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ZONAL AVERAGE CLOUD CHARACTERISTICS FOR GLOBAL ATMOSPHERIC CHEMISTRY MODELLING

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ABSTRACT

A zonal average cloud distribution for the lower (approximately 6 km) troposphere is derived from surface observations of cloud occurrence and the average vertical extent of clouds. In addition, we use assessments of updraft velocities through convective clouds and lifetime estimates of stratiform clouds, to calculate the average time that air spends in clouds and the time between successive cloud encounters, as a function of latitude and altitude. The inferred cloud data compare well with satellite observations, but not very well with data derived from calculations with a general circulation model. We thus conclude that for such models more effort has to be devoted to develop cloud parameterizations in order to produce cloud distributions as needed for global atmospheric chemistry modelling.

Introduction

It has been shown that liquid water clouds (for the remainder: clouds) exert a significant influence on atmospheric photochemistry (Graedel & Weschler, 1981, and Chameides & Davis, 1982). In order to assess the effect of clouds on the concentration of trace gases, it is required to include clouds in global scale models of the atmosphere. As a first step, clouds could be built into models that treat the atmosphere as a two-dimensional system, which averages transport and chemical processes over longitudes between the north and the south pole (e.g. Crutzen & Gidel, 1983, and Rodhe & Isaksen, 1980).

A basic quantity that is needed is the average amount of time that air spends in clouds as a function of altitude and latitude (Isaksen & Rodhe, 1978). In many cases the residence time of air parcels in clouds is considerably shorter than the lifetime of clouds. This is due to rapid vertical transport of air through the clouds. It is therefore not sufficient to know the life times of the clouds themselves. Moreover, in order to be able to study the combined effect of chemical processes going on in cloudy as well as cloud free periods, we also need to know how much time an air parcel spends outside clouds. In a more detailed study, one could also consider the statistical distributions of the periods of time spent inside and outside clouds (Rodhe & Grandell, 1981). In this study we will limit ourselves to average values only.

The parameters introduced above are derived from surface observations of cloud occurrences (Hahn *et al.*, 1982, and Warren *et al.*, 1986). From these, we obtain data that can be compared with results from similar studies which are based on model calculations. Since we also infer the liquid water content of the clouds, we can calculate the vertically integrated amount of liquid water as a function of latitude. The resulting figures are compared with satellite observations.

Cloud observations and uncertainties

In the NCAR cloud atlases (Hahn *et al.*, 1982, and Warren *et al.*, 1986) numerous surface observations of cloudiness are summarized. Results are given with a resolution of 15° latitude by 30° longitude over the oceans and 5° by 5° over the continents. Zonal averages are also given. The observer codes (WMO, 1974) are translated into six cloud types: Cb, Cu, As/Ac, Ns, St/Sc and Ci/Cs/Cc†. In our study, we want to model aqueous-phase chemistry, so that we focus on liquid water clouds. Figures for ice clouds, however, are also included. The cloud coverage is averaged for the four seasons.

A number of biases affect the cloud observations (Warren *et al.*, 1985). Erroneous observations can influence the cloud climatology, especially in oceanic regions. Land observations are generally carried out by personnel with a meteorological training, whereas observations from ships may be of somewhat lower quality. Other biases may arise from the tendency of ships to avoid storms or to travel along preferred routes. However, a comparison of cloud cover reports from weather ships and from transport ships showed an average deviation of only a few percent (Warren *et al.*, 1985, and Quayle, 1980).

An additional source of uncertainties is the relatively small number of observations in very remote parts of the world, for instance the polar regions. The latter, however, is of limited importance for our application, because during a large fraction of the time temperatures at the poles are so low, that the occurrence of liquid water clouds can be neglected.

If we directly employ the figures for Cb clouds as presented in the NCAR cloud atlases, we would overestimate the coverage by Cb for a number of reasons. When a Cb cloud is observed, it often seems that it covers a large part of the sky. This is partly due to the large vertical extent of the cloud, which can create the impression that the horizontal coverage is larger than it actually is (Hughes, 1984). A second reason is that the anvil is generally much wider than the tower.

† See list of symbols and abbreviations

Only the latter part of Cb contains liquid water amounts that are of interest to cloud chemistry modelling. Furthermore, the fact that the synoptic code gives higher priority to Cb than to other cloud types also contributes to overestimation of Cb coverage, and to underestimation of other cloud types. Whenever other cloud types appear together with Cb, the total cloud cover is recorded as Cb.

As a consequence of the large vertical extent and the high liquid water content of Cb, overestimation can significantly influence the results of our analysis. Therefore, a correction is applied by multiplying the Cb coverage by a factor of 0.2 (Olofsson, 1988). This factor is derived from comparison of detailed observations with routine observations at major meteorological stations in Europe and Africa. The 0.2 fraction of the reported Cb represents the region where the strong vertical (upward and downward) wind velocities occur. This is in good agreement with observations reported by LeMone & Zipser (1980), Zipser & LeMone (1980) and Knupp & Cotton (1982), and with a numerical study by Droegemeier & Wilhelmson (1985).

The updraft core constitutes about half of the region with strong vertical motions, which is only 5 to 20% of the surface area of an average Cb cloud (Atkinson, 1981). However, it is mainly the region with strong updrafts that contains a large amount of liquid water (more than 1 g m^{-3}). Therefore, we also apply a correction to the average amount of liquid water in Cb. Instead of 2 g m^{-3} as given by Mason (1971), we assume 1 g m^{-3} (Table 8).

Cloud cover and liquid water content

Warren *et al.* (1986) give the percentage of cloud cover over the continents (Table 1). Hahn *et al.* (1982) give the frequency of occurrence of clouds over the oceans (Table 2). The latter, however, cannot be interpreted as a cloud cover, because occurrence of clouds in general does not imply that they extend over the whole sky. Therefore, we use the cloud observations over land to estimate what the average coverage of a type of cloud is whenever it occurs over the ocean (Warren *et al.*, 1986). These numbers (Table 3) are multiplied with the frequencies of occurrence, in order to estimate the cloud cover over the oceans (Table 4). We thus obtain the cloud cover over the oceans and the continents, which can be integrated into a zonal mean, on the basis of the average fraction which is land (Table 5). The resulting zonal average cloud cover is given in Table 6. The next step is to convert the zonal average values of the horizontal cloud coverage (Table 6) into fractional coverage, expressed as a percentage by volume. This is done by using data on the vertical extent of the different cloudtypes, given by Telegadas & London (1954) and Paltridge & Platt (1976) and references therein (Table 7). The lowest 60 mb of the atmosphere is assumed to be cloudfree. The results are presented in Table 9. The zonal average cover of liquid water clouds is given below the -15°C isotherm. We assume that -15°C is the approximate temperature boundary between the areas where either liquid water or ice clouds dominate. Coverages of ice clouds in high latitudes are also given, although these figures are less accurate because of the limited number of observations, especially in the Antarctic.

The vertical range of Cb as given in Table 7 does not represent the maximum vertical extent these clouds can attain. It is well known that Cb clouds, especially over land in the tropics, can grow violently and reach as high as the tropopause. We believe, however, that the average thickness of Cb as given (nearly 4 km) is more representative as a climatological mean, which pertains to the entire life cycle. Besides that, for the current purpose (aqueous-phase chemistry), we focus on cloudiness below about 6 km, because the amount of liquid water at higher altitudes is very small.

The average liquid water content as calculated is based on Mason (1971, Table 8). The results of vertical integration of the liquid water contents of the clouds are given in Table 9. These values for the total amount of liquid water in the atmosphere are compared with results from satellite studies (see Discussion).

Residence time of air in clouds

The residence time of an air parcel in clouds of type i (i can be Cu, St, etc.) can be approximated by

$$t_{c,i} = \frac{h_i}{w_{u,i}}$$

in which h_i is the average vertical extent of cloud type i (Table 7), and $w_{u,i}$ is the average updraft velocity in cloud type i (Table 8). With respect to Cb, we have defined a coverage of the tower, being 0.2 times the observed coverage. The tower, however, includes updraft as well as downdraft regions. Therefore $w_{u,Cb}$ is actually an average of the up- and downdraft velocities. For our purpose, we do not need to discern in which direction the air goes through the clouds. We must, however, include in our estimate of $w_{u,Cb}$ that updraft velocities in the tower are generally higher than downdraft velocities, so that we decide on a modest value for $w_{u,Cb}$, 5 m s^{-1} (Table 8). Thus, the average time that air is in Cb, $t_{c,Cb}$, based on the mean Cb thickness of 3.8 km (Table 8), is approximately 0.2 hour (about 10–15 min.). A comparable estimate for $t_{c,Cu}$ is 0.3 hour (about 15–20 min.).

The time $t_{c,St/Sc}$ is assumed to be equal to the average lifetime of stratus clouds, 3 hours (Matveev, 1984). The latter number is derived from observations over the USSR. If, for comparison, we assume that the time that air is in stratiform clouds is dependent on the updraft velocity as given in Table 8, $t_{c,St/Sc}$ would be longer than the average cloud lifetime. It should be noted that in some cases large stratiform cloud systems can have a lifetime of a day or longer, so that in these cases $t_{c,St/Sc}$ exceeds the average of 3 hours. However, on the basis of an average cloud thickness of 700 m (Table 8) and a mean updraft velocity of 5 cm s^{-1}, $t_{c,St/Sc}$ would be somewhat less than 4 hours, which does not deviate much from the 3 hours that we have applied.

Very little information is available about the lifetime or $t_{c,i}$ of the cloud types As/Ac and Ns. Since vertical velocities in middle clouds (As/Ac) are in the same range as St/Sc (Starr *et al.*, 1985b), we expect that 3 hours is also an appropriate estimate for $t_{c,As/Ac}$. A similar estimate has been derived by Isaksen & Rodhe

(1978). The latter authors also approximated a lifetime of nimbostratus. We adopt their value, 5.5 hours, for our calculations with $t_{c,Ns}$.

For further derivations, let f_i denote the fraction of the air volume (per grid element) covered with clouds of type i (as derived above). The mean residence time $\overline{t_c}$ of the air parcel in clouds, averaged over all cloud types, can then be estimated by

$$\overline{t_c} = \frac{\sum f_i \, t_{c,i}}{f}$$

in which

$$f = \sum_i f_i.$$

The average time spent outside clouds in a grid box is

$$\overline{t_{nc}} = \frac{1-f}{f} \, \overline{t_c}.$$

Results are listed in Table 1. The implicit assumption made is that an air parcel only resides in one grid box. The time scale of air advection throughout parts of the atmosphere with the same spatial dimensions as our grid boxes, is at least one day, usually more. Since the sum of $\overline{t_c}$ and $\overline{t_{nc}}$, here defined as the cloud cycle time, is generally less than a day, our assumption does not seem an oversimplification. This does not apply to the turbulent lower part of the atmosphere, where vertical exchange processes can occur on a much shorter time scale. We therefore determine a lower layer between 950 and 700 mb in Table 10. This layer coincides with the part of the atmosphere where cumuliform cloudiness occurs (Table 7). The assumption is also not valid for cases of deep convection by Cb. However, the actual coverage of the parts of Cb in which vertical mixing processes are important is so low (on average less than 1%), that this effect can be neglected. We emphasize that rapid vertical exchange by Cb clouds (short $t_{c,Cb}$), although hardly directly affecting cloud chemical processes, is important for vertical transport of reactive trace gases from the lower to the upper troposphere. This, in turn, has significant impact on photochemical processes (Chatfield & Crutzen, 1984, and Pickering *et al.*, 1989).

Discussion of cloud data

From the cloud cover over land (Table 1) we can clearly recognize the influence of the mean meridional (Hadley) circulation. Coverages are generally higher in the tropics and between 50° and 70° latitude (mainly in the summer) than in the subtropics. Cloudiness in the tropics also seems to reflect quite well the shifting of the ITCZ from its most southerly position in January to its most northerly in July. In the zonal average cloud cover (Table 6), however, the agreement with meridional circulation patterns is diminished, largely because the latitudinal differences in cloudiness over the oceans are very small. The fact that convective cloud types occur in unstable air and stratiform cloudiness in more stable air, further obscures the latitudinal differences that one might expect on the basis of the Hadley circulation (Table 9).

However, when we look at the average times between successive passages through clouds, the cloud cycle time $\overline{t_c} + \overline{t_{nc}}$ (see Table 10), meridional differences becomes more strongly manifest again. The shortest cycle times appear in the tropics and between 50° and 70° latitude, the longest cycle times in the subtropics and at the poles. Upward motion in the ascending branches of the tropical Hadley cells is accompanied by cumuliform cloudiness. The slower upward motion between 50° and 70° latitude, largely associated with passages of fronts, is a larger scale phenomenon, which causes a relatively high coverage by stratiform clouds.

The integrated amounts of liquid water, as given in Table 9, enable comparison of our results with satellite data. Njoku & Swanson (1983) present the results of liquid water measurements over the oceans during July and August 1978. The spatial resolution of their satellite-borne instrument is somewhat more than 50 km. The reported amounts of liquid water are approximately 40–80 g m^{-2} over the Atlantic, 80 g m^{-2} over the Indian Ocean and 80–120 g m^{-2} over the Pacific. Similar measurements by Prabhakara *et al.* (1983), during February and March 1979, result in 50–300 g m^{-2} over the tropical oceans and 25–200 g m^{-2} at midlatitudes. Our results indicate an increase from approximately 120 to 220 g m^{-2}, going from midlatitudes to the tropics. The differences between the measurements and our results are thus not very large. On average, it seems that the satellite data indicate somewhat less liquid water, particularly the data of Njoku & Swanson (1983). However, the satellite measurements only concern oceanic regions. Especially in the tropics, convection over land can result in more liquid water than over the oceans (Roeckner & Schlese, 1989). Besides that, the estimated accuracy of the satellites measurements is not very high, approximately a factor of 2.

A first attempt to estimate time scales connected with cloudiness has been made by Hamrud & Rodhe (1986). This was based on three-dimensional wind and humidity fields, obtained from meteorological observations in the first GARP global experiment (winds, temperature, pressure and humidity), which were analysed with a General Circulation Model (GCM) at the European Centre for Medium range Weather Forecasting (ECMWF). The cloud parameterization scheme was adopted from Geleyn *et al.* (1982). The scheme was tested against the parameterization of Slingo (1980), which showed very similar results. By means of three-dimensional trajectory calculations, estimates were made between the "release" of an air parcel and the first cloud encounter (comparable with $\overline{t_{nc}}$ as mentioned above). Since the spatial resolution of the GCM is about 200 km, it can only predict the major cloud systems that generally cause precipitation. The time scales derived by Hamrud & Rodhe (1986) may thus be more representative for the statistics of rain cloud encounters than for cloud encounters in general.

The calculated times preceeding clouds events along the trajectories ($\overline{t_{nc}}$) given by Hamrud & Rodhe (1986), average 5 to 10 days. This is much longer than $\overline{t_{nc}}$ as we derive in Table 10, which is about 0.5 to 2 days. We conclude, therefore, that the GCM models, although adequate in predicting precipitation and precipitation scavenging, are not suited for describing a cloud distribution as needed for global cloud chemistry modelling, at least not until more accurate subgrid scale cloud parameterization schemes have been developed.

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List of symbols and abbreviations

Ac	altocumulus
As	altostratus
Cb	cumulonimbus
Ci	cirrus
Cs	cirrostratus
Cc	cirrocumulus
Cu	cumulus
Ns	nimbostratus
Sc	stratocumulus
St	stratus
LWA	vertically integrated liquid water amount in g m^{-2}
LWC	cloud liquid water content in g m^{-3}
f_i	fraction of air volume covered by cloud type i
h_i	vertical extent of cloud type i
$t_{c,i}$	residence time of air in cloud of type i
$\overline{t_c}$	average residence time of air in clouds
$\overline{t_{nc}}$	average time outside clouds
$\overline{t_c} + \overline{t_{nc}}$	cloud cycle time
z_0	height of cloud top in km
z_b	height of cloud base in km
GCM	General Circulation Model
GLOMAC	Global Modelling of Atmospheric Chemistry subproject of the European research effort EUROTRAC

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Table 1a

Cloud cover† (%), from Warren *et al.* (1986)

Continents : December/January/February

Southern Hemisphere:

	degrees latitude								
	90-80	80-70	70-60	60-50	50-40	40-30	30-20	20-10	10-0
Cb	0	0	1	4	3	3	4	7	6
Cu	0	0	2	6	6	5	7	12	12
As/Ac	24	19	38	45	22	15	19	37	47
Ns	4	7	15	13	6	3	3	5	4
St/Sc	4	12	38	50	25	18	16	22	23
Ci/Cs/Cc	29	29	25	28	23	14	15	31	27

Northern Hemisphere:

	degrees latitude								
	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90
Cb	4	1	1	3	2	3	2	1	0
Cu	10	4	2	2	1	1	0	0	0
As/Ac	24	10	12	17	20	20	20	18	13
Ns	2	1	2	6	10	15	15	12	15
St/Sc	13	7	12	18	26	25	19	16	17
Ci/Cs/Cc	28	26	14	24	25	32	29	17	11

† before applying the 0.2 correction factor to Cb

Table 1b

Cloud cover† (%), from Warren *et al.* (1986)

Continents : March/April/May

Southern Hemisphere:

	degrees latitude								
	90-80	80-70	70-60	60-50	50-40	40-30	30-20	20-10	10-0
Cb	0	0	1	4	2	2	2	4	6
Cu	0	0	1	4	4	4	5	10	12
As/Ac	13	8	34	36	25	18	16	21	41
Ns	3	5	17	12	9	4	3	2	4
St/Sc	2	13	33	50	27	22	15	16	21
Ci/Cs/Cc	22	31	25	22	24	17	11	20	25

Northern Hemisphere:

	degrees latitude								
	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90
Cb	9	3	3	5	3	6	4	1	0
Cu	11	4	4	4	4	3	2	0	0
As/Ac	35	14	13	16	20	21	20	18	15
Ns	3	1	2	3	7	9	9	12	11
St/Sc	14	6	10	14	21	21	20	23	19
Ci/Cs/Cc	34	29	15	28	30	33	31	24	22

† before applying the 0.2 correction factor to Cb

Table 1c

Cloud cover† (%), from Warren *et al.* (1986)

Continents : June/July/August

Southern Hemisphere:

	degrees latitude								
	90-80	80-70	70-60	60-50	50-40	40-30	30-20	20-10	10-0
Cb	0	0	0	7	3	1	1	1	2
Cu	0	0	1	4	3	3	3	6	11
As/Ac	10	6	31	32	27	19	13	10	26
Ns	1	5	15	11	11	6	3	1	1
St/Sc	1	14	28	46	27	24	14	13	18
Ci/Cs/Cc	20	28	22	23	24	19	8	9	15

Northern Hemisphere:

	degrees latitude								
	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90
Cb	9	7	7	6	5	10	8	3	0
Cu	11	5	5	5	6	6	5	1	1
As/Ac	42	32	18	14	19	23	24	26	27
Ns	4	3	3	2	3	6	7	12	13
St/Sc	21	13	12	10	15	22	29	49	40
Ci/Cs/Cc	30	34	13	16	20	26	25	21	20

† before applying the 0.2 correction factor to Cb

Table 1d

Cloud cover[†] (%), from Warren *et al.* (1986)

Continents : September/October/November

Southern Hemisphere:

	degrees latitude								
	90-80	80-70	70-60	60-50	50-40	40-30	30-20	20-10	10-0
Cb	0	0	0	5	4	2	2	4	5
Cu	0	0	1	5	5	5	4	9	13
As/Ac	13	13	33	35	25	17	15	21	34
Ns	2	5	15	11	8	4	2	2	2
St/Sc	2	8	32	48	26	20	14	16	19
Ci/Cs/Cc	44	32	27	22	25	17	11	16	23

Northern Hemisphere:

	degrees latitude								
	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90
Cb	10	4	3	3	2	7	6	3	0
Cu	10	5	4	4	3	2	1	1	0
As/Ac	36	20	14	14	19	24	24	22	19
Ns	3	2	3	3	6	12	16	17	19
St/Sc	16	8	11	12	23	31	34	38	31
Ci/Cs/Cc	30	30	12	16	21	30	29	19	14

[†] before applying the 0.2 correction factor to Cb

Table 2a

Frequency of occurrence[†] (%), from Hahn *et al.* (1982)

Oceans : December/January/February

Southern Hemisphere:

	degrees latitude								
	90-80	80-70	70-60	60-50	50-40	40-30	30-20	20-10	10-0
Cb	-	-	3	7	7	7	13	14	16
Cu	-	-	8	17	25	32	46	48	50
As/Ac	-	-	52	51	47	43	42	43	44
Ns	-	-	20	16	11	6	4	4	4
St/Sc	-	-	36	30	35	40	37	35	32
Ci/Cs/Cc	-	-	38	34	32	30	29	33	36

Northern Hemisphere:

	degrees latitude								
	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90
Cb	12	10	8	8	9	9	19	19	-
Cu	48	45	42	26	31	15	13	13	-
As/Ac	41	39	37	44	42	40	35	35	-
Ns	4	3	3	9	14	18	24	24	-
St/Sc	33	37	42	37	37	37	34	34	-
Ci/Cs/Cc	31	27	23	27	26	26	35	35	-

† before applying the 0.2 correction factor to Cb

Table 2b

Frequency of occurrence[†] (%), from Hahn *et al.* (1982)

Oceans : March/April/May

Southern Hemisphere:

	degrees latitude								
	90-80	80-70	70-60	60-50	50-40	40-30	30-20	20-10	10-0
Cb	-	-	-	12	11	10	13	15	17
Cu	-	-	-	19	24	30	46	50	53
As/Ac	-	-	56	45	44	44	40	40	41
Ns	-	-	23	17	12	7	4	4	3
St/Sc	-	-	65	62	54	47	33	28	23
Ci/Cs/Cc	-	-	48	32	31	30	26	31	35

Northern Hemisphere:

	degrees latitude								
	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90
Cb	14	12	9	6	6	7	14	14	-
Cu	49	46	43	25	20	15	12	12	-
As/Ac	42	40	37	44	44	45	43	43	-
Ns	3	3	3	7	11	15	17	17	-
St/Sc	25	28	32	51	56	62	50	50	-
Ci/Cs/Cc	35	31	28	33	33	33	42	42	-

† before applying the 0.2 correction factor to Cb

Table 2c

Frequency of occurrence[†] (%), from Hahn *et al.* (1982)

Oceans : June/July/August

Southern Hemisphere:

	degrees latitude								
	90-80	80-70	70-60	60-50	50-40	40-30	30-20	20-10	10-0
Cb	-	-	-	14	13	12	11	12	13
Cu	-	-	-	12	19	26	40	45	49
As/Ac	-	-	-	39	40	41	37	38	38
Ns	-	-	-	14	10	7	4	3	3
St/Sc	-	-	-	63	55	48	39	35	30
Ci/Cs/Cc	-	-	-	32	29	25	18	22	26

Northern Hemisphere:

	degrees latitude								
	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90
Cb	18	17	15	7	5	4	8	8	-
Cu	43	44	46	29	21	12	10	10	-
As/Ac	53	48	43	43	48	54	53	53	-
Ns	6	4	3	6	10	13	14	14	-
St/Sc	31	30	29	46	57	68	62	62	-
Ci/Cs/Cc	43	38	34	34	38	43	44	44	-

[†] before applying the 0.2 correction factor to Cb

Table 2d

Frequency of occurrence† (%), from Hahn *et al.* (1982)

Oceans : September/October/November

Southern Hemisphere:

	degrees latitude								
	90-80	80-70	70-60	60-50	50-40	40-30	30-20	20-10	10-0
Cb	-	-	-	10	9	9	10	11	13
Cu	-	-	-	16	21	26	41	44	48
As/Ac	-	-	-	46	46	46	41	41	41
Ns	-	-	-	15	11	7	3	3	3
St/Sc	-	-	72	64	57	51	40	36	32
Ci/Cs/Cc	-	-	-	35	33	31	23	25	28

Northern Hemisphere:

	degrees latitude								
	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90
Cb	17	15	13	8	8	8	13	13	-
Cu	46	47	48	32	25	18	10	10	-
As/Ac	50	45	39	43	44	46	44	44	-
Ns	5	4	3	6	10	14	19	19	-
St/Sc	29	28	27	45	53	61	62	62	-
Ci/Cs/Cc	40	35	31	31	31	31	33	33	-

† before applying the 0.2 correction factor to Cb

Table 3

Coverage when a cloudtype is present[†]

	%
Cb	60
Cu	35
As/Ac	60
Ns	95
St/Sc	70
Ci/Cs/Cc	50

† Derived from cloud observations over land (Warren *et al.*, 1986). These numbers are used to multiply with the frequencies of occurrence, in order to obtain the cloud cover over the oceans

Table 4a

Cloud cover† (%)

Oceans : December/January/February

Southern Hemisphere:

	degrees latitude								
	90-80	80-70	70-60	60-50	50-40	40-30	30-20	20-10	10-0
Cb	-	-	2	4	4	4	8	8	10
Cu	-	-	3	6	9	11	16	17	18
As/Ac	-	-	31	31	28	26	25	26	26
Ns	-	-	19	15	11	6	4	4	4
St/Sc	-	-	18	21	25	28	25	25	24
Ci/Cs/Cc	-	-	19	17	16	15	15	16	18

Northern Hemisphere:

	degrees latitude								
	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90
Cb	7	6	5	5	5	5	11	11	-
Cu	17	17	15	9	11	5	5	5	-
As/Ac	25	24	24	26	25	24	21	21	-
Ns	4	3	3	9	13	17	23	23	-
St/Sc	24	25	29	24	25	25	24	24	-
Ci/Cs/Cc	15	14	12	14	13	13	17	17	-

† before applying the 0.2 correction factor to Cb

Table 4b

Cloud cover† (%)

Oceans : March/April/May

Southern Hemisphere:

	degrees latitude								
	90-80	80-70	70-60	60-50	50-40	40-30	30-20	20-10	10-0
Cb	-	-	-	7	7	6	8	9	10
Cu	-	-	-	7	8	11	16	17	18
As/Ac	-	-	34	27	26	26	24	24	24
Ns	-	-	22	16	11	7	4	4	3
St/Sc	-	-	46	43	38	33	23	20	16
Ci/Cs/Cc	-	-	24	16	15	15	13	16	17

Northern Hemisphere:

	degrees latitude								
	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90
Cb	8	7	5	4	3	4	8	8	-
Cu	17	16	15	9	7	5	4	4	-
As/Ac	25	24	22	26	26	27	26	26	-
Ns	3	3	3	7	10	14	16	16	-
St/Sc	18	20	22	36	39	43	35	35	-
Ci/Cs/Cc	17	16	14	16	17	16	21	21	-

† before applying the 0.2 correction factor to Cb

Table 4c

Cloud cover† (%)

Oceans : June/July/August

Southern Hemisphere:

	degrees latitude								
	90-80	80-70	70-60	60-50	50-40	40-30	30-20	20-10	10-0
Cb	-	-	-	8	8	7	7	7	8
Cu	-	-	-	4	7	9	14	16	17
As/Ac	-	-	-	23	23	24	22	22	22
Ns	-	-	-	13	10	7	4	3	3
St/Sc	-	-	-	44	39	24	27	25	21
Ci/Cs/Cc	-	-	-	16	15	12	9	11	13

Northern Hemisphere:

	degrees latitude								
	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90
Cb	11	10	10	4	3	3	5	5	-
Cu	15	15	16	10	7	4	4	4	-
As/Ac	32	29	26	26	29	32	32	32	-
Ns	6	4	3	6	10	12	13	13	-
St/Sc	21	21	21	33	40	48	43	43	-
Ci/Cs/Cc	21	19	17	17	19	21	22	22	-

† before applying the 0.2 correction factor to Cb

Table 4d

Cloud cover† (%)

Oceans : September/October/November

Southern Hemisphere:

	degrees latitude								
	90-80	80-70	70-60	60-50	50-40	40-30	30-20	20-10	10-0
Cb	-	-	-	6	5	5	6	7	8
Cu	-	-	-	6	7	9	14	15	17
As/Ac	-	-	-	28	28	28	25	25	25
Ns	-	-	-	14	10	7	3	3	3
St/Sc	-	-	50	45	40	36	28	25	22
Ci/Cs/Cc	-	-	-	17	17	15	12	12	14

Northern Hemisphere:

	degrees latitude								
	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90
Cb	10	9	8	5	5	5	8	8	-
Cu	16	16	17	11	9	6	4	4	-
As/Ac	30	27	23	26	26	27	26	26	-
Ns	5	4	3	6	9	13	18	18	-
St/Sc	20	20	19	31	37	43	43	43	-
Ci/Cs/Cs	20	17	16	16	15	15	16	16	-

† before applying the 0.2 correction factor to Cb

Table 5

Average fraction that is land (%)

Southern Hemisphere:

degrees latitude								
90-80	80-70	70-60	60-50	50-40	40-30	30-20	20-10	10-0
100	69	11	1	4	12	23	22	25

Northern Hemisphere:

degrees latitude								
0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90
24	27	38	44	53	59	74	35	8

Table 6a

Zonal average cloud cover† (%)

December/January/February

Southern Hemisphere:

	degrees latitude								
	90-80	80-70	70-60	60-50	50-40	40-30	30-20	20-10	10-0
Cb	0	0	2	4	4	4	7	8	9
Cu	0	0	3	6	9	10	14	16	17
As/Ac	24	19	32	31	28	24	23	28	30
Ns	4	7	19	15	11	6	4	4	4
St/Sc	4	12	21	22	25	26	24	24	24
Ci/Cs/Cc	29	29	20	17	19	15	15	19	20

Northern Hemisphere:

	degrees latitude								
	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90
Cb	6	5	4	4	4	4	4	1	0
Cu	16	14	10	6	6	3	1	0	0
As/Ac	25	21	19	23	22	22	20	18	13
Ns	4	3	3	8	11	16	17	12	15
St/Sc	22	21	22	22	26	25	21	16	17
Ci/Cs/Cc	18	17	13	18	19	24	26	17	17

† before applying the 0.2 correction factor to Cb

Table 6b

Zonal average cloud cover† (%)

March/April/May

Southern Hemisphere:

	degrees latitude								
	90-80	80-70	70-60	60-50	50-40	40-30	30-20	20-10	10-0
Cb	0	0	1	7	7	6	7	8	9
Cu	0	0	1	7	8	10	13	15	17
As/Ac	13	8	34	27	26	25	22	23	28
Ns	3	5	21	16	11	7	4	4	3
St/Sc	2	13	45	43	38	32	21	19	17
Ci/Cs/Cc	22	31	24	16	15	15	13	17	19

Northern Hemisphere:

	degrees latitude								
	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90
Cb	9	6	4	4	3	5	5	5	0
Cu	16	13	11	6	5	4	3	3	0
As/Ac	27	21	19	22	23	23	22	23	15
Ns	3	2	3	5	8	11	11	15	11
St/Sc	17	16	17	26	29	30	24	31	19
Ci/Cs/Cc	21	20	14	21	24	26	28	22	22

† before applying the 0.2 correction factor to Cb

Table 6c

Zonal average cloud cover† (%)

June/July/August

Southern Hemisphere:

	degrees latitude								
	90-80	80-70	70-60	60-50	50-40	40-30	30-20	20-10	10-0
Cb	0	0	8	8	7	6	6	7	11
Cu	0	0	1	4	7	9	12	14	16
As/Ac	10	6	31	23	23	24	20	20	23
Ns	1	5	15	13	10	7	4	3	3
St/Sc	1	14	28	44	39	33	25	22	20
Ci/Cs/Cc	20	28	22	16	15	13	9	11	14

Northern Hemisphere:

	degrees latitude								
	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90
Cb	11	9	8	5	4	6	6	3	0
Cu	14	13	12	8	7	5	4	1	1
As/Ac	34	30	24	21	24	26	26	26	27
Ns	6	4	3	4	7	9	9	12	13
St/Sc	21	19	18	23	27	34	33	49	40
Ci/Cs/Cc	23	23	15	17	20	24	24	22	20

† before applying the 0.2 correction factor to Cb

Table 6d

Zonal average cloud cover[†] (%)

September/October/November

Southern Hemisphere:

	degrees latitude								
	90-80	80-70	70-60	60-50	50-40	40-30	30-20	20-10	10-0
Cb	0	0	0	6	5	5	5	6	7
Cu	0	0	1	6	7	9	12	14	16
As/Ac	13	13	33	28	28	27	23	24	27
Ns	2	5	15	14	10	7	3	3	3
St/Sc	2	8	48	45	39	34	25	23	21
Ci/Cs/Cc	44	32	27	17	17	15	12	13	16

Northern Hemisphere:

	degrees latitude								
	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90
Cb	10	8	6	4	3	6	7	6	0
Cu	15	13	12	8	6	4	2	3	0
As/Ac	31	25	20	16	22	25	25	25	19
Ns	4	8	3	5	7	12	17	18	19
St/Sc	19	15	16	23	30	36	36	41	31
Ci/Cs/Cc	22	21	14	16	18	24	26	17	14

† before applying the 0.2 correction factor to Cb

Table 7

Vertical extent of clouds (km), average for both hemispheres and for all seasons, from Telegadas and London (1954), Paltridge and Platt (1976, 1981), and Starr *et al.* (1985a,b).

	degrees latitude				
	90-80	80-70	70-60	60-50	50-40
Cb	1.2-3.0	1.3-3.0	1.3-4.0	1.5-4.2	1.6-4.7
Cu	1.0-1.7	1.0-1.8	1.0-2.0	1.2-2.2	1.3-2.3
As/Ac	2.1-2.6	2.1-2.9	2.4-3.6	2.6-3.4	3.2-4.0
Ns	0.8-2.4	0.8-2.5	1.0-3.6	1.2-3.6	1.3-4.0
St/Sc	0.6-1.0	0.6-1.0	0.6-1.0	0.7-1.2	0.8-1.3
Ci/Cs/Cc	6.2-7.2	6.5-7.5	6.7-7.7	7.2-8.2	8.0-9.0

	degrees latitude			
	40-30	30-20	20-10	10-0
Cb	2.0-6.0	1.8-6.3	1.6-6.1	1.4-6.0
Cu	1.8-2.8	2.0-3.0	1.8-2.8	1.5-2.3
As/Ac	3.9-4.7	4.1-5.0	4.0-4.8	3.8-4.4
Ns	1.8-4.7	2.0-5.0	1.8-4.8	1.5-4.4
St/Sc	0.9-1.8	1.0-2.0	0.8-1.8	0.6-1.5
Ci/Cs/Cc	9.5-10.5	10.0-11.0	9.8-10.8	9.3-10.3

Table 8

Average liquid water content (LWC in g m^{-3}) per cloud type (after Mason, 1971)†, updraft velocities in clouds‡ (w_u in m s^{-1}) (from Atkinson, 1981, Churchill & Houze, 1984, Matveev, 1984, Nicholls, 1984, and Starr *et al.*, 1985a,b), and average cloud thickness ($z_0 - z_b$ in km)*

	LWC	w_u	$z_0 - z_b$
Cb	1.0	5–10 (5.0)	3.8
Cu	0.5	0.5–2 (1.0)	1.0
As/Ac	0.1	0.005–0.5(0.05)	0.8
Ns	0.1	0.005–0.5(0.05)	2.7
St/Sc	0.3	0.005–0.5(0.05)	0.7
Ci/Cs/Cc	–	0.02-0.4(0.2)	1.0

† Although Mason (1971) gives an average LWC for Cb of 2 g m^{-3}, we assume 1 g m^{-3} (see text).

‡ The numbers between parentheses are averages as used for calculating the mean time that air is in clouds (Table 10); the time that air is in stratiform clouds is determined by the lifetime of these clouds, not by w_u.

*A correction has been applied for the fact that the earth's surface area per latitude decreases towards the poles.

Table 9a

Zonal average cloud cover and LWC†

December/January/February, Southern hemisphere

mbar		90-80	80-70	70-60	60-50	50-40	40-30	30-20	20-10	10-0
		degrees latitude								
500-600	C	-	-	-	-	-	10	17	14	8
	LWC	-	-	-	-	-	0.1	0.1	0.2	0.3
600-700	C	-	-	16	21	22	14	8	11	14
	LWC	-	-	0.1	0.1	0.1	0.2	0.3	0.3	0.2
700-800	C	13	18	32	30	15	15	18	19	11
	LWC	0.1	0.1	0.1	0.2	0.2	0.3	0.4	0.4	0.4
800-950	C	4	8	19	17	17	22	16	16	21
	LWC	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.4
integrated	LWA	25	42	105	158	129	182	185	209	222

† C is average coverage in volume %, LWC is liquid water content of the clouds in g m^{-3}, the vertically integrated liquid water amount (LWA) is in g m^{-2}

Table 9b

Zonal average cloud cover and LWC†

December/January/February, Northern hemisphere

mbar		0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90
		degrees latitude								
500-600	C	6	11	14	10	-	-	-	-	-
	LWC	0.3	0.2	0.2	0.2	-	-	-	-	-
600-700	C	12	8	6	16	19	18	(19)	-	-
	LWC	0.2	0.2	0.2	0.1	0.1	0.1	-	-	-
700-800	C	10	15	13	14	14	27	(30)	(20)	(11)
	LWC	0.4	0.4	0.4	0.3	0.2	0.1	-	-	-
800-950	C	20	15	15	18	16	17	(17)	(12)	(17)
	LWC	0.4	0.3	0.3	0.3	0.3	0.2	-	-	-
integrated	LWA	202	166	160	159	119	96	-	-	-

† C is average coverage in volume %, LWC is liquid water content of the clouds in g m^{-3}, the vertically integrated liquid water amount (LWA) is in g m^{-2}. The figures between parentheses represent coverages of ice clouds (except Ci).

Table 9c

Zonal average cloud cover and LWC[†]

March/April/May, Southern hemisphere

mbar		90-80	80-70	70-60	60-50	50-40	40-30	30-20	20-10	10-0
		degrees latitude								
500-600	C	-	-	-	-	-	11	16	12	7
	LWC	-	-	-	-	-	0.1	0.2	0.2	0.3
600-700	C	-	-	28	20	22	16	7	10	12
	LWC	-	-	0.1	0.1	0.1	0.2	0.3	0.2	0.2
700-800	C	(8)	(9)	42	30	15	16	17	18	10
	LWC	-	-	0.1	0.2	0.2	0.2	0.4	0.4	0.5
800-950	C	(3)	(7)	25	25	21	26	14	15	16
	LWC	-	-	0.2	0.3	0.3	0.3	0.3	0.3	0.4
integrated	LWA	-	-	145	193	147	192	184	185	191

[†] C is average coverage in volume %, LWC is liquid water content of the clouds in g m^{-3}, the vertically integrated liquid water amount (LWA) is in g m^{-2}. The figures between parentheses represent coverages of ice clouds (except Ci).

Table 9d

Zonal average cloud cover and LWC†

March/April/May, Northern hemisphere

mbar		degrees latitude 0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90
500-600	C	7	10	14	9	-	-	-	-	-
	LWC	0.3	0.2	0.1	0.1	-	-	-	-	-
600-700	C	12	7	7	12	18	16	17	-	-
	LWC	0.2	0.2	0.2	0.2	0.1	0.1	0.1	-	-
700-800	C	10	14	14	11	10	22	25	(26)	(11)
	LWC	0.5	0.5	0.4	0.4	0.2	0.2	0.1	-	-
800-950	C	16	12	11	20	15	17	15	(19)	(14)
	LWC	0.4	0.3	0.3	0.3	0.3	0.3	0.3	-	-
integrated	LWA	190	158	134	167	106	137	110	-	-

† C is average coverage in volume %, LWC is liquid water content of the clouds in g m^{-3}, the vertically integrated liquid water amount (LWA) is in g m^{-2}. The figures between parentheses represent coverages of ice clouds (except Ci).

Table 9e

Zonal average cloud cover and LWC†

June/July/August, Southern hemisphere

mbar		degrees latitude								
		90-80	80-70	70-60	60-50	50-40	40-30	30-20	20-10	10-0
500-600	C	-	-	-	-	-	10	15	10	9
	LWC	-	-	-	-	-	0.1	0.1	0.2	0.4
600-700	C	-	-	(24)	17	20	15	7	8	11
	LWC	-	-	-	0.2	0.2	0.2	0.3	0.3	0.3
700-800	C	(5)	(7)	(35)	25	13	15	16	15	10
	LWC	-	-	-	0.2	0.2	0.2	0.4	0.4	0.5
800-950	C	(2)	(7)	(18)	21	20	26	17	16	18
	LWC	-	-	-	0.3	0.3	0.3	0.3	0.3	0.4
integrated	LWA	-	-	-	179	156	187	177	176	227

† C is average coverage in volume %, LWC is liquid water content of the clouds in g m^{-3}, the vertically integrated liquid water amount (LWA) is in g m^{-2}. The figures between parentheses represent coverages of ice clouds (except Ci).

Table 9f

Zonal average cloud cover and LWC[†]

June/July/August, Northern hemisphere

mbar		0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90
		degrees latitude								
500-600	C	9	9	14	9	-	-	-	-	-
	LWC	0.3	0.2	0.1	0.1	-	-	-	-	-
600-700	C	16	18	11	12	18	16	18	-	-
	LWC	0.2	0.2	0.2	0.1	0.1	0.2	0.1	-	-
700-800	C	16	16	16	12	10	20	26	27	18
	LWC	0.5	0.5	0.5	0.4	0.3	0.2	0.1	0.1	0.1
800-950	C	19	14	12	18	15	18	17	21	19
	LWC	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2
integrated	LWA	253	197	158	162	115	153	120	90	75

[†] C is average coverage in volume %, LWC is liquid water content of the clouds in g m^{-3}, the vertically integrated liquid water amount (LWA) is in g m^{-2}.

Table 9g

Zonal average cloud cover and LWC[†]

September/October/November, Southern hemisphere

mbar		degrees latitude								
		90-80	80-70	70-60	60-50	50-40	40-30	30-20	20-10	10-0
500-600	**C**	-	-	-	-	-	11	17	12	7
	LWC	-	-	-	-	-	0.1	0.1	0.2	0.3
600-700	**C**	-	-	24	19	22	16	7	9	9
	LWC	-	-	0.1	0.1	0.1	0.2	0.2	0.2	0.2
700-800	**C**	(7)	(13)	35	28	13	15	15	16	9
	LWC	-	-	0.1	0.1	0.2	0.2	0.4	0.4	0.4
800-950	**C**	(3)	(6)	23	25	20	26	17	14	18
	LWC	-	-	0.2	0.3	0.3	0.3	0.3	0.4	0.4
integrated	**LWA**	-	-	128	159	138	190	168	190	183

[†] C is average coverage in volume %, LWC is liquid water content of the clouds in g m^{-3}, the vertically integrated liquid water amount (LWA) is in g m^{-2}. The figures between parentheses represent coverages of ice clouds (except Ci).

Table 9h

Zonal average cloud cover and LWC†

September/October/November, Northern hemisphere

mbar		degrees latitude 0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90
500-600	C	8	14	15	7	-	-	-	-	-
	LWC	0.3	0.2	0.1	0.1	-	-	-	-	-
600-700	C	15	15	6	9	17	17	22	-	-
	LWC	0.2	0.2	0.2	0.2	0.1	0.2	0.1	-	-
700-800	C	11	20	15	10	10	24	33	(28)	(16)
	LWC	0.4	0.4	0.5	0.4	0.2	0.2	0.1	-	-
800-950	C	17	12	11	19	16	19	22	(25)	(22)
	LWC	0.4	0.3	0.3	0.3	0.3	0.3	0.2	-	-
integrated	LWA	200	192	158	150	109	168	121	-	-

† C is average coverage in volume %, LWC is liquid water content of the clouds in g m^{-3}, the vertically integrated liquid water amount (LWA) is in g m^{-2}. The figures between parentheses represent coverages of ice clouds (except Ci).

Table 10a

Average time that air is in clouds[†].

December/January/February, Southern hemisphere

mbar		degrees latitude 90-80	80-70	70-60	60-50	50-40	40-30	30-20	20-10	10-0
500-600	$\overline{t_c}$	-	-	-	-	-	3.3	3.1	2.9	2.4
	$\overline{t_{nc}}$	-	-	-	-	-	30.4	14.7	18.4	28.4
600-700	$\overline{t_c}$	-	-	2.9	3.8	3.7	3.9	3.8	3.5	3.2
	$\overline{t_{nc}}$	-	-	14.9	14.5	12.9	24.4	44.3	28.0	20.0
700-950	$\overline{t_c}$	3.7	3.8	3.8	3.8	3.5	2.4	2.3	2.1	2.4
	$\overline{t_{nc}}$	44.4	28.1	12.0	13.1	18.1	10.3	11.3	10.3	11.8

[†] $\overline{t_c}$ is average time that air is in clouds, and $\overline{t_{nc}}$ is average time outside clouds (both in hours, averaged over all cloudtypes)

Table 10b

Average time that air is in clouds[†].

December/January/February, Northern hemisphere

mbar		degrees latitude 0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90
500-600	$\overline{t_c}$	2.5	3.0	3.1	3.4	-	-	-	-	-
	$\overline{t_{nc}}$	37.8	25.6	19.4	29.6	-	-	-	-	-
600-700	$\overline{t_c}$	3.4	3.6	3.9	4.1	3.9	4.0	4.0	-	-
	$\overline{t_{nc}}$	25.7	41.4	63.3	21.8	16.3	18.5	16.9	-	-
700-950	$\overline{t_c}$	2.4	2.1	2.4	2.8	3.7	4.1	4.4	4.1	4.6
	$\overline{t_{nc}}$	13.0	12.0	14.7	14.8	20.5	15.3	15.5	22.7	27.6

† $\overline{t_c}$ is average time that air is in clouds, and $\overline{t_{nc}}$ is average time outside clouds (both in hours, averaged over all cloudtypes)

Table 10c

Average time that air is in clouds[†]**.**

March/April/May, Southern hemisphere

mbar		degrees latitude								
		90-80	80-70	70-60	60-50	50-40	40-30	30-20	20-10	10-0
500-600	$\overline{t_c}$	-	-	-	-	-	3.2	3.1	2.8	2.3
	$\overline{t_{nc}}$	-	-	-	-	-	26.7	15.8	21.3	29.1
600-700	$\overline{t_c}$	-	-	4.0	3.8	3.7	3.9	3.8	3.5	3.0
	$\overline{t_{nc}}$	-	-	10.5	14.8	13.2	20.9	47.6	31.5	21.4
700-950	$\overline{t_c}$	4.0	3.9	4.2	3.6	3.4	2.5	2.3	2.1	2.1
	$\overline{t_{nc}}$	81.1	48.1	8.9	9.5	14.7	9.0	12.7	11.2	13.1

† $\overline{t_c}$ is average time that air is in clouds, and $\overline{t_{nc}}$ is average time outside clouds (both in hours, averaged over all cloudtypes)

Table 10d

Average time that air is in clouds†.

March/April/May, Northern hemisphere

mbar		0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90
		degrees latitude								
500-600	$\overline{t_c}$	2.3	2.4	3.4	3.7	-	-	-	-	-
	$\overline{t_{nc}}$	29.4	17.9	21.2	38.3	-	-	-	-	-
600-700	$\overline{t_c}$	3.0	3.2	3.3	3.8	3.7	3.7	3.7	-	-
	$\overline{t_{nc}}$	22.4	41.2	45.2	27.1	17.3	20.2	17.8	-	-
700-950	$\overline{t_c}$	2.1	1.9	3.0	2.6	3.6	3.7	3.8	3.9	4.3
	$\overline{t_{nc}}$	13.0	13.2	14.4	13.5	23.7	16.0	16.1	14.1	29.6

† $\overline{t_c}$ is average time that air is in clouds, and $\overline{t_{nc}}$ is average time outside clouds (both in hours, averaged over all cloudtypes)

Table 10e

Average time that air is in clouds†.

June/July/August, Southern hemisphere

mbar		degrees latitude								
		90-80	80-70	70-60	60-50	50-40	40-30	30-20	20-10	10-0
500-600	$\overline{t_c}$	-	-	-	-	-	3.2	3.1	2.9	2.9
	$\overline{t_{nc}}$	-	-	-	-	-	28.2	17.3	25.0	30.4
600-700	$\overline{t_c}$	-	-	3.6	3.7	3.7	3.9	3.9	3.4	2.9
	$\overline{t_{nc}}$	-	-	11.4	18.1	14.9	21.8	50.3	37.1	23.0
700-950	$\overline{t_c}$	3.4	4.0	3.9	3.8	3.5	2.6	2.4	2.1	2.3
	$\overline{t_{nc}}$	127.4	53.1	11.7	13.2	16.2	9.5	12.1	11.2	10.4

† $\overline{t_c}$ is average time that air is in clouds, and $\overline{t_{nc}}$ is average time outside clouds (both in hours, averaged over all cloudtypes)

Table 10f

Average time that air is in clouds[†].

June/July/August, Northern hemisphere

mbar		0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90
		degrees latitude								
500-600	$\overline{t_c}$	2.3	2.7	2.9	3.0	-	-	-	-	-
	$\overline{t_{nc}}$	22.7	28.0	17.7	32.3	-	-	-	-	-
600-700	$\overline{t_c}$	3.2	3.3	3.3	3.6	3.6	3.5	3.5	-	-
	$\overline{t_{nc}}$	16.6	15.2	27.8	27.7	16.4	18.1	15.6	-	-
700-950	$\overline{t_c}$	2.7	2.2	2.1	2.2	3.3	3.5	3.5	3.6	3.9
	$\overline{t_{nc}}$	13.9	12.4	13.3	12.0	22.1	14.5	13.6	11.5	17.1

† $\overline{t_c}$ is average time that air is in clouds, and $\overline{t_{nc}}$ is average time outside clouds (both in hours, averaged over all cloudtypes)

Table 10g

Average time that air is in clouds†.

September/October/November, Southern hemisphere

mbar		degrees latitude								
		90-80	80-70	70-60	60-50	50-40	40-30	30-20	20-10	10-0
500-600	$\overline{t_c}$	-	-	-	-	-	3.2	3.1	2.9	2.4
	$\overline{t_{nc}}$	-	-	-	-	-	25.9	15.7	21.9	32.4
600-700	$\overline{t_c}$	-	-	3.8	3.7	3.7	3.9	3.7	3.5	2.6
	$\overline{t_{nc}}$	-	-	12.0	15.8	13.1	20.5	53.2	34.5	25.1
700-950	$\overline{t_c}$	3.7	3.8	3.9	3.6	3.6	2.6	2.3	2.1	2.3
	$\overline{t_{nc}}$	88.8	42.0	13.1	10.2	17.6	9.4	12.1	11.1	13.2

† $\overline{t_c}$ is average time that air is in clouds, and $\overline{t_{nc}}$ is average time outside clouds (both in hours, averaged over all cloudtypes)

Table 10h

Average time that air is in clouds†.

September/October/November, Northern hemisphere

mbar		degrees latitude 0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90
500-600	$\overline{t_c}$	2.3	3.1	3.0	3.2	-	-	-	-	-
	$\overline{t_{nc}}$	26.5	18.9	17.4	40.6	-	-	-	-	-
600-700	$\overline{t_c}$	3.1	4.0	3.7	3.6	3.7	3.7	3.8	-	-
	$\overline{t_{nc}}$	18.3	23.4	56.0	37.3	18.6	17.8	13.5	-	-
700-950	$\overline{t_c}$	2.4	3.0	2.1	2.2	3.4	3.6	4.0	3.8	4.4
	$\overline{t_{nc}}$	13.4	16.6	14.6	12.1	22.2	13.1	11.0	10.8	18.3

† $\overline{t_c}$ is average time that air is in clouds, and $\overline{t_{nc}}$ is average time outside clouds (both in hours, averaged over all cloudtypes)

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Zonal average cloud characteristics for global atmospheric chemistry modelling

17 Project leader/Auther(s)

Henning Rodhe

18 Abstract (goal, method, technique, result etc.)

A zonal average cloud distribution for the lower (approximately 6 km) troposphere is derived from surface observartions of cloud occurrence and the average vertical extent of clouds. In addition, we use assessments of updraft velocities through convective clouds and lifetime estimates of stratiform clouds, to calculate the average time that air spends in clouds and the time between successive cloud encounters, as a function of latitude and altitude. The inferred cloud data compare well with satellite observations, but not very well with data derived from calculations with a general circulation model. We thus conclude that for such models more effort has to be devoted to develop cloud parameterizations in order to produce cloud distributions as needed for global atmospheric chemistry modelling.

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