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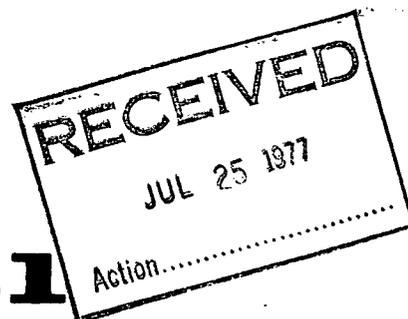
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# **Technical Memoranda**

## ESTIMATING MONTHLY POND EVAPORATION USING TEMPERATURE, WIND AND SUNSHINE DATA

by

H.L. Ferguson and B. Van Meurs

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4905 Dufferin Street  
Downsview, Ontario

ESTIMATING MONTHLY POND EVAPORATION USING  
TEMPERATURE, WIND AND SUNSHINE DATA

by

H. L. Ferguson and B. Van Meurs

ABSTRACT

Monthly evaporation from ponds, reservoirs and small lakes having negligible advection and storage effects can be estimated using Class A evaporation pan data. As an alternative a modified form of the Christiansen equation using temperature, wind and sunshine data is described. Monthly coefficients are tabulated for 73 Canadian locations. The technique can be applied to longer term climatological data to supplement shorter-term pan information or to computations for individual months at locations where pan data are not available.

CALCUL DE L'ÉVAPORATION MENSUELLE D'UN BASSIN À L'AIDE  
DES DONNÉES SUR LA TEMPÉRATURE, LE VENT ET L'INSOLATION

par

H. L. Ferguson et B. Van Meurs

RÉSUMÉ

Le calcul de l'évaporation mensuelle des bassins, réservoirs et petits lacs dont les effets de l'advection et de l'emmagasinage sont négligeables peut se faire à l'aide des données des bacs d'évaporation de catégorie A. Comme autre solution possible, les auteurs décrivent une forme modifiée de l'équation de Christiansen qui utilise des données sur la température, le vent et l'insolation. Les coefficients mensuels sont calculés pour 73 localités du Canada. La méthode peut être appliquée à des données climatologiques à longue échéance permettant de compléter des données du bac d'évaporation à courte échéance ou encore à des calculs relatifs à des mois particuliers dans certaines localités où il n'existe pas de données de bacs d'évaporation.

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(Manuscript received January 24, 1977)

## 1. Availability of Network Data for Evaporation Estimates

The standard climatological network instrument in North America for measuring evaporation is the Class A Pan. A correction factor (Kohler, Nordenson and Fox, 1955) is applied to daily panwater losses to obtain equivalent values of "lake evaporation", representing evaporation from small lakes, reservoirs or ponds having negligible storage and advection effects. This correction factor is a function of station pressure and elevation, wind speed, pan water temperature and air temperature. The principal effect requiring "correction" is heat transfer through the sides and bottom of the pan. The correction factor assumes idealized conditions and is based on empirical averages, so that daily or weekly results are not reliable. Research is continuing on this problem (Ferguson and Mukammal, 1975). Reasonable monthly estimates of evaporation from a given pond can often be obtained from near-by pan readings (i. e., accumulated values of daily "lake evaporation" computed from the pan data). However, interpolation problems may be significant.

As of December 1976 there were 148 network pans in operation in Canada. However there are sizeable data gaps in the present network (for example there are no pans in Central or Western Newfoundland, none in Prince Edward Island and only four in all of the Northwest Territories). It is also clear from Table 1 that the length of record at most pan stations is relatively short. Consequently the pan network data have serious limitations for application to pond evaporation estimates for individual months in the past or for developing climatological monthly mean values.

In an earlier study (Ferguson, O'Neill and Cork, 1970) it was shown that monthly "lake evaporation" estimates based on an equation developed by Christiansen (1966) were highly correlated to the values obtained from Class A Pan data. The Christiansen equation can be applied to climatological data available from denser networks with longer periods of record. By employing this technique to augment the

available pan information, a set of provisional mean monthly "lake evaporation" maps for Canada was produced (Atmospheric Environment Service, 1970). These maps have recently been checked against subsequent "lake evaporation" data available from the expanded Class A Pan network and appear to be generally consistent with the later data. However, the map isolines are smoothed, and interpolated values should be considered as estimates of average values over areas of about  $10^4$  km<sup>2</sup>.

## 2. The Christiansen Equation

The Christiansen equation can be written in the following form:

$$E_L = 0.328 C_M R C_Z C_T C_W C_S C_H \quad (1)$$

- where  $E_L$  = monthly pond evaporation  
 $C_M$  = a monthly coefficient  
 $R$  = extraterrestrial radiation for the month in evaporation units  
 $C_Z = 0.9654 + 0.1187Z - 0.0172Z^2$   
where  $Z$  is the station elevation in thousands of metres  
 $C_T = 0.4888 + 0.02202T + 0.000177T^2$   
where  $T$  is mean monthly temperature in °C  
 $C_W = 0.79 + 0.0023W - 0.00000128W^2$   
where  $W$  is mean daily wind run for the month in kilometres (at pan level)  
 $C_S = 0.402 + 0.019S - 0.00028S^2 + 0.0000017S^3$   
where  $S$  is the percentage of possible bright sunshine for the month  
 $C_H = 1.202 - 0.00353H - 0.0000381H^2$   
where  $H$  is the mean daytime relative humidity for the month in percent.

Values of  $R$  for a given latitude and month are readily available in standard references. The dimensionless coefficients  $C_Z$ ,  $C_T$ ,  $C_W$ ,  $C_S$ , and  $C_H$  can be calculated at network stations or experimental sites where the basic variables are measured. Table 1 shows the availability of relevant network data in Canada in comparison with Class A Pan data. Graphs of coefficient values are presented in Figures 1 to 6.

These coefficients each have values close to unity during months of significant evaporation at elevations up to a few hundred metres. Second and third order terms in the coefficient equations are relatively unimportant. It is therefore possible to obtain rough estimates using the equation when one or more of the basic variables is unknown, by either estimating the missing values or assuming coefficient values of unity.

In practical applications in Canada it has been found that the availability and reliability of the relative humidity coefficient  $C_H$  presents problems. Therefore a modified form of the equation has been used in which  $C_H$  is assumed to be unity (which is equivalent to incorporating the variability of  $C_H$  in the monthly coefficient):

$$E_L = 0.328 C'_M R C_Z C_T C_W C_S \quad (2)$$

### 3. Evaluation of Monthly Coefficient $C'_M$

In Canada there are 73 locations where Class A Pan, temperature, wind and sunshine data are available for evaluating the monthly coefficient  $C'_M$ . This was done by equating the lake evaporation obtained from pan data,  $E_{LP}$ , to  $E_L$  in equation (2) and solving for  $C'_M$  for each month of record available. Average monthly values of  $C'_M$  are related to humidity variations, as would be expected. To illustrate this, relative humidities for July for selected stations are shown in Figure 7. From this figure the noon LST relative humidity was read and used to obtain  $C_H$  (an alternative suggested by Christiansen, 1966) from Figure 6. The  $C_H$  values were then compared to  $C'_M$  values for these stations as shown in Figure 8. There is clearly a consistent relationship between  $C_H$  and  $C'_M$  although it is also clear that the humidity variation does not account for all of the variation in the monthly coefficient  $C'_M$ .

The larger-scale regional variation in  $C'_M$  is also evident from Table 4 which provides weighted averages of  $C'_M$  by month and area based on the Table 2 data. Lower values of  $C'_M$  are found in the regions of maritime climate while higher values are found in the interior continental regime. This is also illustrated by the British Columbia data in Table 2. The  $C'_M$  values for semi-arid low elevation locations in the Okanagan Basin, Kelowna and Penticton, are much higher than those at other more humid locations in British Columbia. While the  $C'_M$  values in Table 3 can be used for rough estimates of  $E_L$ , it is preferable to refer to  $C'_M$  values in Table 2 for interpolating values at specific new locations since the local variability within a province can be significant.

Table 3 shows that regional average  $C'_M$  values do not exhibit much seasonal variation except in the prairies where spring and fall values are somewhat higher than those in mid-summer.

#### 4. Application of the Modified Christiansen Equation

To estimate pond evaporation for a month at a specific location where appropriate data are available the suggested procedure is as follows:

- 1) Determine the coefficients  $R$ ,  $C_Z$ ,  $C_T$ ,  $C_W$  and  $C_S$  using equations provided above, or graphically using Figures 1 to 5.
- 2) Obtain  $C'_M$  for the appropriate month from Table 2 referring to a near-by location or locations listed in the Table.
- 3) Solve equation (2) for  $E_L$ .

Rough estimates can be made using Table 3 and graphical values of the coefficients.

#### 5. Acknowledgements

Thanks are due to Messrs. F. D. Manning and M. E. Malone for data abstraction and preparation of figures.

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Table 1

AES Networks for Selected Variables  
1956-1976 (Number of Stations)

	December 1956	December 1966	December 1976
Mean Monthly Temperature	1176	1704	2165
Mean Monthly Wind Speed	233	210	238
Mean Daytime Relative Humidity for the Month	238	242	250
Percentage of Possible Bright Sunshine for the Month	135	203	307
Class A Pan Monthly Evaporation	1	72	148

Table 2

Average Values of the Monthly Coefficient  $C'_M$ 

Station	Latitude Longitude				MONTHLY VALUES							Record Length Years
					May	Jun	Jul	Aug	Sept	Oct	Year	
<u>BC</u>												
Agassiz CDA	49	15	121	46	0.93	0.88	0.92	0.92	0.91	0.96	0.92	10
Kelowna A	49	57	119	23	1.07	1.12	1.10	1.14	1.09	----	1.10	2
McCulloch	49	48	119	12	0.94	0.88	1.01	1.03	0.94	0.88	0.94	4
Saanichton CDA	48	37	123	25	0.92	0.92	0.96	0.98	0.93	0.85	0.93	5
Penticton	49	28	119	36	1.23	1.14	1.10	1.15	1.18	1.06	1.14	2
Topley Landing	54	49	126	10	0.94	0.93	0.96	0.82	0.75	----	0.86	6
Vancouver UBC	49	15	123	15	0.89	0.86	0.89	0.89	0.82	0.75	0.85	10
<u>YT</u>												
Haines Junction	60	46	137	35	1.30	1.25	1.10	1.12	1.04	----	1.16	9
<u>NWT</u>												
Fort Smith	60	01	111	58	1.23	1.14	1.10	1.15	1.18	1.06	1.14	2
Norman Wells	65	17	126	48	----	1.12	1.07	1.03	1.12	----	1.09	7
Resolute	74	43	94	59	----	----	1.01	1.00	----	----	1.00	6
Yellowknife	62	28	114	27	----	1.05	1.02	0.92	0.93	----	0.98	5
<u>ALTA</u>												
Beaverlodge	55	11	119	22	1.12	1.00	0.98	1.01	0.99	----	1.02	11
Calgary	51	06	114	01	0.89	1.02	1.01	1.02	1.18	----	1.02	10
Edmonton	53	19	113	35	1.14	0.99	0.97	0.99	1.12	----	1.04	7
Kananaskis	51	02	115	03	----	0.93	1.01	1.05	1.04	----	1.00	2
Lacombe CDA	52	28	113	45	0.95	1.01	0.95	0.95	0.94	1.14	0.99	2
Lethbridge	49	42	112	47	1.16	1.08	1.09	1.13	1.27	----	1.16	7

Table 2 (cont'd)

Station					MONTHLY VALUES						Record Length Years	
	Latitude	Longitude	May	Jun	Jul	Aug	Sept	Oct	Year			
Manyberries	49	07	110	28	1.06	0.98	1.04	1.04	1.14	----	1.05	4
Slave Lake	55	18	114	47	1.08	0.94	0.90	0.91	1.03	----	0.97	2
Vauxhall CDA	50	03	112	08	1.18	1.12	1.12	1.19	1.28	----	1.18	5
<u>SASK</u>												
Broadview	50	23	102	35	0.97	0.96	1.02	0.99	1.05	----	1.00	3
Cree Lake	57	21	107	08	1.45	0.86	0.85	0.87	0.89	----	0.98	4
Estevan	40	04	103	00	1.03	0.98	0.98	1.04	1.14	1.02	1.03	11
Matador	50	42	107	43	----	1.08	1.11	1.08	----	----	1.09	2
Nipawin	53	20	104	00	0.93	0.99	0.93	1.04	----	----	0.97	1
Ormiston	49	43	105	22	1.08	0.98	0.99	1.07	1.22	----	1.07	4
Outlook PFRA	51	29	107	03	1.14	1.04	1.01	1.09	1.21	----	1.10	11
Regina	50	26	104	40	1.11	1.00	1.02	1.08	1.21	----	1.08	12
Saskatoon SRC	52	09	106	36	1.06	1.02	0.95	1.03	1.12	----	1.04	3
Swift Current CDA	50	16	107	44	1.09	1.02	1.02	1.09	1.24	----	1.09	10
Wynyard	51	46	104	12	1.08	0.95	0.92	0.97	1.08	----	1.00	7
Yorkton	51	16	102	28	0.92	0.93	0.94	1.01	1.12	----	0.98	4
<u>MAN</u>												
Bissett	51	02	95	40	----	1.01	0.98	1.02	1.01	----	1.00	6
Churchill	58	45	94	04	----	0.91	0.89	0.86	0.97	----	0.91	8
Gimli	50	38	97	03	0.97	0.94	0.90	0.91	1.23	1.05	1.00	2
Grand Rapids	53	11	99	16	1.17	1.02	0.99	1.08	1.05	----	1.06	3
Indian Bay	49	37	95	12	1.00	0.93	0.93	0.89	0.93	1.00	0.95	7
Rivers	50	01	100	19	1.05	0.95	0.95	0.96	1.06	----	1.00	5
Thompson	55	48	97	52	----	0.97	0.99	1.09	1.10	----	1.04	6
Winnipeg	49	54	97	14	1.05	0.98	0.98	1.02	1.13	1.17	1.06	12

Table 2 (cont'd)

Station	Latitude Longitude				MONTHLY VALUES							Record Length Years
					May	Jun	Jul	Aug	Sept	Oct	Year	
<u>ONT</u>												
Atikokan	48	45	91	37	----	0.90	0.94	0.96	0.95	----	0.94	8
Burketon McLaughlin	44	02	78	48	0.83	0.82	0.88	0.82	0.81	0.78	0.82	5
Delhi CDA	42	52	80	33	0.86	0.81	0.88	0.88	0.80	0.88	0.85	4
Elora Research Station	43	39	80	25	0.88	0.81	0.88	0.88	0.86	0.77	0.85	5
Guelph OAC	43	31	80	14	0.90	0.91	0.94	0.89	0.89	0.85	0.90	9
Hamilton RBG	43	17	79	53	0.97	0.79	0.92	0.92	0.93	0.98	0.92	10
Harrow CDA	42	02	82	54	0.91	0.90	0.92	0.90	0.94	0.99	0.93	10
Kemptville	45	00	75	38	----	0.85	0.89	0.87	0.89	0.94	0.89	4
Moosonee	51	16	80	39	----	0.90	0.77	0.77	0.82	----	0.82	3
Morven IHD	44	15	76	51	0.86	0.90	0.93	1.00	0.93	0.77	0.91	3
Ottawa CDA	45	23	75	43	0.98	0.92	0.94	0.90	0.93	0.86	0.92	13
Rawson Lake	49	39	93	43	----	0.84	0.88	0.85	0.79	----	0.84	4
<u>QUE</u>												
Amos	48	34	78	08	0.99	0.90	0.87	0.88	0.84	0.90	0.90	7
Caplan CDA	48	06	65	39	0.87	0.80	0.81	0.80	0.76	0.84	0.81	6
Duchesnay	46	52	71	39	0.84	0.88	0.84	0.72	0.87	0.97	0.85	3
Foret Montmorency	47	19	71	09	----	0.82	0.77	0.76	0.77	0.92	0.81	5
Knob Lake	54	48	66	49	----	0.86	0.82	0.77	0.81	----	0.82	5
Lac Humqui	48	17	67	37	----	0.79	0.72	0.73	0.86	----	0.78	2
L'Assumption CDA	45	49	73	26	0.81	0.80	0.82	0.79	0.80	0.82	0.81	6
Lennoxville CDA	45	22	71	51	0.77	0.83	0.95	0.84	0.99	----	0.88	2
Nitchequon	53	12	70	54	----	0.81	0.69	0.69	0.84	----	0.76	6
St. Augustin	46	44	71	30	0.81	0.73	0.77	0.73	0.75	0.70	0.75	9
St. Isidore D'Auckland	45	16	71	31	0.79	0.77	0.74	0.75	0.81	0.74	0.77	5
St. Ludger	45	45	70	40	0.93	0.86	0.88	0.86	0.90	1.10	0.92	3
Schefferville	54	48	66	49	----	0.83	0.66	0.64	0.69	----	0.71	3

Table 2 (cont'd)

Station	Latitude	Longitude	MONTHLY VALUES								Record Length Years	
			May	Jun	Jul	Aug	Sept	Oct	Year			
<u>NFLD</u>												
Churchill Falls	53	33	64	06	----	0.82	0.86	0.86	----	----	0.85	2
Gander	48	57	54	34	----	0.77	0.71	0.69	0.74	----	0.73	2
St. John's	47	37	52	45	----	0.72	0.75	0.74	0.74	----	0.74	2
<u>NB</u>												
Royal Road IHD	46	03	66	43	0.82	0.85	0.84	0.86	0.86	0.80	0.84	8
<u>NS</u>												
Fraser Brook IHD	45	20	63	10	0.78	0.81	0.76	0.79	0.86	0.94	0.82	6
Shart Brook IHD	45	01	64	38	----	0.85	0.82	0.84	0.79	----	0.83	5
Truro	45	22	63	16	0.85	0.76	0.80	0.76	0.83	0.78	0.80	4

Table 3

Weighted Average Values of the Coefficient  
 $C'_M$  by Month and Region

	May	Jun	Jul	Aug	Sept.	Oct
British Columbia	0.94	0.91	0.95	0.94	0.89	0.87
Northwest Territories	----	1.10	1.04	1.01	1.06	----
Alberta	1.07	1.02	1.02	1.04	1.13	----
Saskatchewan	1.09	0.99	0.99	1.04	1.16	----
Manitoba	1.04	0.96	0.95	0.98	1.05	1.10
Ontario	0.92	0.87	0.91	0.89	0.90	0.89
Quebec	0.86	0.82	0.79	0.77	0.81	0.84
Atlantic Provinces	0.81	0.81	0.80	0.81	0.82	0.84

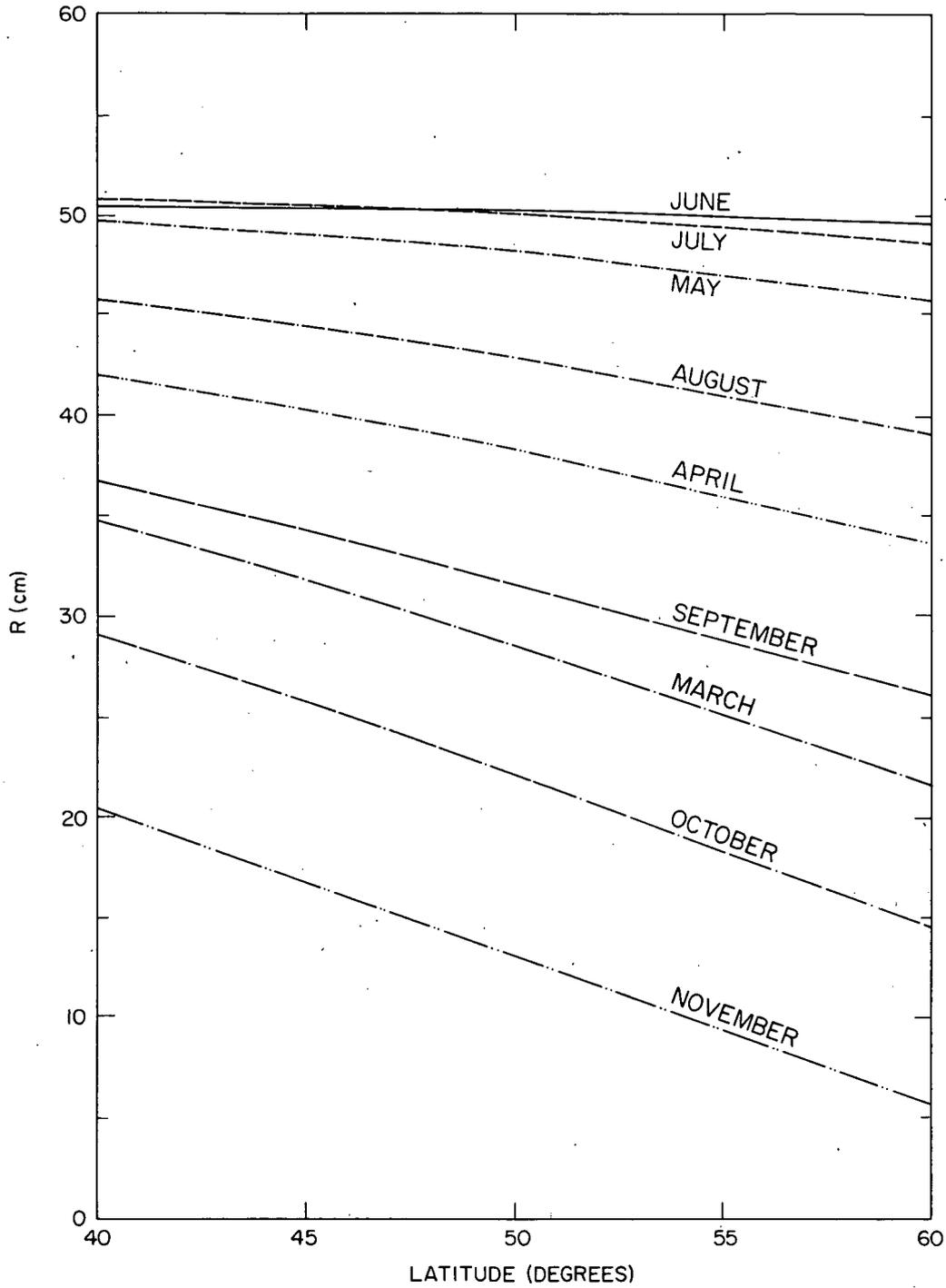


Figure 1

Solar radiation, R, at top of atmosphere, expressed as equivalent evaporation at 20°C (from Christiansen, 1966)

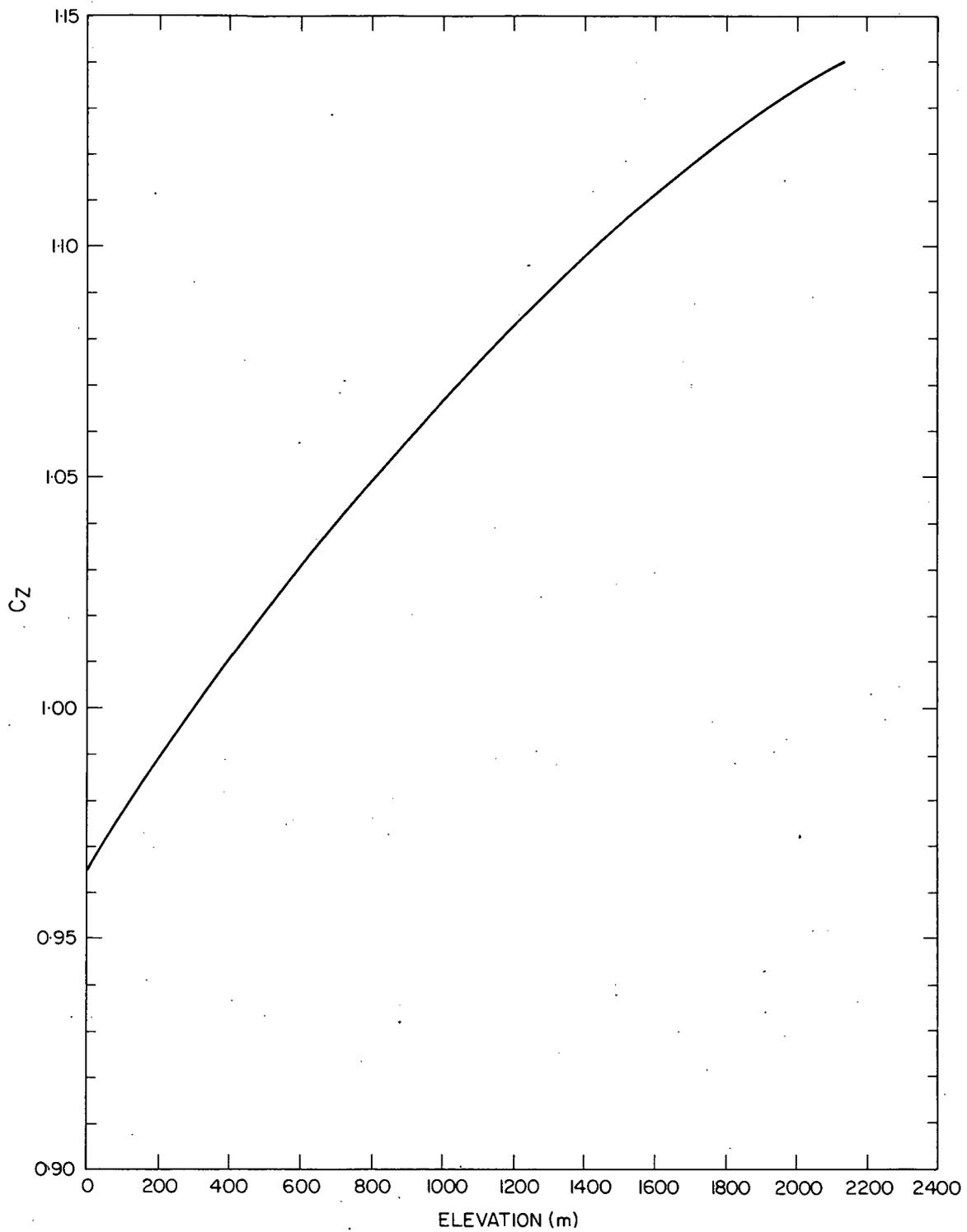


Figure 2  
The elevation coefficient  $C_Z$

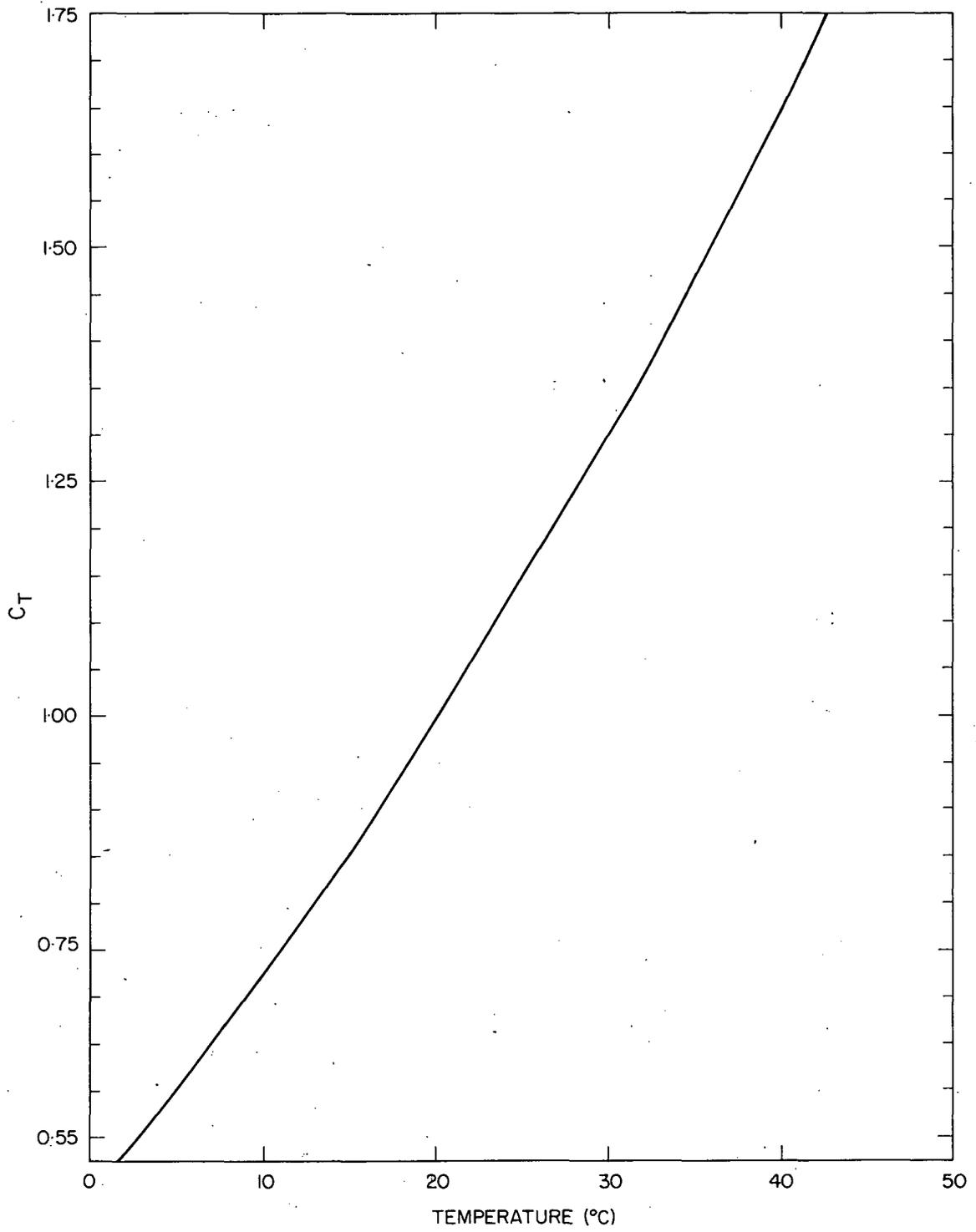


Figure 3

The temperature coefficient  $C_T$

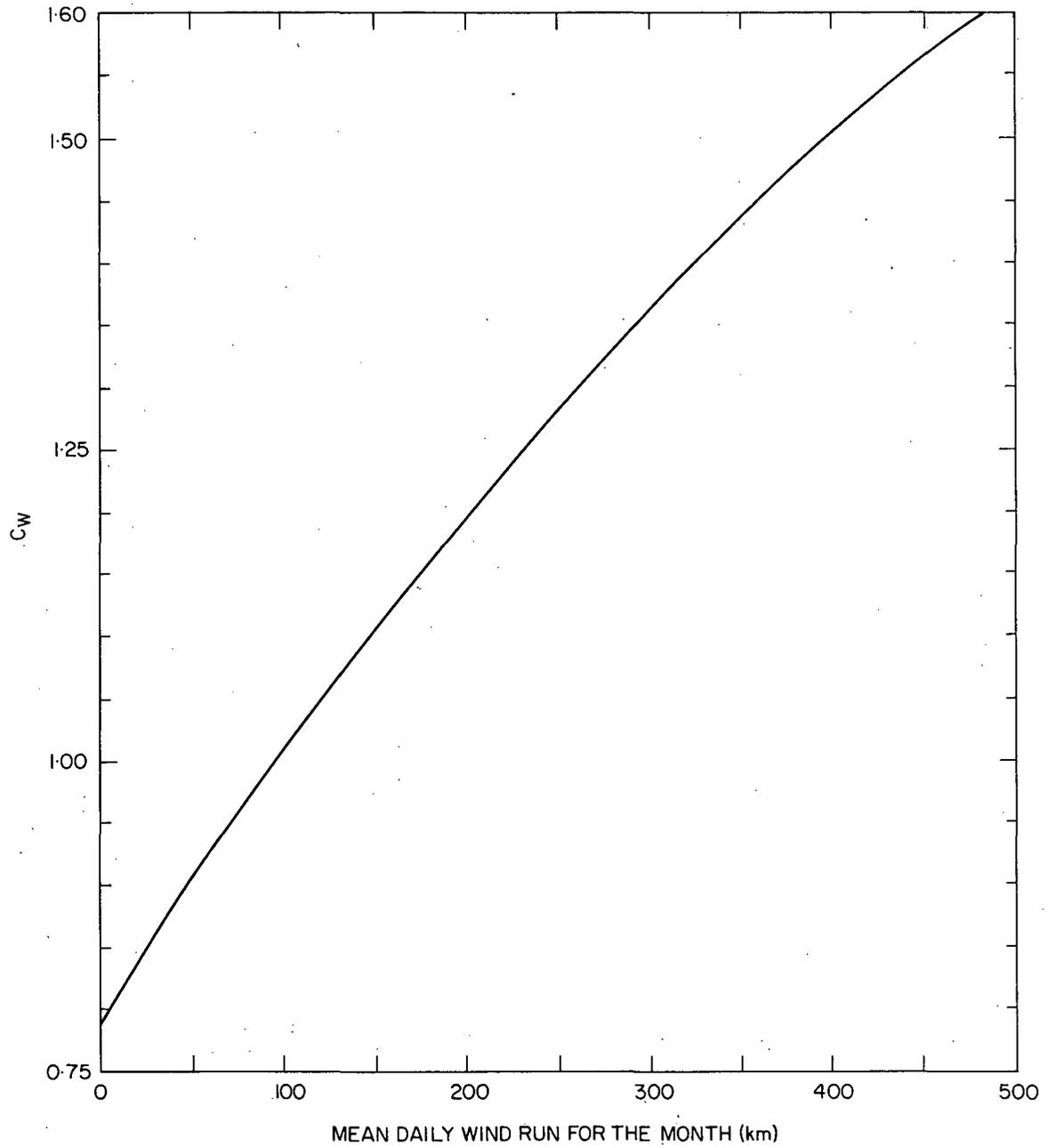


Figure 4

The wind run coefficient  $C_w$

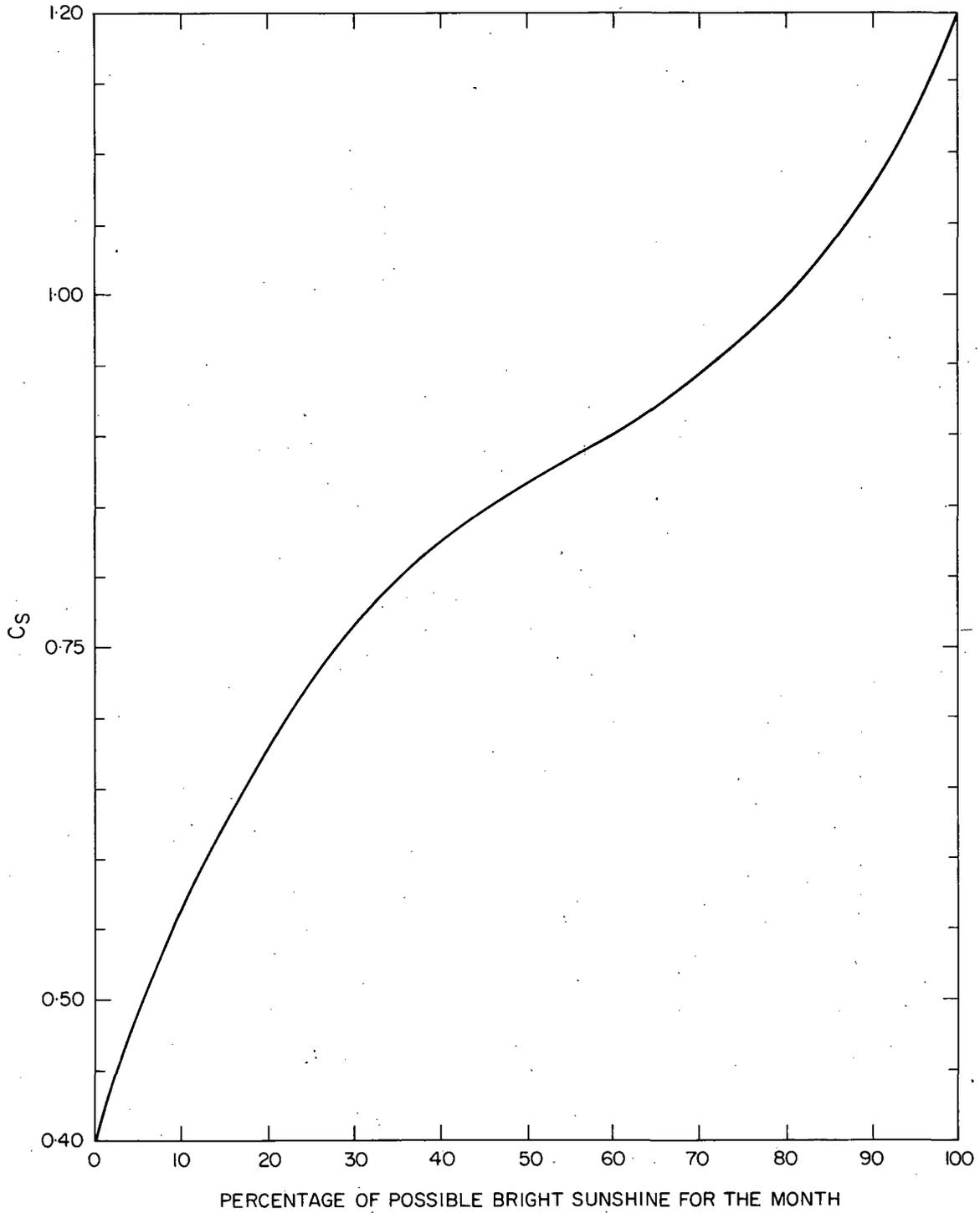


Figure 5

The sunshine coefficient  $C_s$

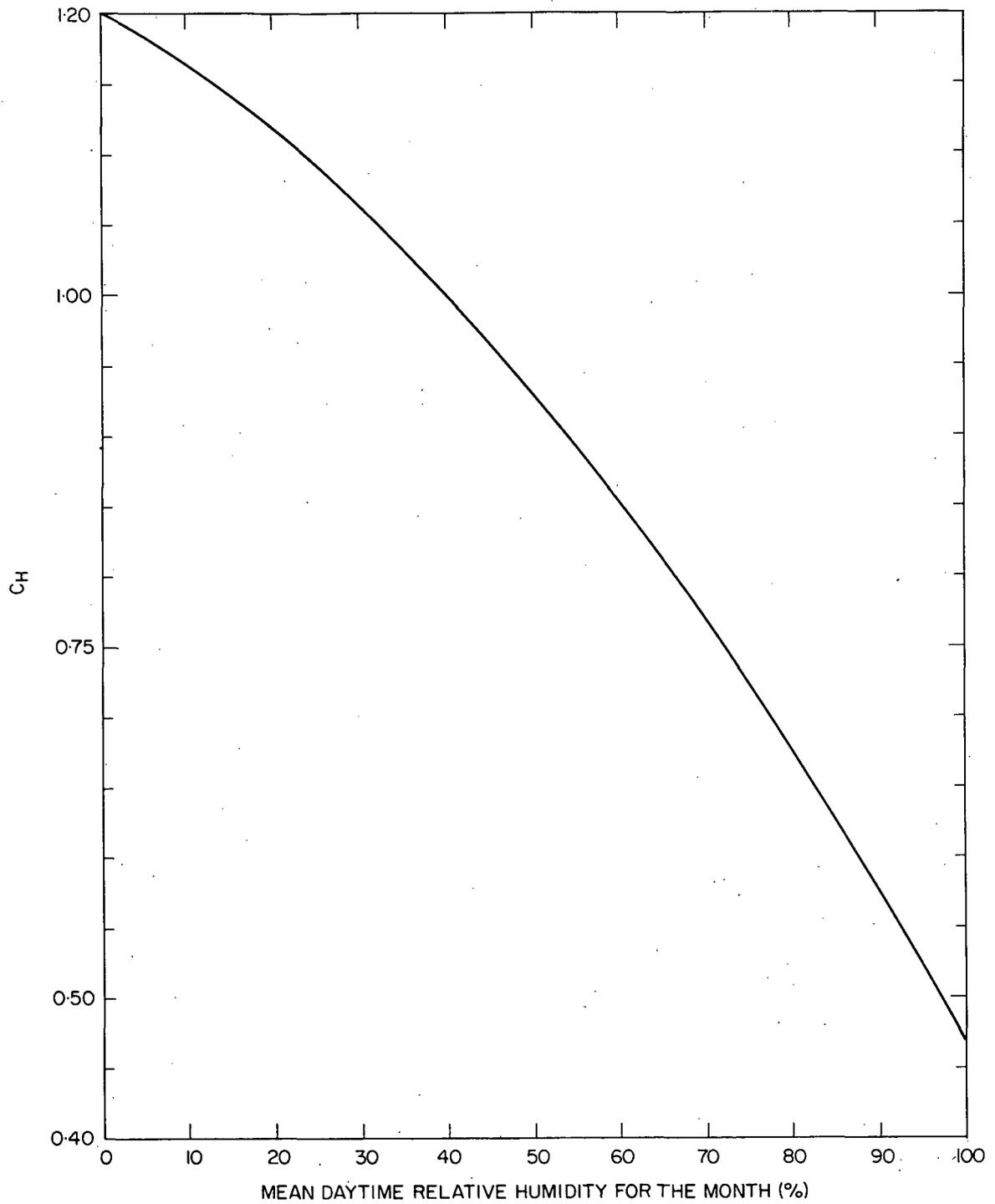


Figure 6

The relative humidity coefficient  $C_H$

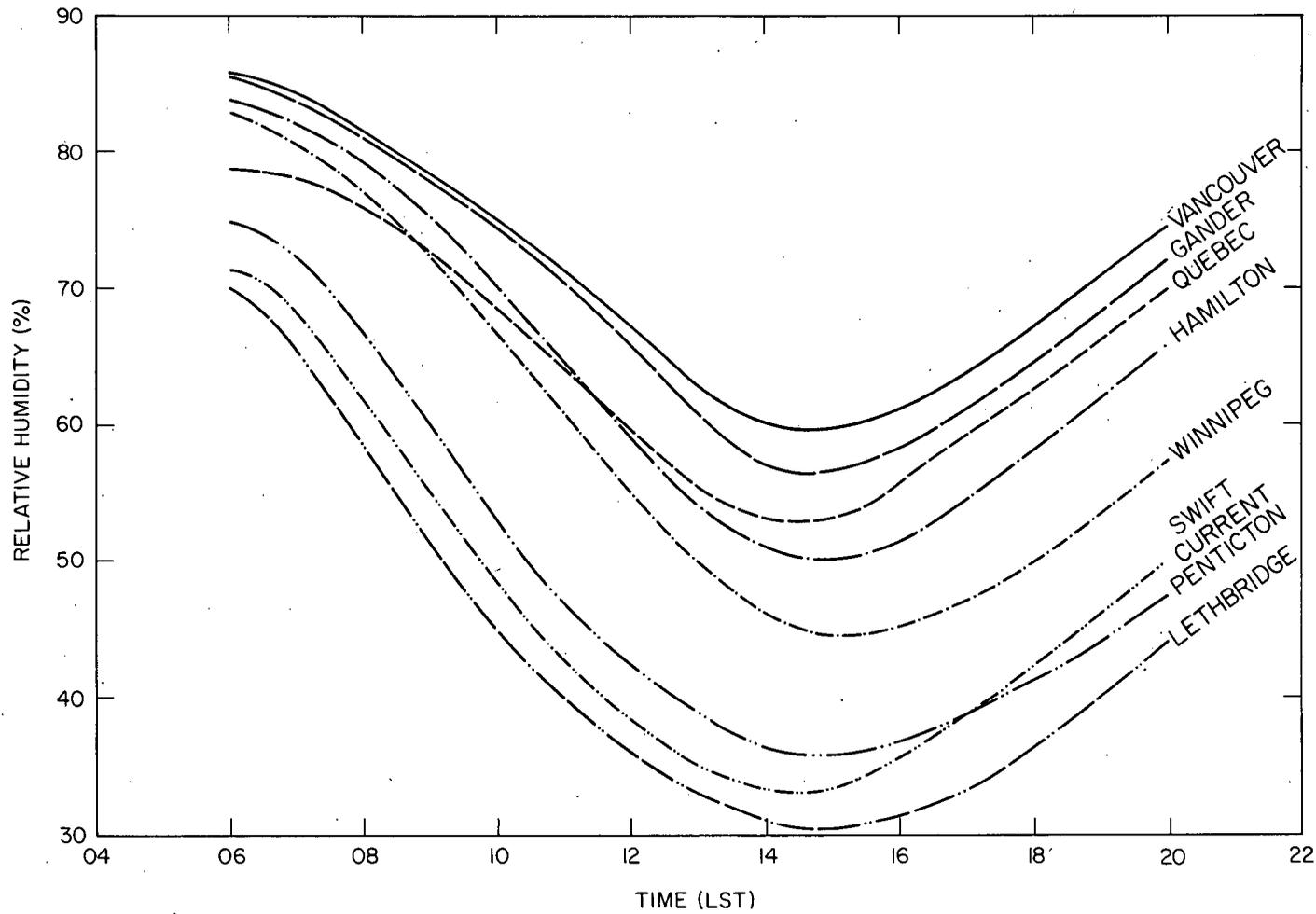


Figure 7

Average July daytime relative humidity variations for selected stations, 1957-1966 (based on Atmospheric Environment Service, 1968)

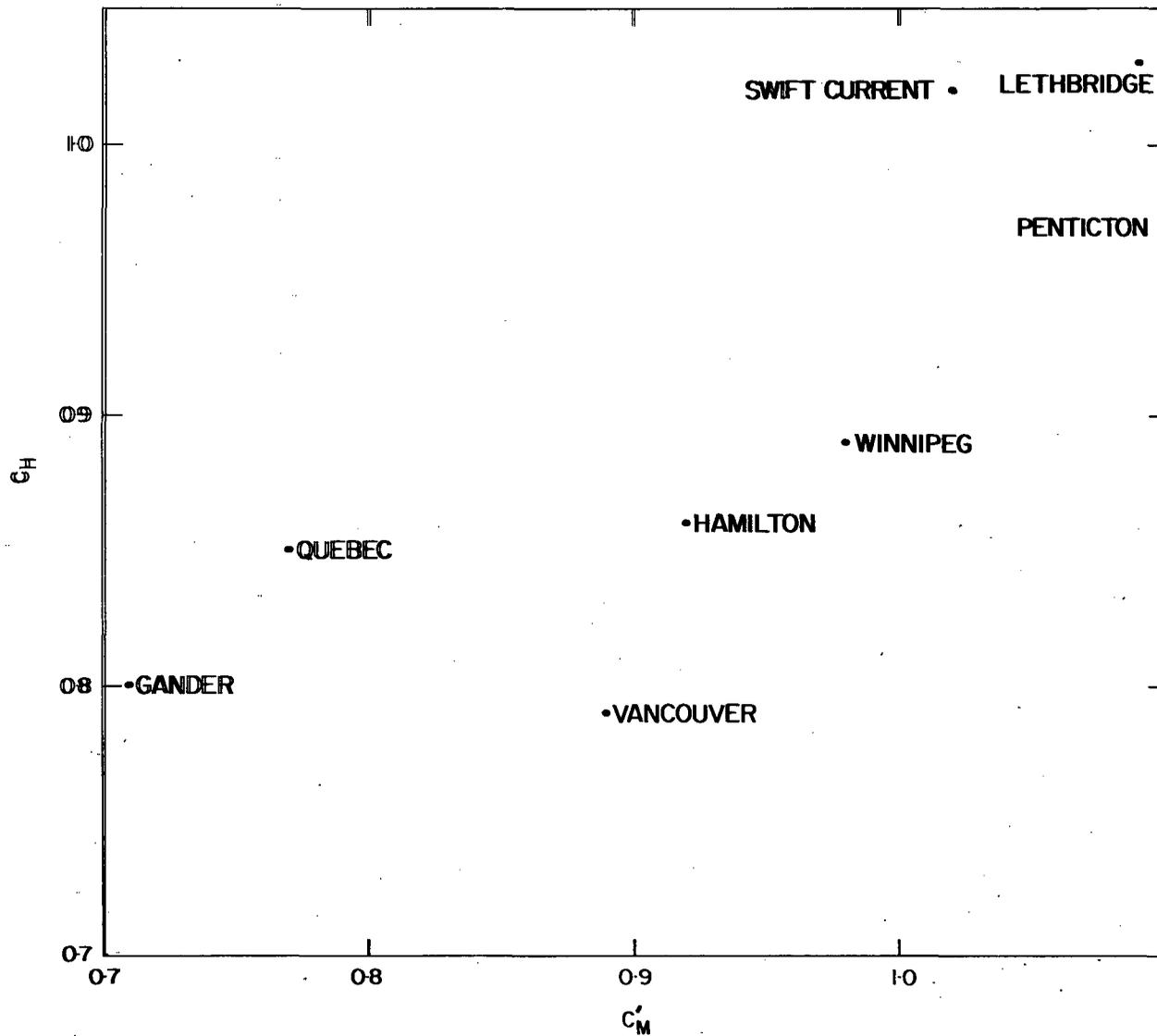


Figure 8

Comparison of coefficients  $C'_M$  and  $C'_H$  for July for selected stations

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2. Estimating

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