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ESTIMATING NET RADIATION AT NIGHT OVER A WATER SURFACE

by

C. GRIFFITH

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ABSTRACT

This paper attempts to develop a statistical model capable of estimating net long-wave radiation over water, under clear and overcast sky condition.

Using a multiple stepwise regression technique eight regression models were produced incorporating pre-determined meteorological variables (air temperature, water temperature, and vapour pressure).

Overcast skies at inland stations (Niagara, Perch and Rawson) generated the highest multiple correlation coefficients (+.61 to +.67). Clear sky conditions gave higher correlation (0.72) at Ocean Weather Station "P".

The report concludes by comparing the regression equation developed here with another estimating equation. The regression model proved to be a better predictor of net long-wave radiation for a time period of four months or longer.

In view of the subjective nature of obtaining some of the data the results are considered good, and might serve as a model for predicting net long-wave radiation over water for other mid-latitude Canadian locations.

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ÉVALUATION DU BILAN RADIATIF LA NUIT, AU-DESSUS D'UNE SURFACE AQUATIQUE

par

C. Griffith

RÉSUMÉ

Dans le présent article, l'auteur cherche à mettre au point un modèle statistique pour l'évaluation du bilan du rayonnement de grandes longueurs d'onde au-dessus de l'eau lorsque le ciel est clair ou couvert.

En appliquant une technique de régression multiple par étapes, on a obtenu huit modèles de régression en introduisant des variables météorologiques déterminées à l'avance (température de l'air, température de l'eau et pression de vapeur).

Lorsque le ciel est couvert, ce sont les stations de l'intérieur des terres (Niagara, Perch et Rawson) qui fournissent les coefficients de corrélation multiple les plus élevés (de .61 à .67) tandis que par ciel clair on obtient une plus forte corrélation (0. 72) pour la station météorologique océanique "P".

Pour conclure le rapport, une comparaison entre l'équation de régression mise au point par l'auteur et une autre équation d'évaluation. Les possibilités du modèle en ce qui concerne la prévision du bilan radiatif des grandes longueurs d'onde pour une période de quatre mois ou plus s'avèrent meilleures.

Compte tenu de la part de subjectivité qui entache l'obtention de certaines données, on estime que les résultats sont bons et qu'ils sont susceptibles de servir de modèle pour la prévision du bilan radiatif des grandes longueurs d'onde au-dessus de l'eau pour d'autres endroits situés à une latitude moyenne au Canada.

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by

C. Griffith

(Manuscript received September 9, 1974)

1. Introduction

Radiation is the most important meteorological element known to man. It controls the energy balance of the earth by being the primary energy input to the surface, hence driving the "atmospheric engine". Due to its paramount importance a physical understanding of all its processes is essential.

By night, net long-wave radiation is the balance between radiation emitted upwards by the underlying surface and the radiation absorbed from the atmosphere above. The emitted radiation is a function of the surface temperature alone, while the absorbed radiation is proportional to both the thermal and moisture characteristics of the atmosphere above.

Studies of net long-wave radiation over water are few. Consequently an estimation of net radiation over a water environment using readily available measurements is desirable. The net gain or loss of radiation heat by bodies of water is imperative for studies concerned with heat storage, transport of energy by currents, heat and vapour fluxes between the air and water, and other related hydrometeorological problems.

The objective of this studyis to obtain a statistical model for estimating net long-wave radiation at night over a water surface, during clear and overcast sky conditions.

2. Methodology

Data were obtained from four over-water sites, all equipped with C.S.I.R.O. pyrradiometers (Funk) which measure the vertical flux of solar and terrestrial radiation. These included two small lakes - Rawson, near Kenora, Ontario and Perch, close to Chalk River, Ontario; Niagara Tower just below the falls and Ocean Weather Station "P" of the coast of British Columbia. Table I lists their coordinates, elevations and periods of record.

From the numerous multivariate methods available, stepwise multiple regression was chosen as it affords the advantage of efficiently selecting significant predictors to generate a series of regression equations. This technique involves adding independent variables one at a time. These variables enter the regression model in the order of the variables contributing most to the unexplained variance remaining in the dependent variable after the last independent variable had been selected. The stepwise procedure continues until all specified independent variables are included or until there are no more independent variables which explain a specific minimum value of variance.

Although many of the essential criteria of regression techniques are satisfied, one criterion is not met. There is the problem as to whether some of the independent variables are highly correlated (multicollinearity). For this study, however, multicollinearity was not considered critical since the variables selected do not appear to be highly correlated physically.

Based on their ease of measurement and meteorological and statistical significance, three independent variables were selected as predictors of net long-wave radiation: (a) water temperature, T_w(C), (b) air temperature T_a(C) and (c) vapour pressure, e (mb).

All data were averaged over a three-hour period, between the hours 02 - 04 GMT and 06 - 08 GMT to ensure night conditions. For seasons unrelated to this study a water temperature constraint was imposed on the Niagara Tower data. No temperatures exceeding 2C were used (only two cases were omitted). Recorded net radiation charts were used to differentiate between clear and overcast sky conditions for the three inland stations. If the radiation trace was uniform and considerably below the zero value, it was assumed clear. Similarly, if the trace was uniform and near the zero value, it was assumed overcast for the specified time periods. This procedure was used as no alternative cloud cover observations were available.

Observations of sky cover from Ocean station "P" were obtained from ship log manuals, with a sky cover of 8/10 - 10/10 for overcast conditions and 3/10 and less for clear sky.

3. Results and Discussion

A. Regression Models

Table II summarizes the results of the stepwise multiple regression analysis, including the final regression equations for estimating net long-wave radiation over water, and the statistical tests necessary to demonstrate the effectiveness of the regression equations.

A number of inferences are obvious:

1. Overcast skies for the three inland stations give the highest multiple correlation coefficients, ranging from +0.61 to +0.69. Under clear skies the correlation was lower, from +0.43 to +0.51.

2. Ocean Station "P" manifests a reversal of the continental pattern. Clear sky conditions produced the higher correlation (+0.72), while overcast skies (+0.42) were lower.

3. An "F" test indicated that T_w, T_a and e for all stations contributed significantly at the 1% level to each prediction by decreasing the amount of unexplained variance.

4. In order to investigate the lower correlation for clear skies at Niagara Tower a table of residuals was examined in greater detail. Two occasions, January 12 and 13, 1969 which had been assumed to have clear sky, were found by an analysis of surface weather charts to have been overcast. This error resulted in a lower correlation for the Niagara clear sky regression equation. The corrected R value is +0.44 (see Table II).

B. Mean Values

Table III shows mean values and ranges for the observations. While mean net long-wave radiation for the three inland stations increased with cloud cover (-8 to -3 ly hr^{-1}), a change of less than one langley occurred at Station "P". This indicates the relative insensitivity of net radiation to cloud cover at Ship "P". There is little variation in the mean values for overcast or clear conditions. Overland mean air temperatures increased by approximately 4C and mean vapour pressure close to 2 mb for the increase in cloud. It is not surprising that water temperature shows little variation with cloud cover amount, at all four stations. It should be noted from the Stefan-Boltzman law that an error of 0.5C in the surface water temperature will result in an error of about 0.2 ly hr^{-1} for surface long-wave radiation.

The reason for the large variation between inland mean values is due to the time of year when the data were observed. Niagara observations were wintertime readings while these at Perch and Rawson were taken during the summer.

If the independent variables are ranked in order of appearance in the regression analysis one may deduce how representative each regression analysis is (Table IV). Rank "1" indicates the highest correlation.

Inland, vapour pressure is the best predictor of net long-wave radiation, followed by air temperature. The predictor ranking and the observed data means are quite similar for Perch and Rawson, as one might expect form the corresponding observation periods and lake characteristics. The one major element of difference, their spatial positioning with respect to the Great Lakes, appears not to be significant in the prediction of net long-wave radiation.

4. Comparison with Other Methods

Several empirical methods for estimating net long-wave radiation using standard weather observations (air temperature and humidity) have been described in Sellers (1965).

For this study estimated values were calculated using Ångström's equation (Sellers 1965) and then compared with the Perch Lake regression equation for clear sky conditions. Ångström's equation is $I = E \sigma T^4 (1 - a_o + b_o 10^{-c_o e})$ where I = net radiation, E = emissivity coefficient (assumed = 1), σ = Stefan-Boltzman constant (8.14×10^{-11} ly $min^{-1} K^4$), T = air temperature near the surface in K, e = vapour pressure near the surface in mb, a_o, b_o and c_o are empirical constants, where $a_o = 0.820$, $b_o = 0.250$ and $c_o = 0.094$. These coefficients are representative of atmospheric conditions around the German Baltic coast (Geiger 1966). The Perch Lake regression is

$$R_N = 4.0 - 0.351\ T_w - 0.194\ T_a + 0.466\ e \text{ where:}$$

R_N = net radiation (ly hr^{-1})
T_w = surface water temperature (C)
T_a = surface air temperature (C)
e = surface vapour pressure (mb)

Abraham (after Sellers, 1965) found from various charts and equations for estimating net long-wave radiation, that Ångström's method gave one of the most accurate results. Yet in this study the Ångström equation under-predicted all but one of the measured net radiation observations. However, Abraham found that it tended to over-estimate the actual values.

The small variation in the estimated values (-6.2 ly hr^{-1} to -7.2 ly hr^{-1}) reflects the insensitivity of Ångström's equation to the data (see Table V). The regression model had an average error of -0.8 ly hr^{-1} as opposed to -1.9 ly hr^{-1} for Ångström's. The dispersion of the regression-model computed values was within the observed range and yet closer to the observed dispersion than that computed according to Ångström.

Although this study is concerned with both clear and overcast sky conditions, the lack of specific cloud data prevents a comparison of the overcast sky conditions. Had cloud height and type been known a comparison would have been possible.

The relative accuracy of the regression equation shows that the meteorological variables, air temperature, water temperature and vapour pressure are better predictors of net long-wave radiation under clear sky conditions for this test case.

5. Conclusions

On the basis of the results, the following conclusions seemed warranted:

1. The regression model developed here is a good predictor of net long-wave radiation over a water surface at night, under clear and overcast sky conditions. Multiple correlation coefficients ranged from +0.43 to +0.51 for clear skies and from +0.61 to +0.69 for overcast sky conditions at the three inland stations. At Ship "P" values of +0.42 under cloudy conditions and +0.72 for clear were obtained.

2. Using a restricted sample, values computed by the regression equation method, had an average error within 1 ly hr^{-1}.

3. The high correlation found when data from all four stations were combined may indicate the general applicability of this model to mid-latitude Canadian locations.

6. Acknowledgement

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APPROVED,

J.R.H. Noble,
Assistant Deputy Minister,
Atmospheric Environment Service.

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2. Geiger, R., 1966: The Climate Near the Ground. Harvard University Press, Cambridge.

TABLE I

Summary of Test Sites

Station	Location	Station Elevation above M.S.L. (m)	Period Tested
Niagara Tower	43° 04' N 79° 03' W	150	Dec.-March 1969, 1970-71
Perch Lake	46° 02' N 77° 22' W	150	June-Sept. 1970-72
Rawson Lake	49° 39' N 93° 43' W	450	June-Sept. 1970-71
Ship "P"	50° 00' N 145° 00' W	Sea Level	March-May 1968-69, 1972

TABLE II

Regression Equations and Statistical Methods Used
In Estimating Net Radiation Over a Water Surface

Station	Regression Equations	Multiple Correlation Coefficients	Standard Error	Number of Observations
Niagara				
Clear	$R_n = -12.01 - 1.78\ T_w - 0.21\ T_a + 1.39\ e$	+0.44	1.96	66
Overcast	$R_n = -2.63 + 0.137\ T_w + 0.117\ T_a + 0.388\ e$	+0.69	1.05	54
Perch				
Clear	$R_n = -4.0 - 0.351\ T_w - 0.194\ T_a + 0.466\ e$	+0.43	1.74	42
Overcast	$R_n = -1.59 - 0.321\ T_w + 0.190\ T_a + 0.109\ e$	+0.61	1.00	39
Rawson				
Clear	$R_n = -6.20 - 0.262\ T_w + 0.029\ T_a + 0.280\ e$	+0.51	1.49	72
Overcast	$R_n = -2.88 - 0.401\ T_w + 0.157\ T_a + 0.167\ e$	+0.61	1.24	34
Ship "P"				
Clear	$R_n = -4.85 + 0.339\ T_w + 0.850\ T_a - 0.306\ e$	+0.72	1.69	24
Overcast	$R_n = -2.82 - 0.617\ T_w + 0.460\ T_a + 0.225\ e$	+0.42	1.30	96
All Stations				
Clear	$R_n = -5.75 - 0.374\ T_w + 0.109\ T_a + 0.340\ e$	+0.57	2.12	203
Overcast	$R_n = -1.52 - 0.339\ T_w + 0.182\ T_a + 0.142\ e$	+0.72	1.17	215

R_n = net radiation (ly hr^{-1}) T_w = water temperature (C) T_a + air temperature (C) e = vapour pressure (mb)

TABLE III

Summary of Mean and Range Values for Variables

Clear Sky	Independent Variables (means) T_w (C)	T_a (C)	e (mb)	Dependent Variable (ly hr^{-1}) Mean	Standard Deviation	Range
Niagara	0.26	-6.7	2.7	-6.1	2.3	-9.7 to -1.9
Perch	20.1	12.3	13.3	-7.92	1.9	-11.4 to -3.2
Rawson	20.7	16.8	13.2	-7.84	1.7	-10.3 to -2.9
Ship "P"	5.0	4.3	8.4	-2.0	2.3	-6.0 to 0.0
Overcast Sky						
Niagara	0.20	-2.6	4.4	-1.4	1.4	-5.8 to 0.0
Perch	20.1	15.2	15.8	-3.4	1.2	-5.0 to -1.9
Rawson	19.5	16.3	14.0	-2.9	1.5	-6.0 to + .1
Ship "P"	5.2	5.4	8.2	-1.2	1.4	-6.0 to 1.0

TABLE IV

Rank of Independent Variable Selection
Based on Their Simple Correlation

	Clear Night Skies T_w	T_a	e	Overcast Night Skies T_w	T_a	e
Niagara	1	3	2	3	1	2
Perch	2	3	1	2	3	1
Rawson	2	3	1	2	3	1
Ship "P"	3	1	2	2	1	3

TABLE V

Comparison of Methods for Estimating Net Long-Wave Radiation (ly/hr) Over Water

Date/72	Ta(C)	e (mb)	Ångström's Equation	Regression Equation	Measured Values
6/13	14	14.9	-6.3	-7.1	- 8.0
6/15	17	15.4	-6.5	-6.7	- 7.7
6/16	9	7.4	-7.1	-8.9	-11.4
6/17	8.6	10.2	-6.4	-8.2	- 9.0
6/18	13.5	12.6	-6.5	-9.1	- 9.6
6/19	20	22	-6.6	-6.8	- 7.9
6/28	18	19	-6.4	-6.8	- 7.7
7/19	19	20	-6.4	-7.8	- 7.6
7/28	13	14.3	-6.2	-7.8	- 7.8
7/29	13	13	-6.3	-7.9	- 7.9
7/30	16	17	-6.3	-7.9	- 8.3
8/1	18	17	-6.5	-7.9	-10.1
8/4	12.5	13.6	-6.2	-7.1	- 8.3
8/5	8.0	9.6	-6.4	-8.1	- 9.7
8/10	11.2	12	-6.2	-6.3	- 5.4
8/19	12	13	-6.2	-7.1	- 7.2
8/20	15	16	-6.5	-7.4	- 7.8
9/17	12	13	-6.2	-6.4	- 7.8
9/19	3.2	7.3	-6.5	-7.1	- 7.5
9/20	10	9.2	-6.7	-7.6	-10.1
Mean			-6.4	-7.5	- 8.3
Standard Deviation			0.22	0.76	1.03

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