Hahn *et al.*, 1984; Warren *et al.*, 1986) refers to a situation when an observer fails to detect the presence of middle or upper level clouds because they are obscured by a (non-overcast) lower layer and do not overlap into the clear region of the sky (Figure 35). The likelihood of incurring PUB increases as the amount of the non-overcast obscuring layer increases and such an occurrence repeated many times leads to a systematic underestimate in the frequency of occurrence of middle and upper clouds. This, in turn, is likely to reduce the quality of surface-based cloud climatologies.

The use of contingency probabilities in such cases has been suggested as a means of avoiding PUB in surface retrievals where they would be employed by the observer whenever PUB was suspected. Specifically, two types of probability have been defined. The first defines the likelihood that given the presence of a lower cloud L upper cloud U is also present and is denoted by  $P(L \Rightarrow U)$ . A second type of probability is simply the opposite of  $P(L \Rightarrow U)$  termed  $P(U \Rightarrow L)$ . The latter type is seen as a possible means of using surface observations to aid satellite retrievals in multilayered cloud



**Schematic Illustration of Partial Undercast Bias**

**Figure 35** Illustration of the way partial undercast bias occurs.

scenes where the satellite was only detecting the upper cloud U. Use of  $P(U \Rightarrow L)$  could improve the retrieval in the long term — although it would sometimes falsely predict the presence of some types.

If contingency probabilities were to be used operationally, the observer must know how the values vary over the whole range of lower cloud amounts, i.e. whether he should use the same value for 2 oktas of L as he would for 7 oktas. The values of  $P(L \Rightarrow U)$  computed by Hahn *et al.* (1982, 1984) were constructed on the assumption that the value of  $P(L \Rightarrow U)$  is invariant over the whole range of amounts of L including when L is overcast. They tested the assumption on data from the northern hemisphere for the months of March, April and May 1971, plotting  $P(L \Rightarrow U)$  as a function of the amount of L when L was not overcast. Their findings are shown in Figures 36 and 37. In Figure 36 'As' denotes the cloud types altostratus and altocumulus whilst 'Ci' in Figure 37 denotes cirrus, cirrostratus and cirrocumulus and in both diagrams 'St' denotes the cloud types stratus and stratocumulus. The assumption is relevant only for  $U =$  altostratus or cirrus explaining why the particular combinations of L and U were used. No analysis was carried out for the combination  $L =$  altostratus,  $U =$  cirrus because the observer can only gauge amounts of altostratus correctly when there are no obscuring lower clouds and such cases might be unrepresentative of the whole set of altostratus observations. In both diagrams there is no strong indications that the value of  $P(L \Rightarrow U)$  changes greatly over the range of amounts of L and the values corresponding to 6 or 7 oktas differ only by a few percent from the mean for 1-7 oktas. Hahn, Warren and London concluded from these results that, overall, their assumption about  $P(L \Rightarrow U)$  could be deemed valid and was subsequently taken to be so.

The global data for January 1985 and July 1983 provided the opportunity to check the behaviour of  $P(L \Rightarrow U)$  over different areas of the world including the southern hemisphere. Areas of Australasia, eastern Asia, Africa and Scandinavia (Figure 38) were selected, the United States

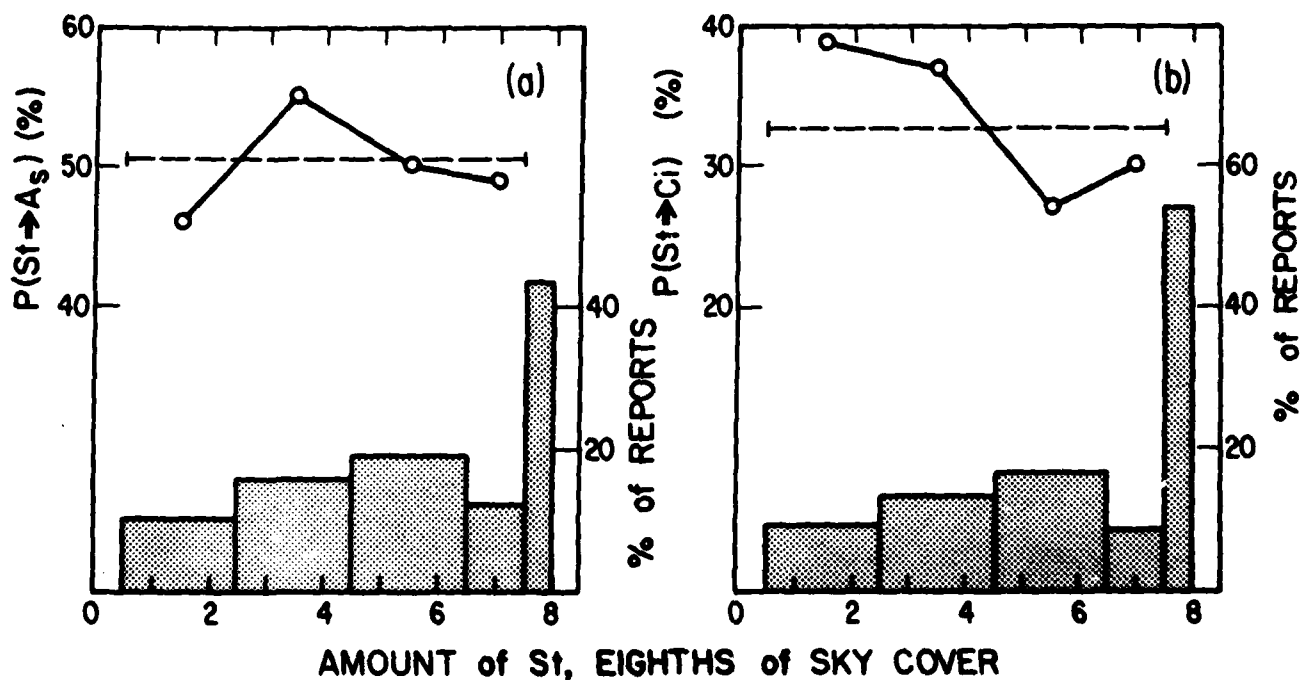


Figure 36 Variation of contingency probability of  $A_s/A_c$  for given amounts of  $St/Sc$ . Histogram bars show the relative number of observations contributing to each point. Dashed line indicates mean value of all the observations contributing to the 4 points. Data from the northern hemisphere, March, April, May, 1971 (From Hahn *et al.*, 1982).

Figure 37 Variation of contingency probability of  $C_i/C_s/C_c$  for given amounts of  $St/Sc$ . Histogram bars show the relative number of observations contributing to each point. Dashed line indicates mean value of all the observations contributing to the 4 points. Data from the northern hemisphere, March, April, May 1971 (From Hahn *et al.*, 1982).

not included because the majority of the reports there were of the airways category which described cloud cover as either clear, broken, scattered or overcast rather than with a specific okta value. For each region the contingency probability  $P(L \Rightarrow U)$  was calculated for amounts of L in the range 1 to 7 oktas. The method involves dividing the number of occasions on which L and U were seen together by the number of times L was observed and the level appropriate to U reported (either with or without U). The results for L = stratus/stratocumulus and U = altocumulus/altostratus are shown in Figures 39 to 46 and those where L = stratus/stratocumulus and U = cirrus/cirrostratus/cirrocumulus are in Figures 47 to 54. Each diagram contains 2 vertical axes — the left-hand axis relating to the contingency probability, the right-hand axis being a percentage scale for the bar histogram.

## 2.7 Results

### i) L = St/Sc, U = Ac/As

The overall trend in both January and July is for  $P(L \Rightarrow U)$  to decrease with increasing U but there is considerable variability between the countries. The largest decrease occurs over Scandinavia, approximately 35% in January and 45% in July for amounts of St/Sc ranging from 3 to 7 oktas. The horizontal bars in Figure 40 indicate the mean value of  $P(L \Rightarrow U)$  over 1-7 oktas (upper bar) and the mean value over 6-7 oktas (lower bar), the difference between them amounting to almost 25% cloud amount (absolute). Over eastern Asia the decrease, although steady is less pronounced, the bars in Figure 41 being separated by only 10%. The assumption that  $P(L \Rightarrow U)$  is constant for all amounts of U could not be said to hold over these areas. A similar conclusion can be drawn from the Asian data in July where the decrease of  $P(L \Rightarrow U)$  is almost linear. Here too the chance of observing altostratus or altocumulus appears to decrease with increasing St/Sc. In other words, in all the above cases the risk of PUB is somewhat lower for more lower level cloud, in conflict with the assertions of Hahn, Warren and London.

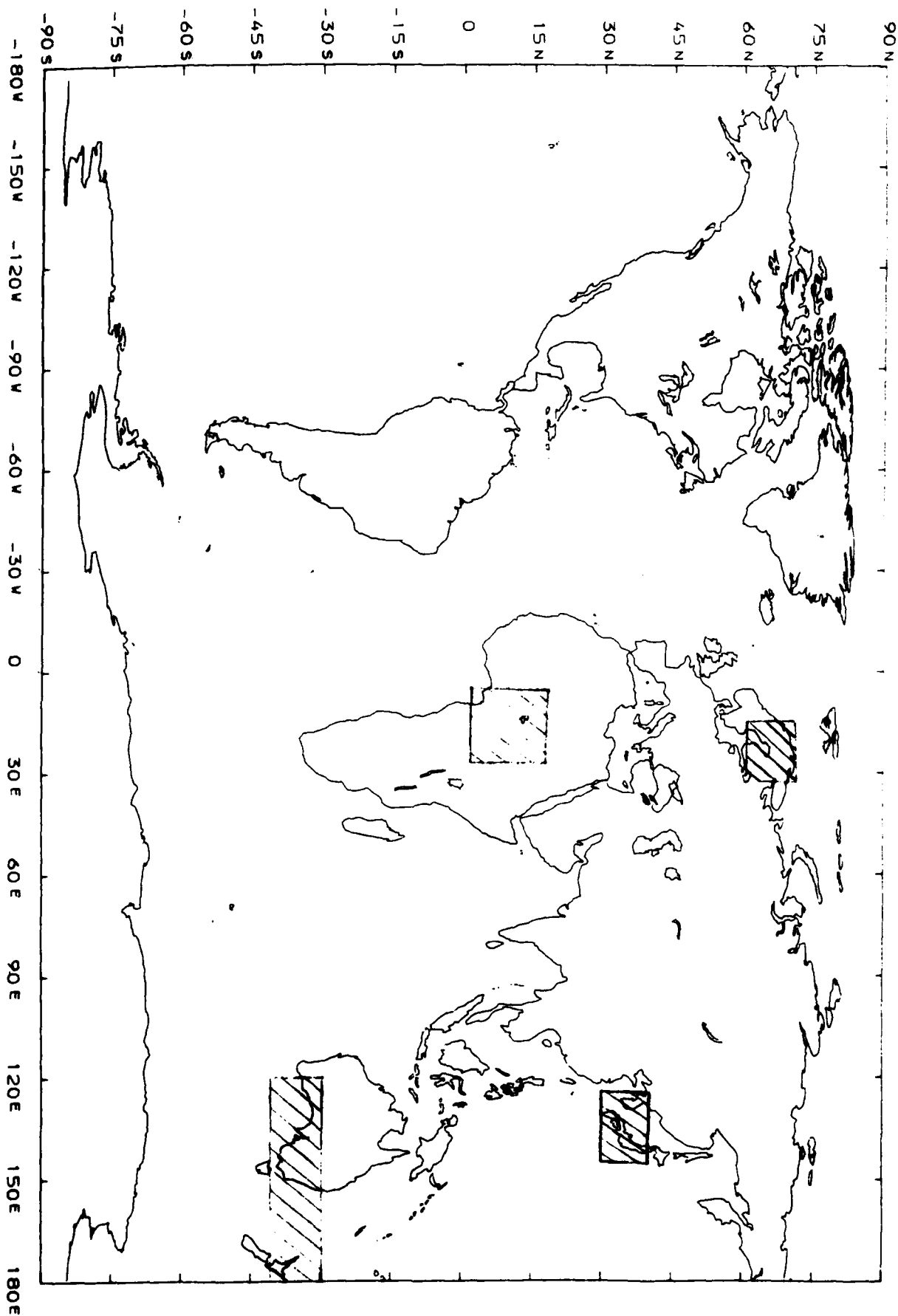


Figure 38 Analysis regions for partial undercast bias investigation.

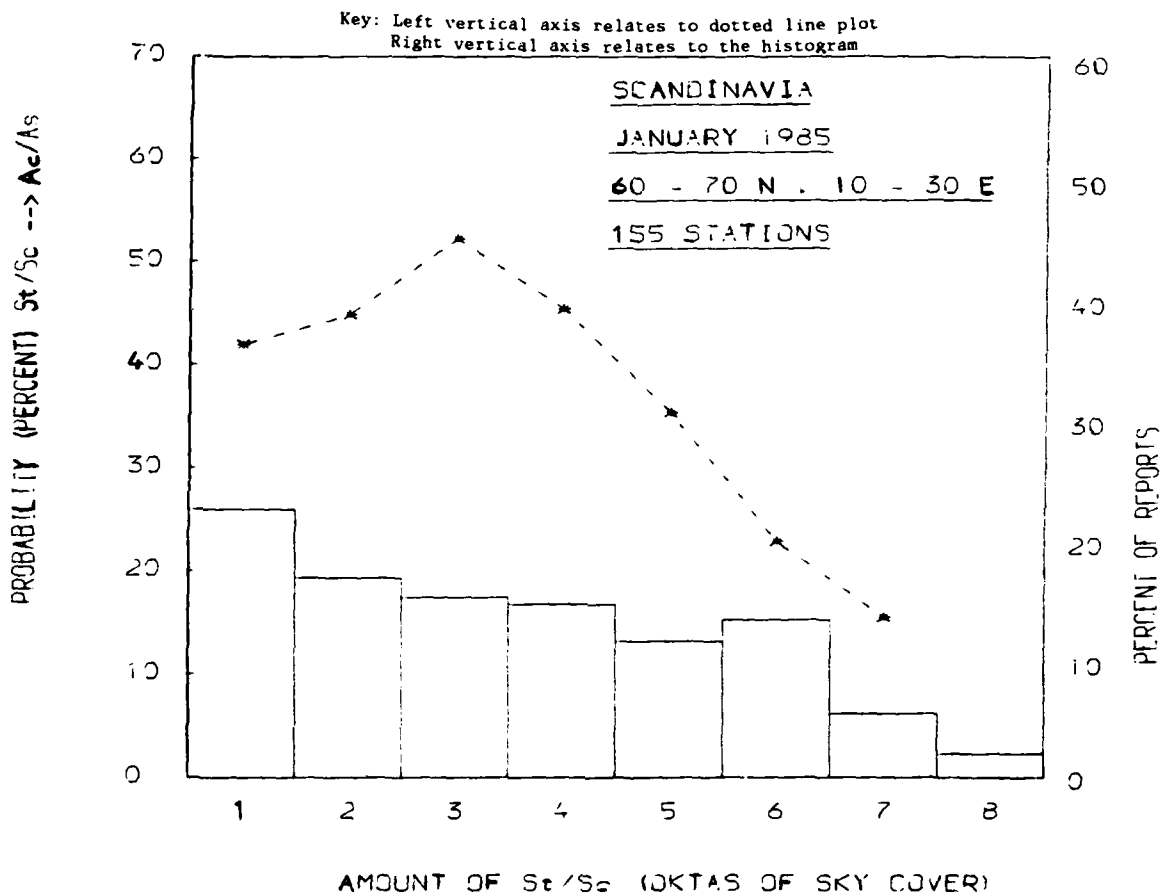


Figure 39 Variation of contingency probability for As/Ac with given amounts of St/Sc over Scandinavia, January 1985.

Figure 40 Variation of contingency probability for As/Ac with given amounts of St/Sc over Scandinavia, July 1983.

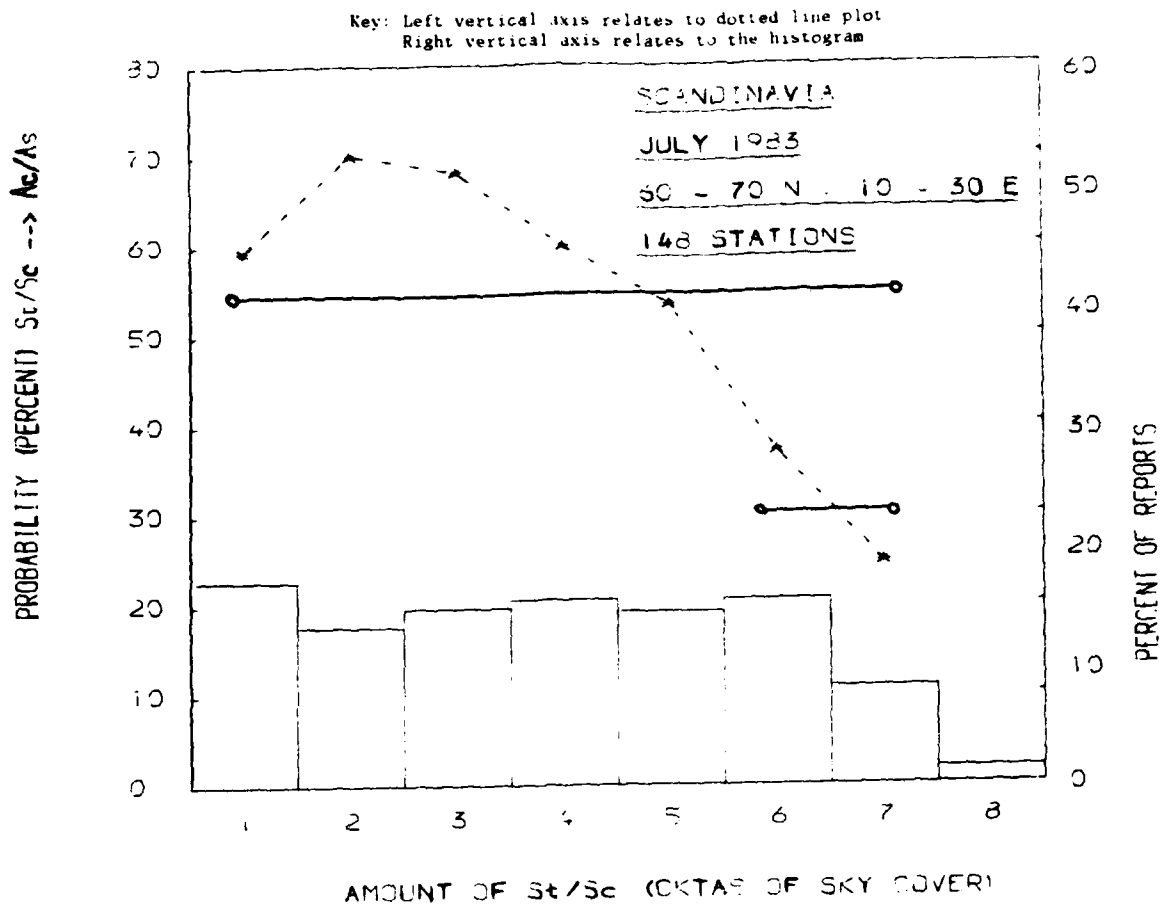
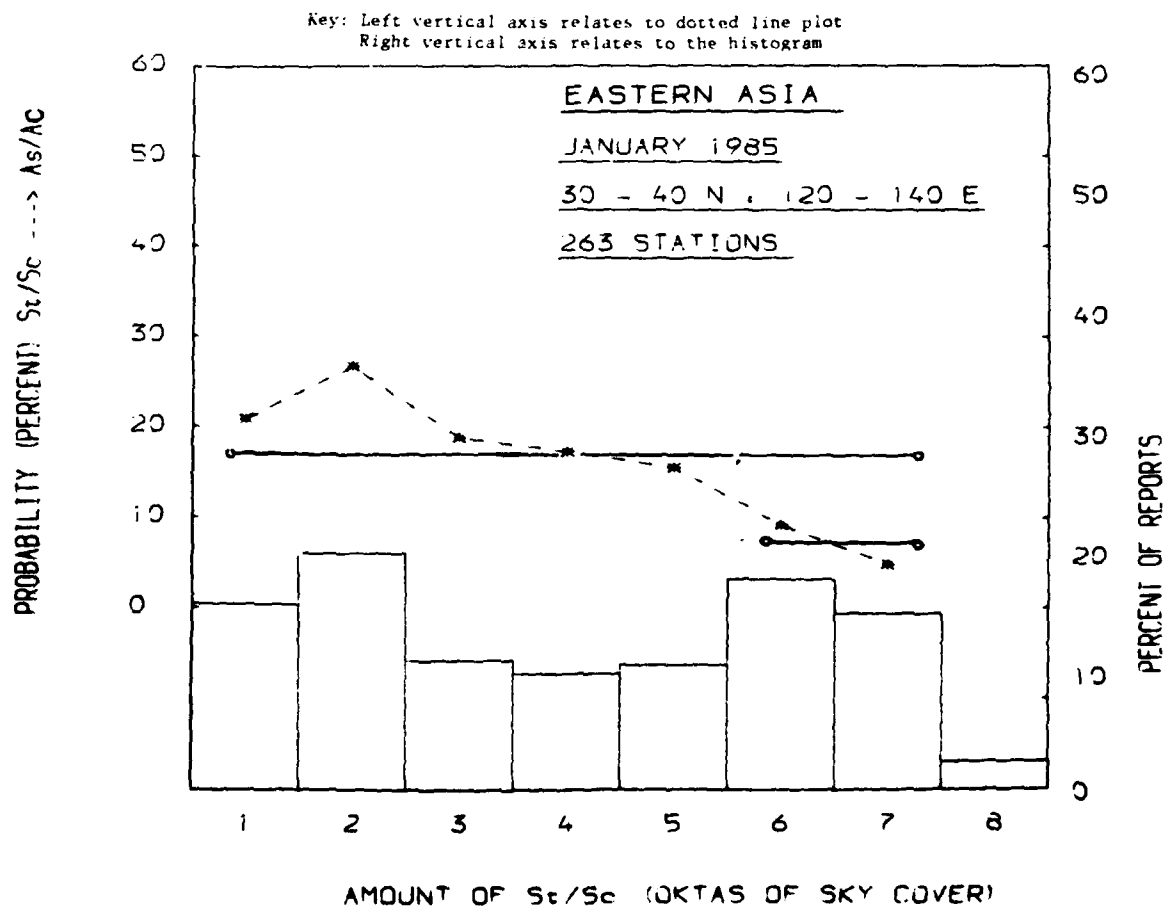


Figure 41 Variation of contingency probability for As/Ac with given amounts of St/Sc over eastern Asia, January 1985.



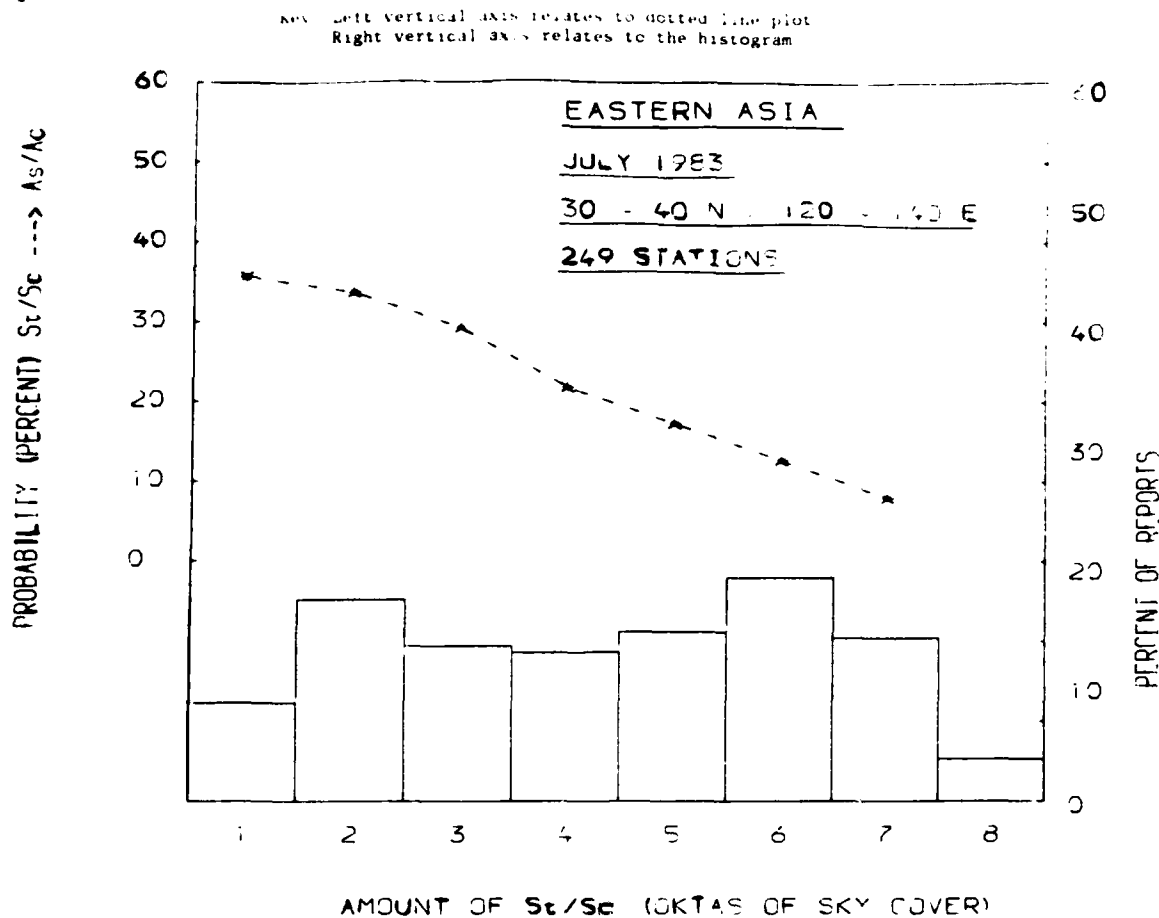
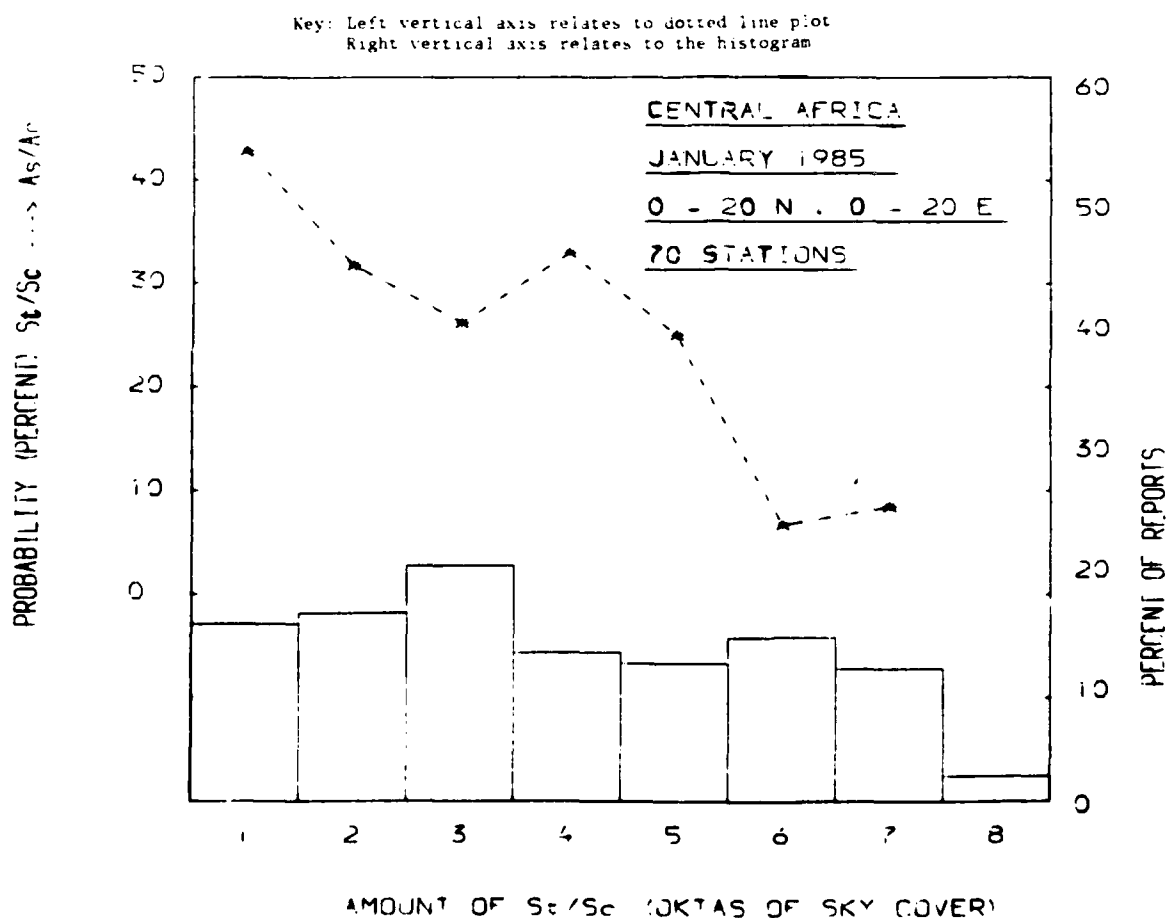


Figure 42 Variation of contingency probability for As/Ac with given amounts of St/Sc over eastern Asia, July 1983.

Figure 43 Variation of contingency probability for As/Ac with given amounts of St/Sc over central Africa, January 19



Contrasting results were obtained for the central African data. In January (Figure 43), the value of  $P(L \Rightarrow U)$  falls off by 25% in progressing from 4 to 7 oktas St/Sc but the July trace (Figure 44) is almost horizontal until the considerable decrease at 7 oktas. As the number of reports less than 7 oktas constitutes 75% of the total, the use of a single mean value of  $P(L \Rightarrow U)$  over the whole range of amounts of L would give only slightly higher frequencies of As/Ac when 7 or 8 oktas St/Sc were present.

Only over Australasia (Figures 45 and 46) do the results bear close resemblance to those obtained by Hahn *et al.* An interesting feature of all the plots is the small percentage of reports associated with the lower cloud overcasts (<10% in each case) compared to greater than 40% found by Hahn *et al.*

ii)  $L = \text{St/Sc}, U = \text{Ci/Cs/Cc}$

Similar trends in contingency probability were obtained, particularly over Scandinavia where the assumption is shown to be invalid for the data over both months. (Figures 47 and 48). Over Asia and Australasia (Figures 49, 50, 53 and 54) the trend is rather steadier as the amount of St/Sc is increased and the mean values do not differ from the values at 6 or 7 oktas by more than 10%. The contrast in the African data between January and July is much reduced as is evident from the horizontal bars. Overall, it appears that the tendency for high cloud to be present is greater when there is less than 4 oktas of stratus or stratocumulus.

Although the results presented here do not permit general conclusions to be drawn, they show some disagreement from those of Hahn *et al.* Variation around the globe is evident. The frequency with which different cloud types occur simultaneously giving rise to PUB should help to promote the idea of contingency probabilities but the results presented here i) cast doubt on the choice of a single value for  $P(L \Rightarrow U)$  for given types of L and U and all amounts of L and ii) suggest that PUB is perhaps not so common for higher amounts of L as might have been thought. The concept of contingency probabilities is recent and their future role seems likely to be in the construction of

Key: Left vertical axis relates to dotted line plot  
Right vertical axis relates to the histogram

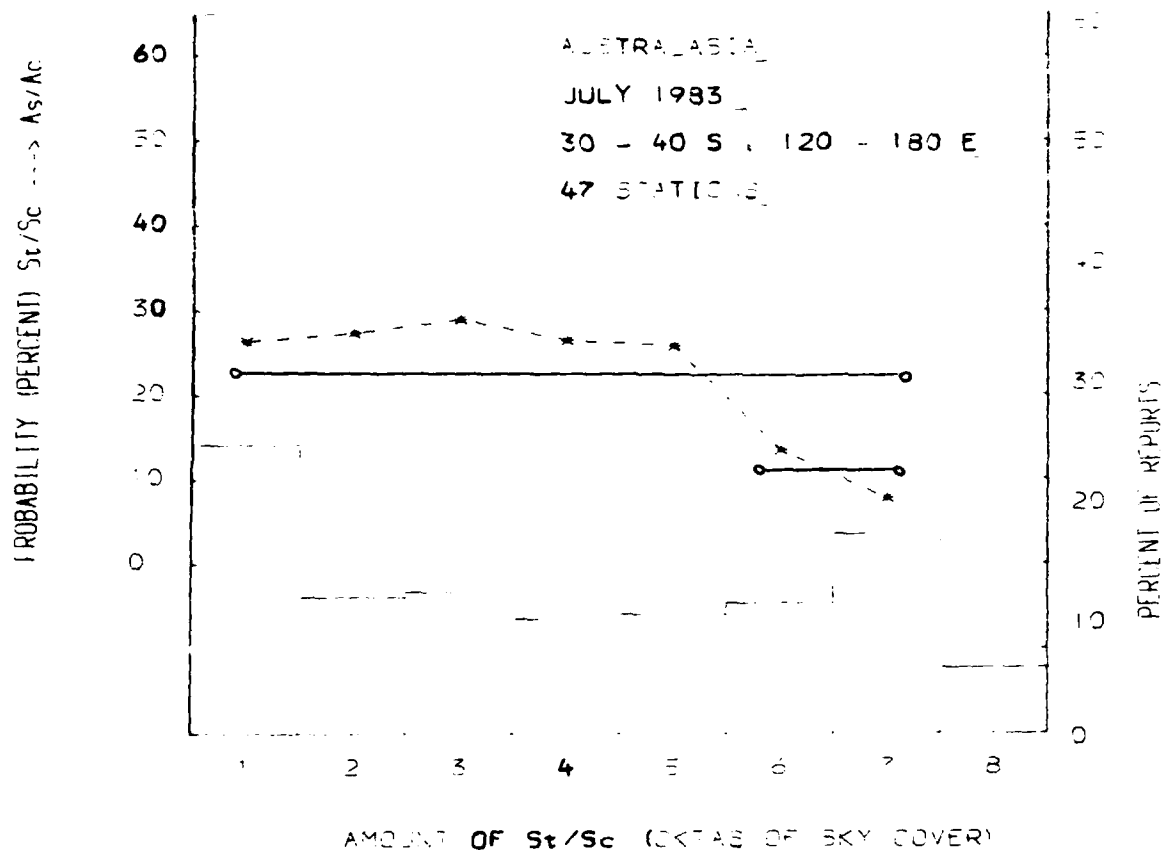


Figure 46 Variation of contingency probability for As/Ac with given amounts of St/Sc over Australasia, July 1983.

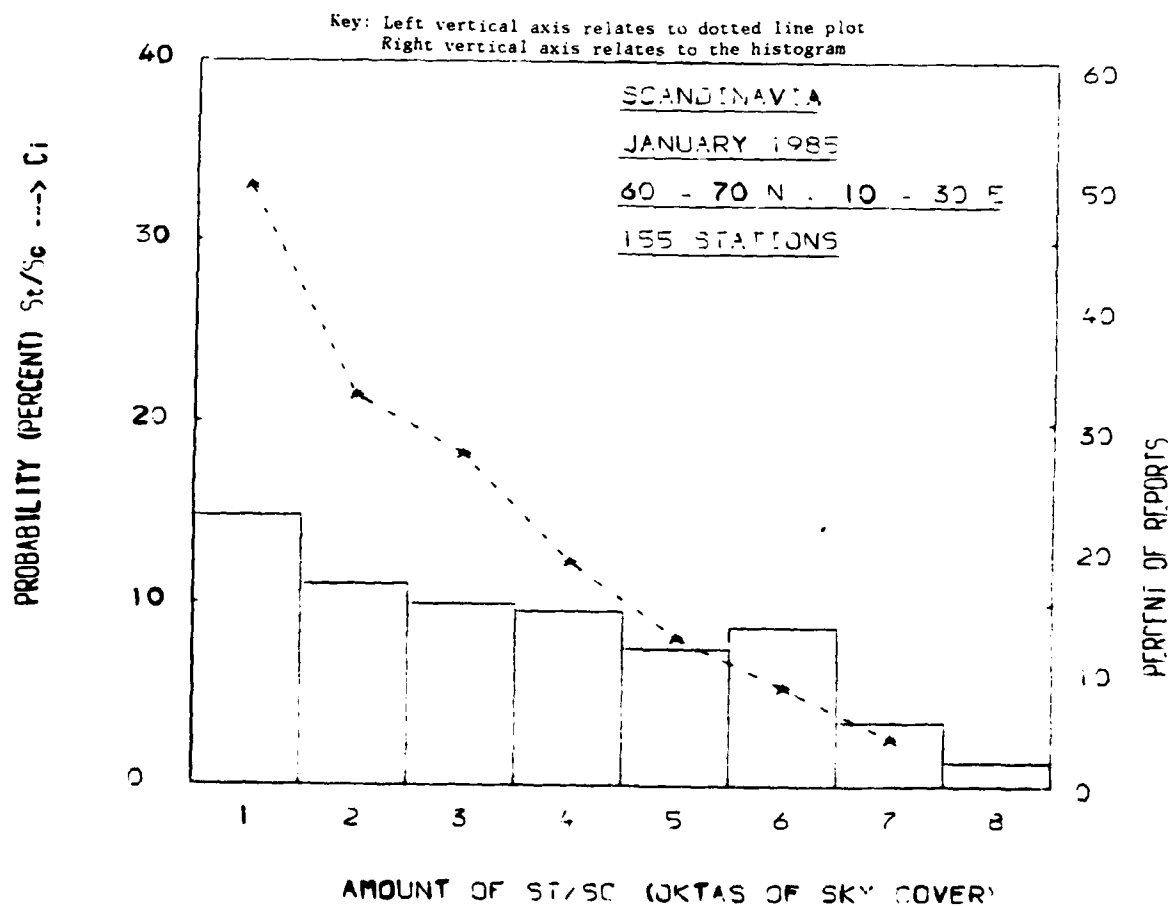


Figure 47 Variation of contingency probability for Ci/Cs/Cc for given amounts of St/Sc over Scandinavia, January 1985.

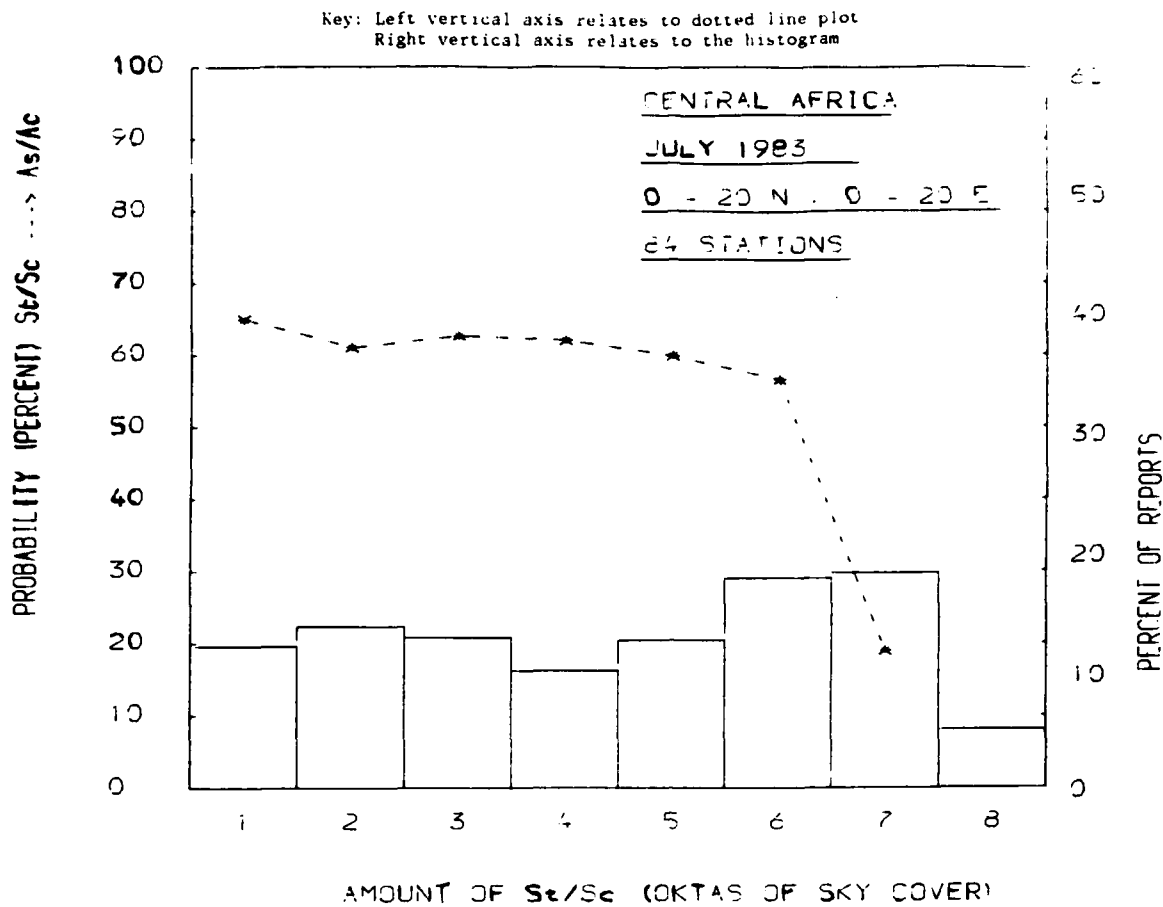
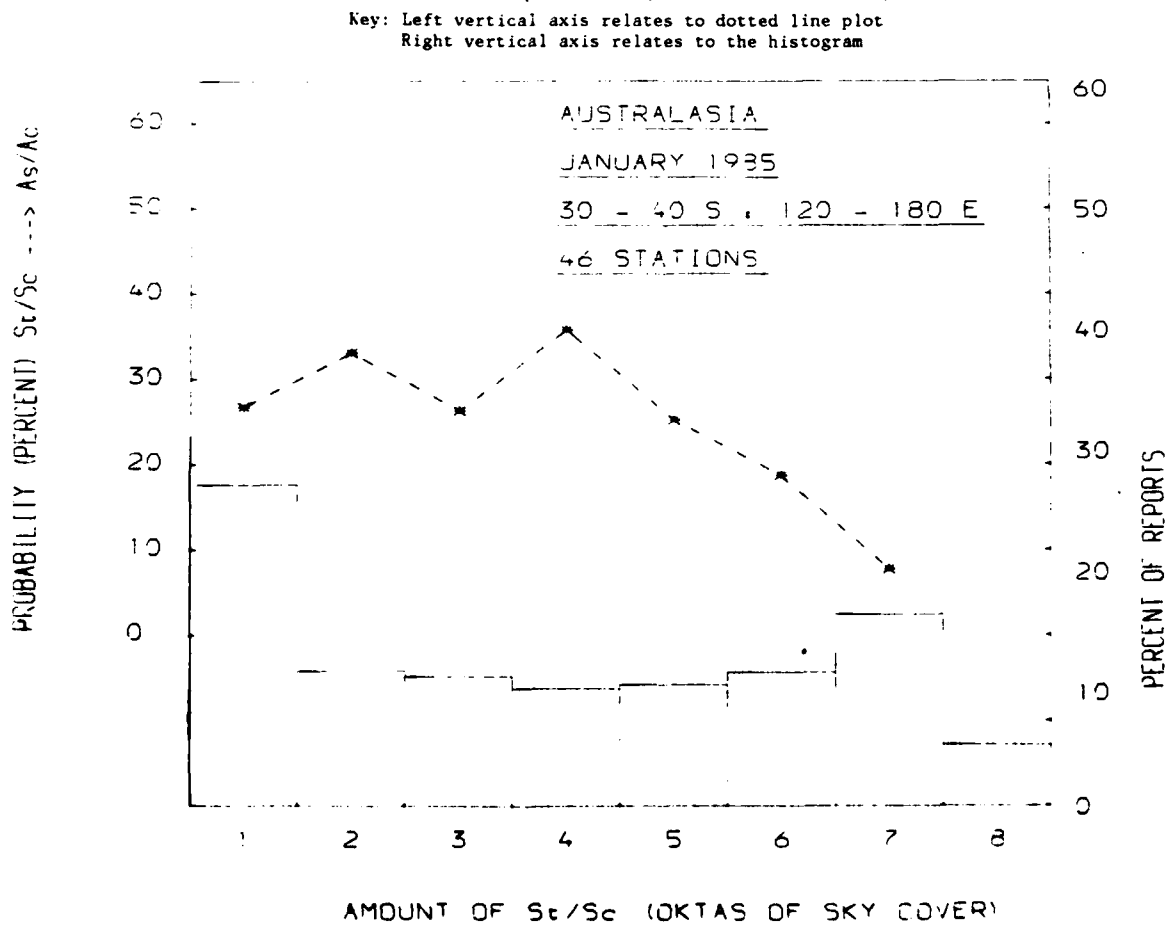


Figure 44 Variation of contingency probability for As/Ac with given amounts of St/Sc over central Africa, July 1983.

Figure 45 Variation of contingency probability for As/Ac with given amounts of St/Sc over Australasia, January 1985.



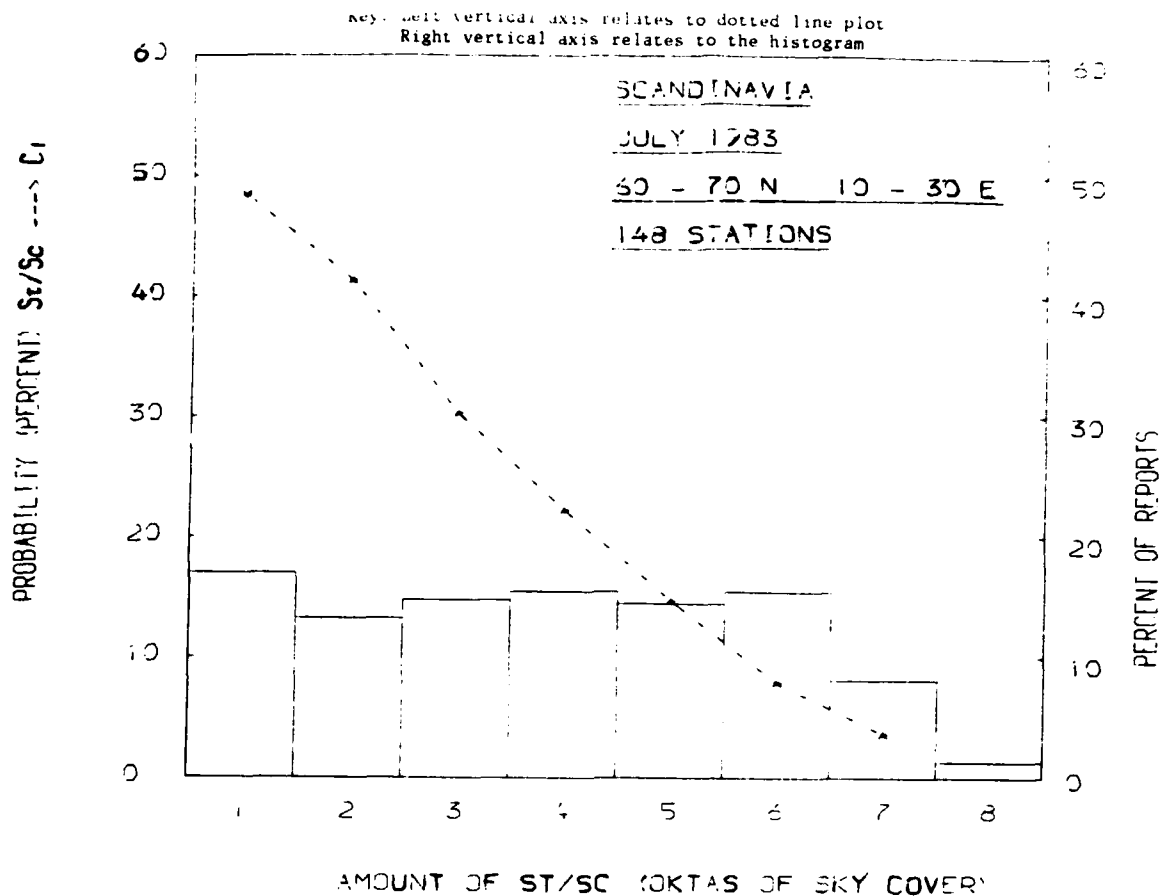


Figure 48 Variation of contingency probability for  $C_i/C_s/C_c$  for given amounts of  $St/Sc$  over Scandinavia, July 1983.

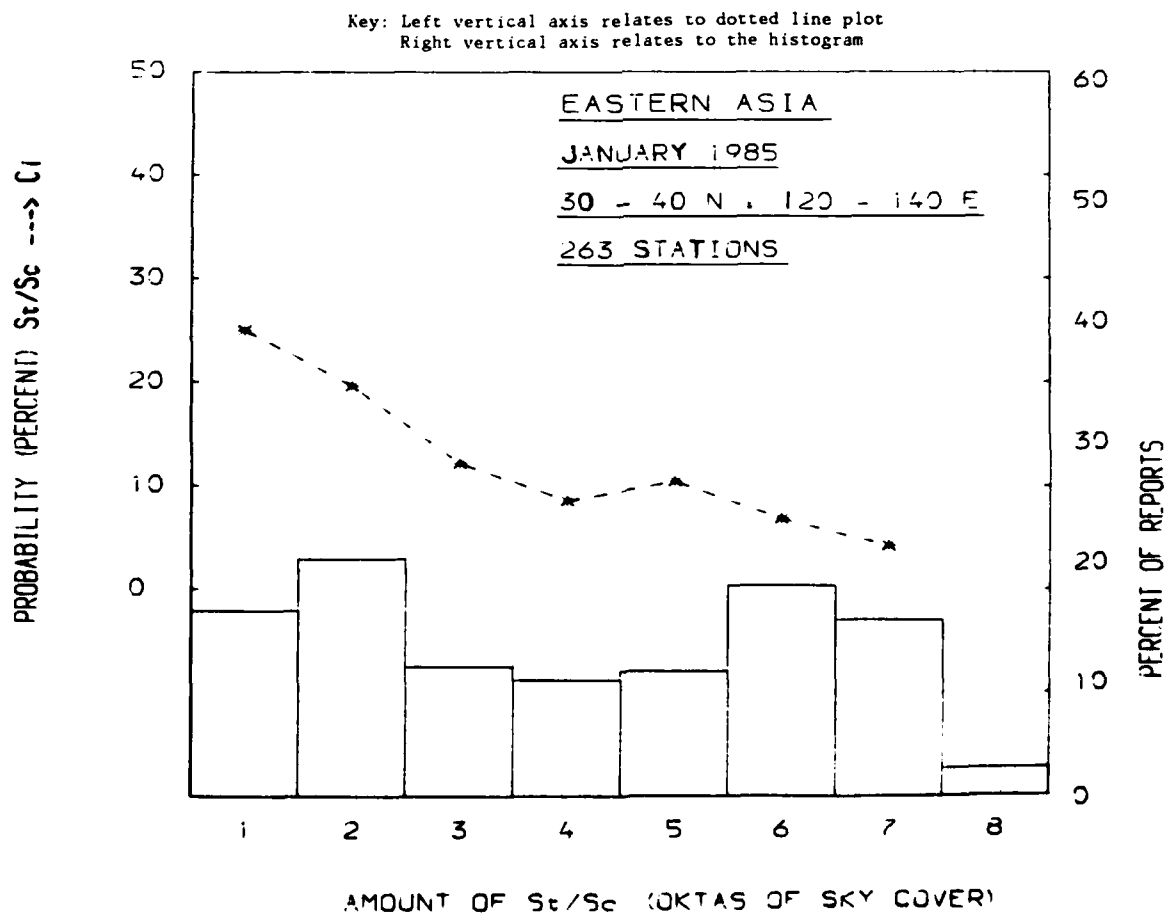


Figure 49 Variation of contingency probability for  $C_i/C_s/C_c$  for given amounts of  $St/Sc$  over eastern Asia, January 1985.

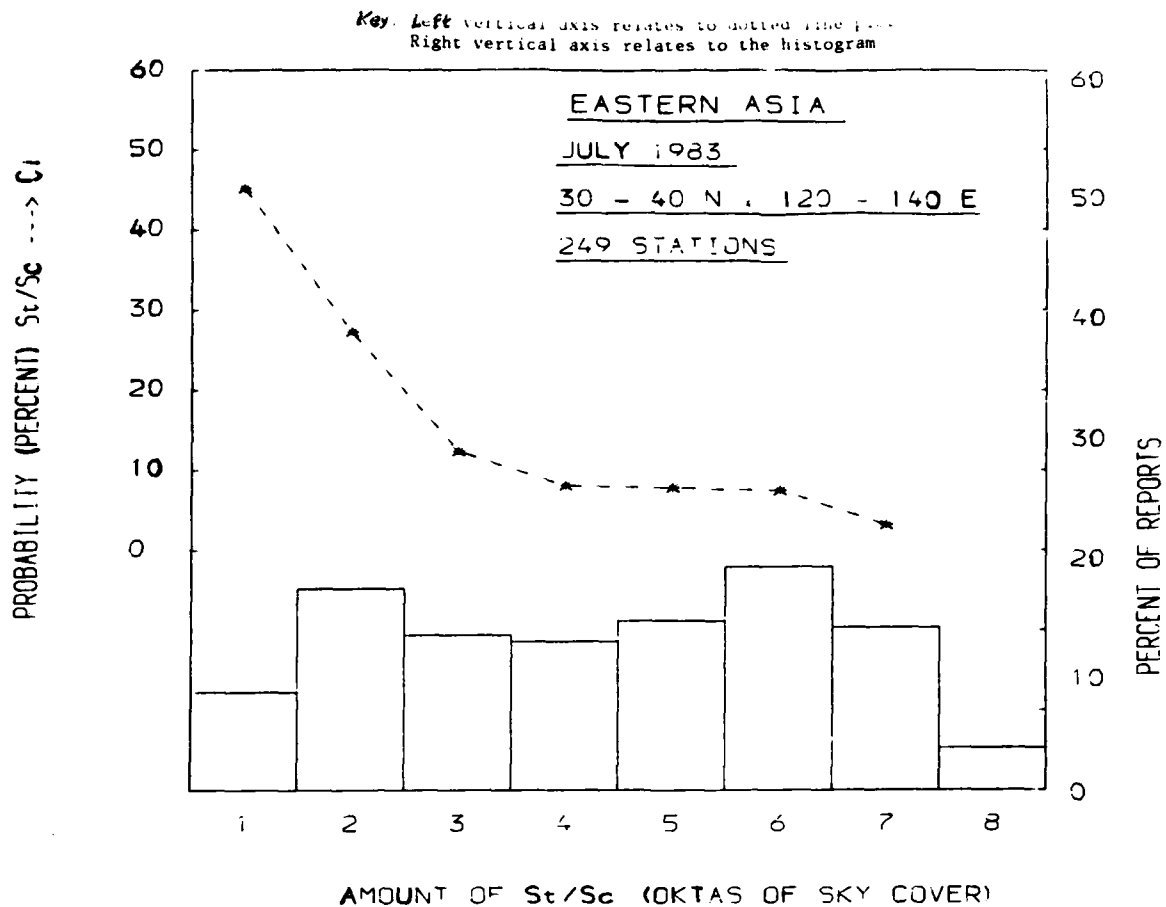


Figure 50 Variation of contingency probability for Ci/Cs/Cc for given amounts of St/Sc over eastern Asia, July 1983.

Figure 51 Variation of contingency probability for Ci/Cs/Cc for given amounts of St/Sc over central Africa, January 1985

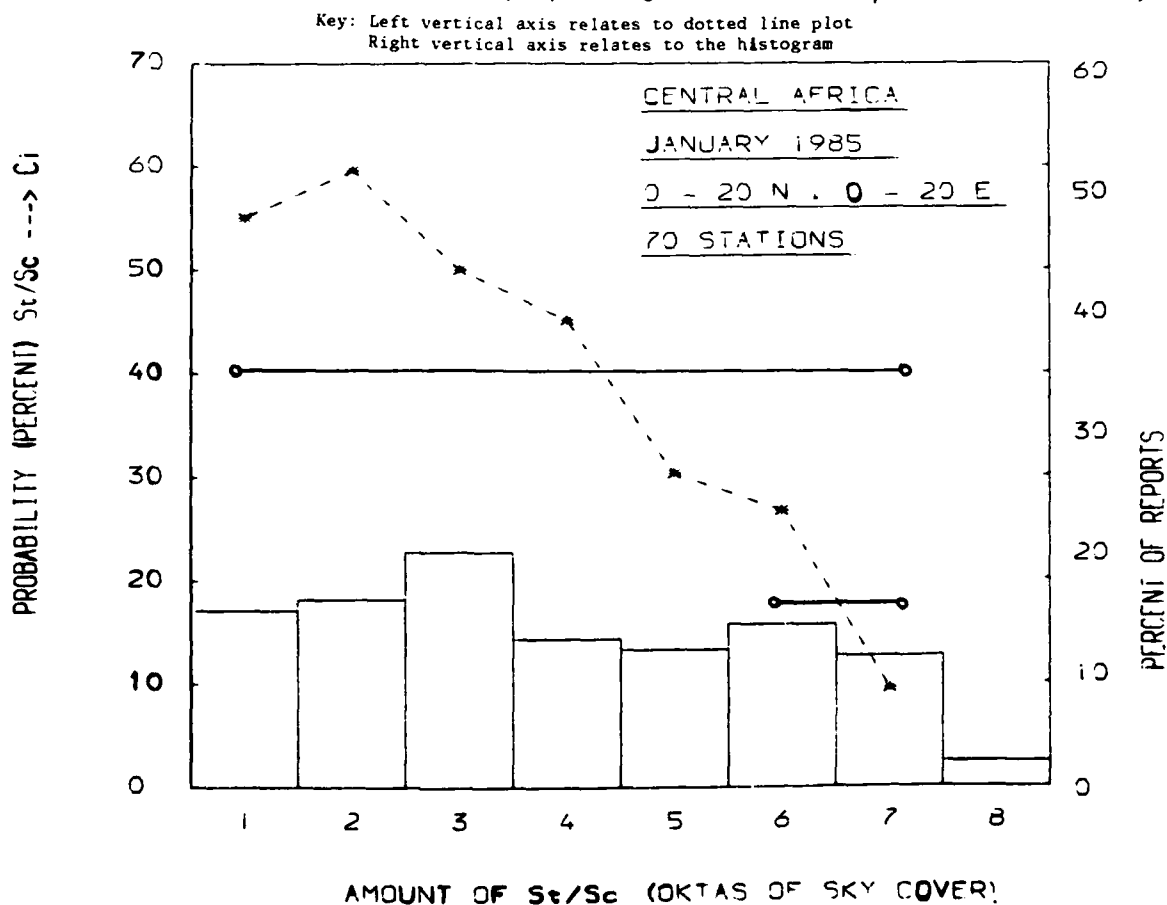


Figure 52 Variation of contingency probability for  $C_i/C_s/C_c$  for given amounts of  $St/Sc$  over Central Africa, July 1983

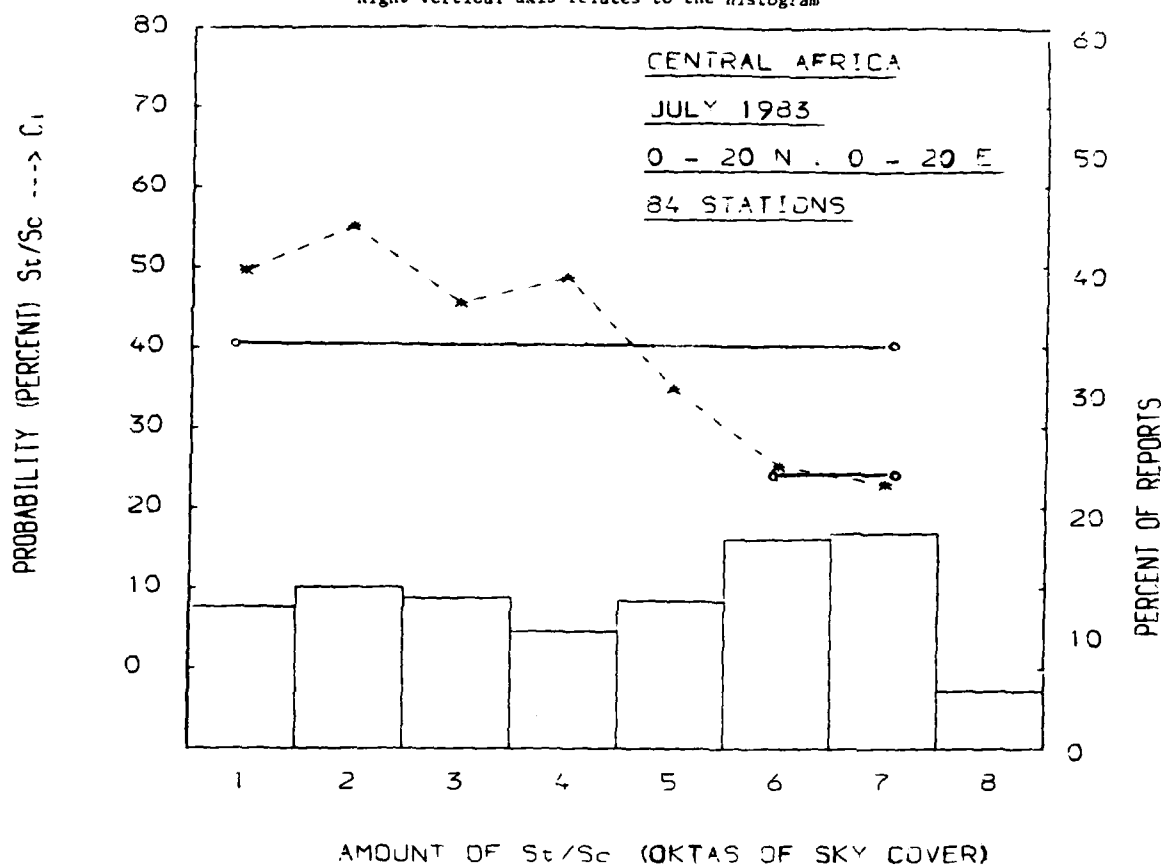
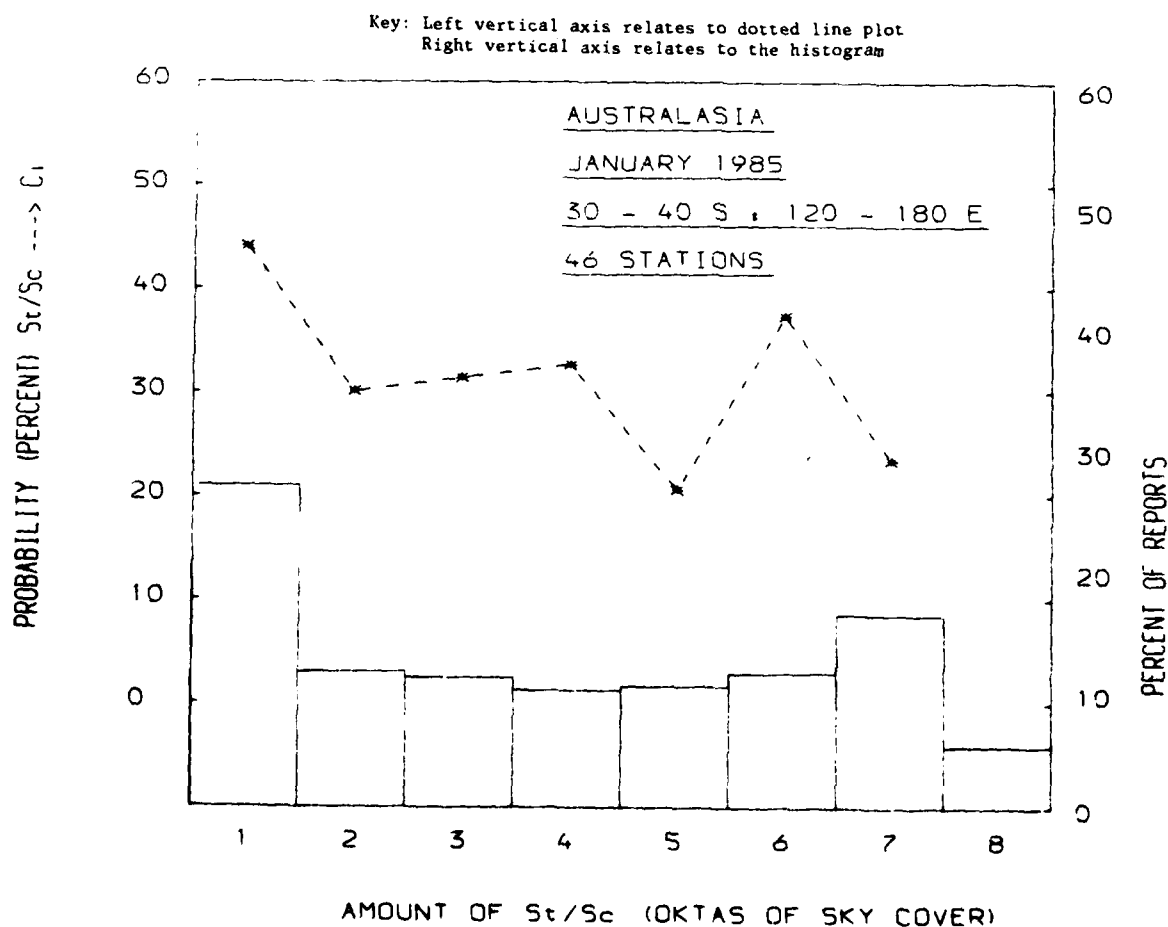


Figure 53 Variation of contingency probability for  $C_i/C_s/C_c$  for given amounts of  $St/Sc$  over Australasia, January 1985.



Key: Left vertical axis relates to dotted line plot  
Right vertical axis relates to the histogram

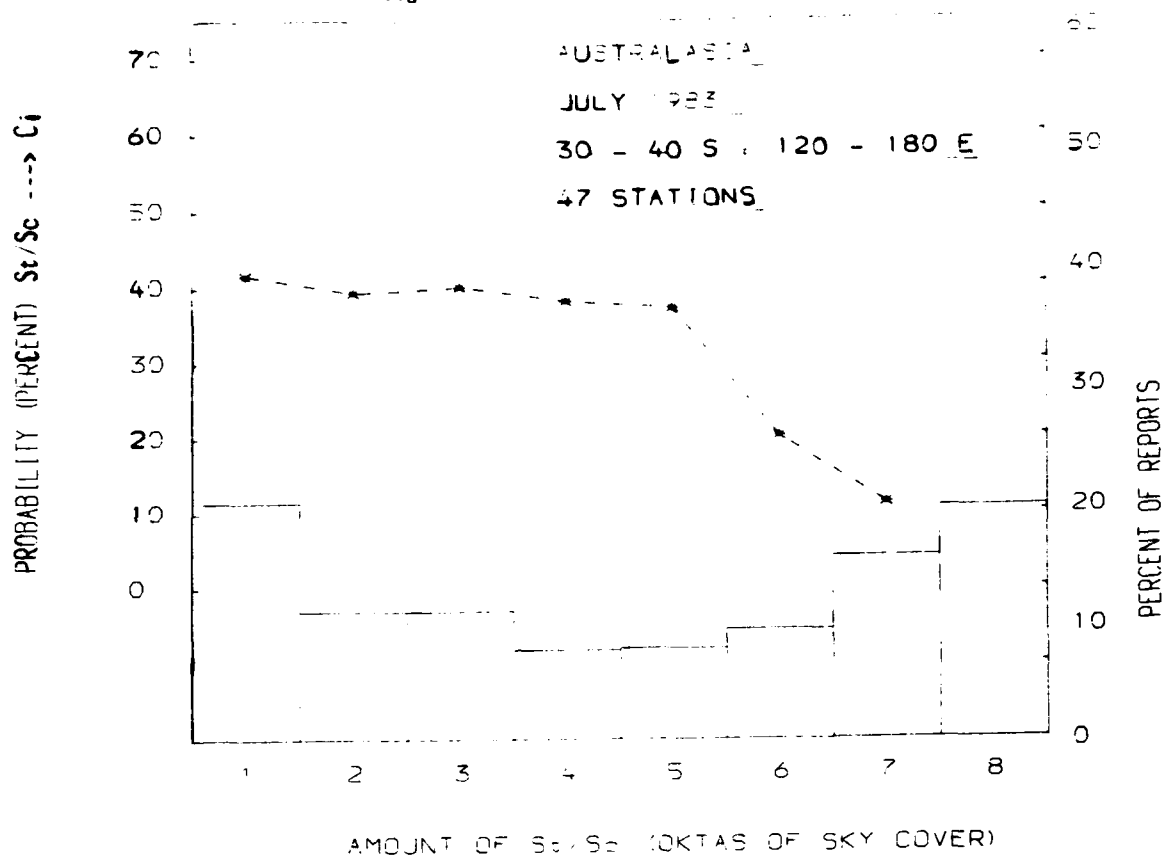


Figure 54 Variation of contingency probability for Ci/Cs/Cc for given amounts of St/Sc over Australasia, July 1983.

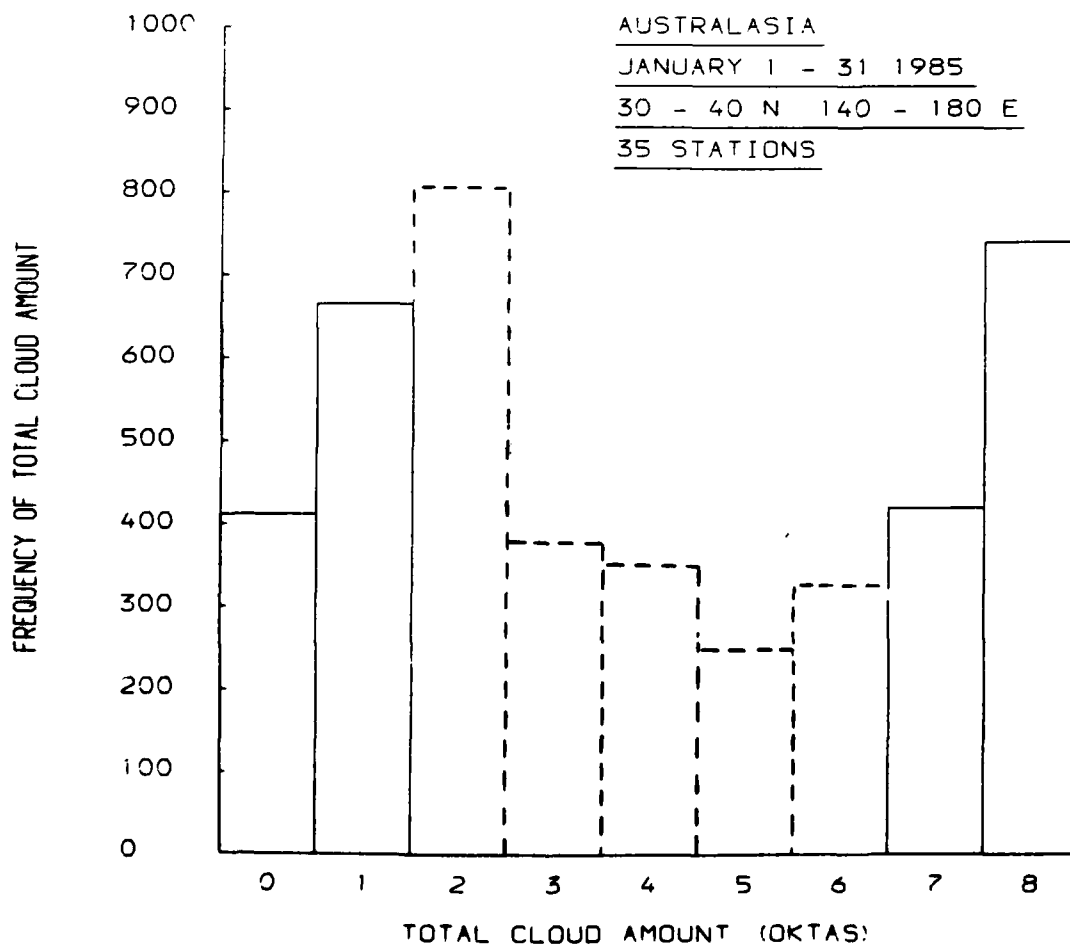


Figure 56 Total cloud amount frequency histogram for Australasia, January 1985

surface-based cloud climatologies for climate studies, especially modelling. At present attention is focussed primarily upon satellite-derived climatologies and hence the potential role of the opposite probability, viz.  $P(U \Rightarrow L)$ , should be further investigated.

### *2.8 1 and 7 okta bias*

The WMO procedure for reporting total cloud amount assigns special rules concerning values of 1 and 7 oktas. It requires that the observer report 1 okta of cloud even if the amount present is less than half an okta, i.e. every cloud present must be recorded. At the other end of the scale small gaps in a cloud sheet, even if they amount to less than half an okta or are only suspected to be present, should be recorded as 7 oktas rather than 8. These rules are not always strictly adhered to and observers around the world may tend to round off their estimate to the nearest okta, often in an attempt to record the more realistic value. Very small clouds or gaps are easily visualised, e.g. a thin streak of cirrus in an otherwise cloudless sky, remnants of daytime cumulus at dusk, isolated cumuli and the small holes characteristic of stratocumulus decks. Assuming that observers stick to the accepted procedure small biases in the total cloud amount may arise if a location experiences frequent cases of either very small clouds or small gaps. If both cases occur often the overestimation of cloud amount by using 1 okta counters the underestimate of cloud amount caused by using 7 oktas and any bias is considerably reduced. Remembering that an okta is 12.5% cloud amount serves to highlight the observer's choice of okta value.

As a brief exercise aimed at checking for cases where there is a strong suggestion that 1 or 7 okta bias might prevail, areas of Australasia, Europe, India and South America were chosen (Figure 55) and the frequency of occurrence of total cloud amounts plotted as a histogram for all the stations within each area. The histograms were examined for incidences of very high (or very low) relative frequency of 1:0 oktas and 7:8 oktas that suggest under or overestimation of the monthly mean cloud amount due to the (correct) application of the observing rules. These histograms are shown in Figures 56 to 61 and show 3 interesting examples. The July histogram for

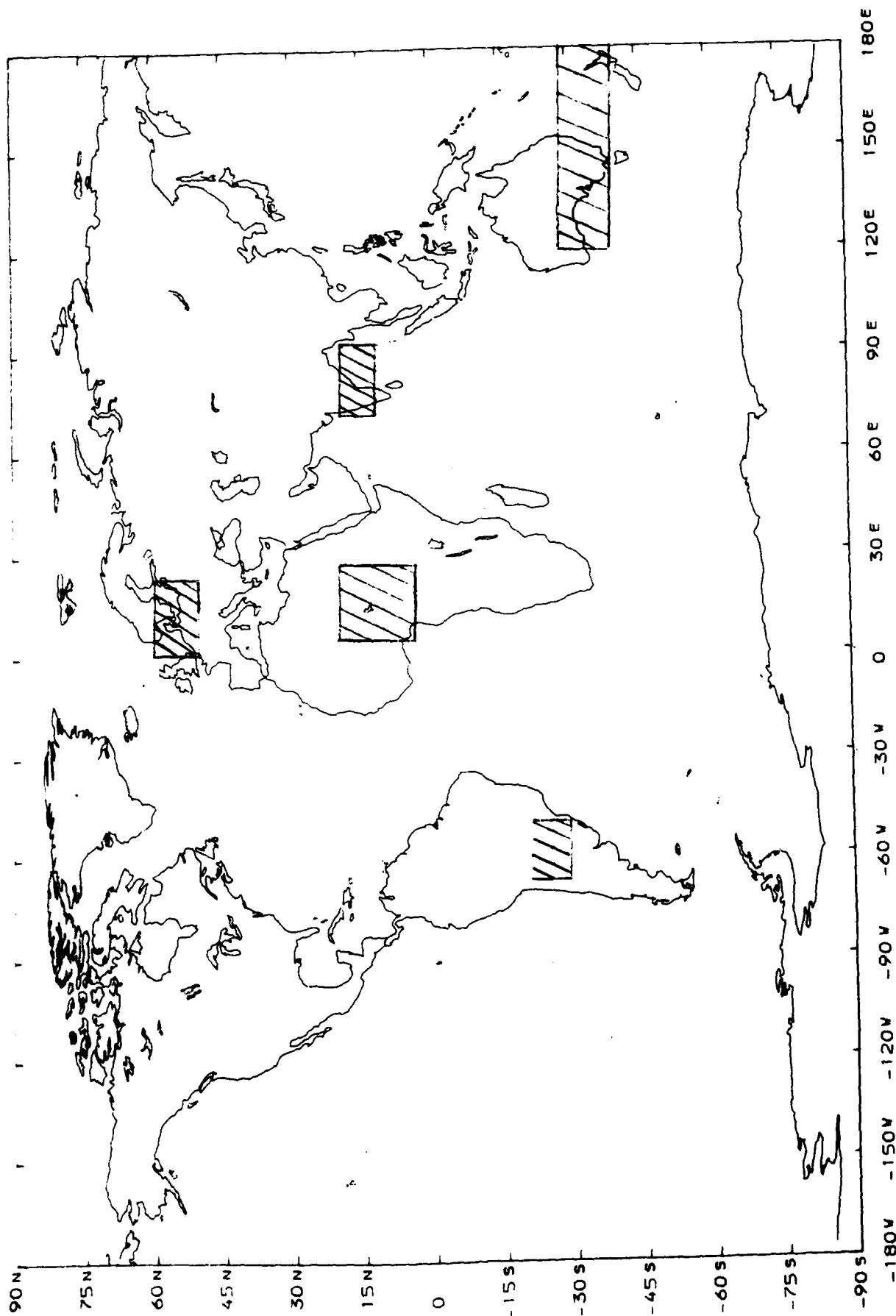


Figure 55 Analysis regions for 1, 7 okta bias investigation.

Figure 57 Total cloud amount frequency histogram for Australasia, July 1983.

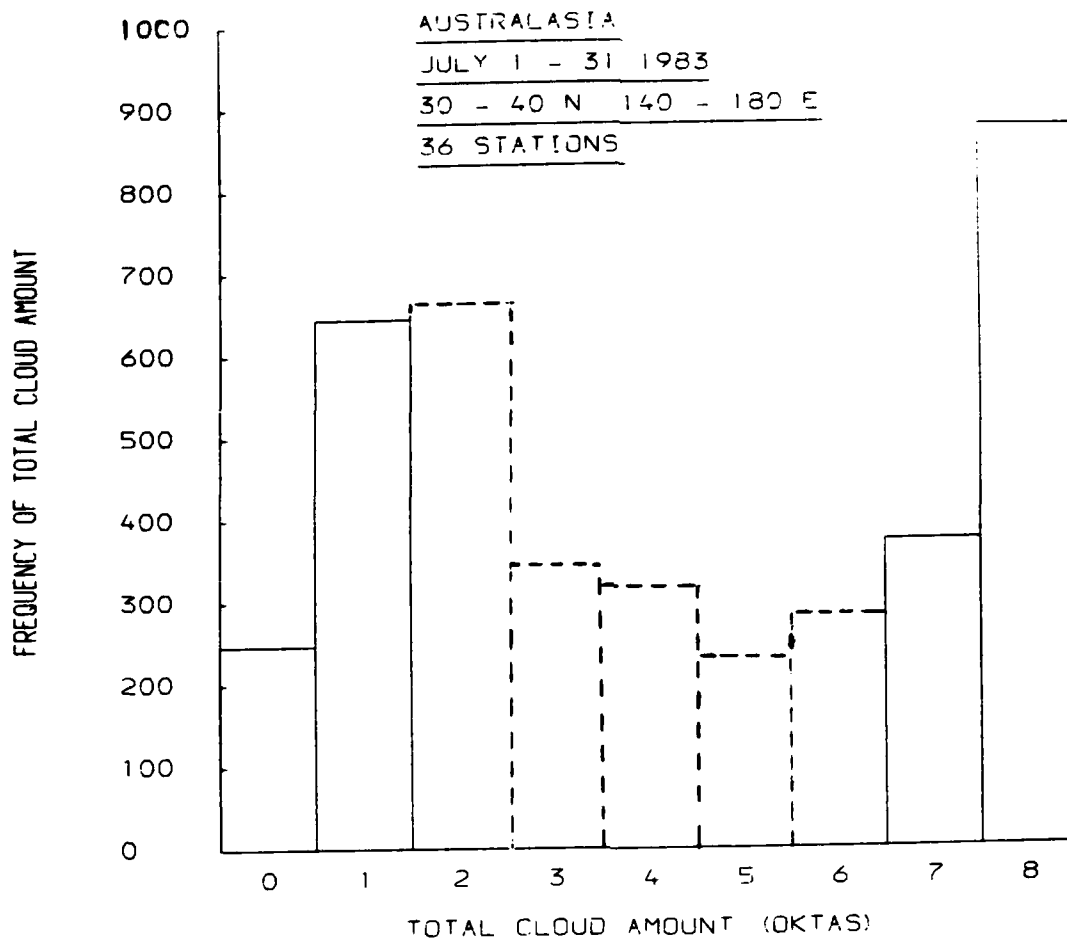


Figure 58 Total cloud amount frequency histogram for western Europe, January 1985.

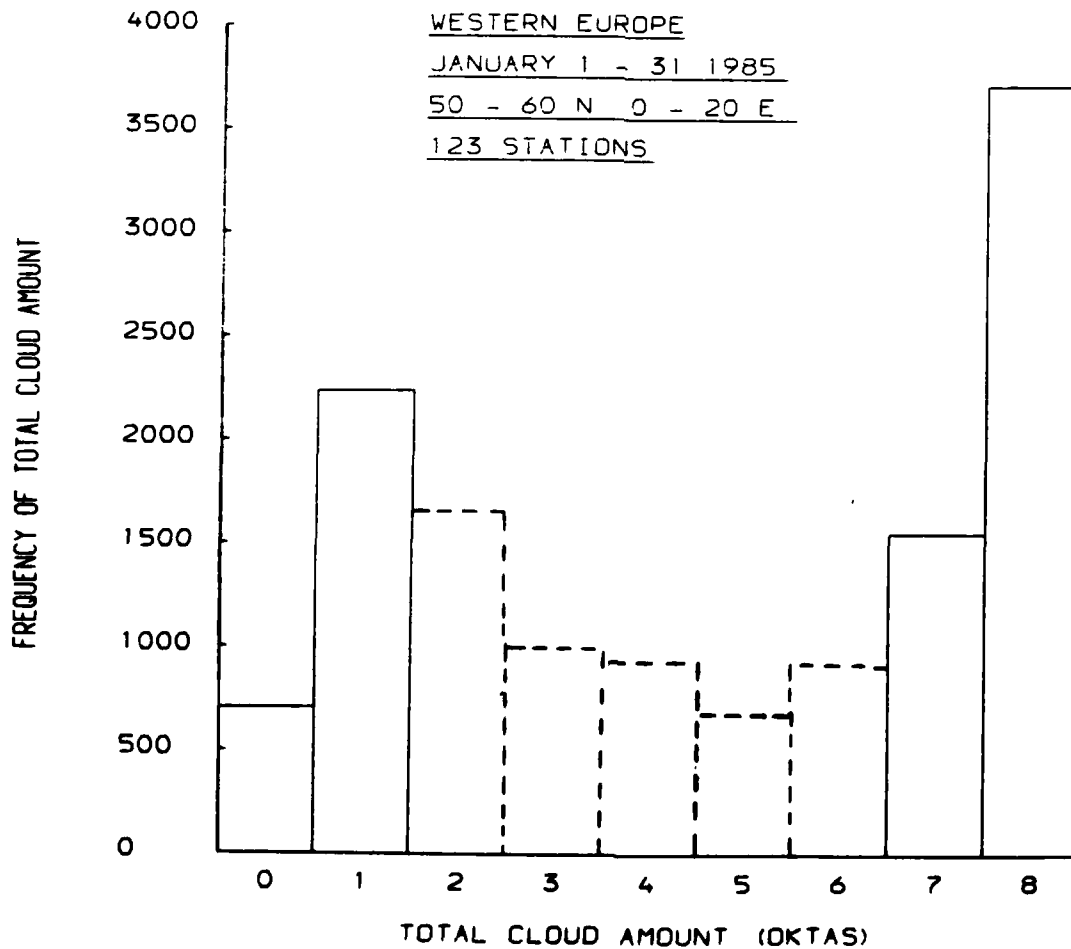


Figure 59 Total cloud amount frequency histogram for western Europe, July 1983.

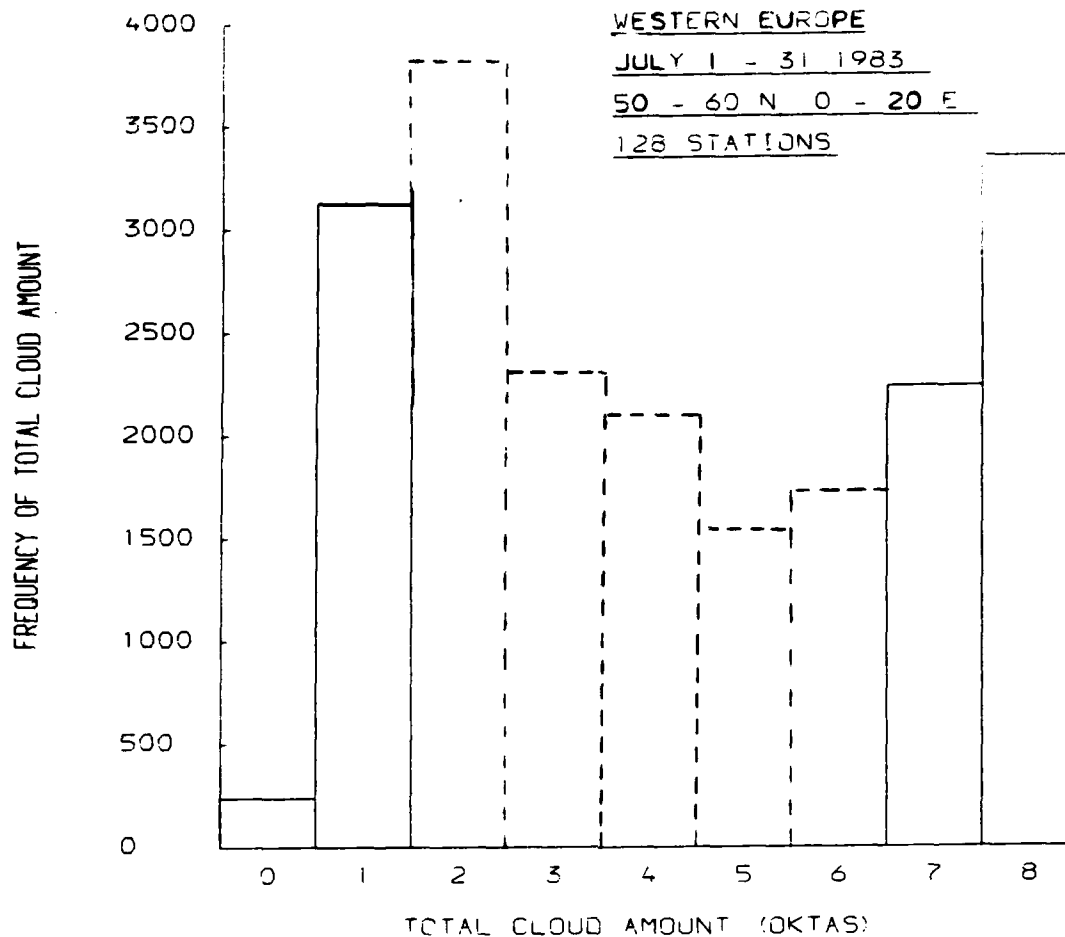
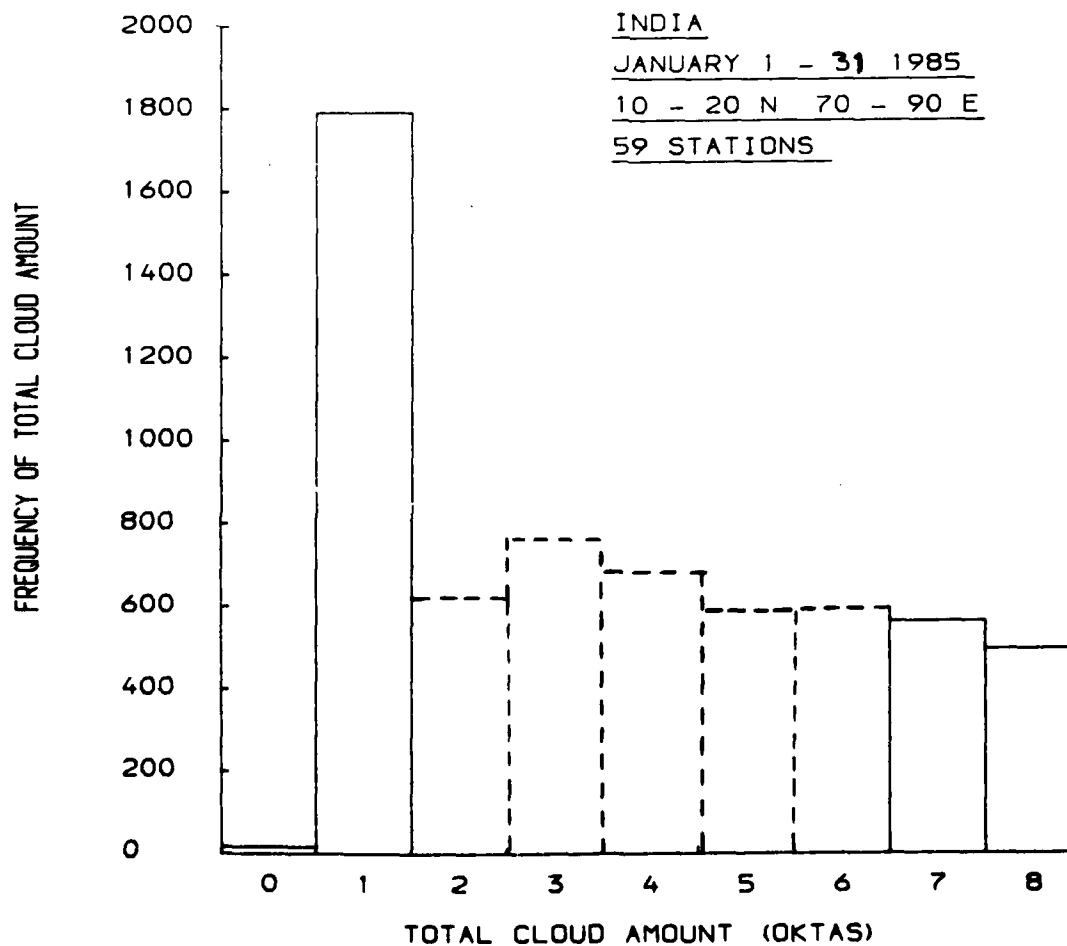


Figure 60 Total cloud amount frequency histogram for India, January 1985.



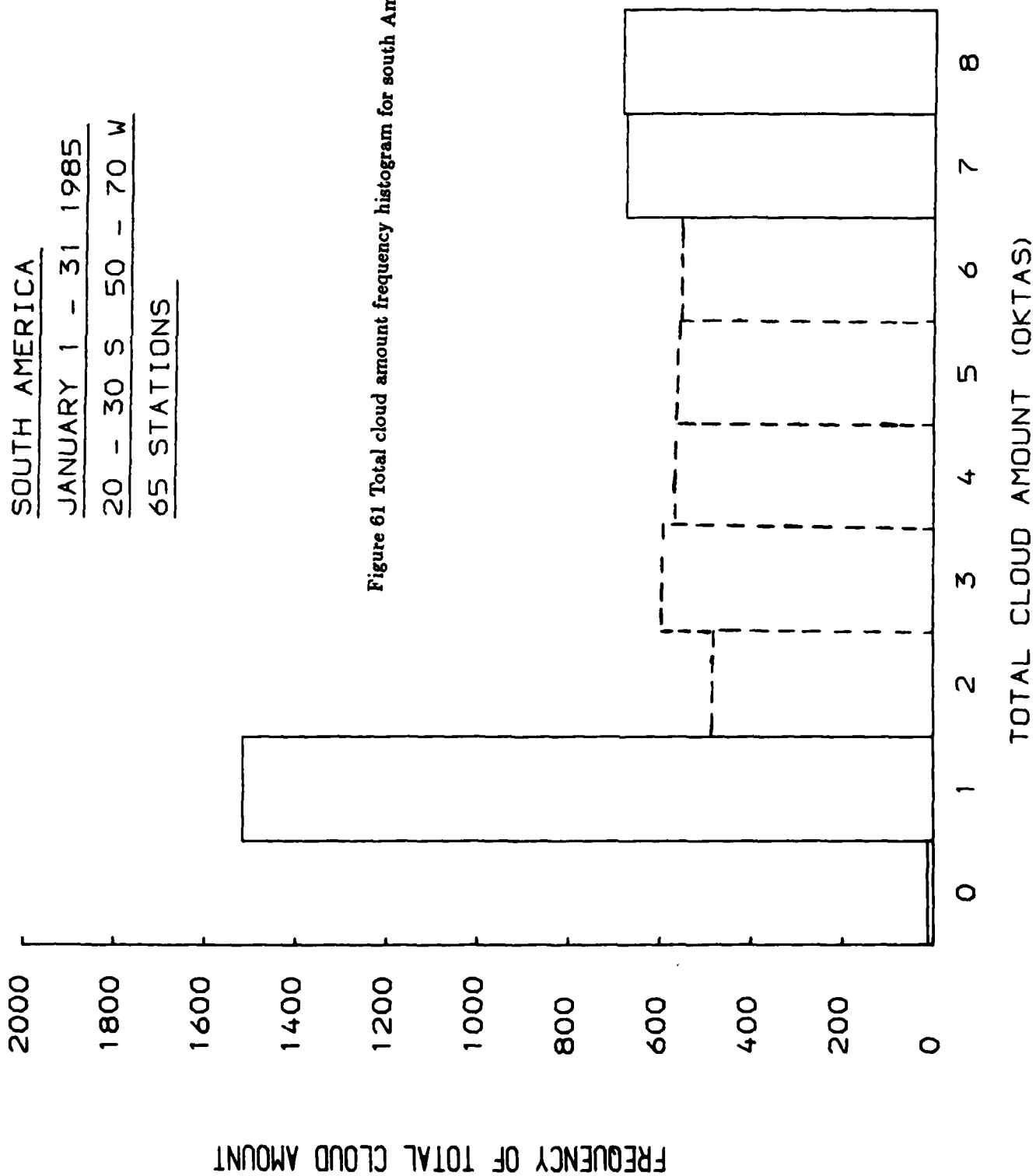


Figure 61 Total cloud amount frequency histogram for south America, January 1985.

western Europe (Figure 59) shows cases of clear sky comprising about 2% of the total reports with a ratio of incidences of 1:0 oktas of the order of 15:1. The frequency of clear sky is well below the mean long-term value over the area for June, July and August 1971-1980 of 10% quoted in Hahn *et al.* (1984) and it was by no means an abnormally cloudy month over the region.

Sharp peaks in the histograms for 1 okta were also found over India and South America for January 1985 with less than 1% of the total number of reports in each case showing 0 oktas. The corresponding climatological frequencies quoted in Hahn *et al.* are many times higher and since in both cases the frequency of 7 and 8 oktas is very similar (not ruling out 7 okta bias but suggesting that no strong preference for 7 oktas exists) it seems likely that the reporting practice is in these two examples (particularly over India) leading to an overestimate in the mean monthly cloud amount. With only two months of data at our disposal it is not possible to determine whether the above were isolated cases or whether this bias is more extensive. It is generally assumed that the observing procedure is self-compensating in respect of this type of bias and so little, if anything, seems to have been done to correct for it in the past. Although it may be of limited importance compared to the other biases discussed here, the examples above indicate it worthy of further consideration.

### 3. Global evaluation of surface cloud observations

#### 3.1 Data

The data set is identical to that used in the bias investigation, the source and format of which was outlined in Section 2.2. Data used for climatological purposes should be as representative of an area (or station) as possible. Therefore despite the problem of likely attendant bias, nighttime observations were included in the analyses and given the same weighting as daytime reports. No substantial diurnal sampling bias was discovered although it is known that a few stations do not report at night. The numbers of reports from land stations considerably outweighed the numbers

received from ships, partly due to the fewer stations at sea and partly because clouds are recorded only at 6-hourly intervals from ships (0, 6, 12 and 18 GMT) whilst synoptic reports on land are required every 3 hours (0, 3, 6, 9, 12, 15, 18 and 21 GMT). All reports were coded according to the WMO cloud classification (WMO, 1984).

### **3.2 Biases within the observations**

Surface cloud observations decrease somewhat in value when the clouds assume complex layered arrangements and their correct reporting becomes subject to varying degrees of bias, particularly during the hours of darkness. Problems of nighttime detection and those associated with "partial undercast" situations are discussed in Section 2, as are the slight biases resulting from the accepted definitions of 1 or 7 oktas cloud amount. In addition to these the observer is unable to detect middle or upper level clouds in the presence of an obscuring overcast. This layer obscuration bias can result in systematic underestimates of cirrus in many cases. Over the oceans observations made from transient ships may be affected by the use of inexperienced or untrained observers who may fail to record the presence of a particular cloud type or misinterpret other types. Certain ships are likely to alter course slightly if it permits them to bypass severe weather, thus introducing what is termed "fair-weather" bias. Bunker (1976) and Quayle (1980) compared observations from weather ships with those from passing vessels to assess the impact of these two biases whilst Hahn *et al.* (1982) analysed the data from Quayle to compare cloud amount estimates, finding that there was very little difference between estimates from stationary weatherships and passing ships in close proximity.

The need to avoid contamination of reports by bias prompted Warren *et al.* (1986) to use only daytime observations of cirrus, altostratus and altocumulus for constructing their global maps of frequency of occurrence of these cloud types. As increasing amounts of low and middle cloud increase the risk of incurring partial undercast bias, reports of upper cloud in multilayered situations were restricted by Warren *et al.* to those with no more than 6 oktas of lower cloud present.

**Table 6 Sources of Bias within Surface Observations**

- i) Night-detection bias
- ii) Partial-undercast bias
- iii) 1, 7 okta bias
- iv) Fair-weather bias
- v) Observer bias
- vi) Layer obscuration bias

Surface cloud retrievals are known to "overestimate" cloud amount systematically compared to satellite data (Godshall, 1971; Hoyt, 1977). The skycover measured by an observer on the ground may exceed the earthcover detected by the satellite when the clouds have significant vertical as well as horizontal dimensions. A relationship between the two quantities has been proposed by Malick *et al.* (1979) on the basis of the analysis of a large number of all-sky photographs. It should also be noted that the sides of vertically developed clouds bias (upwards) any satellite-derived estimate of cloud amount when look angles are other than zero.

Eliminating reports in which bias is suspected represents the easiest method of removing the effects due to bias since at present they have not been quantified. However, such a policy was not adopted here. A list of the principal biases is given in Table 6.

### 3.3 Analysis Procedure

#### i) Extraction of Required Information

The first requirement for any report, either from land or ocean, to be used was that its source, i.e. latitude and longitude both fell within sensible bounds. All reports originating from bogus locations were rejected from the analysis to avoid mislocation. A complete report comprised a value of total cloud amount in oktas, 9 being used to indicate obscuration of the sky by either mist/fog or falling precipitation; a number in the range 0-9 describing the type of low, middle and high cloud present according to the WMO classification as given in Tables 1-3 with 255 denoting obscuration of the appropriate layer; a value for low cloud amount in oktas (or middle level amount in the absence of low cloud) and a subsequent report of the type, level and amount of the "first reported layer". It was difficult to identify any definite trend as to which layer the first reported layer referred. If there were additional layers to report these were detailed in the "additional data section" of each report with the type and amount supplied for each additional layer. In some cases difficulties arose when it was discovered that all the relevant data were located in the additional data

section after the main section of the report had indicated no information available. As a precaution a contingency operation was used to make sure that all available information was extracted from each report.

## ii) Cloud Type Categories

Tables 1 to 3 are derived from the WMO manual on codes (WMO, 1984) and define the 27 cloud types of the synoptic code that are known to occur. All these classifications are well illustrated in the most recent WMO cloud atlas (WMO, 1987). Nine separate categories are defined for low, middle and high clouds; however, a more simplified grouping of cloud types was required for the purpose of global evaluation. The 27 categories were merged into six following the method of Hahn *et al.* (1982). Table 7 defines the six merged groupings and the WMO codes associated with each grouping. The 27 original categories do not always define specific occurrences of individual types, particularly for middle and low clouds. For example low cloud category 9 ( $C_L = 9$ ) denotes principally cumulonimbus whilst permitting the possible presence of cumulus, stratocumulus and stratus. In such cases it was decided that the principal cloud type defined in a code would be exclusive to that code number. This policy may have been responsible for the introduction of slight biases for certain cloud types. As there was no code number defined exclusively for nimbostratus the requirement for its presence in the codes  $C_M = 2$  and 7, was that the station was experiencing precipitation at the time. The present weather code was checked in such cases. It was also decided that if  $C_L = 7$  was reported together with precipitation, then nimbostratus was present too. Cases of clear sky were defined by zero sky cover or, if unavailable, by the absence of clouds from each of the three reporting levels.

## iii) Cloud Amounts

Total cloud amount represents the skycover as estimated by the observer in oktas. Whenever a value of 9 was encountered the present weather code was checked for fog or precipitation events. It was decided that in either case the use of 8 oktas would be representative despite the small

**Table 7 Merged Cloud Types**

| <i>Cloud types referred<br/>to here</i>              | <i>WMO Observer Codes<br/>assigned to each type</i>                          |
|------------------------------------------------------|------------------------------------------------------------------------------|
| 1. Cirrus (Ci)/Cirrostratus(Cs)/<br>Cirrocumulus(Cc) | C <sub>H</sub> 1-9                                                           |
| 2. Altostratus(As)/Alto cumulus(Ac)                  | C <sub>M</sub> 1,3,4,5,6,8,9<br>and C <sub>M</sub> 2,7 if no precipitation   |
| 3. Nimbostratus (Ns)                                 | C <sub>M</sub> 2,7 if precipitation<br>and C <sub>L</sub> 7 if precipitation |
| 4. Cumulus (Cu)                                      | C <sub>L</sub> 1,2                                                           |
| 5. Cumulonimbus (Cb)                                 | C <sub>L</sub> 3,9                                                           |
| 6. Stratus(St)/Stratocumulus(Sc)                     | C <sub>L</sub> 4,5,6,8<br>and C <sub>L</sub> 7 if no precipitation           |

Notation used in text and  
figures is,

group 1 is hereafter referred to as Ci/Cs/Cc  
group 2 is hereafter referred to as As/Ac  
group 3 is hereafter referred to as Ns  
group 4 is hereafter referred to as Cu  
group 5 is hereafter referred to as Cb  
group 6 is hereafter referred to as St/Sc

number of occasions in which precipitation does not descend from an overcast sky for example, at the end of a shower when skies are clearing. Values of '9' were discarded if the present weather code failed to indicate fog or precipitation. The code parameter  $N_H$  referred to the amount of low cloud present ( $C_L = 1-9$ ) or middle cloud ( $C_M = 1-9$ ) if no low cloud was recorded. Information relating to the "first reported layer" often gave the amount of cloud in the same level as for  $N_H$  making it redundant.

The maps depicting the distribution of cloud amount were constructed only from reports where the cloud was present. They, therefore, depict the average "amount when present" and are representative of exactly what the observer sees (in terms of amount in each layer), i.e. for separate observations in the presence of two layers, the random overlap equation was not adopted. The time-averaged cloud amount is defined as the product of the frequency of occurrence of cloud at a particular level and the mean amount when present for the same cloud. These maps have not yet been constructed for the data concerned but may serve a useful purpose in comparison with time-averaged products from ISCCP (Table 1, Rossow *et al.*, 1985).

#### iv) Frequency of Occurrence of Cloud Types

The frequency of occurrence of a cloud type is defined as the number of times the cloud type is observed divided by the number of occasions information about that cloud level is received, i.e. the code for the level lies in the range 0-9 or is supplied in the additional data section. As expected the number of reports supplying information about the middle and upper levels is rather less than the number contributing to the low cloud statistics. The frequency of clear sky was defined as the total number of occasions when either the skycover was zero or each level was devoid of clouds, divided by the times when information on all three levels was available.

The maps for low level cloud should be representative of reality but figures computed for middle and upper level clouds are affected (to an unknown degree) by partial undercast bias, causing a systematic underestimation in the frequencies of both cirriform ( $C_i$ ,  $C_s$ ,  $C_c$ ) and altiliform ( $A_s$ ,  $A_c$ )

clouds. The contingency probabilities (part vi) provide a measure of the likelihood of middle or upper cloud being present when partial undercast bias is suspected. As the future role of the maps, if any, would lie in comparison with satellite retrievals rather than in climate modelling studies, the frequencies have not been modified to include biases and the contingency probabilities are evaluated separately.

#### v) Exclusive Probability

The exclusive probability of occurrence refers to the chance of an observer detecting an individual cloud type by itself. It was defined here as the number of occasions a particular type was reported alone divided by the number of times information concerning all three cloud levels was given in a report. Individual types occurring with regularity by themselves, especially cirrus, indicate useful testing grounds for algorithms aiming to retrieve a particular type (cf. Starr, 1987).

#### vi) Contingency Probabilities

The concept of contingency probabilities as applied to the co-occurrence of cloud types was introduced by Hahn *et al.* (1982, 1984). Examples of contingency probabilities of the type  $P(\text{Lower} \Rightarrow \text{Upper})$  are presented here for various combinations of lower and upper cloud (Table 8). The idea was introduced as a means of avoiding unnecessary levels of bias in surface observations. If, for example, an observer suspected the presence of cirrus cloud but could not detect any through a small gap in a stratocumulus layer, the contingency probability  $P(\text{Sc} \Rightarrow \text{Ci})$  would indicate the (long term) likelihood of cirrus being present. The values computed for these maps assume that the likelihood of the upper cloud being there is the same when it is visible to the observer as when it is invisible to the observer due to the lower cloud being overcast. Whether this assumption conforms to reality is discussed in Section 2.

The probabilities are computed as follows. The number of occasions on which both lower and upper cloud types were present is divided by the number of times the lower cloud is present and information about the upper level was available, i.e. it was not obscured from view. No probability

**Table 8 Combinations of Lower (L) and Upper (U) Cloud Type Used in  
Contingency Probability Determination  $P(L \Rightarrow U)$**

|    | L     | U        |
|----|-------|----------|
| 1. | Cu    | Ci/Cs/Cc |
| 2. | Cb    | Ci/Cs/Cc |
| 3. | Ns    | Ci/Cs/Cc |
| 4. | As/Ac | Ci/Cs/Cc |
| 5. | St/Sc | Ci/Cs/Cc |
| 6. | Cu    | As/Ac    |
| 7. | Cb    | As/Ac    |
| 8. | St/Sc | As/Ac    |

was computed if a grid square contained less than 20 occasions on which both upper and lower clouds were observed.

### 3.4 Map Format

The maps are divided into two sections, those for land and those over the ocean. There were approximately half the number of ocean stations (ships) as there were land stations, in both months ( $\sim 5000$  compared to  $\sim 9000$ ). The land data are mapped at a resolution of  $5^\circ \times 5^\circ$  (ISCCP data are to be mapped at a resolution of  $2.5^\circ \times 2.5^\circ$ ) for the area of the globe lying between  $60^\circ\text{N}$  and  $60^\circ\text{S}$ . To maintain an approximately equal area within each grid square the resolution was increased to  $10^\circ \times 10^\circ$  poleward of  $60^\circ\text{N}$  and  $60^\circ\text{S}$ , although it is recognised that this is by no means a perfect remedy to the problem of the Earth's curvature at higher latitudes. The oceanic data were plotted at a resolution of  $10^\circ \times 20^\circ$  except for cloud amounts which were mapped at  $10^\circ \times 10^\circ$ . The world coastline has been superimposed on to the ocean maps but is absent from the land maps although in most cases the outline of the continents is recognisable.

The numbers have been plotted at the geographical centre of each grid square and in certain cases may overlap onto neighbouring land (or ocean). In such situations the number will be representative only of the land (or ocean) fraction contributing to the grid square. The ocean data except for the distribution of observations are given as percentages but in order to avoid numbers running into one another over the higher-resolution grid squares on land, the percentages are represented as single integers representing 10 percent increments, even though this process is rather downgrading the information. Maps showing the density of observations are presented in tens over the ocean and in hundreds over land. A plus sign indicates a grid square containing in excess of 1000 observations for the month. Where no number is found for a grid square either the square was devoid of stations or the value of the associated parameter was less than or equal to 10%. Table 9 gives a description of

**Table 9 Classification of Cloud Maps**

| <i>Figure</i>  |         | <i>Month</i> | <i>Contents</i>                                   |
|----------------|---------|--------------|---------------------------------------------------|
| <i>Numbers</i> |         |              |                                                   |
| <b>Land</b>    |         |              |                                                   |
| 62-66          | January |              | Distribution of observation type                  |
| 67-71          | July    |              | Distribution of observation type                  |
| 72-78          | January |              | Frequency of occurrence of cloud types            |
| 79-85          | July    |              | Frequency of occurrence of cloud types            |
| 86-93          | January |              | Total + level cloud amounts + standard deviations |
| 94-101         | July    |              | Total + level cloud amounts + standard deviations |
| 102-107        | January |              | Exclusive probabilities                           |
| 108-113        | July    |              | Exclusive probabilities                           |
| 114-121        | January |              | Contingency probabilities                         |
| 122-129        | July    |              | Contingency probabilities                         |
| <b>Ocean</b>   |         |              |                                                   |
| 130            | January |              | Distribution of observations                      |
| 131            | July    |              | Distribution of observations                      |
| 132-137        | January |              | Exclusive probabilities                           |
| 138-143        | July    |              | Exclusive probabilities                           |
| 144-151        | January |              | Contingency probabilities                         |
| 152-159        | July    |              | Contingency probabilities                         |
| 160-163        | January |              | Total and level cloud amounts                     |
| 164-167        | July    |              | Total and level cloud amounts                     |

the map contents. Figures 62-129 are maps of land distributions of cloud information and Figures 130-167 show oceanic distributions of cloud information.

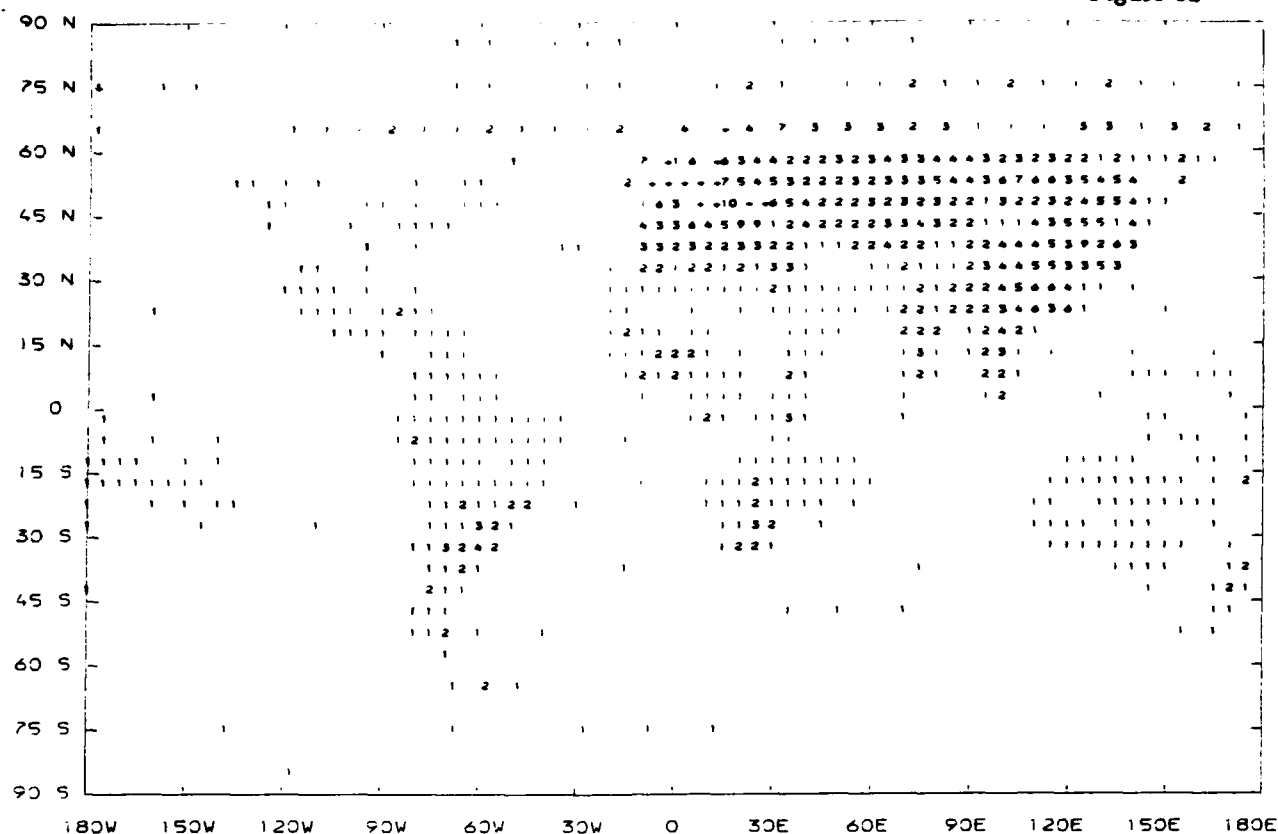
### 3.5 Discussion

The maps shown in Figures 62-167 give a general insight into the distribution of reports throughout the world for the respective months and illustrate how the frequency of occurrence of the various cloud types and their respective amounts varies on the global scale.

Both months of data fall within the operational period of ISCCP and one of the uses of the maps might be in comparison with ISCCP products over interesting areas such as those with a high exclusive probability of cirrus or which are frequently covered by a particular cloud type combination. Being derived for the months of January and July the maps naturally exhibit one or two of the expected climatological features but because they are single monthly means they are also liable to show considerable anomalies with respect to longer term climatologies such as those of Hahn *et al.* (1982, 1984). This point is illustrated in many of the maps but nowhere more so than in the frequency maps for stratus and stratocumulus over land which, for both months (Figures 77 and 84), unusually show values over many parts of the world many times higher than those quoted in Hahn *et al.*

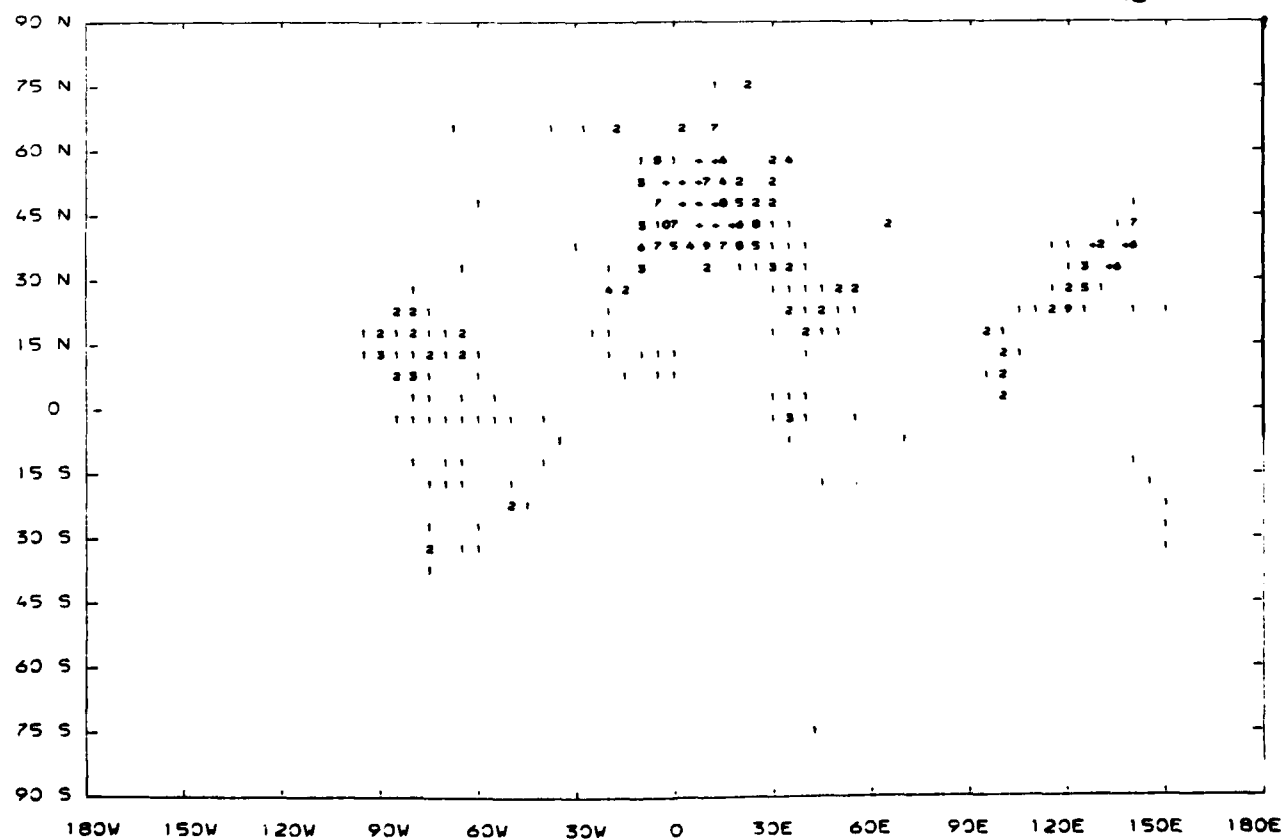
The density of stations is greater overland but even here the observing network is spatially very heterogeneous and any future comparative exercises must be carried out over the denser areas of the network. Despite the variation in station density, the numbers of observations within the majority of grid squares means that in most cases the land data are fairly representative of the area within each grid square. Unfortunately, much of the ocean is very poorly sampled and in grid squares containing less than 200 observations the results cannot be treated with confidence. The pattern of observation distribution over the ocean means that only a few regions, particularly it seems those bordering on the continents, are giving representative results, the inference being that many more months of data would be required to build up a fully representative oceanic data set.

Figure 62



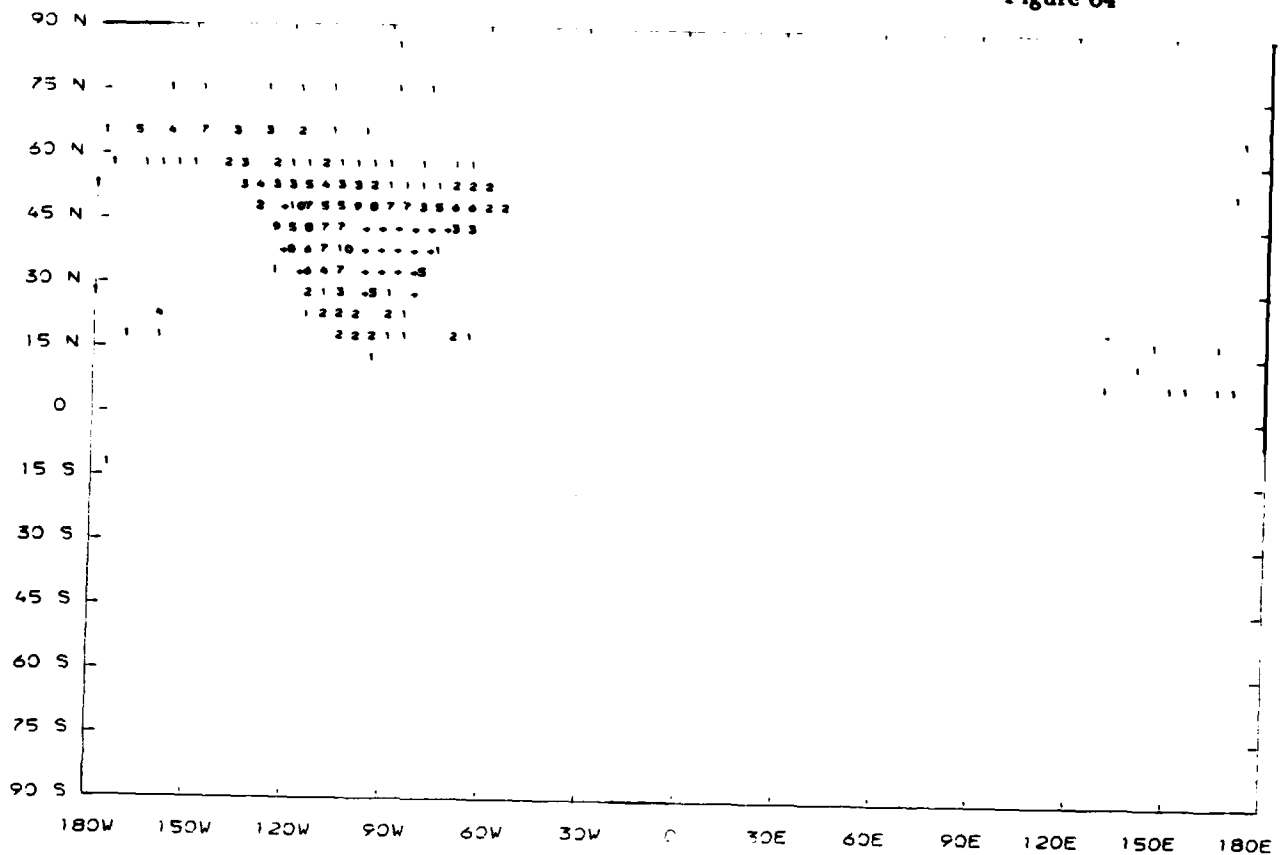
DISTRIBUTION OF SYNOPTIC OBSERVATIONS (IN HUNDREDS)  
JANUARY 1-31 1985

Figure 63



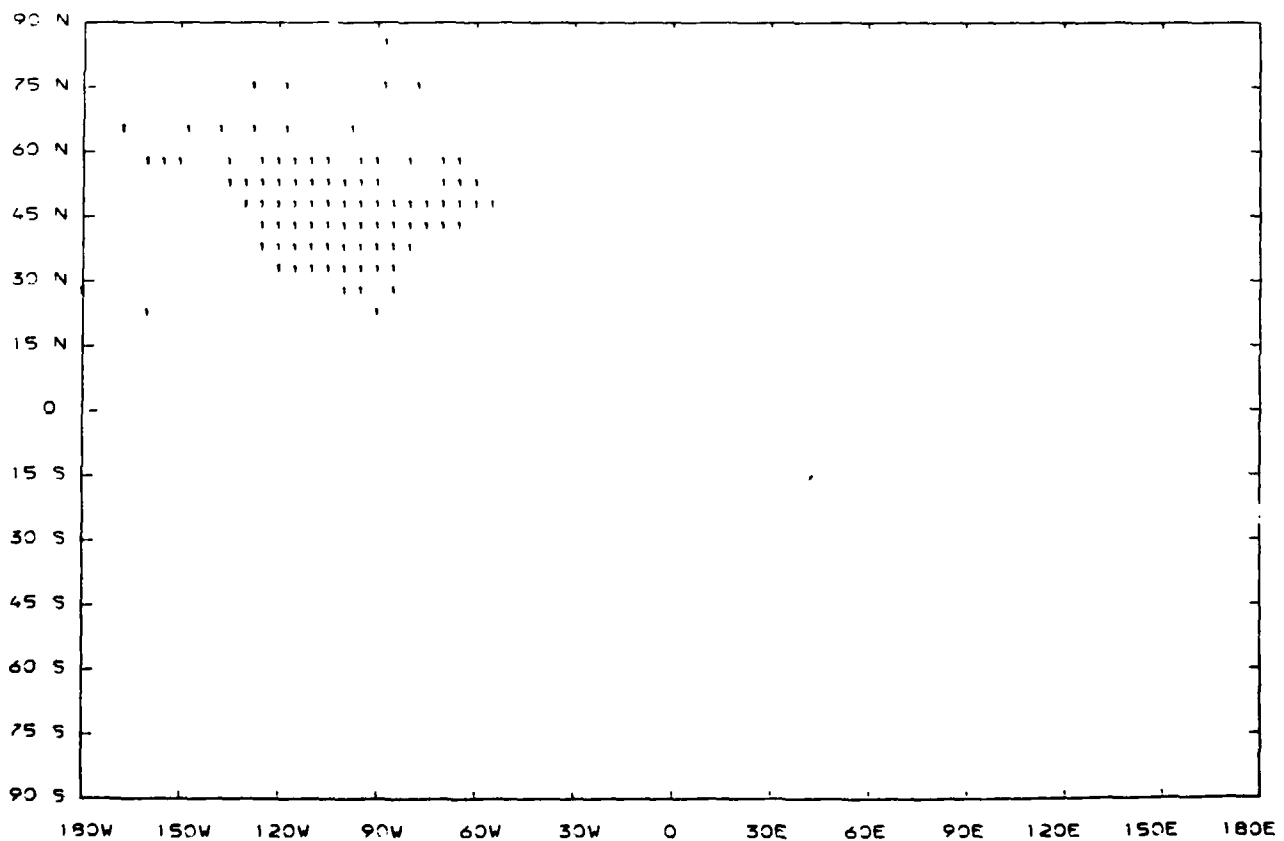
DISTRIBUTION OF MERGED SYNOPTIC-AIRWAYS OBSERVATIONS (IN HUNDREDS)  
JANUARY 1-31 1985

Figure 64

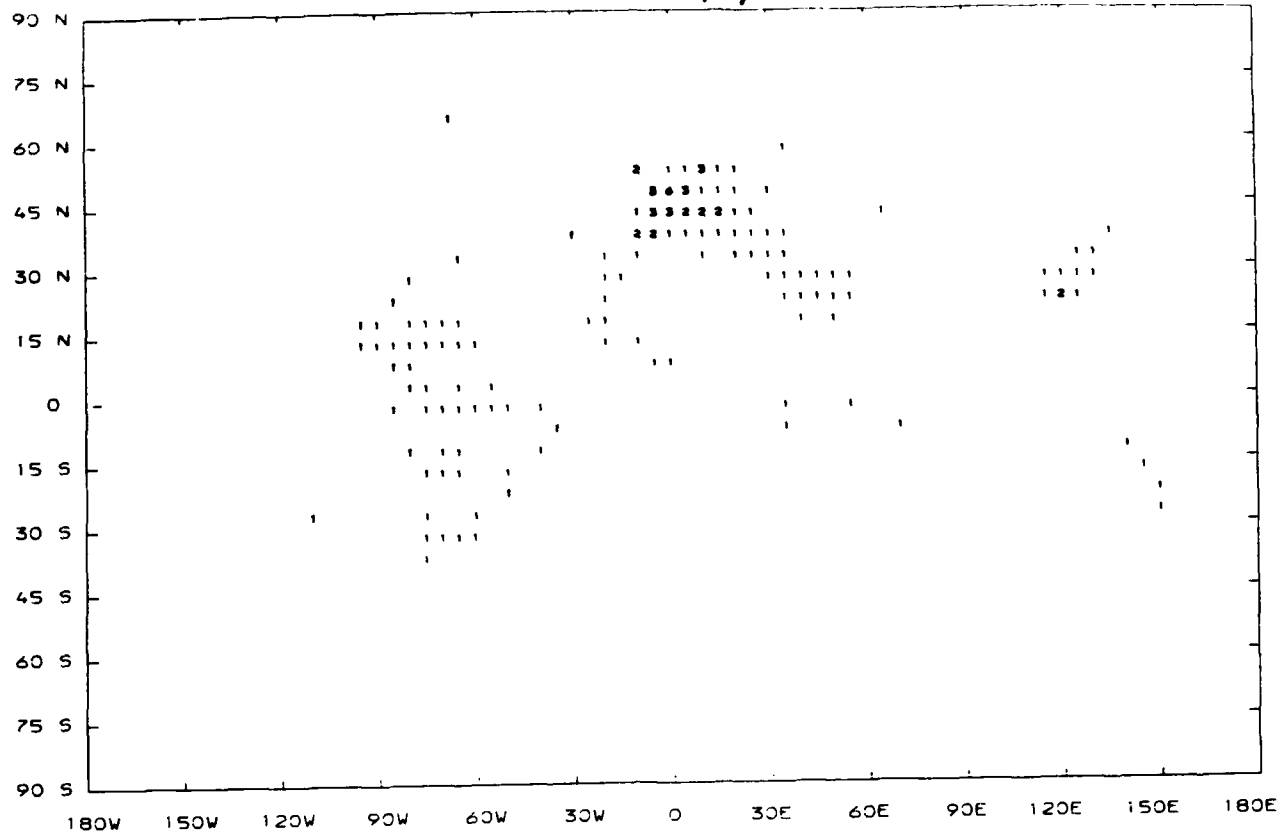


DISTRIBUTION OF AIRWAYS OBSERVATIONS (IN HUNDREDS)  
JANUARY 1-31 1985

Figure 65

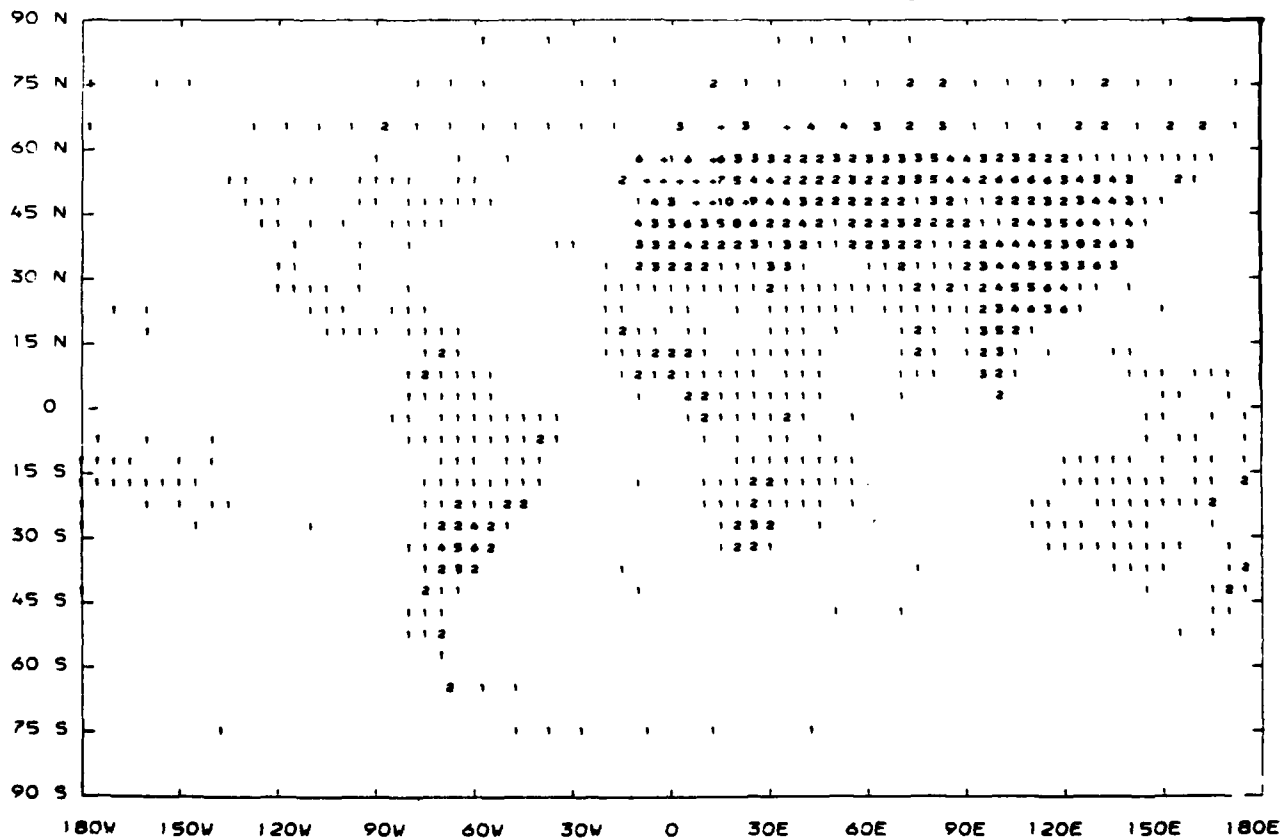


DISTRIBUTION OF METAR OBSERVATIONS (IN HUNDREDS)  
JANUARY 1-31 1985



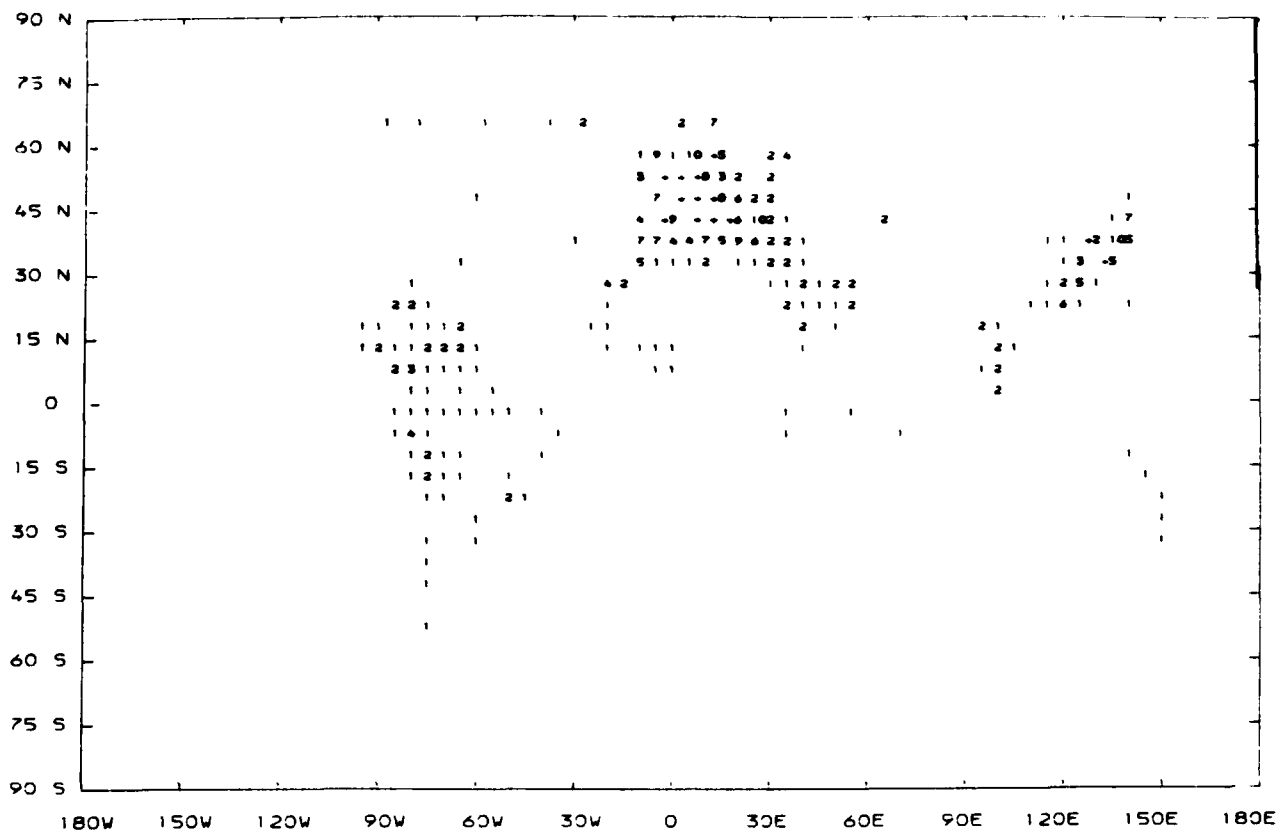
DISTRIBUTION OF MERGED SYNOPTIC-METAR OBSERVATIONS (IN HUNDREDS)  
JANUARY 1-31 1985

Figure 67



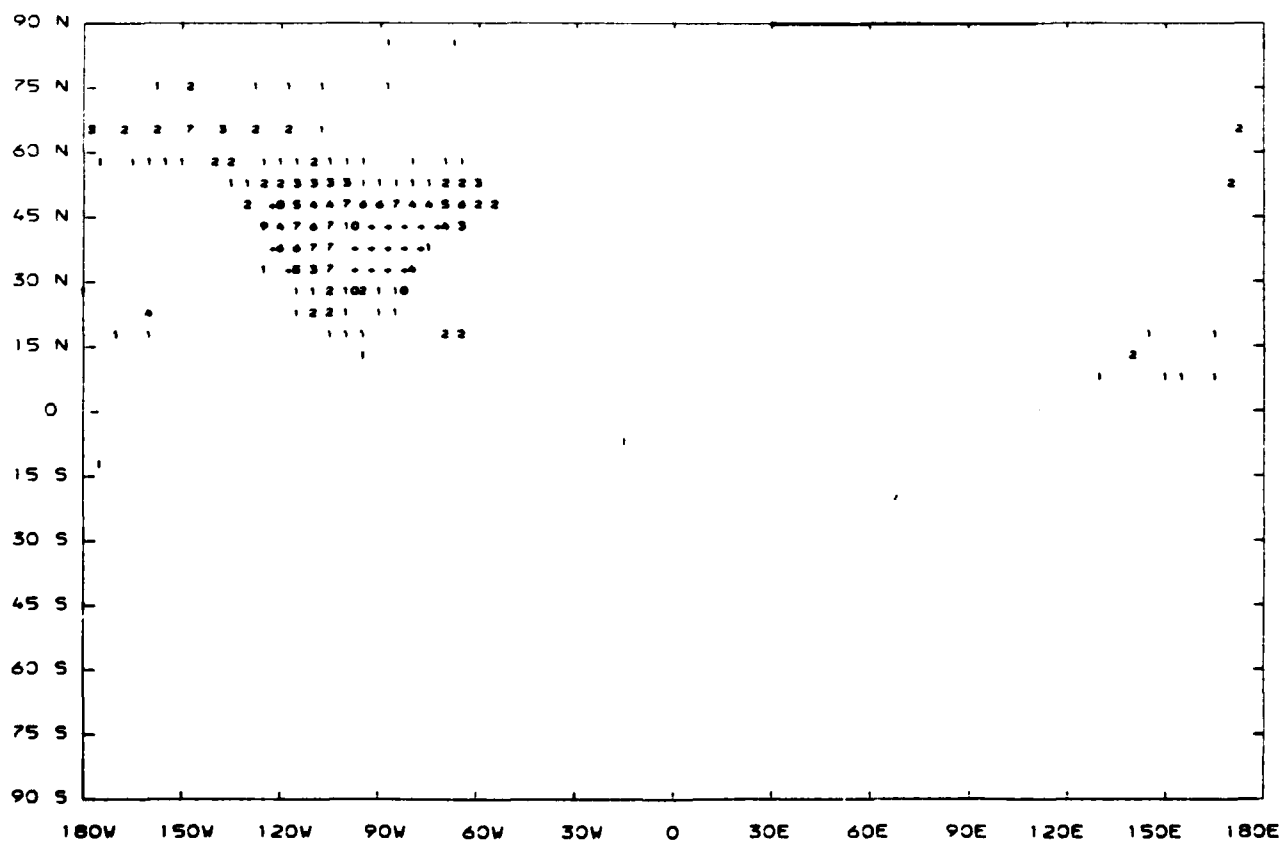
DISTRIBUTION OF SYNOPTIC OBSERVATIONS (IN HUNDREDS)  
JULY 1-31 1983

Figure 68



DISTRIBUTION OF MERGED SYNOPTIC-AIRWAYS OBSERVATIONS (IN HUNDREDS)  
JULY 1-31 1983

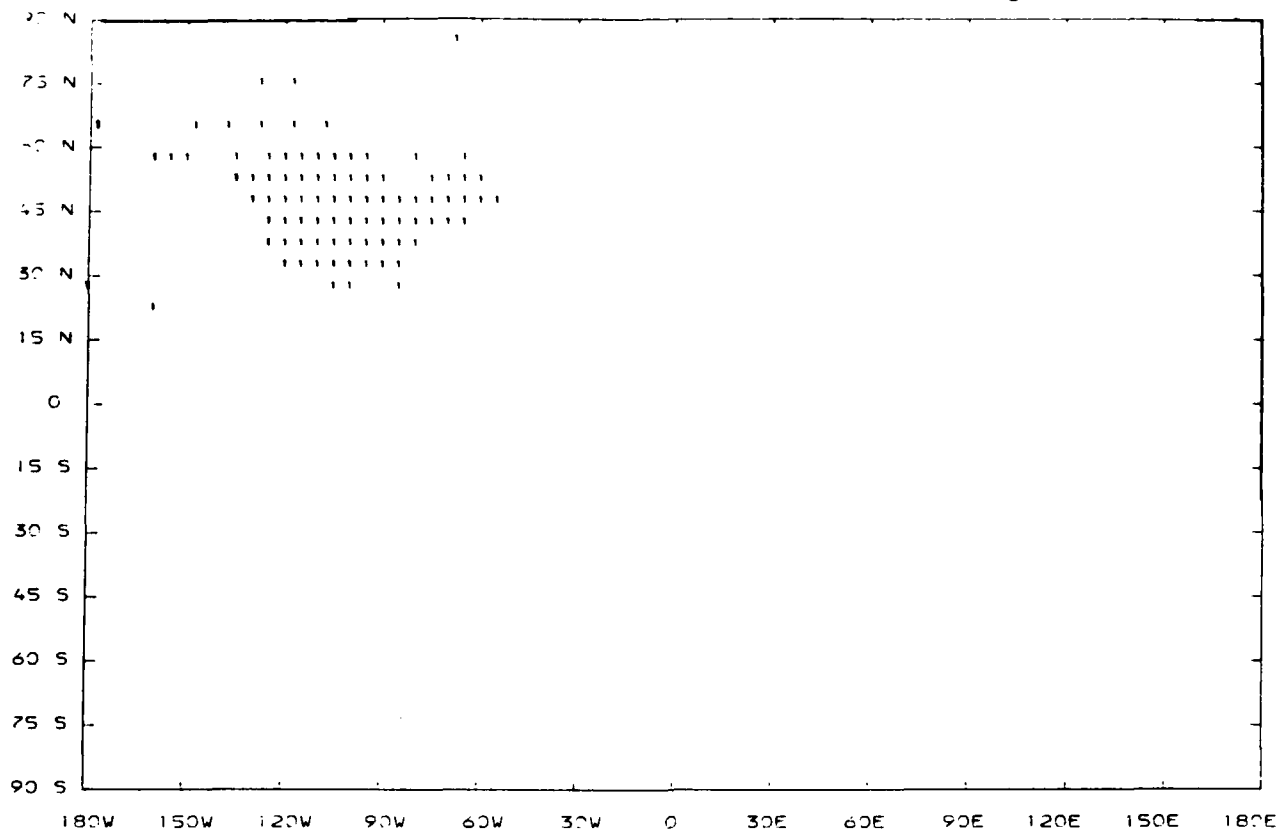
Figure 69



DISTRIBUTION OF AIRWAYS OBSERVATIONS (IN HUNDREDS)

JULY 1-31 1983

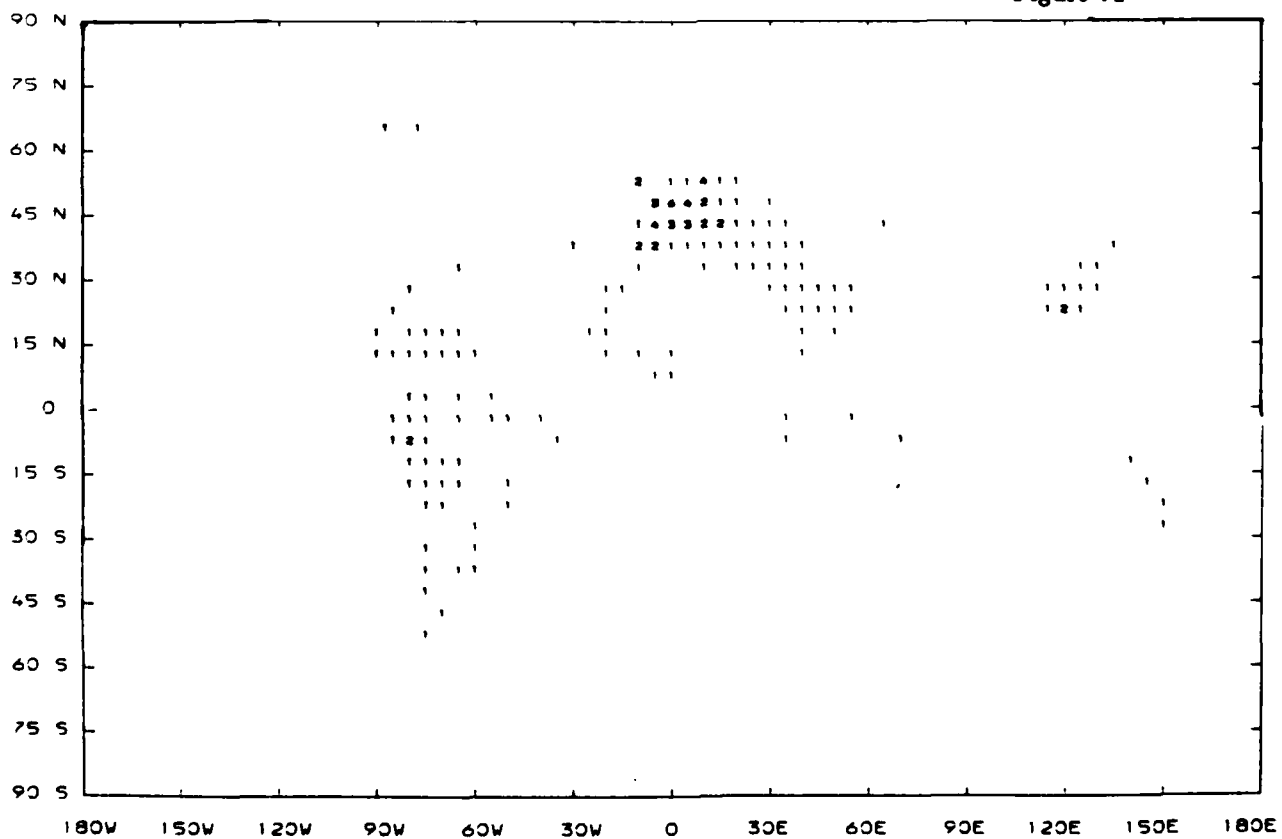
Figure 70



DISTRIBUTION OF METAR OBSERVATIONS (IN HUNDREDS)

JULY 1-31 1983

Figure 71



DISTRIBUTION OF MERGED SYNOPTIC-METAR OBSERVATIONS (IN HUNDREDS)

JULY 1-31 1983

74

Figure 72

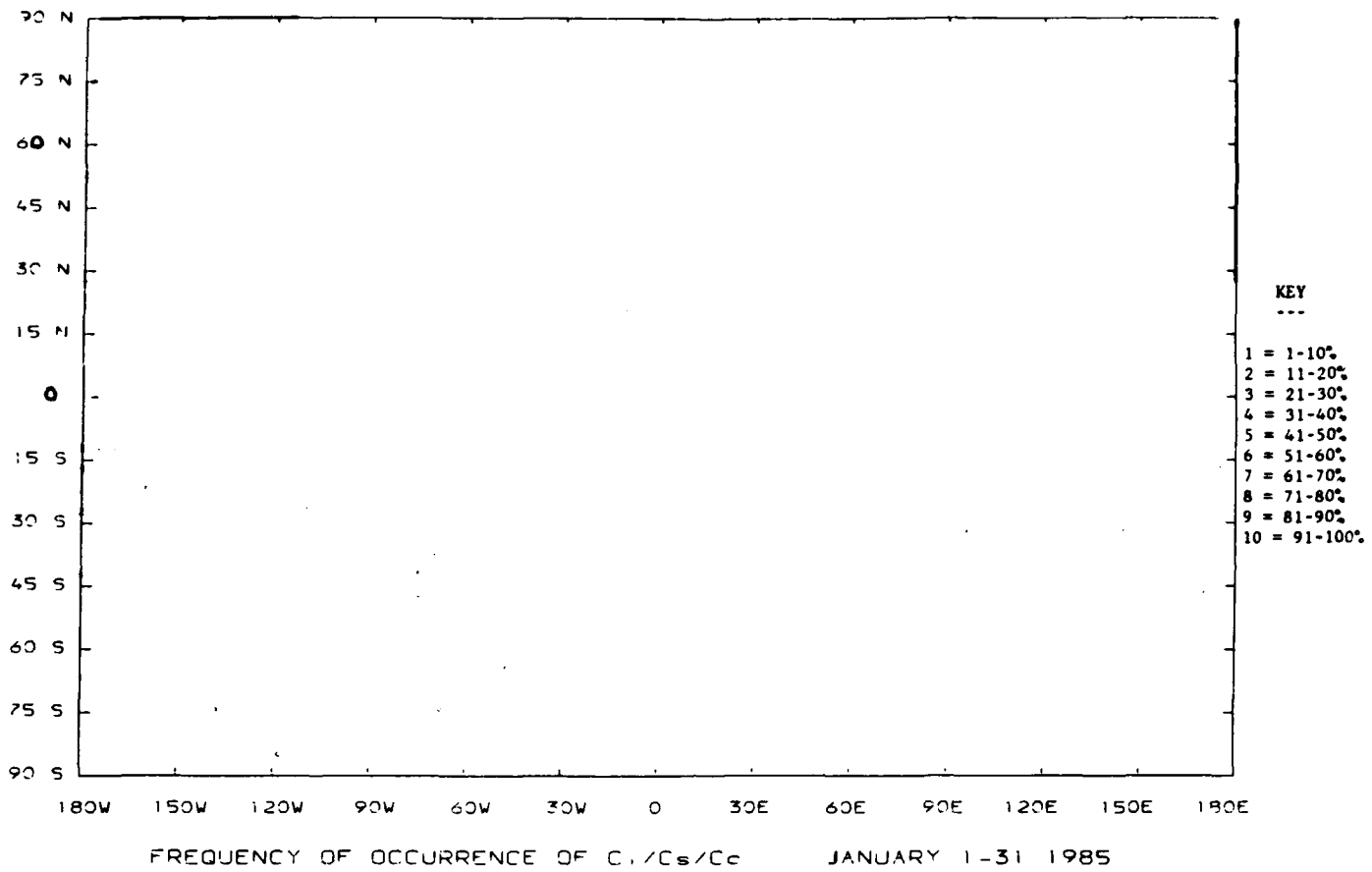
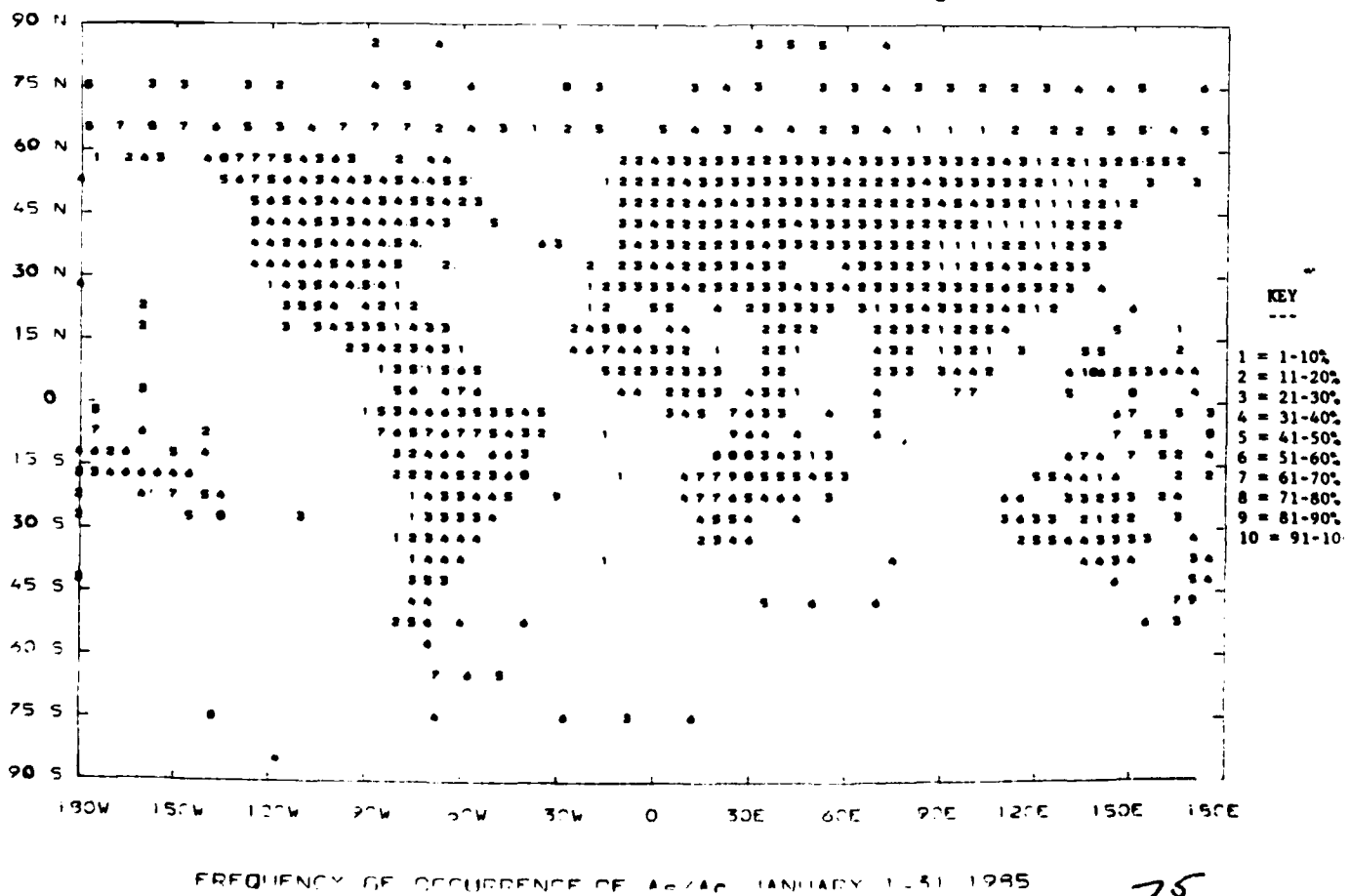
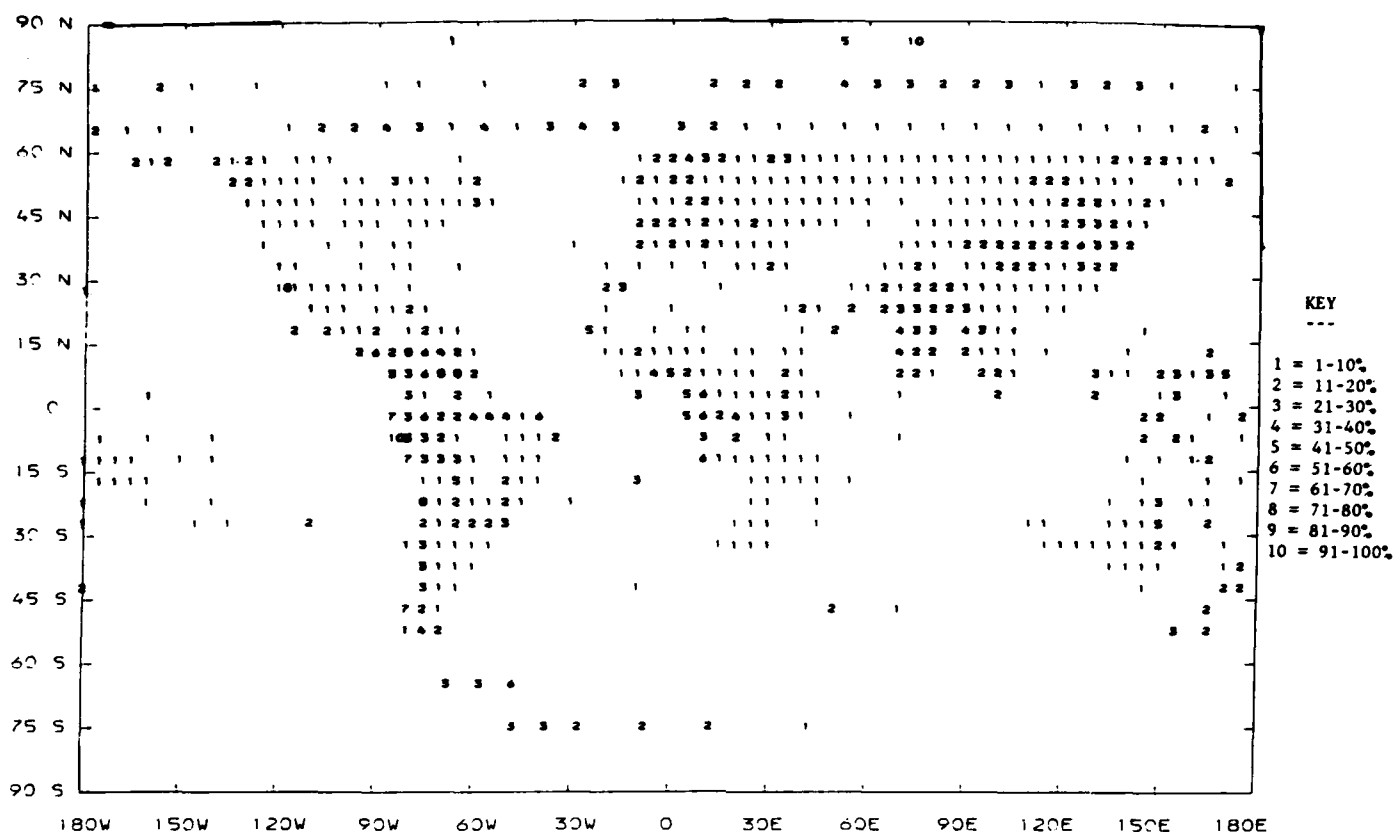


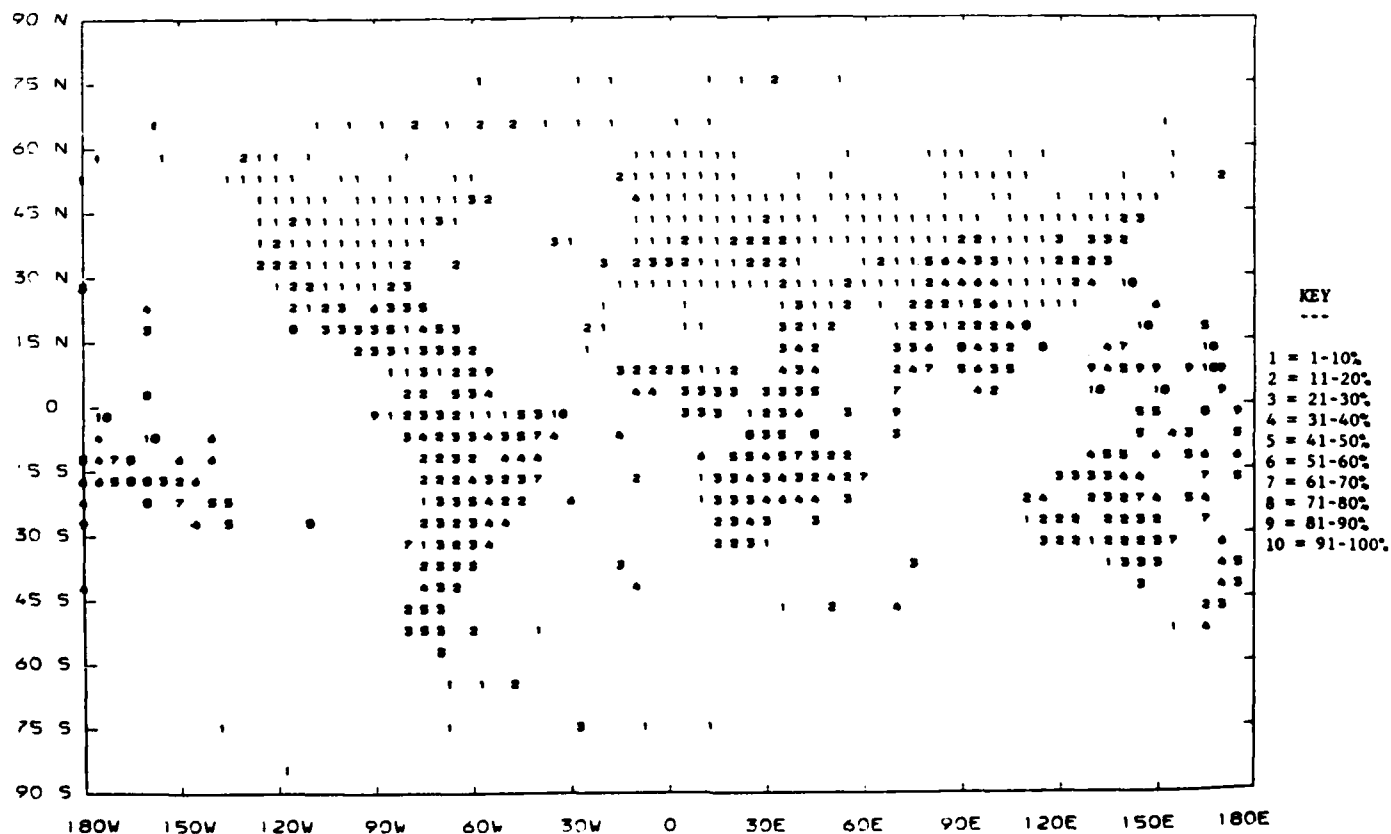
Figure 73





FREQUENCY OF OCCURRENCE OF NIMBOSTRATUS JANUARY 1-31 1985

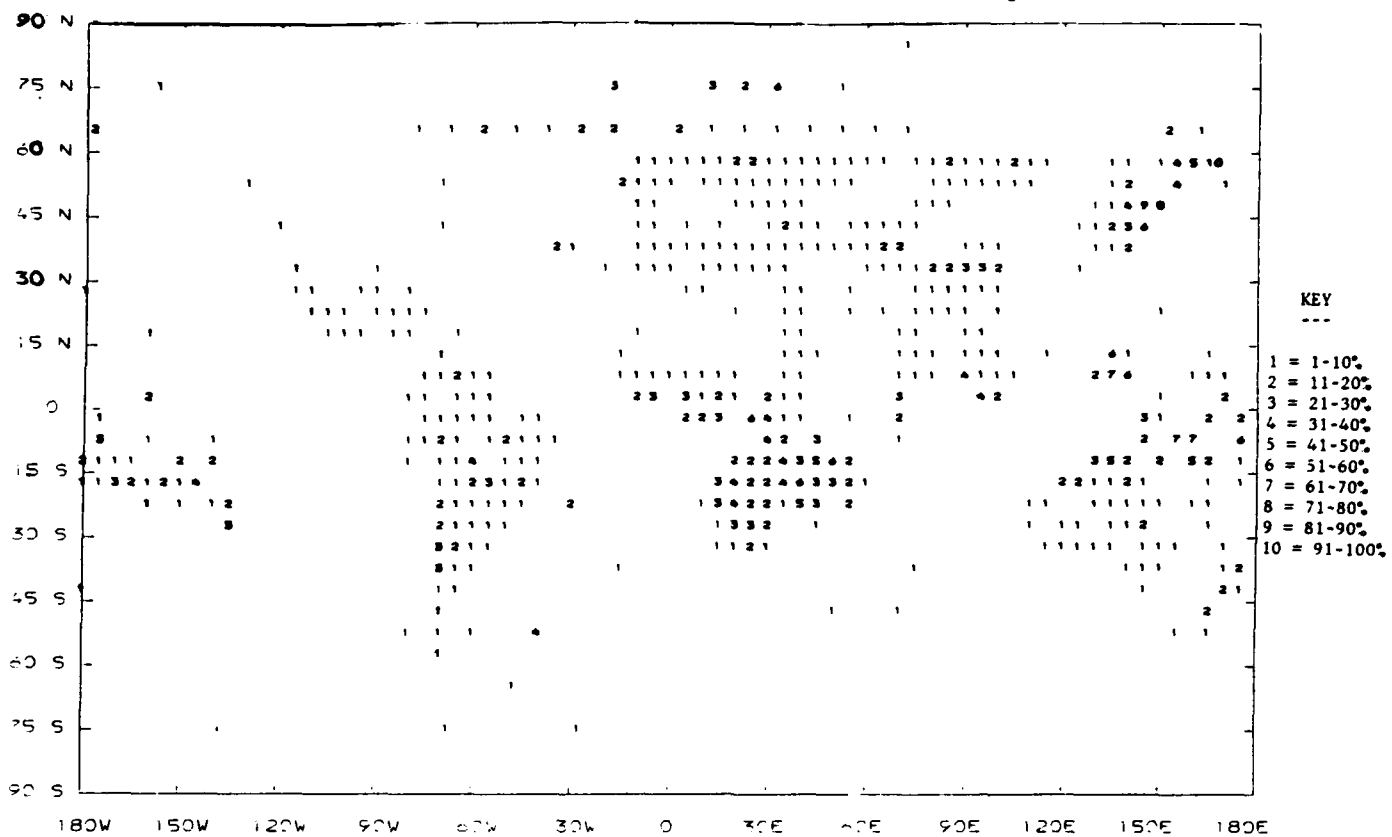
Figure 74



FREQUENCY OF OCCURRENCE OF CUMULUS JANUARY 1-31 1985

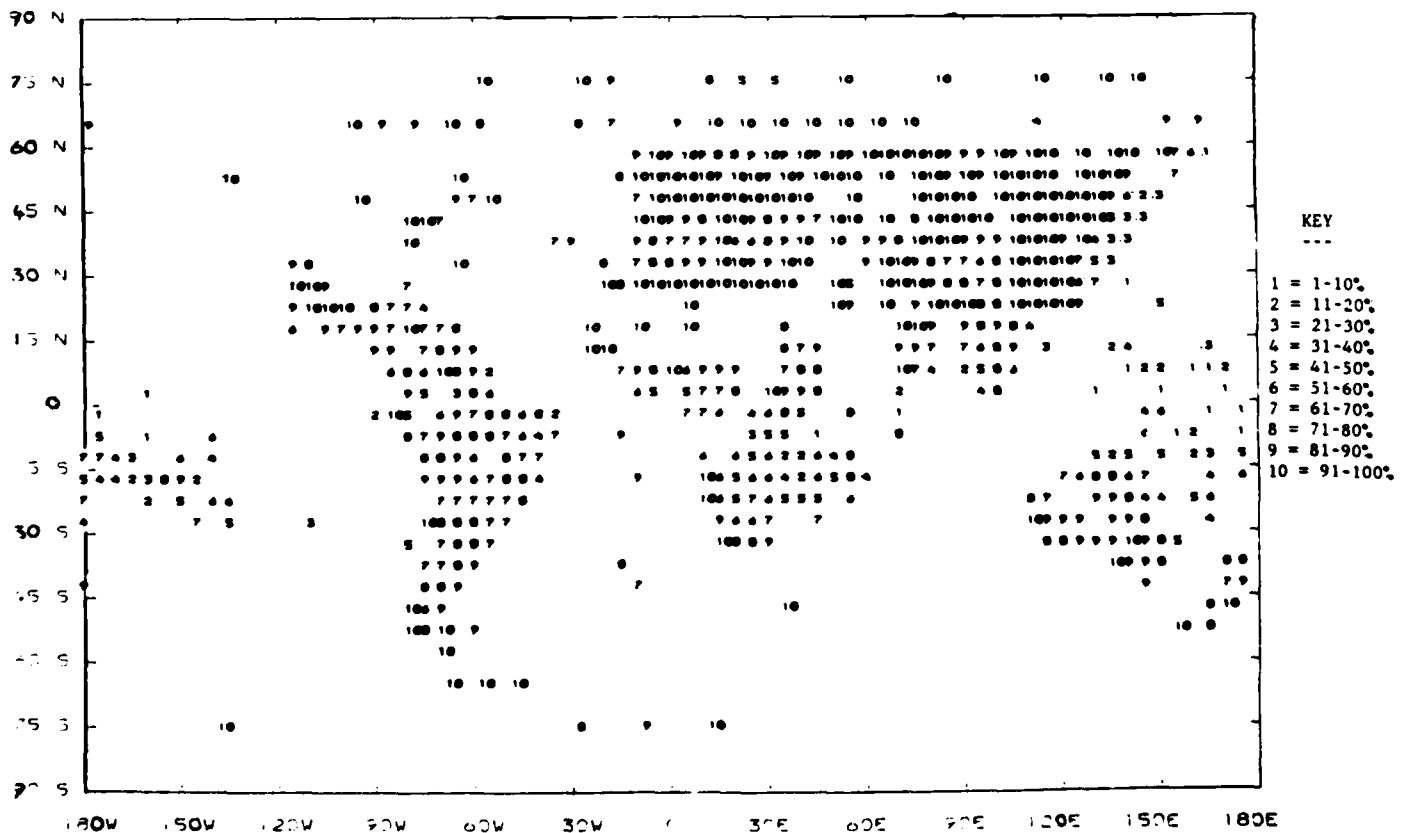
Figure 75

Figure 76



FREQUENCY OF OCCURRENCE OF CUMULONIMBUS JANUARY 1-31 1985

Figure 77



FREQUENCY OF OCCURRENCE OF Severe JANUARY 1-31 1985

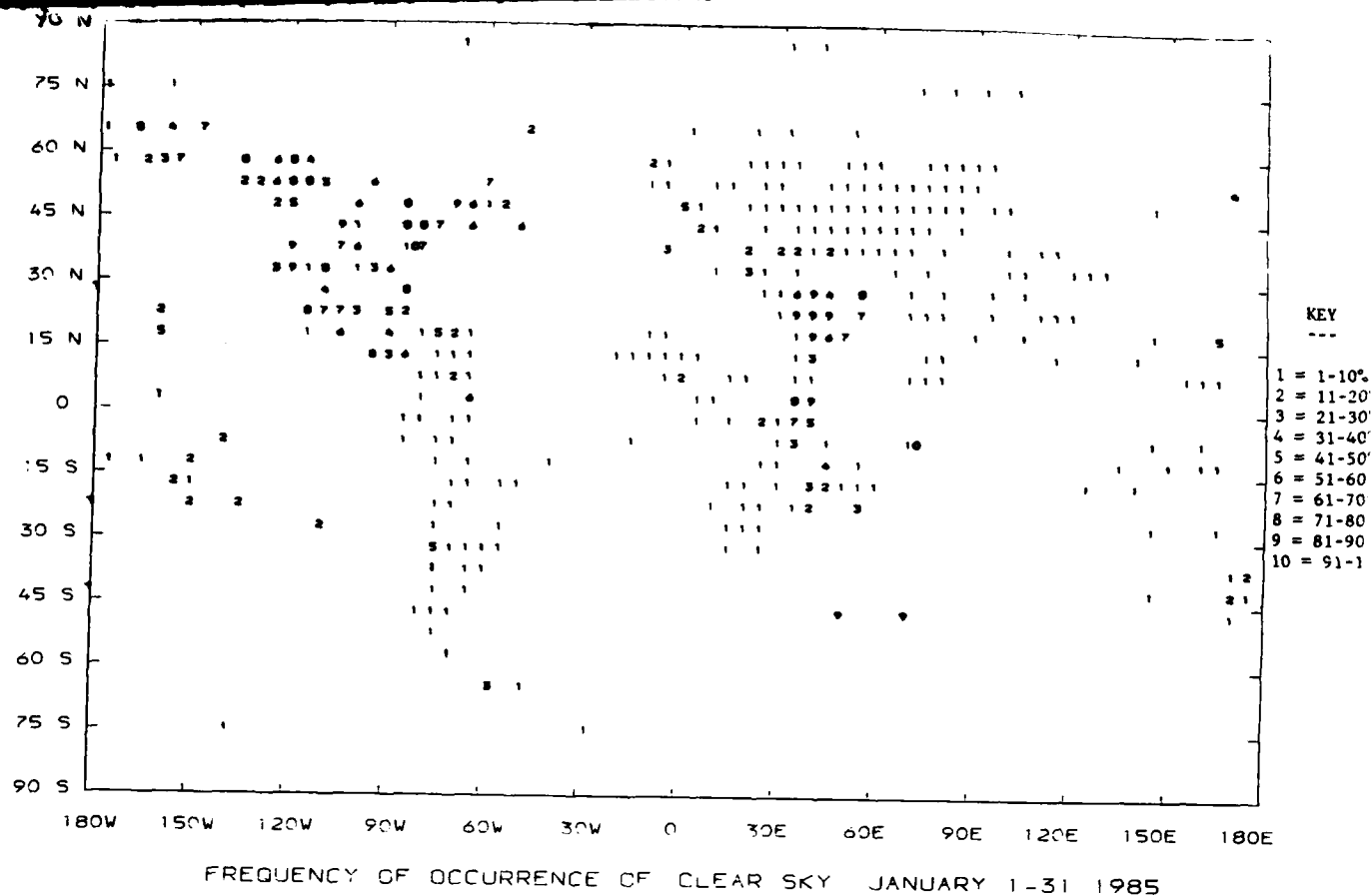


Figure 78

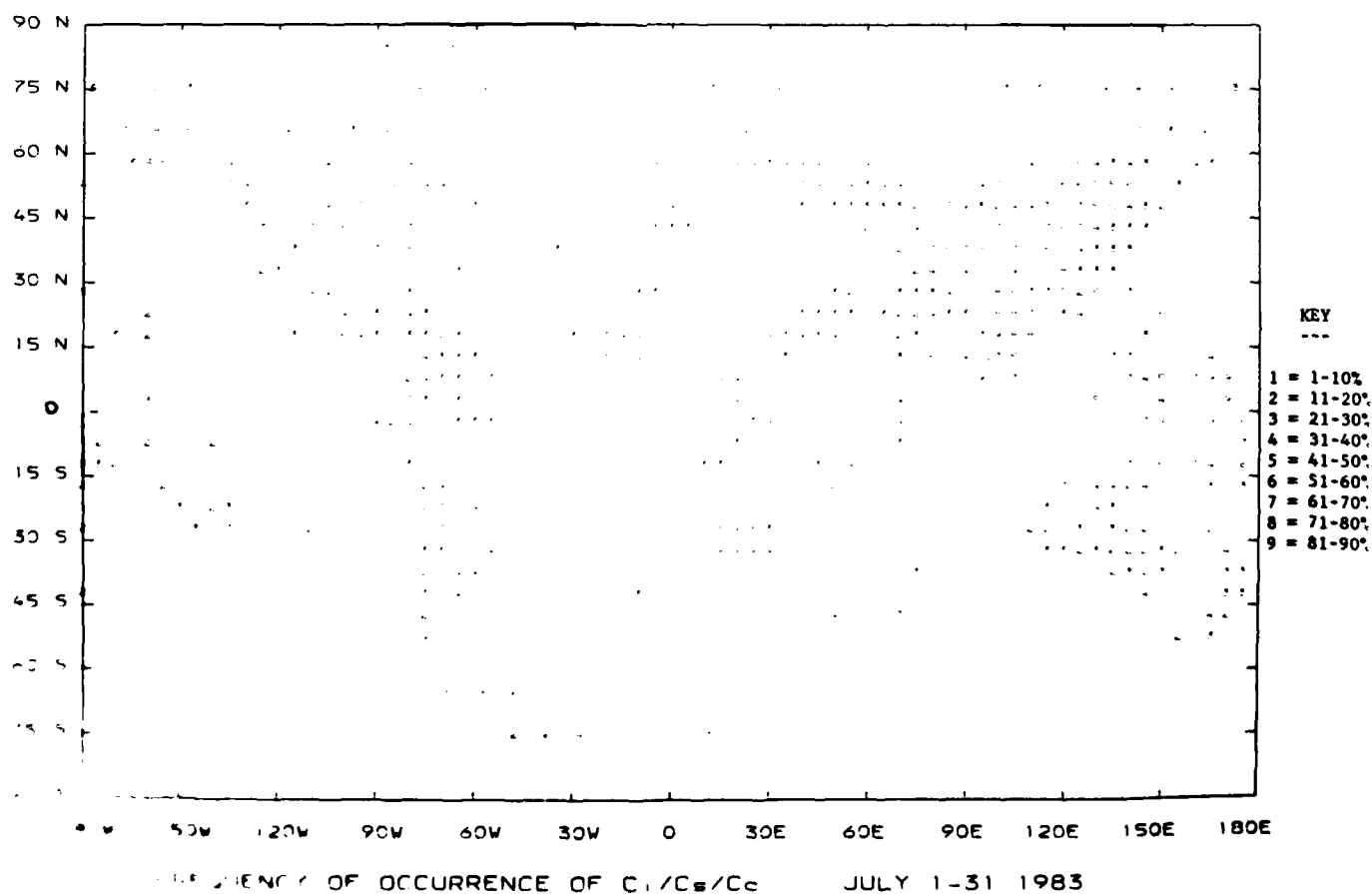


Figure 79

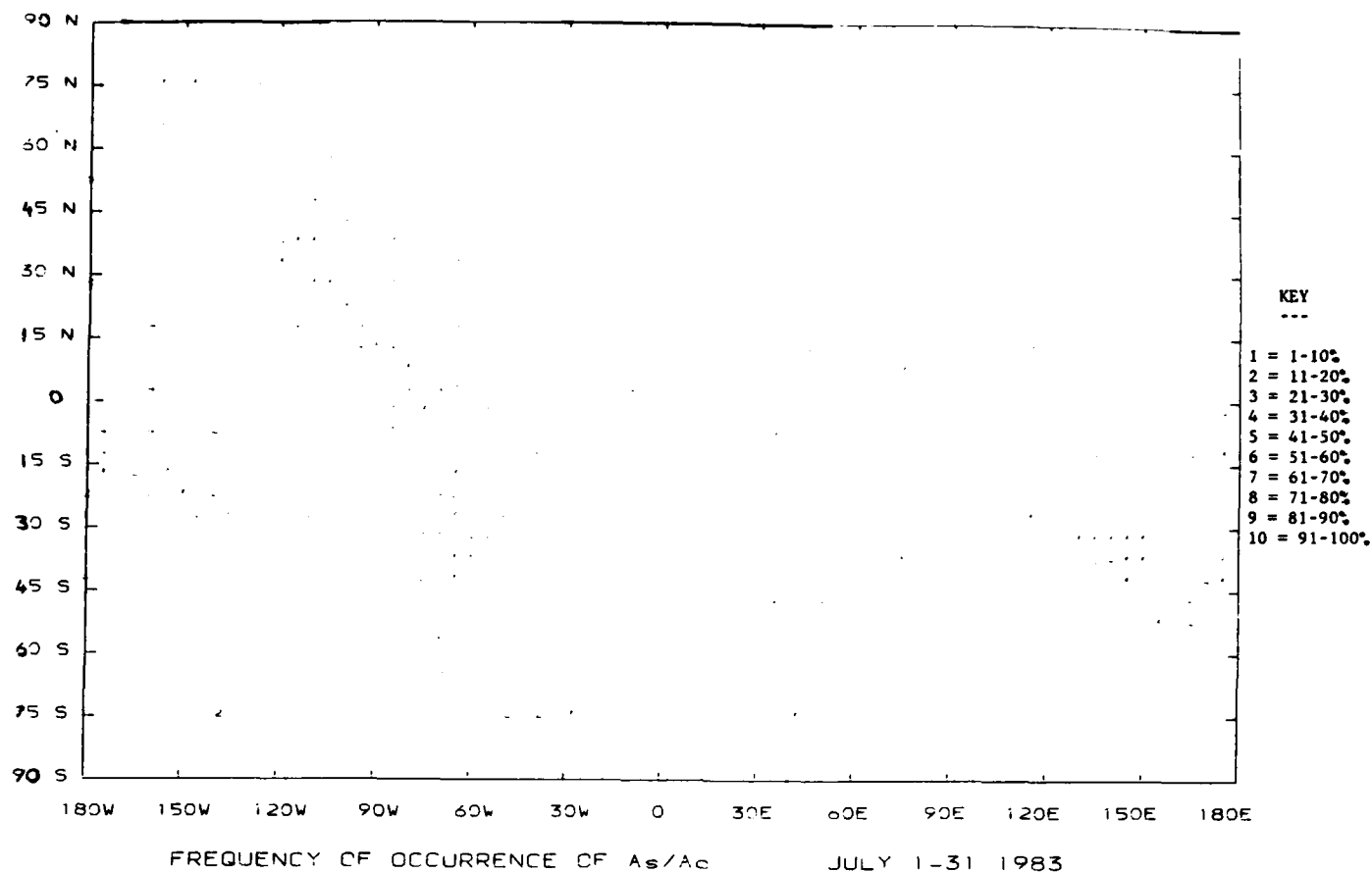


Figure 80

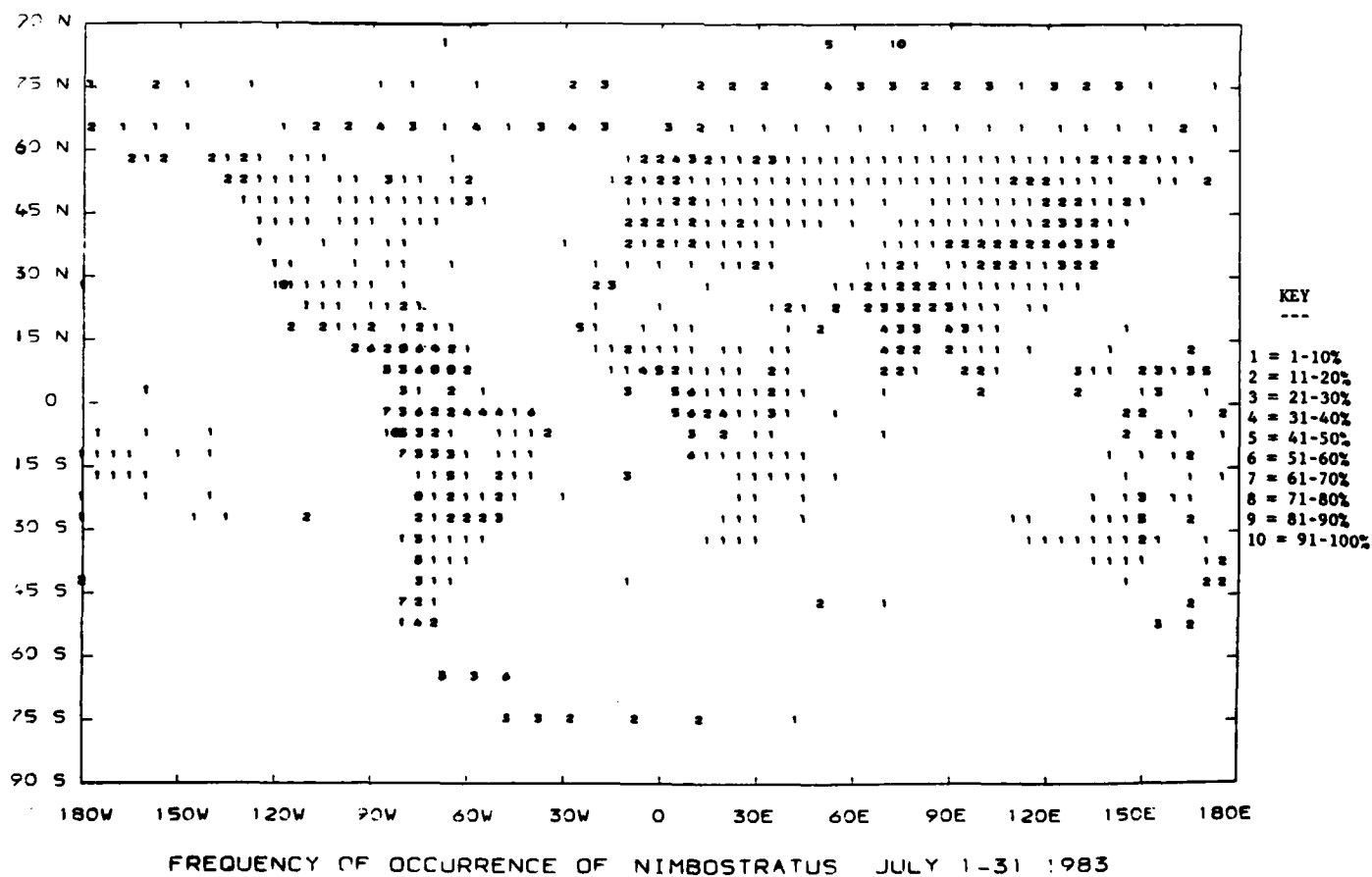


Figure 81

Figure 82

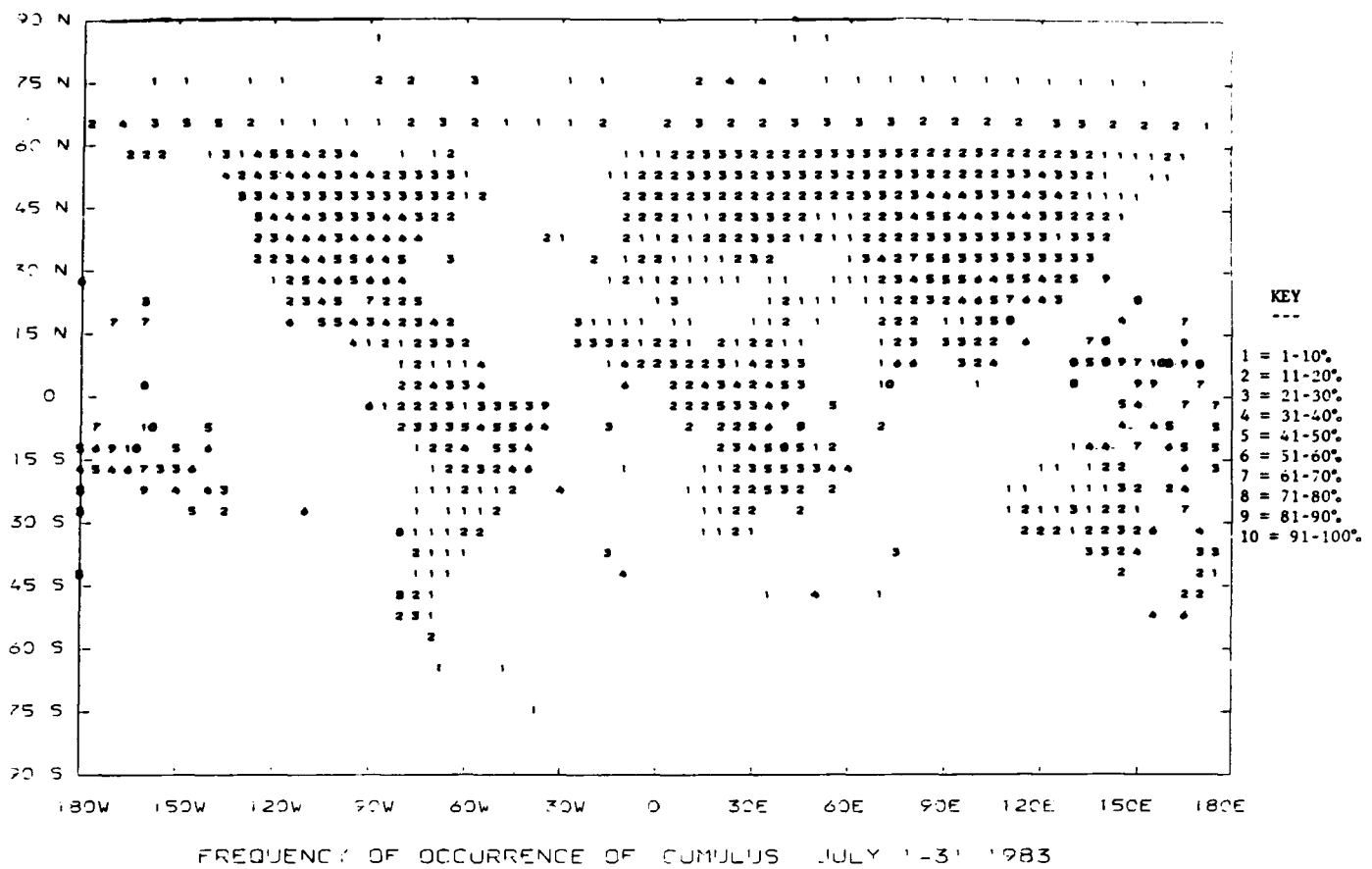


Figure 83

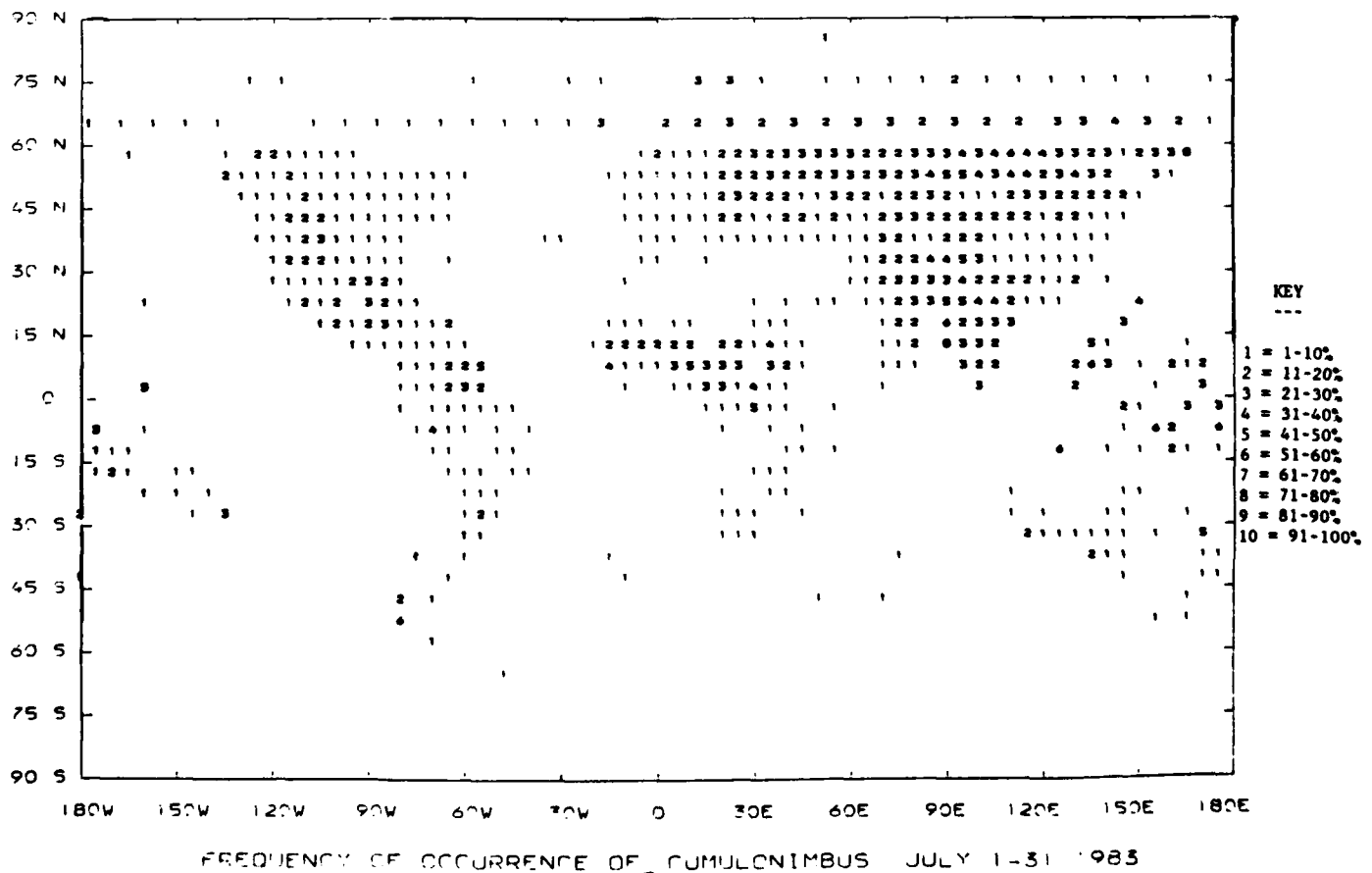


Figure 84

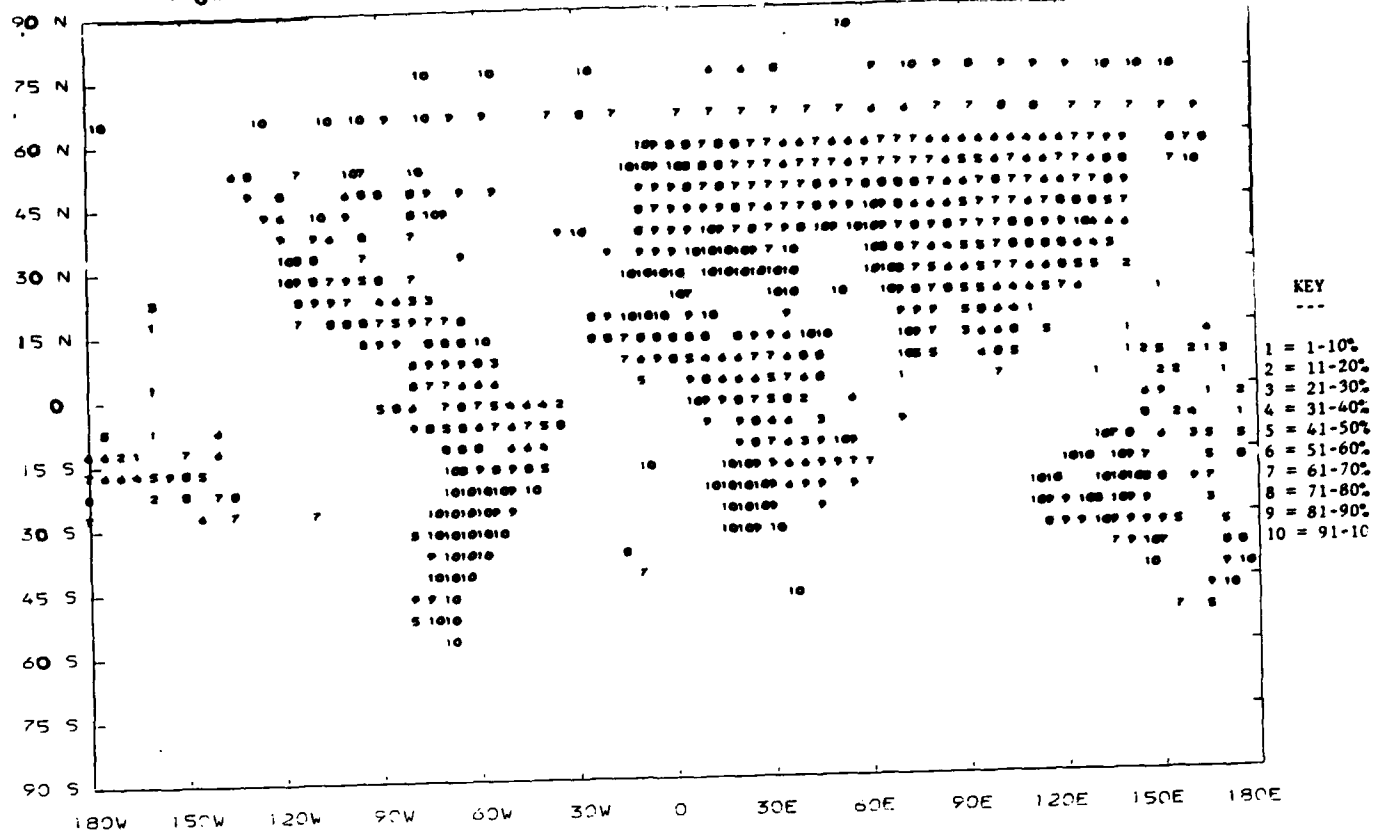


Figure 85

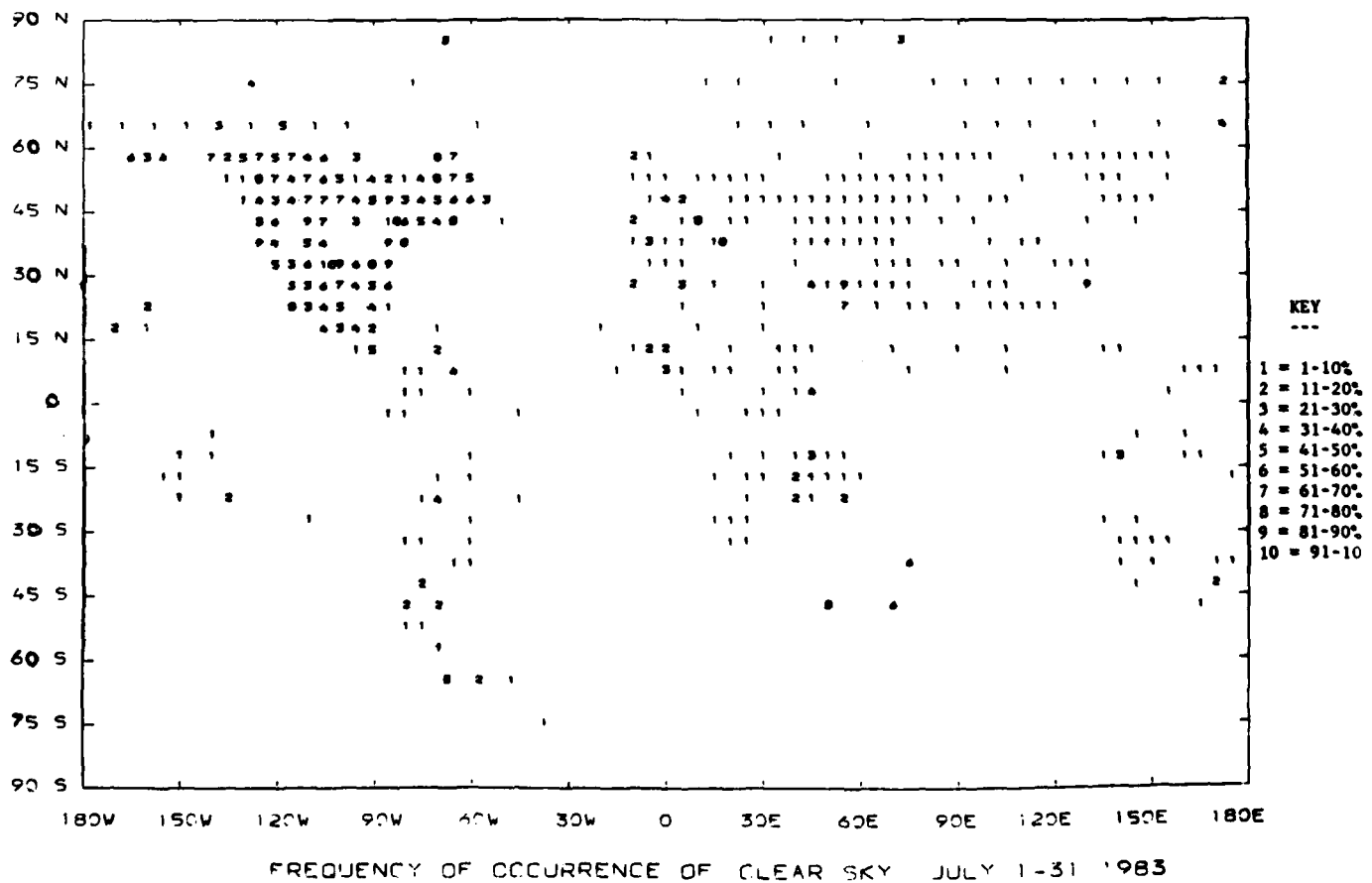


Figure 86

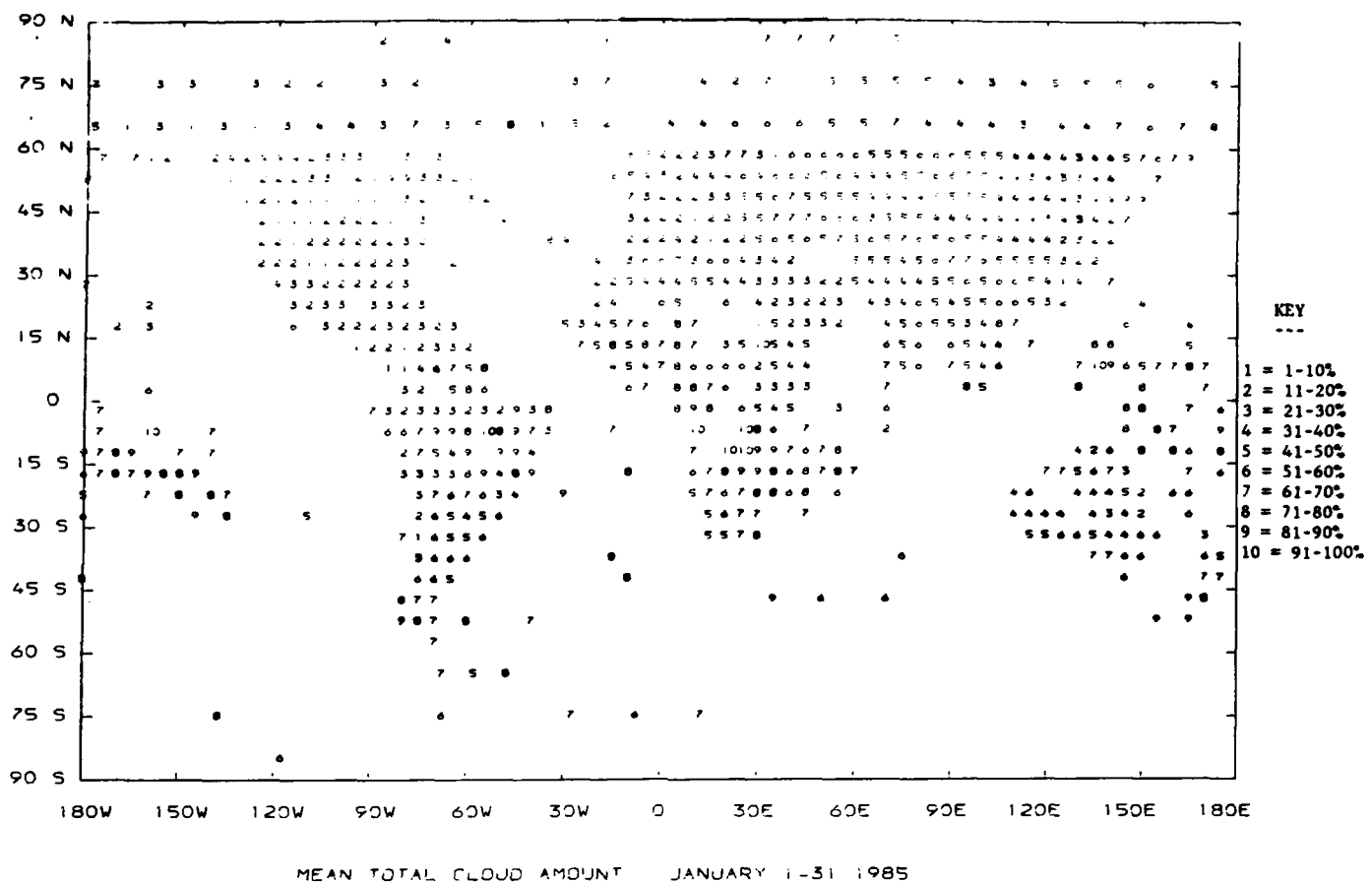


Figure 87

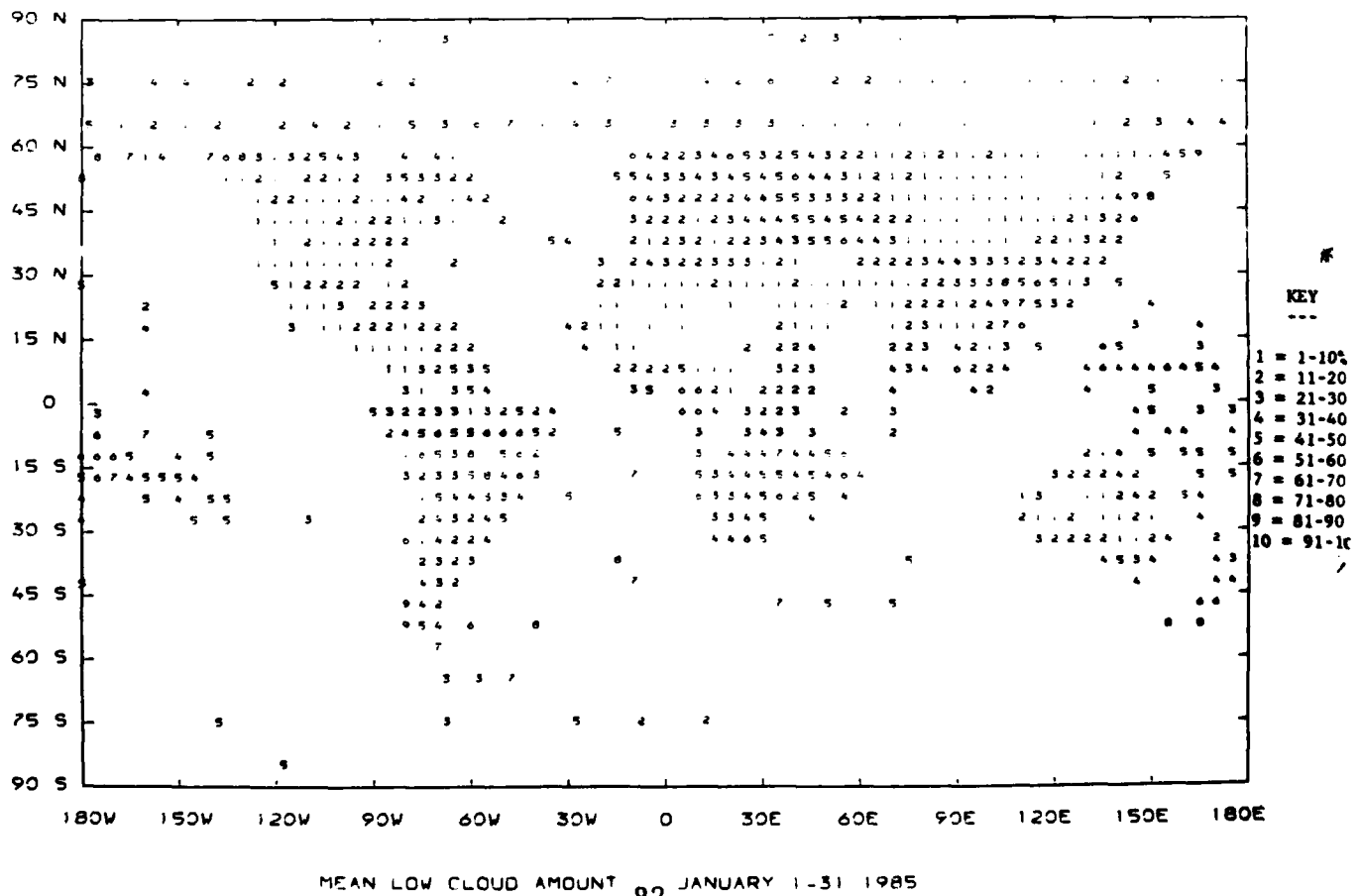


Figure 88

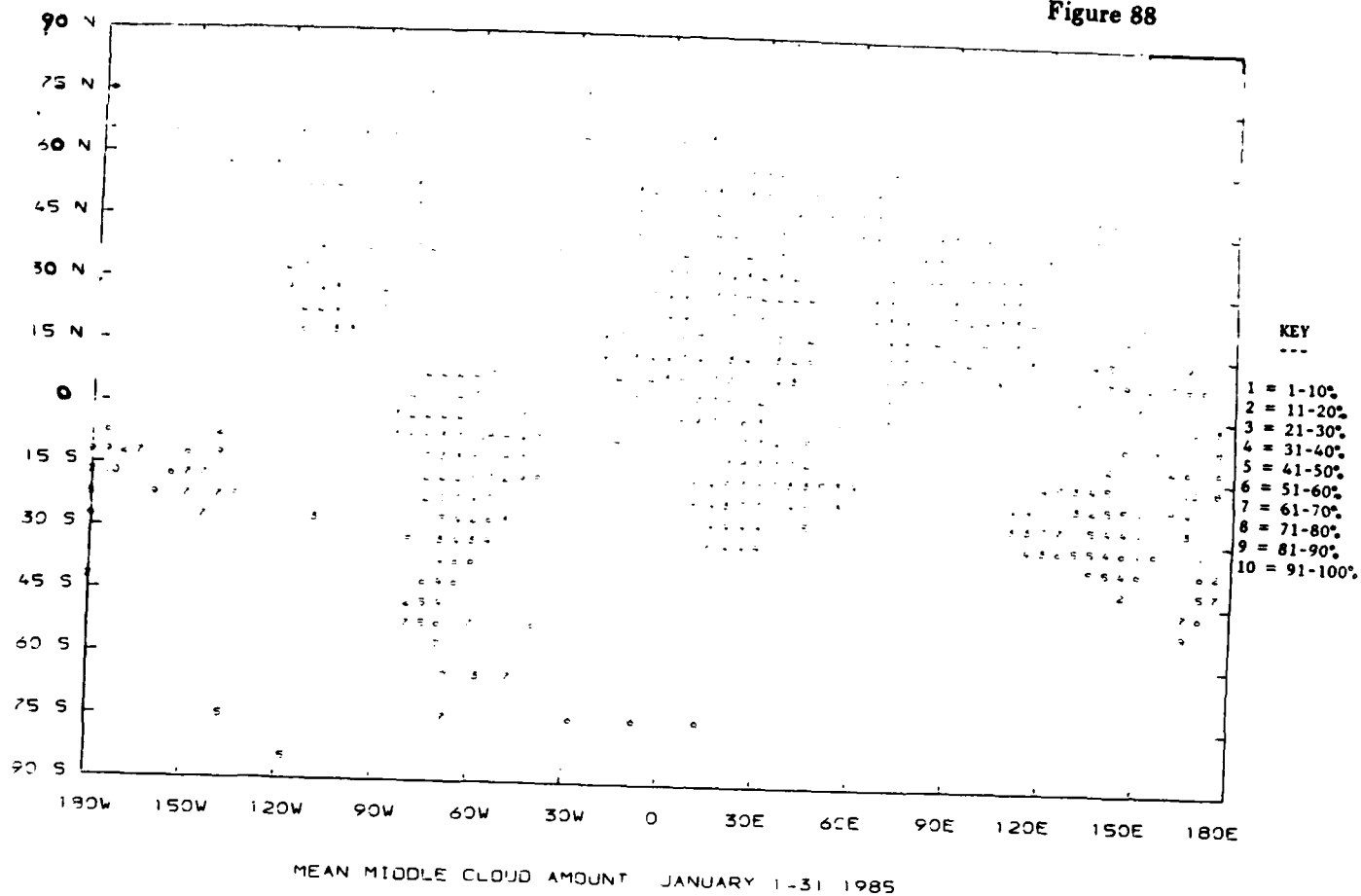
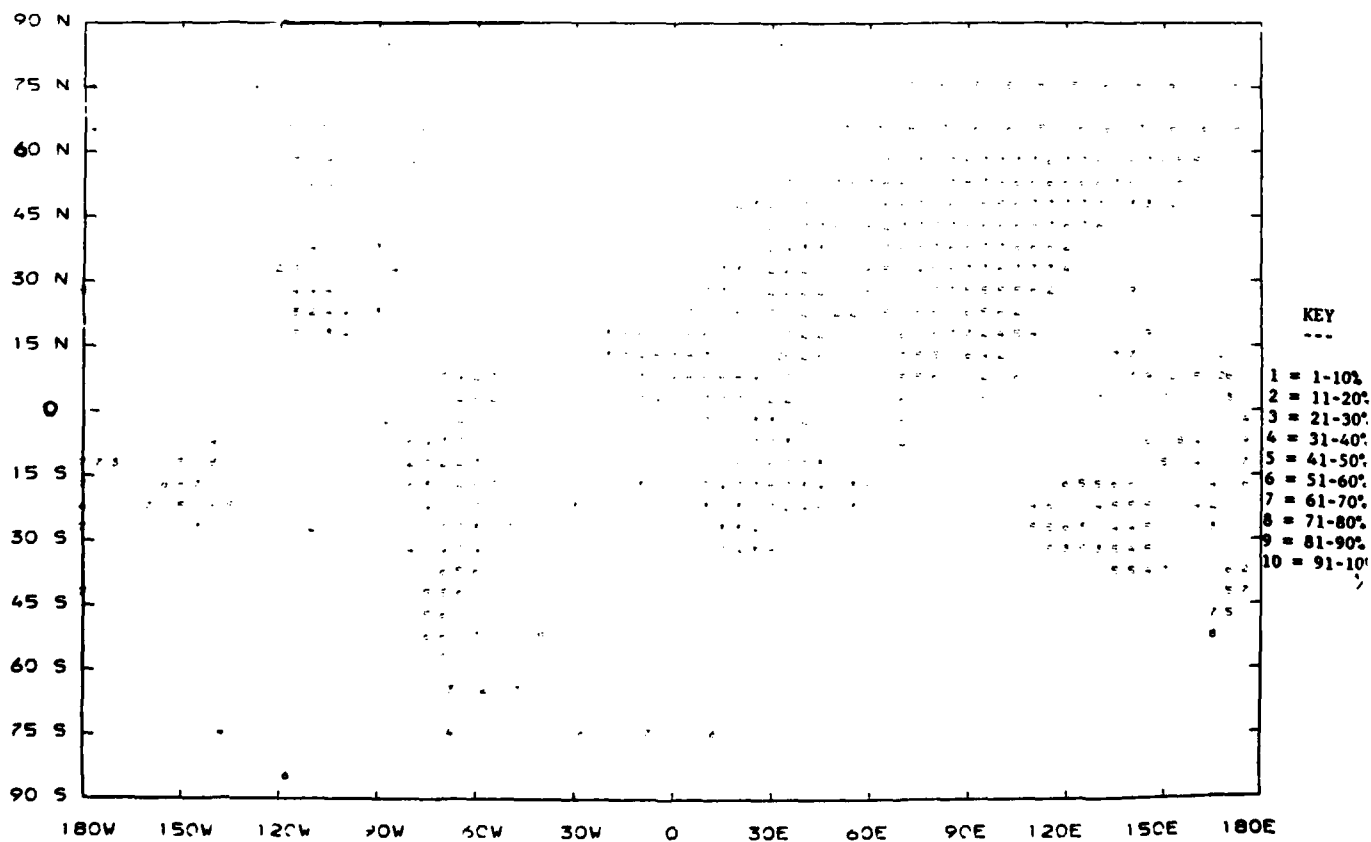
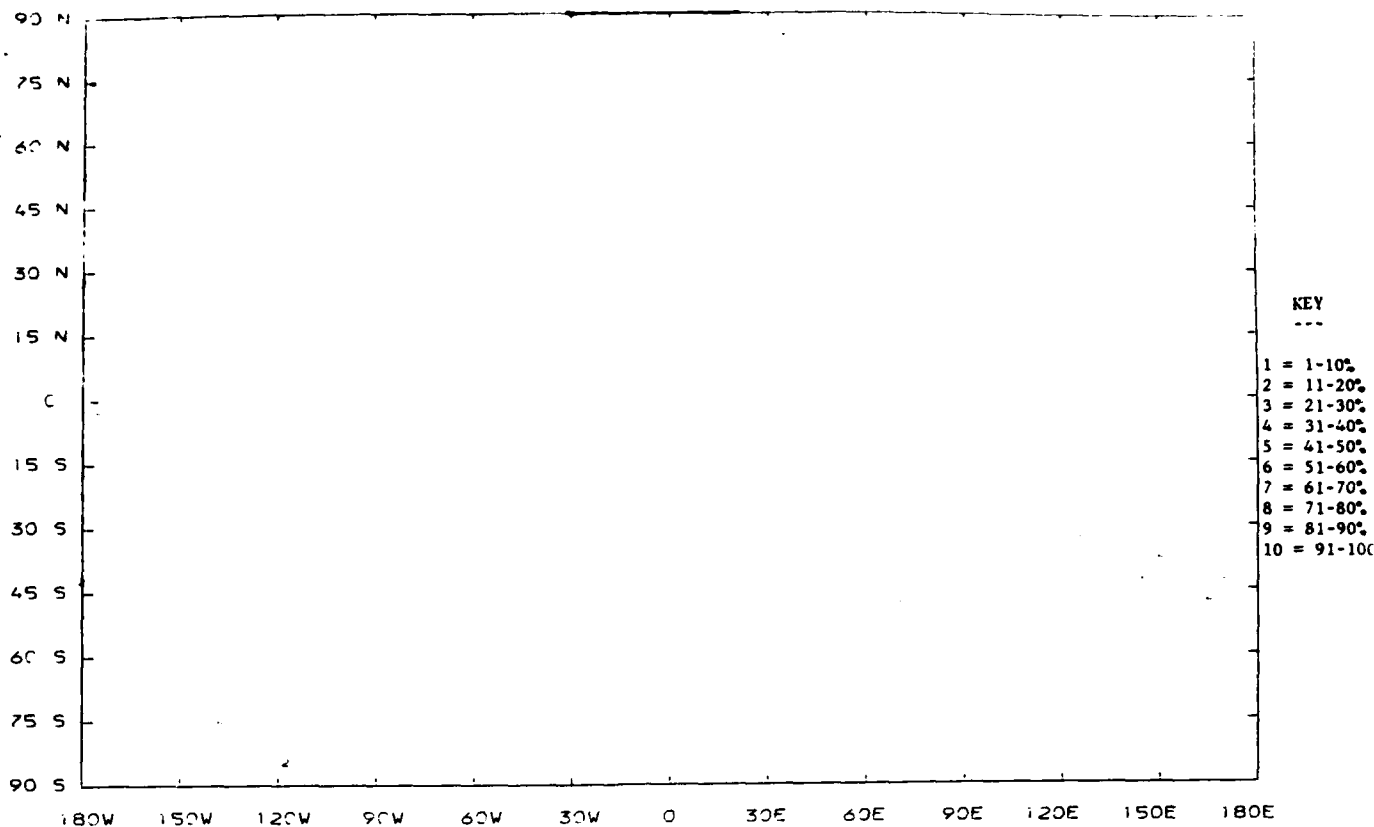


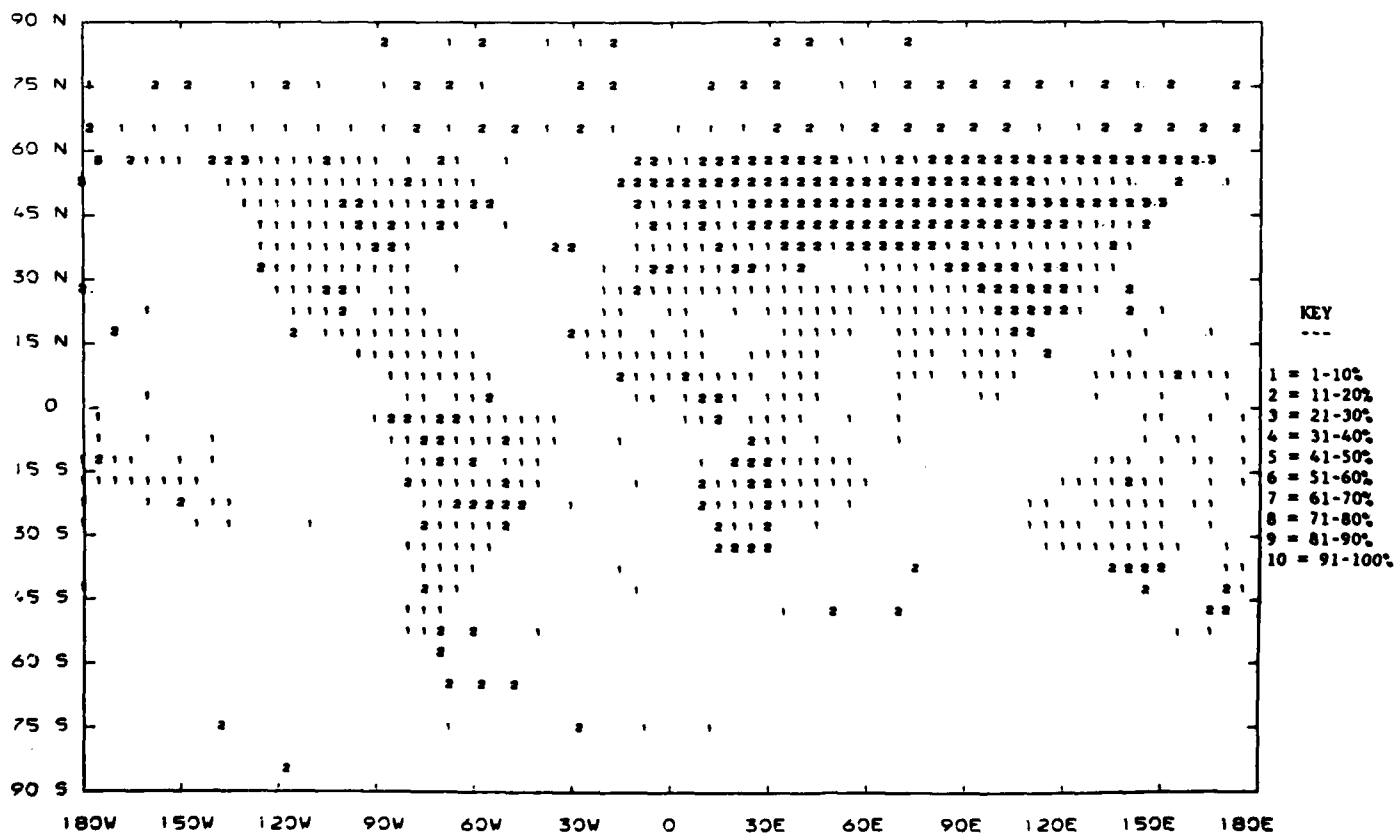
Figure 89





TOTAL CLOUD AMOUNT MEAN STANDARD DEVIATION JANUARY 1-31 1985

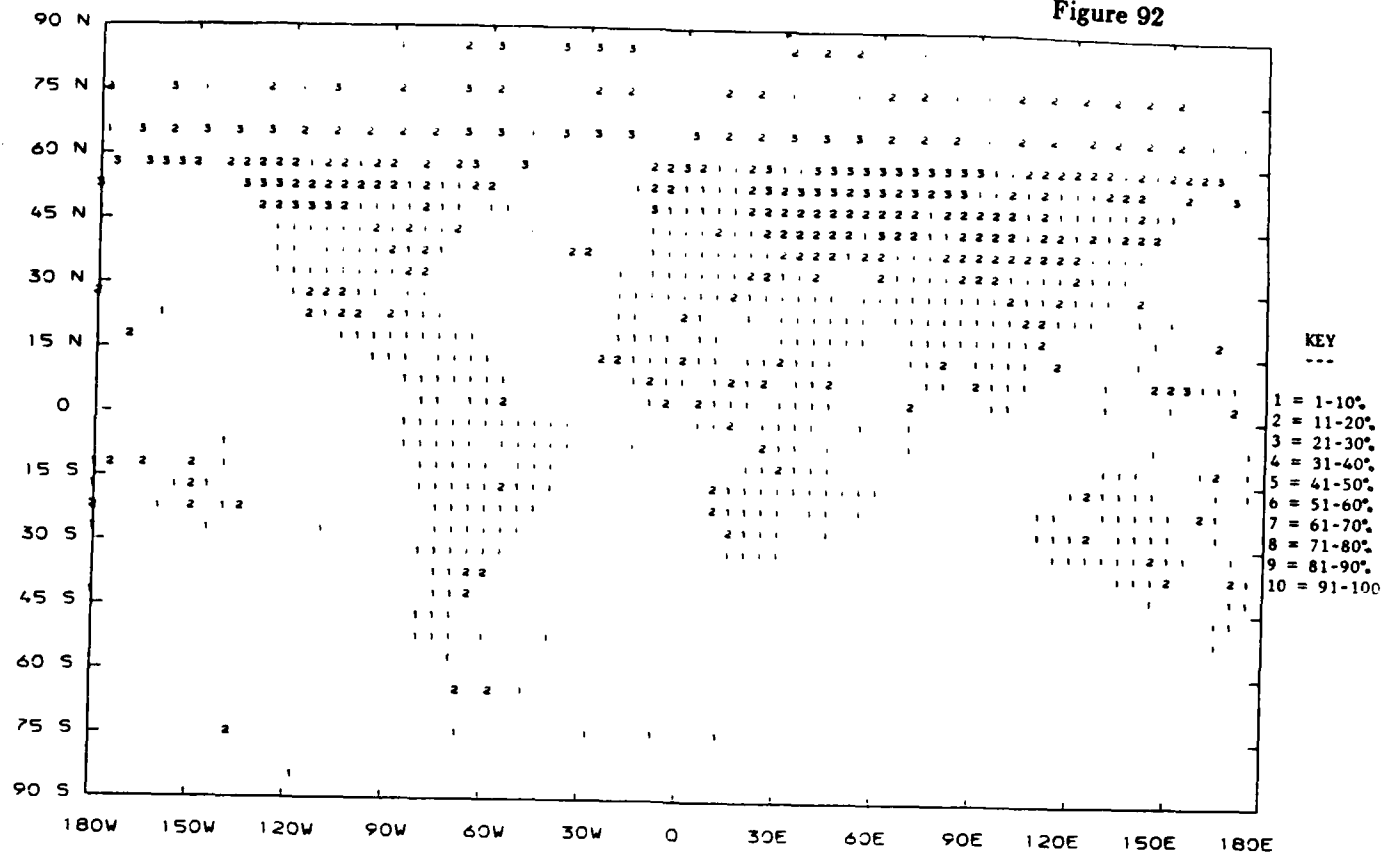
Figure 91



STANDARD DEVIATION - MEAN LOW CLOUD AMOUNT

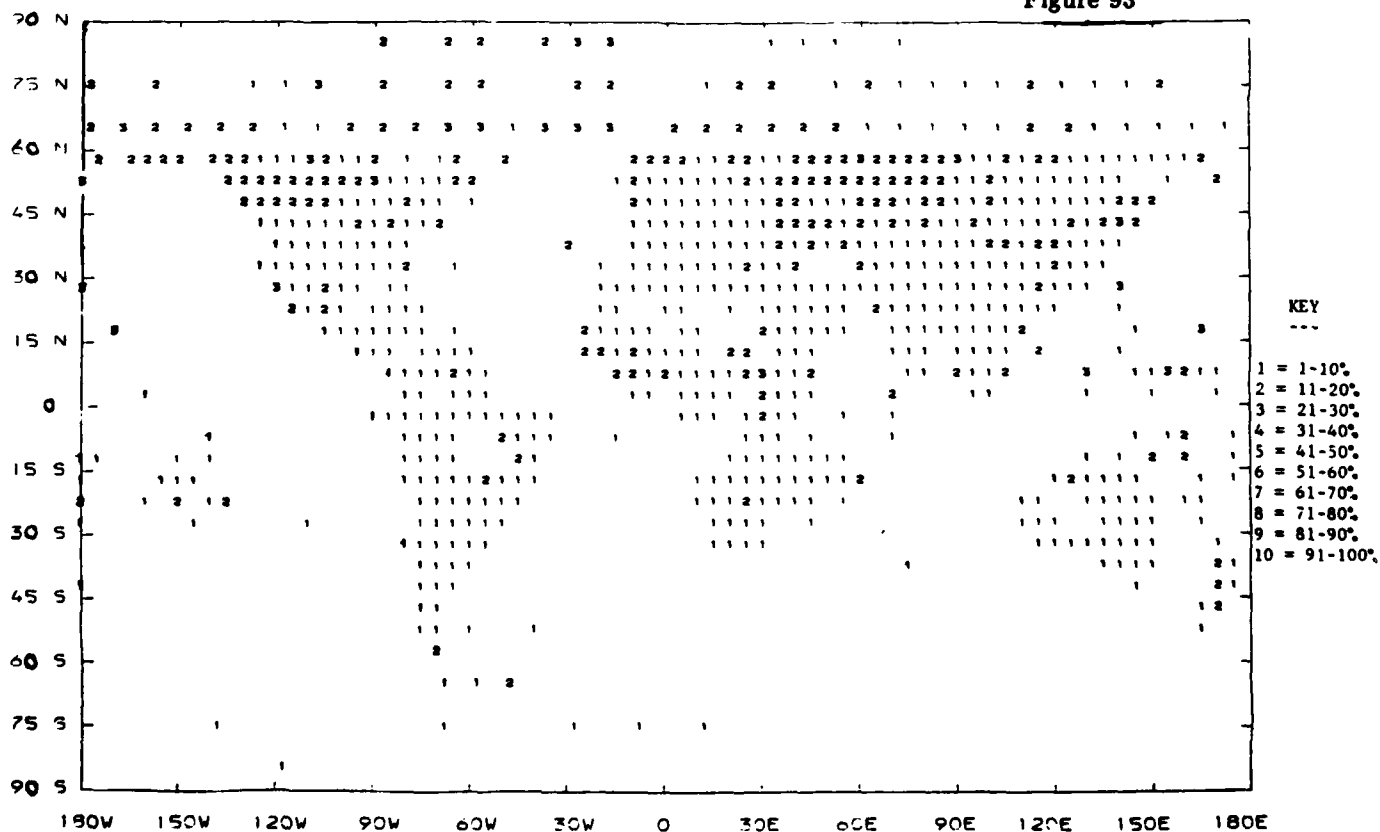
JANUARY 1-31 1985 gm 54

Figure 92



STANDARD DEVIATION - MEAN MIDDLE CLOUD AMOUNT  
JANUARY 1-31 1985

Figure 93



STANDARD DEVIATION MEAN HIGH CLOUD AMOUNT  
JANUARY 1-31 1985

Figure 94

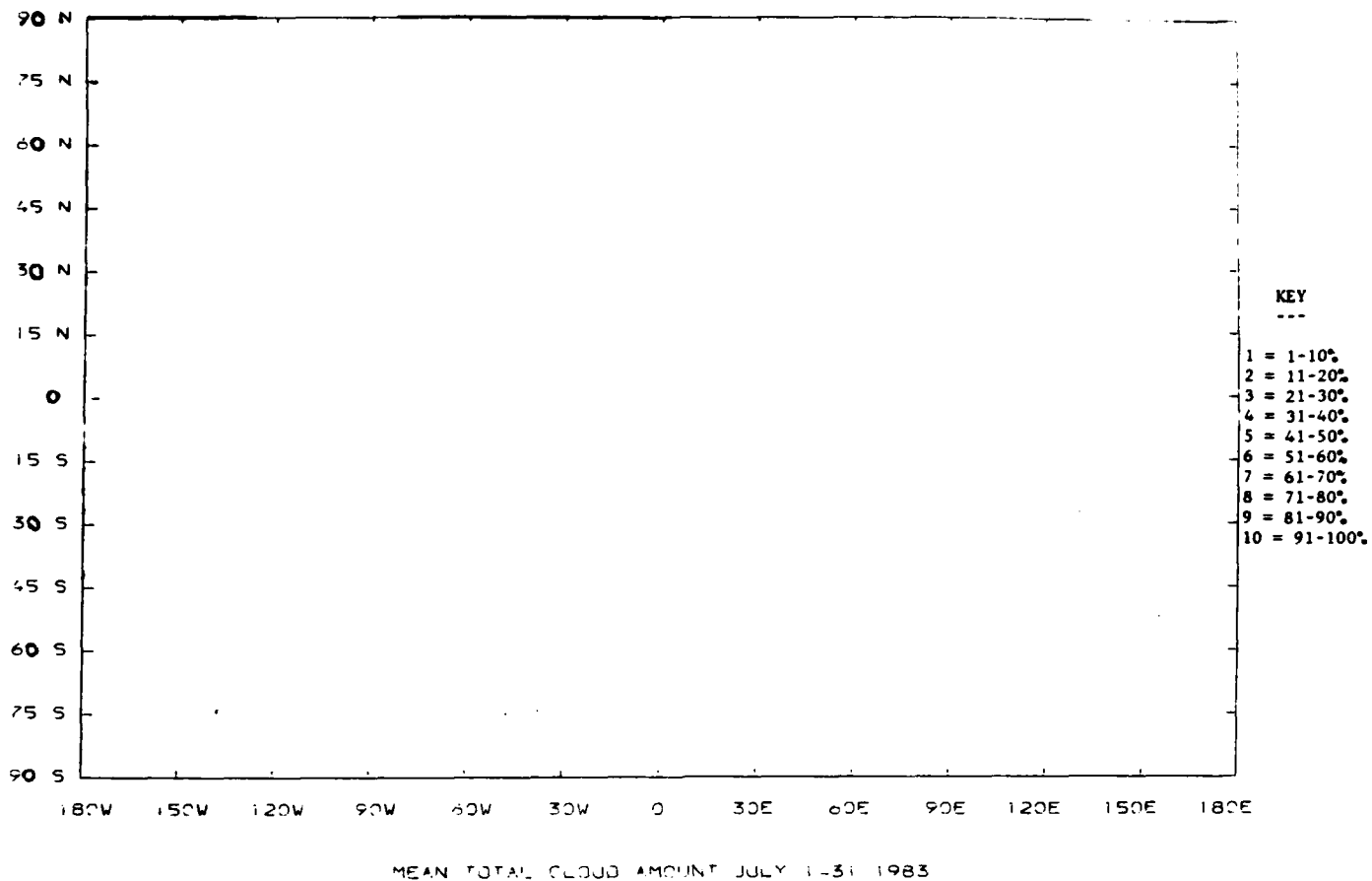


Figure 95

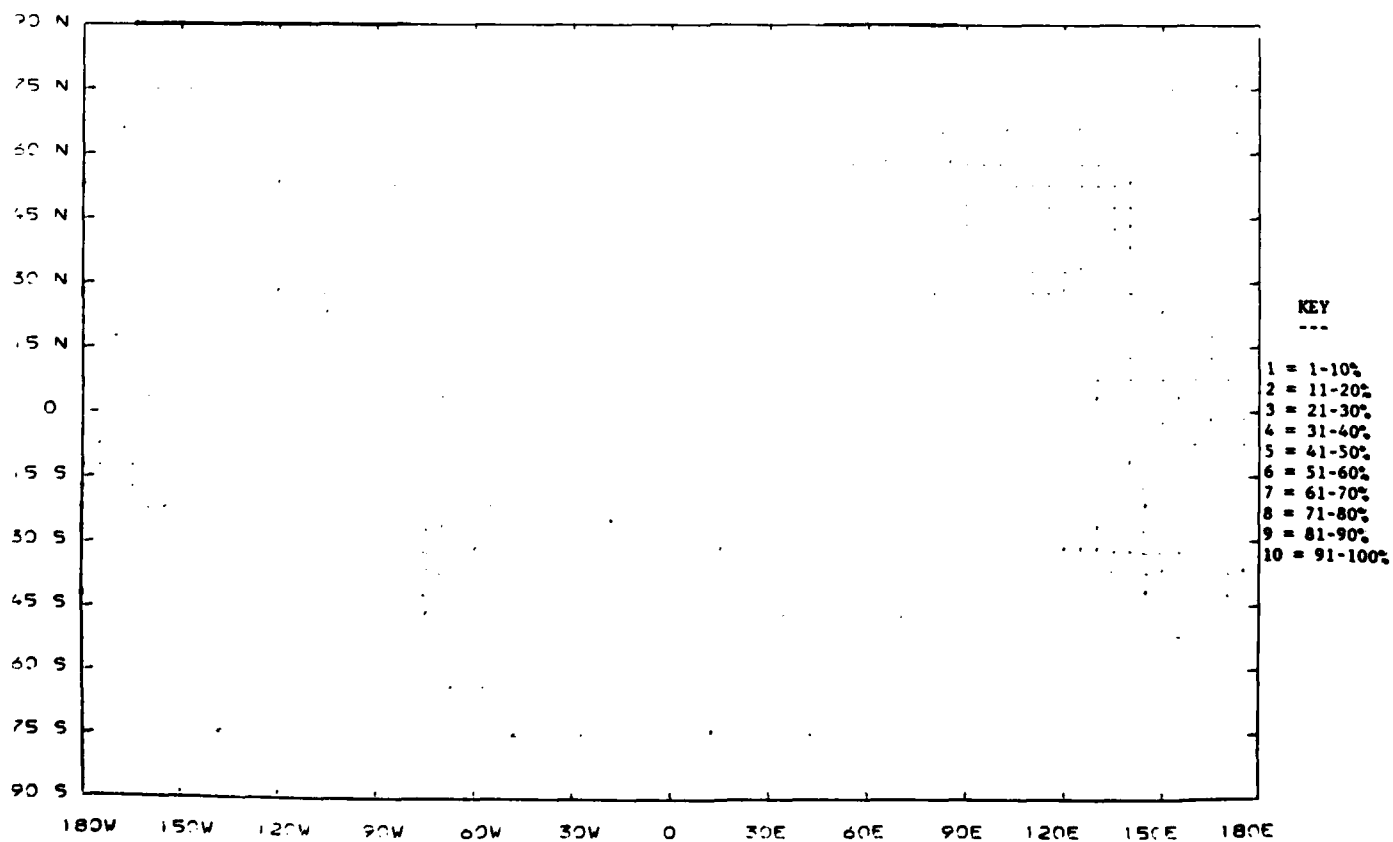


Figure 96

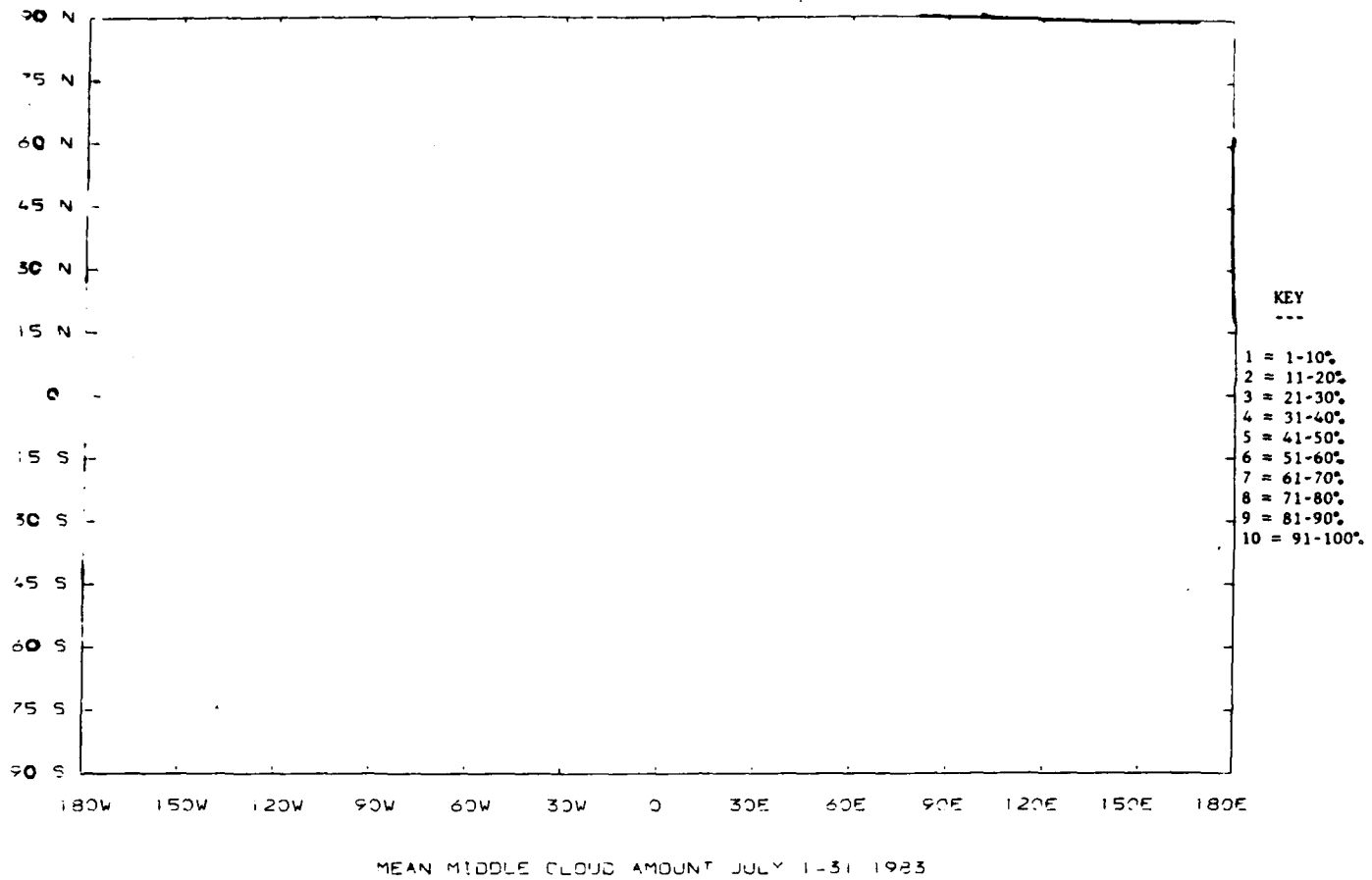


Figure 97

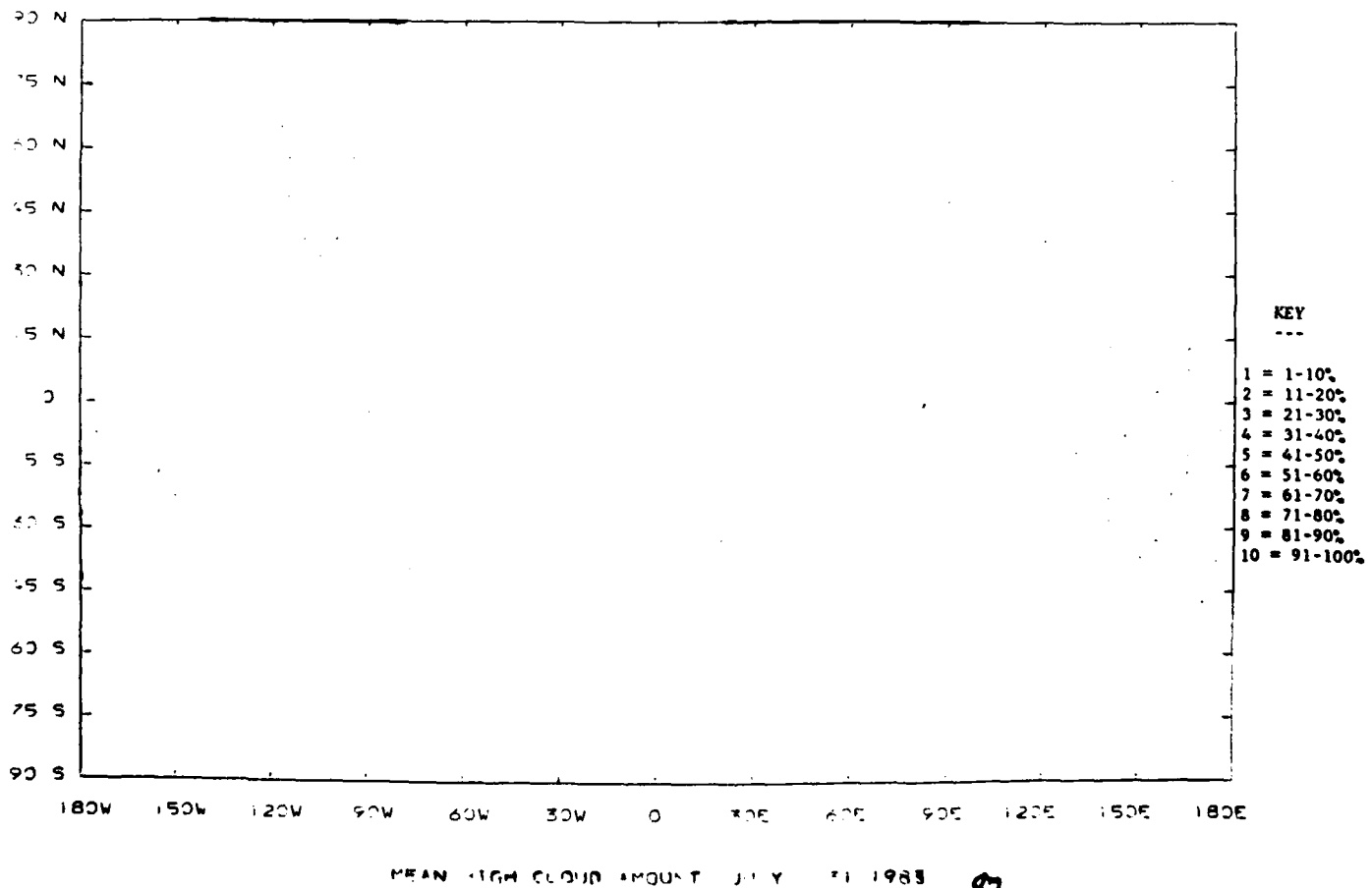
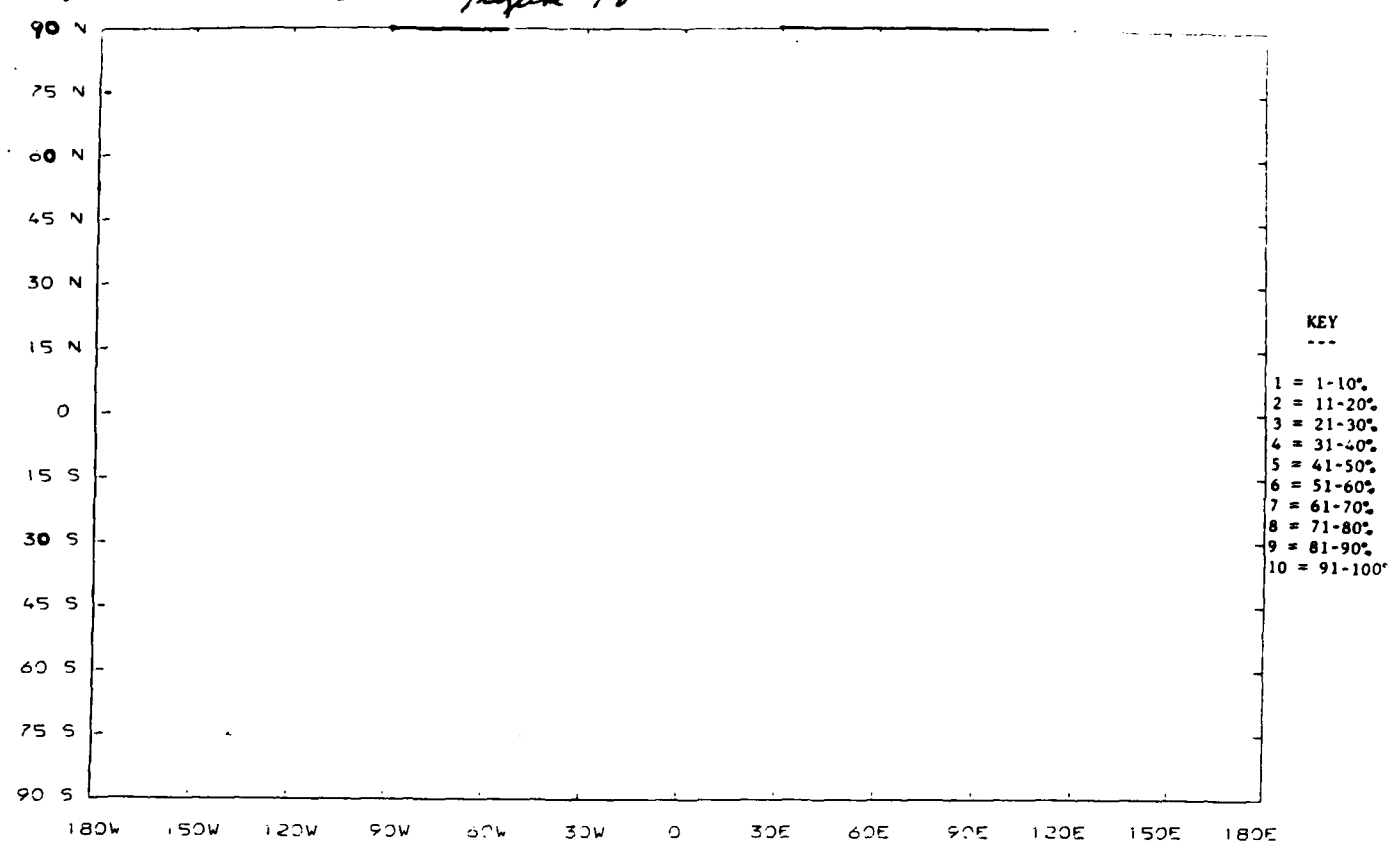
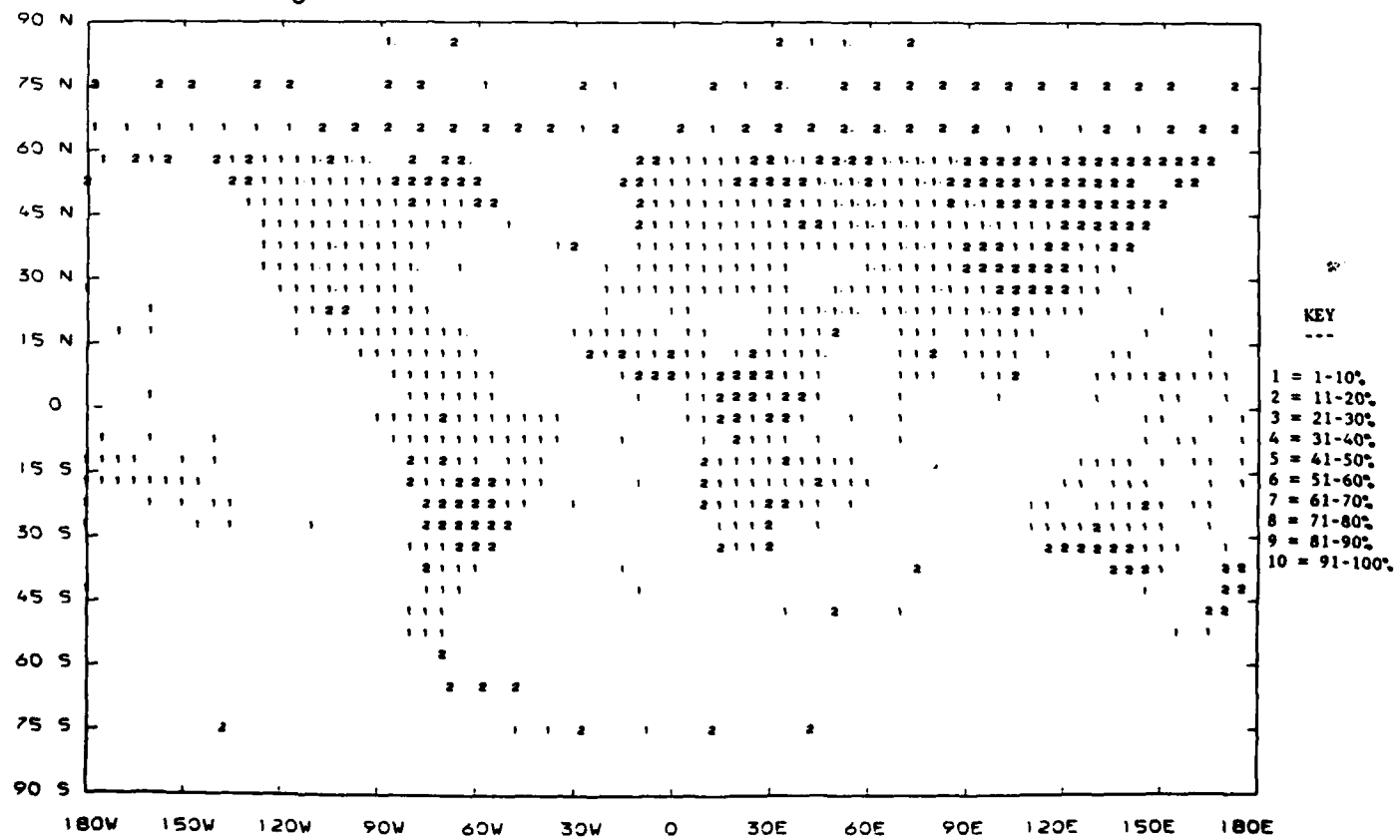


Figure 98



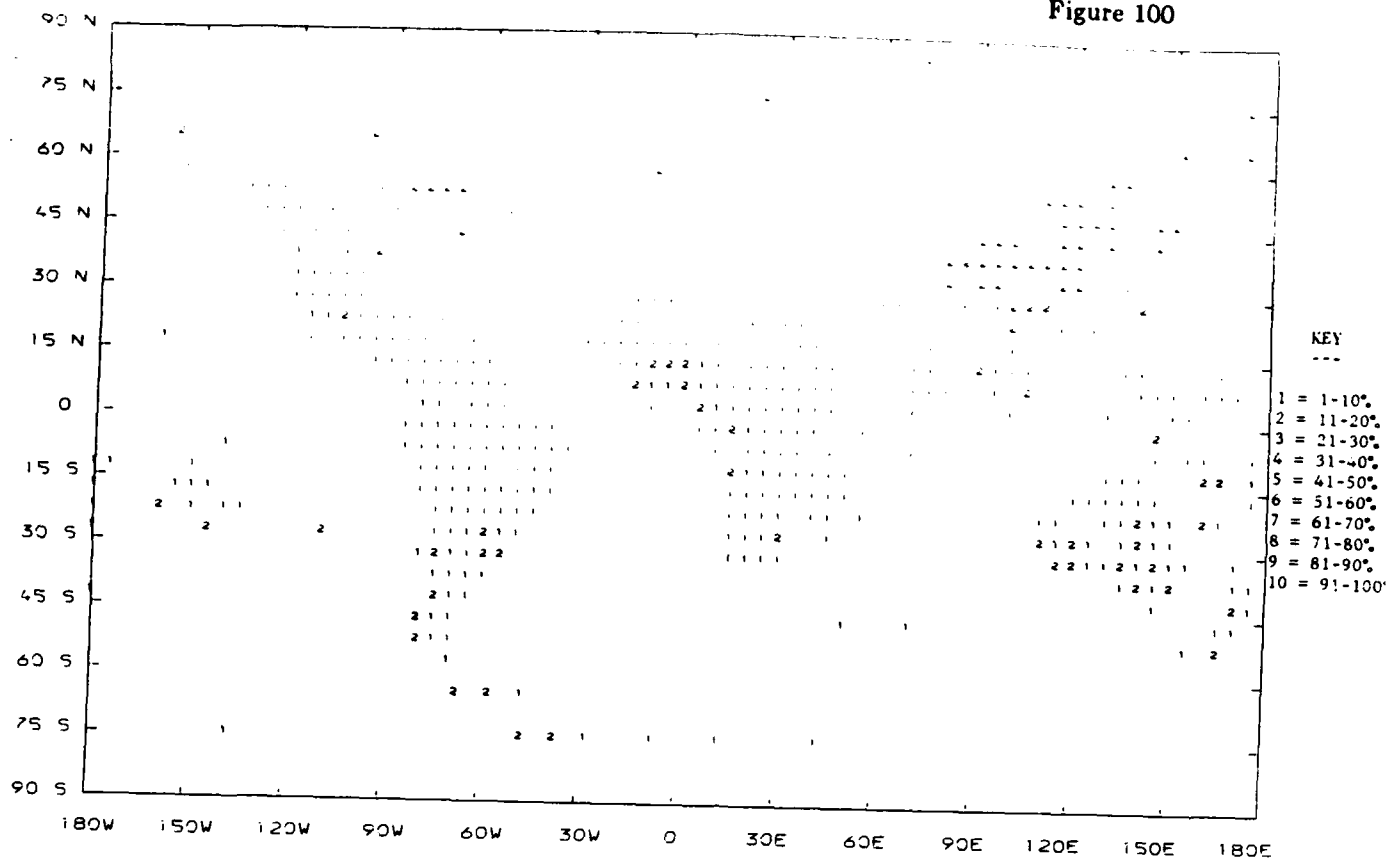
TOTAL CLOUD AMOUNT MEAN STANDARD DEVIATION JULY 1-31 1983

Figure 99



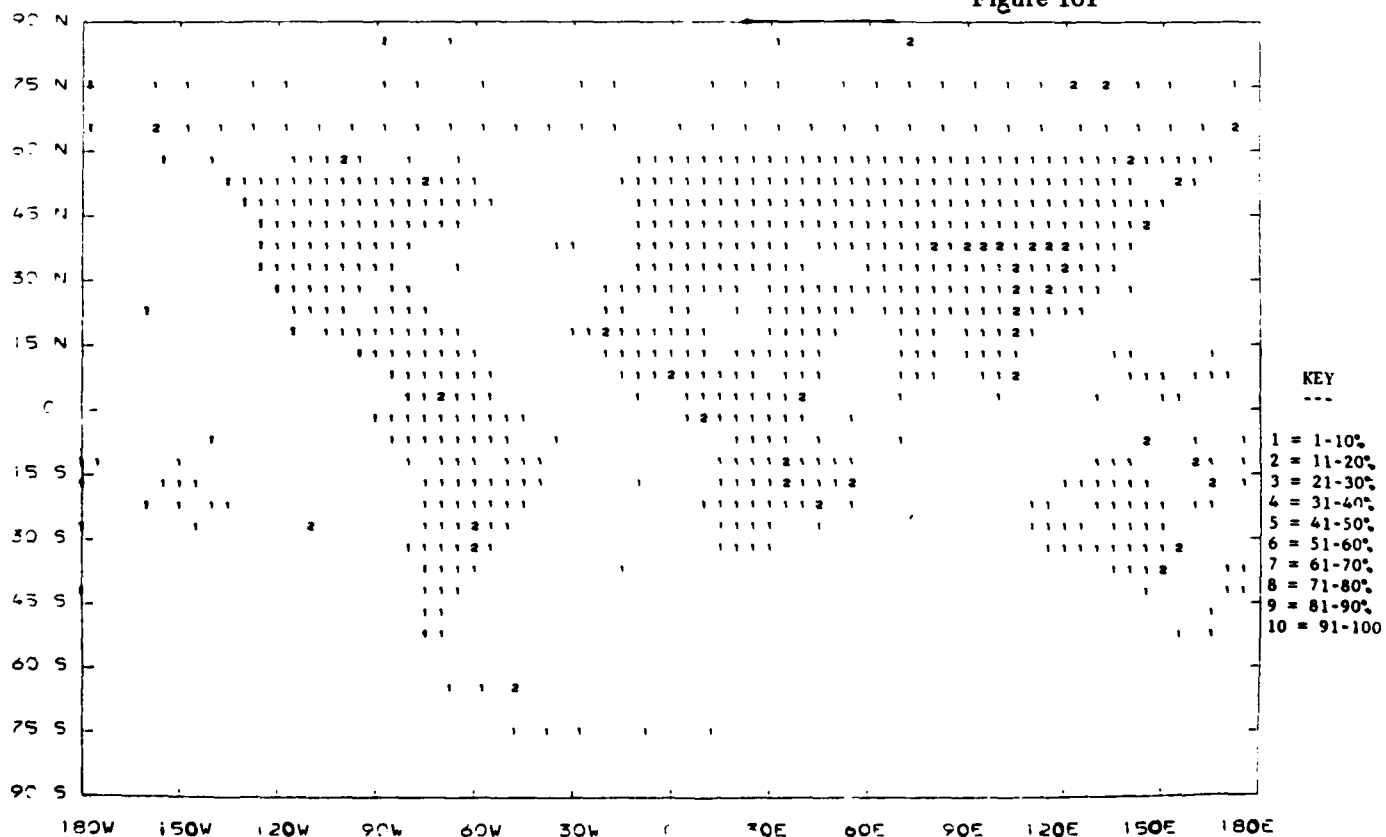
STANDARD DEVIATION - MEAN LOW CLOUD AMOUNT  
RR

Figure 100



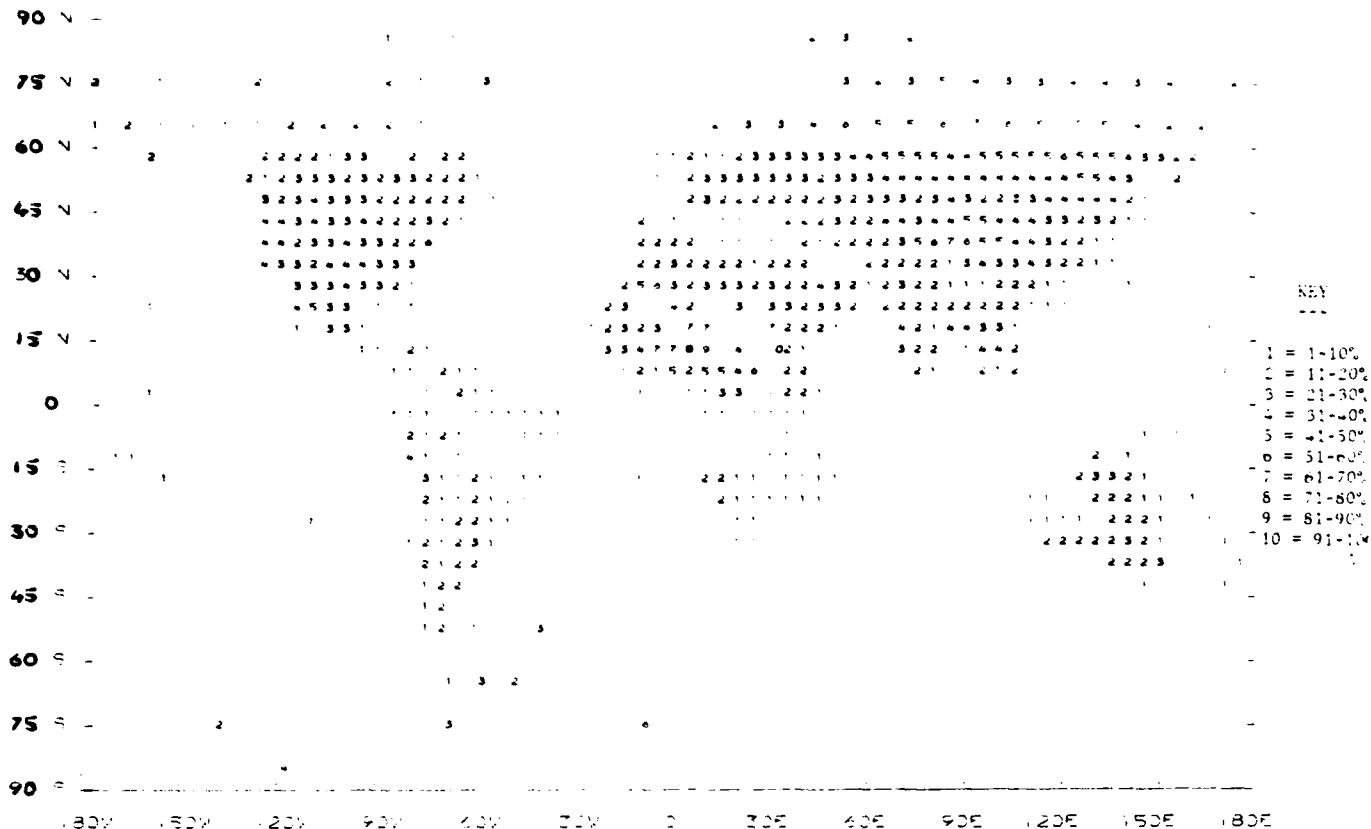
STANDARD DEVIATION - MEAN MIDDLE CLOUD AMOUNT  
JULY 1-31 1983

Figure 101



STANDARD DEVIATION MEAN HIGH CLOUD AMOUNT  
JULY 1-31 1983

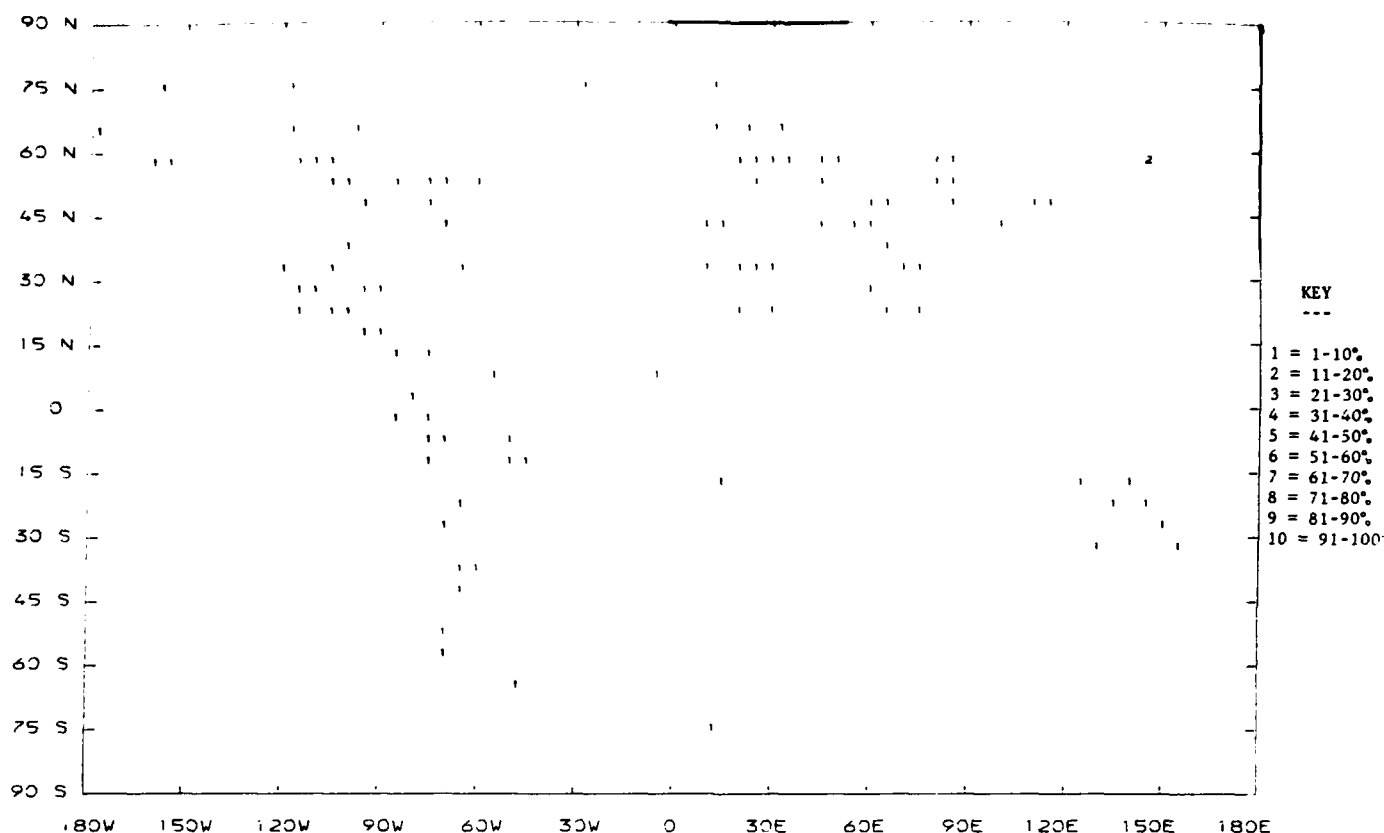
Figure 102



FREQUENCY OF OCCURRENCE OF 10 KNOTS ONLY  
JANUARY 1-31, 1985

Figure 103

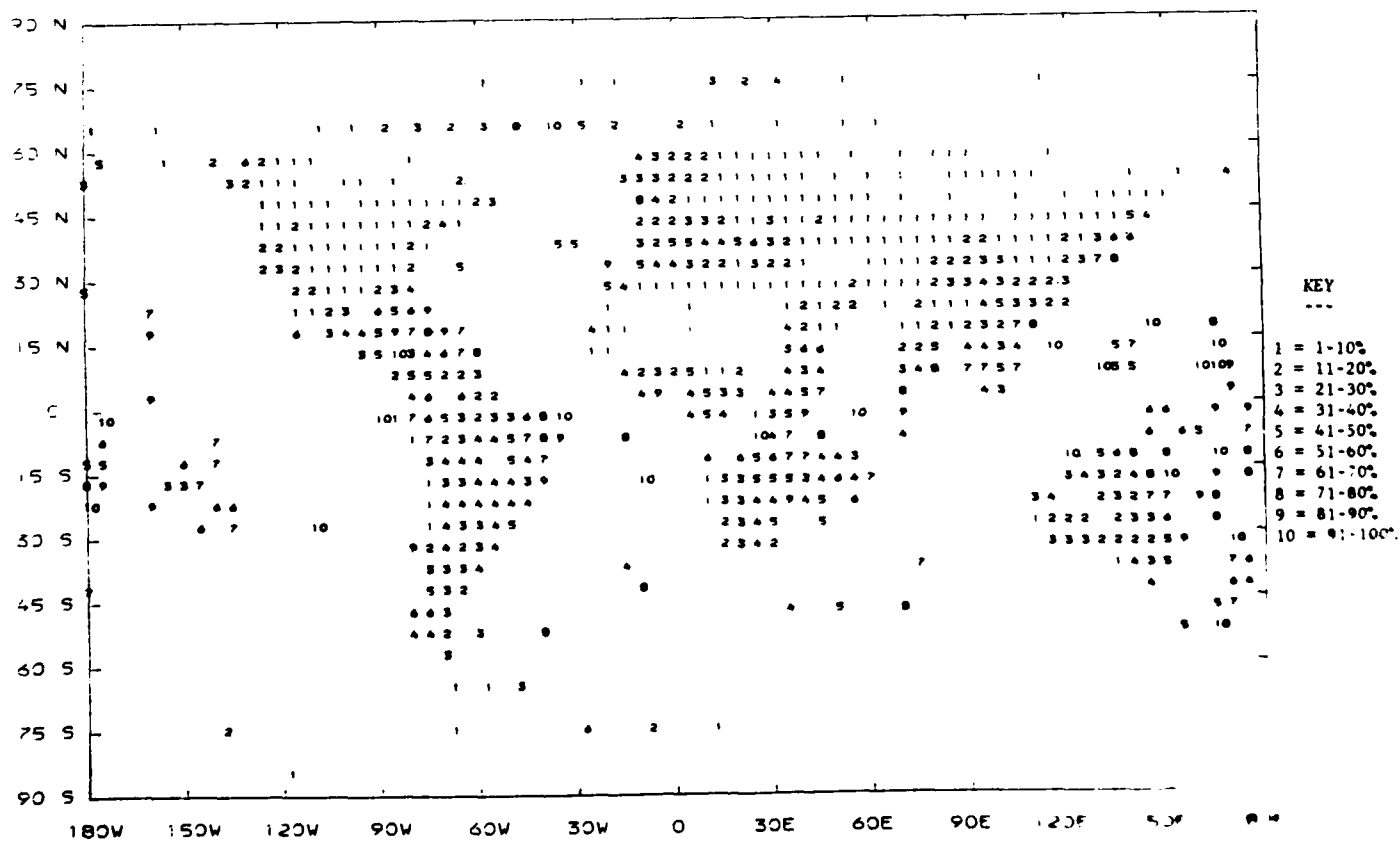




FREQUENCY OF OCCURRENCE OF NIMBOSTRATUS ONLY

JANUARY 1-31 1985

Figure 104



FREQUENCY OF OCCURRENCE OF CUMULUS ONLY

JANUARY 1-31 1985

Figure 105

AD-A188 523

HOMOGENIZING SURFACE AND SATELLITE OBSERVATIONS OF  
CLOUD ASPECTS OF BIAS I. (U) LIVERPOOL UNIV (ENGLAND)  
DEPT OF GEOGRAPHY A HENDERSON-SELLERS ET AL. 18 NOV 87  
BOARD-IR-87-11 AFOSR-86-0299 F/G 4/2

2/2

UNCLASSIFIED

NL

END  
DATE  
FILMED  
8

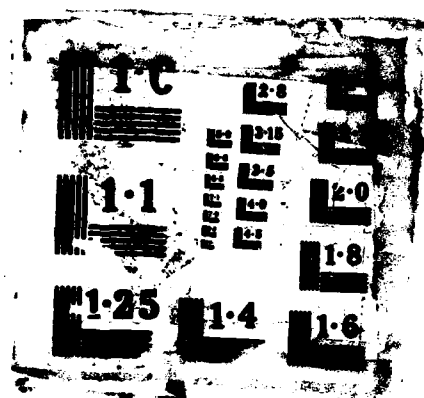


Figure 106

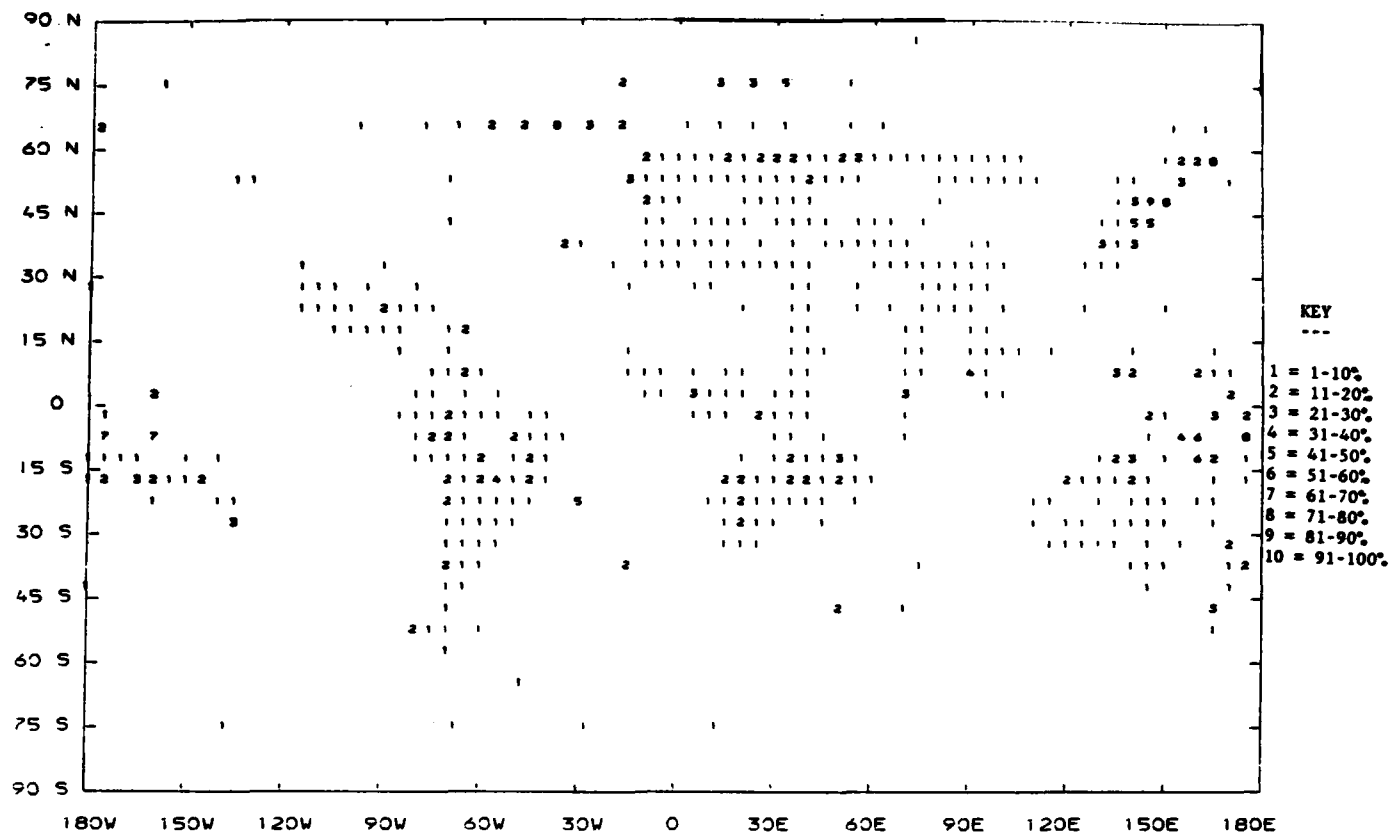


Figure 107

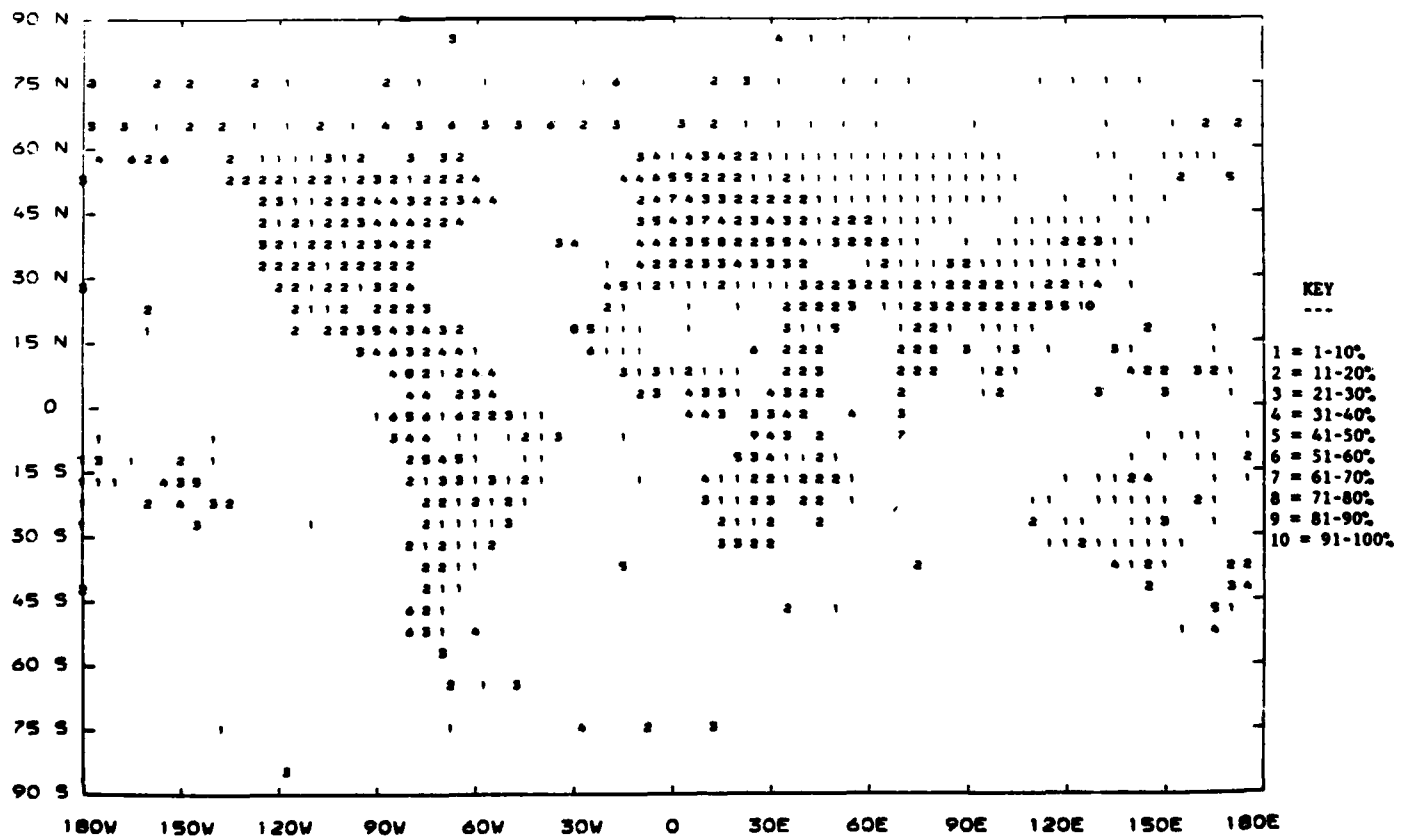


Figure 108

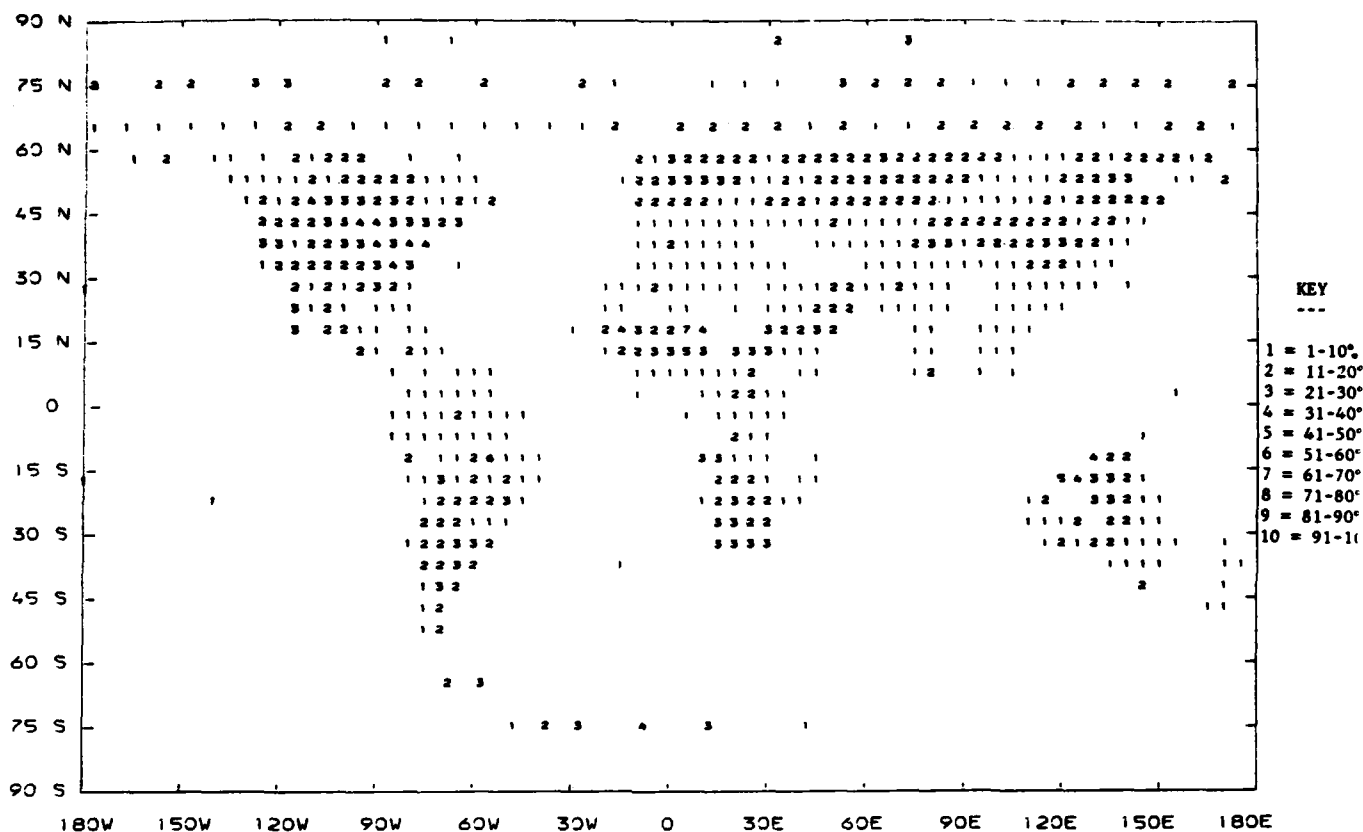


Figure 109

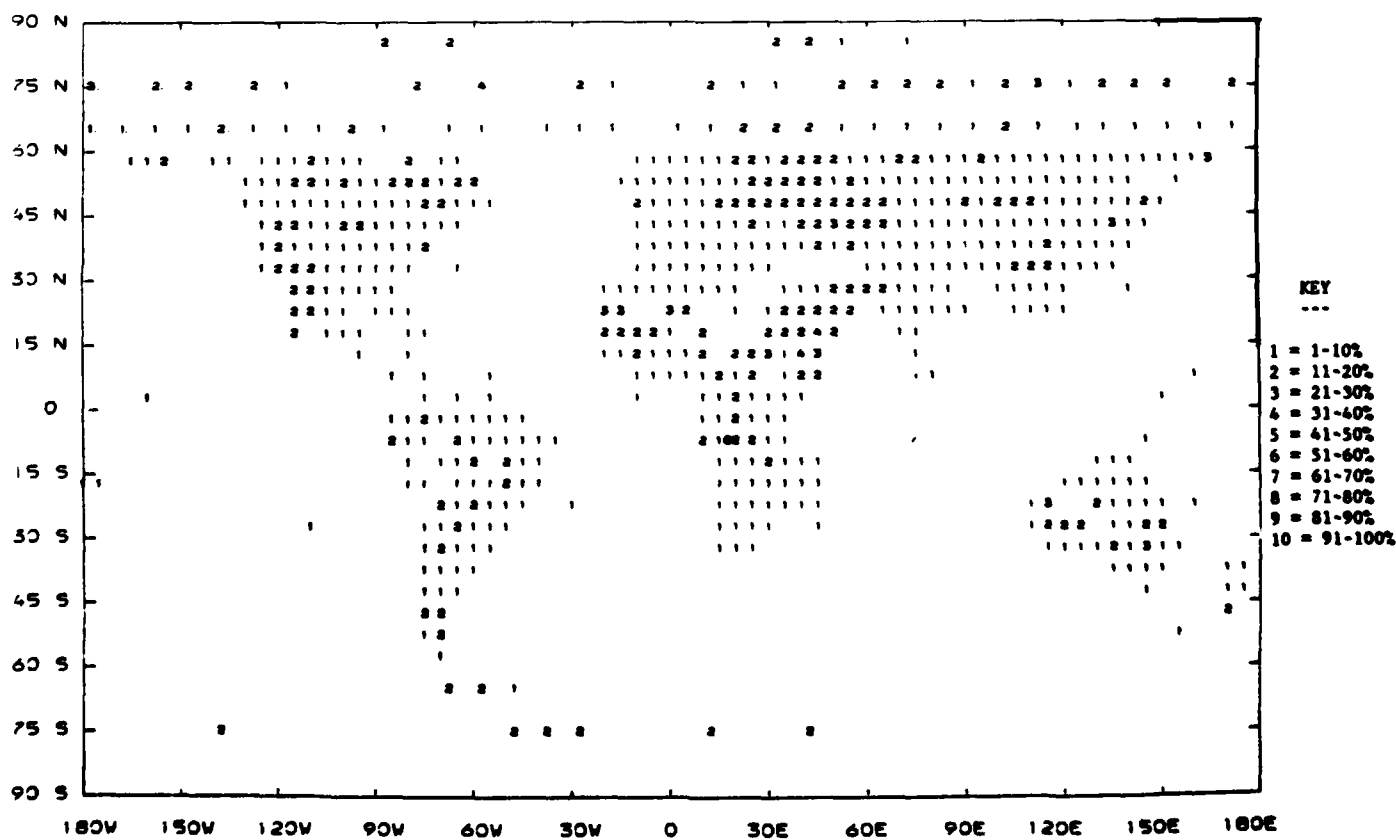


Figure 110

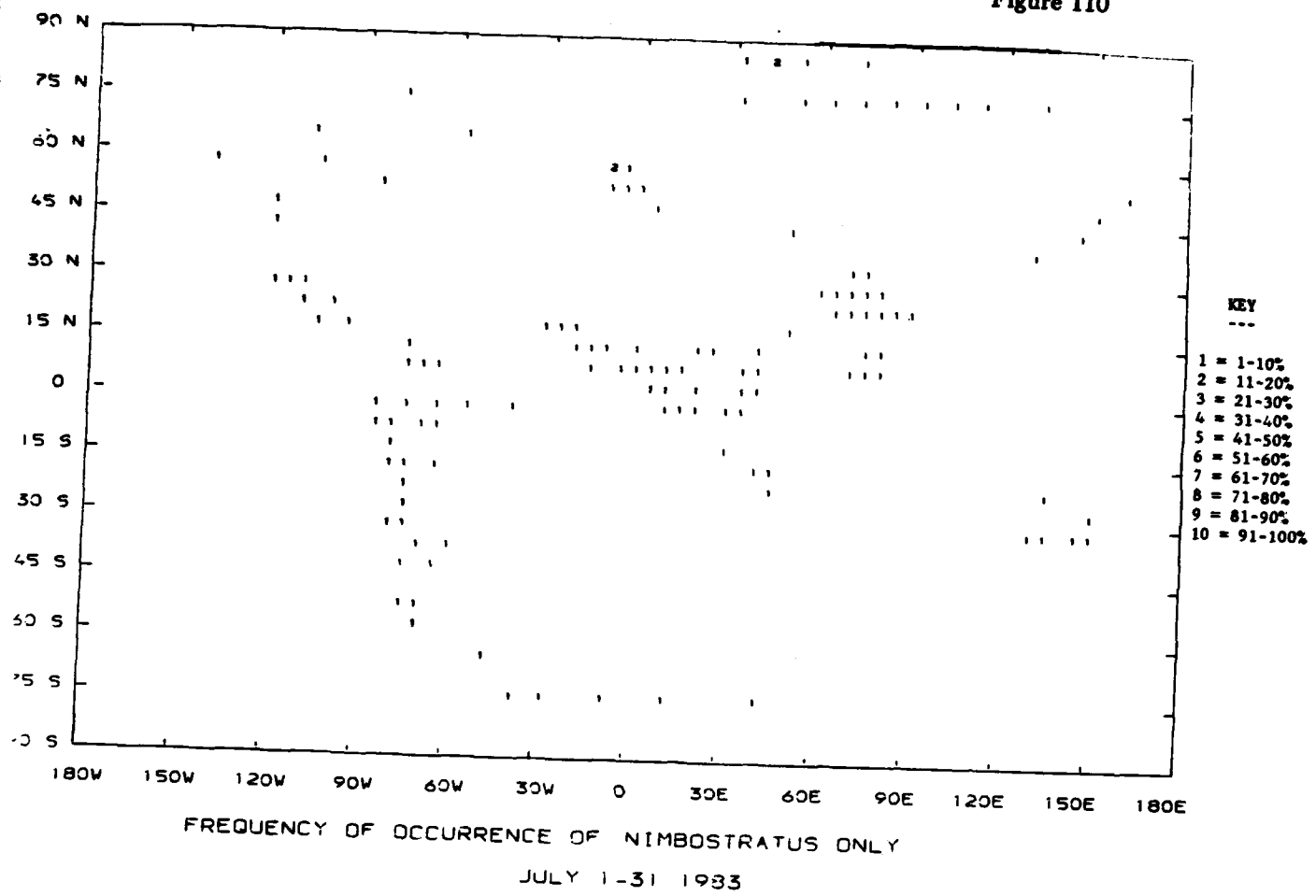


Figure 111

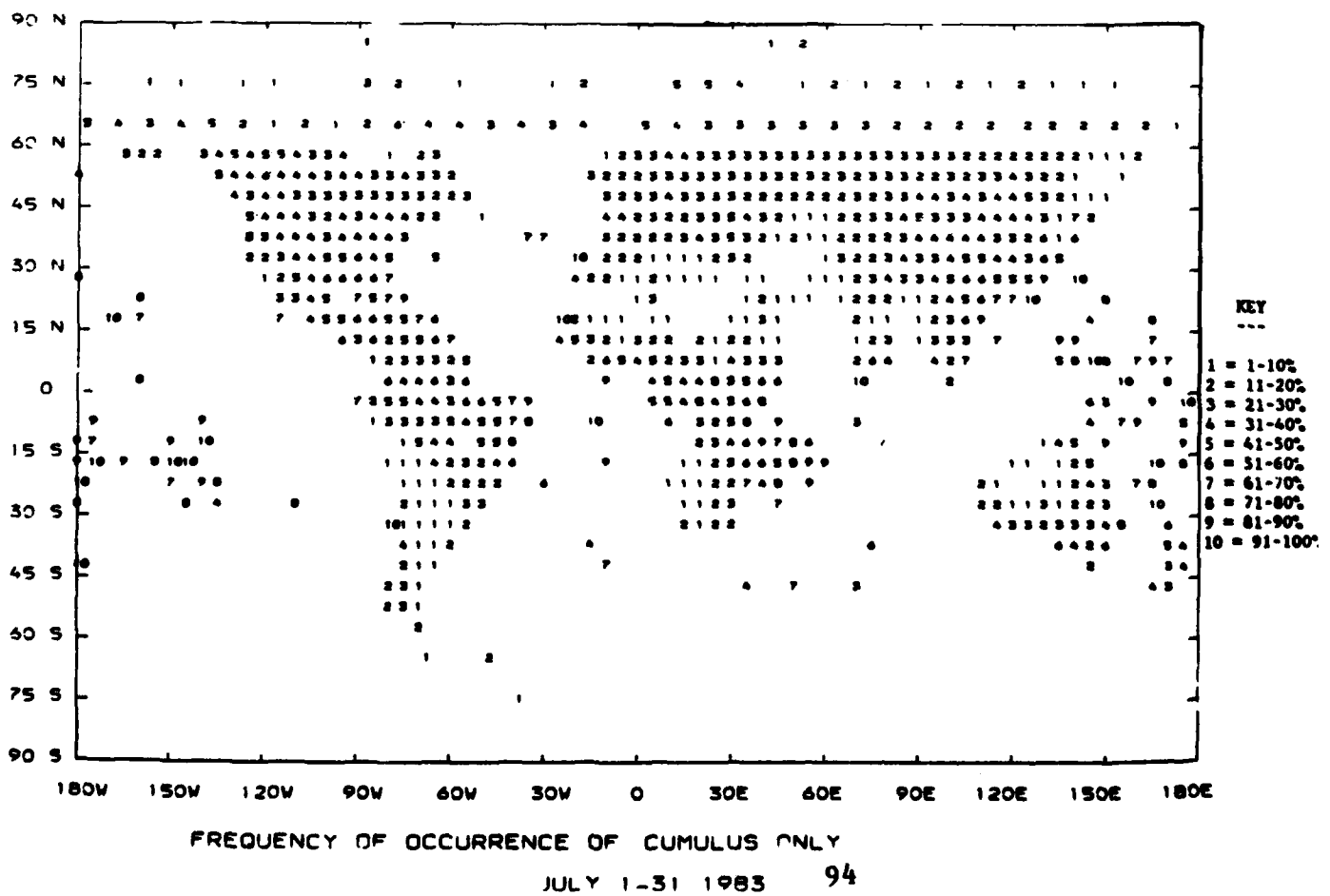
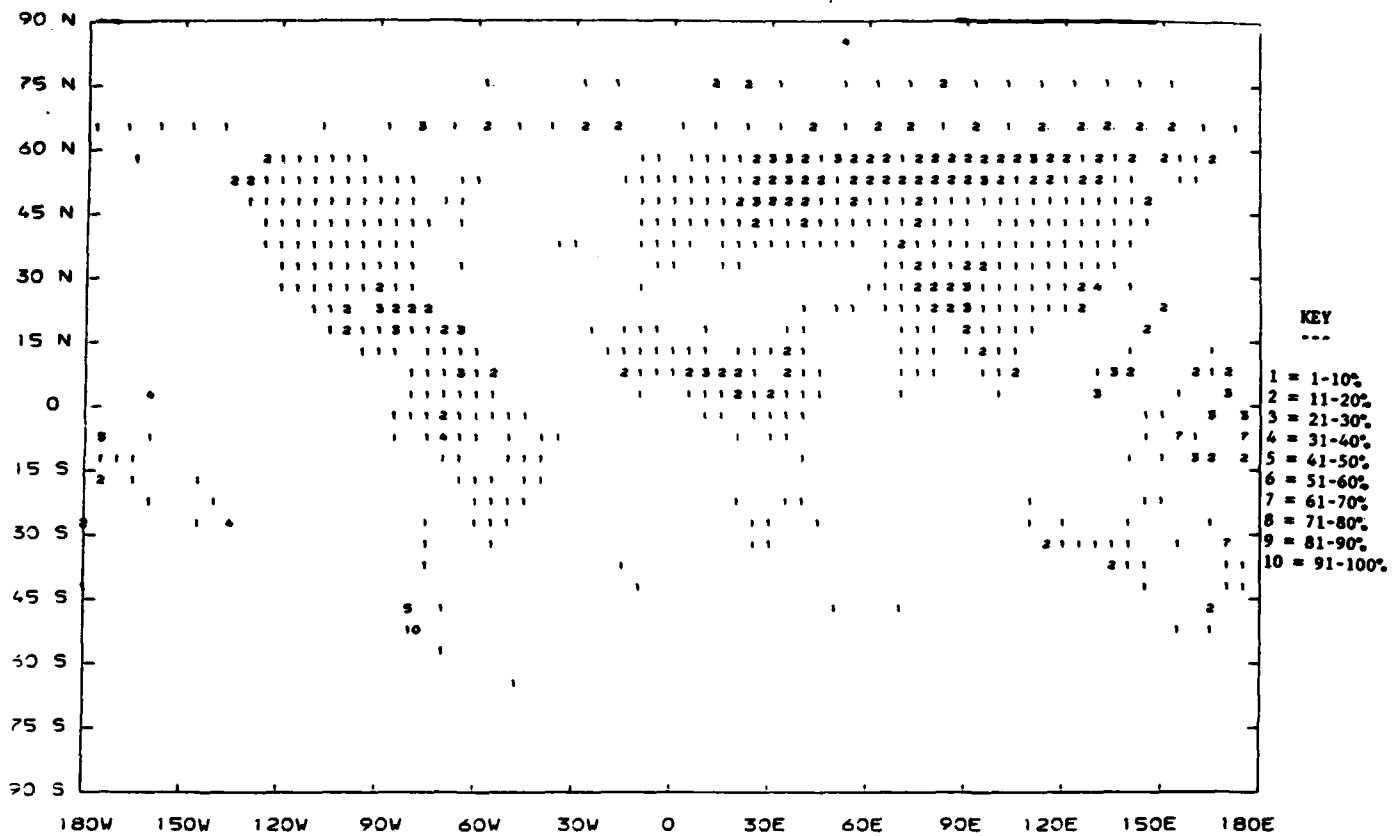


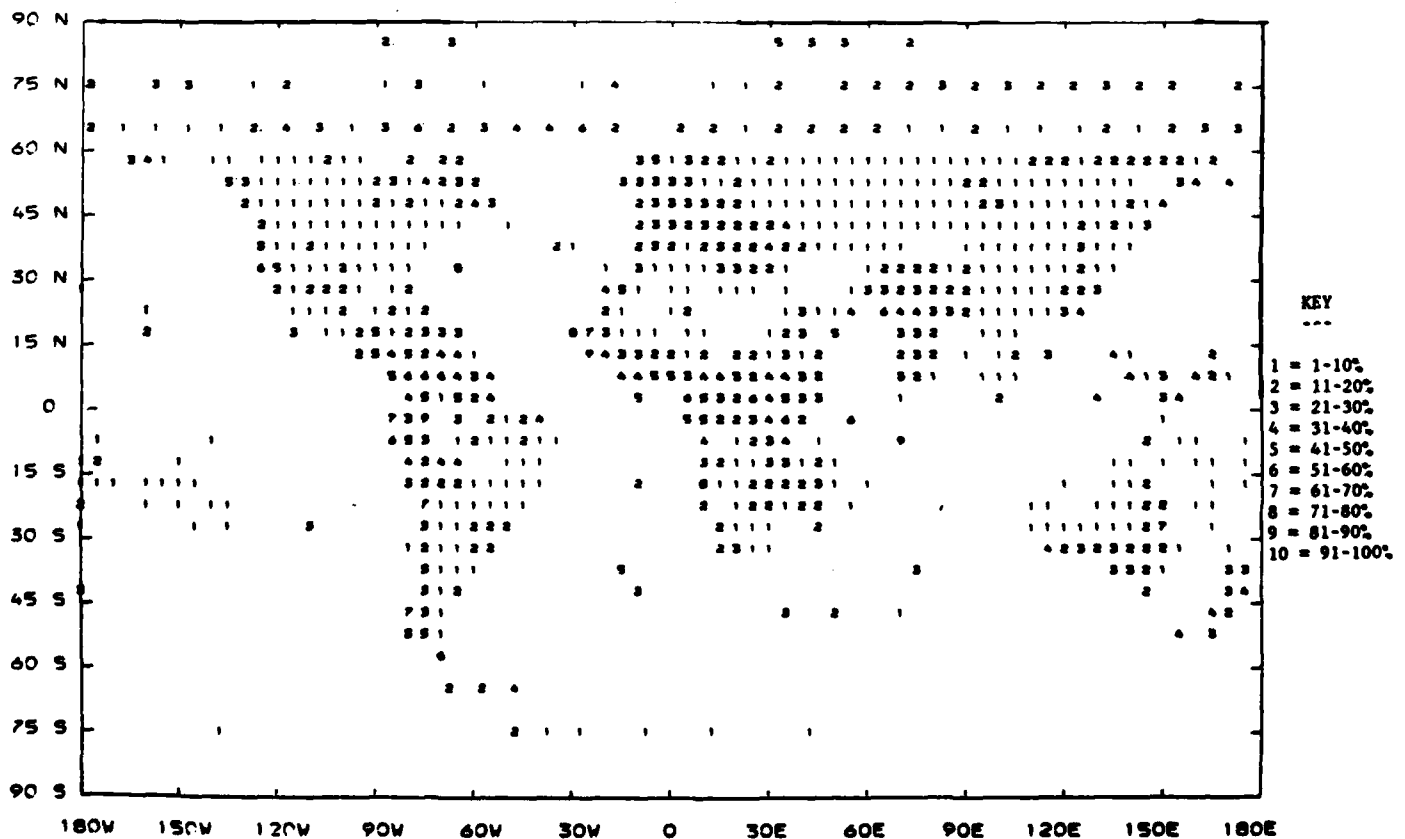
Figure 112



FREQUENCY OF OCCURRENCE OF CUMULONIMBUS ONLY

JULY 1-31 1983

Figure 113



FREQUENCY OF OCCURRENCE OF St/Sc ONLY

JULY 1-31 1983

Figure 114

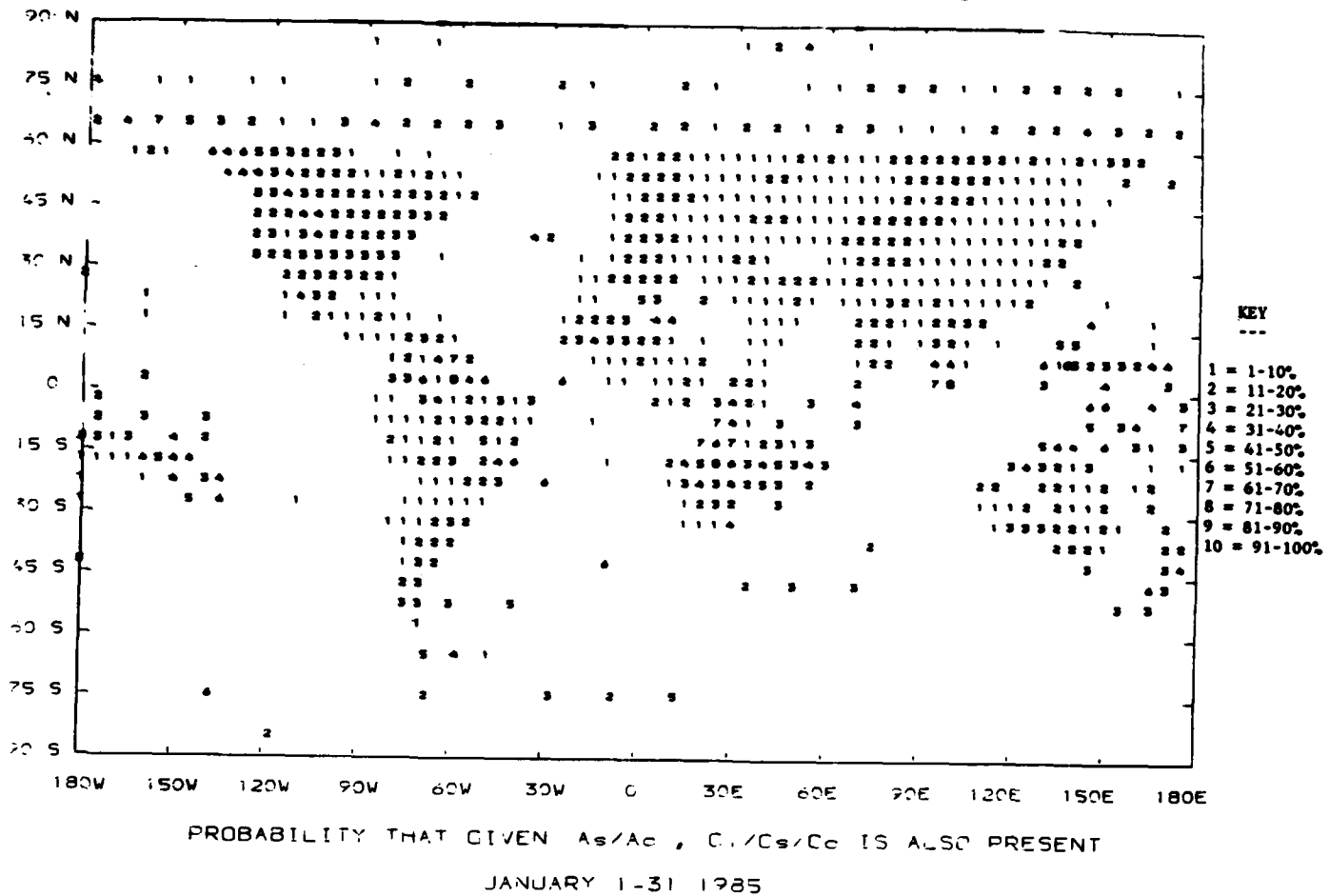


Figure 115

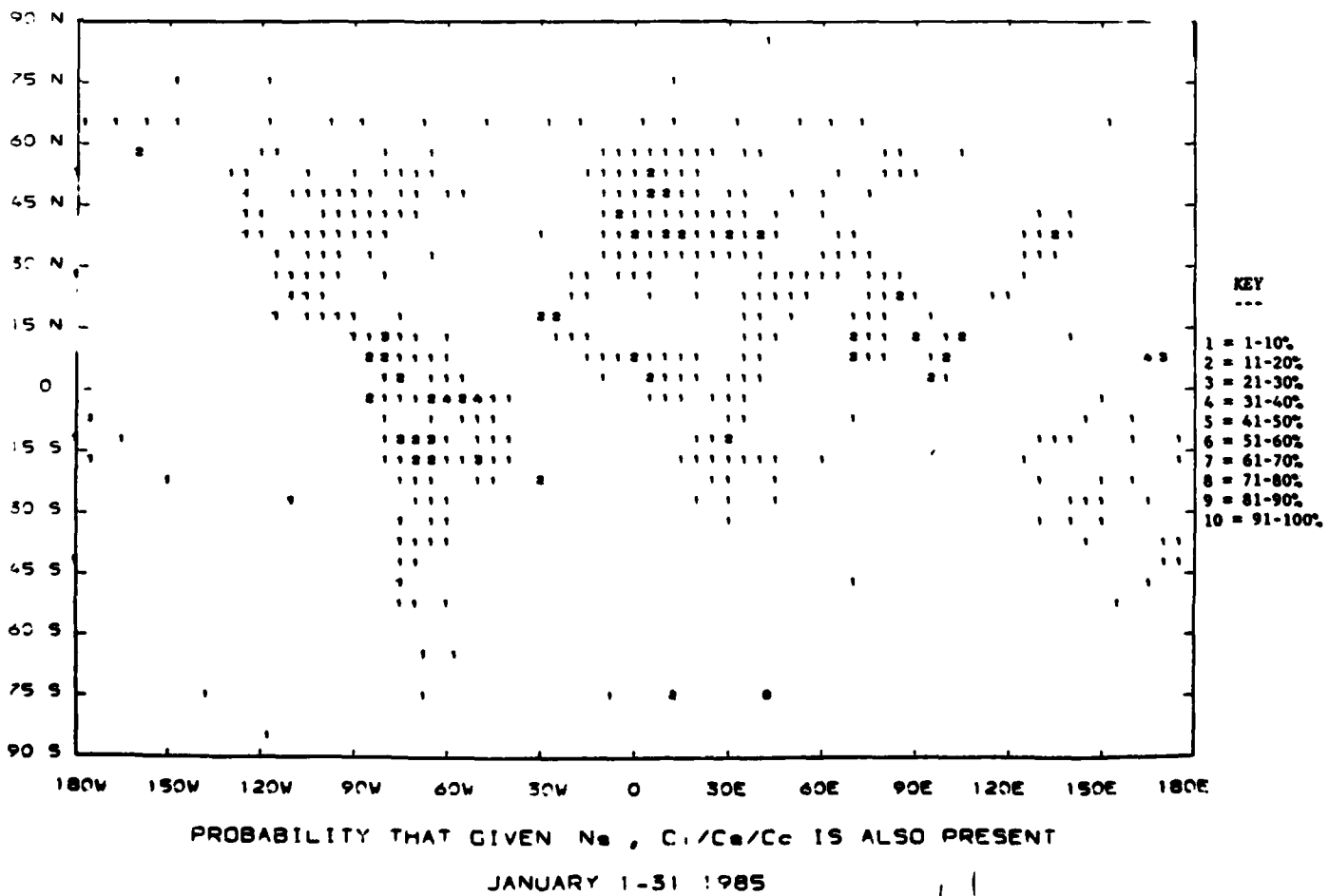


Figure 116

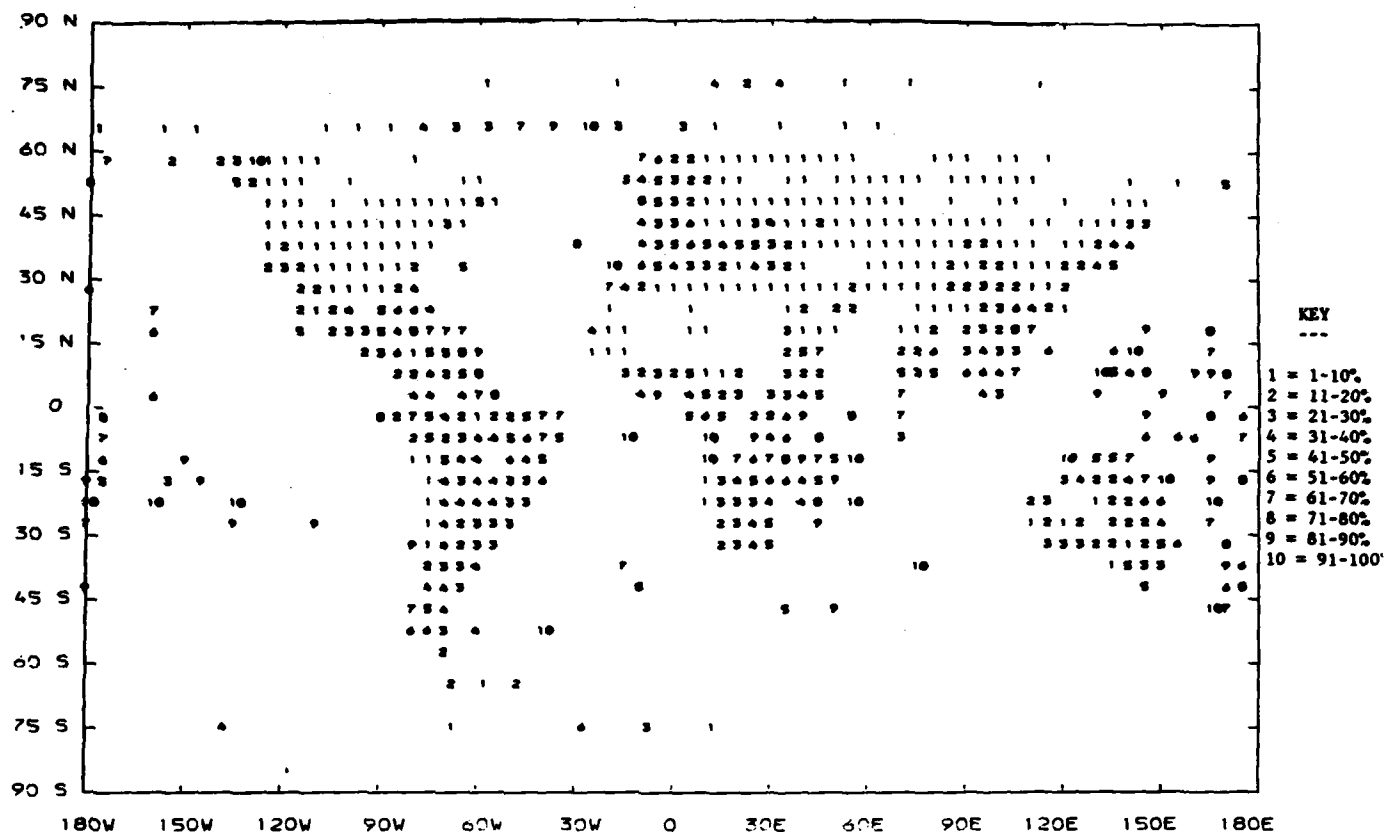


Figure 117

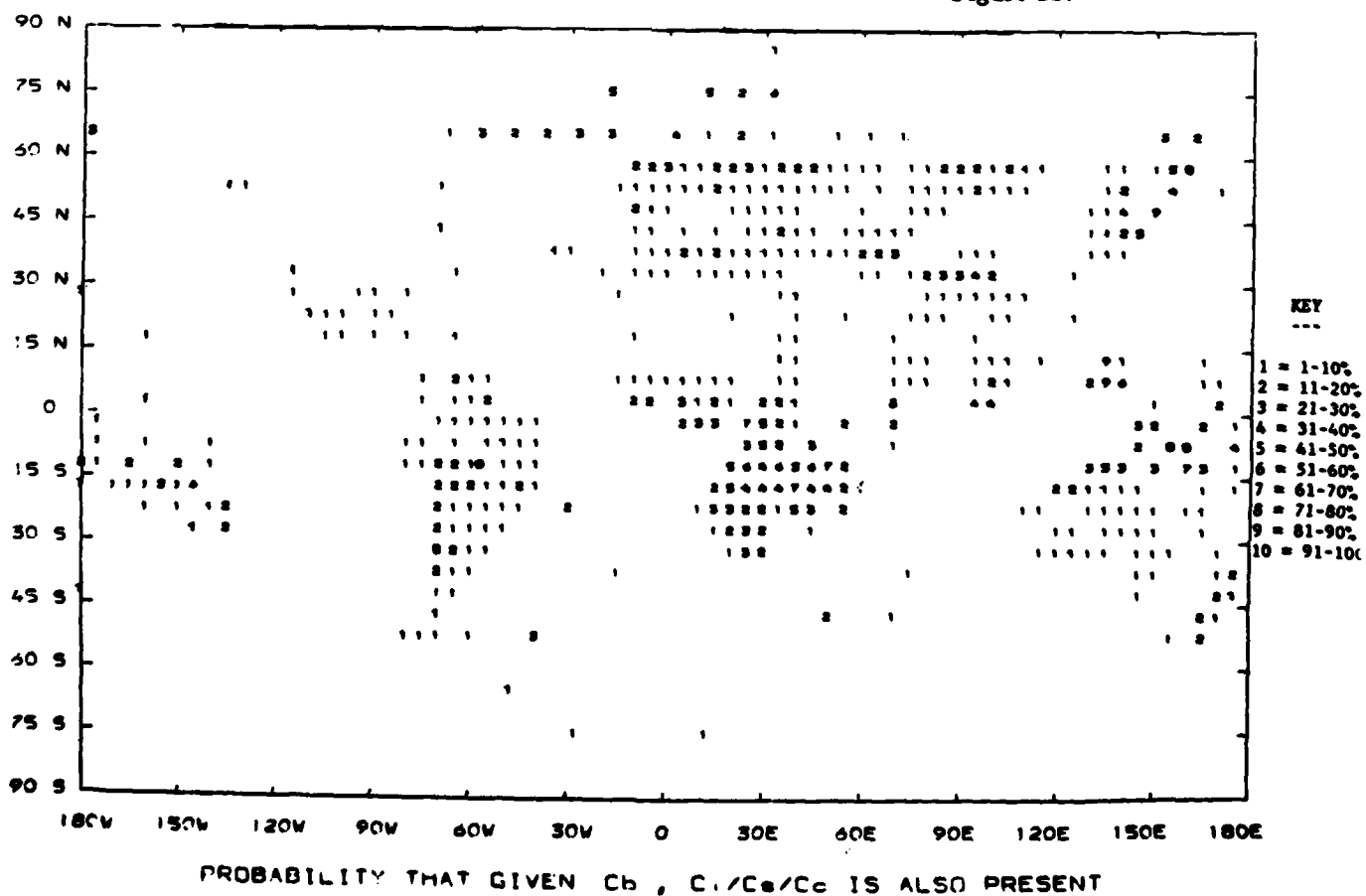


Figure 118

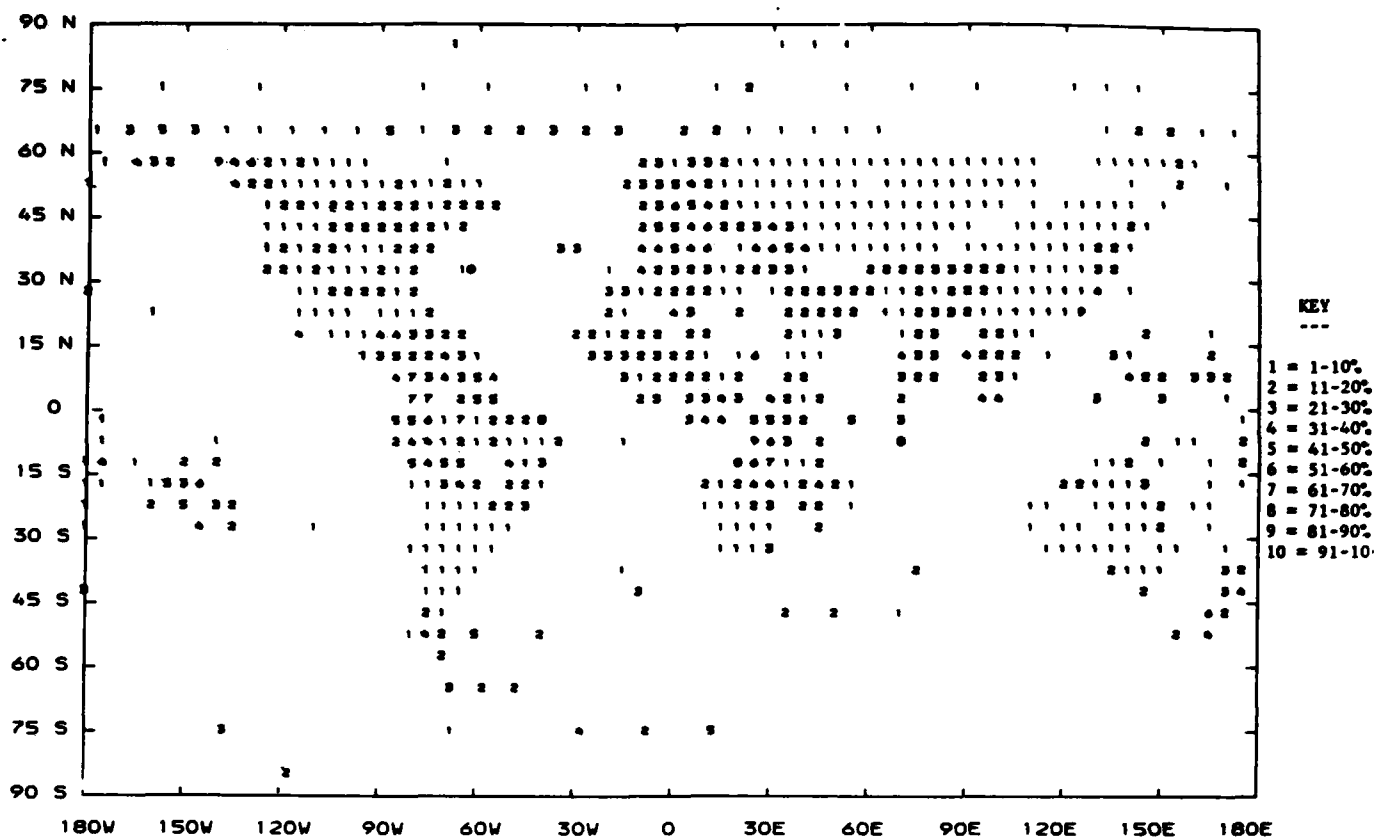


Figure 119

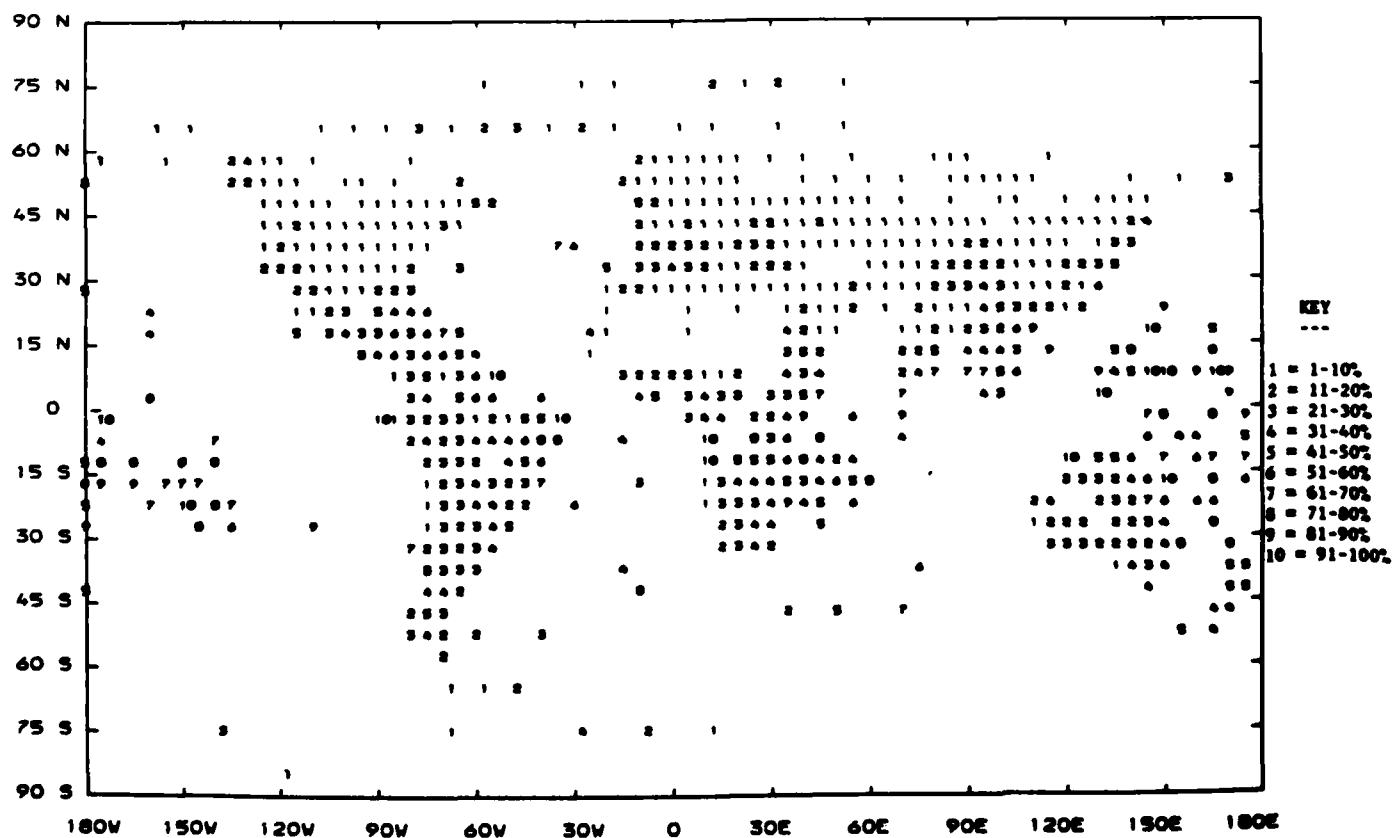


Figure 120

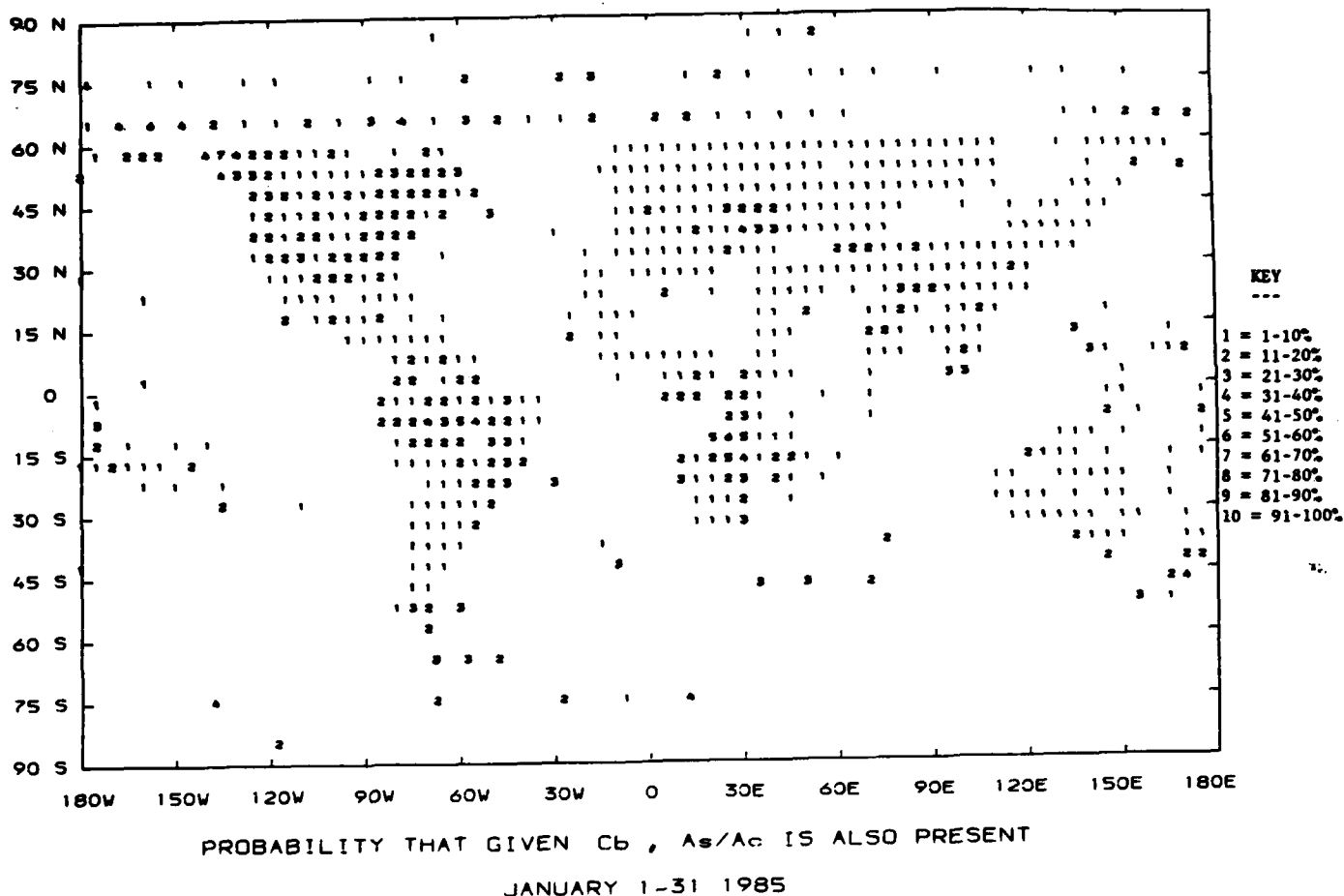


Figure 121

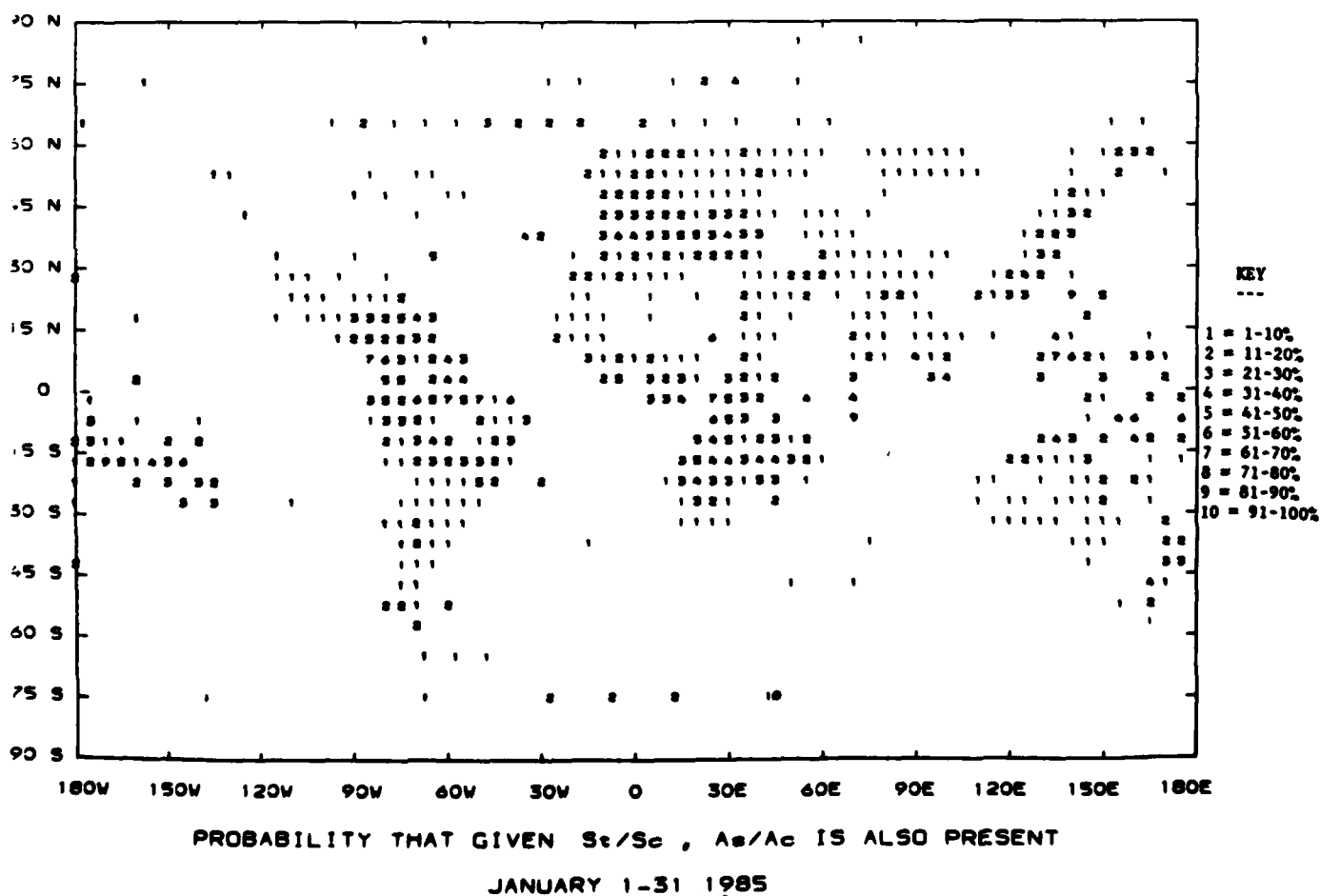


Figure 122

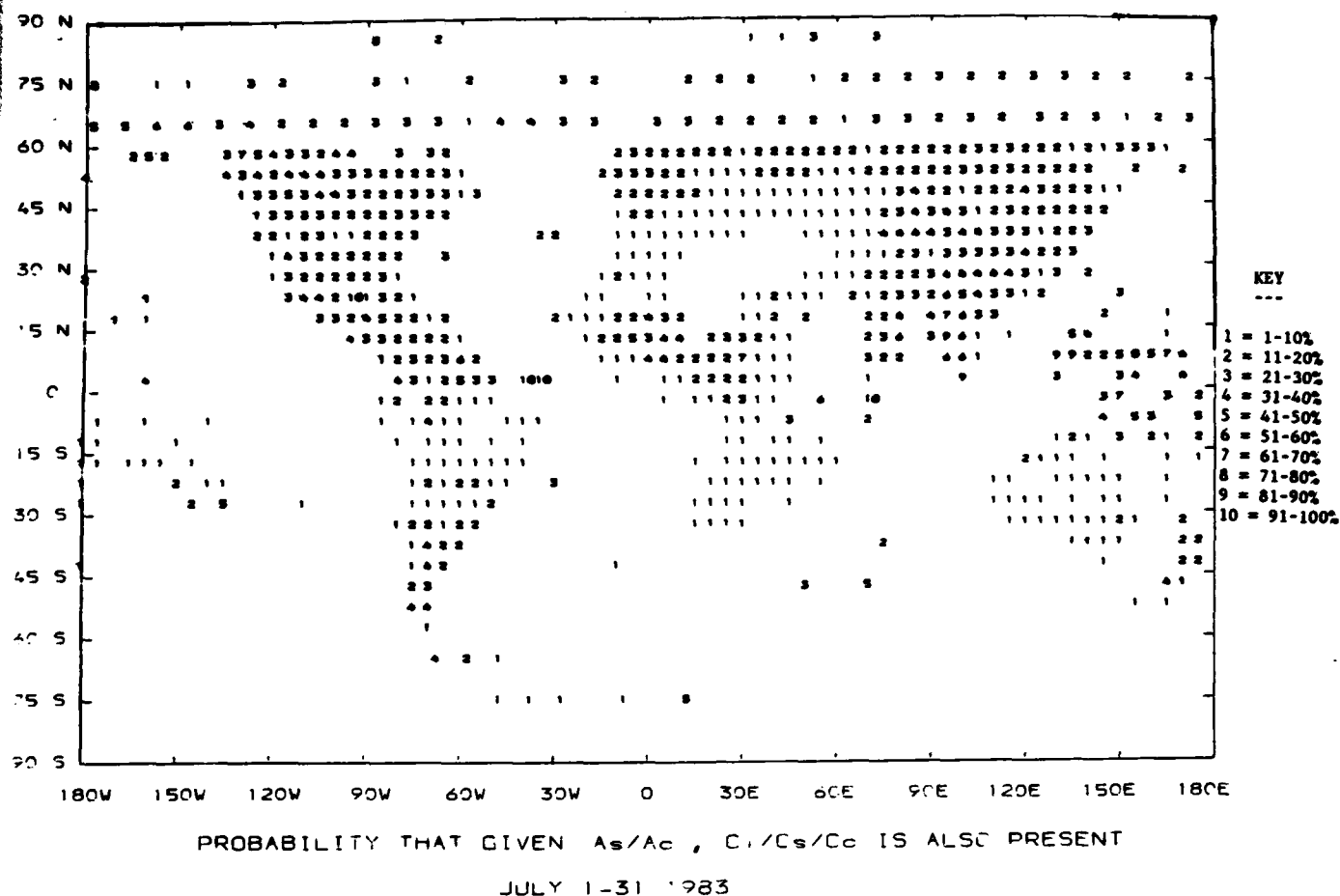
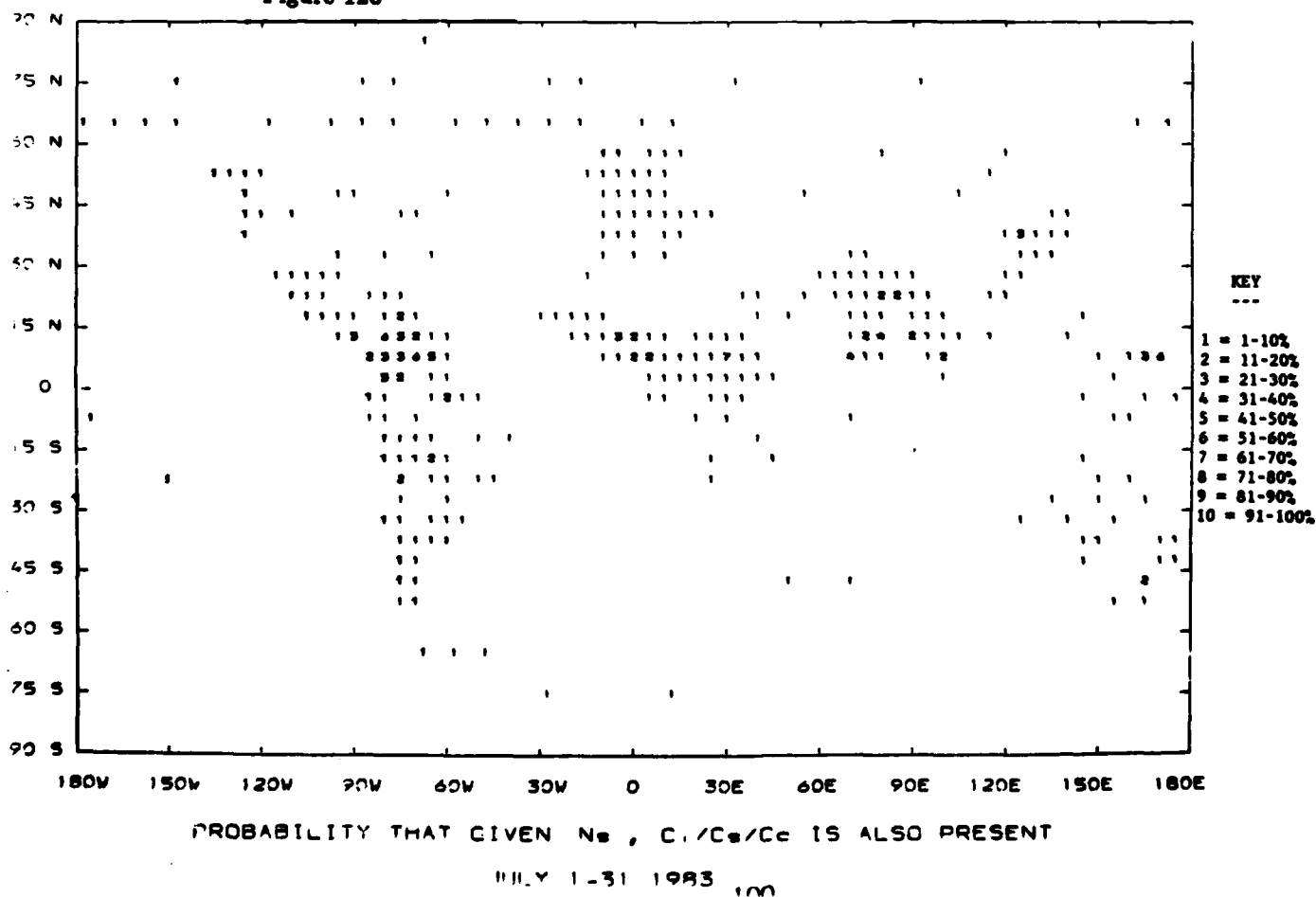


Figure 123



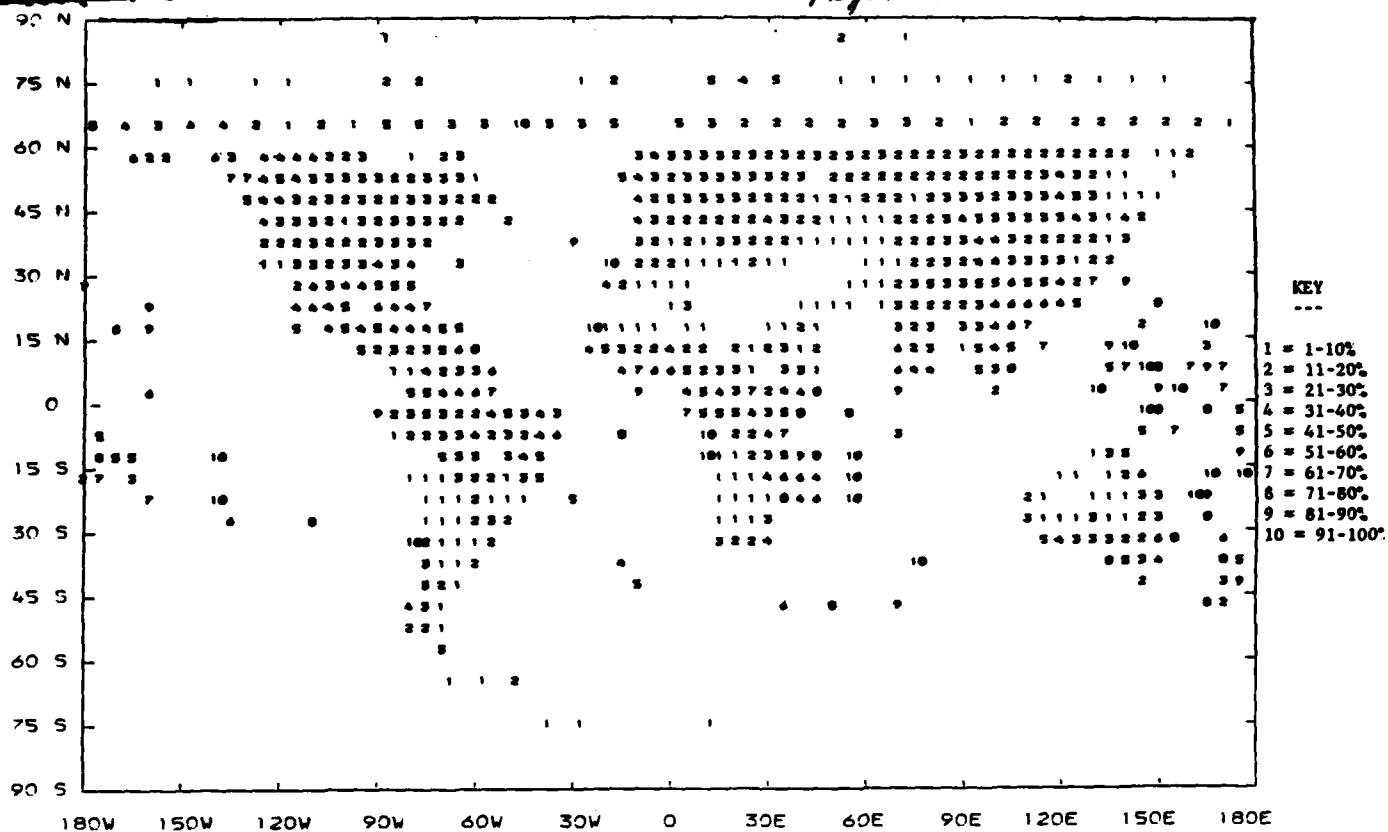
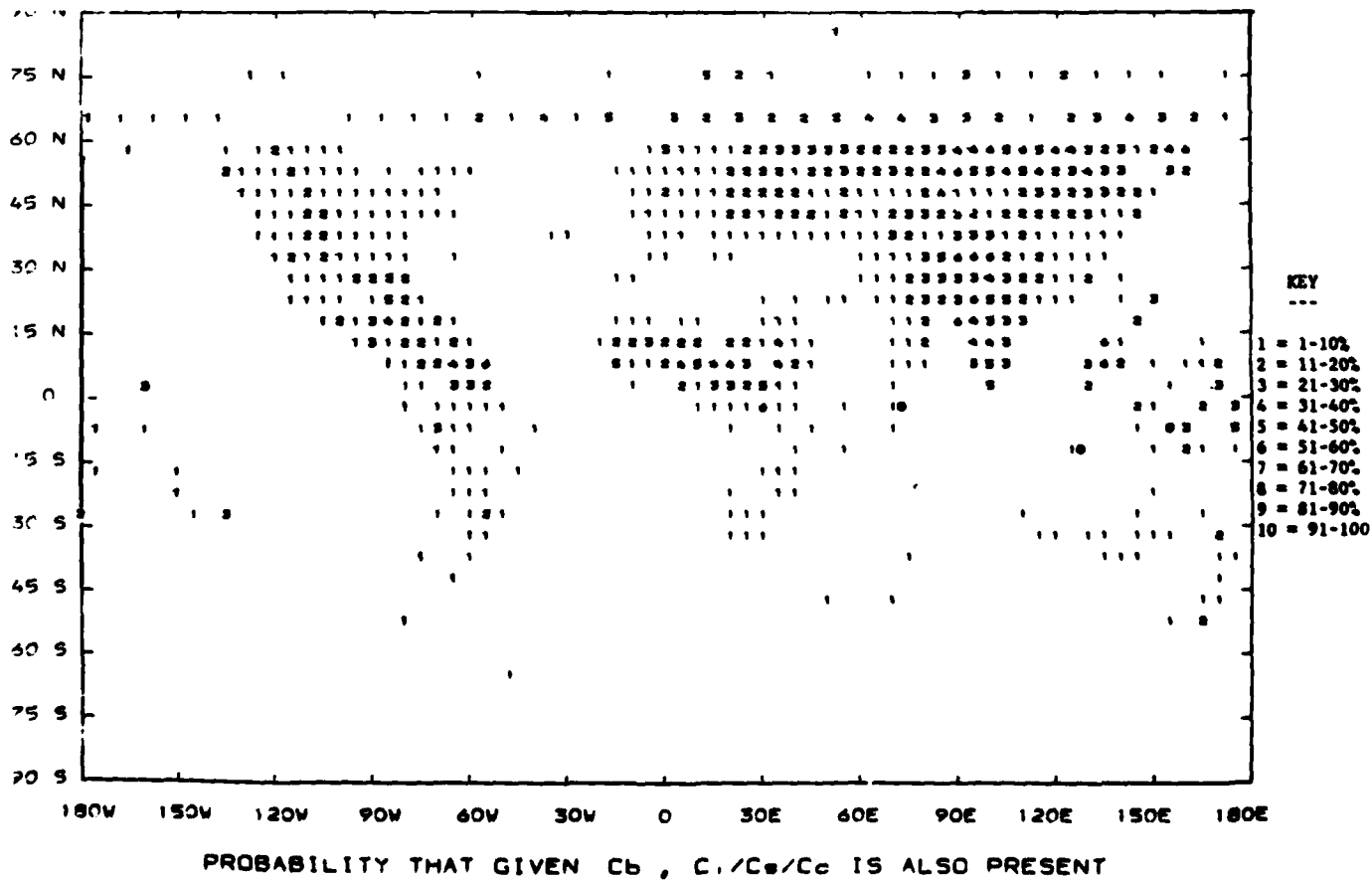
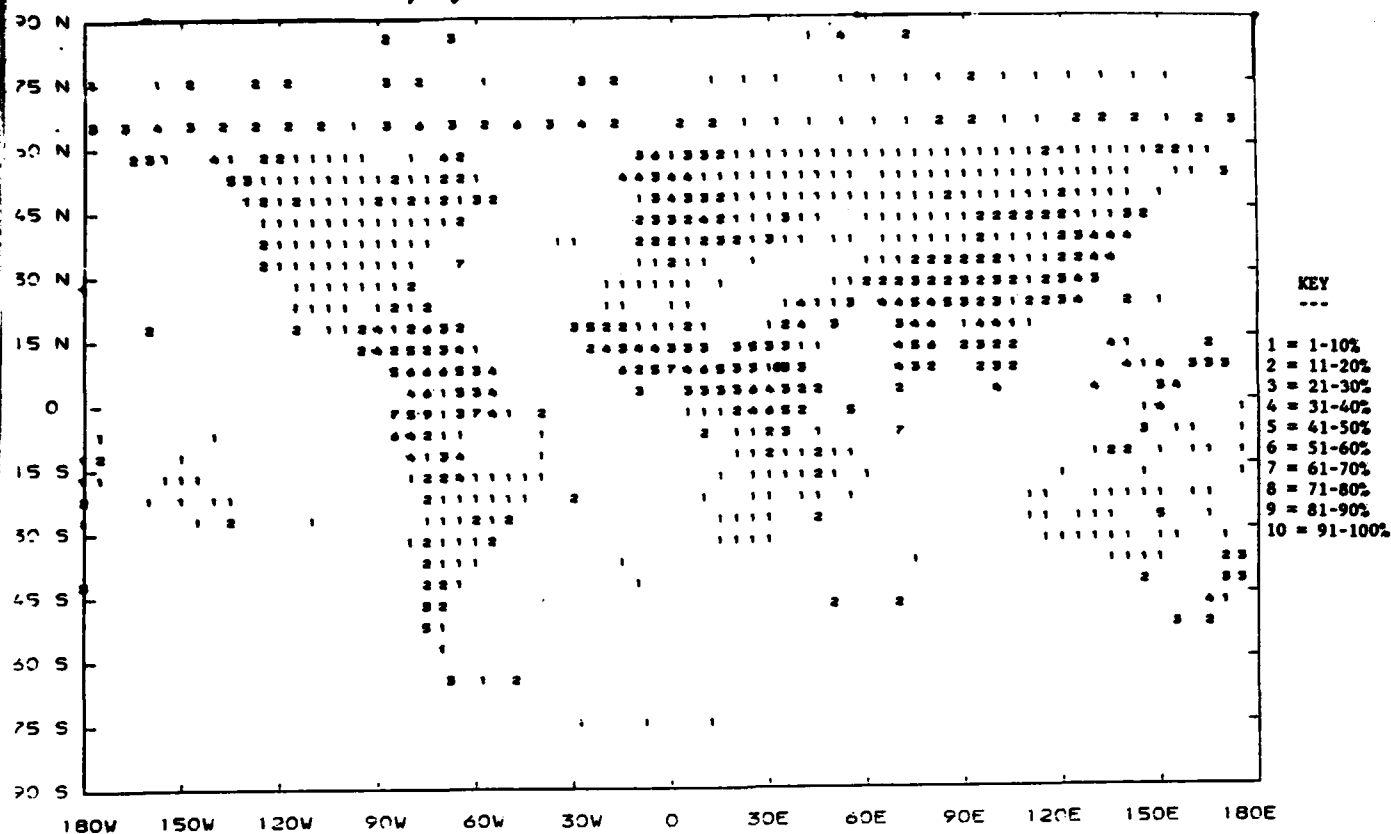


Figure 125

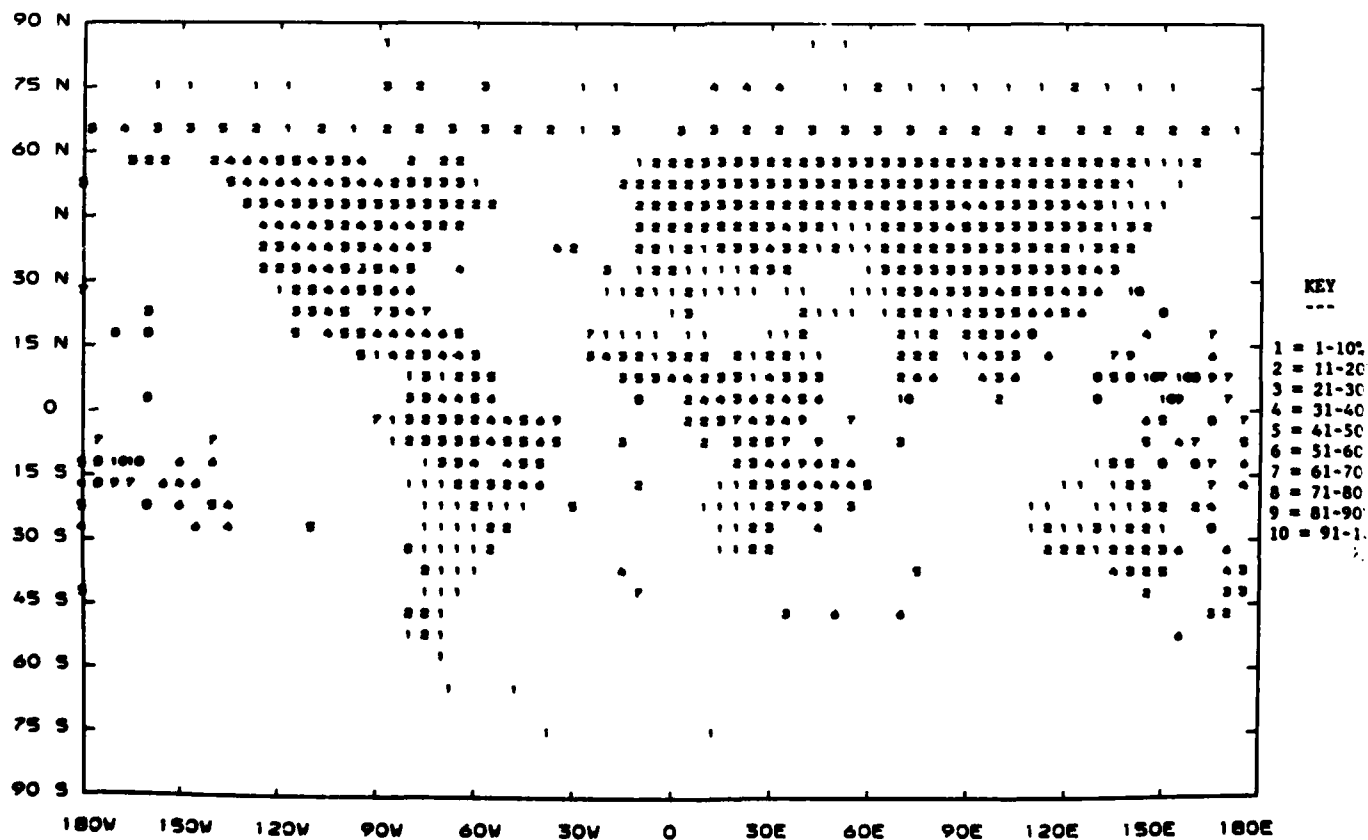




PROBABILITY THAT GIVEN  $S_e/S_c$ ,  $C_i/C_s/C_c$  IS ALSO PRESENT

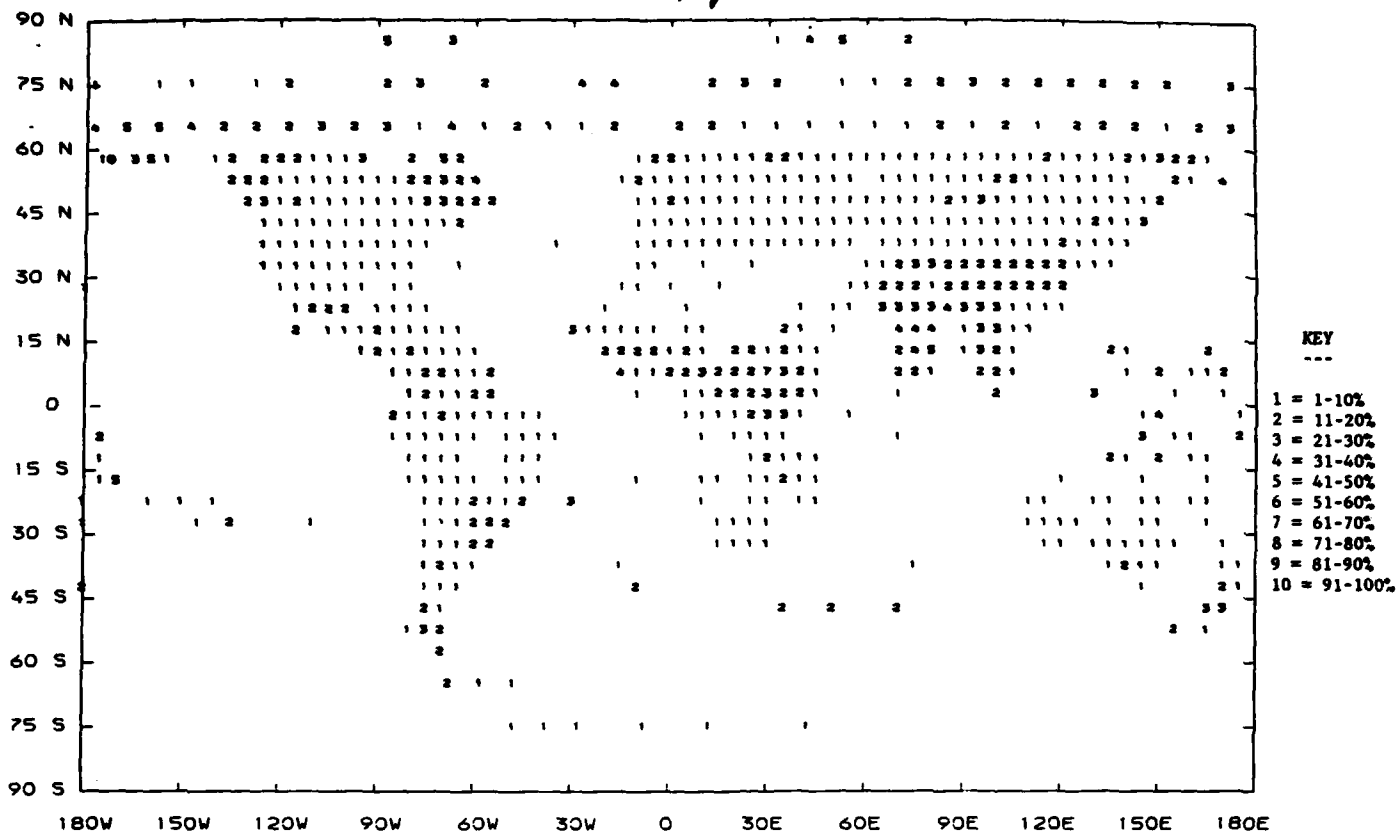
JULY 1-31 1983

Figure 127



PROBABILITY THAT GIVEN  $C_u$ ,  $A_e/A_c$  IS ALSO PRESENT

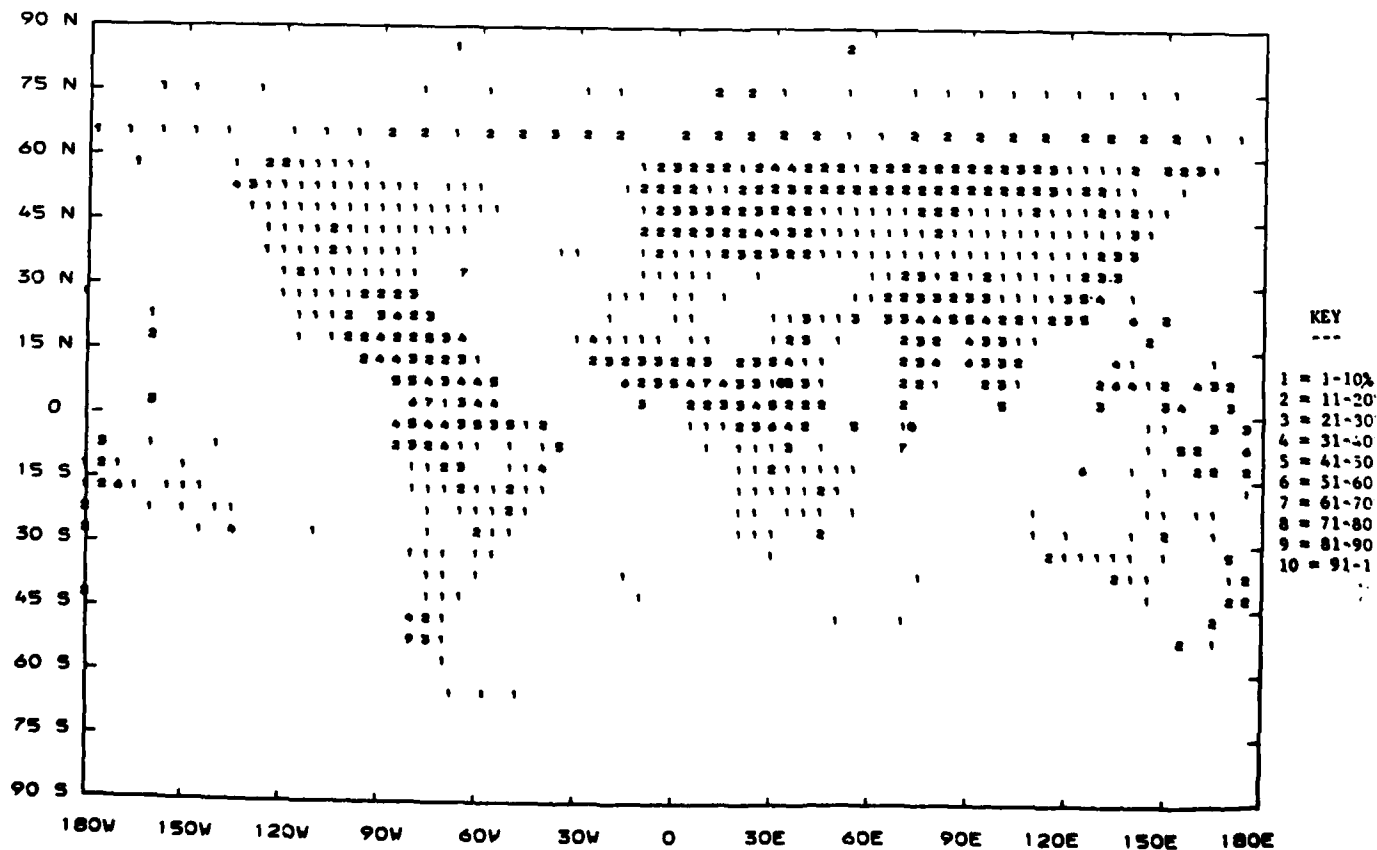
JULY 1-31 1983



PROBABILITY THAT GIVEN  $C_b$ ,  $A_s/A_c$  IS ALSO PRESENT

JULY 1-31 1983

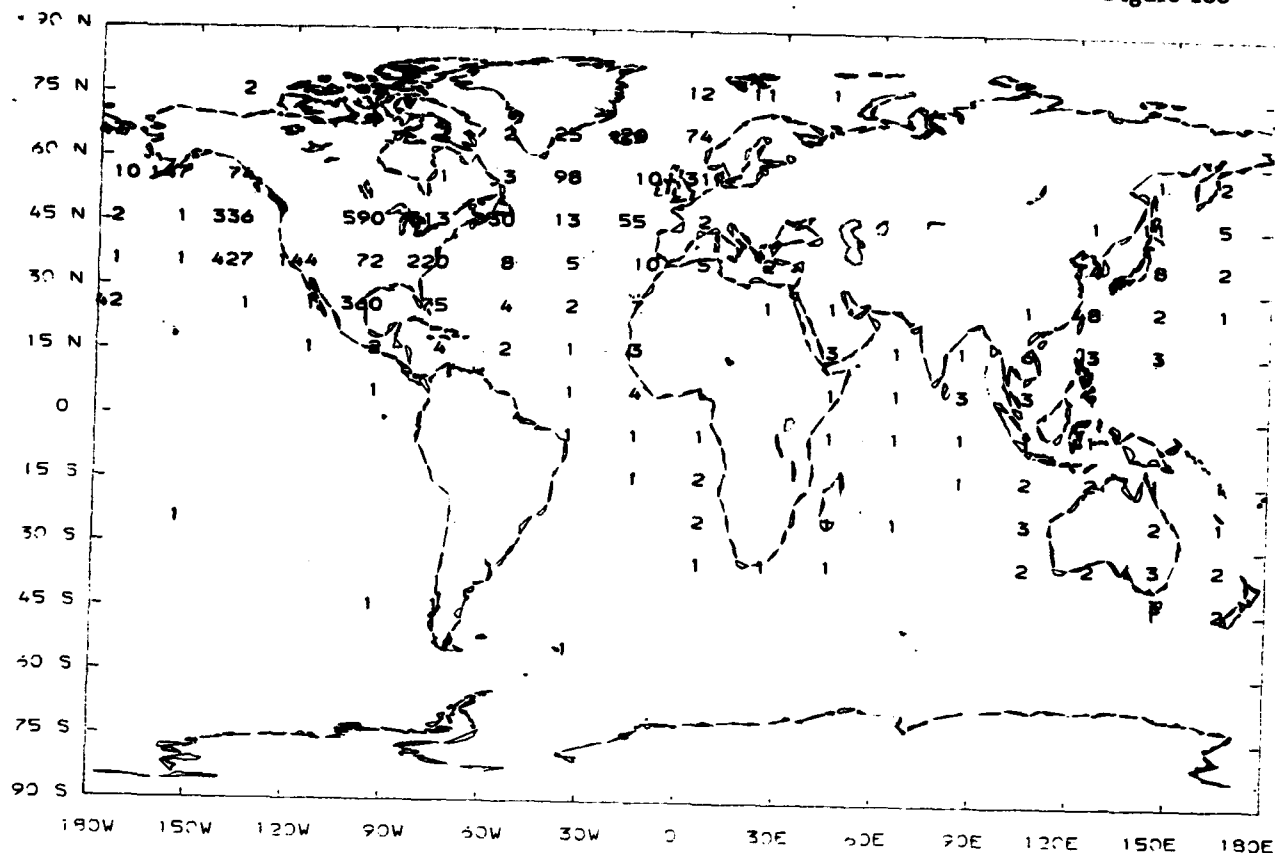
Figure 129



PROBABILITY THAT GIVEN  $St/Sc$ ,  $A_s/A_c$  IS ALSO PRESENT

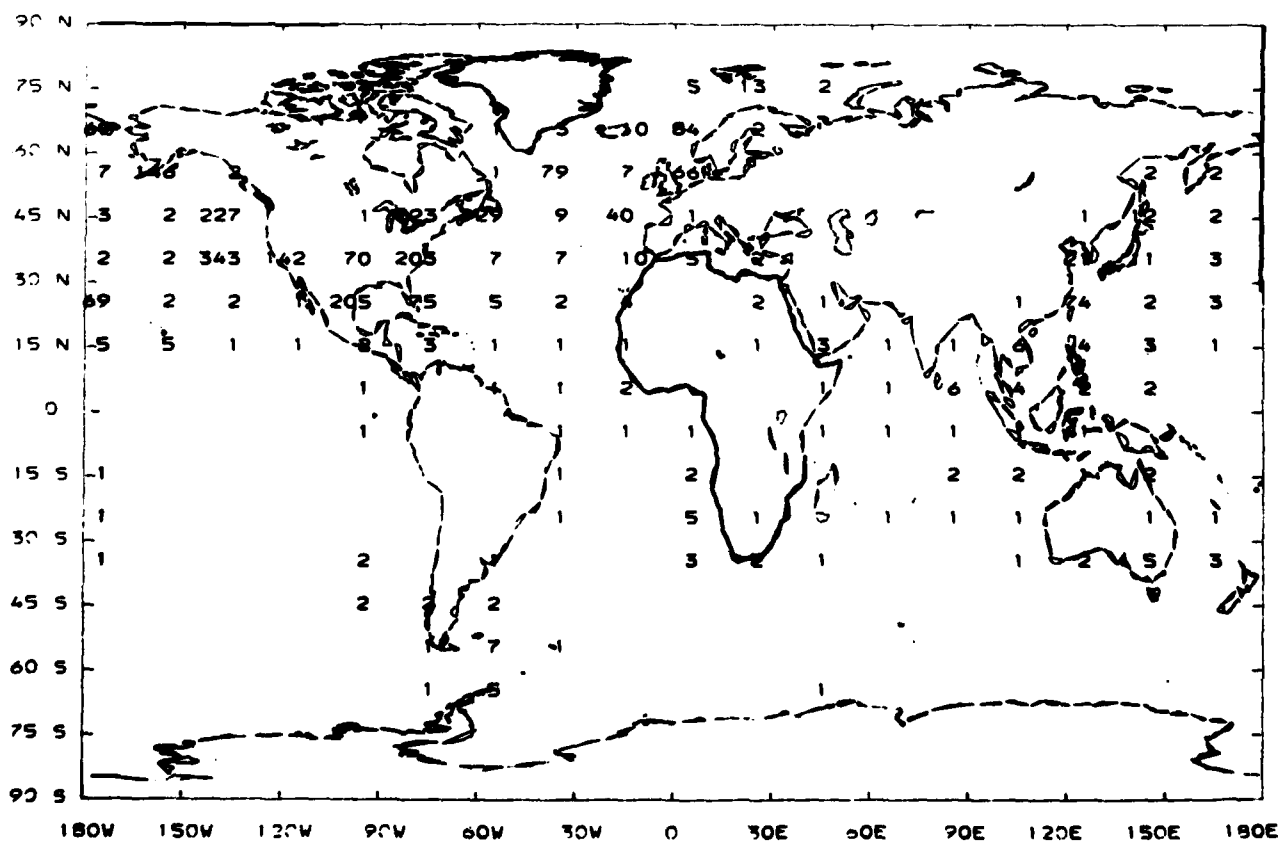
JULY 1-31 1983

Figure 130



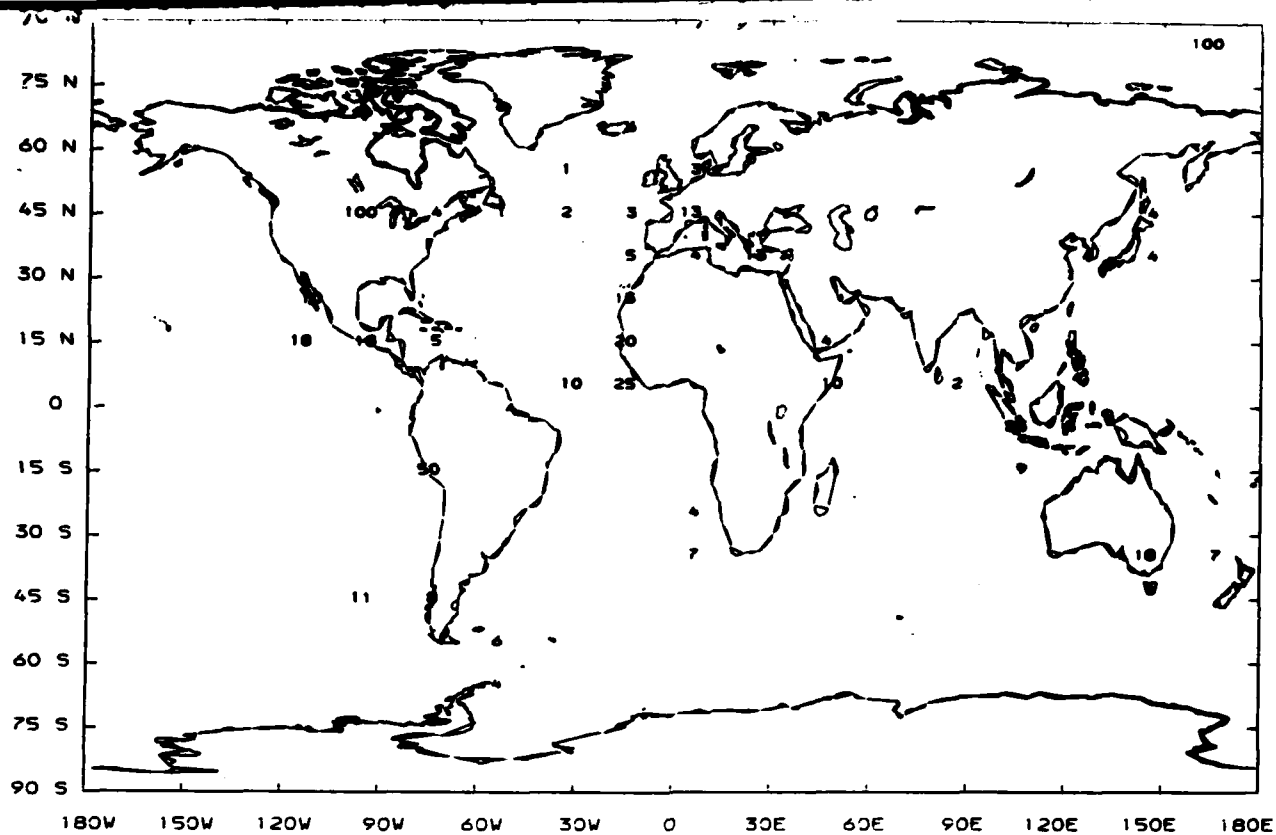
DISTRIBUTION OF SYNOPTIC OBSERVATIONS IN TENS  
JULY 1-31 1983

Figure 131



DISTRIBUTION OF SYNOPTIC OBSERVATIONS IN TENS

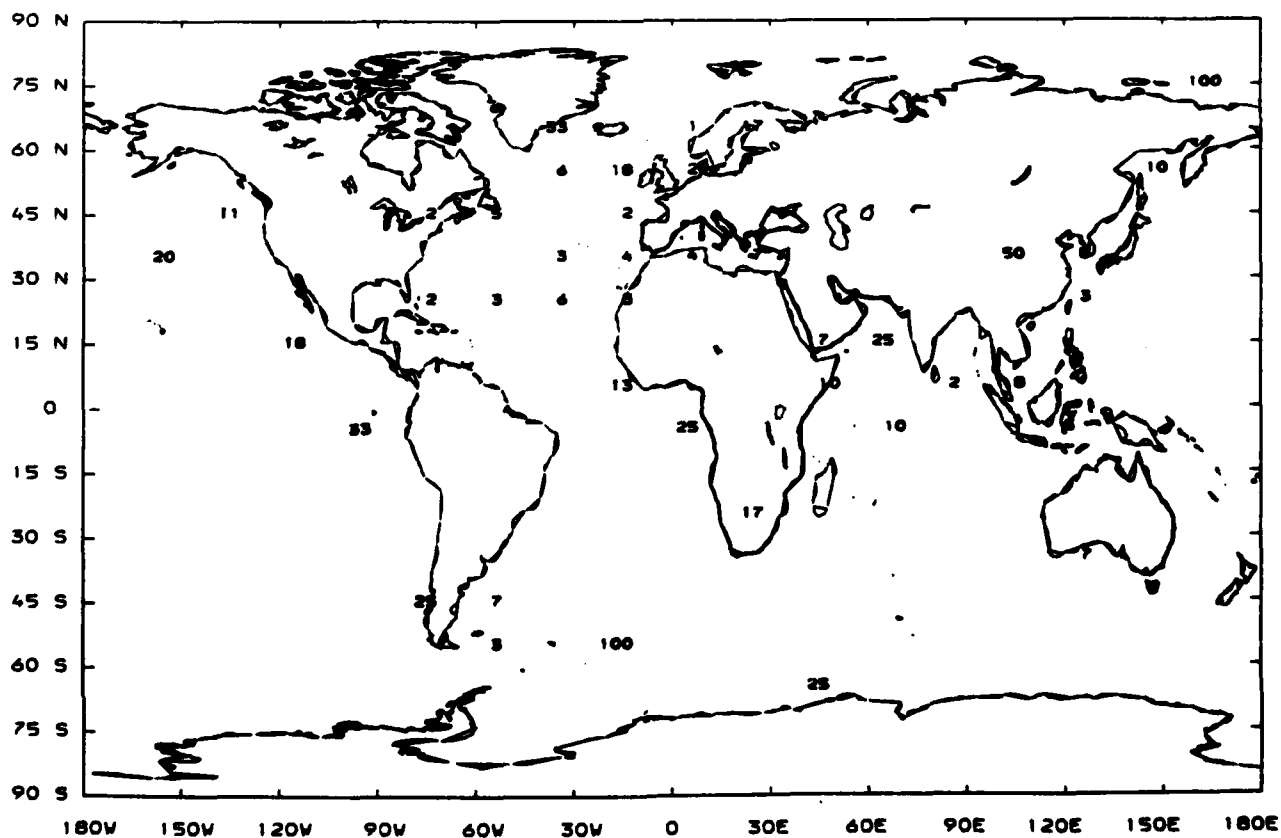
JANUARY 1-31 1985



FREQUENCY OF OCCURRENCE (PERCENT) OF  $C_1/C_s/C_c$  ONLY

JANUARY 1-31 1985

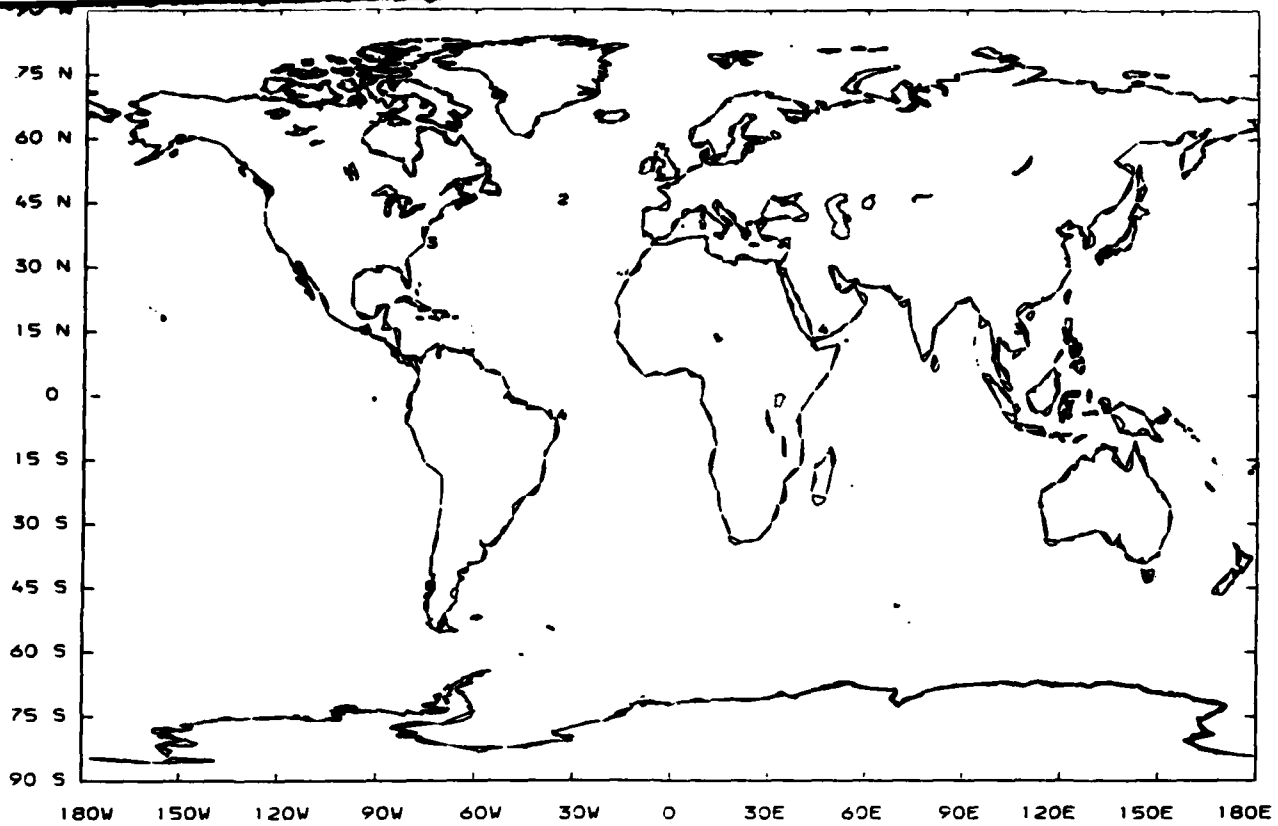
Figure 132



FREQUENCY OF OCCURRENCE (PERCENT) OF  $A_a/A_c$  ONLY

JANUARY 1-31 1985

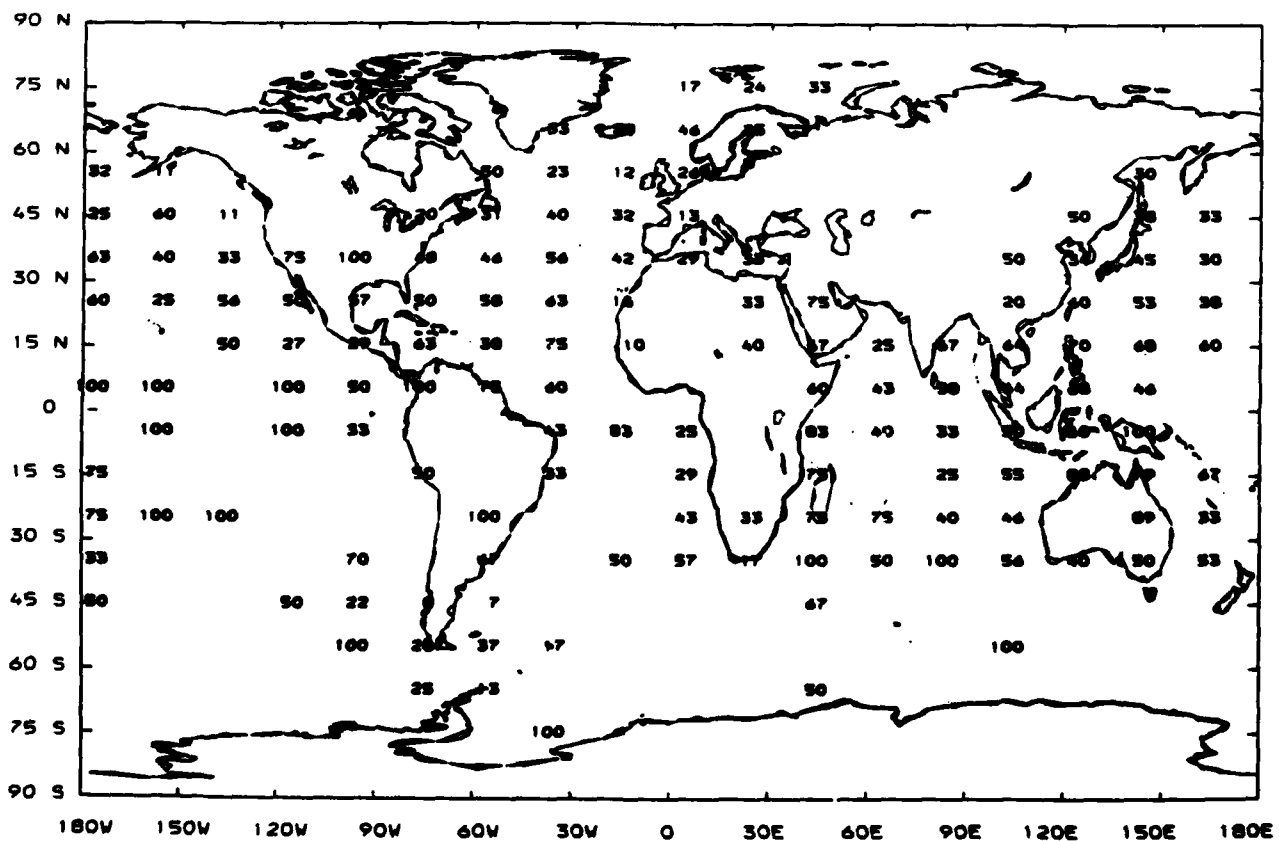
Figure 133



FREQUENCY OF OCCURRENCE (PERCENT) OF NIMBOSTRATUS ONLY

JANUARY 1-31 1985

Figure 134

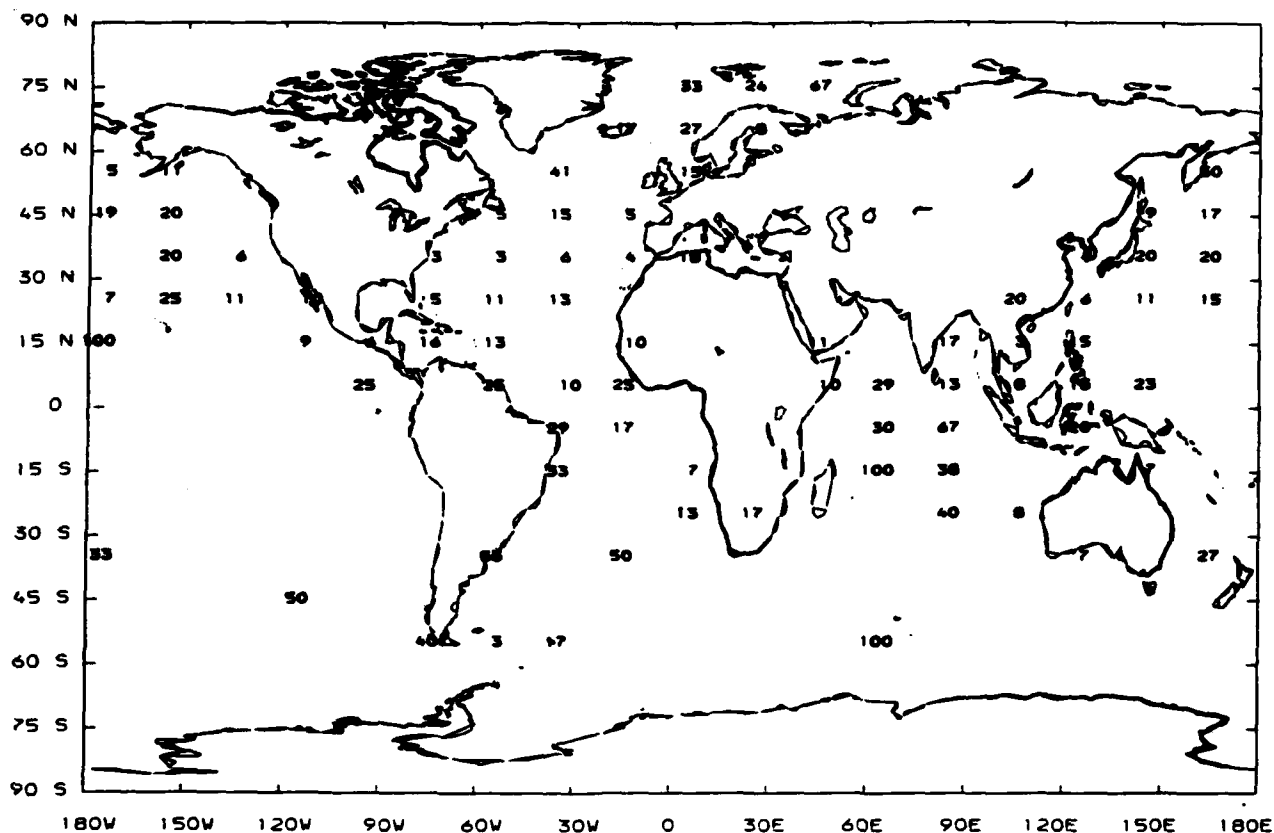


FREQUENCY OF OCCURRENCE (PERCENT) OF CUMULUS ONLY

JANUARY 1-31 1985

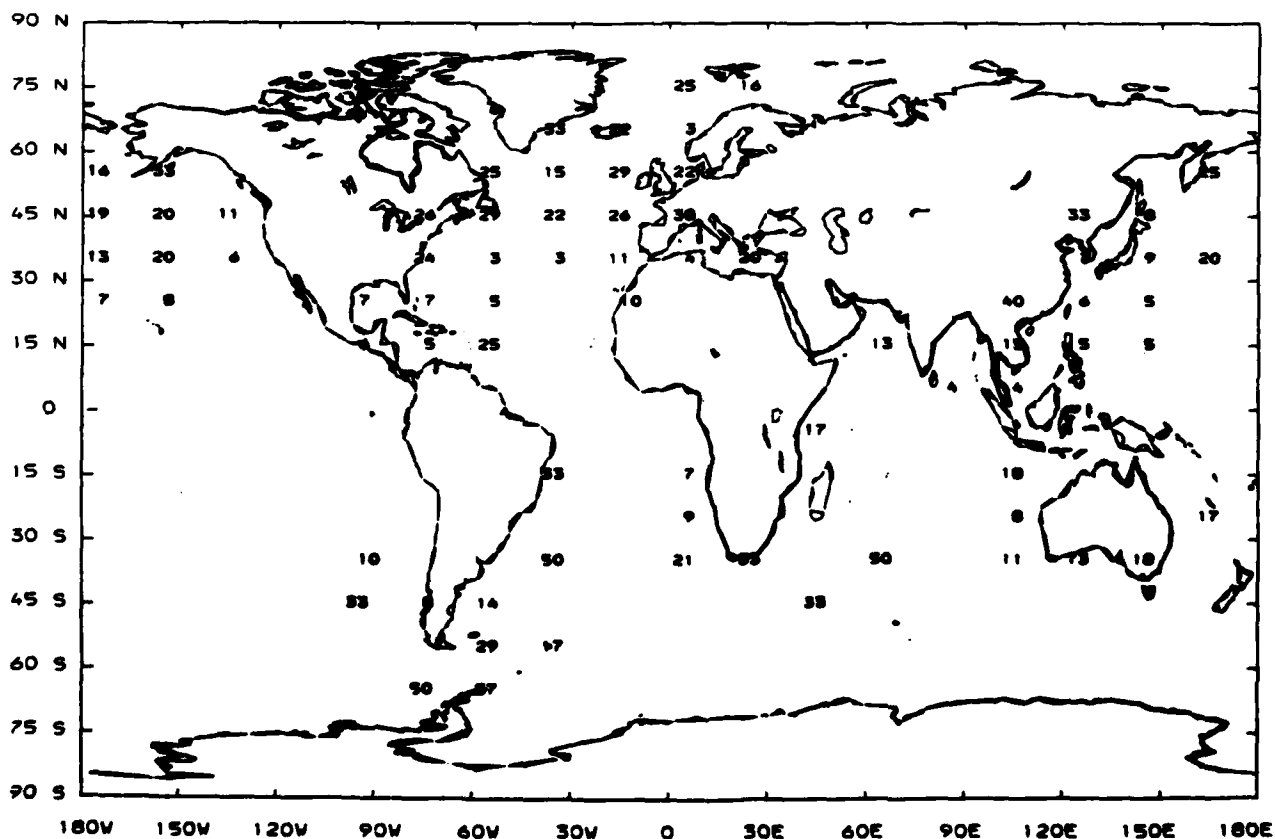
Figure 135

Figure 136



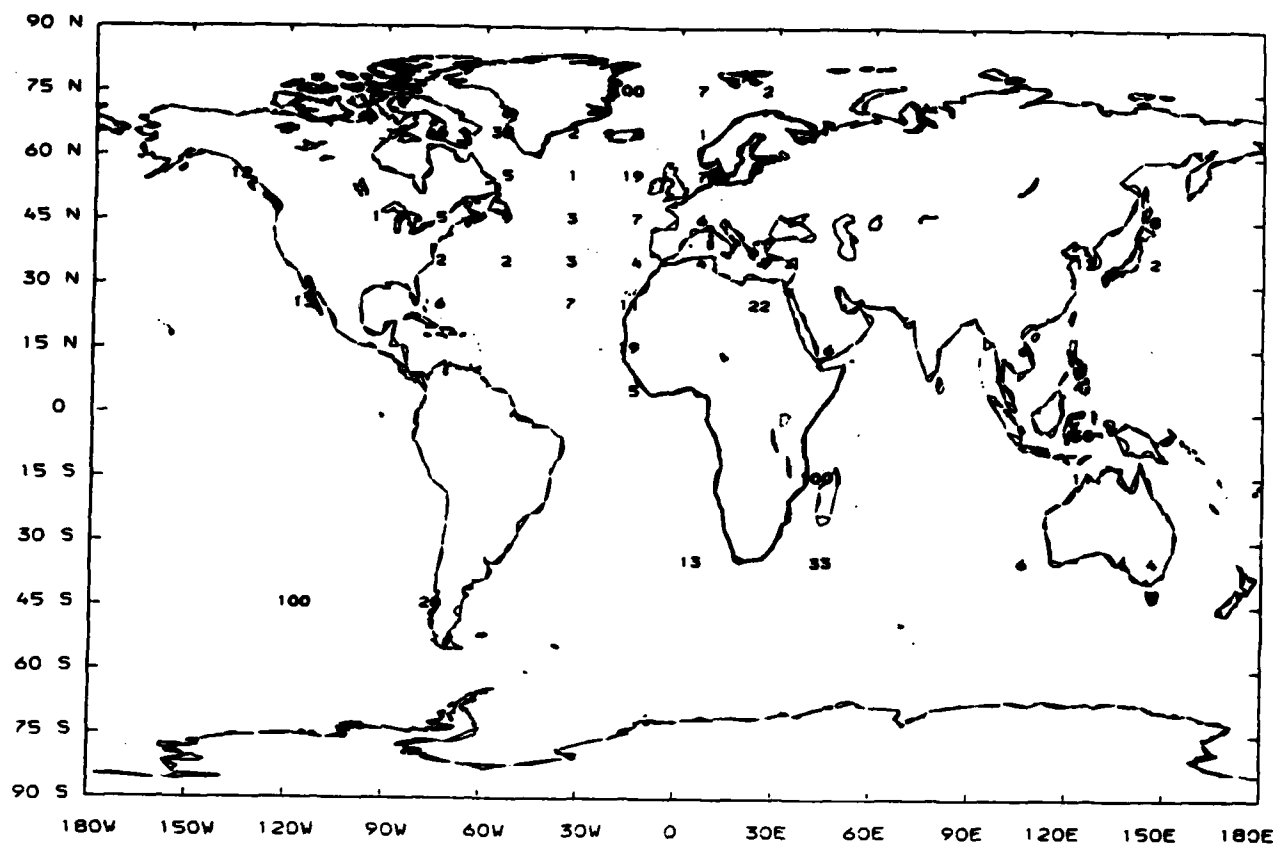
FREQUENCY OF OCCURRENCE (PERCENT) OF CUMULONIMBUS ONLY  
JANUARY 1-31 1985

Figure 137



FREQUENCY OF OCCURRENCE (PERCENT) OF St/Sc ONLY  
JANUARY 1-31 1985

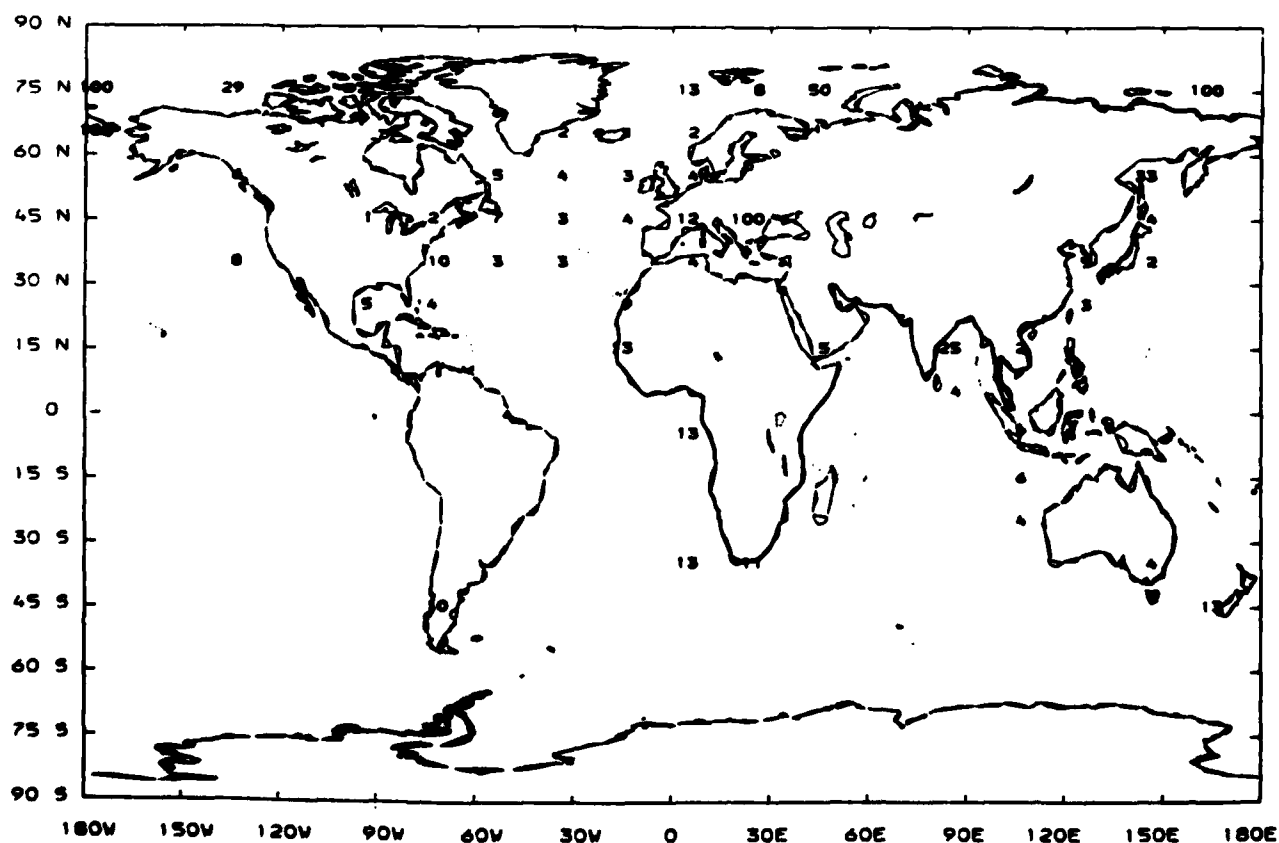
Figure 138



FREQUENCY OF OCCURRENCE (PERCENT) OF C<sub>1</sub>/C<sub>s</sub>/C<sub>c</sub> ONLY

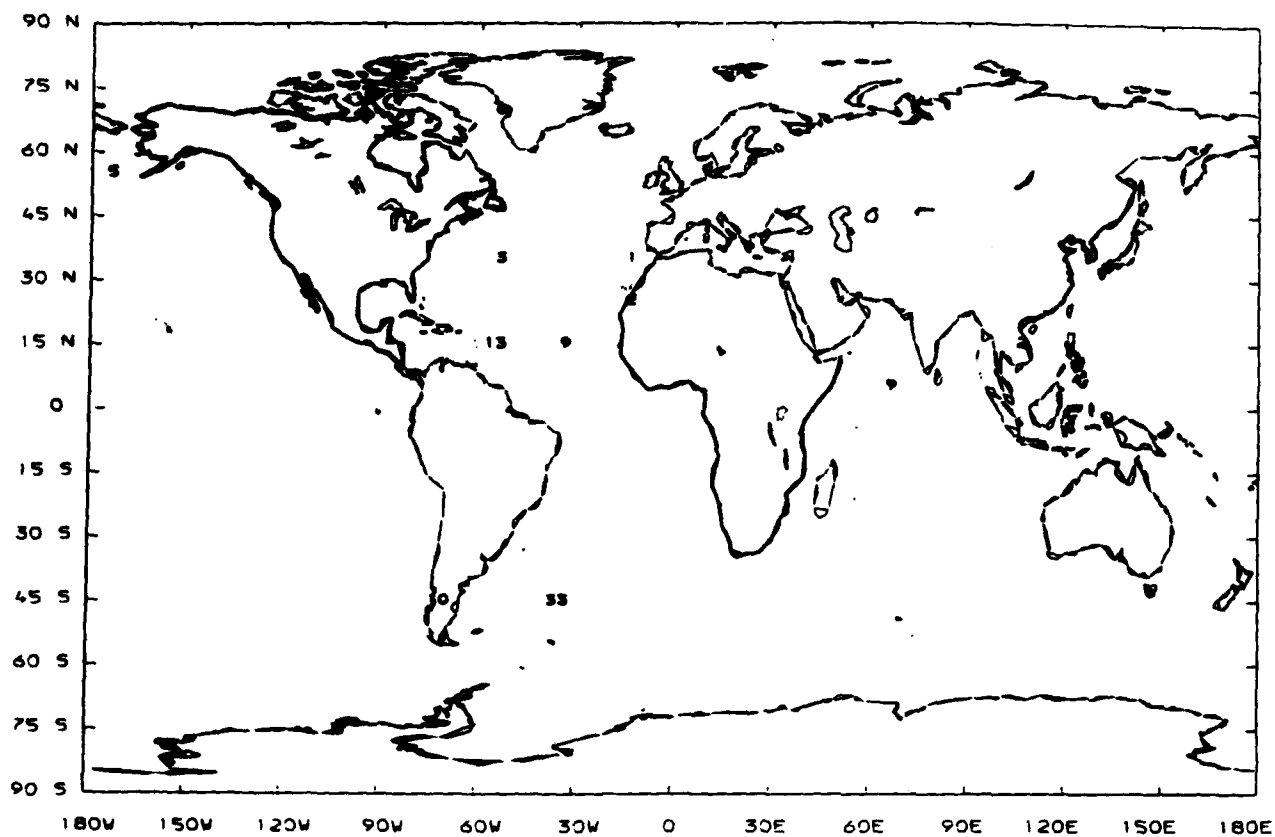
JULY 1-31 1983

Figure 139



FREQUENCY OF OCCURRENCE (PERCENT) OF A<sub>a</sub>/A<sub>c</sub> ONLY

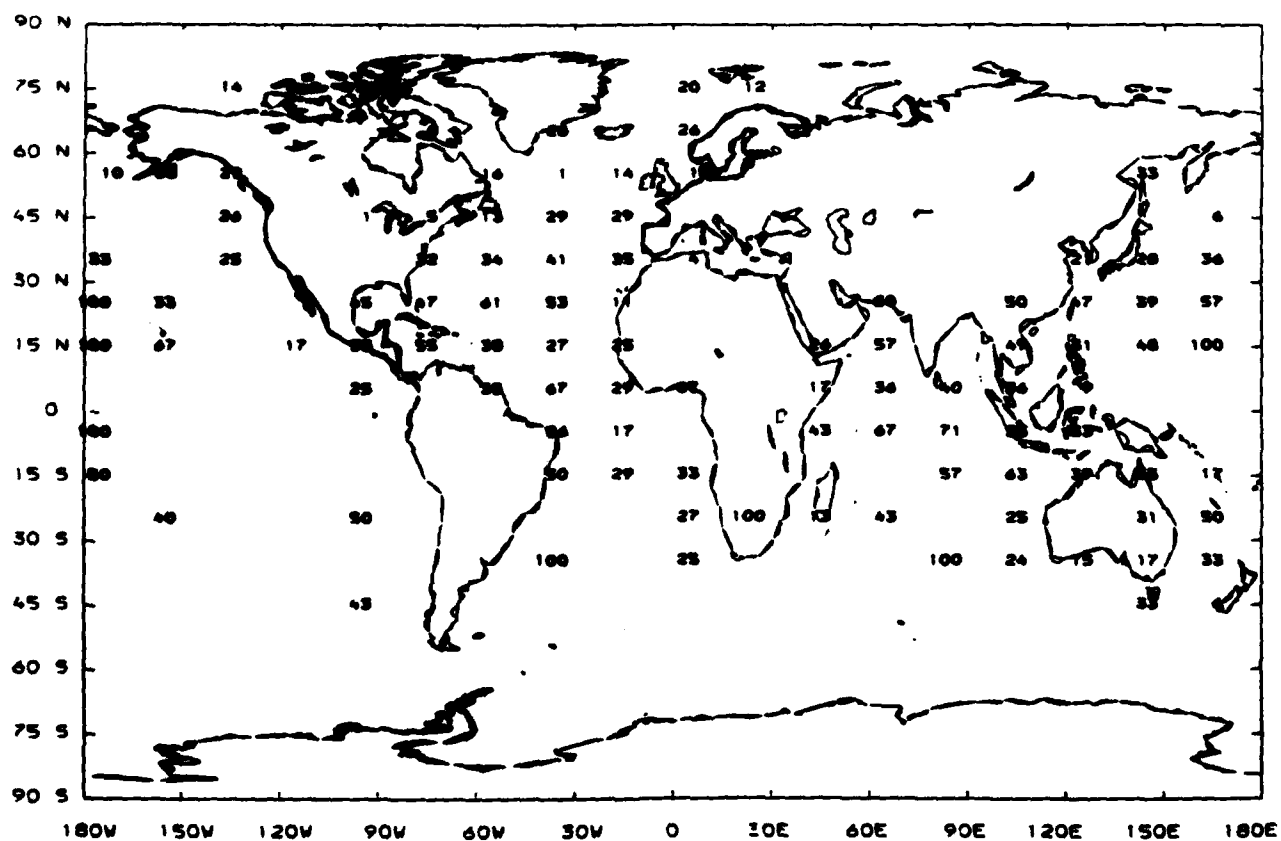
JULY 1-31 1983



FREQUENCY OF OCCURRENCE (PERCENT) OF NIMBOSTRATUS ONLY

Figure 140

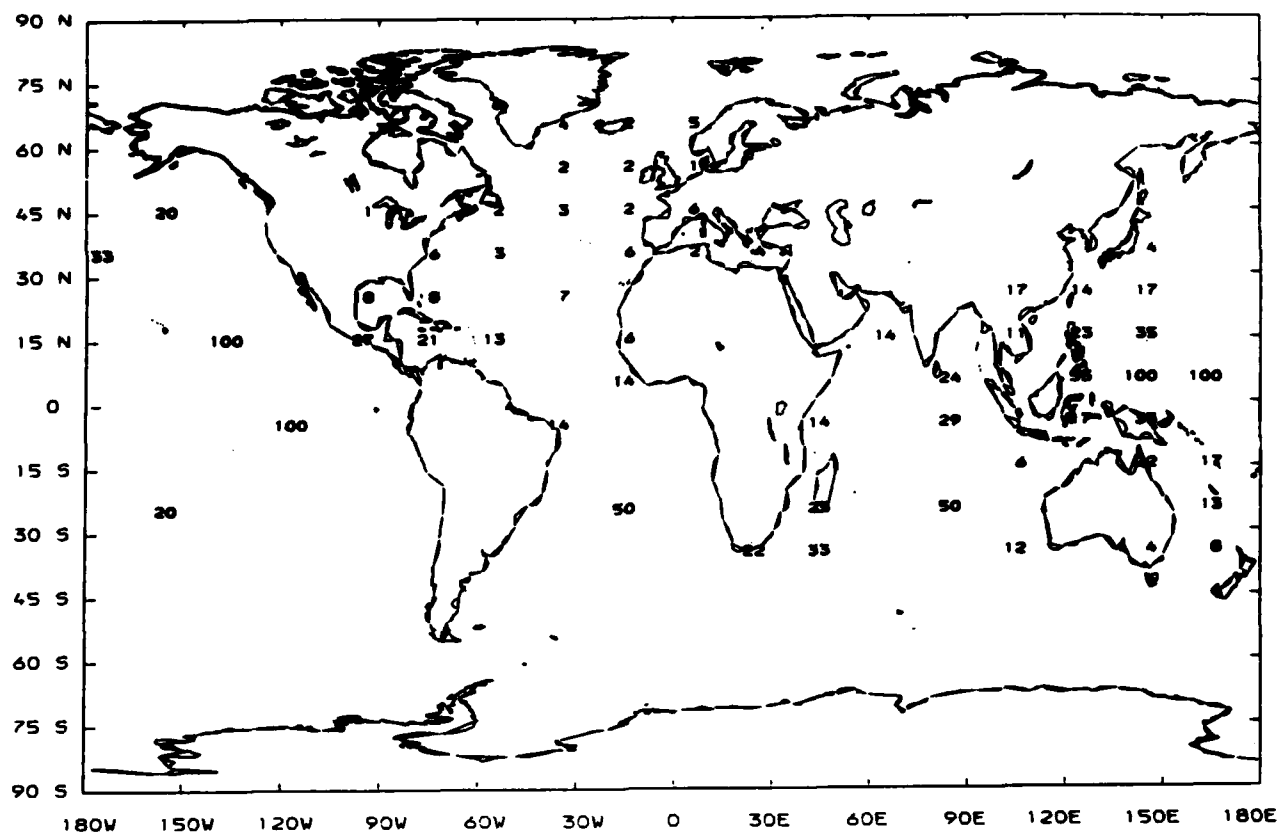
JULY 1-31 1983



FREQUENCY OF OCCURRENCE (PERCENT) OF CUMULUS ONLY

Figure 141

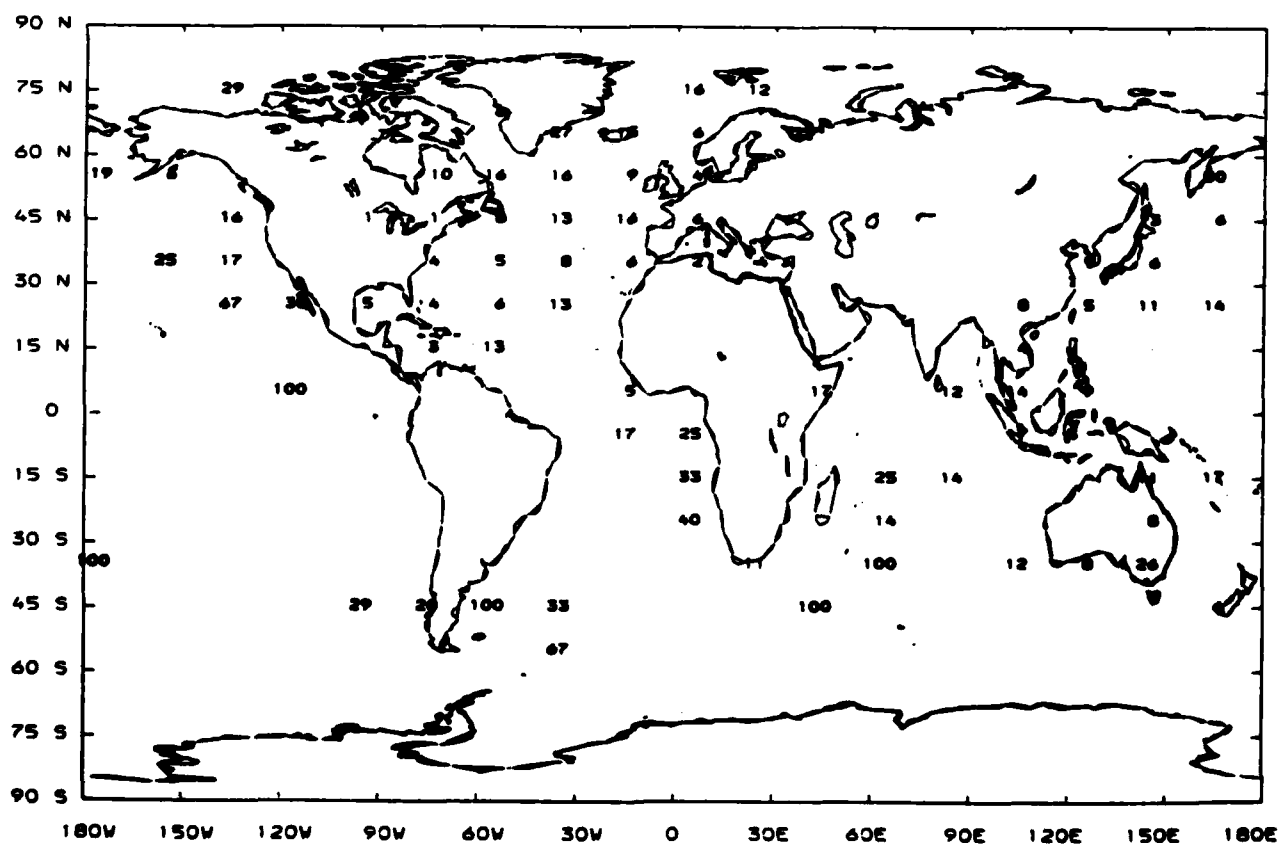
JULY 1-31 1983



FREQUENCY OF OCCURRENCE (PERCENT) OF CUMULONIMBUS ONLY

Figure 142

JULY 1-31 1983

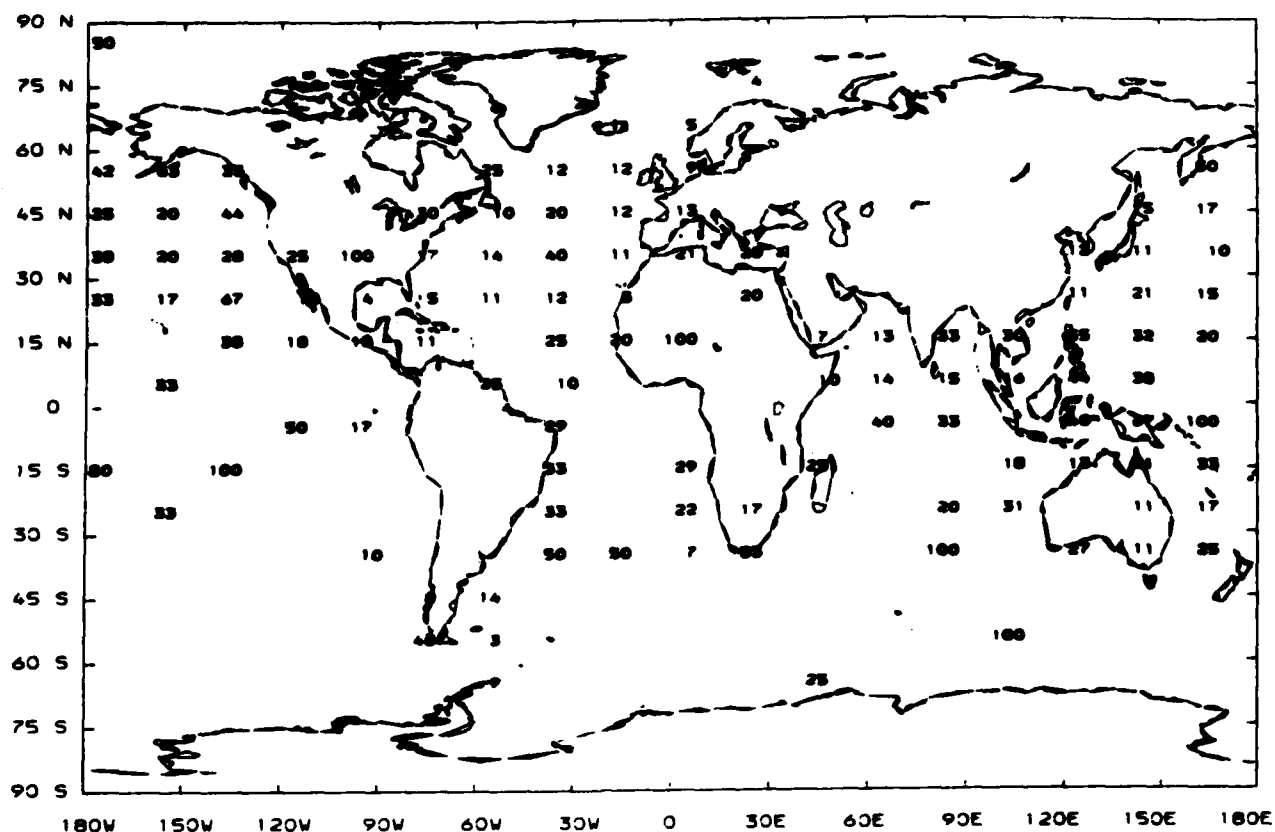


FREQUENCY OF OCCURRENCE (PERCENT) OF St/Sc ONLY

Figure 143

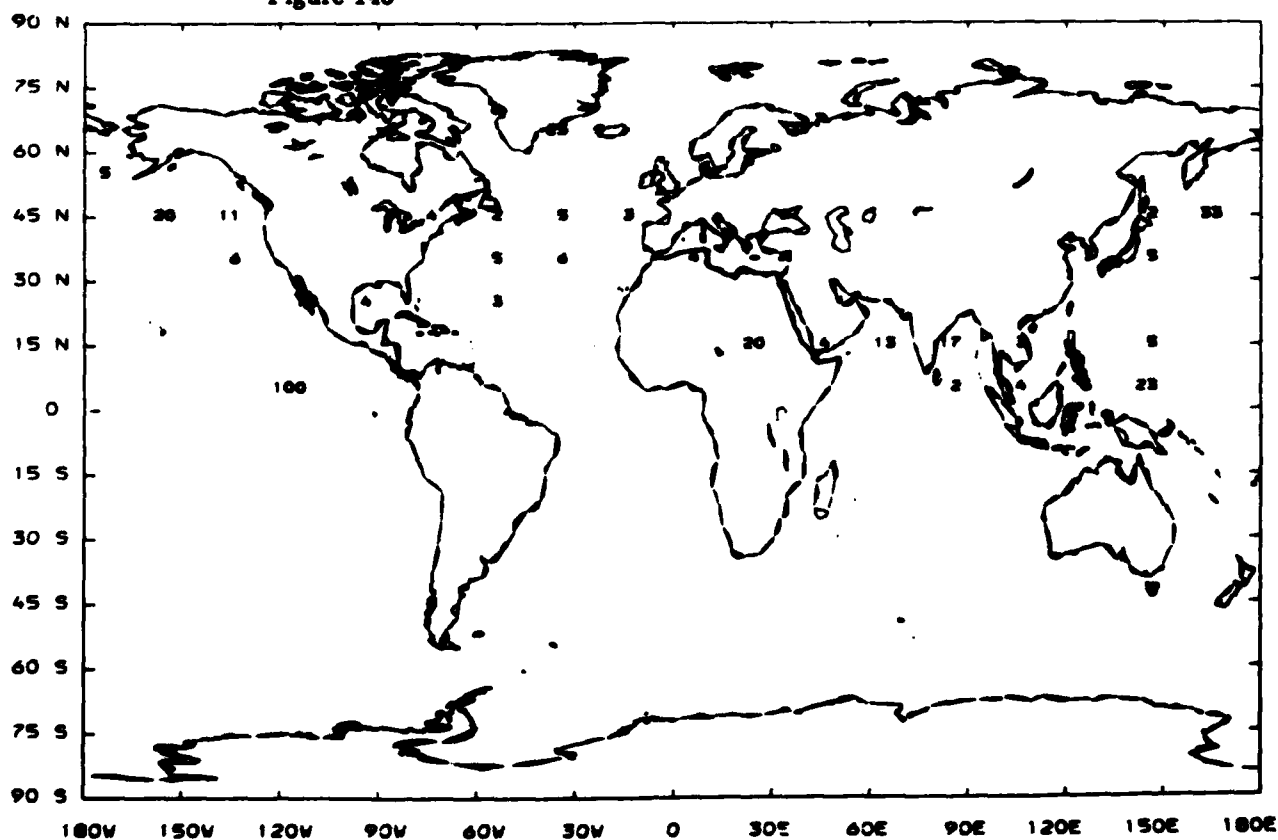
JULY 1-31 1983

Figure 144



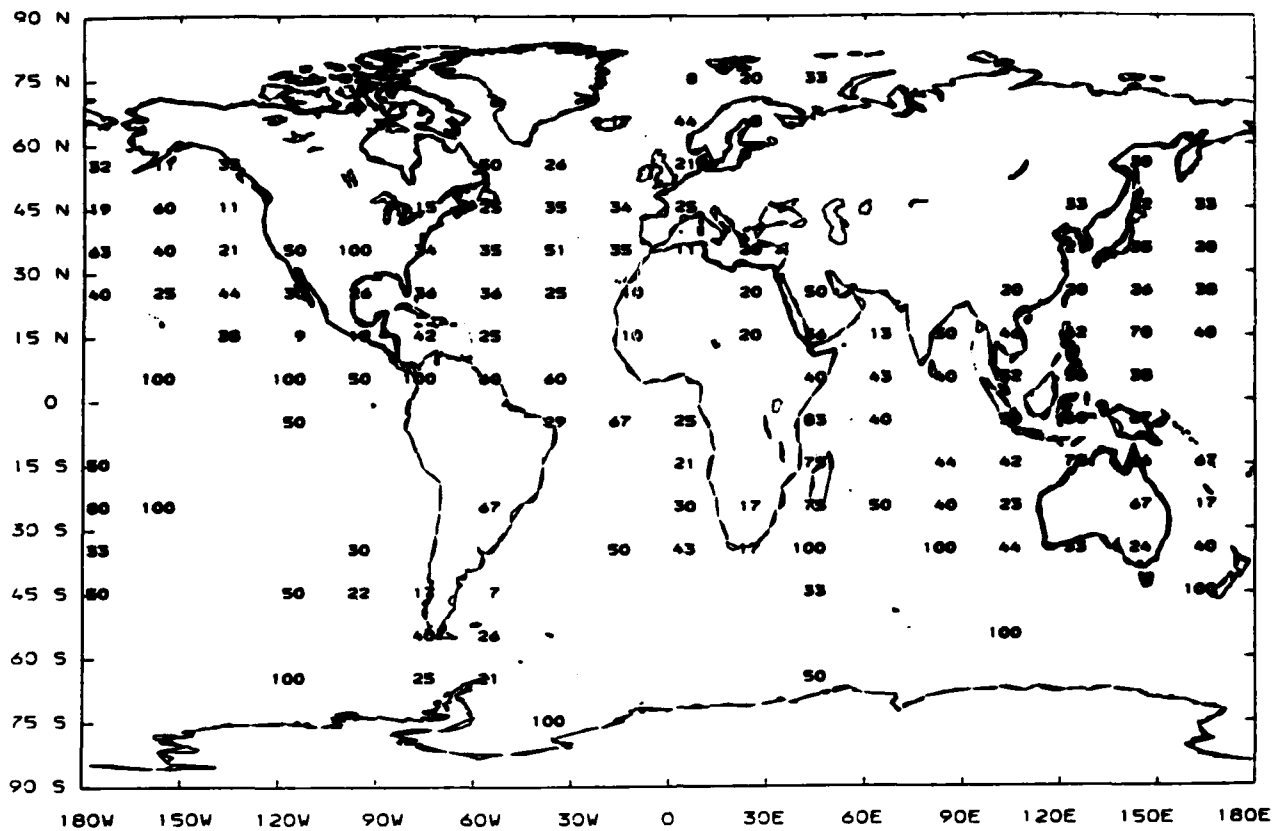
PROBABILITY (PERCENT) THAT GIVEN  $A_e/A_c$ ,  $C_i/C_e/C_c$  IS ALSO PRESENT  
JANUARY 1-31 1985

Figure 145



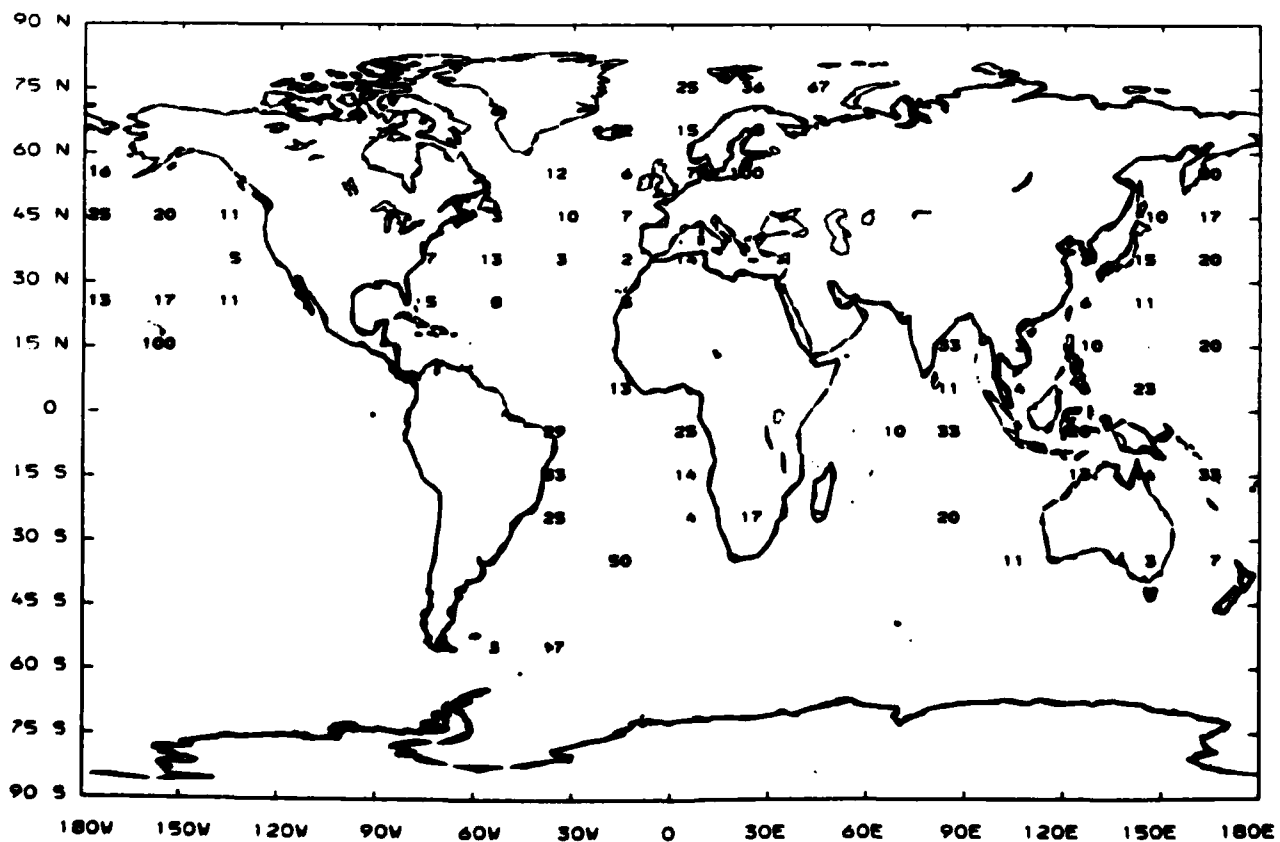
PROBABILITY (PERCENT) THAT GIVEN  $N_e$ ,  $C_i/C_e/C_c$  IS ALSO PRESENT  
JANUARY 1-31 1985

Figure 146



PROBABILITY (PERCENT) THAT GIVEN  $C_1$ ,  $C_1/C_2/C_3$  IS ALSO PRESENT  
JANUARY 1-31 1985

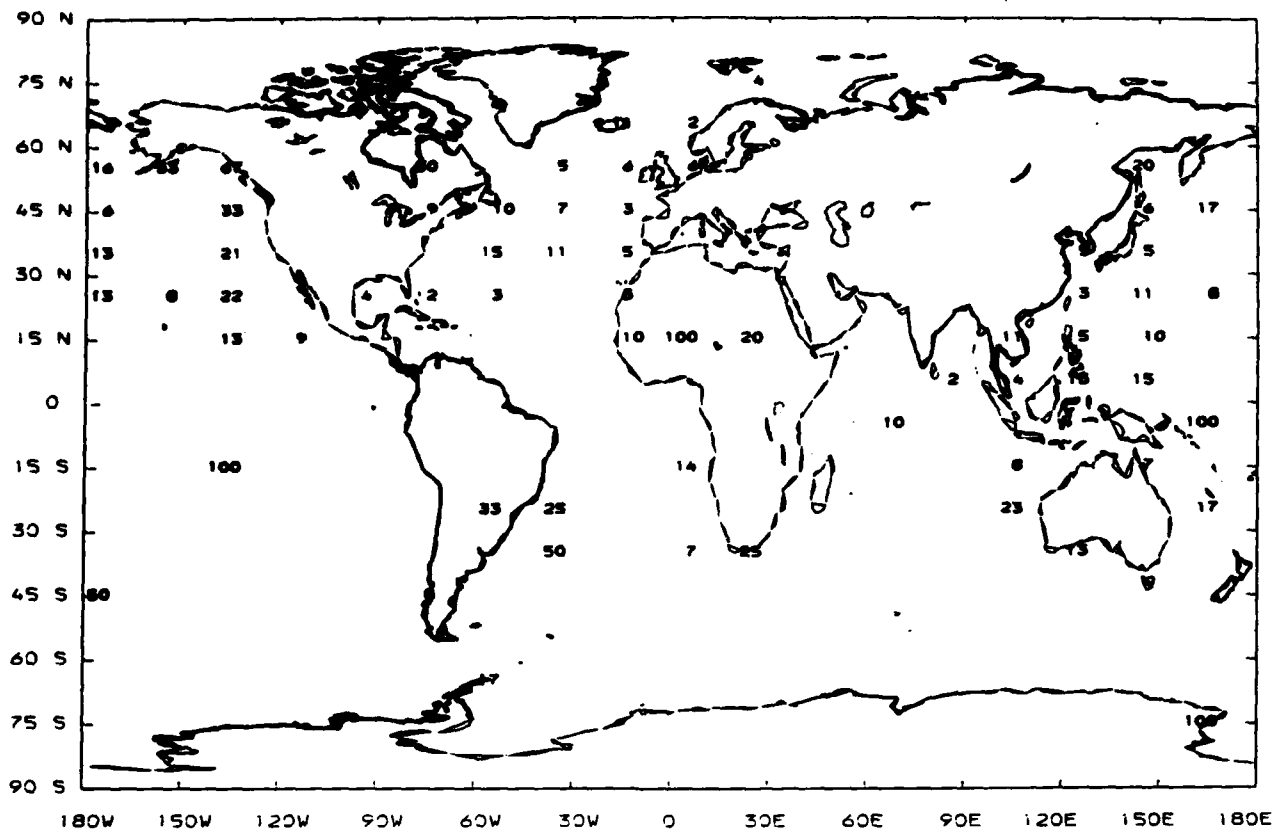
Figure 147



PROBABILITY (PERCENT) THAT GIVEN  $C_1$ ,  $C_1/C_2/C_3$  IS ALSO PRESENT  
JANUARY 1-31 1985

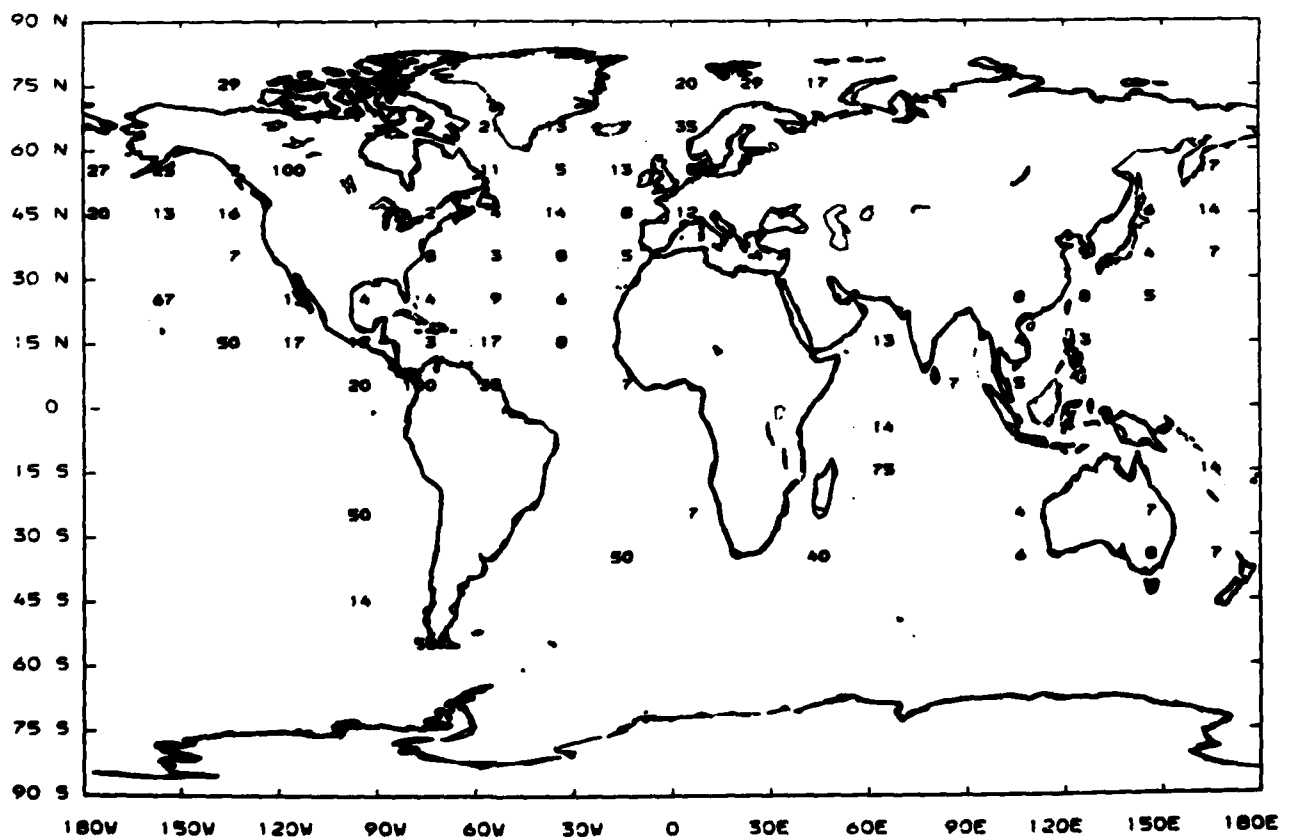
112

Figure 148



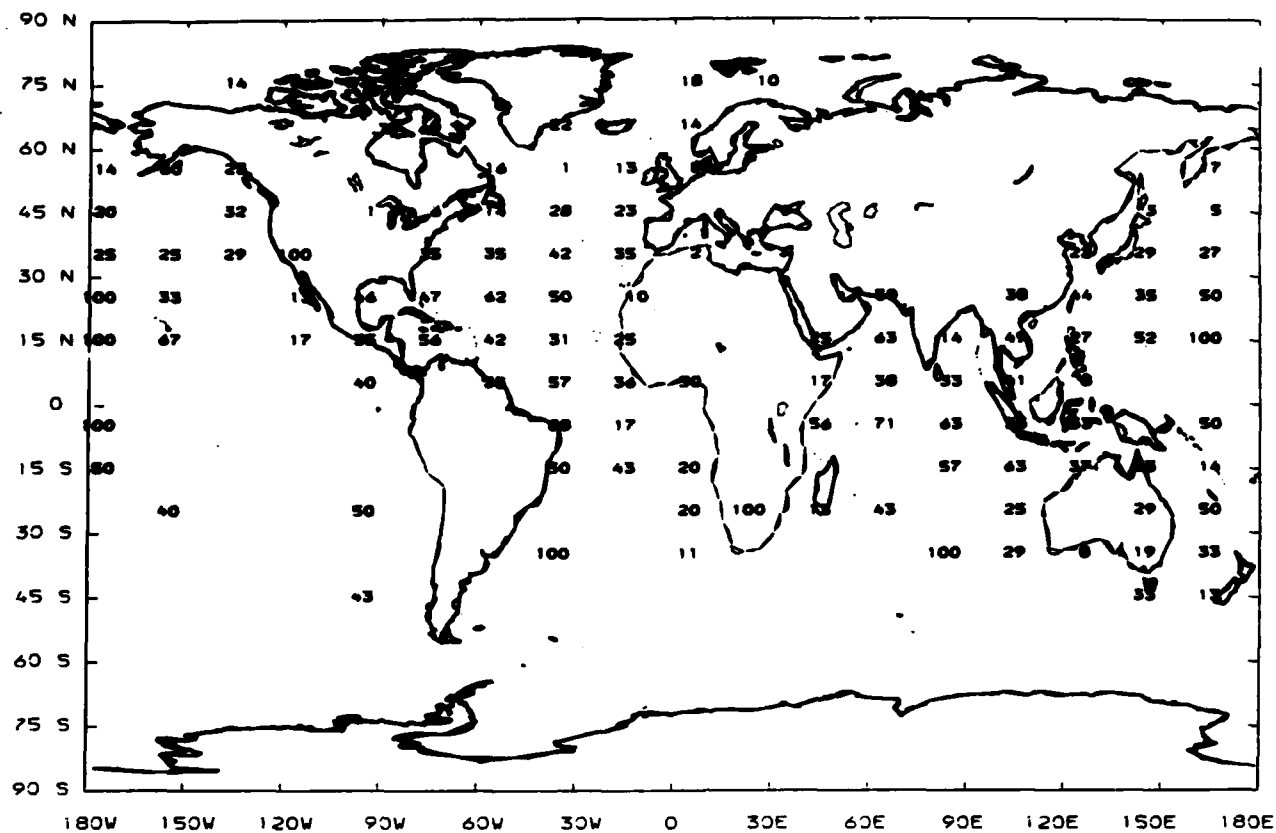
PROBABILITY (PERCENT) THAT GIVEN  $S_e/S_c$ ,  $C_i/C_s/C_c$  IS ALSO PRESENT  
JANUARY 1-31 1985

Figure 149



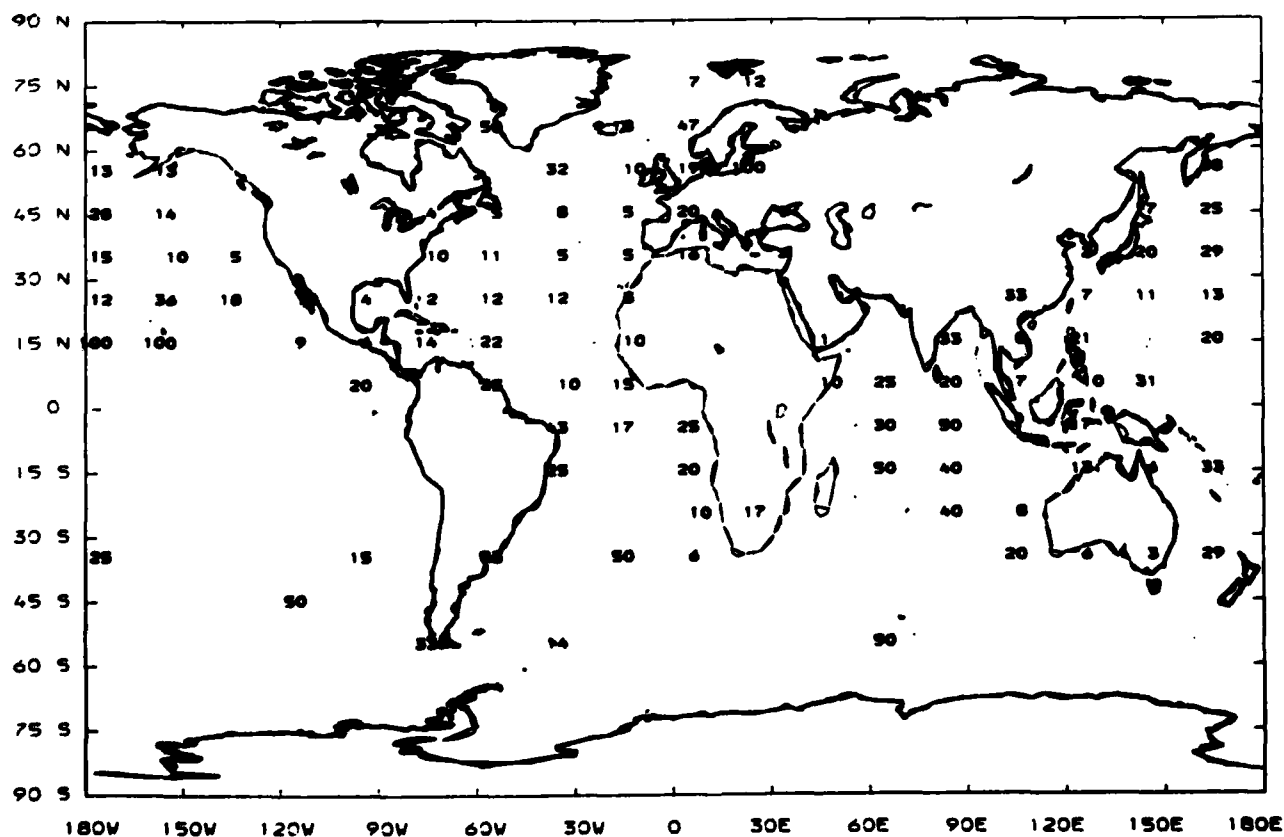
PROBABILITY (PERCENT) THAT GIVEN  $C_b$ ,  $A_s/A_c$  IS ALSO PRESENT  
JANUARY 1-31 1985

Figure 150



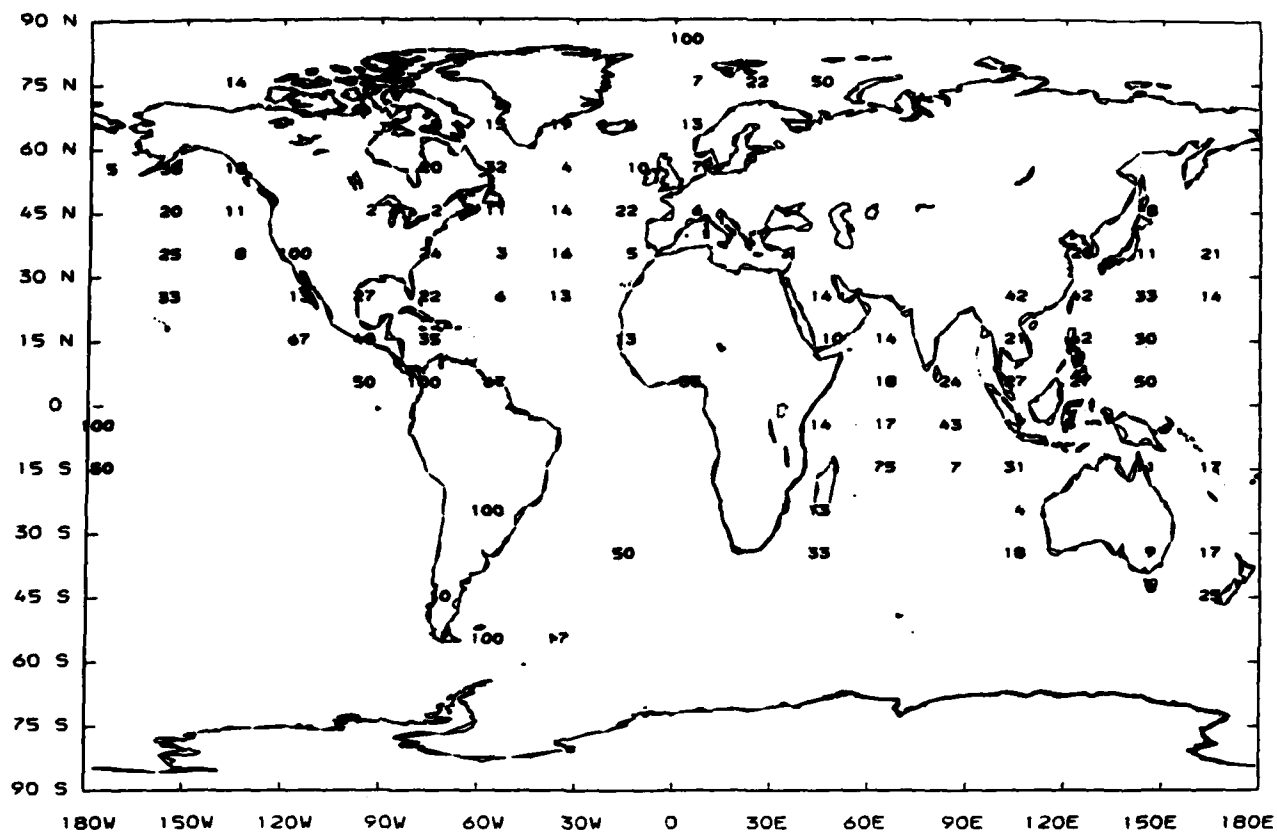
PROBABILITY (PERCENT) THAT GIVEN  $Cu$ ,  $As/Ac$  IS ALSO PRESENT  
JANUARY 1-31 1985

Figure 151



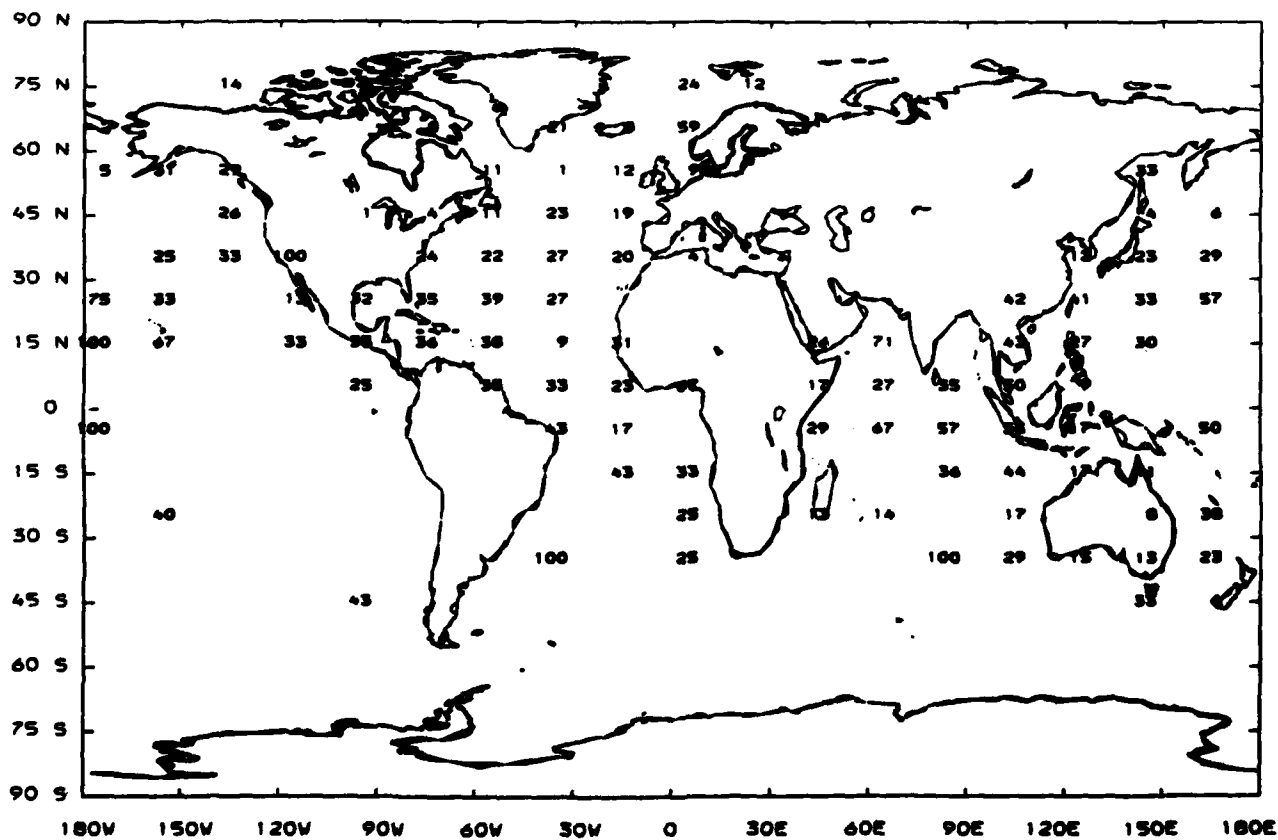
PROBABILITY (PERCENT) THAT GIVEN  $Sc/Sc$ ,  $As/Ac$  IS ALSO PRESENT  
JANUARY 1-31 1985

Figure 152



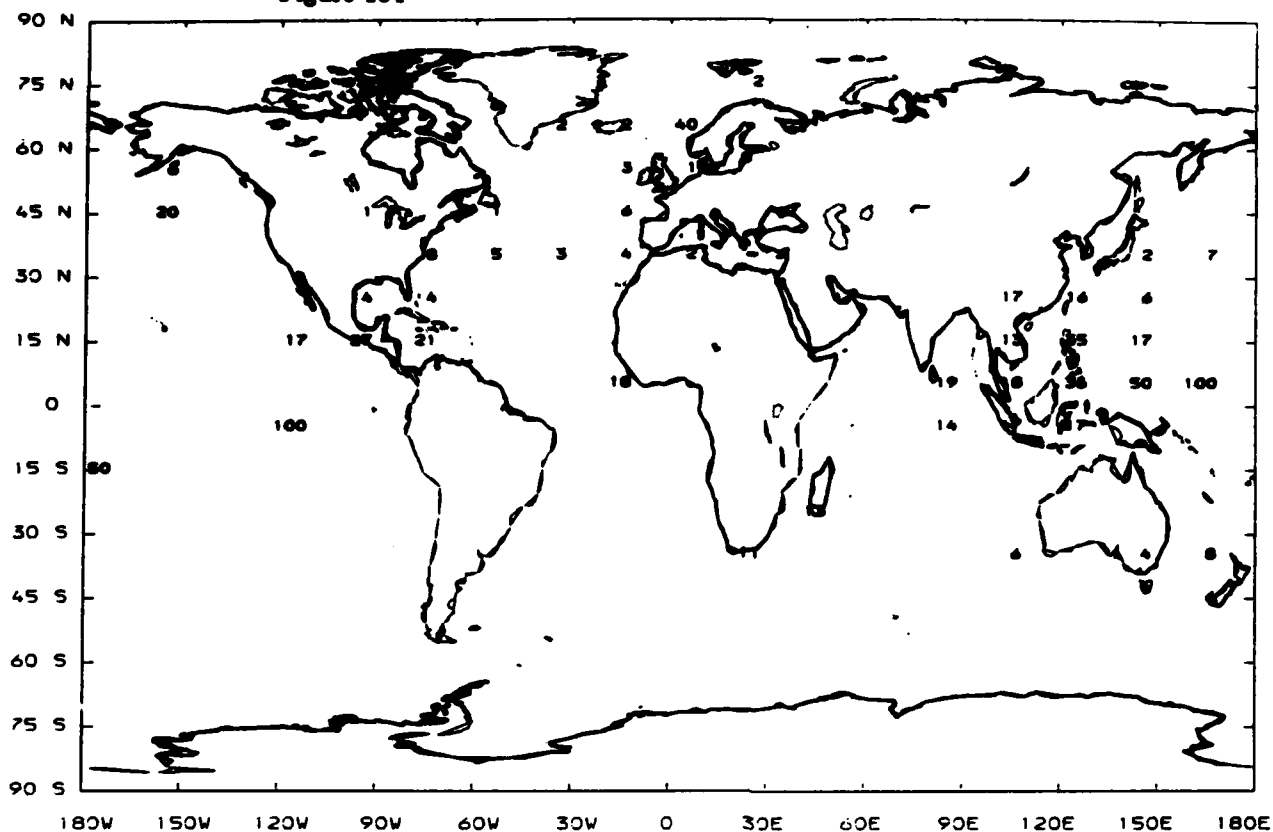
PROBABILITY (PERCENT) THAT GIVEN  $A_s/A_c$ ,  $C_i/C_s/C_c$  IS ALSO PRESENT  
JULY 1-31 1983

Figure 153



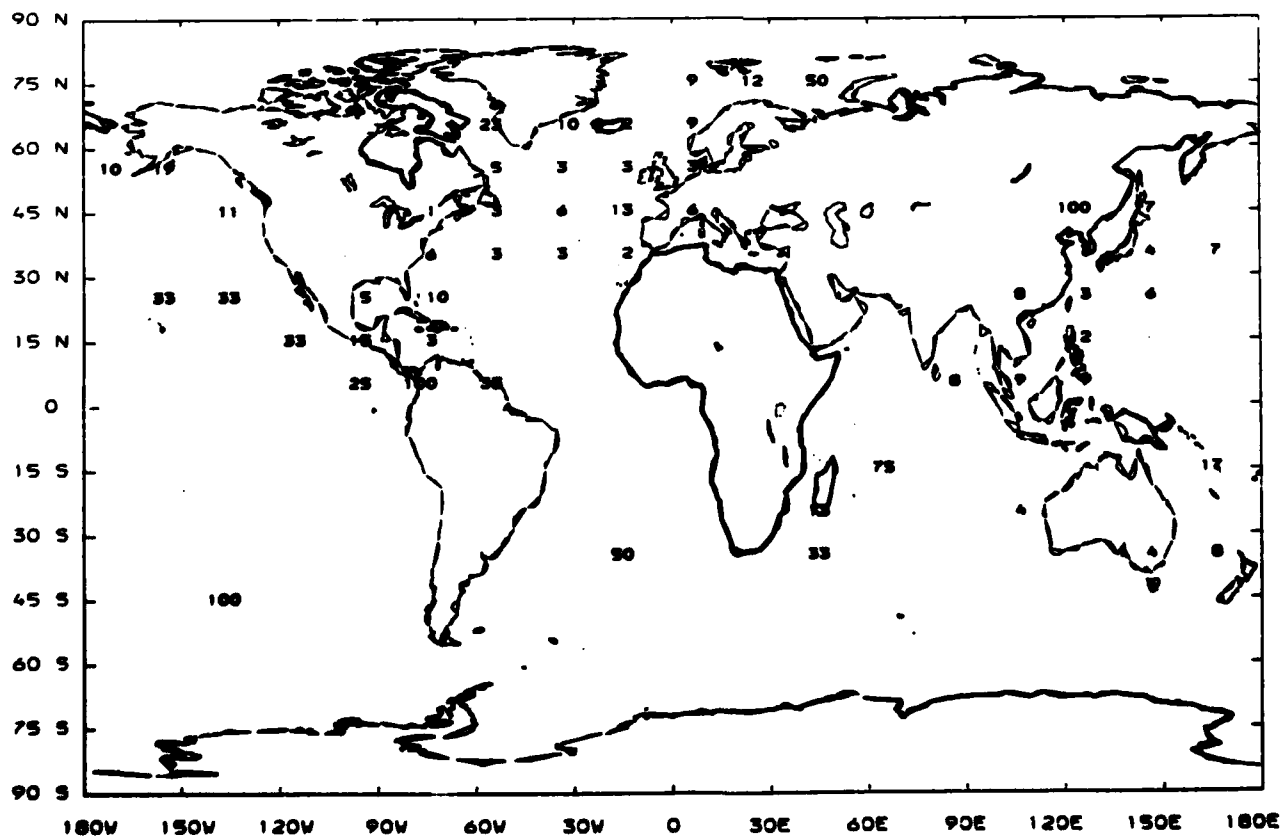
PROBABILITY (PERCENT) THAT GIVEN  $C_u$ ,  $C_i/C_s/C_c$  IS ALSO PRESENT  
JULY 1-31 1983

Figure 154



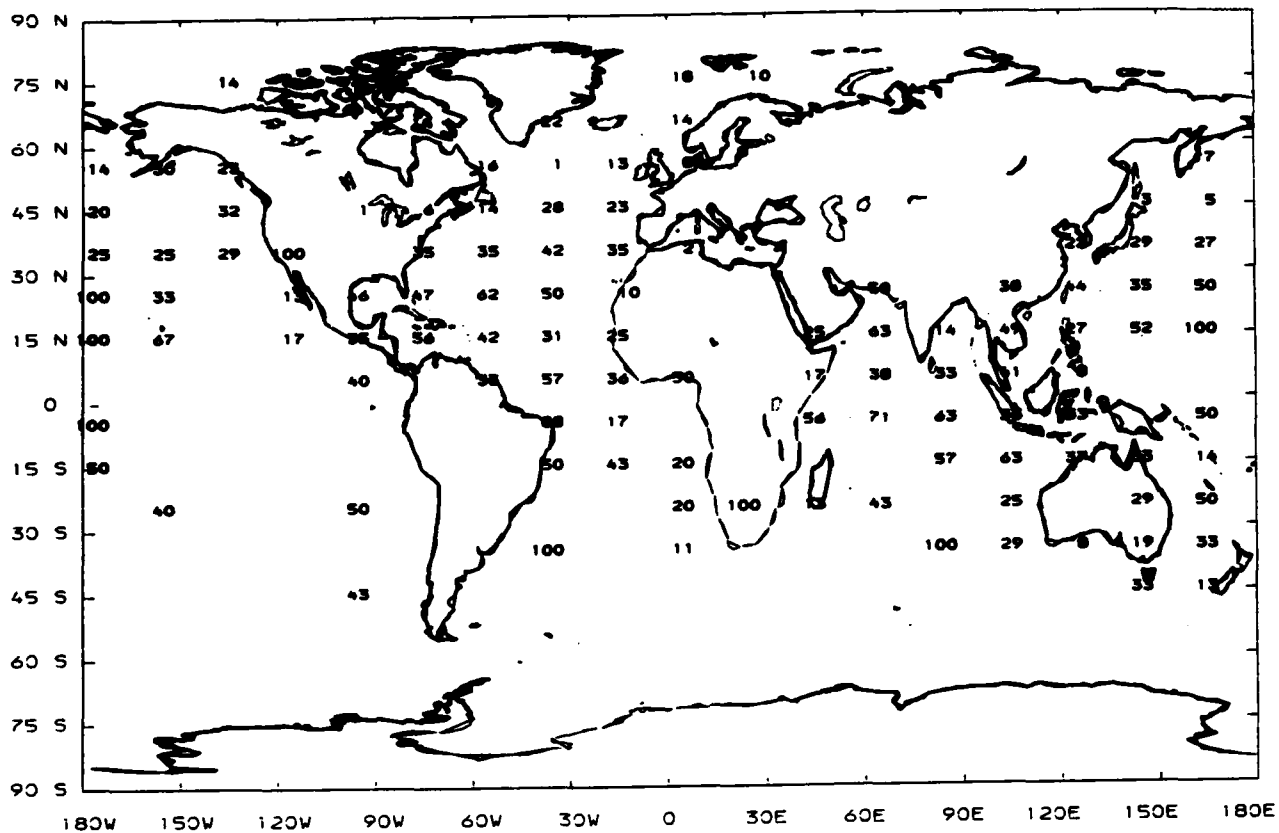
PROBABILITY (PERCENT) THAT GIVEN  $C_b$ ,  $C_i/C_s/C_c$  IS ALSO PRESENT  
JULY 1-31 1983

Figure 155



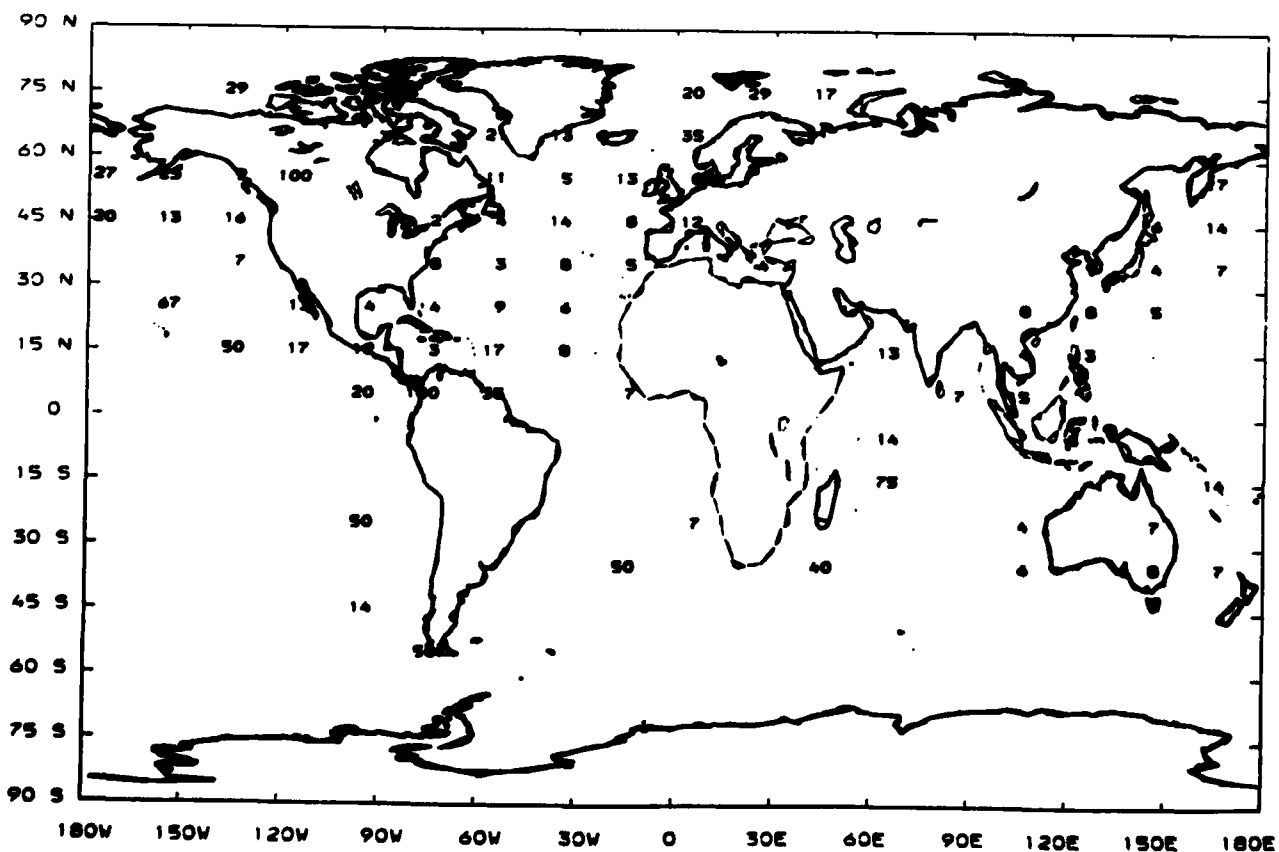
PROBABILITY (PERCENT) THAT GIVEN  $S_e/S_c$ ,  $C_i/C_s/C_c$  IS ALSO PRESENT  
JULY 1-31 1983

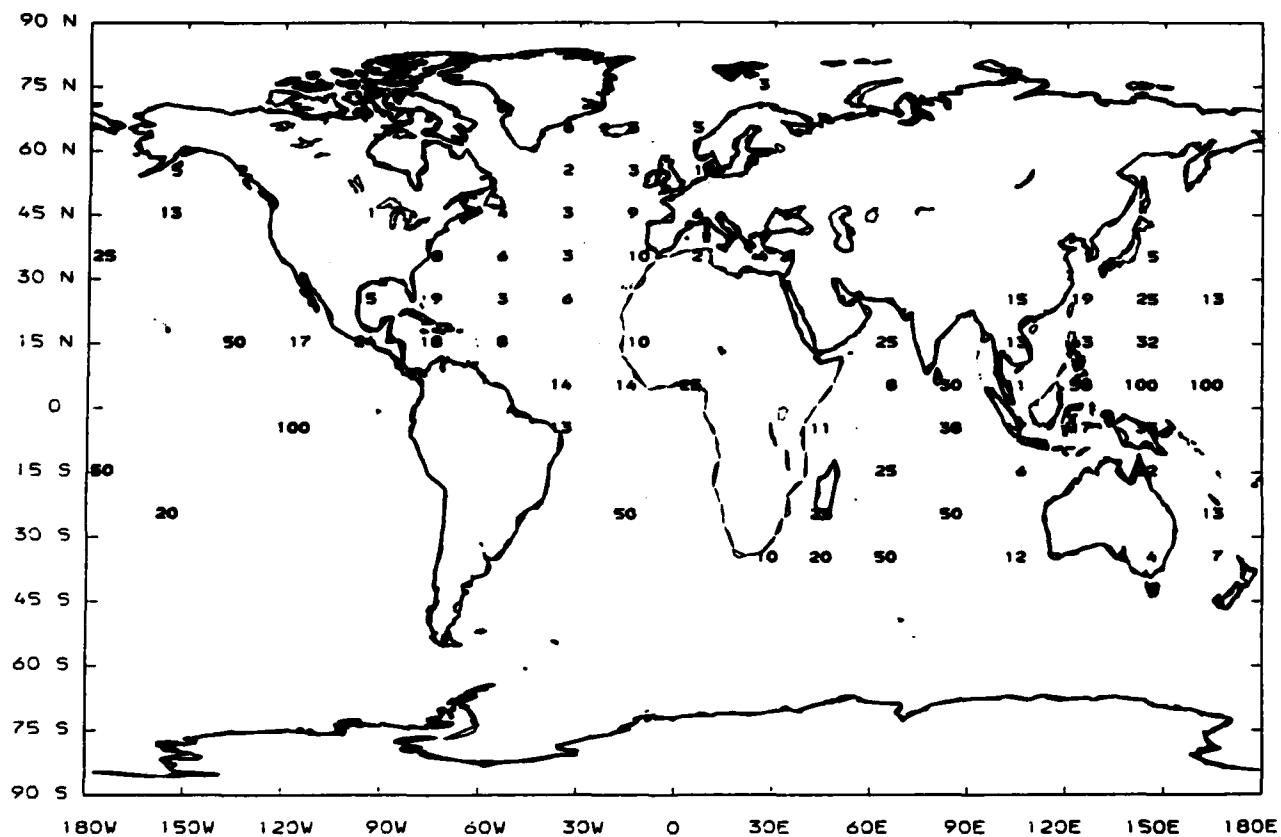
Figure 156



PROBABILITY (PERCENT) THAT GIVEN Cu, As/Ac IS ALSO PRESENT  
JULY 1-31 1983

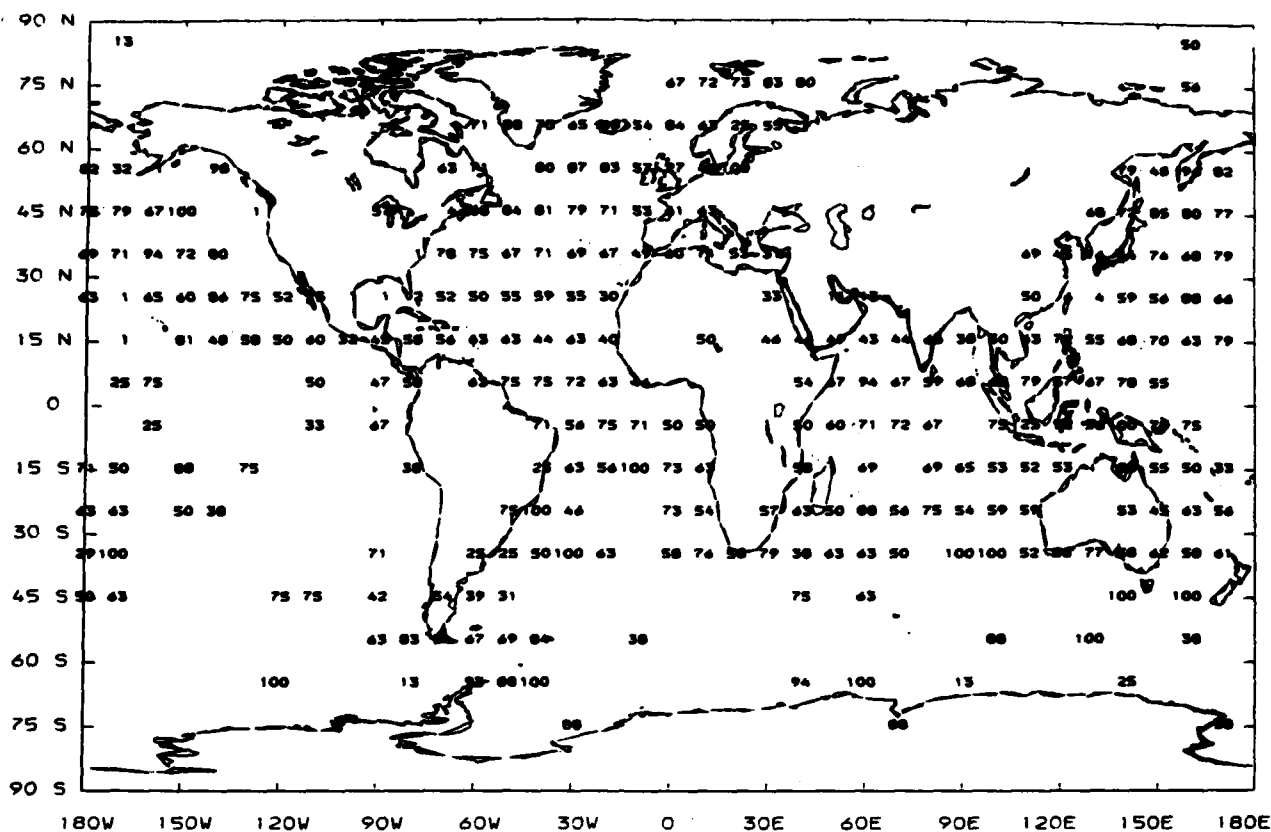
Figure 157





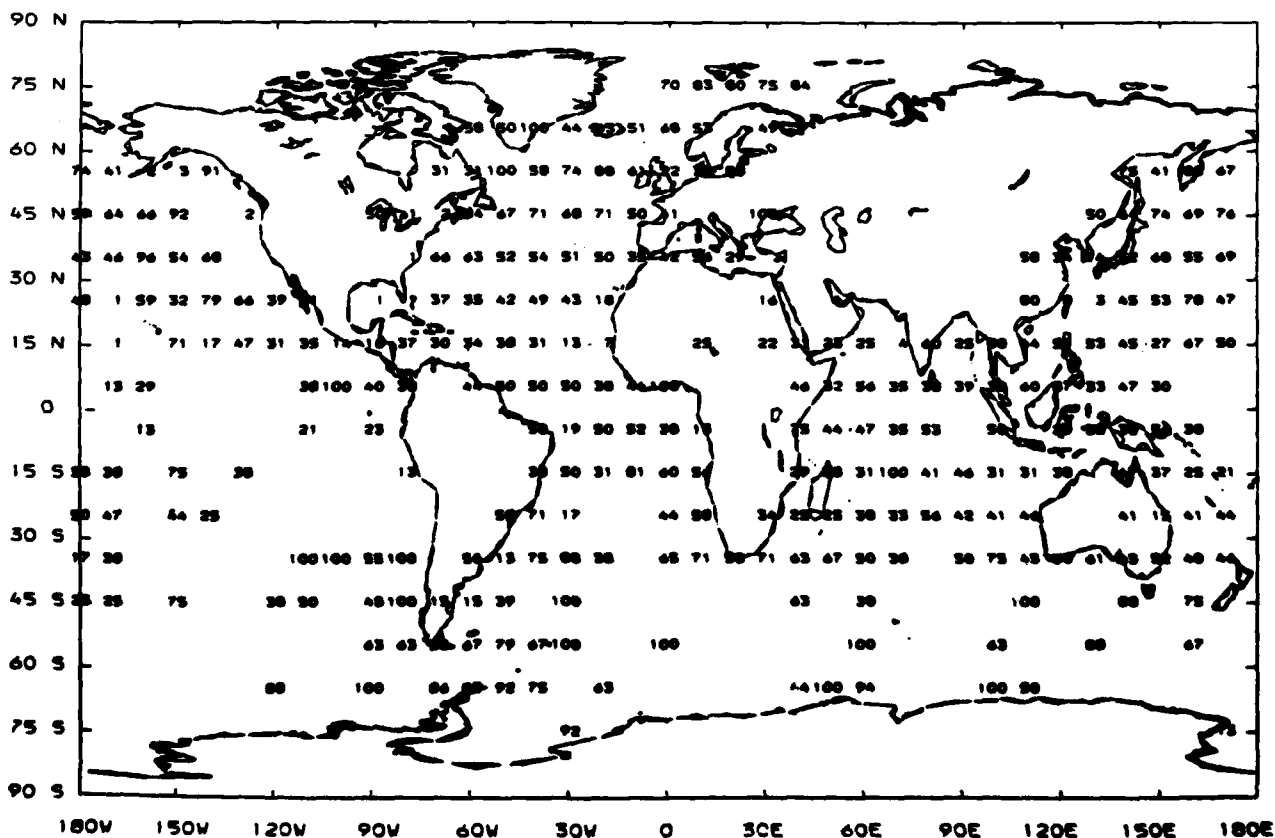
PROBABILITY (PERCENT) THAT GIVEN  $S_t/S_c$ ,  $A_s/A_c$  IS ALSO PRESENT  
JULY 1-31 1983

Figure 158



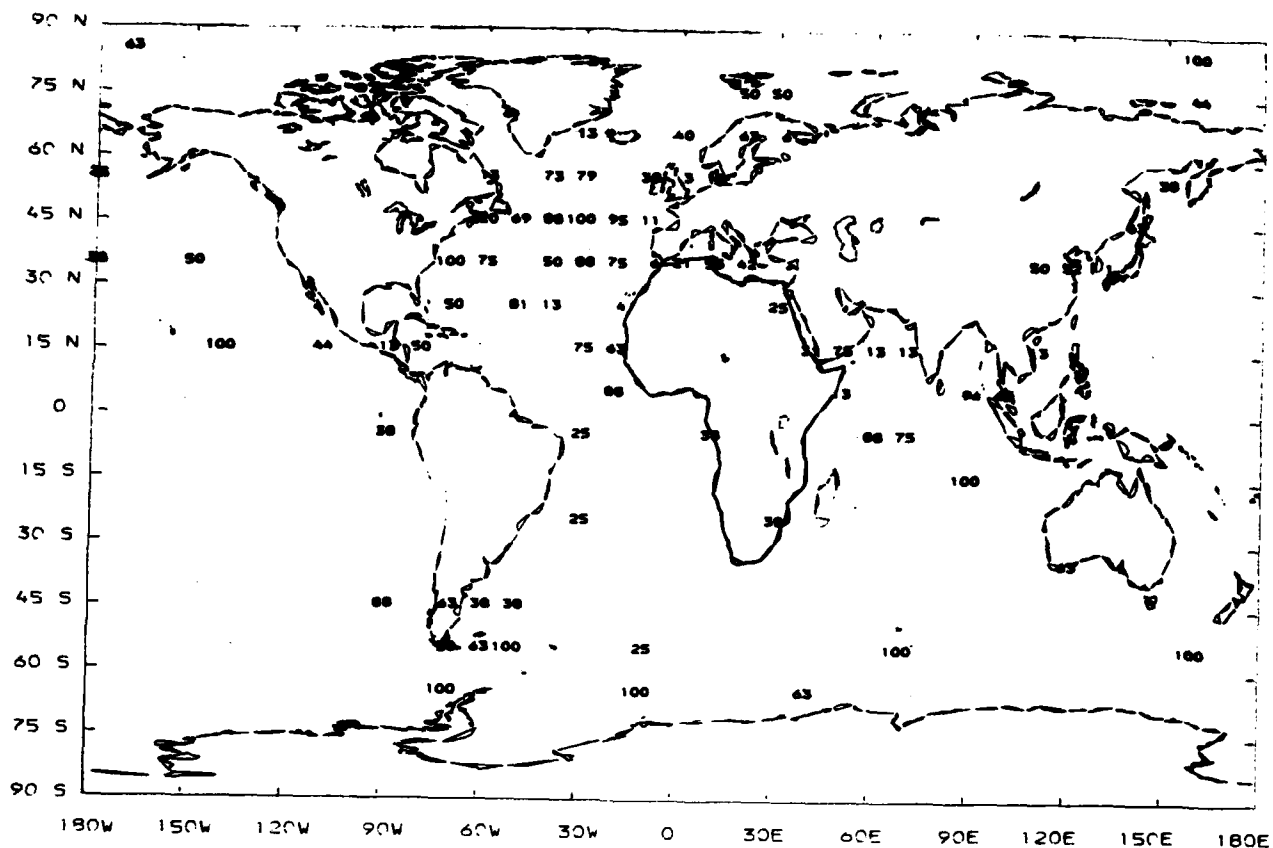
MEAN TOTAL CLOUD AMOUNT (PERCENT) JANUARY 1-31 1985

Figure 160



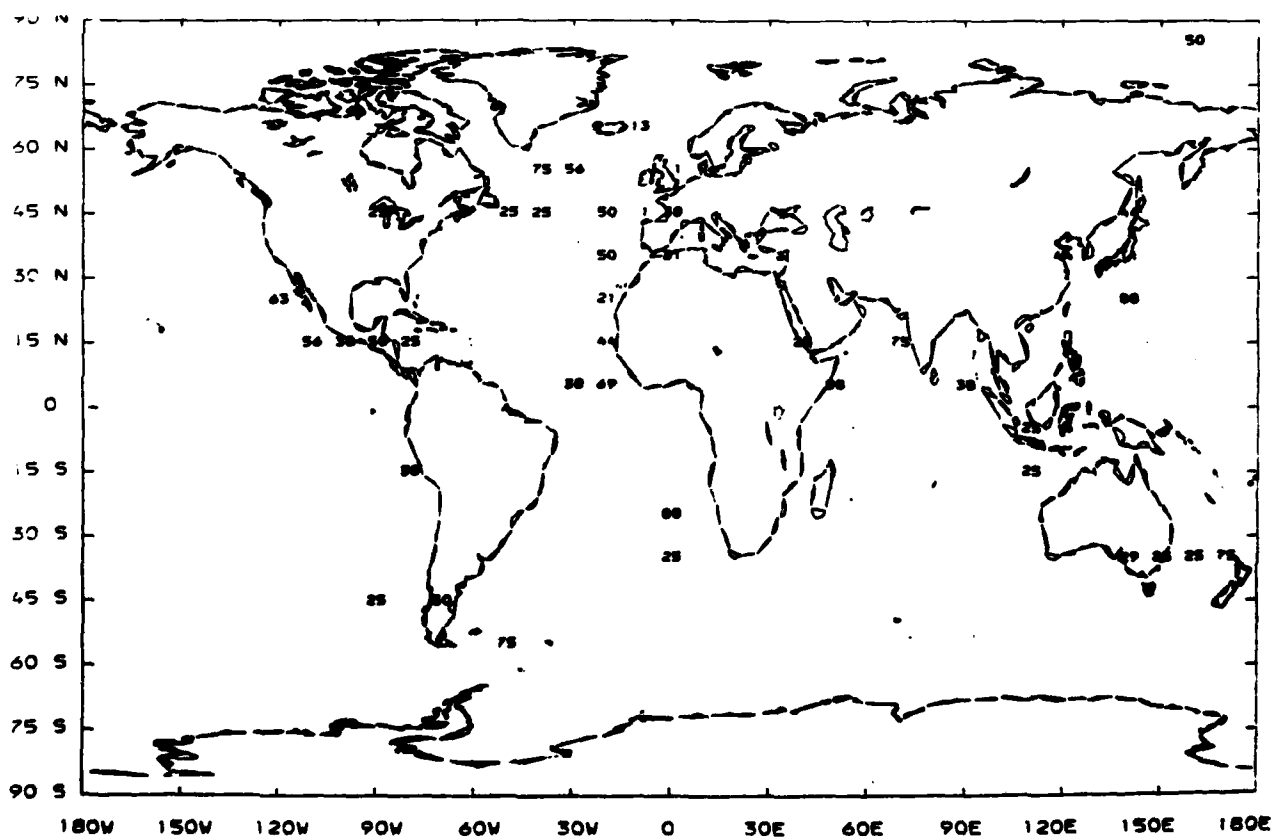
MEAN LOW CLOUD AMOUNT (PERCENT) JANUARY 1-31 1985

Figure 161



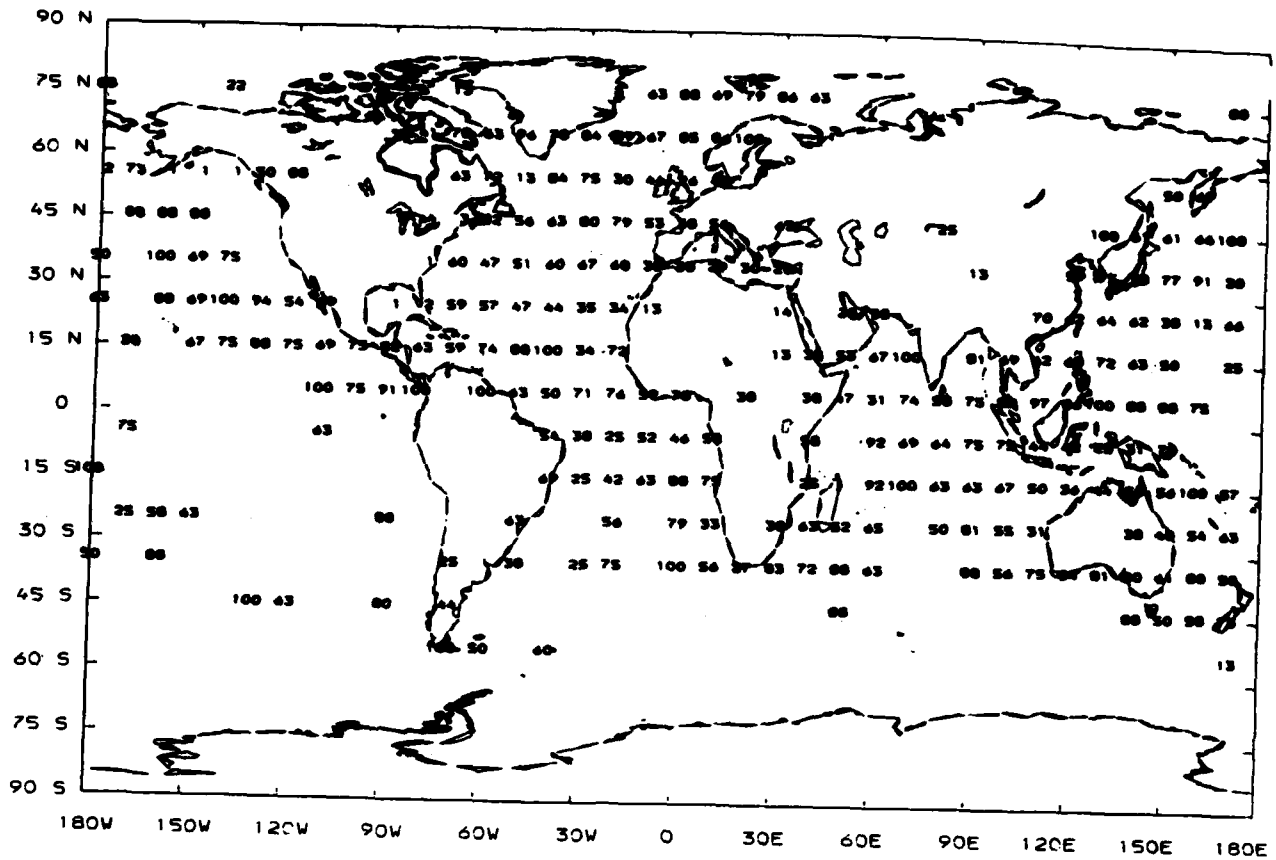
MEAN MIDDLE CLOUD AMOUNT (PERCENT) JANUARY 1-31 1985

Figure 162



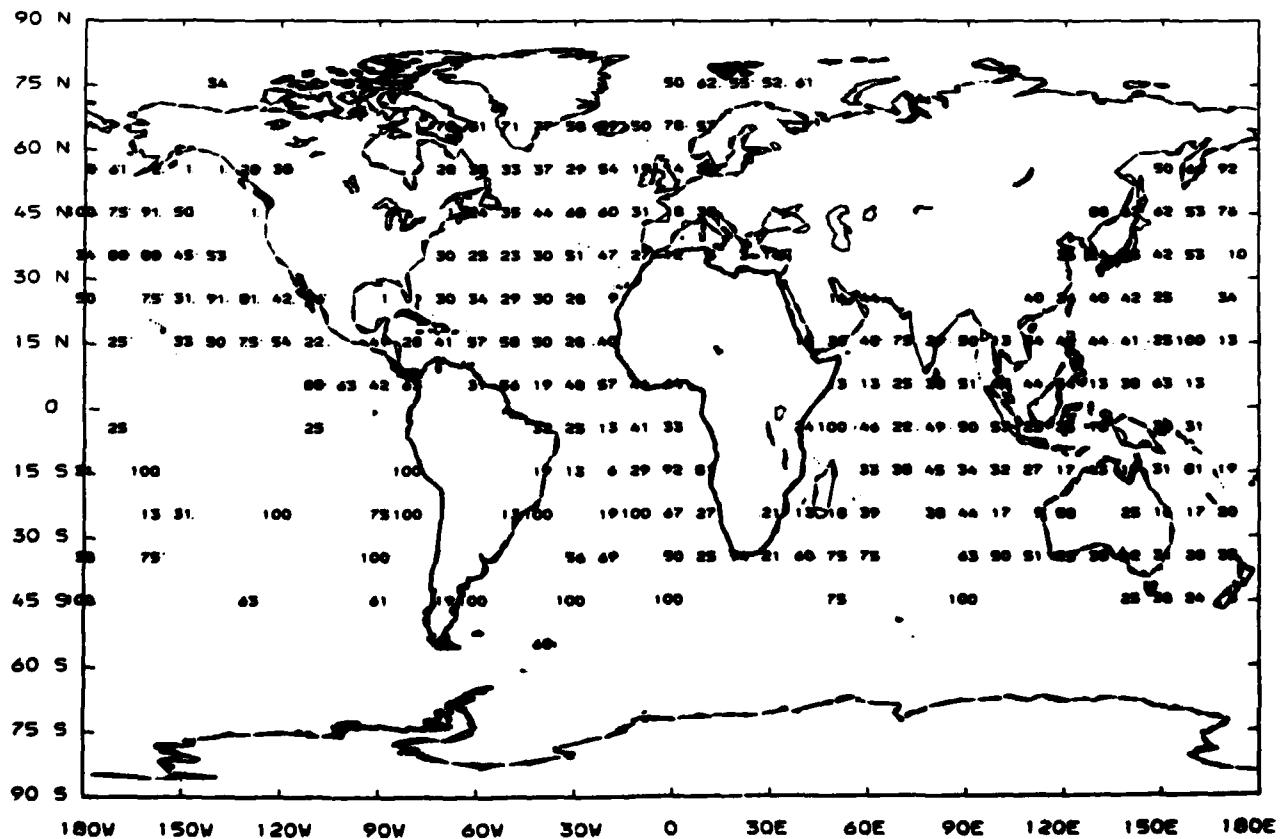
MEAN HIGH CLOUD AMOUNT (PERCENT) JANUARY 1-31 1985

Figure 163



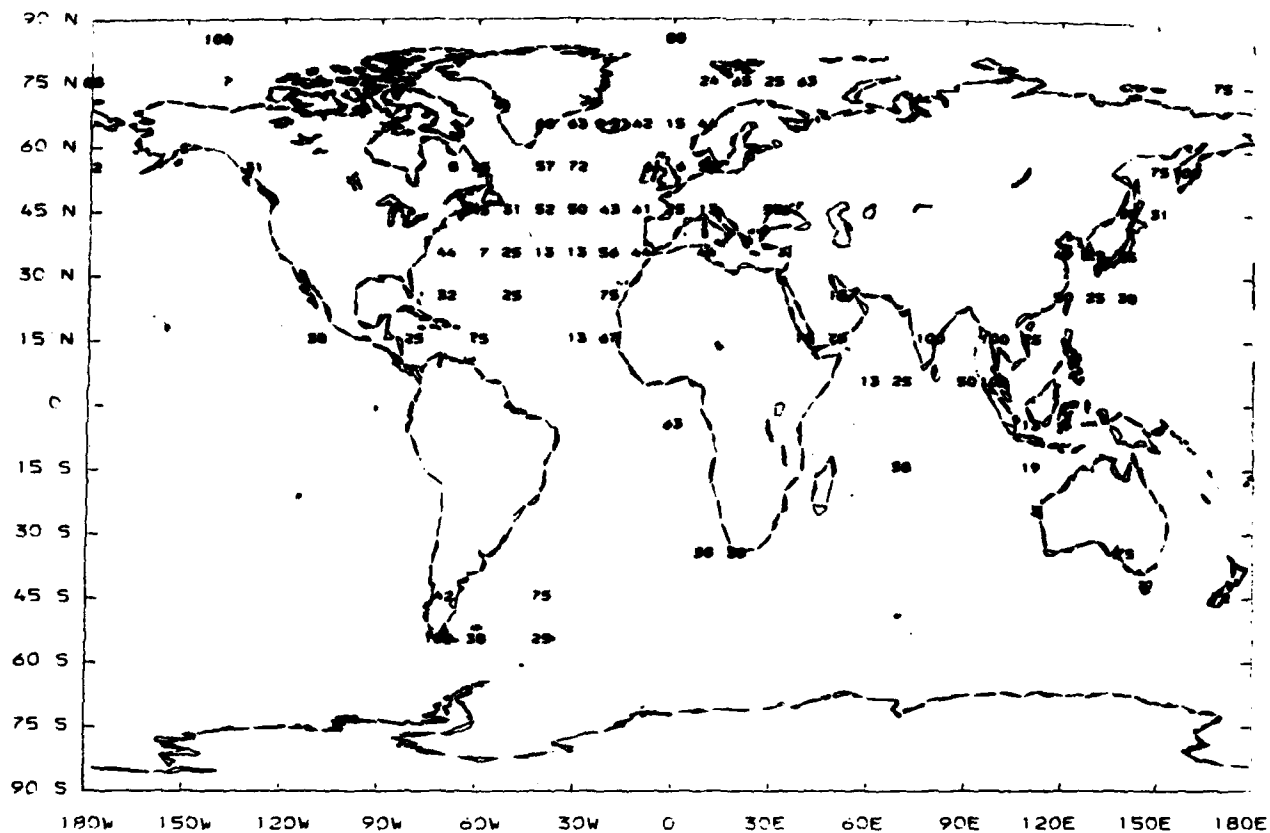
MEAN TOTAL CLOUD AMOUNT (PERCENT) JULY 1-31 1983

Figure 164



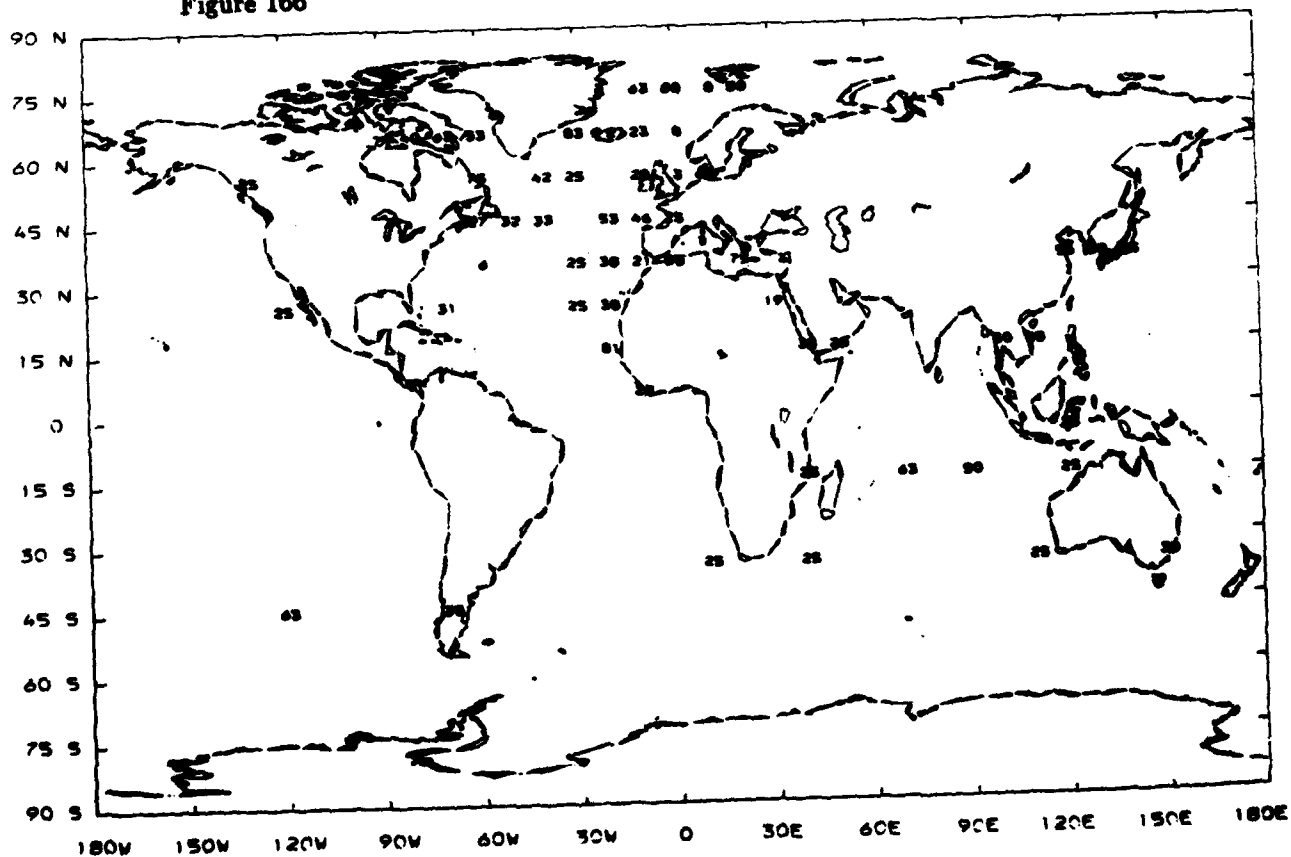
MEAN LOW CLOUD AMOUNT (PERCENT) JULY 1-31 1983

Figure 165



MEAN MIDDLE CLOUD AMOUNT (PERCENT) JULY 1-31 1983

Figure 166



MEAN HIGH CLOUD AMOUNT (PERCENT) JULY 1-31 1983

The climatologies built-up from only a couple of months of data, are of insufficient timespan to be of longstanding use in climate modelling exercises but can provide scope for intercomparison with satellite data in exercises such as the evaluation of new retrieval algorithms.

#### 4. Summary and Conclusions

↳ A preliminary investigation into certain forms of bias known to affect surface observations of clouds <sup>was</sup> ~~has been~~ made using two separate months of global cloud reports. A search for evidence of nighttime detection bias gave variable results but over the analysis region of Scandinavia, where the evidence would be strongest, due to the ability to compare reports over short and long nights, there was good reason to believe that observers were consistently failing to detect cirrus (particularly) and altostratus at the local scale as well as over larger areas. If such bias is prevalent over many regions of the world the value of surface-derived climatologies must be reduced.

Contrary to earlier assertions, contingency probabilities (and the associated risk of partial undercast bias) were generally found to decrease for higher amounts of lower cloud, a result and suggesting that further examination of cloud data sets is required. The role of contingency probabilities should be established further, especially with regard to obscuring overcasts.

> Finally, the global data were assembled into maps depicting frequency of occurrence, contingency probabilities and level amounts. The data highlighted such features as monthly variability compared to long-term statistics and the paucity of oceanic data, which are overall, unreliable as a result. The land data are more representative and may be of use when results from ISCCP are released. *Keywords OKta observing scale. 4*

## **5. Presentations and Publications**

### ***Presentations***

**Constructing global nephanalyses: a review of recent progress in cloud detection and analysis, A.H. Goodman and A. Henderson-Sellers, Thirteenth Annual Conference of the Remote Sensing Society, University of Nottingham, 7-11 September 1987 (poster presentations)**

**Global cloud data: problems in synthesis of heterogeneous sources, K. McGuffie, A.H. Goodman and A. Henderson-Sellers, Twenty-First International Symposium on Remote Sensing of Environment, Ann Arbor, Michigan, 26-30 October 1987 (poster and oral presentation)**

**An investigation of bias in surface-observed cloudiness for the globe for July 1983 and January 1985, A.H. Goodman and K. McGuffie, Clouds in Climate II Workshop, Columbia, Maryland, 19-23 October 1987 (oral presentation)**

**The problems and benefits of combining heterogeneous data sources into global nephanalyses, A.H. Goodman, seminar at AFGL, 26 October 1987**

### ***Publications***

**Constructing global nephanalyses: a review of recent progress in cloud detection and analysis, A.H. Goodman and A. Henderson-Sellers, 1987, in *Advances in Digital Image Processing*, Remote Sensing Society, London, 446-452**

**Global cloud data: problems in synthesis of heterogeneous sources, K. McGuffie, A.H. Goodman and A. Henderson-Sellers, in *Proceedings of Twenty-First International Symposium on Remote Sensing of Environment*, Ann Arbor, Michigan**

**Clouds for climate: recent progress in cloud detection and analysis A.H. Goodman and A. Henderson-Sellers, submitted to *Atmospheric Research***

## 6. References

- Arking, A. and Childs, J.D., 1985, Retrieval of cloud cover parameters from multispectral satellite measurements, *J. Clim. Appl. Meteor.*, **24**, 322-333.
- Berlyand, T.G. and Strokina, L.A., 1980, *Global distribution of total cloud amount*, Gidrometeoizdat, Leningrad, 72pp.
- Brooks, C.E.P., 1927, The mean cloudiness over the earth, *Mem. Roy. Meteor. Soc.*, **1**, 127-138.
- Bunker, A.F., 1976, Computations of surface energy flux and annual air-sea interaction cycles of the North Atlantic Ocean, *Mon. Weather Rev.*, **104**, 1122-1140.
- Chahine, M.T., 1982, Remote sounding of cloud parameters, *J. Atm. Sci.*, **29**, 159-170.
- Chou, M.D., Childs, J.D. and Dorian, P., 1986, Cloud cover estimation using bispectral satellite measurements, *J. Clim. Appl. Meteor.*, **25**, 1280-1292.
- Coakley, J.A., 1987, A dynamic threshold method for obtaining cloud cover from satellite imagery data, *J. Geophys. Res.*, **92**, 3985-3990.
- Coakley, J.A. and Bretherton, F.P., 1982, Cloud cover from high resolution scanner data: detecting and allowing for partially filled fields of view, *J. Geophys. Res.*, **87**, 4917-4932.
- Cox, S., McDougall, D., Randal, D. and Schiffer, R., 1987, FIRE — The first ISCCP regional experiment, *Bull. Amer. Meteor. Soc.*, **68**, 114-118.
- Desbois, M., Sèze, G. and Szejwach, G., 1982, Automatic classification of clouds on METEOSAT imagery: Application to high level clouds, *J. Appl. Meteor.*, **21**, 401-412.
- Fye, F.K., 1978, *The AFGWC automated cloud analysis model*, AFGWC TM 78-002, AFGWC, Nebraska, 97pp.
- Godshall, F.A., 1971, The analysis of cloud amount from satellite data, *Trans. New York Acad. Sci.*, **33**, 436-453.

- Hahn, C.J., Warren, S.G., London, J., Chervin, R.M. and R. Jenne, 1982, *Atlas of simultaneous occurrence of different cloud types over the ocean*, NCAR:TN-201+STR, NCAR Technical Note, National Center for Atmospheric Research, Boulder, Colorado, 34pp and 188 maps.
- Hahn, C.J., Warren, S.G., London, J., Chervin, R.M. and R. Jenne, 1984, *Atlas of simultaneous occurrence of different cloud types over land*, NCAR: TN-241-STR, NCAR Technical Note, National Center for Atmospheric Research, Boulder, Colorado, 21pp and 188 maps.
- Hastenrath, S. and Lamb, P.J., 1977, *Climatic Atlas of the Tropical Atlantic and Eastern Pacific Oceans*, The University of Wisconsin Press, 15pp and 97 charts.
- Henderson-Sellers, A., Sèze, G., Drake, F. and Desbois, M., 1987, Surface-observed and satellite-derived cloudiness compared for the ISCCP special study area in Europe, *J. Geophys. Res.*, **92**, 4019-4033.
- Henderson-Sellers, A. and Hughes, N.A., 1985, Global 3D-nephanalysis of total cloud amount climatology for 1979, *J. Clim. Appl. Meteor.*, **24**, 669-686.
- Hoyt, D.V., 1977, Percent of possible sunshine and the total cloud cover, *Mon. Weather Rev.*, **105**, 648-652.
- Hughes, N.A., 1984, Global cloud climatologies: A historical review, *J. Clim. Appl. Meteor.*, **23**, 724-751.
- Inoue, T., 1985, On the temperature and emissivity determination of semi-transparent cirrus clouds by bispectral measurements in the 10 micrometer window region, *J. Met. Soc. Japan*, **63**, 88-102.
- Liljas, E., 1984, *Processed satellite imagery for operational forecasting*, SMHI, Swedish Meteorological and Hydrological Institute, Norrköping, 43pp.

- Liljas, E., 1986, *Use of the AVHRR 3.7 micrometer channel in multispectral cloud classification*, SMHI, Swedish Meteorological and Hydrological Institute, Norrköping, 23pp.
- London, J., 1957, *A study of the atmospheric heat balance*, Final Report, contract AF19(122)-165, College of Engineering, New York University.
- Malberg, H., 1973, Comparison of mean cloud cover obtained by satellite photographs and ground-based observations over Europe and the Atlantic, *Mon. Weather Rev.*, 101, 893-897.
- Malick, J.D., Allen, J.H. and Zakanycz, S., 1979, Calibrated and analytical modelling of cloud free intervals, *Proc. Soc. Photo-Optical Instrumentation Engineering*, 195, 142-147.
- Quayle, R.G., 1980, Climatic comparison of estimated and measured winds from ships, *J. Appl. Meteor.*, 19, 142-156.
- Reynolds, D.W. and Vonder Haar, T.H., 1977, A bispectral method for cloud parameter determination, *Mon. Weather Rev.*, 105, 446-457.
- Riehl, H., 1947, Diurnal variation of cloudiness over the sub-tropical Atlantic ocean, *Bull. Amer. Meteor. Soc.*, 28, 37-40.
- Rosow, W.B., Mosher, F., Kinsella, E., Arking, A., Desbois, M., Harrison, E., Minnis, P., Ruprecht, E., Sze, G., Simmer, C. and Smith, E., 1985, ISCCP cloud algorithm intercomparison, *J. Clim. Appl. Meteor.*, 24, 877-903.
- Saunders, R.W., 1986, An automated scheme for the removal of cloud contamination from AVHRR radiances over Western Europe, *Int. J. Remote Sensing*, 7, 867-886.
- Saunders, R.W. and Kriebel, K.T., 1987, An improved method for detecting clear sky and cloudy radiances from AVHRR data, *Int. J. Remote Sensing* (in press).
- Schiffer, R.A. and Rosow, W.B., 1983, The International Satellite Cloud climatology Project, the first project of the World Climate Research Program, *Bull. Amer. Meteor. Soc.*, 64, 779-784.

**Starr, D.O., 1987, A cirrus cloud experiment: Intensive field observations planned for FIRE, *Bull. Amer. Meteor. Soc.*, 68, 119-124.**

**Warren, S.G., Hahn, C.J., London, J., Chervin, R.M. and R. Jenne, 1986, *Global distribution of total cloud cover and cloud type amounts over land*, NCAR:TN-273+STR, NCAR Technical Note, National Center for Atmospheric Research, Boulder, Colorado, 29pp and 199 maps.**

**Warren, S.G., Hahn, C.J., London, J., Chervin, R.M. and R. Jenne, 1987, *Global distribution of total cloud cover and cloud type amounts over the ocean*, NCAR Technical Note in preparation.**

**World Meteorological Organization, 1956, *International Cloud Atlas, Abridged Atlas*, WMO, Geneva, 62pp and 72 plates.**

**World Meteorological Organization, 1974, *Manual on codes, Volume 1*, (WMO Publ. No.306), WMO, Geneva.**

**World Meteorological Organization, 1984, *Manual on codes, Volume 2*, WMO, Geneva.**

**World Meteorological Organization, 1987, *International Cloud Atlas, Volume 2*, WMO, Geneva, 212pp and 196 plates.**

ATE  
LMED  
8