# Downward Atmospheric Longwave Radiation in the City of São Paulo

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**Abstract.** This work evaluates objectively the consistency and quality of a 9 year dataset based on 5 minute average values of downward longwave atmospheric (LW) emission, shortwave radiation, temperature and relative humidity. All these parameters were observed simultaneously and continuously from 1997 to 2006 in the IAG micrometeorological platform, located at the top of the IAG-USP building. The pyrgeometer dome emission effect was removed using neural network technique reducing the downward long wave atmospheric emission error to 3.5%. The comparison, between the monthly average values of LW emission observed in São Paulo and satellite estimates from SRB-NASA project, indicated a very good agreement. Furthermore, this work investigates the performance of 10 empirical expressions to estimate the LW emission at the surface. The comparison between the models indicates that Brunt's one presents the better results, with smallest "MBE", "RMSE" and biggest "d" index of agreement, therefore Brunt is the most indicated model to estimate LW emission under clear sky conditions in the city of São Paulo.

**Keywords:** Long Wave Radiation, Data Analysis, Neural Network, Empirical Models
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## INTRODUCTION

The city of São Paulo, with a population of about 11 million people, together with 38 other smaller cities, forms the Metropolitan Region of São Paulo (MRSP), located about 60 km far away from the Atlantic Ocean. The whole region is occupied by 20.5 million of habitants and has approximately 7 million vehicles. The MRSP has an area of 8,051 $km^2$ and it is the largest urban area in South America and one of the 10 largest in the world (Codato *et al.,* 2008).

The downward long wave atmospheric emission at the surface, (LW; 3.5 - 50 μm) plays an important role in the air-surface interaction. It can be estimated by using radiative transfer models, empirical expressions, satellite estimates, and from *in situ* observations (Oliveira *et al.*, 2006). The LW radiation is one of the key terms in the surface energy budget and is of vital importance 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). LW radiation measurements are taken on a platform located at the top of the IAG-USP building ($23^0$33'35"S; $46^0$43'55"W). The platform altitude is 744 m above MSL and the measurements are taken regularly with a sampling frequency of 0.2 Hz and stored at 5 minutes intervals. Simultaneous measurements of global solar radiation, air temperature and relative humidity are also taken at the platform. The LW has been measured using a pyrgeometer model PIR from Eppley Lab Inc.

The main objective of this work is twofold. First, we will carry out a characterization of the seasonal evolution of LW radiation in the city of São Paulo. Secondly, we will evaluate the performance of the empirical expressions available in the literature to estimate LW in São Paulo for clear sky condition. To accomplish that we will use LW measurements and other meteorological parameters carried out at the micrometeorological platform located at the University of São Paulo campus in the West side of São Paulo city from 1997 to 2006.

## DATA INSPECTION

Initially, it was performed a visual inspection of the entire raw data set. Figure 1a shows raw data from 1997 to 2006. Shortwave radiation, air temperature and LW glitches are easily identified as large incursions of these signals. These problems are related to missing connection between sensor and datalloger, battery failure and rain or dust accumulated over the sensors. In the case of LW data was removed when LW < 0 and LW > 1000Wm$^{-2}$. This interval was chosen because LW, physically, cannot be smaller than zero or higher than 1000 Wm$^{-2}$. To make the data set consistent it was removed simultaneously all three parameters even when the glitches happened only in one of them.

Even though the above procedure removed most of the problems there were periods of time when the pyrgeometer was not totally functional, due to battery malfunctioning. The effects on the LW data were more difficult to identify, because the pyrgeometer was not totally shut down. To attenuate the contamination of these hard to identify glitches from dataset, a second step was applied to the data inspection procedure. This second step consists in removing LW values located out of the two standard deviation interval centered in the mean value (362.37±64.17 Wm$^{-2}$). To guarantee representativeness for the diurnal cycle it was considered as a valid days with 100% of observations. Here, 100% included days with less than 4 missing values (5 minutes each). The final data set is indicated in Figure 1b. Comparatively to the raw data (Fig. 1a) the final series (Fig. 1b) correspond to 602,134 values or about 64 % of the original series.

(a) (b)

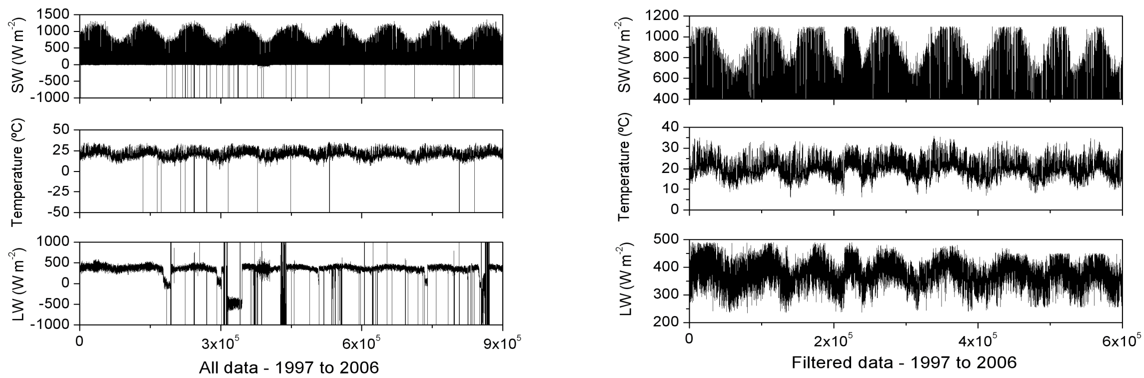


**FIGURE 1. (a)** Time series of global solar radiation (SW), air temperature (Temperature) and atmospheric downward long wave radiation (LW). **(b)** Filtered data set.

## DOME EMISSION EFFECT CORRECTION USING NEURAL NETWORK TECHNIQUE

According to Fairall et al. (1998), considering case ($T_c$) and dome ($T_d$) temperatures in the estimates of LW using a pyrgeometer model PIR from Eppley, reduces the error below 5 %. In the case of São Paulo simultaneous measurements of LW, $T_C$ and $T_D$ were only available after October 15, 2003.

To correct LW measurements carried out prior that, it was used a neural network technique developed by Oliveira et al. (2006). The training set (learning and optimization dataset) employs data measured during years 2004 (7 days) and 2005 (2 days), corresponding to 2,578 observations. These 9 days were chosen based on heuristic method, from patterns defined as dry, wet, cold, cloudy and clear sky days. As carried out in the previous works (Oliveira et al., 2006), the standard back propagation algorithm with a learning rate 0.3 and momentum 0.5 provided a quick and effective learning of the chosen neural network type – multilayer Perceptron neural network (MLP). The first layer contains 4 neurons, second layer 50 neurons and third layer 1 neuron.

The time evolution of the correction ($LW_{CORRECTED}$ - $LW_{NOT\ CORRECTED}$) are indicated in the Fig. 2a. Negative correction confirms the uncorrected pyrgeometer measurements are due to daytime solar radiation heating of the dome. The correlation between LW corrected by neural network and by $LW_{Fairall}$ is indicated in Figure 2b. The correlation coefficient 0.991 indicated a very good matching between synthetic and real LW series.

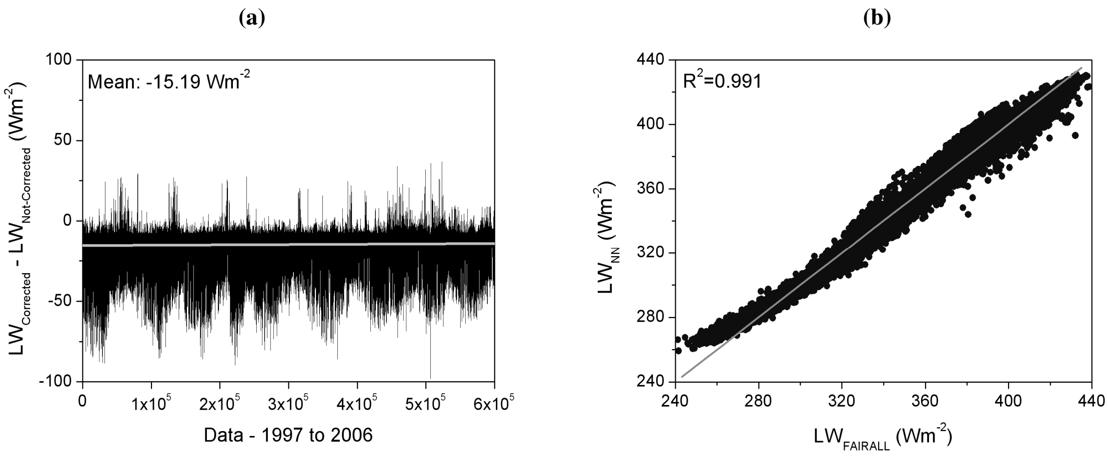


**FIGURE 2.** **(a)** Time evolution of the correction carried out by NN. **(b)** Dispersion diagram of LW obtained from neural network versus LW corrected by Fairall observed during 2004.

# PERFORMANCE OF LONG WAVE MEASUREMENTS

In order to evaluate the performance of LW measurements after the application of 2-steps data inspection and NN corrections it was carried a comparison between LW observed and estimated from satellite data by Project SRB (Surface Radiation Budget) from the National Aeronautics and Space Administration, NASA. The LW model uses a 1° equal-area global grid and 3-hourly time resolution. The seasonal evolution of LW observed in São Paulo, considering filtering and NN corrections matches well the daily values estimated from SRB, fig 3. The corrected values systematically underestimate the SRB data, indicating that the SRB has not considered all the parameters required to estimative LW in São Paulo.

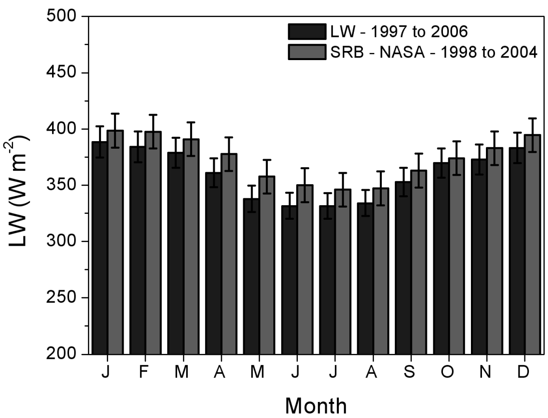


**FIGURE 3.** Seasonal evolution of daily value of LW estimated from SRB and based on observations carried out in São Paulo from 1997-2006.

# MODELING

In this work the performance of 10 empirical expressions will be evaluated to estimate LW in the city of São Paulo for clear sky days (Prata, 1996; Niemelä, 2002). To evaluate the performance of the models it was used three statistical parameters: MBE (Mean bias error), RMSE (Root mean square error) and d (index of agreement;

Willmott, 1981). The performance of all 10 empirical expressions can be visualized by comparing the MBE, RMSE and the index of agreement as indicated in figure 4.

All models used in this work overestimate the LW values because they present a positive MBE. The Brunt's model presents the better result, with the smallest MBE, RMSE and the biggest index of agreement, d (fig 4a). In addition, all the models perform better in the nighttime (fig 4b) because all of them are very sensible to air temperature and vapor pressure fluctuations, which are more intense during daytime due to the shortwave radiation.

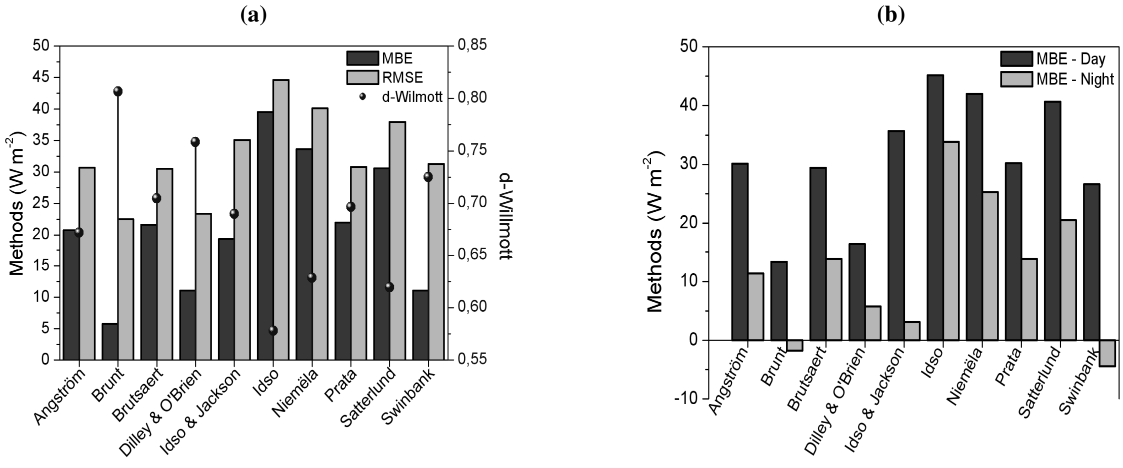


**FIGURE 4. (a)** Performance of the model in terms of MBE, RMSE and d; **(b)** MBE for day and nighttime periods.

## CONCLUSION

The methodology to evaluate data consistency objectively for LW using solar radiation, temperature and relative humidity data was developed and performed satisfactorily. The pyrgeometer dome emission effect was removed using neural network technique reducing the LW emission error to 3.5%. Comparison between the monthly average values of LW emission observed in São Paulo and satellite estimates from SRB-NASA project indicated a very good agreement. The comparison between the models indicates that Brunt's model presents the better results, with smallest "MBE", "RMSE" and biggest "d-index of agreement" therefore this is indicated to estimate the LW, in clear sky conditions, in the city of São Paulo.

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