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The effects of rawinsonde density and frequency on radiation computations

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ABSTRACT

High density and frequency of rawinsonde observations during the International Field Year of the Great Lakes (IFYGL) were used to determine the sensitivity of infrared computations for daily and weekly periods. Model derived values of daily surface flux and radiative heating rates computed from various spatial and temporal distributions of rawinsonde observations exhibited only small changes.

1. Introduction

An increasing number of meteorological field programs are being planned around the world. In most cases, there is a desire to obtain the necessary data at the least cost. Further, the importance of additional data for radiative transfer is acknowledged. However, very little data has been accumulated on the density and frequency of rawinsondes needed to obtain a complete and accurate radiation profile of the atmosphere.

The International Field Year of the Great Lakes (IFYGL), a joint United States and Canadian field program on Lake Ontario, was conducted from April 1972 through March 1973 (Aubert, 1974). As part of IFYGL, an energy balance program was developed to determine evaporation, sensible heat flux, lake heat storage, radiative fluxes, radiative heating rates and advective heat fluxes (Pinsak and Rodgers, 1978). Two basic methods were used to compute the radiation budget during the field year. The first method consisted of the development and operation of a numerical model that computes the radiative fluxes at the surface of Lake Ontario and radiative heating rates in the layers above Lake Ontario, using standard meteorological surface and rawinsonde data (Atwater and Ball, 1978). The second method utilized a network of radiation stations around and on the lake to measure various radiation fluxes (Davies, et al., 1975). The United States sponsored the modelling approach and Canada sponsored the observational approach.

The basic IFYGL data used in the model applications consist of hourly surface weather observations from eight first-order weather stations around Lake Ontario, from the Oswego radar (a total of nine land stations) and from two NOAA research ships. The ships also provided surface water temperature data. During the Fall, from September 22, 1972 through December 10, 1972, rawinsonde observations were also taken at six locations bordering on the lake, as seen in Fig. 1. The frequency of the rawinsonde observations was 3-hourly on 57 days, and 12-hourly on the other 22 days. The temperature and humidity data used in the current study from the soundings were at 50-mb intervals.

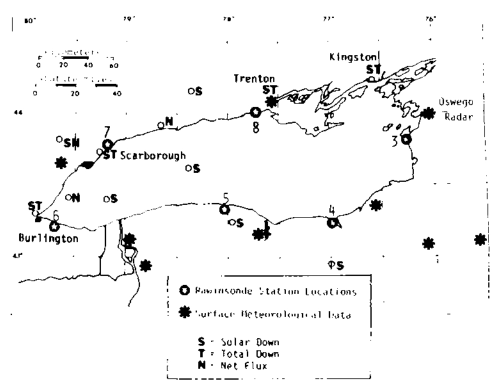

Fig. 1. Rawinsonde and radiation observing sites during IFYGL.

In view of the high density of rawinsonde observations, a study was undertaken to determine the effects of varying the temporal and spatial density of rawinsonde observations used for computing radiative fluxes.

The computation of infrared fluxes is dependent on the vertical distribution of clouds, temperature and moisture. In this study evaluating the effects of varying rawinsonde densities, a single set of cloud analyses was used.

Direct infrared observations during IFYGL were not sufficiently reliable (Phillips and Rasmusson, 1978) so that infrared observations had to be derived from solar and total flux observations. While measurements of incoming solar radiation during IFYGL are available at ten sites, total downward fluxes are available at only three sites. (Total radiation data at Scarborough, Ontario were unreliable.) Data from these three sites (Trenton, Kingston and Burlington, Ontario) are used in this investigation for comparison with model-computed infrared fluxes. At these three sites, the average derived incoming infrared observations varied from 289 Wm^{-2} at Kingston to 321 Wm^{-2} at Burlington for the 79 day period. Model computed values of infrared radiation tended to be greater than observed values at Kingston and less than observed values at Burlington.

2. The infrared radiation model

The development of the infrared radiation model was described by Atwater and Ball (1978) and only the resultant equations will be presented here. The basic equation for downward infrared flux $F\downarrow$ is given for clear skies as

$$F\downarrow = \int_0^{\infty} \sigma T^4(z') \frac{\partial \tau(0,z')}{\partial z'} dz' \quad (1)$$

where σ is the Stefan–Boltzmann constant, T is temperature, z is height, and τ is the transmission function for water vapor and carbon dioxide as given in Table 1. The downward flux is modified in the presence of clouds as

$$F\downarrow = \int_0^{z_c} \sigma T^4(z') \frac{\partial \tau(0,z')}{\partial z'} dz + (1-c) \int_{z_c}^{\infty} \sigma T^4(z') \frac{\partial \tau(0,z')}{\partial z'} dz + c\sigma T_c^4\, \tau(0,z_c) \quad (2)$$

where c is the cloud amount at height z_c and T_c is the cloud base temperature.

Table 1. *Infrared diffuse transmission functions for water vapor path length (u in cm) and carbon dioxide path length (u_c in atm-cm)*

Water vapor:	
$\tau = 1 - 0.11288 \log(1 + 12.63u)$	$\log u \le -4$
$\tau = 0.104 \log(u) - 0.560$	$-4 \le \log u \le -3$
$\tau = 0.121 \log(u) - 0.509$	$-3 < \log u \le -1.5$
$\tau = 0.146 \log(u) - 0.473$	$-1.5 \le \log u < -1$
$\tau = 0.161 \log(u) - 0.458$	$-1 \le \log u \le 0$
$\tau = 0.136 \log(u) - 0.458$	$\log u > 0$
Carbon dioxide:	
$\tau_{CO_2} = \exp(-0.3919 u_c^{0.4})$	

Radiative heating rates $\partial T/\partial t$ are based on the standard equation

$$\frac{\partial T}{\partial t} = \frac{-1}{\rho c_p} \frac{\partial F_n(z)}{\partial z} \quad (3)$$

where $F_n(z)$ is the net flux given by

$$F_n(z) = F\downarrow(z) - F\uparrow(z). \quad (4)$$

ρ is density and c_p is specific heat of air. $F\downarrow(z)$ is the downward flux and $F\uparrow(z)$ is the upward flux at height z, which is computed analogously to eqs. (1) and (2).

Cloud and surface meteorological data obtained from the land and ship stations were objectively analyzed (on an hourly basis) to obtain the required data at the radiation site. Trenton is the only site where surface meteorological data and radiation data coexist. Radiative fluxes were computed each hour and integrated for 1 through 14 day intervals for comparison with observations.

The consistency of computed incoming infrared radiation can be affected by (1) errors in cloud amount and height derived from surface meteorological observations and analyses and (2) errors in temperature and humidity data from the special IFYGL rawinsonde observations (RAOBs). Errors in cloud amount and height should not introduce any systematic bias into the results, since cloud observation errors will be identical for computations using different upper-level soundings. Errors in temperature and humidity profiles could result from some questionable temperature and moisture data that have been identified at the six special IFYGL RAOB stations (Hoexter, 1976). Also, the special soundings used did not contain an intermediate level between 1000 mb and 950 mb. Thus, low level temperature/moisture information is limited on approximately 10 of the 79 days of the sample, when the surface pressure is less than 1000 mb.

3. Results

Values of incoming infrared radiation were computed at Burlington, Trenton and Kingston using the following configurations of rawinsondes: (1) six RAOBS, (2) six RAOBs only at 0000 GMT, (3) RAOBs at Station No. 3 (east end of lake) and Station No. 6 (west end of lake) only, (4) RAOB at Station No. 3 only, and (5) RAOB at Station No. 6 only (see Fig. 1). Root mean square difference (RMSD) is given by

$$\mathrm{RMSD} = \sqrt{\frac{1}{m}\sum_{1}^{m}(F\downarrow - F_0)^2} \qquad (5)$$

where F_0 is the flux at the surface computed from the observation of solar and total fluxes. The RMSDs for these configurations are given in Table 2.

The RMSD of the most dense, spatially and temporally, of daily IR radiative fluxes is generally lowest, as might be expected. When only OOZ special IFYGL soundings are used in the computations, the RMSD increases by about 10% at Trenton, and insignificantly at Kingston and at Burlington when compared with differences obtained using all IFYGL soundings. The differences in RMSD's are quite small between differing rawinsonde densities and are comparable to the change between the special IFYGL soundings at all times and only one time a day.

The above results used an integration period of one day. The results for an integration period varying from one day to two weeks are shown in Fig. 2 for Trenton. The data show that the RMSD's are significantly reduced as the averaging time is increased to about one week. Results at the other two stations are comparable.

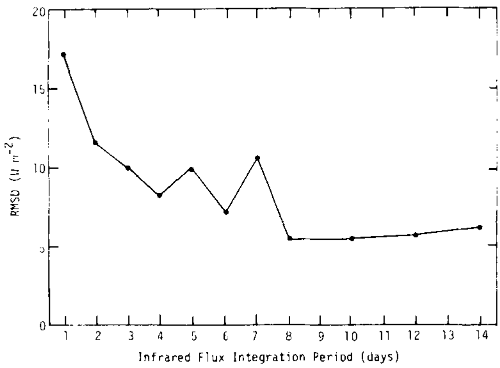

Fig. 2. RMSD at Trenton as a function of integration period using all IFYGL rawinsondes.

Two-day averages of observed and computed downward infrared radiation for the 57 day period at Trenton are given in Fig. 3. The computed values were based on the most dense configuration of rawinsondes, temporally and spatially. It is apparent from the figure that the model-derived values exhibit good agreement with observations throughout the period.

Radiative heating rates were computed for a location over central Lake Ontario with weekly averages of the computed rates shown in Fig. 4. Average cloud cover over the lake is also shown in the figure. Much of the vertical variations are the result of the height of the cloud layers as reported by the surface observations. After Julian Day 295,

Table 2. *Average and RMSD of computed downward infrared radiation for daily integration periods during the fall of IFYGL* ($W\ m^{-2}$)

Verification Station	Average IR	All IFYGL RAOBs	IFYGL RAOBs at OOZ	IFYGL RAOB Sta. 3 and 6	IFYGL RAOB Sta. 3	IFYGL RAOB Sta. 6
Burlington	321	29.9	29.9	29.9	30.8	29.8
Trenton	302	16.6	18.4	16.9	17.9	16.4
Kingston	289	29.5	29.8	29.4	29.9	29.2

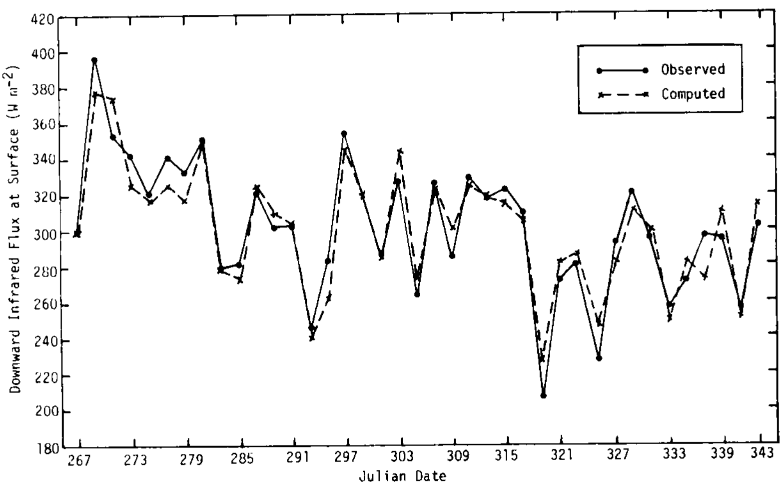

Fig. 3. Two-day averages of observed and computed infrared radiation at Trenton.

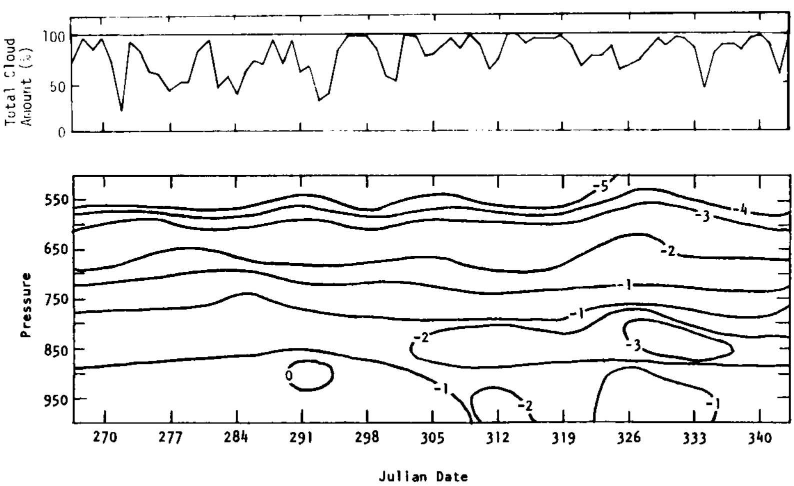

Fig. 4. Total radiative heating rates (°C/day) over central Lake Ontario, 1972.

cloud coverage is quite high, often being near-overcast over the entire region for several consecutive days. The heating rate minimum of −2 °C/day to −3 °C/day centered near 850 mb, reflects persistent low cloud layers. The use of either Station 6, at the western end, or Station 3, at the eastern end of the lake, caused heating rate changes of up to 0.3 °C/day over a period of a month in the lowest levels of the atmosphere, with less than 0.1 °C/day changes above 850 mb. In most cases, this represents less than a 10% change in the total radiative heating rates. The change is most likely caused by changes in the surface or low-level temperatures used in the computations.

4. Conclusions

The RMSD between observed and computed downward infrared radiation at the surface generally changed by less than 10% (1) when special RAOB's changed from up to 8/day to

1/day and (2) when station density changed from 6 to 1. Similarly, the radiative heating rate changes were almost always less than 10% as the density of stations changed. The results suggest that the model-computed values of daily incoming surface infrared radiation were consistent with infrared observations over the range of RAOB densities and frequencies tested. This result is based on 79 days of data during the Fall season with observations available for comparison with model results at three sites. Both the derived infrared observations and special IFYGL RAOB's were subject to limitations discussed in the body of the paper.

The rawinsonde network would undoubtedly have a greater value when dealing with specific meteorological occurrences, such as the Lake Ontario snowstorms. The most appropriate spatial and temporal density of the rawinsonde network should be determined by considerations other than radiation alone.

5. Acknowledgements

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ВЛИЯНИЕ ПЛОТНОСТИ И ЧАСТОТЫ РАДИОЗОНДИРОВАНИЯ НА РАСЧЕТЫ РАДИАЦИИ

Для определения чувствительности расчетов инфракрасной радиации для суточных и недельных периодов использовались данные радиозондирования высокой плотности и частоты, полученные в период Международного года полевых наблюдений Великих озер. Полученные в модели величины суточных потоков радиации на поверхности и скорости радиационного нагрева, вычисленные из различных пространственных и временных распределений радиозондовых наблюдений, проявляют лишь малые изменения.