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Department of Geography (Climatology)
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CLIMATOLOGICAL BULLETIN

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SPATIAL DISTRIBUTION OF RADIATION IN THE COLORADO FRONT RANGE

by

David Greenland*

Introduction

The increasing attention being given to solar energy as an alternate energy source has also given rise to many studies concerning the potential availability of solar energy. Most of these have pointed to the sparsity of the global solar radiation observational network in North America. The paucity of the network itself has stimulated a few investigations of the spatial dimensions of an optimum sampling network and its correlate the predictability of global solar radiation (from here on referred to as radiation) at a given distance away from an observation station (Wilson and Petzold, 1972; Suckling and Hay, 1976). The aim of the present paper is to extend this work in two directions. First the extension will be into mountainous terrain and investigations will focus on the Colorado Front Range. Secondly the extension will be in the temporal sense in which an examination of the relationships between recorded values of radiation at two sites will be made with respect to different seasons and aspects of the synoptic climatology of the Front Range.

The data used in this paper come from two separate investigations, one made in 1965 by J.M. Clark and J.W. Marr (Clark and Marr, 1966) and one undertaken in 1977 by D. Dickson as a student project. First the data will be described then attention will be addressed to relationships between the data themselves and then between the data and synoptic weather conditions.

* David Greenland is Associate Professor in the Department of Geography and Institute of Arctic and Alpine Research, University of Colorado, Boulder, Colorado.

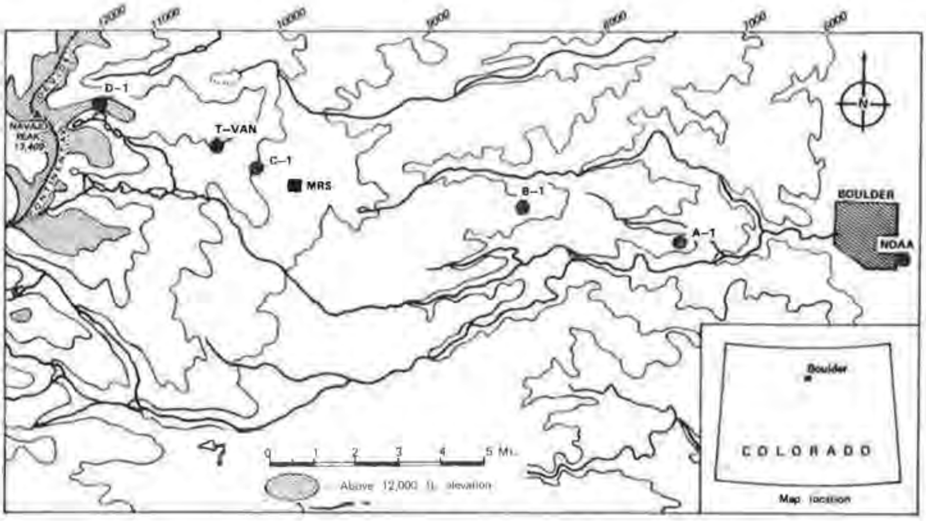


Fig. 1. Location of Observation Sites.

Location and Instrumentation

The Institute of Arctic and Alpine Research has maintained meteorological observing sites across the Colorado Front Range since 1952. The location of the four main sites A1, B1, C1 and D1 is shown on Figure 1 together with the sites of the supplementary T-Van, MRS (Mountain Research Station) and NOAA observing stations. Figure 2 shows the sites to cover an altitudinal range from 3749m at D1 to 1615m at NOAA. The transect runs eastwards from the continental divide, the closest station being D1 which is 2.6km from the divide and the furthest being the NOAA site at 37.0km from the divide. The horizontal distances and elevational differences between the stations used in this study are indicated in Table One. The area lies at approximately 40°N, 105°W.

The instruments used for recording radiation in the 1965 year were Robitzsch bimetallic actinographs operated at sites B1, C1 and D1. Clark and Marr (1966) have considered the accuracy of these recordings and have concluded that when instrumental and data reduction errors are taken into account daily totals of short wave radiation are given to an overall accuracy of ±15%. These authors describe in detail the care with which calibrations were carried out between the actinographs and between the actinographs and a 50 junction Eppley pyrheliometer (itself calibrated

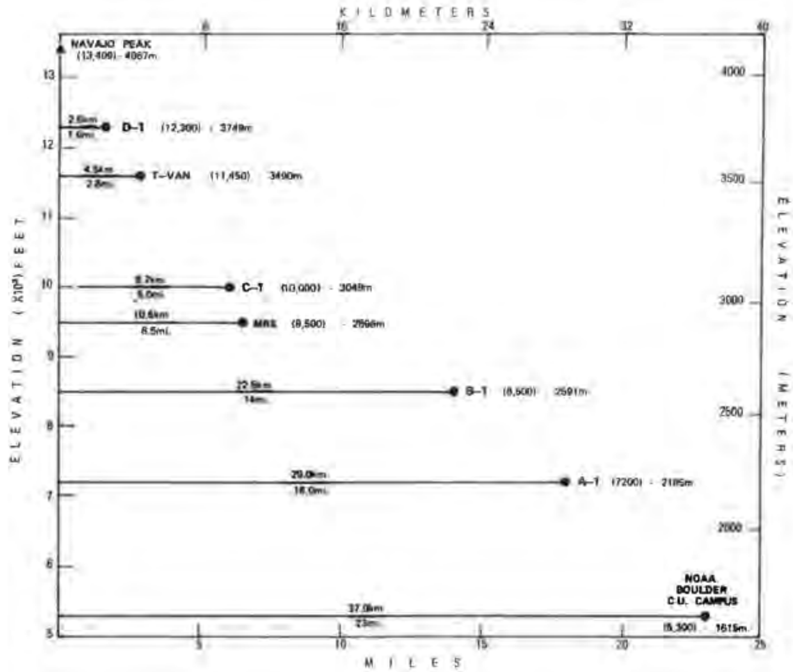


Fig. 2. Spatial and altitudinal relations between the observation sites.

TABLE ONE

Matrices of Distance and Elevation Differences between Recording Sites Used in the Study

(a) Distance in Kilometres

	C1	D1	T-VAN
B1	12.8	19.9	
C1		7.1	
NOAA			32.5

(b) Elevation Differences in Metres

	C1	D1	T-VAN
B1	456	1158	
C1		702	
NOAA			1921

TABLE TWO

Mean Values of Radiation Receipt in $MJm^{-2}day^{-1}$ for the Periods Involved in this Study.

Data Period	Mean Radiation Receipt B1	C1	D1	Boulder NOAA	T-VAN	Number of Cases
All Year 1965	14.6	14.0	14.4			365
Jan., Feb. 1965	8.5	10.1	9.7			59
Mar. - May 1965	15.9	18.1	19.1			92
June - Sept. 1965	19.8	16.0	17.2			122
Oct. - Dec. 1965	10.3	9.6	8.9			92
All data 1977				17.6	17.5	110
Jan. - Feb. 1977				8.3	8.5	25
Mar. - May 1977				19.0	19.2	66
June 1977				22.6	21.4	21

TABLE THREE

Variables Used in 1965 Data Analyses.

Variable	Abbreviation	Mean	Standard Deviation	Unit
Radiation at B1 (Sugarloaf)	R1	14.6	7.5	$MJm^{-2}day^{-1}$
Radiation at C1 (Como)	R2	14.0	7.1	$MJm^{-2}day^{-1}$
Radiation at D1 (Niwot Ridge)	R3	14.4	7.6	$MJm^{-2}day^{-1}$
Mean Temp at B1	TMEANC1	5.2	8.7	°C
Mean Temp at C1	TMEANC2	0.7	8.0	°C
Mean Temp at D1	TMEANC3	-4.1	8.4	°C
Relative Humidity at B1	RHMEAN1	63.1	19.2	%
Relative Humidity at C1	RHMEAN2	67.4	15.6	%
Relative Humidity at D1	RHMEAN3	70.3	26.4	%
Denver Freezing Level	FRELEV	2316.0	2194.1	metres
Denver 1200 GMT temp at 700mb	TEMP	1.5	8.2	°C
Denver 1200 GMT rel. hum. at 700mb	RH	45.1	22.2	%
Denver 1200 GMT wind direction at 700mb	WINDIR	25.0	8.5	degrees
Denver 1200 GMT wind velocity at 700mb	VEL	7.7	5.0	$msec^{-1}$

against ESSA pyrheliometers) operated at C1. An important point with regard to operating efficiency is that radiation instruments on Niwot Ridge seldom suffer from icing or condensation problems because of the dryness of snow, and the general low humidities and high winds encountered in this area. Another point is that all instrument sites are well exposed. No skyline obstructions are significant such that errors due to them would be larger than the errors already inherent in the cosine responses of the instruments.

The instruments used to collect the 1977 data were Eppley precision pyranometers. Both instruments were interfaced with integrating equipment and both had been previously indirectly calibrated together.

Certain other meteorological data were collected during 1965 at the same time as the radiation data. Temperatures and relative humidities were recorded at sites B1, C1 and D1. Mean daily temperatures and relative humidities were computed from the daily maximum and minimum values of these parameters. Data were also taken from the Denver radiosonde observations made at 1200GMT daily. 700mb level observations of temperature, relative humidity, wind direction and velocity were noted. 700mb is the approximate level of the C1 and D1 sites and the Denver radiosonde station is approximately 80km from Niwot Ridge.

Aspects of the Synoptic Climatology of the Front Range

There are three major sources of moisture for the eastern slope of the Front Range (James 1966) and the moisture bearing clouds obviously affect insolation values recorded in this location. Moisture for winter (Nov - Feb) precipitation is carried from the Pacific Coast. Spring (March to May - June) precipitation is mainly derived from Gulf air, while summer (June - July to September) precipitation results from local convective activity.

Between November and February the largest precipitation and by implication cloud amounts are found at the higher elevations (D1). It is quite possible for this station to be covered by crest or foehn wall clouds while the lower elevations remain free. An exception to this is when inversions over the plains cause low level clouds leaving the upper elevations cloud free. As a result, 1965 data can be interpreted to show that during the months of November to February, D1 had more hours of daylight cloud than either B1 or C1.

During the spring months (March to May or June) Gulf air frequently moves up the eastern slope giving the heaviest precipitation to, and causing cloud cover over, the lower and middle elevation stations. This effect does

TABLE FOUR

Correlation Coefficient Martix for 1965 Data (All Year). Coefficients greater than 0.5 are underlined.

	R1	R2	R3	TMEANC1	TMEANC2	TMEANC3	RHMEAN1
R2	.81555						
R3	.69265	.71660					
TMEANC1	.64302	.42860	.42808				
TMEANC2	.60179	.38573	.40870	.97936			
TMEANC3	.59520	.36248	.41409	.95309	.96721		
RHMEAN1	-.28418	-.30467	-.14120	-.37866	-.29894	-.22157	
RHMEAN2	-.20529	-.24794	-.13481	-.31026	-.29237	-.21473	.74078
RHMEAN3	-.22359	-.23441	-.19540	-.24299	-.22361	-.26296	.41198
FRELEV	.49850	.32940	.38448	.70839	.73009	.72727	-.08230
TEMP	.49712	.26342	.27319	.93651	.94194	.92460	-.31605
RH	-.22532	-.22829	-.03189	-.33632	-.26777	-.20836	.69303
WINDIR	.03778	.08557	-.01348	-.09269	-.11118	-.16958	-.23493
VEL	-.16383	-.07186	-.19230	-.27320	-.25372	-.32490	.05086

	RHMEAN2	RHMEAN3	FRELEV	TEMP	RH	WINDIR
RHMEAN3	.46030					
FRELEV	-.12169	-.11653				
TEMP	-.26527	-.20379	.70580			
RH	.53335	.30479	-.13667	-.37443		
WINDIR	-.20453	-.08841	-.13528	-.14068	-.12690	
VEL	.05494	.07347	-.20300	-.23986	-.00408	.28229

not usually penetrate above 3000m.

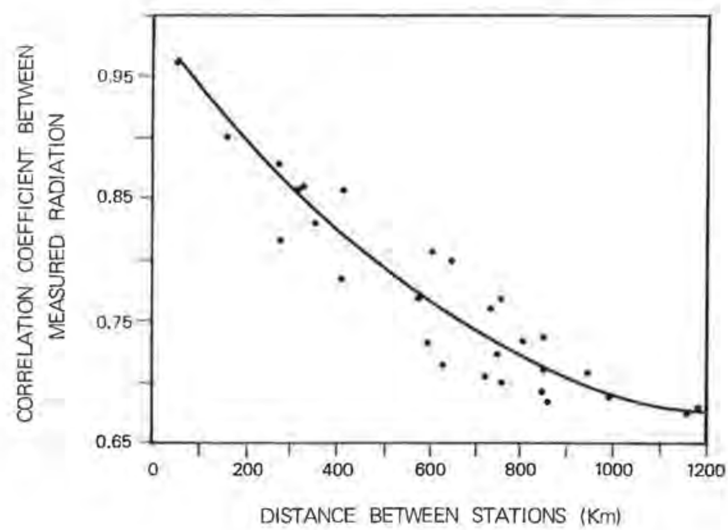
Spectacular cumulus and cumulonimbus clouds are typical of the summer months (June - July to September). Such clouds have the effect of decreasing daily totals of global solar radiations from their potential level. There is some evidence that such clouds tend to be located more over the mountainous rather than the plains areas (Reynolds 1977).

Precipitation and cloud conditions are therefore best explained on the seasonal basis discussed above. As a result the 1965 radiation data were analyzed, not only for the whole year, but also along the seasonal divisions examined here.

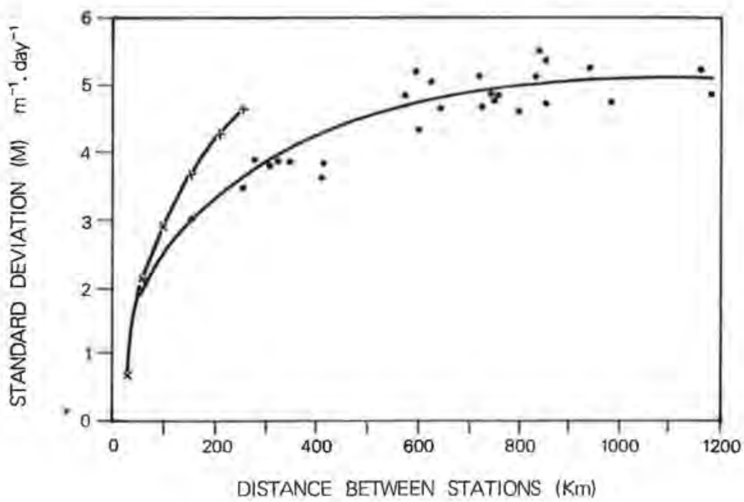
Procedure and Results

Before proceeding to the spatial analyses it is appropriate to address briefly the question of increased radiation receipt with altitude. Assuming a solar constant of $1352Wm^{-2}$, the altitudinal difference examined in this study between 1615m and 3749m under clear sky conditions would lead to a difference of incident energy of between $1103Wm^{-2}$ and $1186Wm^{-2}$ which amounts to 7.6% (Pope, 1977). The existence of cloud reduces this difference. Sutovik (1971) has shown that for Boulder the percentage hours of sun total available ranges from 40% in April to 60% in November. Clark and Marr (1966) use their 1965 radiation data to compute for D1 the percentage of daylight hours with cloud ranges from 41% in October to 84% in August. As a result only three sets of the mean radiation receipt data (Table Two) show a clear increase in radiation receipt with altitude. Thus for the purposes of this initial analysis it has been decided to ignore the altitudinal effect while at the same time acknowledging its existence.

The 1965 data were first analysed using simple and multiple regression techniques. Table Three shows the variables inserted into this analysis together with their abbreviations, units used, and annual means and standard deviations. As a matter of general interest Table Four shows the correlation coefficient matrix between all these variables for the complete year's data. This indicates radiation values and temperature values at the mountain sites to be correlated well between themselves and with the 700mb Denver temperature values. Relative humidity values at the mountain sites are also correlated well among themselves and with the 700mb relative humidity at Denver. This simply illustrates the expected cohesion among these meteorological variables which are observed within a rather small area, as the time scale and sample size becomes rather large.



(a) Distance and measured radiation



(b) Distance and standard deviations

Fig. 3. Correlations between stations.

TABLE FIVE

Variables taken into multiple regression equations where radiation at three sites is used as the dependent variable. Variables are listed in the order in which they were taken into the regressions equations.

Data Period	R1 best explained by variables:	R2 best explained by variables:	R3 best explained by variables:
All Year	R2, TMEANC1, R3	R1, R3, TMEANC3, RHMEAN1	R2, R1, RH, VEL
Jan., Feb.	R2, TMEANC3, RH, RHMEAN2	R1, RHMEAN2, R3, TMEANC2	R2, VEL, FRELEV, TMEANC3
March, April, May	R2, RHMEAN1	R1, R3	RHMEAN2, R2, RH, TMEANC1
June, July, Aug., Sept.	R2, TMEANC1	R1	R2, TMEANC3, TEMP
Oct., Nov., Dec.	R2, FRELEV	R1, R3	R2, FRELEV, RHMEAN3

The stepwise multiple regression technique was used to indicate by which of the variables the radiation observations are best explained. This is shown when the radiation at the three sites is taken in turn as being the dependent variable (Table Five). Although all variables were taken into account in this analysis only those which improve the value of the multiple correlation coefficient by 0.01 when taken into the regression are included in Table Five. The results given in Table Five show that with the aggregate annual data and the seasonally stratified data, the radiation at one site can be estimated from the radiation at the other mountain sites. Furthermore, in most cases values of temperature and relative humidity taken at the same site or at nearby sites can also help improve predictions (more strictly post-dictions) of radiation at that site. With one exception, only the Niwot Ridge radiation is significantly explained by data from the free air over Denver, and this effect is most marked in the winter months. The multiple regression equations used in this analysis are not quoted because they do not, in themselves, have much physical significance. Yet the lowest multiple regression correlation coefficient among them is 0.684 significant at the 99% level and clearly they could be usefully employed to fill in missing data or to estimate radiation receipt at the stations on the Front Range.

It is unlikely however that any one area would have as much data as used in this analysis, so relationships between the radiation values

TABLE SIX

Simple Regression Relationships between the 1965 Radiation Values.
R1 = radiation at B1, R2 = radiation at C1
R3 = radiation at D1. Units = $MJm^{-2}day^{-1}$.

Data Period	Regression Equations	Correlation Coefficients	Cases
All Year	R1 = 0.87R2 + 2.41	0.82	365
	R1 = 0.69R3 + 4.73	0.69	365
	R2 = 0.66R3 + 4.43	0.72	365
Jan, Feb	R1 = 0.64R2 + 2.01	0.84	59
	R1 = 0.33R3 + 5.19	0.51	59
	R2 = 0.53R3 + 4.93	0.61	59
Mar, April, May	R1 = 0.59R2 + 5.20	0.74	92
	R1 = 0.75R3 + 1.44	0.61	92
	R2 = 0.97R3 - 0.48	0.63	92
June, July, Aug, Sept	R1 = 1.09R2 + 2.37	0.90	122
	R1 = 0.56R3 + 10.23	0.59	122
	R2 = 0.47R3 + 7.99	0.59	122
Oct, Nov, Dec	R1 = 0.97R2 + 0.78	0.90	92
	R1 = 0.64R3 + 4.55	0.78	92
	R2 = 0.62R3 + 4.22	0.81	92

TABLE SEVEN

Standard Deviation of Radiation Differences between pairs of stations using the 1965 data. Units = $MJm^{-2}day^{-1}$.

Data Period	Station Pair	Mean	Standard Deviation	Cases
All Year	B1 - C1	0.6548	4.7337	365
	B1 - D1	-0.3881	5.9594	365
	C1 - D1	-1.0428	5.8393	
Jan - Feb	B1 - C1	-1.6780	2.3816	59
	B1 - D1	-1.2971	4.3488	59
	C1 - D1	0.3809	4.1337	59
Mar, April, May	B1 - C1	-2.1913	5.7435	92
	B1 - D1	-3.2586	5.5478	92
	C1 - D1	-1.0673	6.5877	92
June, July, Aug, Sept	B1 - C1	3.8296	3.3080	122
	B1 - D1	2.6281	7.0309	122
	C1 - D1	-1.2015	6.5577	122
Oct, Nov, Dec	B1 - C1	0.5249	1.7954	92
	B1 - D1	1.3840	3.1626	92
	C1 - D1	0.8591	2.9467	92

above are next examined. Table Six shows these relationships. As might be expected the highest correlations are between the stations nearest to each other. B1-C1, C1-D1 and B1-D1 is the order of highest correlation both for the year and when the data are stratified into seasons. In view of the synoptic climatology of the area this ordering of degree of correlation is reasonable. In winter the values of lower stations are best correlated because the higher station is suffering from frequent foehn cloud cover. In spring the lower stations' values are best correlated because they are both affected by the cloud of the upslope conditions. In summer they are best correlated because they are least affected by the cumulonimbus cloud which forms first over the higher elevations. Thus, the interesting situation arises where the order of the degree of correlation between the stations remains the same in different seasons but this occurs for different reasons which rest in the changing synoptic scale conditions.

Suckling and Hay (1976) have demonstrated that there is a fairly steady distance decay function between the correlation coefficient of radiation measured at pairs of stations and the distance between the stations. Their hand drawn curve is reproduced as Figure 3a superimposed on which are the relevant points for the Colorado Front Range 1965 all year data. It is apparent from this and from the correlation coefficients of the stratified data listed in Table Six that the Suckling and Hay relationship does not hold in the mountainous area being considered. The same is true when the standard deviations of radiation differences between station pairings are considered (Fig. 3b).

Figure 3b also includes the results of the study by Wilson and Petzold (1972) which indicates higher values of the standard deviation for a given distance than the Suckling and Hay study. The latter suggest that this could be due to 1) Wilson and Petzold's study being for summer only when high radiation values might give rise to higher standard deviations relative to those for an entire year and 2) the scale of weather systems influencing western Canada being larger than those influencing south eastern Canada, the location of Wilson and Petzold's study. Standard deviations of values of radiation at pairs of stations in the Front Range 1965 data (Table Eight) shows that higher standard deviations are found in the summer for two out of three pairs examined. This supports Suckling and Hay's first point. The second point is also substantiated by the Front Range analysis inasmuch as the synoptic weather conditions affecting the Front Range cloudiness actually manifest themselves as local mesoscale systems within the area being considered.

However, it is necessary to raise the qualification that much of western Canada is mountainous terrain and the present study illustrates that neither the correlation coefficient nor the standard deviation relationships with distance hold in at least one example of mountainous terrain. Hay and Suckling addressed this problem inconclusively in a paper given to the AAG last year.

TABLE EIGHT

Statistics derived from the 1977 data relating radiation receipt between the NOAA station at Boulder and TVAN station on Niwot Ridge.

Data Period	Regression Equation	Correlation Coefficient	SD of Pair	Cases
All data	$R_{NOAA} = 0.97R_{TVAN} + 0.61$	0.86	4.17	110
Jan., Feb.	$R_{NOAA} = 0.87R_{TVAN} + 0.92$	0.85	1.89	25
Mar., April, May	$R_{NOAA} = 1.00R_{TVAN} - 0.23$	0.80	4.52	66
June	$R_{NOAA} = 0.77R_{TVAN} + 6.22$	0.79	4.70	21
Upslope Conditions	$R_{NOAA} = 0.90R_{TVAN} - 1.99$	0.83	3.78	16
Downslope Conditions	$R_{NOAA} = 0.87R_{TVAN} + 3.86$	0.91	3.36	16

Analyses of the daily T-Van and Boulder NOAA data for 110 days in 1977 were made along the same lines as above (Table Eight). However the results from these analyses are not directly comparable to those of 1965 because of nonstationarity and the different amounts of data analyzed. Nevertheless, the results of Table Eight support in a general way the conclusions already reached above. The only major difference is the low standard deviation of the difference in values between the paired stations for January and February. The overall similarity lends support to the conclusions reached in the previous discussion and lends credibility to the earlier less accurate data.

As a minor extension to the 1977 analysis an examination of daily synoptic charts was made in an attempt to determine days with upslope and downslope wind conditions along the Front Range. Although this was rather subjective, of all the 1977 data, 16 days in each category were selected when it was likely that upslope and downslope conditions existed. Results of the regression analysis for these days are added to Table Eight and show that the relationships between the two stations are quite strong for these periods. The mean values of $MJm^{-2}day^{-1}$ for upslope conditions are NOAA (Boulder) 9.07 and TVAN 12.26 implying, as expected, more cloud cover at the lower site. The corresponding values for downslope conditions are NOAA (Boulder) 16.22 and TVAN 14.22 implying (again as expected) greater cloud cover at the upper site. Thus once more the 1965 data results are supported and the importance of synoptic conditions in the spatial relationships of radiation receipt along the Colorado Front Range is demonstrated.

Conclusions

The principal conclusions in this study are:

1) Daily radiation values and mean temperature values at the Front Range sites are well correlated between themselves and with the 700mb Denver temperature values.

2) Values of radiation at one mountain site can be estimated from values at nearby sites and the estimations can be improved by including data on temperature and humidity.

3) Across the Front Range the order of the degree of correlation between radiation values at the three stations remains the same throughout the year (1965) but the result is given by different synoptic conditions.

4) Neither the correlation coefficient nor the standard deviation variation with distance relationships of Suckling and Hay (1976) and Wilson and Petzold (1972) hold over the small distances examined in the Colorado Front Range.

Acknowledgement

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THE EFFECTS OF VARIABLE CLOUD INPUT ON MODEL ESTIMATES OF GLOBAL SOLAR RADIATION

by

L. Skretkowicz*

Introduction

Many models, both physically and statistically based, are available to estimate cloudless sky global solar radiation. With cloud type, amount and transmission characteristics considered, these models can be applied to cloudy sky conditions. A global solar radiation model first presented by Nunez, Davies and Robinson (1972) and refined by Davies, Schertzer and Nunez (1975) utilizes the Houghton (1954) method of cloudless sky global solar radiation estimation together with an amendment for layered cloud effects in the atmosphere. Using hourly cloud observations, this particular model is able to accurately estimate global solar radiation over 5 and 10 day periods. However, its requirement for on-site hourly cloud observations is restrictive as this is not routinely observed at all meteorological stations. A modification of the input criteria to accommodate fewer cloud observations would be desirable as this would extend model applicability to areas where cloud observations are monitored at less frequent intervals.

During the period May through September 1974, a micrometeorological research study was carried out near Simcoe, Ontario. One aspect of this

*Leah Skretkowicz is on the staff of Department of Land Resource Science, University of Guelph, Guelph, Ontario, Canada.

study was the continuous collection of radiation data. In conjunction with this, routine meteorological observations from an adjacent Atmospheric Environment Service observation station were available. A study of the model of Davies, Schertzer and Nunez (1975) based on these data will be considered. Model performance will be examined using hourly and variable cloud observations.

Site and Instrumentation

The measurements of global solar radiation were collected at the Ontario Government Ministry of Agriculture's Horticultural Experiment Station located near Simcoe, Ontario (40°55'N, 80°16'W). This site is approximately 15 km north of Lake Erie. The measurements were made using an Eppley Precision Spectral Pyranometer Model 2 (Eppley Laboratory, Newport, U.S.A.). The sensor signal was recorded on a Honeywell recorder (Electronik 194). The strip charts from this recorder were hand analyzed to produce mean hourly estimates of radiative flux density. The mean hourly values were integrated to give daily totals.

Method of Analysis

The calculation of global solar radiation in the model of Davies, Schertzer and Nunez (1975) requires precipitable water values for cloudless sky, global solar radiation, and hourly observations of cloud for amendment to cloudy sky cases.

The precipitable water values were obtained from 0700 EST upper air measurements taken at Buffalo, New York. The variation in cloud input was accomplished by using cloud data occuring every three, six and twelve hours. Hourly values of randomly generated cloud data were also applied to the cloudless sky global solar radiation daily values. This was done in an effort to estimate the extent to which model performance was affected by the accuracy of the cloud data input. In each of these cases, the estimated radiation values were compared to the measured values.

Theoretical Considerations

Houghton (1954) developed an approach for cloudless sky estimation which has been incorporated into several procedures for cloudy sky estimation. Houghton made four basic assumptions in his model:

1. although the processes of absorption and scattering occur simultaneously in the atmosphere, the direct beam is considered to be absorbed before being scattered;

2. the scattering of radiation is isotropic with half of the scattered radiation reaching the earth's surface as diffuse radiation;
3. half of the dust depletion is due to absorption and half to scattering; and
4. the effects of ozone are neglected.

Global solar radiation which reaches the earth's surface is a product of five transmissions which are expressed as dimensionless coefficients (1-attenuation): water vapour absorption Ψ_{wa}, water vapour scattering Ψ_{ws}, aerosol absorption Ψ_{da}, aerosol scattering Ψ_{ds} and Rayleigh scattering Ψ_{rs}.

These assumptions lead to the definition of direct beam radiation incident on the surface as the amount of radiation transmitted after absorption and scattering:

$$Io \cos Z \; \Psi_{wa} \Psi_{da} \Psi_{ws} \Psi_{ds} \Psi_{rs}$$

where Io = solar constant.

Diffuse radiation is defined in Houghton's work as:

$$Io \cos Z \; \Psi_{wa} \Psi_{da} - Io \cos Z \; \Psi_{wa} \Psi_{da} \Psi_{ws} \Psi_{ds} \Psi_{rs}$$
$$= Io \operatorname{Cos} Z \; \Psi_{wa} \Psi_{da} \; (1 - \Psi_{wa} \Psi_{ds} \Psi_{rs})/2.$$

Cloudless sky global solar radiation reaching the surface therefore is the sum of the direct and diffuse beam components:

$$K{\downarrow}_o = Io \cos Z \; \Psi_{wa} \Psi_{da} \Psi_{ws} \Psi_{ds} \Psi_{rs} + Io \cos Z \; \Psi_{wa} \Psi_{da} \; (1 - \Psi_{wa} \Psi_{ds} \Psi_{rs})/2$$
$$= Io \cos Z \; \Psi_{wa} \Psi_{da} \; [\Psi_{ws} \Psi_{ds} \Psi_{rs} + 1]/2.$$

where $K{\downarrow}_o$ = cloudless sky global solar radiation.

The satisfactory performance of Houghton's cloudless sky estimation procedure has led to the incorporation of the absorption, transmission and reflection effects from clouds to produce a cloudy sky estimation approach. In the cloudy sky approach, consideration must be given to the fact that a part of the radiation reaching a single layer of total cloud amount is reflected from the cloud top and absorbed by the cloud itself. The amount of radiation which is transmitted by the cloud is defined as:

$K{\downarrow}_o\ (1-\alpha_c)\ (1-a_c)$

where α_c = cloud abbedo, and

a_c = cloud absorption coefficient.

However, multiple reflections exist between the ground surface and the cloud base such that a primary term of radiation from the cloud and a secondary reflection term of radiation from the ground exists:

$$K{\downarrow} = K{\downarrow}_o\ (1-\alpha_c)\ (1-a_c) + \alpha_c\ \alpha_g\ [K{\downarrow}_o(1-\alpha_c)\ (1-a_c)]$$
$$= K{\downarrow}_o\ (1-\alpha_c)\ (1-a_c)\ (1+\alpha_c\ \alpha_g)$$

where α_g = surface albedo

In an effort to amend Houghton's procedure for cloudless sky estimation, Monteith (1962) used mean monthly total cloud amounts. He ignored cloud type and assigned a bulk parameter to cloud absorption and reflection. Global solar radiation under cloudy sky conditions was expressed as:

$$K{\downarrow} = S_o(1-c) + D_o(1-c) + cK_o(1-\alpha_c-a_c) + \alpha_g\ \alpha_c\ cK{\downarrow}$$
$$K{\downarrow} = \frac{K{\downarrow}_o[1-c(\alpha_c + a_c)]}{1-\alpha_g\ \alpha_c\ c}$$

where S_o = direct beam radiation in cloudless sky conditions,
D_o = diffuse beam radiation in cloudless sky conditions,
c = total cloud amount, and
(1-c) = gap term.

The model of Davies, Schertzer and Nunez (1975) utilizes the Houghton method of cloudless sky global solar radiation estimation. It adds the effect of one set of reflections between the ground surface and the clouds into its estimation procedure. Cloud transmission coefficients are derived as the ratio of cloudy sky global solar radiation to cloudless sky global solar radiation:

$$t_i = \frac{K{\downarrow}}{K{\downarrow}_o}.$$

Combining cloud amounts and cloud transmission factors for three layers of cloud, the transmissions for each layer i, is expressed as:

$$\Psi c_i = t_i c_i + (1 - c_i)$$
$$= 1 - (1 - t_i) c_i$$

where Ψc_i = transmission through clouds and the gap, and

c_i = cloud amount (fraction of sky covered).

The total cloud transmission is considered to be the product of the individual cloud layer transmissions for the low, middle and high layer cloud:

$$\Psi c = \Psi c_H \, \Psi c_M \, \Psi c_L$$
$$= [1-(1-t_H)c_H][1-(1-t_M)c_M][1-(1-t_L)c_L]$$

where Ψc_H = high layer cluud transmission,

Ψc_M = middle layer cloud transmission, and

Ψc_L = low layer cloud transmission.

The model evaluates global solar radiation under cloudy sky conditions by incorporating cloudless sky global solar radiation with cloud transmissions and a secondary reflection term. Global solar radiation can therefore be expressed as:

$$K\downarrow = K\downarrow_o \; \Psi c(1 + \alpha_g \, \alpha_c \, c_L).$$

Results and Discussion

1) Hourly cloud usage

Good agreement was found in most cases between measured and calculated values of global solar radiation when hourly cloud observations were used. Comparison on a daily basis (Fig.1) reveals variations up to 6 MJ $m^{-2}day^{-1}$. Daily, 5 and 10 day means (Fig.2a) show a slight tendency for underestimation. However, the scatter is quite small with 77% of the daily estimated values within 10% of the 1:1 line. These results agree with those found in the study by Davies, Schertzer and Nunez (1975) using data from five stations in southern Ontario. Examination revealed that no pattern existed between the measured and calculated values on the basis of cloud type or amount. For example, it was found that the daily calculated values of global solar radiation which agreed to within 3% of measured values had varied cloud characteristics. Further, the data did not display a pattern of underestimation with cloud amount between 5/10 and 9/10 or overestimation

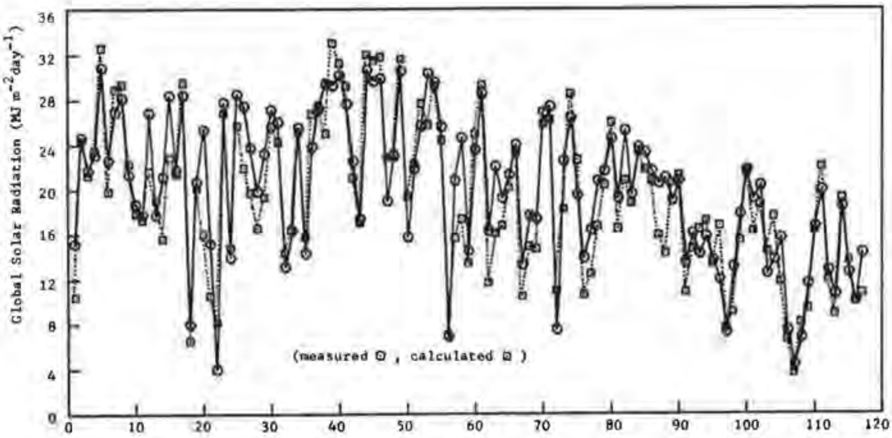
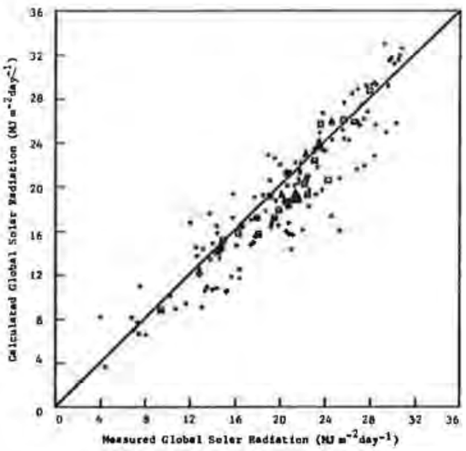


Fig. 1. Comparison of calculated and measured daily global solar radiation values for the period May 29 to September 22 using hourly cloud observations.

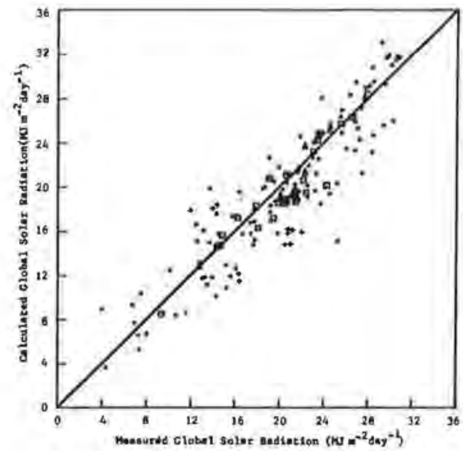
with cloud amount greater than 9/10 as found by Davies, Schertzer and Nunez (1975).

2) Cloud input variations

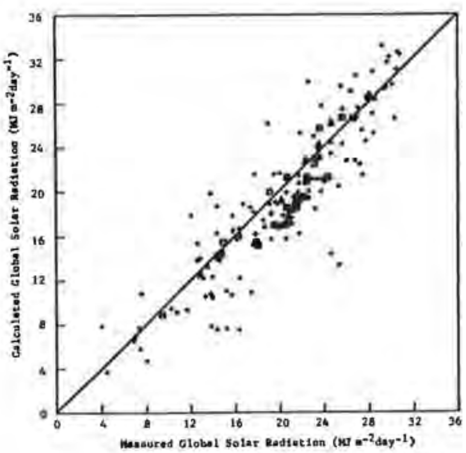
When cloud every three hours was used in the model (Fig.2b) slightly more scatter was produced about the 1:1 line and the same underestimation tendency was evident. The five and ten day mean values were in keeping with and at times better than those produced with hourly cloud. Of the 5 day means, 78% were within 10% of the measured mean values and 90% of the 10 day means were within 10% of the measured mean values. With the use of cloud every six and every twelve hours, the scatter about the 1:1 line increased. For cloud every six hours, 65% of the 5 day means and 65% of the 10 day means were within 10% of the measured mean values. For cloud every twelve hours, 50% of the 5 day means and the 10 day means were within 10% of the measured mean values. The comparison between measured and calculated values for these two variations in cloud input is illustrated in Figures 2c and 2d. These results suggest that the rigid criterion of hourly cloud observations was perhaps unnecessary. With cloud observations taken



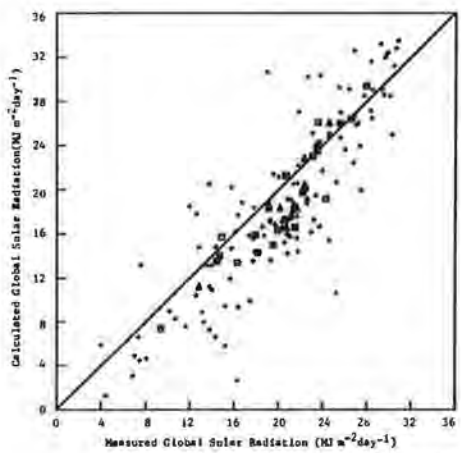
(a) The correlation between calculated and measured values of global solar radiation for daily(+), five day mean(▫) and ten day mean(▲) periods with hourly cloud input.



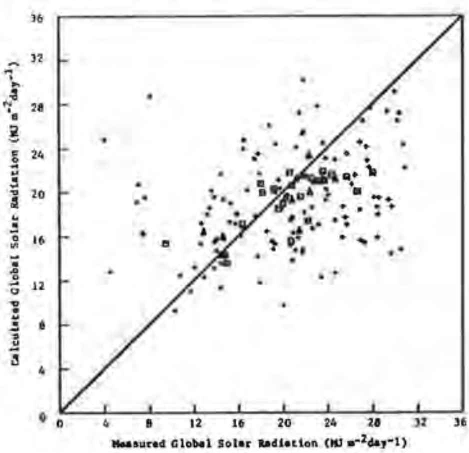
(b) The correlation between calculated and measured values of global solar radiation for daily(+), five day mean(▫) and ten day mean(▲) periods with three hour cloud input.



(c) The correlation between calculated and measured values of global solar radiation for daily(+), five day mean(▫) and ten day mean(▲) periods with six hour cloud input.

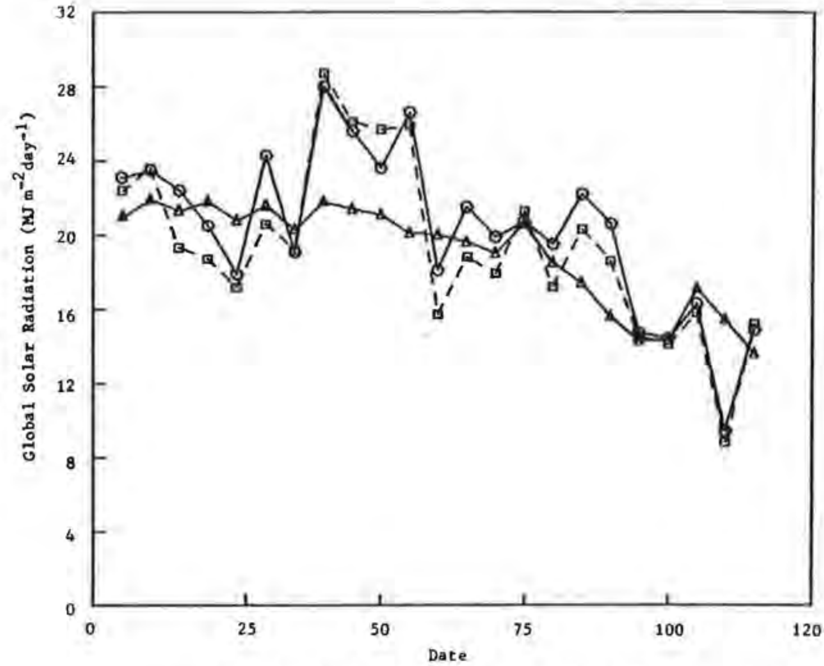


(d) The correlation between calculated and measured values of global solar radiation for daily(+), five day mean(▫) and ten day mean(▲) periods with twelve hour cloud input.

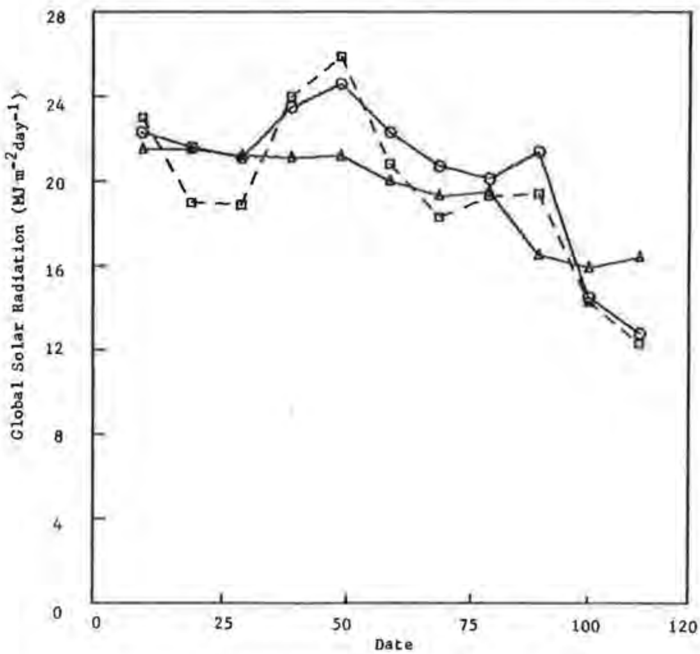


(e) The correlation between calculated and measured values of global solar radiation for daily(+), five day mean(▫) and ten day mean(▲) periods with random cloud input.

Fig. 2. Correlations between calculated and measured global radiation.



(a) Measured and calculated 5 day means of global solar radiation. (measured ⊡ , calculated with hourly cloud ⊙ , calculated with random cloud ▲)



(b) Measured and calculated 10 day means of global solar radiation. (measured ⊡ , calculated with hourly cloud ⊙ , calculated with random cloud △)

Fig. 3. Measured and calculated global radiation - mean day periods.

three times daily the estimated daily values were within 20% of the measured values. The extent of model sensitivity was tested when randomly generated values of cloud amount, type and number of layers were used in place of actually observed data. The results in Figure 2e show quite a large scatter on a daily basis, but the 5 and 10 day means were better by 6% than those produced by cloud every twelve hours.

These random cloud results attest to model insensitivity to cloud observation input over periods of time such as 5 and 10 days. A plot of measured values, hourly cloud values and random cloud values for 5 and 10 day mean periods appears in Figure 3. The figure reveals that over a period of a few days, the fluctuation in radiation values due to daily cloud variability is reduced. This reduction enables random cloud data to have the same chance of estimation over a long period of time as observed cloud data. When the range in variation of data is limited, as in the case of cloud data, the possibility of obtaining good results increases over long periods of time.

Conclusions

Model estimates incorporating hourly cloud observations agree well on a daily, 5 and 10 day basis with those found in the previous study by Davies, Schertzer and Nunez (1975).

Input modification in the form of cloud observations at invervals of three hours produces quite acceptable estimation of global solar radiation on a 5 and 10 day basis. These results indicate that the use of the model in locales where hourly cloud observations are not available has application. The use of random cloud data illustrates the wide variability in cloud input that can be incorporated and still produce results within 10% of measured values on a 5 and 10 day basis. As such, further investigation into schemes to handle cloud variability is necessary. A more stringent method of utilizing cloud and its physical parameters will be required before more accurate modelling on a short term basis will be possible.

Acknowledgements

I am indebted to Dr. J.A. Davies (McMaster University) for providing the opportunity to conduct this study. I gratefully acknowledge the advice given by Dr. W.G. Bailey (Agriculture Canada, Beaverlodge, Alberta.)

LIST OF SYMBOLS

1) UPPER CASE ROMAN

SYMBOL	QUANTITY	UNITS
D	diffuse beam radiation	Wm^{-2}; $MJm^{-2}day^{-1}$
D_o	cloudless sky diffuse beam radiation	Wm^{-2}; $MJm^{-2}day^{-1}$
EST	Eastern Standard Time	hours
I_o	solar constant	Wm^{-2}
$K\downarrow$	global solar radiation	Wm^{-2}; MJm^{-2} day^{-1}
$K\downarrow_o$	cloudless sky global solar radiation	Wm^{-2}; MJm^{-2} day^{-1}
S	direct solar radiation on a horizontal surface for cloudy sky	Wm^{-2}; MJm^{-2} day^{-1}
S_o	direct solar radiation on a horizontal surface for cloudless sky	Wm^{-2}; MJm^{-2} day^{-1}

2) LOWER CASE ROMAN

a_c	cloud absorption coefficient	dimensionless
c	cloud amount	tenths
α_c	cloud albedo	dimensionless
α_g	surface albedo	dimensionless
t	cloud transmission coefficient	dimensionless
z	zenith angle	degrees

3) UPPER CASE GREEK

Ψc	total cloud transmission coefficient	dimensionless
Ψd	total dust depletion coefficient	dimensionless
Ψda	aerosol absorption coefficient	dimensionless
Ψ_{ds}	aerosol scattering coefficient	dimensionless
Ψ_{rs}	Rayleigh scattering coefficient	dimensionless
Ψ_{wa}	water vapour absorption coefficient	dimensionless
Ψ_{ws}	water vapour coefficient	dimensionless

4) SUBSCRIPTS

i	i^{th} cloud layer
H	high cloud layer
M	middle cloud layer
L	low cloud layer

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TEMPERATURE VARIATIONS WITHIN A FOUR-STOREY BUILDING

by

David B. Frost and Halyna Zowtonizka*

Introduction

The four-storey Geography Department building at Concordia University (2090 Mackay Street, Montreal, Quebec) was characterized by high temperatures, particularly on the upper floors, which produced unsuitable working conditions. This paper investigates the reasons for this situation and draws on similar work by Greenwood and Hill (1968) and Latta (1973).

Theoretical Considerations

Buildings function primarily as a shelter for humans by separating undesirable external weather conditions from the desired indoor climate suitable for human comfort. Depending on the thermophysical properties of walls and roofs, a certain amount of the outside elements flow through the materials and upon entering the interior constitute the indoor climate. Where the exterior climate has a significant influence on the interior environment, the diurnal temperature cycles of the two air masses follow a similar pattern of fluctuations with later afternoon maxima and early morning minima, usually separated by a time lag. Internal air is also heated and/or cooled due to the influence of windows, doors, air conditioners, air vents, heating systems and human body heat and thus the effect that walls and roofs

*David B. Frost is Chairman of the Geography Department at Concordia University, Montreal, and Halyna Zowtonizka is with the Department of Geography, Carleton University, Ottawa. This article was originally presented as a paper at the meeting of the New England - St. Lawrence Valley Geographical Society held at Worcester, Massachusetts in October, 1977.

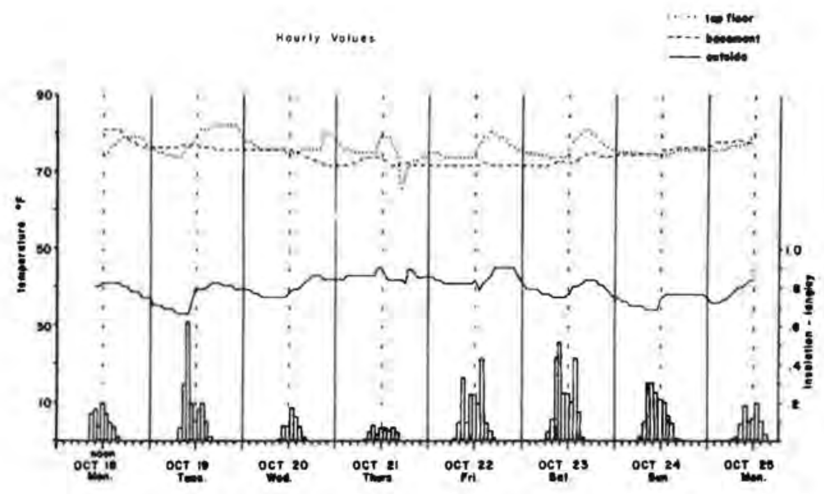


Fig. 1. Internal and External Temperature and Insolation - Oct. 18 - Oct. 25, 1976.

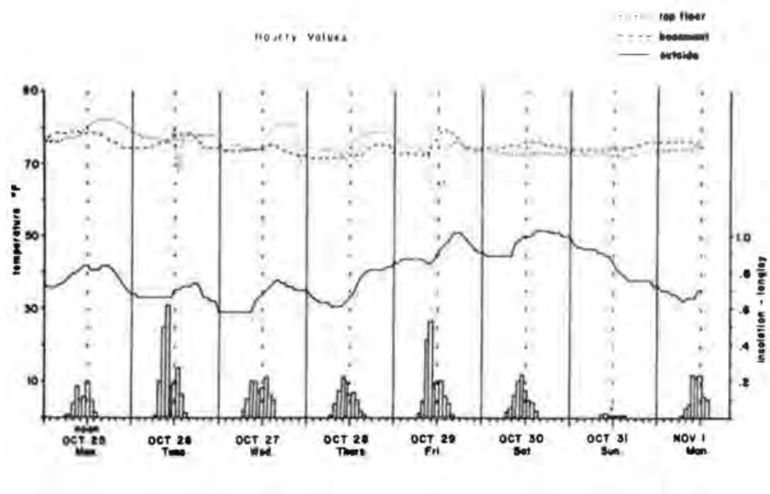


Fig. 2. Internal and External Temperature and Insolation - Oct. 25 - Nov. 1, 1976.

have on the internal environment is modified. Heated air, being warmer and therefore lighter, rises and settles under the ceiling. As doors and openings allow warm air to escape from individual rooms it flows vertically reaching the top floor, whereupon, if no outlet is available the warm air collects under the roof. The consequence of rising warm air in a building or on a floor, is the downward displacement of cooler air. Convection currents are thus created which proceed in this fashion as long as heat is supplied and, without proper ventilation, air at the ceiling becomes gradually warmer as the the day progresses, dispersing only at night when heating is discontinued. These matters are discussed in detail by Aronin (1953) and Givoni (1969) among others.

The Building

The geography building is joined on the north and south to similar adjacent buildings. The stone east wall, some 18-20 inches thick, is the front of the building facing Mackay Street, and the brick west wall, 12 inches thick, faces a back lane. The formerly residential structure dates from the 1880's and despite several renovations it has retained notable Victorian features such as the bay windows, bracketed eaves, gingerbread trim and various internal features like the winding staircase, and generally high ceilinged rooms. There is, however, a low ceilinged top floor, originally quarters for servants.

The basement of the building houses a map collection, the heating system and a physical geography laboratory. The first floor is usually the most occupied as it contains the entrance to the building, a seminar and a reading room. The second floor, consisting largely of one spacious room used for drawing and studying, also contains a corridor leading from the west side to the meteorological station on a west facing sun deck. The top floor is mainly one room frequently occupied during the week for lectures; however, since windows and doors are located on only the west side, there is poor ventilation.

The building is heavily used Monday to Thursday from 10:30 a.m. to 10:30 p.m. and less intensively on Friday and Saturday from 10:30 a.m. to 5:00 p.m.

Instrumentation

Indoor temperatures during the fall of 1976 were recorded by four thermographs during a seven week period, October 18 to December 6.

Temperature differences between the four floors were recorded by setting a thermograph at desk height on each floor for the first two weeks. During the remaining five weeks the four thermographs were situated in different locations on each floor, enabling temperature patterns between the ceiling, floor, east and west sides to be compared (Zowtonizka, 1977). These indoor temperatures were analyzed in conjunction with insolation and outside air temperatures derived from the meteorological station located on the second floor sun deck on the west side of the building (Frost, 1977).

October: Basement vs. Top Floor Temperature Variations

The hourly temperatures on the top floor and in the basement during the two weeks in October 1976 are illustrated graphically in Figures 1 and 2. The outside temperatures and insolation are included to compare their possible influences on internal temperatures. During weekdays the top floor was warmer than the basement but on occasion temperatures on the top floor suddenly fell below basement values due to the sudden entrance of cold air through open windows and doors, or an air conditioner. The daily pattern during weekdays on the top floor is one of afternoon maxima and early morning minima. The basement temperatures indicated no clear diurnal pattern, frequently showing a reversed cycle and this anomaly is attributed to the effects of the central heating system. During the weekends while the building was largely unoccupied, top floor temperatures were consistently lower than those in the basement, a reversal of the weekday pattern.

The weekday fluctuations on the top floor might appear explicable in terms of the external temperature were it not for the absence of fluctuations on the weekends. It is therefore postulated that heat produced by human activity collects during the day on the upper floors increasing the temperature which only declines in the evening when activity decreases and heat flows to the cooler walls. On weekends the absence of human heat permits the top floor to cool through the roof and walls to lower values than those in the basement.

The action of the ventilation and heating systems can be seen during this period and is particularly well illustrated on October 29. The top floor was ventilated at about 10 a.m. dropping the temperature almost immediately by 10°F and within the next hour the heating system attempted to counteract this cooling and raised the basement temperature by about 5°F. Although temperature rose rapidly on the top floor once ventilation ceased, the change was less rapid in the basement.

These results strongly point to the importance of human activity in determining temperatures within the building but this could not be confirmed due to the actions of the heating and cooling systems. Further investigations were undertaken in the summer of 1977 when the heating system was not required.

June and July 1977

Thermographs were placed on the top floor of the building between June 13 and July 25, in the same four locations as described previously, but attention will be concentrated on the readings at desk height. From July 25 to August 8 one thermograph was in the basement and one on the top floor. Care was taken to ensure that no human activity occurred on the top floor and indeed the entire building was virtually deserted during the study. Thus the temperatures recorded could not be influenced by central heating, air conditioning, ventilation or human activity.

Figures 3 and 4 portray the two week period with the greatest external temperature fluctuations, including a period of very hot days, followed immediately by relatively cold weather. Even in these comparatively extreme conditions room temperatures rose and fell slowly and the amplitude of these changes was small compared with those previously recorded. In addition the diurnal increases and decreases so characteristic of the fall record were completely absent. In quantitative terms, sustained increases of 0.6°F/hour were common in the fall but the highest rate in the summer was 0.3°F/hour and similar values apply to rates of temperature decrease.

Prediction of mean room temperature at desk height averaged from noon to noon was attempted by stepwise multiple regression. Examination of Figs. 3 and 4 suggested that there was at least a 12 hour delay between a change in outside temperature and a change within the room. Accordingly outside temperatures were averaged from midnight to midnight to produce a time lag of 12 hours and values were also lagged by a further 24 hours in some cases. Other independent variables were incoming solar radiation, wind kilometers run, precipitation and temperature change from one day's mean to the next. The timing of all variables is indicated diagrammatically in Fig. 5. Analysis showed that four variables emerged as significant for the prediction of room temperature: Out 1, Dif, Dif 1 and Insol, as defined in Figure 5. The multiple correlation coefficient, $R^2 = 0.87$ was significant at the 0.2% level. The primary importance of temperature conditions 36 hours previously suggests that the room is well insulated.

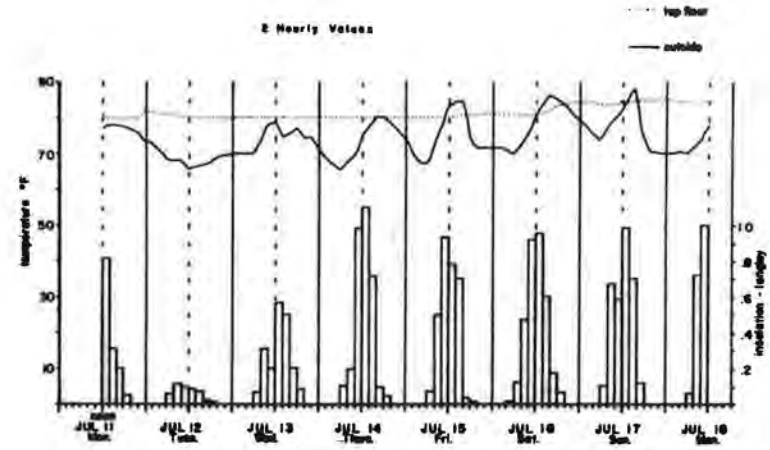


Fig. 3. Internal and External Temperature and Insolation. July 11-18, 1977.

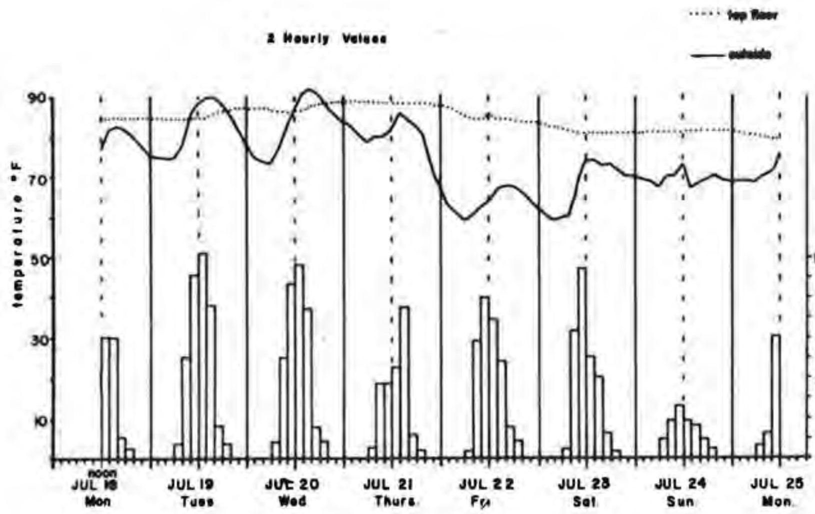
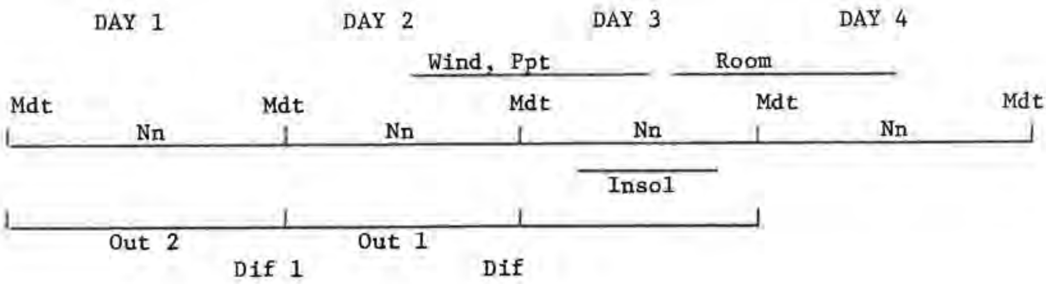


Fig. 4. Internal and External Temperature and Insolation. July 18-25, 1977.



Definition of Variables

Room:	Mean Top Floor Temperatures, °F,	(1200 hrs.day 3-1200 hrs.day 4)
Wind:	Total Wind Kilometers Run,	(1030 hrs.day 2-1030 hrs.day 3)
Ppt:	Precipitation, inches	(1030 hrs.day 2-1030 hrs.day 3)
Insol:	Total incoming solar radiation, lys, *(sunrise-sunset day 3)	
Out:	Mean external temperature, °F	(0000 hrs.day 3-2400 hrs.day 3)
Out 1:	Mean external temperature, °F	(0000 hrs.day 2-2400 hrs.day 2)
Out 2:	Mean external temperature, °F	(0000 hrs.day 1-2400 hrs.day 1)
Dif:	Out 1 - Out	
Dif 1:	Out 2 - Out 1	

Regression Equation

$$\text{Room} = 19.17 + 0.88\text{Out1} + 0.42\text{Dif} - 0.33\text{Dif1} - 0.0008\text{Insol}.$$

$$R^2 = 0.87 \qquad \text{Significance} = 0.2\%$$

Fig.5. Prediction of Mean Top-Floor Temperature
June 13 - July 25, 1977.

The supposition that human activity, mainly body heat and electric lighting, was responsible for the rapid fluctuations recorded in the fall was tested on July 22, regrettably during a period of extreme temperature change both inside and outside the building. A seminar of 12 people caused temperatures in one hour to rise by 2°F at desk height and 5°F at ceiling height. Regrettably the group could not be persuaded to remain in the room without air conditioning for a second hour and the experiment was terminated. Nevertheless it provides convincing proof of the ability of human activity to produce temperature changes of the order of those recorded in October and November.

Fig. 6 portrays temperatures on the top floor, in the basement and outside the building from July 25 to August 1 for comparison with Figures 1 and 2. In summer temperatures on both levels fluctuate together but heating and ventilation prevent this in the fall. During fall weekends,

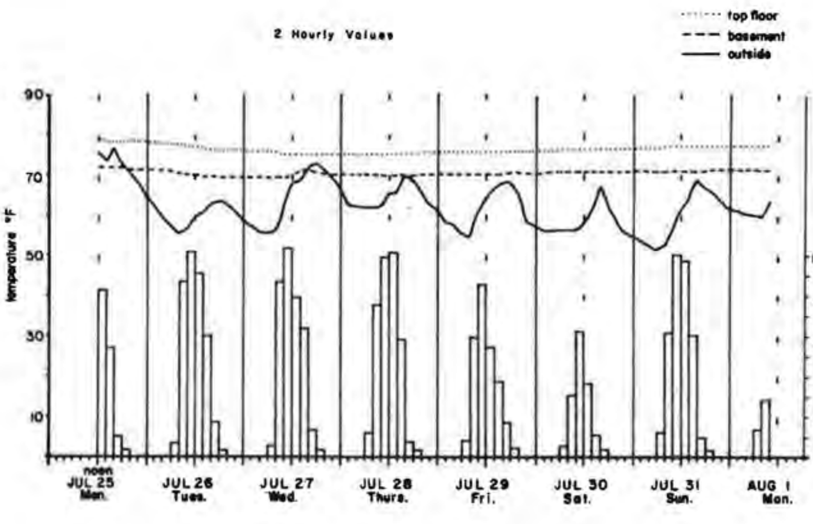


Fig. 6. Internal and External Temperature and Insolation July 25 - Aug. 1, 1977.

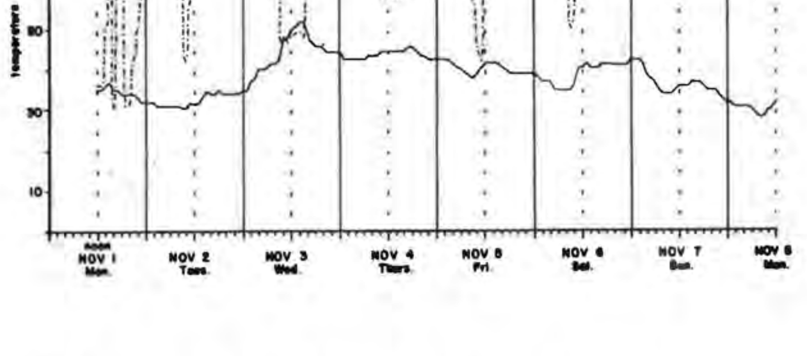


Fig. 7. First Floor Room and External Temperatures Nov. 1-8, 1976.

temperatures on the top floor were lower than in the basement, but this was reversed in summer, and is to be expected where the major heating and cooling of a building is through the roof and walls, and where internal air movement is produced by temperature alone.

Temperature Changes within a High Ceilinged Room

In November 1976 a room measuring 46 x 16 x 11 feet high had two thermographs placed near the center of the room, one on the floor and the other close to the ceiling, together with a third at desk height near a bay window facing north-east and containing an air conditioner. The temperature records of these instruments together with external temperature are portrayed in Fig. 7.

The three internal temperature traces indicate a very wide variety of conditions within the room. At the windows frequent ventilation or air conditioning produced numerous, almost instantaneous changes but 20 feet into the room, even at floor level, change was comparatively slight. At the ceiling ventilation produced apparently no temperature decrease although it may have prevented some increases. Generally temperatures rose in the afternoon and evening, when room occupancy was highest, and declined during the night.

This room illustrates the problem of ventilation in the absence of a through draft and the manner in which warm air produced by human activity can remain trapped at ceiling height unless there is adequate provision for air circulation. The room therefore demonstrates in miniature the conditions within the structure as a whole.

Conclusion

Unpleasant temperature conditions existed in the building during both study periods. In summer, building temperatures were essentially a result of external conditions while in the fall central heating also contributed. At both times of year human activity could rapidly raise temperatures to unacceptable levels, but the building's otherwise satisfactory insulation acts to retain this excess heat particularly near ceilings or upper floors. Provision should therefore be made to circulate air from upper levels to the basement to produce a more even building environment.

Current international moves to increase housing insulation will only be completely successful if the importance of adequate air circulation is recognized, lest extra energy be expended to cool upper floors while heating the rest of the building, as occurred in the structure studies.

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NEWS AND COMMENTS

A news item in Bulletin No. 23 (April, 1978) drew attention to a report contained in the WMO Bulletin for January, 1978 (Vol. XXVII, No. 1) concerning a World Climate Programme to be sponsored by the World Meteorological Organization. A later news release announces that WMO has now launched the World Climate Programme which aims at improving knowledge of the variations of climate due both to natural causes and to human activities. Plans are underway to convene in February 1979 a high level scientific and technical World Climate Conference to discuss in particular the impact of climatic change and variability on man's activities and to prepare for a possible subsequent conference at ministerial level. An important factor in this domain is the concentration of carbon dioxide in the atmosphere and a research and monitoring project on atmospheric carbon dioxide is already underway, with support from UNEP. One of the objectives of the project is to determine the possible impact of changes in the atmospheric content of this gas on climatic trends.

In this connection attention is drawn to an international conference on Climate and History to be held at the University of East Anglia, Norwich, England, from July 8 to 14, 1979. The purpose of the conference is to bring together climatologists, historians, and archaeologists from throughout the world to discuss climate and its possible impact on past and present societies. Persons interested in this conference should write to the Conference Secretary (Climate and History Conference), Climatic Research Unit, School of Environmental Sciences, University of East Anglia, Norwich, NR4 7TJ, England.

Professor John E. Lewis of McGill University has recently initiated a project involving the study of long range transport of pollutants and acid rain concentrations. The study has begun with a survey of synoptic precipitation events in the Schefferville area of Quebec with a view to understanding how different storm tracks have influenced the concentration of sulphates and nitrates in the rain falling on the area. In preparation for further investigation for next year, for extending the project to north-west Europe, Lewis spent three weeks working at the Kevo Subarctic Research Institute in Finland. He also spent two days at the Finnish Meteorological Institute in Helsinki, and visited the Danish Meteorological Institute at Copenhagen.

The 1978 meeting of Friends of Climatology was held at Wilfred Laurier University on Saturday, April 22. Organized by Ken Hewitt, it was attended by some 40 persons, mainly from Ontario and Quebec. The morning session was divided into two parts. The first part involved discussion of various aspects of "Air Pollution Climatology in the Seventies". Four discussants gave the lead to the material and comments offered in this part of the programme: M.S. Hirt, Atmospheric Consultant and President of Meteorological Environment Planning Corporation, H.E. Turner, Chief of the Atmospheric Dispersion Division of AES, and two research scientists with AES, E.H. Fanaki and Ron Portelli. The second part of the session followed a coffee break and consisted of a presentation by E. Vowinckel, of the Department of Meteorology at McGill University. Dr. Vowinckel discussed some "Results of Natural and Artificial Surface Changes on the Water Budget and Climate", illustrating his remarks from work he had undertaken in the region of the upper Nile in the Sudan.

The afternoon session began at 2 p.m. after delegates had done full justice to the excellent pizza and supplies of various wines provided by the meeting's thoughtful organizers. There was a thirty-minute period used for two short reports: one by B.J. Garnier in respect of his activities as Climatologist in Orbit for 1978 (see Bulletin No. 23, April 1978 pp. 31-33), and a second by A.J.W. Catchpole and D. Milton concerning the work being undertaken at the University of Manitoba in the use of historical records in climatological research and the analysis of climatic change. These two short reports were followed by a session on "The Role of Climatology in Geological (Biological) Land Classification". This discussion was chaired by Bruce Findlay of the AES, with lead contributions from W.M. Baker, a Consultant in Tourist, Park and Recreation, and from G. Wickware, a Research Officer with the Lands Directorate at Burlington.

Those Friends who had been able to reach Waterloo the day before the main meeting, met in a workshop session at the University of Waterloo, organized by Elsworth LeDrew and his colleagues. The workshop devoted itself to considering and discussing various examples of computer programming and modelling in the climatic field, with particular reference to energy budget and radiation studies and the factors involved in their characteristics and spatial variations.

The meeting of Friends of Climatology for 1979 is to be held at the University of Western Ontario. Anyone interested who is not already on the mailing list is invited to write to Professor R.W. Packer, Department of Geography, University of Western Ontario, London, Ontario.

Climatology featured prominently in the recent Northeast Regional Meeting of the Association of Collegiate Schools of Architecture. The meeting was held in Montreal starting on the evening of Thursday, October 19, and continuing into Saturday, October 21, 1978. The intervening day, Friday, October 22, was devoted to three main academic sessions, one of which had the title "Topography and Climate". Invited as keynote speaker for the session was B.J. Garnier, Professor of Climatology at McGill University, who reviewed in general terms the subject-matter of the session and provided specific examples from work on the radiation balance of individual sites and slopes, and from studies in human comfort in the City of Montreal. The keynote address was followed by three substantive presentations:

(a) Professor John Lewis, McGill University, on "The Impact of Land Use on Urban Temperature Fields";

(b) Professor Peter Manning, Nova Scotia Technical College on "A Teaching Approach to the Design of a Climatically Responsive Architecture via Simulation and Measurement"; and

(c) Professor Norbert Schoenauer, McGill University, on "Settlement and Building Design in the Sub-Arctic".

The American Meteorological Society is becoming increasingly well-known for its organization or sponsorship of excellent workshops and short courses. Last summer one such short course was held at Boulder, Colorado, to study recent developments in research into the Planetary Boundary Layer. The course lasted a week, from August 7-11, 1978, and drew an attendance of over 50 persons. Among the topics discussed were: "Similarity and Scaling Rules" (H. Tennekes), "Observed Characteristics of the Boundary Layer" (J.W. Deardoff), and "Comprehensive Models used in the Boundary Layer (J.C. Wyngaard). There was also a discussion on the question of parameterization for circulation models with particular reference to interaction between the planetary boundary layer and the free atmosphere, and to the parameterization of vertical fluxes. The presentation and discussions of the study course will form the basis of a new book on the Planetary Boundary Layer to be published in the AEC "Critical Review" series.

Readers of the Bulletin who have enjoyed the contributions by Simon Kevan on human behaviour and characteristics in relation to the seasons and to climate (see for example Bulletin No. 19, pp. 1-16), will be interested in a recent article from him: "The Seasonal Behaviour of Canadians", in Canada's Mental Health' Vol. 26, No. 2, June 1978, pp. 16-18.

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Department of Geography (Climatology)
McGill University
805 Sherbrooke Street West
Montreal, Quebec, Canada
H3A 2K6

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