INTERANNUAL VARIATION OF SEASONAL MEANS AND

SUBSEASONAL VARIABILITY OF CLOUD

STREETS OFF THE EAST COAST OF

NORTH AMERICA 1984-1987

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I. Introduction

Convection waves are a strong function of the original forcing by convection in the boundary layer. This convection can take the form of radom or two-dimensional spatial structure. When clouds are formed as a result of two-dimensional boundary layer forcing (horizontal roll vortices) they are called cloud streets. Cloud streets, when formed under conditions of cold advection, provide a very strong forcing for convection waves since the streets act like a periodic obstruction to the flow, enhancing the formation of waves (Grossman, 1989). When cold continental air flows over a warm water current which in this study is the Gulf Stream, cloud streets are formed.

Convective waves may be important in the global momentum balance. Global circulation models presently overestimate wind speeds in the middle and upper troposphere, and do not account for convective waves. If they are found to be of importance, the current global circulation and operational weather forecast models may be improved.

If the hypothesis that convective waves significantly contribute to momentum transport in the troposphere is correct, then a climatology of cloud streets will help understand convection waves' role in the global momentum balance. If the hypothesis is incorrect, then cloud street climatology is still useful because cloud streets show areas where large amounts of sensible and latent heat are transferred from the ocean to the atmosphere.

The purpose of this paper is to examine and compare interannual variation of seasonal means and subseasonal variability of cloud street

occurrence off the east coast of North America. The months of December, January, and February during 1984-85, 1985-86, and 1986-87 will be examined as will each season.

II. Data and Analysis Method

The original data used to make the maps are DMSP 1:30,000,000 polar stereographic projections. These negative mosaics are compiled from several orbital strips and have a resolution of 5.4 km. Visual and infrared mosaic images were used. I looked for cloud streets off the coast of North America and Asia and outlined the areas on mylar overlays. Each day for both continents had a mylar overlay and log entry. The next step was to digitize each month's overlays and use a program entitled "Atotal" to produce a crude map. After this I would refine the map until the final cartographic product was produced.

The maps use a dasametric surface made up of numbers and letters to indicate the number of days cloud streets were noticed in a given location. The surface is divided up in intervals of four days on the monthly maps and twelve days on the seasonal maps. Thus the monthly and seasonal maps' color contoured surface has been converted to the same percent frequency of occurrence (see Table 1). The columns in the upper portion of the table refer to the maps' surface, while the columns in the lower portion are corresponding conversions of the dasametric surface to percent frequency of occurrence. There are also corresponding means, standard deviations and coefficients of variation. The coefficient of variation has a mean of 4.67%.

Figs. 1-3e and 4 are graphs measuring percent frequency of occurrence, mean, standard deviation and range of a 114 grid point area selected from the map. The 114 grid point area represents a consistent area where maximum cloud street occurrence was noticed. Fig. 1d shows this rectangular area outlined in red, and will be known as the sample area. The maximum shifted beyond the 114 grid points selected at times but the area chosen was acceptable for comparative purposes.

III. Intra-seasonal Variation

There are nine months examined in this study in detail. The reason for looking at each and comparing the months is to look for a pattern, or any possible information that would be pertinent to the study. The following is to be used as a supplement or guide to the maps and graphs presented in this paper, and this information is to be used as a guide to help understanding them.

a. 1984-85 Season

Fig. 2d and Fig. 4 show that this season had the least amount of cloud street occurrences. It's not by much, but one month, being December 1984 (Fig. 1a), accounted for this season being a little below the mean.

In December of 1984 (Fig. 1a), there are two cloud street maximum areas, one being about 37°N, and the larger being on and north of 40°N. There is an area of 14%-26% occurrence over the Labrador Sea with the 60°N parallel almost bisecting the area. The Gulf of Mexico had little cloud street activity as compared to the two other seasons. This season had very little occurrence of cloud streets over land.

The month of December 1984 (Fig. 1a) was an unusual case due to the fact that the maximum occurrence of cloud streets was located north of the 40°N parallel. The maximum 40%-52% occurrence lies on each side of 60°N, with the 14%-39% occurrence stretching to 40°N without any gaps between. This month accounted for all the seasonal overland cloud street occurrences, and for the one day occurrence over Hudson Bay.

January 1985 (Fig. 1b) shows a case of a 40%-52% occurrence for the sample area. There is a definite shift of cloud street activity south from December, but no significant change can be noticed for the Gulf of Mexico. January represents the entire season's most impressive number of occurrences over a large area.

In February 1985 (Fig. 1c), there is a substantial decline in the number of cloud street occurrences as compared to January, but the area where they occur matches January's very closely. February shows the 14%-26% occurrence rate over the same area as January's from roughly 30°N to 47°N. A few 27%-39% occurrence areas are scattered within this area, but no one area can be attributed as the maximum. The 27%-39% occurrence rate is scattered along the flow of the Gulf Stream with a one-day occurrence extending off the map in the NW Atlantic Ocean.

b. 1985-86 Season

The 1985-86 seasonal map (Fig. 2d) shows a large 14%-26% occurrence rate hugging the coast from 30°-50°N, with the maximum area being bisected by 40°N. This maximum area only has a 27%-39% occurrence rate but is more pronounced and uniform than the 1984-85 season. As compared to 1984-85, there is a lack of cloud street activity over the Labrador Sea and increased

activity over the Gulf of Mexico. There is some occurrence over land but most of the activity is near the coast in these cases.

December 1985 (Fig. 2a) is another case of a normal distribution where the maximum occurrence rates are concerned. The 40%-52% occurrence lies within the 27%-39% rate and is surrounded by the yellow 14%-26% rate. The maximum lies within the 114 selected grid points easily and this area is about 2% above the seasonal mean for this area. There are some occurrences at the 14%-26% rate stretching well to the northwest following the Gulf Stream, and some occurrences in the Labrador Sea and Gulf of Mexico.

In January 1986 (Fig. 2b), the map shows a pronounced shift south in the 27%-39% and 40%-52% occurrence rate. There are two maximum areas that still show a normal distribution. There is a great amount of activity in the Gulf of Mexico as compared to other months with a small area of 27%-39% occurrence.

February 1986 (Fig. 2C) shows quite a shift in cloud street occurrence and strength. The maximum area (27%-39%) has shifted well north along with the 14%-26% occurrences. The maximum areas of occurrence lie near 43°W-50° and 62°N-67°N, with another 27%-39% area just off the coast from 40°N-45°N. There is a significant decrease of cloud street occurrence in the Gulf of Mexico and no streets noticed over Florida as with the past two months. Again it looks like the maximum occurrences of cloud streets mirror the flow of the Gulf Stream.

c. 1986-87 Season

Fig. 3d and Fig. 4 show an anomaly as compared to the two previous seasons due to the magnitude of occurrence found in the 114 grid point maximum area. This is owing to February 1987 which will be later dealt with in more detail. The seasonal map shows one grid point at "Z" which represents a 40%-52% occurrence rate for the season. It's almost centered within the 27%-39% area at 40°N. No other seasonal map shows this high rate of occurrence. The other "Z's" on the map represent 35 days of 90 cloud streets were noticed one day less than falling into the 40%-52% class. This large area can be noted as a 39% occurrence rate, which is within the 114 grid point maximum and places it over 7% above the three-season mean. There is a large area of the yellow 14%-26% occurrence rate over the Labrador Sea and Gulf of Mexico for the season, but both these areas are overshadowed by the maximum. This map also shows an occurrence rate well inland over the U.S. stretching from 70°W-90°W, which also makes this season unusual.

December 1986's (Fig. 3a) map shows nothing that unusual as compared to December 1985, however the 14%-26% occurrence rate is quite large, stretching from the Labrador Sea above 60°N to off Cape Hatteras about 35°N. There is only one grid point of 40%-52%, and it is a "D" so it's at the low end, being 40%. This is the month where cloud streets were noticed over the inland U.S. There is some significant activity over the Gulf of Mexico this month, more than off the east coast at 30°N.

January 1987 (Fig. 3b) is somewhat similar to December of 1986 in that the shape and area of the yellow 14%-26% rate is similar. There are

two areas of the 27%-39% occurrence again following the flow of the Gulf Stream. There is a significant area of cloud street activity over the Gulf of Mexico with five grid points showing a 27% rate inside the 14%-26% area. In the NE Atlantic there is a one-day occurrence extending off the map which was only noticed one other day in February 1985.

The final month and map to be detailed will be February 1987 (Fig. 3c). This month has within its maximum area the greatest number of occurrences which accounted for all the "Zs" on the seasonal map. The 114 grid point area represented on the graph shows that this month's maximum area mean is 17% above the area's seasonal mean. This is a large percentage and one can notice this by examining the map. No other map shows the magnitude of cloud street activity that this month's map shows. There is a large area of a 53%-65% occurrence, and one grid point shows an "L" which means this area experienced cloud streets 21 out of the 28 days of the month. That's a 66% occurrence rate. No other map shows an area of the violet 53%-65% occurrence rate. The dasametric distribution indicates a near normal distribution but the areas of 14%-26% and 27%-39% are thin along the maximum area's east and west sides. There is a familiar area of cloud street activity in the Labrador Sea but not many cloud streets were noticed in the Gulf of Mexico this month. There is a one-day occurrence well inland over the U.S.

IV. Interannual Variation

Utilizing the seasonal maps for Fig. 1d-3d and Fig. 4, we can see that the 1986-87 season was quite different due to the intensity of cloud street occurrences. There is at least one explanation that will be

presented that explains why February 1987 experienced such a high degree of cloud street activity. It is already established that cloud streets occur when cold continental air flows over warm water. The greater the air-sea temperature difference, the more likely cloud streets will form. Thus a higher frequency of cold fronts may produce a greater frequency of cloud streets. Is there some event, such as El Nino Southern Oscilation (ENSO) that is tied to a great outbreak of cold fronts in the northern hemisphere?

V. Discussion

Fig. 5 is a graph measuring outgoing long wave radiation from 1971-1990 on a monthly basis covering $5^{\circ}N-5^{\circ}S$, $160^{\circ}E-160^{\circ}W$. OLR is a measure of convective activity. A negative anomaly (from a 15-year mean) indicates increased convective activity. This graph shows a peak of convective activity over the Pacific Ocean during February 1987. Increased convective activity in the area of $5^{\circ}N-5^{\circ}S$ is directly associated with an El Nino Southern Oscilation (ENSO) episode. During ENSO events convective activity at 180° or the date line increases. There is also a significant change in the pattern of baroclinic activity over the northern hemisphere. The hypothesis that an ENSO event caused more frontal activity over the northern hemisphere continents, thereby increasing cold air outbreaks, remains a consistent explanation why February 1987 experienced such an increase in cloud street occurrences off the east coast of North America. This hypothesis may also explain why increased occurrences in the Gulf of Mexico were recorded in December and January due to cold air flow down the Mississippi Valley over the Gulf.

I hope to continue to study this in the future, examining cloud
street occurrences off the east coast of Asia for this period. I also hope
to study and compare other significant ENSO episodes and resulting cloud
street occurrences in the northern hemisphere.

VI. <u>Works Cited</u>

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Table 1: Dasametric Map Conversion Table, Figs. 1-3

	Number of Days		% Frequency of Occurrence	Colors
28 (Feb)	31 (Dec., Jan.)	90 (Seasonal)		
1-4	1-4	1-12	3-13	White
5-8	5-8	13-23	14-26	Yellow
9-12	9-12	24-35	27-39	Orange
13-16	13-16	36-47	40-52	Red
17-20	17-20	48-59	53-65	Violet
21-24	21-24	60-71	66-78	Blue
> 24	> 24	> 71	> 78	Gray

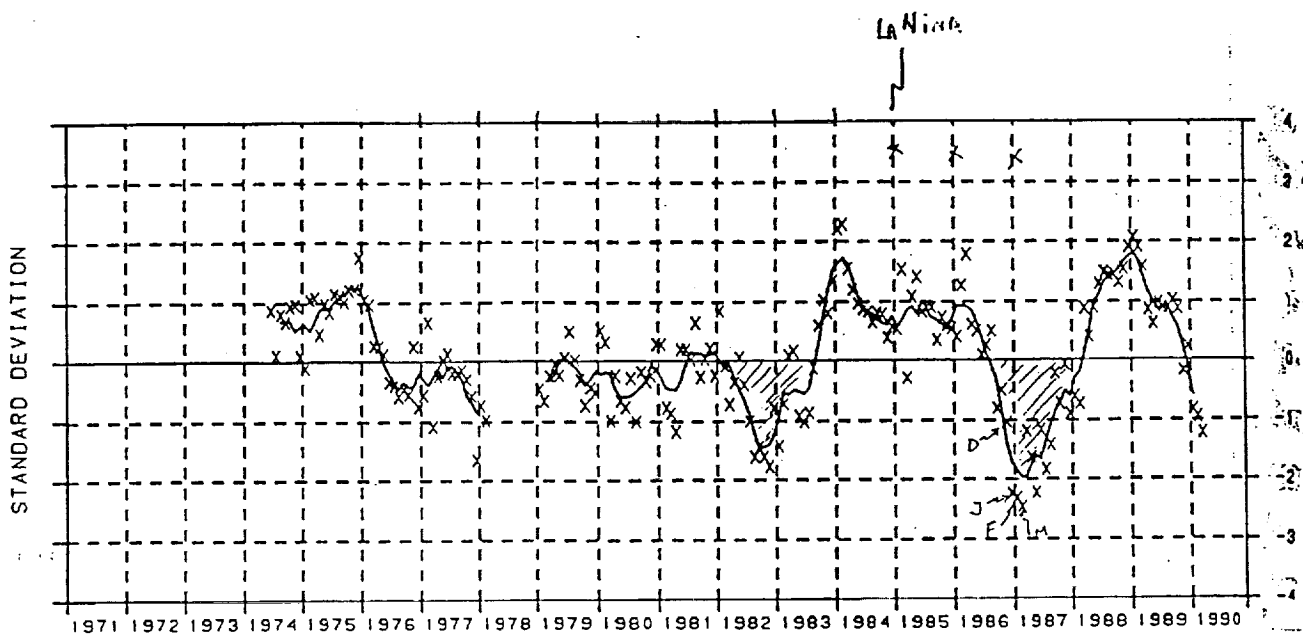| % Frequency Occurrence	% Frequency Occurrence	% Frequency Occurrence	$\bar{x}$	x	$x/$
3.6-14.3	3.2-12.9	1.1-13.3	13.5 ± .59		4.4%
17.9-28.6	16.1-25.8	14.4-25.6	26.7 ± 1.37		5.1%
32.1-42.9	29.0-38.7	26.7-38.8	40.1 ± 1.95		4.9%
46.4-57.1	41.9-51.6	40.0-52.2	53.6 ± 2.46		4.6%
60.7-71.4	54.8-64.5	53.3-65.5	67.1 ± 3.04		4.5%
75.0-85.7	67.7-77.4	66.7-78.8	80.6 ± 3.61		4.5%
> 85.7	> 77.4	> 78.8	$\bar{x}$ 13.5	Range 12.9-14.3-1.4 interval	4.67% of mean

Fig. 5. Five month running means for the standardized monthly anomaly in
outgoing longwave radiation over El Nino ENSO events the area 5°N-5°S,
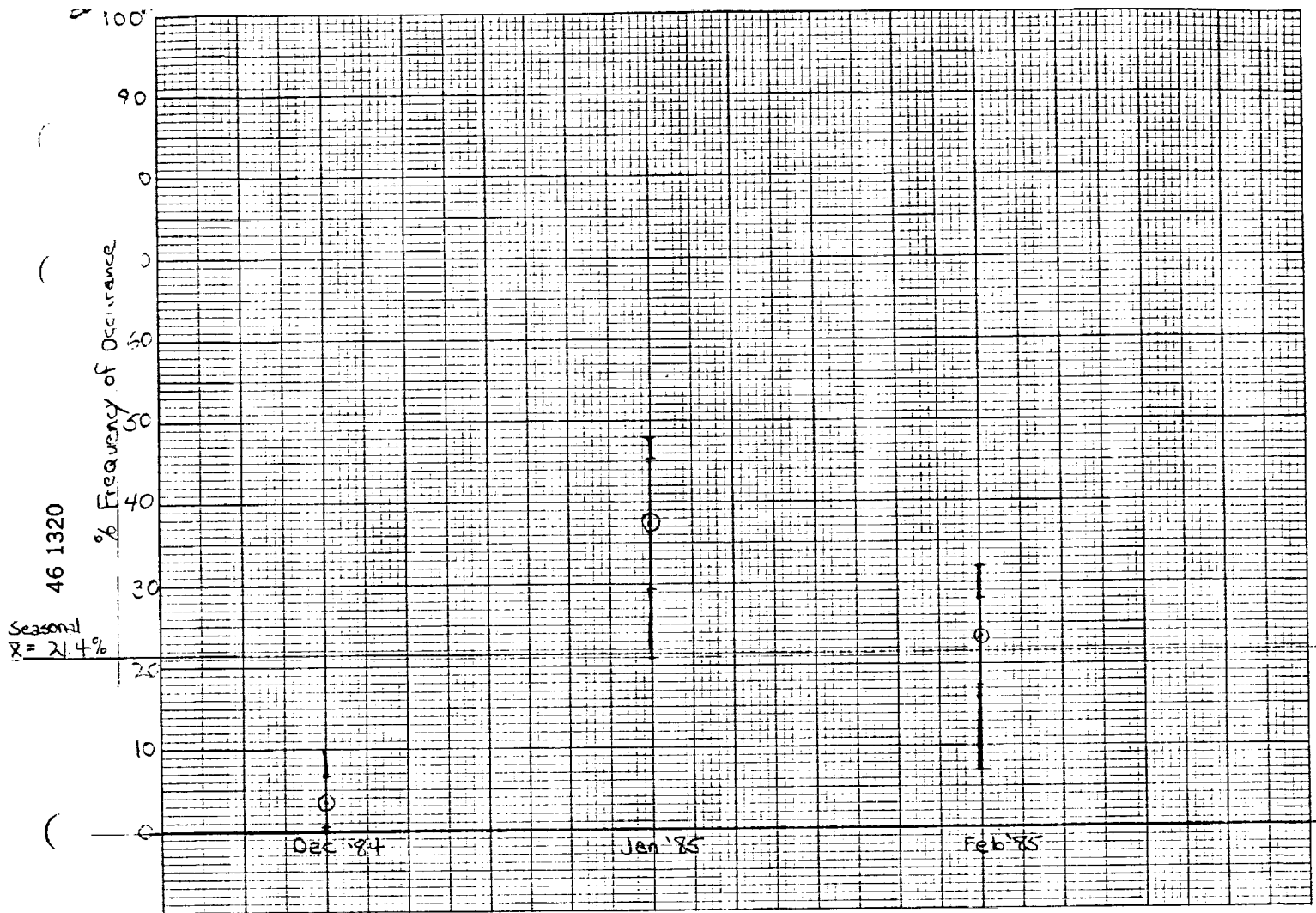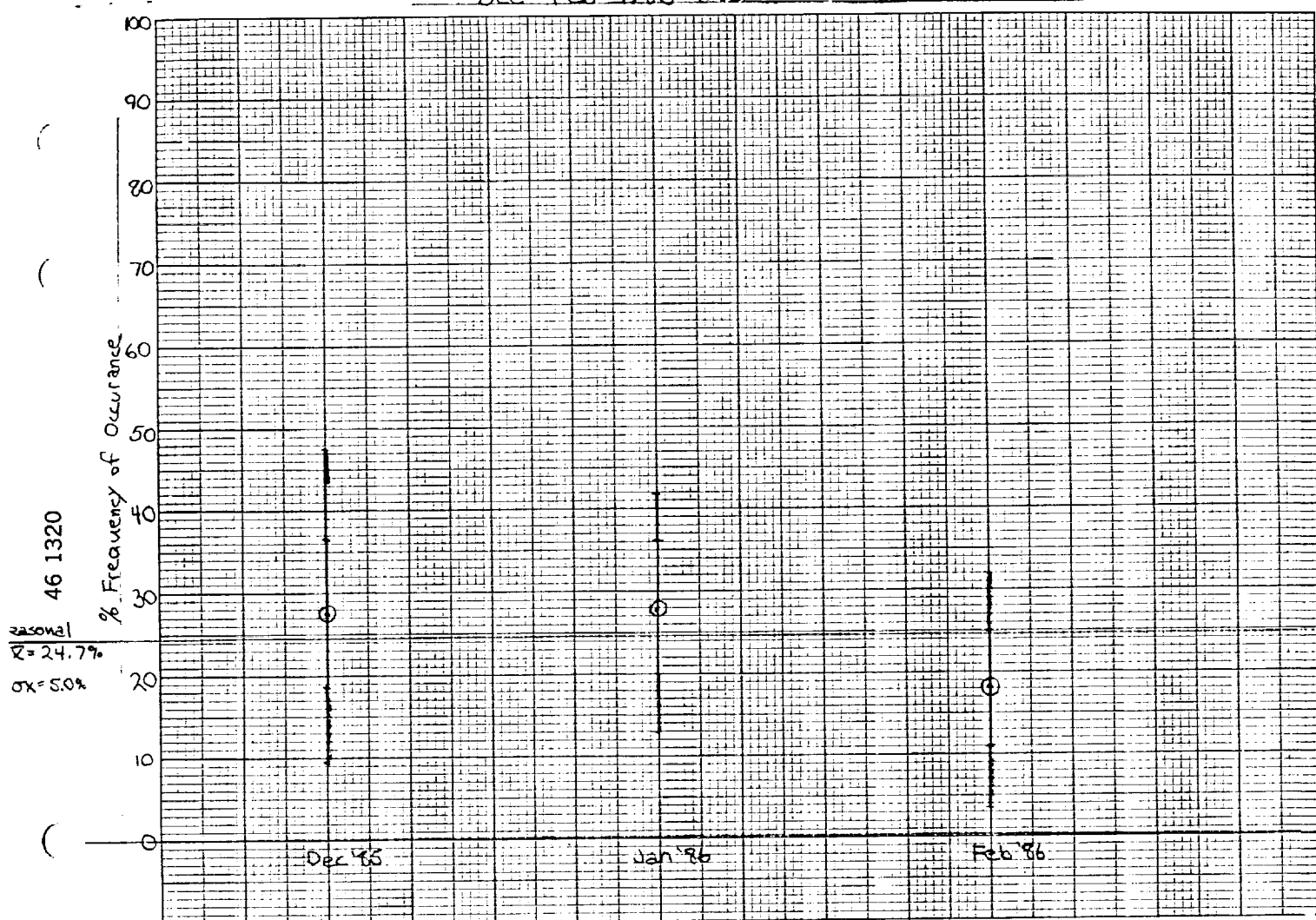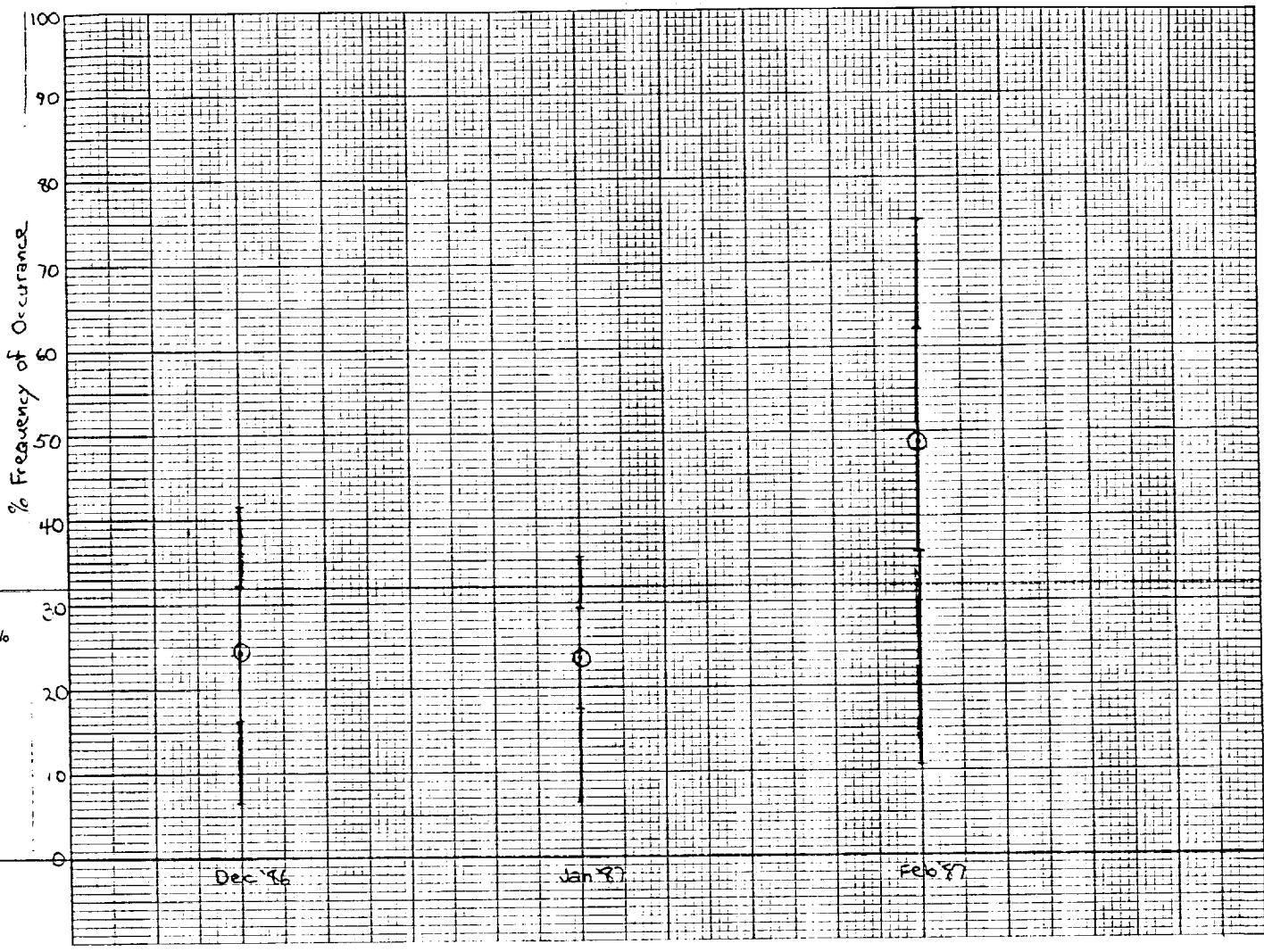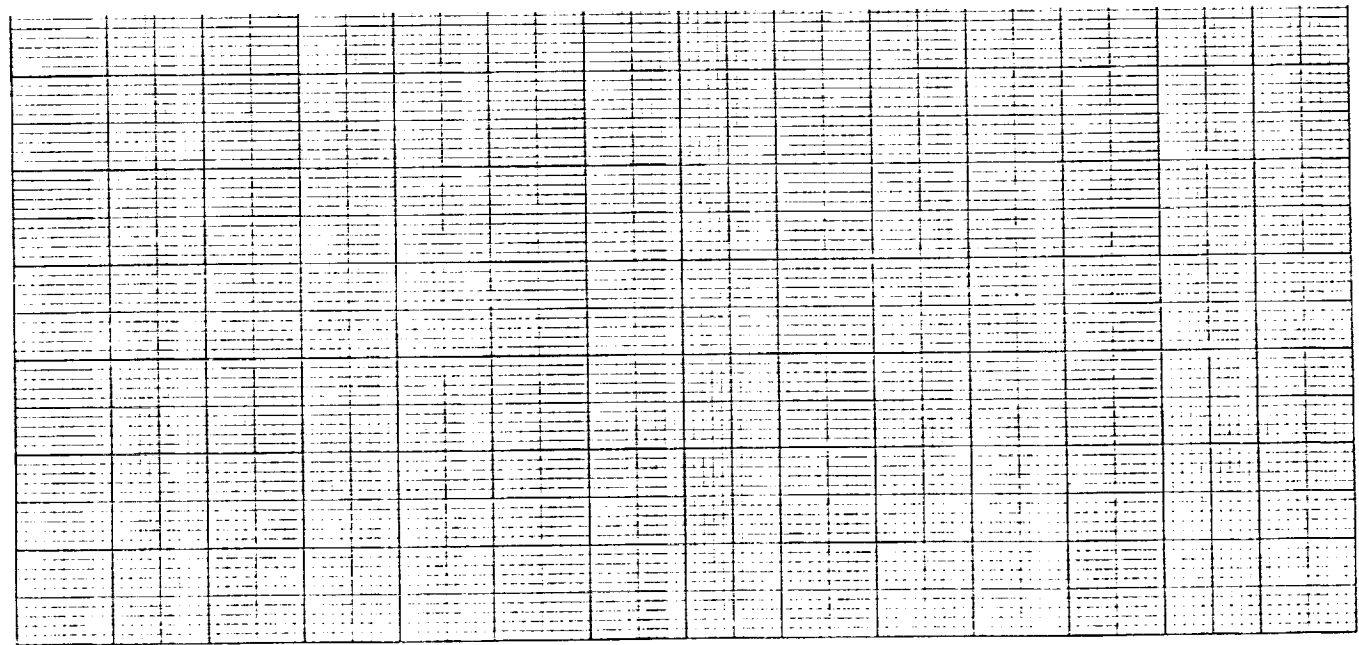El Nino 160°E-160°W.

Fig. 1f Monthly means, standard deviations, and ranges accounting for 114
grid point maximum area of cloud street occurrence.

· = mean   ___ solid line = standard deviation

Red line = range.

Fig. 2℮ Monthly means, standard deviations, and ranges accounting for 114
grid point maximum area of cloud street occurrence.

· = mean   ___ solid line = standard deviation

Red line = range.

Fig. 3ᐸ Monthly means, standard deviations, and ranges accounting for 114
grid point maximum area of cloud street occurrence.

· = mean   ___ solid line = standard deviation
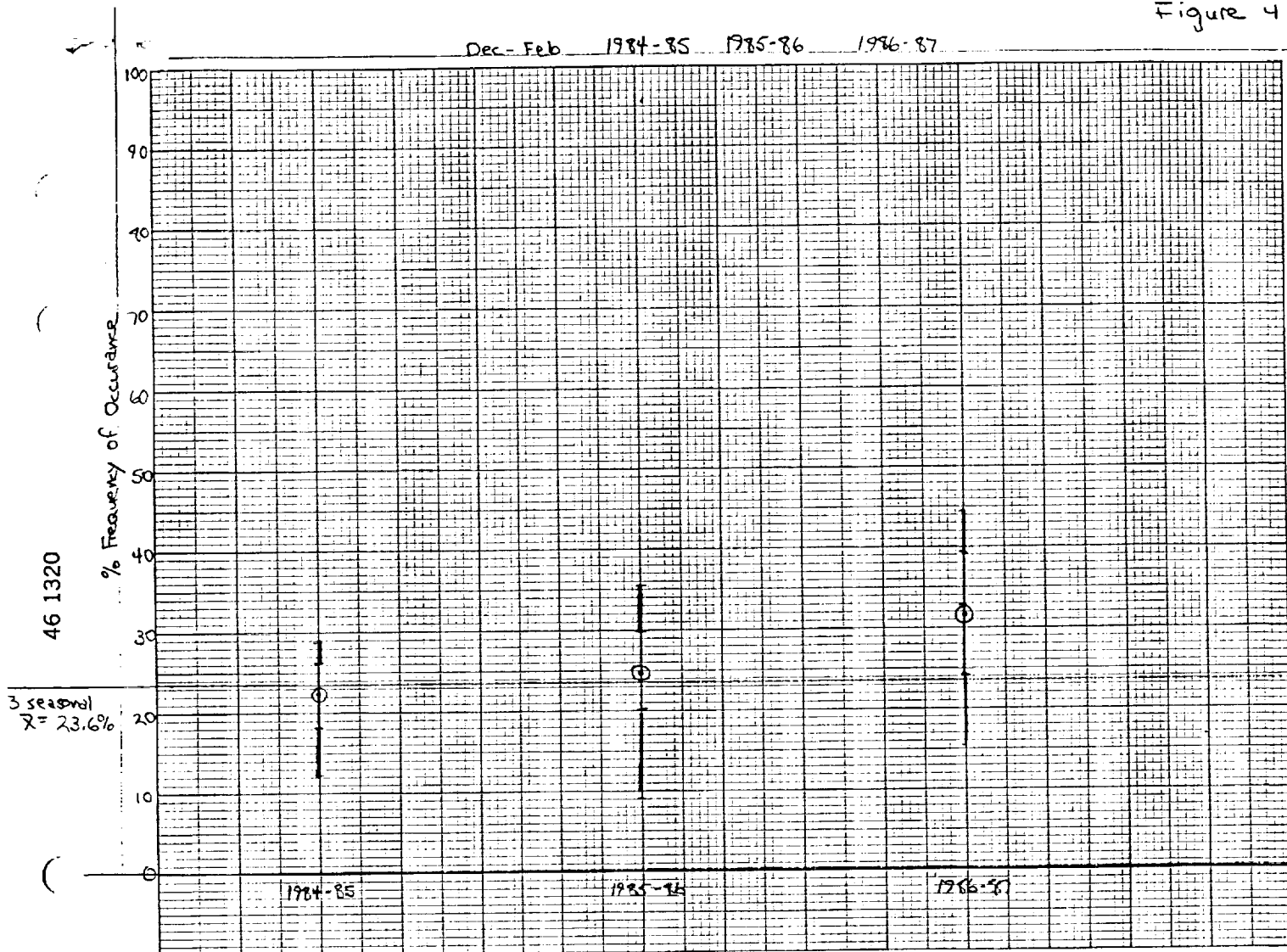
Red line = range.

Figure 4

Fig. 4. Yearly means, standard deviations, and ranges accounting for 114
grid point maximum area of cloud street occurrence.

· = mean   ___ solid line = standard deviation

— Red line = range.