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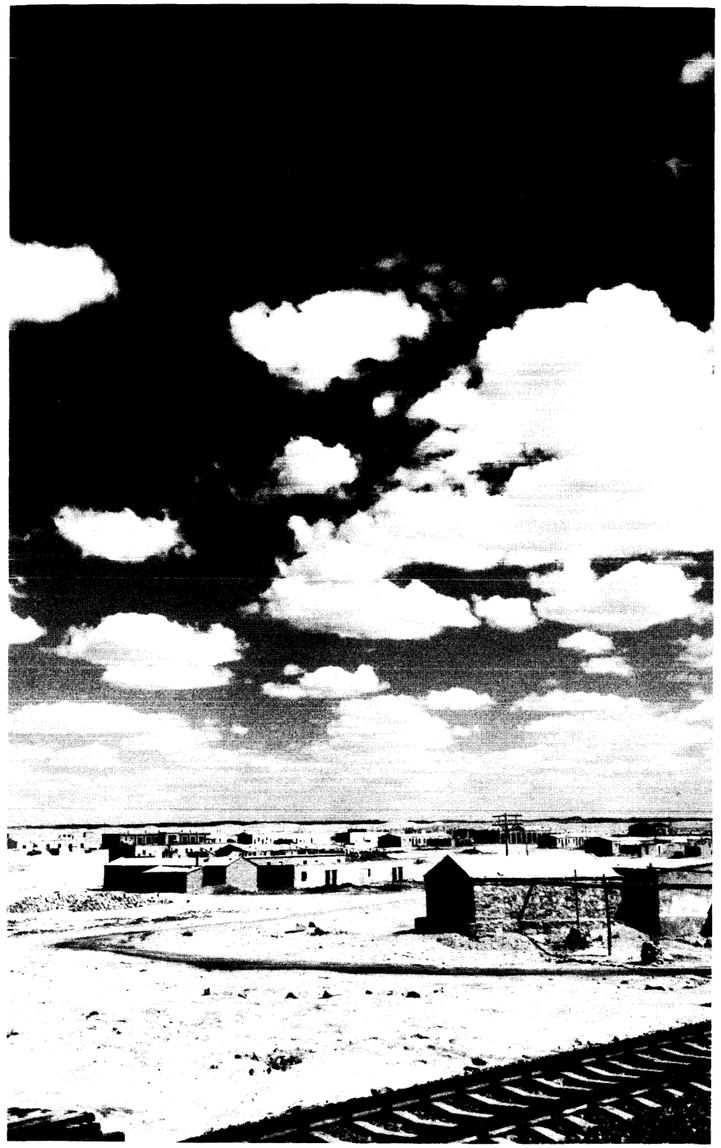
Global Distribution of Total Cloud Cover and Cloud Type Amounts Over Land

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Preface

This is the third of a series of atlases to result from a study of the global cloud climatology from ground-based observations. The first two atlases (NCAR/TN-201+STR and NCAR/TN-241+STR) described the frequency of occurrence of each cloud type and the co-occurrence of different types, but included no information about cloud amounts. The present atlas describes, for the land areas of the earth, the average total cloud cover and the amounts of each cloud type, and their geographical, diurnal, seasonal, and interannual variations, as well as the average base heights of the low clouds. A fourth atlas, in preparation, does the same for the ocean areas of the earth. These atlases are published with the cooperation of the National Center for Atmospheric Research, supported by the National Science Foundation.

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CLOUD MAPS .....

LIST OF CLOUD MAPS

		Map number			
A.	*Fraction of area which is land*	0			
B.	*Distribution of reports*				
	Number of weather stations	1			
		DJF*	MAM	JJA	SON
	Number of cloud reports	2	3	4	5
	Diurnal sampling	6	7	8	9
C.	*Total cloud cover*				
	Average cloud cover	10	11	12	13
	Standard deviation of observations	14	15	16	17
	Diurnal cycle: amplitude	18	20	22	24
	Diurnal cycle: phase	19	21	23	25
	Interannual variation	26	27	28	29
	Total cloud cover by month (Jan-Dec)	30-41			
	Annual cycle: amplitude, phase	42,43			

*Abbreviations used: DJF=December, January, February; MAM=March, April, May; JJA=June, July, August; SON=September, October, November.

LIST OF CLOUD MAPS (continued)

D. *Cloud types*

	Cu	Cb	St	Ns	As	Ci	clear
				frequency of occurrence			
DJF	44	72	100	128	152	168	184
MAM	45	73	101	129	153	169	185
JJA	46	74	102	130	154	170	186
SON	47	75	103	131	155	171	187
				amount-when-present			
DJF	48	76	104	132	156	172	
MAM	49	77	105	133	157	173	
JJA	50	78	106	134	158	174	
SON	51	79	107	135	159	175	
				average cloud amount			
DJF	52	80	108	136	160	176	
MAM	53	81	109	137	161	177	
JJA	54	82	110	138	162	178	
SON	55	83	111	139	163	179	
				average base height			
DJF	56	84	112				
MAM	57	85	113				
JJA	58	86	114				
SON	59	87	115				
				diurnal cycle amplitude, phase			
DJF	60,61	88,89	116,117	140,141			
MAM	62,63	90,91	118,119	142,143			
JJA	64,65	92,93	120,121	144,145			
SON	66,67	94,95	122,123	146,147			
				interannual variation			
DJF	68	96	124	148	164	180	188
MAM	69	97	125	149	165	181	189
JJA	70	98	126	150	166	182	190
SON	71	99	127	151	167	183	191

	DJF	MAM	JJA	SON
Most frequently occurring cloud type	192	193	194	195
Cloud type contributing most to total cloud cover	196	197	198	199

1. INTRODUCTION

Clouds exert large influences on the earth's climate by virtue of their radiative properties both in the solar and thermal-infrared spectral regions, and because of their role in the hydrological cycle. These effects depend on cloud thickness, height and water content, and it is therefore useful to distinguish clouds by type. At present the identification of clouds by type (although not necessarily their areal coverage, as discussed below) is made more accurately from the surface than from satellites, partly because ground-based observers are closer to the clouds and can therefore resolve individual clouds within their field of view.

This atlas presents a method for determining the average fractional coverage of each cloud type, taking into account the overlap of different cloud types which were present simultaneously in a single observation. The method is designed to derive the true average amounts rather than the amounts seen from below or above. (The amounts seen from below or above are referred to below as the non-overlapped amounts.) The method obtains separately the average frequency of occurrence and the average amount-when-present, and multiplies these to derive the average amount of the cloud type. These quantities are mapped for six cloud types, and the average total cloud cover is also mapped, for each of 4 seasons at $5^\circ \times 5^\circ$ latitude-longitude resolution. [Poleward of 50° latitude the size of the grid boxes is increased in longitude to maintain approximately equal area in each box. For convenience, the term "$5^\circ \times 5^\circ$ box" is used to refer to any of the boxes.] Diurnal and interannual variations of cloud type amounts are mapped at the same spatial resolution. More detailed information, not included in this atlas, such as average frequencies and amounts for individual year-seasons and individual reporting-hours, are available on magnetic tape.

All available data were used in computation of the averages plotted on the maps. For $5^\circ \times 5^\circ$ boxes which contained more than one station, data from all stations were averaged in a manner described below. An alternative approach would have been to select a single station for each box which was assumed to be most representative of the entire box. However, in regions of varied topography it is difficult to find any single station which would represent the average. We therefore allowed data from all available stations to contribute to the averages for each box. We recognize that in many regions the cloud climatology varies on spatial scales smaller than 5°. For that reason we have also analyzed one year of data (Dec 1978-Nov 1979; the FGGE year) at $2.5^\circ \times 2.5^\circ$ resolution over land; those results will be presented in a separate atlas.

This text emphasizes discussion of the computation procedures and of the format of the maps; very little discussion of the results is included.

2. DATA SOURCE

The only type of data used here is the routine weather observations, coded by the observers into the WMO synoptic code (WMO, 1974). Synoptic reports from land stations were obtained on magnetic tape from the "SPOT" archive of the Fleet Numerical Oceanography Center (FNOC) in Monterey, California. The SPOT archive begins in October 1966, but for the years 1966-1970 there are many mislocated data and also almost no observations from the Southern Hemisphere. In these early years the SPOT archive is also lacking station identification numbers. The archive consists of high-quality data with global coverage beginning in January 1971. For this atlas we analyzed eleven years of data, 1971-1981, a total of approximately 116 million observations. More data are now available. To obtain the best long-term averages we wanted to use as many years as possible. However, changes in the synoptic code were instituted in January 1982 which would require changes in our analysis procedure that could introduce biases in the results of the years beginning 1982. We therefore do not use observations made after 1981.

The analyses are done for each of the four meteorological seasons, designated by the first letter of each month: DJF, MAM, JJA, SON, where (for example) DJF 1979 includes the months December 1978-February 1979. Because December 1970 is not in the archive, it was replaced (for multi-year averages) by data from December 1981, so that the total number of Decembers used in averages for DJF is the same as the number of Januarys and Februarys. The data therefore include all months January 1971-December 1981.

The observations are normally made every three hours, with somewhat more at GMT hours divisible by 6. Typically about 4100 stations appear in the archive at 0, 6, 12, 18 GMT, of which about 3000 stations also report at 3, 9, 15, 21 GMT. About 20% of the stations do not make observations at night, so that 56% of all the observations were made in daytime. The sequence of steps in the averaging procedure described below is designed with this in mind, to avoid a possible daytime bias. However, of the $5^\circ \times 5^\circ$ boxes which have any stations, 2.5% have no station making nighttime observations, so that at those locations a daytime bias is unavoidable. These locations are indicated on a map.

The SPOT archive of FNOC contains reports only from stations which have been assigned official station numbers by WMO. There are some additional stations, especially in the US, which make reports in the synoptic code but do not enter our statistics because their reports are not archived at FNOC.

3. METHOD OF ANALYSIS

The information on clouds in the synoptic weather reports consists of total cloud cover (N), lower cloud amount (N_h), low cloud type (C_L), middle cloud type (C_M), high cloud type (C_H), present weather (ww), and base height of the lowest cloud (h). If information was lacking in a particular category, a slash (/) was recorded by the observer. The fraction of reports which include these quantities is given in Table 1.

N and N_h are integers from 0 to 8, signifying eighths of sky-cover, rounded to the nearest eighth, except that N=0 means completely clear sky and N=8 means completely unbroken overcast. N=9 means "sky obscured", often due to fog, rain or snow. In cases of N=9 we consult the ww code in order to determine the cloud type, if any; if ww indicates fog, rain, snow, or thunderstorm, a cloud type is then assigned as indicated in Table 2. If the sky is obscured for other reasons, e.g. haze or smoke, the report is discarded (0.1% of the reports). C_L, C_M, and C_H can obtain values 1-9, signifying one of 27 defined types (9 for each level), or 0, meaning no clouds at that level. N_h is the amount of all low clouds present, but if C_L=0 then N_h is the amount of middle clouds. The base height of the lowest cloud present, whether low or middle, is coded in h as a number from 0 to 9. This is the height of the lowest part of the lowest cloud present, even if the predominant low cloud layer is higher.

a. Data Selection and Checking

Some of the observations are internally inconsistent so that they had to be corrected if possible, or else discarded. Each observation was put through a series of tests shown in Figure 1. These tests were possible because of redundancy in the synoptic code. This figure is similar but not identical to Figure 1 of Hahn et al. (1984), principally because it includes the steps necessary for computation of cloud type amounts. The observations missing N_h or C_L were discarded as shown, in the analysis for cloud types. We also rejected observations missing ww, for the following reason. In addition to observations made by observers, the data set also contains observations from automatic weather stations, some of which were improperly coded into the archive. Reports from these stations should not contain any cloud information, so that the cloud fields should be coded as missing (unreported), but they appear instead as zeros (or some other number indicating a cloud) in this data set. By far the largest group of these are in the US, and they have a consistent pattern of code values, in which the present

Table 1.

Inventory of Data

	Quantity	Percent of reports* used for this quantity	
ww	Present weather	98.5	
N	Total cloud cover	98.1	
C_L, N_h	Low cloud type and amount	95.4	
h	Low cloud height	51.7	
C_M	Middle cloud type	80.5	(56% of these used for
C_H	High cloud type	62.7	daytime averages)

*The data set contained 116 million reports. Low clouds are absent about half the time (on global average); this is why low cloud height is included in only about half the reports. The numbers of reports used for C_M and C_H are smaller than the number used for C_L because observations of low overcast lack information about C_M and C_H.

Table 2. Grouping of cloud types

cloud types used in this paper	shorthand notation	observer codes included in each type[1]
Ci/Cs/Cc	Ci	C_H 1-9
As/Ac	As	C_M 1,3,4,5,6,8,9;C_M 2,7 if not precipitating[3]
Ns[2]	Ns	If (precipitating)[3] and (C_M 2,7 or C_L 6,7)
Cu	Cu	C_L 1,2
St/Sc	St	C_L 4,5,8; C_L 6,7 if not precipitating[3] or if C_M = 2,7, /; N = 9 with fog[4]
Cb[5]	Cb	C_L 3,9

[1] C_H = high cloud type; C_M = middle cloud type; C_L = low cloud type. The numbering scheme is defined in WMO (1956).

[2] Ns is also considered to be present when the cloud reports indicate "sky obscured" (N=9) due to rain or snow (present weather code ww 50-75). Note that if the report has both (C_M = 2 or 7) *and* (C_L = 6 or 7) with precipitation, this is counted as a co-occurrence of Ns with St. The case C_M = / and C_L = St with precipitation is also considered to be a co-occurrence of Ns with St. The present weather codes are defined in WMO (1974).

[3] "Precipitating" means present weather code 50-75.

[4] "Fog" means present weather code 10-12 or 40-49.

[5] Cb is also considered to be present when the cloud report indicates "sky obscured" and the present weather code is 80-99. This combination occurs in only 0.1% of the observations.

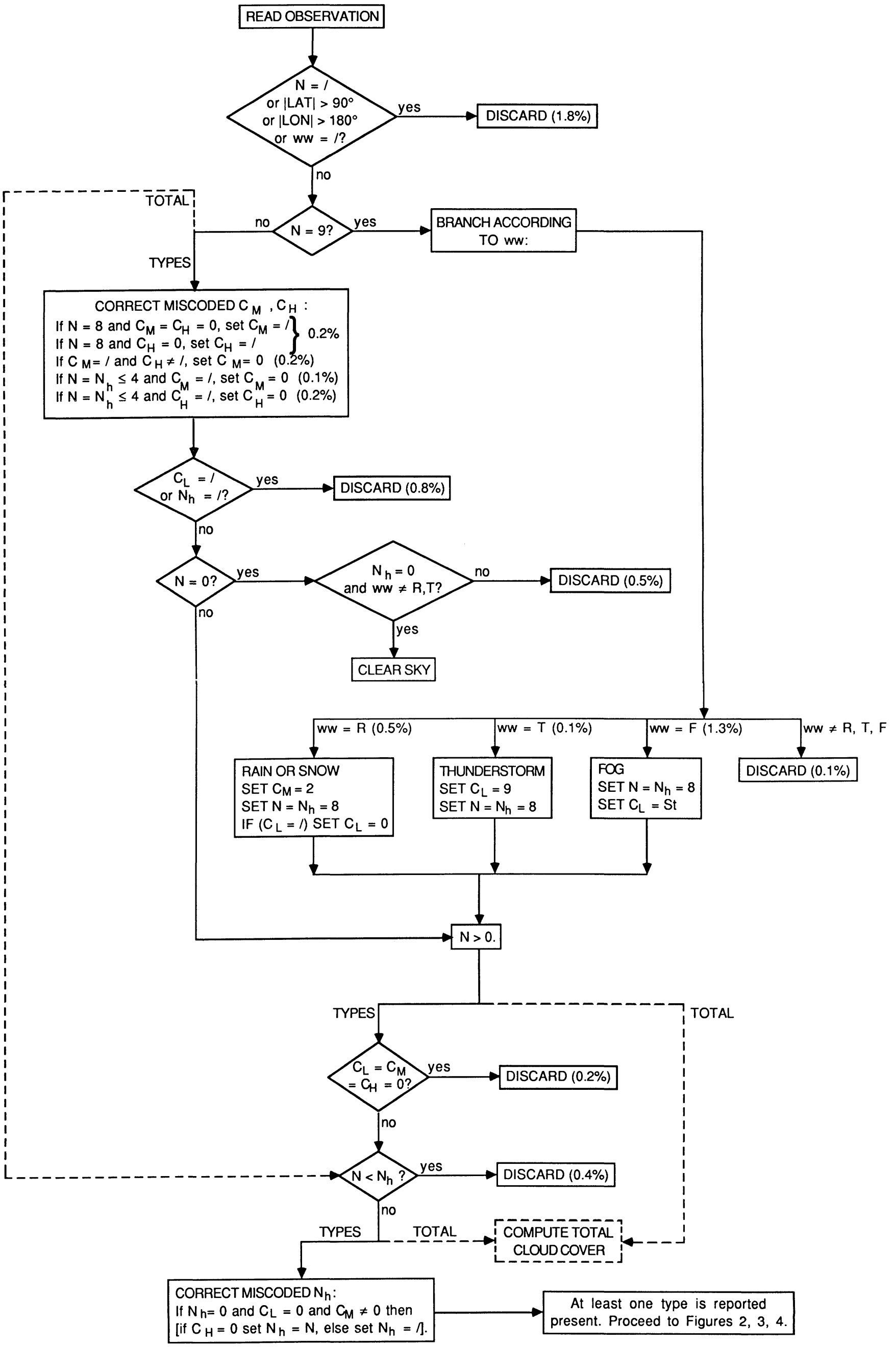


Figure 1. Data selection and checking. Abbreviations used here are defined in Table 3. Two passes are made through this flowchart: once for total cloud cover ("total"; dashed lines) and once for cloud types ("types).

Table 3. Symbols Used

a) in synoptic code

C_H	high cloud type
C_L	low cloud type
C_M	middle cloud type
N	total cloud cover
N_h	amount of low clouds (or of middle cloud, if no low clouds present)
ww	present weather
/	not reported

b) in Figure 1

F	fog (ww 10-12, 40-49)
LAT	latitude
LON	longitude
R	rain or snow (ww 50-75)
T	thunderstorm (ww 80-99)

c) for cloud types

Ac	Altocumulus
As	Altostratus; shorthand for As/Ac
Cb	Cumulonimbus
Cc	Cirrocumulus
Ci	Cirrus; shorthand for Ci/Cs/Cc
Cs	Cirrostratus
Cu	Cumulus
Ns	Nimbostratus
Sc	Stratocumulus
St	Stratus; shorthand for St/Sc/fog

d) in analysis

awp	amount-when-present
f	fractional frequency of occurrence
IAV	interannual variation
sd	standard deviation

weather was coded as missing (ww=/), so we were able to discard them on that basis. The policy (at the top of Figure 1) causes us also to discard some valid cloud observations. However, less than 1% of the observations made by observers prior to 1982 have ww=/, and these tend to be questionable observations in other respects, in that they are often internally inconsistent (e.g. $N_h > N$). Rejecting all observations which lack present weather should therefore not bias our analysis. Another reason for rejecting observations with ww=/ is that cases of N=9 cannot be interpreted as cloud if ww is missing. Thus, including observations in which ww=/ but $N \neq 9$ would cause our computed frequencies of fog, nimbostratus, and cumulonimbus to be too low.

Observations which lack N_h or C_L information cannot be used for cloud type analysis, but they are included in the analysis of total cloud cover. Only about 1% of the observations lacked C_L or N_h.

These tests on N_h, C_L and ww, however, could not be used if we were to analyze the post-1981 data, because changes were made in the synoptic code in 1982 which reduced the amount of redundant information contained in each weather report. Using the new rules, the observer is permitted to omit the ww code if ww=00, 01, 02, or 03, and is permitted to omit the codes for N_h, h, C_L, C_M, C_H if N=0 (no clouds).

Some of the erroneous reports can be corrected. When N_h=8, a common mistake is to code C_M=C_H=0. We change these observations to C_M=C_H=/ prior to our analysis, as shown in Figure 1, because the higher cloud types are not normally observable through a lower overcast. [We thank R.G. Quayle for alerting us to this type of mistake.]

The instructions for coding of N_h have been misinterpreted by some groups of observers. If C_L=0 (no low clouds), then N_h should be coded as the amount of middle clouds. This instruction was consistently ignored in observations at all stations in continental China through 1979: when $C_M \neq 0$ and C_L=0, N_h was always coded as 0. Beginning in 1980, however, the reports of N_h from these stations are consistent with the WMO rule. This same misinterpretation was made in a significant fraction of the observations from Peru and Chile, and in some from Equador and Brazil. We correct these reports by converting N_h=0 to N_h=/, unless C_H=0, in which case the middle cloud is the only cloud present, so N_h=N. This leads to a large fraction of reports missing N_h, especially in China, causing a bias in computing average amount-when-present of altostratus which must be further corrected as described in Section 3f3.

The various tests for inconsistencies shown in Figure 1 caused us to reject, on average, 1.2% of the observations. In addition, 0.6% of the observations contained inconsistencies which we were able to correct so that the observation could be used. The fraction of reports which had each type of error is given in Figure 1. The procedure shown in Figure 1 does not detect all possible inconsistencies, but it does catch the most common ones.

If the latitude or longitude was out of range (top box in Figure 1), this usually meant a missing bit on the tape, which made nonsense of the remaining data in the tape record. Therefore, when an out-of-range latitude or longitude was encountered, the entire tape record (maximum 800 observations) was ignored, so as to avoid contaminating our data with nonsense reports.

b. Total Cloud Cover

The code N was interpreted directly as fractional sky cover in eighths for code values 0-8. The case N=9 ("sky obscured") was handled as shown in Figure 1: if the present weather indicated fog, rain, snow, or thunderstorm, the observation was changed to N=8; otherwise it was not used.

c. Classification Of Types

The 27 cloud types of the synoptic code are grouped into six classes as shown in Table 2, and the detailed procedure for assigning types from a single observation is given in Figures 2-4. This is the same classification used in the earlier work (Hahn et al., 1982; 1984), except for a change in the definition of nimbostratus (Ns). There is no code number which always means Ns. Whenever one of the codes appears which could possibly mean Ns, we designate that cloud as Ns only if rain or snow was actually falling at the observer's location at the time of observation. Previously we allowed ww codes 50-89 to be assigned as Ns if one of the four Ns cloud-type codes was reported, or if the sky was obscured, or if C_M=/. It rarely happened that ww 80-89 was reported along with these cloud-type codes, but we decided for the present work to group ww 80-89 together with 90-99 as indicating Cb rather than Ns, as discussed on page 7 of Hahn et al. (1984).

We also decided not to allow ww=76 (diamond dust) or 78 (isolated snow crystals) to be assigned as Ns because these often fall from a clear sky. When they occurred together with C_M=2 or 7 we had previously called the cloud Ns; now it is called As/Ac. [The Ns frequencies given for Canada in winter in Maps 14 of Hahn et al. (1984), and on the corresponding data tape, are too large for this reason.] Unfortunately, when this

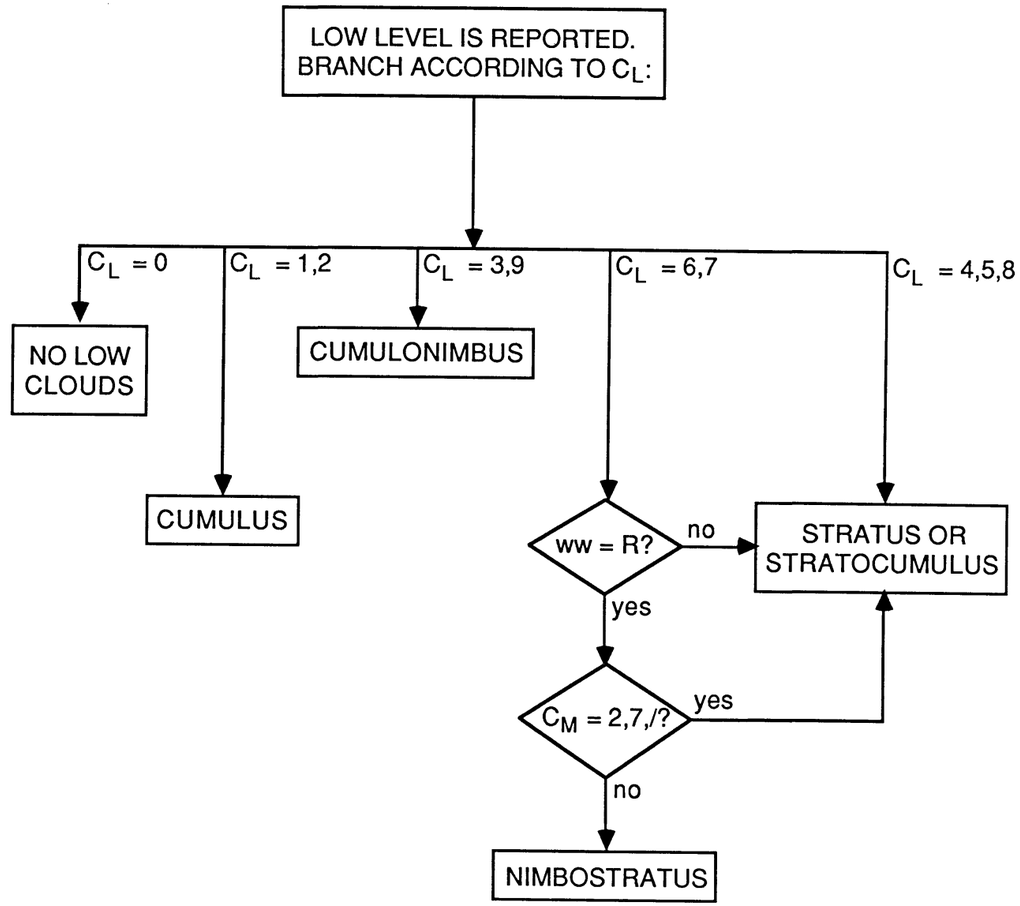


Figure 2. Low cloud type classification

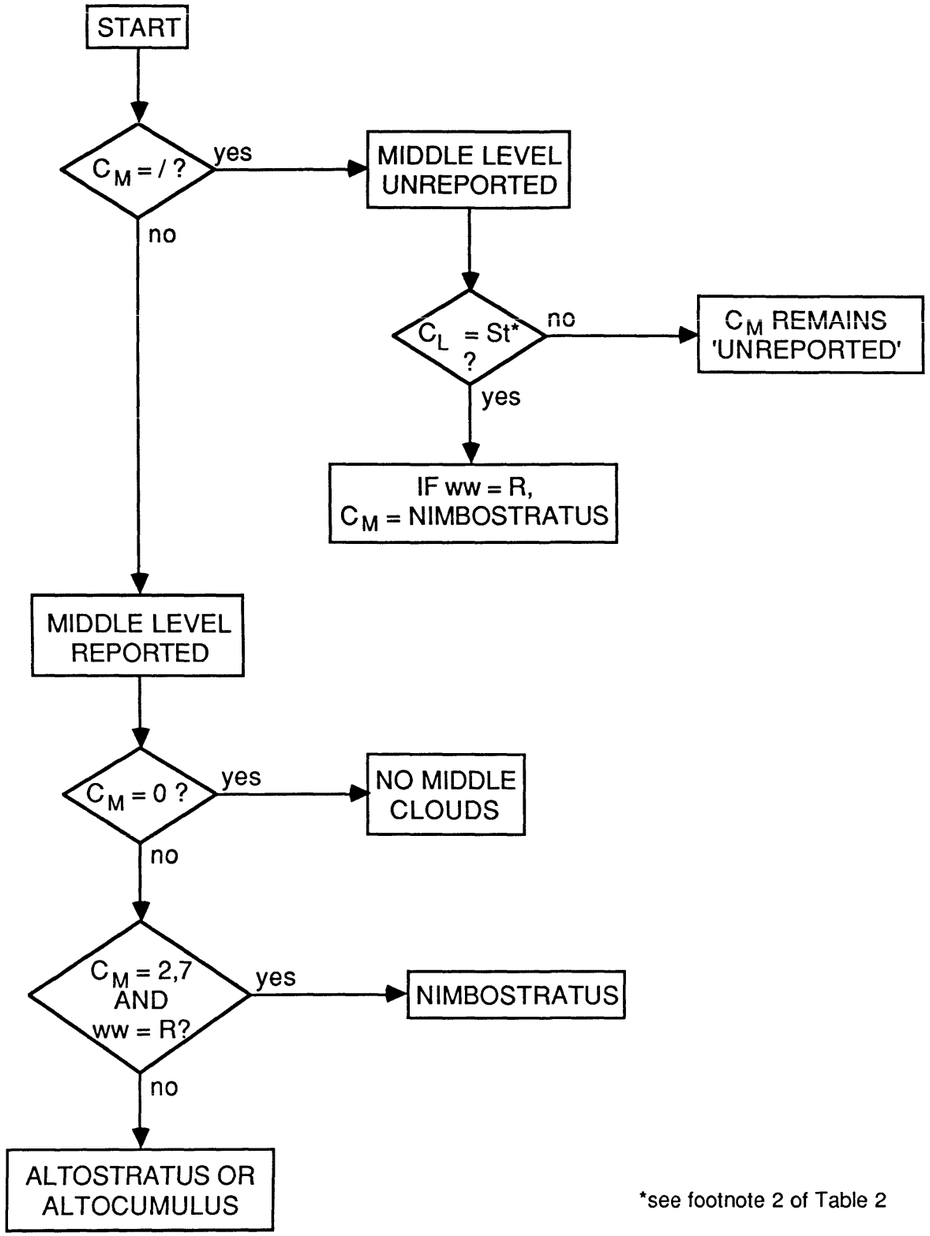


Figure 3. Middle cloud type classification. This figure is the same as Figure 3 of Hahn et al (1984), except for a misprint at the top of that figure which is corrected here.

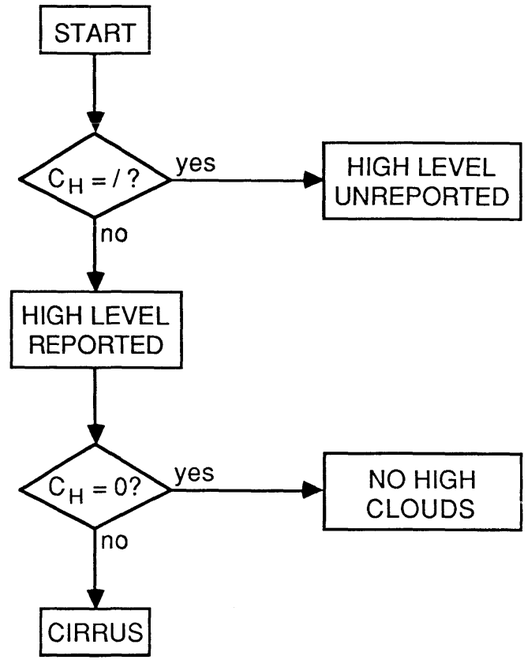


Figure 4. High cloud type classificatio

change was made we also by mistake excluded ww=77 (pellet-snow) and 79 (sleet) from the Ns classification, leading us to underestimate Ns amount in some parts of the polar regions. We estimated the effects of this mistake by reprocessing all the observations for one year only (1979), allowing ww = 77 and 79 to be Ns. The $5^\circ \times 5^\circ$ boxes whose Ns amounts would be affected by more than 1%, based on the 1979 data, are listed in Table 4. Most boxes are not affected at all. The estimated changes for the South Pole are more uncertain than those for the other listed boxes, because only about 140 observations per season were transmitted from that station in 1979. Furthermore, the changes given in Table 4 for the South Pole would not apply generally to individual years (on tape) because in some years the observers there did not use ww = 77 to code for snowfall.

This change also affects a consistency check we make as shown in Figure 1. If ww indicates rain or snow but N=0 (clear sky), the observation is discarded as inconsistent. Now ww=76 has been omitted from the group of codes meaning "snow" so that observations such as (N=0, ww=76) are no longer mistakenly discarded. This sky condition, "diamond dust" or "clear-sky ice crystal precipitation" is common in winter in northern Canada and in all seasons in Antarctica (Schwerdtfeger, 1984). The main effect of this revision of the "snow" category is to increase the frequency of occurrence (f) of clear sky and thus to decrease the frequencies of all cloud types, compared to results given in the co-occurrence atlas. [A minor effect is the conversion of some Ns into As in these regions.] Compared to the co-occurrence atlas, f (clear-sky) increased by about 15% in northern Canada in DJF and 4% at the South Pole. f(Ns) decreased in DJF from 26% to 8% in parts of Canada and from 34% to 5% at the South Pole. f(As) increased by about 4% in Canada and from 25 to 52% at the South Pole. Because of the increase in f(clear), f(Ci) decreased by 4-9%* in DJF in northern Canada and 3-15% in central Antarctica.

The changes in Siberia were very small, although the winter climate is in many ways similar to Canada in winter. The ww codes 76-79 are not used much in Siberia; snow is usually coded as 70-75 there.

One other improvement in the procedure over that used in the co-occurrence atlases is that we no longer discard reports of fog under clear sky. Such reports are not inconsistent, since it is sometimes possible to see that the sky is clear above the fog layer.

*Whenever values for standard deviation, or changes, or differences, or variability of the quantities cloud frequency or amount are given in this atlas, the units are always percent of sky covered, not percent of the mean. For example, if the average cloud cover fraction is 0.5 and its interannual variation is 0.05, we report these values as 50% and 5% respectively.

Table 4.

Estimated changes to Ns maps (%) which would result from allowing ww=77,79 to indicate Ns. (All changes would be positive.) All boxes are listed whose change is more than 1% in any season. These estimates are based on 1979 data only, so they are only an example of the changes that can occur. Most of these boxes are in Scandanavia and western Soviet Union. Different boxes in these regions would appear in the list if different years were tested. The change in amount of Ns is essentially the same as the change in f(Ns) because awp (Ns) $\approx$ 100%. Except at the South Pole, no change in amount of As would result, because elsewhere essentially all observations of ww=77,79 had C_M=/. At the South Pole the change in amount of As is approximately the same as the change in Ns, but with opposite sign.

grid box		Change in Ns amount (%)			
latitude	longitude	DJF	MAM	JJA	SON
80-85 N	40-80 W	1	0	3	2
65-70 N	20-30 E	1	1	0	2
65-70 N	50-60 E	1	1	0	2
65-70 N	150-160 E	1	0	0	2
65-70 N	90-100 E	1	0	0	2
65-70 N	40-50 W	1	0	0	3
60-65 N	10-20 E	2	1	0	1
60-65 N	20-30 E	4	1	0	1
60-65 N	170-180 W	0	2	0	1
60-65 N	50-60 W	0	2	0	0
55-60 N	0-10 E	2	0	0	0
55-60 N	10-20 E	3	0	0	0
55-60 N	70-80 W	0	2	0	0
50-55 N	30-40 E	2	0	0	0
40-45 N	80-85 E	2	0	0	1
50-55 S	30-40 W	0	1	2	2
55-60 S	20-30 W	0	2	0	1
65-70 S	60-70 W	1	3	0	0
70-75 S	0-20 W	5	1	0	0
85-90 S	0-360 E	7	2	7	1

This change caused the frequency of clear sky to increase relative to the values given in the co-occurrence atlas. The largest change in DJF was a box in Siberia (increase of 16%) and in JJA was in Italy (increase of 12%).

For uses which require a finer division of the low cloud types, we present maps of the distribution of each of the nine individual low cloud types (C_L=1-9) for two seasons of one year only (1979), in a special atlas for the FGGE year (Hahn et al., 1987).

d. Cloud Type Amounts

The amount of a cloud type is defined as the fraction of the sky covered by that type (WMO, 1956). The time-averaged amount can be obtained as the product of frequency-of-occurrence (fraction of weather observations in which a cloud of this type is present, whether visible or not) and amount-when-present (the average fraction of the sky which is covered by this cloud type when it is present). [These are the *definitions* of these two quantities, to be distinguished from our methods of estimating them from surface observations which are discussed below.] For example, if cumulus is present in 30% of the weather observations from a station, and if it covers an average of 40% of the sky when it is present, then the average amount of cumulus at that station is 12%. This procedure obtains the average cloud-type amount more accurately than does the procedure used by Telegadas and London (1954). They apportioned the total cloud cover into types (with an allowance for overlap) by assuming that the average amount of each type was proportional to its frequency of occurrence. Thus they implicitly assumed that the average amount-when-present was the same for each type, whereas in fact it typically varies from 33% for cumulus to 96% for nimbostratus.

The method described below is designed to obtain the true average amounts of each type of cloud, not the non-overlapped amounts seen from above or below. The amounts obtained are probably less accurate for the high and middle clouds than for the low clouds, because they often must be obtained indirectly, but the method is designed so as to minimize any bias to either more or less than the true average amounts.

1) Amount-when-present (awp)

The awp is obtained directly from each individual report as N_h for the low clouds Cu, St, and Cb. For the middle and high clouds it is sometimes obtained directly as N_h or N if there are no lower clouds present. In other cases we must make an assumption in order to derive awp.

For individual observations in which exactly two cloud levels are present, we assume random overlap. The amount A_L of the lower level L is obtained from N_h, and the amount A_U of the upper level U is obtained by solving the random-overlap equation:

$$1 - A_T = (1 - A_U)\,(1 - A_L)\,, \qquad (1)$$

where A_L, A_U, and A_T (the total cloud cover) are fractional amounts in the range 0.0 to 1.0 (A_T=N/8 and A_L=N_h/8, since N and N_h are reported in eighths). Equation (1) just says that the clear fraction of the sky is the product of the clear fractions of the layers. [This equation applies only to instantaneous cloud amounts, not to time-average cloud amounts.]

Because A_L and A_T can only have values which are multiples of 1/8, A_U cannot be obtained accurately as A_L becomes large. For N_h=7, only two values of A_U can result from (1): 0.0 or 1.0. Therefore, the equation is used only when $N_h \leqslant 6$.

There are three classes of observations in which middle and high awp cannot be calculated: (a) When clouds are reported present at all three levels, the random overlap equation has two unknowns and cannot be solved. (b) When N_h=7, the random-overlap equation becomes inaccurate as explained above. (c) When N_h=8, not only is the awp of a higher cloud indeterminate but even its presence or absence cannot be determined. For these cases we make the simple assumption that awp for a cloud type when it cannot be calculated is on average the same as when it can be calculated. This assumption is made plausible by the observation that average awp of As or Ci varies only slightly among the various classes of observations in which it can be calculated. For example, Ci may occur alone, or together with a low but no middle cloud, or together with a middle but no low cloud, and the average awp(Ci) typically varies by less than 0.1 among these classes of observations.

2) Frequency of occurrence

The frequency of occurrence (f) of a cloud type is obtained (to first approximation) as the number of times that particular type was reported present, divided by the number of synoptic weather reports which contained information about that cloud level (i.e., in which that level was not coded with a slash). [The fraction of reports that contain information about middle and high levels is given in Maps 8-9 of Hahn et al. (1984) and summarized here in Table 1. It is on average 80% and 63% respectively.] The assumption implicit in this method is that the f for a high or middle cloud is the same when it cannot be seen (because of lower overcast) as when it can be seen (at a particular time of day in a particular season at a particular location). The extent to which this assumption deviates from reality is indicated in the atlases of co-occurrence probability (Hahn et al., 1982; 1984). The results of those atlases are not used in detail in the

computation of f here, but a crude simplification of those results is used as a correction to the assumption given above. The assumption is important only for two of the six types: As and Ci. [The low cloud types Cu, Cb, and St are not obscured by lower clouds, and the presence of Ns is always detectable as a result of a ww report of precipitation, even if C_M=/.] We find that f(As) increases as low cloud amount (when present) increases from 0/8 to 7/8, as shown in the ocean atlas (Warren et al., 1987). This is because the small values of C_L are usually associated with Cu and large values with St, and the probability of As given St is larger than that given Cu [i.e.P(St→ As) > P(Cu→ As)]. The case of C_M=/, when the presence or absence of As cannot be determined, occurs with low overcast (N_h=8), which is likely to be St rather than Cu. For As, therefore, f is assumed to be the same when it cannot be seen as when it can be seen with low cloud amount in the range 3/8-6/8, not 0/8-6/8. [The reason for not using observations with low cloud amount 7/8 is explained in the following paragraph.] No such restriction was applied for Ci because the bias to be avoided is smaller in the case of Ci, as shown in the forthcoming ocean atlas.

The method for obtaining f(Ci) and f(As) is further modified to eliminate the "partial-undercast" bias as much as possible. As explained by Hahn et al. (1984) and by Warren et al. (1985), the frequency of upper clouds may be underestimated due to the possibility that an upper cloud is present behind a partial lower cloud cover yet reported absent because it does not intrude into the region of the sky which is visible through the lower layer. This bias in f can be reduced by excluding from the computation of f(As) and f(Ci) those observations in which a lower cloud layer was present with 7/8 coverage. The partial-undercast bias results in a systematic underestimate of f(Ci) and f(As), but correspondingly leads (via equation 1) to an overestimate in awp of those clouds. This means that the amount is unbiased if the same classes of observation are used for computation of both f and awp. Since computation of awp using (1) is restricted to observations in which $N_h \leqslant 6$, the same restriction is applied to the computation of f.

Since not all observations can be used for f and awp of high and middle clouds the accuracy of our computed cloud-type amounts depends on how well the true averages are represented by those observations which contained information about the upper levels. There are reports which contribute to statistics of f but not of awp, for example the reports in which clouds were present at all three levels and the reports of the absence of the cloud type in question. It appears that awp is more independent of the presence of other clouds than f is, so it is more important to have a large fraction of all observations contributing to f than to awp. This is indeed the case, since on average over land, about 80% of all the daytime reports contribute to statistics of f(As) and 63% to f(Ci), whereas only 61% of the reports in which As was actually present contribute to awp(As) and only 74% of the reports in which Ci was actually present contribute to awp(Ci).

e. Base Heights

The base height of the lowest cloud is sometimes measured, but in most of the reports it is estimated subjectively. To compute the average base height, we assign to each report the midpoint of the range in meters corresponding to the code value (WMO, 1974). Averages can only be formed for cloud types whose bases are always reported as less than the upper limit of the code, 2500 m. These types are Cu, St, and Cb.

f. Calculation of Average Cloud Amounts

The true mean cloud cover, or frequency of occurrence or awp of a cloud type, may differ from the mean of a finite number of reports, which is what we compute. Inadequate sampling can lead to both random errors and biases. We first examine the random error in order to specify a minimum number of reports required to form representative averages. Then we examine possible biases due to sampling error in order to choose the sequence of steps by which averages are formed.

1) Minimum number of reports required to compute an average

An experiment was done to estimate the expected error in average total cloud cover as a function of the number of observations used to compute the average. Three 5 ° ×5 ° boxes in northern Eurasia were used, all of which had large numbers of observations and moderately large standard deviation of individual observations (right hand side of Table 5). [The cloud climatology does not vary greatly among these three boxes, so they are not really three independent tests.] The average of all observations in DJF 1979 was assumed to be the true average cloud cover for that season in that year. Subsets of these pools of observations were repeatedly chosen by random sampling; the average cloud cover formed from each subset was compared to the "true" average cloud cover. For example, in the box at (50-55 ° N, 25-30 ° E) there were 16959 observations made in this season. Ten of these observations were selected randomly and the error in cloud cover (subset mean minus true mean) computed. This was repeated 100 times, and the root-mean-square (rms) error computed. Then 100 subsets of 15 observations each were selected, and so on, up to subsets of 600 observations each (except that in boxes with small numbers of observations the procedure was terminated when the population of the subset exceeded half the total population in the pool because the error goes artificially to zero as the subset population approaches the total population).

Table 5. Data used for estimating expected error in cloud cover as a function of number of observations (Figure 6)

Size of box	2.5° latitude × 2.5° longitude						5° latitude × 5° longitude					
Boundaries of box	60°-62.5°N 82.5°-85°E		52.5°-55°N 80°-82.5°E		52.5°-55°N 25°-27.5°E		60°-65°N 80°-85°E		50°-55°N 80°-85°E		50°-55°N 25°-30°E	
Number of stations in box	1		7		9		3		19		28	
Period of record used	Feb 1979	DJF 1979	Feb 1979	DJF 1979	Feb 1979	DJF 1979	Feb 1979	DJF 1979	Feb 1979	DJF 1979	Feb 1979	DJF 1979
Number of cloud reports	168	516	1128	3589	1400	4591	587	1816	3772	11780	5180	16959
Average cloud cover (%)	60	61	65	63	61	76	61	63	64	64	57	75
Standard deviation of individual observations of %-cloud-cover	46	47	43	44	44	39	46	47	43	43	45	40
RMS error in average %-cloud-cover if only 200 reports used	--	3.0	2.9	3.5	3.0	2.6	2.8	2.9	2.8	2.8	3.2	2.7

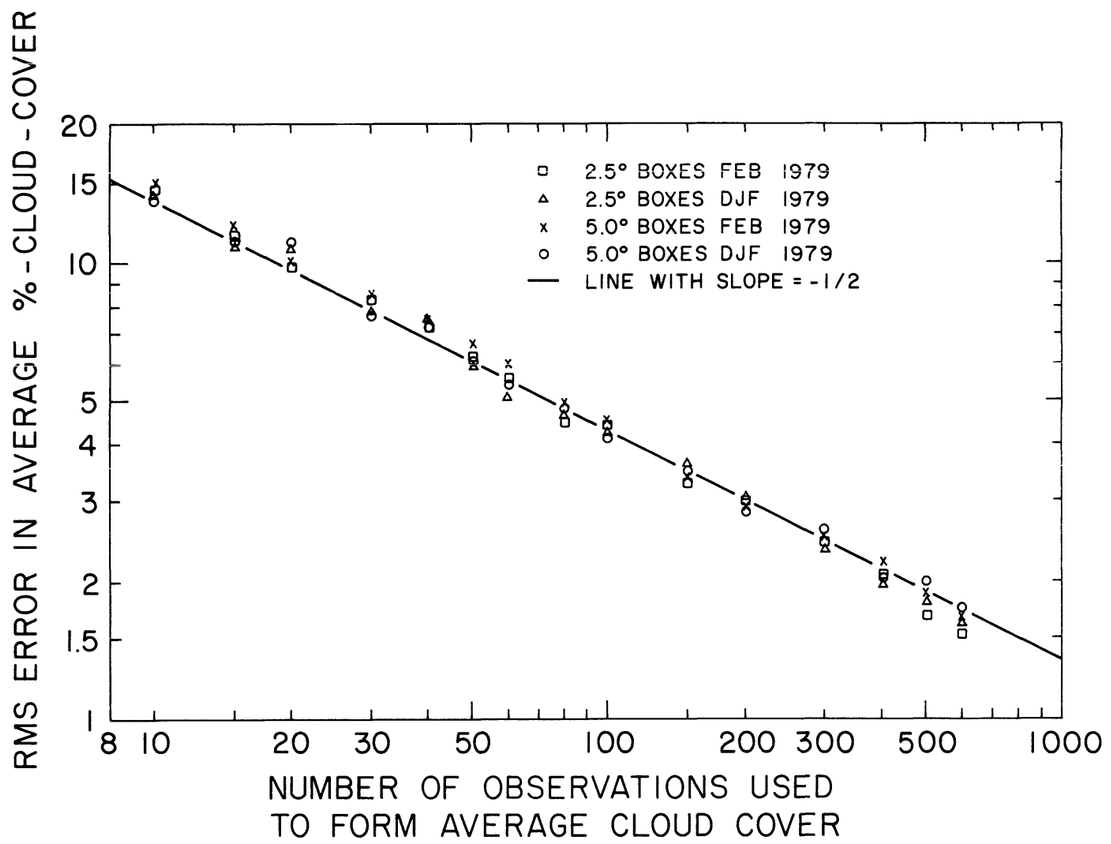


Figure 5. Expected error in seasonal or monthly mean cloud cover, for a 2.5° or 5° box, as a function of the number of observations used to form the mean. The method is described in Section 3f1, and the data source is described in Table 5.

This was also done for one $2.5^\circ \times 2.5^\circ$ box in each of the three $5^\circ \times 5^\circ$ boxes, as given in Table 5. For each of the six boxes the test was also done for the single month Feb. 1979. The results were very similar for each of the three boxes in each of the four tests, so they were averaged for plotting in Figure 5, which shows the rms error versus the number of observations used to form the average. All four tests gave essentially the same results. They fit approximately to a line with slope=-0.5 on this log-log plot, which means that the error is proportional to $\sqrt{n}/n$, where n is the number of observations used. In particular, we find that the use of 200 observations causes an expected error of 0.03 in mean cloud cover. This conclusion is independent of the number of stations in a box, of the size of the box, and of whether a monthly mean or seasonal mean is being computed, as shown in Figure 5, as long as the total number of *possible* observations is much greater than 200. Similar tests done on observations from weather ships (Warren et al., 1987) show that the plot is also independent of whether the pool of reports contains observations made at only one time of day or alternatively throughout the day, and independent of whether the pool contains observations only from a single DJF season or alternatively from many years of DJF. What does affect the plot is the day-to-day or hour-to-hour variability of *instantaneous* cloud cover, expressed as the standard deviation of individual observations. This is above 40% for these land stations (as shown in Table 5), but it is less than 30% for ocean weather ships. Thus, for the same number of observations, the expected sampling error in seasonal mean cloud cover is generally larger for land areas than for ocean areas, due at least in part to surface features. [The reasons for the smaller standard deviation of individual observations over the ocean are (a) the ocean surface is horizontally homogeneous, and (b) the average cloud cover over the ocean is larger than 50%, so that whereas the frequency distribution of cloud-cover reports tends to be U-shaped over land (with peaks at N=0 and N=8), it tends to be J-shaped over the ocean (with a peak at N=8).] This variability of instantaneous cloud cover is much larger than the amplitude of the mean diurnal cycle (typically 7%) and the interannual variation of seasonal means (typically 5%).

On the basis of this analysis we require a minimum of 200 observations to form a multi-year seasonal average cloud cover or an average frequency-of-occurrence for a cloud type in a $5^\circ \times 5^\circ$ box. Boxes which are blank on the maps failed to satisfy this criterion (or other criteria described below). However, this criterion could be changed considerably without causing the number of blank boxes to change much. This is because the blank boxes are mostly areas that have no station. If a box has one station, then it is likely to have a large number of observations. For example, a station reporting four times per day will produce $4 \times 90 \times 11 = 3960$ observations for DJF over eleven years. This means that in most places the accuracy of the maps is not limited by a scarcity of observations but rather by the information content of the individual observations. In other words, in most places the random error due to inadequate sampling is very small, meaning that the bias errors (discussed below) are the major source of error. This situation is opposite that in the ocean areas, where random sampling errors are substantial in many locations away from the major shipping routes (Warren et al, 1987).

2) Order of steps in the averaging procedure

There are several ways in which the multi-year average cloud cover or frequency of occurrence of a cloud type can be obtained for a season:

(a) All observations averaged together, weighted equally;

(b) All observations from a single year averaged together irrespective of time of day, then the 11 means averaged together;

(c) All observations for a particular reporting hour averaged together, irrespective of year, then the eight means averaged together.

This list is, of course, not exhaustive. The averages formed in different ways may differ because of sampling biases. We consider three such biases: diurnal, geographical, and trend.

(1) Diurnal bias. A box may contain one station which reports eight times per day, and a second station which reports only in the daytime, not at night. Since cloud cover may undergo a diurnal cycle, methods (a) and (b) would cause a daytime bias in the average.

(2) Geographical bias. A box of heterogeneous topography may contain one station which was operating throughout the 11-year period, and a second station in a different topographic region of the box which was established midway through the 11-year period. The geographical sampling is done better by methods (a) and (c) than by method (b), but the two stations are not weighted equally by any of these three methods.

(3) Trend bias. If there is a trend in cloud cover, and if the number of stations in the box changed during the 11 years, then method (b) eliminates the bias.

We use method (c) for our analyses. We do not have good evidence for trends, nor do we have evidence that the geographical bias is of such a form as to strongly prefer one method. However, we do know that some cloud types (e.g. cumulus) undergo a systematic diurnal cycle, so our method is designed to reduce the diurnal bias. [We have actually computed averages using all three methods and find that in most places it makes little difference which method is used.]

Method (c) is used as follows. Eight sets of observations are obtained, one for each synoptic hour. Means are formed for the hours with at least 200 reports. If there are at least two such hours, these means are averaged. But if less than two of the eight synoptic hours had 200 reports, then method (a) is used, provided that there are at least 200 reports total when all the hours are pooled. [In the case where only one synoptic hour has at least 200 reports, a diurnal bias would be *introduced* by method (c), rather than eliminated.]

Average values are obtained in this way for total cloud cover, and for frequency and amount of the cloud types. The average awp, however, is just formed as the average of all observations in which the cloud type was present and its amount was computable. This is essentially the same as taking a weighted mean of the awp for the eight synoptic hours, each weighted by the frequency at that hour. The minimum number of observations needed to obtain an average value of awp is usually set lower than 200, as follows.

If f is small, it is not necessary that awp be known accurately in order to obtain an accurate estimate of amount. If there are exactly 200 reports in which the level of a particular type was observable, then the maximum possible number of reports in which awp could be computed is 200×f. But awp can sometimes not be computed (as discussed in Section 3d1), so we set the maximum lower, at 0.6×200×f. This factor 0.6 can be justified by the fact that the awp is observed to be less variable than total cloud cover, to the extent that the line in Figure 5 would be shifted to the left by the factor 0.6 if awp were plotted instead of total cloud cover.

If f is very small, there may be sufficient observations of awp to compute the average amount, yet insufficient observations to obtain reliable values of the awp itself. We require an absolute minimum of 30 observations in order to display an average awp on the maps. For maps of awp we therefore require that awp was computable in at least 30 or 0.6 × 200 × f reports, whichever is larger.

3) Special considerations

It was mentioned above that the instructions for coding of N_h were systematically misinterpreted in China before 1980. This meant that awp(As) was obtained only from a small subset of the observations in which As was present. This subset turned out to be unrepresentative, as we found that the average awp was 20% lower in 1980-1981 than in the 1970s. In the 5°×5° boxes which include Chinese stations we therefore use only the 1980-1981 data when computing awp(As), but data from all years when computing f(As). This same misinterpretation was sometimes also apparent in South America, as noted above. However, in these areas the subset of observations from which awp(As) could be computed appeared to be representative, so no correction was applied.

As noted by Warren et al. (1985), the frequencies of reported cirrus and As/Ac over the ocean undergo a diurnal cycle which we think is partly spurious, due to the frequent inability of observers to detect these clouds when they are present at night. This also may cause a spurious signal in the diurnal cycle computed for the frequency of clear sky, with maximum near midnight. This is a problem which has long been recognized. It was documented by comparing the average cloud cover reported at the time of full moon with that for the time of new moon (Figure 107 of Sverdrup, 1933; Riehl, 1947).

Therefore, for the maps of Ci, As and clear-sky, only observations made between 0600 and 1800 local time were used. This is indicated on the map headings as "6-18 LT". [Poleward of 75° latitude all observations were used.] Frequencies of Ci and of As reported in this atlas therefore differ from those given by Hahn et al. (1984) because that earlier atlas included night-time observations. However, the difference is not as large for land as for the ocean areas. The daytime f(Ci) averages 1.08 times the diurnal mean value over land, but 1.3 over the ocean. There is actually no difference on average between daytime f(As) and the diurnal mean over land. Our policy to use only daytime observations resulted from our detection of the bias in ocean data. The reason for the larger bias in the ocean is probably the more frequent occurrence of low clouds, which make detection of the higher clouds more difficult at night.

g. Diurnal Cycle

In many regions the frequencies and amounts of the cloud types undergo systematic variations over the course of the day. These variations can also cause a diurnal cycle in total cloud cover. The diurnal cycle is sampled at most eight times per day because synoptic reports are made only at GMT hours divisible by 3.

Here we examine only one aspect of the diurnal variations: the amplitude and phase of the first Fourier component (24-hour period) of the mean diurnal cycle. Multi-year seasonal mean values of cloud amount are formed for each of the eight synoptic hours as described above. A cosine curve is fitted to these eight values if all are available (i.e. if there were at least 200 observations at each synoptic hour so that an average could be formed at each hour); otherwise to the four values for 0, 6, 12, 18 GMT if those four were all available.

There are potential biases which can cause a geographical variation to appear as a spurious diurnal variation, and we attempt to avoid these biases. For example, there may be several stations in a 5°×5° box, some of which do not make reports at night.

We largely avoid spurious diurnal cycles due to this cause ("day-night geographic bias") by computing the cosine curve only if either (a) $n_{night} > 0.55 \times n_{day}$, where n is number of observations (the factor 0.55 was determined empirically), or (b) there are at least three stations in the box reporting at night (so that geographical variation is probably adequately sampled). Four percent of the boxes failed this test; they appear blank on the maps of diurnal cycle amplitude and phase.

Similarly, there may be several stations in a box, some reporting every six hours (0, 6, 12, 18 GMT) but others reporting eight times per day, i.e. also at the intermediate hours 3, 9, 15, 21 GMT. If there are at least three stations in the box reporting every three hours, or if $n_3 > 0.55 \times n_6$, then all eight averages are used to compute the cosine curve (where n_6 is the number of observations at 0, 6, 12, 18; n_3 the number at 3, 9, 15, 21 GMT). Otherwise the curve is computed only from the four six-hourly averages.

The amplitude and phase (local time of maximum) of the cosine curve are mapped. [Local time is the mean solar time at the center of the box. It may differ from civil time in use in the various countries.] Examples are shown in Figure 6. The phase we report is the maximum of the cosine curve, not necessarily the peak of the daily cycle. The amplitude we report is the amplitude of the cosine curve, which may be more (Figure 6a) or less (Figure 6b, 6d) than half the range of the eight values.

It is possible for the amplitude to be larger than the mean reported on the maps for two reasons. (a) The first harmonic may describe only part of the diurnal variation and its minimum may be negative if the average amount is small. This is very common for cumulus (Figure 6b). (b) The diurnal cycle may refer to a different mean. All times (as many as eight) with at least 200 observations contributed to the map of average amount, but often only four synoptic hours contributed to the harmonic analysis of the daily cycle (as explained above).

Figure 6a shows the large diurnal cycle of St on the coast of southern California, with the maximum in early morning as is typical also in the ocean to the west. Figure 6b shows the smaller cycle of Cu in eastern India with maximum near noon. Cumulonimbus (Figures 6c, 6d) has its maximum later in the afternoon.

No diurnal cycles are reported here for Ci, As, and clear sky, because of the nighttime bias mentioned above. [The values are, however, archived on tape.] The diurnal cycle of total cloud cover is reported but it may be contaminated to some extent by the spurious diurnal cycle of Ci. Day-only values of total cloud cover are available on tape but are not included in this atlas. They are larger than the average of all synoptic hours, by .3% on global average.

The diurnal variation is not always well represented by a single harmonic, as illustrated in Figure 6d. The average values for each of the eight synoptic hours are archived on tape, as well as the variance accounted for by the first harmonic, and these can be consulted if more detail is desired about the diurnal cycle.

The diurnal cycle is reported here for cloud-type amounts, but not for f and awp. Their diurnal cycles are available on tape. The amplitude of the diurnal cycle reported here for the cloud types may appear to be rather small; this is because it is the cycle of amount, not amount-when-present, and because it is the absolute amplitude, not a fraction of the mean.

h. Zonal and Global Averages

A zonal average (land areas only) is computed, and is listed off the right-hand side of each map, if the quantity to be averaged was available for at least one-third of the land boxes in that zone. The box values are averaged, weighted by the fraction of land area in each box.

In the desert interiors there are seven boxes with no stations: one in Australia and six in North Africa. On our maps there is also a missing box in Arabia, deleted because data from that station are erroneous, as explained below. Because of the rather homogeneous surface conditions in these regions, we decided to include them in zonal averages, interpolating from neighboring boxes in the same zone to obtain values for the blank boxes. The resulting zonal averages are probably more correct than they would be if those boxes were just omitted.

There are also many missing boxes in Antarctica; the zones 70-75 °S and 75-80 °S have only one station each in the interior of East Antarctica. For computing zonal averages these stations are allowed to represent the entire East-Antarctic sector of their zones. The South Pole Station is used to represent the entire ten-degree zone 80-90 °S (2.5% of the earth's land area) because there are no other stations poleward of 80 °S.

The zonal averages are further averaged (weighted by the land area in each zone) to obtain the global average printed at the bottom of each map. A global average (for land only) is formed if the zones used for the average contain at least half the earth's total land area. [On most maps more than 90% of the land area is represented in the global average.]

The zonal and global averages of awp are averages of awp for boxes, not weighted by f for each box, so the zonal and global averages of amount may not exactly equal the product of zonal and global averages of f and awp.

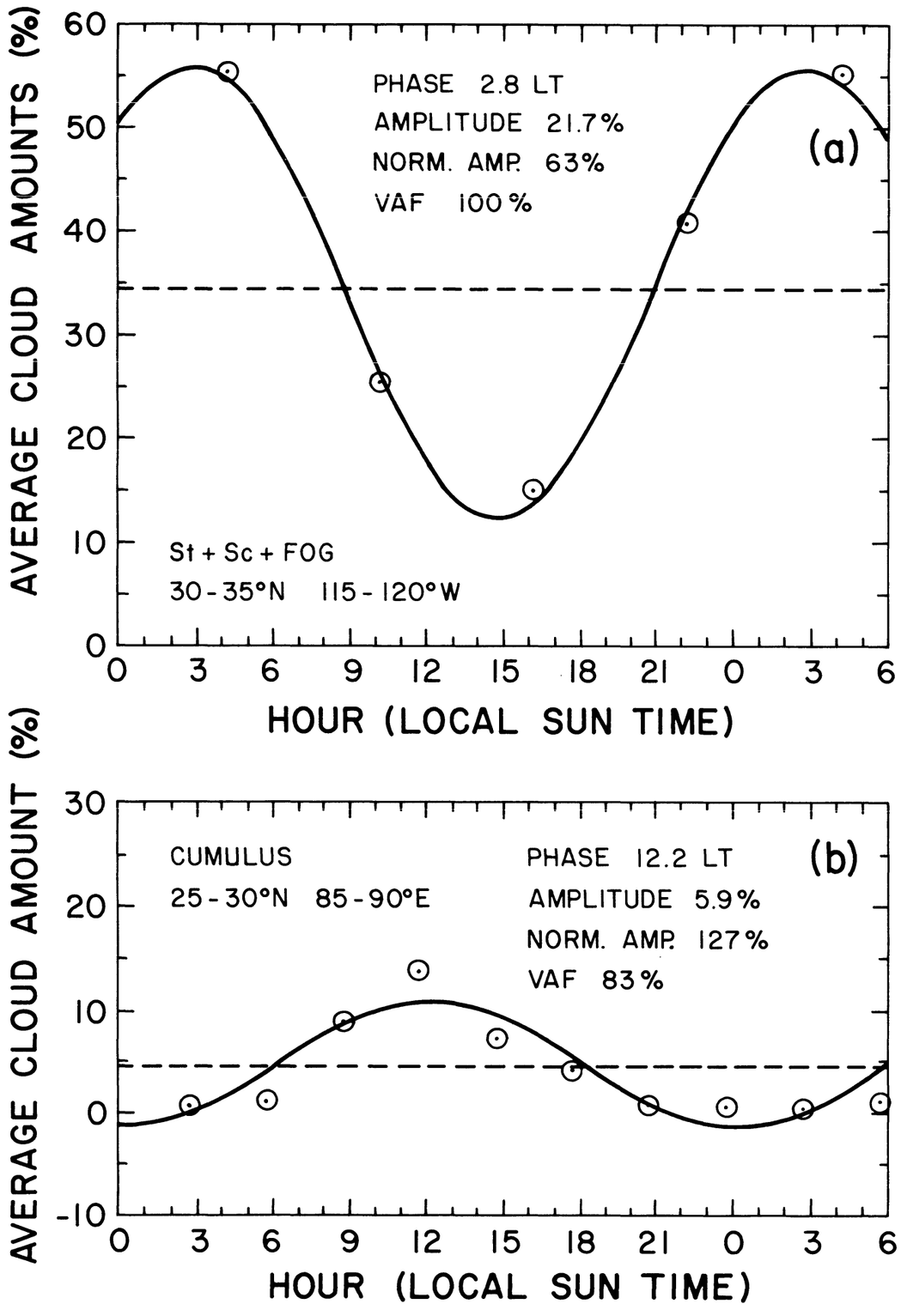


Figure 6. Examples of diurnal cycles. All are for JJA 1971-1981. A cosine curve (solid line) is fitted to the four or eight data points shown. Phase is the local time of maximum of the cosine curve (mean solar time for the center of the 5° × 5° box.) The diurnal mean is shown as the dashed line. Amplitude is given in percent cloud cover. Normalized amplitude is the amplitude as a percentage of the mean. "vaf" is the percent of the total variance which is accounted for by the cosine curve.

i. Interannual Variations

Values of cloud-type amounts were formed for individual seasons of individual years. The standard deviation of these 11 seasonal means (1971-1981) is reported on maps in this atlas. [Only 10 seasonal means were used for DJF because our data set begins in January 1971.]

This procedure leads to computed interannual variations which in some boxes are larger than the true interannual variations, because a geographical variation can cause a change in the seasonal mean as stations within the box are established or retired during the 11-year period. This bias is small in boxes which contain many stations, so its presence can in some cases be ruled out by referring to Map 1 showing the number of stations in each box.

The interannual variations (IAV) as computed here can also be larger than the true IAV in boxes with small numbers of observations, due to error in the seasonal means caused by inadequate sampling (Figure 5). This effect will be insignificant for boxes with several thousand observations per season.

Long-term trends in cloud amount were not computed because of the short period (11 years) of analyzed data. The values reported for interannual variation have not been "de-trended".

4. BIASES

Biases that have been substantially eliminated by the method of analysis were discussed above. This section discusses biases which are inherent in the synoptic code used by weather observers.

a. N-endpoint bias

A bias can be introduced by the fact that the code values 1 and 7 for N and N_h may not correspond exactly to cloud cover 1/8 and 7/8 on average. The code 1 is also used if any cloud, however small, is present, even if its amount is less than 0.5/8. Similarly, code 7 is used if any break, however small, is present in the overcast, even if the area of the breaks is less than 0.5/8. [These rules are not always followed, however. Some observers just round off any cloud amount to the nearest eighth, so that a very small amount would round to zero.] Our procedure assumes that code 1 is on average 1/8 of sky cover, and that code 7 is on average 7/8 of sky cover. The bias, if any, in average cloud cover caused by this procedure would vary with location because its sign depends on whether code 1 or code 7 occurs more frequently. It is probably a very small bias.

b. C_L-flowchart bias

There is a bias which is introduced by the method used to classify the cloud types (p. 41 of WMO, 1956), which is in the form of a flow-chart. If any Cb is present in the sky, the low cloud type must be coded as Cb even if other low clouds cover more of the sky. The low cloud amount N_h is the amount of all the low clouds, not just the Cb, but our procedure assigns all of this amount to Cb. This is the reason for the large average amount-when-present (55%) for Cb on global average. This causes our reported average amounts of Cb to be somewhat larger than the true sky cover of Cb (which in turn is larger than the "earth cover" of Cb, as shown in the next paragraph). We have not yet estimated the size of this bias.

c. Earth-cover vs. sky-cover

The fractional cloud amounts we report are fractional "sky cover", which is the fraction of the celestial hemisphere (2π steradians) covered by clouds. This is in general larger than the "earth cover", which is the fraction of earth covered by clouds when the clouds are projected vertically. There is of course no difference between the two quantities if the cloud cover is 0% or 100%. The difference depends on the ratio of vertical to horizontal dimension of the cloud, so is most significant for Cu and Cb. Ground observers are instructed to report sky cover (p. 35 of WMO, 1956), although some observers perform a mental compensation so as to report earth cover rather than sky cover.

A relation between earth-cover E and sky-cover S has been obtained empirically by Malick et al. (1979) as $E = 1 - (1 + 3S)\, S/4$, from three years of all-sky photographs taken at Columbia, Missouri by Lund and Shanklin (1973). This relation gives maximum difference at S=0.7, E=0.5. The difference derived from the all-sky camera is due to the fact that in a partly-cloudy situation the region near the horizon has on average larger fractional cloud cover than does the overhead region. The empirical relation would be different from this in locations which have different ratios of cloud thickness to cloud width. It applies only to individual observations, not to the time-average cloud amounts we report.

The difference between E and S for time-averaged amounts is not known; it is an important subject for future research. It will vary with location and will be much smaller than the maximum difference of 0.2 for individual observations because cloud reports of 0/8 and 8/8 sky cover are more common than reports of 4/8. This bias is

probably partly responsible for some of the difference between cloud cover estimates from satellite observations and those from surface observations; however, it must be kept in mind that satellites also do not observe earth cover unless they look straight down.

5. STATIONS MAKING ERRONEOUS REPORTS

Eighteen boxes are left blank on the maps not because they had insufficient observations, but because they contained one or more stations from which a large fraction of the reports were erroneous. These stations are listed in Table 6. Most of them are island stations in oceanic boxes, so they represent very little of the earth's land area. There are additionally some automatic weather stations whose reports were improperly transmitted as mentioned above; they were eliminated by rejecting all observations with ww=/, so their boxes did not have to be set blank if those boxes also contained manned stations.

In some of the boxes there may be more than one station making bad reports, even if only one is listed in Table 6. There may also be other boxes, not listed in Table 6, in which erroneous reports are frequently made but which we have not noticed because their effects were minor. Only one of the boxes in Table 6 (15-20 ° N, 45-50 ° E) had been blanked in our co-occurrence atlas (Hahn et al., 1984); the values given in that atlas for the other boxes listed in Table 6 should be ignored because they should also have been blanked.

Until very recently (1986), the South Pole Station has had a policy of never reporting low clouds (p. 24 of Schwerdtfeger, 1984). Thus, low clouds of liquid water, which do occur quite often in summer less than 1 km above the surface, were coded as Ac or As rather than Sc or St. This policy was only occasionally disregarded during the 11 years covered by our atlas; the St/Sc amounts for that station, and for the 80-90 ° S zone which it represents, are therefore too low.

There are also some stations whose reports differ greatly from those of their neighbors but are not obviously wrong. These contrasts may be due to differences in observing procedure or to true local variations in the cloud climatology, so that a station may not be representative of its box. For example, the two boxes in the Sahara Desert at 15-20 ° N, 5-15 ° E, represented by one station each, almost never report clear sky. These stations, Agadez and Bilma, both report regularly. Nearly all the reports are of a partial cover of cirrus, usually alone, causing f(Ci)=0.99. These reports, and the occasional reports that differ from these, are all self-consistent. We will assume they are correct. Perhaps the persistent cirrus is caused by orographic lifting over the nearby Aïr mountains.

Table 6. 5 ° × 5 ° boxes deleted from maps because of erroneous reports. Station descriptions are given by WMO (1979).

Typical Error	5 ° × 5 ° box	station number
$N < N_h$	0-5S, 150-155W	91902
	0-5S,155-160W	91901
	10-15S, 135-140W	91953
	10-15S, 150-155W	91903
	20-25S, 135-140W	91952
	20-25S, 145-150W	91954
	20-25S, 150-155W	91951
	25-30S, 130-135W	91960
	25-30S, 140-145W	91958
	20-25N, 90-95W	76580,76689,76690
Automatic station; N=3 always	15-20S, 155-160E	91574
	15-20S, 160-165E	91570
$N=N_h=3$, $C_L=9$ nearly always	20-25N, 50-55E	40456
80% Cb, 20% snow	15-20N, 45-50E	40571
C_H=0 or / usually.	55-60N, 140-150W	70360
(deleted for Ci and As/Ac only)	0-5N, 65-70W	82067
	45-50S, 75-80W	85889
	55-60S, 60-70W	85972

6. FORMAT OF THE MAPS

The resolution of the maps is 5° latitude by 5° longitude, between 50°N and 50°S. At higher latitudes the size of the boxes is increased in longitude to maintain approximately equal area in each box. The resolution is 5°×10° for 50°-70° latitude, 5°×20° for 70°-80° latitude, 5°×40° for 80°-85°, and 5°×360° for 85°-90°. For convenience, the term "5°×5° box" refers to any of these. Although many of the boxes contain some ocean area, the values plotted apply only to the land portion of the box. The land area of each box was determined from the topographic data tape of the US Navy (which is gridded to 10 minutes of latitude and longitude) but corrected so that Antarctic ice shelves are counted as land rather than ocean. All lakes are also counted as land. Any box which contains at least 0.1% land is included on the maps. The fraction of each box, and of each zone, which is land is given at the beginning as Map 0.

For most of the mapped quantities there are four maps: one for each of the four seasons. Blanks occur on the maps where there were insufficient observations to obtain reliable average values by the criteria described above. Zonal averages are printed along the right side if values are available in at least one-third of the possible land boxes in the zone. The global average is printed at the bottom, formed from the zonal values weighted by the land area in each zone, if at least half the earth's total land area is represented in the zonal averages. The maps are presented in the following order.

a. Distribution of Reports

1) Average number of WMO Weather Stations contributing to the data set (Map 1)

This is an approximate average over the 11 years. It is not strictly the number of stations, but rather the number of stations from which reports were received. Some reports are transmitted late and are not received by FNOC in time to be included in the processing for that hour. Some hours are also missing for the entire earth because of tape-writing errors at FNOC. Map 1 shows that there are often island stations in oceanic boxes with very little land area. Although the cloud climatology for these islands does not represent a large area of the earth's land surface, it is included for comparison with the ocean atlas (Warren et al., 1987) so that the island climate can be compared with that of the surrounding ocean.

2) Number of cloud reports (Maps 2-5)

This is the number of reports (in thousands) which had some information about clouds, present or absent. All these reports included total cloud cover and present weather and passed the consistency tests for total cloud cover in Figure 1. Nearly all (about 97.3 %) reported C_L and N_h and passed the consistency tests for types in Figure 1. Smaller percentages included C_M and C_H because the upper levels are sometimes obscured by a lower overcast. The fraction of daytime reports which contribute to the statistics of middle and high levels for individual boxes are essentially the same as those given by Maps 8 and 9 of Hahn et al. (1984). On average 80% of the daytime reports contribute to statistics of As and 63% contribute to statistics of Ci. For a box with one station, the maximum possible number of reports is (11 seasons)×(91 days per season)×(8 synoptic hours per day) or about 8 thousand. Numbers are smaller than this where stations report only four times per day (US and Canada) or where a station was in existence for only part of the 11-year period. The largest numbers of reports are in Europe, where there may be as many as 100 stations per box. In most locations the number of reports is sufficient to reduce the random sampling error to a negligible level (Figure 5).

3) Diurnal sampling: Number of synoptic hours (of 8 possible) with at least 200 reports (Maps 6-9).

We require at least 200 reports in one synoptic hour to form a mean for that hour. The maps show that all eight synoptic hours usually pass this criterion in Europe and Asia, but only four in North America, where observations are normally made only at 0, 6, 12, 18 GMT. These maps are included to show for each box how well the diurnal cycle was represented in computation of average cloud cover and cloud type amounts. Boxes in which all these synoptic hours were in the "daytime" (defined as 0600-1800 local time, inclusive) are marked with an asterisk. A daytime bias may exist in the averages for these boxes, if their cloud cover undergoes a diurnal cycle.

b. Total Cloud Cover

1) Average (Maps 10-13)

Values are shown as percent sky cover. The method for computing the average was discussed in Section 3f. Blanks on this map appear where there was no station, or where a station gave erroneous reports (Table 7).

2) Standard deviation of individual observations (Maps 14-17)

There are many possible measures of the variability of cloud cover. We have chosen to display three of them: standard deviation of all observations, diurnal cycle, and interannual variation. For maps 14-17, all observations in the season were pooled irrespective of year or time of day or location within the box. This variation thus includes interannual, geographical (within the box), and diurnal variation of the *mean*

cloud cover, as well as hour-to-hour or day-to-day variation of *instantaneous* cloud cover. However, this last variation is much larger than the first three (Section 3f1), so that if the standard deviation is computed only for observations made at one station at a single hour on many days in a single season of a single year, it usually differs by less than one percent from the values shown on Maps 14-17. [The standard deviations plotted on these maps refer to a mean which is the mean of all observations.] These values should not be confused with the uncertainty in *mean* cloud cover, which is usually less than 1% due to sampling error alone as shown in Figure 5.

The mapped values are in percent cloud cover, not percent of the mean; e.g. an average of 60% and a standard deviation of 30% means 0.60± 0.30. The frequency distribution of cloud cover reports tends to be U-shaped, with peaks at N=0 and N=8. Thus the standard deviation of the observations is often larger than that of a set of random integers from 0 to 8, which would be 32%. Because the reports of N do not follow a Gaussian distribution, the two parameters of the beta-distribution (a bounded distribution) have been proposed (Falls, 1974) to describe the frequency distribution of values of N. Falls showed that these two parameters can be best estimated from knowledge of the mean and the variance, so beta-distributions can be computed for each box, if desired, from the information on Maps 10-13 together with Maps 14-17.

3) Diurnal cycle (Maps 18-25)

For boxes which had at least 200 observations in four or eight equally-spaced synoptic hours, a cosine curve of period 24 hours was fitted to the cloud cover values as described above in Section 3g. The amplitude and phase of this first harmonic function are displayed on facing pages. The phase is the hour (local time) of the maximum; it is displayed only if the variance accounted for by the first harmonic is at least 30%, and if the amplitude is either larger than 2% cloud cover, or larger than 10% of the mean.

4) Interannual variation (Maps 26-29)

The standard deviation of up to 11 seasonal means of total cloud cover is mapped here if there were at least five years in which the seasonal mean could be computed. [A minimum of 50 observations for each synoptic hour were required to compute a mean for each year.] This is given in units of percent cloud cover, not percent of the mean. These values may be larger than the true interannual variability of cloud cover for some boxes because of stations being established or retired during the 11-year period, as described above in Section 3i.

5) Total cloud cover by month (Maps 30-43)

Maps 30-41 give the average cloud cover for each month. Only the average values are given for the 12 months; not the standard deviation (sd) of individual observations nor the number of observations. A minimum of 100 observations was required to form an average. The sd is very similar to that for the corresponding season, and the number of observations is about one-third the value given on Maps 2-5.

The 12 monthly values of average total cloud cover are fitted to a cosine curve with period one year: its amplitude and phase are displayed in Maps 42 and 43. The phase is the month of maximum, given by number (1=January, etc.) It is plotted only if the amplitude is larger than 2% sky cover.

c. Cloud Types (Maps 44-199)

Most of the remaining maps of the atlas are grouped by cloud type: cumulus (Maps 44-71), cumulonimbus (72-99), stratus + stratocumulus + fog (100-127), nimbostratus (128-151), altostratus + altocumulus (152-167), cirrus + cirrostratus + cirrocumulus (168-183), and completely clear sky (184-191). The same quantities are mapped for each of the six types, with some omissions explained below. Maps of the frequency of sky-obscured-due-to-fog are not included; they have already been published as Maps 11 of Hahn et al. (1984).

1) Frequency of occurrence

The frequency of occurrence (f) is the number of times that a particular cloud type was reported present, divided by the number of reports in which the level of that type was observable, subject to the modifications discussed in Section 3d2 above. The maps of f in this atlas should be more accurate than those in Hahn et al. (1984) but are usually very similar. They are different for the following reasons:

a) Only daylight observations are used here for the maps of Ci, As, and clear-sky (Section 3f3).

b) The partial-undercast bias (Hahn et al., 1984) has been reduced by restricting the analysis of upper clouds to reports in which the amount of obscuring lower clouds was at most 6/8 (Section 3d2).

c) The definition of Ns was slightly modified (Section 3c).

d) Reports of fog together with clear sky are now counted as clear sky (Section 3c).

e) Eleven years, instead of ten, are used for the present atlas.

2) Amount-when-present

Amount-when-present (awp) is the average sky cover of a cloud type, when that cloud type is present at an observing station. It is the total amount, not the non-

overlapped amount as seen from below. The method of computing awp was described in Section 3d1. The average awp printed on the maps may not exactly equal the ratio of the printed values of amount and frequency, because different numbers of synoptic hours may have satisfied the criteria for use in computing the averages of the three quantities (Section 3f2).

3) Average cloud amount

Average cloud amount is the overall average percent of the sky covered by a cloud type, including times when it was not present. For each of the eight synoptic hours in which sufficient observations were available, the amount is computed as the product of average frequency and average amount-when-present. The average cloud amount given on the maps is then the mean of these synoptic-hour averages. There are more blank boxes on these maps than on the maps of total cloud cover because we do not use night-time observations for As and Ci, and because in some cases there were not enough observations in which awp of middle or high clouds was computable even if there were sufficient observations to obtain f, and because there are slightly more observations of N than of N_h.

If the total amount of clouds in each of three layers is desired, a very good estimate can be made by adding the amounts given in this atlas for Cu, St and Cb to obtain the low cloud amount (including fog), and by adding the Ns and As amounts to obtain the middle cloud amount.

4) Average base height

The average base height of the cloud type (when present) is given in tens of meters. It is only computed for the three types whose bases are always less than 2500 m above the surface: Cu, Cb, St. Fog is included in the maps of St amount but is excluded from maps of St base height, so that these heights apply only to above-ground St/Sc. Base heights are displayed on the maps if at least 100 observations of base height were reported for that cloud type.

The standard deviation of the individual observations of base height is not given here; it is included in the archive on tape. It is typically 300 meters; it would probably be smaller if the spacing of the code values for h were not so coarse.

5) Diurnal cycle; interannual variation

These quantities have already been discussed for the total cloud cover above; their meanings are the same when applied to cloud types. These variations are shown only for cloud amount, but the diurnal and interannual variations of f and awp are available on tape. The diurnal cycle is not mapped for As, Ci, and clear-sky because of the night-detection bias, but the computed values are available on tape.

Because the amounts of the cloud types are small, their interannual variations and diurnal amplitudes are often 1% or less, even if they are a significant fraction of the mean. For this reason, both the interannual variation and the diurnal amplitude are given to tenths of a percent. Note that although the decimal point is omitted from the individual $5^\circ \times 5^\circ$ grid values on the map in order to conserve space, it is included in the value of the global average.

6) Most-frequently occurring cloud type

For each box (for each season) the type with largest f is indicated on Maps 192-195.

7) Cloud type contributing most to total cloud cover

The type with largest amount is indicated on Maps 196-199. In general, this is probably also the type which contributed the most to total cloud cover, but it is only approximately true because there is some tendency for different types to occur together (Hahn et al., 1984).

7. DISCUSSION OF RESULTS

Global average values of f, awp, amount, and base height of the cloud types are summarized in Table 7a, along with their geographical variability (standard deviation of individual box values). The amounts of the six types add to more than the total cloud cover because of overlap. Interannual variation of the global average cloud type amounts is given in Table 7b for each season, as well as for the annual mean.

a. Total cloud cover

The global annual average total cloud cover for the land areas is 52.4%. In DJF the smallest values are 11% in western India and the largest values (above 80%) are in the Amazon and Congo basins, because of the presence of the ITCZ during this season, as well as the subantarctic islands. In JJA the least cloud cover is over the eastern Sahara (2-3%) whereas values over 80% are found in western India, which undergoes the largest seasonal cycle of any place on earth, due to the Indian monsoon. Strong gradients are seen in JJA in the transition from Sahel to Sahara, and at the coast of Namibia. This is the dry season in Southwestern Africa but also the time of greatest Sc cover in the nearby South Atlantic Ocean.

The standard deviation (sd) of individual observations (Maps 14-17) is smallest where the average cloud cover is close to 0% or 100%, as it must be. The largest possible sd is 50%, which would occur if the average cloud cover were 50% and all observations were either N=0 or N=8. Some values on the maps approach this maximum

Table 7a. Annual average global cloud type quantities for land areas*

cloud type	frequency (%)		amount–when–present (%)		amount (%)		base height (m)	
	average	geog. sd	average	geog. sd	average	geog. sd	average	geog. sd
Cu	14	12	33	8	4.6	5	1050	280
Cb	7	9	55	15	4.0	5	890	280
St	27	18	59	16	17.5	13	850	270
Ns	6	6	96	3	5.3	5	-	-
As	35	15	56	13	20.9	12	-	-
Ci	47	19	48	11	23.4	12	-	-
clear sky	18	16	-	-	-	-	-	-
sky obscured due to fog	1	1	-	-	-	-	-	-
total cloud cover	-	-	-	-	52.4	17	-	-

*Values were formed for each season; listed here are the averages of all four seasons. Geographical standard deviation is standard deviation of individual 5 ° ×5 ° box values.

Table 7b. Global average seasonal cloud type amounts and their interannual variations*, for land areas. Units are percent cloud amount.

cloud type	DJF		MAM		JJA		SON		average of four seasons	
	amount	IAV	amount	IAV	amount	IAV	amount	IAV	amount	IAV
Cu	3.9	0.2	4.8	0.3	5.4	0.1	4.3	0.2	4.6	0.2
Cb	2.6	0.2	4.1	0.2	5.2	0.2	4.0	0.2	4.0	0.1
St	17.7	0.5	16.2	0.5	17.4	0.5	18.6	0.3	17.5	0.3
Ns	6.8	0.2	4.9	0.2	3.9	0.2	5.7	0.2	5.3	0.1
As	21.3	0.5	20.4	0.7	21.1	0.5	20.8	0.4	20.9	0.5
Ci	24.7	0.3	25.8	0.6	20.2	0.3	22.8	0.7	23.4	0.3
total cloud cover+	52.8	0.3	52.9	0.5	51.4	0.3	52.4	0.7	52.4	0.3

*Interannual variation (IAV) is the standard deviation of seasonal means of global average cloud cover. If a zone was missing in a particular year the multi-year mean value for that zone was used when forming the global average for that year.

+The sum of the six cloud-type amounts is greater than the total cloud cover because of overlap.

possible value, indicating an approximate U-shaped distribution of cloud cover fraction.

The diurnal cycle (Maps 18-25) shows maximum cloud cover near noon for most areas. The different cloud types differ in their phases, so the diurnal amplitude for individual types is often larger than that for total cloud cover. These diurnal amplitudes are larger over land than over the ocean (Warren et al., 1987), undoubtedly because diurnal temperature changes are larger on the land surface.

The annual cycle of total cloud cover (Maps 42-43) has large amplitude, often above 30%, in the monsoon regions, as expected: in Brazil, Sahel, southern Africa, south and southeast Asia, northern Australia, and Central America. The amplitude is small in Arizona and northwestern Mexico because in this region a semi-annual cycle is dominant. The seasonal movement of the intertropical convergence zone (ITCZ) is apparent in this map.

b. Cumulus

Cumulus amounts are large in the monsoon areas during the wet seasons, in the midlatitude continents in summer, and at the tropical islands in all seasons. However, there are also very large amounts in Japan during DJF, where low-level convection is a result of cold air from Siberia flowing out over warm water in the Sea of Japan. The diurnal maximum is in early afternoon everywhere, as expected.

c. Cumulonimbus

Cumulonimbus patterns are similar to those of cumulus. The average frequency of Cb is less than that of Cu, but its awp is nearly twice as large so that the global average amount of Cb is nearly the same as that of Cu. Cb amounts are large in the monsoon areas, as expected. Somewhat surprising are the large amounts in eastern Tibet at all seasons, not just summer, and the extremely large amounts in Hokkaido, the Kuril Islands, and Kamchatka during DJF. This activity is due to the advection of cold air from the Asiatic continent over relatively warm adjacent water as was suggested to explain the similar pattern for cumulus. The average amount here exceeds 30% over a large area but its diurnal amplitude is less than 1%, indicating that the relatively large amount of Cb is not the result of a diurnal heating effect. A similar condition may be responsible for the larger amounts of Cb on the northwest coast of Iceland than elsewhere on the island in DJF; here the source of cold air would be Greenland. These Cb, as well as those along the coast of Norway in DJF, are usually associated with snow showers (ww 83-88). An isolated box in Brazil with large amounts of Cb in all seasons except JJA appears anomalous, but this box contains two stations which agree in their

reports, so it is likely to be correct.

There may be some differences in how observers are instructed in different countries to distinguish Cu from Cb. Average Cb amounts in JJA are much larger in Siberia than in Canada, although their climates are rather similar in other respects. The Cu amounts are larger in Canada, so that the sum Cu+Cb is not much larger in Siberia than in Canada.

The diurnal amplitudes are largest in continental regions where the Cb amount is large: the Sahel and Sudan region, Tibet, and the central Rocky Mountains. The diurnal maximum occurs about three hours later than that of cumulus.

As discussed above in Section 4, the analysis procedure must be understood in order to interpret these Cb amounts for particular purposes. By comparing mean vertical motion in the tropics to vertical motion in Cb clouds, Riehl (1979, p. 180) estimated that ascending towers of Cb can occupy only 0.1% of the equatorial region 10 ° N-10 ° S. Our Cb amounts are much larger than this, for three reasons: (1) our values are sky cover not earth cover; (2) Cb is coded as the cloud type even if other low clouds cover more area, but our analysis assigns all of N_h to the single type given by C_L; and (3) most importantly, the ascending towers occupy only a fraction of the total earth cover of Cb.

d. Stratus

Stratus + stratocumulus + fog (St) has the greatest average coverage of any low cloud type. The "fog" which is included here is only the cases of "sky obscured" due to fog, which is responsible for only about one-third of the total number of reports of fog. Fog at a distance, and thin fog through which the sky can be seen, are not included here. Sky-obscured-due-to-fog occurs about 1% of the time on global average. Its distribution is given in Maps 11 of Hahn et al. (1984).

The maximum amounts of stratus occur in Europe and southern China during DJF, the Arctic Coast in JJA, and the Aleutian Islands and subantarctic islands in all seasons. Stratus is also very common in all seasons along the Atlantic coast of Africa, with the amount decreasing rapidly inland. The same is true of the west coast of the United States and of southern South America, especially in JJA.

The diurnal cycle of St usually shows a morning maximum, which is also true for fog alone.

e. Base heights

The base heights of the low clouds are on average about 50% higher over land than over ocean. The heights of the convective clouds increase with distance from the ocean. This is especially noticeable in the desert regions: north Africa, western Australia, and southwestern United States.

f. Nimbostratus

Nimbostratus is found in middle and high latitudes, especially in coastal regions. Large amounts are found in northern Europe, eastern North America, eastern Asia, and the subantarctic. The frequency of occurrence is about the same as the amount, because awp$\approx$ 100% for Ns. The diurnal cycle usually shows a maximum in early morning. When Ns is present, St is also present below it about 60% of the time (Table 2 of Warren et al., 1985).

g. Altostratus

Altostratus daytime amounts are largest in the region of the ITCZ, the maximum moving north and south with the seasons in Africa and South America. In JJA both f and awp decrease rapidly with latitude from Indonesia to Australia, as expected during the Australian winter monsoon.

h. Cirrus

Cirrus daytime amounts are large in the tropics at all seasons and in North America and Asia during DJF. Cirrus is assumed to overlap randomly with Cb, but Cb tops may be as high as cirrus so the sum of the high clouds may be slightly greater than the Ci amount if non-overlapped Cb is also to be counted. Cirrus is more common over inland areas than over the ocean or the coastal regions, and in North America and Asia the cirrus amounts are larger in winter than in summer. This pattern can be summarized by saying that cirrus amounts on our maps are generally larger wherever low clouds are less common. We are not certain whether this is real, or is instead the result of a bias in the observations which we have not yet perceived. Satellite observations of high clouds may help answer this question.

i. Clear sky

Clear-sky frequency of occurrence (daytime) is generally large in the desert areas as expected, and close to zero at all islands, in agreement with the low frequency found in reports from ships in the open ocean. [The two boxes in the Sahara which almost never

report clear sky were discussed in Section 5; the observers almost always see some cirrus.] Maximum values of f(clear) in DJF are in western India, and in JJA from the eastern Sahara to Pakistan, in the Kalahari Desert, and in parts of Australia.

j. Interannual variations

The interannual variations of the cloud types are in many cases not only random fluctuations about a mean; they also often include a considerable trend (not mapped in this atlas). Unfortunately we have only 11 years of data, so it is difficult to judge the significance of these trends. Over most of South America the reported total cloud cover decreased from 1971 to 1981 in all seasons, by amounts that are on average greater than 10%. In Eastern Europe the few boxes that do exhibit clear trends show increases of total cloud cover by 5-10% in all seasons. There are also large trends in total cloud cover in particular seasons at other locations, but no significant trend in global average cloud cover.

All six cloud types contribute to the negative trend in total cloud cover in South America. These trends cannot be due to geographical bias because they are coherent over large regions with 10-20 boxes. These regions include many different countries, so a change in observing procedure also seems unlikely to be responsible. It would therefore be desirable to analyze the cloud observations over a longer period than covered here to provide quantitative estimates of decade-scale variations of average cloud amounts.

k. Zonal averages

The eleven-year zonal averages of cloud type amounts and total cloud cover for the land area are given in Figures 7 and 8. The main features are similar to those shown in the graphs of zonal average frequency-of-occurrence given in Figure 5 of Hahn et al (1984). The reader is referred to the extensive discussion of that figure, on pages 9-12 of that atlas, which applies also to Figure 7 here. The seasonal movement of the ITCZ, with the associated Hadley cells, causes the maximum cloud cover near the equator and minimum in the subtropics of both hemispheres apparent in both figures. Additional maxima in most cloud types are found near 60 ° N and 60 ° S. The large stratus amount near 60 ° S is characteristic of the oceanic climate since the small amount of land area is influenced by the nearby ocean; it does not vary seasonally as does the stratus amount at 60 ° N.

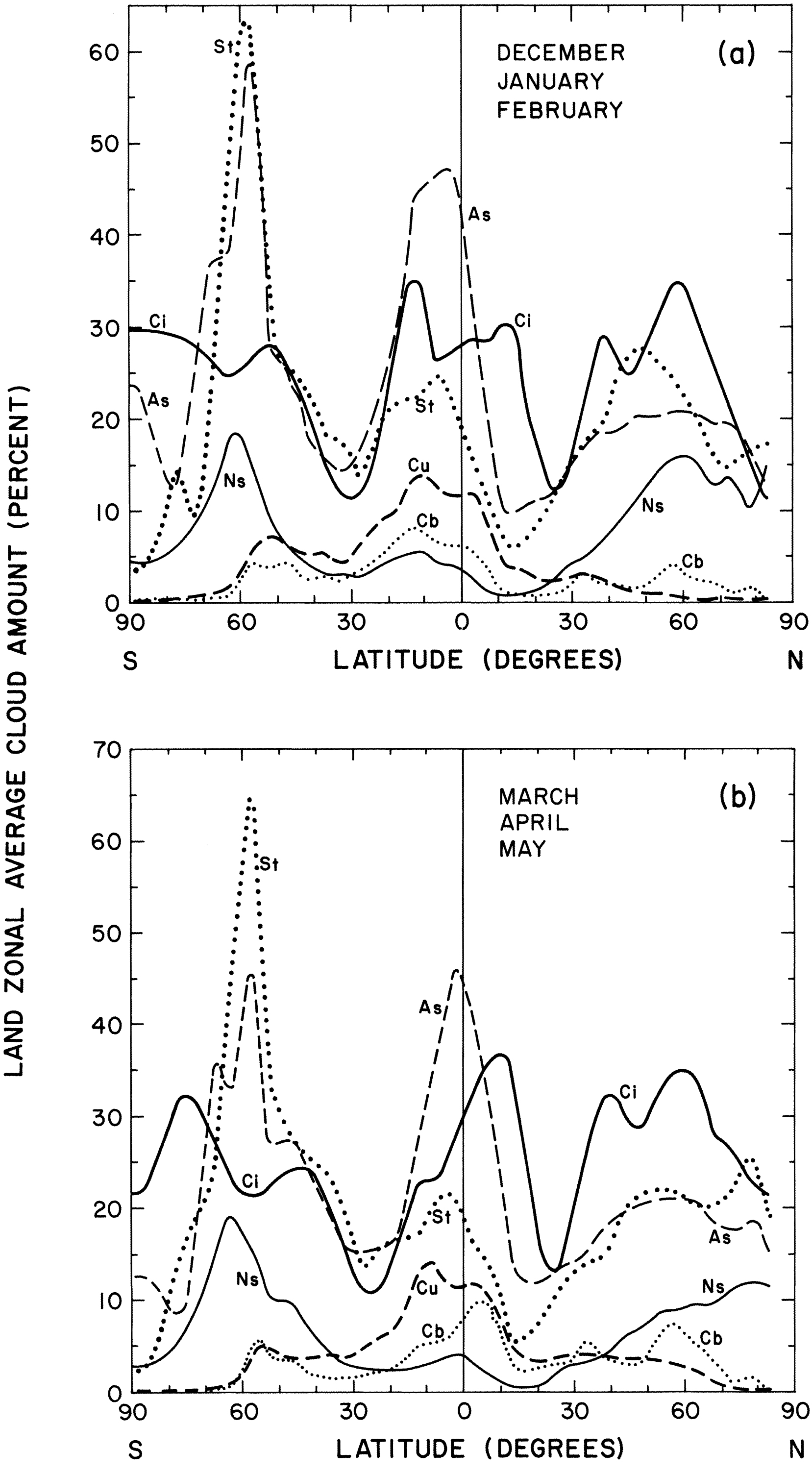
Combined land-ocean zonal average cloud amounts will be available after the ocean atlas (Warren et al, 1987) is completed; those results can then be compared with zonal averages of other published cloud climatologies.

8. RESULTS ON DATA TAPE

The numbers plotted on the maps, as well as more detailed information listed in Table 8, are available on magnetic tape from the Data Support Section at NCAR and from the Carbon Dioxide Information Center (Department of Energy, Oak Ridge, Tennessee). The long-term average monthly and seasonal total cloud cover is given, along with the standard deviation and number of observations. The average for each of the eight individual synoptic hours and for each of the eleven years is given; these values were the basis for our analysis of the diurnal cycle and interannual variation. The same is done for seasonal values for each of the cloud types. To obtain the total amount of low clouds (including fog), the amounts of Cu, St, and Cb should be added; the total amount of middle-level clouds can be estimated as the sum of Ns and As amounts.

At locations where Table 4 gives values different from those on the maps, the values on the tape are the same as those on the maps.

As discussed in Section 3c, the definition of nimbostratus was changed slightly from that used in the analysis of co-occurrence of different cloud types (Hahn et al, 1982, 1984). That analysis has not been redone with the revised definition, so the values on tape for cloud co-occurrence are the same as those given on the maps in those earlier atlases.


DECEMBER
JANUARY
FEBRUARY
(a)
St
As
Ci
Ns
Cu
Cb
60
50
40
30
20
10
0
90
60
30
0
30
60
90
S
LATITUDE (DEGREES)
N
LAND ZONAL AVERAGE CLOUD AMOUNT (PERCENT)
MARCH
APRIL
MAY
(b)
70

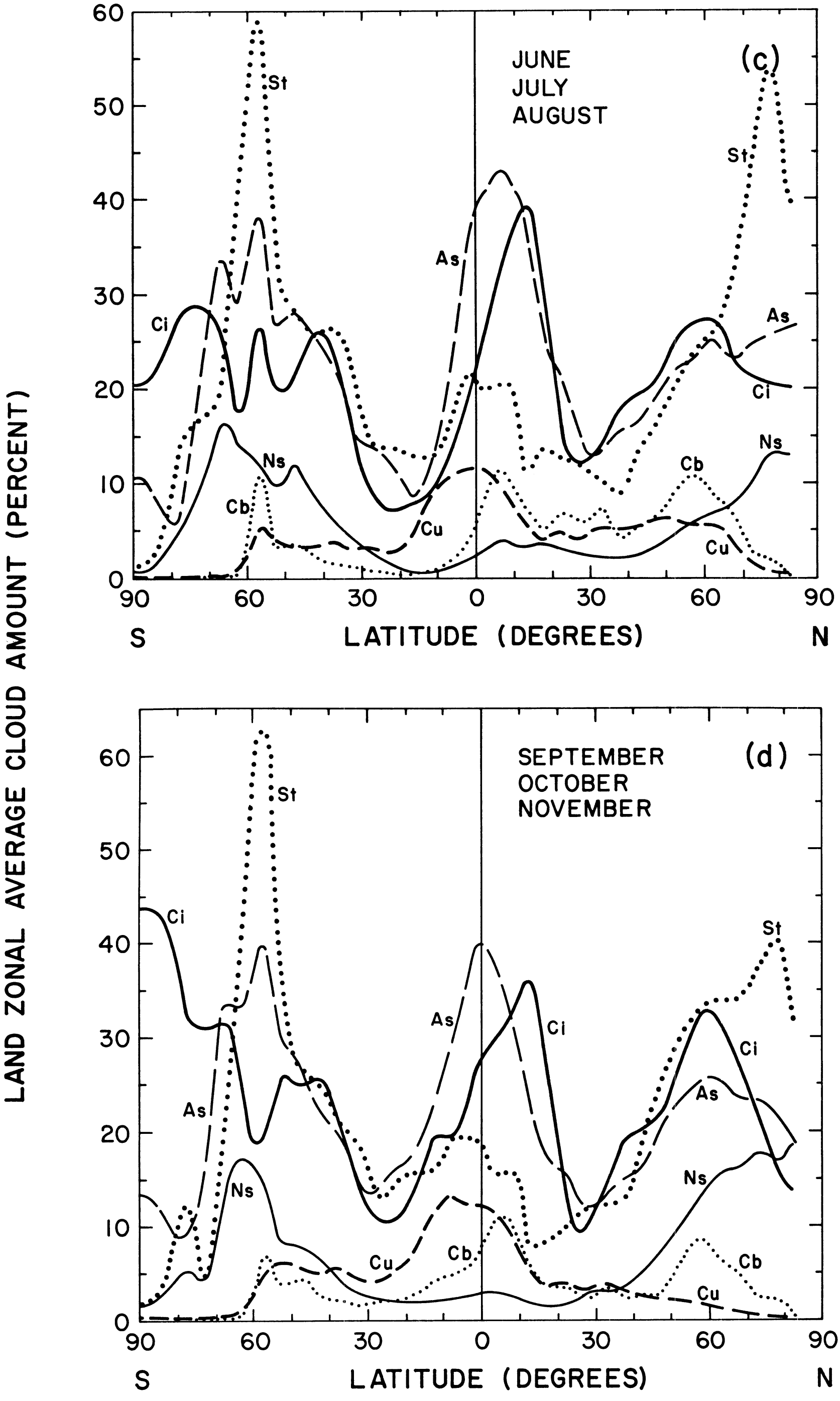


Figure 7. Zonal average amount of each cloud type over land as a function of latitude. Smooth curves were drawn through the data points for 5-degree zones listed on the right side of maps 52-55, 80-83, 108-111, 136-139, 160-163, and 176-179.

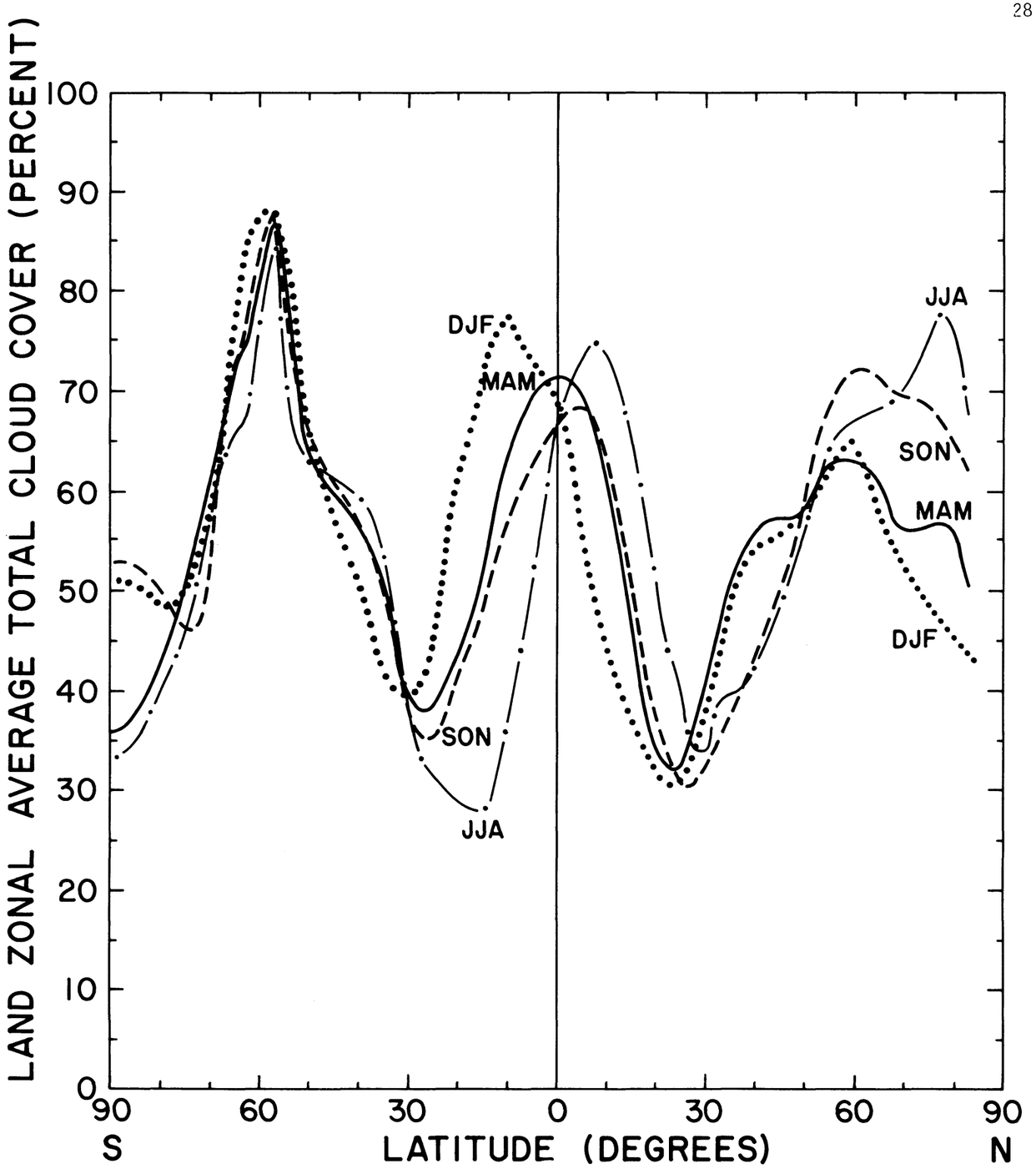


Figure 8. Zonal average total cloud cover over land as a function of latitude, for four seasons. Smooth curves were drawn through the data points for 5-degree zones listed on the right side of maps 10-13.

Table 8. Quantities archived on magnetic tape for each 5°×5° box*

A. Total cloud cover
   1. 12 months
      a) long-term average, sd, n
      b) individual years average, sd, n
   2. Four seasons
      a) long-term average, sd, n (all times)
      b) long-term average, sd, n (daytime only)
      c) diurnal cycle (multi-year average)
         1) A, ϕ, vaf of first harmonic
         2) eight individual synoptic hours
      d) interannual variations
         1) sd of season means
         2) number of years contributing to IAV
         3) span of years contributing to IAV
         4) ten-year trend
      e) individual years: average, sd, n (average of all synoptic hours)
   3. A, ϕ of annual cycle

B. Cloud types, for each of four seasons, for each of six types and clear-sky and fog, for each of three quantities (amount, awp, f). [Number of observations also included where appropriate.]
   1. long-term average
   2. individual years
   3. diurnal cycle (multi-year average)
      a) A, ϕ, vaf of first harmonic
      b) eight individual time periods
   4. interannual variations
      a) sd of season means
      b) number of years contributing to IAV
      c) span of years contributing to IAV
      d) ten-year trend

C. Base heights of Cu, St, Cb: average, sd, n

*Abbreviations used:

A	amplitude
awp	amount-when-present
f	frequency of occurrence
IAV	interannual variation
n	number of reports
sd	standard deviation
vaf	variation accounted for
ϕ	phase

Acknowledgments

The observations from land stations were provided to NCAR by Jim Zuver of the Fleet Numerical Oceanography Center and made available to this project by Dennis Joseph and Gregg Walters of the Data Support Section of NCAR. Jim Zuver was very cooperative over many years in helping NCAR obtain archives of the observations used in this atlas. He retired early in 1986 because of a battle with cancer and died soon thereafter. This is a sad loss for us.

The cloud maps were generated on the DICOMED D48 Graphic COM System located in the NCAR Scientific Computing Division, with programming help from David Kennison. The NCAR Photographics staff produced the final prints. Tom Schlatter and Mark Albright provided advice (not always followed) on the grouping of cloud types for our classification. SGW thanks the meteorologists at South Pole Station (Sharon King, Kitt Hughes and Frank Gilpatrick) for helpful discussion about observing practices. Tom Charlock alerted us to the partial-undercast bias. Pat Kennedy and Tony Slingo critically reviewed the manuscript.

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References

Falls, L.W., 1974: The beta distribution: A statistical model for world cloud cover. *J. Geophys. Res., 79,* 1261-1264.

Hahn, C.J., S.G. Warren, J. London, R.M. Chervin, and R. Jenne, 1982: *Atlas of Simultaneous Occurrence of Different Cloud Types over the Ocean*, NCAR Technical Note TN-201+STR, Boulder, CO, 212 pp. (NTIS number PB83-152074).

Hahn, C.J., S.G. Warren, J. London, R.M. Chervin, and R. Jenne, 1984: *Atlas of Simultaneous Occurrence of Different Cloud Types over Land*, NCAR Technical Note TN-241+STR, Boulder, CO, 216 pp.

Hahn, C.J., S.G. Warren, J. London, R.M. Chervin and R.L. Jenne, 1987: *Atlas of Cloud Type Distributions during FGGE*, NCAR Technical Note in preparation.

Lund, I.A., and M.D. Shanklin, 1973: Universal methods for estimating probabilities of cloud-free lines-of-sight through the atmosphere. *J. Appl. Meteorol., 12,* 28-35.

Malick, J.D., J.H. Allen and S. Zakanycz, 1979: Calibrated analytical modeling of cloud-free intervals. *Proc. Society for Photo-optical Engineering*, San Diego, August 1979.

Riehl, H., 1947: Diurnal variation of cloudiness over the subtropical Atlantic Ocean. *Bull. Am. Meteorol. Soc., 28,* 37-40.

Riehl, H., 1979: *Climate and Weather in the Tropics,* Academic Press, London, 611 pp.

Schwerdtfeger, W., 1984: *Weather and Climate of the Antarctic*, Elsevier, Amsterdam, 261 pp.

Sverdrup, H.U., 1933: *The Norwegian North Polar Expedition with the "Maud", 1918-1925, Scientific Results*, Vol. II: Meteorology, Part I, Discussion, pub. John Griegs, Bergen, 331 pp.

Telegadas, K., and J. London, 1954: *A Physical Model of the Northern Hemisphere Troposphere for Winter and Summer.* New York University College of Engineering Scientific Report No. 1 [AF 19(122)-165], 55 pp.

Warren, S.G., C.J. Hahn, and J. London, 1985: Simultaneous occurrence of different cloud types. *J. Clim. Appl. Meteorol., 24,* 658-667.

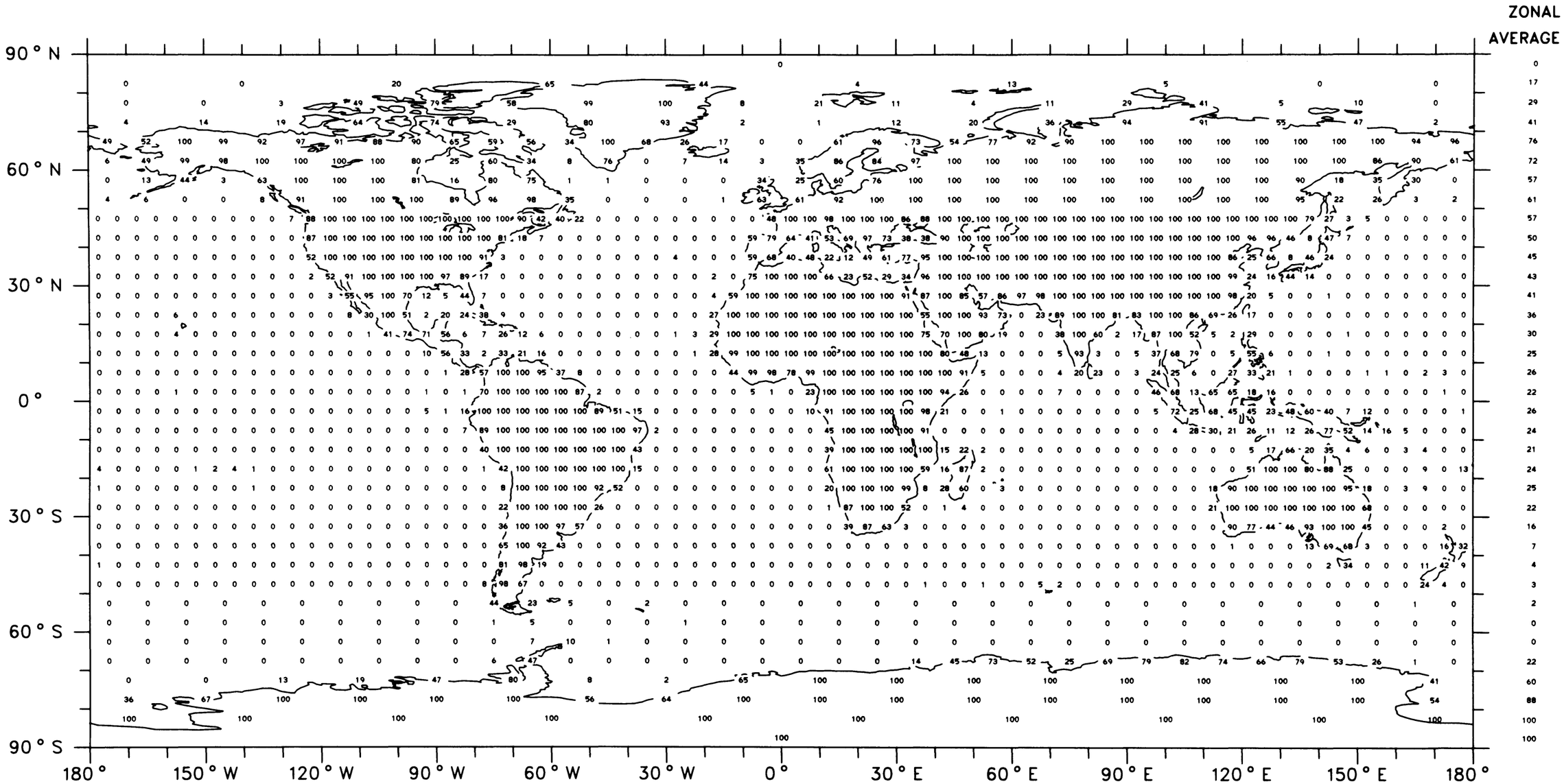
Warren, S.G., C.J. Hahn, J. London, R.M. Chervin and R.L. Jenne, 1987: *Global Distribution of Total Cloud Cover and Cloud Type Amounts over the Ocean.* NCAR Technical Note in preparation.

World Meteorological Organization, 1956: *International Cloud Atlas, Abridged Atlas,* WMO, Geneva, 62 pp. + 72 Plates.

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

World Meteorological Organization, 1979: *Weather Reporting, Volume A: Observing Stations.* (WMO Publ. No. 9), WMO, Geneva.

Fraction of Area Which Is Land (%)



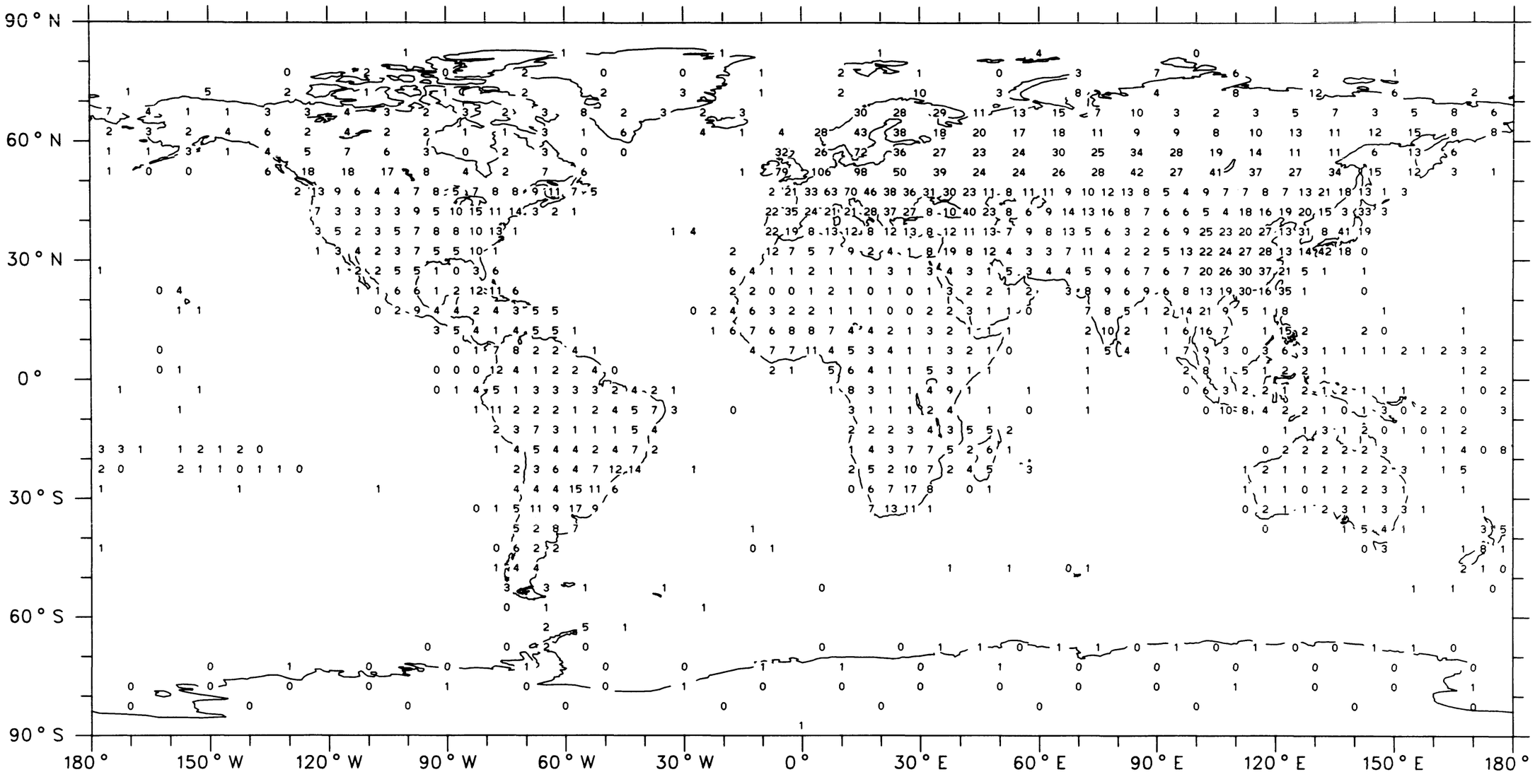
Map 0

GLOBAL AVERAGE 30.3 %

Average Number of WMO Weather Stations Contributing to the Data Set

1971-1981

Land Areas Only

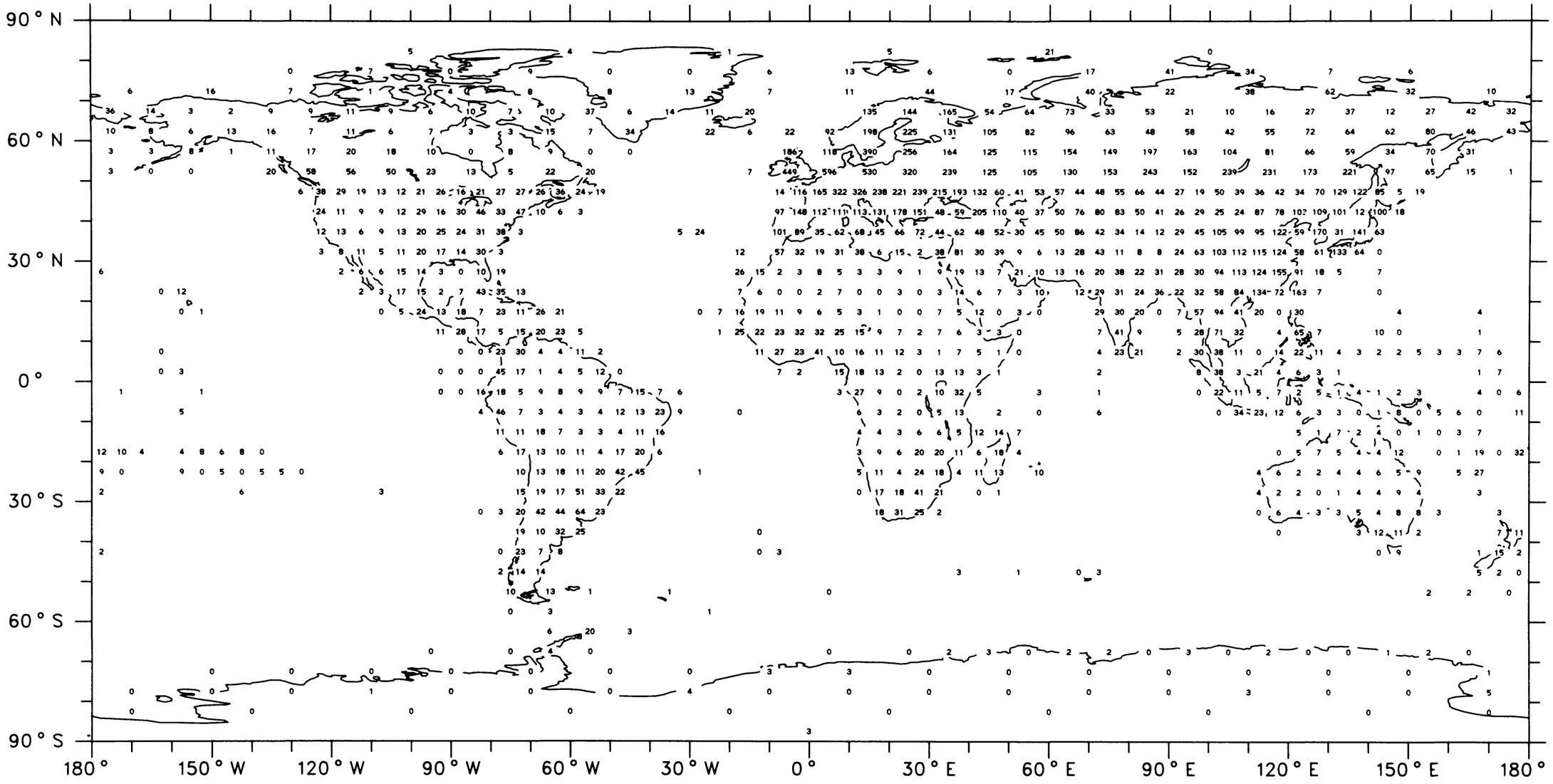


Map 1

Number of Cloud Reports (thousands)

December, January, February (1971-1981)

Land Areas Only

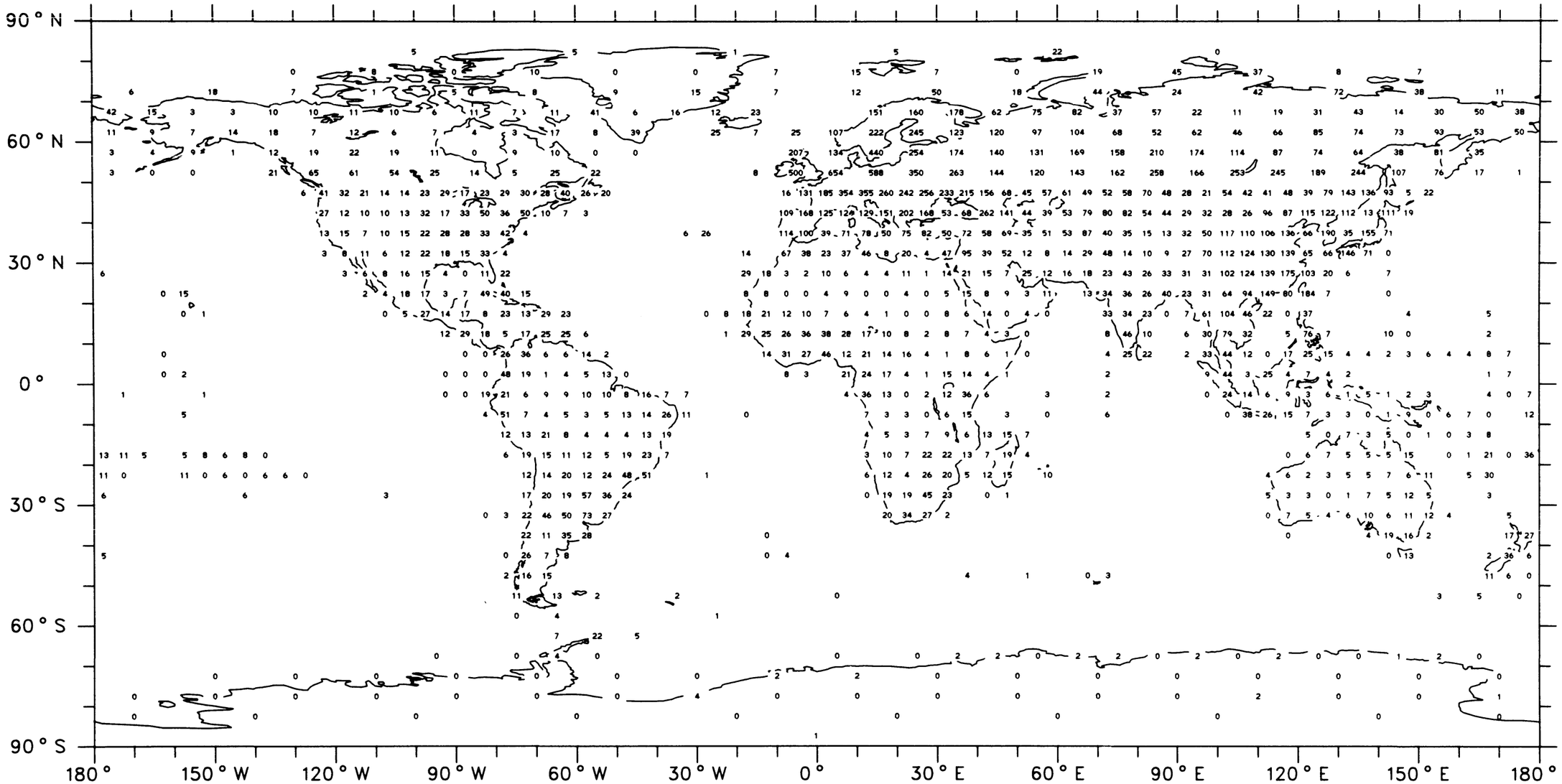


Map 2

Number of Cloud Reports (thousands)

March, April, May (1971-1981)

Land Areas Only

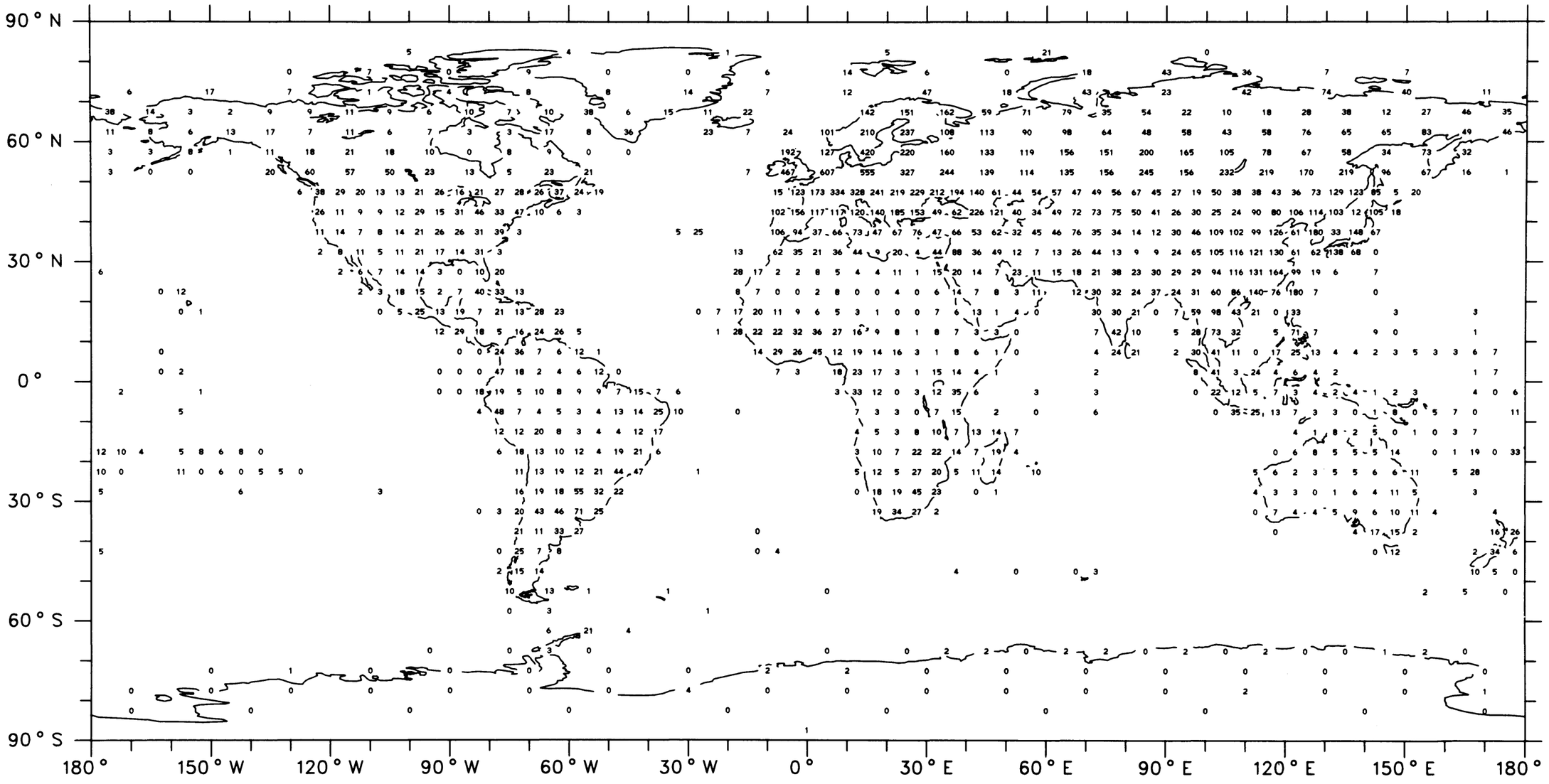


Map 3

Number of Cloud Reports (thousands)

June, July, August (1971-1981)

Land Areas Only

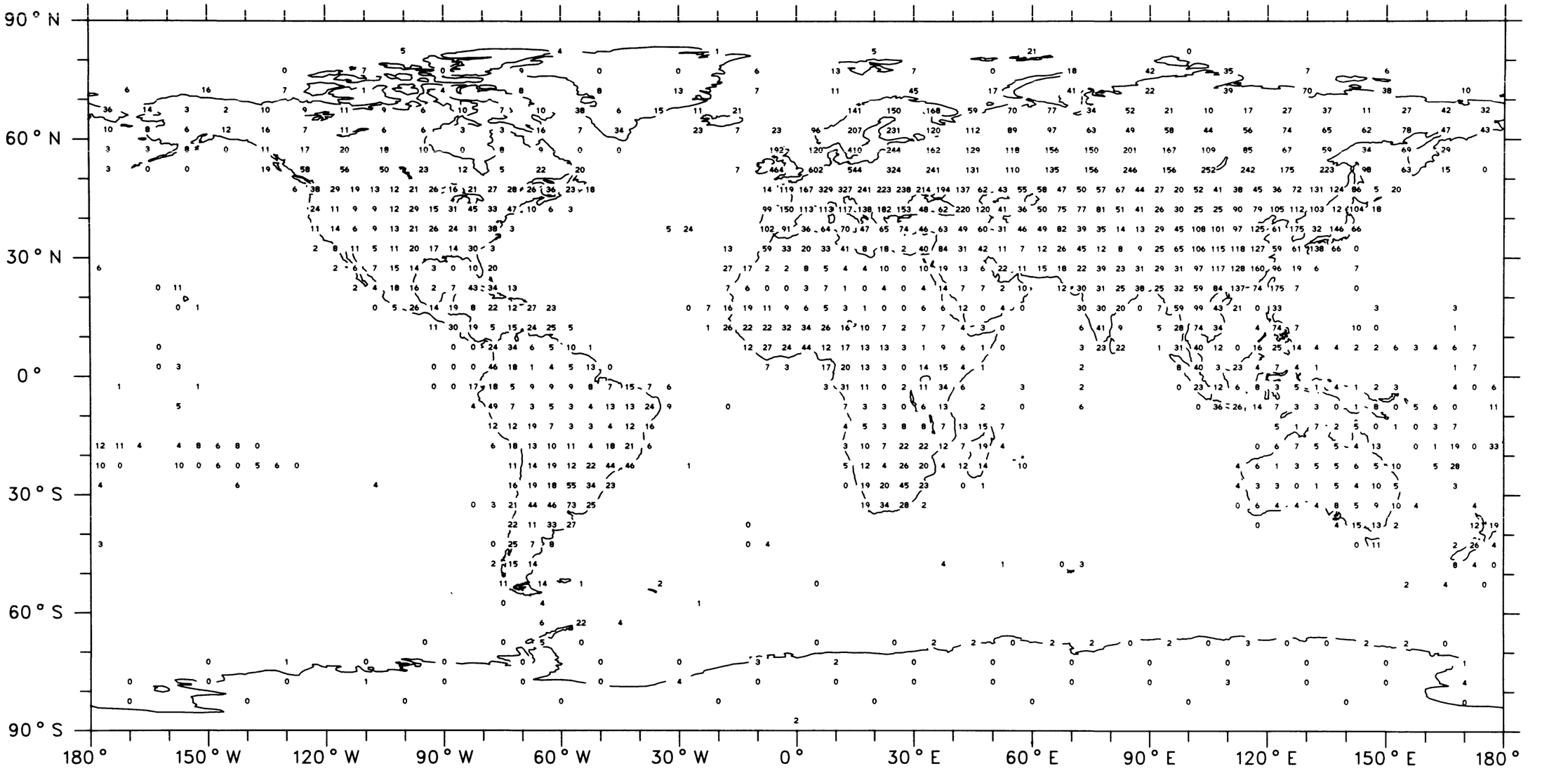


Map 4

Number of Cloud Reports (thousands)

September, October, November (1971-1981)

Land Areas Only

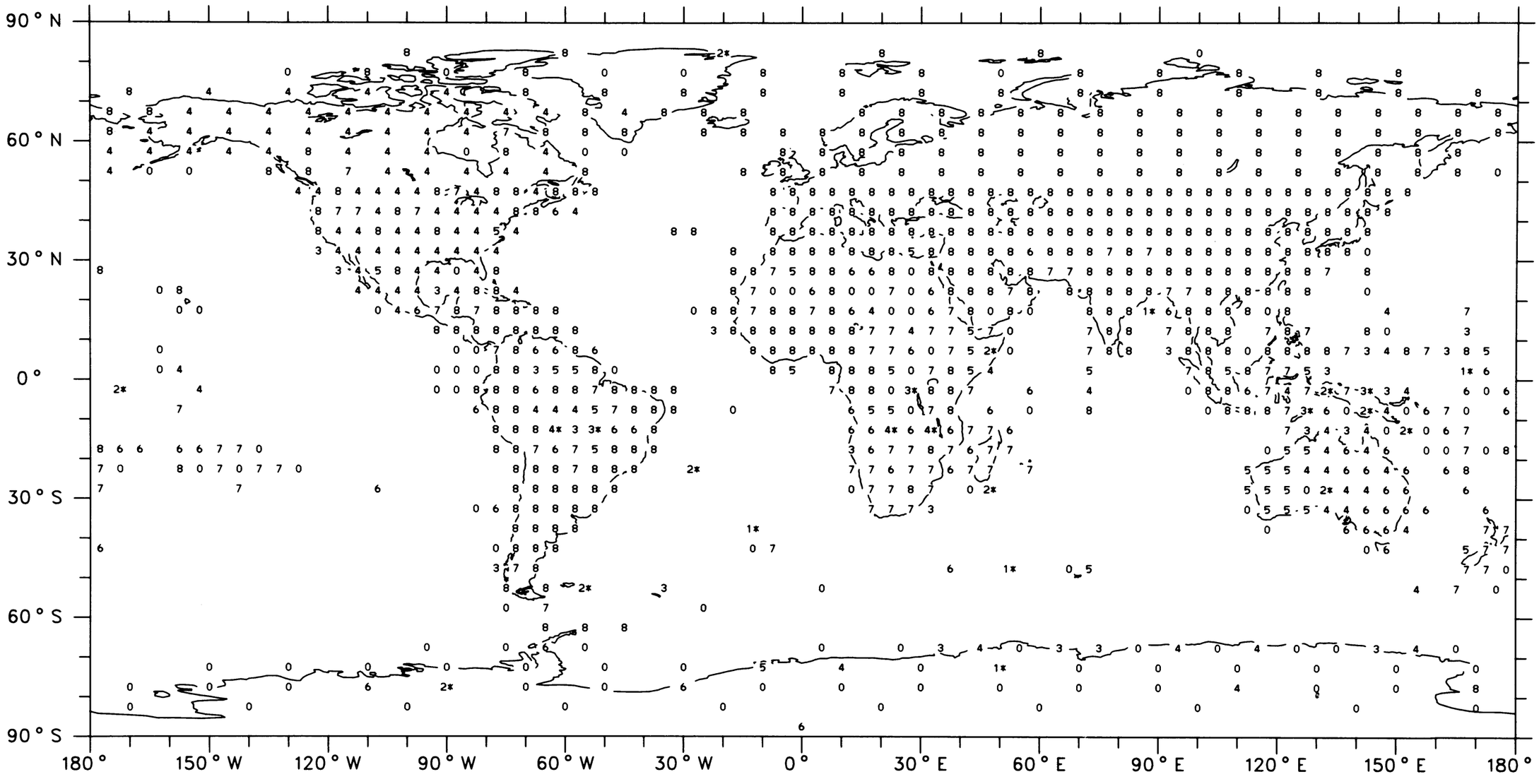


Map 5

Diurnal Sampling: Number of Synoptic Hours (of 8 possible) with At Least 200 Reports

December, January, February (1971-1981)

Land Areas Only

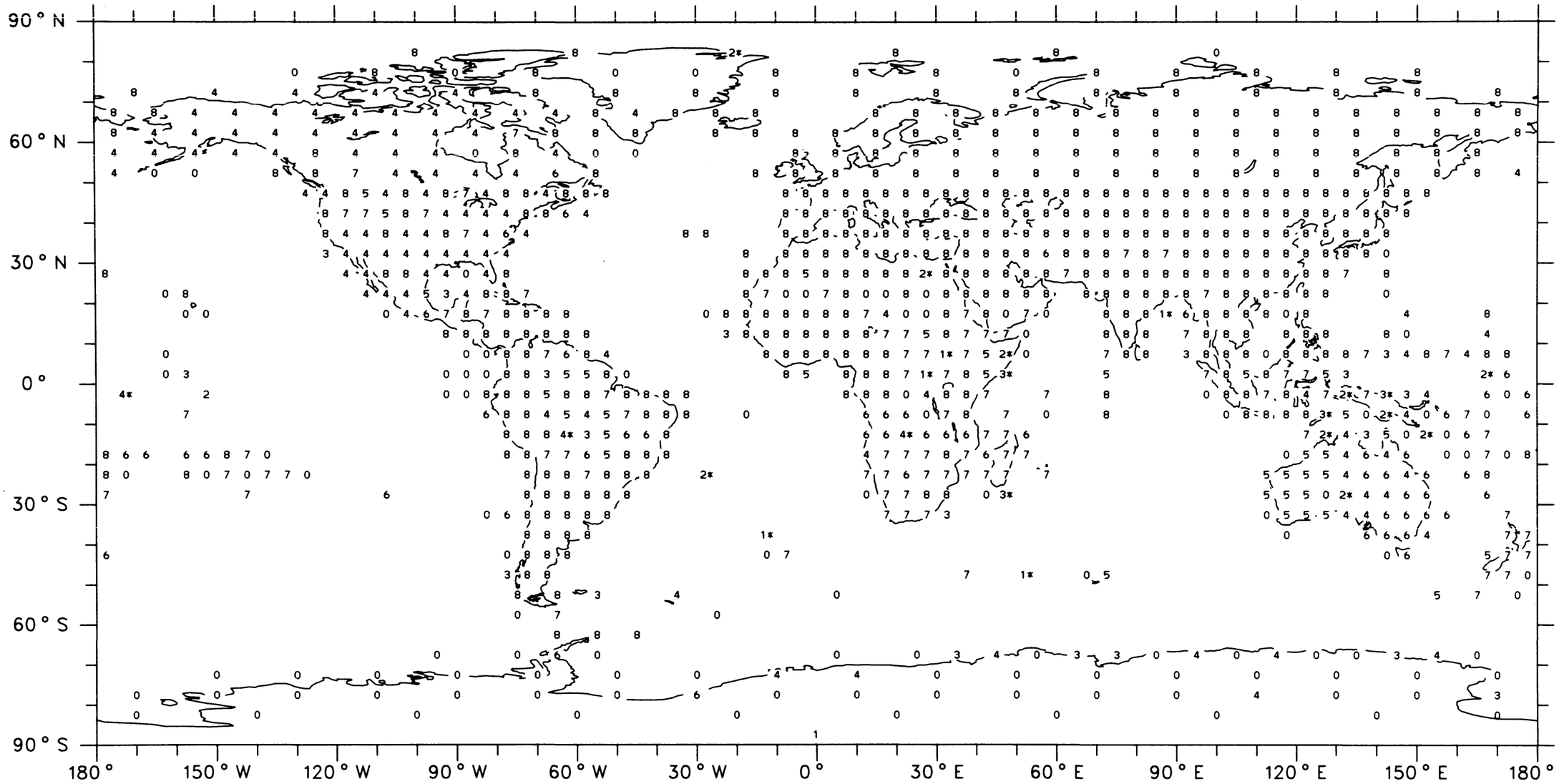


Map 6

Diurnal Sampling: Number of Synoptic Hours (of 8 possible) with At Least 200 Reports

March, April, May (1971-1981)

Land Areas Only

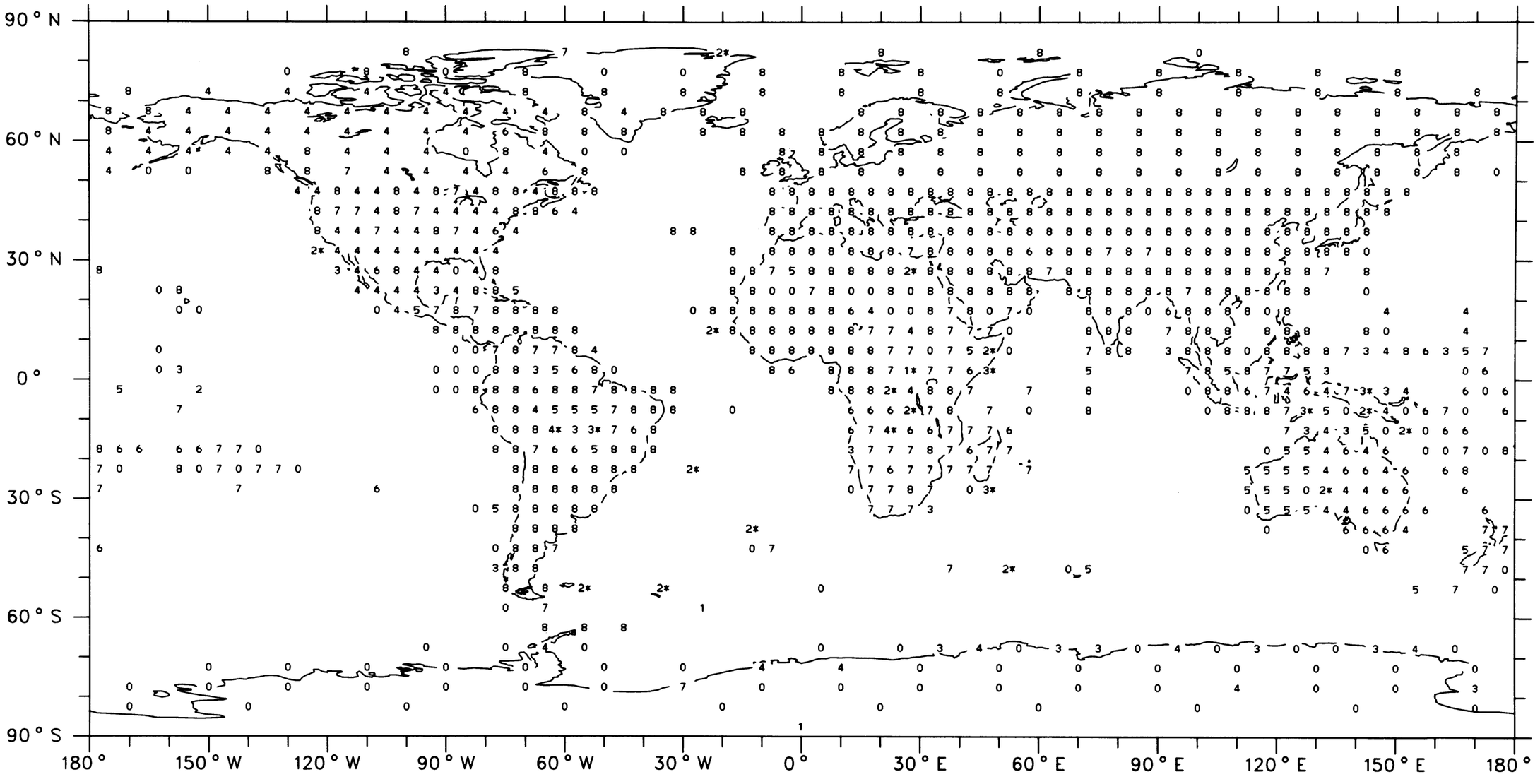


Map 7

Diurnal Sampling: Number of Synoptic Hours (of 8 possible) with At Least 200 Reports

June, July, August (1971-1981)

Land Areas Only

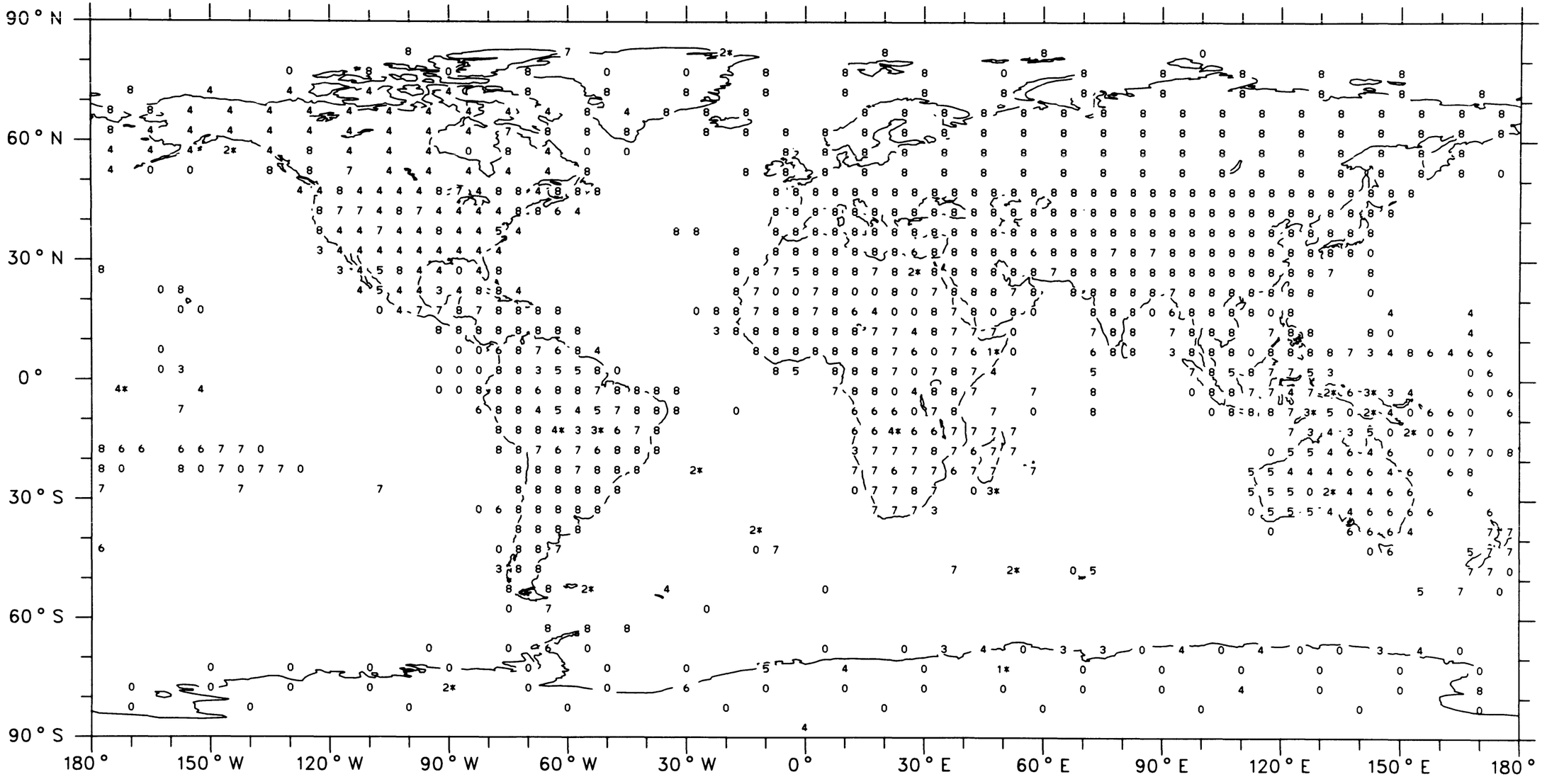


Map 8

Diurnal Sampling: Number of Synoptic Hours (of 8 possible) with At Least 200 Reports

September, October, November (1971-1981)

Land Areas Only

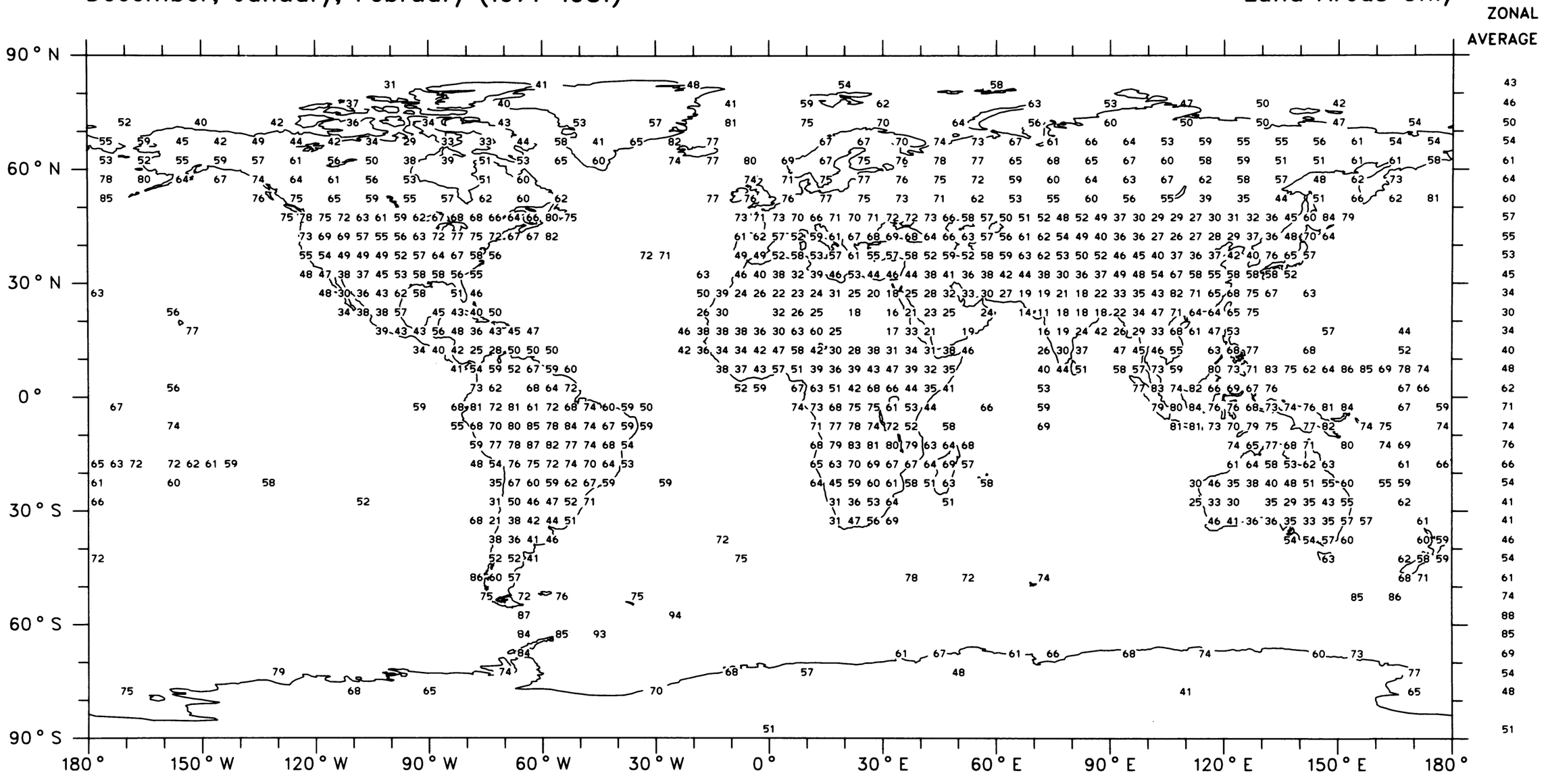


Map 9

Average Total Cloud Cover (%)

December, January, February (1971-1981)

Land Areas Only



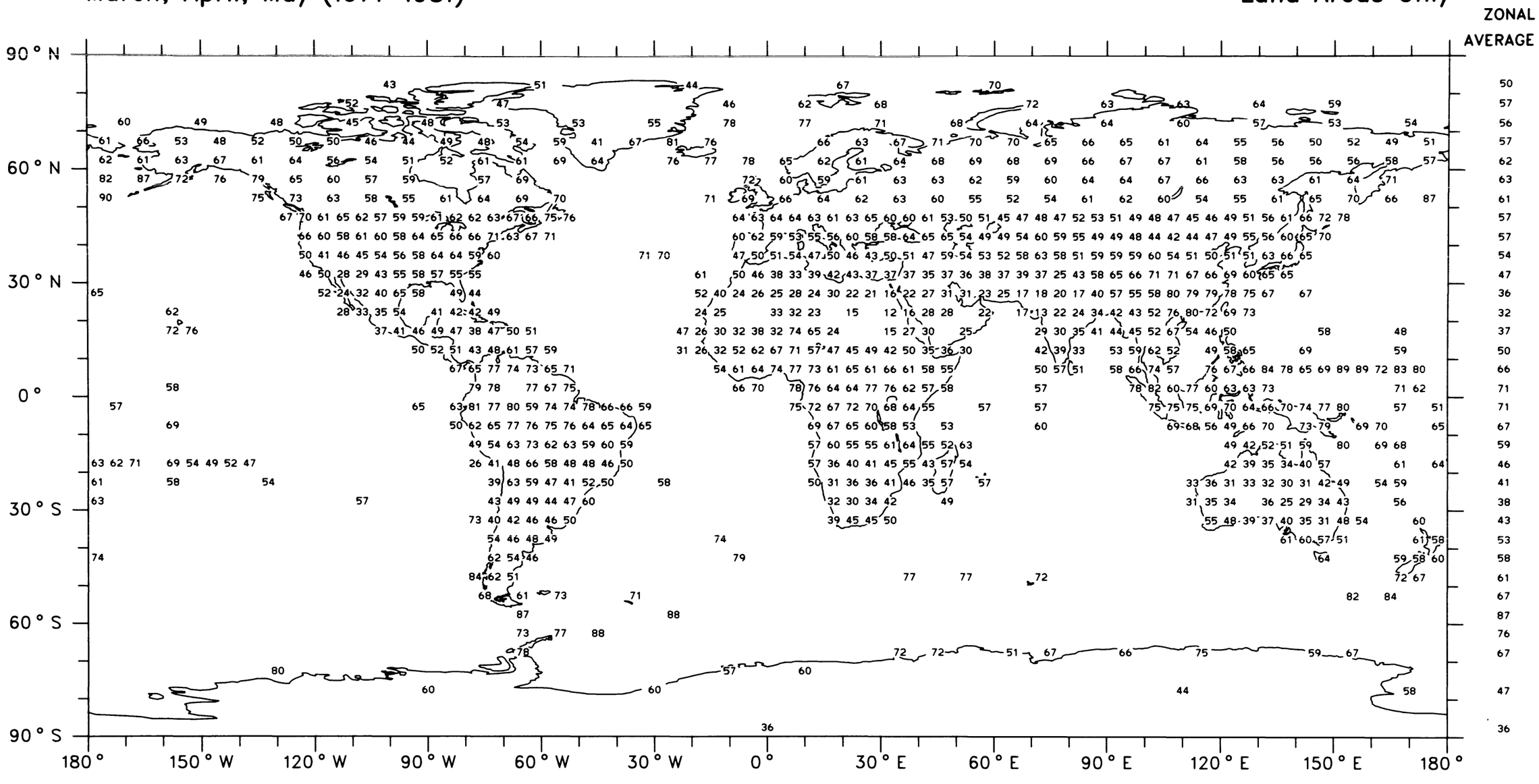
Map 10

GLOBAL AVERAGE (LAND) 53 %

Average Total Cloud Cover (%)

March, April, May (1971-1981)

Land Areas Only



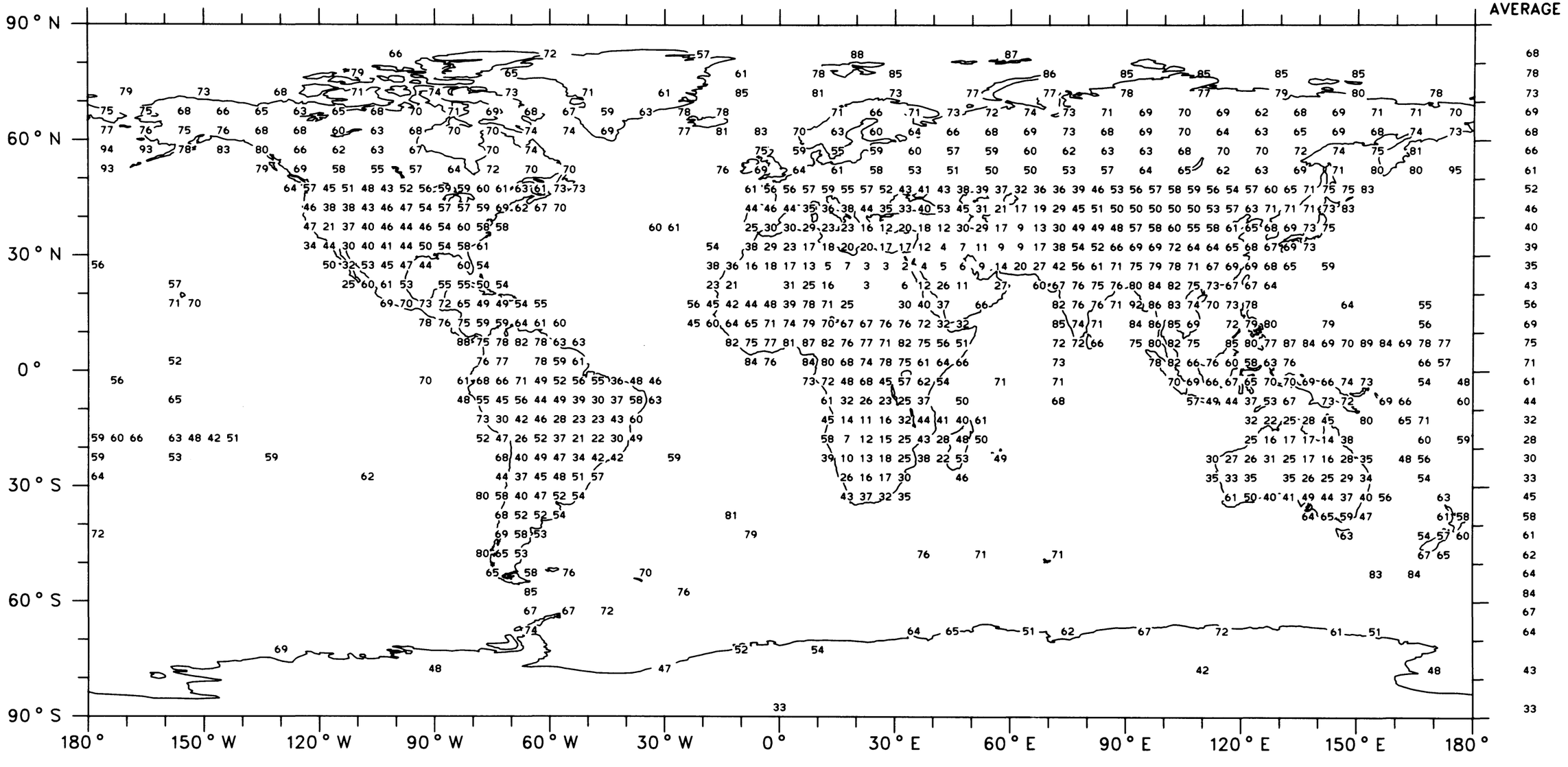
GLOBAL AVERAGE (LAND) 53 %

Map 11

Average Total Cloud Cover (%)

June, July, August (1971-1981)

Land Areas Only



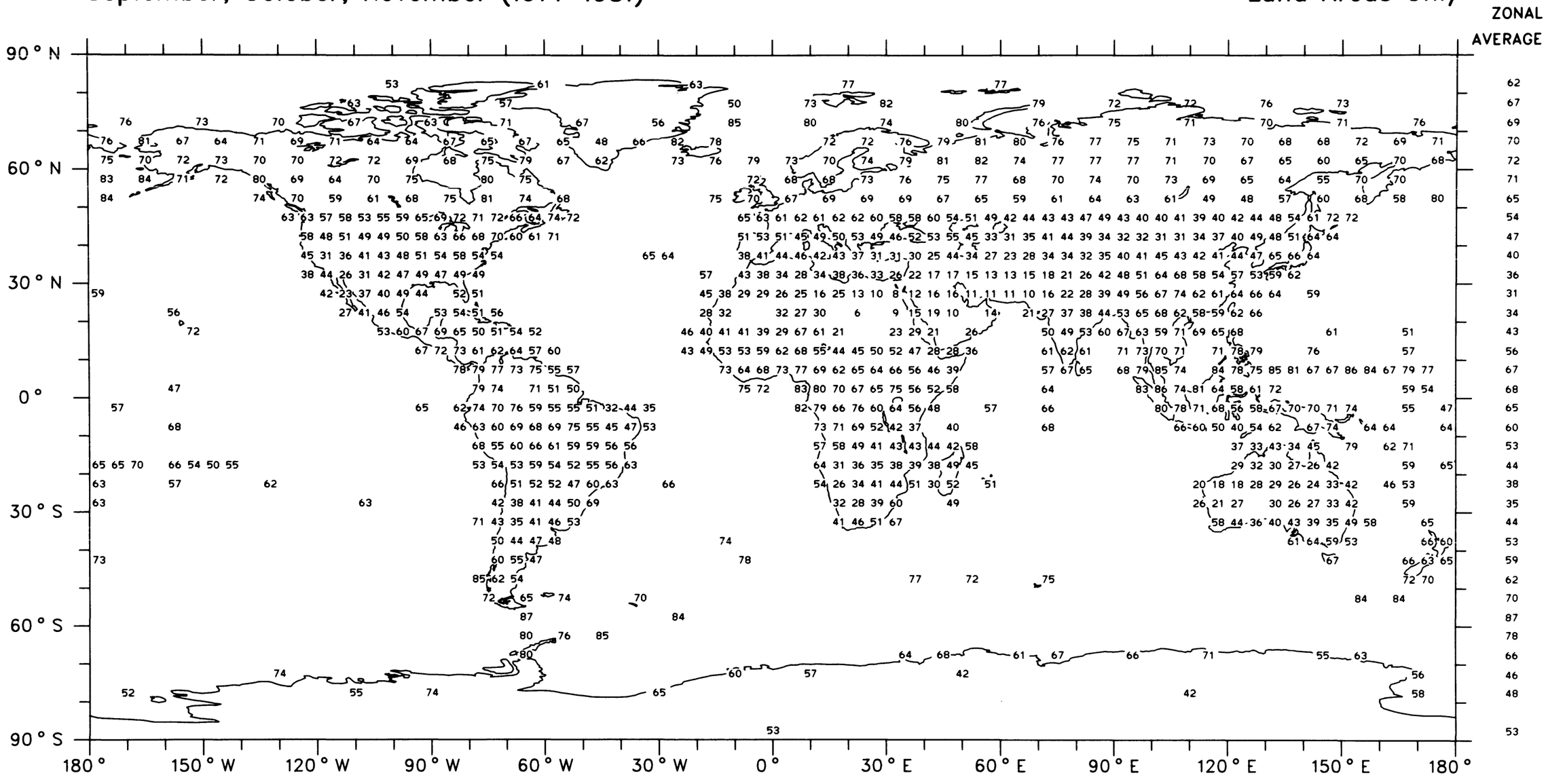
Map 12

GLOBAL AVERAGE (LAND) 51 %

Average Total Cloud Cover (%)

September, October, November (1971-1981)

Land Areas Only



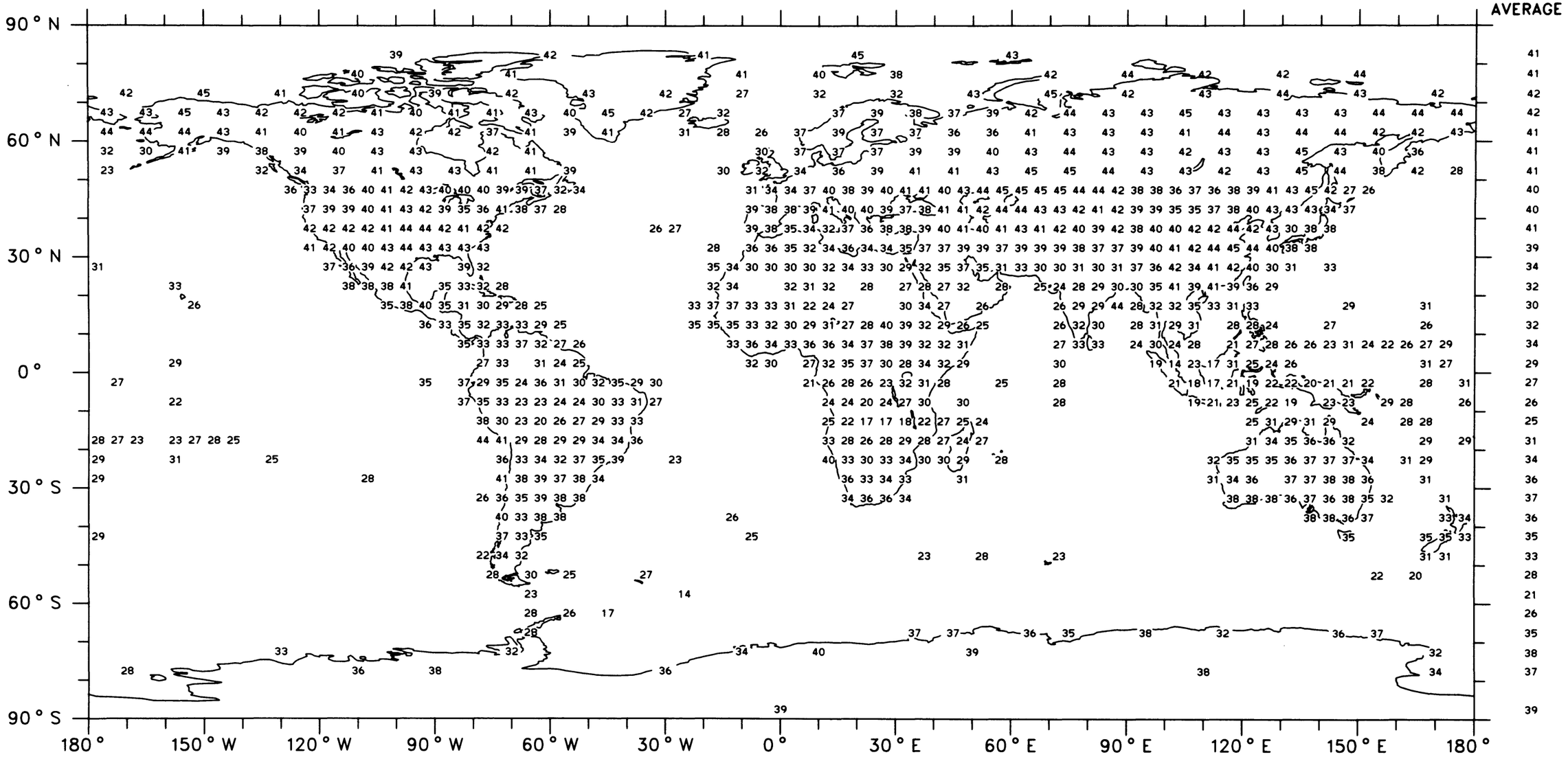
GLOBAL AVERAGE (LAND) 52 %

Map 13

Standard Deviation of Individual Observations of Total Cloud Cover (%)

December, January, February (1971-1981)

Land Areas Only



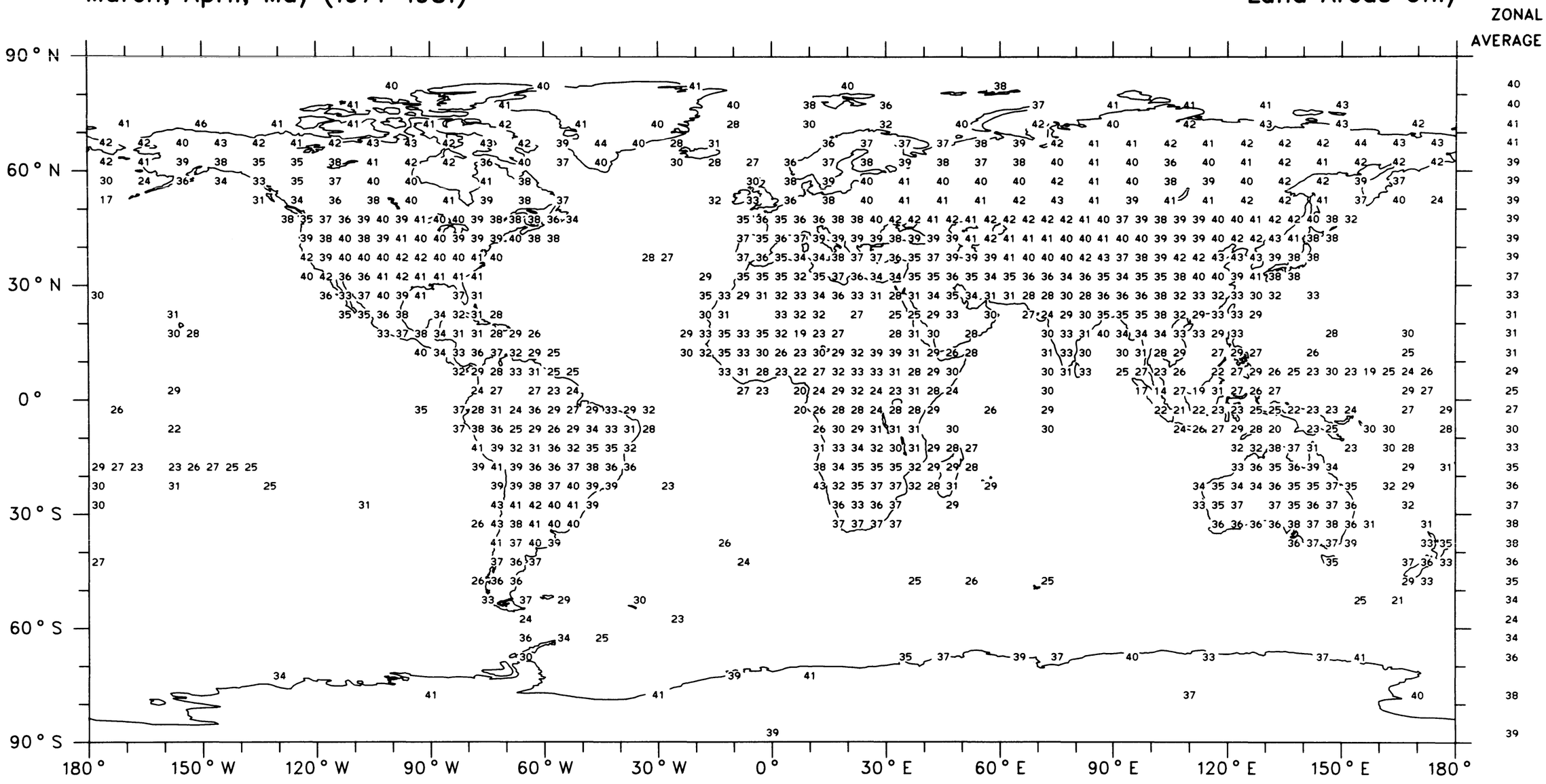
Map 14

GLOBAL AVERAGE (LAND) 36 %

Standard Deviation of Individual Observations of Total Cloud Cover (%)

March, April, May (1971-1981)

Land Areas Only



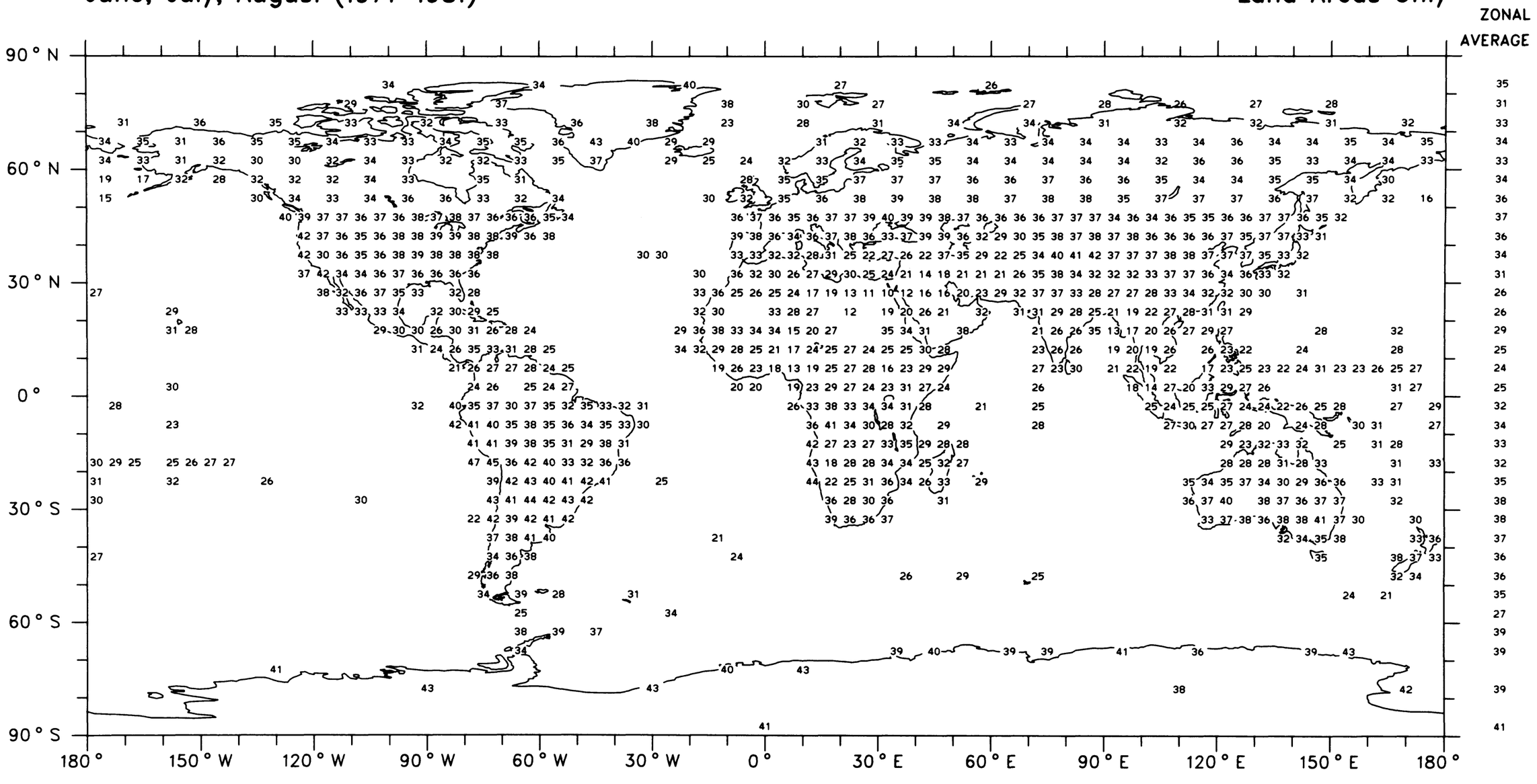
GLOBAL AVERAGE (LAND) 36 %

Map 15

Standard Deviation of Individual Observations of Total Cloud Cover (%)

June, July, August (1971-1981)

Land Areas Only



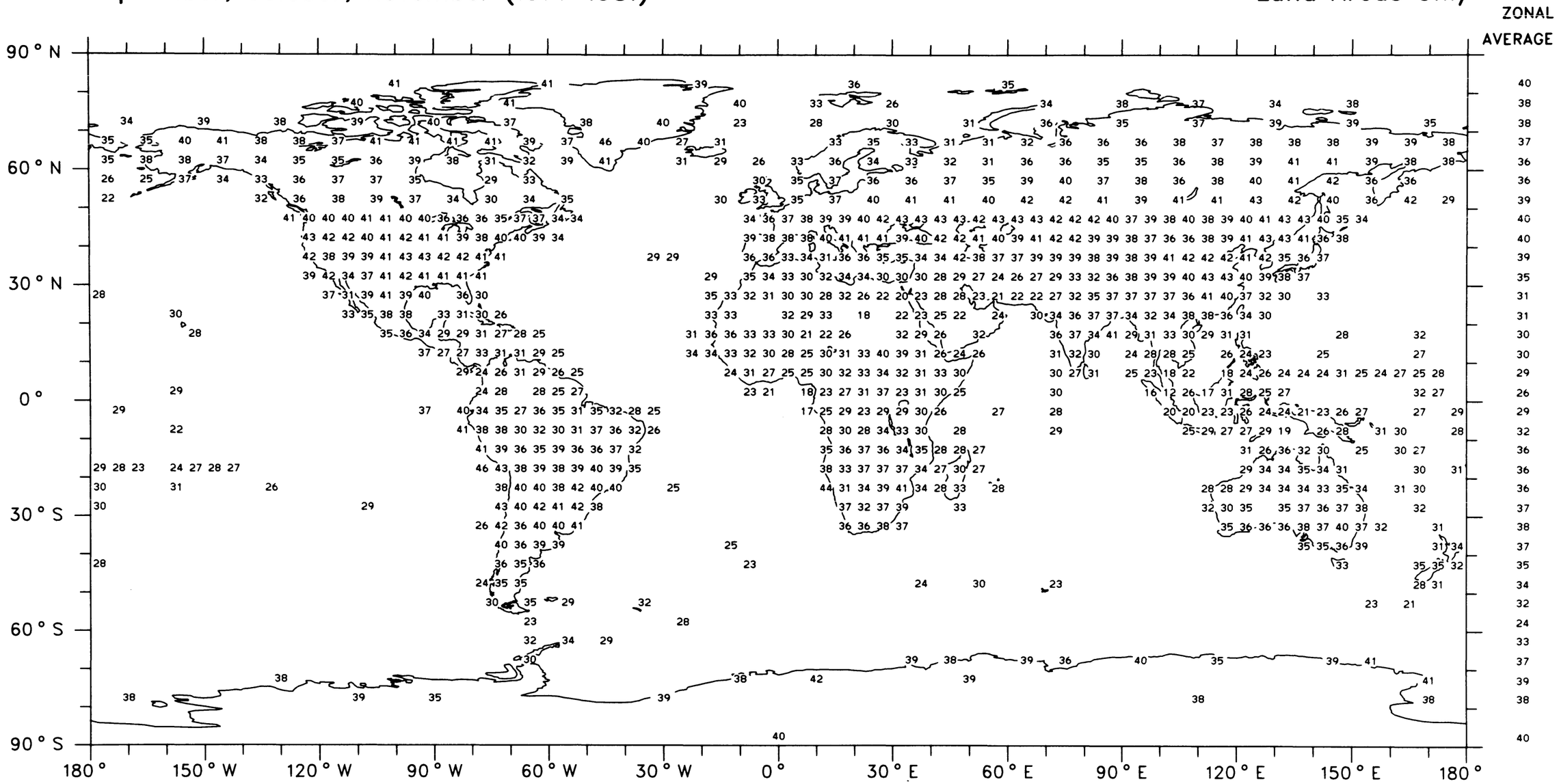
Map 16

GLOBAL AVERAGE (LAND) 33 %

Standard Deviation of Individual Observations of Total Cloud Cover (%)

September, October, November (1971-1981)

Land Areas Only



GLOBAL AVERAGE (LAND) 35 %

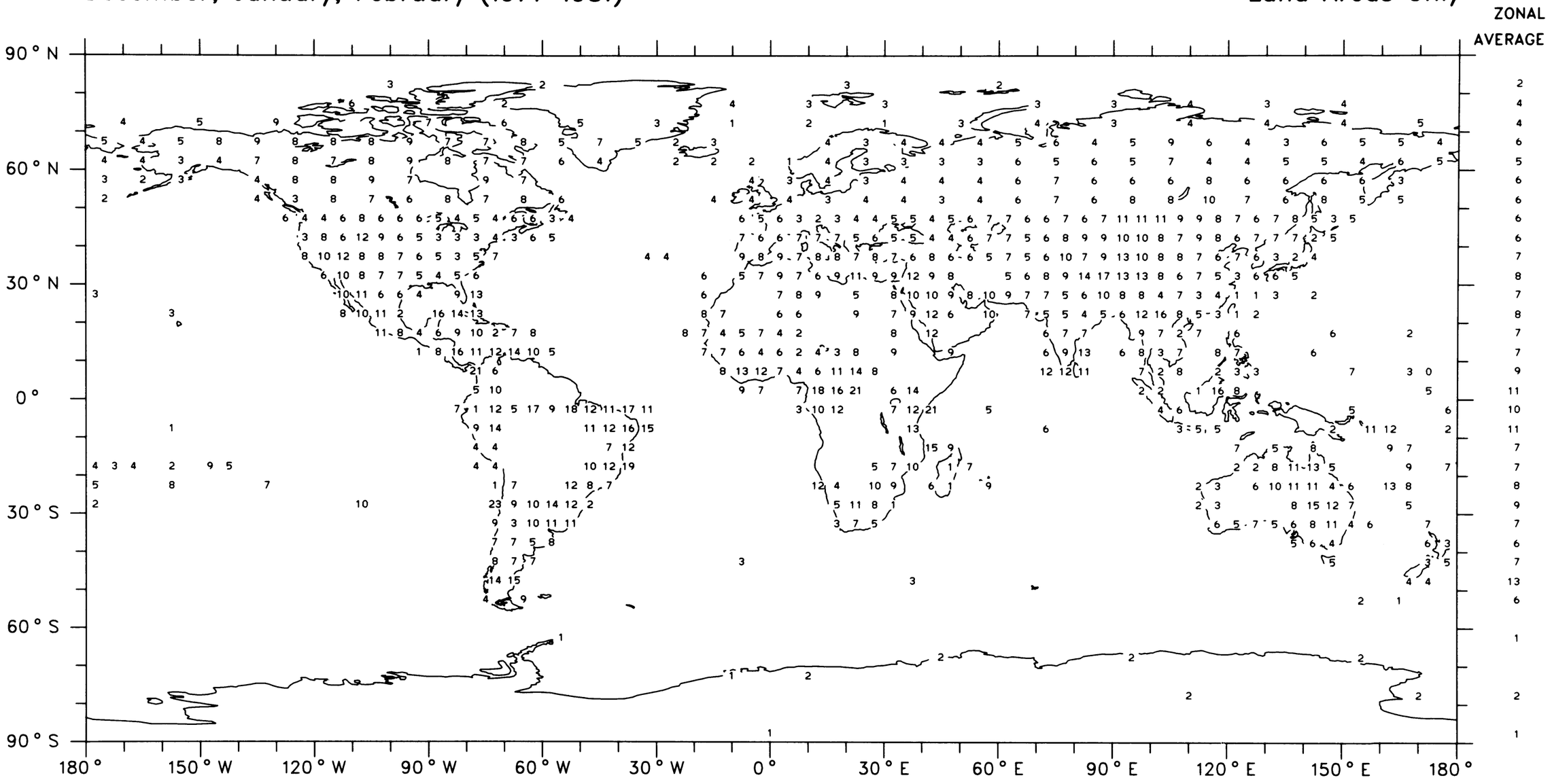
Map 17

Total Cloud Cover

Amplitude of Diurnal Cycle (% Cloud Cover)

December, January, February (1971-1981)

Land Areas Only



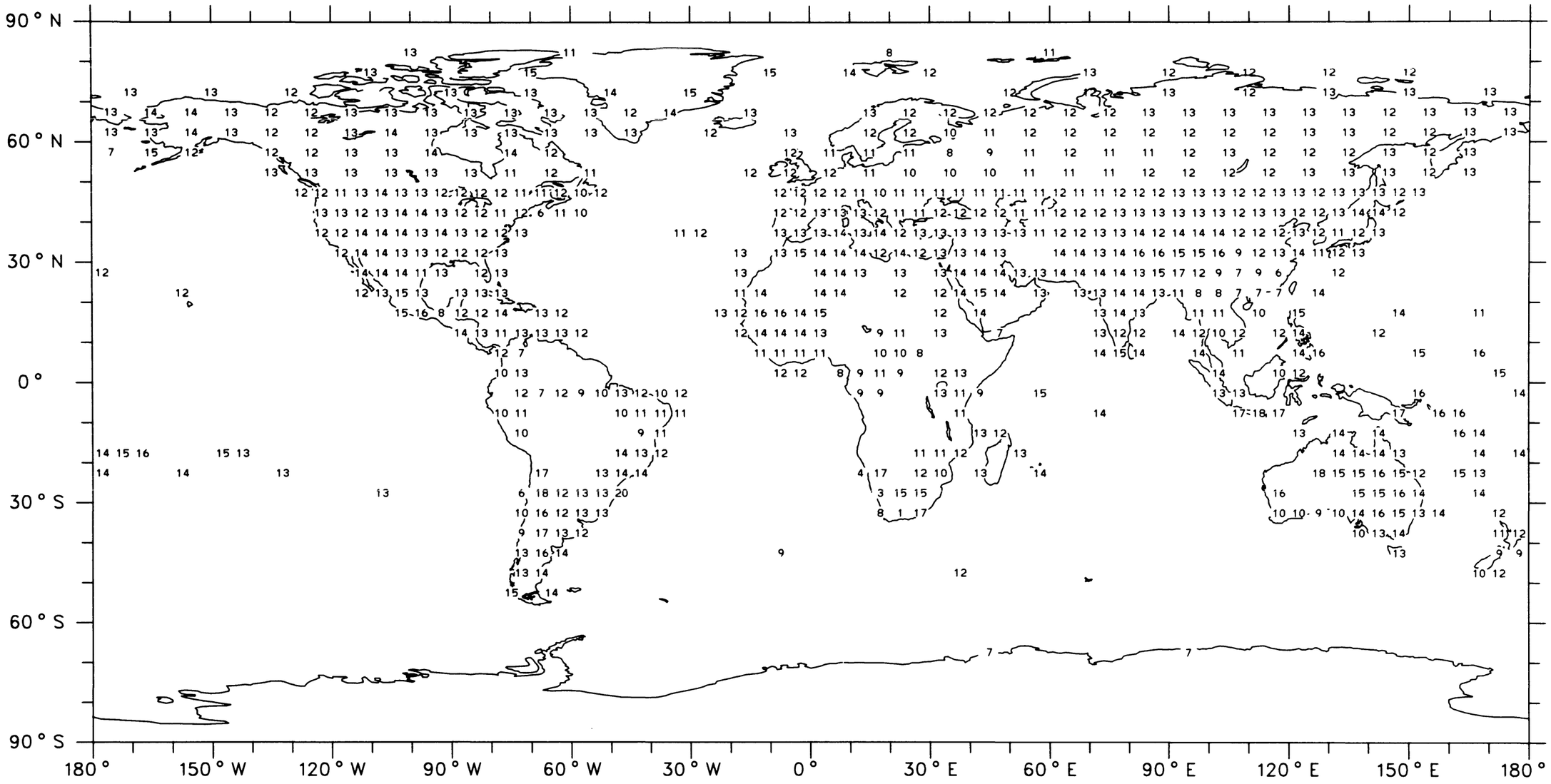
Map 18

GLOBAL AVERAGE (LAND) 7 %

Total Cloud Cover

Phase of Diurnal Cycle (Local Time of Maximum)

December, January, February (1971-1981) **Land Areas Only**



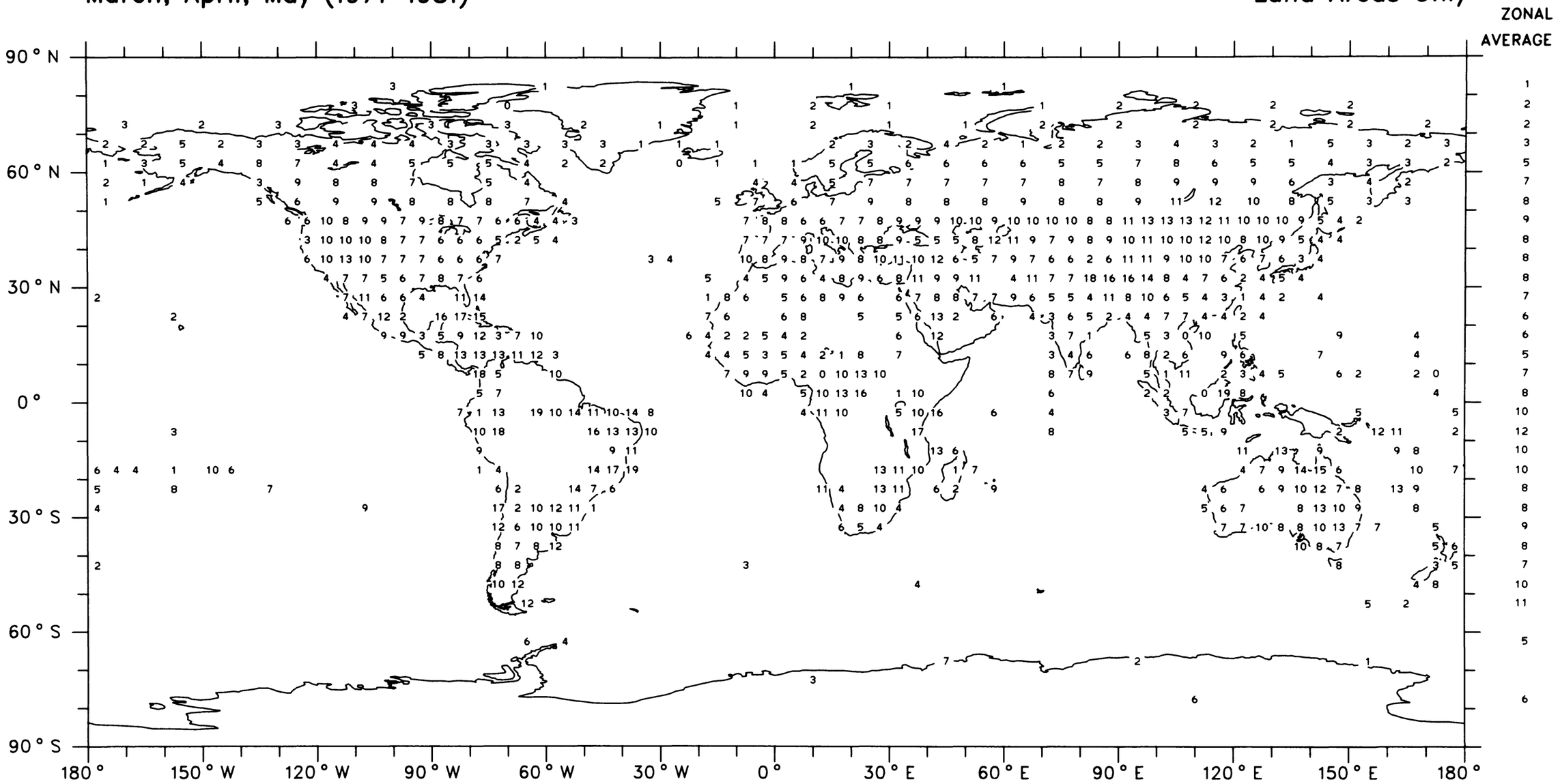
Map 19

Total Cloud Cover

Amplitude of Diurnal Cycle (% Cloud Cover)

March, April, May (1971-1981)

Land Areas Only



Map 20

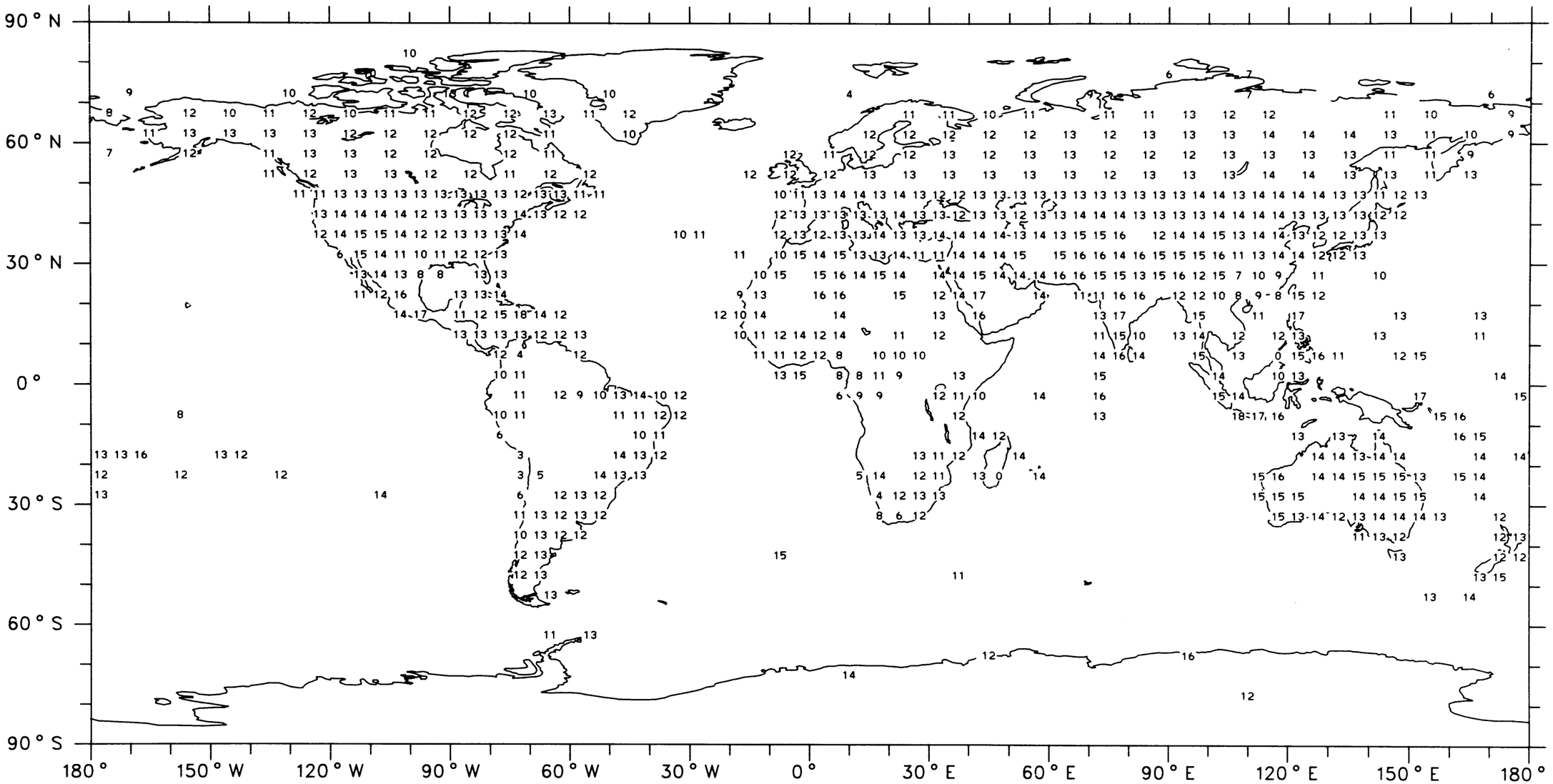
GLOBAL AVERAGE (LAND) 7 %

Total Cloud Cover

Phase of Diurnal Cycle (Local Time of Maximum)

March, April, May (1971-1981)

Land Areas Only



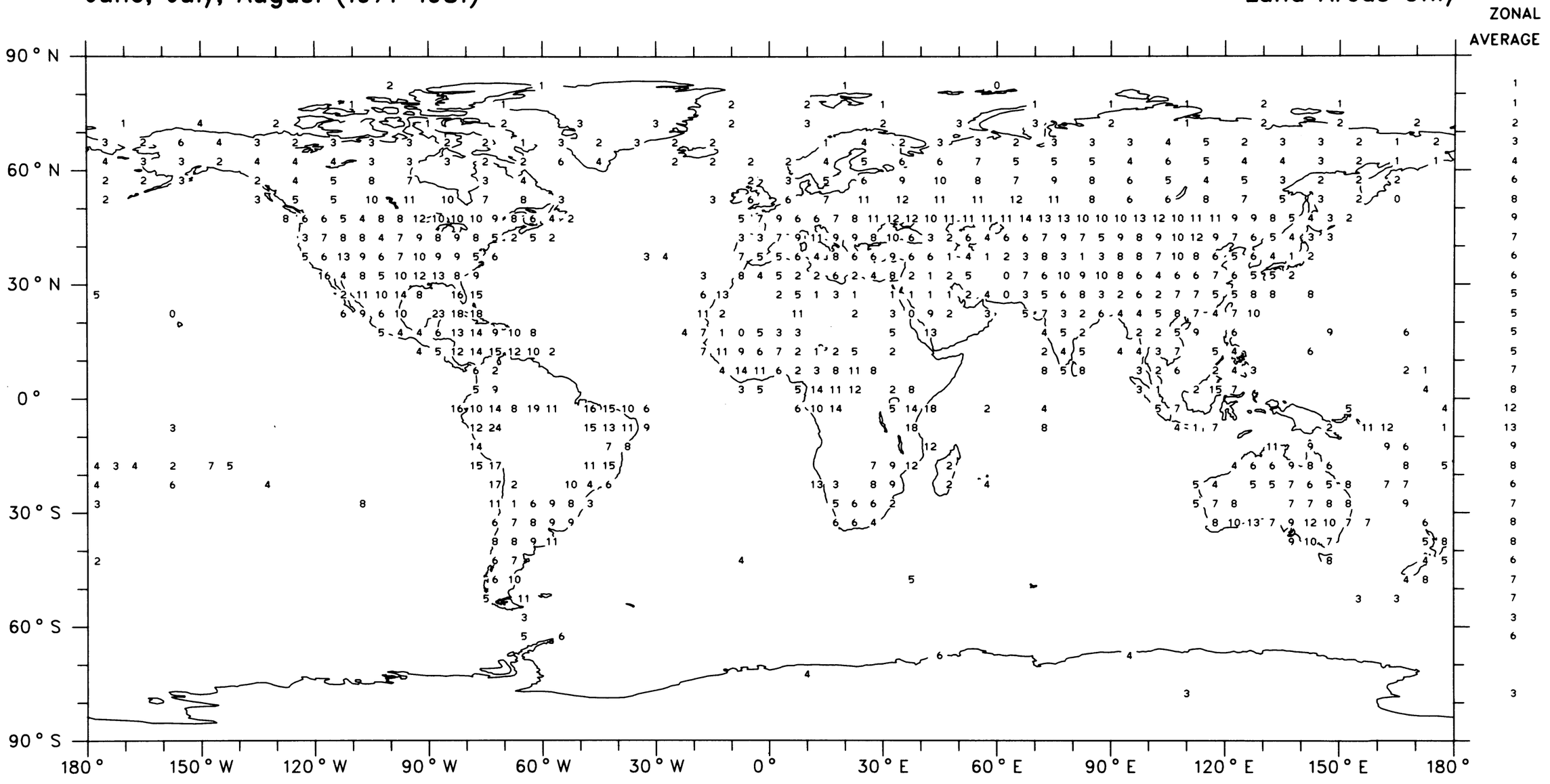
Map 21

Total Cloud Cover

Amplitude of Diurnal Cycle (% Cloud Cover)

June, July, August (1971-1981)

Land Areas Only



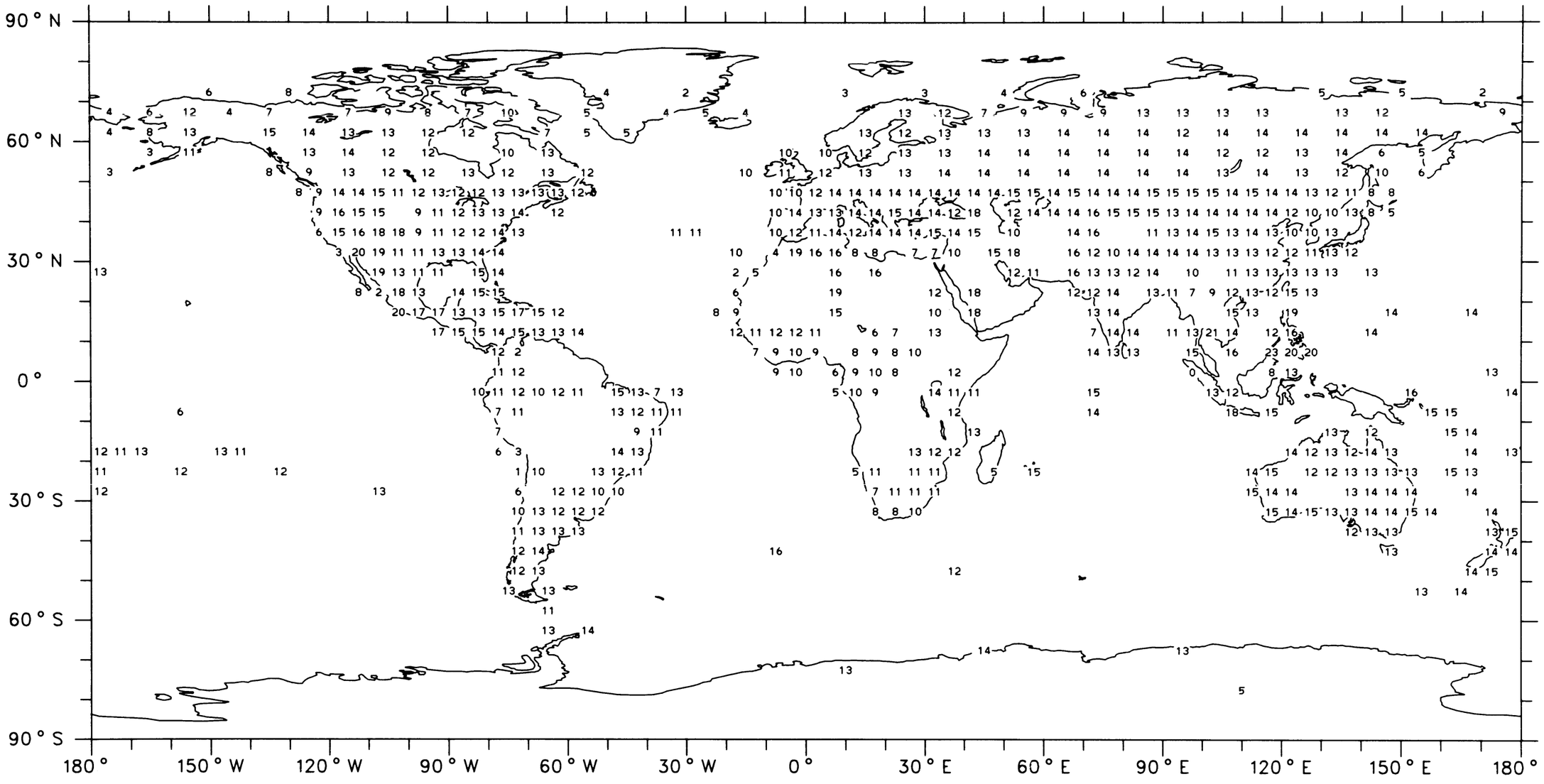
Map 22

GLOBAL AVERAGE (LAND) 7 %

Total Cloud Cover

Phase of Diurnal Cycle (Local Time of Maximum)

June, July, August (1971-1981) **Land Areas Only**



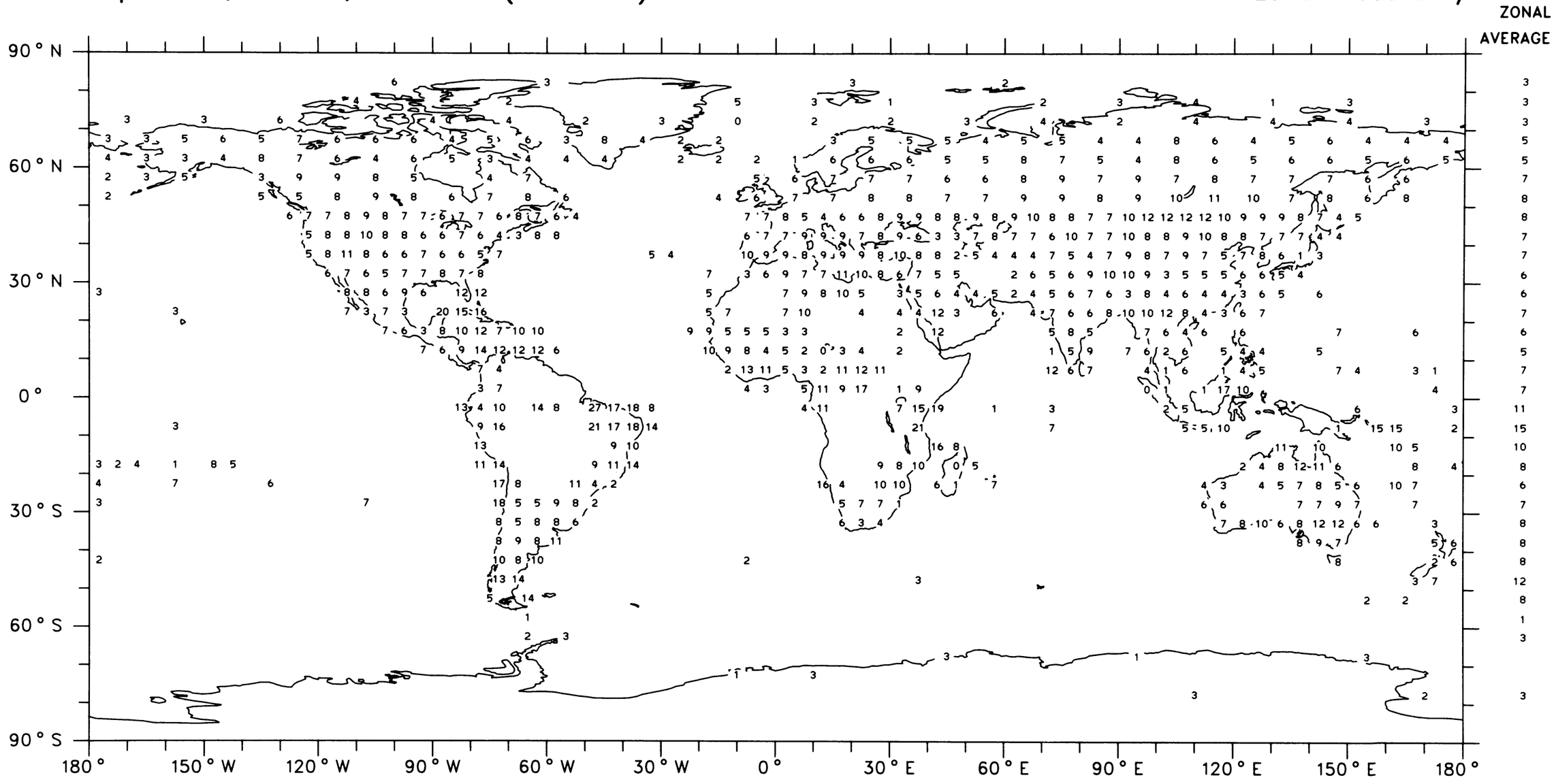
Map 23

Total Cloud Cover

Amplitude of Diurnal Cycle (% Cloud Cover)

September, October, November (1971-1981)

Land Areas Only



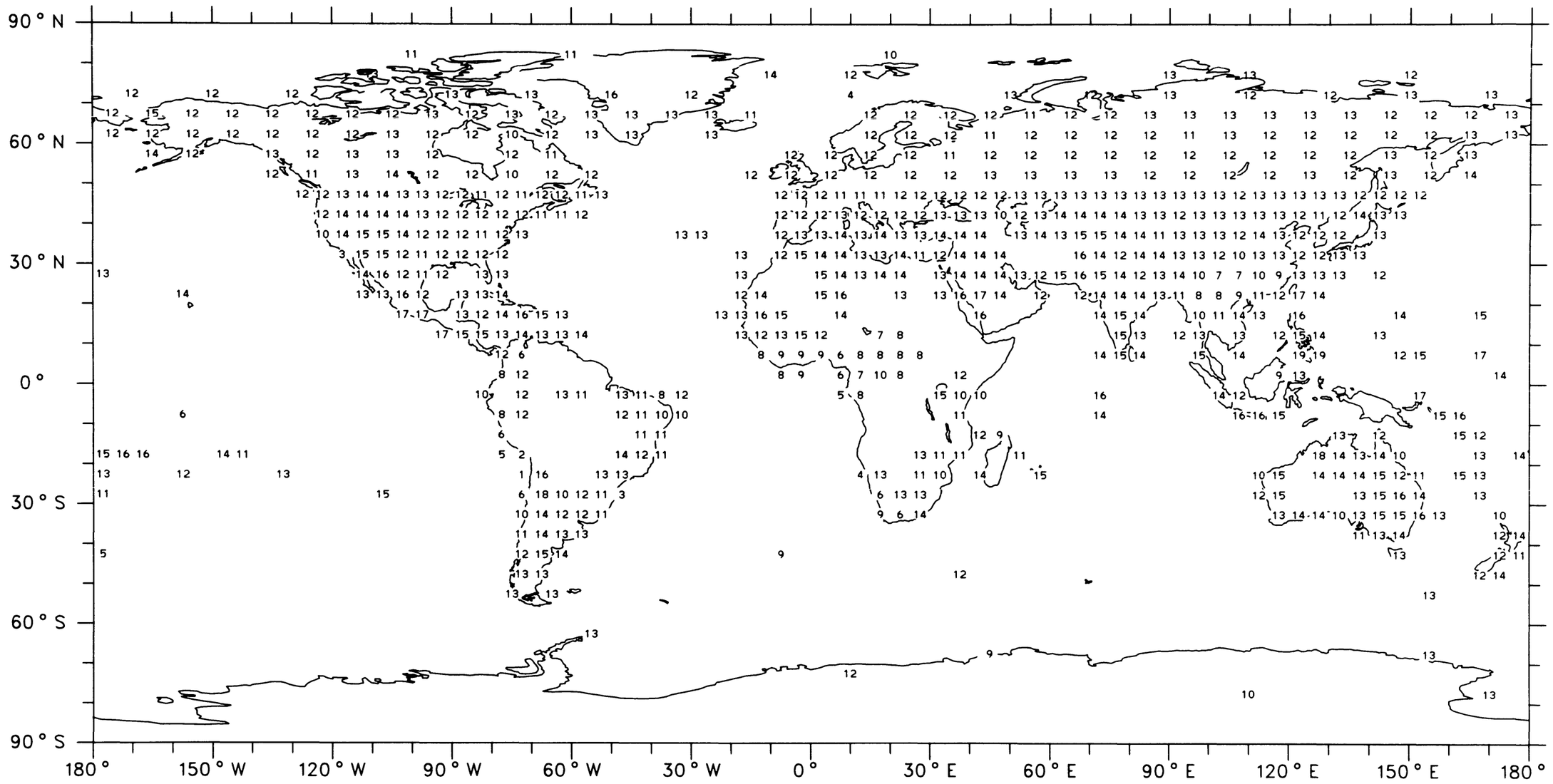
Map 24

GLOBAL AVERAGE (LAND) 7 %

Total Cloud Cover

Phase of Diurnal Cycle (Local Time of Maximum)

September, October, November (1971-1981) — **Land Areas Only**



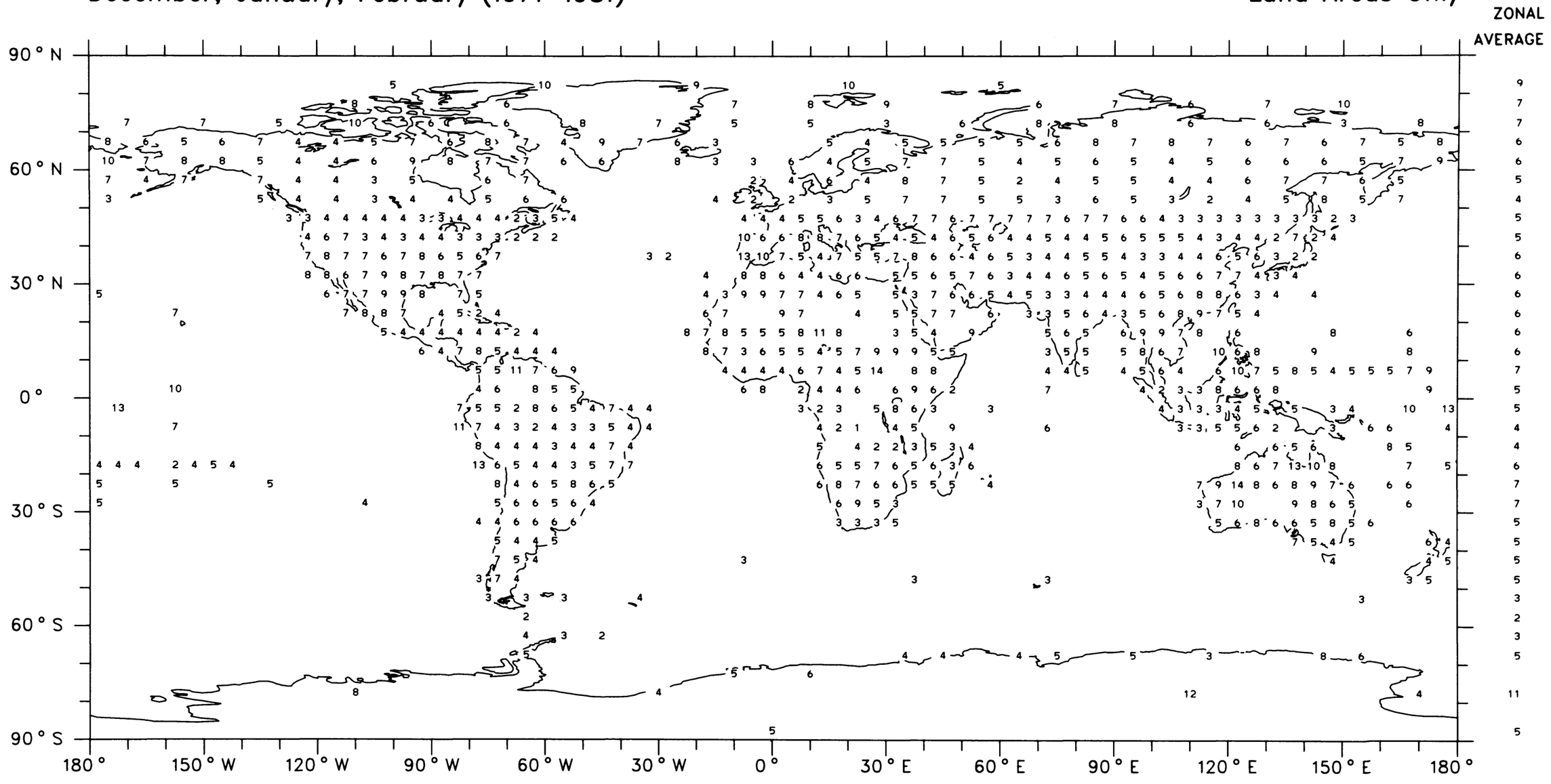
Map 25

Interannual Variation of Total Cloud Cover :

Standard Deviation of Seasonal Means (% Cloud Cover)

December, January, February (1971-1981)

Land Areas Only



Map 26

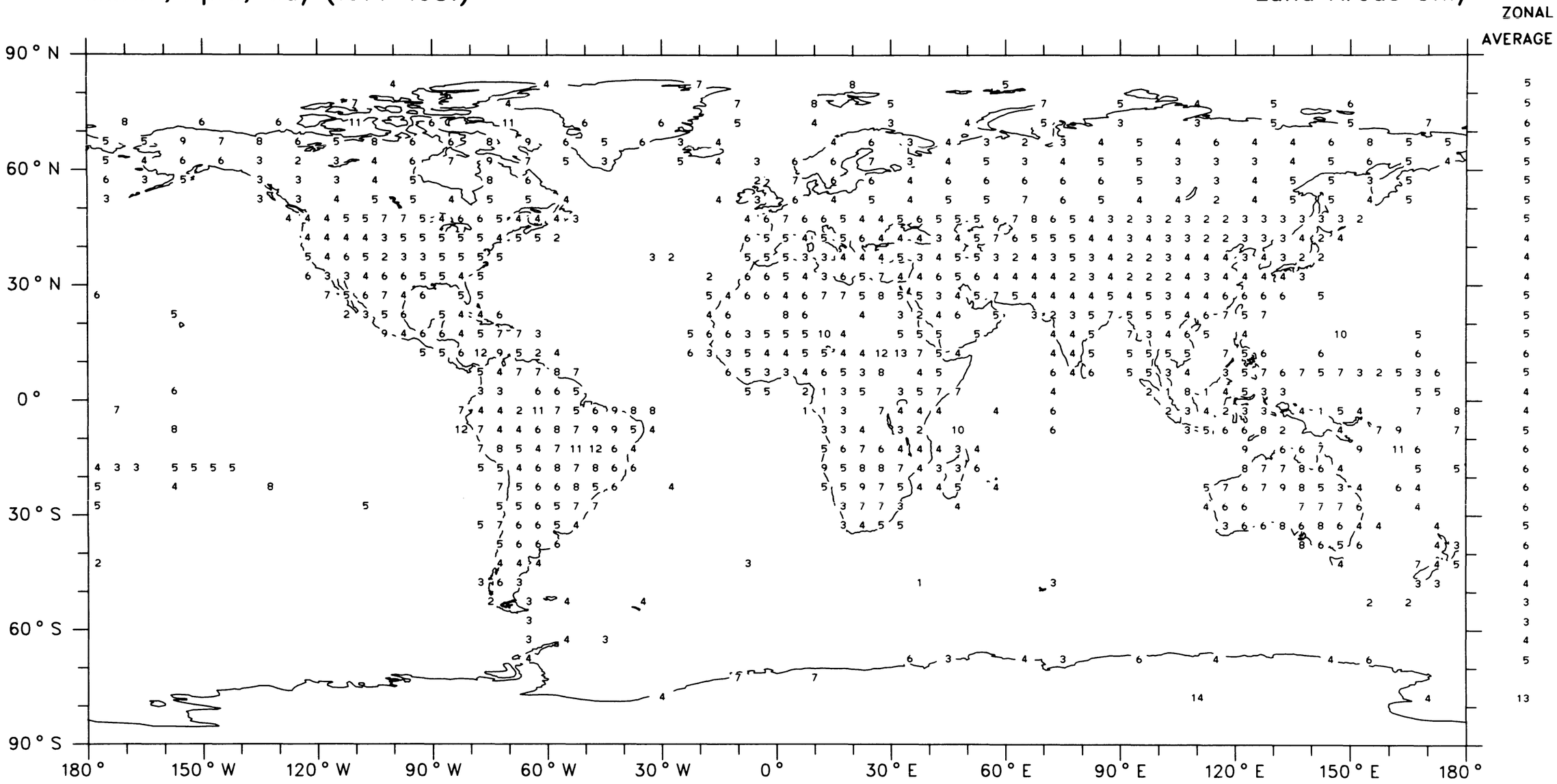
GLOBAL AVERAGE (LAND) 6 %

Interannual Variation of Total Cloud Cover :

Standard Deviation of Seasonal Means (% Cloud Cover)

March, April, May (1971-1981)

Land Areas Only



GLOBAL AVERAGE (LAND) 5 %

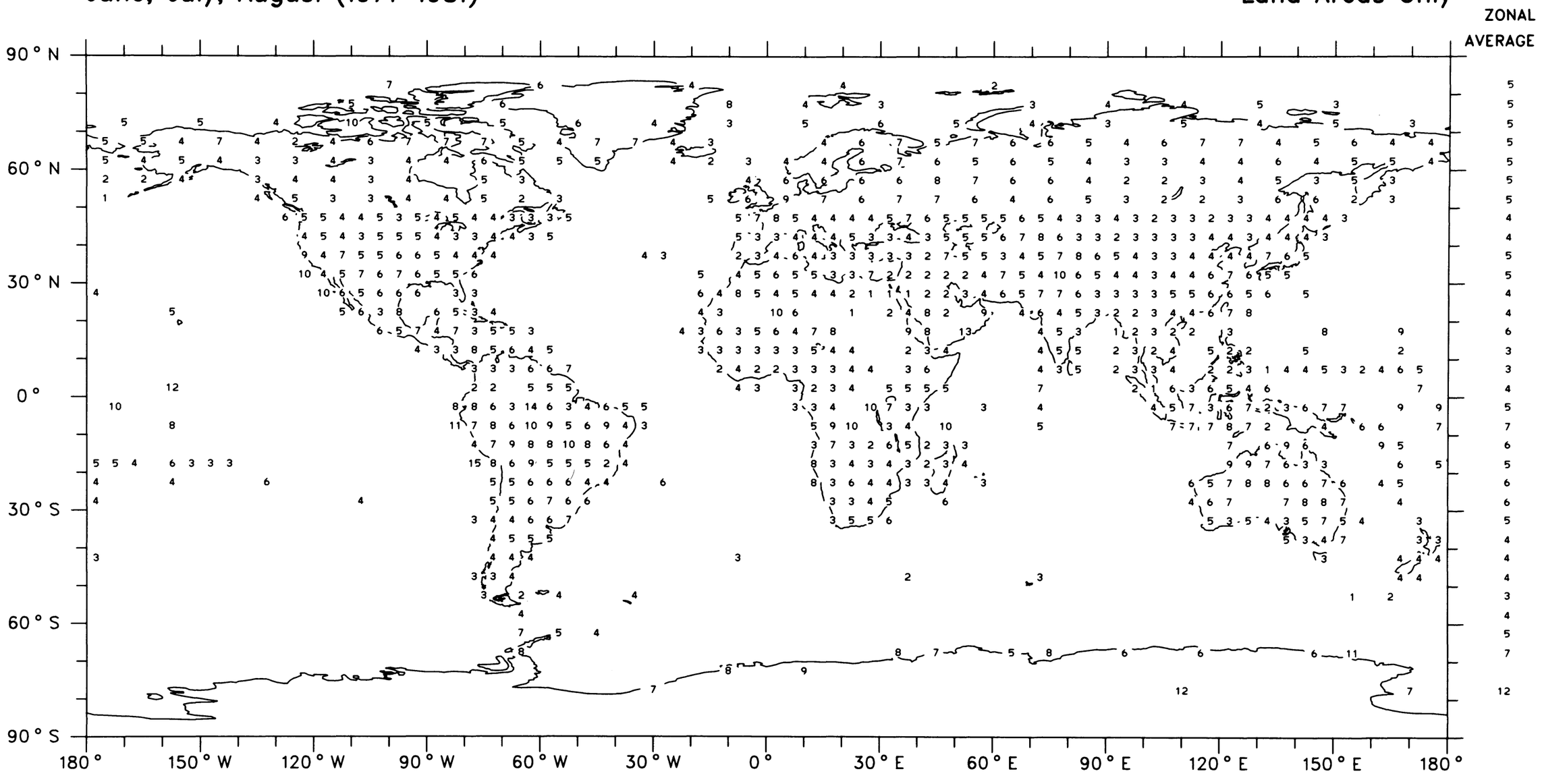
Map 27

Interannual Variation of Total Cloud Cover :

Standard Deviation of Seasonal Means (% Cloud Cover)

June, July, August (1971-1981)

Land Areas Only



Map 28

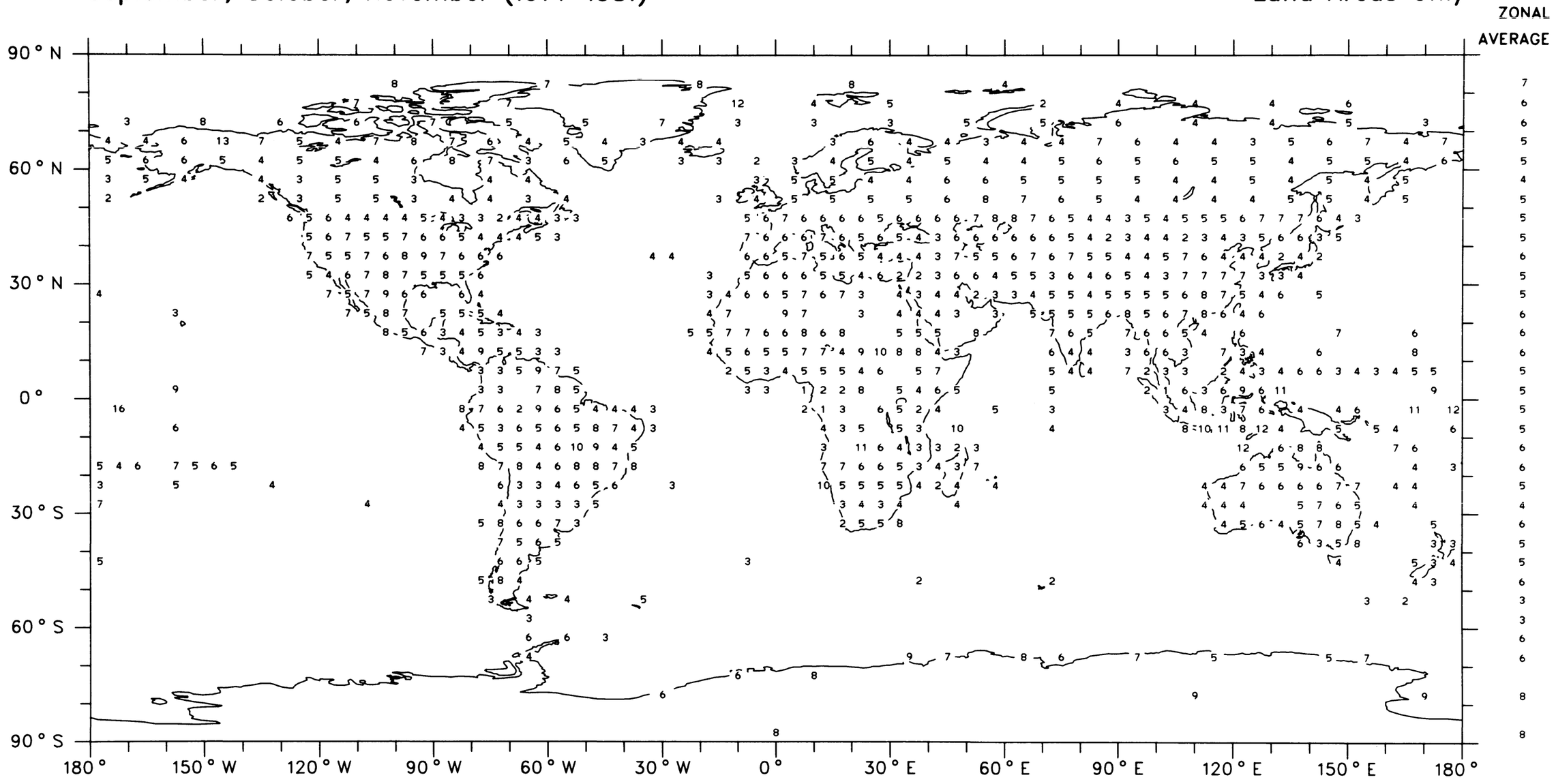
GLOBAL AVERAGE (LAND) 5 %

Interannual Variation of Total Cloud Cover :

Standard Deviation of Seasonal Means (% Cloud Cover)

September, October, November (1971-1981)

Land Areas Only



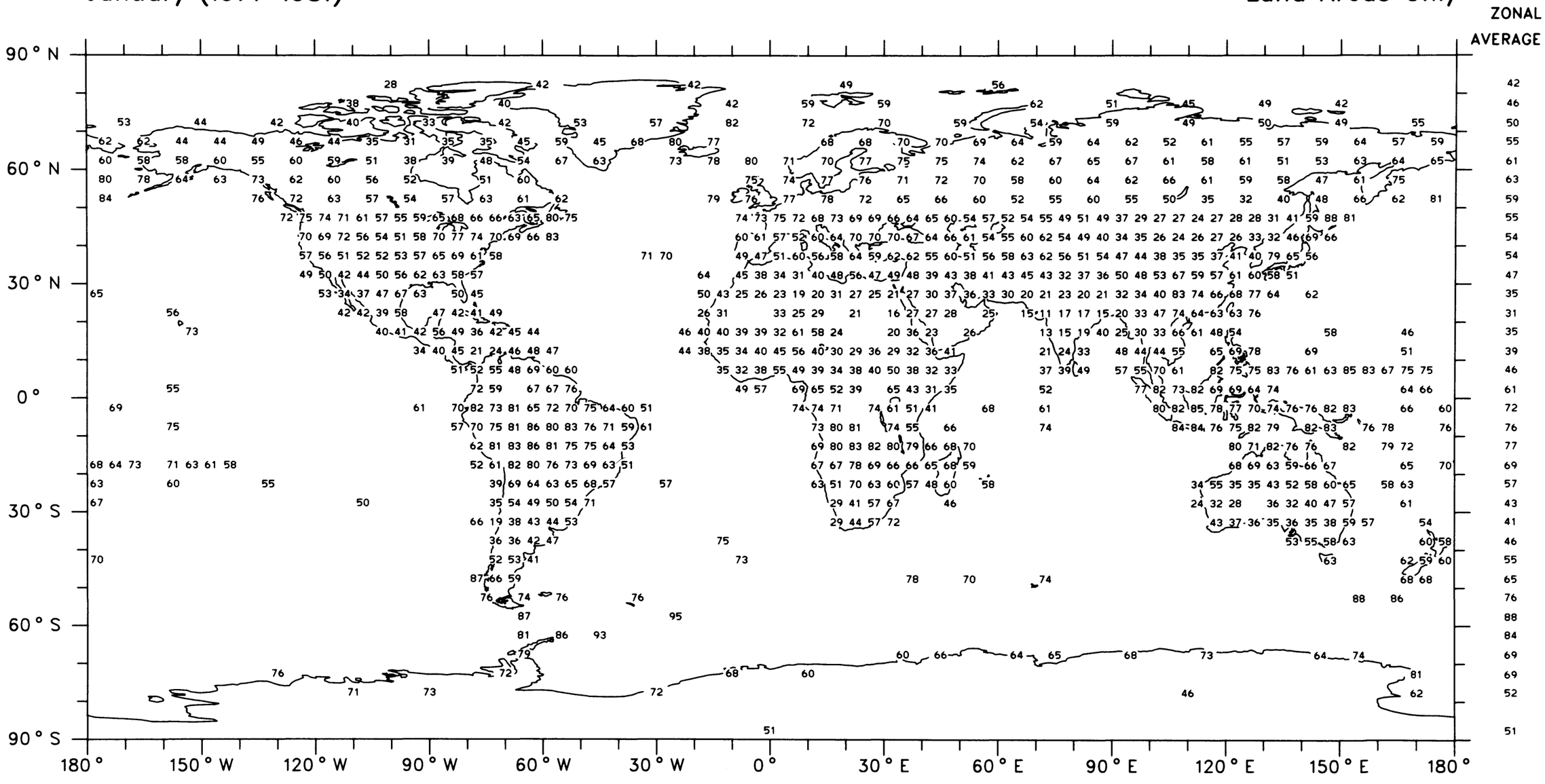
GLOBAL AVERAGE (LAND) 5 %

Map 29

Average Total Cloud Cover (%)

January (1971-1981)

Land Areas Only



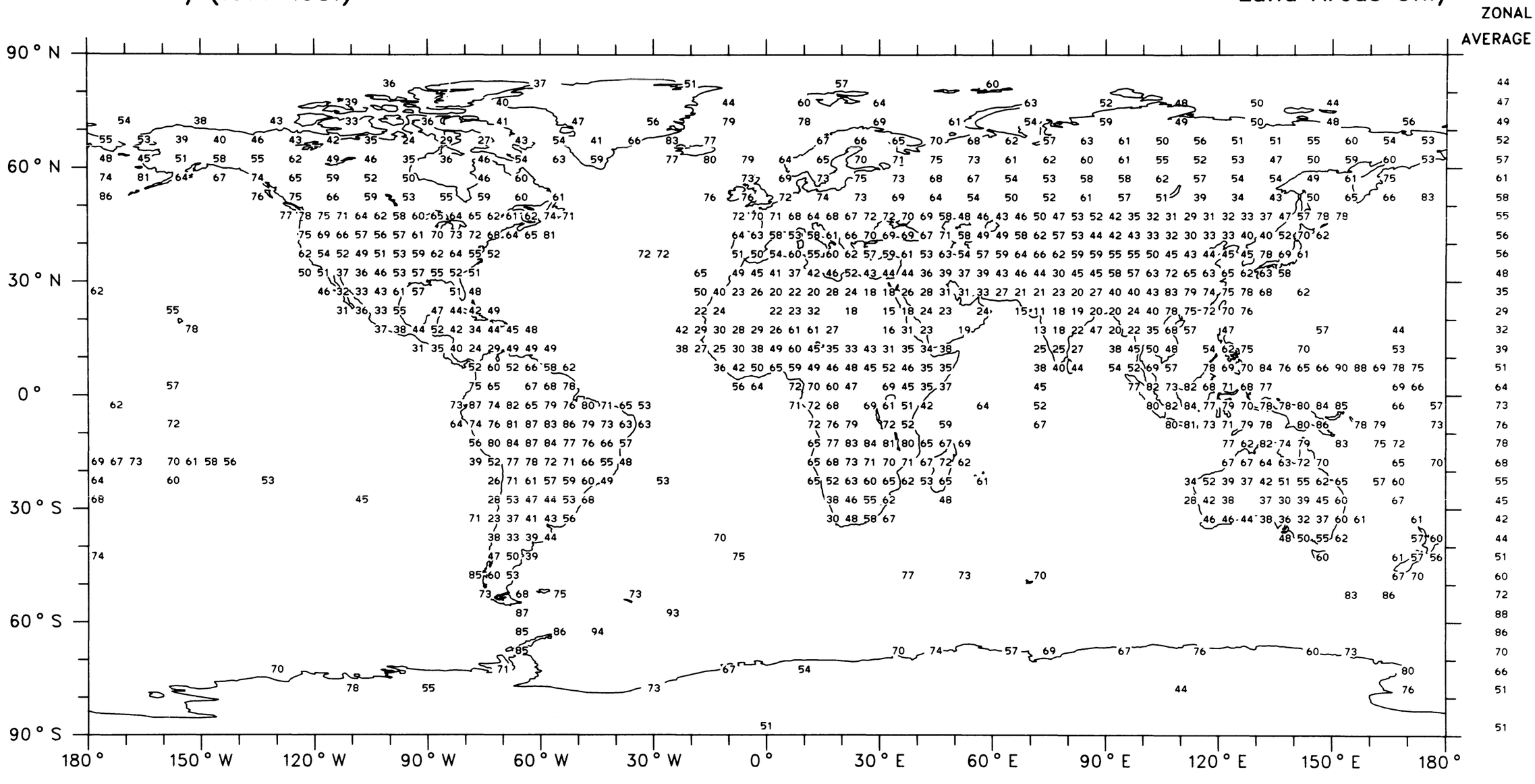
Map 30

GLOBAL AVERAGE (LAND) 54 %

Average Total Cloud Cover (%)

February (1971-1981)

Land Areas Only



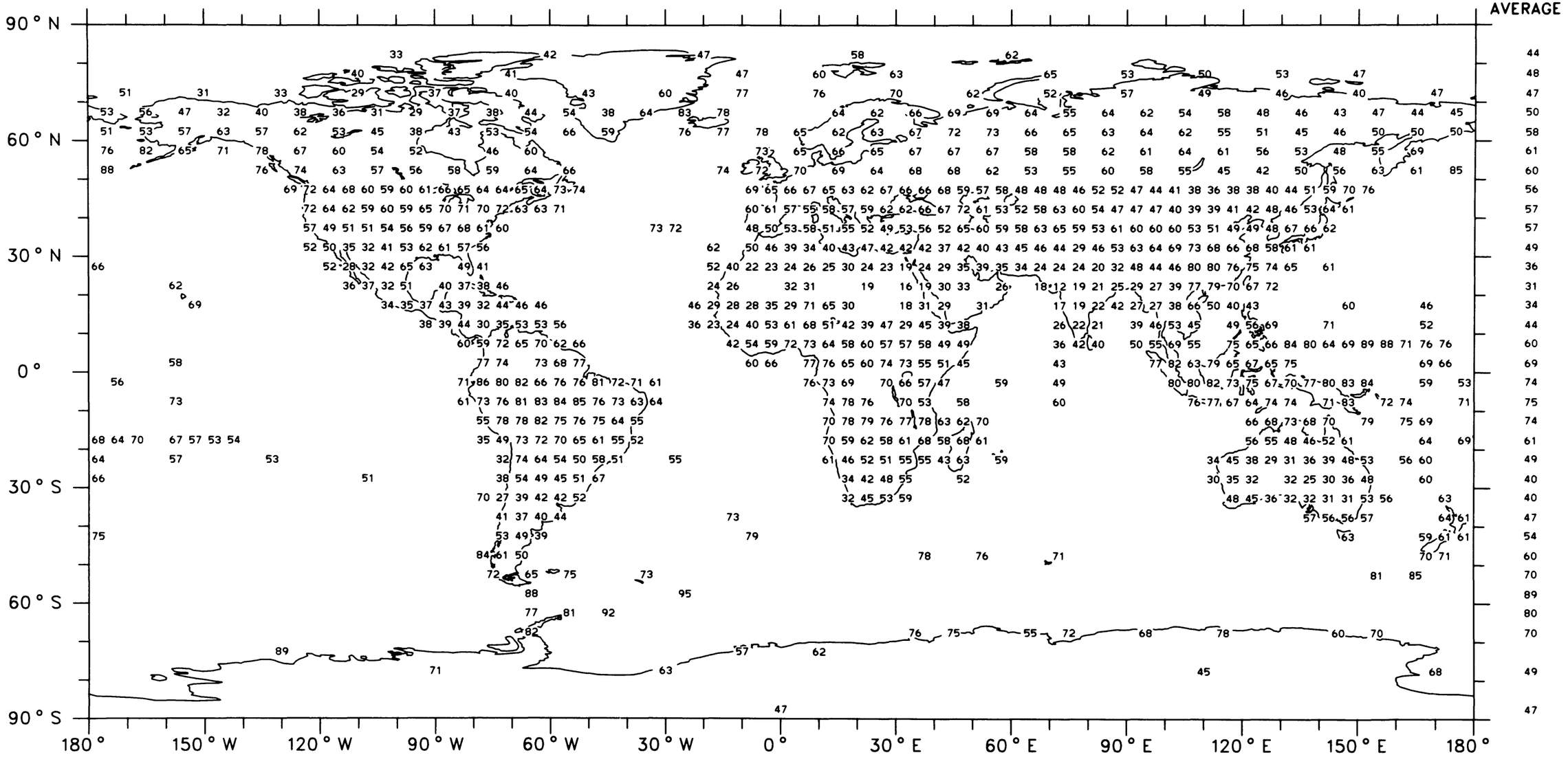
GLOBAL AVERAGE (LAND) 53 %

Map 31

Average Total Cloud Cover (%)

March (1971-1981)

Land Areas Only



Map 32

GLOBAL AVERAGE (LAND) 53 %

Average Total Cloud Cover (%)

April (1971-1981)

Land Areas Only

ZONAL AVERAGE

90 ° N
60 ° N
30 ° N
0 °
30 ° S
60 ° S
90 ° S

180 ° 150 ° W 120 ° W 90 ° W 60 ° W 30 ° W 0 ° 30 ° E 60 ° E 90 ° E 120 ° E 150 ° E 180 °

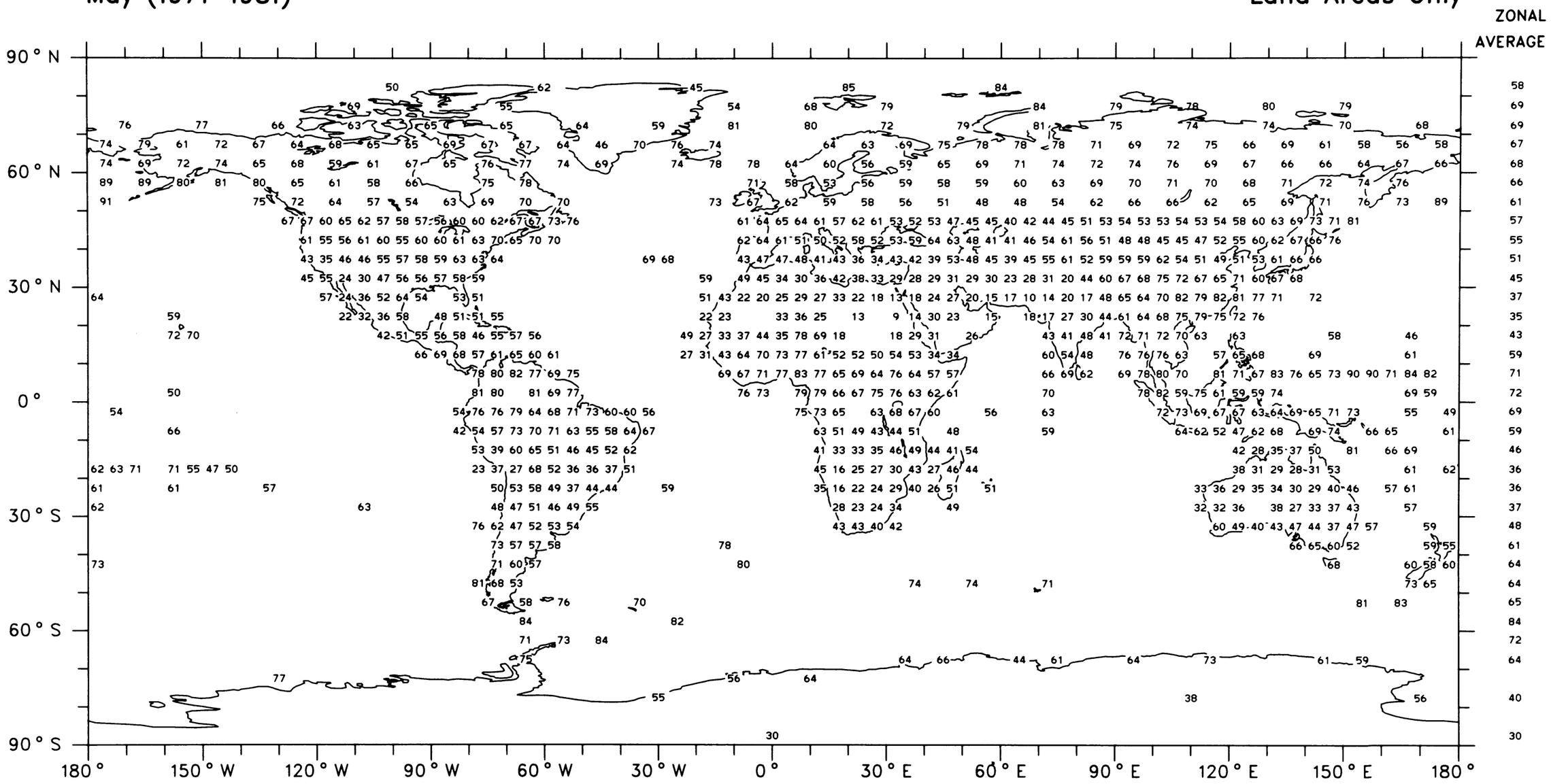
GLOBAL AVERAGE (LAND) 53 %

Map 33

Average Total Cloud Cover (%)

May (1971-1981)

Land Areas Only



Map 34

GLOBAL AVERAGE (LAND) 53 %

Average Total Cloud Cover (%)

June (1971-1981)

Land Areas Only

ZONAL AVERAGE

90 ° N
60 ° N
30 ° N
0 °
30 ° S
60 ° S
90 ° S

180 ° 150 ° W 120 ° W 90 ° W 60 ° W 30 ° W 0 ° 30 ° E 60 ° E 90 ° E 120 ° E 150 ° E 180 °

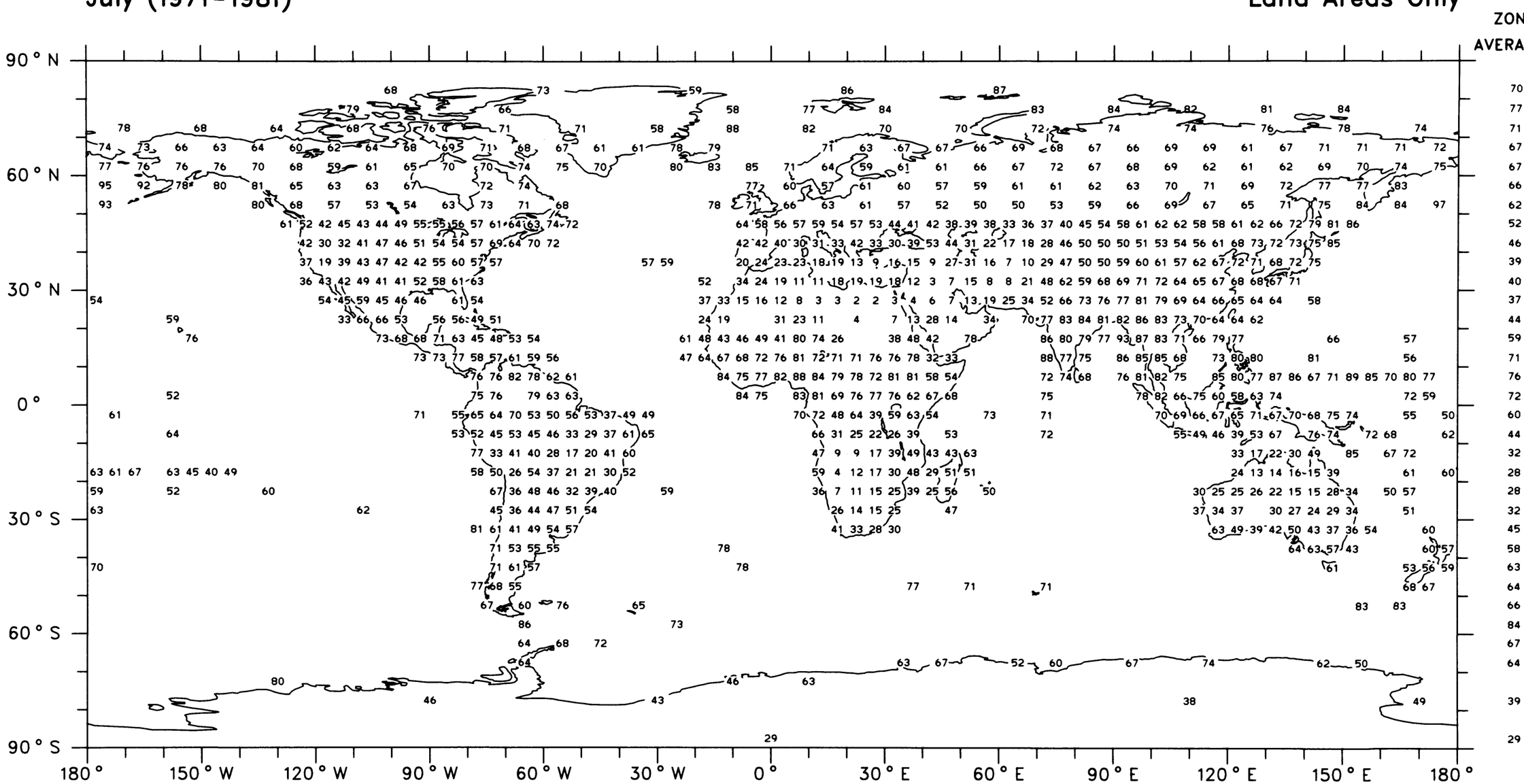
GLOBAL AVERAGE (LAND) 52 %

Map 35

Average Total Cloud Cover (%)

July (1971-1981)

Land Areas Only



Map 36

GLOBAL AVERAGE (LAND) 51 %

Average Total Cloud Cover (%)

August (1971-1981)

Land Areas Only

ZONAL AVERAGE

90 ° N
60 ° N
30 ° N
0 °
30 ° S
60 ° S
90 ° S

180 ° 150 ° W 120 ° W 90 ° W 60 ° W 30 ° W 0 ° 30 ° E 60 ° E 90 ° E 120 ° E 150 ° E 180 °

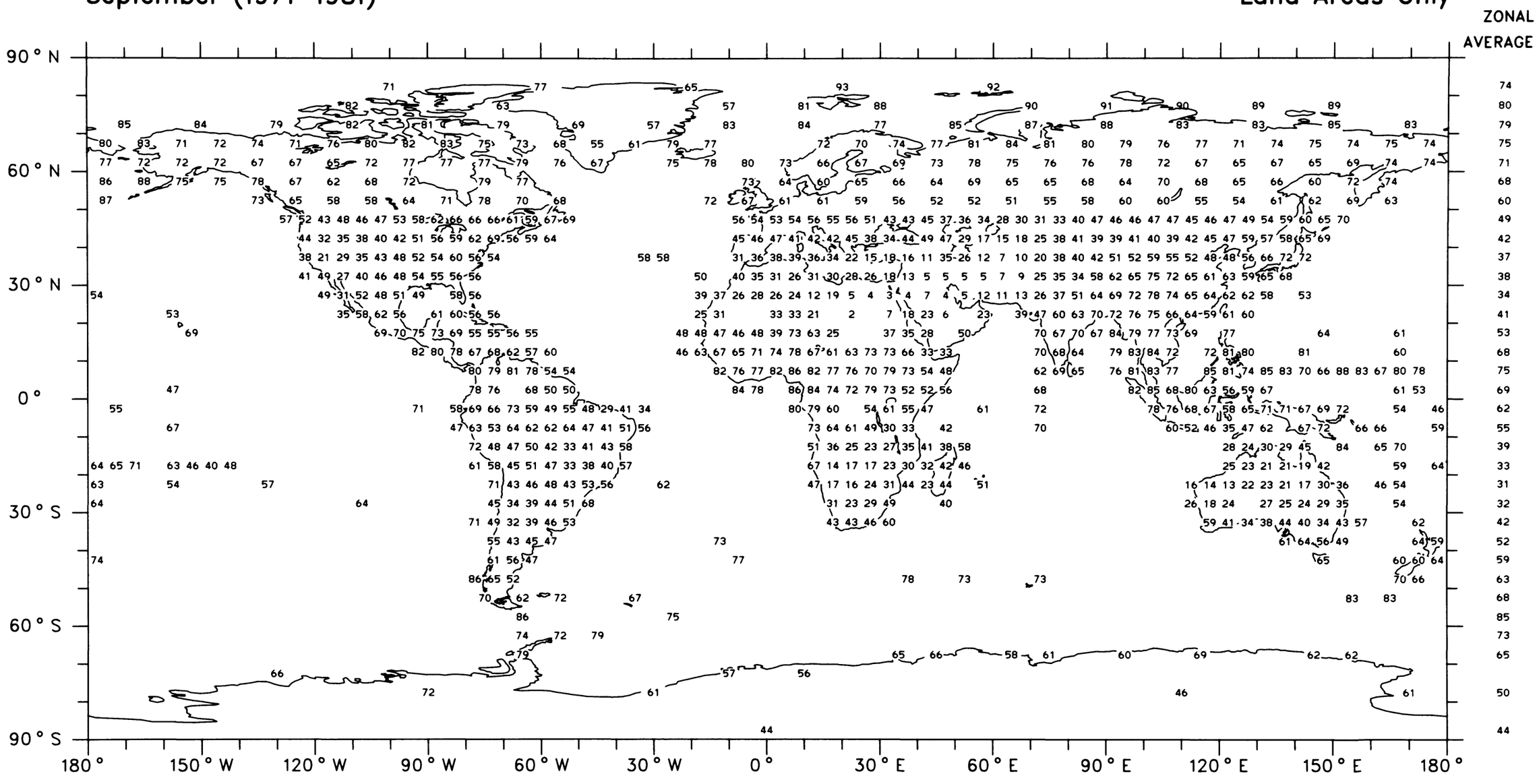
GLOBAL AVERAGE (LAND) 52 %

Map 37

Average Total Cloud Cover (%)

September (1971-1981)

Land Areas Only



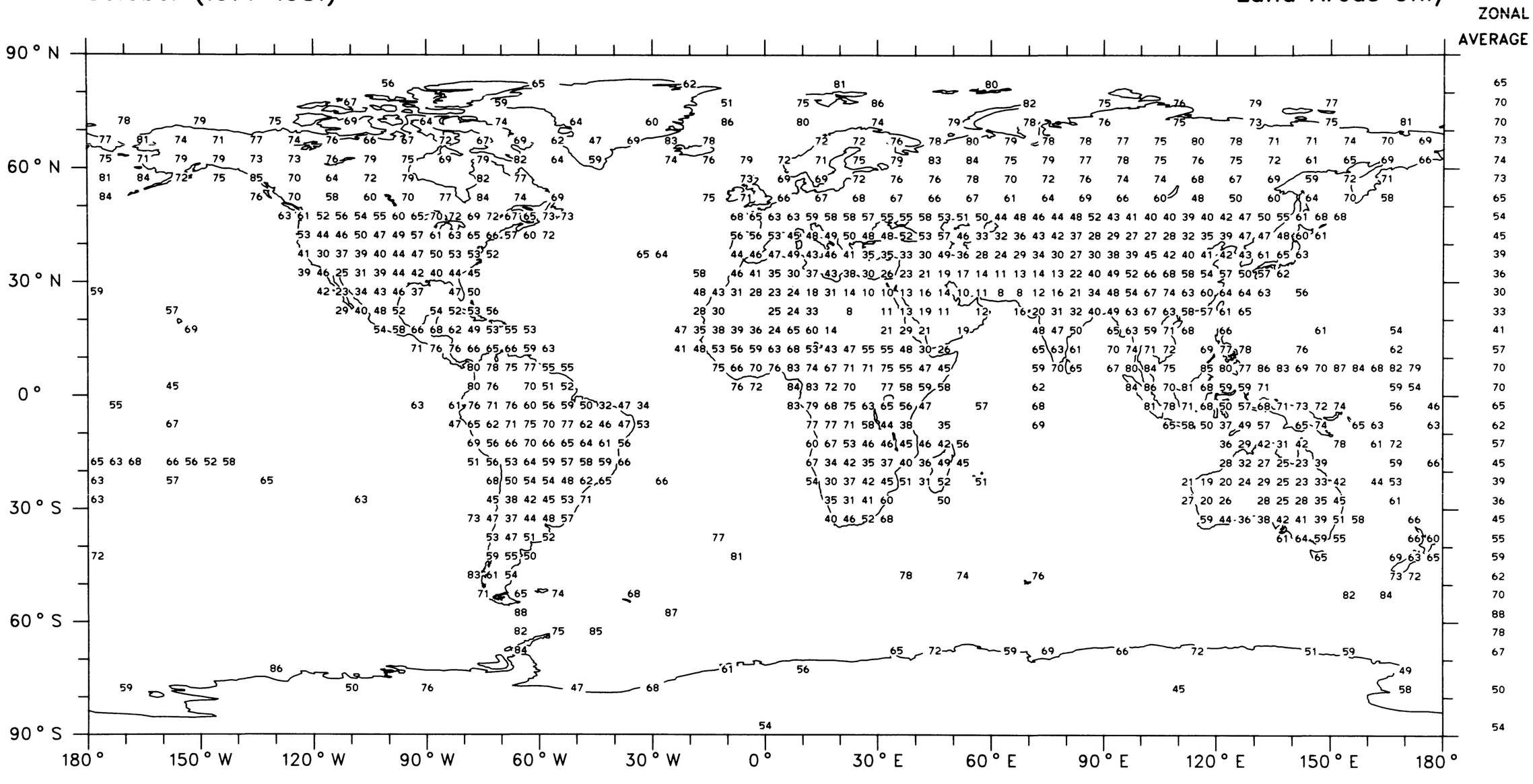
Map 38

GLOBAL AVERAGE (LAND) 52 %

Average Total Cloud Cover (%)

October (1971-1981)

Land Areas Only



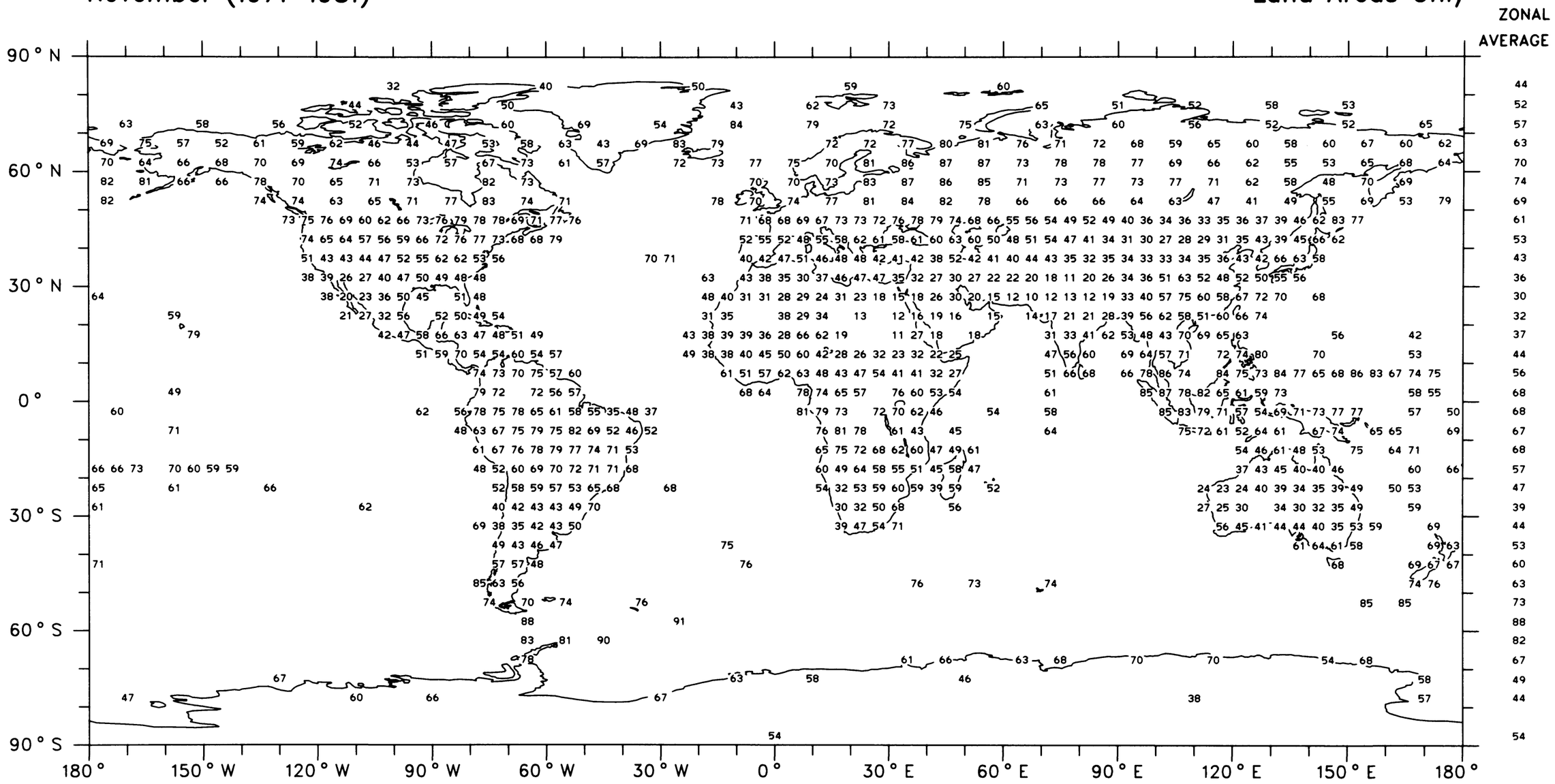
GLOBAL AVERAGE (LAND) 53 %

Map 39

Average Total Cloud Cover (%)

November (1971-1981)

Land Areas Only



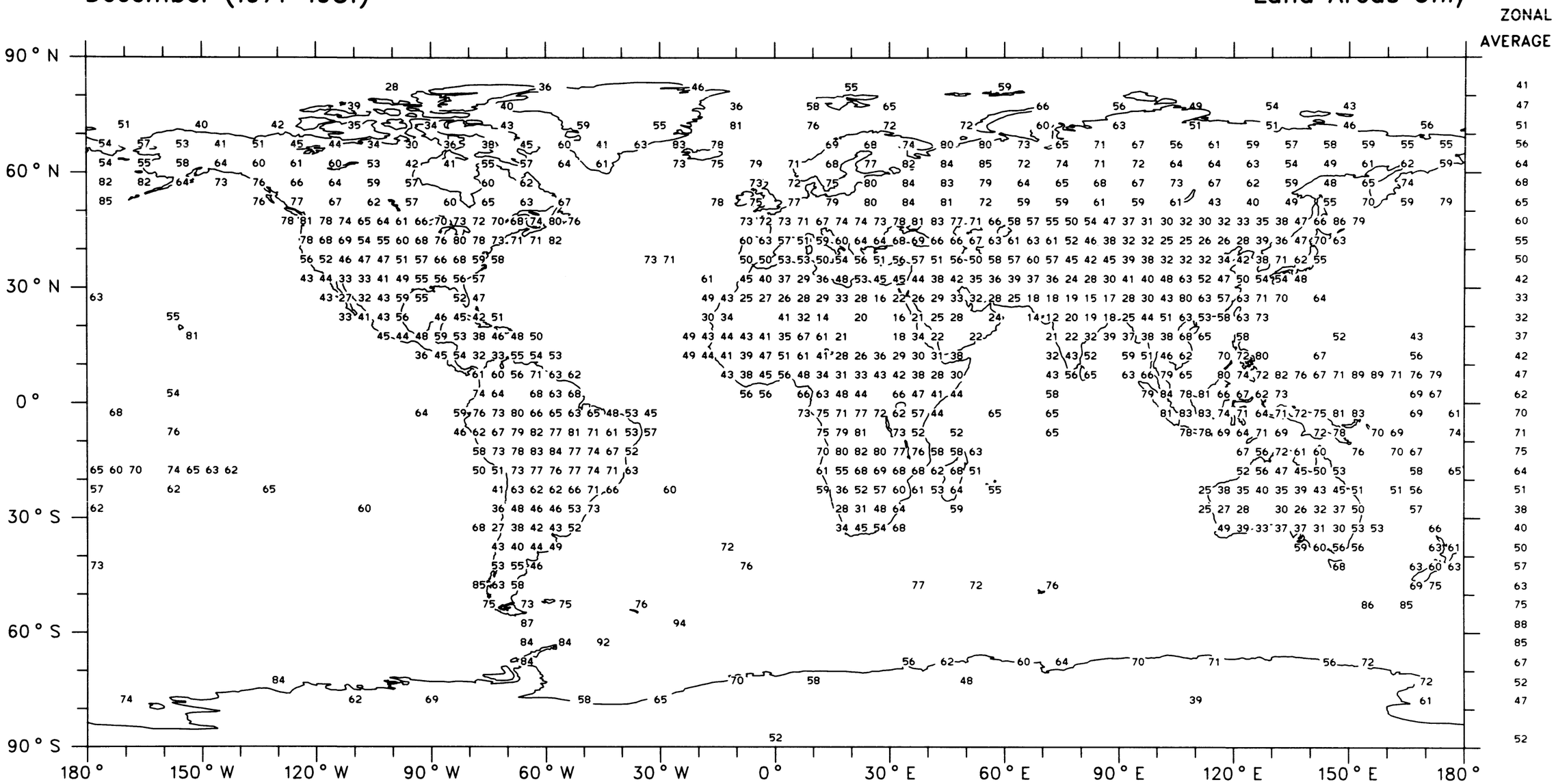
Map 40

GLOBAL AVERAGE (LAND) 53 %

Average Total Cloud Cover (%)

December (1971-1981)

Land Areas Only



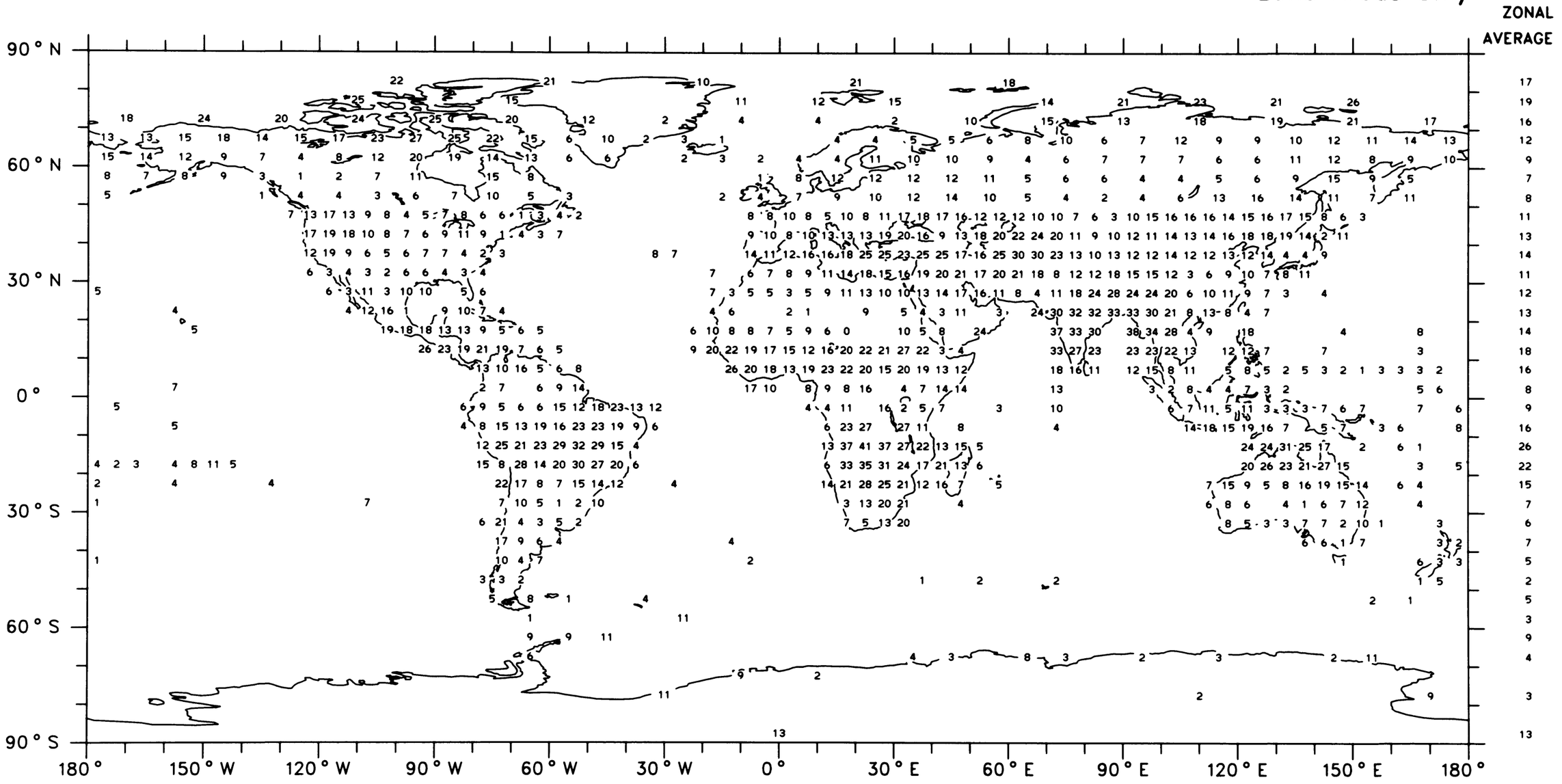
GLOBAL AVERAGE (LAND) 53 %

Map 41

Total Cloud Cover

Amplitude of Annual Cycle (% Cloud Cover)

Land Areas Only



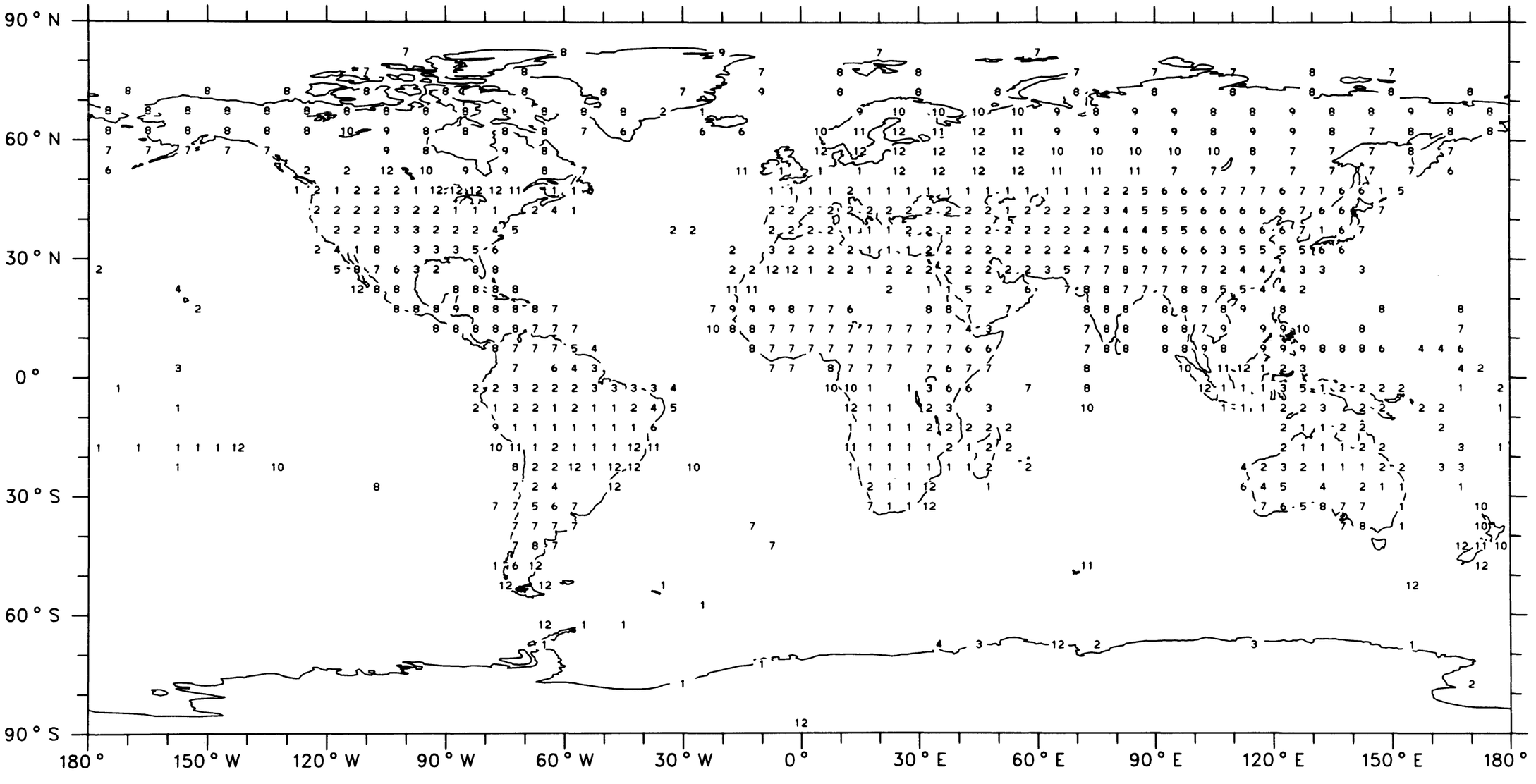
Map 42

GLOBAL AVERAGE (LAND) 12 %

Total Cloud Cover

Phase of Annual Cycle (Month of Maximum)

Land Areas Only



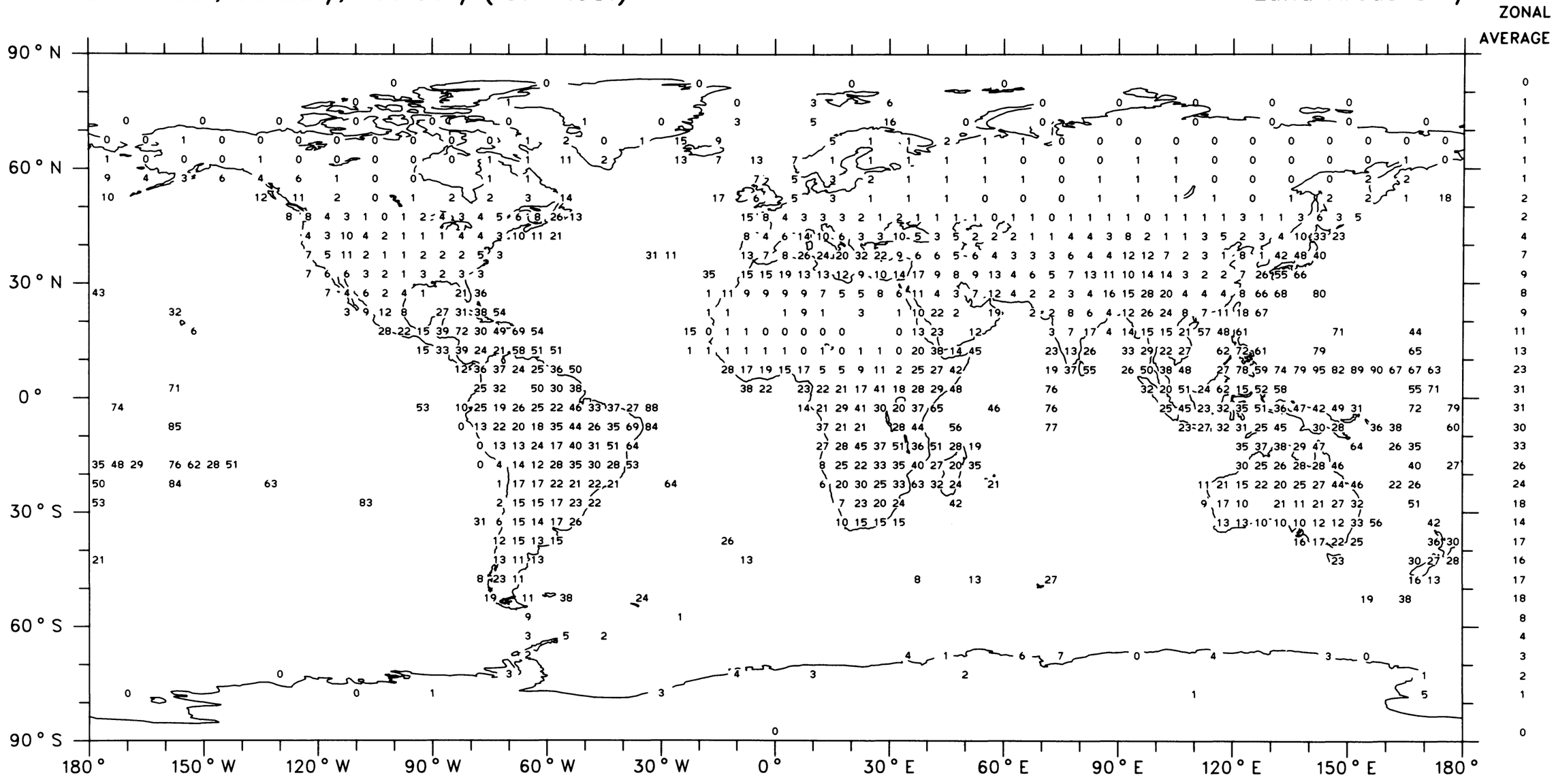
Map 43

Cumulus

Frequency of Occurrence (%)

December, January, February (1971-1981)

Land Areas Only



Map 44

GLOBAL AVERAGE (LAND) 11 %

Cumulus

Frequency of Occurrence (%)

March, April, May (1971-1981)

Land Areas Only

ZONAL AVERAGE

90° N
60° N
30° N
0°
30° S
60° S
90° S

180° 150° W 120° W 90° W 60° W 30° W 0° 30° E 60° E 90° E 120° E 150° E 180°

GLOBAL AVERAGE (LAND) 14 %

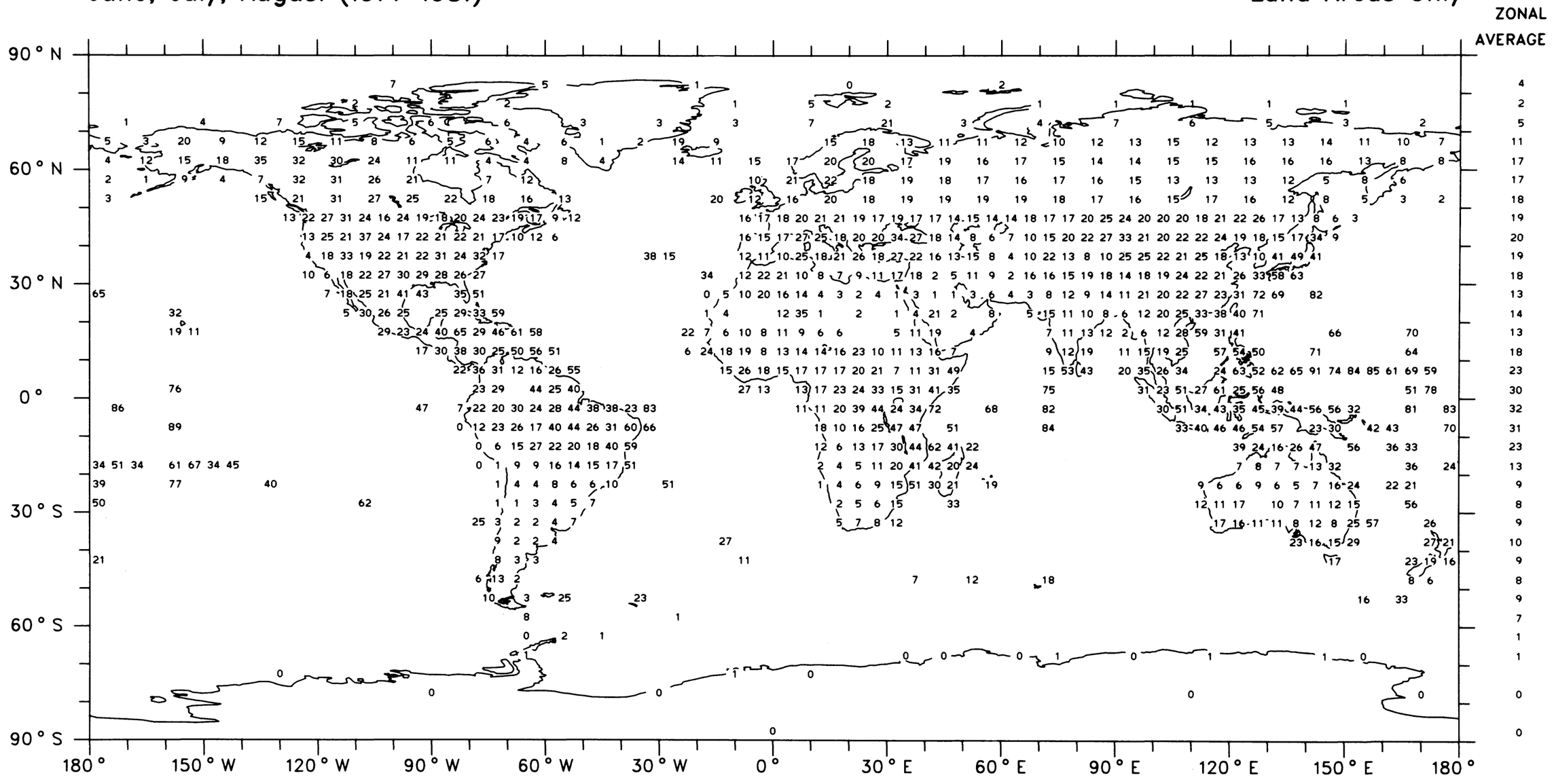
Map 45

Cumulus

Frequency of Occurrence (%)

June, July, August (1971-1981)

Land Areas Only



Map 46

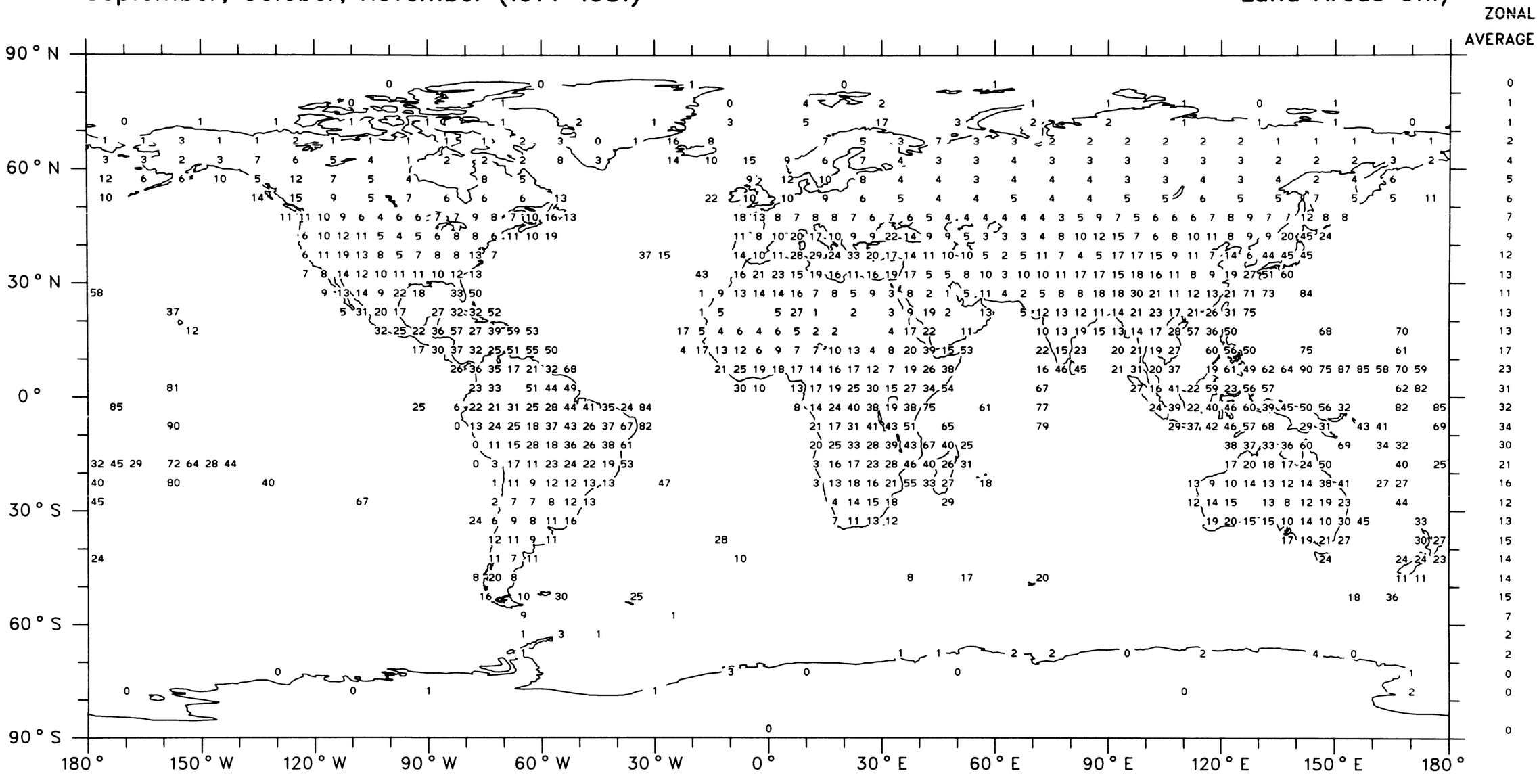
GLOBAL AVERAGE (LAND) 16 %

Cumulus

Frequency of Occurrence (%)

September, October, November (1971-1981)

Land Areas Only



GLOBAL AVERAGE (LAND) 13 %

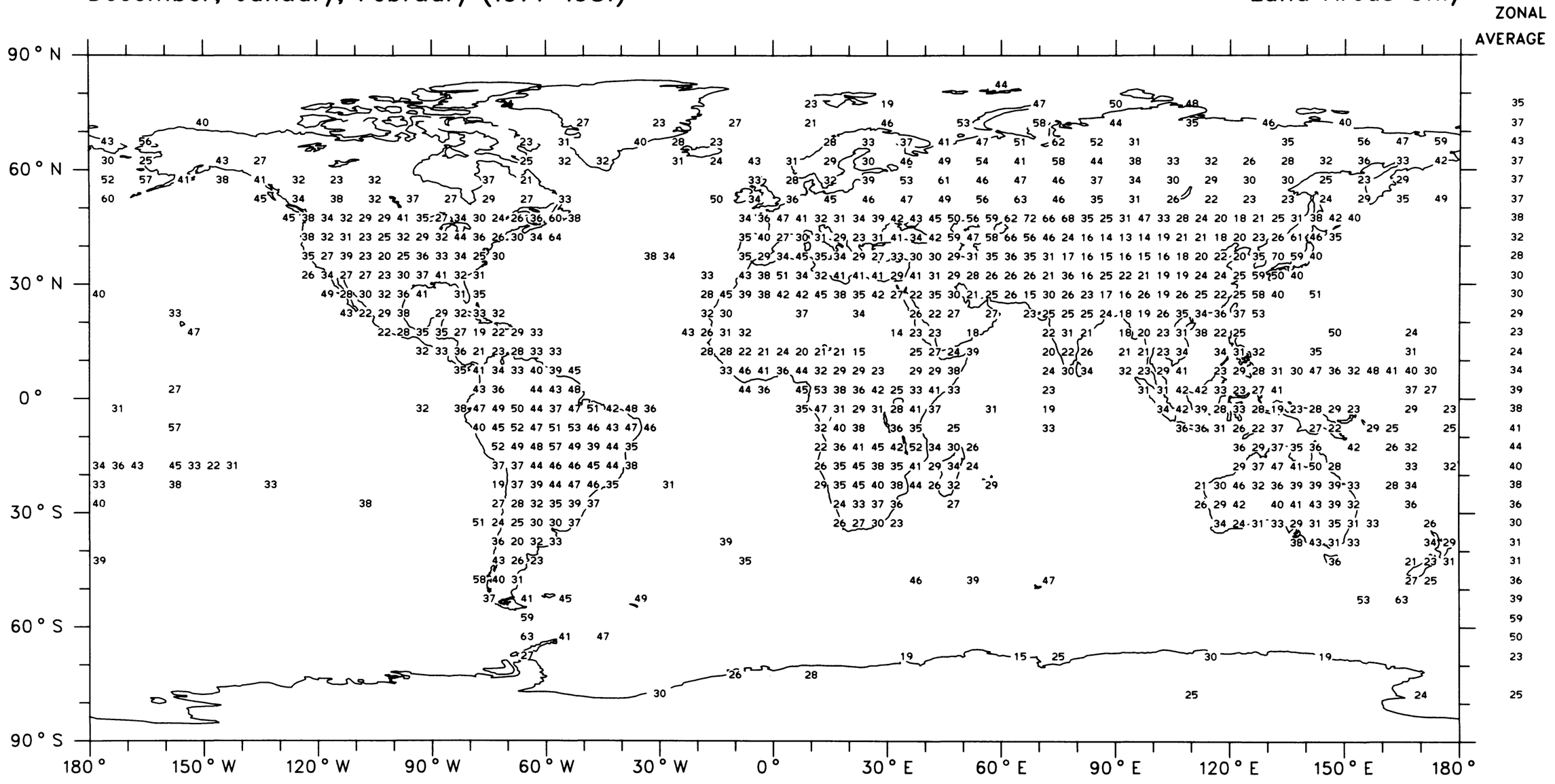
Map 47

Cumulus

Amount - When - Present (%)

December, January, February (1971-1981)

Land Areas Only



Map 48

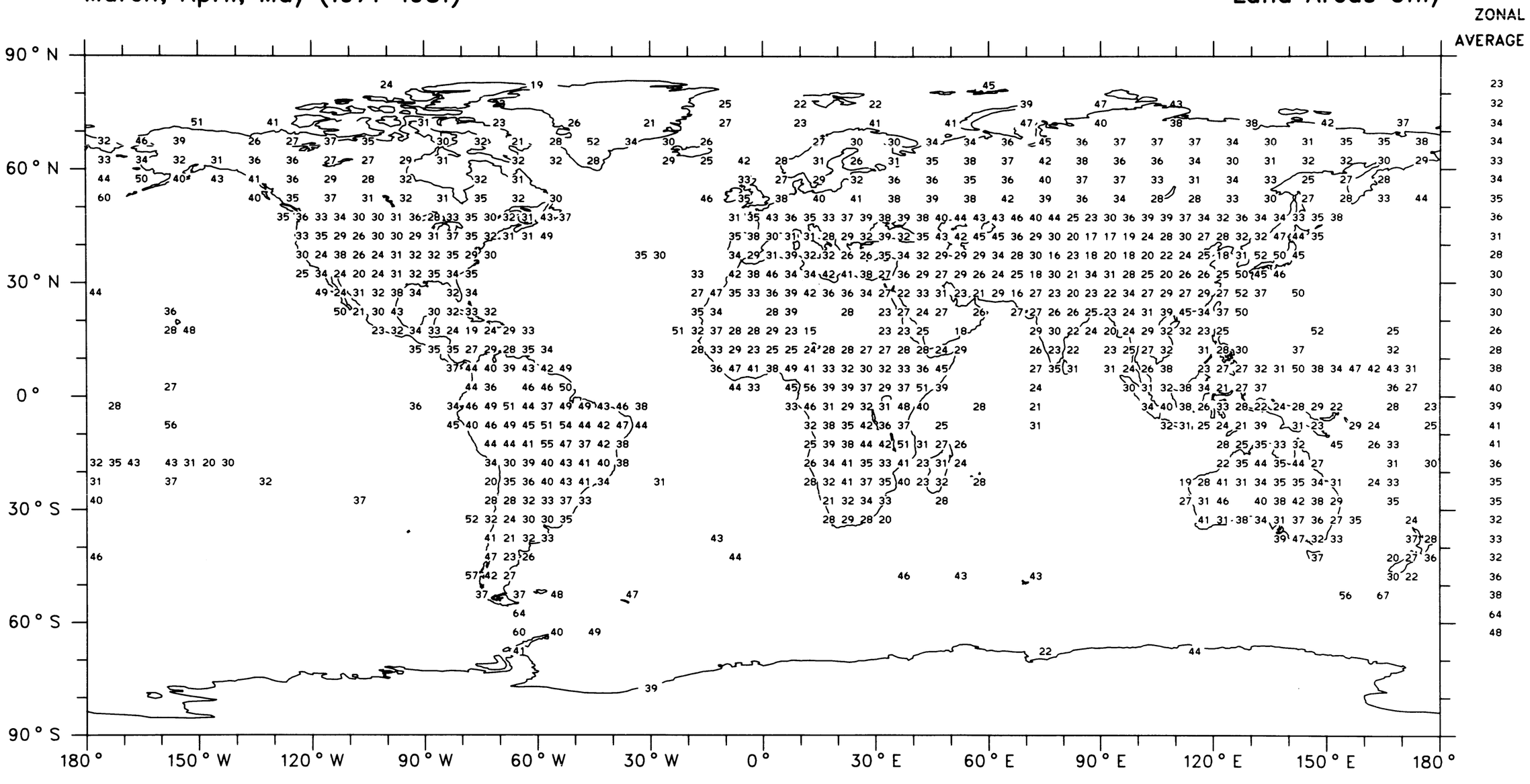
GLOBAL AVERAGE (LAND) 34 %

Cumulus

Amount - When - Present (%)

March, April, May (1971-1981)

Land Areas Only



GLOBAL AVERAGE (LAND) 33 %

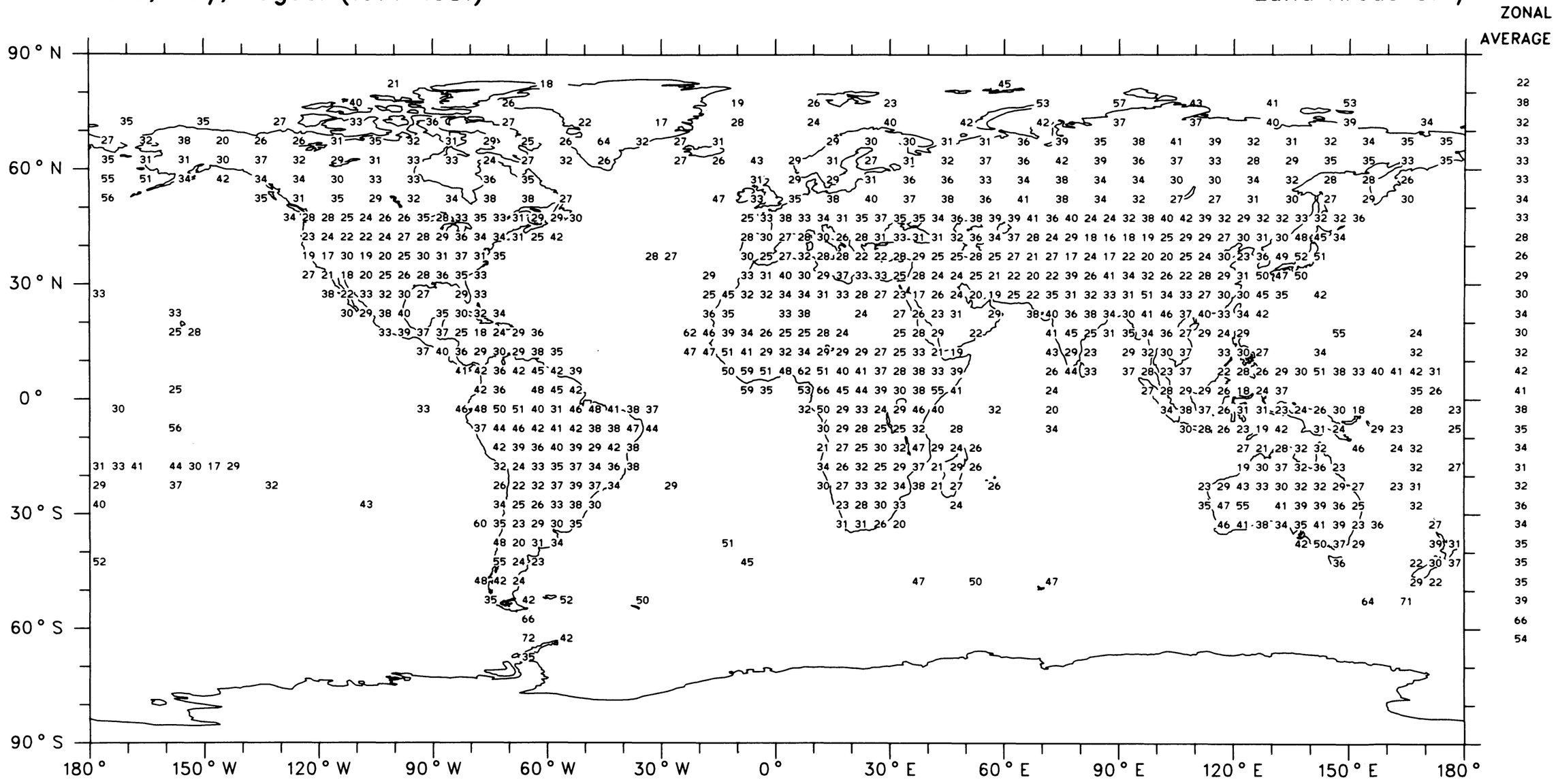
Map 49

Cumulus

Amount-When-Present (%)

June, July, August (1971-1981)

Land Areas Only



Map 50

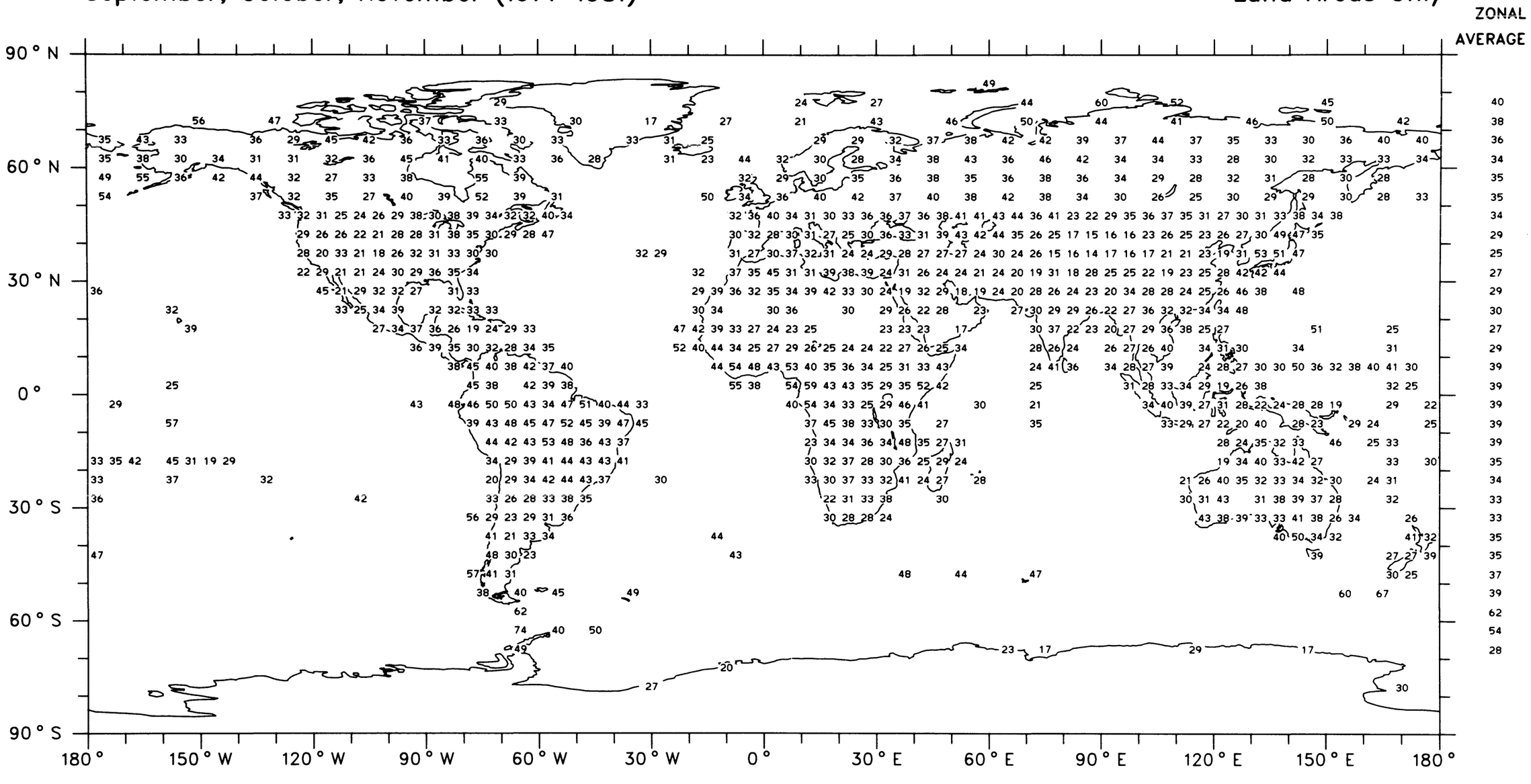
GLOBAL AVERAGE (LAND) 33 %

Cumulus

Amount - When - Present (%)

September, October, November (1971-1981)

Land Areas Only



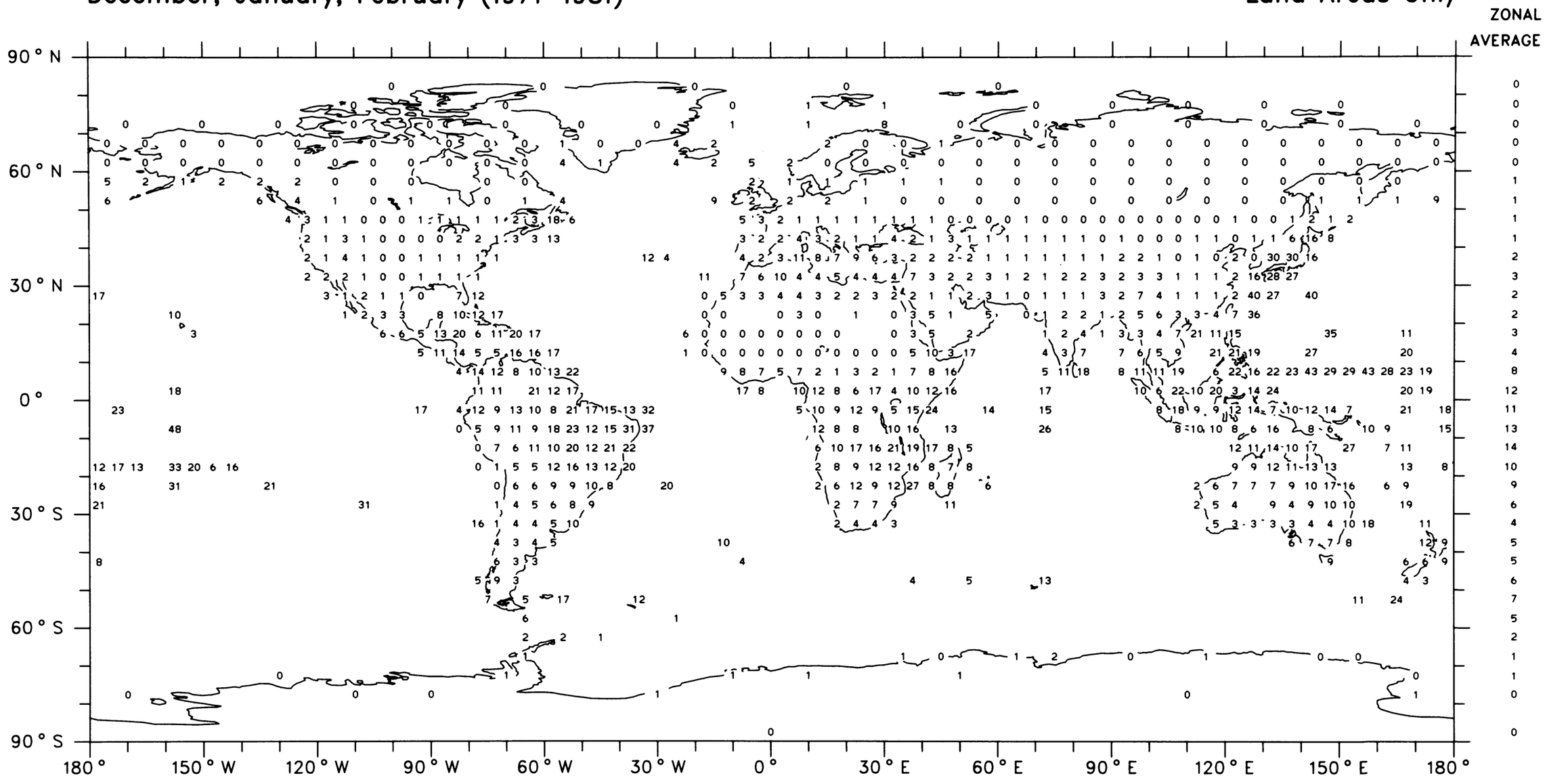
GLOBAL AVERAGE (LAND) 33 %

Map 51

Cumulus

Average Cloud Amount (%)

December, January, February (1971-1981) **Land Areas Only**



Map 52

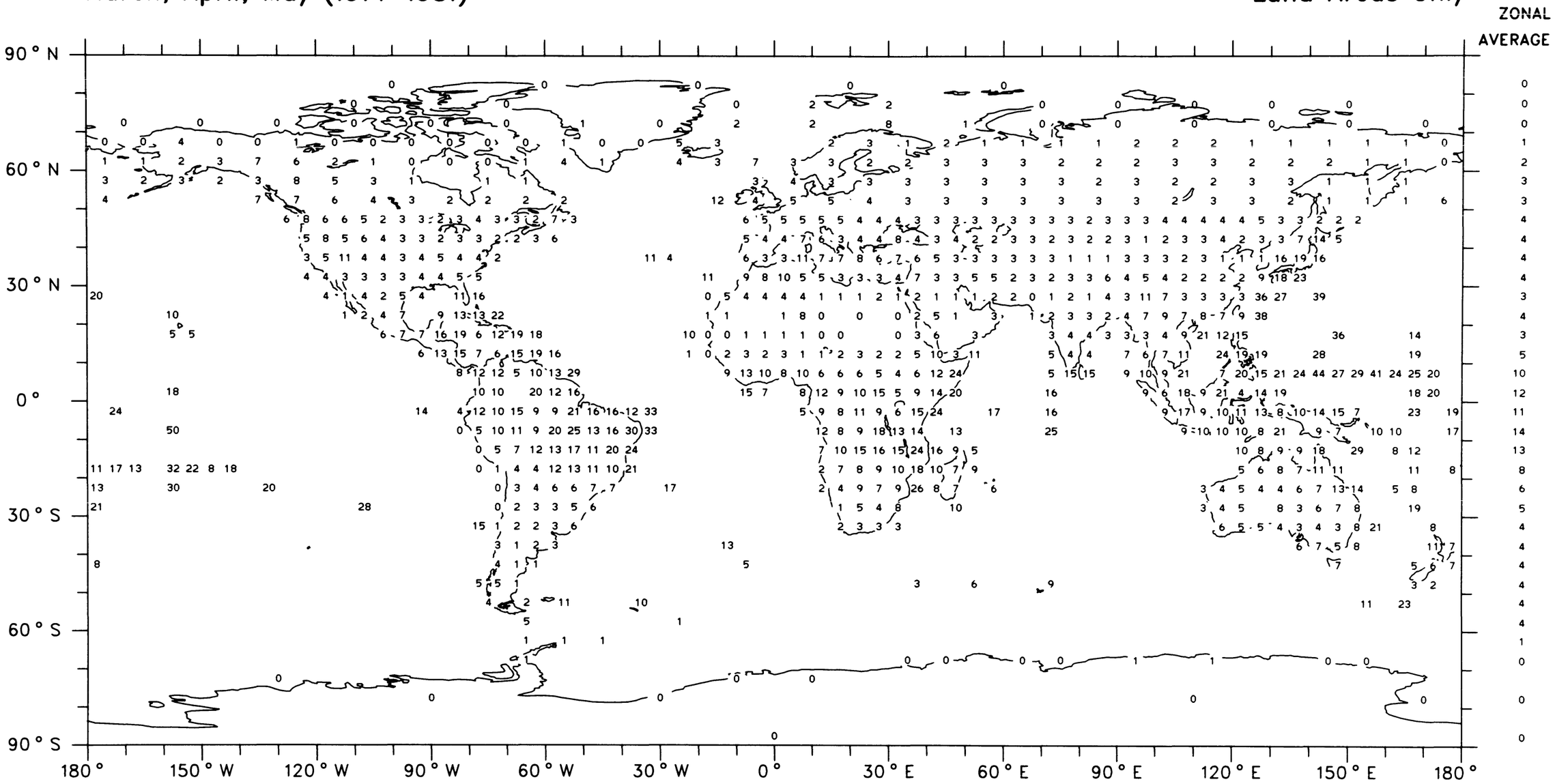
GLOBAL AVERAGE (LAND) 4 %

Cumulus

Average Cloud Amount (%)

March, April, May (1971-1981)

Land Areas Only



GLOBAL AVERAGE (LAND) 5 %

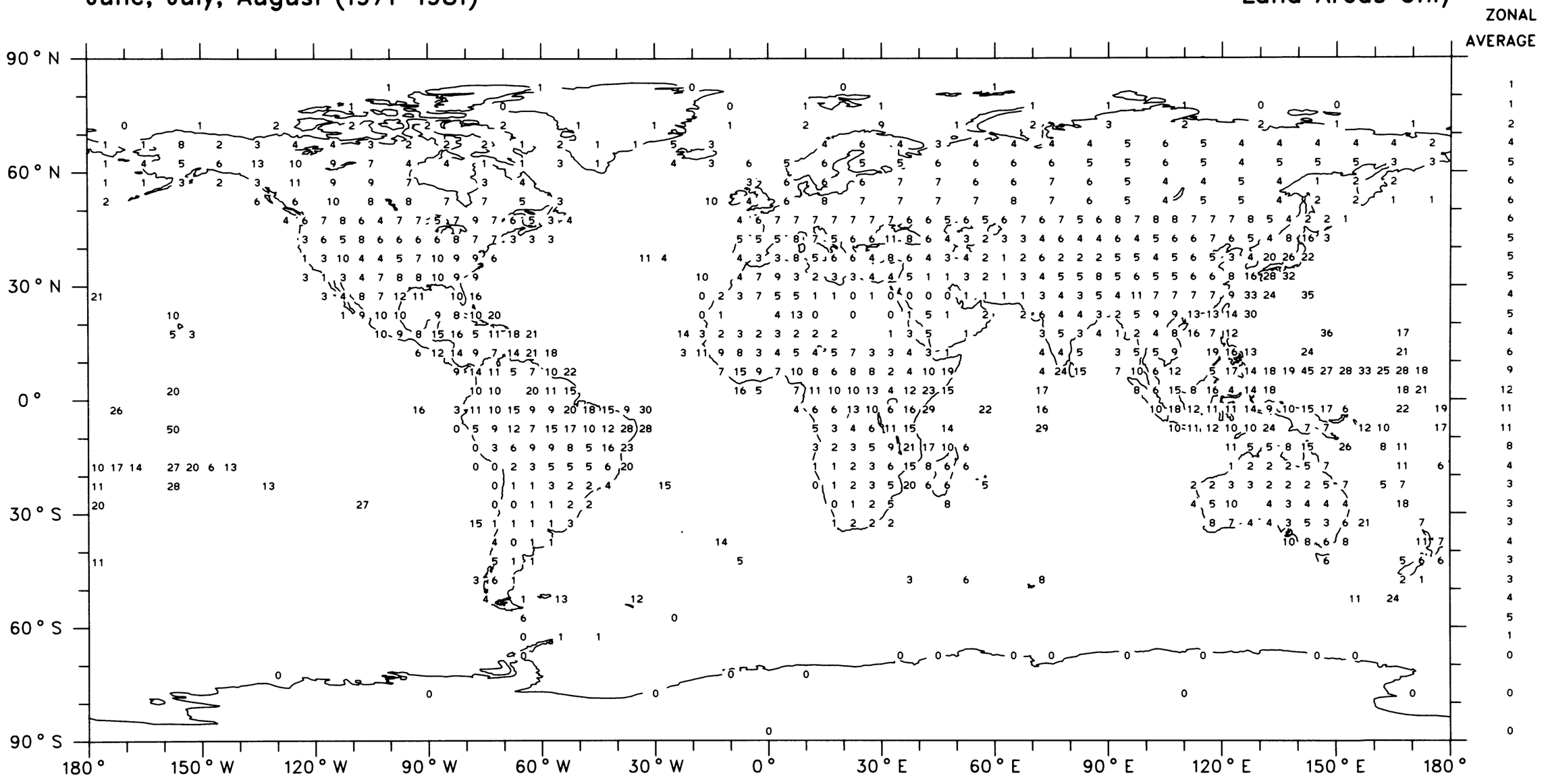
Map 53

Cumulus

Average Cloud Amount (%)

June, July, August (1971-1981)

Land Areas Only



Map 54

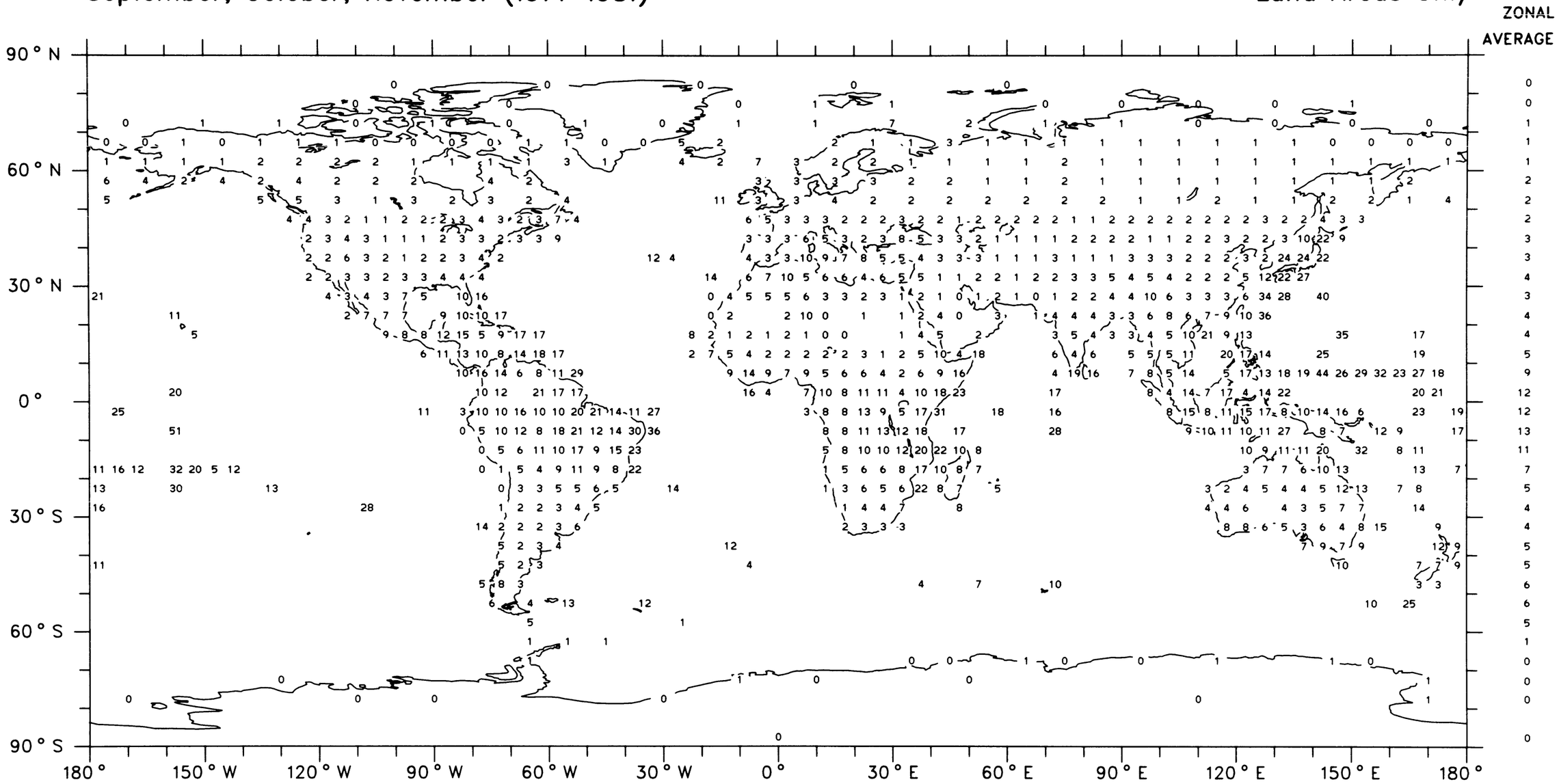
GLOBAL AVERAGE (LAND) 5 %

Cumulus

Average Cloud Amount (%)

September, October, November (1971-1981)

Land Areas Only



GLOBAL AVERAGE (LAND) 4 %

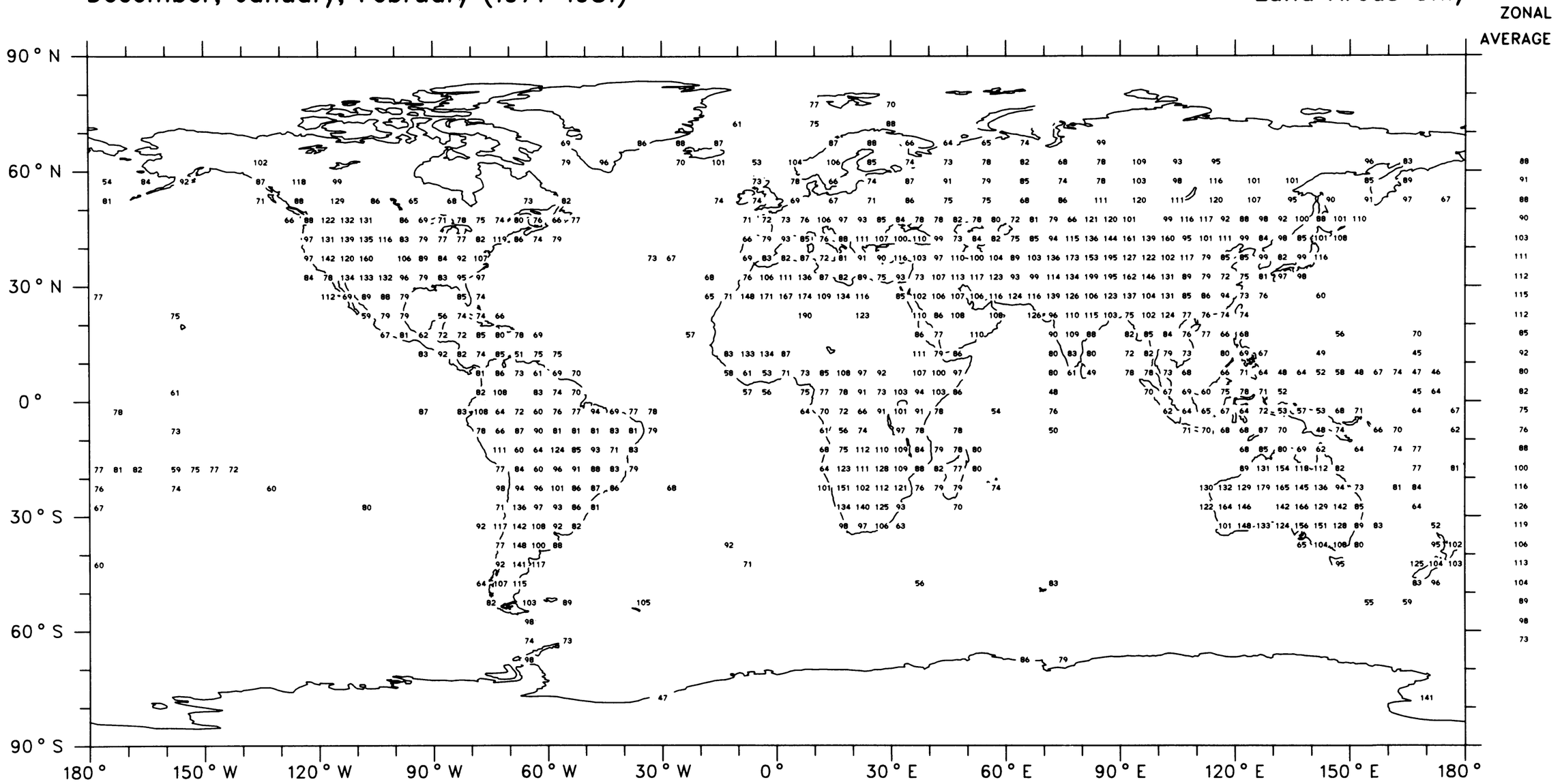
Map 55

Cumulus

Average Base Height (decameters)

December, January, February (1971-1981)

Land Areas Only



Map 56

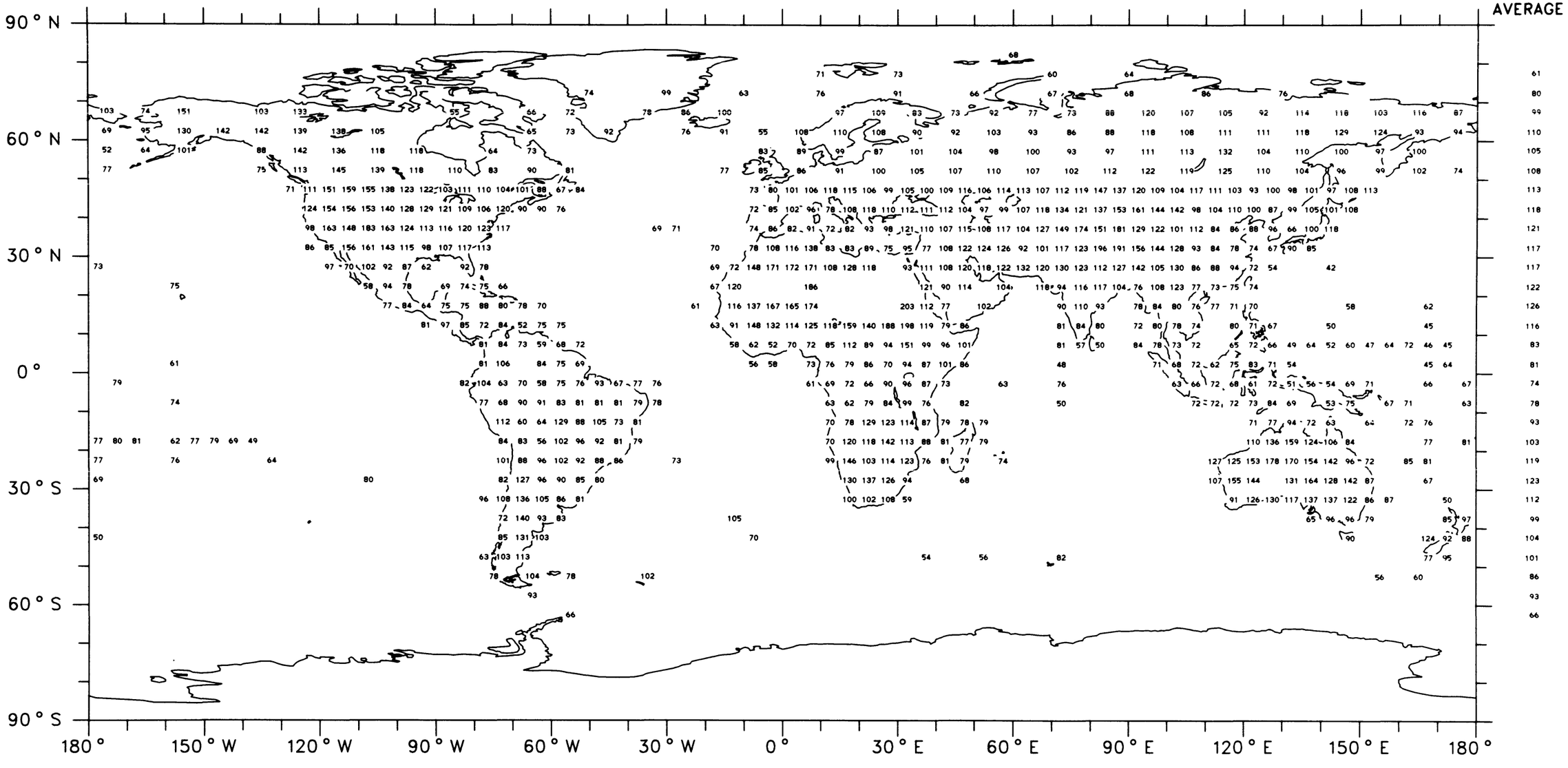
GLOBAL AVERAGE (LAND) 977 METERS

Cumulus

Average Base Height (decameters)

March, April, May (1971-1981)

Land Areas Only



GLOBAL AVERAGE (LAND) 1067 METERS

Map 57

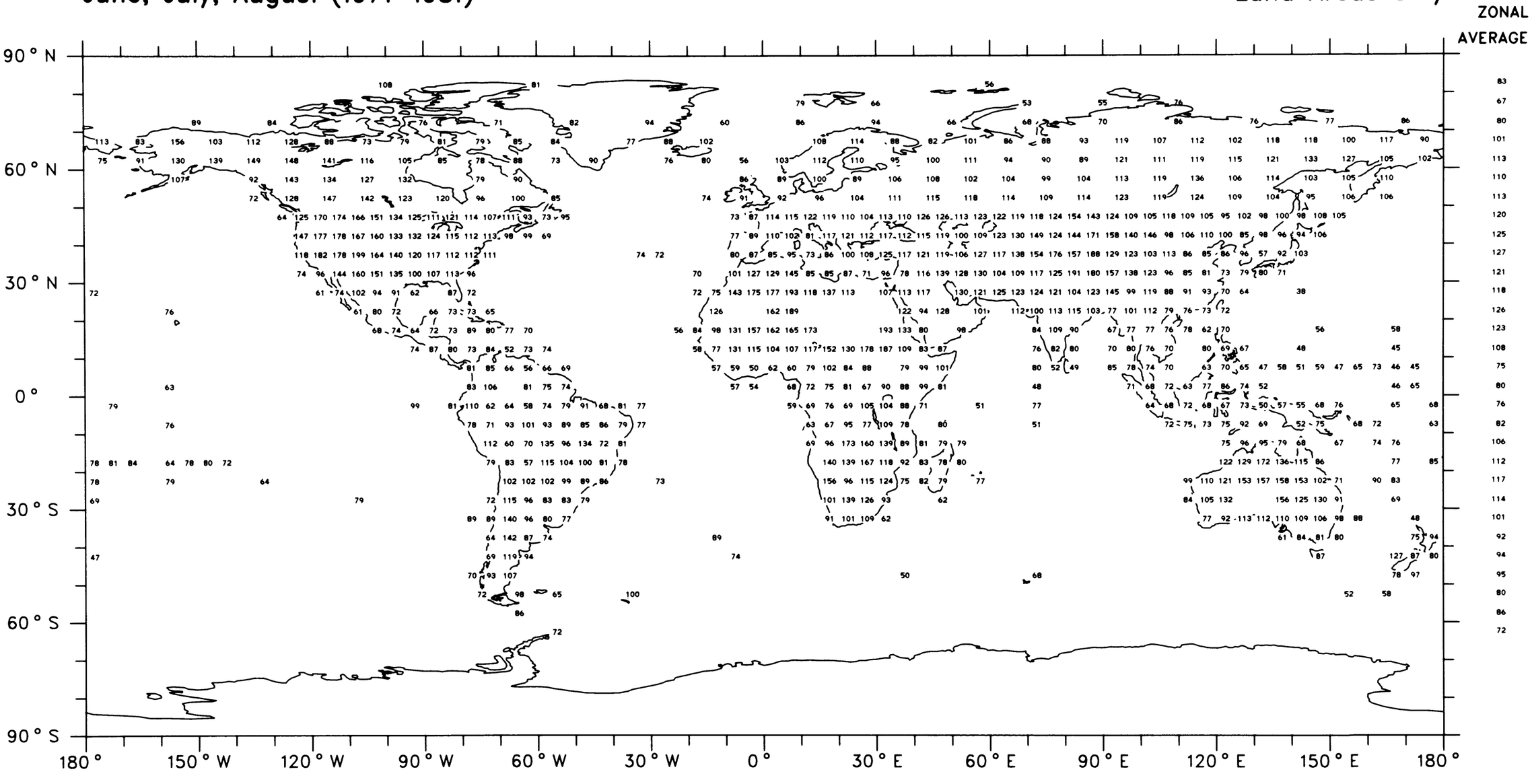
Cumulus

Average Base Height (decameters)

June, July, August (1971-1981)

Land Areas Only

ZONAL AVERAGE



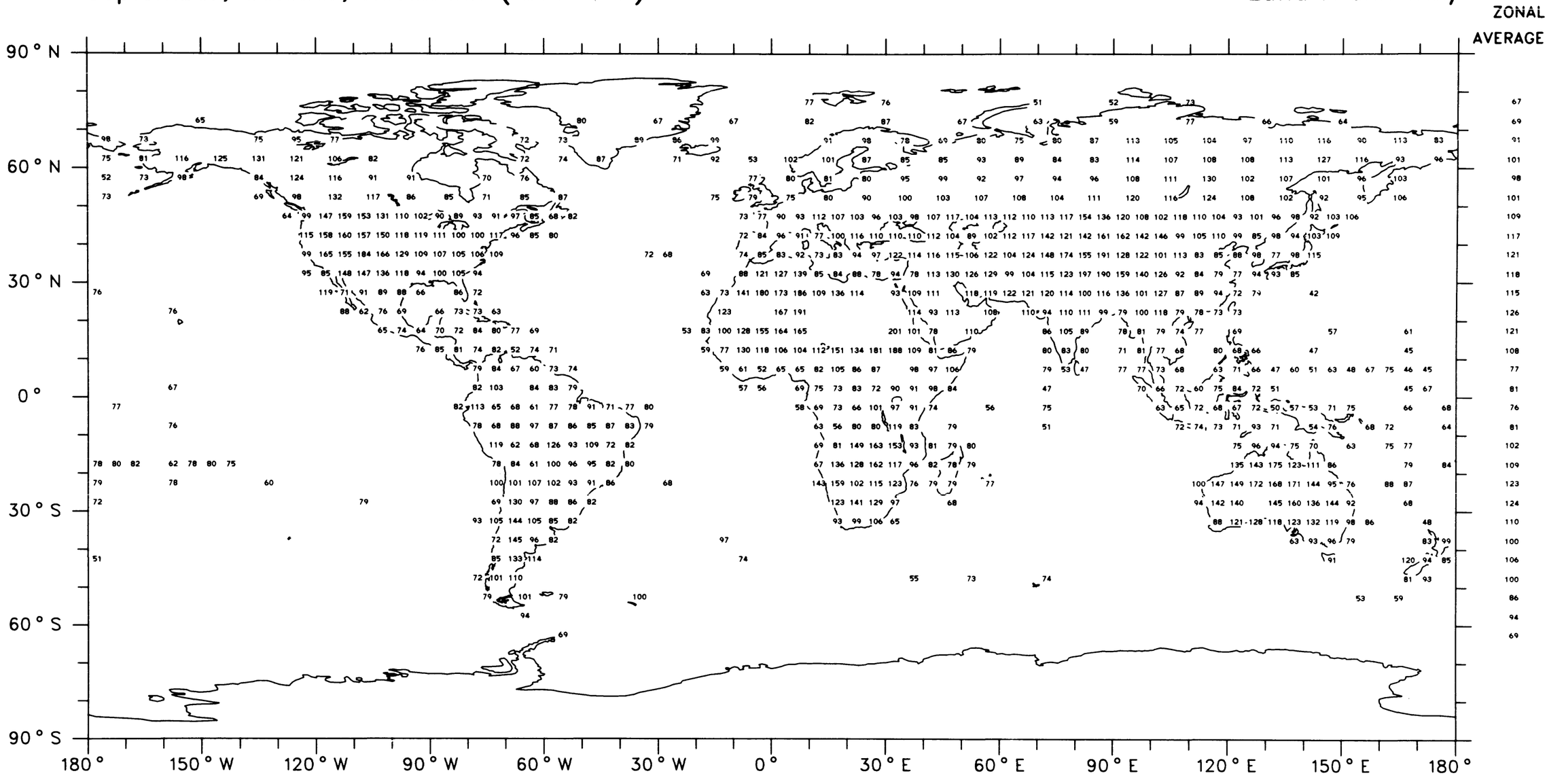
Map 58

GLOBAL AVERAGE (LAND) 1086 METERS

Cumulus

Average Base Height (decameters)

September, October, November (1971-1981) **Land Areas Only**



GLOBAL AVERAGE (LAND) 1049 METERS

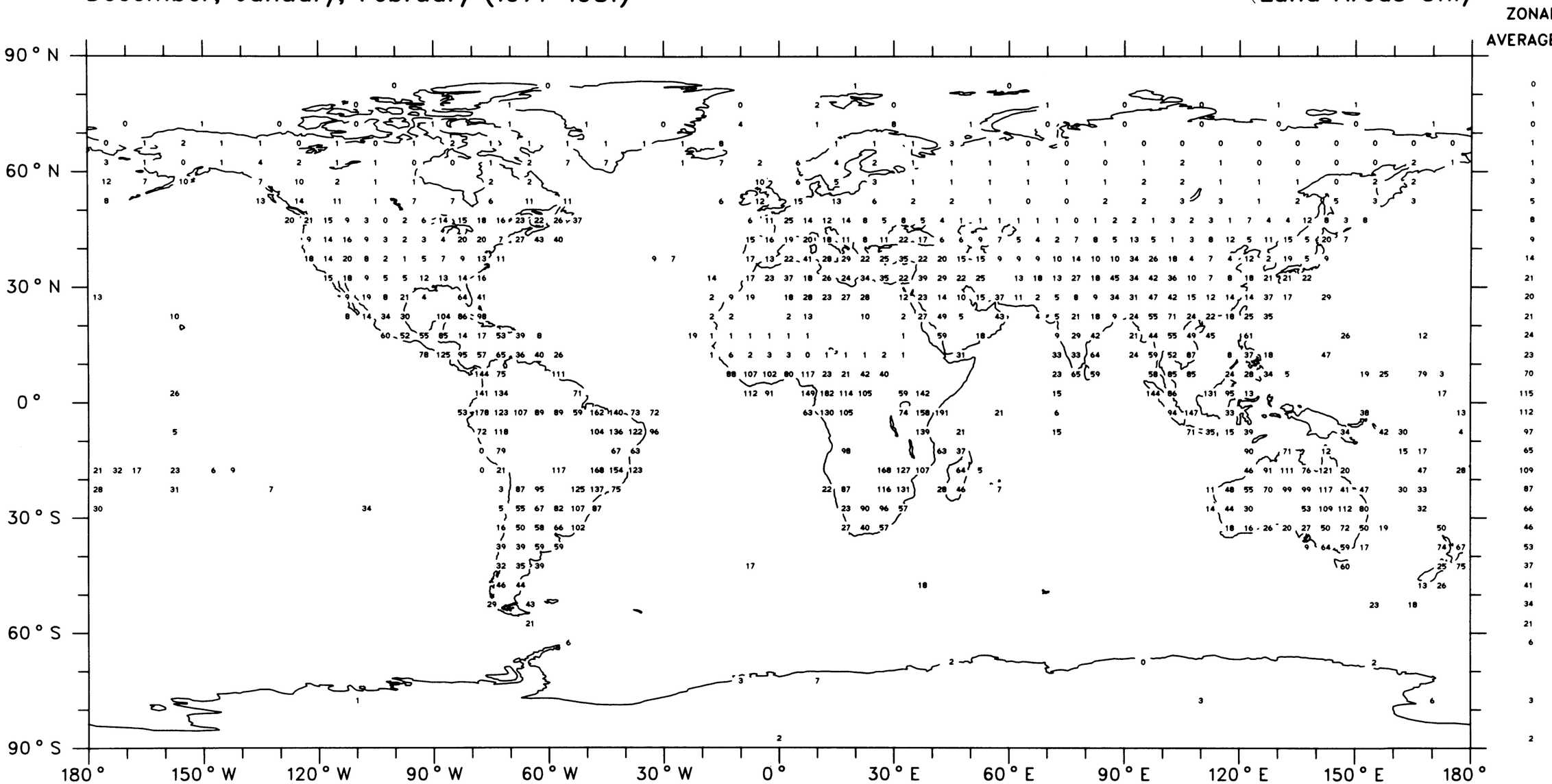
Map 59

Cumulus

Amplitude of Diurnal Cycle (0.1 % Cloud Amount)

December, January, February (1971-1981)

Land Areas Only



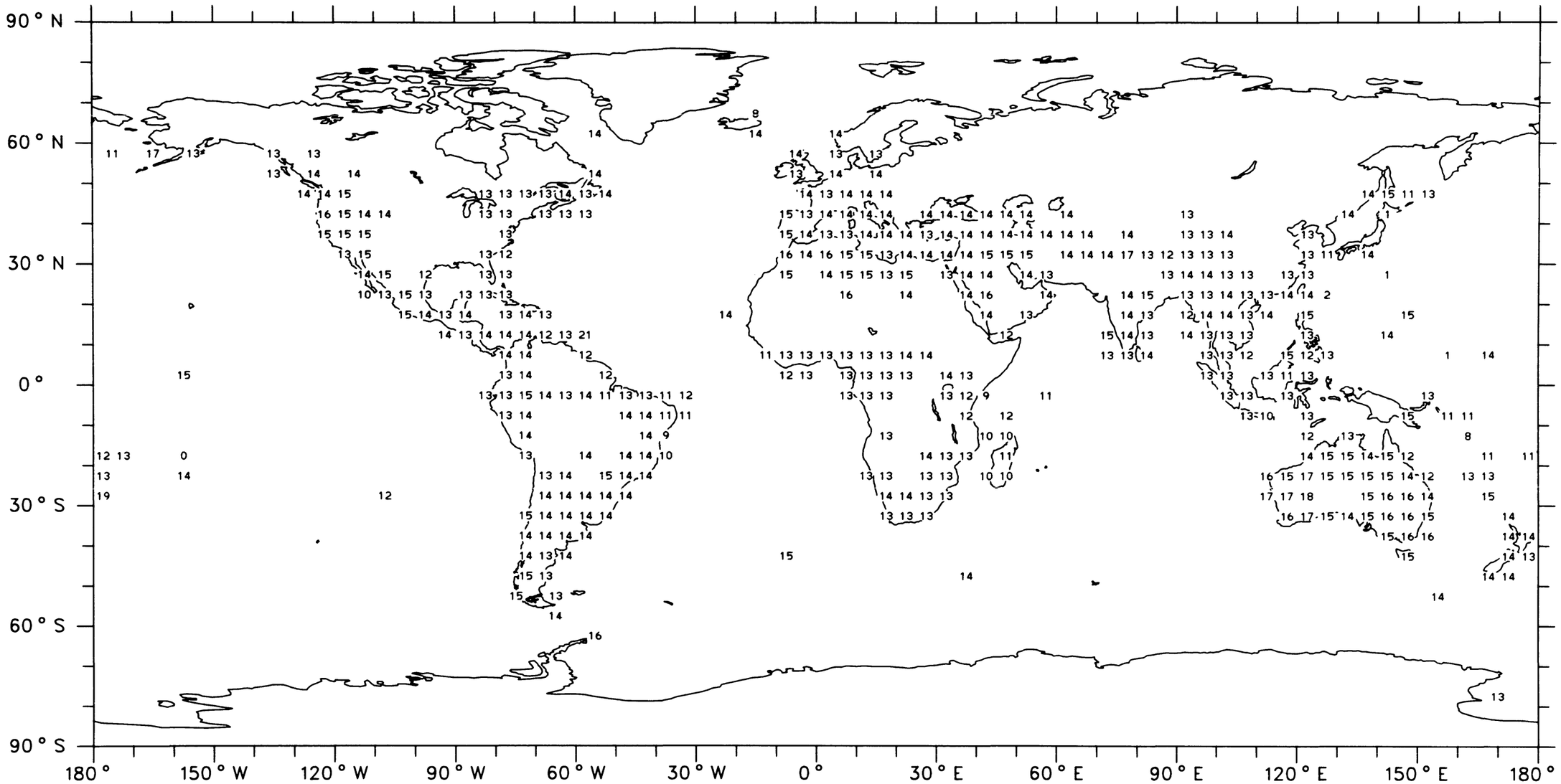
Map 60

GLOBAL AVERAGE (LAND) 3.4 %

Cumulus

Phase of Diurnal Cycle (Local Time of Maximum Cloud Amount)

December, January, February (1971-1981) **Land Areas Only**



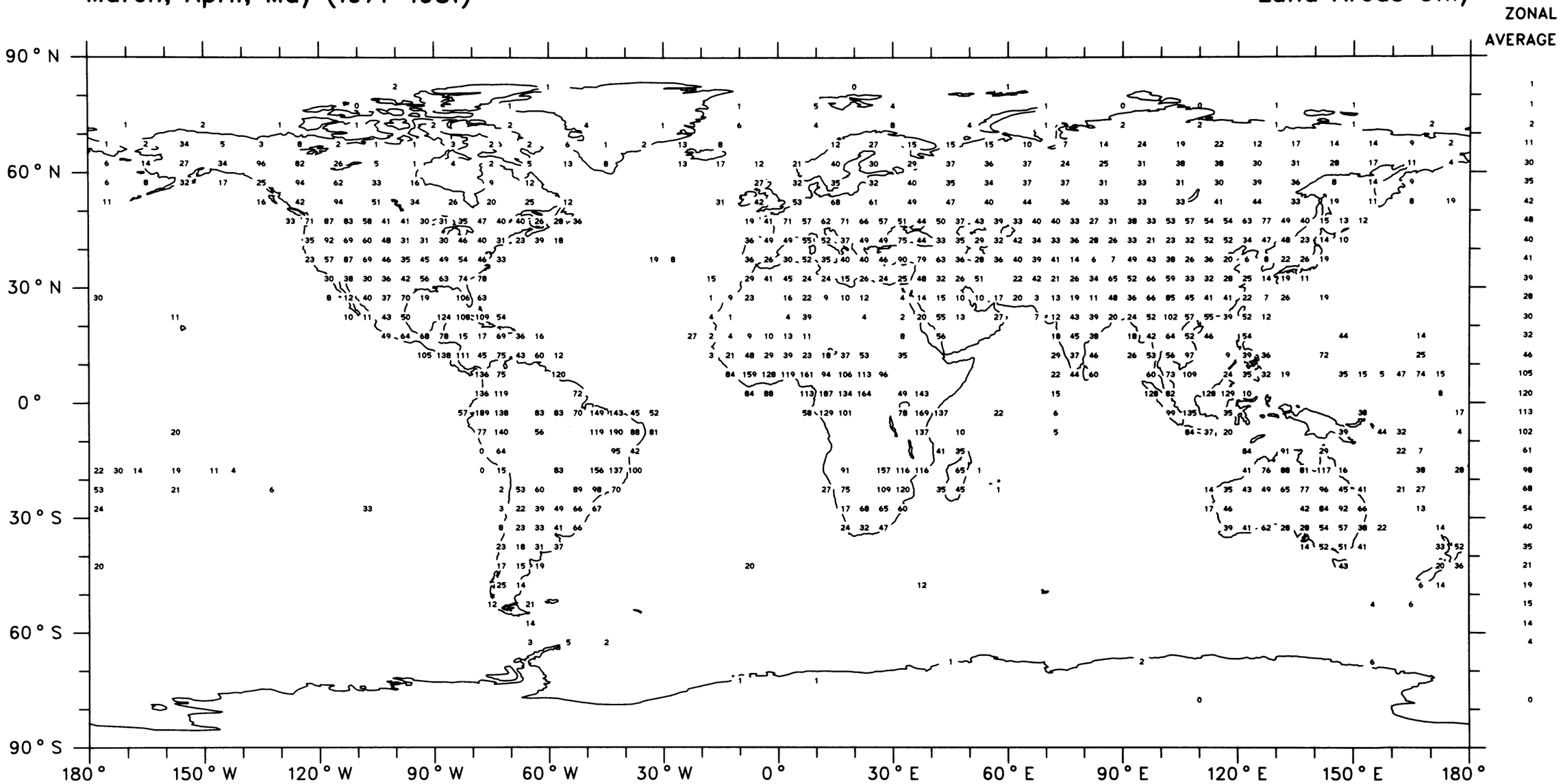
Map 61

Cumulus

Amplitude of Diurnal Cycle (0.1 % Cloud Amount)

March, April, May (1971-1981)

Land Areas Only



Map 62

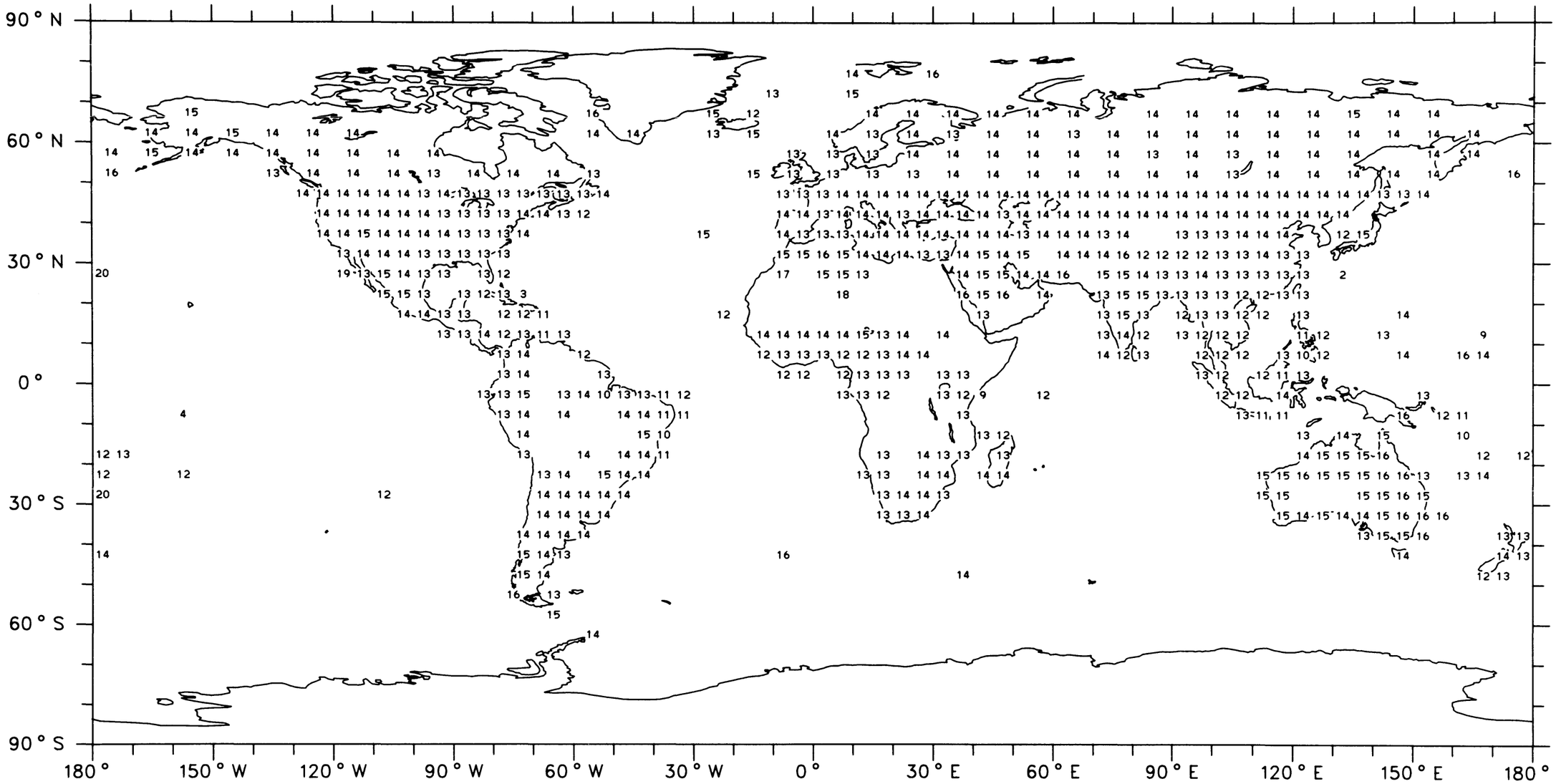
GLOBAL AVERAGE (LAND) 4.9 %

Cumulus

Phase of Diurnal Cycle (Local Time of Maximum Cloud Amount)

March, April, May (1971-1981)

Land Areas Only



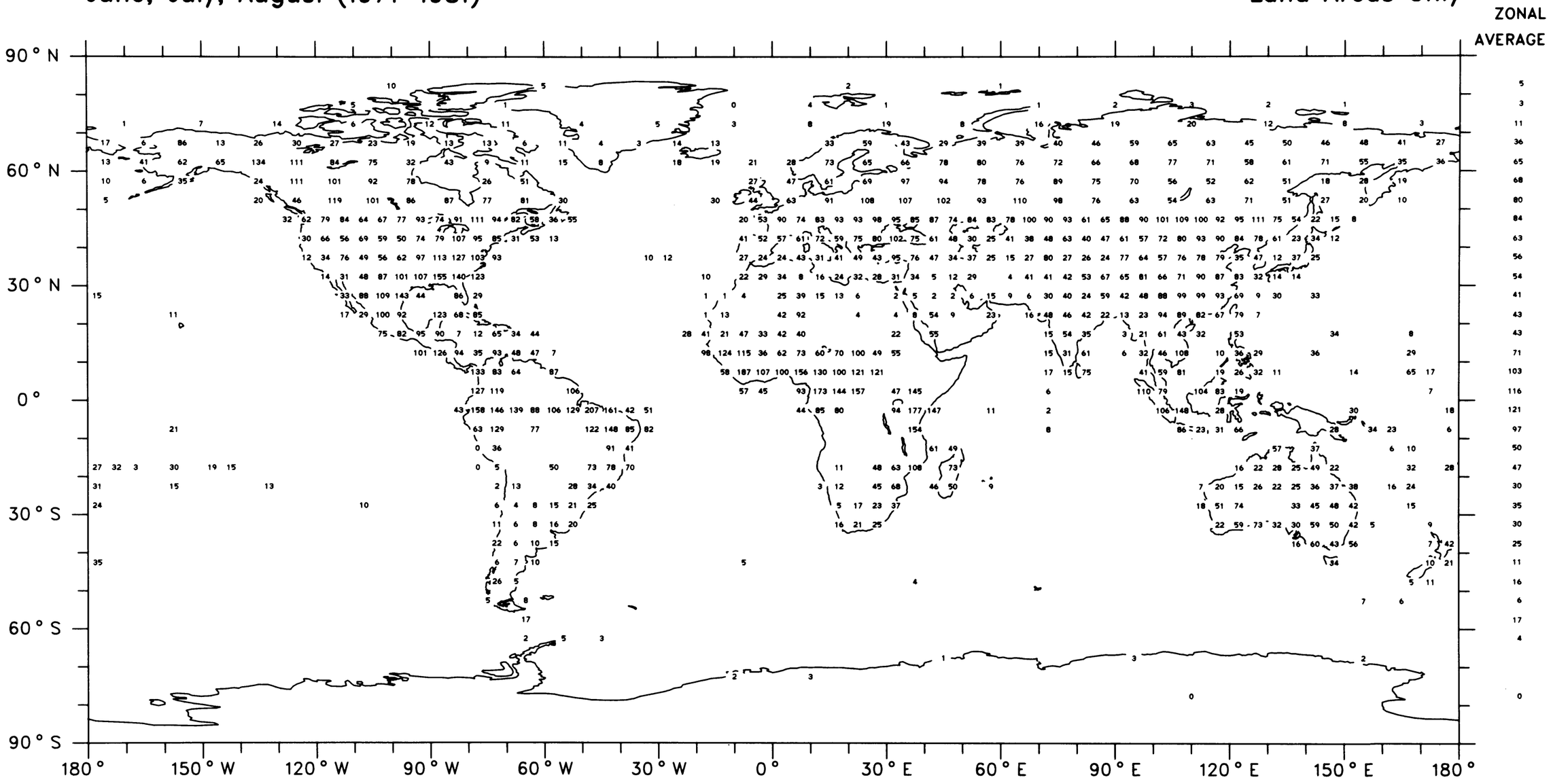
Map 63

Cumulus

Amplitude of Diurnal Cycle (0.1 % Cloud Amount)

June, July, August (1971-1981)

Land Areas Only



Map 64

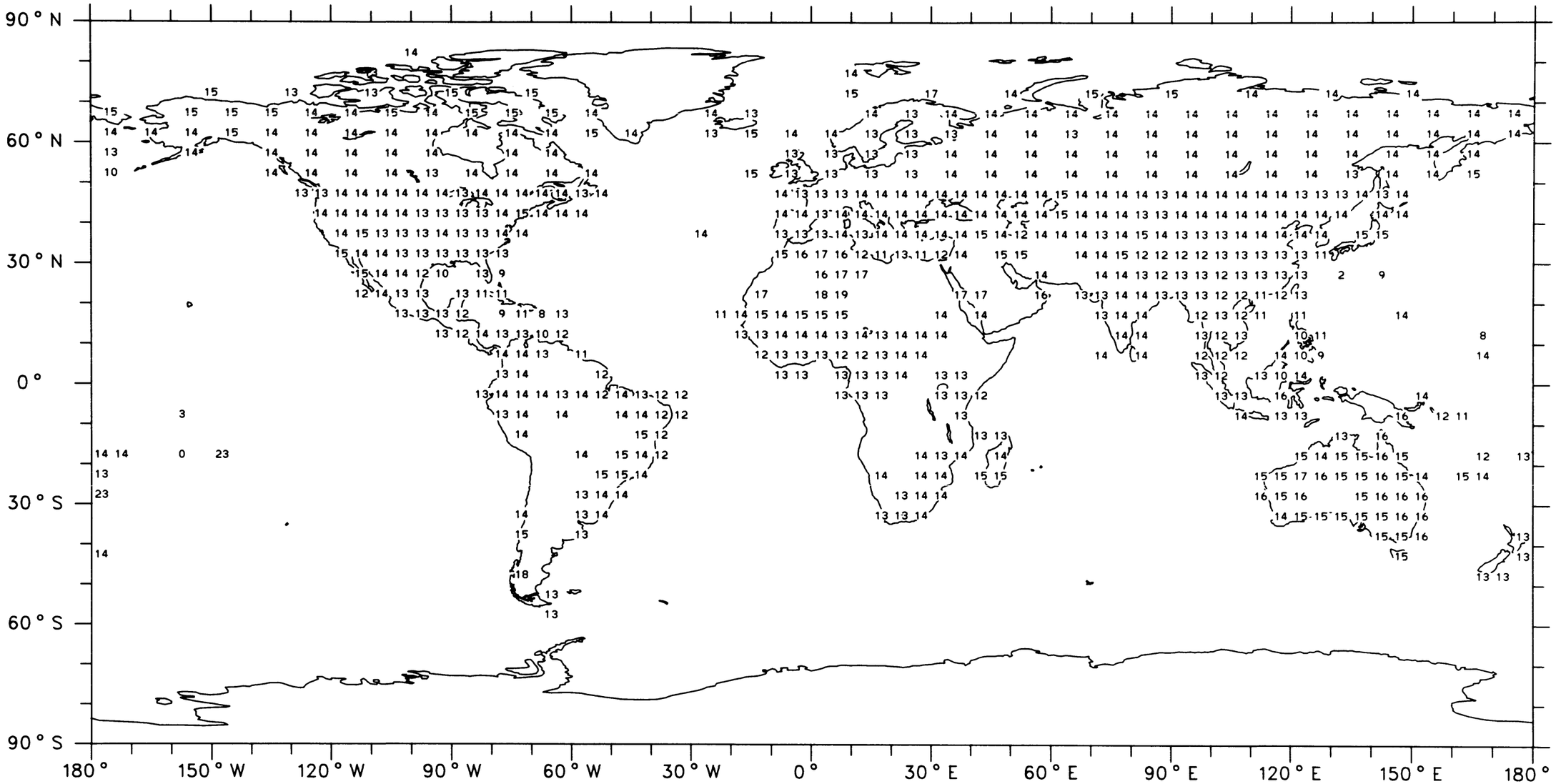
GLOBAL AVERAGE (LAND) 5.9 %

Cumulus

Phase of Diurnal Cycle (Local Time of Maximum Cloud Amount)

June, July, August (1971-1981)

Land Areas Only

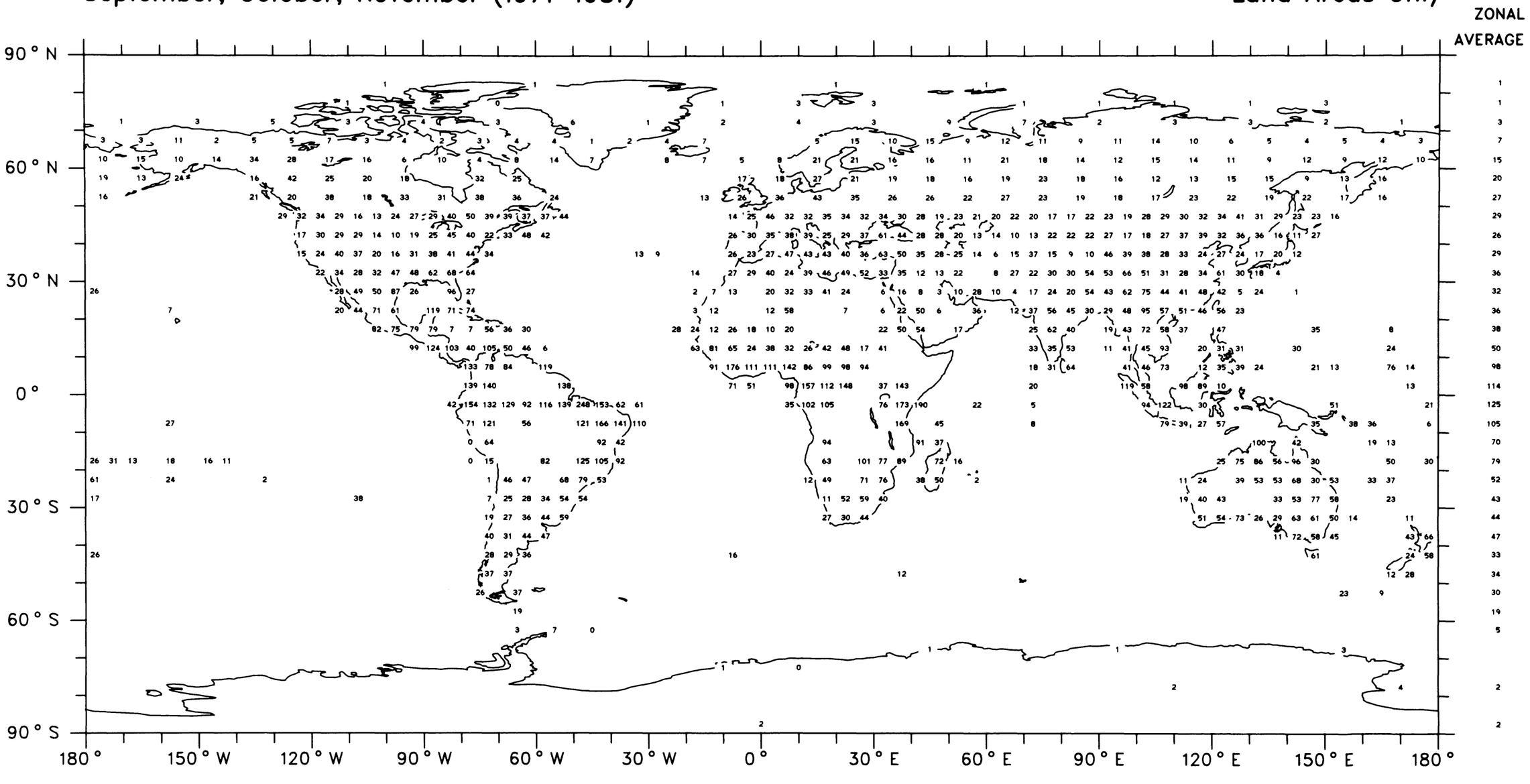


Map 65

Cumulus

Amplitude of Diurnal Cycle (0.1 % Cloud Amount)

September, October, November (1971-1981) **Land Areas Only**



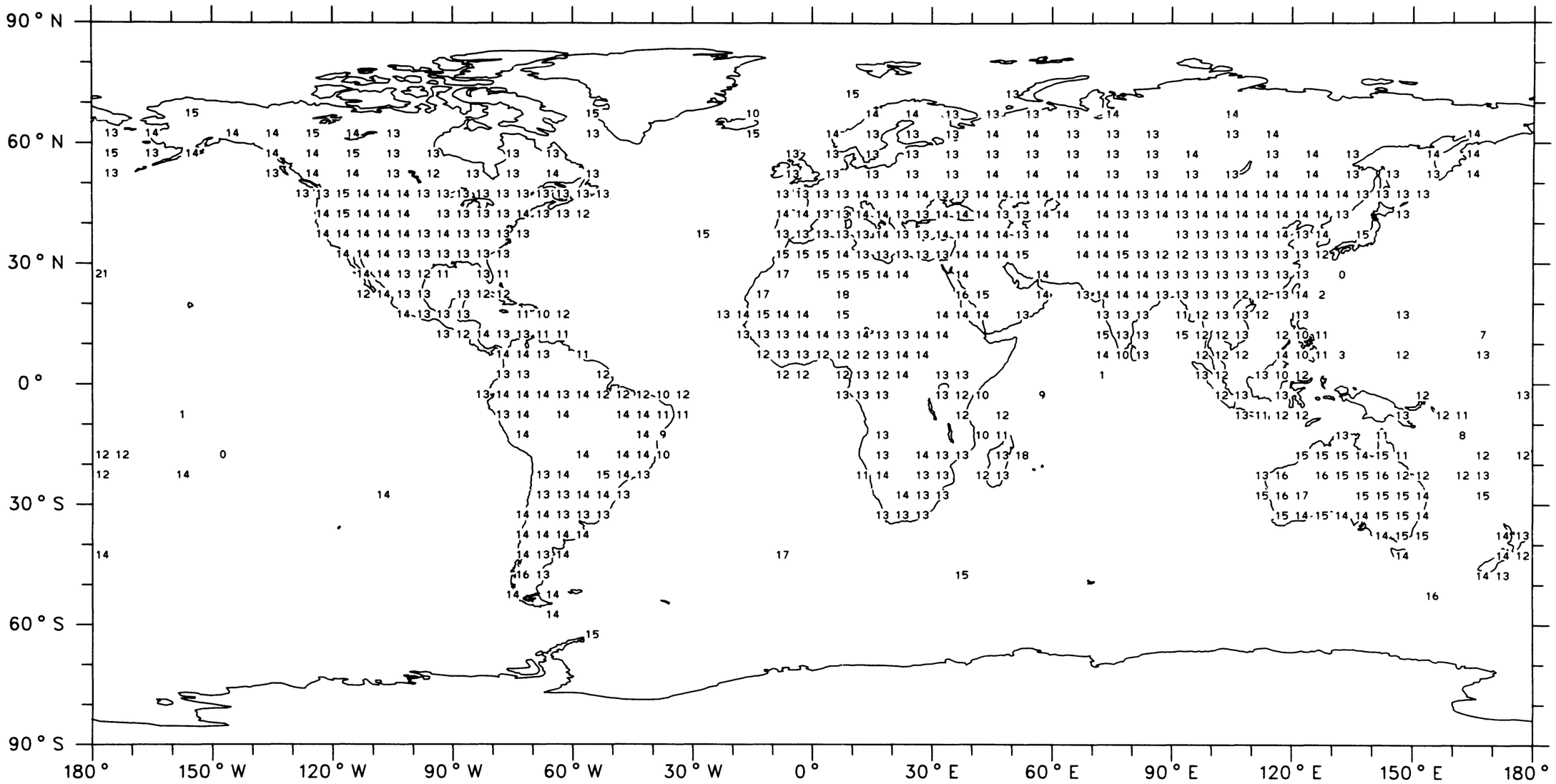
Map 66

GLOBAL AVERAGE (LAND) 4.3 %

Cumulus

Phase of Diurnal Cycle (Local Time of Maximum Cloud Amount)

September, October, November (1971-1981) **Land Areas Only**



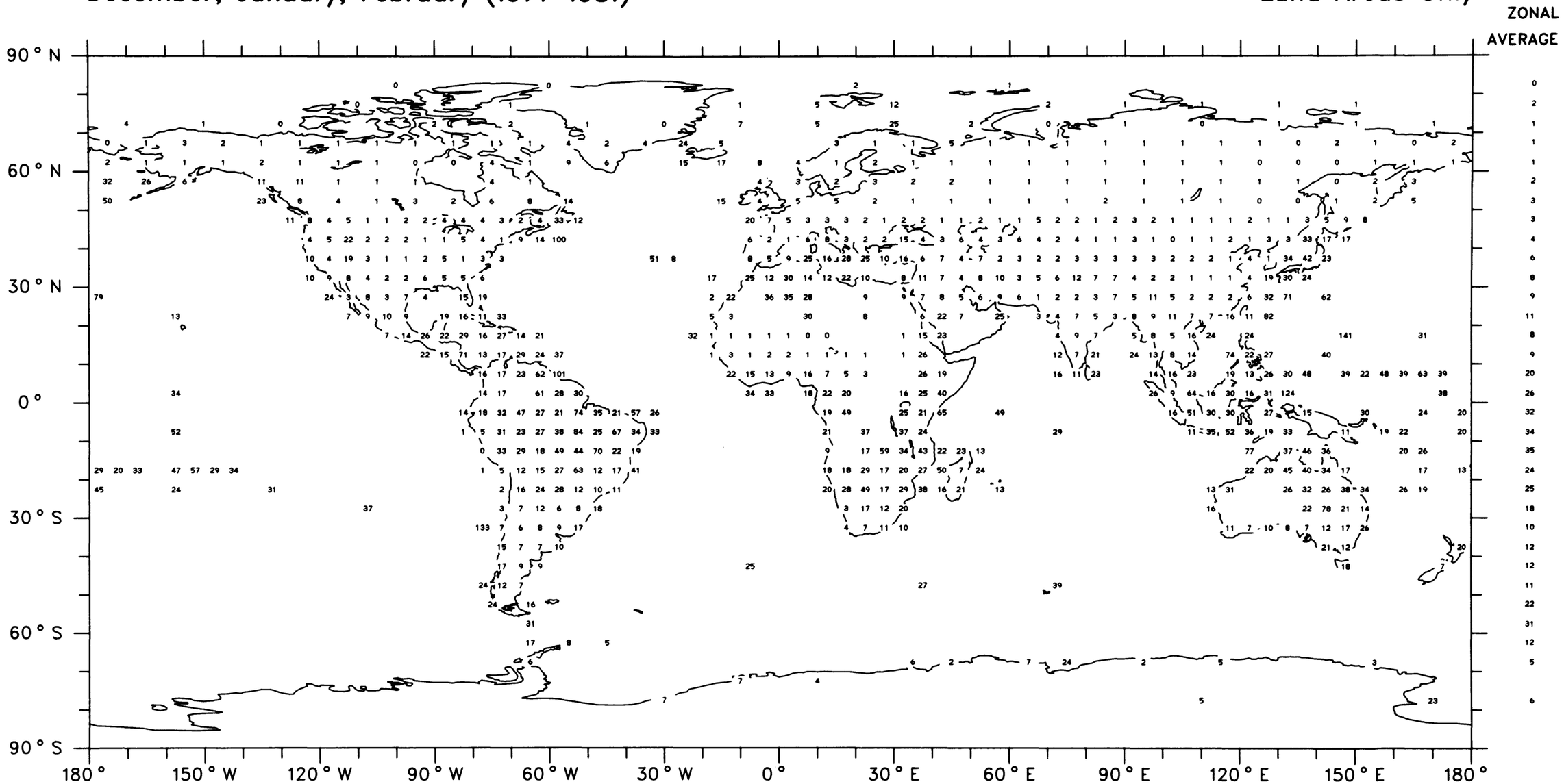
Map 67

Interannual Variation of Cumulus :

Standard Deviation of Seasonal Means (0.1 % Cloud Amount)

December, January, February (1971-1981)

Land Areas Only



Map 68

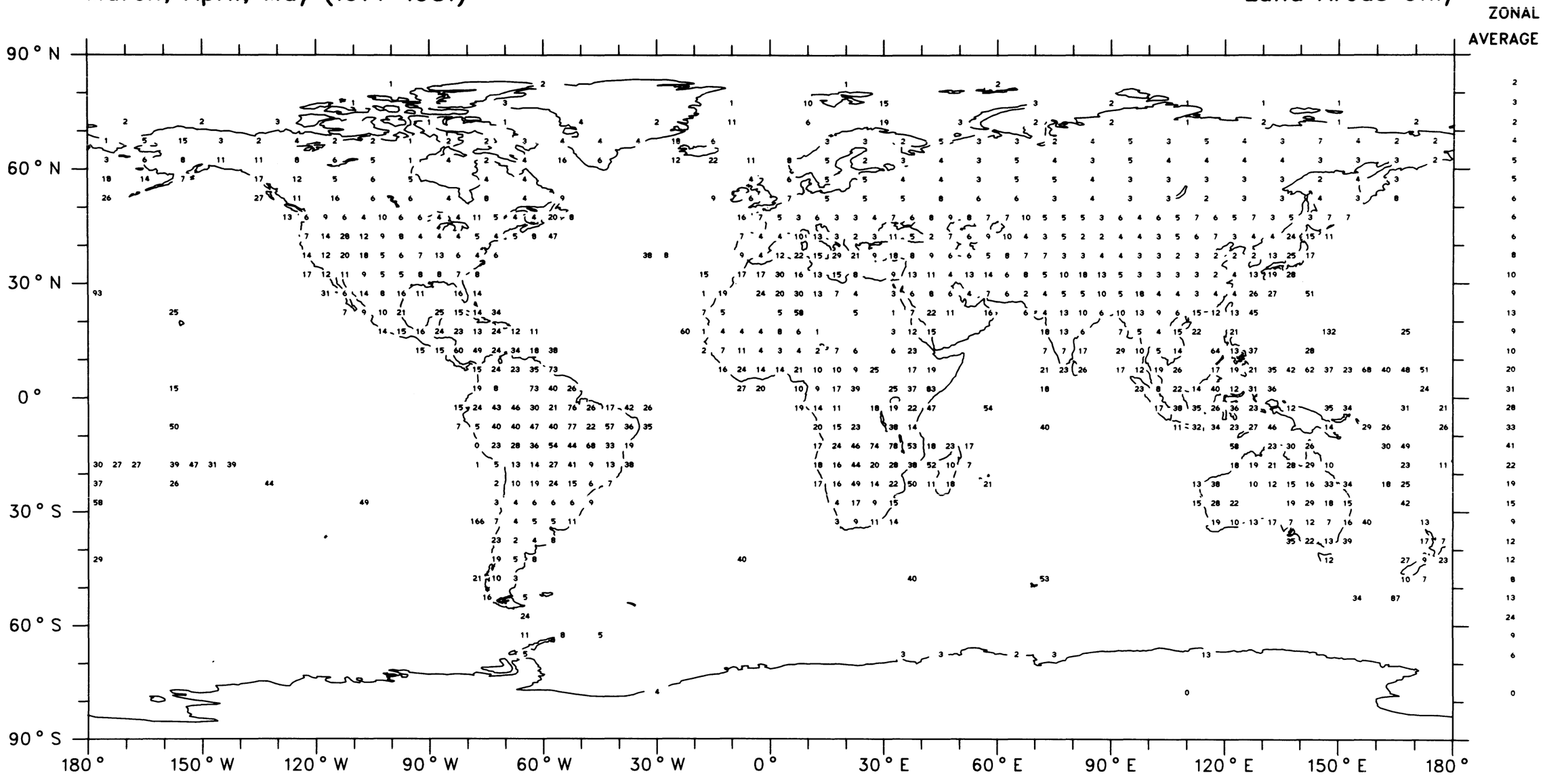
GLOBAL AVERAGE (LAND) 1.1 %

Interannual Variation of Cumulus :

Standard Deviation of Seasonal Means (0.1 % Cloud Amount)

March, April, May (1971-1981)

Land Areas Only



GLOBAL AVERAGE (LAND) 1.2 %

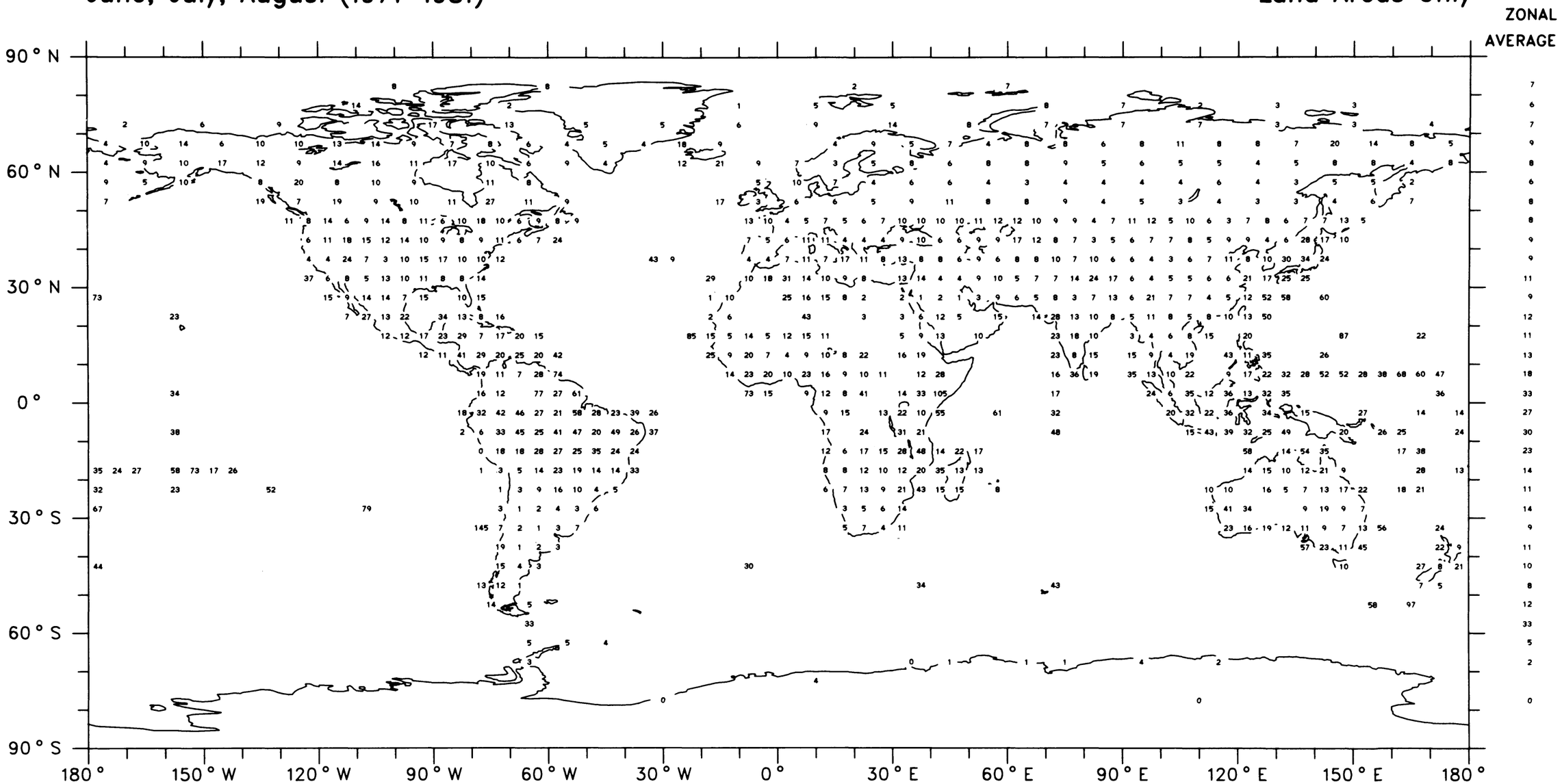
Map 69

Interannual Variation of Cumulus :

Standard Deviation of Seasonal Means (0.1 % Cloud Amount)

June, July, August (1971-1981)

Land Areas Only



Map 70

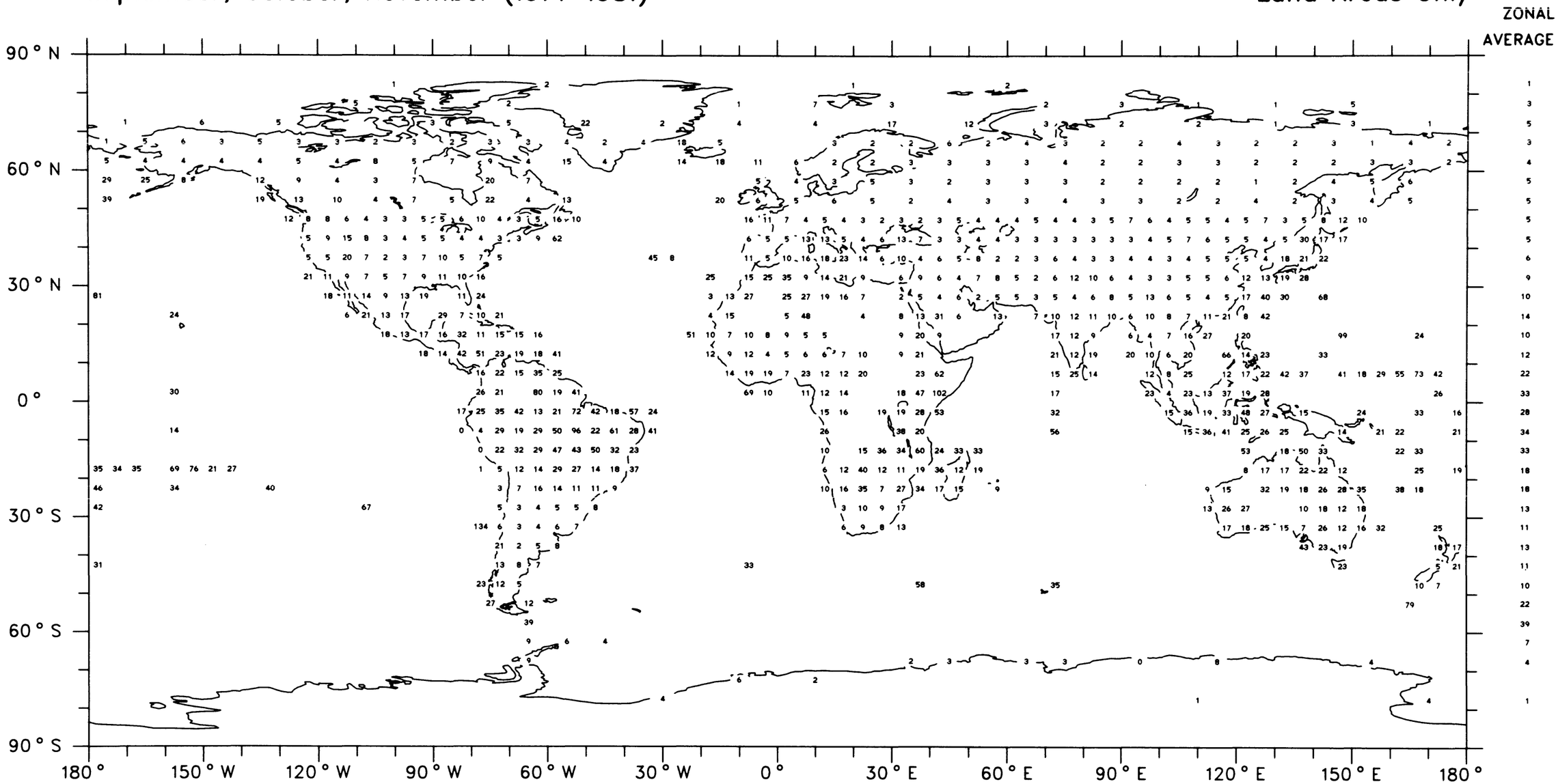
GLOBAL AVERAGE (LAND) 1.2 %

Interannual Variation of Cumulus :

Standard Deviation of Seasonal Means (0.1 % Cloud Amount)

September, October, November (1971-1981)

Land Areas Only



GLOBAL AVERAGE (LAND) 1.2 %

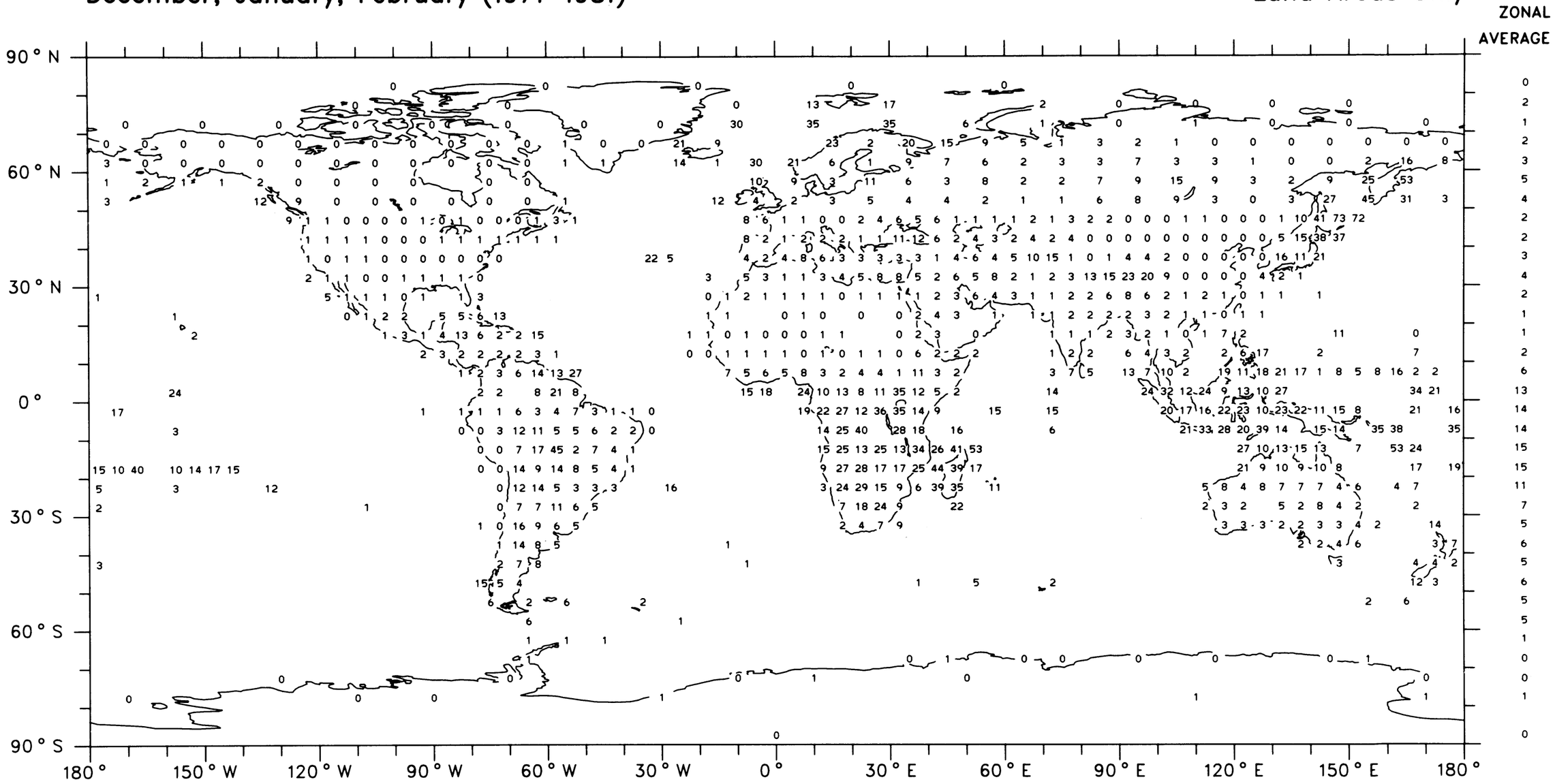
Map 71

Cumulonimbus

Frequency of Occurrence (%)

December, January, February (1971-1981)

Land Areas Only



Map 72

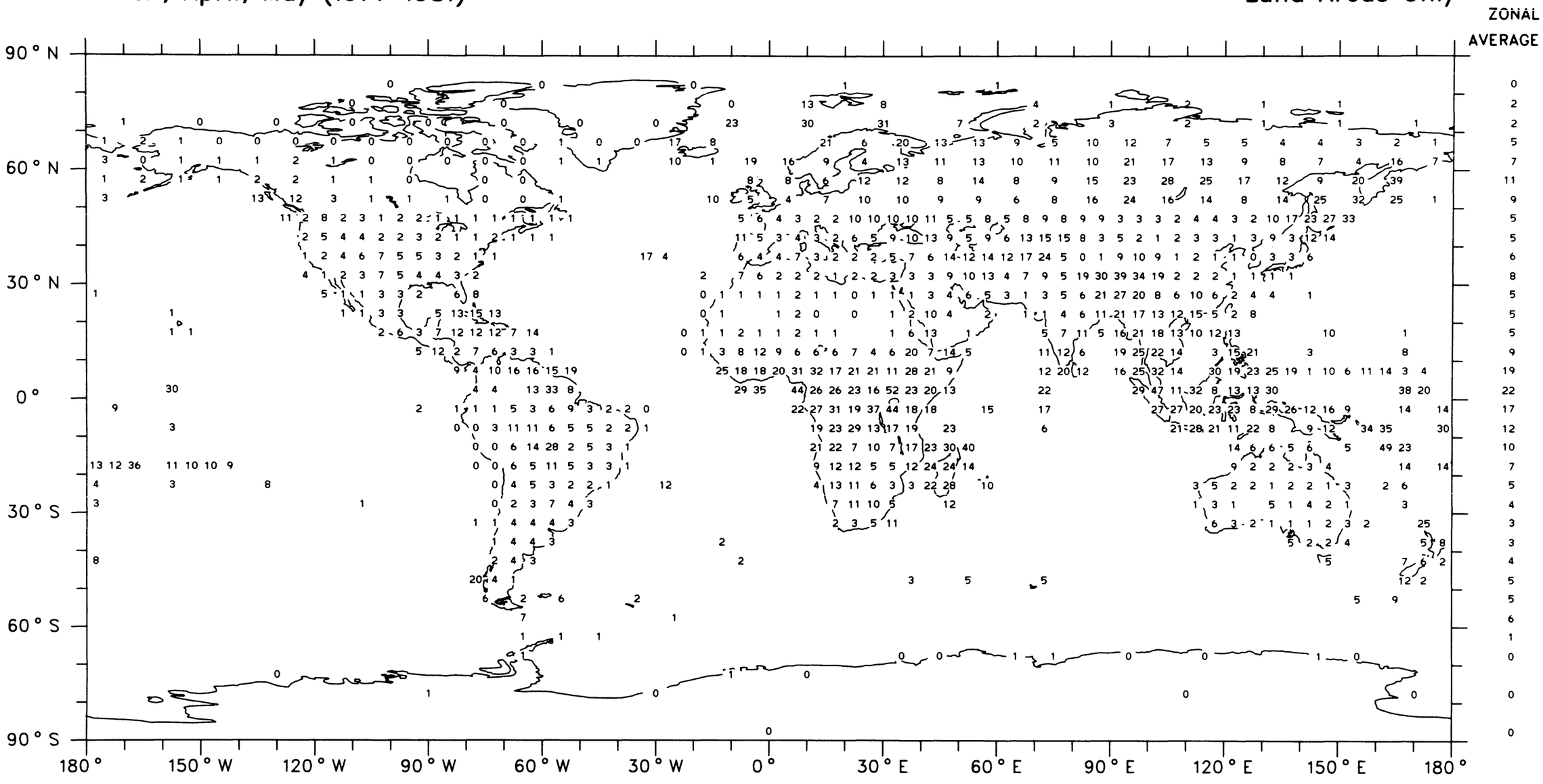
GLOBAL AVERAGE (LAND) 5 %

Cumulonimbus

Frequency of Occurrence (%)

March, April, May (1971-1981)

Land Areas Only



GLOBAL AVERAGE (LAND) 7 %

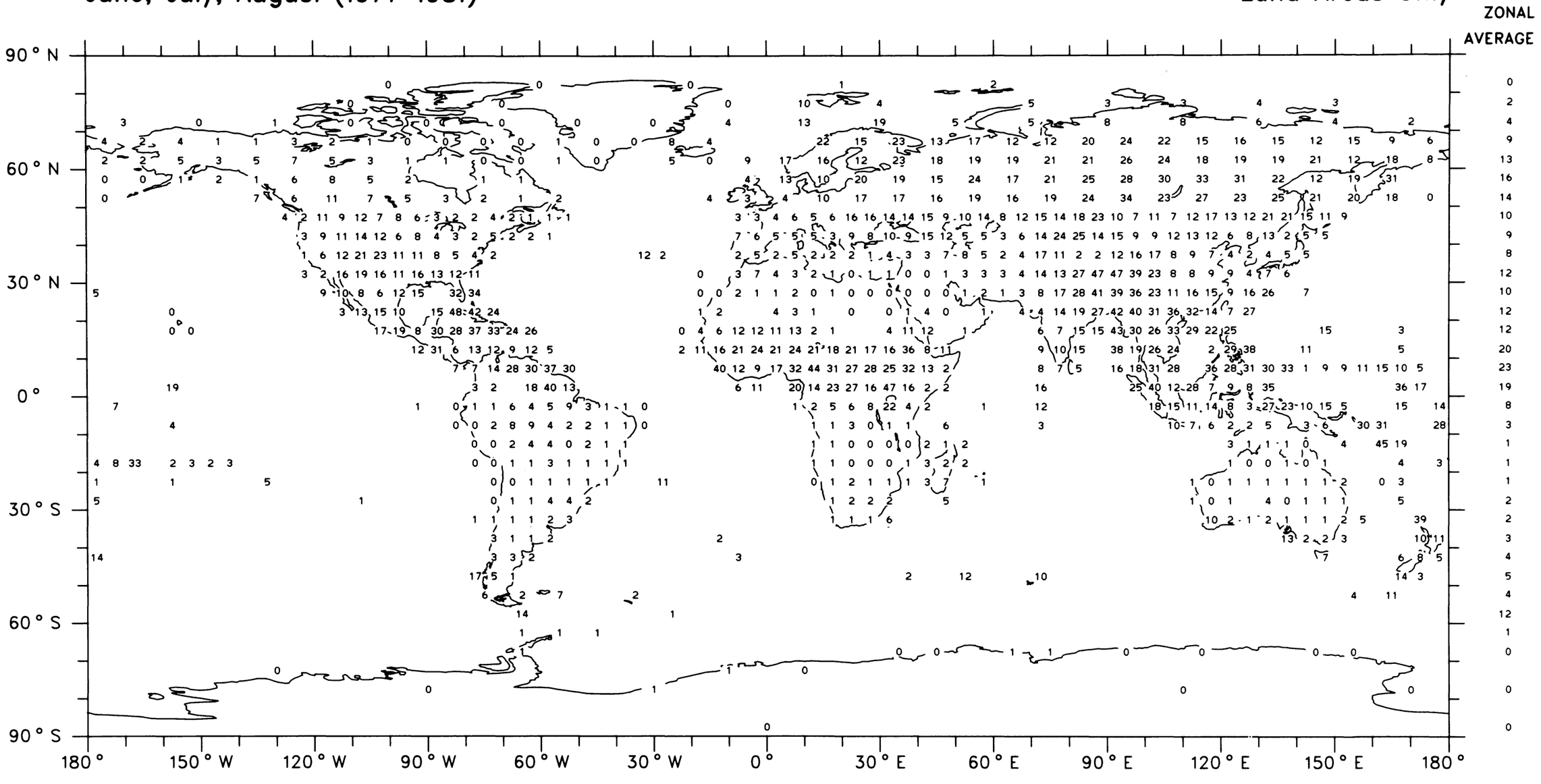
Map 73

Cumulonimbus

Frequency of Occurrence (%)

June, July, August (1971-1981)

Land Areas Only



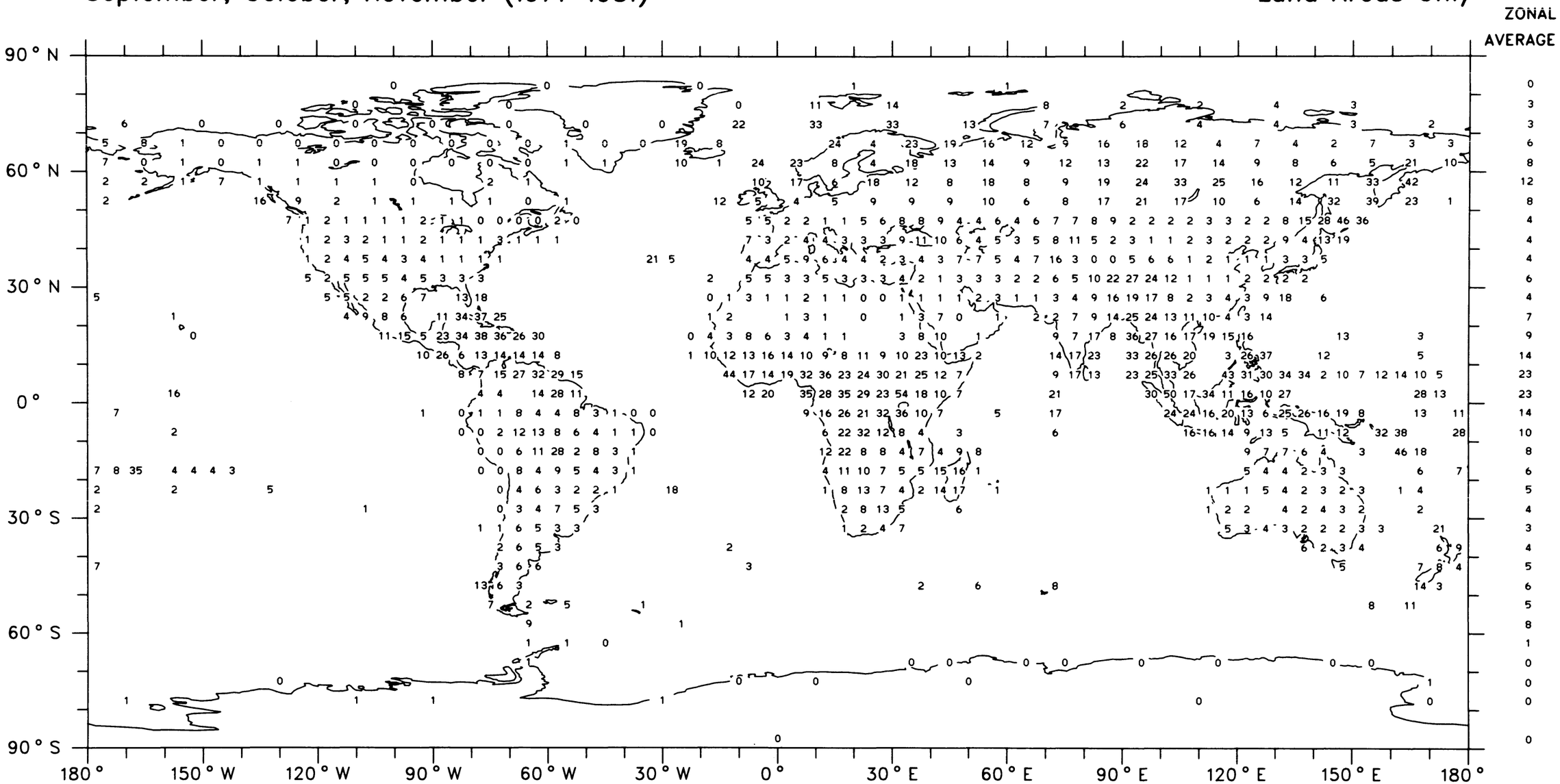
Map 74

GLOBAL AVERAGE (LAND) 9 %

Cumulonimbus

Frequency of Occurrence (%)

September, October, November (1971-1981) **Land Areas Only**



GLOBAL AVERAGE (LAND) 7 %

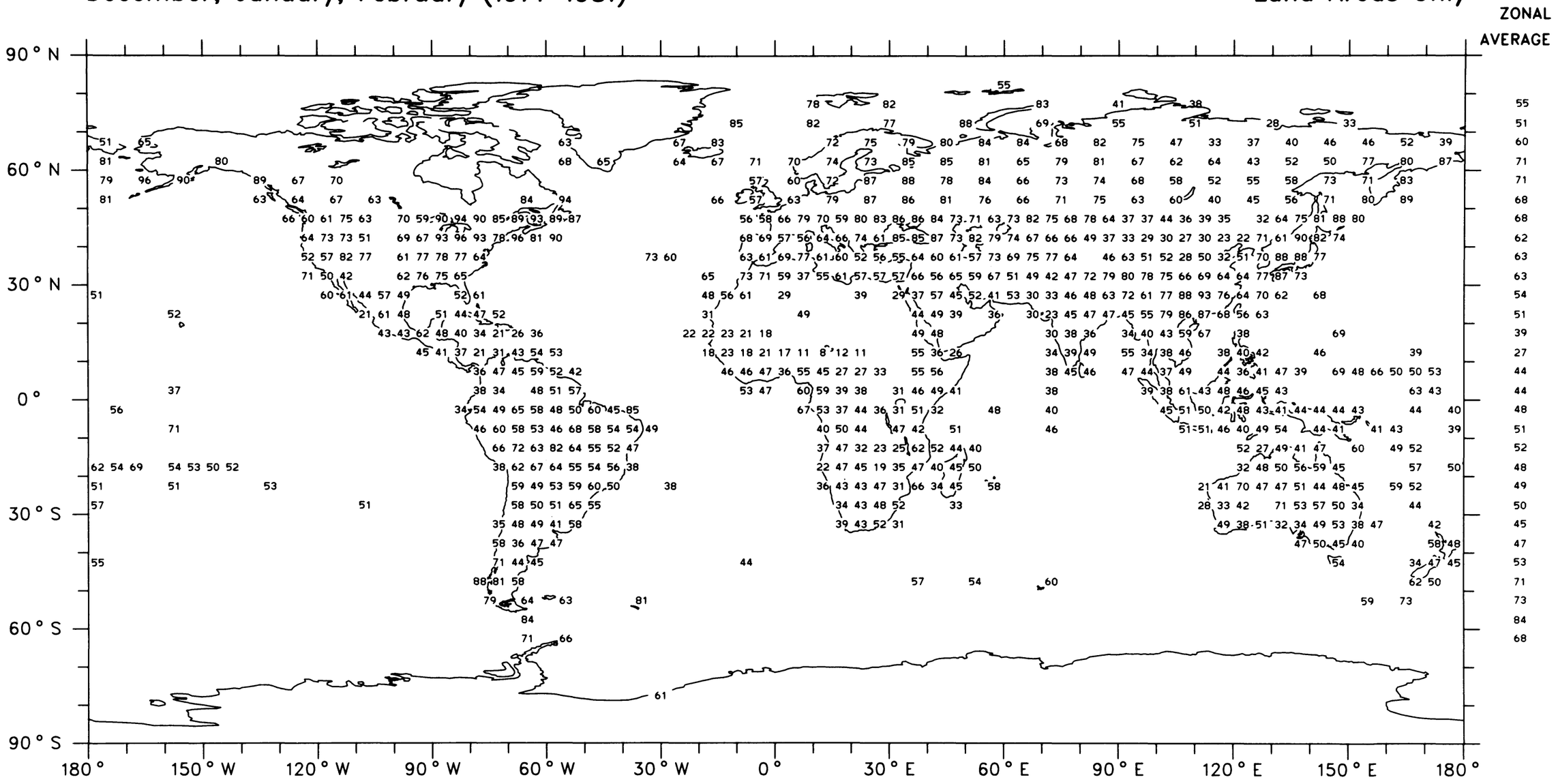
Map 75

Cumulonimbus

Amount - When - Present (%)

December, January, February (1971-1981)

Land Areas Only



Map 76

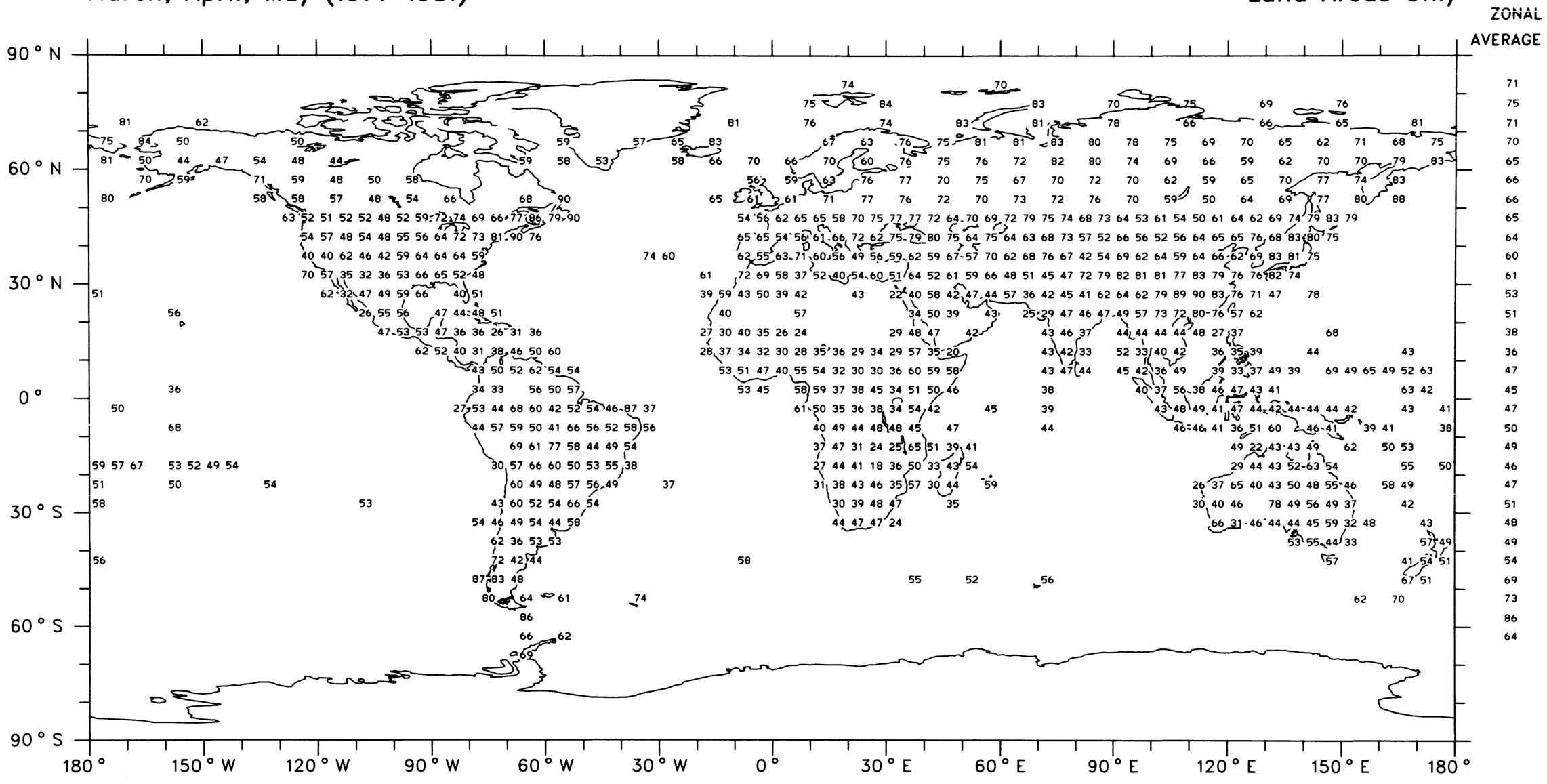
GLOBAL AVERAGE (LAND) 55 %

Cumulonimbus

Amount-When-Present (%)

March, April, May (1971-1981)

Land Areas Only



GLOBAL AVERAGE (LAND) 56 %

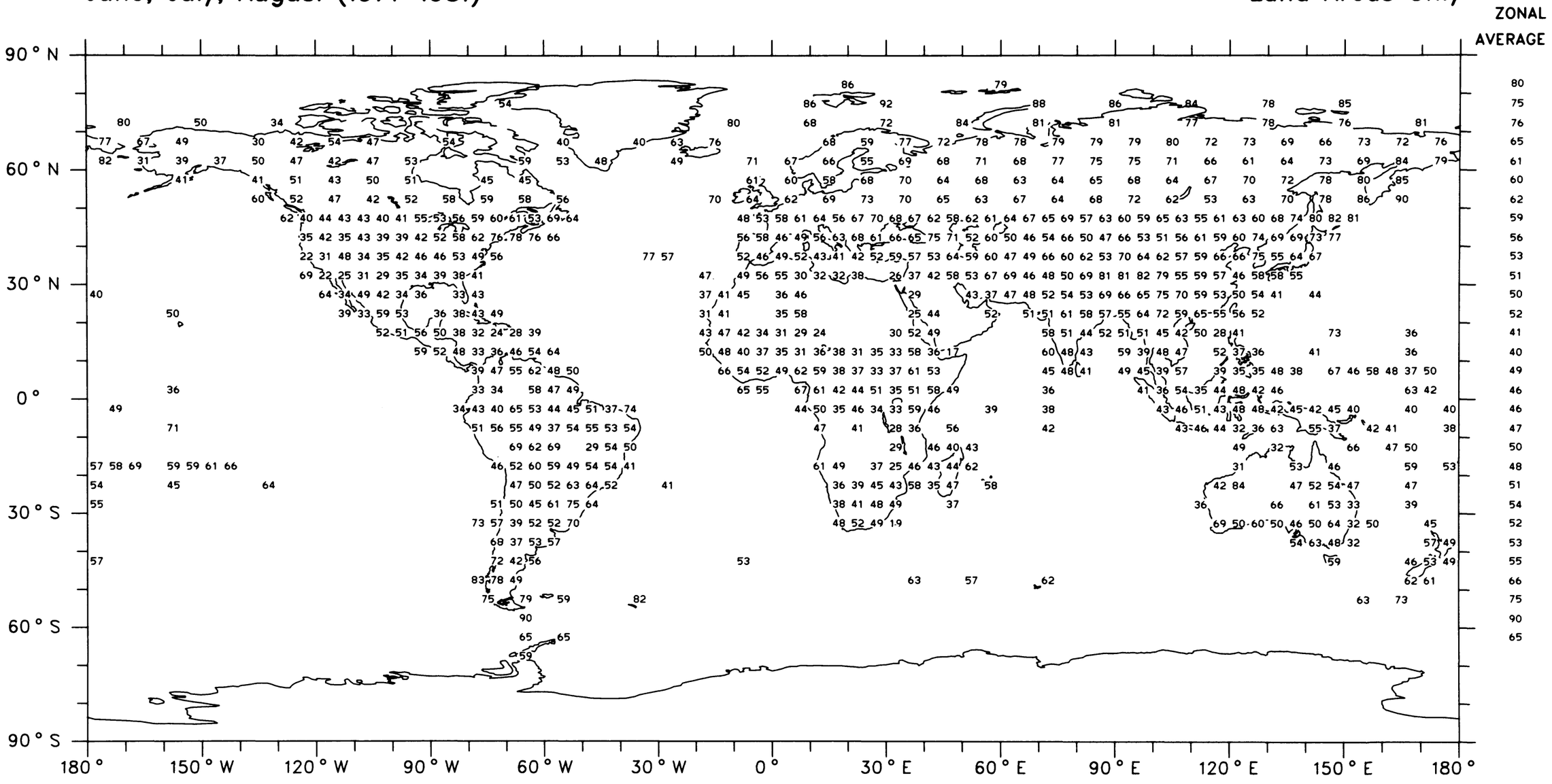
Map 77

Cumulonimbus

Amount - When - Present (%)

June, July, August (1971-1981)

Land Areas Only



Map 78

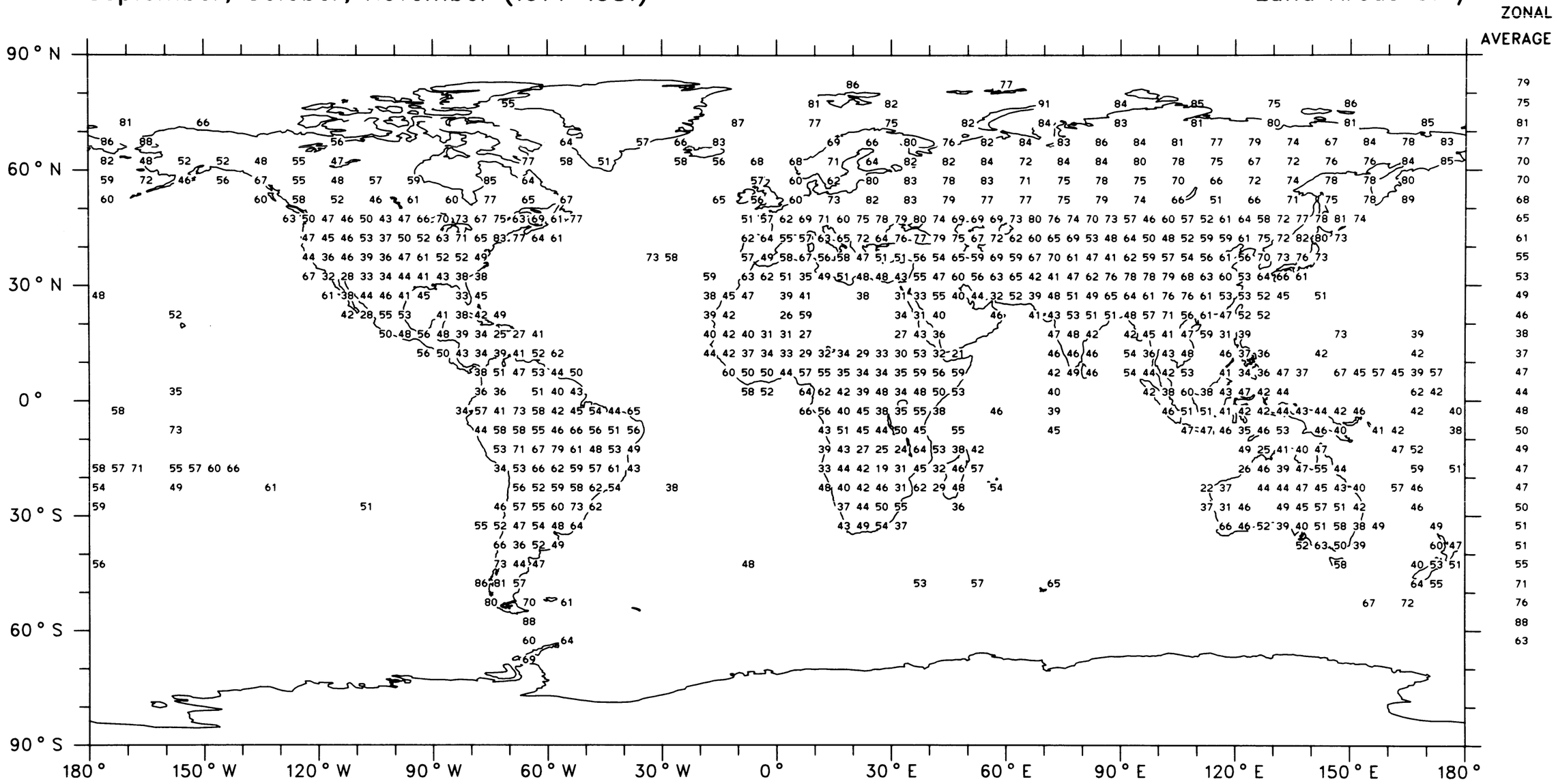
GLOBAL AVERAGE (LAND) 54 %

Cumulonimbus

Amount - When - Present (%)

September, October, November (1971-1981)

Land Areas Only



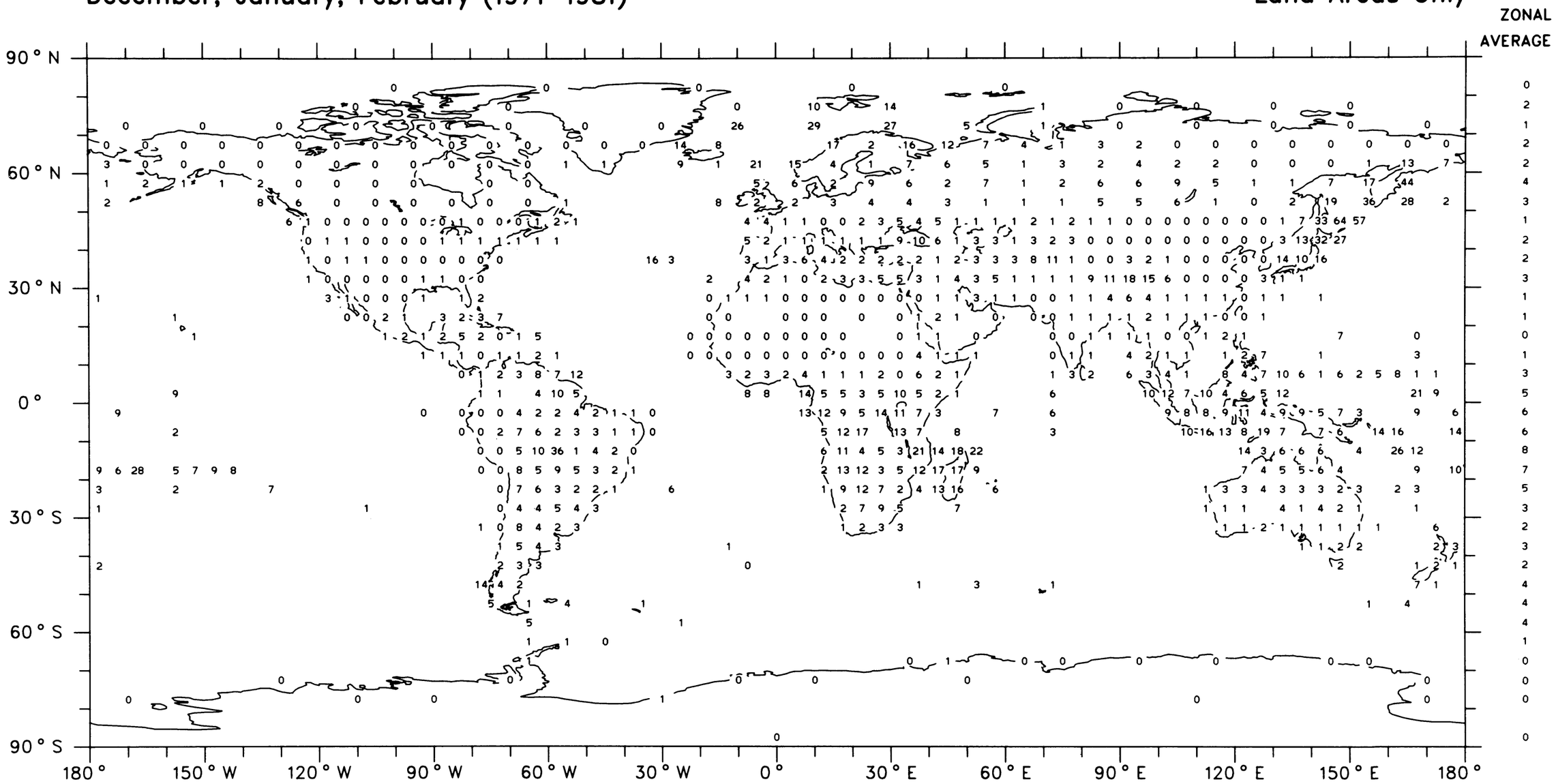
GLOBAL AVERAGE (LAND) 55 %

Map 79

Cumulonimbus

Average Cloud Amount (%)

December, January, February (1971-1981) **Land Areas Only**



Map 80

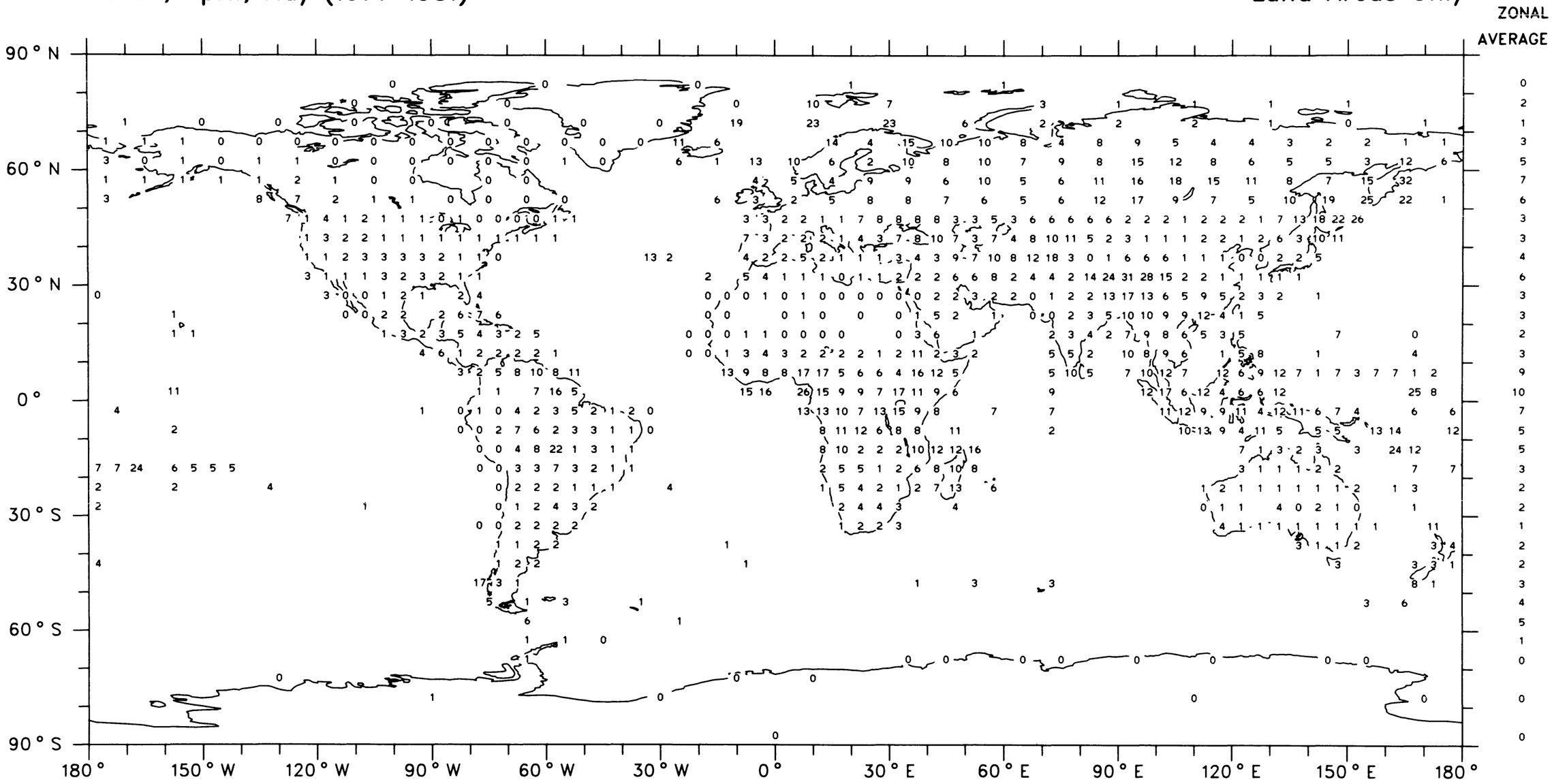
GLOBAL AVERAGE (LAND) 3 %

Cumulonimbus

Average Cloud Amount (%)

March, April, May (1971-1981)

Land Areas Only



GLOBAL AVERAGE (LAND) 4 %

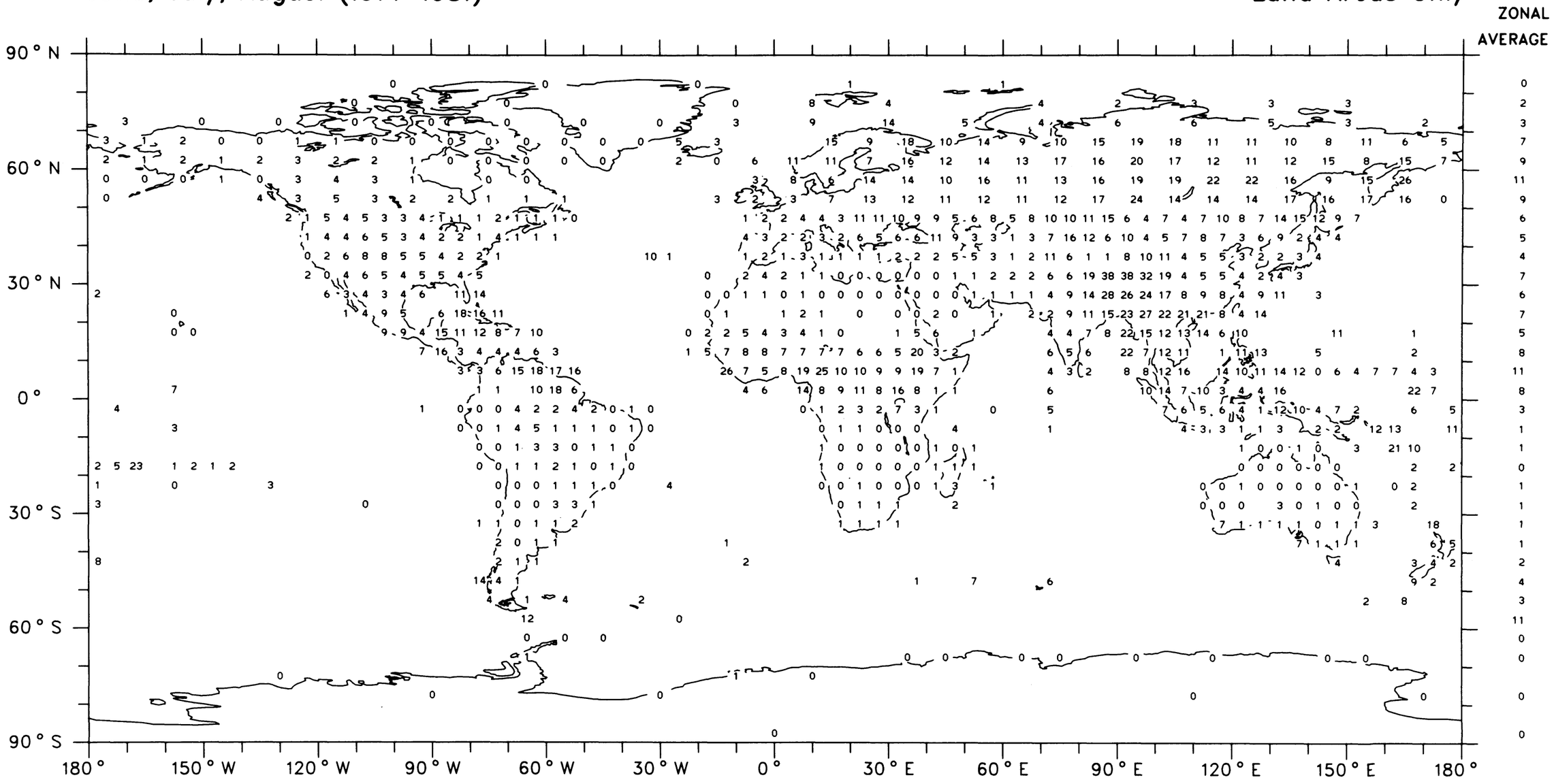
Map 81

Cumulonimbus

Average Cloud Amount (%)

June, July, August (1971-1981)

Land Areas Only



Map 82

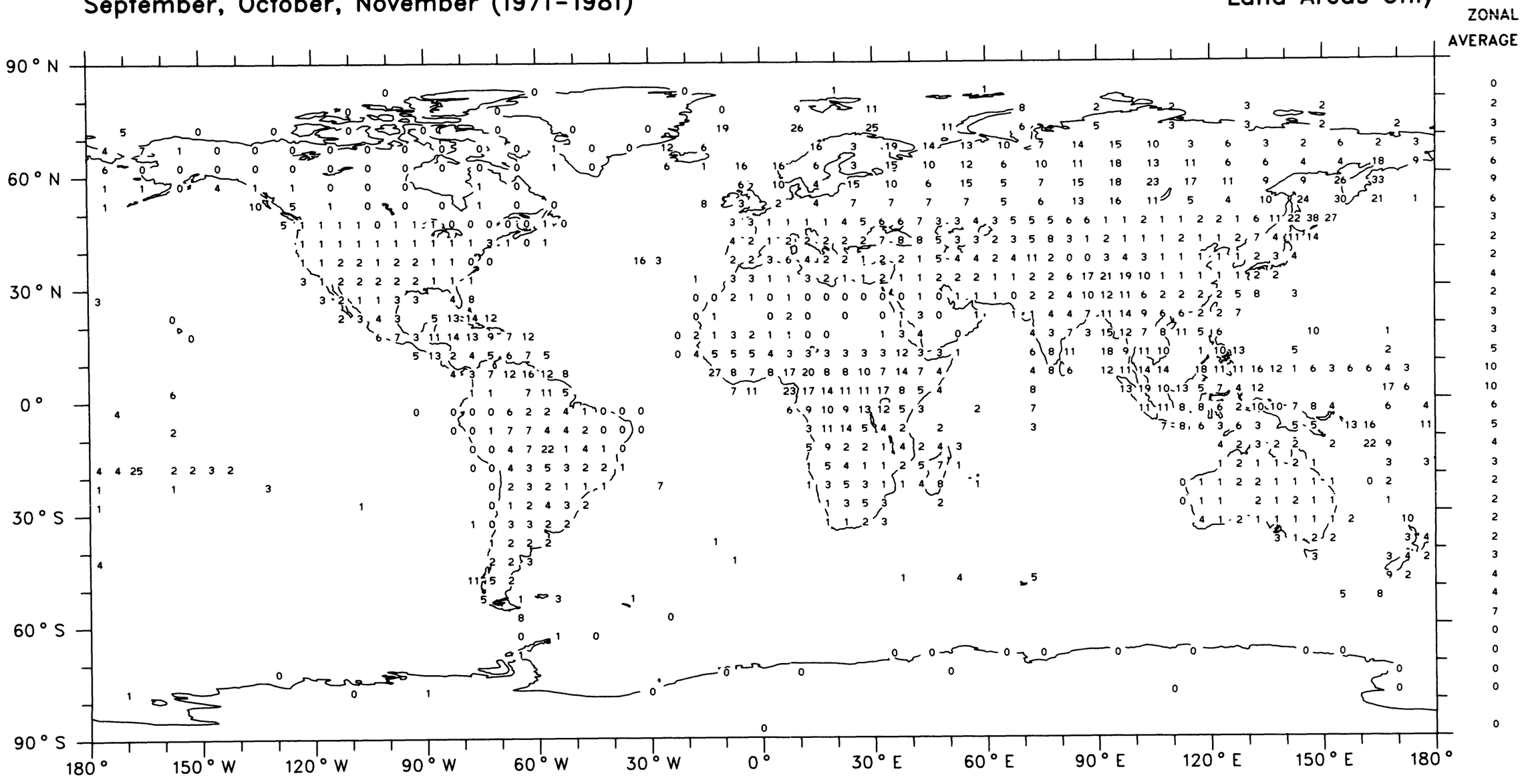
GLOBAL AVERAGE (LAND) 5 %

Cumulonimbus

Average Cloud Amount (%)

September, October, November (1971-1981)

Land Areas Only



GLOBAL AVERAGE (LAND) 4 %

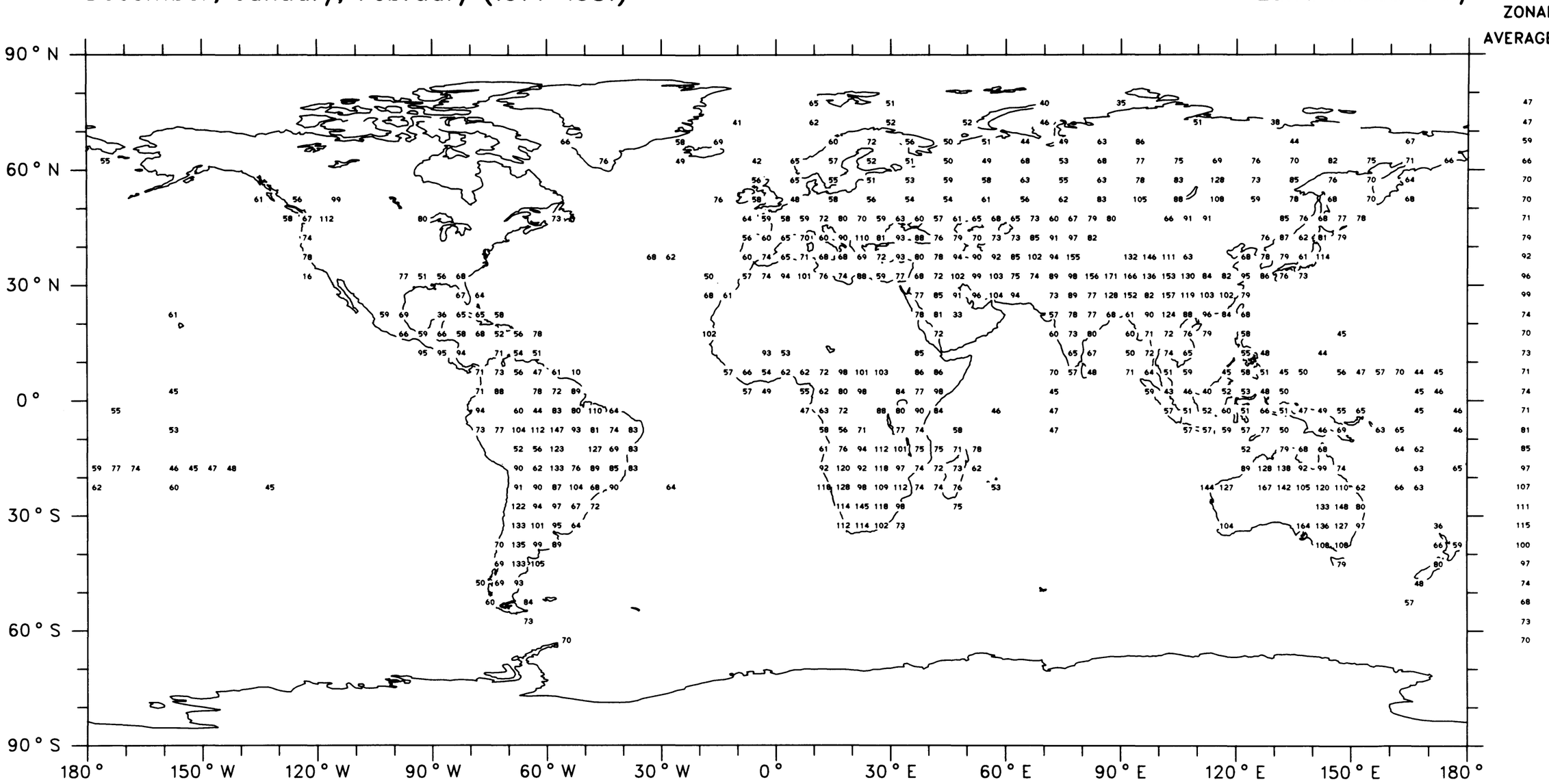
Map 83

Cumulonimbus

Average Base Height (decameters)

December, January, February (1971-1981)

Land Areas Only



Map 84

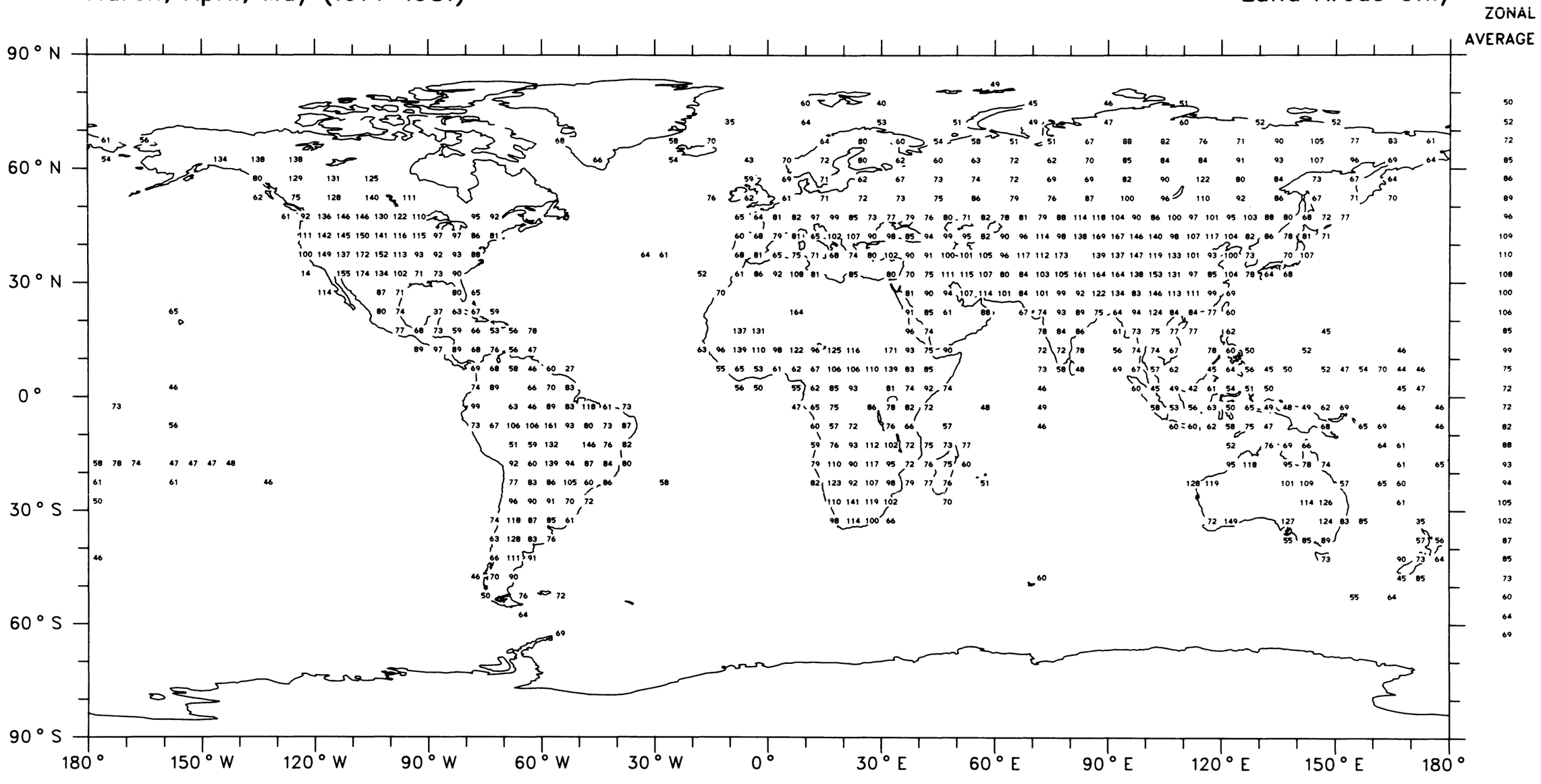
GLOBAL AVERAGE (LAND) 802 METERS

Cumulonimbus

Average Base Height (decameters)

March, April, May (1971-1981)

Land Areas Only



GLOBAL AVERAGE (LAND) 912 METERS

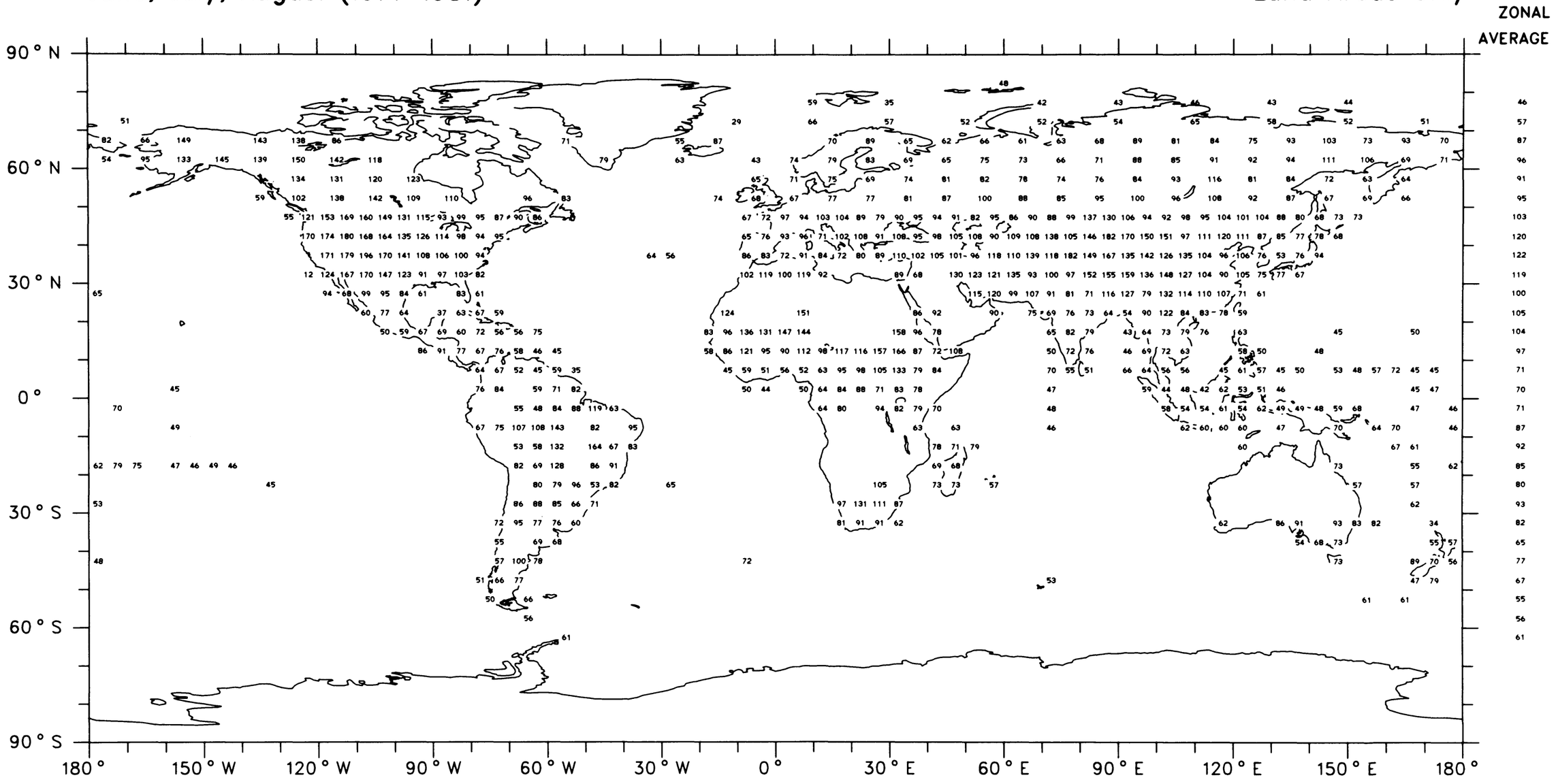
Map 85

Cumulonimbus

Average Base Height (decameters)

June, July, August (1971-1981)

Land Areas Only



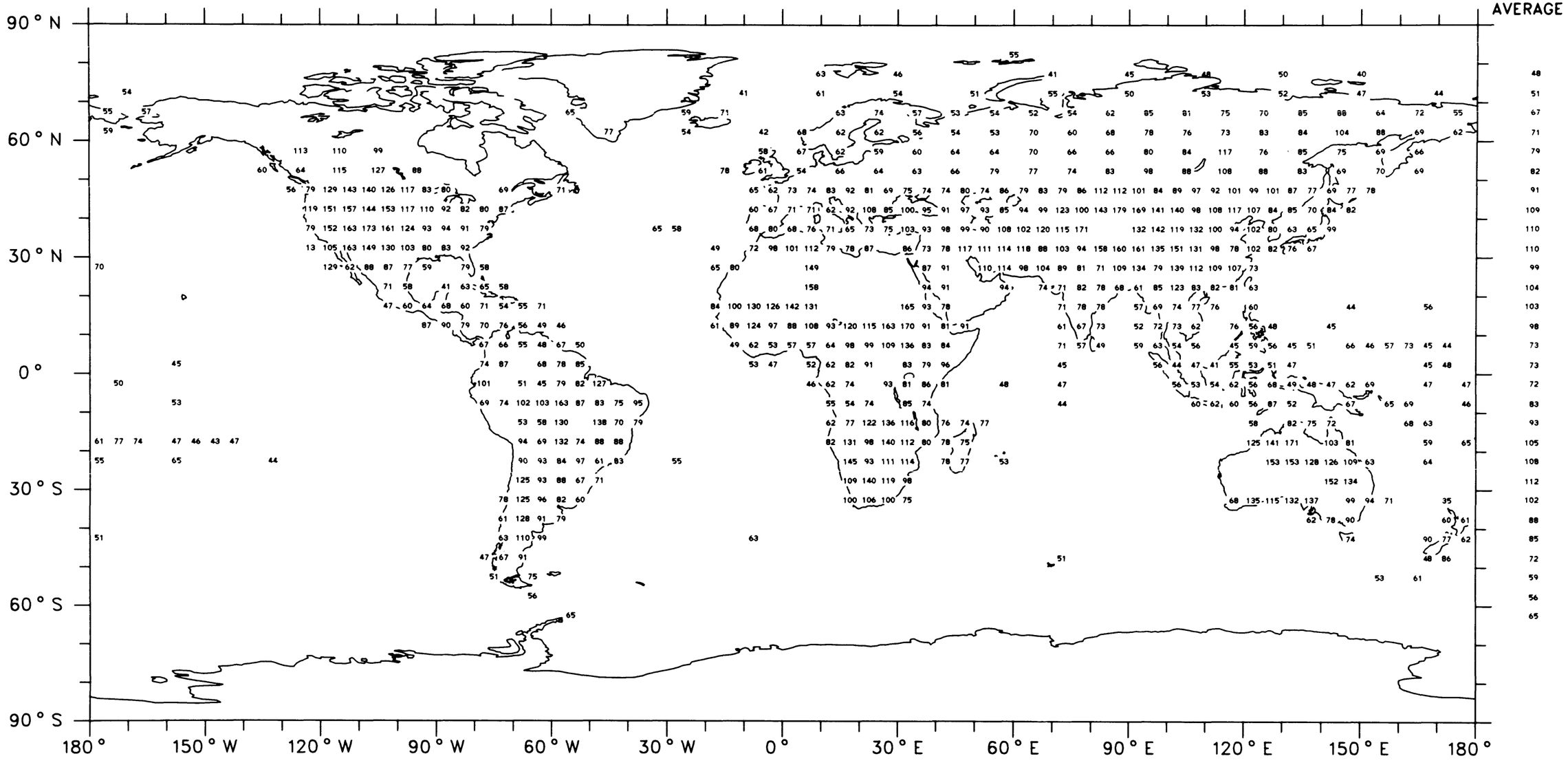
Map 86

GLOBAL AVERAGE (LAND) 944 METERS

Cumulonimbus

Average Base Height (decameters)

September, October, November (1971-1981) **Land Areas Only**



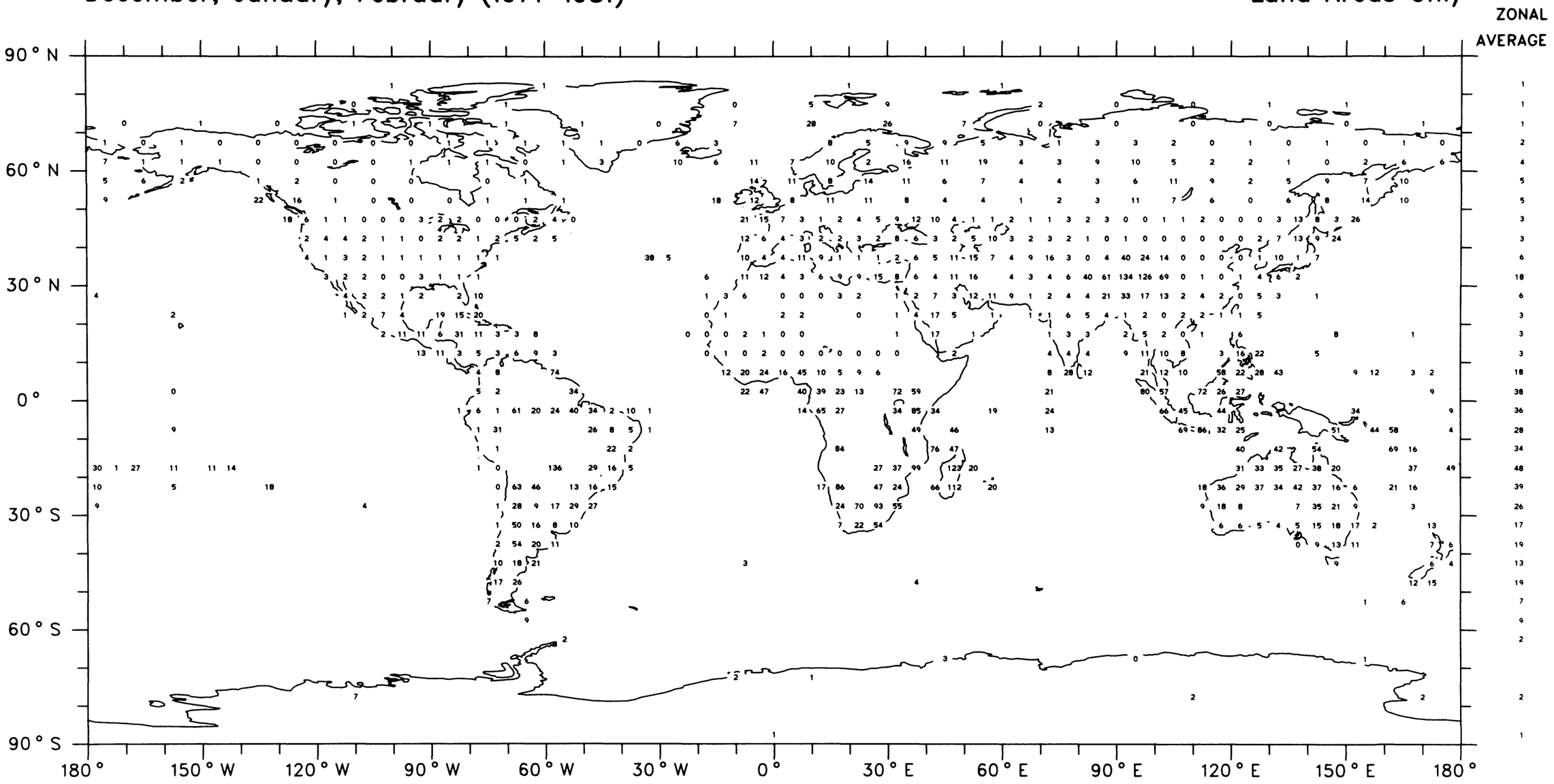
GLOBAL AVERAGE (LAND) 913 METERS

Map 87

Cumulonimbus

Amplitude of Diurnal Cycle (0.1 % Cloud Amount)

December, January, February (1971-1981) **Land Areas Only**



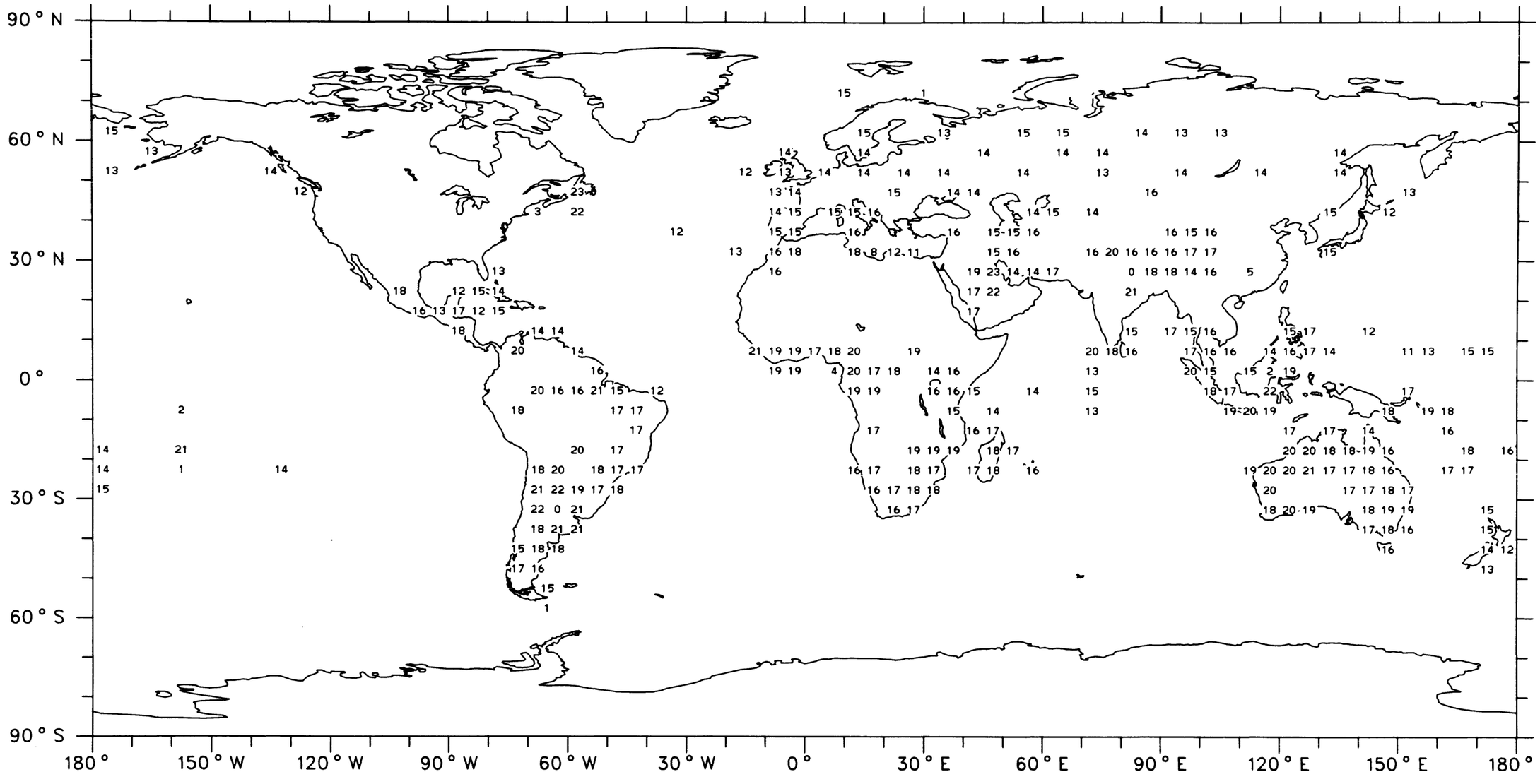
Map 88

GLOBAL AVERAGE (LAND) 1.3 %

Cumulonimbus

Phase of Diurnal Cycle (Local Time of Maximum Cloud Amount)

December, January, February (1971-1981) **Land Areas Only**



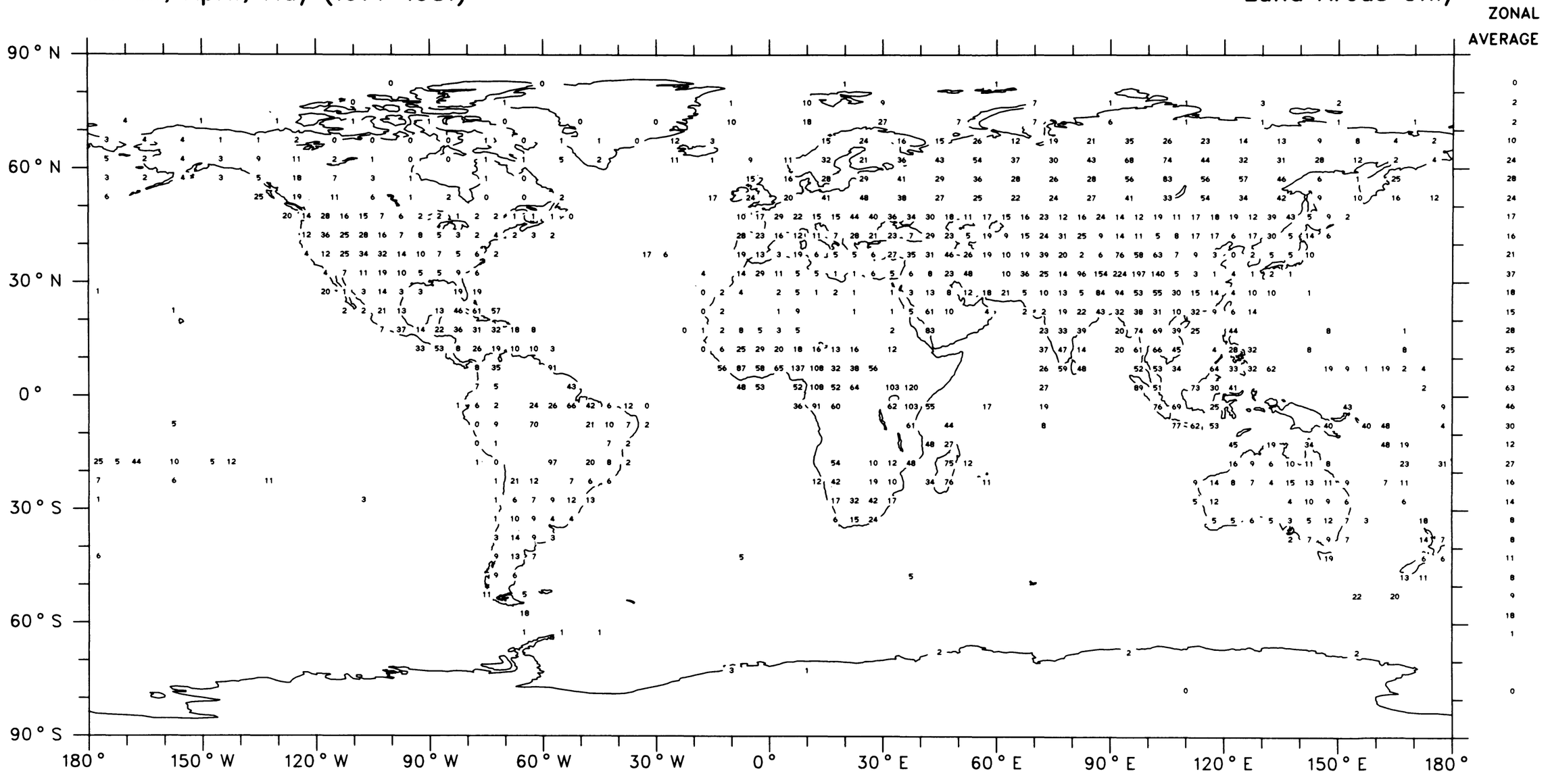
Map 89

Cumulonimbus

Amplitude of Diurnal Cycle (0.1 % Cloud Amount)

March, April, May (1971-1981)

Land Areas Only



Map 90

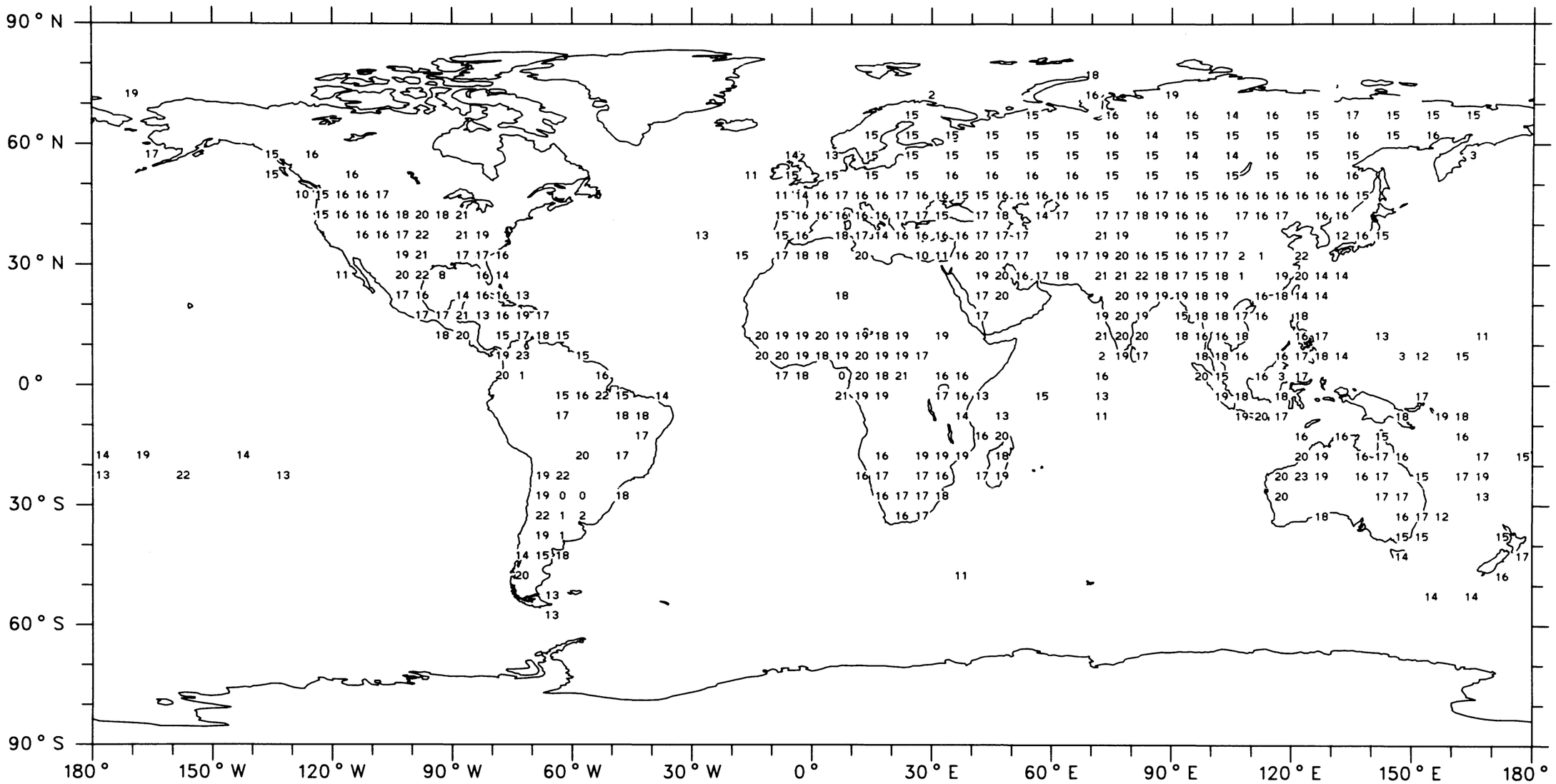
GLOBAL AVERAGE (LAND) 2.4 %

Cumulonimbus

Phase of Diurnal Cycle (Local Time of Maximum Cloud Amount)

March, April, May (1971-1981)

Land Areas Only



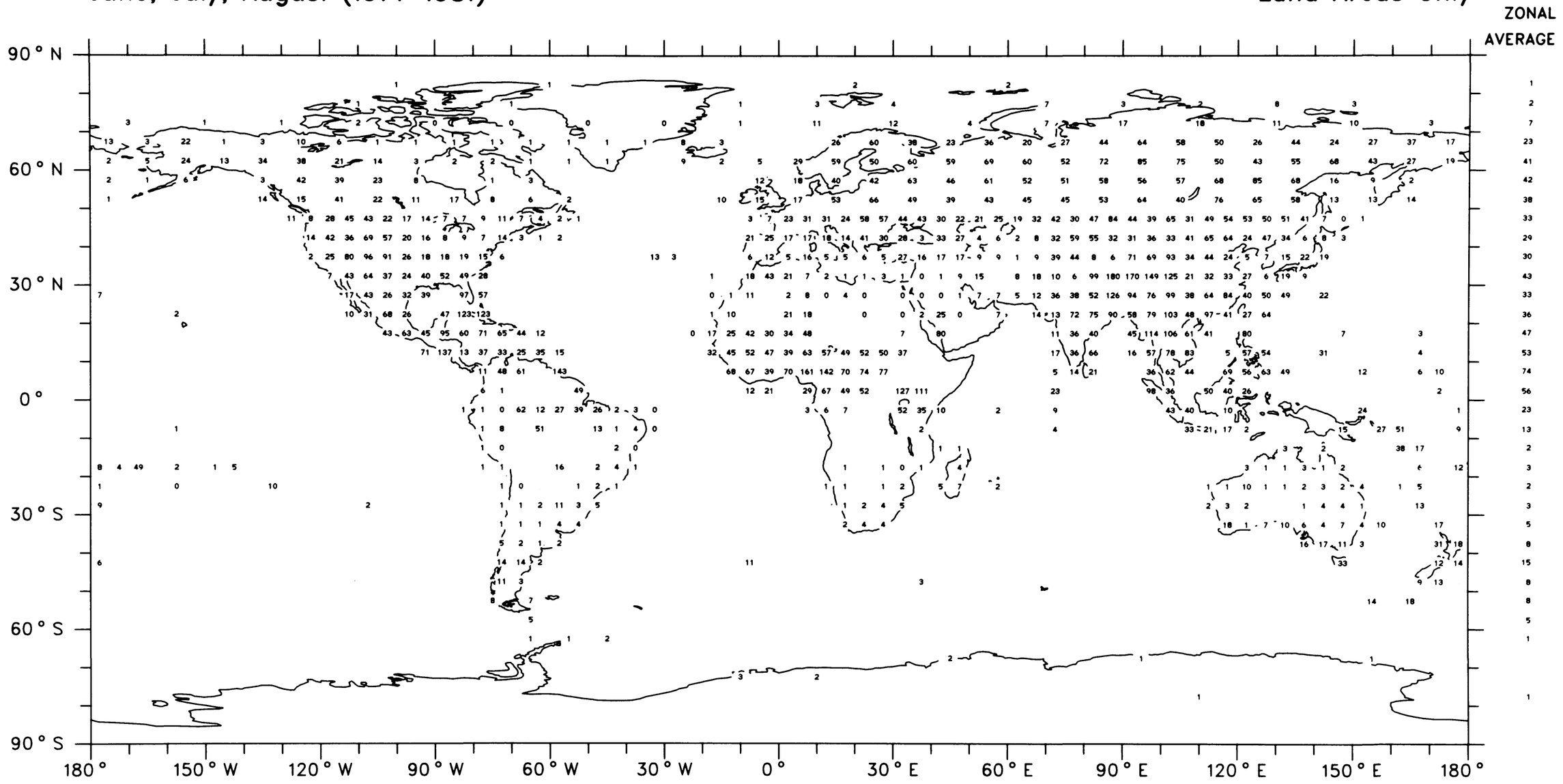
Map 91

Cumulonimbus

Amplitude of Diurnal Cycle (0.1 % Cloud Amount)

June, July, August (1971-1981)

Land Areas Only



Map 92

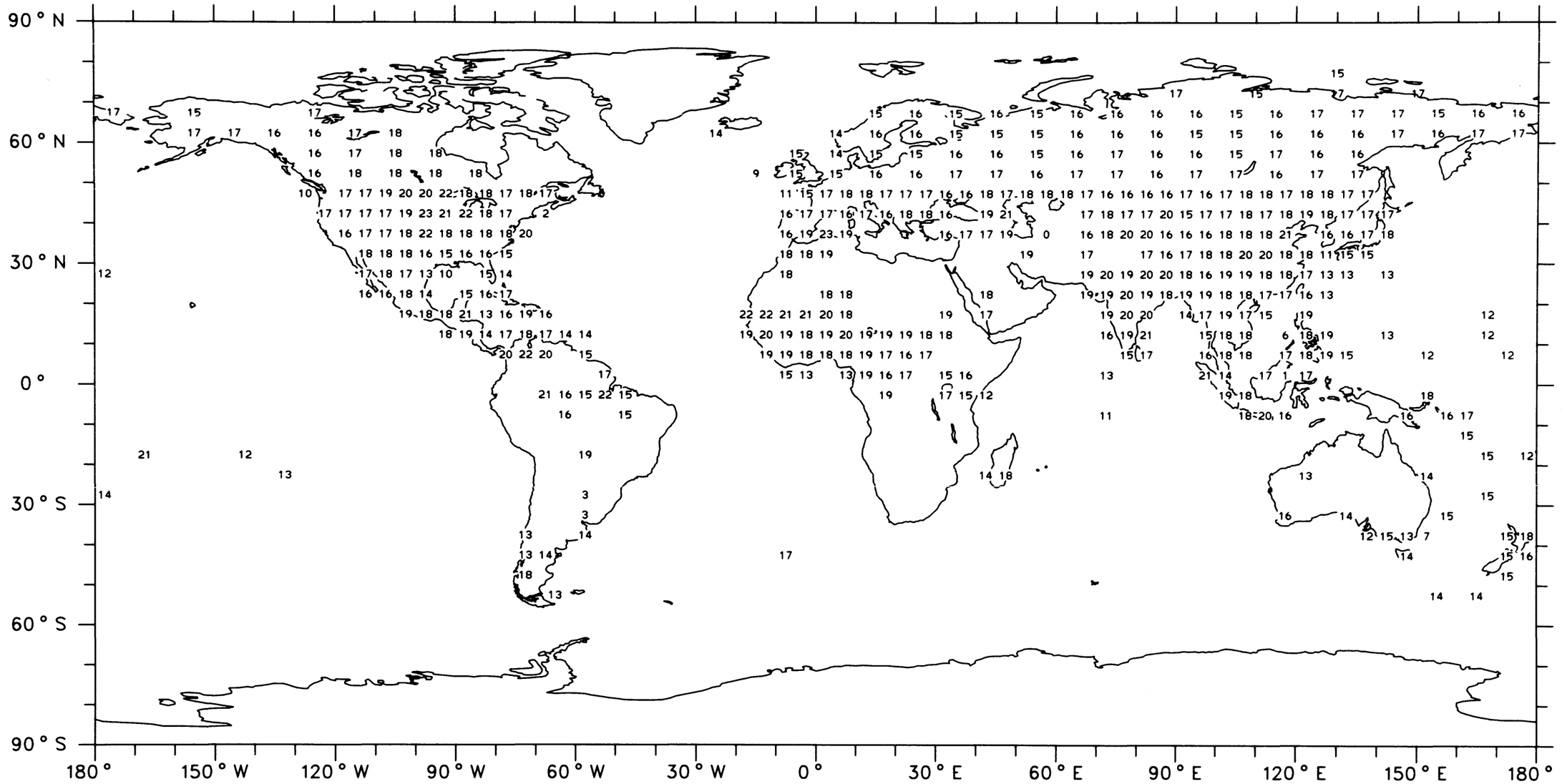
GLOBAL AVERAGE (LAND) 3.0 %

Cumulonimbus

Phase of Diurnal Cycle (Local Time of Maximum Cloud Amount)

June, July, August (1971-1981)

Land Areas Only

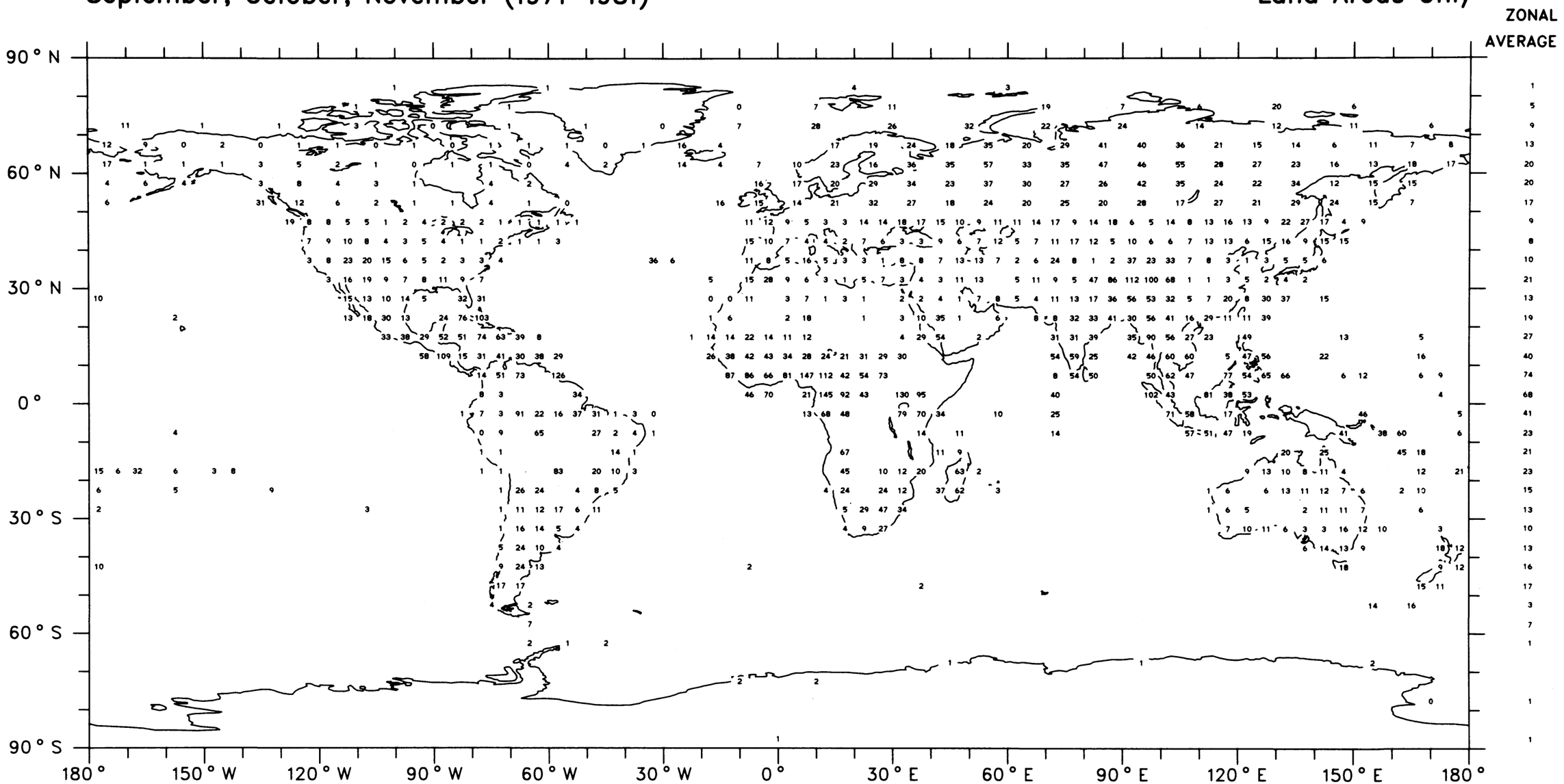


Map 93

Cumulonimbus

Amplitude of Diurnal Cycle (0.1 % Cloud Amount)

September, October, November (1971-1981) **Land Areas Only**



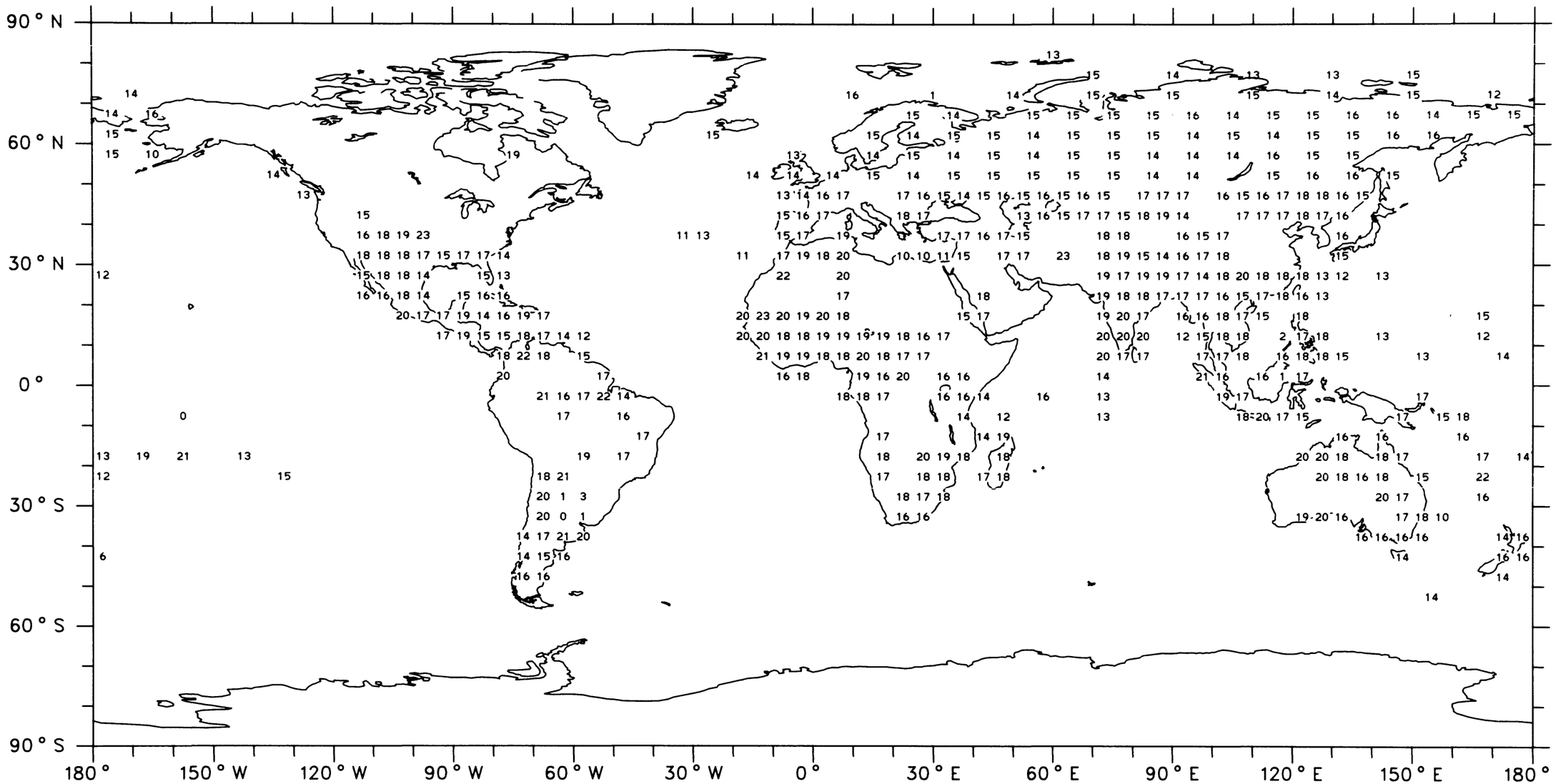
Map 94

GLOBAL AVERAGE (LAND) 2.1 %

Cumulonimbus

Phase of Diurnal Cycle (Local Time of Maximum Cloud Amount)

September, October, November (1971-1981) **Land Areas Only**



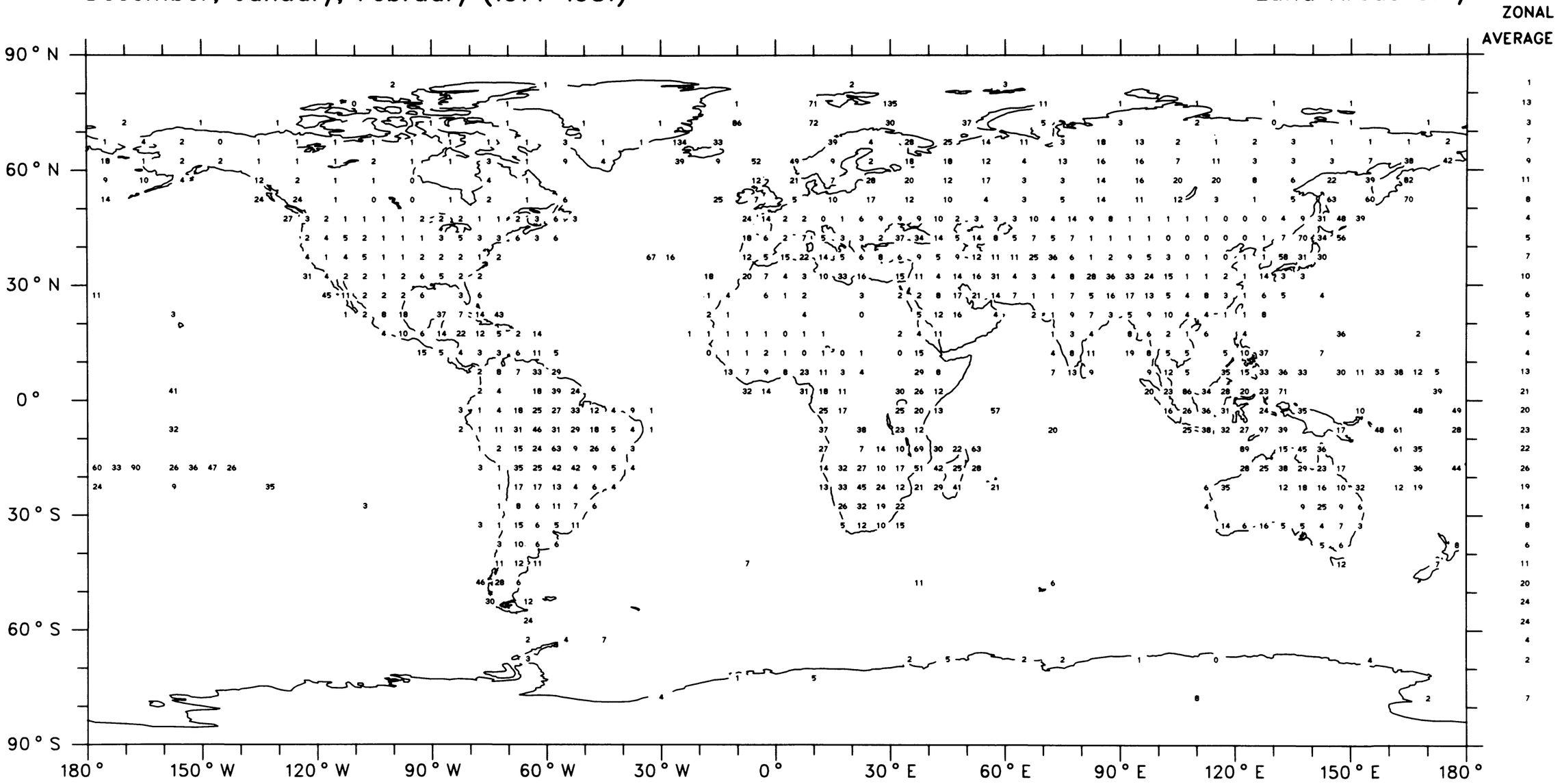
Map 95

Interannual Variation of Cumulonimbus :

Standard Deviation of Seasonal Means (0.1 % Cloud Amount)

December, January, February (1971-1981)

Land Areas Only



Map 96

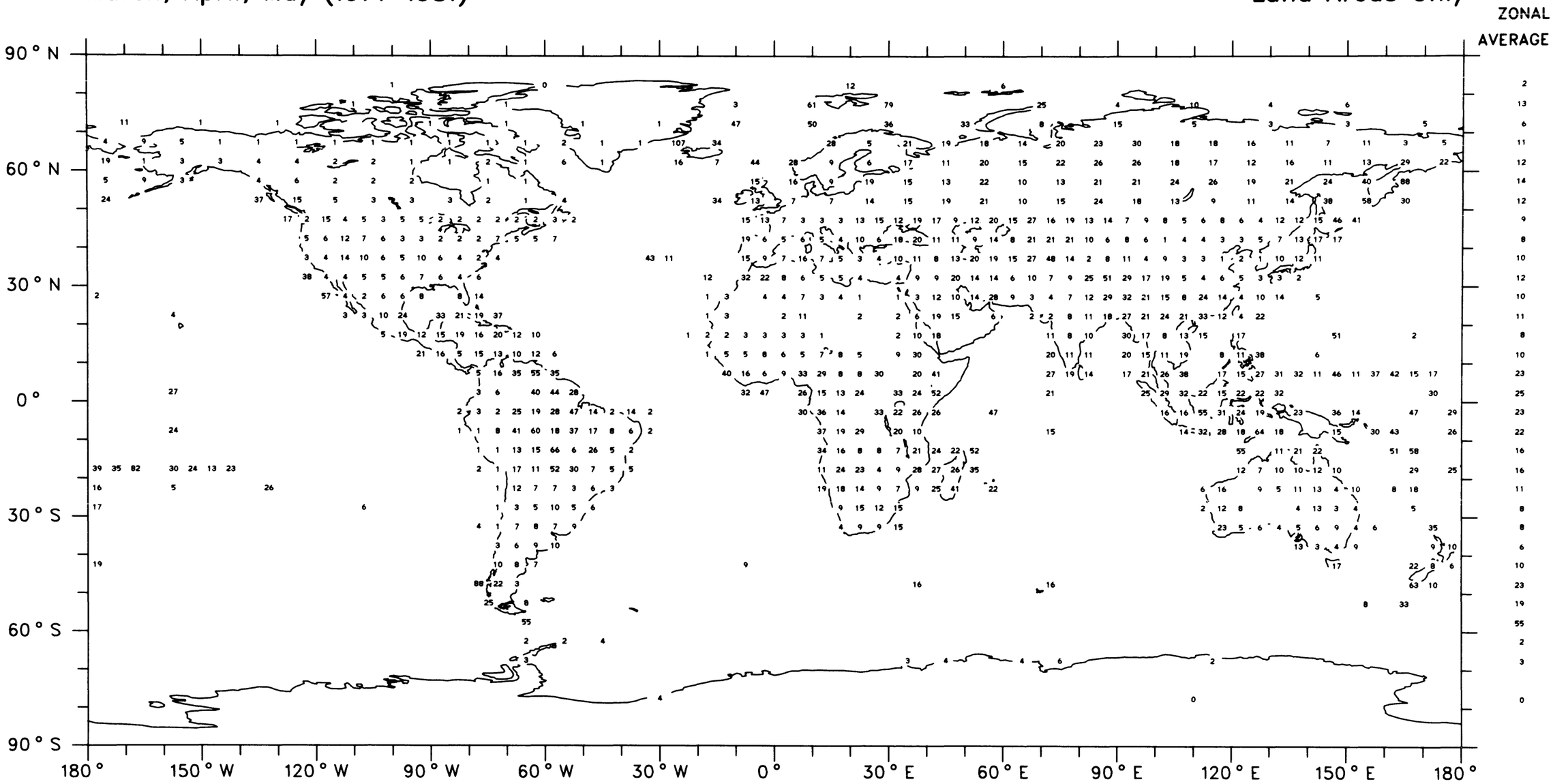
GLOBAL AVERAGE (LAND) 1.1 %

Interannual Variation of Cumulonimbus :

Standard Deviation of Seasonal Means (0.1 % Cloud Amount)

March, April, May (1971-1981)

Land Areas Only



GLOBAL AVERAGE (LAND) 1.2 %

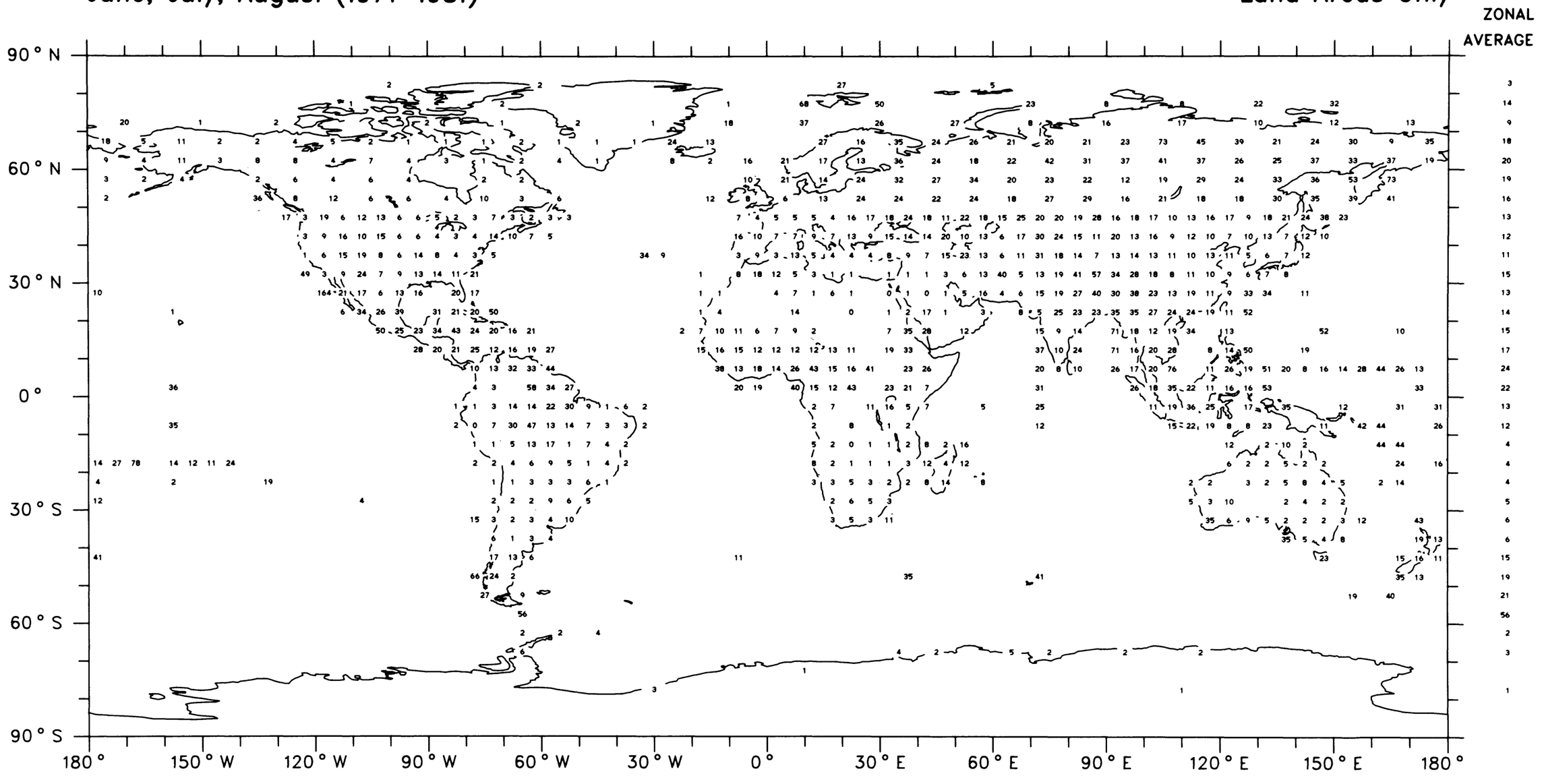
Map 97

Interannual Variation of Cumulonimbus :

Standard Deviation of Seasonal Means (0.1 % Cloud Amount)

June, July, August (1971-1981)

Land Areas Only



Map 98

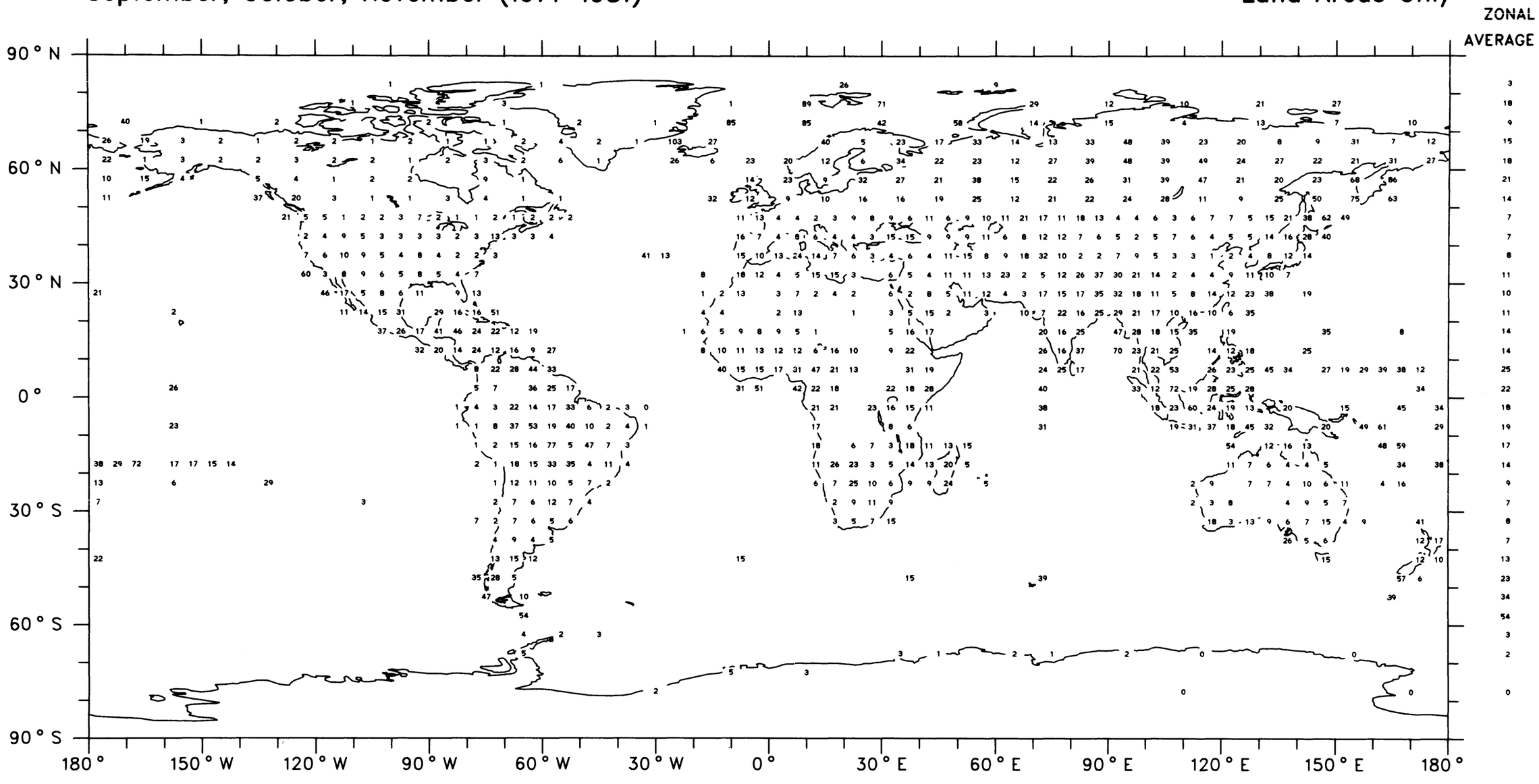
GLOBAL AVERAGE (LAND) 1.3 %

Interannual Variation of Cumulonimbus :

Standard Deviation of Seasonal Means (0.1 % Cloud Amount)

September, October, November (1971-1981)

Land Areas Only



GLOBAL AVERAGE (LAND) 1.3 %

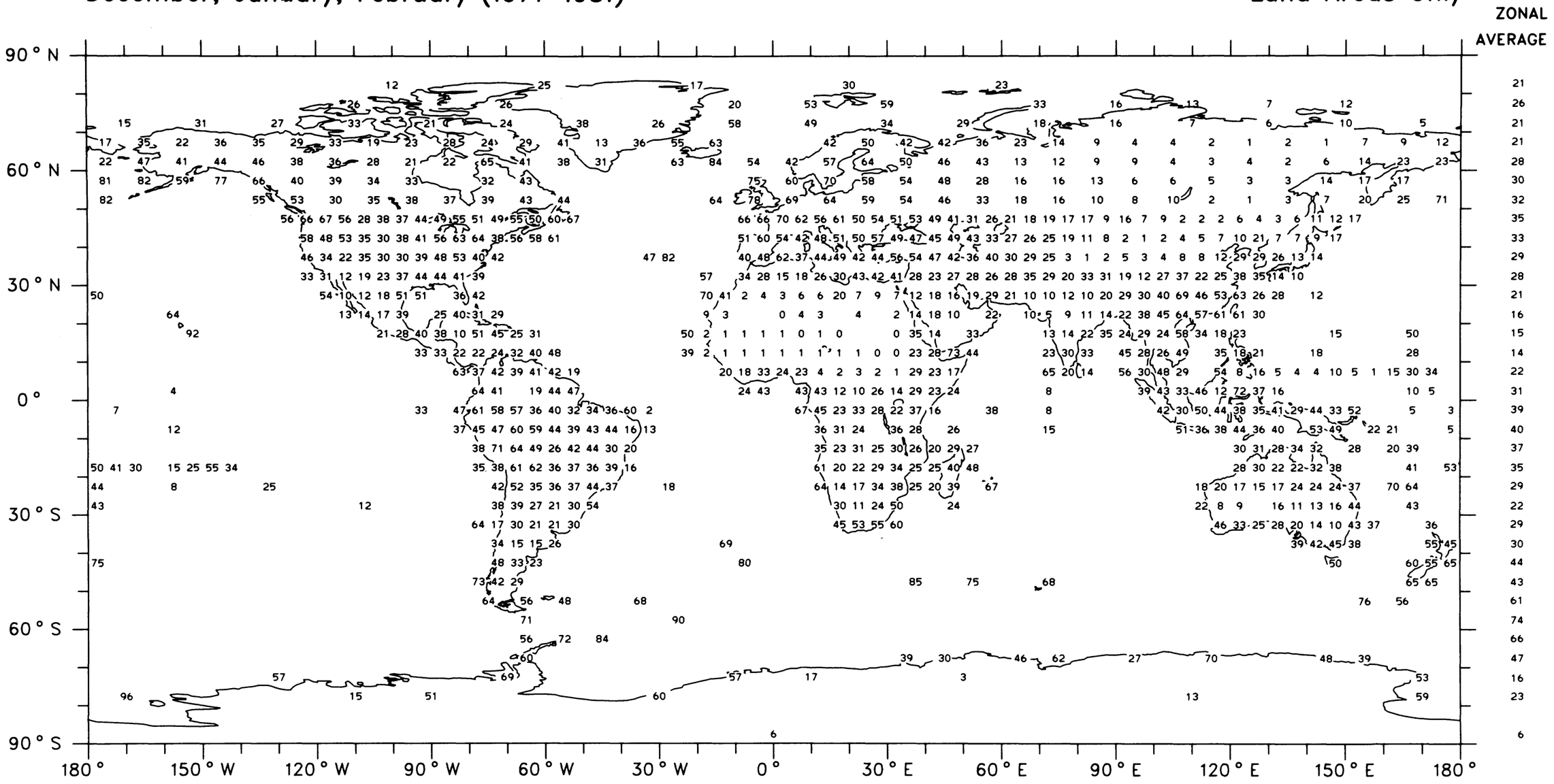
Map 99

Stratus + Stratocumulus + Fog

Frequency of Occurrence (%)

December, January, February (1971-1981)

Land Areas Only



Map 100

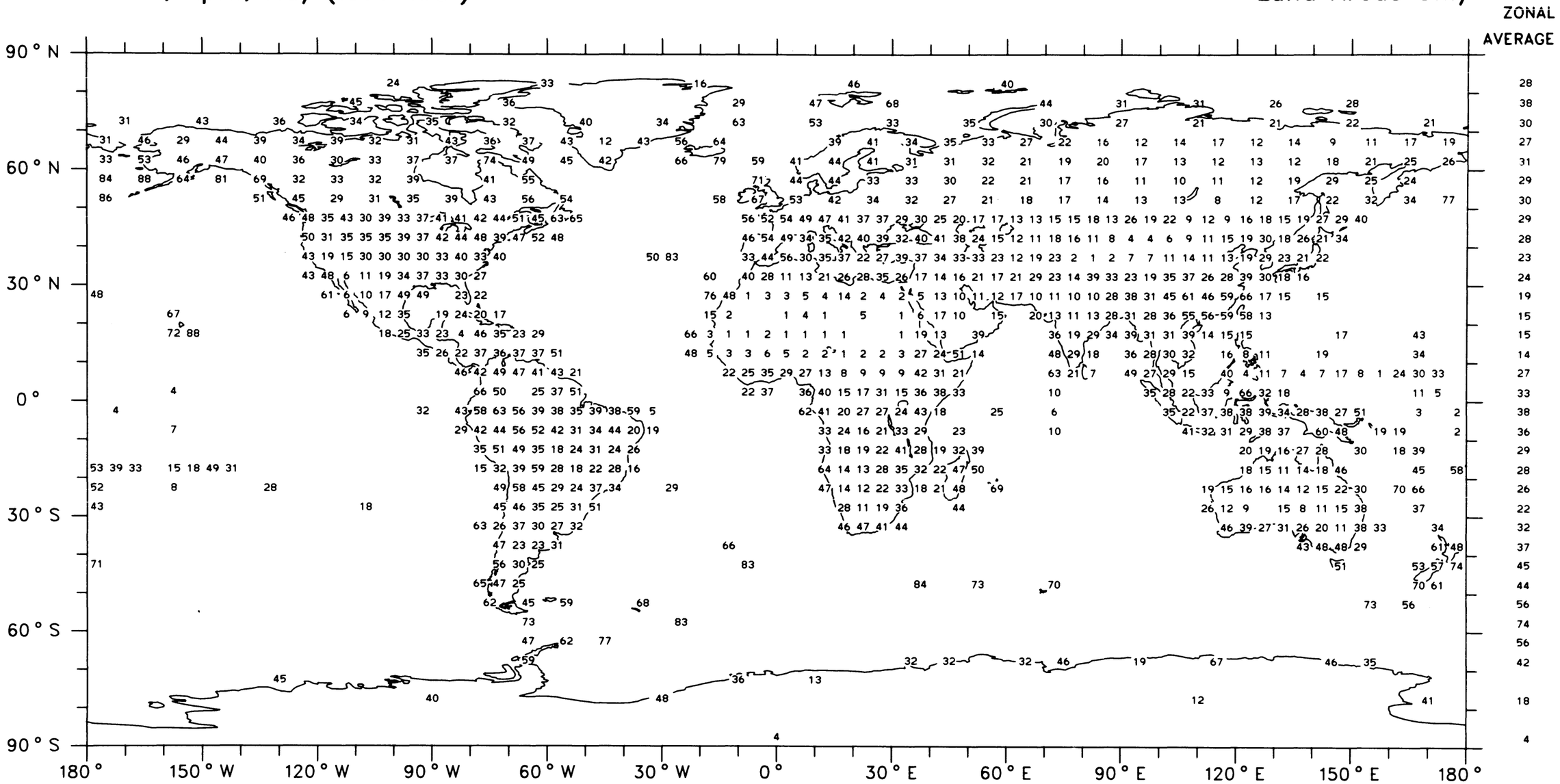
GLOBAL AVERAGE (LAND) 27 %

Stratus + Stratocumulus + Fog

Frequency of Occurrence (%)

March, April, May (1971-1981)

Land Areas Only



GLOBAL AVERAGE (LAND) 26 %

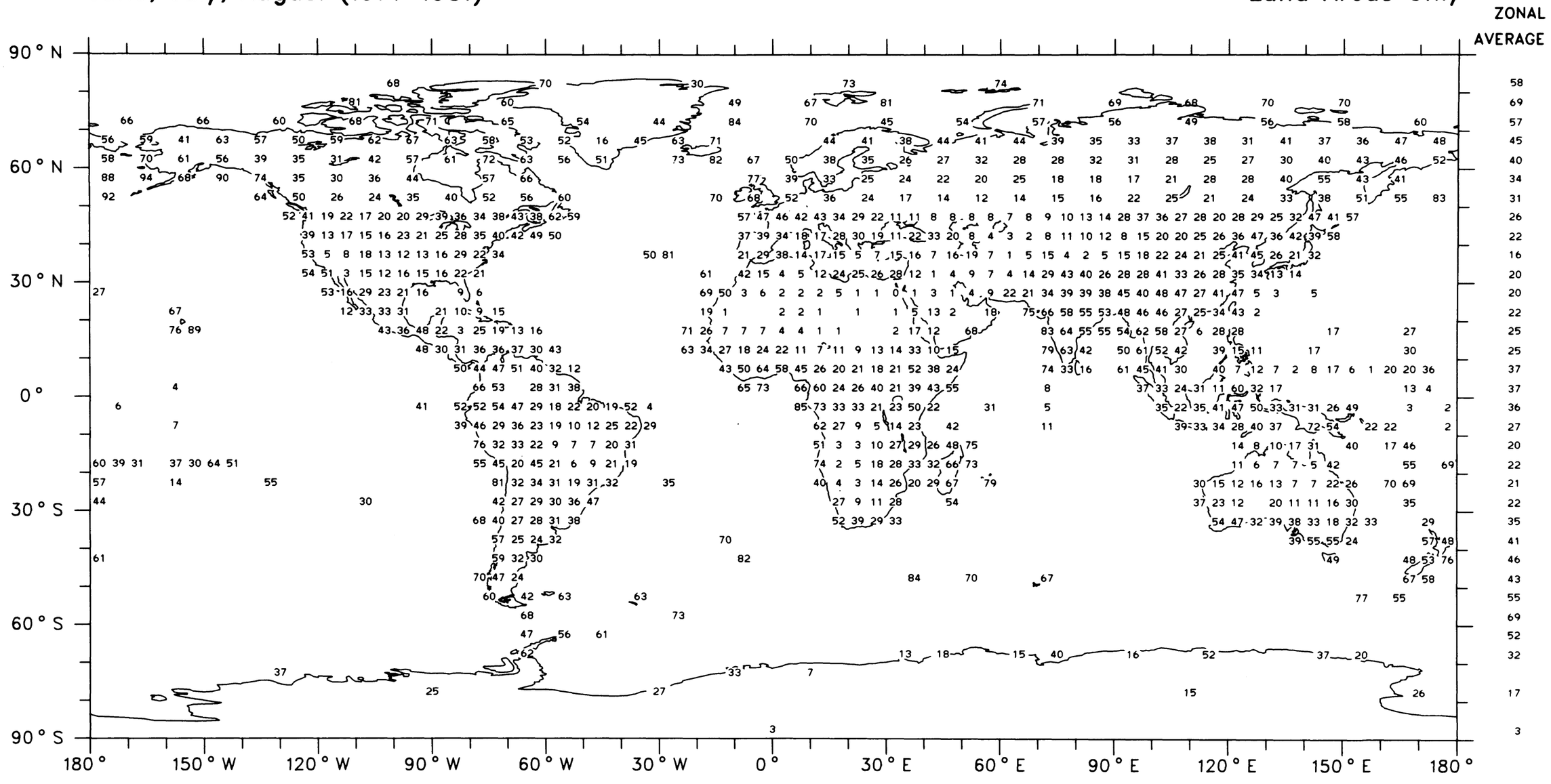
Map 101

Stratus + Stratocumulus + Fog

Frequency of Occurrence (%)

June, July, August (1971-1981)

Land Areas Only



Map 102

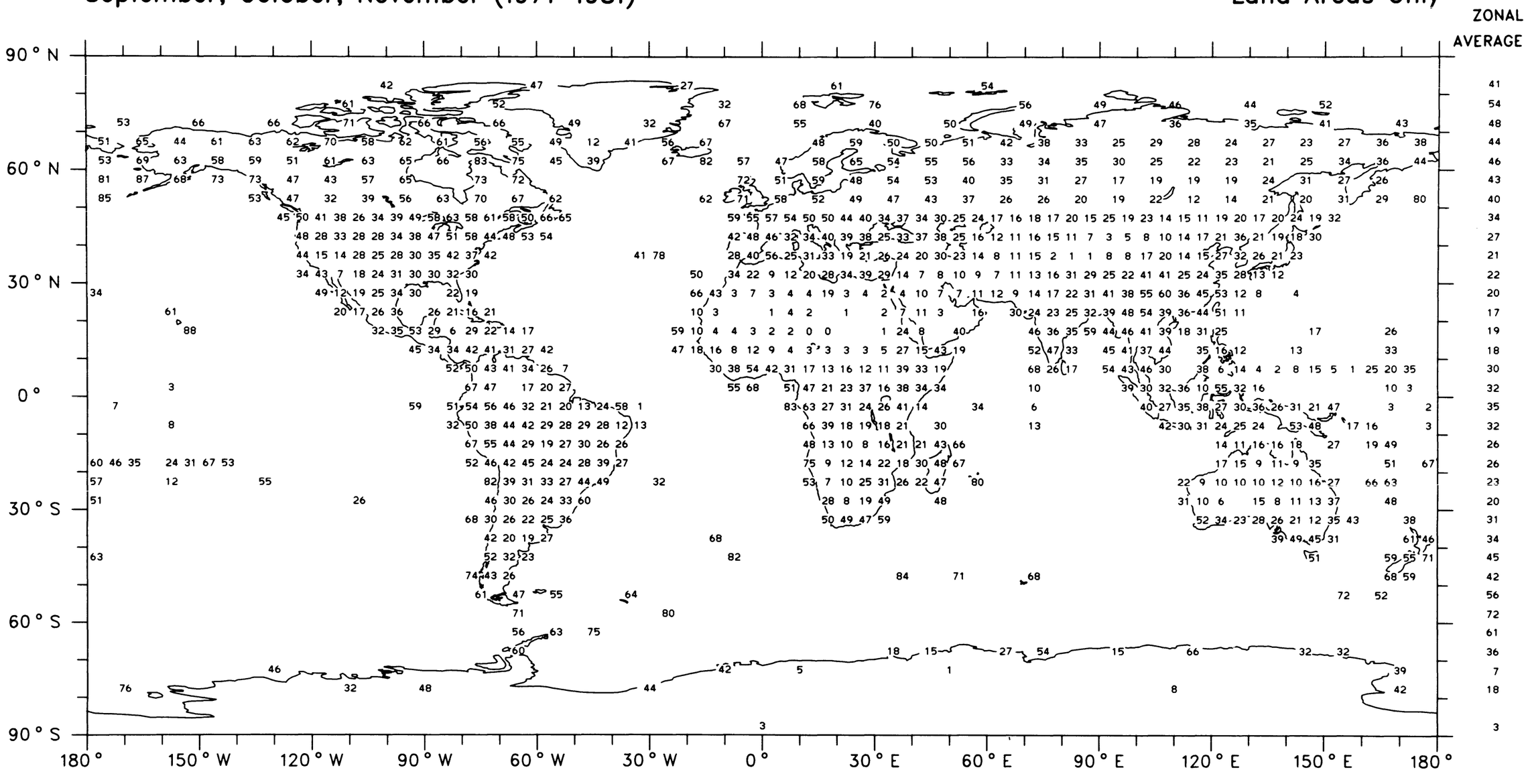
GLOBAL AVERAGE (LAND) 28 %

Stratus + Stratocumulus + Fog

Frequency of Occurrence (%)

September, October, November (1971-1981)

Land Areas Only



GLOBAL AVERAGE (LAND) 28 %

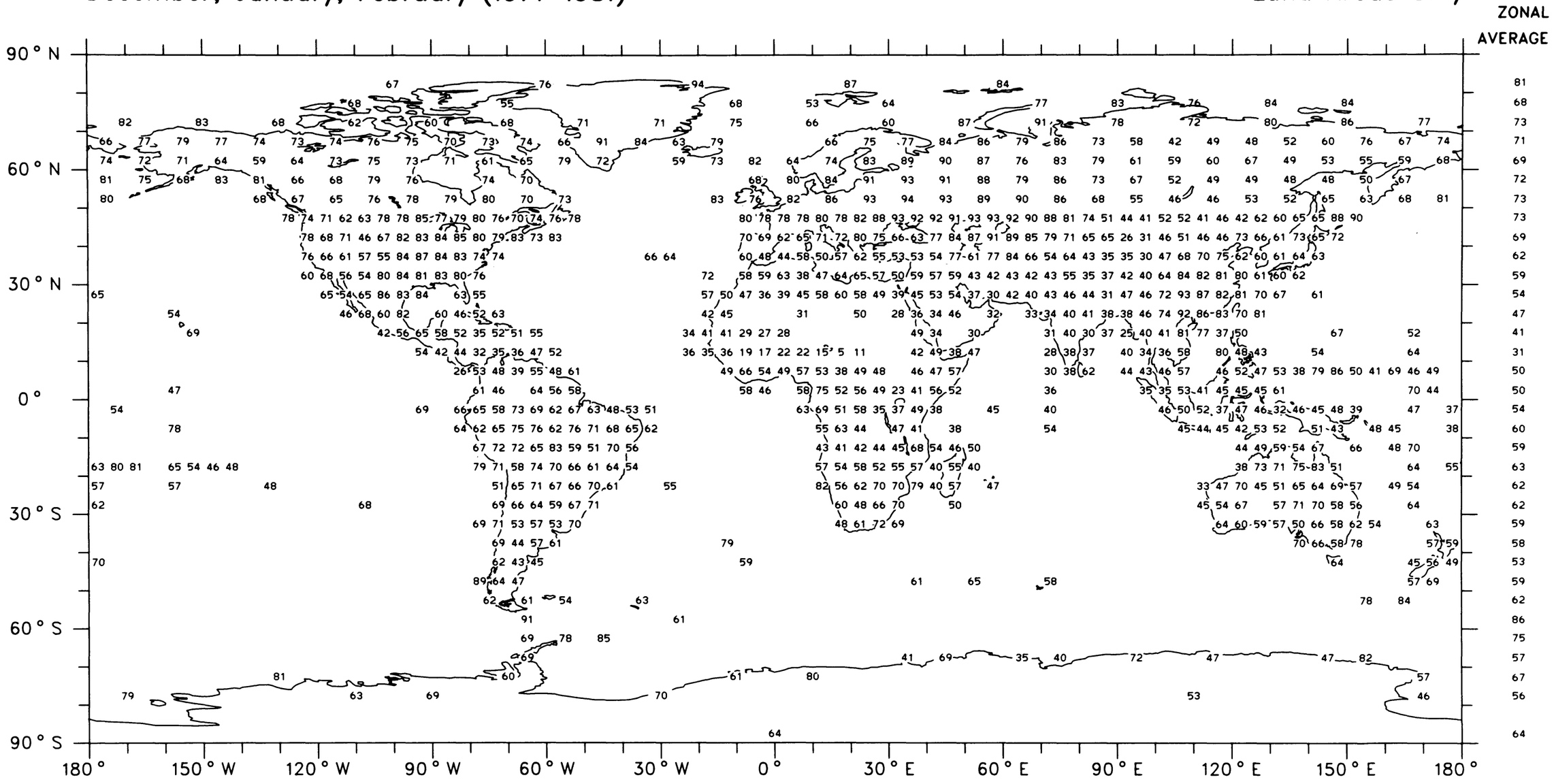
Map 103

Stratus + Stratocumulus + Fog

Amount-When-Present (%)

December, January, February (1971-1981)

Land Areas Only



Map 104

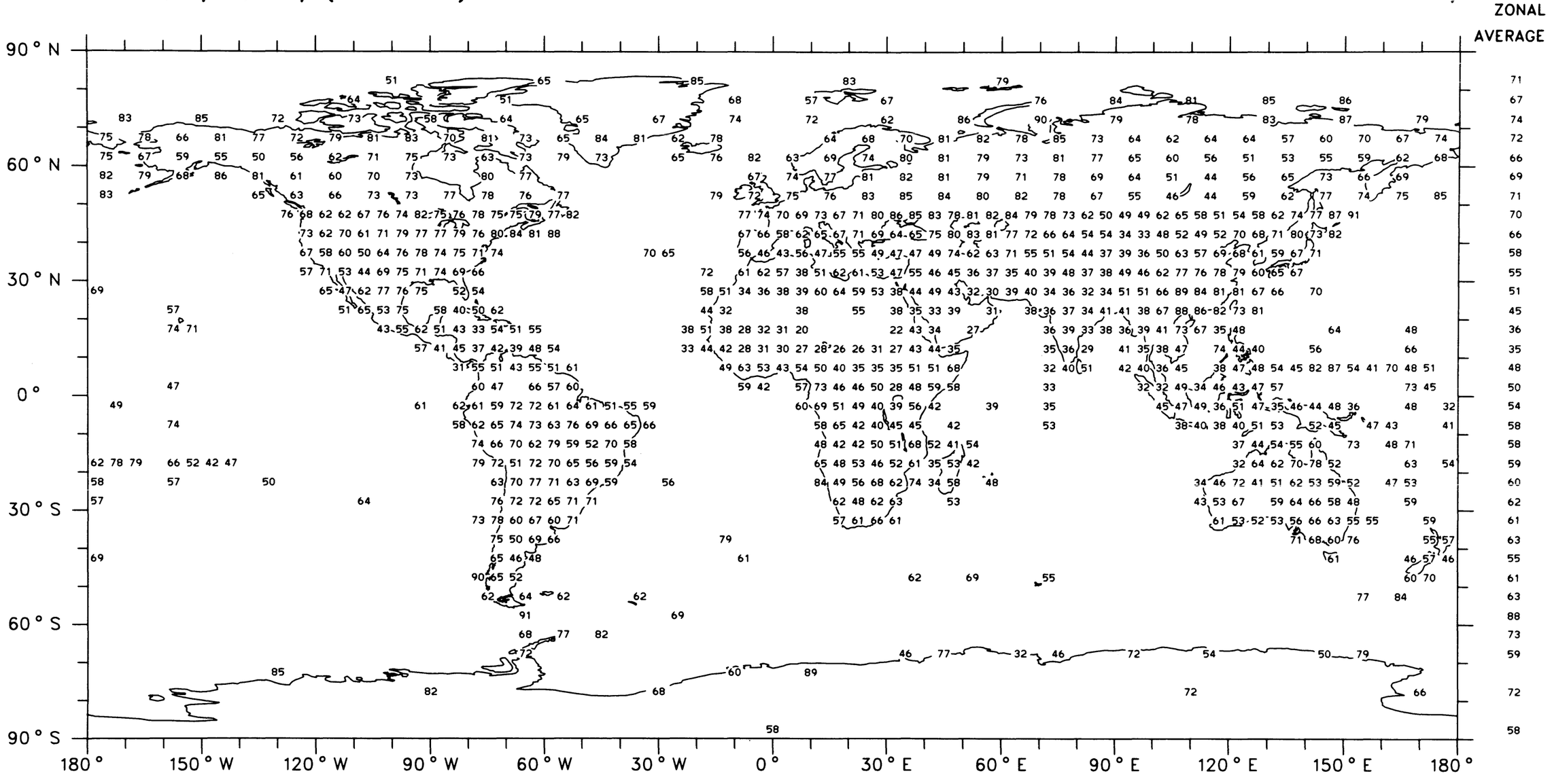
GLOBAL AVERAGE (LAND) 60 %

Stratus + Stratocumulus + Fog

Amount-When-Present (%)

March, April, May (1971-1981)

Land Areas Only



GLOBAL AVERAGE (LAND) 59 %

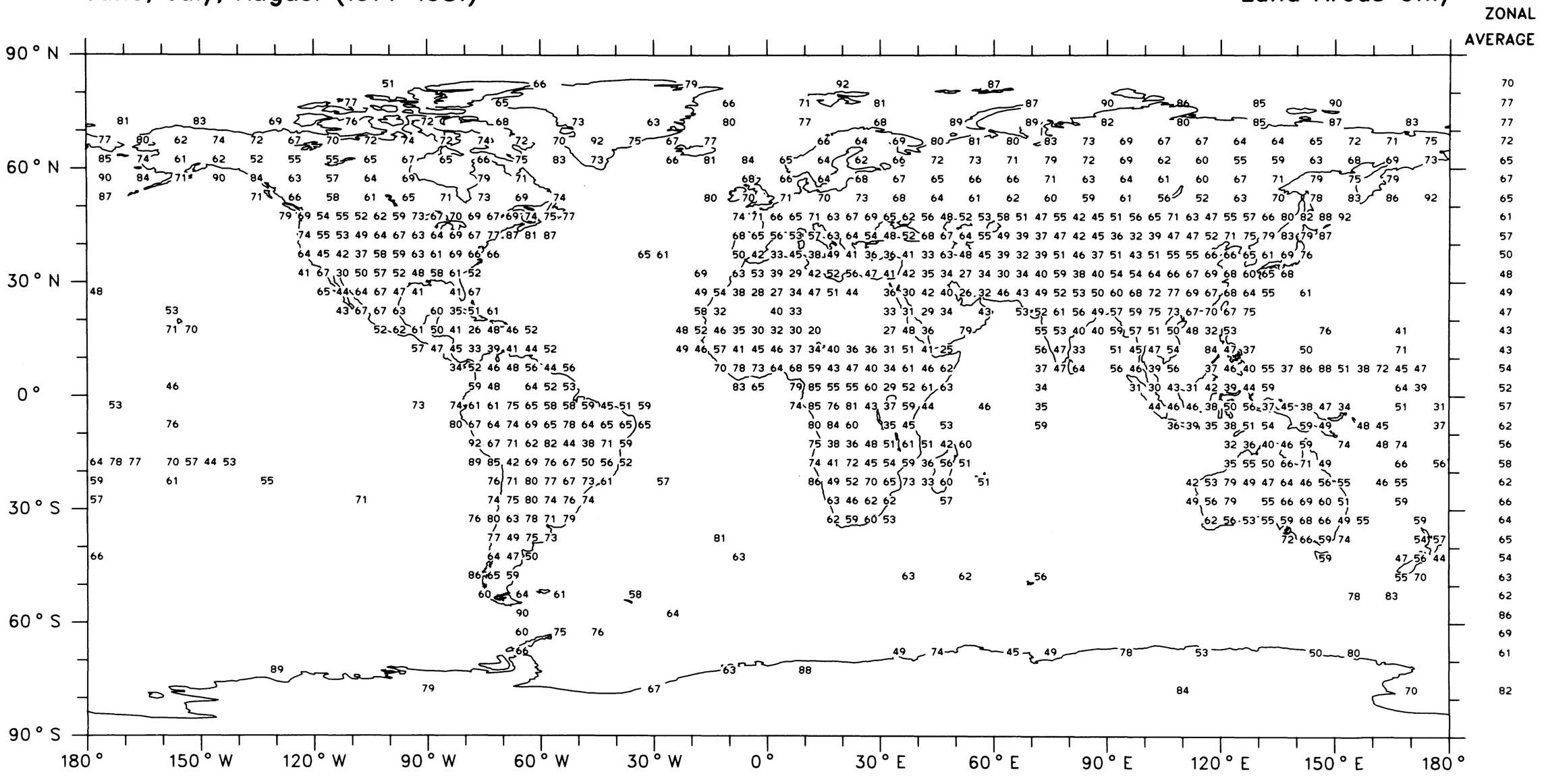
Map 105

Stratus + Stratocumulus + Fog

Amount-When-Present (%)

June, July, August (1971-1981)

Land Areas Only



Map 106

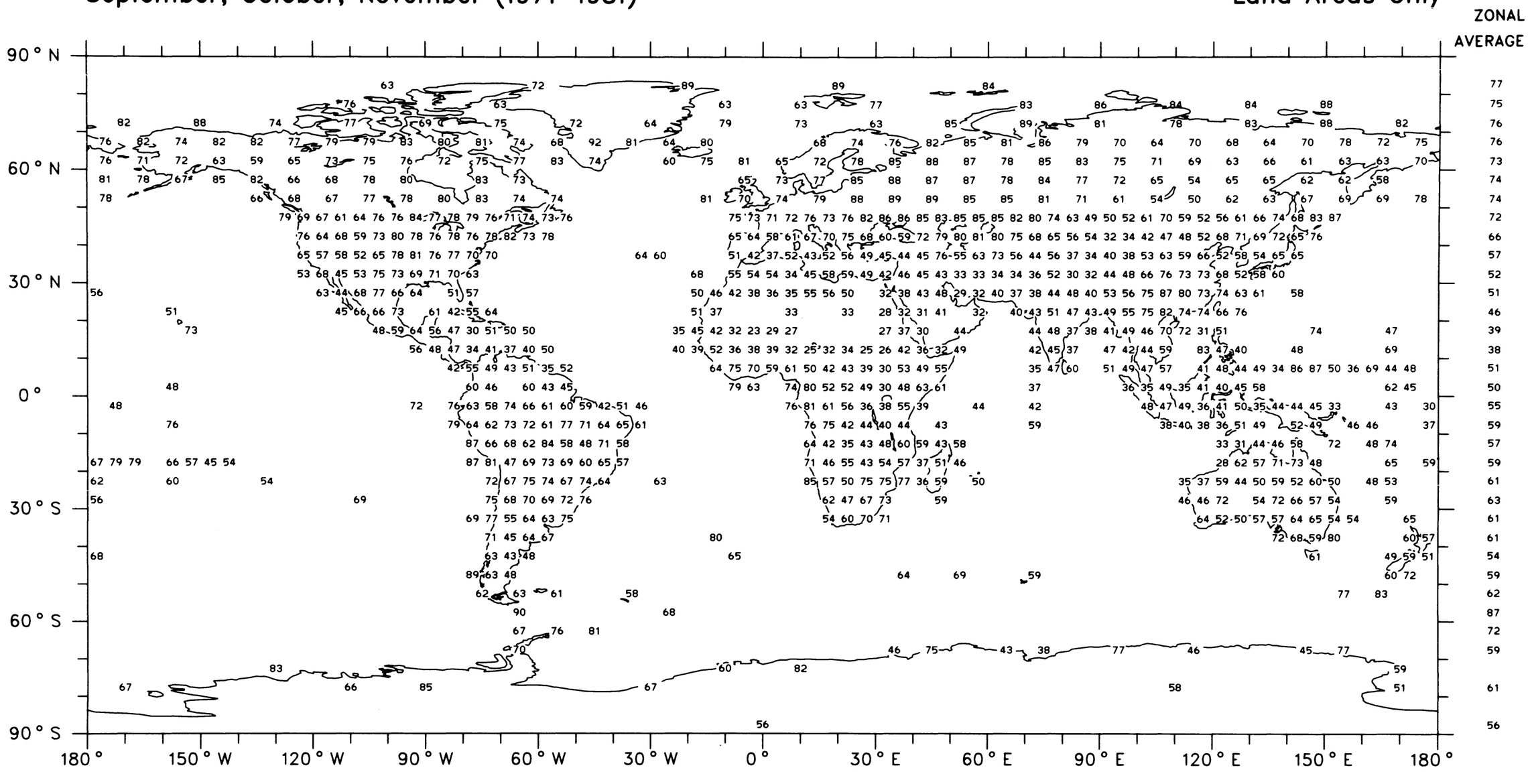
GLOBAL AVERAGE (LAND) 58 %

Stratus + Stratocumulus + Fog

Amount-When-Present (%)

September, October, November (1971-1981)

Land Areas Only



GLOBAL AVERAGE (LAND) 60 %

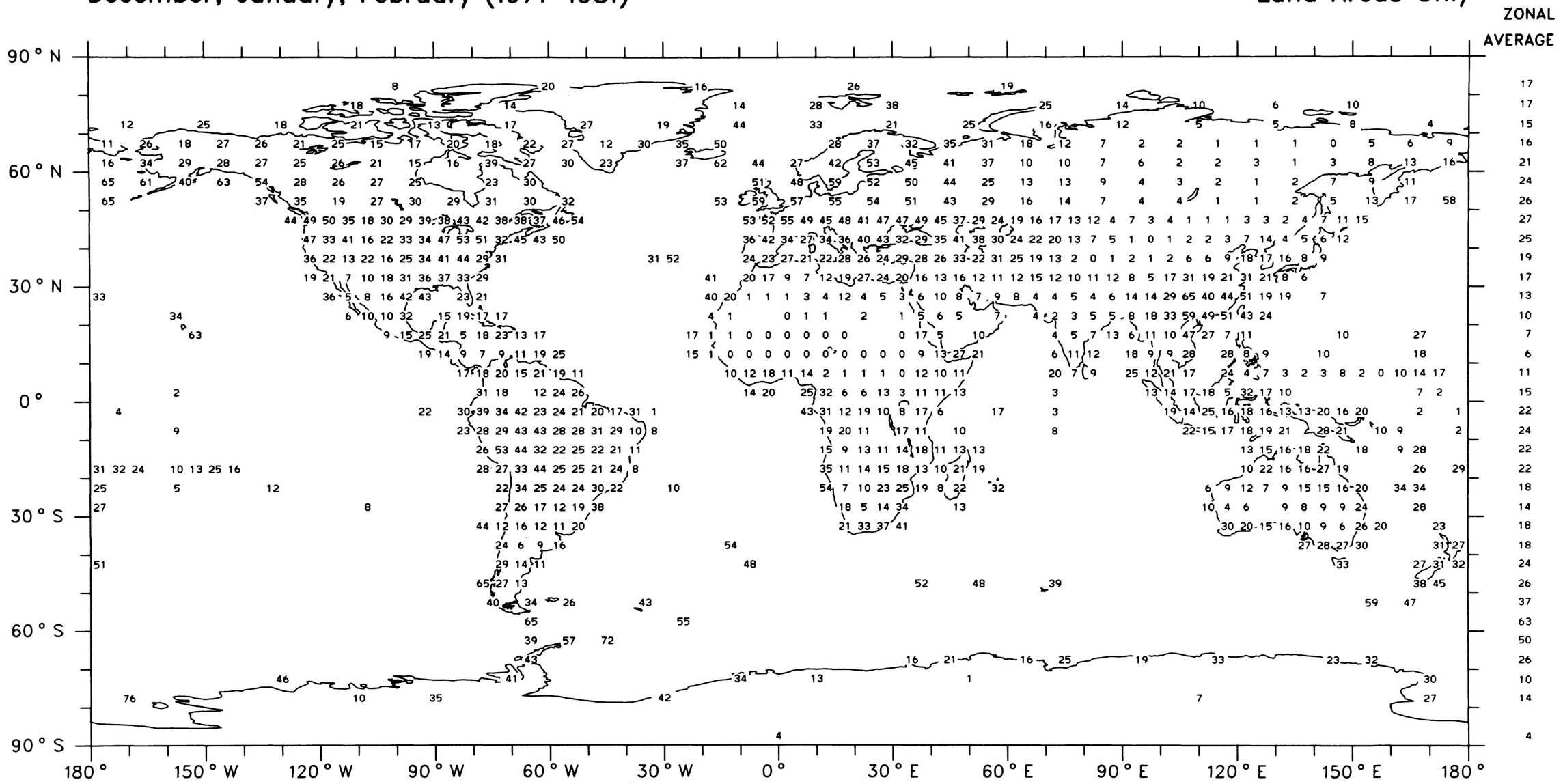
Map 107

Stratus + Stratocumulus + Fog

Average Cloud Amount (%)

December, January, February (1971-1981)

Land Areas Only



Map 108

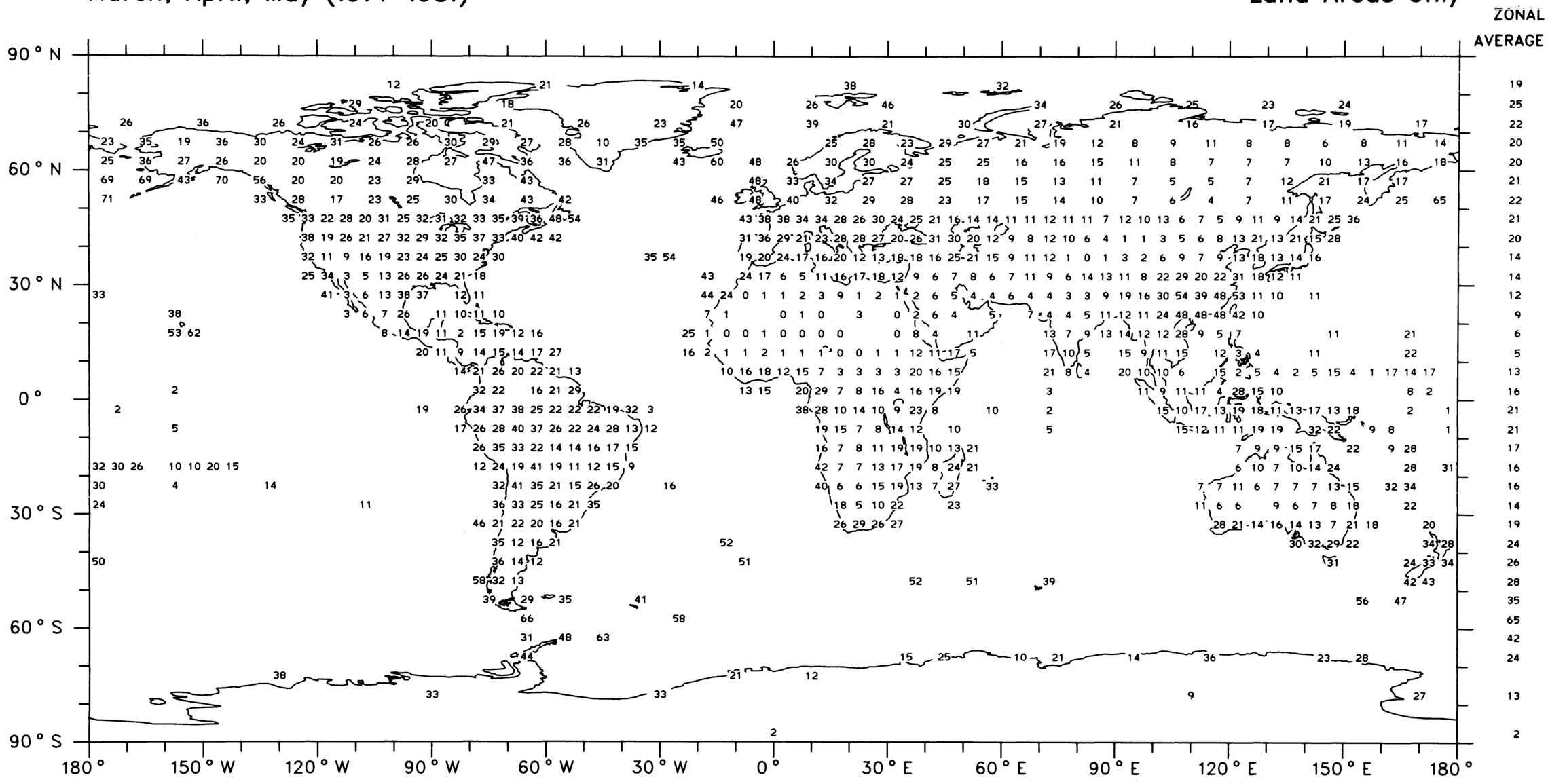
GLOBAL AVERAGE (LAND) 18 %

Stratus + Stratocumulus + Fog

Average Cloud Amount (%)

March, April, May (1971-1981)

Land Areas Only



GLOBAL AVERAGE (LAND) 16 %

Map 109

Stratus + Stratocumulus + Fog

Average Cloud Amount (%)

June, July, August (1971-1981)

Land Areas Only

ZONAL AVERAGE

90 ° N
60 ° N
30 ° N
0 °
30 ° S
60 ° S
90 ° S

180 ° 150 ° W 120 ° W 90 ° W 60 ° W 30 ° W 0 ° 30 ° E 60 ° E 90 ° E 120 ° E 150 ° E 180 °

40 54 44 32 26 24 20 16 14 9 10 12 12 14 11 21 20 21 16 13 13 14 14 22 26 26 28 34 59 37 19 14 1

Map 110

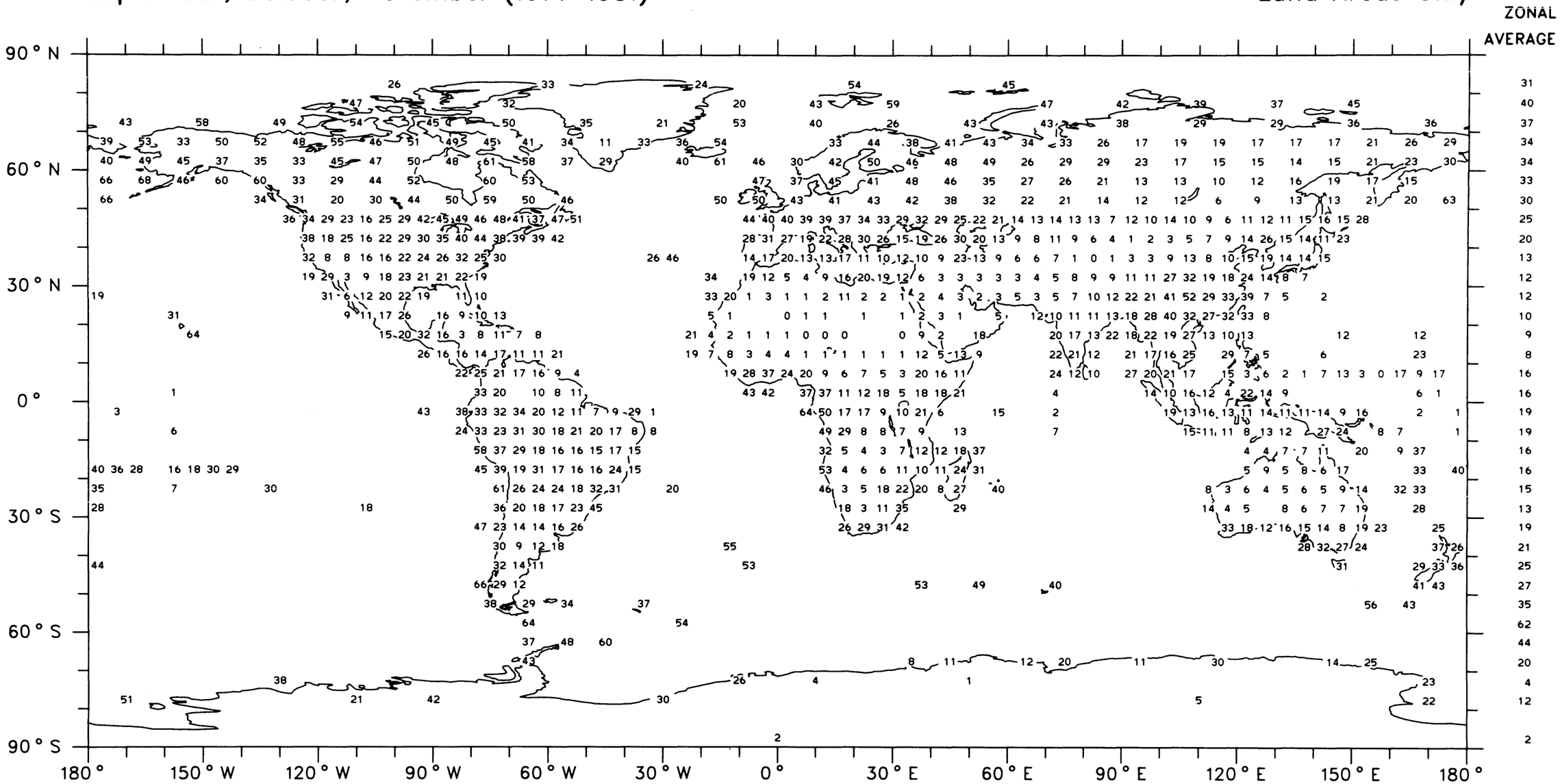
GLOBAL AVERAGE (LAND) 17 %

Stratus + Stratocumulus + Fog

Average Cloud Amount (%)

September, October, November (1971-1981)

Land Areas Only



GLOBAL AVERAGE (LAND) 19 %

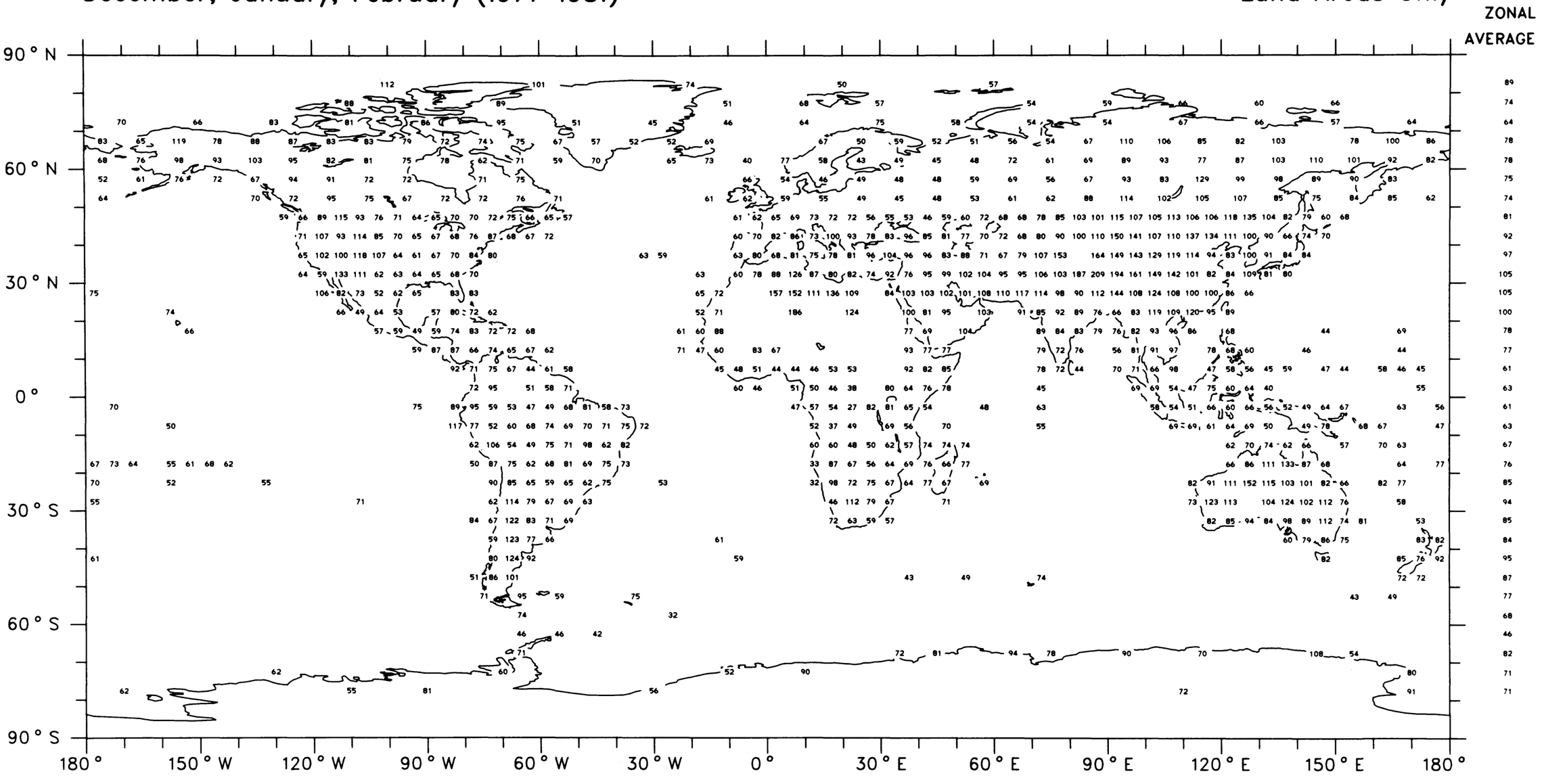
Map 111

Stratus + Stratocumulus (excluding fog)

Average Base Height (decameters)

December, January, February (1971-1981)

Land Areas Only



Map 112

GLOBAL AVERAGE (LAND) 814 METERS

Stratus + Stratocumulus (excluding fog)

Average Base Height (decameters)

March, April, May (1971-1981)

Land Areas Only

ZONAL AVERAGE

90 ° N
60 ° N
30 ° N
0 °
30 ° S
60 ° S
90 ° S

180 ° 150 ° W 120 ° W 90 ° W 60 ° W 30 ° W 0 ° 30 ° E 60 ° E 90 ° E 120 ° E 150 ° E 180 °

GLOBAL AVERAGE (LAND) 853 METERS

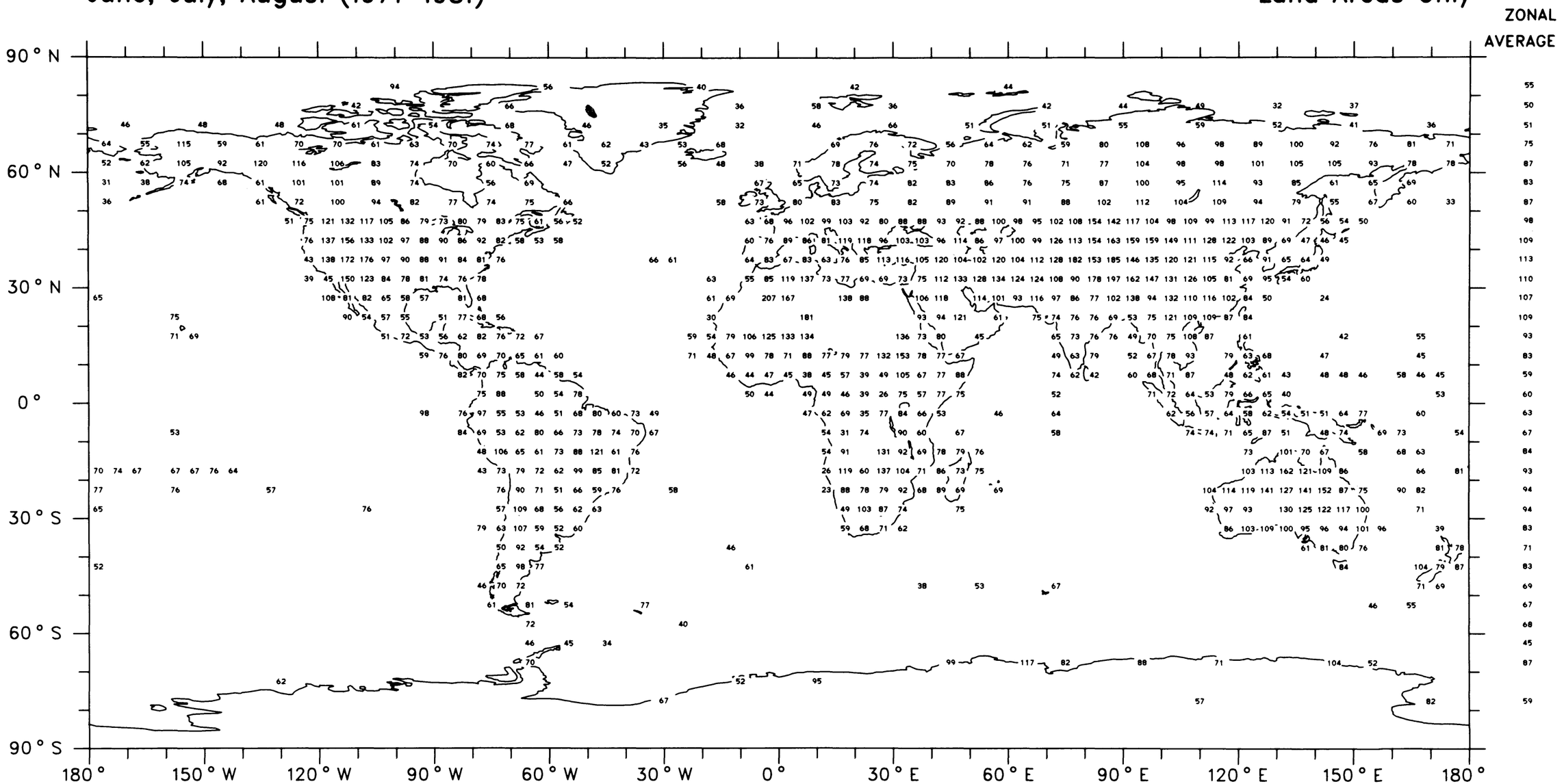
Map 113

Stratus + Stratocumulus (excluding fog)

Average Base Height (decameters)

June, July, August (1971-1981)

Land Areas Only



Map 114

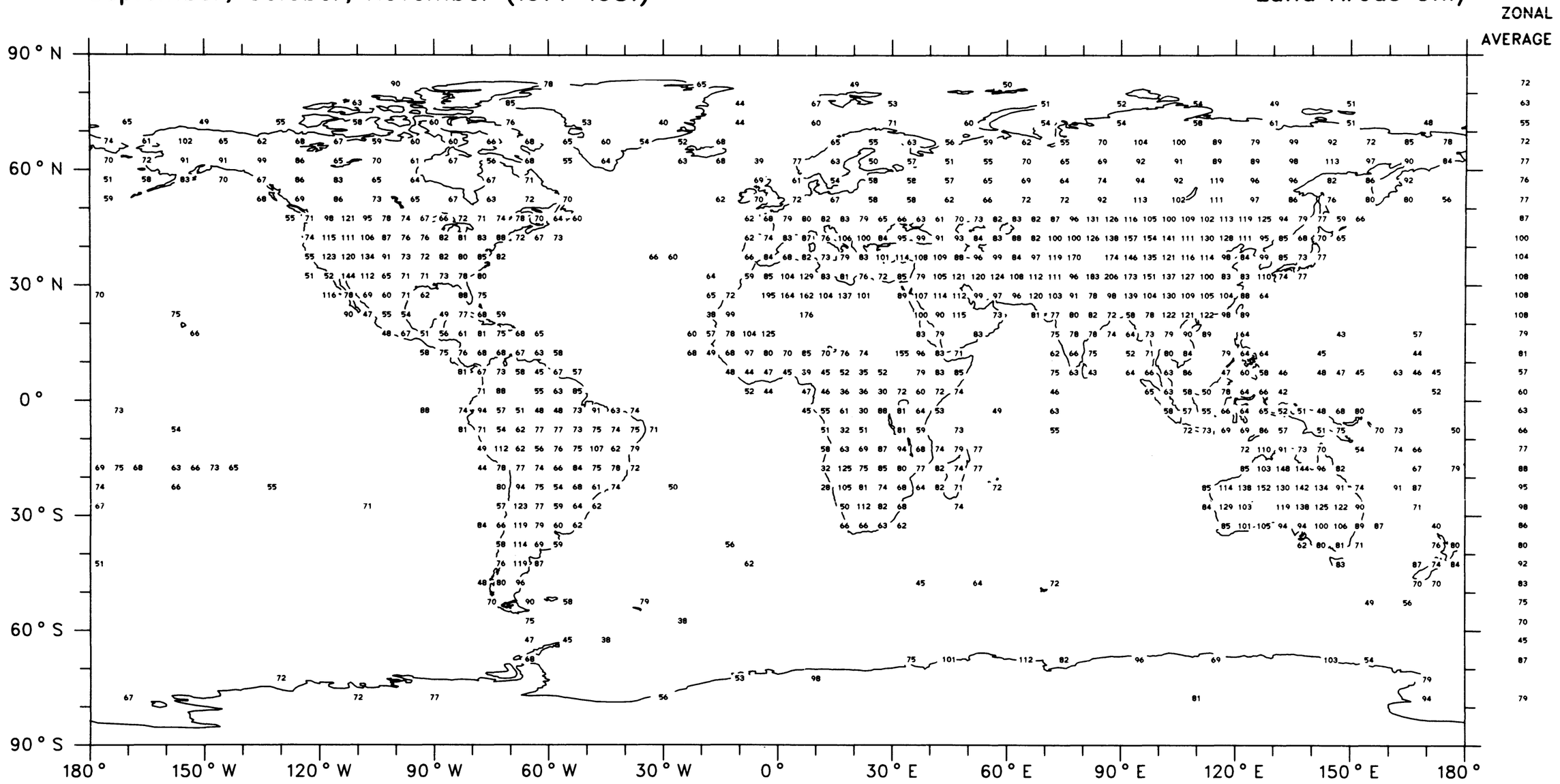
GLOBAL AVERAGE (LAND) 878 METERS

Stratus + Stratocumulus (excluding fog)

Average Base Height (decameters)

September, October, November (1971-1981)

Land Areas Only



GLOBAL AVERAGE (LAND) 846 METERS

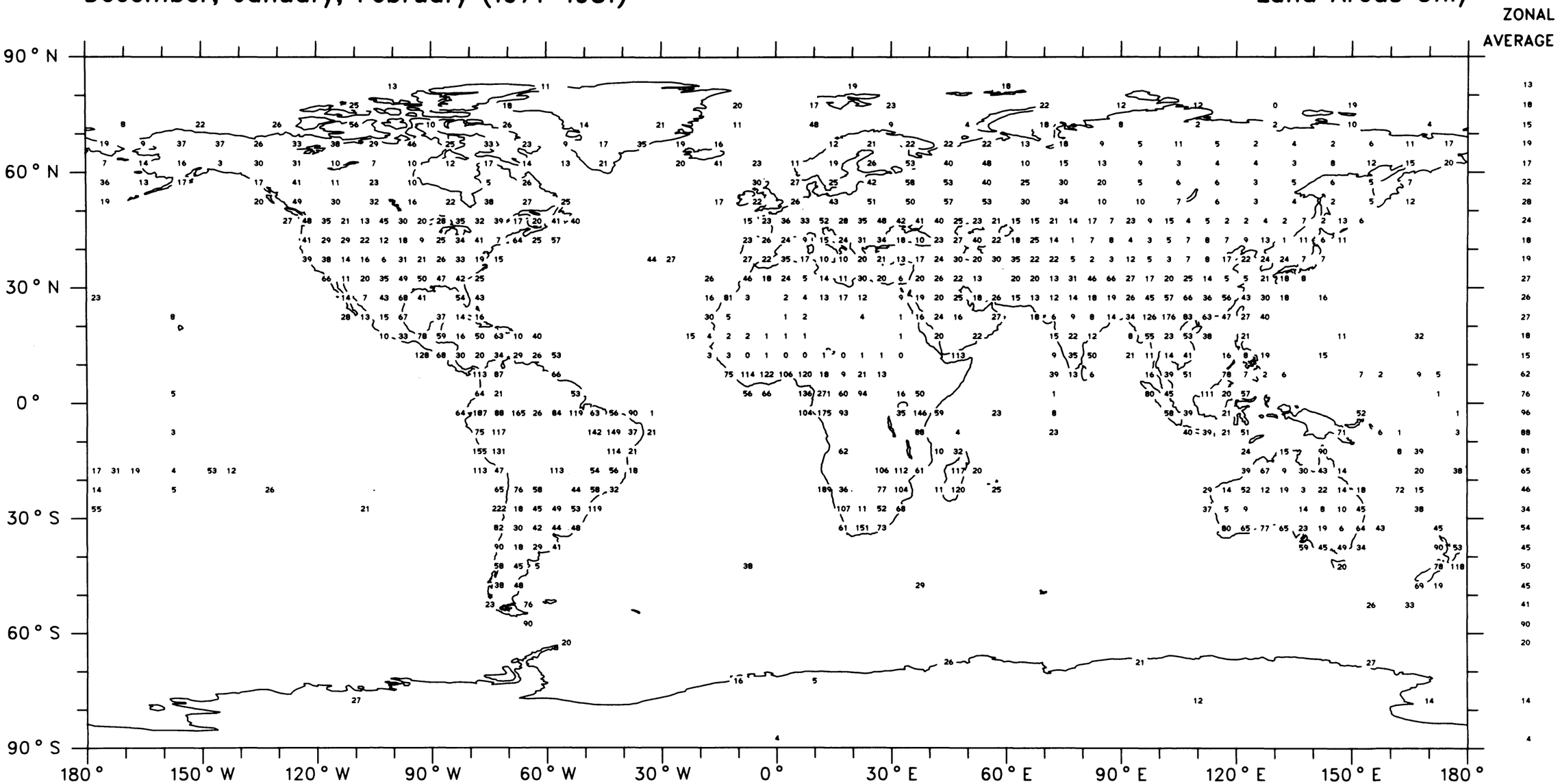
Map 115

Stratus + Stratocumulus + Fog

Amplitude of Diurnal Cycle (0.1 % Cloud Amount)

December, January, February (1971-1981)

Land Areas Only



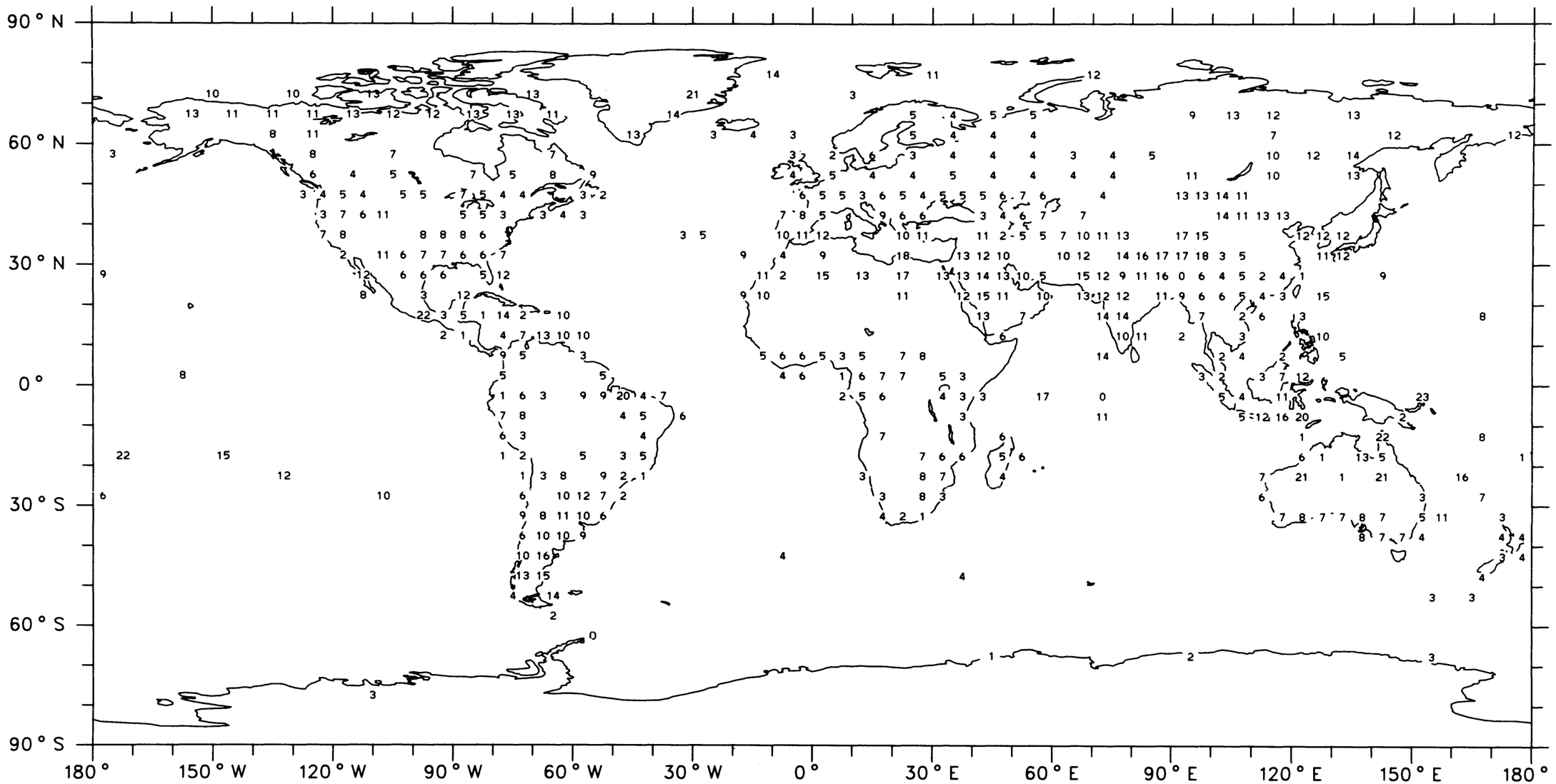
Map 116

GLOBAL AVERAGE (LAND) 3.5 %

Stratus + Stratocumulus + Fog

Phase of Diurnal Cycle (Local Time of Maximum Cloud Amount)

December, January, February (1971-1981) **Land Areas Only**



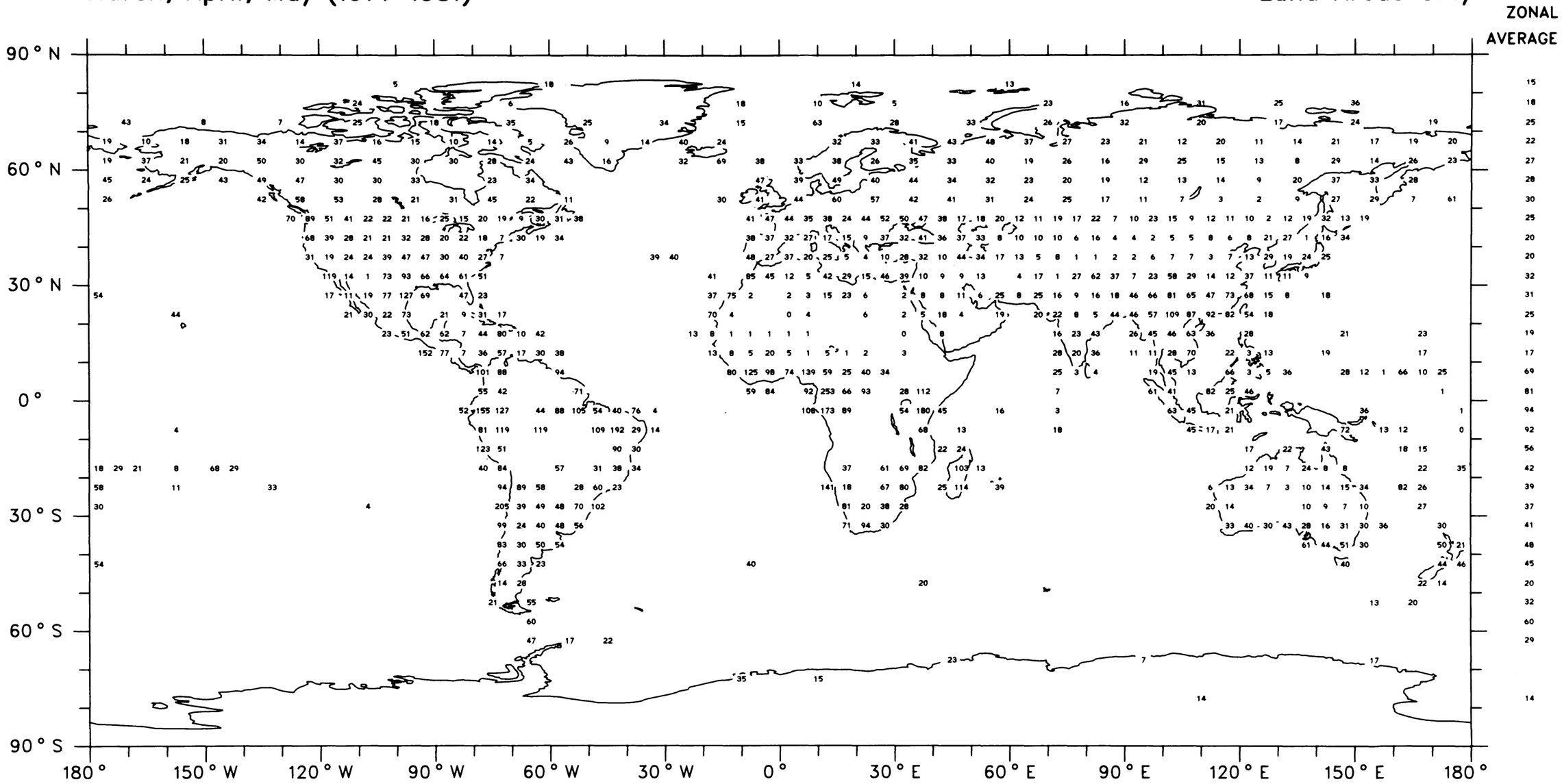
Map 117

Stratus + Stratocumulus + Fog

Amplitude of Diurnal Cycle (0.1 % Cloud Amount)

March, April, May (1971-1981)

Land Areas Only



Map 118

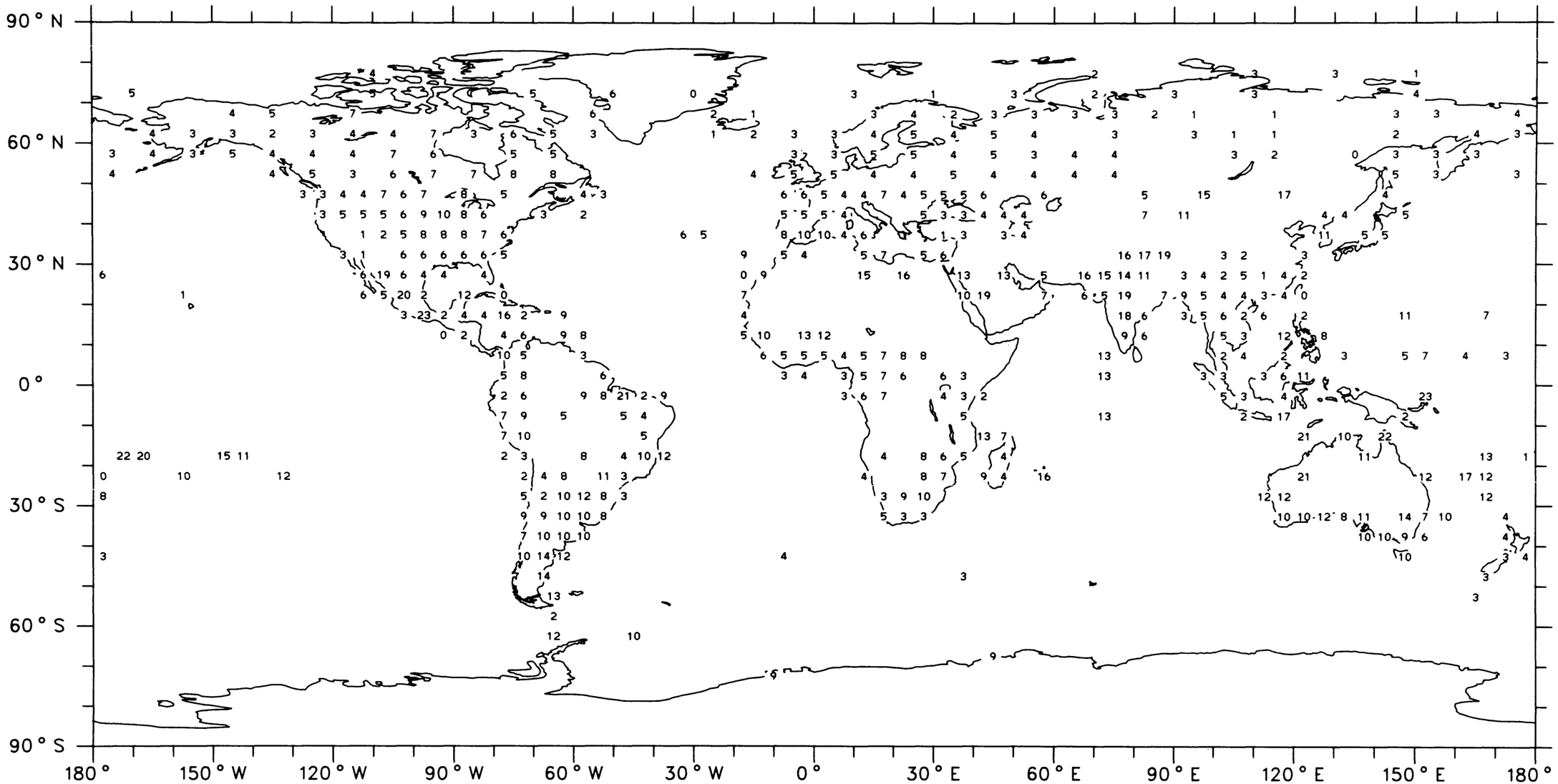
GLOBAL AVERAGE (LAND) 3.7 %

Stratus + Stratocumulus + Fog

Phase of Diurnal Cycle (Local Time of Maximum Cloud Amount)

March, April, May (1971-1981)

Land Areas Only



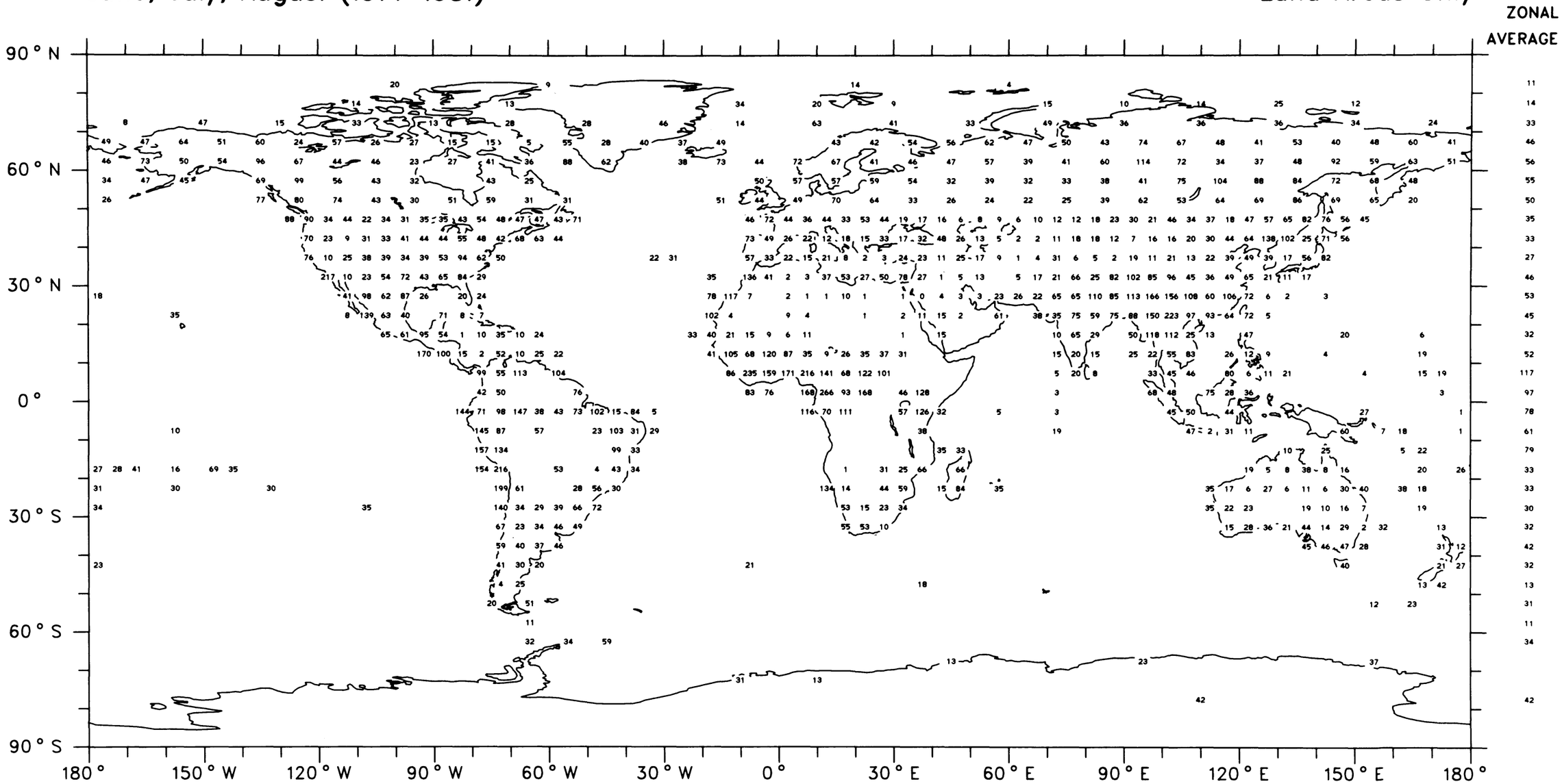
Map 119

Stratus + Stratocumulus + Fog

Amplitude of Diurnal Cycle (0.1 % Cloud Amount)

June, July, August (1971-1981)

Land Areas Only



Map 120

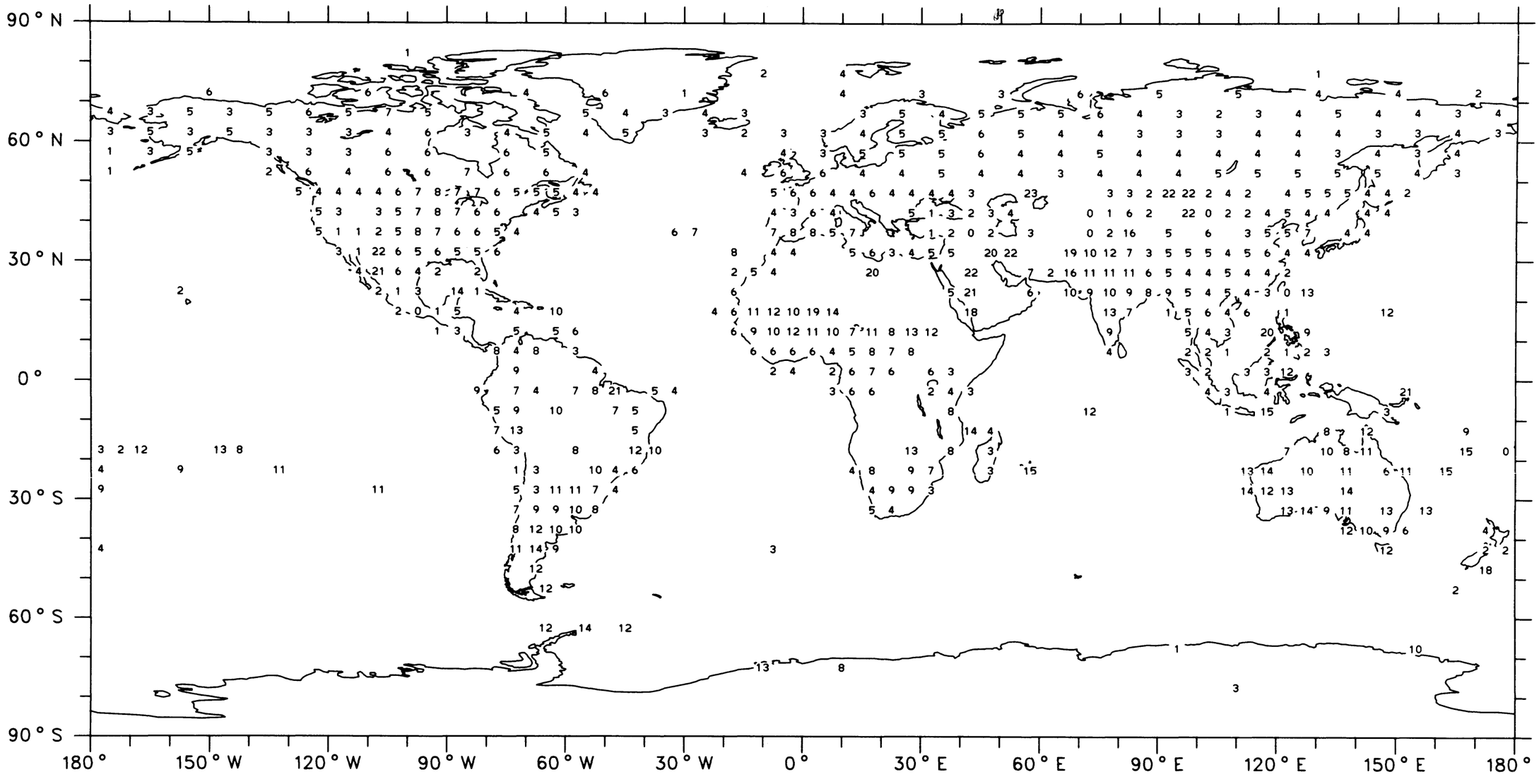
GLOBAL AVERAGE (LAND) 4.9 %

Stratus + Stratocumulus + Fog

Phase of Diurnal Cycle (Local Time of Maximum Cloud Amount)

June, July, August (1971-1981)

Land Areas Only



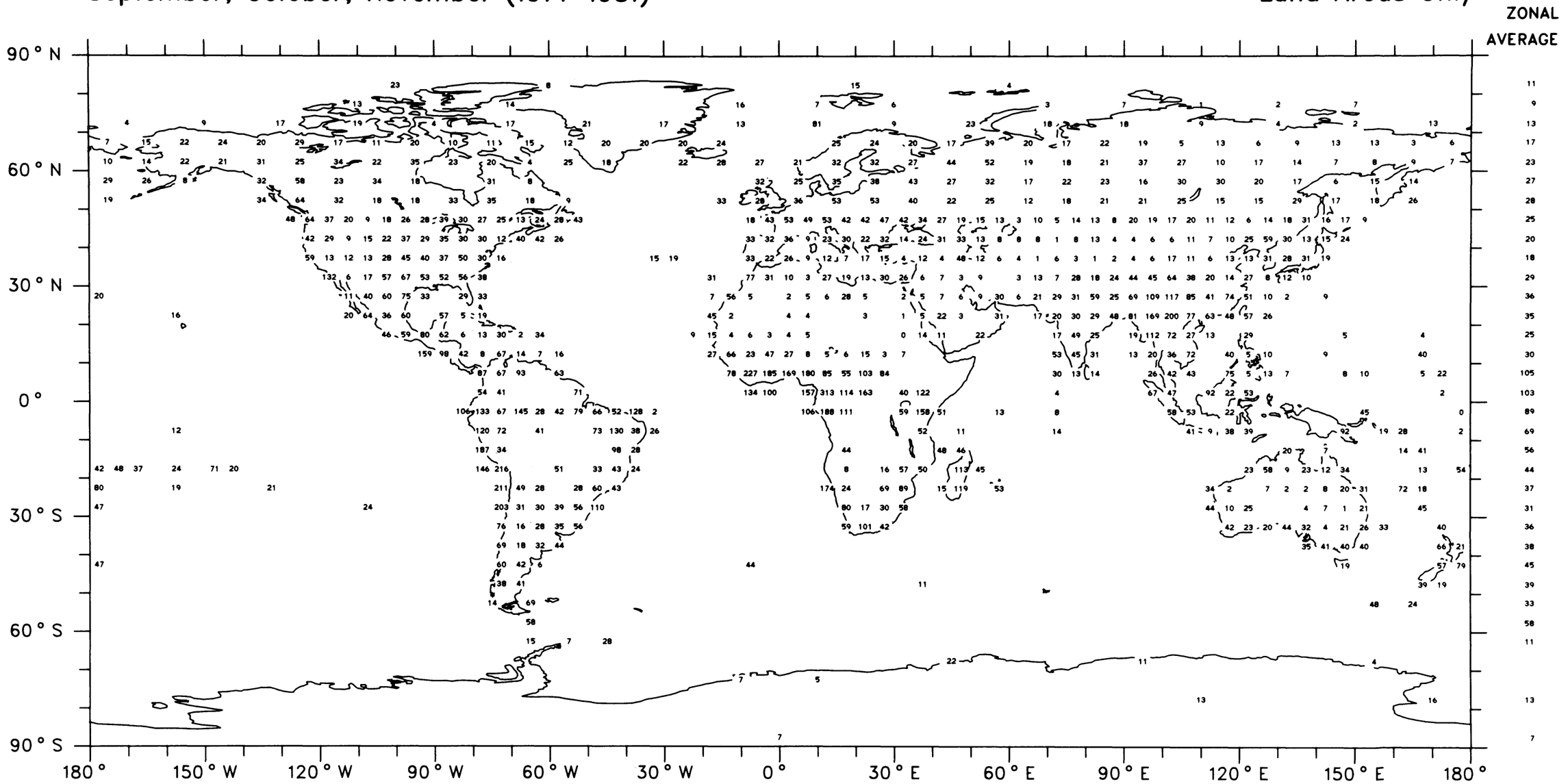
Map 121

Stratus + Stratocumulus + Fog

Amplitude of Diurnal Cycle (0.1 % Cloud Amount)

September, October, November (1971-1981)

Land Areas Only



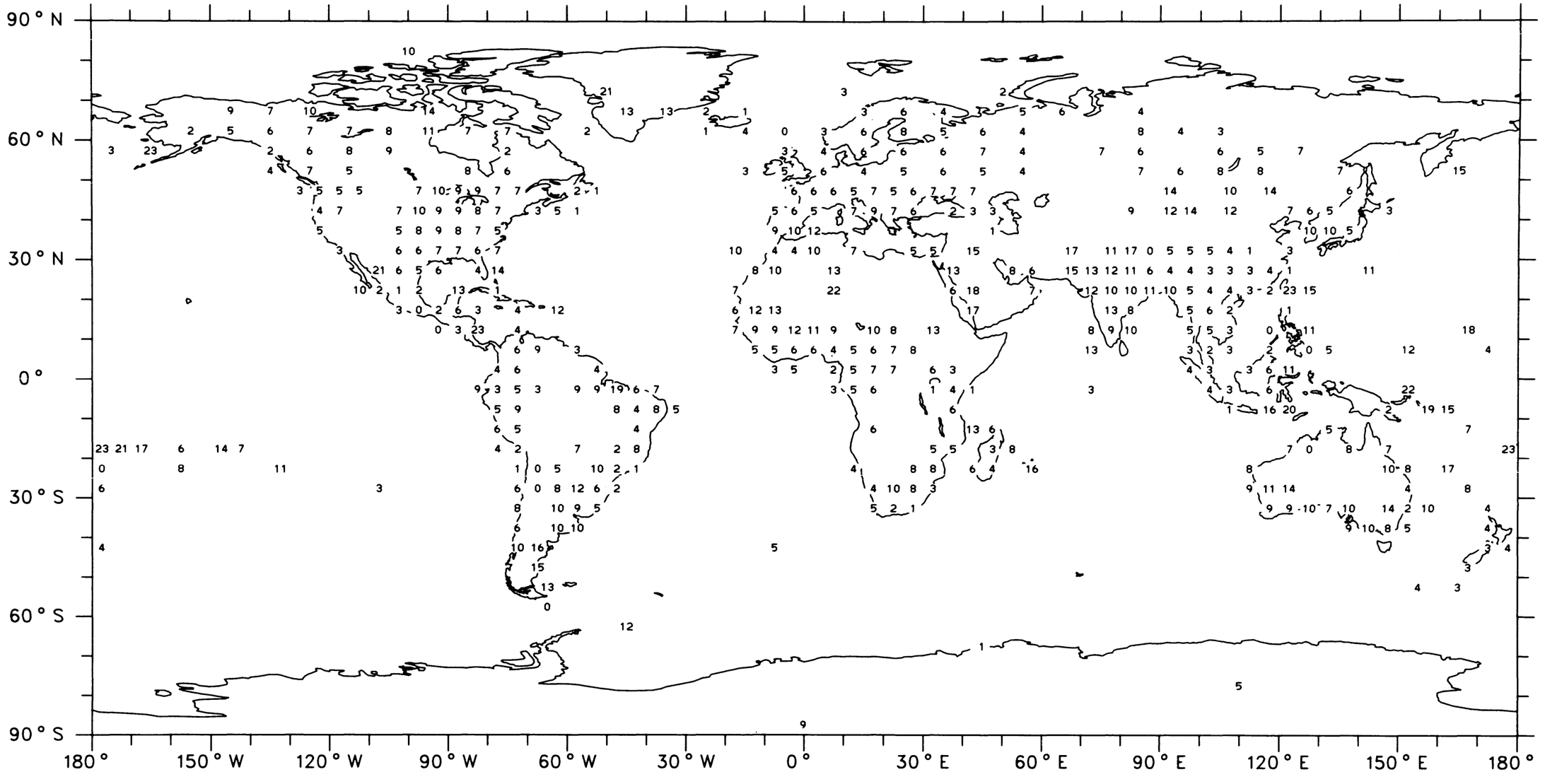
Map 122

GLOBAL AVERAGE (LAND) 3.7 %

Stratus + Stratocumulus + Fog

Phase of Diurnal Cycle (Local Time of Maximum Cloud Amount)

September, October, November (1971-1981) **Land Areas Only**



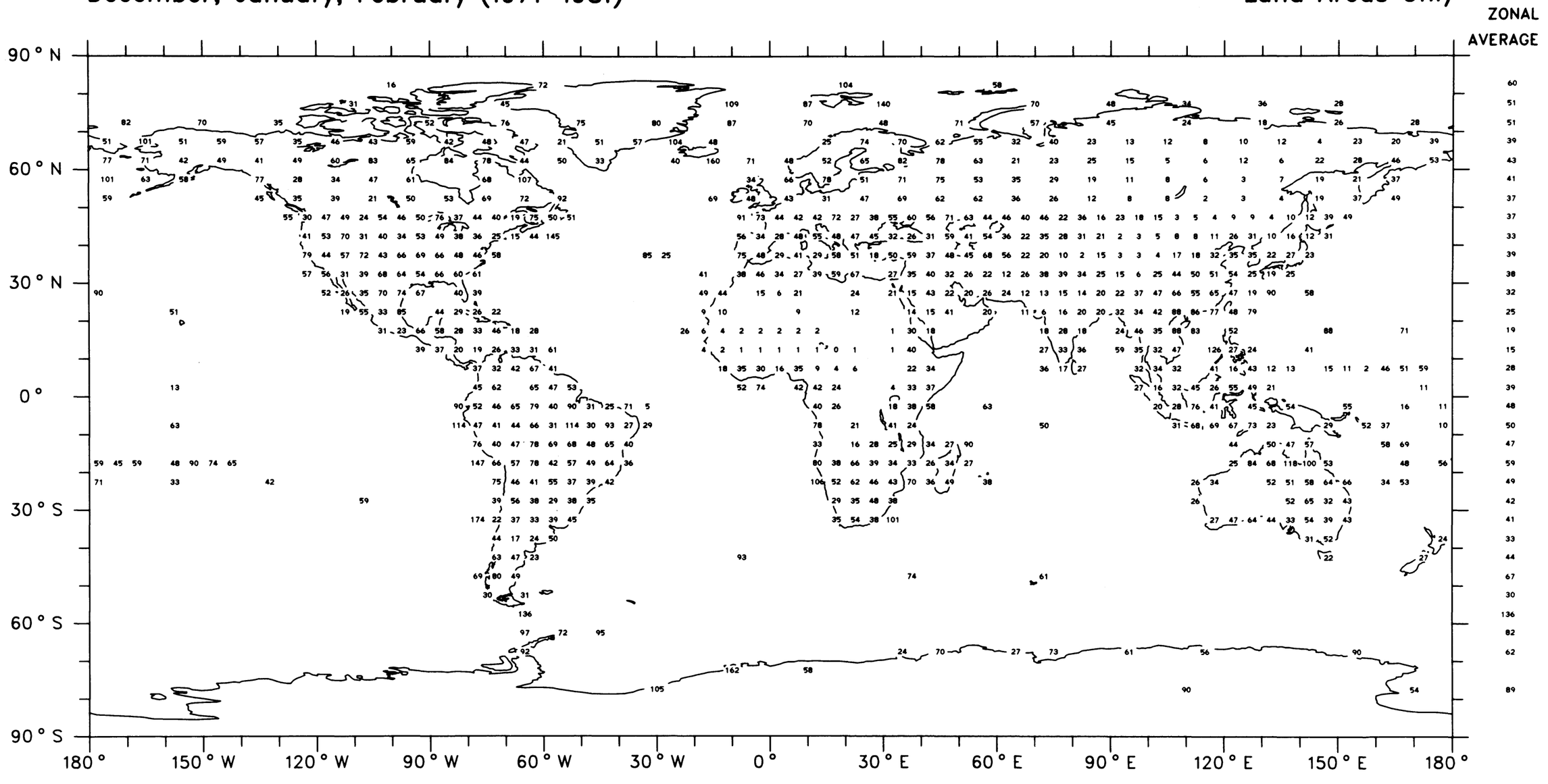
Map 123

Interannual Variation of Stratus + Stratocumulus + Fog :

Standard Deviation of Seasonal Means (0.1 % Cloud Amount)

December, January, February (1971-1981)

Land Areas Only



Map 124

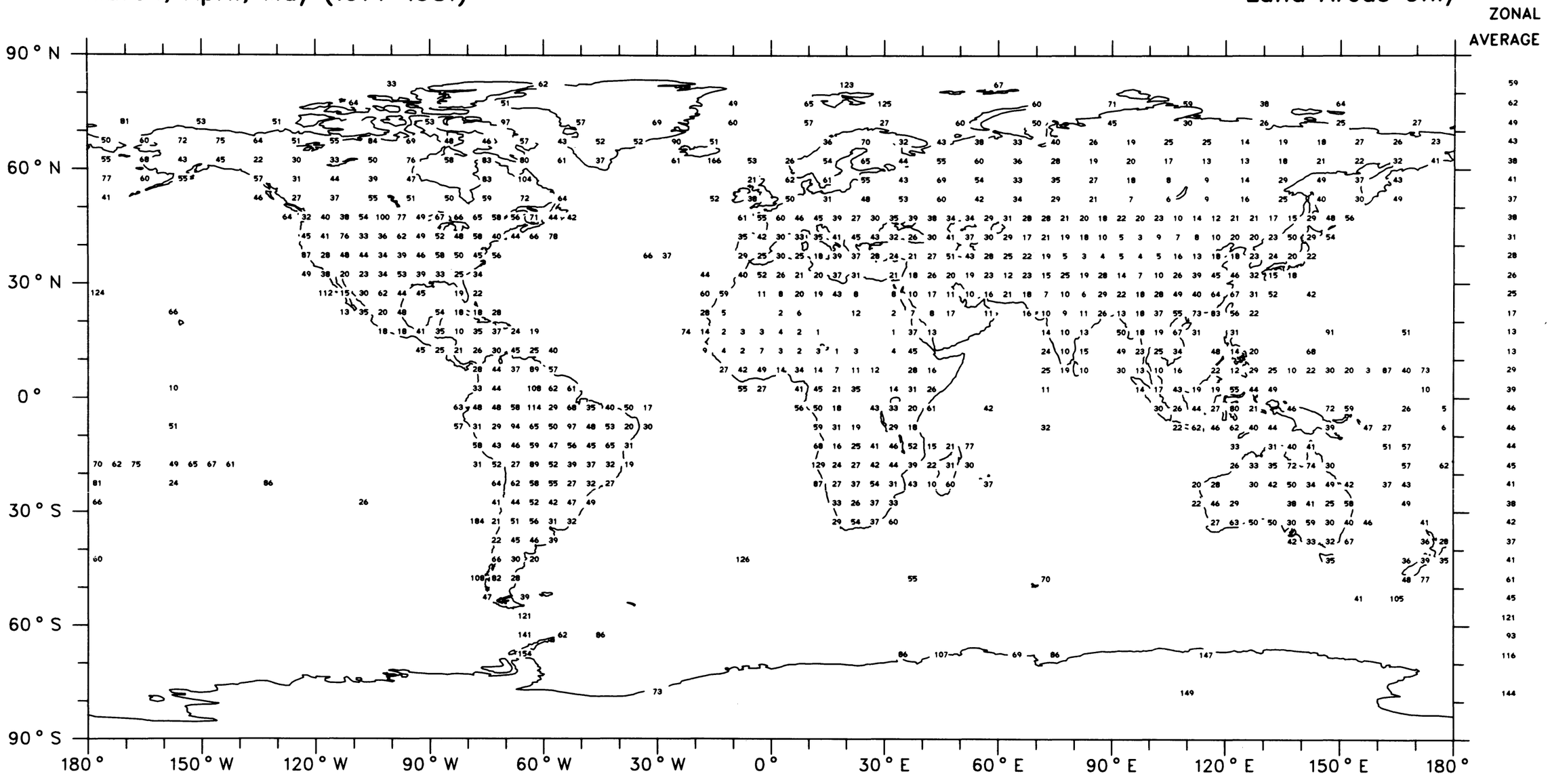
GLOBAL AVERAGE (LAND) 4.0 %

Interannual Variation of Stratus + Stratocumulus + Fog :

Standard Deviation of Seasonal Means (0.1 % Cloud Amount)

March, April, May (1971-1981)

Land Areas Only



GLOBAL AVERAGE (LAND) 3.9 %

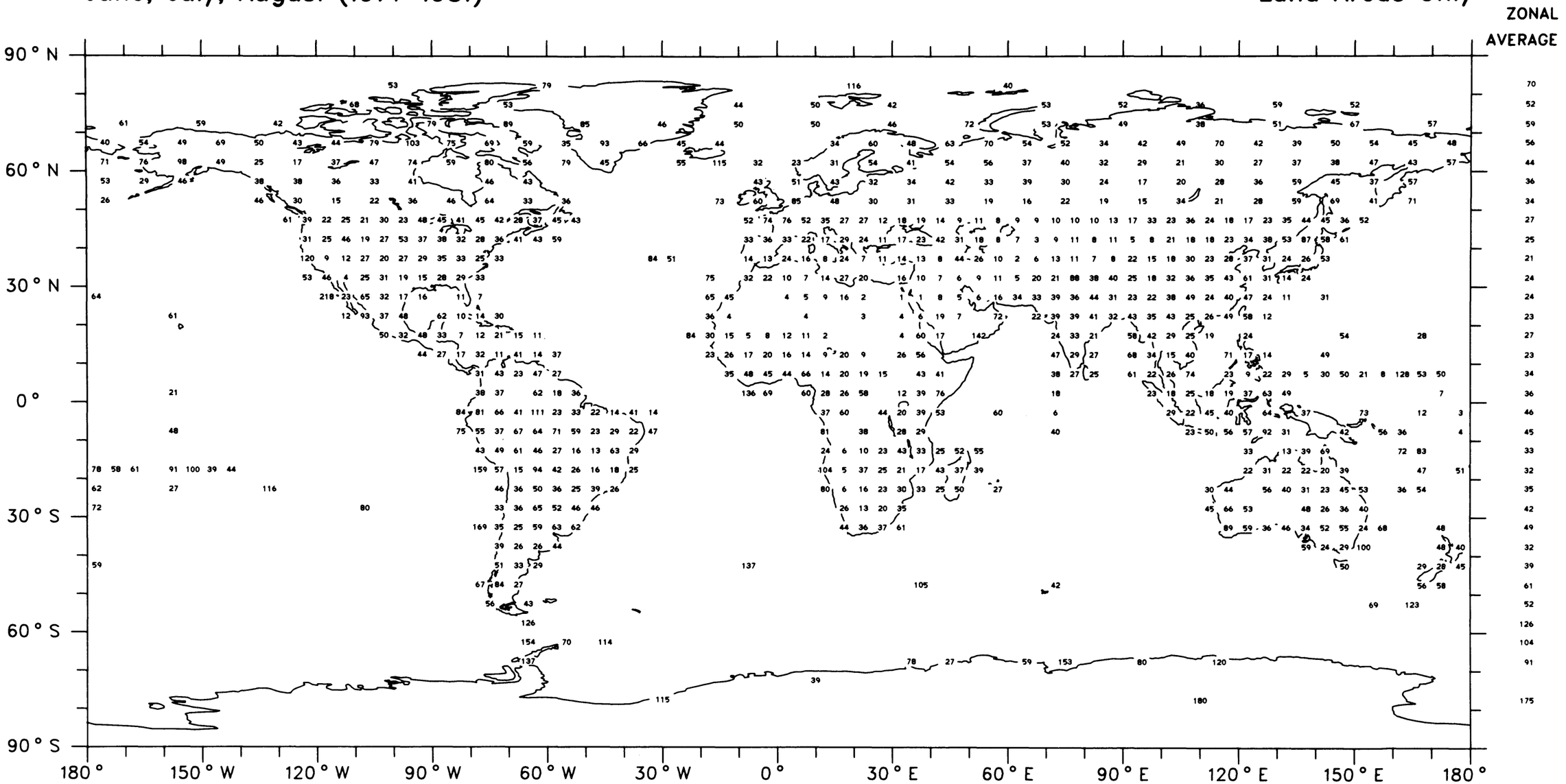
Map 125

Interannual Variation of Stratus + Stratocumulus + Fog :

Standard Deviation of Seasonal Means (0.1 % Cloud Amount)

June, July, August (1971-1981)

Land Areas Only



Map 126

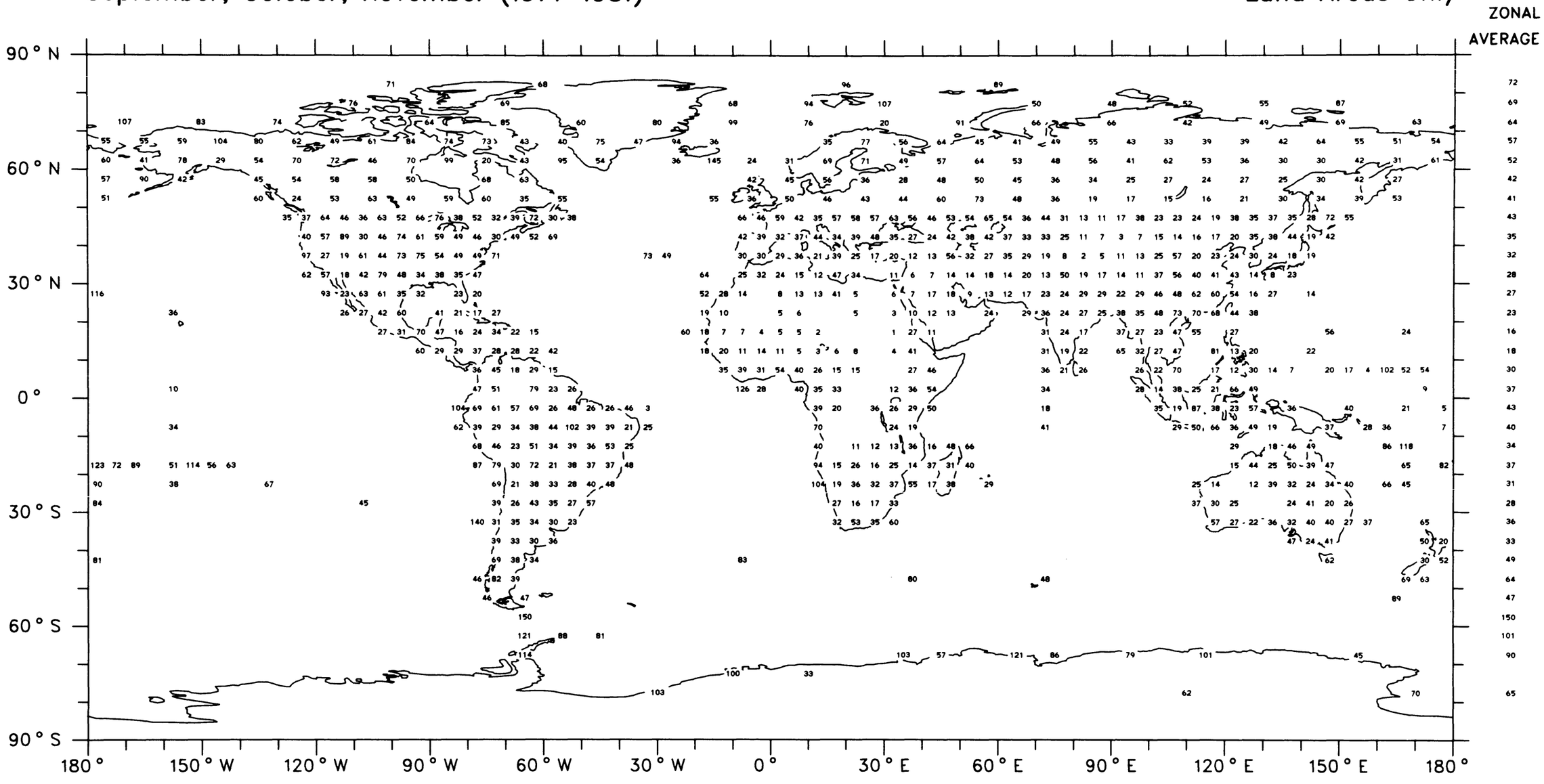
GLOBAL AVERAGE (LAND) 3.9 %

Interannual Variation of Stratus + Stratocumulus + Fog :

Standard Deviation of Seasonal Means (0.1 % Cloud Amount)

September, October, November (1971-1981)

Land Areas Only



GLOBAL AVERAGE (LAND) 3.8 %

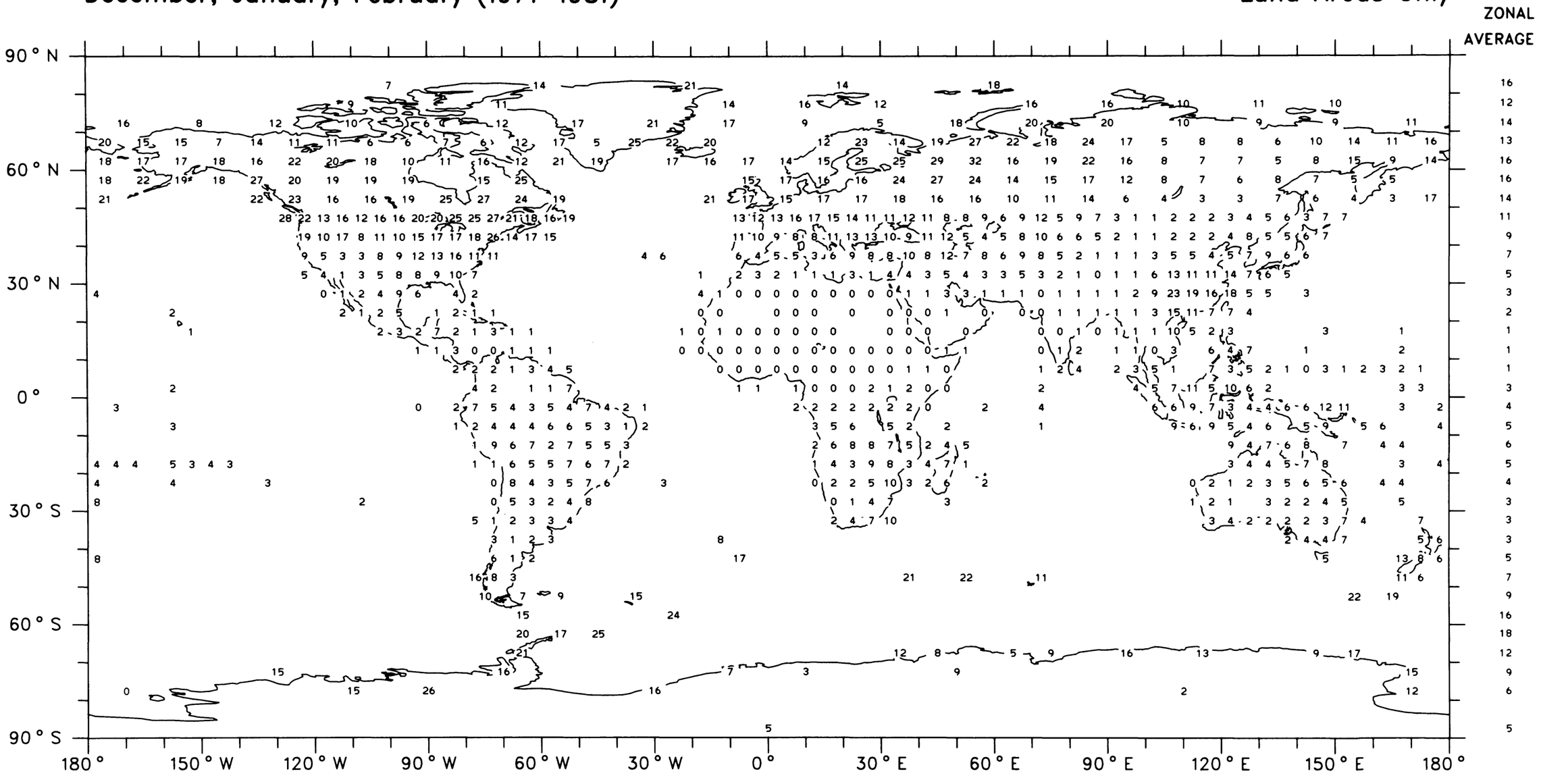
Map 127

Nimbostratus

Frequency of Occurrence (%)

December, January, February (1971-1981)

Land Areas Only



Map 128

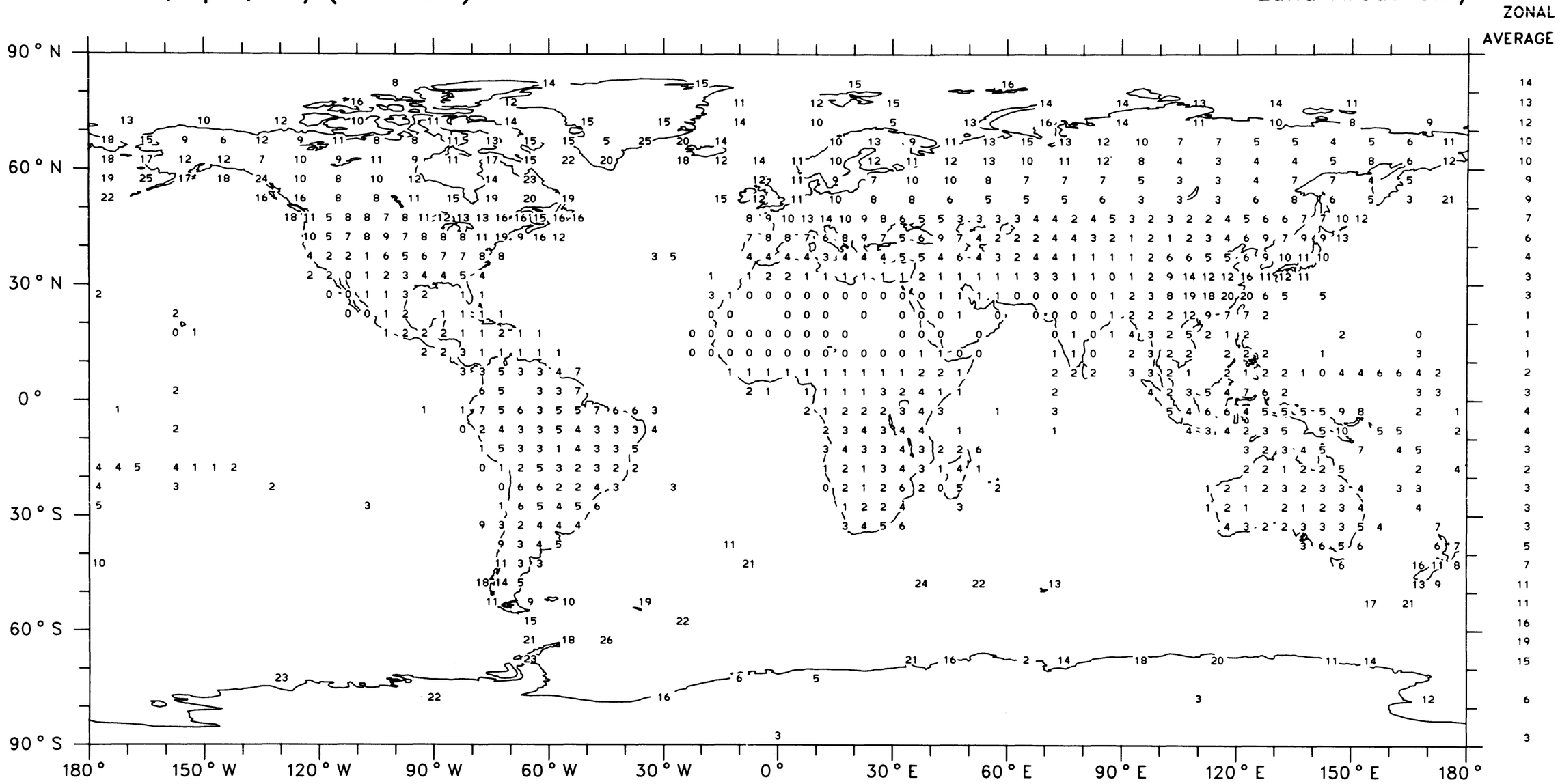
GLOBAL AVERAGE (LAND) 7 %

Nimbostratus

Frequency of Occurrence (%)

March, April, May (1971-1981)

Land Areas Only



GLOBAL AVERAGE (LAND) 5 %

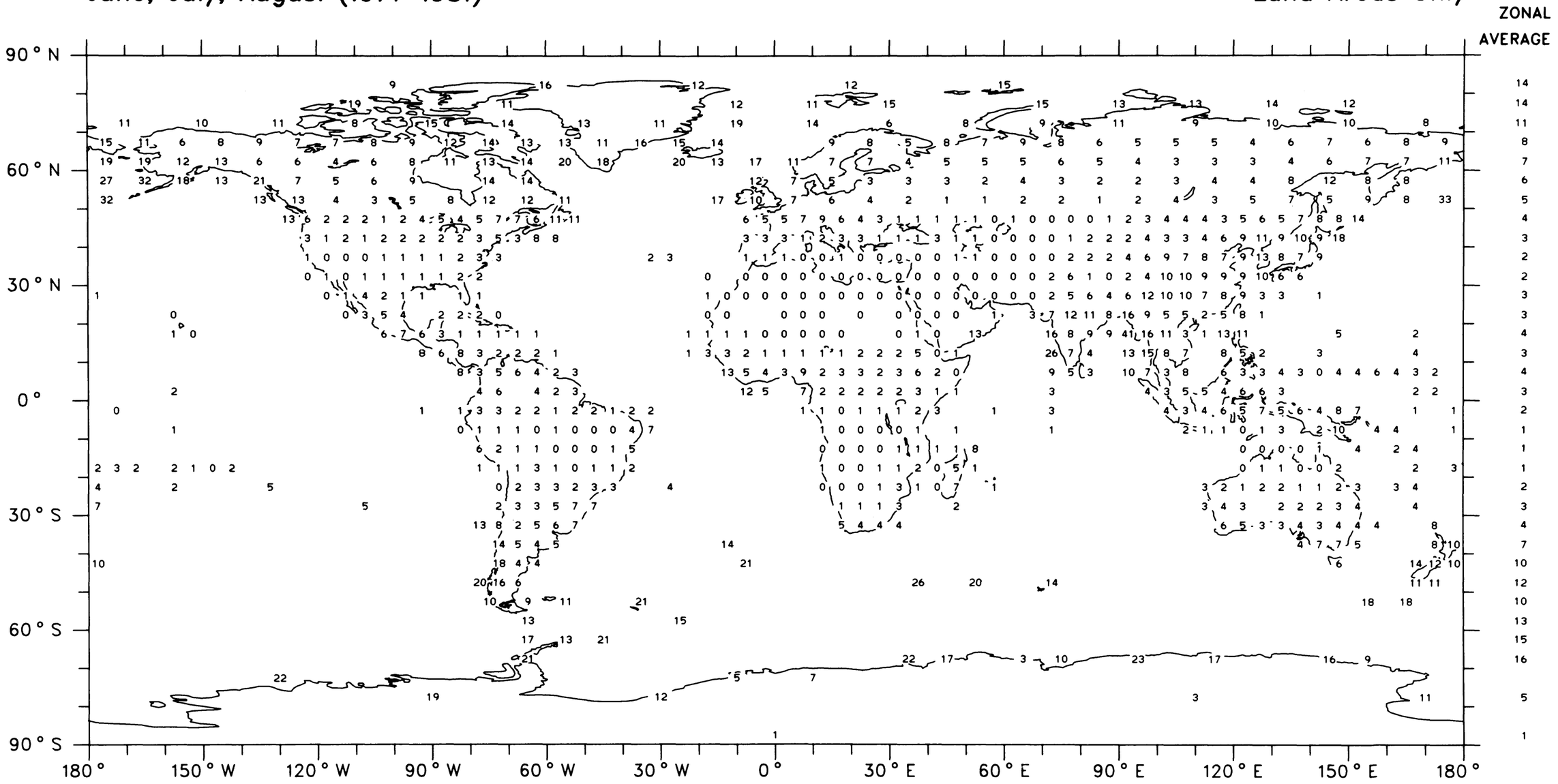
Map 129

Nimbostratus

Frequency of Occurrence (%)

June, July, August (1971-1981)

Land Areas Only



Map 130

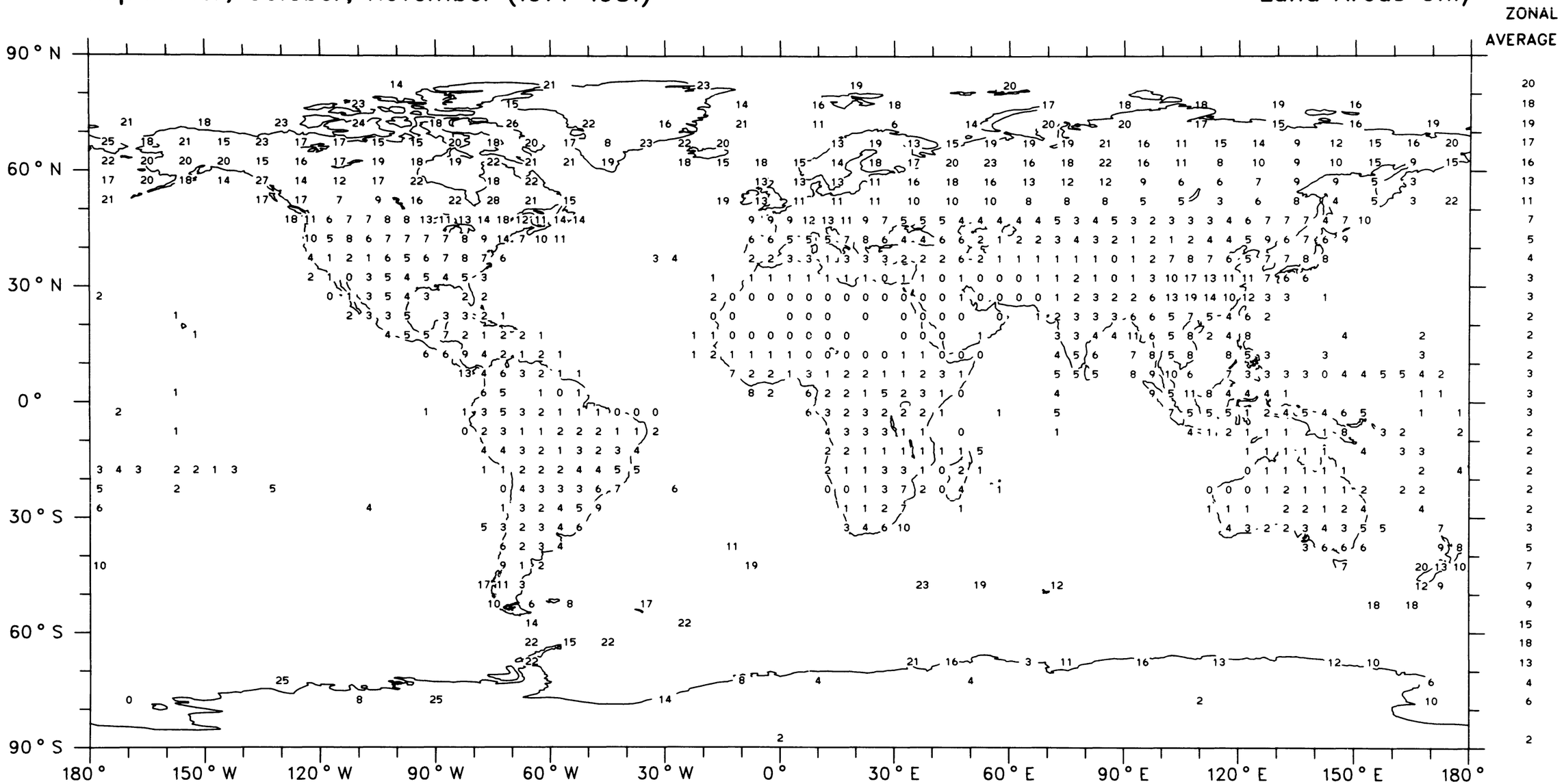
GLOBAL AVERAGE (LAND) 4 %

Nimbostratus

Frequency of Occurrence (%)

September, October, November (1971-1981)

Land Areas Only



GLOBAL AVERAGE (LAND) 6 %

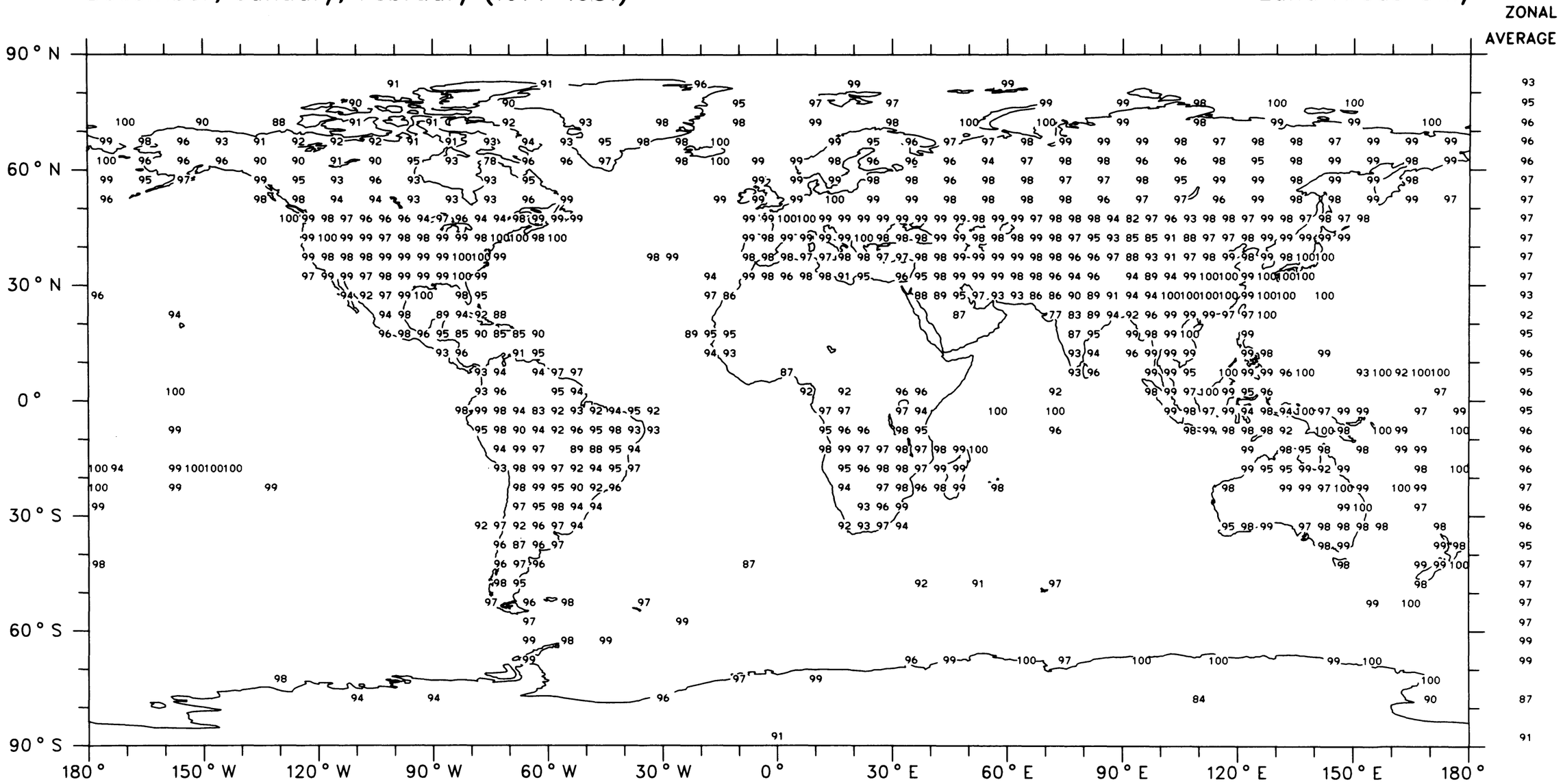
Map 131

Nimbostratus

Amount - When - Present (%)

December, January, February (1971-1981)

Land Areas Only



Map 132

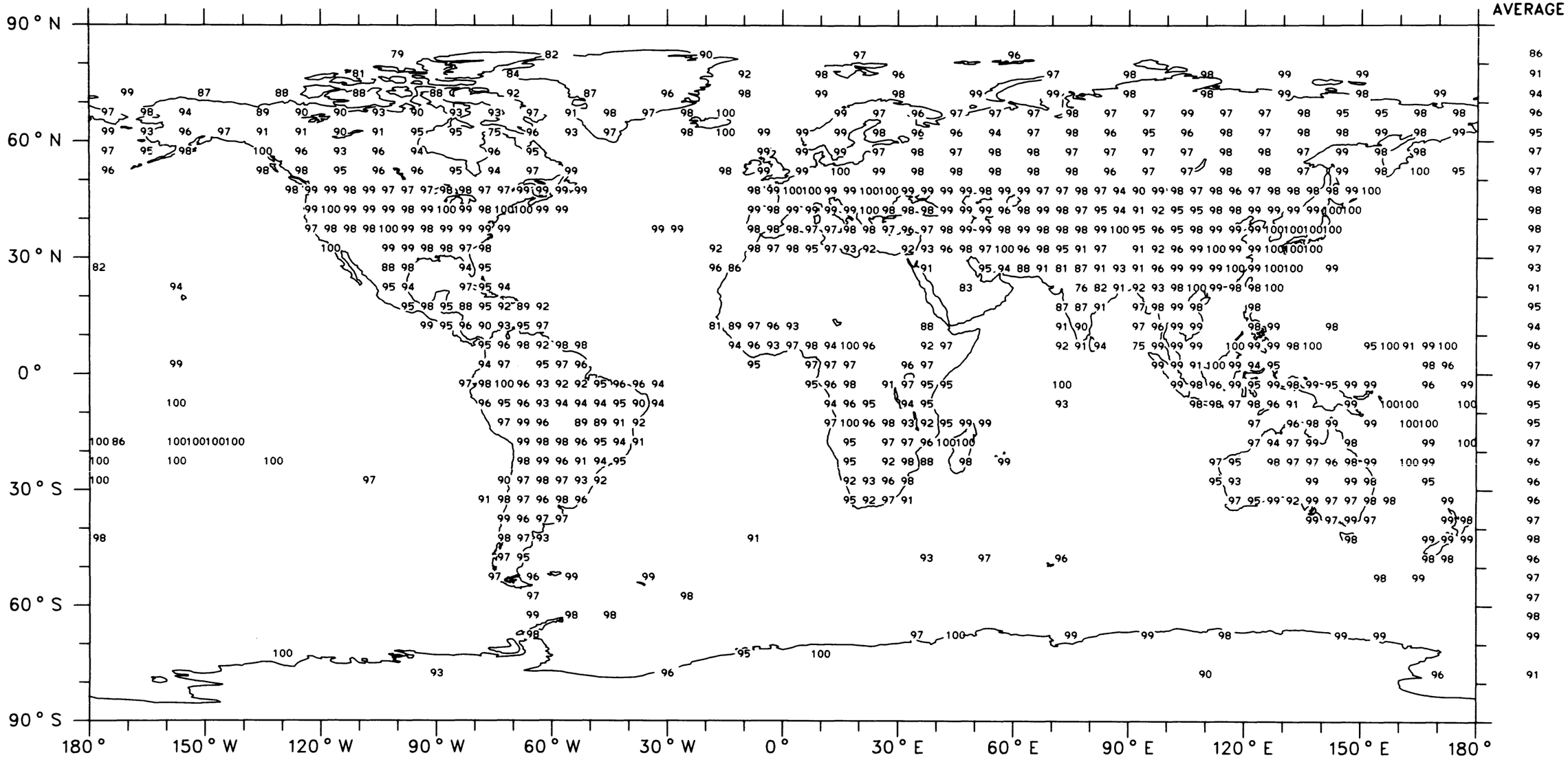
GLOBAL AVERAGE (LAND) 96 %

Nimbostratus

Amount - When - Present (%)

March, April, May (1971-1981)

Land Areas Only



GLOBAL AVERAGE (LAND) 96 %

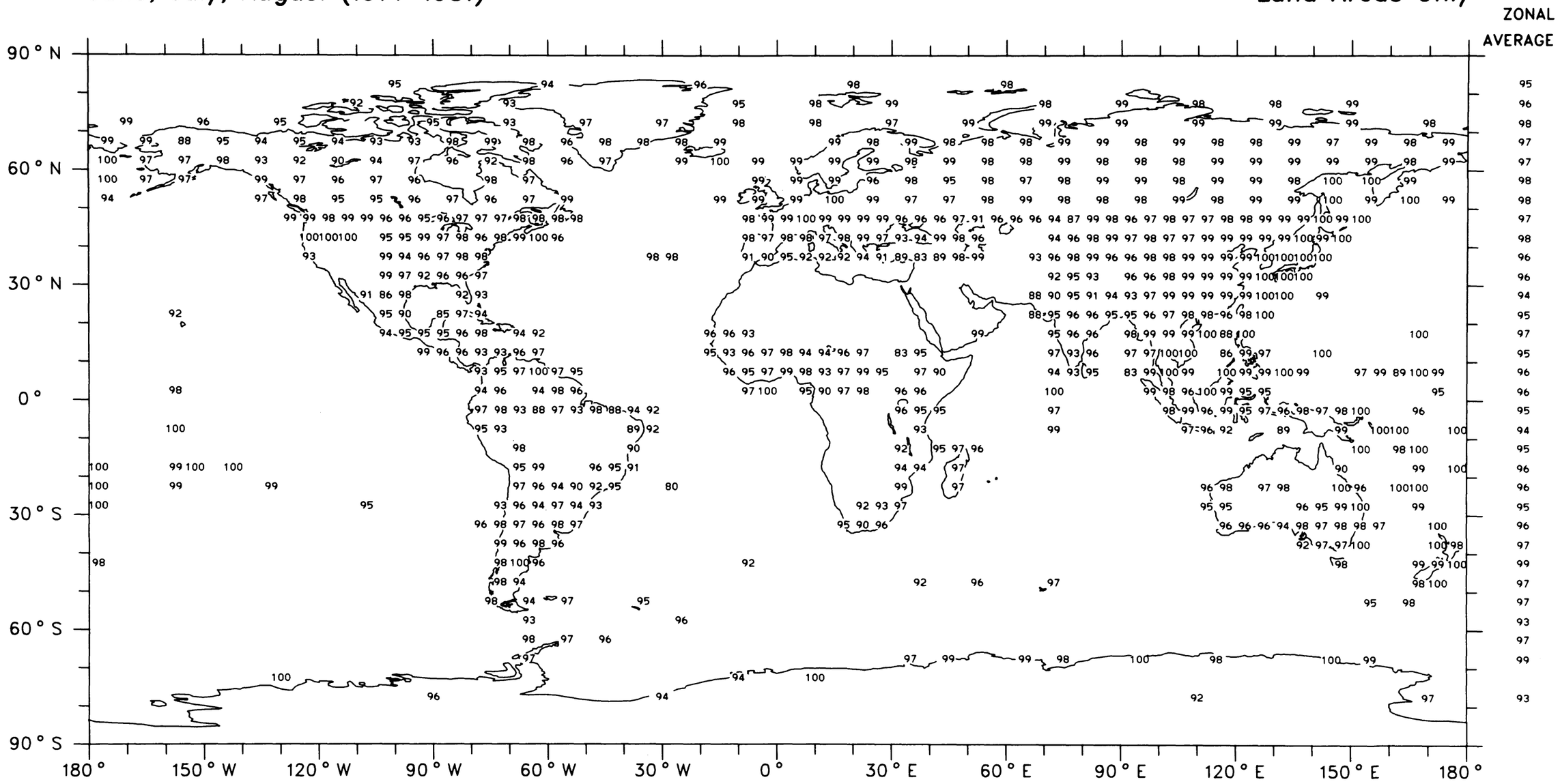
Map 133

Nimbostratus

Amount - When - Present (%)

June, July, August (1971-1981)

Land Areas Only



Map 134

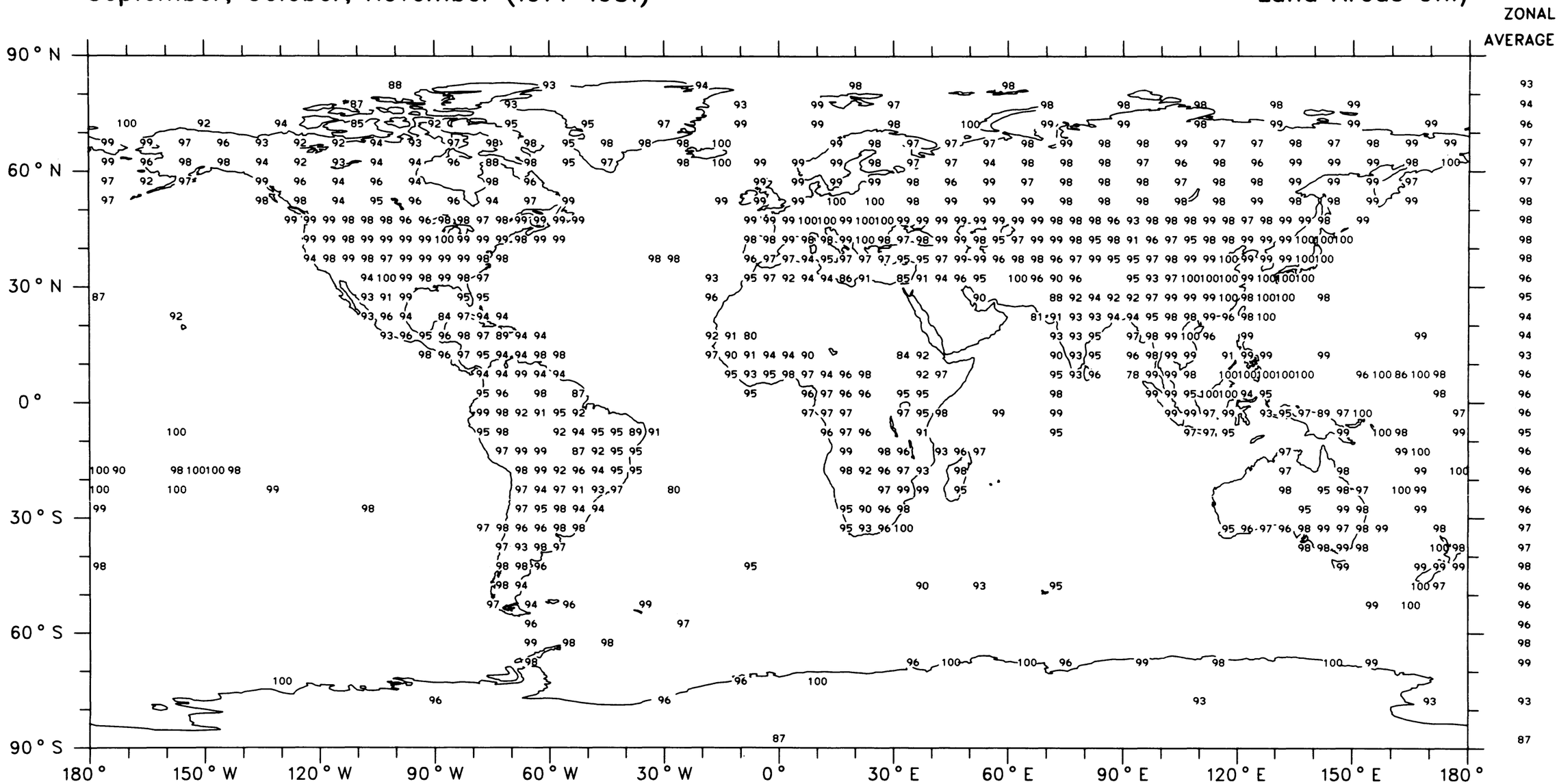
GLOBAL AVERAGE (LAND) 96 %

Nimbostratus

Amount-When-Present (%)

September, October, November (1971-1981)

Land Areas Only



GLOBAL AVERAGE (LAND) 96 %

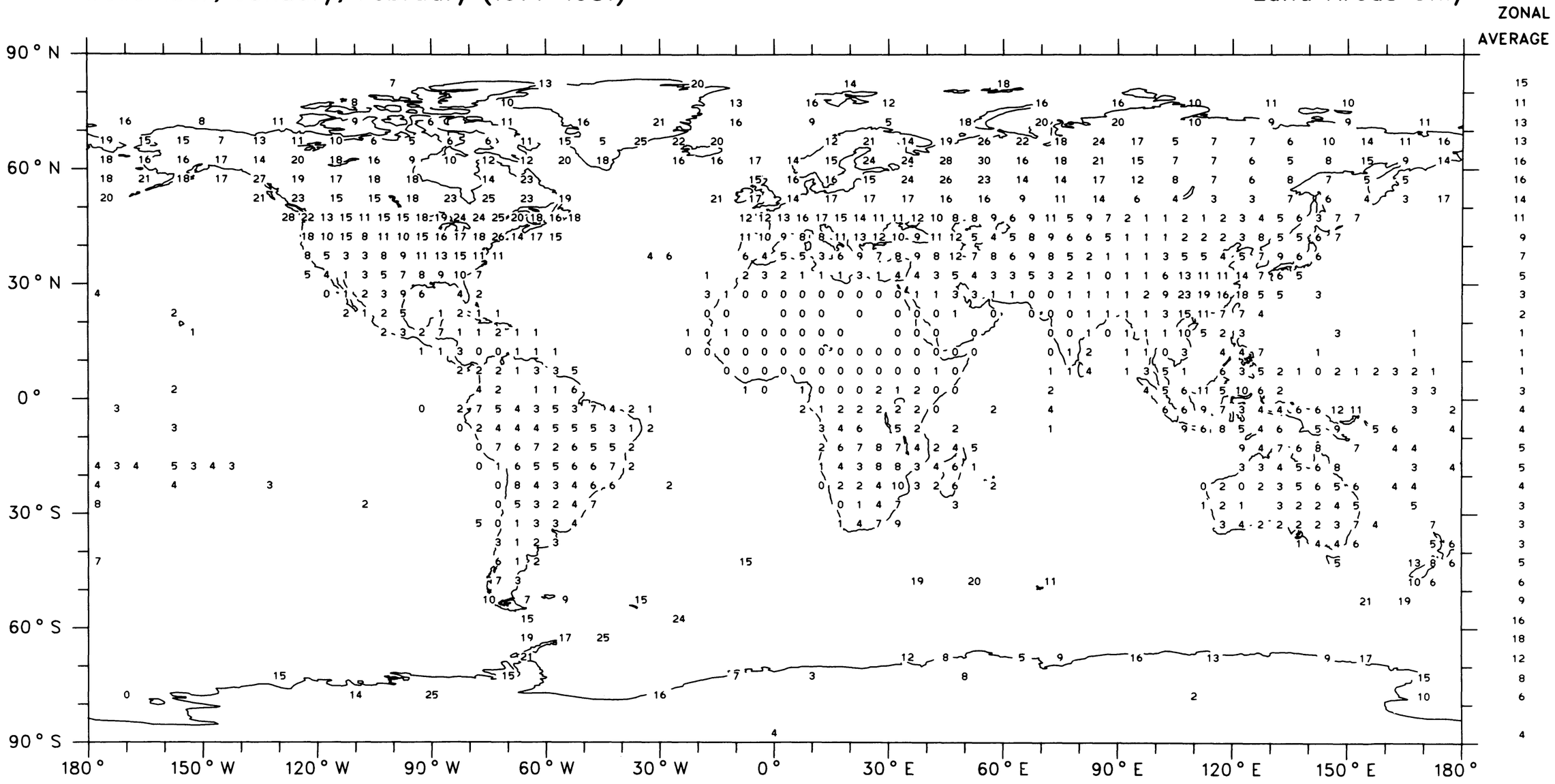
Map 135

Nimbostratus

Average Cloud Amount (%)

December, January, February (1971-1981)

Land Areas Only



Map 136

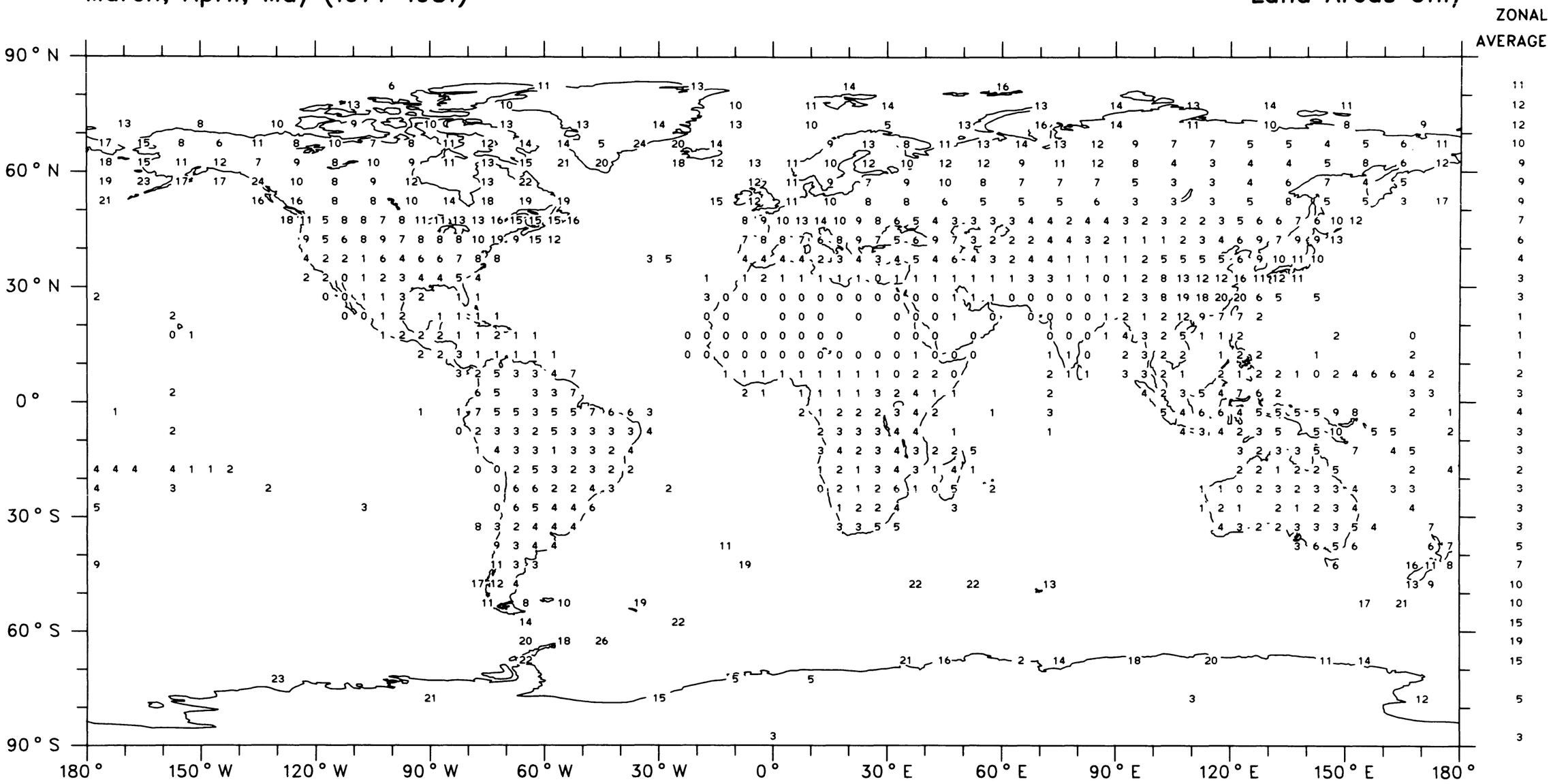
GLOBAL AVERAGE (LAND) 7 %

Nimbostratus

Average Cloud Amount (%)

March, April, May (1971-1981)

Land Areas Only



GLOBAL AVERAGE (LAND) 5 %

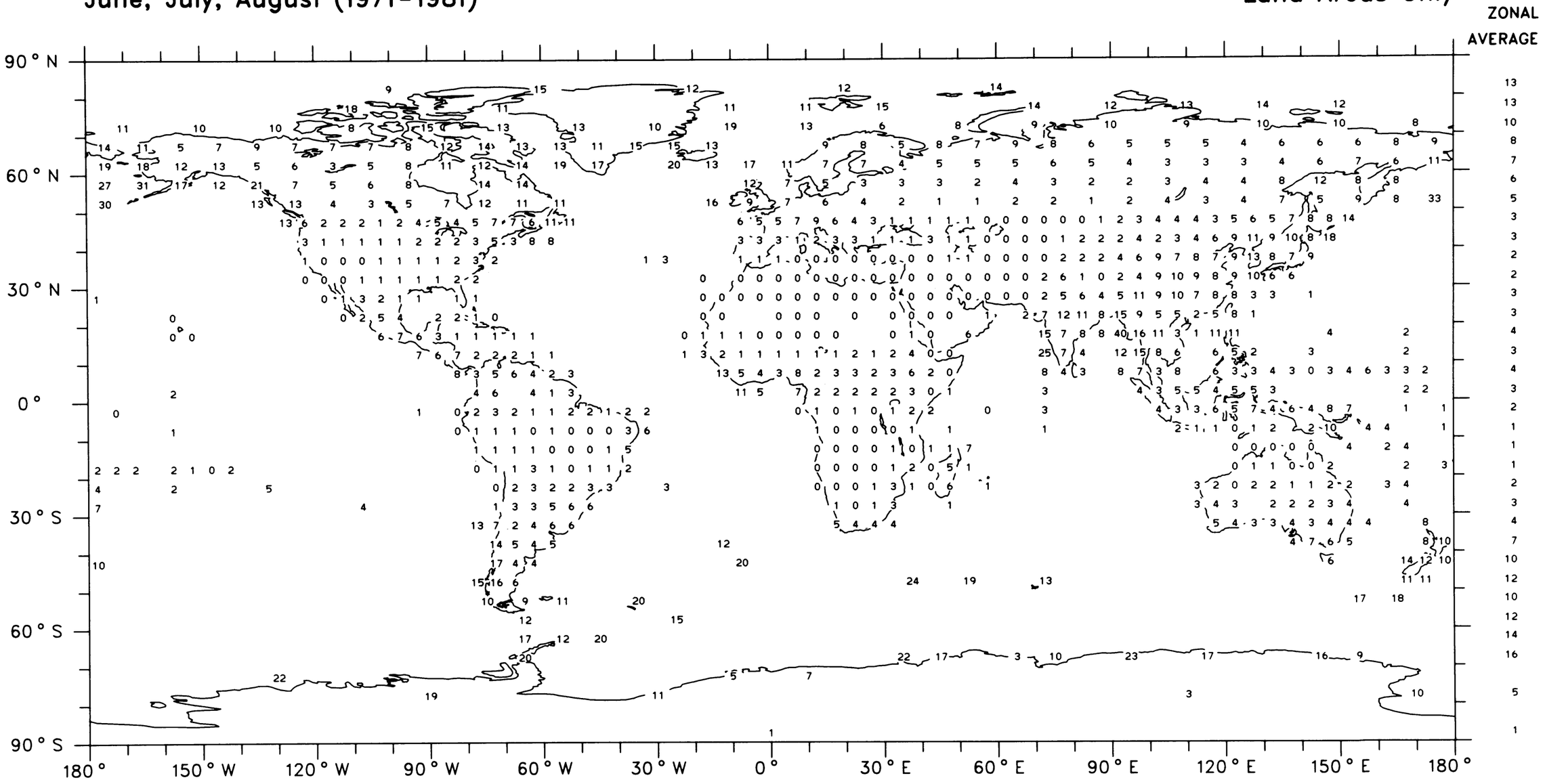
Map 137

Nimbostratus

Average Cloud Amount (%)

June, July, August (1971-1981)

Land Areas Only



Map 138

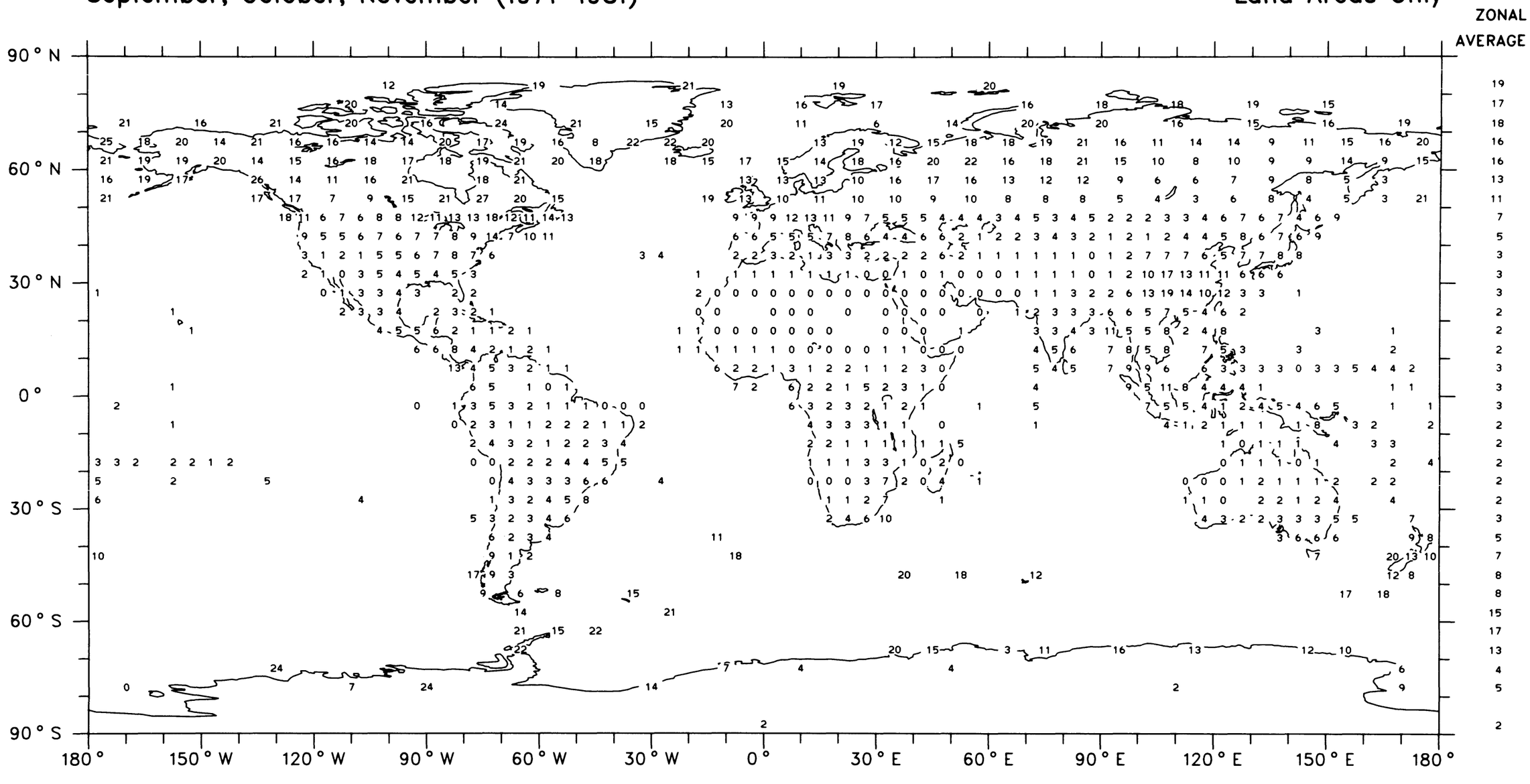
GLOBAL AVERAGE (LAND) 4 %

Nimbostratus

Average Cloud Amount (%)

September, October, November (1971-1981)

Land Areas Only



GLOBAL AVERAGE (LAND) 6 %

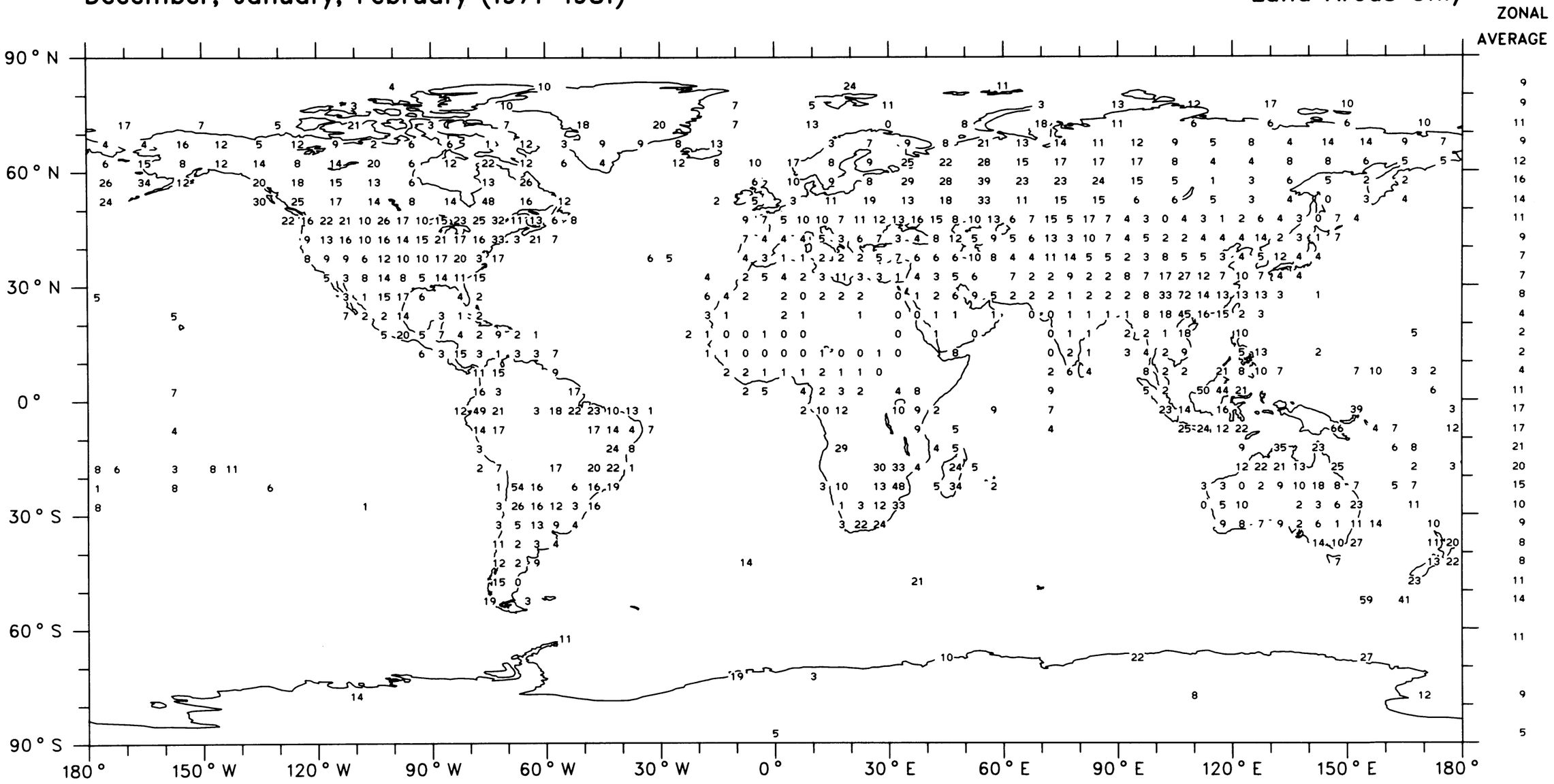
Map 139

Nimbostratus

Amplitude of Diurnal Cycle (0.1 % Cloud Amount)

December, January, February (1971-1981)

Land Areas Only



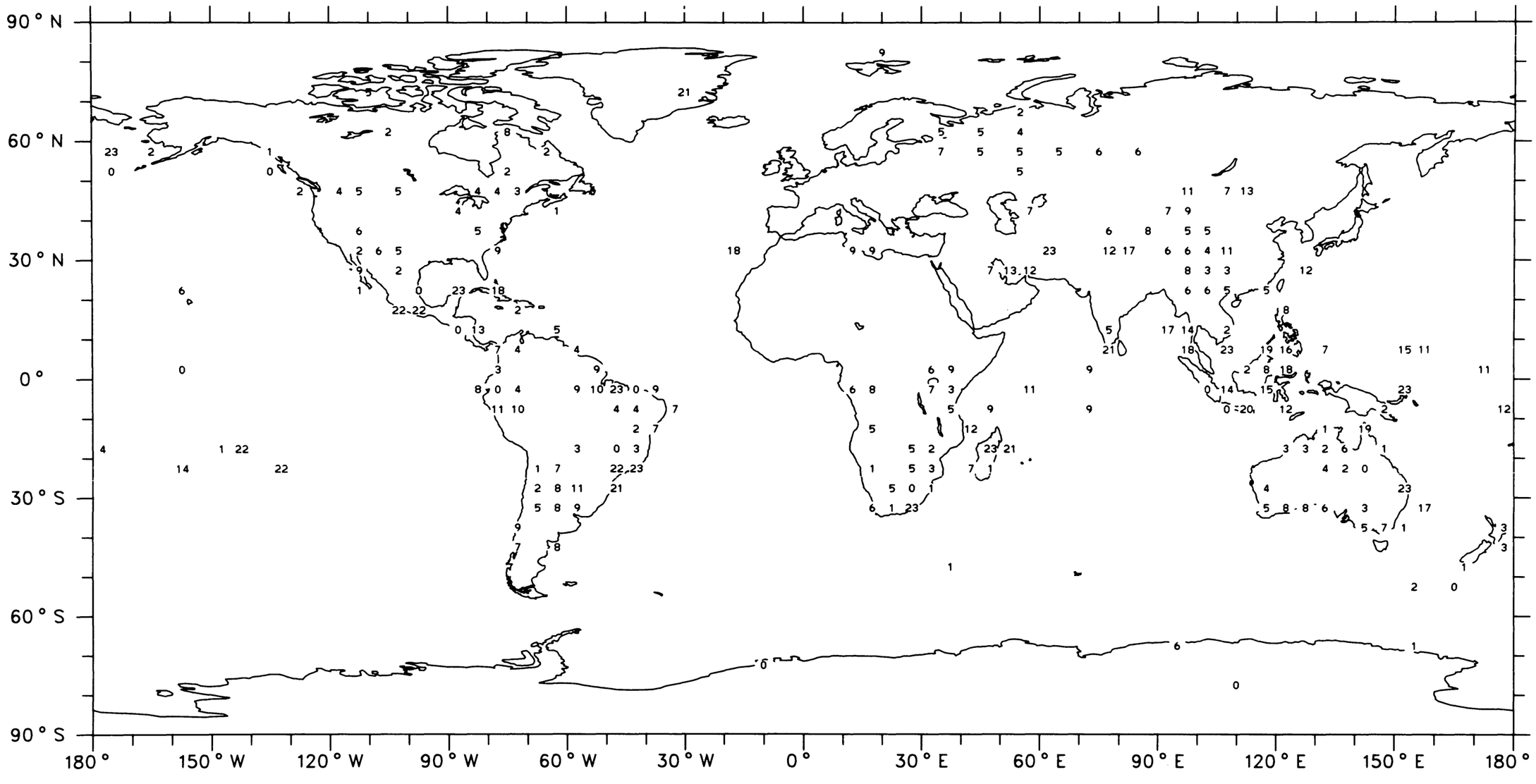
Map 140

GLOBAL AVERAGE (LAND) 1.0 %

Nimbostratus

Phase of Diurnal Cycle (Local Time of Maximum Cloud Amount)

December, January, February (1971-1981) **Land Areas Only**



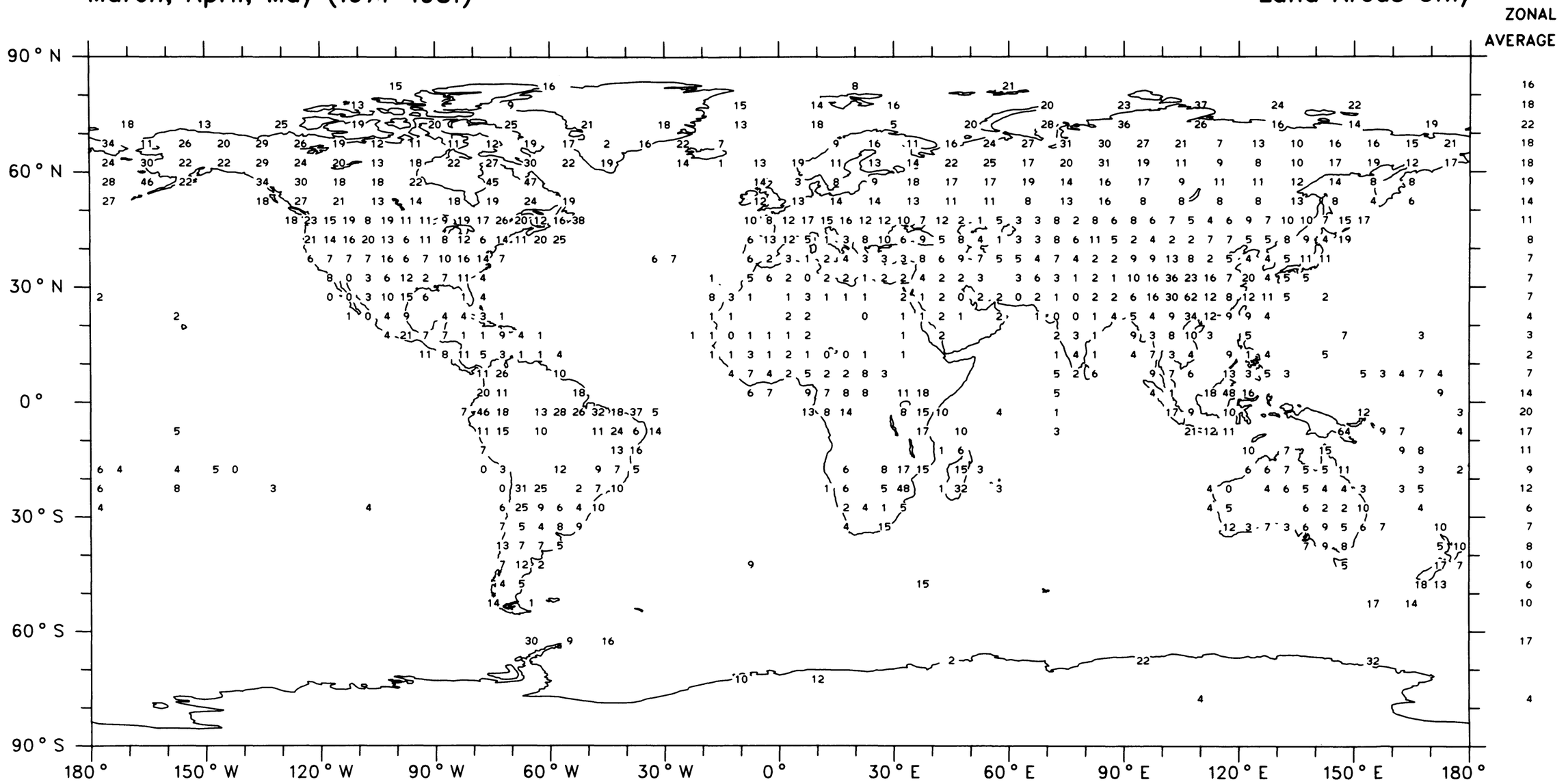
Map 141

Nimbostratus

Amplitude of Diurnal Cycle (0.1 % Cloud Amount)

March, April, May (1971-1981)

Land Areas Only



Map 142

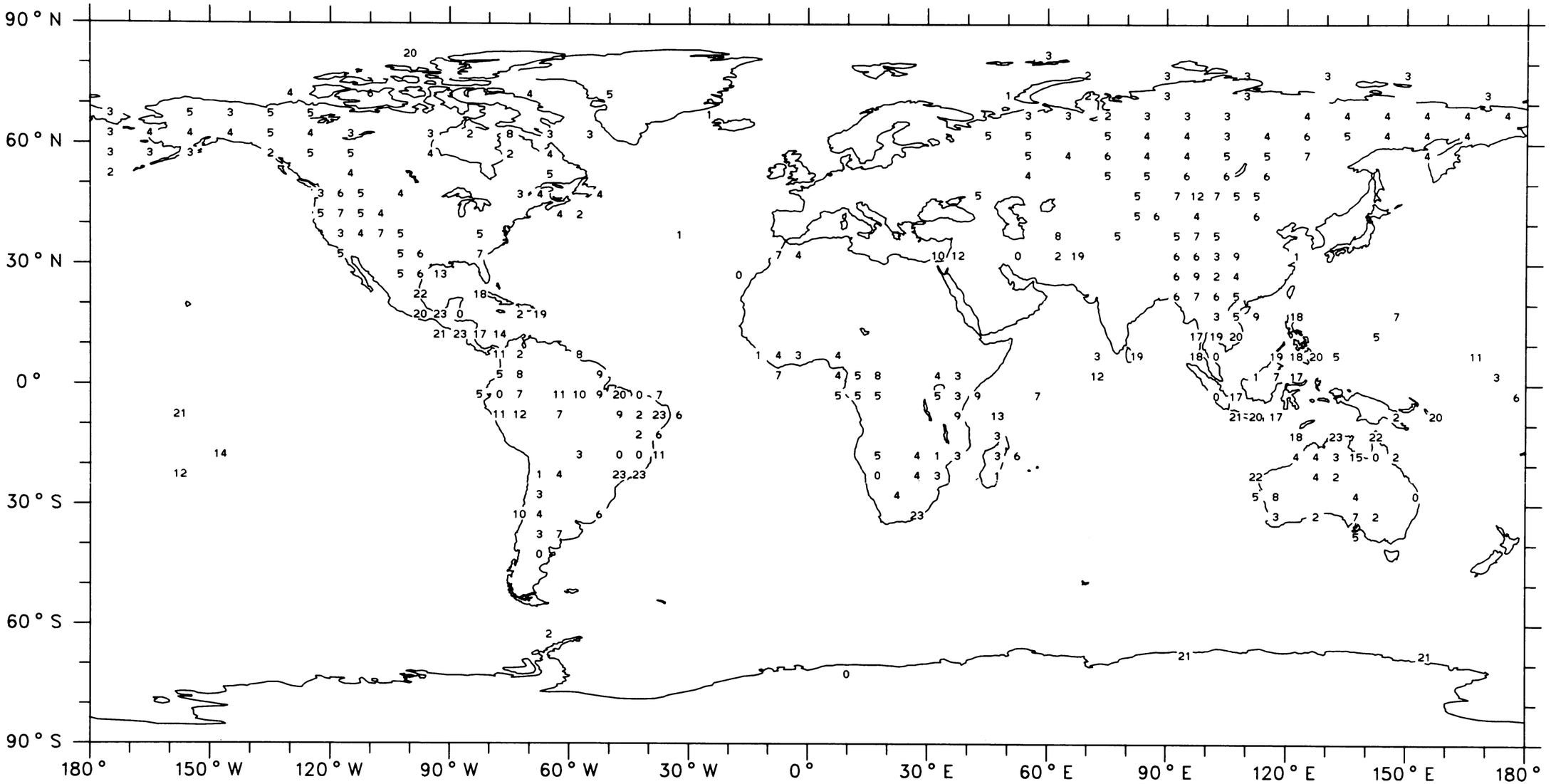
GLOBAL AVERAGE (LAND) 1.0 %

Nimbostratus

Phase of Diurnal Cycle (Local Time of Maximum Cloud Amount)

March, April, May (1971-1981)

Land Areas Only



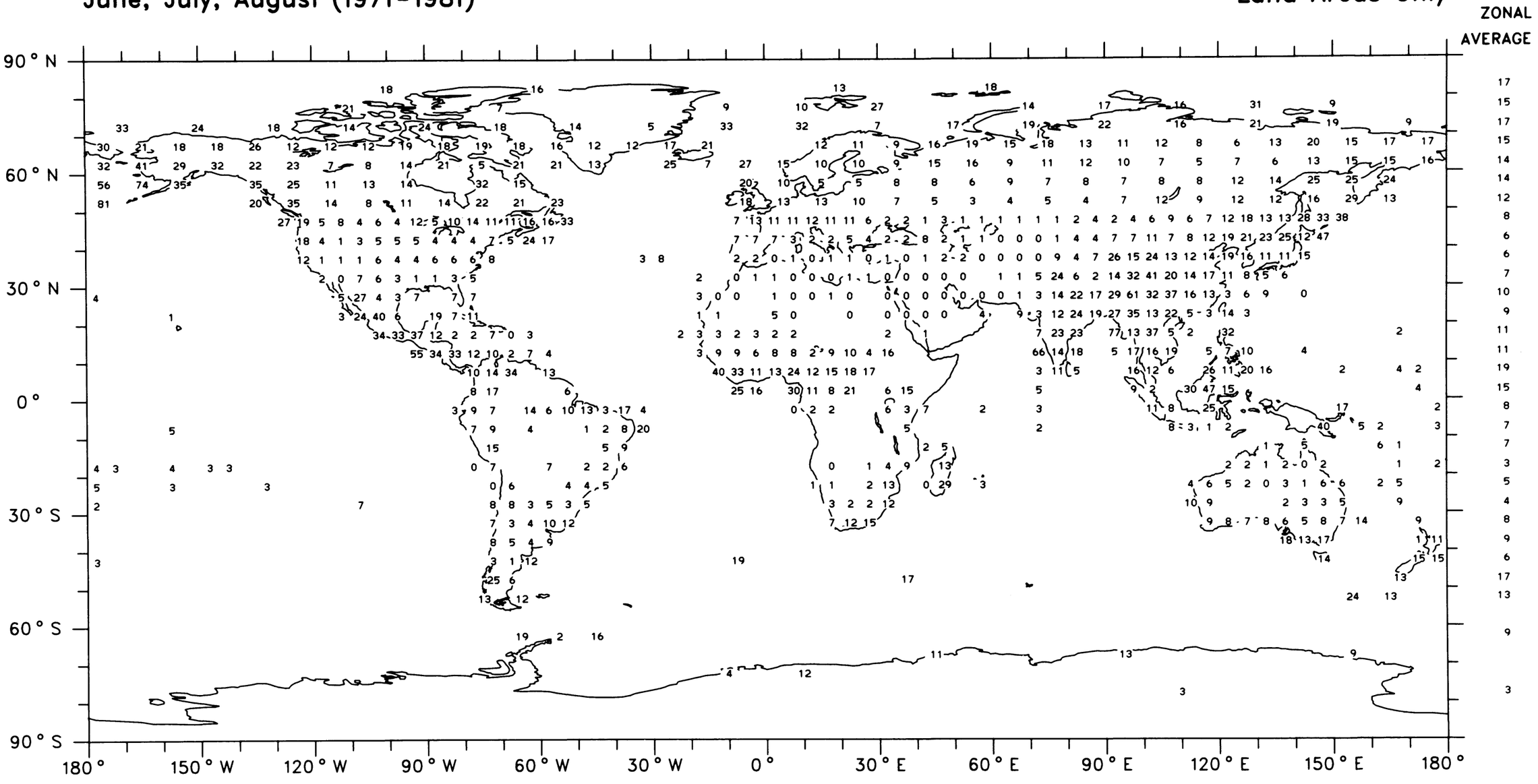
Map 143

Nimbostratus

Amplitude of Diurnal Cycle (0.1 % Cloud Amount)

June, July, August (1971-1981)

Land Areas Only



Map 144

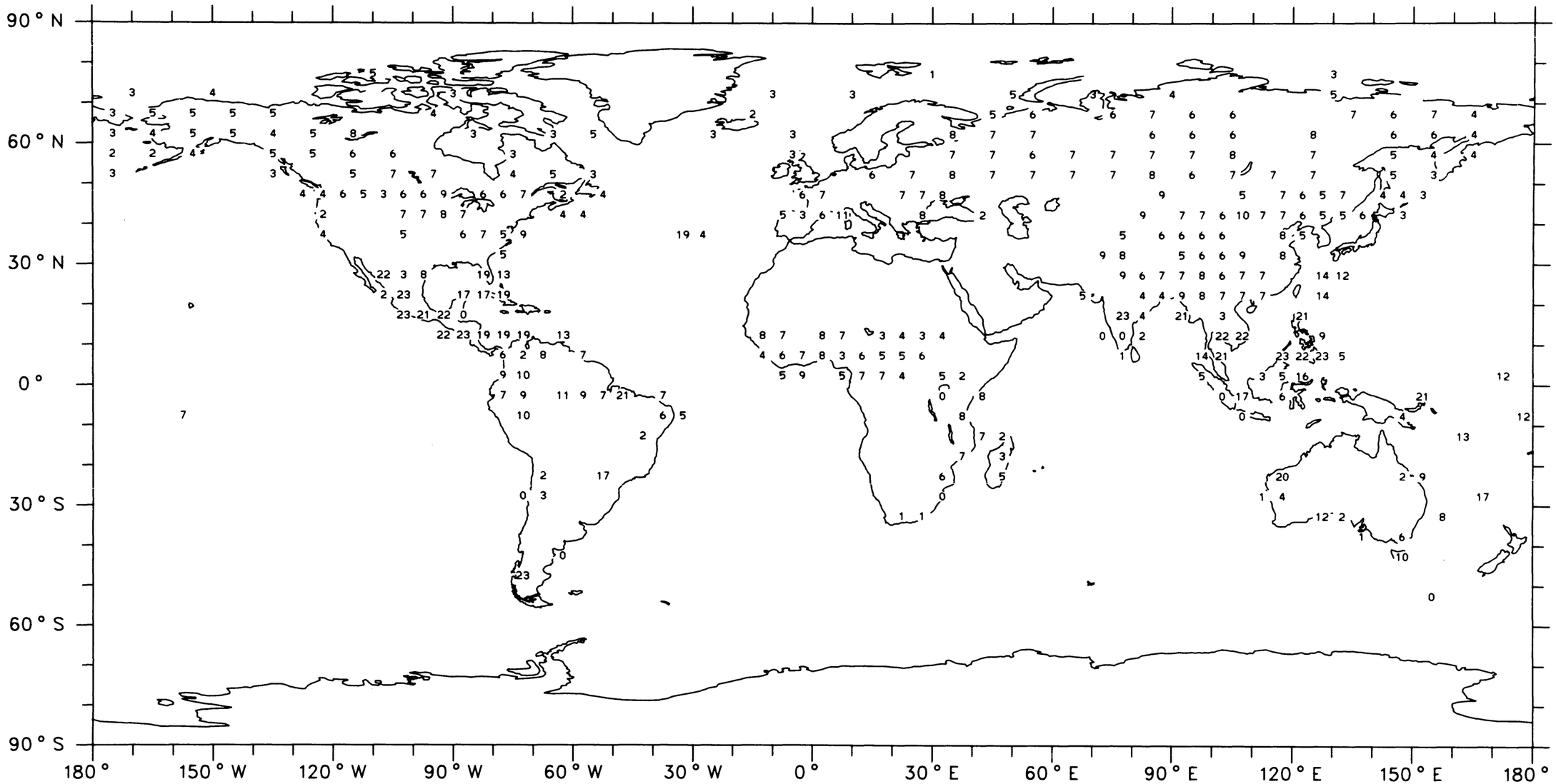
GLOBAL AVERAGE (LAND) 1.0 %

Nimbostratus

Phase of Diurnal Cycle (Local Time of Maximum Cloud Amount)

June, July, August (1971-1981)

Land Areas Only



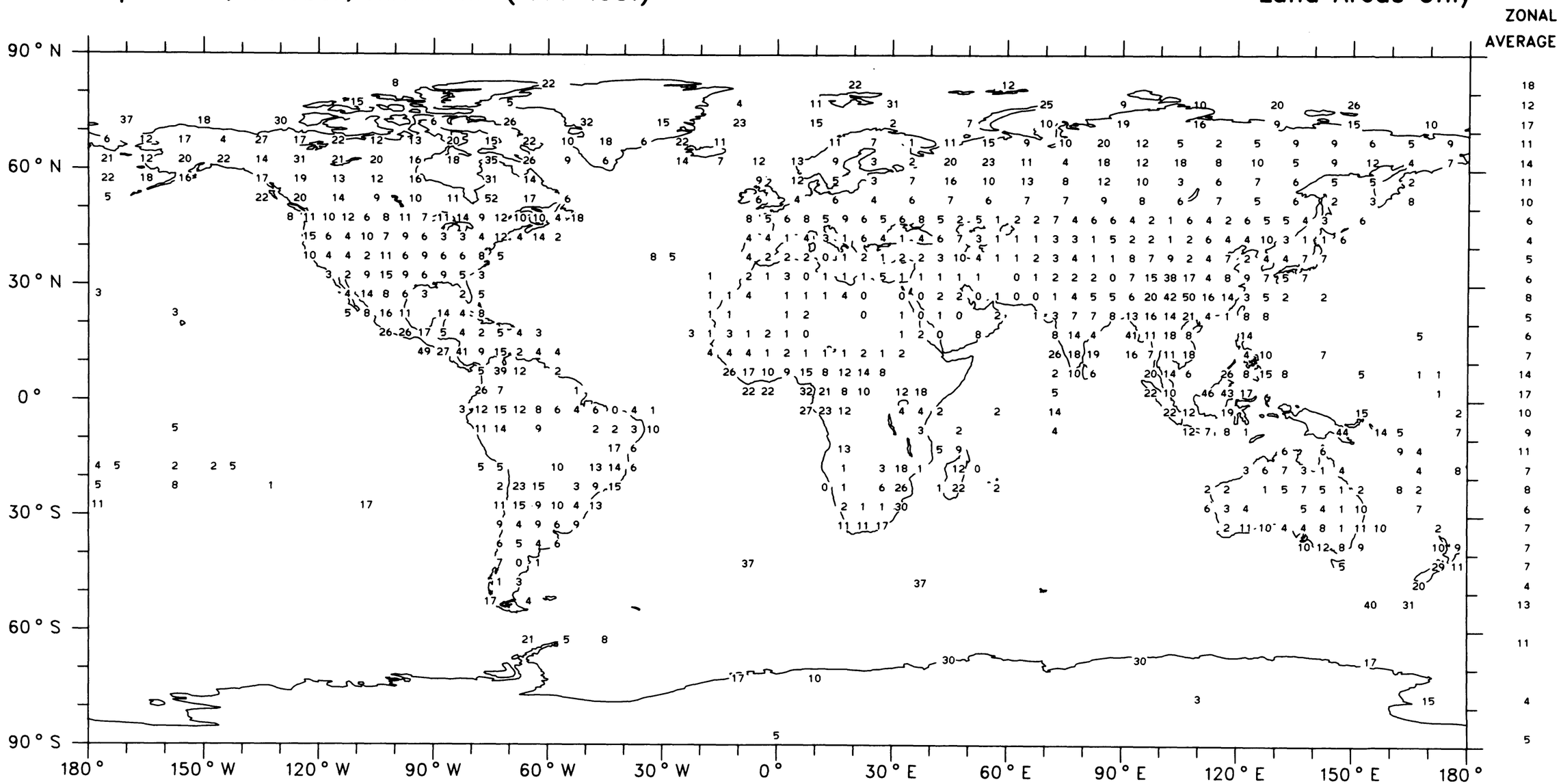
Map 145

Nimbostratus

Amplitude of Diurnal Cycle (0.1 % Cloud Amount)

September, October, November (1971-1981)

Land Areas Only



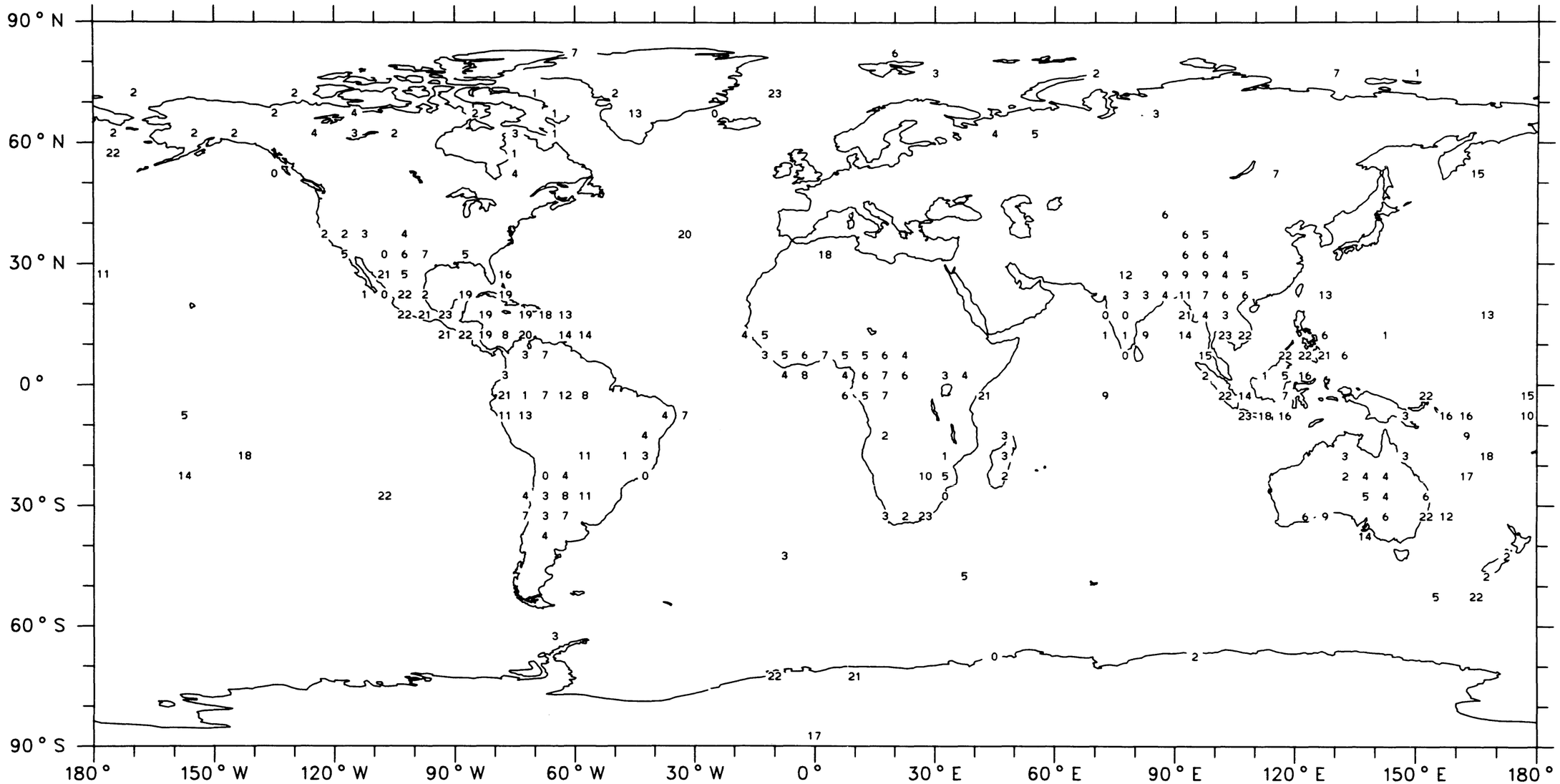
Map 146

GLOBAL AVERAGE (LAND) 0.9 %

Nimbostratus

Phase of Diurnal Cycle (Local Time of Maximum Cloud Amount)

September, October, November (1971-1981) **Land Areas Only**



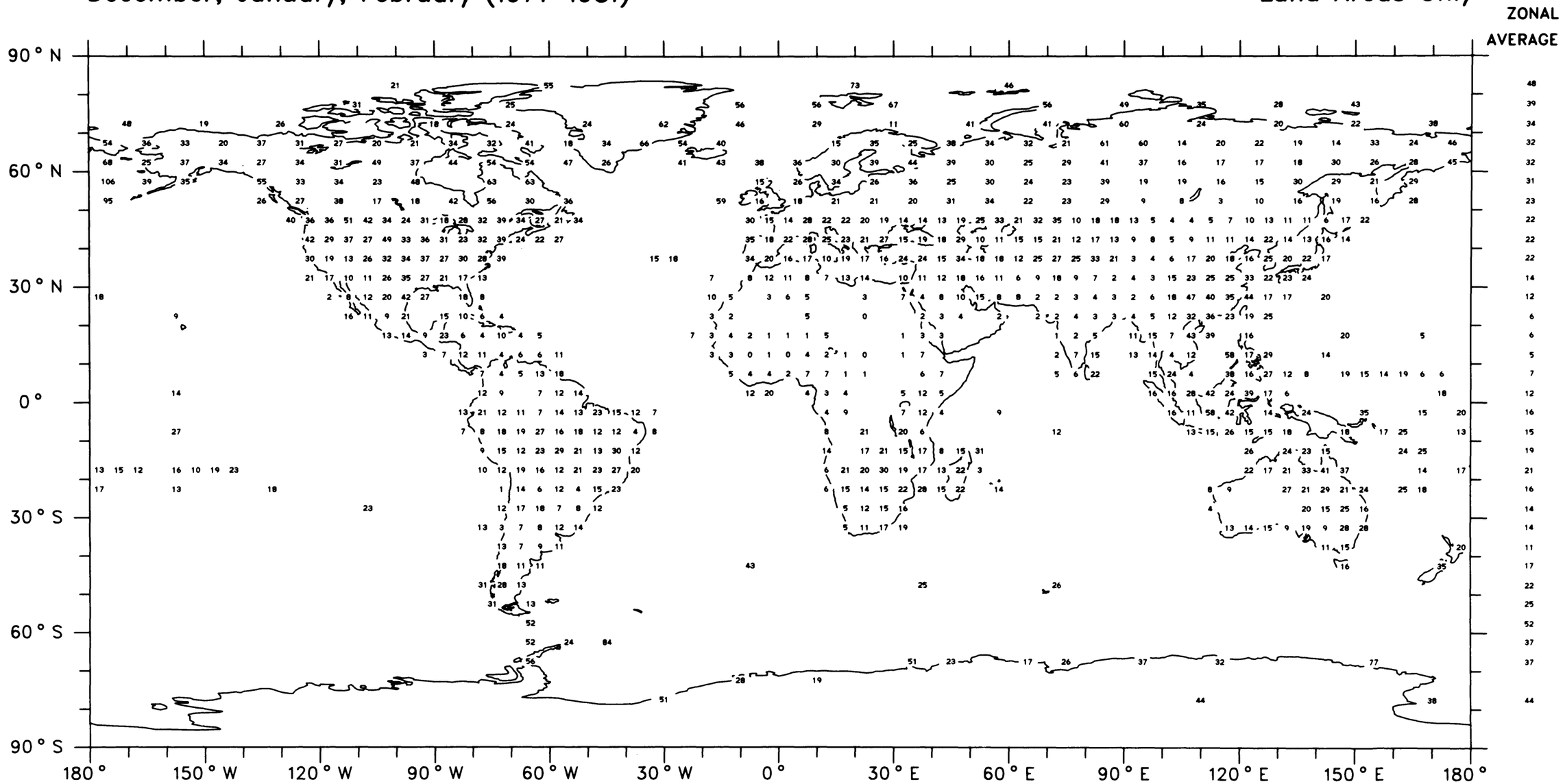
Map 147

Interannual Variation of Nimbostratus :

Standard Deviation of Seasonal Means (0.1 % Cloud Amount)

December, January, February (1971-1981)

Land Areas Only



Map 148

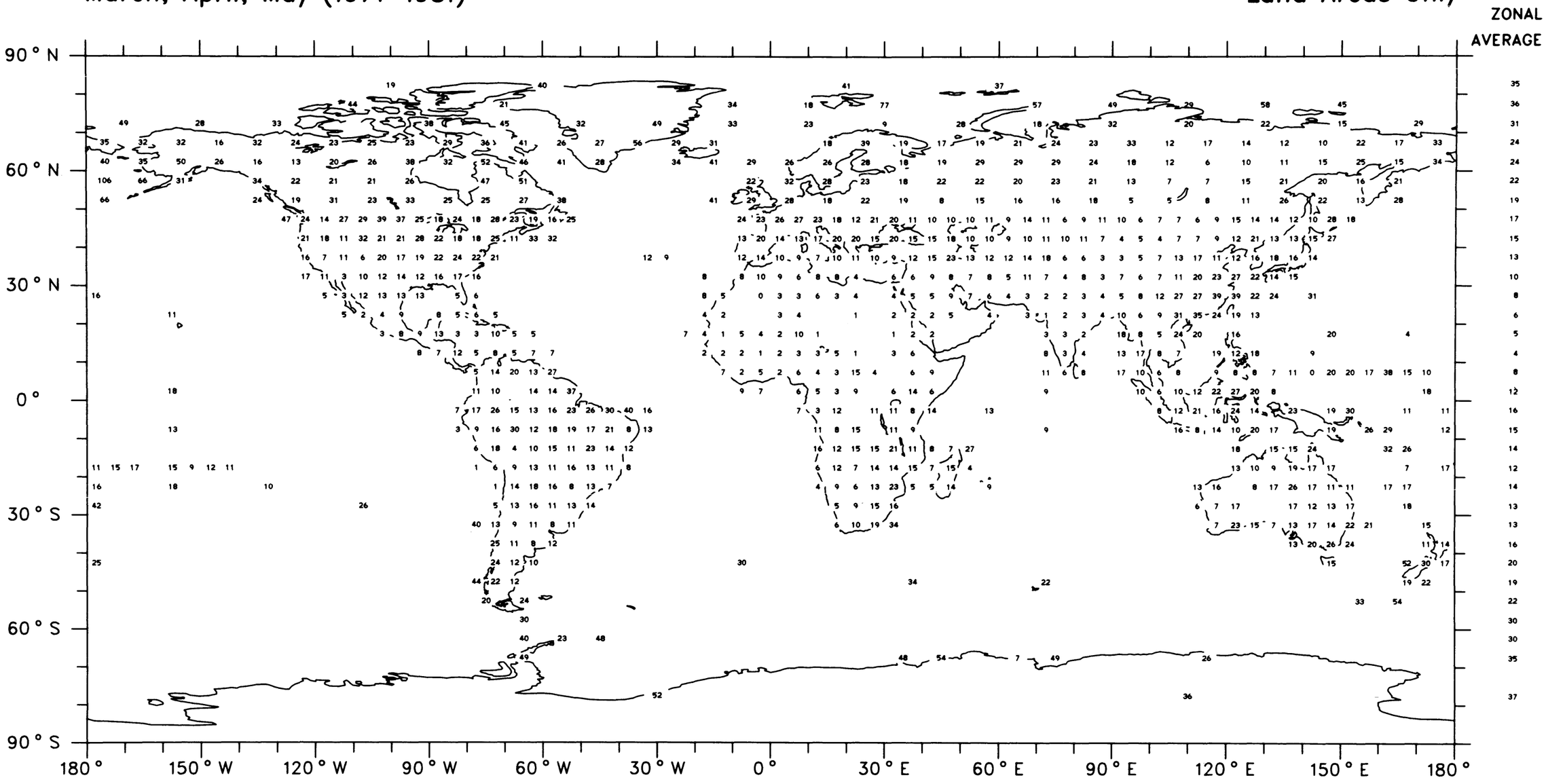
GLOBAL AVERAGE (LAND) 1.9 %

Interannual Variation of Nimbostratus :

Standard Deviation of Seasonal Means (0.1 % Cloud Amount)

March, April, May (1971-1981)

Land Areas Only



GLOBAL AVERAGE (LAND) 1.5 %

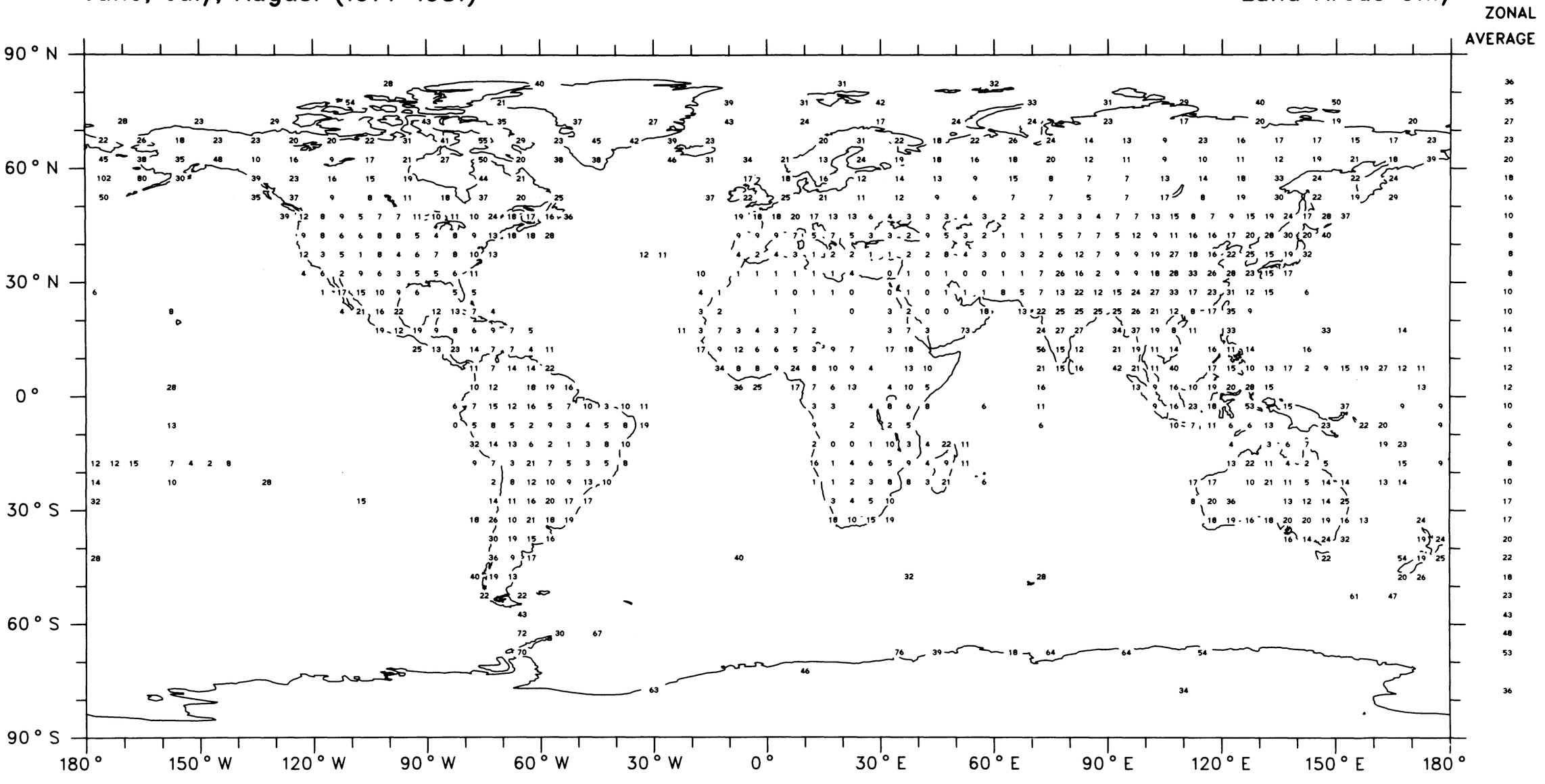
Map 149

Interannual Variation of Nimbostratus :

Standard Deviation of Seasonal Means (0.1 % Cloud Amount)

June, July, August (1971-1981)

Land Areas Only



Map 150

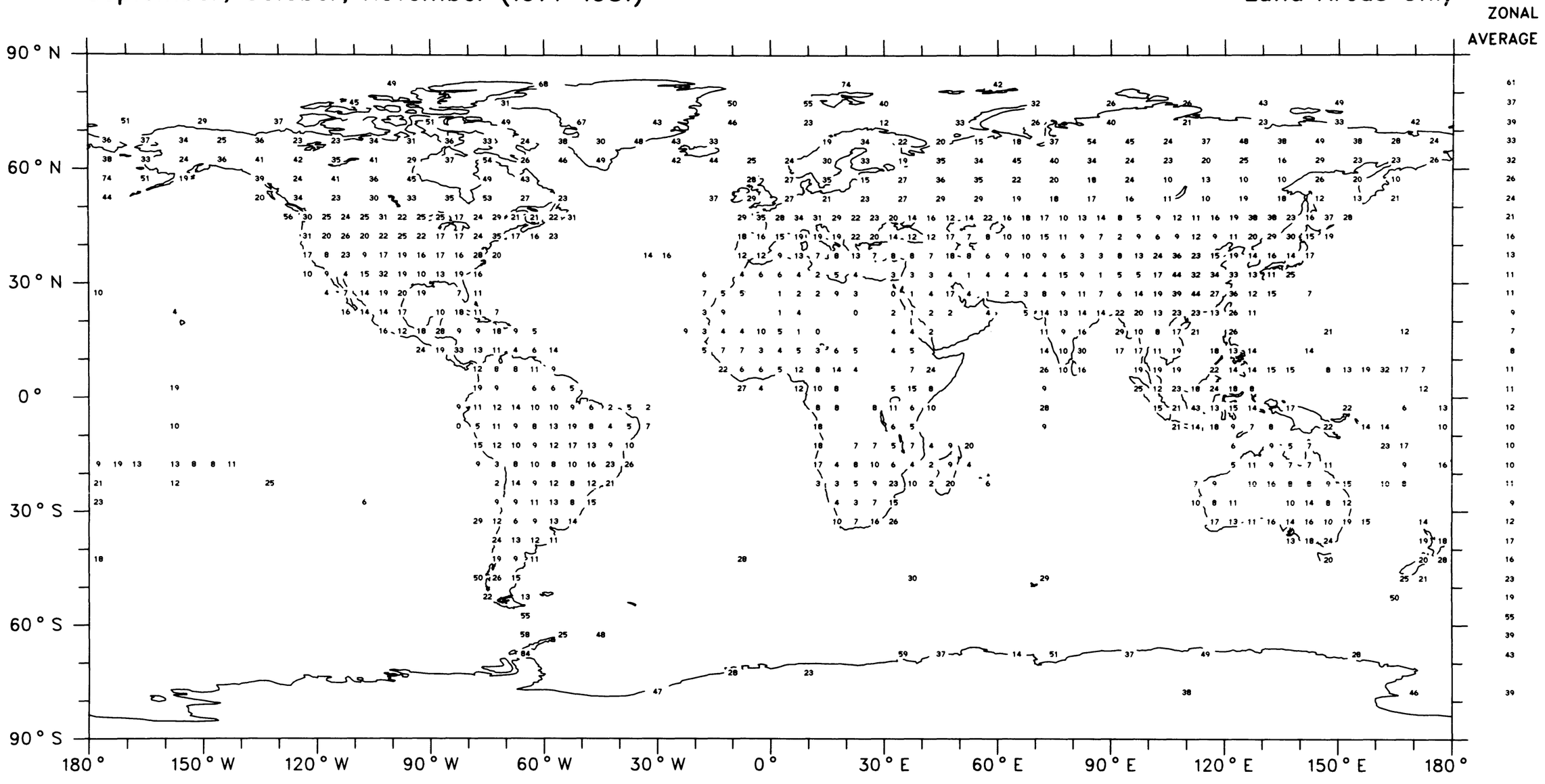
GLOBAL AVERAGE (LAND) 1.4 %

Interannual Variation of Nimbostratus :

Standard Deviation of Seasonal Means (0.1 % Cloud Amount)

September, October, November (1971-1981)

Land Areas Only



GLOBAL AVERAGE (LAND) 1.7 %

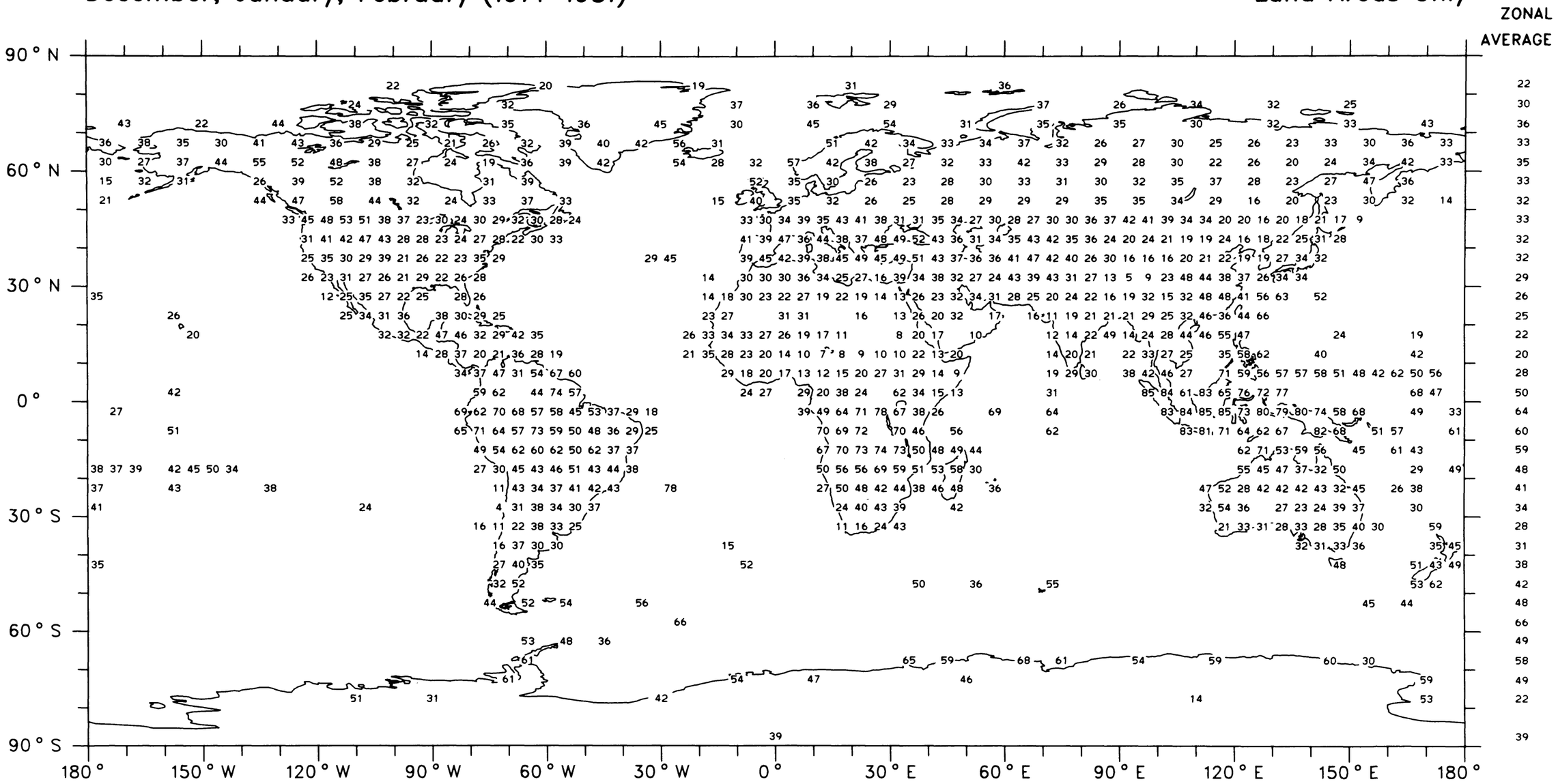
Map 151

Altostratus + Altocumulus

Frequency of Occurrence (%), 6-18 LT

December, January, February (1971-1981)

Land Areas Only



Map 152

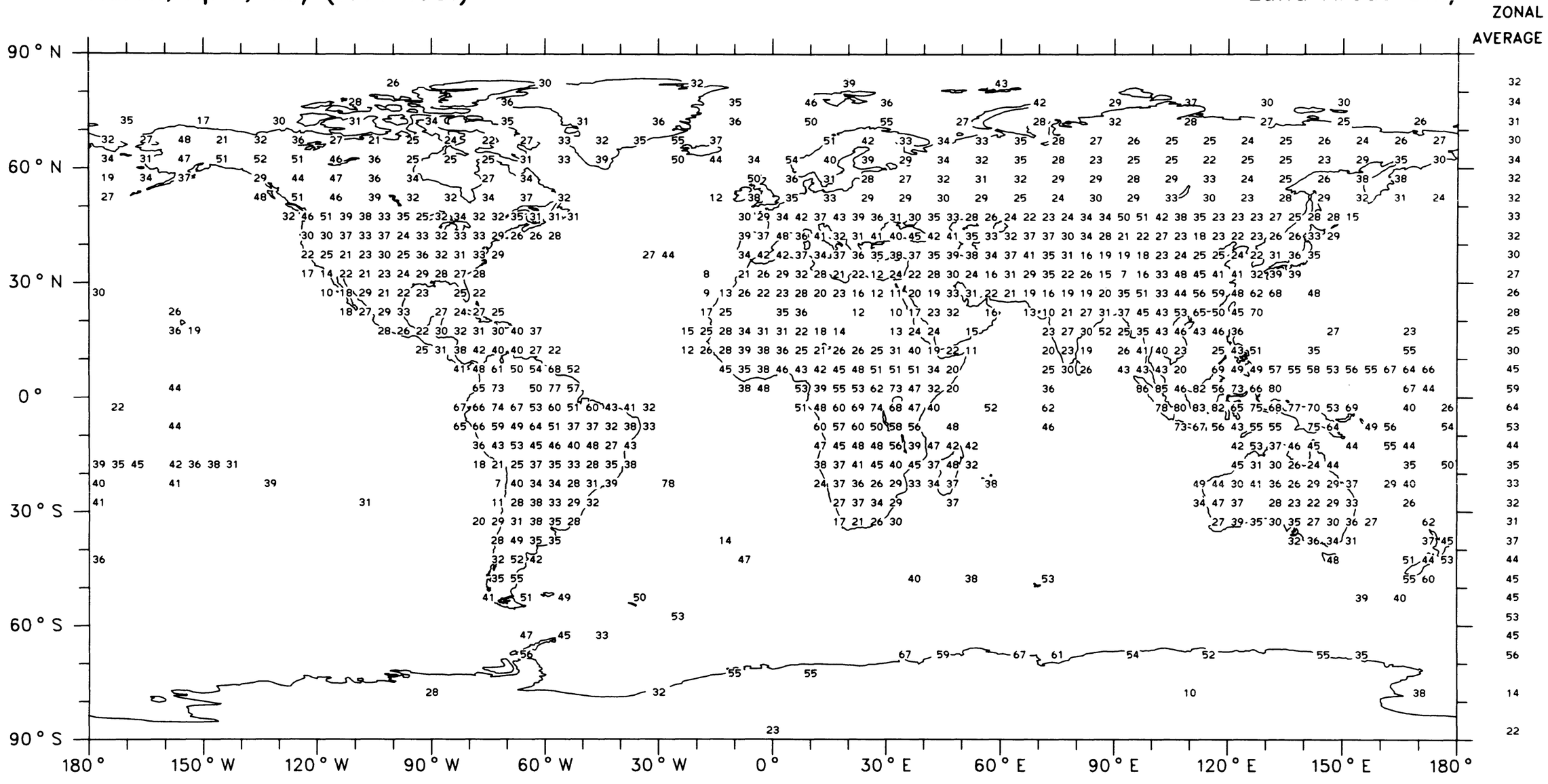
GLOBAL AVERAGE (LAND) 36 %

Altostratus + Altocumulus

Frequency of Occurrence (%), 6-18 LT

March, April, May (1971-1981)

Land Areas Only



GLOBAL AVERAGE (LAND) 34 %

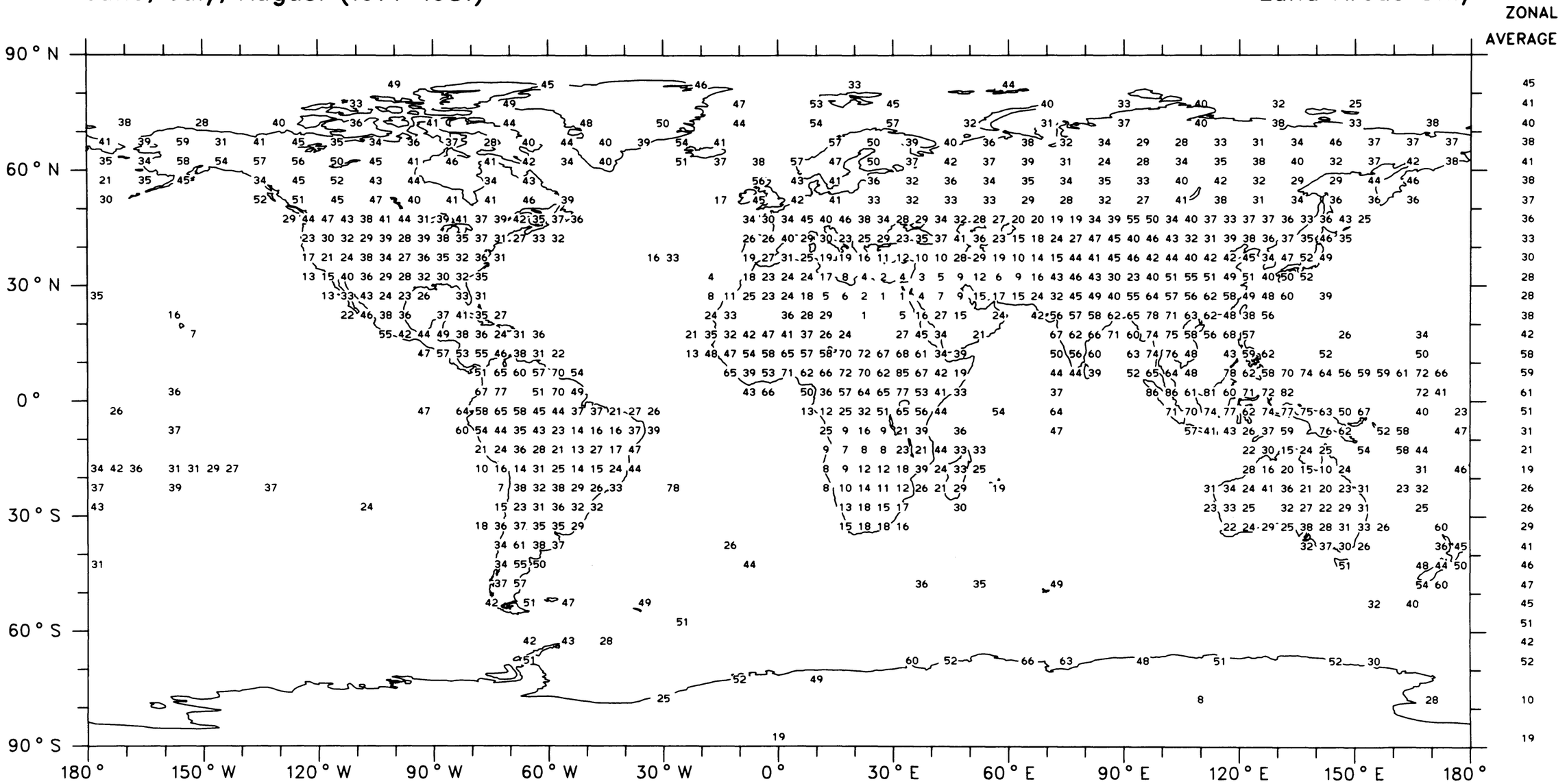
Map 153

Altostratus + Altocumulus

Frequency of Occurrence (%), 6-18 LT

June, July, August (1971-1981)

Land Areas Only



Map 154

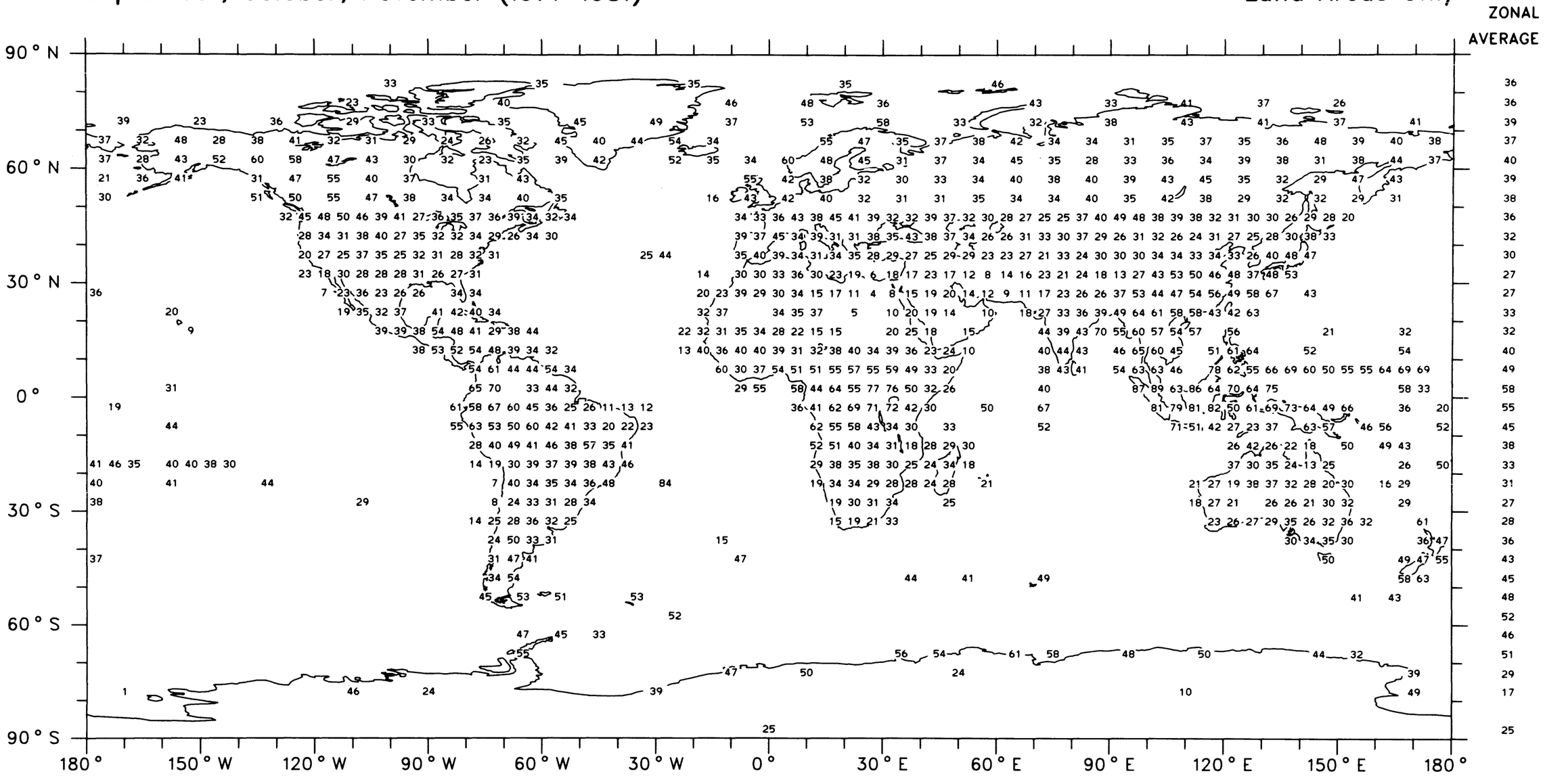
GLOBAL AVERAGE (LAND) 36 %

Altostratus + Altocumulus

Frequency of Occurrence (%), 6-18 LT

September, October, November (1971-1981)

Land Areas Only



GLOBAL AVERAGE (LAND) 36 %

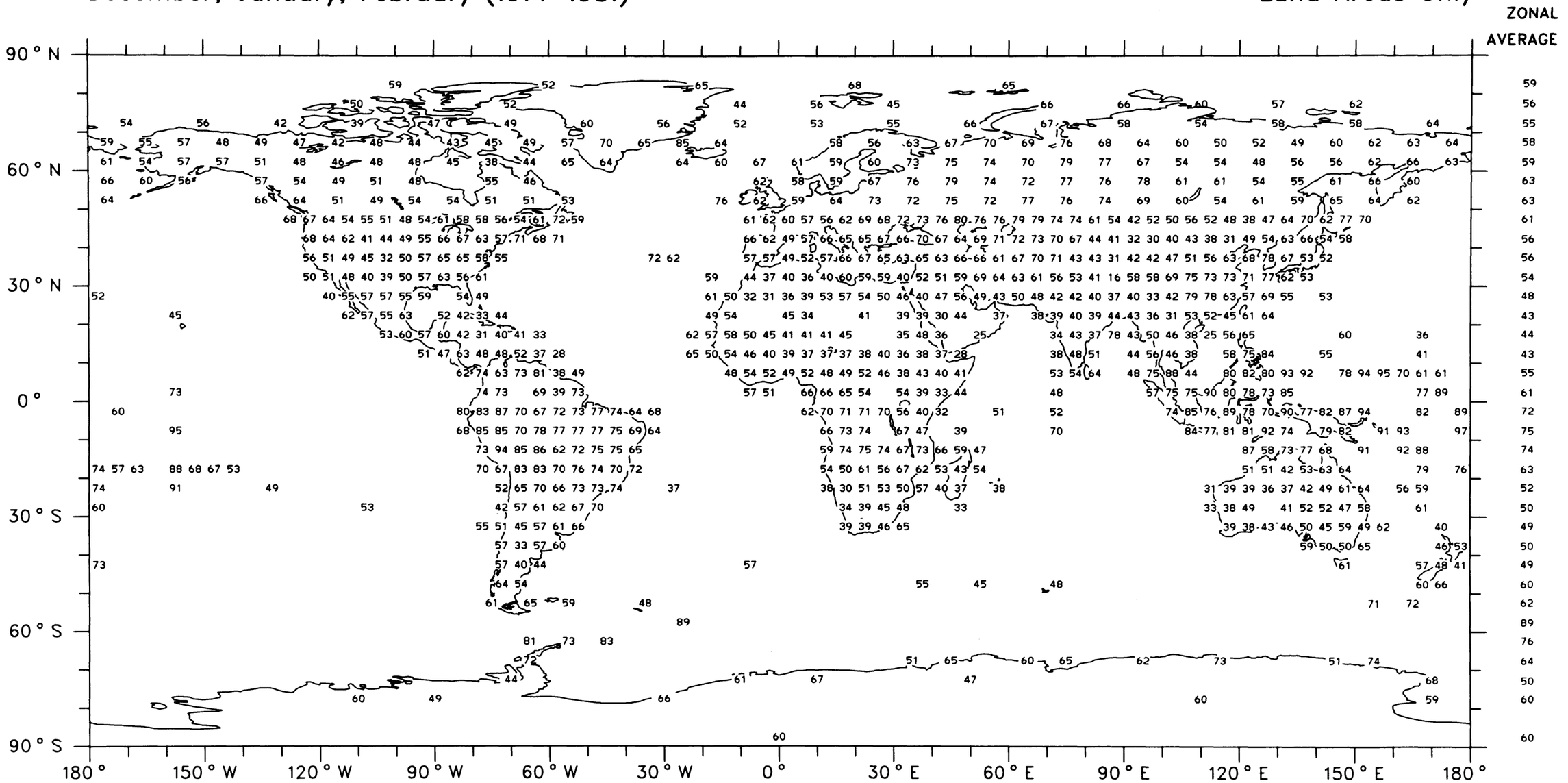
Map 155

Altostratus + Altocumulus

Amount-When-Present (%), 6-18 LT

December, January, February (1971-1981)

Land Areas Only



Map 156

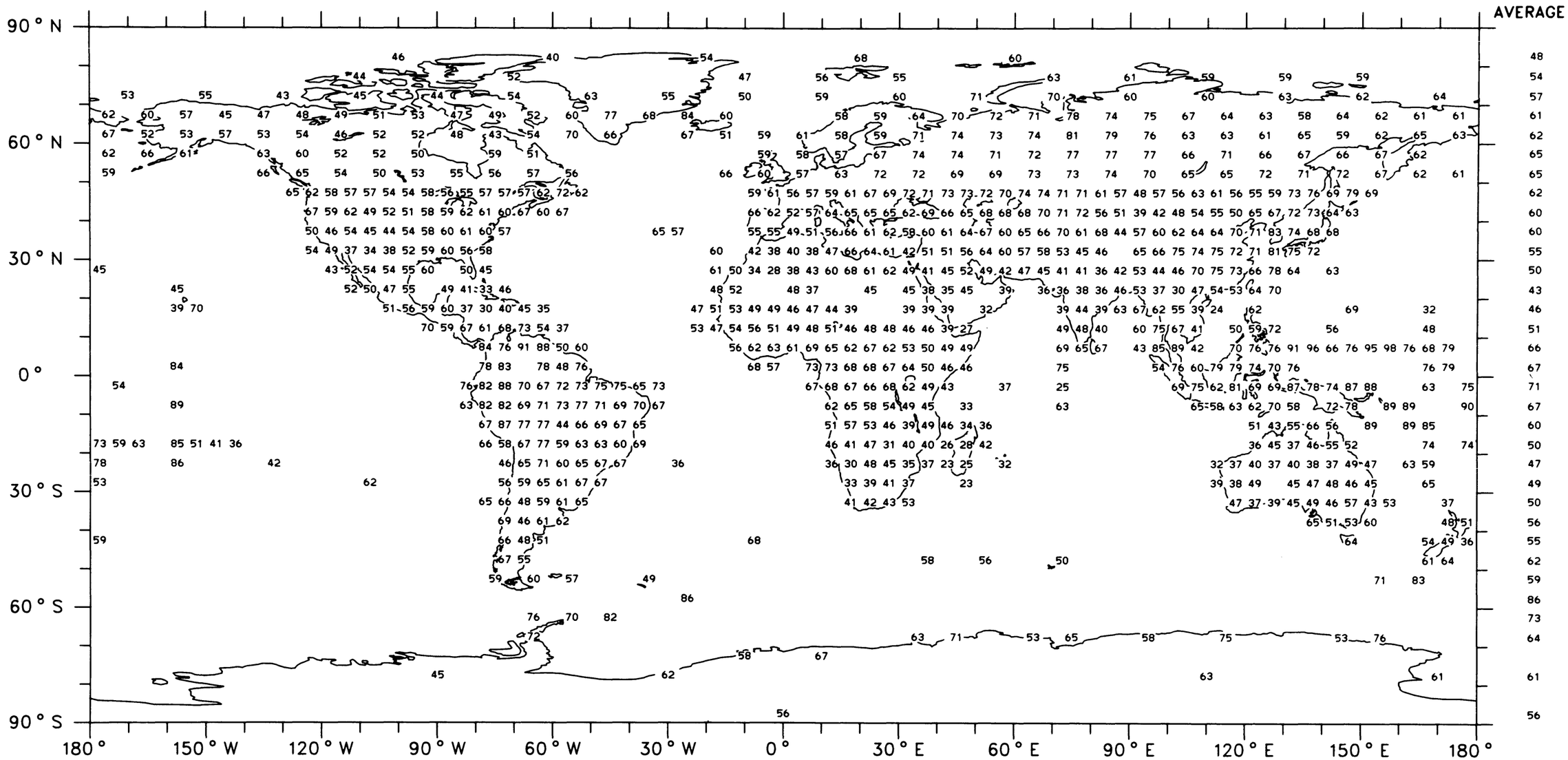
GLOBAL AVERAGE (LAND) 57 %

Altostratus + Altocumulus

Amount-When-Present (%), 6-18 LT

March, April, May (1971-1981)

Land Areas Only



GLOBAL AVERAGE (LAND) 58 %

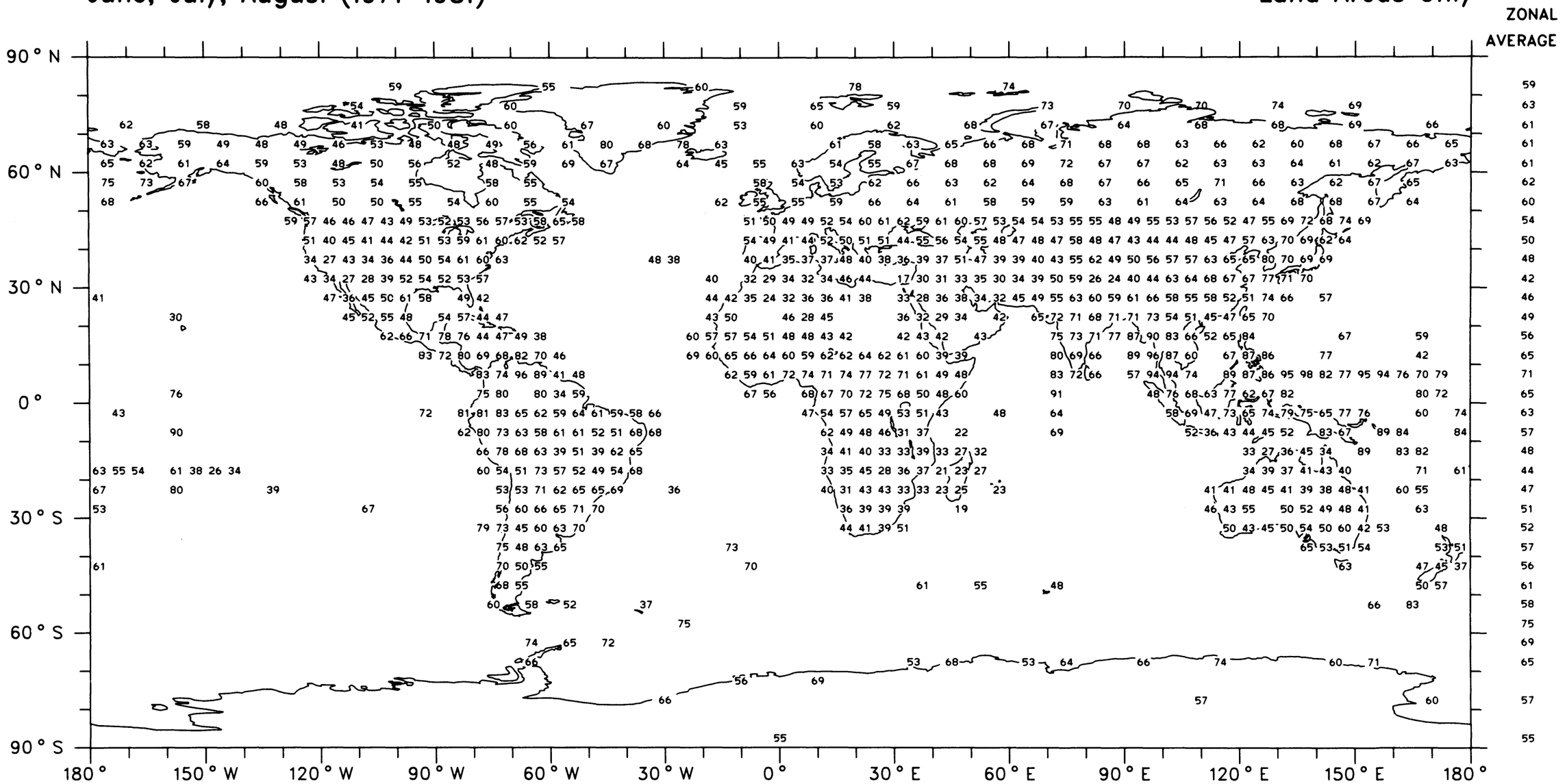
Map 157

Altostratus + Altocumulus

Amount-When-Present (%), 6-18 LT

June, July, August (1971-1981)

Land Areas Only



Map 158

GLOBAL AVERAGE (LAND) 55 %

Altostratus + Altocumulus

Amount-When-Present (%), 6-18 LT

September, October, November (1971-1981)

Land Areas Only

ZONAL AVERAGE

90 ° N
60 ° N
30 ° N
0 °
30 ° S
60 ° S
90 ° S

180 ° 150 ° W 120 ° W 90 ° W 60 ° W 30 ° W 0 ° 30 ° E 60 ° E 90 ° E 120 ° E 150 ° E 180 °

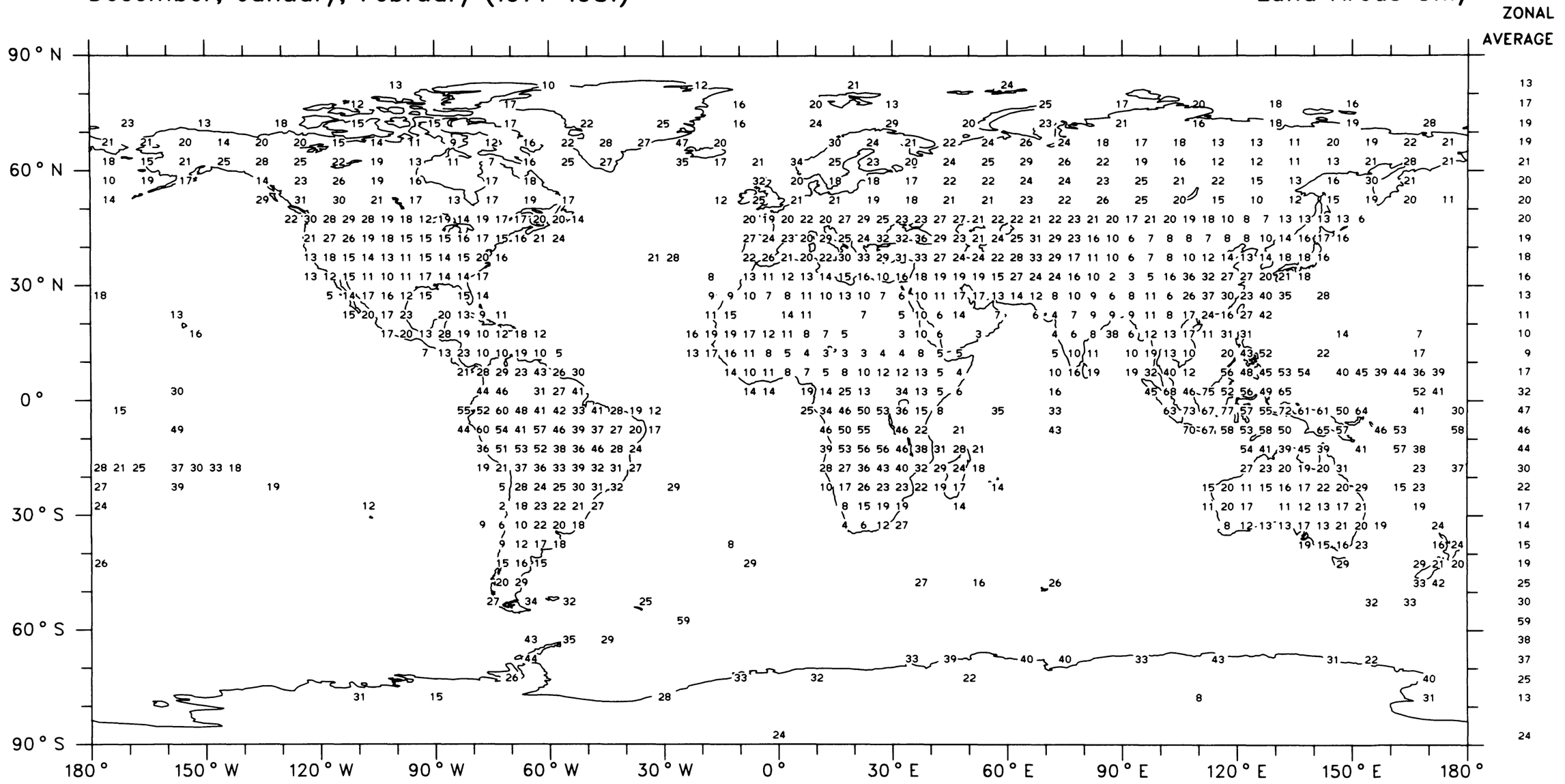
GLOBAL AVERAGE (LAND) 56 %

Map 159

Altostratus + Altocumulus

Average Cloud Amount (%), 6-18 LT

December, January, February (1971-1981) **Land Areas Only**



Map 160

GLOBAL AVERAGE (LAND) 21 %

Altostratus + Altocumulus

Average Cloud Amount (%), 6-18 LT

March, April, May (1971-1981)

Land Areas Only

ZONAL AVERAGE

90 ° N
60 ° N
30 ° N
0 °
30 ° S
60 ° S
90 ° S

180 ° 150 ° W 120 ° W 90 ° W 60 ° W 30 ° W 0 ° 30 ° E 60 ° E 90 ° E 120 ° E 150 ° E 180 °

GLOBAL AVERAGE (LAND) 20 %

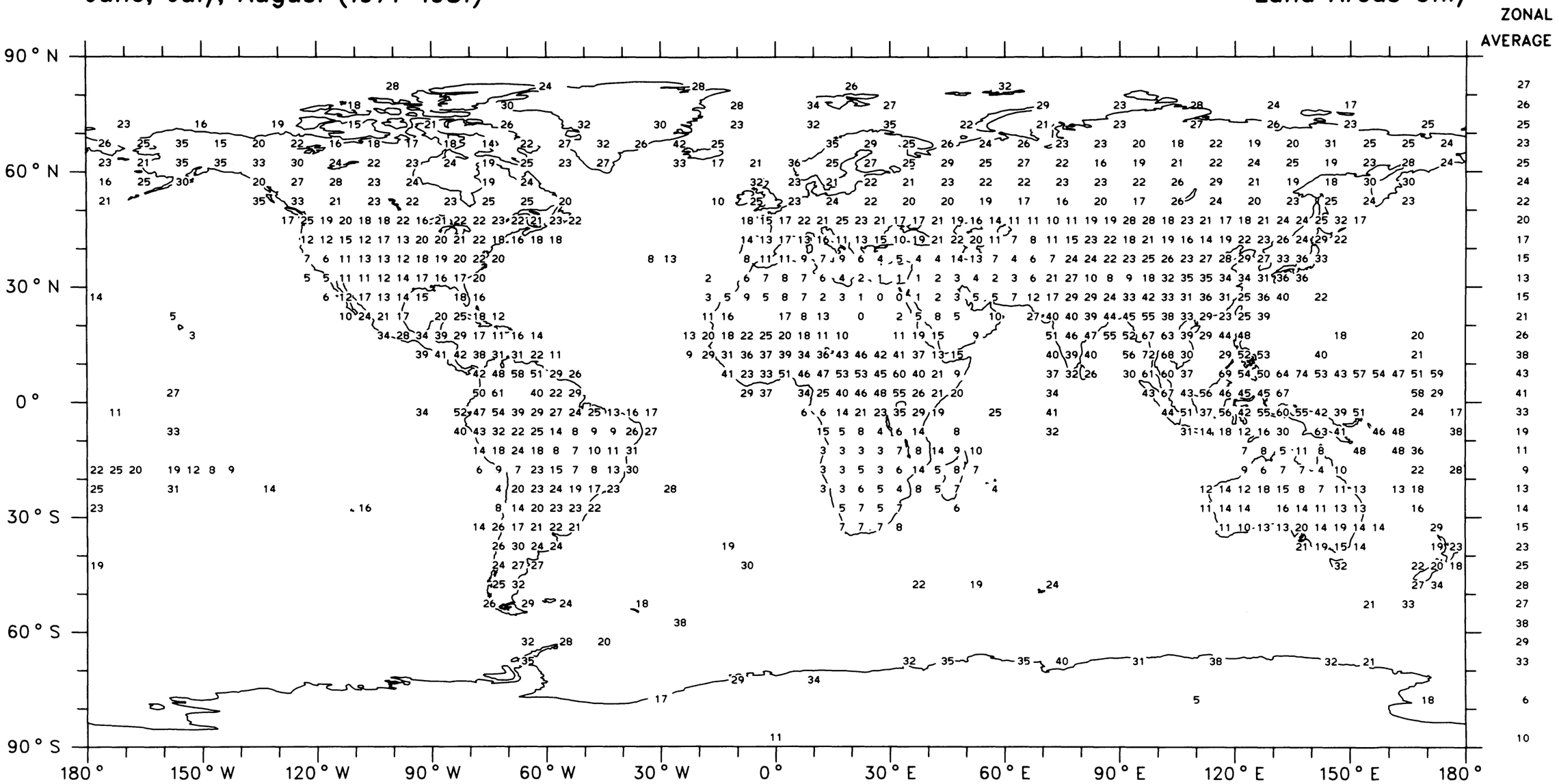
Map 161

Altostratus + Altocumulus

Average Cloud Amount (%), 6-18 LT

June, July, August (1971-1981)

Land Areas Only



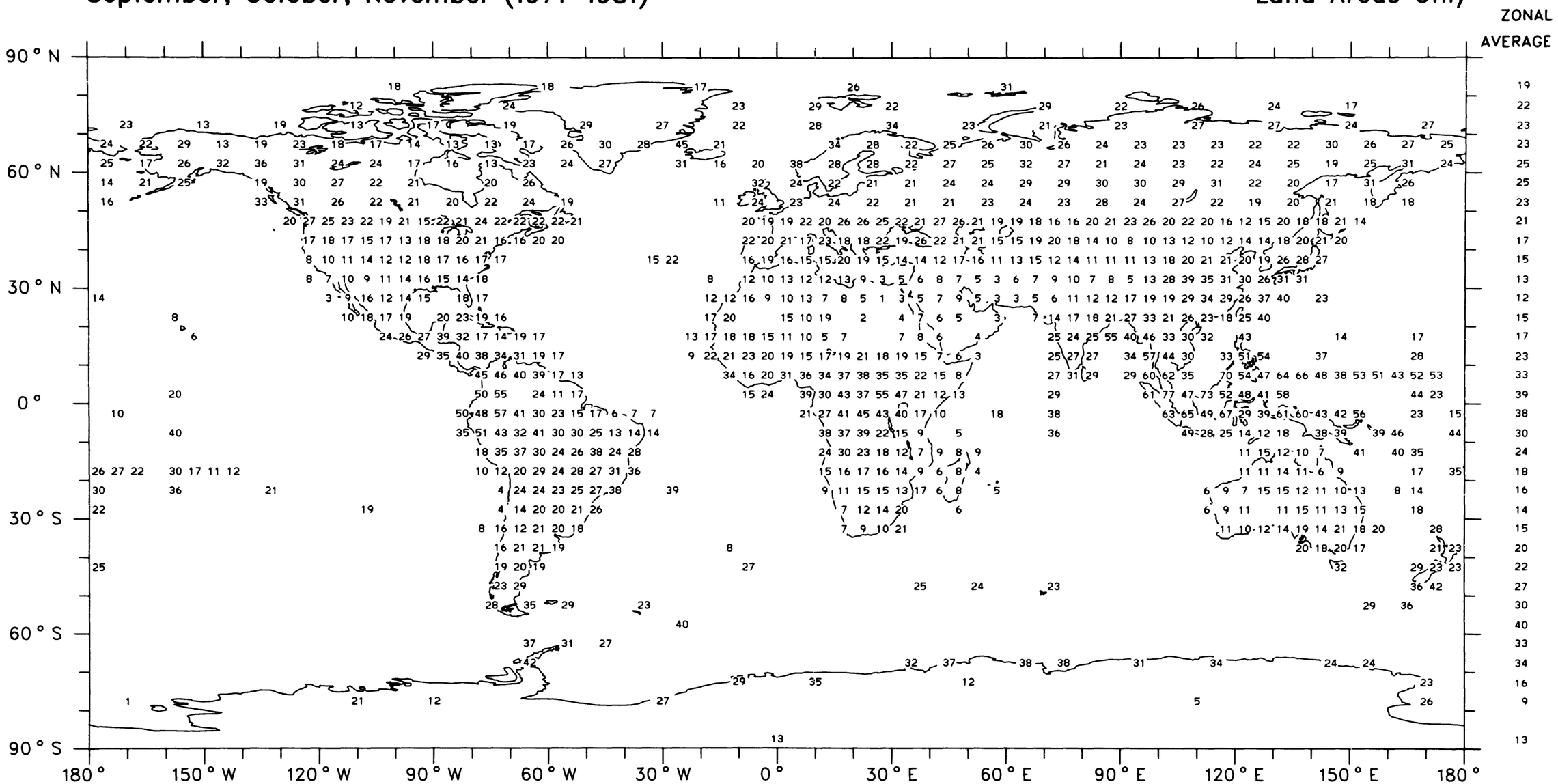
Map 162

GLOBAL AVERAGE (LAND) 21 %

Altostratus + Altocumulus

Average Cloud Amount (%), 6-18 LT

September, October, November (1971-1981) **Land Areas Only**



GLOBAL AVERAGE (LAND) 21 %

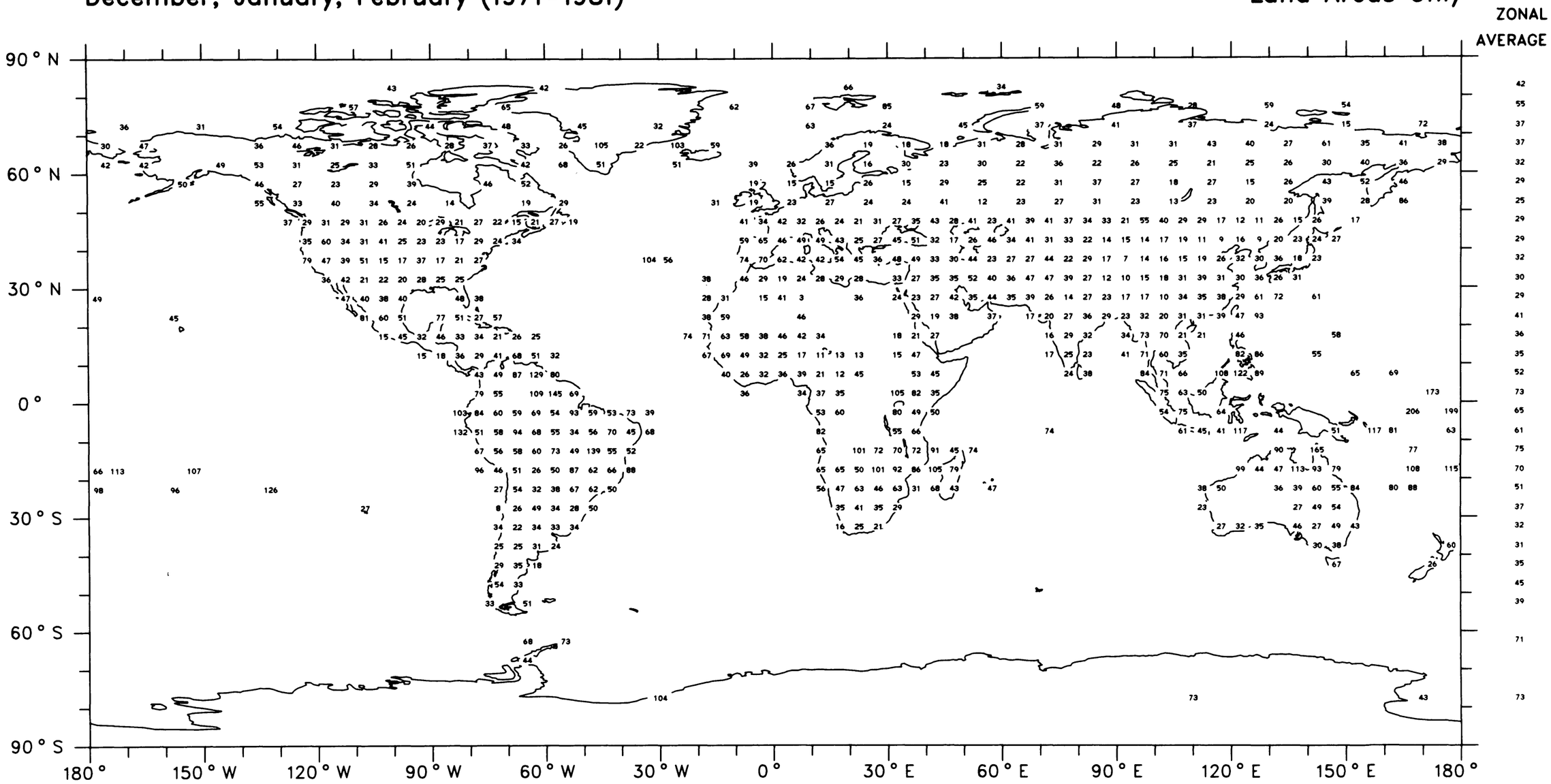
Map 163

Interannual Variation of Altostratus + Altocumulus :

Standard Deviation of Seasonal Means (0.1 % Cloud Amount)

December, January, February (1971-1981)

Land Areas Only



Map 164

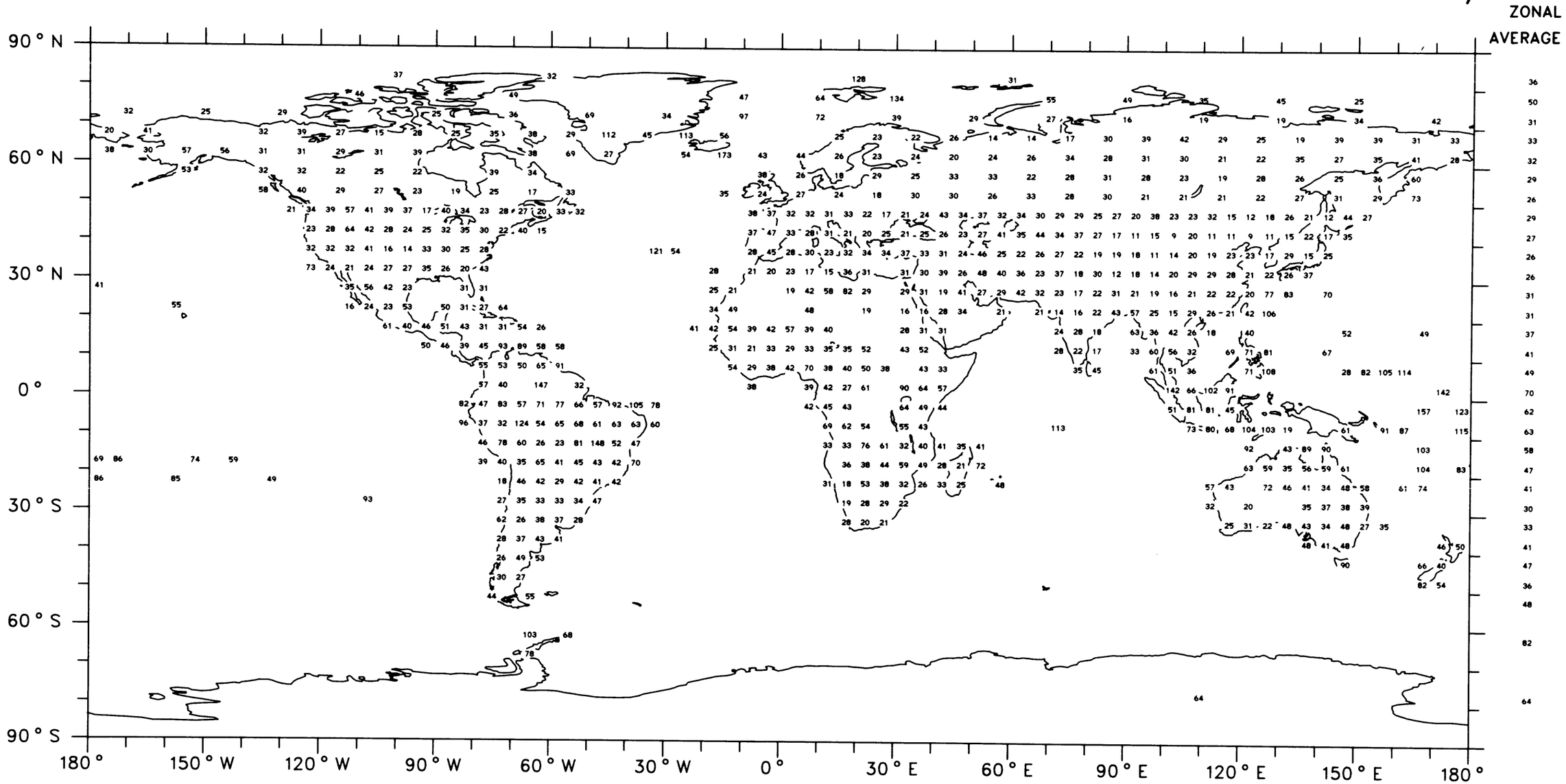
GLOBAL AVERAGE (LAND) 4.2 %

Interannual Variation of Altostratus + Altocumulus :

Standard Deviation of Seasonal Means (0.1 % Cloud Amount)

March, April, May (1971-1981)

Land Areas Only



GLOBAL AVERAGE (LAND) 3.8 %

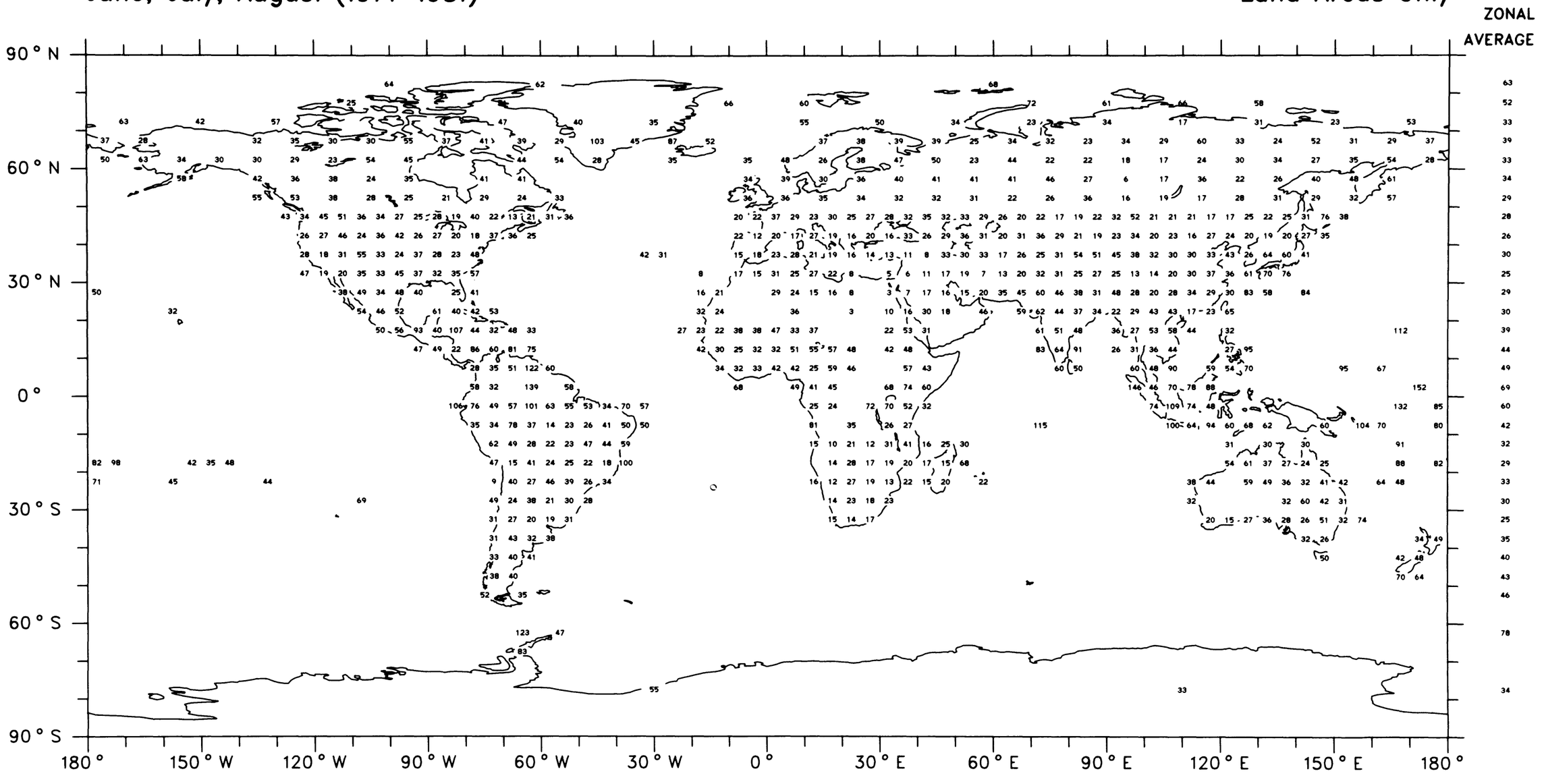
Map 165

Interannual Variation of Altostratus + Altocumulus :

Standard Deviation of Seasonal Means (0.1 % Cloud Amount)

June, July, August (1971-1981)

Land Areas Only



Map 166

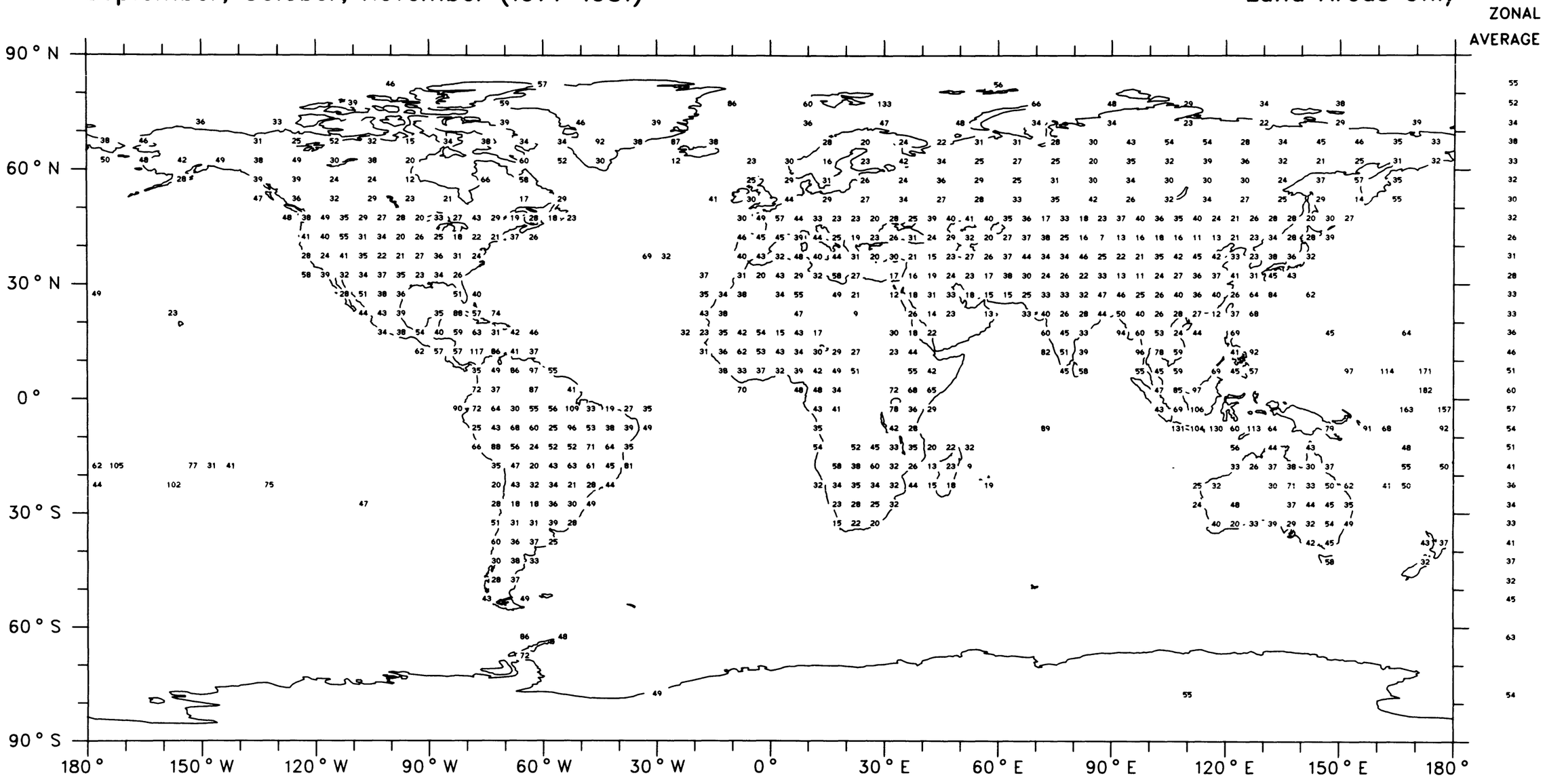
GLOBAL AVERAGE (LAND) 3.5 %

Interannual Variation of Altostratus + Altocumulus :

Standard Deviation of Seasonal Means (0.1 % Cloud Amount)

September, October, November (1971-1981)

Land Areas Only



GLOBAL AVERAGE (LAND) 3.8 %

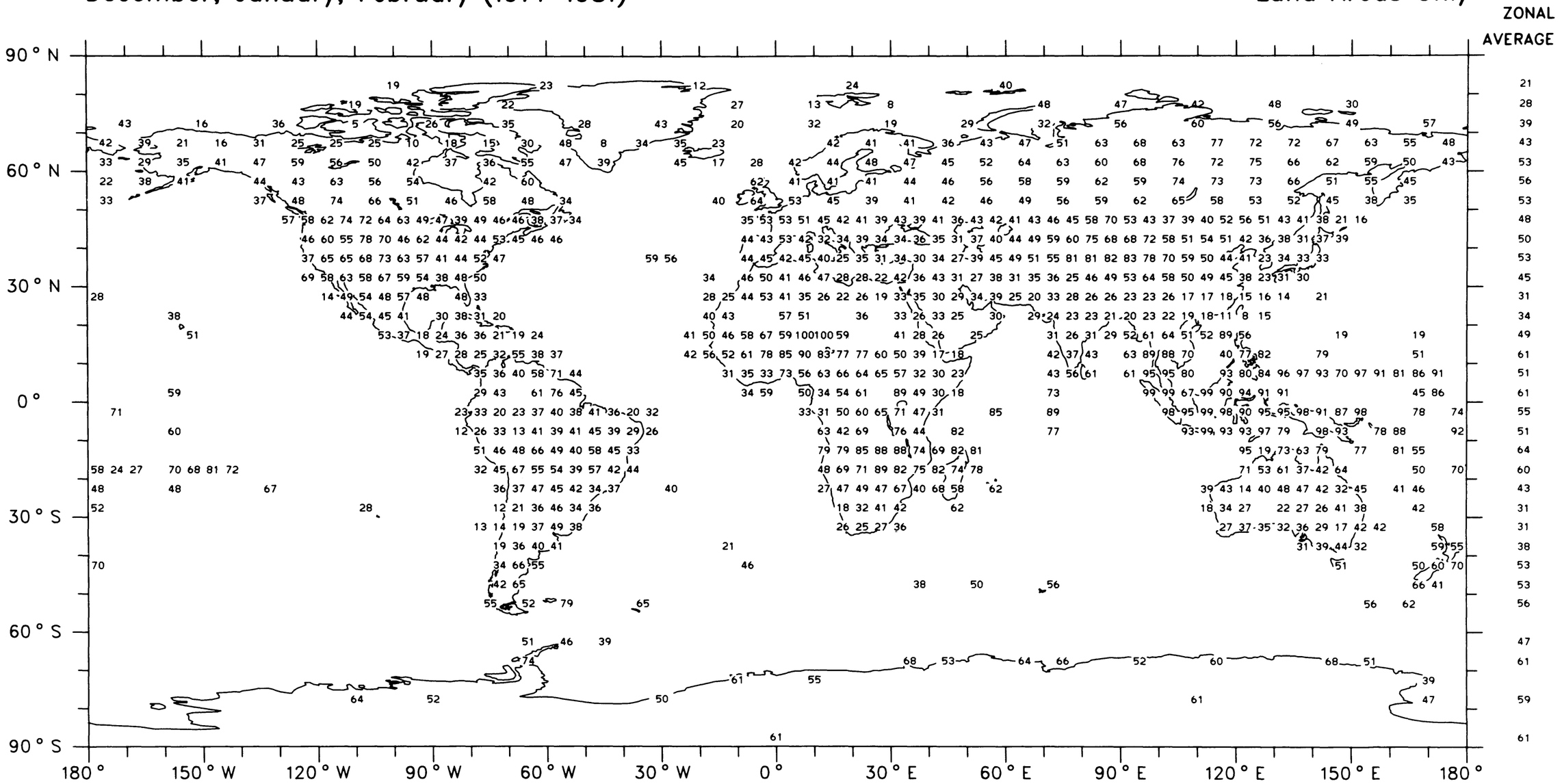
Map 167

Cirrus + Cirrostratus + Cirrocumulus

Frequency of Occurrence (%), 6-18 LT

December, January, February (1971-1981)

Land Areas Only



Map 168

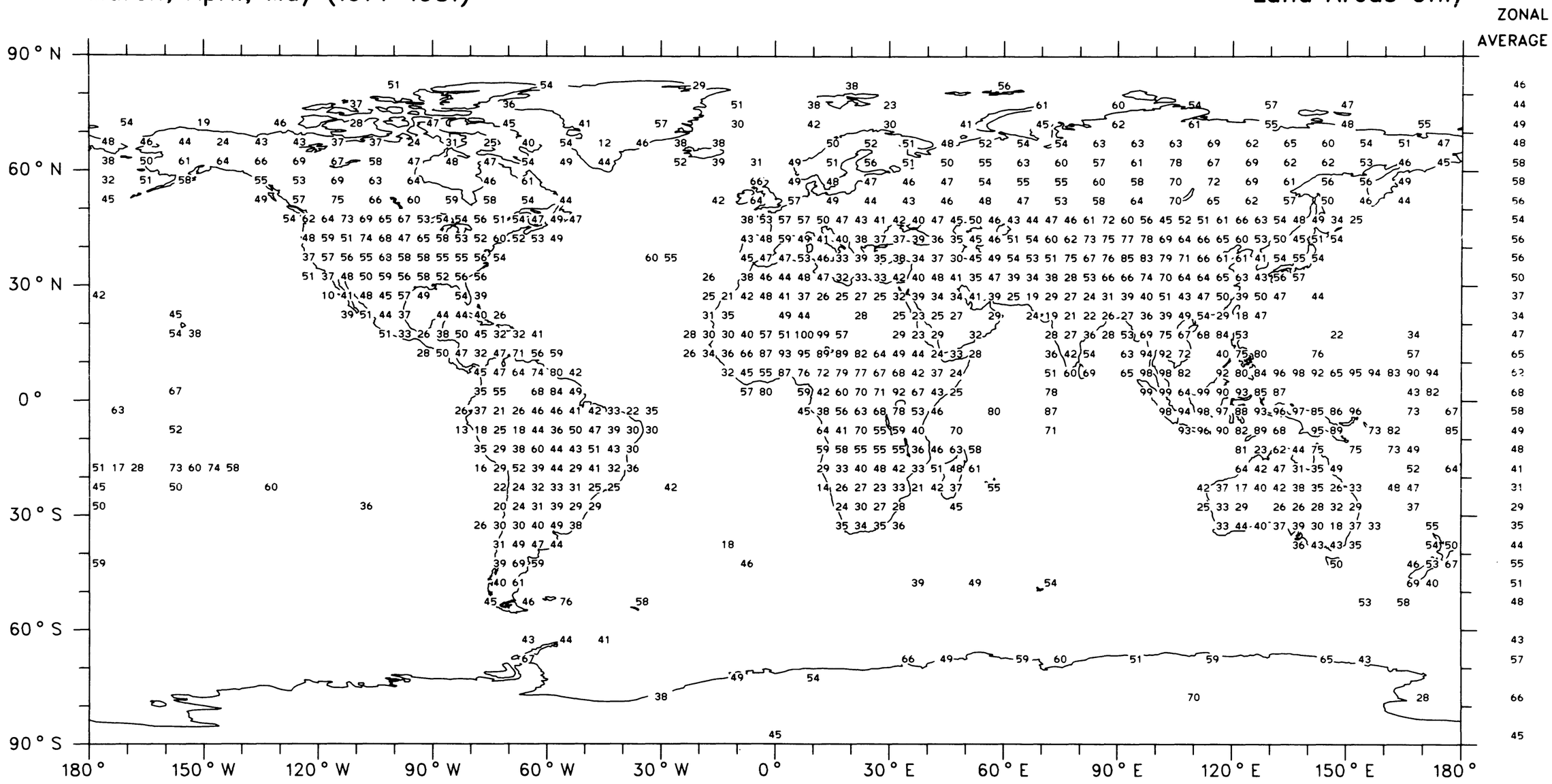
GLOBAL AVERAGE (LAND) 49 %

Cirrus + Cirrostratus + Cirrocumulus

Frequency of Occurrence (%), 6-18 LT

March, April, May (1971-1981)

Land Areas Only



GLOBAL AVERAGE (LAND) 50 %

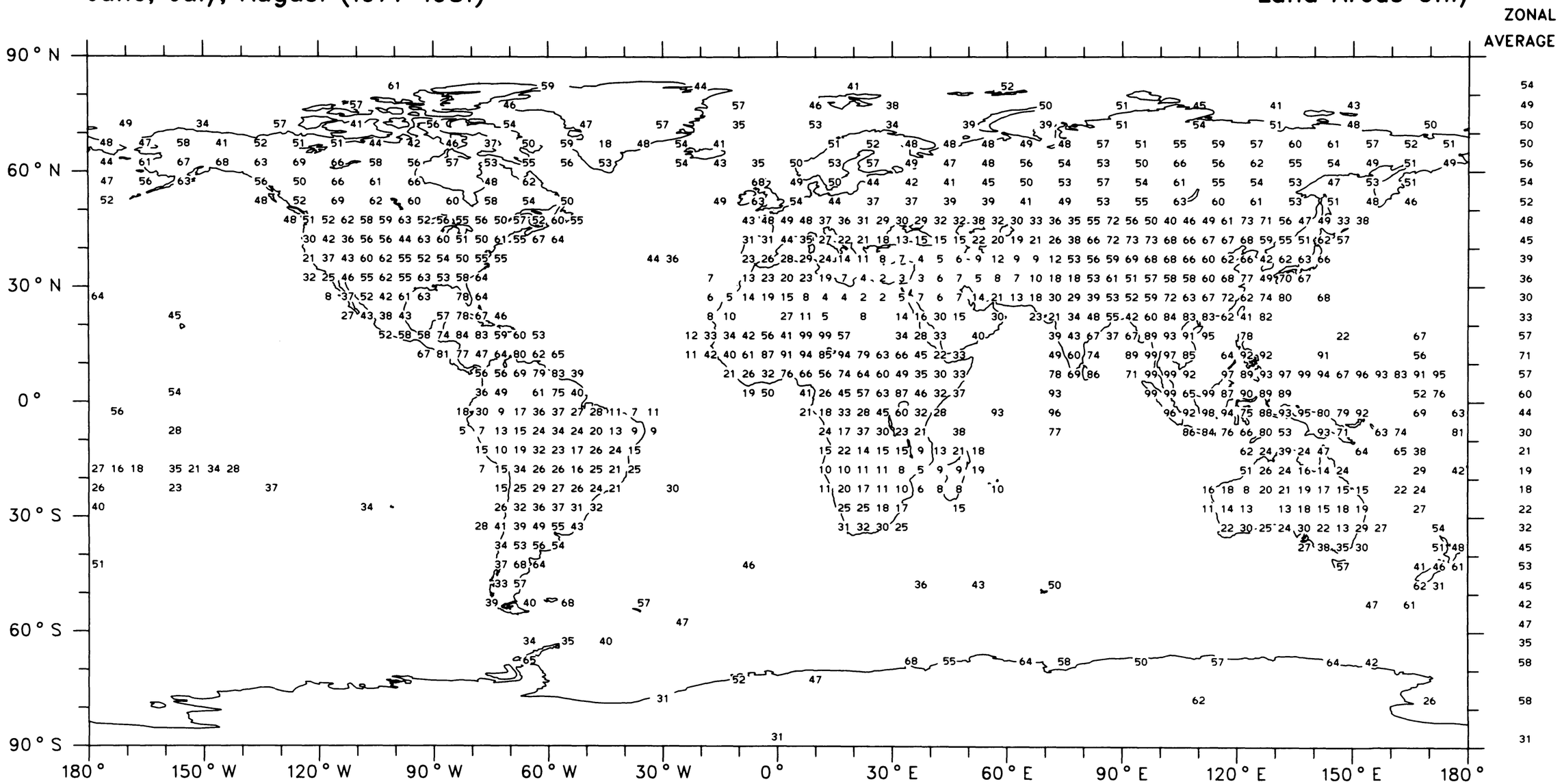
Map 169

Cirrus + Cirrostratus + Cirrocumulus

Frequency of Occurrence (%), 6-18 LT

June, July, August (1971-1981)

Land Areas Only



Map 170

GLOBAL AVERAGE (LAND) 43 %

Cirrus + Cirrostratus + Cirrocumulus

Frequency of Occurrence (%), 6-18 LT

September, October, November (1971-1981) — **Land Areas Only**

ZONAL AVERAGE

90 ° N
60 ° N
30 ° N
0 °
30 ° S
60 ° S
90 ° S

180 ° 150 ° W 120 ° W 90 ° W 60 ° W 30 ° W 0 ° 30 ° E 60 ° E 90 ° E 120 ° E 150 ° E 180 °

GLOBAL AVERAGE (LAND) 47 %

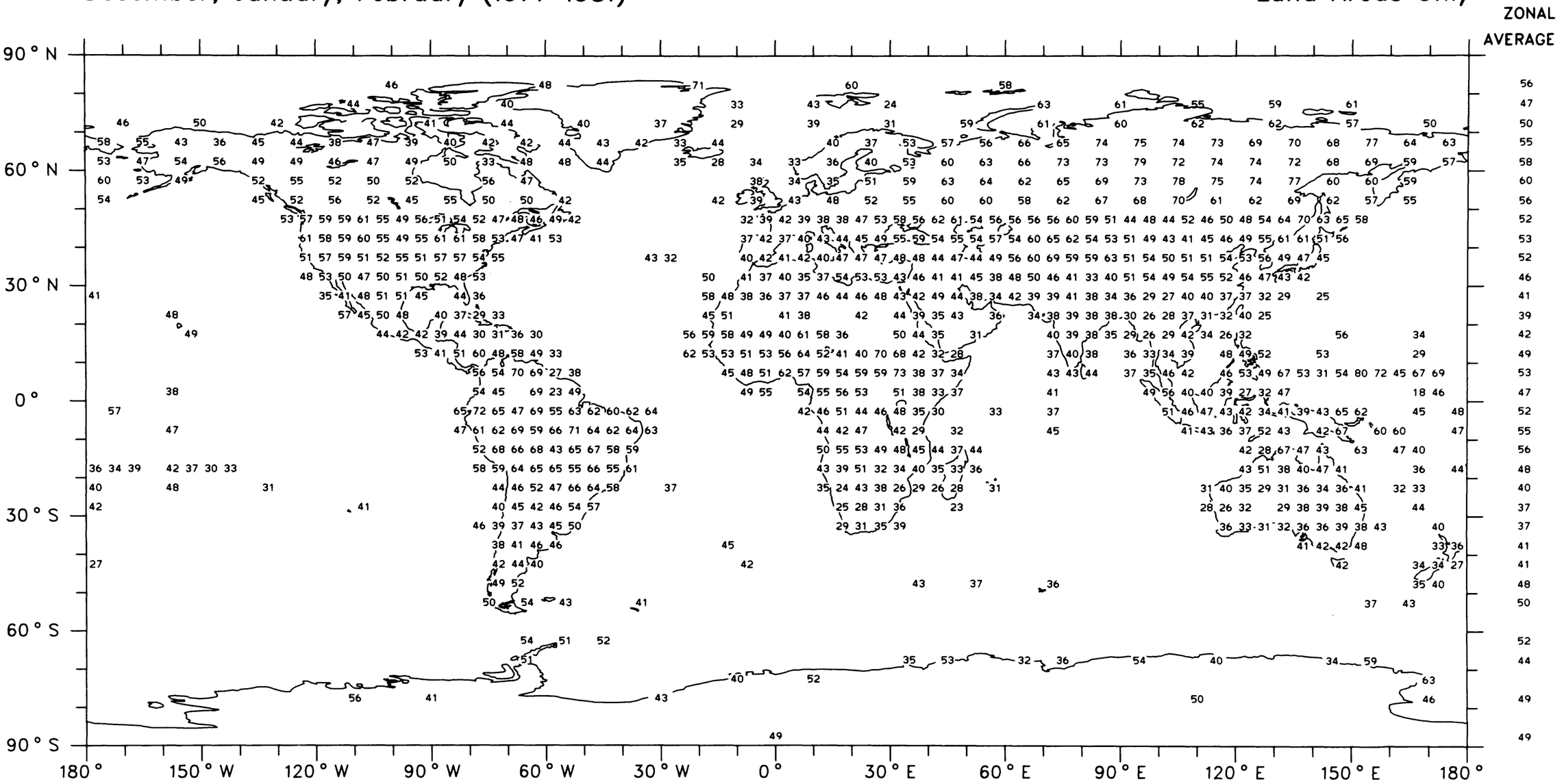
Map 171

Cirrus + Cirrostratus + Cirrocumulus

Amount-When-Present (%), 6-18 LT

December, January, February (1971-1981)

Land Areas Only



Map 172

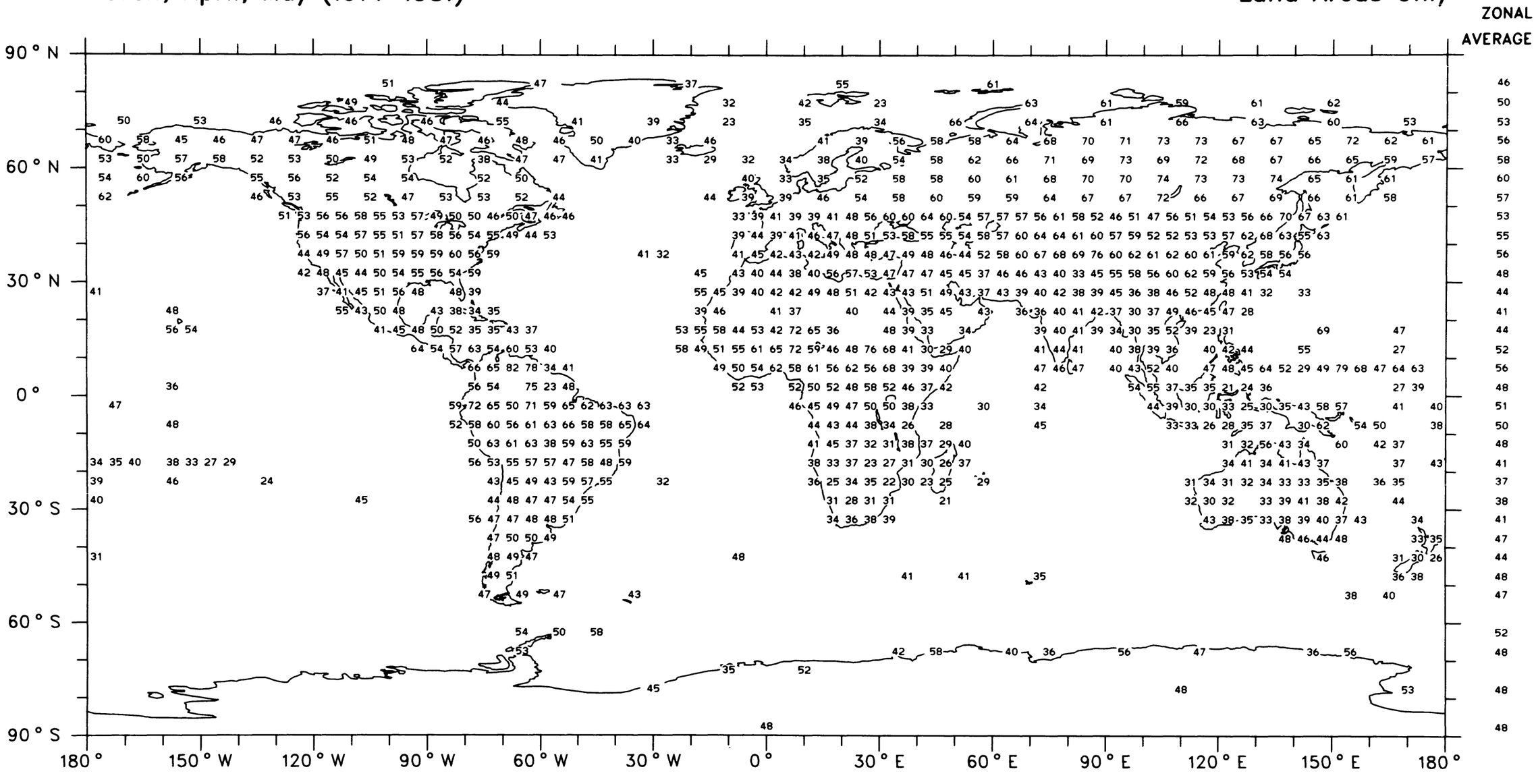
GLOBAL AVERAGE (LAND) 49 %

Cirrus + Cirrostratus + Cirrocumulus

Amount-When-Present (%), 6-18 LT

March, April, May (1971-1981)

Land Areas Only



GLOBAL AVERAGE (LAND) 50 %

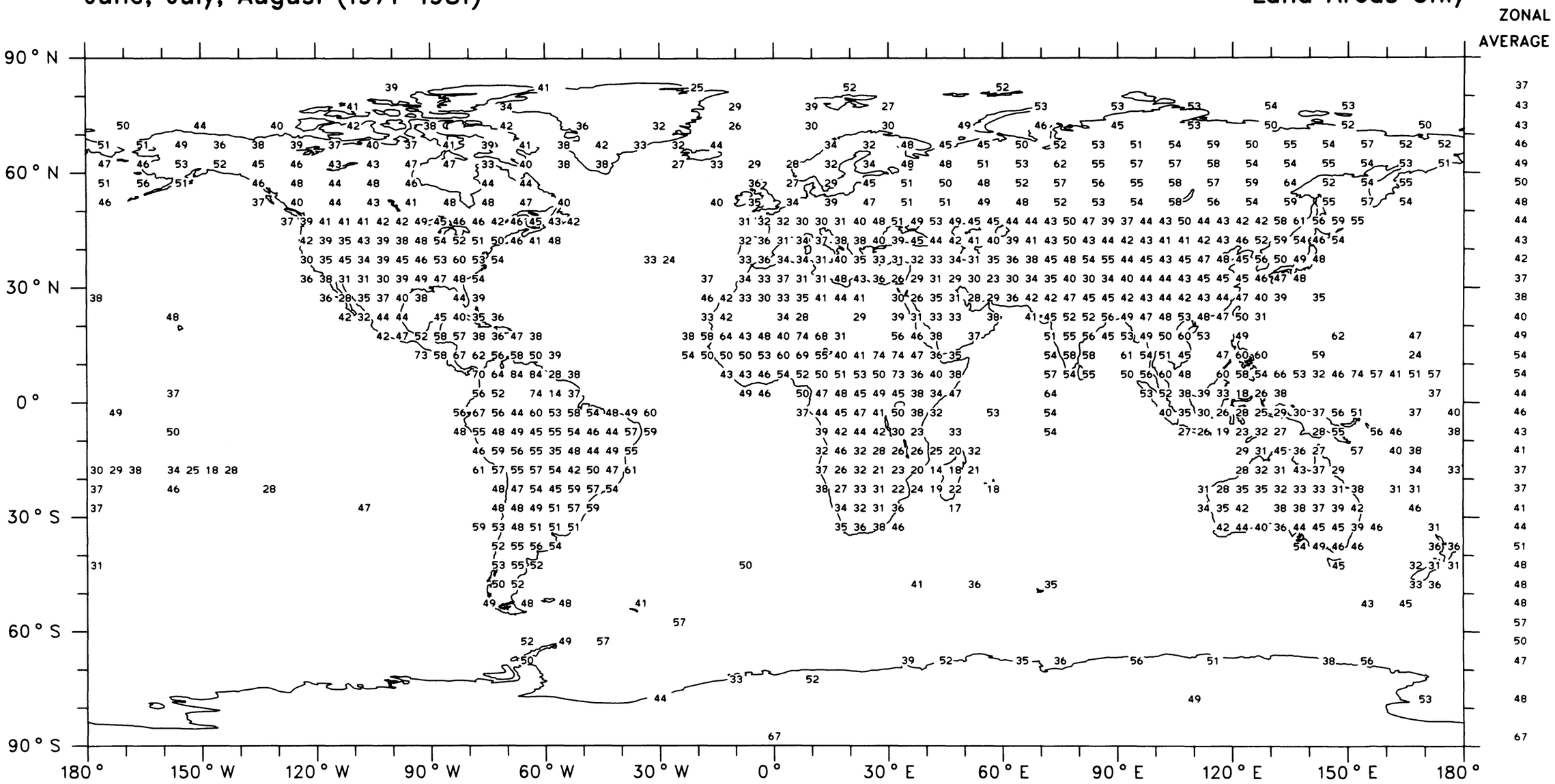
Map 173

Cirrus + Cirrostratus + Cirrocumulus

Amount-When-Present (%), 6-18 LT

June, July, August (1971-1981)

Land Areas Only



Map 174

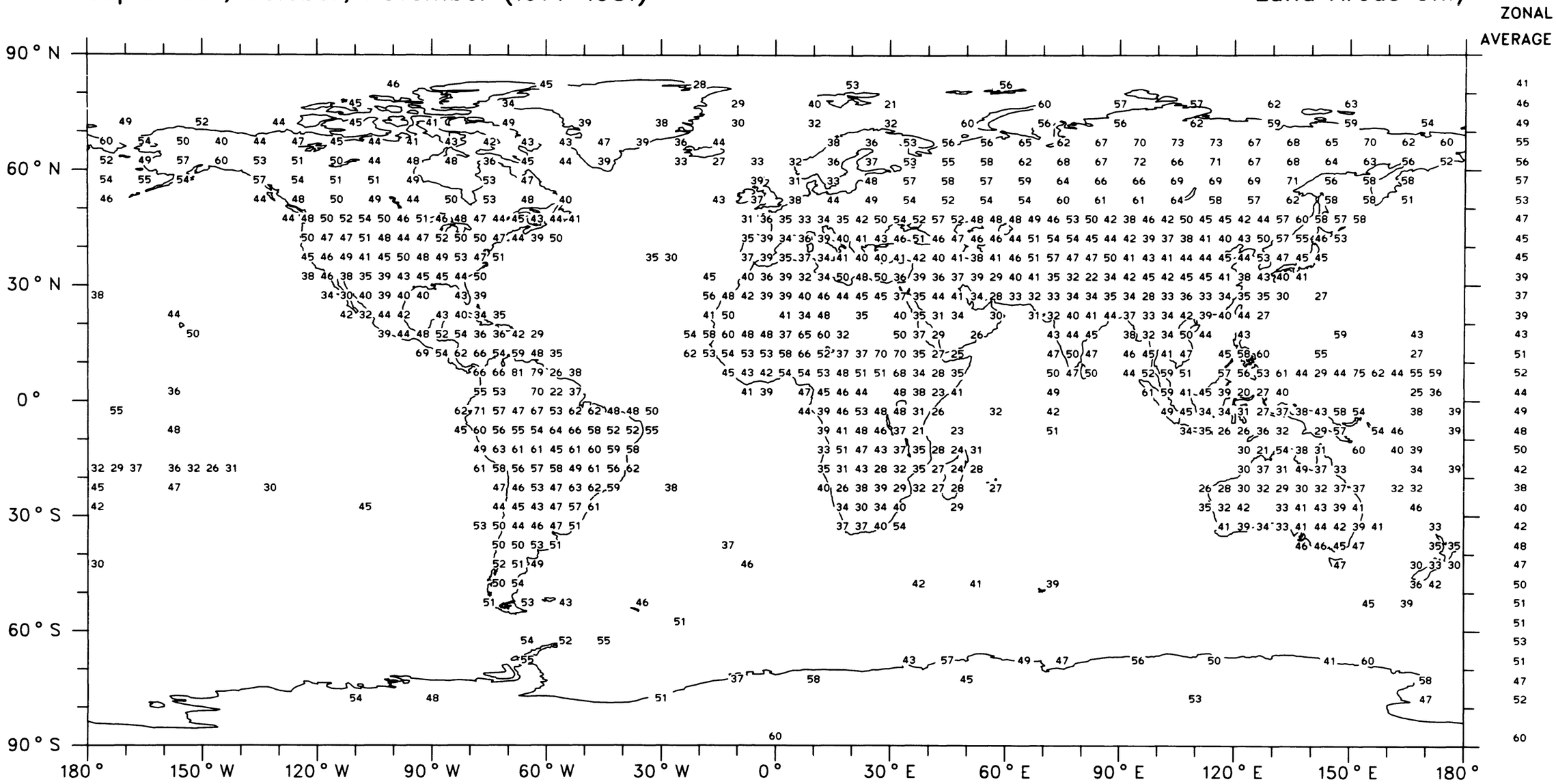
GLOBAL AVERAGE (LAND) 45 %

Cirrus + Cirrostratus + Cirrocumulus

Amount-When-Present (%), 6-18 LT

September, October, November (1971-1981)

Land Areas Only



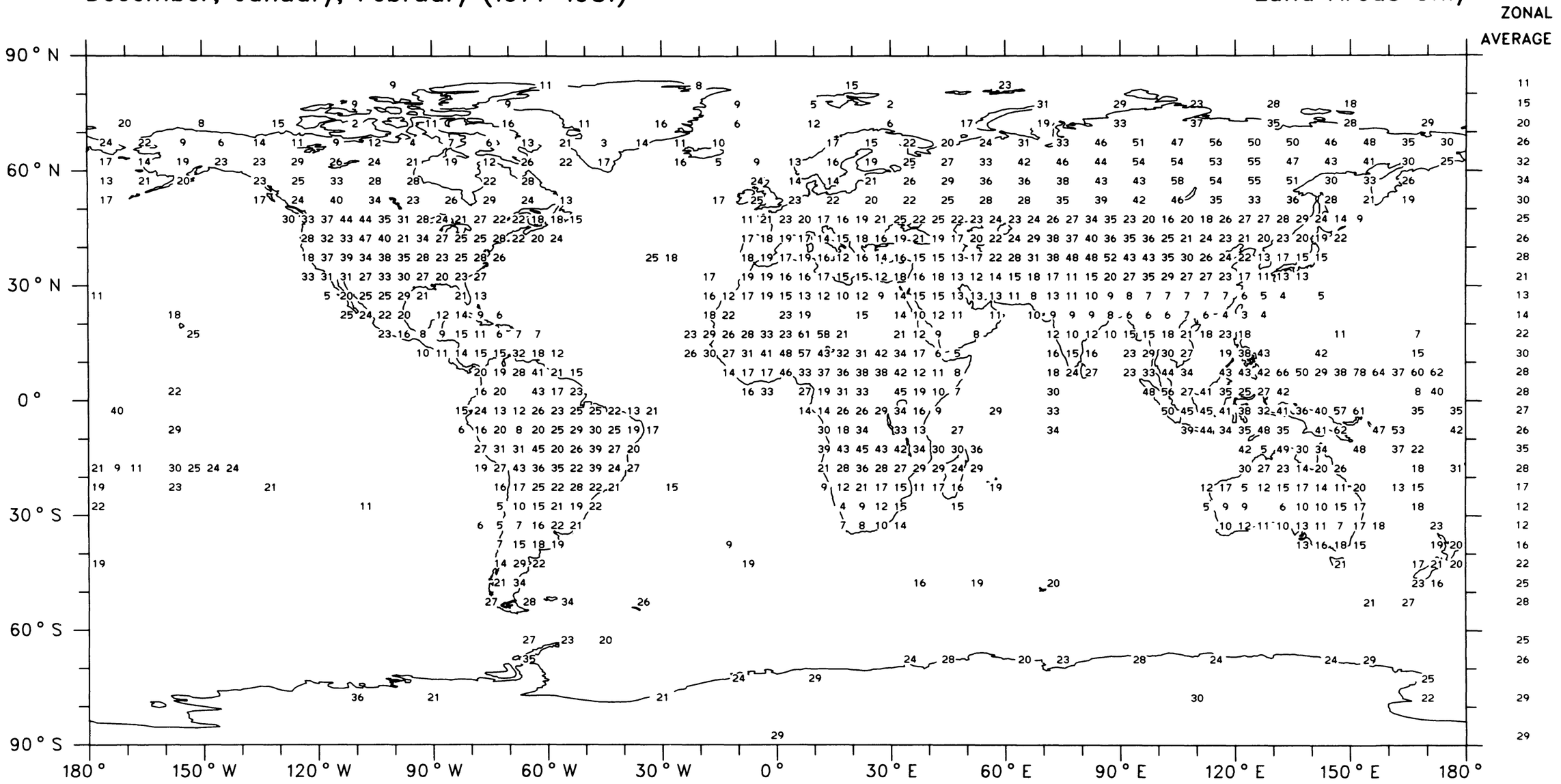
GLOBAL AVERAGE (LAND) 47 %

Map 175

Cirrus + Cirrostratus + Cirrocumulus

Average Cloud Amount (%), 6-18 LT

December, January, February (1971-1981) **Land Areas Only**



Map 176

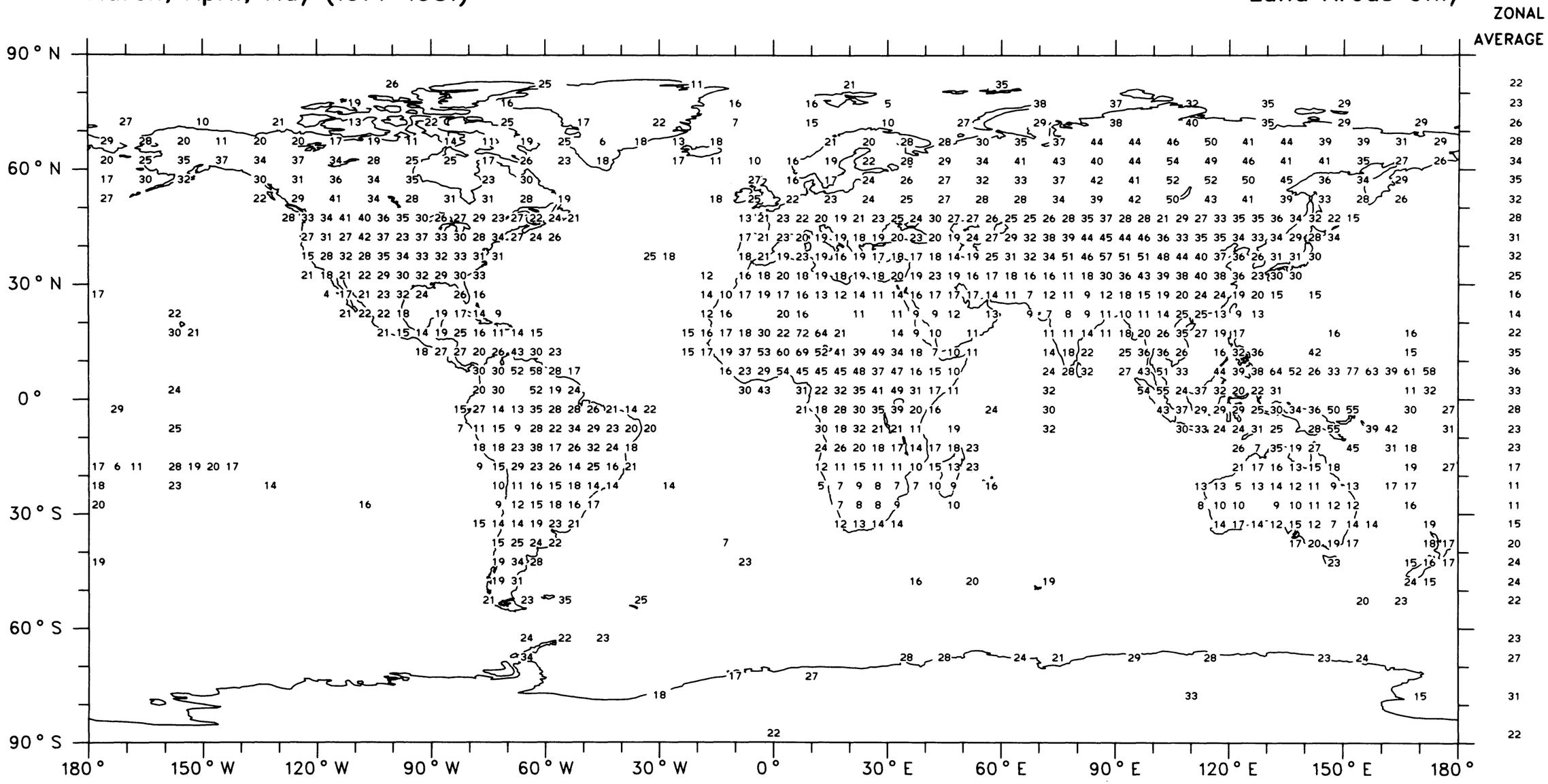
GLOBAL AVERAGE (LAND) 25 %

Cirrus + Cirrostratus + Cirrocumulus

Average Cloud Amount (%), 6-18 LT

March, April, May (1971-1981)

Land Areas Only



GLOBAL AVERAGE (LAND) 26 %

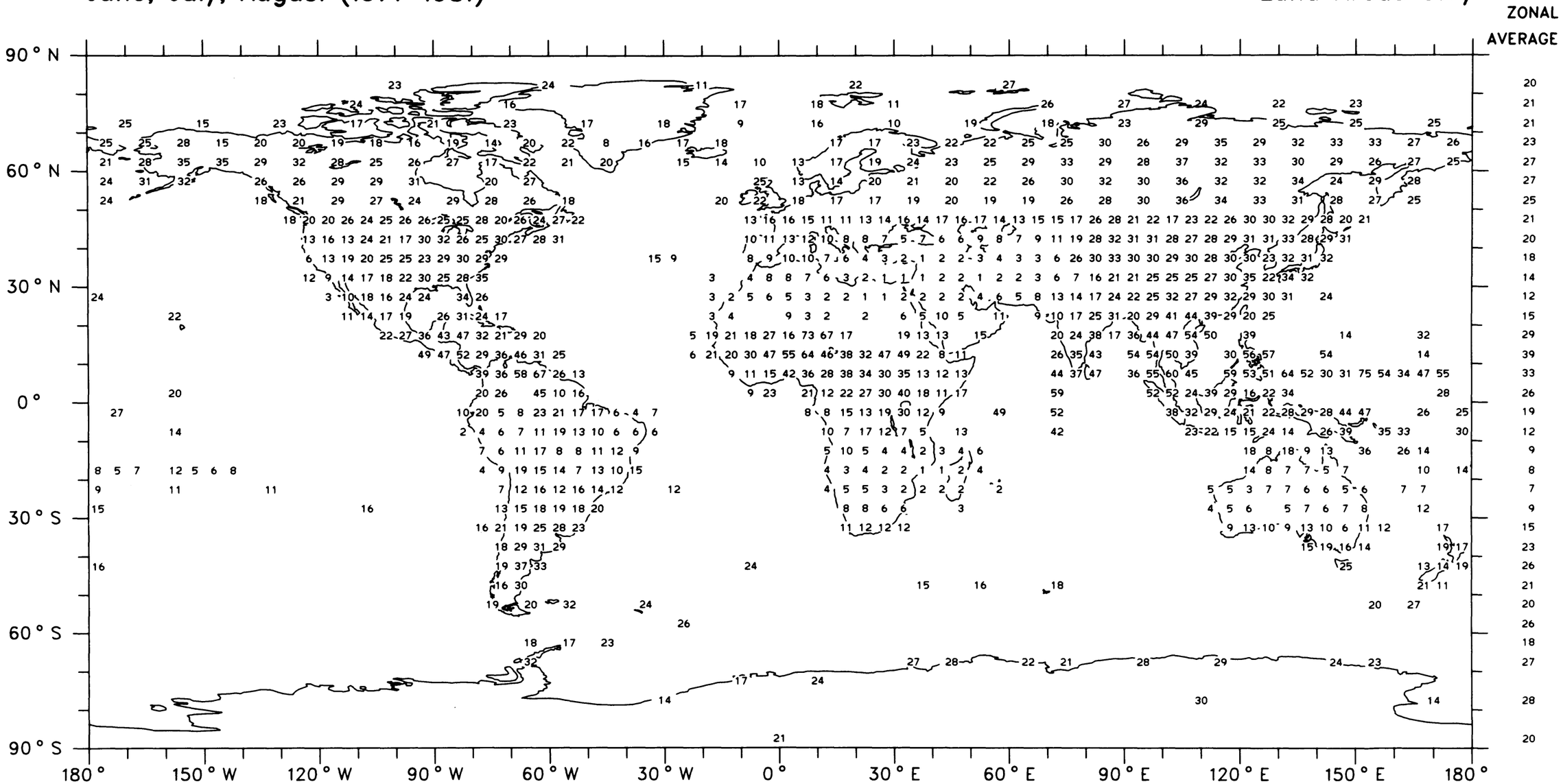
Map 177

Cirrus + Cirrostratus + Cirrocumulus

Average Cloud Amount (%), 6-18 LT

June, July, August (1971-1981)

Land Areas Only



Map 178

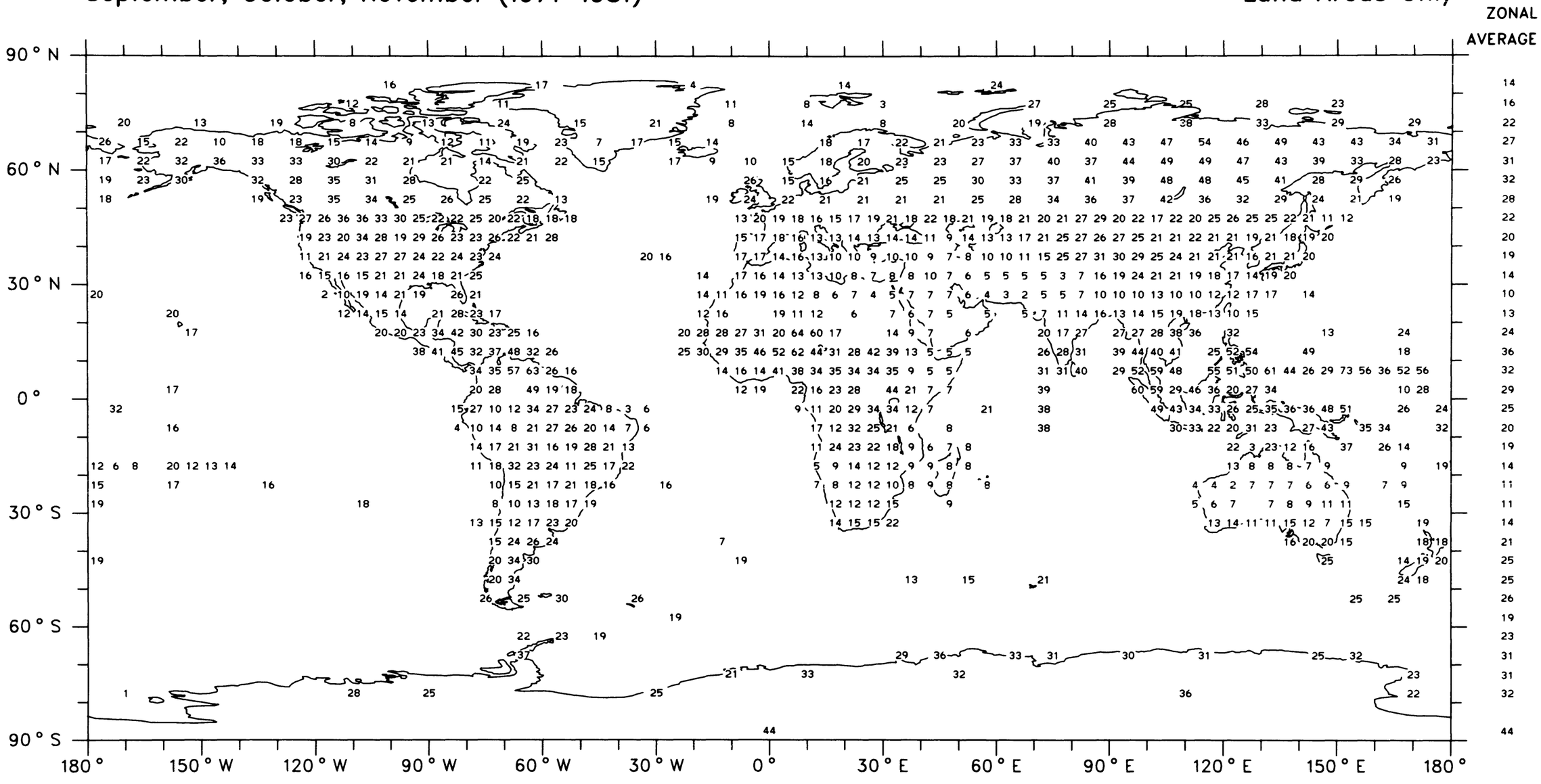
GLOBAL AVERAGE (LAND) 20 %

Cirrus + Cirrostratus + Cirrocumulus

Average Cloud Amount (%), 6-18 LT

September, October, November (1971-1981)

Land Areas Only



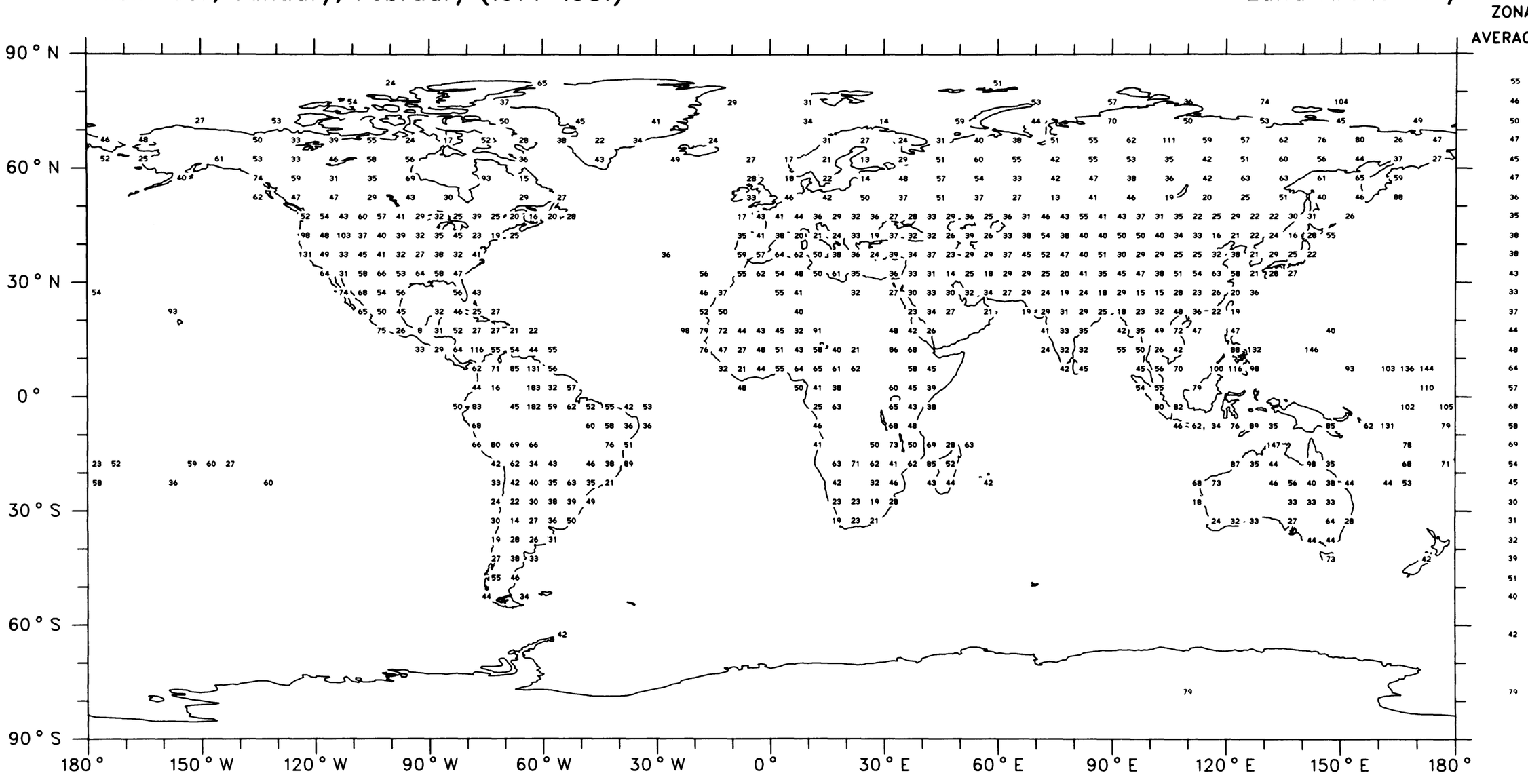
GLOBAL AVERAGE (LAND) 23 %

Map 179

Interannual Variation of Cirrus + Cirrostratus + Cirrocumulus :

Standard Deviation of Seasonal Means (0.1 % Cloud Amount)

December, January, February (1971-1981) — **Land Areas Only**



Map 180

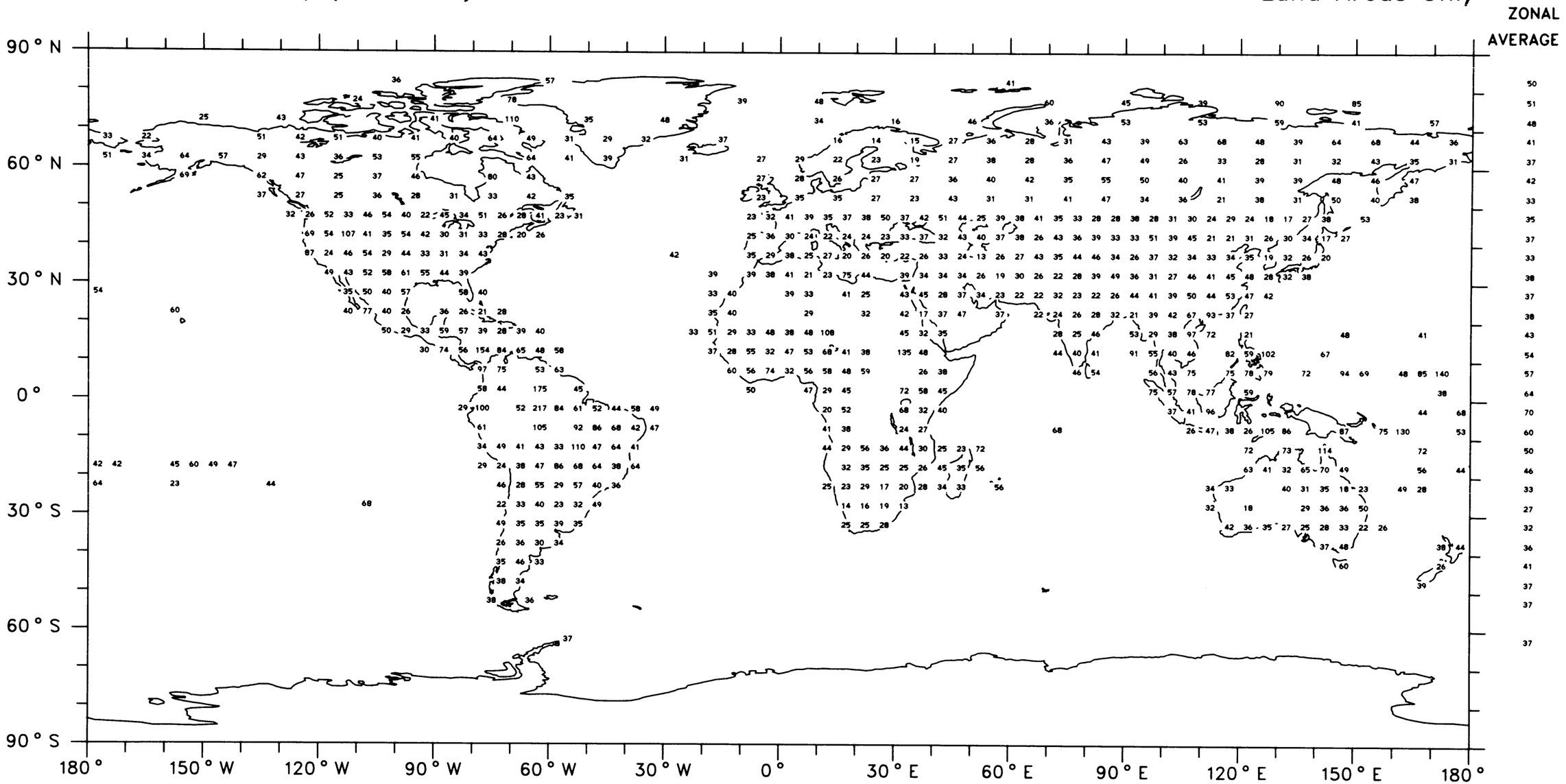
GLOBAL AVERAGE (LAND) 4.6 %

Interannual Variation of Cirrus + Cirrostratus + Cirrocumulus :

Standard Deviation of Seasonal Means (0.1 % Cloud Amount)

March, April, May (1971-1981)

Land Areas Only



GLOBAL AVERAGE (LAND) 4.2 %

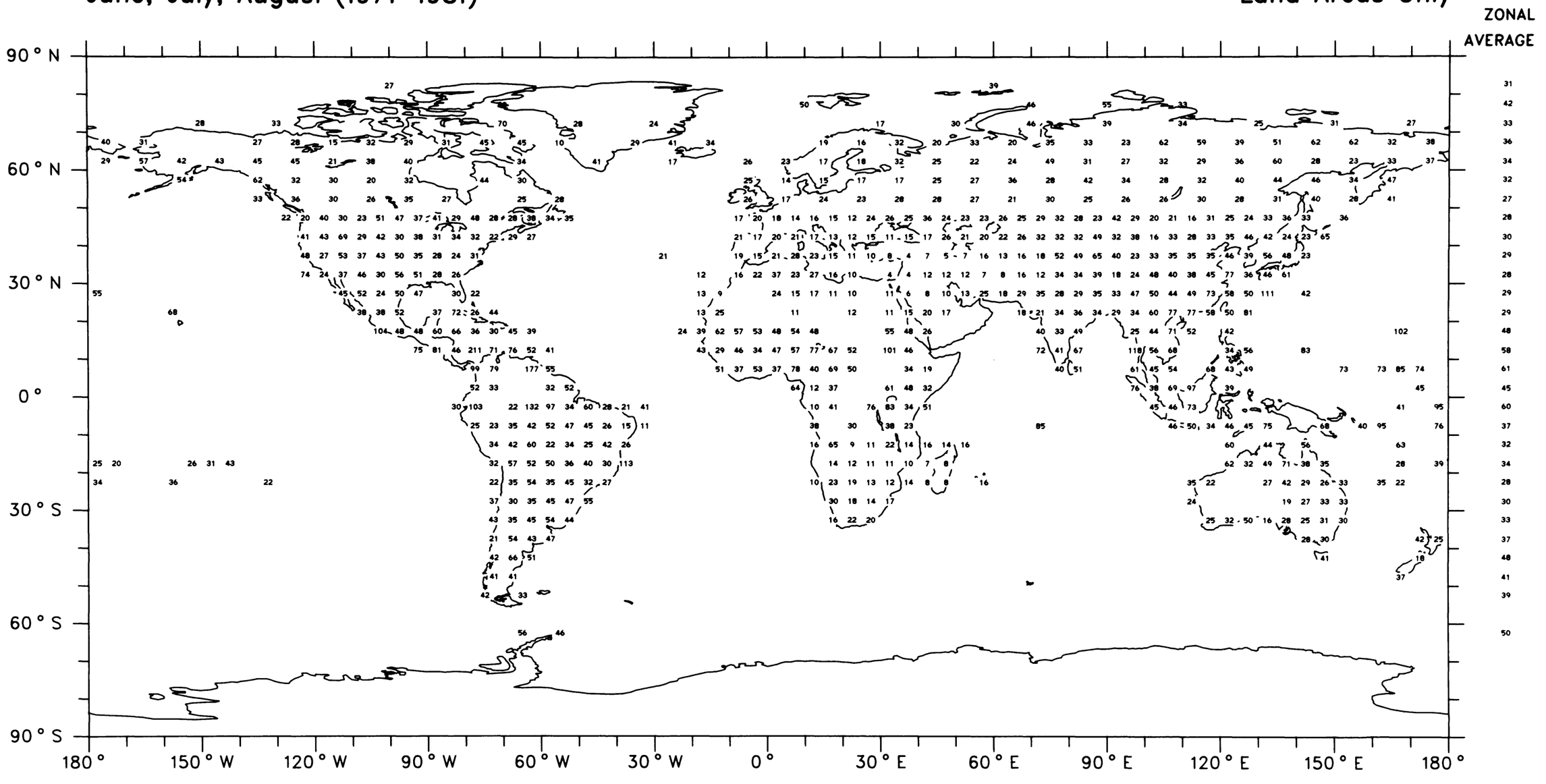
Map 181

Interannual Variation of Cirrus + Cirrostratus + Cirrocumulus :

Standard Deviation of Seasonal Means (0.1 % Cloud Amount)

June, July, August (1971-1981)

Land Areas Only



Map 182

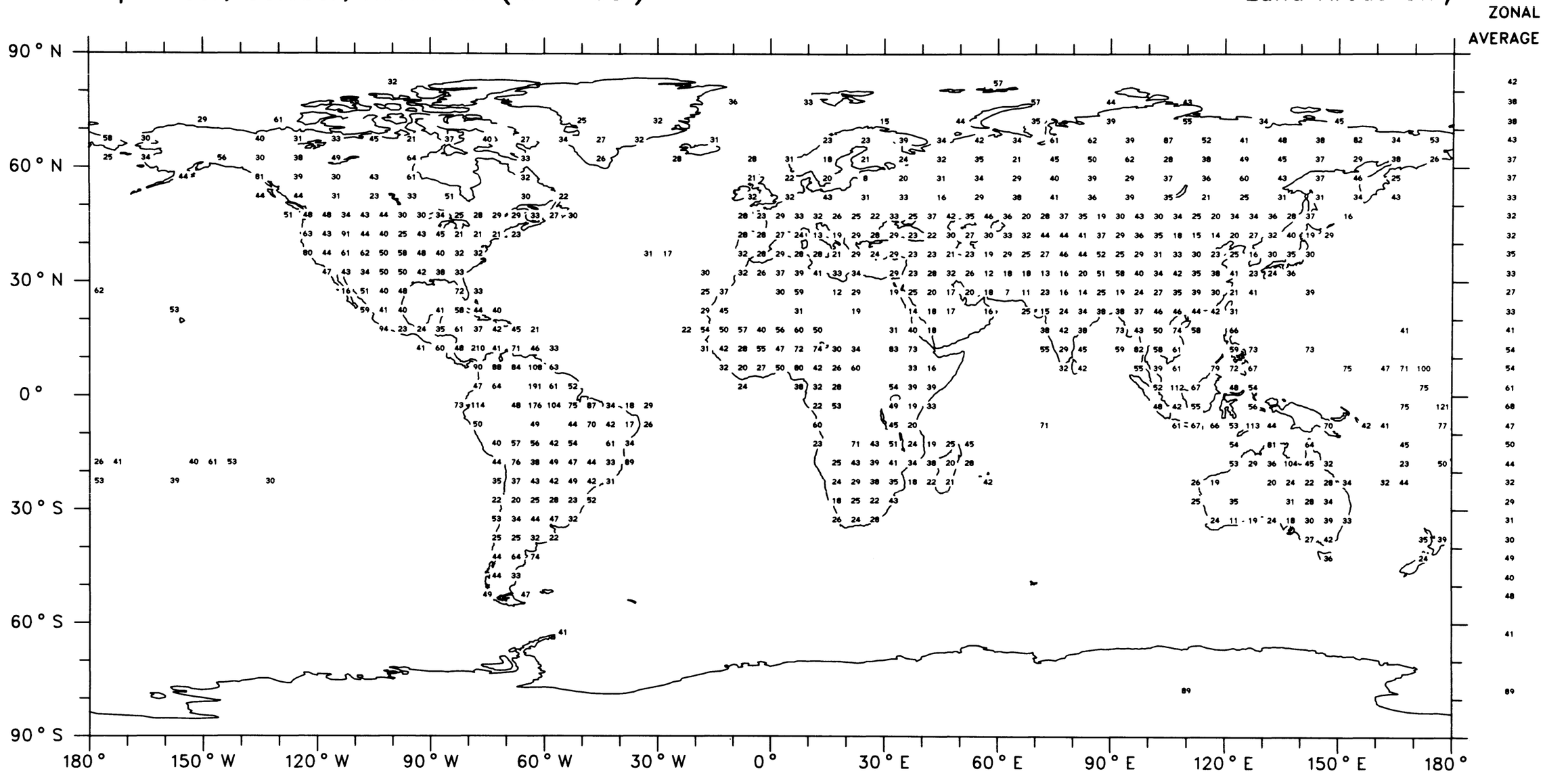
GLOBAL AVERAGE (LAND) 3.6 %

Interannual Variation of Cirrus + Cirrostratus + Cirrocumulus :

Standard Deviation of Seasonal Means (0.1 % Cloud Amount)

September, October, November (1971-1981)

Land Areas Only



GLOBAL AVERAGE (LAND) 4.1 %

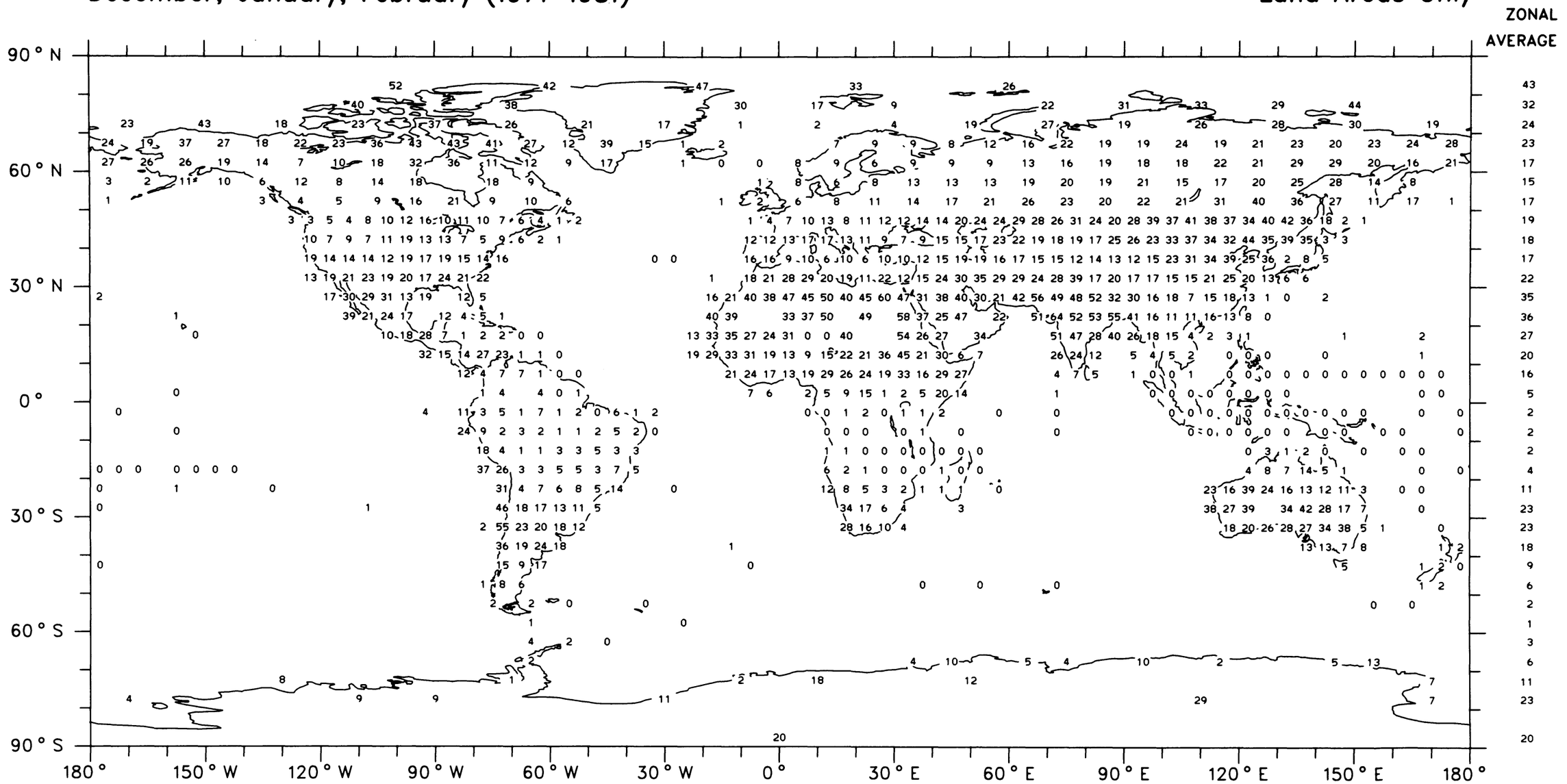
Map 183

Completely Clear Sky

Frequency of Occurrence (%), 6-18 LT

December, January, February (1971-1981)

Land Areas Only



Map 184

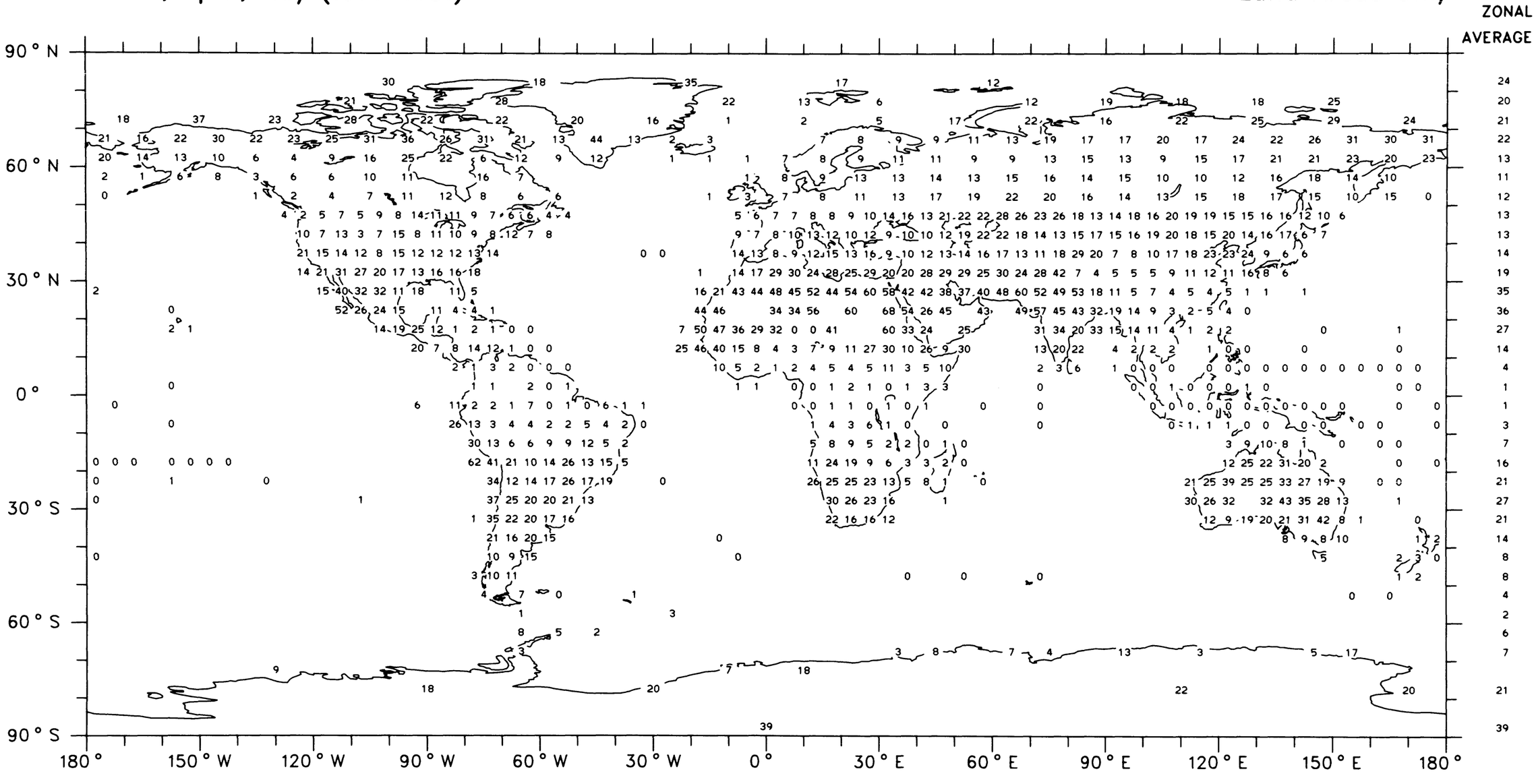
GLOBAL AVERAGE (LAND) 18 %

Completely Clear Sky

Frequency of Occurrence (%), 6-18 LT

March, April, May (1971-1981)

Land Areas Only



GLOBAL AVERAGE (LAND) 17 %

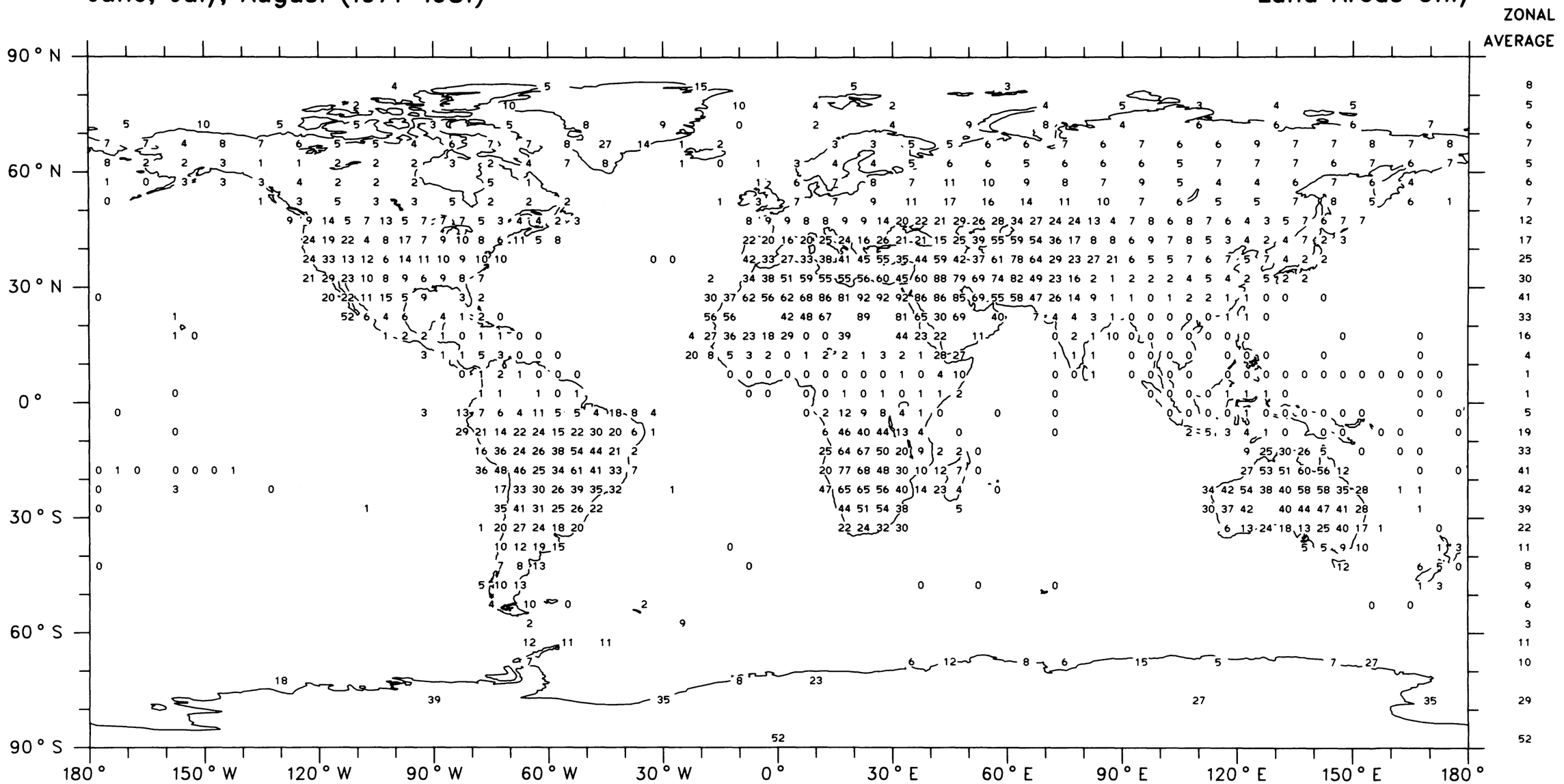
Map 185

Completely Clear Sky

Frequency of Occurrence (%), 6-18 LT

June, July, August (1971-1981)

Land Areas Only



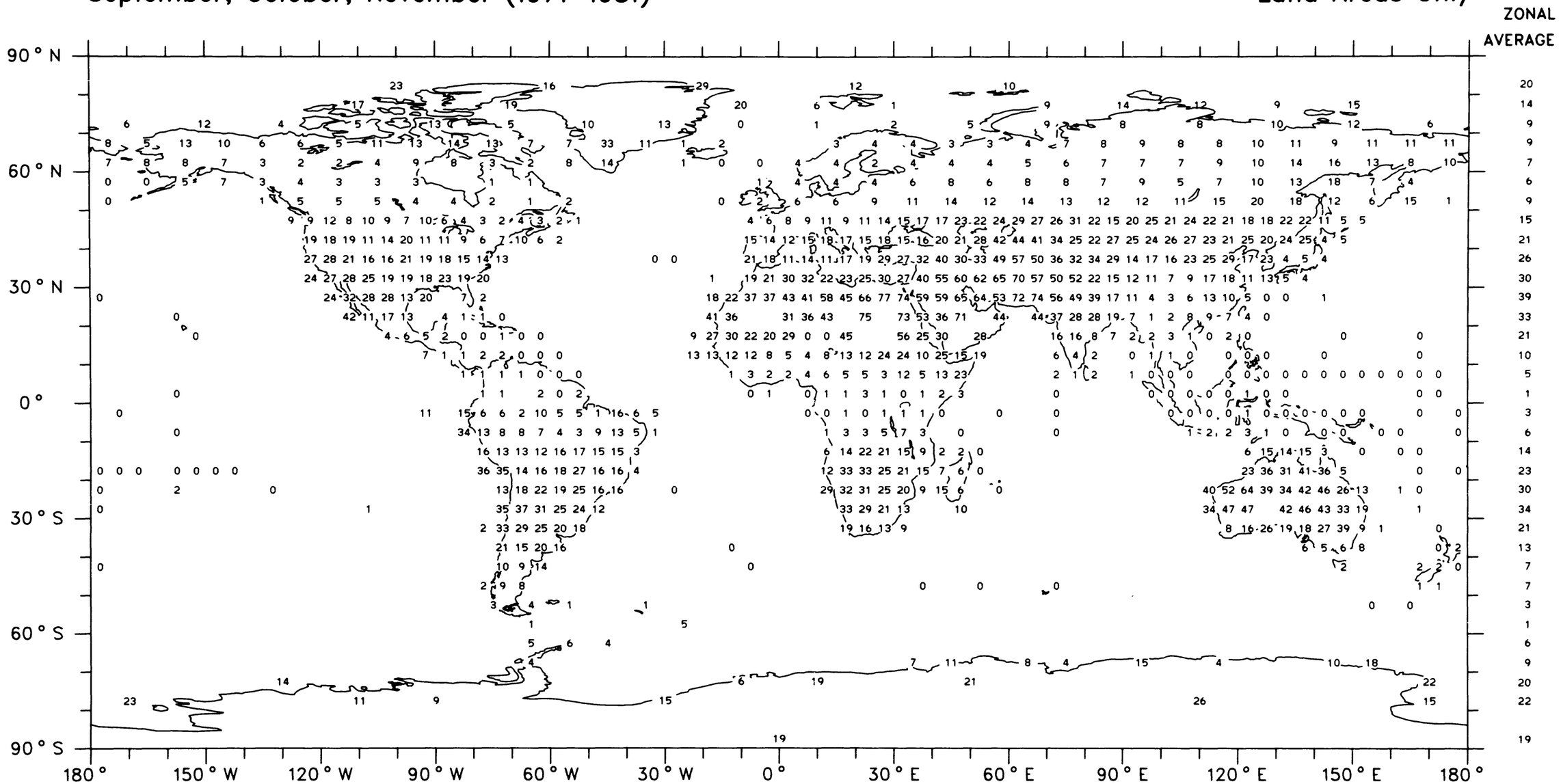
Map 186

GLOBAL AVERAGE (LAND) 19 %

Completely Clear Sky

Frequency of Occurrence (%), 6-18 LT

September, October, November (1971-1981) **Land Areas Only**



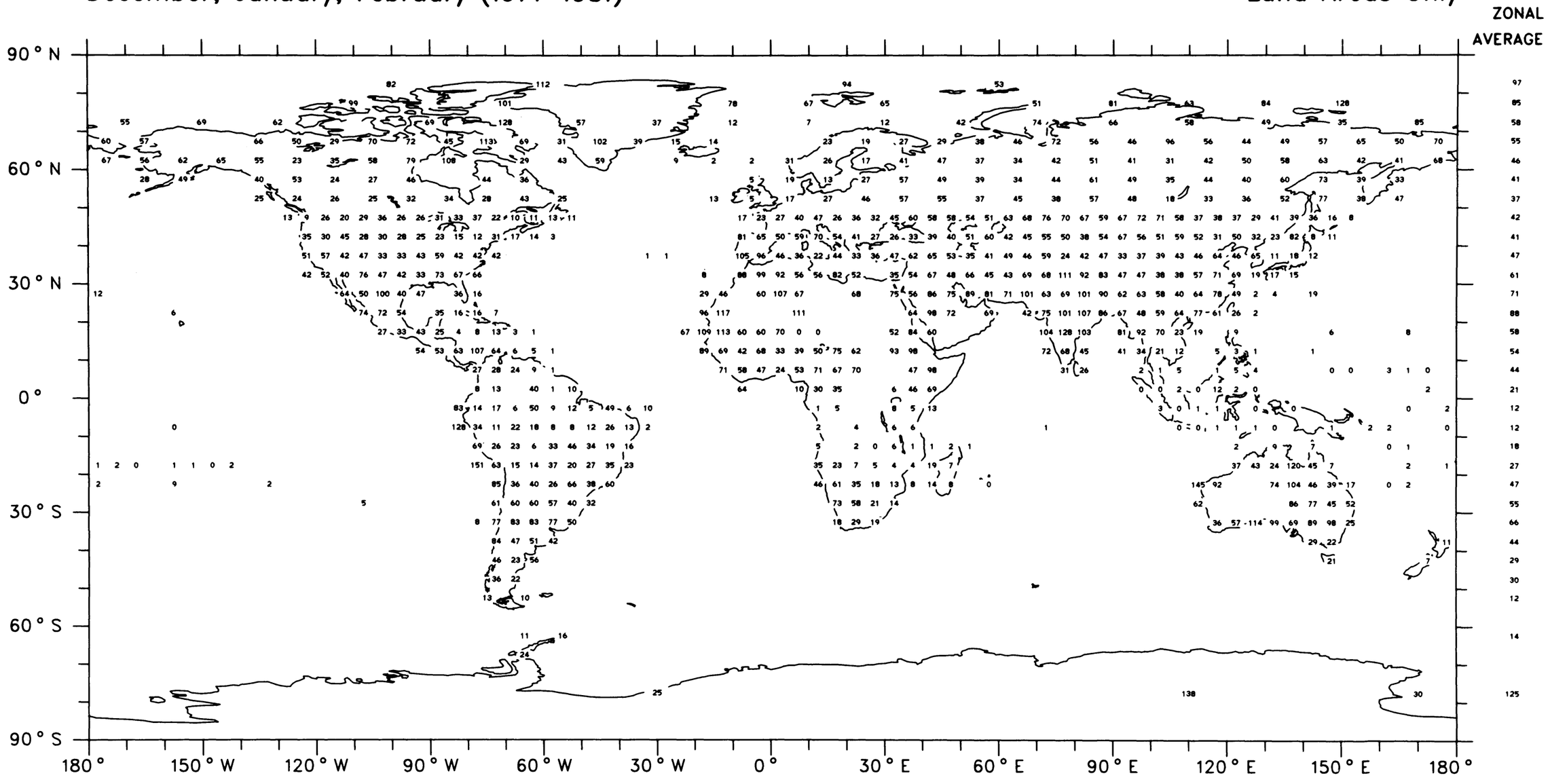
GLOBAL AVERAGE (LAND) 17 %

Map 187

Interannual Variation of Completely-Clear-Sky :

Standard Deviation of Seasonal Means (0.1 % Frequency-of-Occurrence)

December, January, February (1971-1981) **Land Areas Only**



Map 188

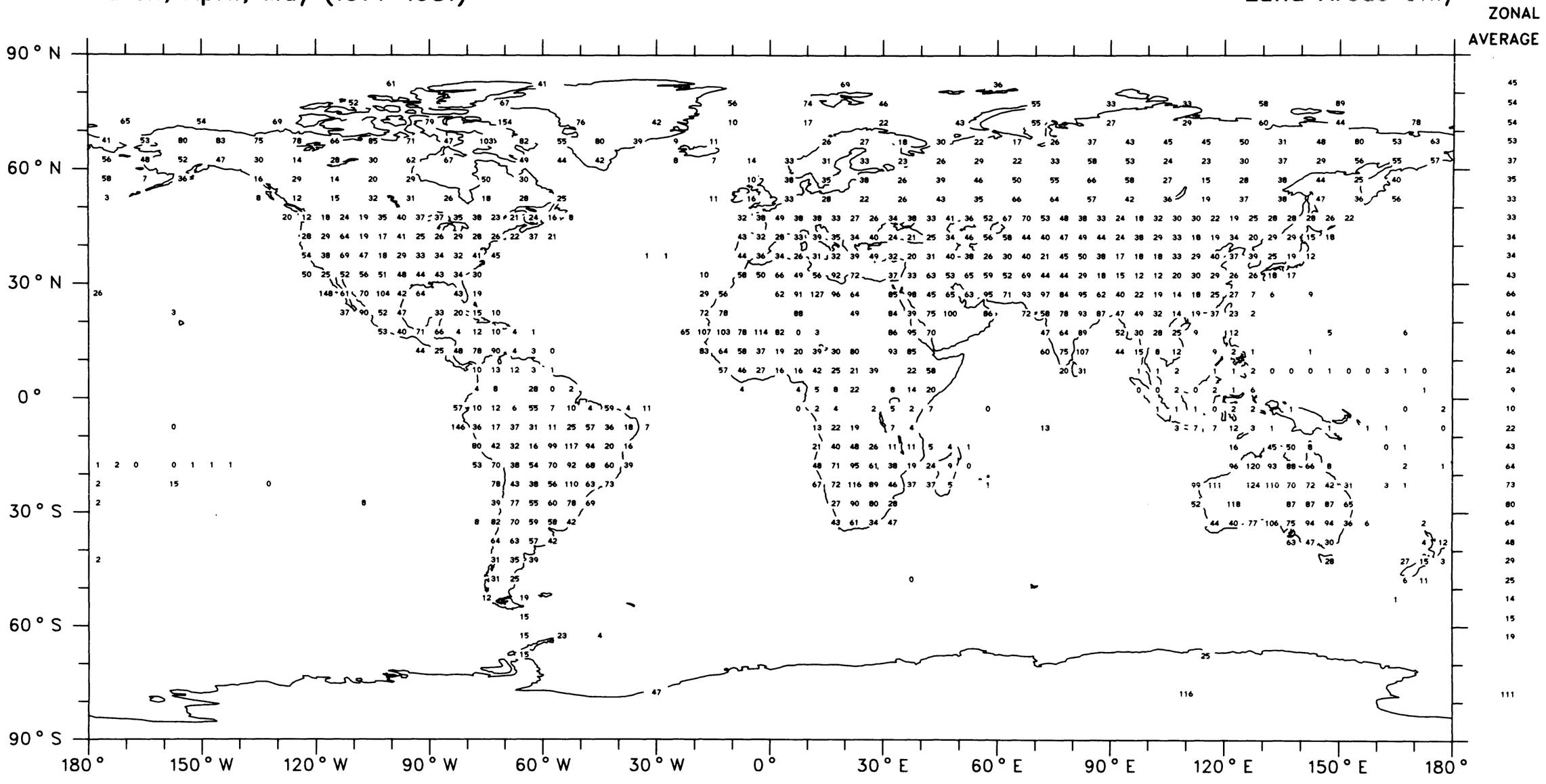
GLOBAL AVERAGE (LAND) 4.9 %

Interannual Variation of Completely-Clear-Sky :

Standard Deviation of Seasonal Means (0.1 % Frequency-of-Occurrence)

March, April, May (1971-1981)

Land Areas Only



GLOBAL AVERAGE (LAND) 4.6 %

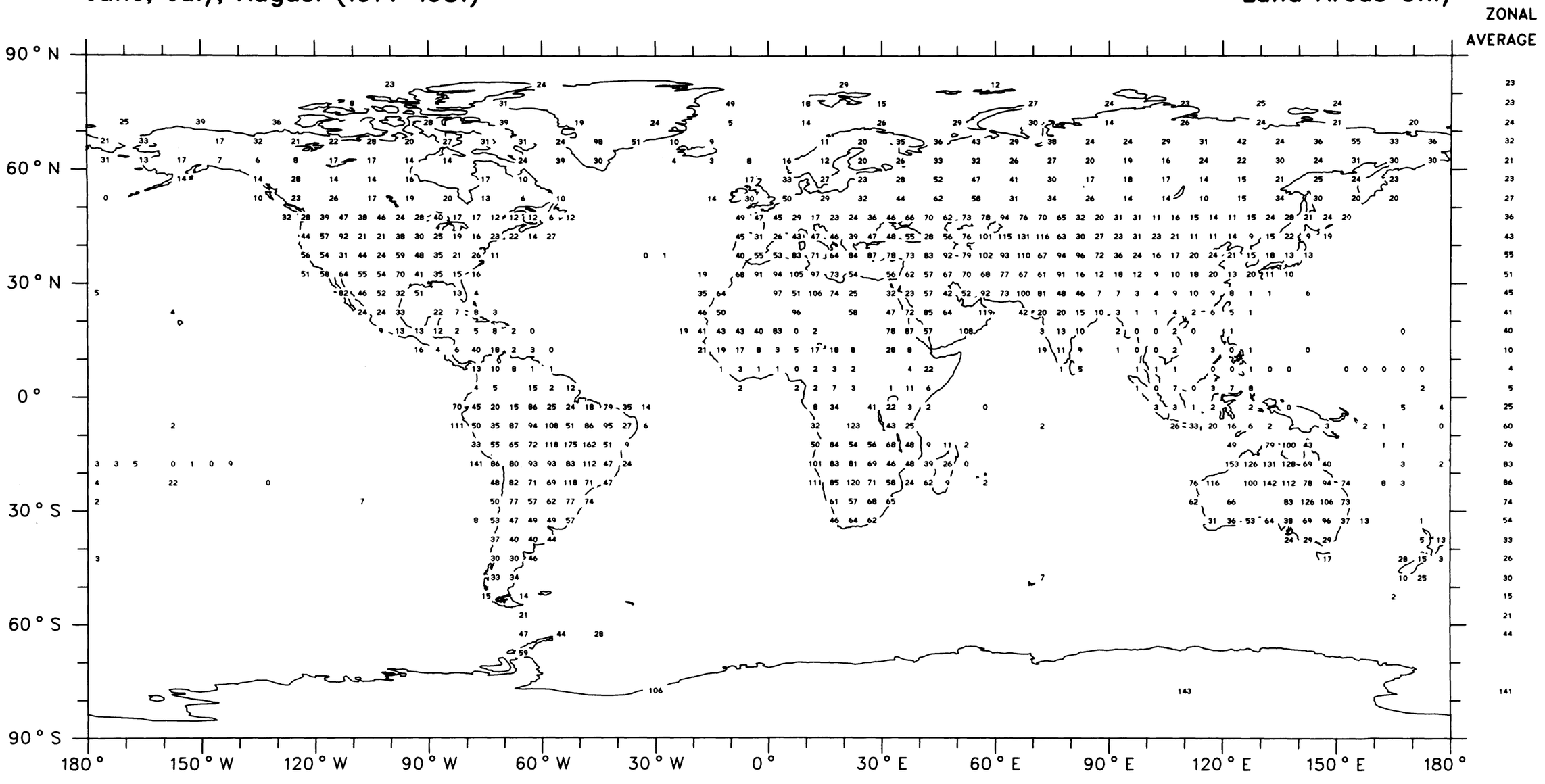
Map 189

Interannual Variation of Completely-Clear-Sky :

Standard Deviation of Seasonal Means (0.1 % Frequency-of-Occurrence)

June, July, August (1971-1981)

Land Areas Only



Map 190

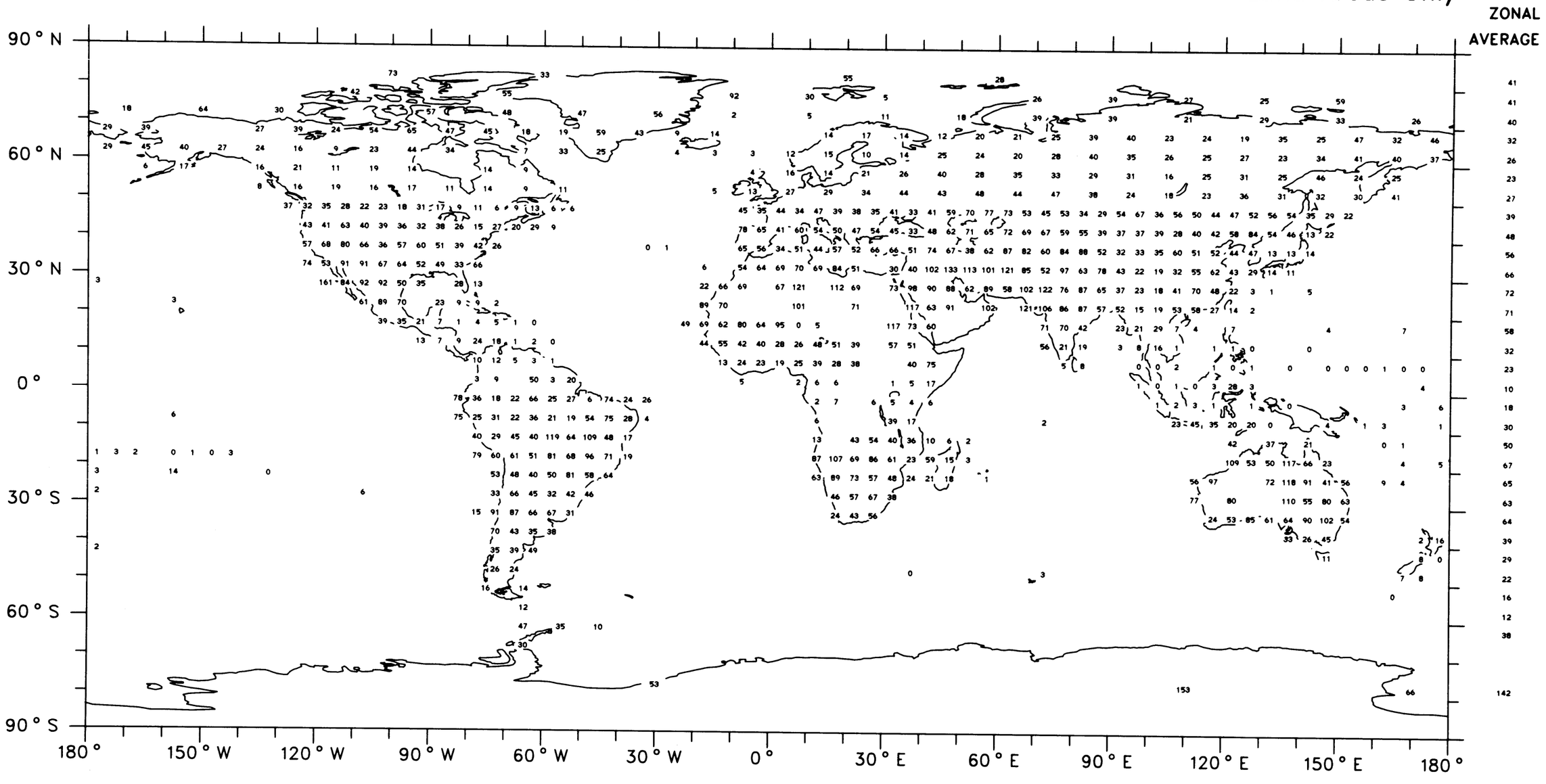
GLOBAL AVERAGE (LAND) 4.3 %

Interannual Variation of Completely-Clear-Sky :

Standard Deviation of Seasonal Means (0.1 % Frequency-of-Occurrence)

September, October, November (1971-1981)

Land Areas Only



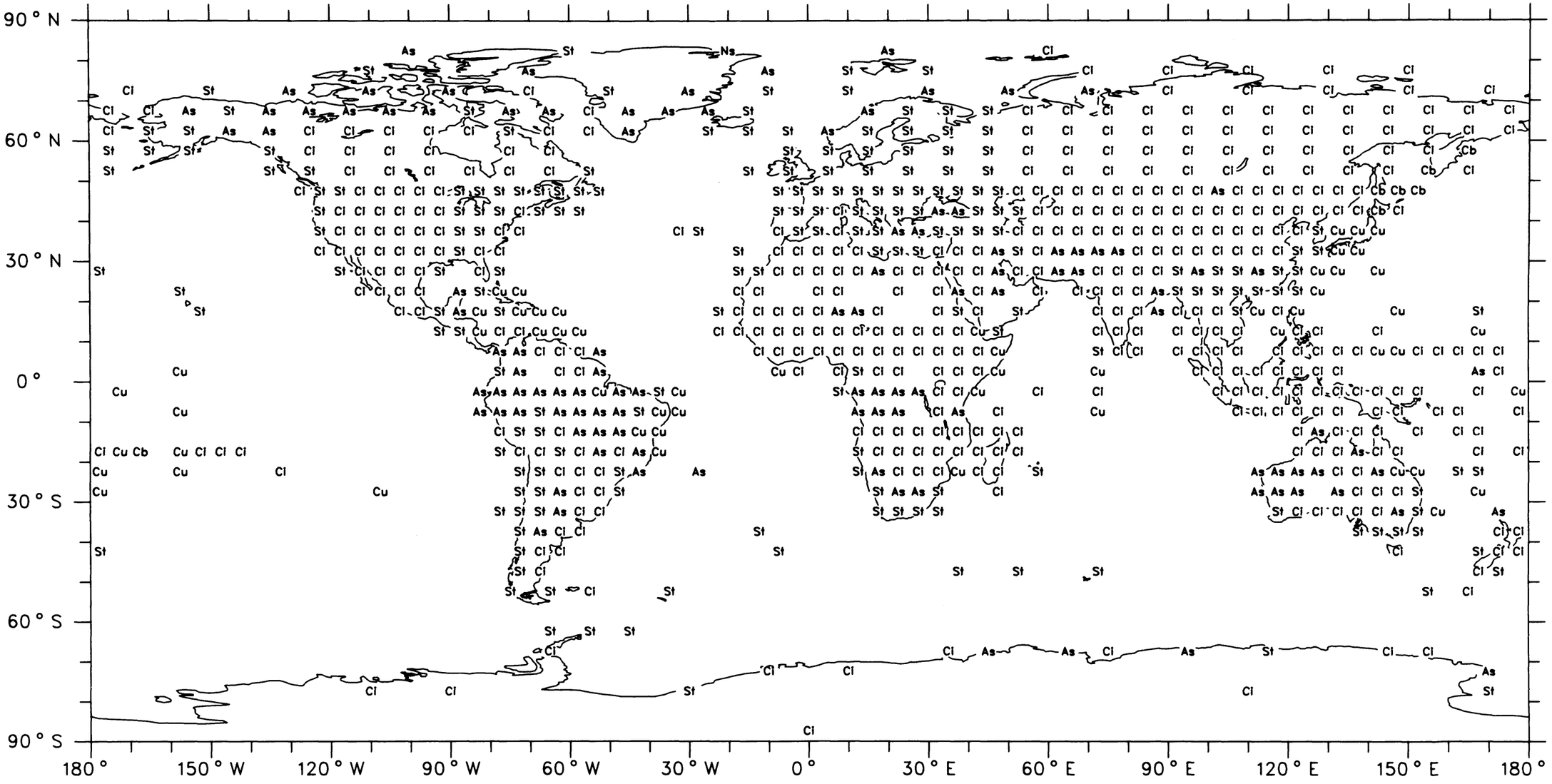
GLOBAL AVERAGE (LAND) 4.7 %

Map 191

Most-Frequently-Occurring Cloud Type

December, January, February (1971-1981)

Land Areas Only

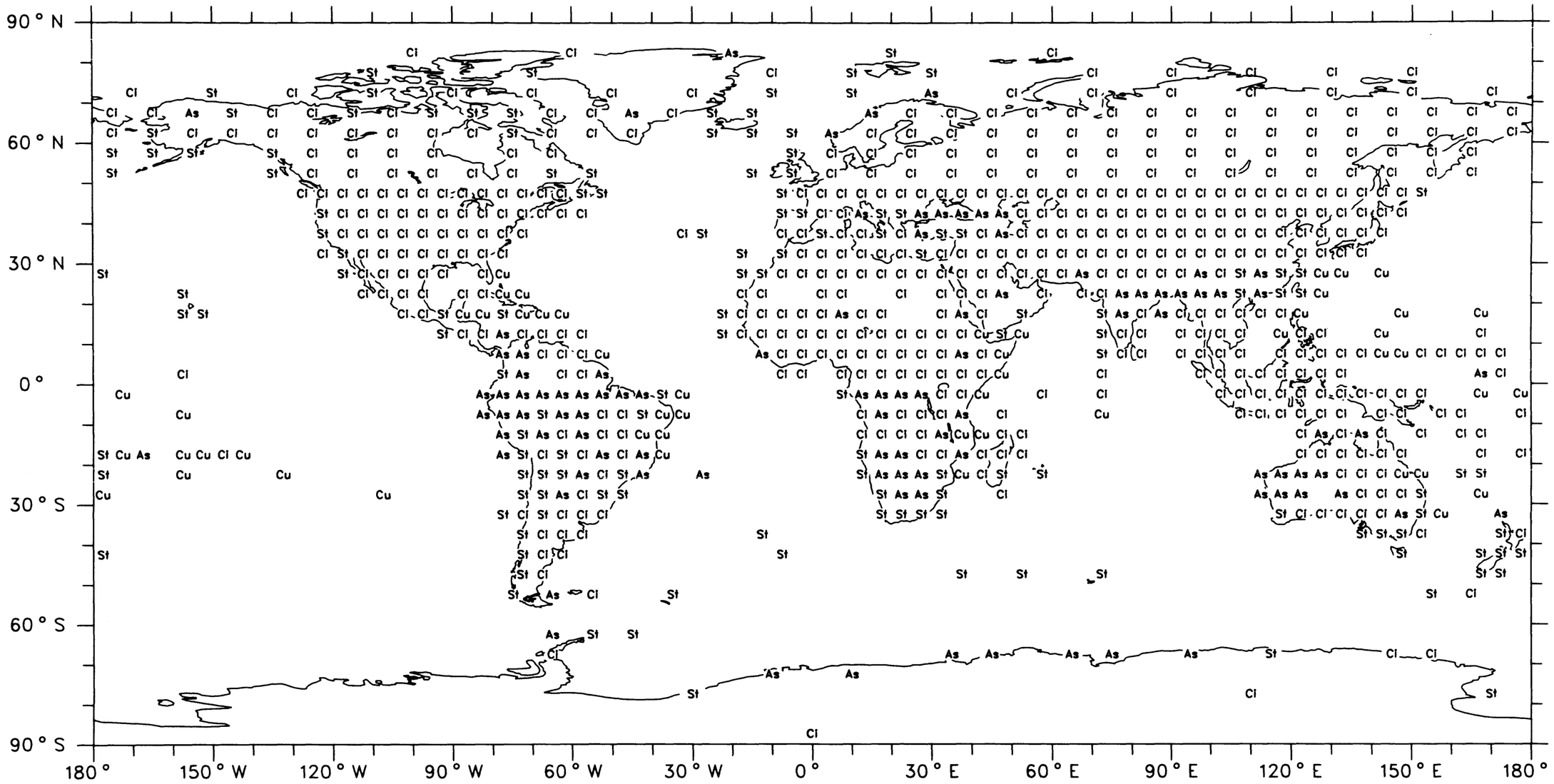


Map 192

Most-Frequently-Occurring Cloud Type

March, April, May (1971-1981)

Land Areas Only

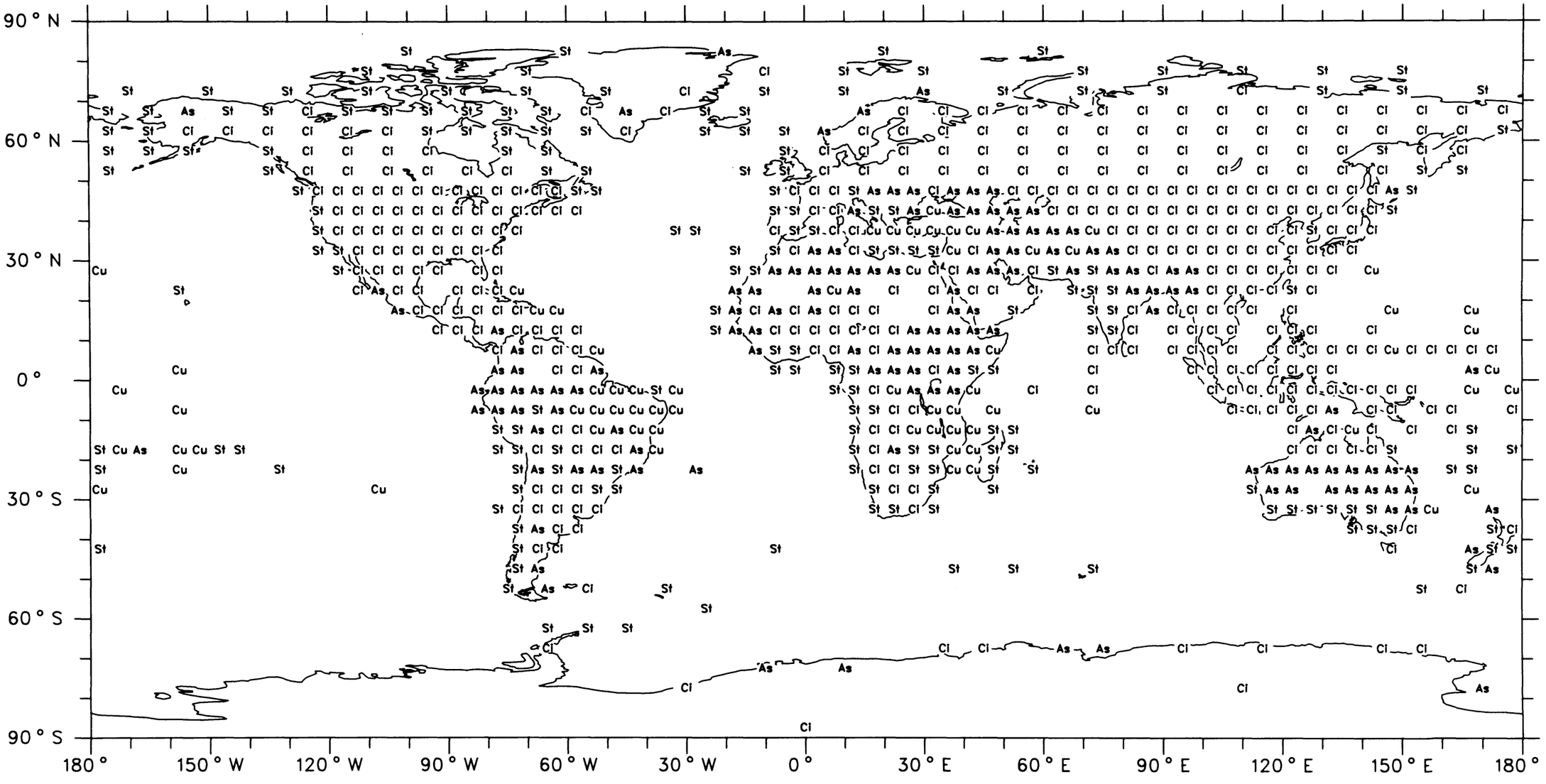


Map 193

Most-Frequently-Occurring Cloud Type

June, July, August (1971-1981)

Land Areas Only

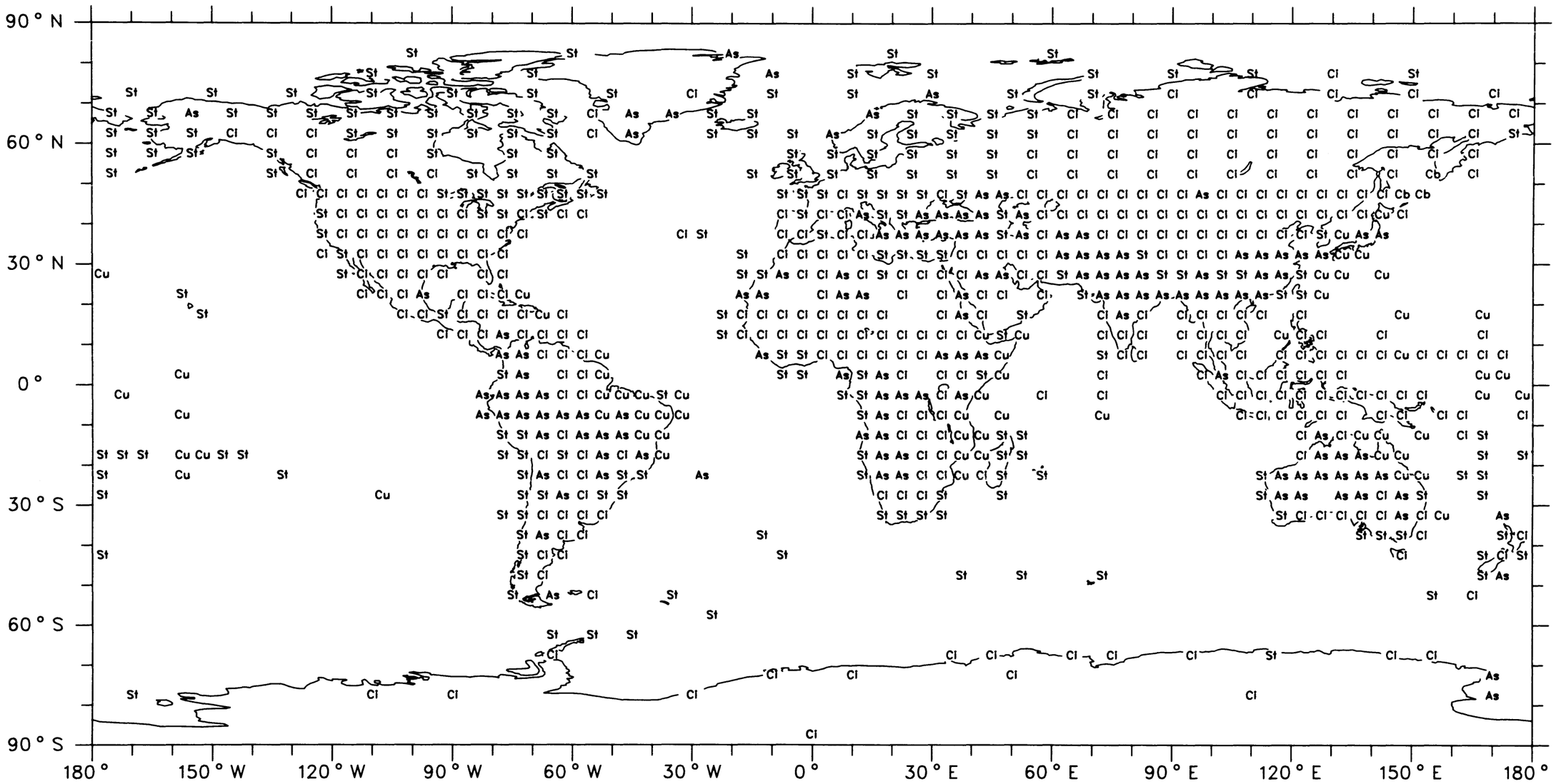


Map 194

Most-Frequently-Occurring Cloud Type

September, October, November (1971-1981)

Land Areas Only

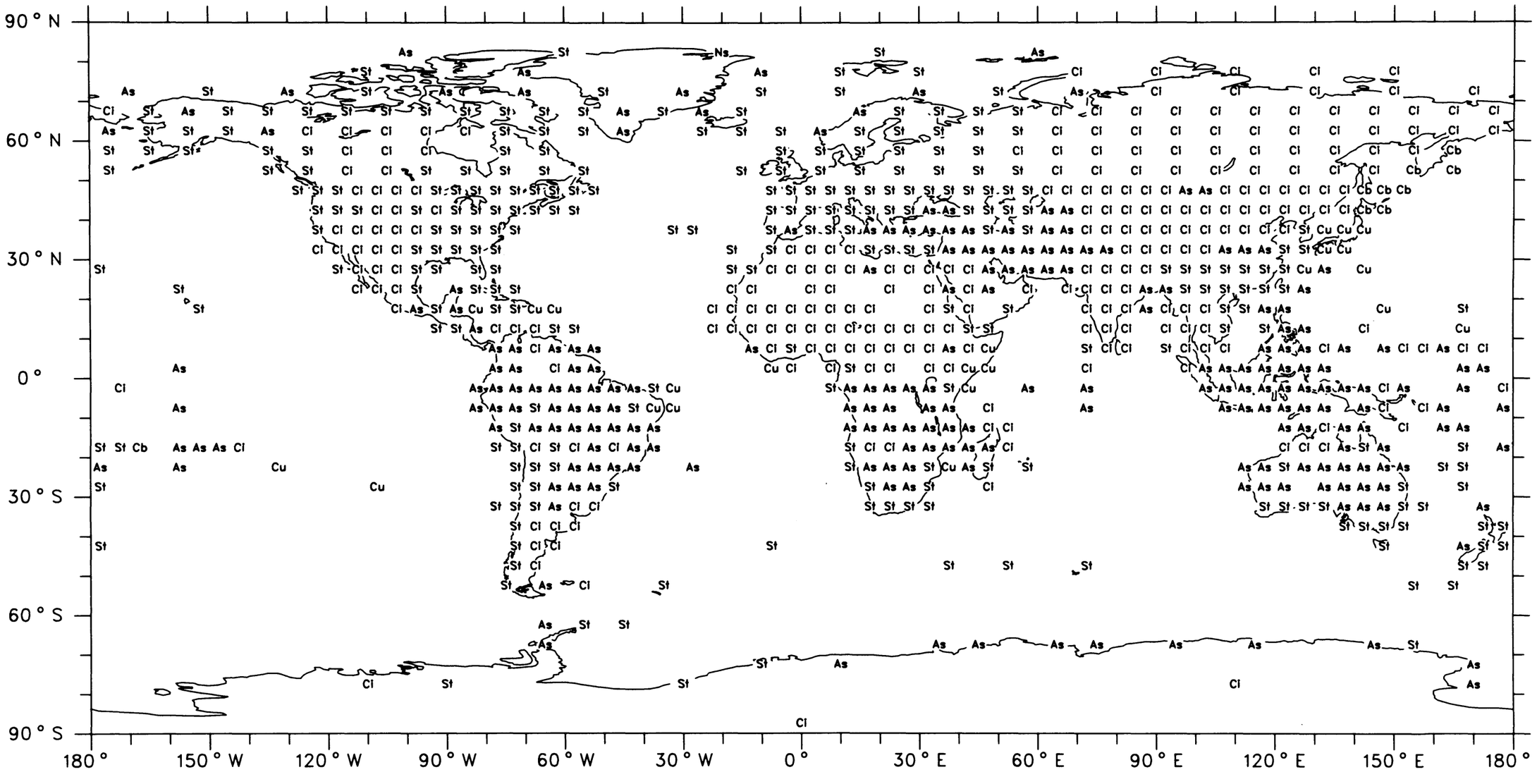


Map 195

Type Contributing Most to Total Cloud Cover

December, January, February (1971-1981)

Land Areas Only

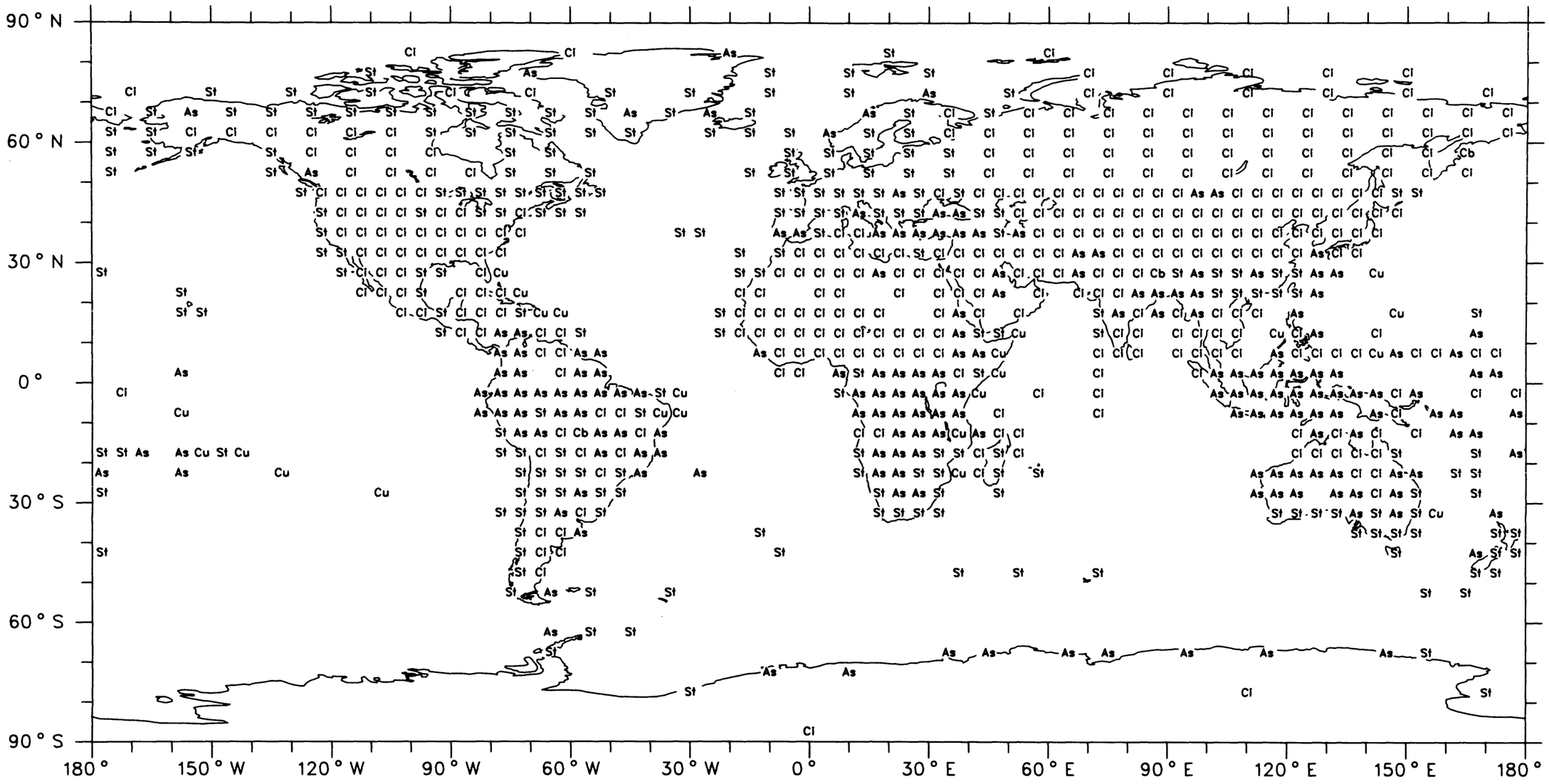


Map 196

Type Contributing Most to Total Cloud Cover

March, April, May (1971-1981)

Land Areas Only

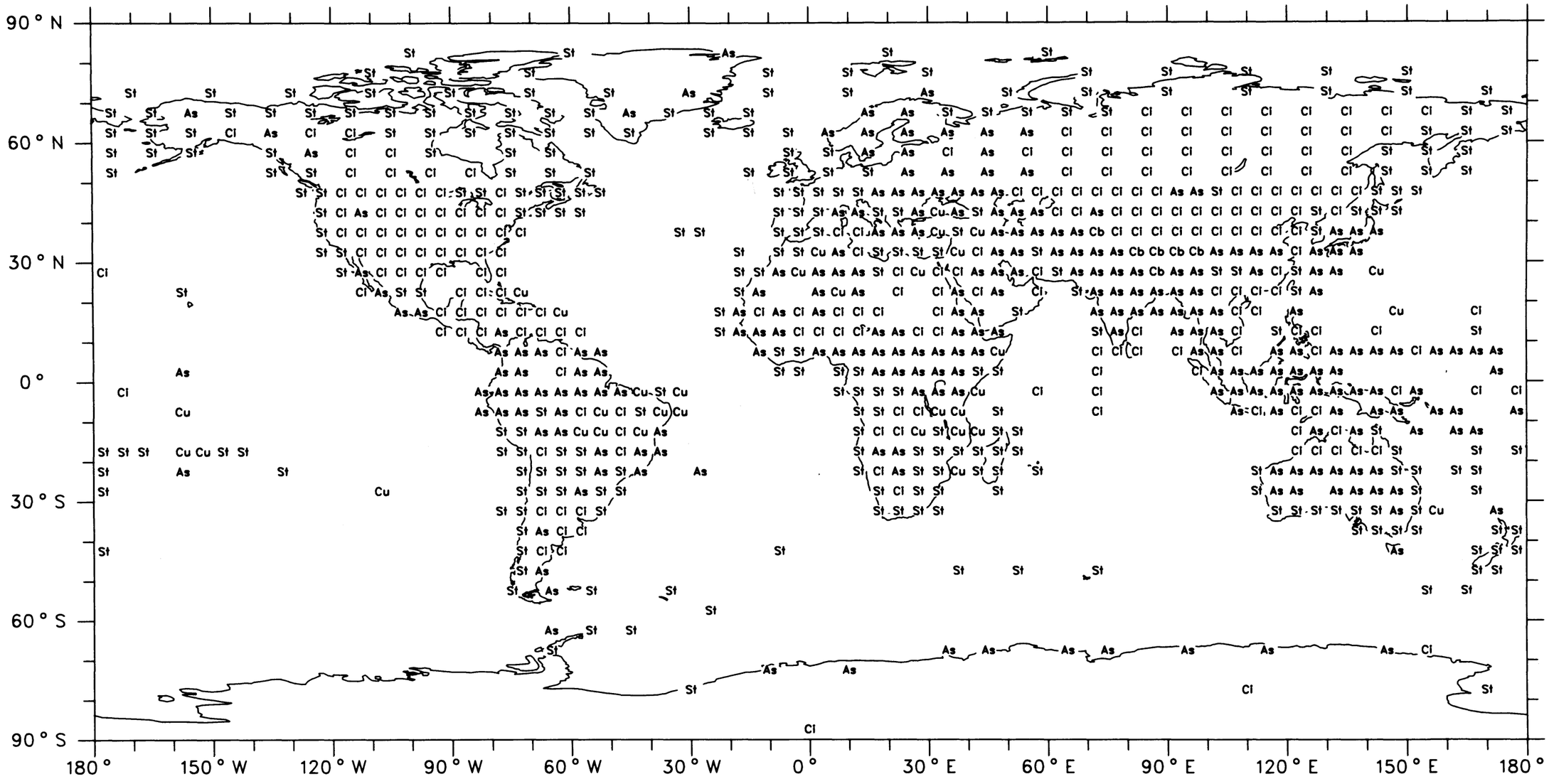


Map 197

Type Contributing Most to Total Cloud Cover

June, July, August (1971-1981)

Land Areas Only

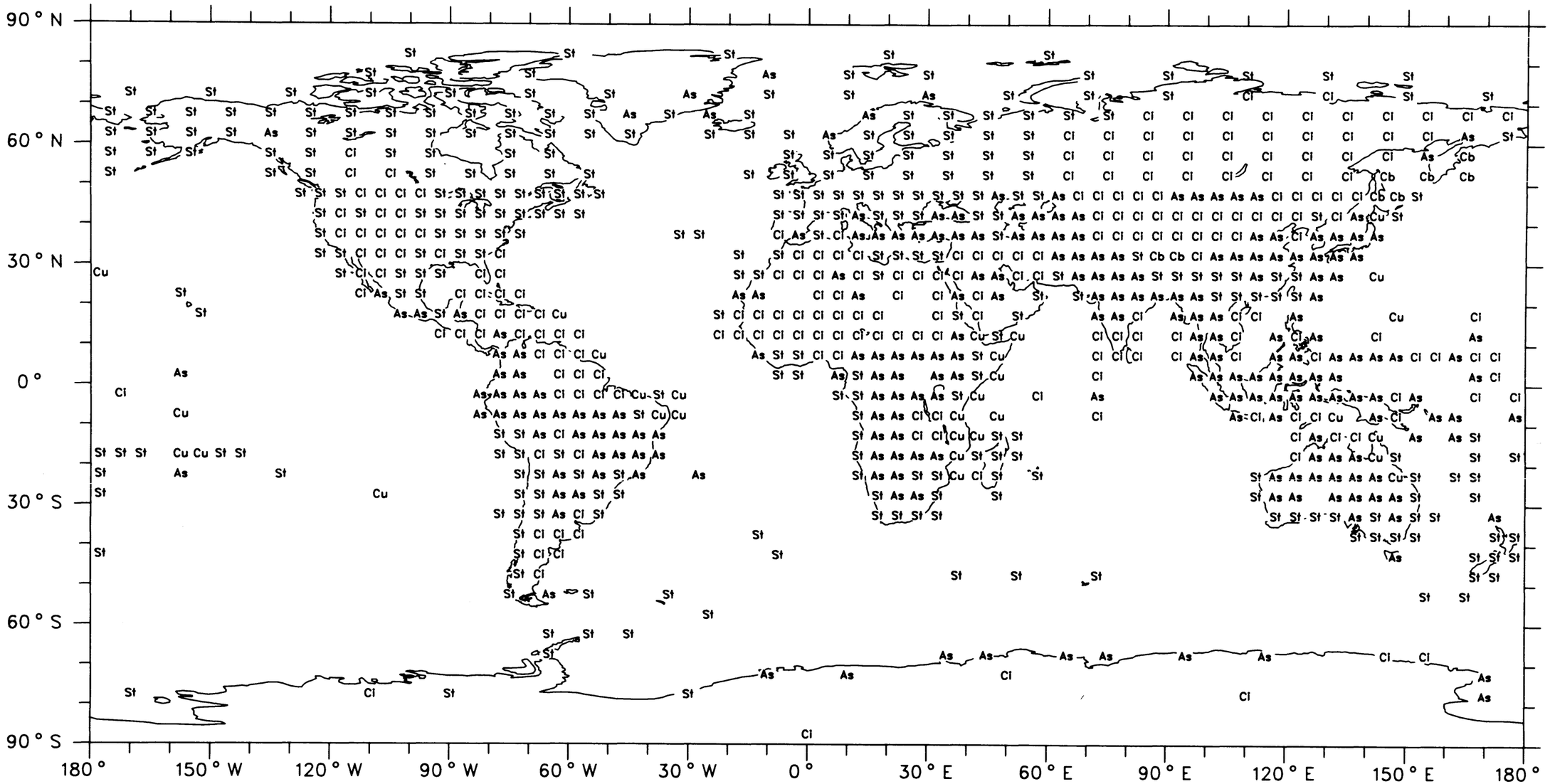


Map 198

Type Contributing Most to Total Cloud Cover

September, October, November (1971-1981)

Land Areas Only



Map 199

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