OBSERVATIONAL STUDY OF DOWNWARD ATMOSPHERIC LONGWAVE RADIATION AT THE SURFACE IN THE CITY OF SÃO PAULO

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RESUMO

O presente trabalho tem como objetivo avaliar o desempenho dos métodos empíricos de estimativa da emissão de onda longa da atmosfera em reproduzir o ciclo diurno da emissão de onda longa da atmosfera da cidade de São Paulo. Foram utilizadas observações de emissão de onda longa, temperatura e umidade do ar colhidas na plataforma micrometeorológica do IAG-USP, durante 12 dias de céu claro no ano de 2005. A evolução da emissão de onda longa a cada 5 minutos foi estimada utilizando 10 formulações disponíveis na literatura. A comparação entre os valores estimados e observados de onda longa indicou que a expressão de Brunt tem o melhor desempenho, com menores MBE e RMSE e coeficiente de determinação igual a 0,64.

ABSTRACT

The main goal of this work is to evaluate the performance of empirical expressions to estimate the downward longwave atmospheric radiation at the surface in the city of São Paulo. The observations of atmospheric emission, temperature and relative humidity were carried out in the micrometeorological platform, located in the IAG-USP building, during 12 clear sky days in 2005. The evolution of 5 minutes average atmospheric emission values were estimated using 10 expressions available in the literature. The comparison indicated that the expression proposed by Brunt performed better, with the smallest MBE and RMSE and a coefficient of determination equal to 0.64.

Palavras-Chave: Radiação de onda longa, Cidade de São Paulo, Métodos empíricos.

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INTRODUCTION

Downwelling flux of longwave radiation is one of the key terms in the surface energy budget and vitally important for climate studies and many other applications such as agricultural meteorology (e.g. prediction of frost) and air-sea-ice interaction studies (Niemelä *et al.*, 2001). The downward longwave radiation fluxes at the surface play an important role in the air surface interaction. It can be estimated from radiative transfer models, from empirical expressions and from observations (Oliveira *et al.*, 2006). Empirical formulas can be useful because it uses only the screen-level water vapor pressure and the screen-level air temperature.

Estimating atmospheric emission using transference radiative models is not easy to accomplish because they require detailed information about the thermodynamic structure of the atmosphere, gases and aerosols content.

One reasonable alternative is to employ empirical expressions. They are easy to use but due to local effects they may respond differently to the conditions that differ from the ones used to derive them. Therefore, the objective of this work is to compare, among the most common empirical expressions available in the literature (Prata, 1996, Niemelä, 2002), the performance of estimating the diurnal evolution of longwave atmospheric emission in the city of São Paulo.

COMPARISON

Most of the schemes presented here are based on empirical relationships derived from the radiative transfer theory (Niemelä *et al.*, 2001). Table 1 presents 10 expressions based on Prata (1996) and Niemelä (2002) that will be used here to estimate downward atmospheric longwave emission at the surface.

The performance of the each expression is evaluated using 12 days with clear sky, observed during 2005 in São Paulo. The selection of clear sky days was based on the diurnal evolution of global solar radiation (Oliveira *et al.*, 2002). To compare the performance of the expressions it was used the mean bias error (MBE), root mean square error (RMSE) and the coefficient of determination (R^2).

The MBE analyzes the entire sample (long-term) whereas the RMSE considers the sample term by term. The MBE and RMSE are defining below:

$$MBE = \frac{1}{N}\sum_{i=1}^{N} d_i \qquad (1)$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N} d_i^2} \qquad (2)$$

Where d_i is the difference between empirical expression and observation and N is the number of observations. The coefficient of determination is the square of the Pearson linear correlation coefficient.

Table 1. Empirical expressions used to estimate the atmospheric longwave emission at the surface.

Author	Expression
Ångström (1918)	$(0.83 - 0.18\times 10^{-0.067 e_0})\sigma T_0^{\,4}$
Brunt (1932)	$(0.52 + 0.065\sqrt{e_0})\sigma T_0^{\,4}$
Swinbank (1963)	$(9.2\times 10^{-6} T_0^{\,2})\sigma T_0^{\,4}$
Idso-Jackson (1969)	$\left[1 - 0.261\exp\left(-7.77\times 10^{-4}(273 - T_0)^2\right)\right]\sigma T_0^{\,4}$
Brutsaert (1975)	$1.24\left(\frac{e_0}{T_0}\right)^{\frac{1}{7}}\sigma T_0^{\,4}$
Satterlund (1979)	$1.08\left[1 - \exp\left(-e_0^{\frac{T_0}{2016}}\right)\right]\sigma T_0^{\,4}$
Idso (1981)	$\left[0.7 + 5.95\times 10^{-5} e_0 \exp\left(\frac{1500}{\mathrm{T}_0}\right)\right]\sigma T_0^{\,4}$
Prata (1996)	$\left\{1 - \left(1 + 46.5\left(\frac{e_0}{T_0}\right)\right)\exp\left[-\left(1.2 + 3\left(46.5\left(\frac{e_0}{T_0}\right)\right)\right)^{\frac{1}{2}}\right]\right\}\sigma T_0^{\,4}$
Dilley & O´Brien (1998)	$59.38 + 113.7\left(\frac{T_0}{273.16}\right)^6 + 96.96\sqrt{18.6\left(\frac{e_0}{T_0}\right)}$
Niemelä (2001)	$\left[0.72 + 0.009(e_0 - 2)\right]\sigma T_0^{\,4}$

Where e_0, T_0 and σ are, respectively, the water vapor pressure (hPa), air temperature (K) measured at screen-level, and Stefan Boltzmann constant (5.67x10^{-8} Wm^{-2}K^{-4}).

In table 2 is indicated the MBE and RMSE for all 10 methods. All values of MBE are positive, indicating that all methods overestimate systematically the observed atmospheric emission.

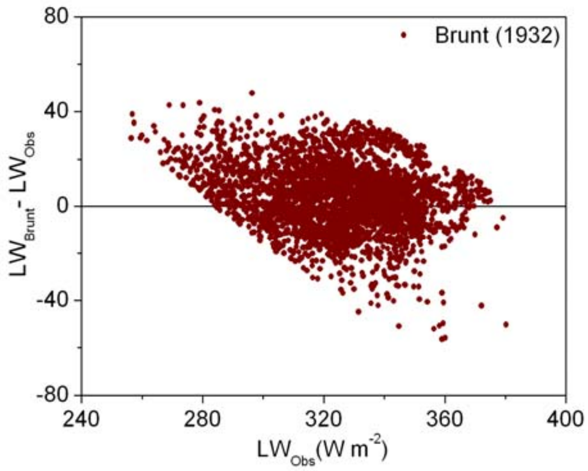
During the night, all the empirical formulations perform better. Nevertheless (except Brunt and Swinbank), all formulations overestimate the observed atmospheric emission. The smallest values of MBE and RMSE, respectively 4.53 W m^{-2} and 14.38 W m^{-2} were obtained using Brunt expression. The largest values, respectively 38.33 W m^{-2} and 40.58 W m^{-2} were obtained using Idso expression. The other methods performed in between these two. It is interesting to observe that all methods are very well correlated with the observations because in all cases the determination coefficient is between 0.56 and 0.64. Figure 1 shows how the deviation from the observations behaves in the case of Brunt and Idso. The deviation distribution in the case of Brunt is around zero

(Fig. 1a,c). In the case of Idso the cloud of points are very similar, however, it is displaced far from zero (Fig. 1b,d).

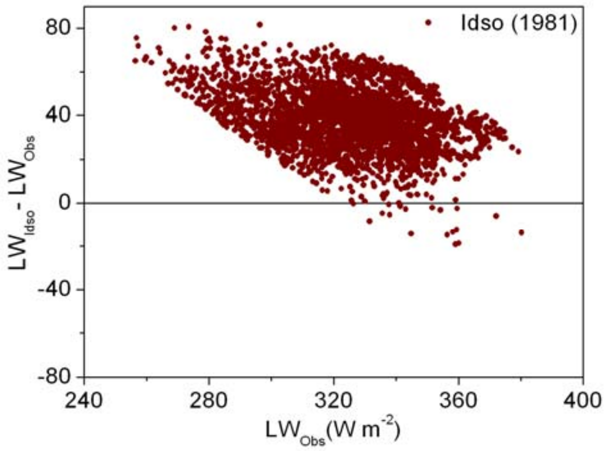
Table 2. Statistical parameters derived from the comparison between empirical expressions and observations of 5 minutes averaged values of atmospheric longwave emission at the surface.

Author	MBE			RMSE			R^2
	Total	Day	Night	Total	Day	Night	
Ångström (1918)	16.99	24.28	9.70	22.00	27.05	15.37	0.60
Brunt (1932)	4.53	10.78	-1.73	14.38	16.30	12.15	0.64
Swinbank (1963)	7.51	19.98	-4.96	21.77	27.26	14.30	0.56
Idso-Jackson (1969)	15.93	29.21	2.66	26.82	35.24	14.00	0.56
Brutsaert (1975)	20.16	26.60	13.73	24.28	29.16	18.13	0.64
Satterlund (1979)	27.43	35.41	19.44	31.03	37.53	22.75	0.61
Idso (1981)	38.33	42.83	33.83	40.58	44.61	36.10	0.62
Prata (1995)	19.94	26.54	13.35	24.07	29.09	17.78	0.64
Dilley & O´Brien (1998)	8.40	12.45	4.35	15.03	16.93	12.85	0.63
Niemelä (2001)	32.90	39.93	25.87	36.03	42.07	28.76	0.63

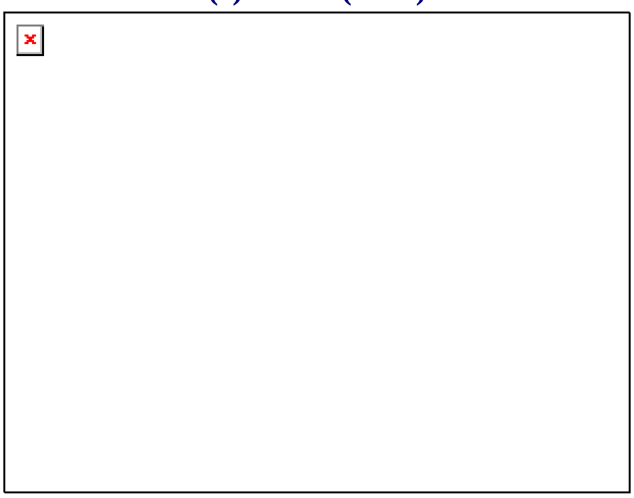
(a) Brunt (1932)



(b) Idso (1981)



(c) Brunt (1932)



(d) Idso (1981)

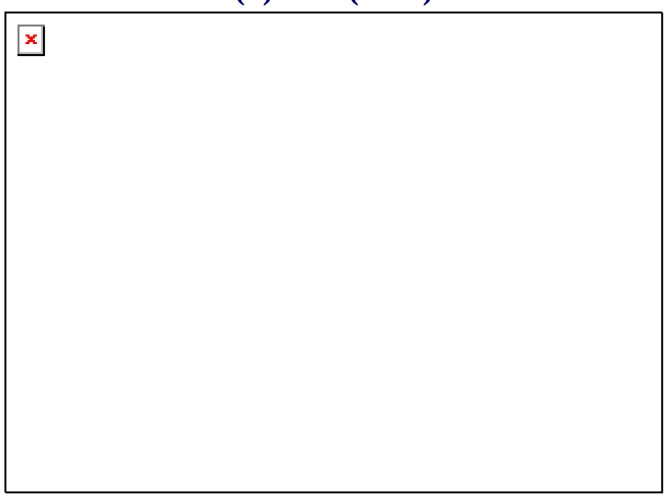


Figure 1. Dispersion diagram of estimated and observed values of downward atmospheric longwave emission at the surface using (a) Brunt and (b) Idso empirical expressions. Histogram of deviation for (c) Brunt and (d) Idso.

CASE STUDY

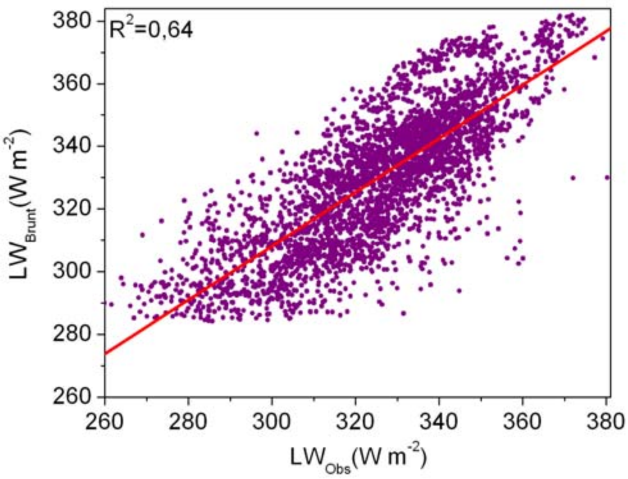
To understand the behavior of the expressions used in this work it was analyzed the evolution of longwave radiation observed on year day 185 (July 4th of 2005). On this day the atmospheric condition in the city of São Paulo was considered typical of a clear sky day during winter period.

The agreement between observed and modeled can be visualized in Fig. 1a,b for year day 185 and for the entire data set. The determination coefficient for year day 185 (0.88) is larger than that obtained for 12 clear sky days (0.64), as displayed in Fig. 1a,b.

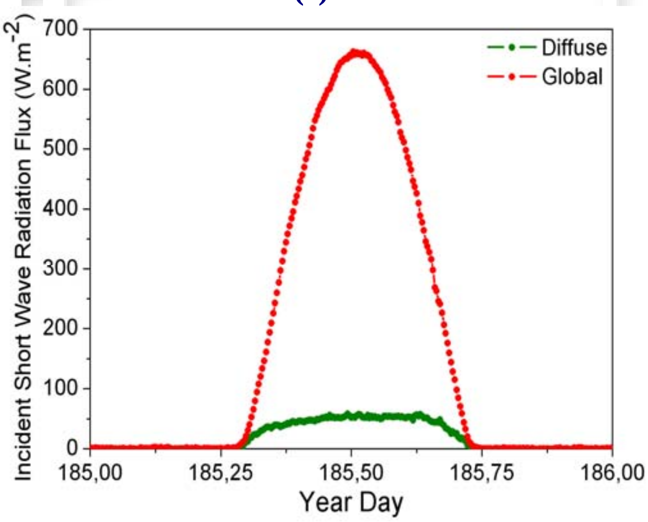
The diurnal evolution of the global and diffuse solar radiation is smooth, as expected for a clear sky day (Fig. 2c). The content of moisture did not change much in the course of the day (Fig. 2d). The evolution of longwave radiation follows the evolution of the temperature (Fig. 2e-f).

(a)

(b)



(c)



(d)

(e)

(f)

Figure 2: Dispersion diagram of (a) year day 185 and (b) all clear-sky days. Diurnal evolution of (c) global and diffuse solar radiation for year day 185, (d) specific humidity, (e) temperature and (f) longwave radiation for year day 185

Comparatively, all methods respond to the diurnal evolution of temperature in a similar way on this day. They all have a tendency to overestimate the atmospheric emission during all day (Fig.

3a). The deviation between longwave emissions estimated by Brunt expression seems to depend less on the specific humidity (Fig 3b) than on the temperature (Fig. 3c).

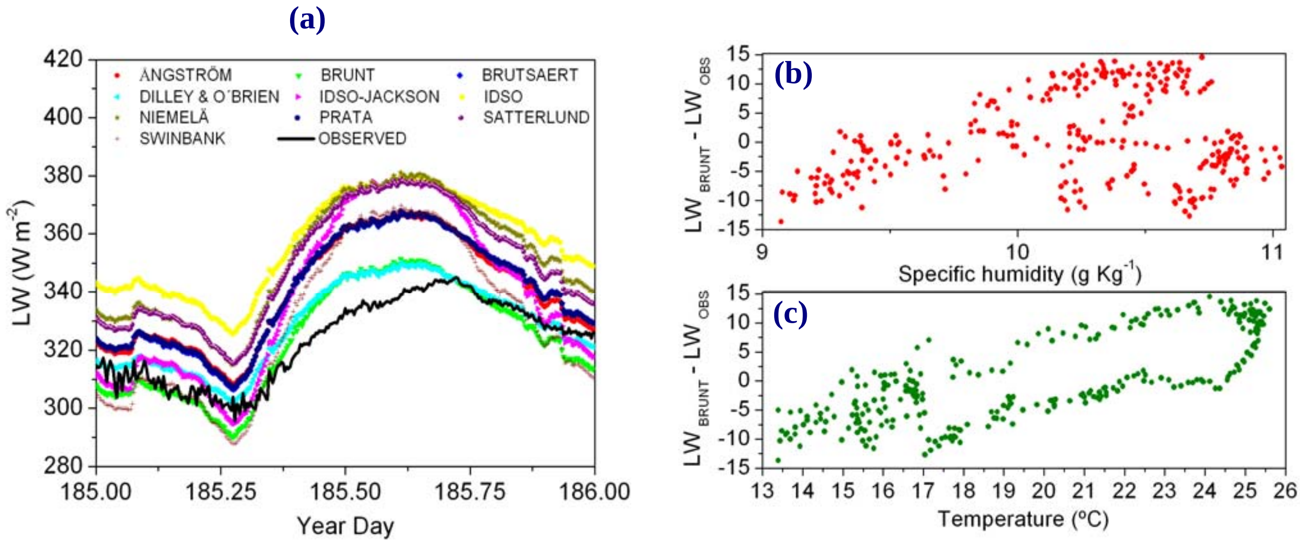


Figure 3: Diurnal evolution of (a) longwave radiation estimated using empirical expressions in Table 1, for year day 185. Dispersion diagram between (b) longwave deviation using Brunt and specific humidity and (c) longwave deviation using Brunt and temperature for year day 185.

CONCLUSION

Brunt expression performed better than the other nine formulations used here; therefore it is indicated to estimate the atmospheric downward longwave emission in the city of São Paulo. The main sources of error may be related to the lack of representativeness of the temperature measurements, carried out in the top of a building and to the emission associated to the presence of atmospheric pollution. These factors will be taken into consideration in the future.

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