KONINKLIJK NEDERLANDS METEOROLOGISCH INSTITUUT
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Wetenschappelijk Rapport W.R. 66-1 (R III-298-1966)

Dr. H.J. de Boer

Attenuation of solar radiation due to air pollution in Rotterdam and its surroundings.

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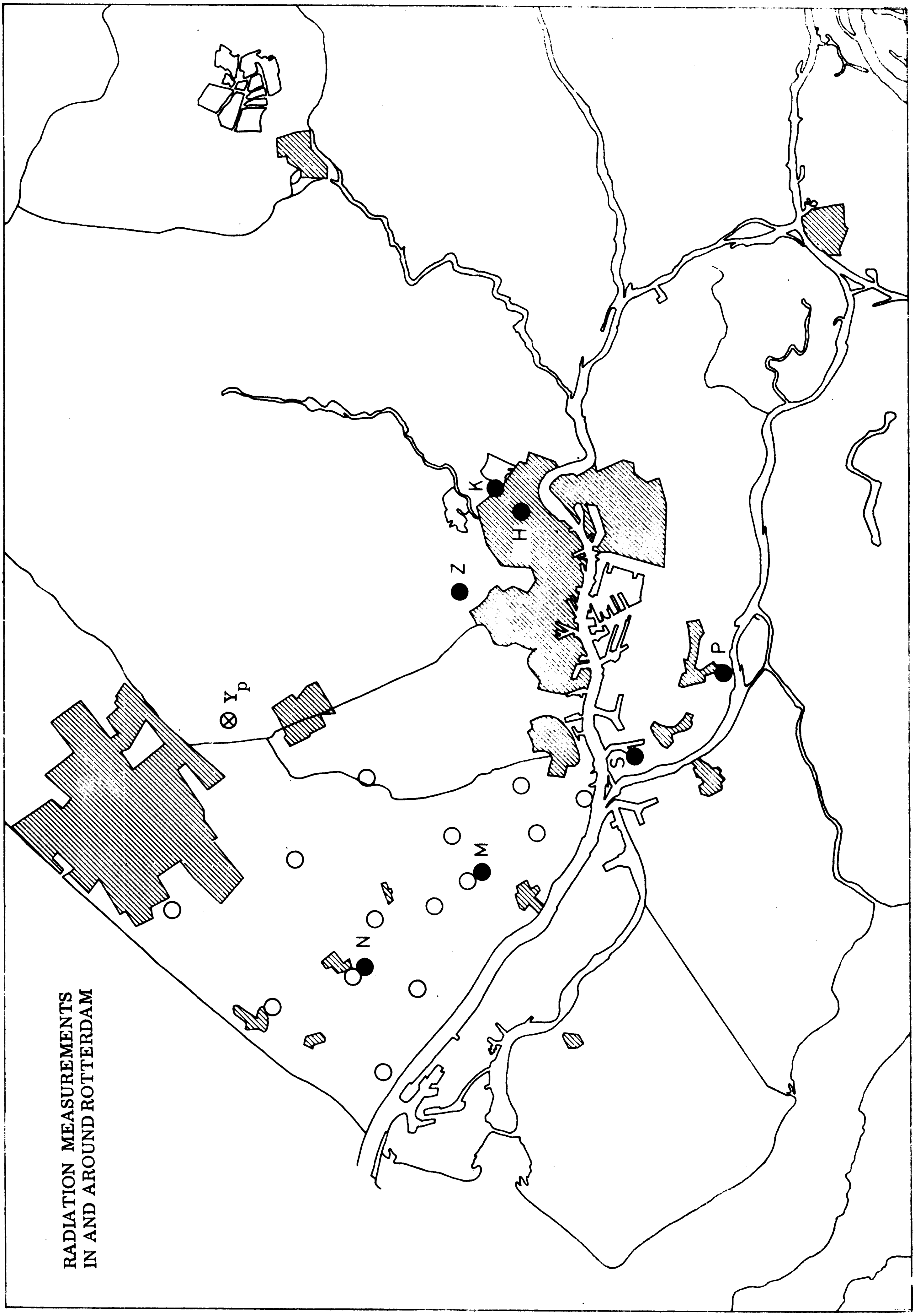
RADIATION MEASUREMENTS
IN AND AROUND ROTTERDAM

Fig. 1.

1. INTRODUCTION

One of the expedients for investigating the industrial air pollution in the region of the Nieuwe Waterweg near Rotterdam was the continuous measurement of global radiation at seven stations in and around Rotterdam. Global radiation is the solar radiation from sun and sky with wavelengths from 0.3 μ up to about 3 μ on a horizontal surface. This kind of radiation was measured with the aid of pyranometers of the Moll-Gorczynski type and recorded by a millivolt-meter with a printing device.

The seven stations, denoted by full black circles in fig. 1 were situated

1. at Naaldwijk (N) on the observation field of the "Experimental Station for the Culture of Vegetables and Fruit in Warehouses";
2. at Maasland (M) on a private agricultural farm;
3. at the Aerodrome Zestienhoven (Z) on the roof of the Meteorological Office;
4. on the fringe of Rotterdam near the locks of the Kralingse Verlaat (K);
5. in the city of Rotterdam on the roof of the Heliport (H);
6. at Poortugaal (P) near a Climatological Station of the K.N.M.I.;
7. at Pernis (S) on the roof of one of the buildings of the Royal Dutch Shell oil refinery.

From fig. 1 on which also city-limits are indicated, it may be seen that three stations are situated in a more or less rural area (N,M and P) and the remaining four stations in an industrial and urban area.

Though the horizons of the seven measuring sets are not completely free the part of the global radiation intercepted by obstacles, such as trees, buildings, chimneys, is negligible. Moreover, recordings of only those hours were evaluated in which the direct sun radiation could not be intercepted in any way. These hours, expressed in Local Apparent Time (L.A.T.), are

Jan	12 - 14	Apr	09 - 17	Jul	09 - 17	Oct	11 - 15
Feb	11 - 15	May	09 - 17	Aug	09 - 17	Nov	12 - 14
Mar	10 - 16	Jun	09 - 17	Sep	10 - 16	Dec	12 - 14

There was one station, namely P, where the intercepted sky radiation could amount to roughly 1% of the unintercepted sky radiation during the summers when the trees had their leaves. On the average the interrupted sky radiation amounted to much less than 1% of the unintercepted global radiation, since the direct solar radiation was never interrupted whenever the sun was shining during the mentioned hours throughout the months.

There was another station, namely K, where the sky radiation was intercepted to the same extent. From April 1960 that station showed not great, but nevertheless definite departures (10 - 20%)

from the expected amount of global radiation. In spite of the fact that both receiver and recorder were often checked, the origin of those departures could not be found. After the conclusion of the observations, it turned out that as a result of a small defect in the mechanism the deflection of the millivoltmeter from zero was strongly dependent on the orientation of the instrument. Therefore all measurements at Kralingse Verlaat were rejected.

The observation period started on November 1, 1959 and ended on November 1, 1961. Thus, two years of measurements at six stations had to be evaluated. The diagrams of the six stations were received at the K.N.M.I. where all necessary preparations for the evaluation were carried out every ten days. The evaluation proper of the amount of radiational energy per quarter of an hour into cal/cm^2.15 min. was performed by the "Afdeling Bewerking Waarnemingsuitkomsten T.N.O." at The Hague.

In order to be able to handle so great a number of observational data punching cards were used. In one card were punched the year, the month, the day, the quarter of an hour, the six stations each with its global radiation in cal per cm^2 15 min together with wind direction dd, windspeed ff, total amount of clouds N, amount of low (and middle clouds) N_h and visibility V estimated by the Meteorological Office at Zestienhoven in the relevant quarter of an hour. The quarters were numbered per 24 hours from 01 up to and including 96 from midnight up to midnight local time.

Berlage [1] has studied the influence of the air pollution on the global radiation received at the six stations from the measurements between November 1, 1959, up to August 1, 1960, but only for situations when N at Zestienhoven was equal to 0 or to 1. In the summary of his interim report he states that for several reasons only tentative indications on the existence of artificial attenuation could be given and that only a further investigation of all observational material will allow to give more exact answers to various questions.

2. GLOBAL RADIATION AS A FUNCTION OF WIND DIRECTION AND WIND SPEED FOR SIX STATIONS IN AND AROUND ROTTERDAM

If a year is divided into 4 climatological seasons, then from the two years of observation one may expect in the winter season (Dec., Jan. and Feb.) during the interval 1-11-1959 up to 1-11-1961 1889 values of global radiation; in the spring season 5392 values; in the summer season 5888 values and in the fall season 2912 values for any of the six stations. Every station shows gaps in the series of measurements and in order to avoid a comparison of heterogeneous material, we took into consideration only the values of global radiation of those quarters of an hour which are present for all six stations. This condition reduces the number of observations in the winter season to 800, in the spring season to 3510, in the summer season to 2128 and in the fall season to 1968.

For each of the four seasons the number of observations is mechanically split up into 37 classes according to wind direction , namely 00 (calm), 01, 02, 03, ..., 35 and 36, and into 7 classes according to wind speed, namely 02 is 1-3 knots, 03 is 4-6 knots, 04 is 7-10 knots, 05 is 11-16 knots, 06 is 17-21 knots, 07 is 22-27 knots, 08 is 28-33 knots and higher.

After having studied the material thus arranged, it turned out that there existed no appreciable relationship between the amount of global radiation and wind speed. Therefore the speed classes for every direction were recombined, so that finally the number of observations, each extending over a quarter of an hour, only have been split into 37 classes according to wind direction.

The result of this classification may be found in table I, where under the heading of the season the six stations show how much global radiation has been received on the average for every of the 36 wind directions and for calms; this amount of energy is expressed in cal/cm^2.15 min. up to one decimal and has been placed in the left-hand part of the column headed by the particular wind direction. In the right-hand part of each column the amount of radiational energy for each of the six stations expressed in a percentage of the mean for the six stations has been inserted.

As an example, for the winter season and direction 06 Heliport shows an amount of energy of 5.8 cal/cm^2.15 min. averaged over 38 observations. The average energy of the six stations amounts to 5.9 cal/cm^2.15 min. Therefore Heliport has only 98% of the average energy. Naaldwijk appears to have an amount of energy equal to 6.2 and Maasland 6.4 averaged over 38 observations, the percentages are therefore 105 and 108 respectively. In the left-hand part of the penultimate column, headed by "TOTAL", the weighted mean of the energy, averaged over all 37 classes and for each of the six stations is inserted; in the right-hand part the percentages of the average of the six stations are found. As an example, for Heliport in the winter season the mean global radiation is 3.7 cal/cm^2.15 min., which is 92% of the mean for all six stations amounting to 4.0 cal/cm^2.15 min.

In the left-hand part of the last column the ratio of the amount of energy in column 00 and the amount of energy in column total for each of the six stations has been entered. In the right-hand part of this column those ratios are expressed in percentages of the mean of the six ratios.

If we want to compare the values of the global radiation for the six stations and to study resulting differences between the various stations or between various wind directions for each separate stations, then we have to know the error in any of the many values in order to judge whether a difference between two values is significant or not.

Suppose that we have satisfied ourselves concerning the significance of occurring differences in global radiation then the question arises what the cause is of those differences. For example, a difference may be due solely to a difference in cloudiness, or to a difference in air pollution or to both causes. Moreover an industrial area may give rise to a local circulation due to the heat production in that area. This fact has been pointed out by Schmidt and Boer [3] .

TABLE I. Average amount of global radiation in cal/cm^2 15 min of six stations for each wind direction dd in each of the four seasons and the same averages expressed in percentages of the mean of those of the six stations.

Winter

dd	00	01	02	03	04	05	06	07	08	09	10
Naaldwijk	3.3 106	2.4 141	2.4 109	1.8 86	5.7 102	4.7 89	6.2 105	4.3 110	4.2 117	2.9 100	5.4 98
Maasland	3.7 119	2.1 124	2.7 123	2.7 129	6.0 107	5.7 108	6.4 108	3.8 97	4.1 114	2.9 100	6.0 109
Pernis	2.4 77	1.3 76	2.0 91	2.1 100	5.1 91	4.9 92	5.4 92	3.7 95	3.1 86	2.7 93	5.5 100
Poortugaal	3.1 100	2.1 124	1.8 82	1.6 76	5.4 96	5.1 96	5.5 93	3.6 92	3.6 100	2.8 97	5.8 105
Zestienhoven	3.7 119	1.4 82	2.4 109	2.3 110	6.2 111	5.8 109	6.0 102	4.7 121	3.8 106	3.6 124	5.7 104
Heliport	2.5 81	0.9 53	1.8 82	2.1 100	5.0 89	5.5 104	5.8 98	3.6 92	3.1 86	2.8 97	4.8 87
Mean	3.1	1.7	2.2	2.1	5.6	5.3	5.9	3.9	3.6	2.9	5.5
nr.observations	23	1	8	9	11	22	38	10	22	20	8

dd	11	12	13	14	15	16	17	18	19	20	21
Naaldwijk	3.8 106	4.4 105	4.8 107	5.3 106	4.0 105	4.3 113	3.2 114	3.4 110	4.9 100	3.1 97	2.9 112
Maasland	3.9 108	4.4 105	4.6 102	5.1 102	3.6 95	4.2 111	3.0 107	3.2 103	5.2 106	3.8 119	3.0 115
Pernis	3.4 94	3.8 90	4.2 93	4.6 92	3.6 97	3.5 92	2.7 96	2.8 90	4.5 92	3.0 94	2.5 96
Poortugaal	3.7 103	4.1 98	4.7 104	5.1 102	4.0 105	3.7 97	2.6 93	3.0 97	5.0 102	3.0 94	2.5 96
Zestienhoven	3.7 103	4.3 102	4.8 107	5.2 104	4.0 105	3.7 97	2.7 96	3.2 103	5.3 108	3.3 103	2.3 88
Heliport	3.0 83	3.9 93	4.1 91	4.9 98	3.7 97	3.3 87	2.6 93	3.1 100	4.5 92	3.1 97	2.1 81
Mean	3.6	4.2	4.5	5.0	3.8	3.8	2.8	3.1	4.9	3.2	2.6
nr. observations	24	37	37	25	39	51	39	35	54	23	35

dd	22	23	24	25	26	27	28	29	30	31	32
Naaldwijk	4.5 110	3.9 108	4.6 110	5.5 106	6.4 112	5.5 110	5.2 108	4.2 108	3.2 97	4.1 114	- -
Maasland	4.4 107	3.9 108	4.6 110	5.2 100	6.1 107	5.9 118	5.0 104	4.1 105	3.8 115	5.1 142	- -
Pernis	4.0 98	3.5 97	3.7 88	4.7 90	4.5 79	3.8 76	4.1 85	3.2 82	3.1 94	3.1 86	- -
Poortugaal	4.1 100	3.6 100	4.5 107	5.0 96	5.5 96	5.3 106	4.3 90	4.0 103	3.0 91	3.5 97	- -
Zestienhoven	4.0 98	3.5 97	4.3 102	5.8 112	6.6 116	5.2 104	5.2 108	4.2 108	3.7 112	3.2 89	- -
Heliport	3.8 93	3.2 89	3.7 88	5.1 98	5.1 89	4.3 86	5.0 104	3.8 97	3.2 97	2.6 72	- -
Mean	4.1	3.6	4.2	5.2	5.7	5.0	4.8	3.9	3.3	3.6	-
nr. observations	27	25	14	20	44	8	14	23	8	7	0

Winter

TABLE I (cont'd)

dd	33	34	35	36	TOTAL	00/total
Naaldwijk	3.2 107	2.4 89	1.6 89	3.2 110	4.3 108	0.77 98
Maasland	3.5 117	2.6 96	1.9 106	3.1 107	4.3 108	0.86 110
Pernis	2.3 77	2.6 96	1.8 100	2.9 100	3.7 92	0.65 84
Poortugaal	3.0 100	2.9 107	1.9 106	3.0 103	4.0 100	0.78 100
Zestienhoven	2.9 97	2.8 104	1.9 106	2.9 100	4.3 105	0.88 113
Heliport	3.4 113	2.8 104	1.8 100	2.4 83	3.7 92	0.68 88
Mean	3.0	2.7	1.8	2.9	4.0	0.78
nr. observations	3	9	8	19	800	

Spring

dd	00	01	02	03	04	05	06	07	08	09	10
Naaldwijk	4.9 109	12.9 124	11.7 127	10.8 114	8.9 117	9.2 114	71. 115	6.8 115	8.1 112	10.4 107	8.7 107
Maasland	5.4 120	11.7 112	9.4 102	9.7 102	7.5 99	8.5 105	6.7 108	6.4 108	7.7 107	10.1 104	8.4 104
Pernis	2.8 62	8.8 85	7.9 86	8.7 92	6.7 88	7.7 95	5.7 92	5.5 93	6.7 93	9.0 93	7.6 94
Poortugaal	4.7 104	9.6 92	8.5 92	9.0 95	7.7 101	7.6 94	5.9 95	5.8 98	7.2 100	9.6 99	8.1 100
Zestienhoven	4.2 93	9.6 92	8.8 96	9.4 99	7.3 96	7.6 94	5.9 95	5.4 92	6.7 93	9.3 96	7.9 98
Heliport	5.3 118	9.6 92	9.0 98	9.3 98	7.4 97	7.9 98	5.8 94	5.5 93	6.9 96	9.6 99	8.0 99
Mean	4.5	10.4	9.2	9.5	7.6	8.1	6.2	5.9	7.2	9.7	8.1
nr. observations	48	57	76	103	132	115	134	109	124	116	136

dd	11	12	13	14	15	16	17	18	19	20	21
Naaldwijk	9.3 108	8.6 104	6.9 103	8.0 107	7.6 115	7.6 112	9.1 105	7.3 109	9.0 110	8.0 111	8.1 117
Maasland	8.7 101	8.2 99	6.6 99	7.8 104	6.4 97	7.0 103	8.9 102	7.3 109	8.7 106	7.6 106	7.6 110
Pernis	8.2 95	7.9 95	6.4 96	7.0 93	5.6 85	6.0 88	8.0 92	6.3 94	7.5 91	6.7 93	6.2 90
Poortugaal	8.6 100	8.2 99	7.2 107	7.5 100	6.2 94	7.0 103	8.7 100	6.5 97	8.2 100	7.4 103	6.9 100
Zestienhoven	8.3 97	8.0 96	6.5 97	7.3 97	7.3 111	6.9 101	8.9 102	6.6 99	8.0 98	6.8 94	6.3 91
Heliport	8.6 100	8.7 105	6.4 96	7.3 97	6.7 102	6.6 97	8.7 100	6.1 91	7.8 95	6.9 96	6.5 94
Mean	8.6	8.3	6.7	7.5	6.6	6.8	8.7	6.7	8.2	7.2	6.9
nr. observations	83	56	50	32	27	54	34	67	97	105	64

Spring

TABLE I (cont'd)

dd	22	23	24	25	26	27	28	29	30	31	32
Naaldwijk	9.6 114	9.5 127	10.0 119	9.2 118	9.6 116	8.7 112	8.6 115	9.0 120	9.2 110	9.5 109	11.3 116
Maasland	9.0 107	8.1 108	9.0 107	8.5 109	9.1 110	8.4 108	8.0 107	8.1 108	8.7 104	9.2 106	10.6 109
Pernis	7.9 94	6.4 85	7.6 90	7.2 92	7.3 88	7.0 90	6.9 92	7.0 93	7.7 92	8.2 94	9.2 95
Poortugaal	8.5 101	7.1 95	8.3 99	7.2 92	8.5 102	7.8 100	7.1 95	7.1 95	8.2 98	8.4 97	8.2 85
Zestienhoven	7.9 94	7.1 95	8.3 99	7.7 99	7.8 94	7.8 100	7.2 96	7.5 100	8.3 99	8.6 99	9.1 94
Heliport	7.8 93	6.6 88	7.3 87	6.8 87	7.5 90	7.0 90	6.9 92	6.7 89	8.1 96	8.6 99	9.5 98
Mean	8.4	7.5	8.4	7.8	8.3	7.8	7.5	7.5	8.4	8.7	9.7
nr. observations	99	86	126	114	118	151	150	109	107	41	58

dd	33	34	35	36	TOTAL	00/total
Naaldwijk	9.9 114	11.2 113	10.7 116	12.0 122	9.3 115	0.53 95
Maasland	9.2 106	10.5 106	10.1 110	11.1 113	8.6 106	0.63 113
Pernis	8.3 95	9.2 93	8.4 91	8.8 90	7.4 91	0.38 68
Poortugaal	8.5 98	9.4 95	8.5 92	9.0 92	7.9 98	0.59 106
Zestienhoven	8.3 95	9.5 96	8.7 95	9.3 95	7.8 96	0.54 97
Heliport	8.1 93	9.7 98	8.5 92	8.4 86	7.6 94	0.70 126
Mean	8.7	9.9	9.2	9.8	8.1	0.56
nr. observations	93	133	145	161	3510	

Summer

dd	00	01	02	03	04	05	06	07	08	09	10
Naaldwijk	6.0 107	14.0 124	7.4 116	8.9 107	7.4 95	11.2 101	9.0 112	7.7 95	7.0 104	10.0 103	10.3 98
Maasland	5.3 95	13.6 120	7.1 111	9.3 112	8.0 103	11.1 100	7.5 94	8.1 100	6.7 100	9.4 97	10.1 96
Pernis	4.5 80	10.1 89	6.4 100	7.7 93	7.5 96	11.2 101	8.0 100	6.6 81	5.9 88	9.6 99	10.0 95
Poortugaal	5.6 100	8.0 71	5.8 91	7.3 88	7.1 91	9.9 89	7.8 98	8.3 102	6.9 103	10.0 103	11.0 105
Zestienhoven	6.0 107	11.5 102	6.2 97	8.7 105	8.2 105	10.9 98	7.7 96	8.1 100	6.3 94	9.6 99	10.8 103
Heliport	6.5 116	10.8 96	5.7 89	8.0 96	8.8 113	12.4 112	7.8 98	9.8 121	7.2 107	9.5 98	11.1 106
Mean	5.6	11.3	6.4	8.3	7.8	11.1	8.0	8.1	6.7	9.7	10.5
nr. observations	24	12	24	36	34	26	10	22	16	11	30

Summer

TABLE I (cont'd)

dd	11	12	13	14	15	16	17	18	19	20	21
Naaldwijk	12.8 108	12.5 107	11.9 103	10.2 103	11.2 94	7.6 96	8.2 122	6.2 107	6.4 103	8.6 102	7.5 107
Maasland	11.1 94	11.5 98	11.4 98	10.0 101	11.8 99	7.8 99	7.1 106	6.4 110	6.8 110	8.6 102	7.3 104
Pernis	12.1 103	11.7 100	11.8 102	9.8 99	11.9 100	7.6 96	5.9 88	5.5 95	6.1 98	8.3 99	7.0 100
Poortugaal	11.9 101	12.3 105	11.9 103	10.0 101	12.0 101	8.3 105	6.4 96	5.7 98	6.5 105	8.5 101	6.5 93
Zestienhoven	11.1 94	10.4 89	11.2 97	9.4 95	11.8 99	7.9 100	6.3 94	5.4 93	5.9 95	8.1 96	6.6 94
Heliport	11.5 97	11.8 101	11.5 99	9.9 100	12.4 104	8.4 106	6.1 91	5.7 98	6.2 100	8.2 98	7.2 103
Mean	11.8	11.7	11.6	9.9	11.9	7.9	6.7	5.8	6.2	8.4	7.0
nr.observations	26	24	32	22	24	20	18	73	83	48	58

dd	22	23	24	25	26	27	28	29	30	31	32
Naaldwijk	8.0 104	9.5 125	11.7 111	12.0 111	10.6 106	10.1 111	9.6 109	10.5 108	11.9 111	11.6 112	12.7 117
Maasland	8.3 108	8.3 109	11.0 105	11.8 109	10.7 107	9.9 109	9.3 106	10.5 108	11.8 110	11.4 110	11.4 105
Pernis	7.2 94	6.8 89	10.3 98	10.0 93	9.2 92	8.5 93	8.2 93	9.3 96	10.0 93	10.1 97	10.9 100
Poortugaal	7.7 100	6.9 91	10.1 96	10.6 98	10.1 101	8.7 96	8.9 101	9.5 98	9.7 91	9.7 93	10.4 95
Zestienhoven	7.5 97	6.8 89	9.8 93	10.5 97	9.8 98	8.7 96	8.3 94	9.4 97	10.5 98	10.2 98	10.6 97
Heliport	7.3 95	7.4 97	10.0 95	9.8 91	9.5 95	8.6 95	8.2 93	8.8 91	10.0 93	9.5 91	9.2 84
Mean	7.7	7.6	10.5	10.8	10.0	9.1	8.8	9.7	10.7	10.4	10.9
nr.observations	34	74	120	114	180	196	168	156	97	92	60

dd	33	34	35	36	TOTAL	00/total
Naaldwijk	14.2 123	11.3 130	12.2 117	10.4 132	10.2 111	0.59 96
Maasland	12.7 110	9.2 106	12.6 121	9.3 118	9.9 108	0.54 88
Pernis	11.7 102	8.4 97	11.3 109	6.2 78	8.8 96	0.51 83
Poortugaal	9.7 84	7.5 86	8.4 81	6.8 86	8.9 97	0.63 103
Zestienhoven	10.4 90	7.4 85	8.9 86	7.6 96	8.9 97	0.67 110
Heliport	10.3 90	8.1 93	9.2 88	7.1 90	8.8 96	0.74 121
Mean	11.5	8.7	10.4	7.9	9.2	0.61
nr.observations	44	60	32	28	2128	

Fall

TABLE I (cont'd)

dd	00	01	02	03	04	05	06	07	08	09	10
Naaldwijk	5.8 118	7.7 113	9.7 118	9.3 112	8.2 102	9.6 107	8.9 110	10.5 111	7.1 104	5.2 91	5.9 102
Maasland	5.9 120	7.0 103	9.0 110	8.9 107	8.3 104	9.5 106	9.0 111	10.1 106	7.4 109	5.6 98	5.9 102
Pernis	4.1 84	6.3 93	7.9 96	7.5 90	7.5 97	8.4 93	7.2 89	9.0 95	6.5 96	5.7 100	5.8 100
Poortugaal	5.2 106	6.1 90	7.6 93	7.3 88	7.5 94	8.6 96	7.8 96	9.2 97	6.7 99	5.5 96	5.7 98
Zestienhoven	4.4 90	7.1 104	7.5 91	8.6 104	8.5 106	9.4 104	7.9 98	9.4 99	6.6 97	5.9 104	5.9 102
Heliport	4.2 86	6.8 100	7.4 90	8.0 96	8.0 100	8.5 94	7.5 93	9.0 95	6.6 97	5.9 104	5.7 98
Mean	4.9	6.8	8.2	8.3	8.0	9.0	8.1	9.5	6.8	5.7	5.8
nr. observations	56	25	24	22	42	26	30	39	57	71	90

dd	11	12	13	14	15	16	17	18	19	20	21
Naaldwijk	8.6 101	7.7 99	8.7 112	6.3 105	7.9 107	6.3 109	5.1 102	4.8 107	4.3 108	5.9 116	7.1 111
Maasland	8.8 104	7.9 101	8.1 104	6.1 102	7.8 105	6.1 105	5.0 100	4.9 109	4.3 108	5.5 108	6.8 106
Pernis	8.4 99	7.7 99	7.4 95	5.9 98	7.1 96	5.5 95	4.8 96	4.2 93	3.8 95	4.8 94	5.8 91
Poortugaal	8.2 96	7.8 100	7.6 97	6.1 102	6.9 93	5.7 98	4.8 96	4.3 96	3.7 92	5.0 98	6.1 95
Zestienhoven	8.6 101	7.8 100	7.8 100	5.9 98	7.3 99	5.8 100	5.3 106	4.6 102	4.0 100	4.9 96	6.6 103
Heliport	8.4 99	7.9 101	7.5 96	6.0 100	7.2 97	5.7 98	4.9 98	4.4 98	3.7 92	4.4 86	5.8 91
Mean	8.5	7.8	7.8	6.0	7.4	5.8	5.0	4.5	4.0	5.1	6.4
nr. observations	63	38	50	33	52	69	96	94	103	126	66

dd	22	23	24	25	26	27	28	29	30	31	32
Naaldwijk	6.7 106	6.8 113	6.7 126	7.5 121	6.7 112	6.9 115	5.2 127	5.8 107	6.0 115	7.1 108	7.9 108
Maasland	6.6 105	6.2 103	5.8 109	6.7 108	5.9 98	6.1 102	4.2 102	5.8 107	5.8 112	6.9 105	7.7 105
Pernis	6.3 100	5.6 93	4.7 89	5.8 94	5.7 95	5.5 92	3.6 88	4.4 81	4.9 94	6.2 94	7.2 99
Poortugaal	6.2 98	6.1 102	5.1 96	5.9 95	6.3 105	5.8 97	4.3 105	5.5 102	4.5 87	6.1 92	6.5 89
Zestienhoven	6.0 95	6.1 102	4.7 89	5.7 92	6.0 100	5.9 98	3.8 93	5.6 104	5.2 100	6.8 103	7.2 99
Heliport	5.8 92	5.4 90	5.0 94	5.6 90	5.2 87	6.1 102	3.6 88	5.2 96	4.7 90	6.8 103	7.3 100
Mean	6.3	6.0	5.3	6.2	6.0	6.0	4.1	5.4	5.2	6.6	7.3
nr. observations	83	82	62	70	64	56	34	26	40	32	32

Fall

TABLE I (cont'd)

dd	33	34	35	36	TOTAL	00/total	year total
Naaldwijk	8.9 117	7.8 111	7.1 106	8.7 118	6.8 110	0.85 107	8.5 113
Maasland	8.1 107	7.7 110	7.9 118	7.8 105	6.5 105	0.91 114	8.0 106
Pernis	6.8 89	6.8 97	5.7 85	6.5 88	5.8 94	0.71 89	7.0 93
Poortugaal	6.7 88	6.4 91	6.4 96	7.5 101	6.0 97	0.87 109	7.3 97
Zestienhoven	7.6 100	6.6 94	6.5 97	7.5 101	6.1 98	0.72 92	7.3 97
Heliport	7.6 100	6.5 93	6.4 96	6.6 89	5.9 95	0.71 91	7.1 94
Mean	7.6	7.0	6.7	7.4	6.2	0.80	7.55
nr. observations	39	27	23	26	1968		

As a consequence of such local circulation systems and the production of air pollution differences in cloudiness may occur.

We may therefore say that the values of the global radiation as shown in table I depend, apart from the sun's elevation, on cloudiness, on air pollution and on cloudiness due to the presence of an industrial area. It is our intention to analyse various sets of values of global radiation in such a way that the attenuation of solar radiation caused by each of the three quantities, may be determined.

3. ESTIMATION OF ERRORS IN THE MEASUREMENTS

If we want to study the cause of the differences in global radiation between various stations under the same conditions, then we have to know whether those differences as displayed in table I are significant or in simple words, whether those differences may be considered as real.

In the first place estimations of the possible errors in the determination of the values in cal/cm^2.15 min. in table I have to be made. When the recording of the millivoltmeter is read or better said when the mean deflection during 15 minutes of registration from zero is estimated in mm, this is done to the nearest millimeter. This means that an error of $\pm$ 0.5 mm is introduced. Examples of estimates of the standard deviation of the average 15-minutes values of global radiation at the six stations for each climatological season and for the wind directions 19, 03, 12, 29, 36, calm and all directions together have been given in table II. The direction 19 has been taken since it is representative for cases when air pollution from Shell Pernis passes over Vlaardingen. Taking the gustiness of the wind into account the direction 19 has been computed as the weighted mean of (18) + (19) + (20), the weights being the numbers of observation. The case that the air pollution from The Hague passes over Naaldwijk is represented by the direction 03 or rather the weighted mean of (02) + (03) + (04). The direction 36 has been chosen because The Hague is situated north of Maasland. The direction 12 has been selected as the direction when the wind from Rotterdam passes over Maasland and Naaldwijk. The direction 29 has been chosen as a direction from where no artificial air pollution flows over Naaldwijk and Maasland. For the first wind direction these estimations are given in greater detail. Thus, in column (1) the average 15-minutes value has been inserted. In column (2) we find the percentual error of the value in (1) due to the reading.

Due to the temperature dependence of the thermopile, to the more than linear decrease in absorption of the black paint on the thermopile when the cosine of the sun's altitude is increasing and to similar irregularities the values in (1) show an error which is generally assumed to amount to 5%. This percentage has been indicated in column (3). The effect of (2) and (3) has been collected in (4) as an amount of calories/cm^2.15 min.

There is still another source of error. The average values in (1) have originated from many different values as a result of varying cloud amounts and cloud genera. The statistical relationship between

TABLE II. Determination of the error in the average amount of global radiation for some selected wind directions in the four seasons and for the six stations.

Season I - winter (Dec.,Jan.,Feb.)

	wind 19;n=112						wind 03;n=28		wind 12;n=98	
Naaldwijk	3.8	±3.6%	5%	±0.35	±1.47	±0.14	3.7	±0.26	4.4	±0.15
Maasland	4.1	±3.3%	5%	±0.36	±1.48	±0.14	4.2	±0.27	4.4	±0.15
Pernis	3.3	±3.6%	5%	±0.31	±1.43	±0.14	3.4	±0.26	3.9	±0.15
Poortugaal	3.7	±3.0%	5%	±0.32	±1.44	±0.14	3.4	±0.25	4.2	±0.15
Zestien-hoven	3.9	±3.3%	5%	±0.36	±1.48	±0.14	4.1	±0.26	4.3	±0.15
Heliport	3.6	±3.8%	5%	±0.33	±1.45	±0.14	3.4	±0.26	3.7	±0.15
	(1)	(2)	(3)	(4)	(5)	(6)	(1)	(6)	(1)	(6)

Season II - spring (Mar.,Apr.,May)

	wind 19;n=269						wind 03;n=312		wind 12;n=189	
Naaldwijk	8.1	±1.7%	5%	±0.54	±2.54	±0.16	10.2	±0.15	8.4	±0.19
Maasland	7.9	±1.8%	5%	±0.53	±2.53	±0.16	8.7	±0.15	8.0	±0.18
Pernis	6.7	±2.0%	5%	±0.47	±2.47	±0.16	7.7	±0.14	7.6	±0.18
Poortugaal	7.4	±1.7%	5%	±0.50	±2.50	±0.16	8.3	±0.14	8.1	±0.18
Zestien-hoven	7.1	±1.9%	5%	±0.49	±2.49	±0.16	8.4	±0.14	7.7	±0.18
Heliport	6.9	±2.2%	5%	±0.49	±2.49	±0.16	8.4	±0.15	8.0	±0.19

Season III - summer (Jun.,Jul.,Aug.)

	wind 19;n=222						wind 03;n=94		wind 12;n=82	
Naaldwijk	7.0	±2.0%	5%	±0.49	±2.67	±0.18	8.2	±0.28	12.1	±0.32
Maasland	7.2	±1.9%	5%	±0.50	±2.68	±0.18	8.5	±0.28	11.0	±0.32
Pernis	6.5	±2.1%	5%	±0.46	±2.64	±0.18	7.4	±0.27	11.5	±0.32
Poortugaal	6.7	±1.9%	5%	±0.46	±2.64	±0.18	6.9	±0.27	11.8	±0.32
Zestien-hoven	6.3	±2.1%	5%	±0.45	±2.63	±0.18	8.1	±0.27	10.8	±0.31
Heliport	6.6	±2.2%	5%	±0.48	±2.66	±0.18	8.0	±0.28	11.3	±0.32

TABLE II. Determination of the error in the average amount of global radiation for some selected wind directions in the four seasons and for the six stations.

Season IV - autumn (Sep.,Oct.,Nov.)

	wind 19;n=323						wind 03;n=88		wind 12;n=151	
Naaldwijk	5.1	±2.8%	5%	±0.40	±1.94	±0.11	8.9	±0.23	8.4	±0.17
Maasland	4.9	±2.9%	5%	±0.39	±1.93	±0.11	8.7	±0.22	8.4	±0.17
Pernis	4.3	±3.0%	5%	±0.34	±1.88	±0.10	7.6	±0.22	7.9	±0.17
Poortugaal	4.4	±2.8%	5%	±0.34	±1.88	±0.10	7.5	±0.22	7.9	±0.17
Zestienhoven	4.5	±3.0%	5%	±0.36	±1.90	±0.11	8.2	±0.22	8.1	±0.17
Heliport	4.2	±3.4%	5%	±0.35	±1.89	±0.11	7.9	±0.22	8.0	±0.17
	(1)	(2)	(3)	(4)	(5)	(6)	(1)	(6)	(1)	(6)

(1) Average 15-minutes value of the global radiation in cal/cm^2 for windspeeds from 1 - 5 knots;

(2) percentual error due to reading the diagram of one observation of 15 minutes to the nearest full mm.;

(3) error due to instrument sensitivity for temperature during an interval of 15 minutes in %;

(4) (2) + (3) in cal/cm^2.15 minutes;

(5) (4) + estimated error in (1) per 15 minutes observation owing to the distribution of values of which the value in (1) is its average;

(6) estimated standard variation of (1) or the error inserted in $(5)/\sqrt{n}$.

TABLE II. Season I - winter (Dec.,Jan.,Feb.)

	wind 29;n=45		wind 36;n=28		calm;n=23		wind 01-36;n=800			
Naaldwijk	4.5	±0.18	2.7	±0.19	3.3	±0.30	4.3	8.4%	±1.41	±0.050
Maasland	4.5	±0.18	2.8	±0.19	3.7	±0.30	4.3	8.3%	±1.46	±0.052
Pernis	3.5	±0.17	2.5	±0.19	2.4	±0.29	3.7	8.5%	±1.41	±0.050
Poortugaal	4.0	±0.18	2.7	±0.19	3.1	±0.29	4.0	8.0%	±1.42	±0.051
Zestienhoven	4.3	±0.18	2.8	±0.19	3.7	±0.30	4.3	8.3%	±1.46	±0.052
Heliport	3.9	±0.18	2.4	±0.19	2.5	±0.29	3.7	8.8%	±1.45	±0.052
	(1)	(6)	(1)	(6)	(1)	(6)	(1)	(2)+(3)	(5)	(6)

Season II - spring (Mar.,Apr.,May)

	wind 29;n=366		wind 36;n=363		calm;n=48		wind 01-36;n=3510			
Naaldwijk	8.9	±0.15	11.7	±0.14	4.9	±0.34	9.3	6.6%	±2.61	±0.044
Maasland	8.5	±0.15	10.8	±0.14	5.4	±0.35	8.6	6.6%	±2.57	±0.043
Pernis	7.5	±0.15	8.6	±0.13	2.8	±0.33	7.4	6.8%	±2.50	±0.042
Poortugaal	7.8	±0.15	9.0	±0.14	4.7	±0.34	7.9	6.6%	±2.52	±0.042
Zestienhoven	8.0	±0.15	9.1	±0.14	4.2	±0.34	7.8	6.7%	±2.52	±0.042
Heliport	7.7	±0.15	8.6	±0.14	5.3	±0.35	7.6	7.0%	±2.53	±0.043

Season III - summer (Jun.,Jul.,Aug.)

	wind 29;n=421		wind 36;n=72		calm;n=24		wind 01-36;n=2128			
Naaldwijk	10.1	±0.14	11.8	±0.34	6.0	±0.53	10.2	6.35%	±2.85	±0.062
Maasland	10.3	±0.14	11.5	±0.34	5.3	±0.53	9.9	6.4%	±2.84	±0.062
Pernis	9.0	±0.13	9.1	±0.33	4.5	±0.52	8.8	6.6%	±2.76	±0.060
Poortugaal	9.3	±0.14	7.7	±0.32	5.6	±0.53	8.9	6.5%	±2.76	±0.060
Zestienhoven	9.2	±0.14	8.8	±0.32	6.0	±0.53	8.9	6.5%	±2.76	±0.060
Heliport	8.9	±0.14	8.7	±0.33	6.5	±0.54	8.8	6.7%	±2.77	±0.060

Season IV - autumn (Sep.,Oct.,Nov.)

	wind 29;n=100		wind 36;n=74		calm;n=56		wind 01-36;n=1968			
Naaldwijk	5.8	±0.19	8.2	±0.25	5.8	±0.26	6.8	7.1%	±2.02	±0.046
Maasland	5.4	±0.19	7.8	±0.25	5.9	±0.26	6.5	7.2%	±2.01	±0.045
Pernis	4.3	±0.18	6.4	±0.24	4.1	±0.25	5.8	7.4%	±1.97	±0.044
Poortugaal	4.8	±0.18	7.0	±0.24	5.2	±0.26	6.0	7.1%	±1.97	±0.044
Zestienhoven	4.9	±0.19	7.4	±0.25	4.4	±0.25	6.1	7.3%	±1.99	±0.045
Heliport	4.6	±0.18	6.7	±0.24	4.2	±0.25	5.9	7.5%	±1.98	±0.045
	(1)	(6)	(1)	(6)	(1)	(6)	(1)	(2)+(3)	(5)	(6)

global radiation and relative duration of sunshine is often written as Ångström's formula:

$$G = G_0 \{ \alpha + (1-\alpha) s/s_0 \} , \quad (1)$$

where G is the estimated or measured amount of global radiation;
G_0 is the estimated amount of global radiation if $s/s_0=1$;
α is a constant;
s is the duration of sunshine in tenths of hours;
s_0 is the longest possible duration of sunshine in tenths of hours.

If the quantity s/s_0 is not known, then a different quantity, which is closely related, may be used, namely the cloudiness N. As $s/s_0 + 0.1\,N$ has to be equal to 1 the expression (1) may also be written:

$$G = G_0 \{ \alpha + (1-\alpha) (1-0.1\,N) \} \quad (2)$$

Very often N is replaced by N_h = amount of low (and middle) clouds in tenth parts of the sky, as very often the sun remains shining through high clouds. Therefore expression (2) may be changed into:

$$G = G_0 \{ \alpha + (1-\alpha) (1-0.1\,N_h) \} \quad (2a)$$

We shall make use of this formula for estimating the standard deviation of G since the computation of this quantity for so many values in Table I is by far too laborious.

The largest value of G is equal to G_0, if $N_h = 0$, and the smallest one is found equal to αG_0, if $N_h = 10$. Both values of G are statistical averages and though the following assumption is theoretically not true for various reasons, we put the difference between the largest and the smallest value of G equal to four times the standard deviation s_1 of G or

$$(1-\alpha)\, G_0 = 4\, s_1 \quad (3)$$

This assumption implies, that the values of G are normally distributed, so that 95% of all G-values are situated between G_0 and αG_0. However, the distribution of the N_h-values is likely to be U-shaped so that the G-values follow more or less the same distribution. The greater part of the G-values lie scattered around two values corresponding with the most frequent values of N_h. In the first place and mainly around αG_0 and in the second place around G_0, so that less than 95% of all measured G-values are situated between αG_0 and G_0. That fact makes the value of s_1, determined from all measured G-values, to be greater than the s_1-value estimated following (3). As the average value of N_h is nearer to 10 than to 0 and the greatest frequency of G-values is clustered around $N_h=10$ there is also a tendency that the observational value of s_1 is smaller than the estimated s_1-value. A combination of both reasonings gives us a feeling that an estimation of s_1 following expression (3) is not too bad.

Moreover it cuts out an enormous amount of computational work, which should have been performed had all the standard deviations be computed from the measured G-values.

If the average value of N_h for Zestienhoven in the case of all observations with wind direction 01-36 is inserted for each of the four seasons in formula (2a) together with the corresponding G-values of Zestienhoven and the corresponding α-values for De Bilt [see 2], namely 0.30, 0.34, 0.32 and 0.33 respectively, one obtains an estimated average value of G_o for each season. After insertion of α and G_o in formula (3) one gets an estimated standard deviation s_1 of the G-values mentioned in column (1), as if there was only one observation. Those values of s_1 for the four seasons are respectively 1.12, 2.00, 2.18 and 1.54.

The values of the errors in column (4) are combined with the s_1-value for the corresponding season. The result of that combination is inserted in column (5).

Finally the values in column (5) have been divided by the square root of n; the results have been indicated in column (6). The values in column (6) are the estimated errors of the corresponding G-values in column (1).

For the wind directions 03, 12, 29, 36 and calm only the columns (1) and (6) have been inserted, whereas for the total of all directions 01-36 the columns (1), (2)+(3), (5) and (6) have been gathered in the table.

It is now the intention to judge the significance of the differences between the global radiation of the six stations for each of the 7 wind directions in every season. In principle the deviations of the average values in the various columns (1) show a skew frequency distribution between zero and the infinite, but we know from experience that those deviations show a more or less Gaussian distribution in the summer months and in general that, if the average value is greater than 4 times the standard deviation of one observation (c.f. column (5) of table II), the deviations show a distribution, which does not significantly depart from a Gaussian one, provided the sample is sufficiently large. Though it is only true for a part, we nevertheless assumed that distributions of the values of the global radiation around their averages are Gaussian ones and that the departures from the averages of all stations are mutually independent, then two average values in the same class m_1 and m_2 may be said to differ significantly, if the two intervals $m_1 \pm 2s$ and $m_2 \pm 2s$ do not overlap.

Application of this rule to table II yields table III. Thus for the winter season and wind direction 19 it appears that Maasland is significantly greater than Pernis, since $4.3 - 2 \times 0.14 \geqslant 3.6 + 2 \times 0.14$, and that Zestienhoven (4.2) is also significantly greater than Pernis (3.6), for $4.2 - 2 \times 0.14 \geqslant 3.6 + 2 \times 0.14$.

Of every odd-even combination (1-2, 3-4, 5-6, 7-8 and 9-10), read in vertical direction, the odd number indicates that the global radiation at that station is significantly greater than that at the station or stations with the even number. So we may see from table III for spring and wind direction 03, that Naaldwijk (1) is greater than any

TABLE III. Survey of significant differences in global radiation between the six stations for selected directions.

Winter season

wind direction	19	03	12	29	36	calm	01-36
Naaldwijk			1	1			1
Maasland	1		3	3		1	3
Pernis	2 4			2 4 6		2 4	2 4 6 8
Poortugaal							2 4 6 7
Zestienhoven	3		5	5		3	5
Heliport			2 4 6			2 4	2 4 6 8

Spring season

wind direction	19	03	12	29	36	calm	01-36
Naaldwijk	1	1	1	1	1	7	1
Maasland	3	2 3		3	2 3	1	2 3
Pernis	2 4	2 4 6 8 10	2	2 4	2 4	2 4 6 8 10	2 4 6 8
Poortugaal	2	2 9		2 4	2 4	5	2 4 5
Zestienhoven	2 4	2 5		2	2 4	9	2 4 7
Heliport	2 4	2 7		2 4	2 4	3	2 4 6 8

Summer season

wind direction	19	03	12	29	36	calm	01-36
Naaldwijk		1	1	1	1		1
Maasland	1	3		3	3		2 3
Pernis		2 4		2 4	2 4 5		2 4
Poortugaal		2 4 6 8		2 4	2 4 6		2 4
Zestienhoven	2	5	2	2 4	2 4		2 4
Heliport		7		2 4	2 4		2 4

TABLE III. Survey of significant differences in global radiation between the six stations for selected directions.

Fall season

wind direction	19	03	12	29	36	calm	01-36
Naaldwijk	1	1		1	1	3	1
Maasland	3	3		3	3	1	2 3
Pernis	2 4	2 4		2 4	2 4	2 4 6	2 4 6 8
Poortugaal	2 4	2 4		2	2	5	2 4 7
Zestienhoven	2			2		2 4	2 4 5
Heliport	2 4			2 4	2 4	2 4	2 4 6

of the other 5 stations (2) and that successively Maasland (3), Zestienhoven (5), Heliport (7) and Poortugaal (9) are greater than Pernis (4), (6), (8) and (10).

From the result in the wind direction classes 19, 03, 12, 29 and 36, which are crucial directions, for the four seasons it may be concluded, that the numbers of observations are indeed too small generally for a classification according to 36 wind directions and to calms. The only inference, which may be drawn, is that Naaldwijk shows generally somewhat more global radiation than Maasland, though both stations belong to one class (i.e. they have no significant difference in global radiation) against Pernis with its smallest amounts and Heliport with amounts only slightly greater than those at Pernis (S and H also form one class), while Poortugaal and Zestienhoven form a class between the two above mentioned classes.

Those conclusions may be drawn even with greater reliability from the class 01-36 for the four seasons in the last column of table III:

1. In most cases Naaldwijk is significantly greater than the other five stations;
2. In general Maasland is significantly greater than the remaining four stations;
3. Pernis is significantly smaller than Naaldwijk, Maasland, Zestienhoven and Poortugaal except in summer, when it is smaller than Naaldwijk and Maasland only;
4. The event that Heliport is significantly smaller than other stations is only slightly less frequent than that for Pernis. Therefore Pernis and Heliport belong to the same class;
5. In the same way it may be decided that Zestienhoven and Poortugaal belong to the same class, though Zestienhoven is a little bit higher than Poortugaal.

If the number of odd and of even cases behind the stations in the directions 01-36 for the whole year is determined, the results may be seen in table IV under the heading (01-36; odd and even).

TABLE IV. Classification of stations according to significant differences in the amounts of global radiation

	01-36		calm	
	odd	even	odd	even
Naaldwijk	4	-	2	-
Maasland	4	3	3	-
Pernis	-	14	-	10
Poortugaal	3	9	2	-
Zestienhoven	3	6	2	2
Heliport	-	13	1	4

Those results in table IV corroborate of course the same five conclusions mentioned above and they also show that the six stations fall into three categories, namely Naaldwijk-Maasland, Zestienhoven-Poortugaal and Heliport-Pernis.

The numbers of observations for each season headed by calm in table II are small and it is therefore difficult to judge the significance of the differences between the various mean amounts of global radiation under the condition of calm. Nevertheless the odd and even cases have been added and the result is inserted in the right-hand part of table IV. From this it may be inferred that Maasland shows the highest amounts of global radiation and that Pernis still shows the lowest ones. In the left-hand part Naaldwijk shows the greatest amounts and Maasland the greatest amounts but one, while in the right-hand part Maasland is the first and Naaldwijk occupies the second and the third place together with Poortugaal.

It is easily understood that the production of air pollution near a station results in a much greater attenuation of global radiation when there is a calm than when the wind is blowing moderately. Therefore one is inclined to infer from this reasoning that Pernis produces a lot of air pollution and that Naaldwijk, though it is situated in the countryside, produces air pollution. That latter fact is undoubtedly due to central heating of warehouses around Naaldwijk in a part of the autumn, in winter and in spring.

In order to demonstrate our thus far obtained results more clearly, we copy the columns 01-36 and calm for table I for the four seasons in table V so that the average 15-minutes amounts of global radiation are expressed in percentages of those of Maasland under the assumption that Maasland represents the pure countryside.

<u>TABLE V.</u> <u>Presentation of the percentages of the attenuation of global radiation for the three classes of stations</u>

	winter		spring		summer		autumn		year	
	calm	01-36	calm	01-36	calm	01-36	calm	01-36	calm	01-36
Naaldwijk	89	100.0	91	108.1	113	103.0	98	104.6	96	103.9
Maasland	100	100.0	100	100.0	100	100.0	100	100.0	100	100.0
Pernis	65	86.0	52	86.0	85	88.9	70	89.2	68	87.5
Poortugaal	84	93.0	87	91.9	106	89.9	88	92.3	91	91.8
Zestienhoven	100	97.7	78	90.7	113	89.9	75	93.8	91	93.0
Heliport	68	86.0	98	88.4	123	88.9	71	90.8	90	88.5

Table V is a very instructive table. If the last column headed by "year" is studied, then its right-hand part indicates that averaged over the year Poortugaal and Zestienhoven situated at the fringe of the industrial area show an attenuation of global radiation of 7-12% with respect to the pure countryside and that Pernis and Heliport, respectively situated in the centre of an industrialized area and in the middle of the city of Rotterdam show a decrease of 12-16%.

That attenuation may be caused by differences in cloudiness resulting from differences in the nature of the earth's surface (water, bare soil, soil covered with various sorts of vegetation, soil covered with houses and buildings) and therefore due to various local circulations, by air pollution and by cloudiness stimulated and originated by air pollution. It can not be decided from table V for which part of the attenuation each of the mentioned causes is responsible.

If the left-hand and the right-hand part of the last column are compared with each other and if per definition Maasland does not produce air pollution then it is clear that Naaldwijk and its surroundings produce air pollution as "calm" indicates 96.1% and "01-36" denotes 103.9%; a difference of about 8%. In the same way it may be said that Pernis produces quite a lot of air pollution as "calm" indicates 67.8% and "01-36" denotes 87.5%; a difference of 20%. It may be pointed out that the mentioned differences in global radiation may be attributed not only to the local production of air pollution, but also to other causes. Apparently Poortugaal, Heliport and Zestienhoven do not show any production of air pollution averaged over the year. They can easily be believed for Poortugaal and Zestienhoven, but not for Heliport, a station which is situated in the city. This fact may possibly be explained by the stronger turbulence at Heliport, due to the heating of houses and buildings during the one part of the year and to insolation during the other part of the year. Then it is clear that at Heliport air pollution is dispersed more or less at the same rate during the whole year; even in the cases that Z notes a calm.

If we consider the percentages on the right-hand part of the column of the summer season, then it appears that the percentages for Pernis, Poortugaal, Zestienhoven and Heliport are nearly the same. That fact may occur in summer, when turbulence due to heating of the earth's surface contributes to the mixing capacity of the blowing wind.

As the numbers of observation for calm are very small, especially in summer and in winter, the percentages in the left-hand parts of the columns under the four seasons are less reliable, so that no inference is to be drawn from those figures. There is only one feature to be mentioned. The average magnitude of the percentages under calm in summer is much greater than those in other seasons. That is probably also caused by the previously mentioned turbulence as the air gets clearer owing to the dispersion of the pollution.

That Pernis and Heliport produce air pollution and that the mentioned turbulence plays an important role in the dispersion may be concluded from the different behaviour of the percentages for the stations S and H and those for P and Z in the column 01-36 in winter and in summer. The non-producing stations, namely P and Z show in winter, season I, greater percentages than in summer: respectively 93.0 and 97.7 to respectively 89.9 and 89.9, while the producing stations S and H show the opposite effect: respectively 86.0 and 86.0 to respectively 88.9 and 88.9. In summer the turbulence smoothes the differences of the percentages of the producing and the non-producing stations. This smoothing caused by the mentioned turbulence takes also place in spring and in autumn, though to a lesser degree than in summer.

4. GENERAL INFLUENCE OF ROTTERDAM AND THE HAGUE AS SOURCES OF AIR POLLUTION ON GLOBAL RADIATION

In the previous section it turned out that the number of observations in the various classes of wind directions is generally too small to allow conclusive results. Nevertheless we want to know the influence of the urban conglomerations Rotterdam and The Hague. Under the heading Rotterdam are collected the cities of Rotterdam, Schiedam and Vlaardingen and the village Pernis with its industrial area, under The Hague are collected the city of The Hague and the villages Rijswijk and Voorburg. Moreover we shall try and include the influence of the city of Delft, though its industrial area is only small. In table VI we shall indicate under which wind directions Rotterdam, The Hague and Delft may be seen from the six stations N, M, Z, P, H and S.

TABLE VI. Wind directions from which Rotterdam, The Hague and Delft may be seen from the six stations

	N	M	Z	P	H	S
Rotterdam	11-14	10-14	14-23	32-05	01-36	35-09
The Hague	02-05	36-01	32-33	-	31-33	34-01
Delft	08	04-05	32-33	-	-	-

As it is clear that the sectors under which the three sources may be seen from the 6 observing stations differ, we shall not study now the amounts of energy presented in table I but the percentages indicated in the right-hand part of the columns headed by the 37 directions. In this way the influence of the amount of cloudiness, which differs very much with the wind direction is more or less eliminated. The average percentage for the sector 11-14 is obtained by computing the weighted mean of the percentages for the directions 11, 12, 13 and 14, the weights being the numbers of observations of the four directions.

In that way the influence of Rotterdam on the six stations has been computed for the four seasons and the results are given in table VII. Each column headed by the name of the station is divided in two parts. In the left-hand part the percentages (%) are inserted and in the right-hand part the number of observations (n) on which the percentages are based. The various numbers of observations in table VII make it easy to suppose that the corresponding percentages are reliable. The percentages for the year have been obtained by simply averaging the percentages of the four seasons. Before proceeding to the explanation of the figures in the table a general remark should be made. The stations N, M, Z and P have sectors in the direction of Rotterdam, which embrace the whole industrial area; H is completely surrounded by the city of Rotterdam, whereas S has a sector which embraces the cities of Rotterdam, Schiedam and Vlaardingen without the industrial area of Pernis.

If the annual percentages of the six stations are mutually compared the the conclusion may be drawn that the amounts of global

TABLE VII. Influence of Rotterdam on the global radiation at the six stations in the four seasons

Rotterdam on	N		M		Z		P		H		S	
	%	n	%	n	%	n	%	n	%	n	%	n
winter	106	123	104	131	100	353	97	90	92	800	93	168
spring	106	221	102	357	97	665	94	1073	94	3510	91	1272
summer	105	104	97	134	94	454	88	356	96	2128	94	251
autumn	104	184	103	274	100	804	92	286	95	1968	94	385
year	105	632	102	896	98	2276	93	1805	94	8406	93	2076

TABLE VIII. Influence of The Hague on the global radiation at five stations in the four seasons

The Hague on	N		M		Z		H		S	
	%	n	%	n	%	n	%	n	%	n
winter	95	50	108	20	97	3	85	10	98	37
spring	117	426	113	218	95	151	96	192	91	496
summer	104	120	119	40	94	104	89	196	95	132
autumn	108	114	104	51	100	71	101	103	91	101
year	106	710	111	329	96	329	93	501	94	766

TABLE IX. Influence of Delft on the global radiation at three stations in the four seasons

Delft on	N		M		Z	
	%	n	%	n	%	n
winter	117	22	108	33	97	3
spring	112	124	102	247	95	151
summer	104	16	102	60	94	104
autumn	104	57	105	68	100	71
year	109	219	104	408	96	329

radiation decrease from N in the direction of Rotterdam, and that H, P and S show about the same percentages. That latter fact is not surprising for H and S as these stations, owing to their situation, experience the influence of the pollution of the city complex and not or nearly not the influence of the Pernis complex. On the other hand P is situated farther away from Rotterdam but the source S is very near, so that P experiences the influence of both sources Rotterdam and Pernis. In that way one may understand that through the year P, H and S show about the same percentages.

Another remarkable, but understandable fact has to be mentioned. In the summer season the percentages of the source stations H and S are higher than in the other seasons. Owing to the convection the air pollution in the sources reaches to a much greater height than in other seasons. Air pollution in and above a town may have three causes: 1. industry, 2. domestic fuel and 3. raising of town dust. In winter 1 and 2 cooperate, but in summer 1 and 3 are the causes of air pollution. As a consequence of convection in summer turbulence in the air is greater than in other seasons so that in that season the air pollution not only reaches a higher vertical extension but also a greater spatial dispersion. It is the latter factor which causes a maximum of percentages in summer for both source stations H and S. For the non-source stations P, Z, M and N the situation is just the opposite: in summer the percentages are smallest (P = 88; Z = 94; M = 97 and N = 105). For all seasons it is true that the percentages are increasing from Z to N, which is easily understood as all stations experience the influence of air pollution generated by the industrial area of Rotterdam decreasing with the distance from Rotterdam. Superimposed on that effect the influence of dust, locally raised by convection, has to be considered. As convection is greatest in summer the percentages are smallest in that season for all non-source stations. Automatically in winter the percentages are a maximum as convection does not occur. The winter maximum is less outspoken as could be expected; this is due to a local increase of air pollution generated by burning of domestic fuel. It is specially true for N where there are so many centrally heated warehouses and a slight indication may be found in the percentages for N, where in winter and in spring the percentages are equally high.

In table VIII and in table IX are respectively represented the influence of The Hague on N, M and Z and of Delft on N, M and Z for the four seasons and for the year. These tables are set up in the same way as table VII. There is one drawback however. The number of observations is in many cases too small to draw reliable conclusions. Therefore we shall mainly consider the figures for the year.

Table VIII shows that in general the percentage for N is smaller than for M which is easily understood as N is nearer to The Hague than M. For Z one should have expected a percentage much greater than that for M as Z is farther from The Hague than M. However, Delft is situated just halfway between The Hague and Z. Therefore the percentage for Z is even smaller than that for N. It is a pity that the number of observations for N in the winter season amounts to only 50. Nevertheless the percentage of 95 for this season gives perhaps an indication of the influence of the generation of air pollution by the central heatings of a great number of warehouses between N and The Hague.

Table IX shows a percentage for N greater than that for M, which is easily understood, as the distance Delft - M is smaller than the distance Delft - N.

5. COMPUTATION OF THE ATTENUATION OF SOLAR RADIATION DUE TO AIR POLLUTION ONLY

At the end of chapter 2 it has been stated that except on the sun's altitude the amount of global radiation depends on three factors: 1. natural cloudiness; 2. air pollution; 3. cloudiness stimulated and generated by an industrial area. Owing to local differences in all three causes the global radiation at the stations H and S suffers a loss of 12 - 16% relative to the countryside stations N and M, while the stations Z and P suffer a loss of only 7 - 12% compared with N and M; the latter facts have been reported in chapter 3.

The influence of cloudiness on the amount of global radiation is easily calculated. For this purpose use is made of formula 2a, Ångström's formula, where the value of α for the four seasons have been taken from [2]; winter $\alpha = 0.30$, spring: $\alpha = 0.34$, summer: $\alpha = 0.32$, autumn: $\alpha = 0.33$. The values of N_h may be taken from table XII where for various wind directions the amounts of cloudiness N_h, averaged for the four seasons over the hours during which global radiation has been evaluated, and expressed as decimal fractions of the sky covered, have been inserted for both aerodromes Ypenburg and Zestienhoven (see fig. 1). Table VI shows the meaning of the various wind sectors mentioned in table XII. The total amounts of cloudiness under the same conditions again expressed as fractions of the sky, have been also inserted. n is the number of observations. From table XII the values for the wind direction 01 - 36 (i.e. all directions together) have been used only; the data have been inserted in formula 2a.

The results of the computations may be found in table X. In its first column the four seasons and the year are indicated. In the subsequent columns the data of the six stations N, M, Z, H, P and S have been entered, while in the last column the meaning of the various lines have been indicated. $\overline{G^h_{N_h}}$ is the averaged amount of global radiation for an average height of the sun h and for an average amount of low and middle clouds N_h. $\overline{G^h_o}$ is the same quantity for $N_h = 0$, estimated by means of formula 2a. The ratio $\overline{G^h_{N_h}} / \overline{G^h_o}$ is of course the same for all six stations, but its value differs from season to season. For the winter its value is 0.615, for the spring it amounts to 0.670, for the summer it is 0.667 and for the fall it is 0.671. That the ratio $\overline{G^h_{N_h}} / \overline{G^h_o}$ is the same for all six stations in one and the same season is due to the fact that for all stations the value N_h for Z has been used.

If all values $\overline{G^h_o}$ are expressed in percentages of the $\overline{G^h_o}$-value for Zestienhoven and if 100 percent are subtracted from these percentages then the resulting figures may be found in every third line of the four seasons. Those resultant percentages denote how much greater or smaller the global radiation at various stations is than at Z. The four percentages for the four seasons of every station have been averaged and those average percentages have been inserted after the word "year" in column 1 of table X. From those percentages may be concluded the same facts as already reported in chapter 3, namely that the losses in global radiation at the fringe of the industrial and urban area with

TABLE X. Computation of amounts of global radiation with a cloudless sky by using cloudiness figures measured at Z.

season	Naald-wijk	Maas-land	Zestien-hoven	Heli-port	Poortu-gaal	Pernis	
winter	4.27	4.31	4.27	3.72	3.97	3.66	$\overline{G^h_{N_h}}$
	6.94	7.01	6.94	6.05	6.46	5.95	G^h_o
	0	+1.0	0	-12.8	-6.9	-14.3	%
spring	9.26	8.61	7.79	7.63	7.86	7.41	$\overline{G^h_{N_h}}$
	13.82	12.85	11.63	11.39	11.73	11.06	G^h_o
	+18.8	+10.5	0	-2.1	+0.9	-4.9	%
summer	10.16	9.86	8.87	8.81	8.90	8.80	$\overline{G^h_{N_h}}$
	15.24	14.79	13.30	13.21	13.33	13.20	G^h_o
	+14.5	+11.2	0	-0.7	+0.3	-0.8	%
fall	6.76	6.53	6.13	5.88	5.98	5.83	$\overline{G^h_{N_h}}$
	10.06	9.72	9.13	8.75	8.90	8.68	G^h_o
	+10.3	+6.5	0	-4.2	-2.5	-4.9	%
year	+10.9	+7.3	0	-5.0	-2.0	-6.2	%

TABLE XI. Computation of amounts of global radiation with a cloudless sky by using cloudiness figures estimated for each separate station.

season	Naald-wijk	Maas-land	Zestien-hoven	Poortu-gaal	
winter	4.27	4.31	4.27	3.97	$\overline{G^h_{H_h}}$
	7.10	7.26	6.94	6.66	G^h_o
	+2.3	+4.6	0	-4.0	%
spring	9.26	8.61	7.79	7.86	$\overline{G^h_{N_h}}$
	13.30	13.11	11.63	11.50	G^h_o
	+14.4	+12.7	0	-1.1	%
summer	10.16	9.86	8.87	8.90	$\overline{G^h_{N_h}}$
	14.93	15.25	13.30	12.60	G^h_o
	+12.3	+14.7	0	-5.3	%
fall	6.76	6.53	6.13	5.98	$\overline{G^h_{N_h}}$
	10.27	10.23	9.13	8.84	G^h_o
	+12.6	+12.2	0	-3.1	%
year	+10.4	+11.0	0	-3.4	%

TABLE XII. Average cloudiness figures at Ypenburg and at Zestienhoven computed from half hourly estimates made within the daily periods during which global radiation has been recorded.

	Aerodrome Ypenburg				Aerodrome Zestienhoven			
wind direction	season	N	N_h	n	season	N	N_h	n
14-23	winter	0.88	0.68	278	winter	0.82	0.60	315
	spring	0.75	0.51	209	spring	0.72	0.46	289
	summer	0.81	0.60	304	summer	0.80	0.54	399
	autumn	0.80	0.59	402	autumn	0.75	0.51	432
11-14	winter	0.65	0.41	67	winter	0.65	0.45	57
	spring	0.71	0.45	67	spring	0.61	0.44	99
	summer	0.58	0.29	43	summer	0.38	0.18	39
	winter	0.62	0.44	72	autumn	0.56	0.31	67
02-05	winter	0.80	0.69	46	winter	0.74	0.64	36
	spring	0.71	0.55	163	apring	0.64	0.51	154
	summer	0.62	0.49	52	summer	0.46	0.39	46
	autumn	0.62	0.55	49	autumn	0.52	0.38	42
10-14	winter	0.61	0.42	76	winter	0.64	0.48	68
	spring	0.66	0.41	100	apring	0.56	0.40	151
	summer	0.51	0.25	54	summer	0.39	0.18	52
	autumn	0.66	0.48	98	autumn	0.58	0.35	101
36-01	winter	0.70	0.60	35	winter	0.75	0.72	10
	spring	0.71	0.62	191	spring	0.64	0.54	94
	summer	0.58	0.50	48	summer	0.64	0.50	37
	autumn	0.70	0.56	30	autumn	0.62	0.44	21
32-33	winter	0.95	0.72	5	winter	1.00	1.00	1
	spring	0.78	0.64	59	spring	0.71	0.62	63
	summer	0.79	0.70	100	summer	0.71	0.62	96
	autumn	0.74	0.60	28	autumn	0.72	0.54	23
32-05					winter	0.72	0.66	55
					spring	0.68	0.56	484
					summer	0.68	0.58	294
					autumn	0.59	0.42	106
01-36	winter	0.79	0.62	657	winter	0.72	0.55	652
	spring	0.72	0.55	1532	spring	0.68	0.50	1533
	summer	0.74	0.55	1657	summer	0.68	0.49	1655
	autumn	0.75	0.58	910	autumn	0.70	0.49	879

TABLE XIII. Estimated N_h-cloudiness figures for N, M and P, computed from N- and N_h-figures at Ypenburg and Zestienhoven and N-figures estimated at N and P.

	Ypenburg		Zestienhoven		Naaldwijk		Maasland		Poortugaal	
season	N	N_h	N	N_h	N	N_h	N	N_h	N	N_h
winter	0.79	0.62	0.72	0.55	0.73	0.57	-	0.58	0.74	0.57
spring	0.72	0.55	0.68	0.50	0.60	0.46	-	0.52	0.63	0.46
summer	0.74	0.55	0.68	0.49	0.62	0.47	-	0.52	0.62	0.45
autumn	0.75	0.58	0.70	0.49	0.68	0.51	-	0.54	0.68	0.48

wind direction 01 - 36

$N_h(Na) = N_h(Yp) \times N(Na)/N(Yp)$

$N_h(Po) = N_h(Ze) \times N(Po)/N(Ze)$

$N_h(Ma) = \{N_h(Yp) + N_h(Ze)\}/2.$

respect to the countryside amount to 7 - 13% and that the losses at the centre of the industrial and urban area with respect to the countryside amount to 12 - 17%. The losses in global radiation may also be determined for the four seasons and those figures deviate more or less from the annual figures.

We have to look now for differences in cloudiness between the various stations as a partial cause of the losses. For the aerodromes Ypenburg and Zestienhoven the necessary cloudiness data may be taken from table XII and the data for the direction 01-36 have been copied in table XIII. Naaldwijk and Poortugaal are climatological stations so that we are able to produce the corresponding N-values for those stations; the values have been inserted in table XIII too. As Ypenburg is situated rather close to N the N_h-values for N have been taken the corresponding N_h-values of Ypenburg times a factor; this factor being the ratio N(Na)/N(Yp). The same procedure has been followed for the calculation of the N_h-values for Poortugaal, but then Ypenburg is replaced by Zestienhoven. Finally the N_h-values for M have been computed as the arithmetic means of the corresponding N_h-values of Yp and Z. The results of these considerations and calculations have been collected in table XIII.

After inserting the N_h-values of Z, N, M and P for the four seasons in formula 2a we have computed for these four stations the corresponding $\overline{G}^h_o$-values from the $\overline{G}^h_{N_h}$ -values. The computed $\overline{G}^h_o$-values have been put in every second line of the four seasons in table XI. The ratios in percentages of the differences between the $\overline{G}^h_o$-values of the four stations and the $\overline{G}^h_o$-value of Z and the $\overline{G}^h_o$ -value of Z itself have been entered in every third line of the four seasons in table XI. Finally the averages of the percentages of the four seasons are considered as the percentages for the year and they have been entered in the table after the word "year".

From table XI may be concluded that now the losses in global radiation between the countryside and the fringe of the industrial and urban area amount to 10 - 14%. That means compared with the "year" figures of table X (7 - 13%) a displacement of about 2% to the greater percentages. If we should have measured in a different two years-period or at different places in the same period we should also have found different percentages. Averaged over the area under consideration except in a belt of 2-4 kilometer along the North Sea coast and averaged over a long period of time one gets only one N_h-value for each season and therefore one determines $\overline{G}^h_o$-values and percentages, which show the same ratios as the ratios of $\overline{G}^h_{N_h}$ -values, mutually compared. From that we may conclude that the percentages (%) for each station of table X are samples of the mean percentages of the population of percentages for each zone of the area.

In that case one only uses one N_h-value for the whole area for each season. Therefore the percentages depend on the $\overline{G}^h_{N_h}$ -values only and not on the N_h-values; that is simply due to the use of Ångström's formula (2a). From those facts we may draw the important conclusion that the differences in global radiation between the countryside and the fringe of the industrial and urban area and between the countryside and the centre of that area, respectively amounting to 8 - 12% and 13 - 17% for all wind directions, are only due to differences in air pollution, while, owing to cloudiness only, the loss of global radiation averaged over the whole year and the the whole area amounts to 34.4%, as $\overline{G}^h_{N_h} / \overline{G}^h_o = 0.656$.

For the following reasoning we shall only consider $\overline{G}^h_o$-values or amounts of global radiation for a cloudless sky. Let us assume that a radiation station A is situated at the centre of a region which is a source of man made air pollution. At that station the global radiation will always suffer the same loss from whatever direction the wind is blowing. At a station B outside the source region the depreciation of the global radiation, if the wind at B is not blowing in a direction from the source region, will be less, than if the wind is blowing in a direction from the source. That means that the amount of global radiation at B averaged over all directions will be greater than the amount averaged over the angle under which the source region may be seen from B. The just mentioned considerations explain the difference in conclusions from the last line of table VII and those of the last line of table X. The difference in depreciation of the global radiation from the countryside (N and M) to the fringe of the source region amounts to 7 - 9% and from the countryside to the centre of the source (H and S) to 9 - 11% if the wind is blowing from the source region to the mentioned stations. Those conclusions for a cloudless sky could be drawn from the last line of table VII and that this could be done is simply a consequence of the way in which those percentages in the last line of table VII have been computed.

In table XIV we have collected the mean amount of global radiation with a cloudless sky in cal/cm^2 x quarter of an hour for the six stations for each of the four seasons with respect to three types of wind direction , namely 1. all directions; 2. the direction from Rotterdam and Pernis to each of the six stations and 3. the direction from The Hague to each of the stations. In table XIV each season contains three lines. The first line has been taken over from every second line in table X and is valid for all directions. We also assume that the station Pernis (S), as it is situated in the centre of an industrial area, shows the same amount of global radiation for every wind direction. Therefore the three figures in each season under the heading S are equally high. For the calculation of the amounts of global radiation for the direction from Rotterdam and that from The Hague we make use of the percentages in table VII and VIII. In season I 5.95 is put equal to 93% (see table VII) and so the percentages of the remaining stations have been computed. The results of this computation have been inserted in every second line of table XIV. For the influence of The Hague presented in table VIII 5.95 cal/cm^2 x 15 min is now put equal to 98% in season I; after that the 85% of H, the 97% of Z, etc. have been converted into calories and the resulting figures have been entered in line three of season I of table XIV. In the same way the figures in line three of the remaining seasons have been inserted. Finally the arithmetical means of the four average seasonal amounts of global radiation of each of the six stations have been called the annual means for each station and for each of the three kinds of wind direction. Next to every $\overline{G}^h_o$-value in cal cm^{-2} is inserted the number of observations n on which the $\overline{G}^h_o$-value is based. The n-values have been taken from tables VII and VIII.

It is easily understood that the ratios of the figures in the second and third line after the heading "year" in table XIV do not agree with the annual figures in table VII and VIII, as the latter ones are mean values of percentages and the former ones are mean values of real quantities, which show the annual variation of global radiation.

TABLE XIV. Calculated values of global radiation with cloudless sky at the six stations for three kinds of directions in the four seasons.

season	Naaldwijk		Maasland		Zestienhoven		Heliport		Poortugaal		Pernis		wind direction
	$\overline{G}_o^h$	n	$\overline{G}_o^h$	n	$\overline{G}_o^h$	n	$\overline{G}_o^h$	n	$\overline{G}_o^h$	n	$\overline{G}_o^h$	n	
winter	6.94	800	7.01	800	6.94	800	6.05	800	6.46	800	5.95	800	all directions
	6.78	123	6.66	131	6.40	353	5.89	800	6.21	90	5.95	168	from R'dam-Pernis
	5.77	50	6.56	20	5.89	3	5.16	10	--	--	5.95	37	from The Hague
spring	13.82	3510	12.85	3510	11.63	3510	11.39	3510	11.73	3510	11.06	3510	all directions
	12.87	221	12.40	357	11.79	665	11.43	3510	11.43	1073	11.06	1272	from R'dam-Pernis
	14.22	426	13.73	218	11.55	151	11.67	192	--	--	11.06	496	from The Hague
summer	15.24	2118	14.79	2118	13.30	2118	13.21	2118	13.33	2118	13.20	2118	all directions
	14.75	104	13.62	134	13.20	454	13.48	2118	12.36	356	13.20	251	from R'dam-Pernis
	14.45	120	16.53	40	13.06	104	12.37	196	--	--	13.20	132	from The Hague
fall	10.06	1968	9.72	1968	9.13	1968	8.75	1968	8.90	1968	8.68	1968	all directions
	9.60	184	9.51	274	9.23	804	8.77	1968	8.50	286	8.68	385	from R'dam-Pernis
	10.30	114	9.92	51	9.54	71	9.63	103	--	--	8.68	101	from The Hague
year mean of four seasons	11.52	8406	11.09	8406	10.25	8406	9.85	8406	10.10	8406	9.72	8406	all directions
	11.00	632	10.55	896	10.16	2276	9.89	8406	9.62	1805	9.72	2076	from R'dam-Pernis
	11.18	710	11.68	329	10.01	329	9.71	501	--	--	9.72	766	from The Hague

As a general remark may be said that conclusions drawn from the first two lines of each season and of the year are reliable, as the figures in those are based on a great number of observations. As for the influence of The Hague represented in every third line it may be said that the conclusions are less trustworthy as there are various figures in those lines based on too few observations.

In all four seasons the amounts of global radiation of the non-source stations (N, M, Z and P) are invariably greater for all directions than when the wind blows from Rotterdam and Pernis. It may also be mentioned that the figures for N are greater than those for M and Z and that those for M in their turn are greater than those of Z. There is only one exception to this rule, namely th value of N for all directions in season I is slightly smaller than its corresponding value of M.

The ratios of the various values have been discussed from table VII and table VIII.

As the figures for the influence of The Hague are less reliable we shall limit ourselves to a few general remarks concerning the third line of the annual figures. It seems as if at N the amount of global radiation is equally great whether the wind comes from Rotterdam or from The Hague. At M the amount of global radiation is greater than at N; moreover, how it is understood, is an other question, it is greater than in the first and second line. On the other side it is easily understood that the amount of global radiation at Z is more or less of the same magnitude, as that in the second line; for the line which connects The Hague, Delft and Z is a straight line. It is also clear that for all three kinds of direction the amounts of global radiation at H are of the same order.

In general it may be said that table XIV is very instructive. We want to end this analysis by giving two examples (table XV and table XVI), which show very clearly that one has to be exceedingly careful not to take too small samples from a population.

In table 3 of reference [1] have been collected values of the global radiation in tenths of calories per 15 minutes averaged over a certain number of observations with an average altitude of the sun, when the amount of cloudiness N = 0 at Z, for the six stations N, M, Z, H, P and S at several days of various months. In table 4 of the same reference [1] have been collected values of the global radiation under the same conditions, but when the amount of cloudiness N = 1 at Z. In both cases we have gathered for each of the stations N, M, Z, H and S the amount of global radiation observed during the winter season, spring, summer and fall. After that the amounts have been averaged with the number of observations as weights. Those averaged amounts for N = 1 have been inserted in table XV after the symbol $\overline{G}^h_1$ in every first line of the four seasons. We shall continue now with the winter season of this table. The values $\overline{G}^h_1$ may be easily converted into values $\overline{G}^h_o$ for a clear sky following the formula for season I:

$$\overline{G}^h_1 = \overline{G}^h_o \, (0.30 + 0.70 \times 0.9). \qquad (4)$$

In the second line those $\overline{G}^h_o$-values have been entered. In line 3, line 4 and line 5 have been inserted respectively the averaged altitude $\overline{h}$ of the sun, the total number of observations n and m = the number of earth's

TABLE XV. Reduction of Berlage's average values of global radiation for N=1 at five stations with different mean altitudes of the sun to values of the global radiation with cloudless sky with the same mean altitude of the sun for all five stations as found for the $\overline{G^h_{N_h}}$-values in table X.

season	quantity	N	M	Z	H	S
winter	$\overline{G_1^h}$	6.06	6.92	6.91	6.96	5.88
	$\overline{G_o^h}$	6.52	7.44	7.43	7.48	6.32
	$\bar{h}$	19°.36	19°.36	18°.36	19°.36	18°.68
	n	53	56	56	53	59
	m	2.97	2.97	3.14	2.97	3.08
	$\overline{D_o^h}$	1.63	1.86	1.93	1.87	1.64
	$\overline{S_o^h}$	4.89	5.58	5.50	5.61	4.68
	$\overline{S_o^1}$	14.75	16.83	17.45	16.92	14.61
	α	0.236	0.191	0.169	0.189	0.230
	S_{co}^v	23.46	24.53	25.07	24.57	23.59
	$\overline{S}_o^{18^\circ.41}$	4.49	5.17	5.52	5.18	4.56
	$\overline{G}_o^{18.41}$	6.05	6.98	7.46	7.00	6.16
	%	-18.9	-6.4	0	-6.2	-17.4
spring	$\overline{G_1^h}$	11.44	11.58	11.10	11.54	10.51
	$\overline{G_o^h}$	12.25	12.40	11.88	12.36	11.25
	$\bar{h}$	37°.59	36°.57	37°.76	36°.89	38°.34
	n	201	214	240	224	216
	$\overline{S_o^v}$	20.95	21.72	22.83	21.37	19.56
	$\overline{G}_o^{39^\circ.44}$	12.98	13.73	14.84	13.37	11.65
	%	-12.5	-7.5	0	-9.9	-21.5
summer	$\overline{G_1^h}$	14.50	13.15	13.90	14.93	13.79
	$\overline{G_o^h}$	15.56	14.11	14.91	16.02	14.80
	$\bar{h}$	50°.59	48°.46	50°.85	50°.59	50°.53
	n	193	48	189	193	191
	$\overline{S_o^v}$	19.39	18.67	18.71	19.83	18.67
	$G_o^{47^\circ.09}$	14.27	13.55	13.58	14.71	13.54
	%	+5.1	-0.2	0	+8.3	-0.3
autumn	$\overline{G_1^h}$	5.21	5.37	5.07	5.47	4.98
	$\overline{G_o^h}$	5.58	5.76	5.43	5.86	5.34
	$\bar{h}$	17°	17°	17°	17°	17°
	n	15	15	15	15	15
	$\overline{S_o^v}$	23.66	23.89	23.47	24.00	23.35
	$\overline{G}_o^{25^\circ.11}$	9.39	9.59	9.21	9.70	9.09
	%	+2.0	+4.1	0	+5.3	-1.3
year	$\overline{\overline{G}}_o$	10.67	10.96	11.27	11.20	10.11
	%	-5.3	-2.8	0	-0.6	-10.3

TABLE XVI. Reduction of Berlage's average values of global radiation for N=0 at five stations with different mean altitudes of the sun to values of the global radiation for N=0 with the same mean altitude of the sun for all five stations as found for the $G^h_{N_h}$ -values in table X.

season	quantity	N	M	Z	H	S
winter	$\overline{G_1^h}$	-	-	-	-	-
	$\overline{G_o^h}$	7.20	5.70	6.09	6.95	6.11
	$\bar{h}$	20°06	16°57	16°57	19°35	19°35
	n	18	7	7	23	23
	m	2.89	3.48	3.48	2.97	2.97
	$\overline{D_o^h}$	1.76	1.60	1.70	1.77	1.56
	$\overline{S_o^h}$	5.44	4.10	4.39	5.18	4.55
	$\overline{S_o^1}$	15.86	14.38	15.40	15.64	13.73
	α	0.217	0.208	0.189	0.216	0.260
	$\overline{S_o^v}$	23.90	24.11	24.59	23.93	22.90
	$\overline{S_o^{18°41}}$	4.76	4.89	5.20	4.94	4.34
	$\overline{G_o^{18°41}}$	6.00	6.16	6.55	6.21	5.24
	%	-8.4	-6.0	0	-5.2	-20.0
spring	$\overline{G_1^h}$	-	-	-	-	-
	$\overline{G_o^h}$	11.96	12.13	11.45	12.10	10.71
	$\bar{h}$	40°70	40°18	40°70	40°77	40°70
	n	122	114	122	117	122
	$\overline{S_o^v}$	19.31	19.68	18.76	19.45	17.98
	$G_o^{39°44}$	11.43	11.77	10.93	11.56	10.23
	%	+4.6	+7.7	0	+5.8	-6.4
summer	$\overline{G_1^h}$	-	-	-	-	-
	$\overline{G_o^h}$	14.94	13.60	13.99	14.68	13.96
	$\bar{h}$	50°06	41°00	50°06	50°06	50°06
	n	34	2	34	34	34
	$\overline{S_o^v}$	18.98	20.92	18.05	18.73	18.02
	$\overline{G_o^{47°09}}$	13.84	15.83	12.92	13.61	12.90
	%	+7.1	+22.5	0	+5.3	-0.2
autumn	$\overline{G_1^h}$	-	-	-	-	-
	$\overline{G_o^h}$	6.29	6.30	5.86	6.22	-
	$\bar{h}$	20°38	20°38	20°38	20°38	-
	n	8	8	8	8	-
	$\overline{S_o^v}$	22.69	22.71	22.13	22.60	-
	$G_o^{25°11}$	8.51	8.44	8.02	8.43	-
	%	+5.4	+5.2	0	+5.1	-
year	$\overline{\overline{G_o}}$	9.94	10.55	9.60	9.95	-
	%	+3.5	+9.9	0	+3.6	-

atmospheres passed through by the sun's rays, the sun's altitude being h; m is computed by Bemporad's formula. As those $\bar{h}$-values not only differ mutually but also from the common $\bar{h}$-value in season I of table X, we want to reduce those $\bar{h}$-values to $\bar{h} = 18^{\circ}.41$ in winter. The same shall be done for the remaining three seasons. In that way one is able to compare the various homogeneous $\overline{G_o^h}$ - values.

The global radiation $\overline{G_o^h}$ may be separated into two parts: the diffuse radiation $\overline{D_o^h}$ and the direct solar radiation $\overline{S_o^h}$. That separation may be executed if use is made of fig. 1 in [4]. That figure presents the value of the ratio $\overline{D_o^h}/\overline{G_o^h}$ as a function of the sun's height $\bar{h}$. In that way $\overline{D_o^h}$ and $\overline{S_o^h}$ have been entered in the subsequent lines. From $\overline{S_o^h}$ the amount of solar radiation perpendicular to the sun's rays ($\overline{S_o^I}$) is easily computed: $\overline{S_o^h} = \overline{S_o^I} \sin h$. If now $\overline{S_o^I}$ is known, then the rest is easy to calculate. Let us assume that the amount of direct solar radiation outside the atmosphere $\overline{S_o^o}$ equals 15 x 1.98 = 29.7 cal/cm.^{2} quarter of an hour^{-1} then the attenuation coefficient α of the atmosphere at that particular station and in that season is easily computed with the aid of the formula:

$$\overline{S_o^I} = \overline{S_o^o}\, e^{-\alpha m} . \tag{5}$$

A quantity independent of the sun's altitude and therefore most appropriate for use through the seasons is the direct solar radiation at the earth's surface, if the sun is in the zenith ($\overline{S_o^v}$)

$$\overline{S_o^v} = \overline{S_o^o}\, e^{-\alpha} \tag{5a}$$

That quantity may be computed by means of formula (5a).

From $\overline{S_o^o}$ we finally compute $\overline{S_o^{18^{\circ}.41}}$ in a retrograde order. With the aid of fig. 1 [5] again the quantity $\overline{G_o^{18^{\circ}.41}}$ may be composed. The ratios of the differences in the $\overline{G_o^{18^{\circ}.41}}$-values with respect to that of Z and the $\overline{G_o^{18^{\circ}.41}}$-value of Z itself have been inserted in percentages in the last line of the winter season.

The execution of the reduction of the $\overline{G_o^h}$-values took a rather long way. Nevertheless the reduction has been carried out for the remaining seasons, but the principal quantities have been entered in table XV. If we mutually compare the corresponding percentages of the 5 stations in the four seasons, then it turns out that they are not conformable, i.e. the differences in percentages of the stations change haphazardly from season to season.

If finally the $\overline{G_o^{18^{\circ}.41}}$-values for the seasons are averaged, then those averages $\overline{G_o}$ have been inserted in the "year" row. In that way we get the absurd result that averaged over the year Z and H show the greatest values of global radiation for a cloudless sky.

In table XVI the results of the reduction of the $\overline{G_o^h}$-values from table 3 [1] have been entered in the same way as in table XV.

If we compare the corresponding percentages in both tables then we may conclude that in spring and in summer there is no agreement and that in winter and autumn there is some conformity. But if the annual percentages of both tables are compared, then there is no agreement at all.

Finally if the percentages of tables XV and XVI are compared with those of table X then it turns out that there is no conformity between the percentages of the three tables. As the number of observations, on which the result of table X have been based, is very great and moreover is very much greater than the numbers of observations occurring in tables XV and XVI, the differences in behaviour of the percentages in tables XV and XVI with respect to the behaviour of the percentages in table X may be attributed to the effect of small samples.

6. SUMMARY

From November 1, 1959, up to November 1, 1961, measurements of global radiation have been made at six stations: Naaldwijk (N), Maasland (M), Zestienhoven (Z), Heliport (H), Poortugaal (P) and Pernis (S). For the situation of these stations may be referred to fig. 1. The measurements were carried out in order to make investigations into the consequences of the air pollution generated by the urban and industrial area in and around Rotterdam.

Several conclusions may be drawn from the results of the measurements. In the first place it turned out that the amount of global radiation does not depend on the speed of the wind, but certainly on its direction and that station N is surrounded by an area which produces some pollution mainly in the winter season.

If the sky is clear then the increase of the amount of global radiation, averaged over the whole period and over all wind directions, from the centre of the urban and industrial area of Rotterdam and Pernis to the fringes of that area amounts to 3-6% and from the centre to the countryside, which is supposed to be more or less free from man made air pollution, the increase amounts to 13-17%. Superimposed on these amounts of global radiation is a decrease in global radiation due to cloudiness; in season I (climatological winter season) this decrease amounts to 38.5%, in season II to 33.0%, in season III to 33.3% and in season IV to 32.9%.

With a clear sky the increase of the amount of global radiation, averaged over the whole period, in the direction to which the wind is blowing from the centre of the urban and industrial area, amounts to 3-5% from that centre to the fringes of the area and to 7-13% from that centre to the countryside.

It appears that the amount of air pollution generated by Rotterdam and Pernis is much greater than that produced by The Hague according to its effect on the global radiation at Naaldwijk. One has to be careful not to draw conclusions from too small samples of observations.

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REFERENCES

[1] Berlage, H.P.: "Eerste aanwijzingen omtrent kunstmatige versluieringen, verkregen uit metingen van de totale straling op het horizontale vlak op 7 posten in en rondom Rotterdam, bij wolkenloze hemel en nagenoeg wolkenloze hemel van november 1959 tot en met juli 1960", Kon.Ned.Met.Inst., De Bilt, Verslagen V-107 (RIII-271-1962),1962.

[2] Boer, H.J. de: "A calculation of global radiation in the Netherlands with the aid of the relative duration of sunshine", Arch.Met.Geoph.Biokl., B,10 (1961), pp. 537-546.

[3] Schmidt, F.H. and Boer, J.H.: "Local circulation around an industrial area", Berichte des Deutschen Wetterdienstes Nr.91 (1963), pp.28-31.

[4] Nicolet, M. et Dogniaux, R.: "Etude de la radiation globale du soleil", Institut Royal Météorologique de Belgique, Uccle, Mémoires, Vol.XLVII.

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