PATTERNS OF LONGWAVE RADIATION AT THE SURFACE IN THE MEGACITY OF SÃO PAULO, BRAZIL – PART II: SEASONAL EVOLUTION AND POLLUTION IMPACT

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RESUMO: Este trabalho descreve a variação sazonal da evolução diurna da radiação de onda longa (OL) emitida pela atmosfera na cidade de São Paulo. Os dados deste trabalho correspondem aos valores médios de 5 minutos de OL, temperatura e umidade relativa do ar, observados simultaneamente e de forma contínua de 1997 a 2006 na plataforma micrometeorológica do IAG-USP. A OL apresenta uma variação sazonal do ciclo diurno determinada pela temperatura e umidade na superfície. A presença de nuvens aumenta a emissividade da atmosfera na superfície em cerca de 8 %. Na ausência de nuvens, a evolução sazonal da emissividade atmosférica na superfície em São Paulo está relacionada com a evolução da temperatura e umidade. Não foi encontrada nenhuma relação direta com a concentração de material particulado observado na RMSP. Durante o inverno o índice AI indica que o aerossol em São Paulo absorve mais do que espalha radiação.

ABSTRACT: This work describes the seasonal variation of diurnal evolution of the downward long wave atmospheric emission (LW) at the surface in the city of São Paulo. This work is based on 5 minutes average values of downward atmospheric emission, air temperature and relative humidity. All these parameters were observed simultaneously and continuously from 1997 to 2006 in the micrometeorological platform of IAG-USP. The LW and respective atmospheric emissivity diurnal cycle shows a seasonal variation that is determined by temperature and relative humidity evolution at the surface. Presence of clouds intensifies the monthly-average atmospheric emissivity at the surface in about 8 %. When cloud effect is removed, the LW shows a strong correlation with air temperature and relative humidity. No statistically significant correlation was found between particulate matter concentration and atmospheric emissivity. During winter the AI index indicates that aerosol in RMSP absorbs more than scatters radiation.

Key-Words: Long Wave Radiation, Emissivity, São Paulo, Particulate Matter, Pollution.

1. INTRODUCTION

There are strong evidences that pollution in metropolitan region of São Paulo (MRSP) has even altered the local climate by affecting the diurnal evolution of diffuse, direct and global solar irradiance components at the surface locally (Oliveira *et al.*, 2002) and in the regional scale (Codato *et al.,* 2008). Even though pollution is the most dramatic environmental problem in the MRSP, the assessment of the pollution impact on the local climate is still incipient. In the first part of this work (Bárbaro *et al.,* 2008a) the quality and consistency LW dataset were evaluated and neural network technique was successfully applied reducing the error in downward long wave atmospheric radiation at the surface (LW) observations in São Paulo to about 3.5%. The objective of this second work is to characterize the seasonal variation of diurnal evolution of LW at the surface in the city of São Paulo. It will be given special emphasis on the assessment of the impact caused by air pollution, especially by aerosol.

2. SEASONAL EVOLUTION

The seasonal variation of monthly average hourly values of LW in MRSP is displayed in Figure 1. There, the LW observed in São Paulo shows a maximum during daytime and during summer. This pattern reflects the local climate of temperature, moisture, cloud and pollution. Diurnal evolution of monthly average LW, atmospheric emissivity (LW/σT^4, where σ is the Stefan-Boltzmann constant, T is the air temperature measured at the top of IAG building), air temperature, relative humidity during August in RMSP are displayed below. In order to isolate cloud effect, it was included in Figure 2 the monthly averaged values evaluated considering only clear-sky days according to Bárbaro *et al.* (2008). The amplitude of LW under clear sky conditions (daytime) is larger than when all conditions were considered. Clouds have a larger impact in the nighttime evolution, increasing the LW (Fig 2a). Diurnal evolution of temperature during clear sky days does not differ much of the mean behavior when clouds are included in the statistics (Fig. 2b). Similar behavior is presented by the relative humidity (Fig. 2c).

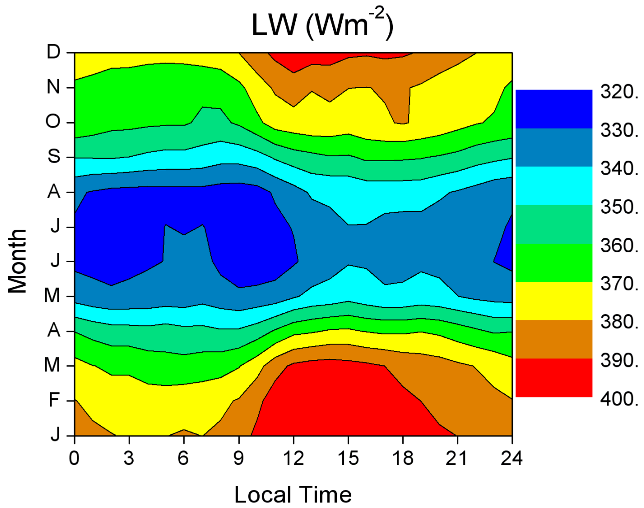

Figure 1. Seasonal variation of the diurnal evolution of LW in MRSP. Observations carried out in the micrometeorological platform of the IAG-USP.

However, the diurnal evolution of atmospheric emissivity during clear sky days (Fig. 2d) shows a more drastic contrast compare to the other parameters. The reason for this is that cloud yields a large contribution in the emission of the atmosphere in São Paulo in comparison to thermal and moisture contrast observed when clouds are present in RMSP.

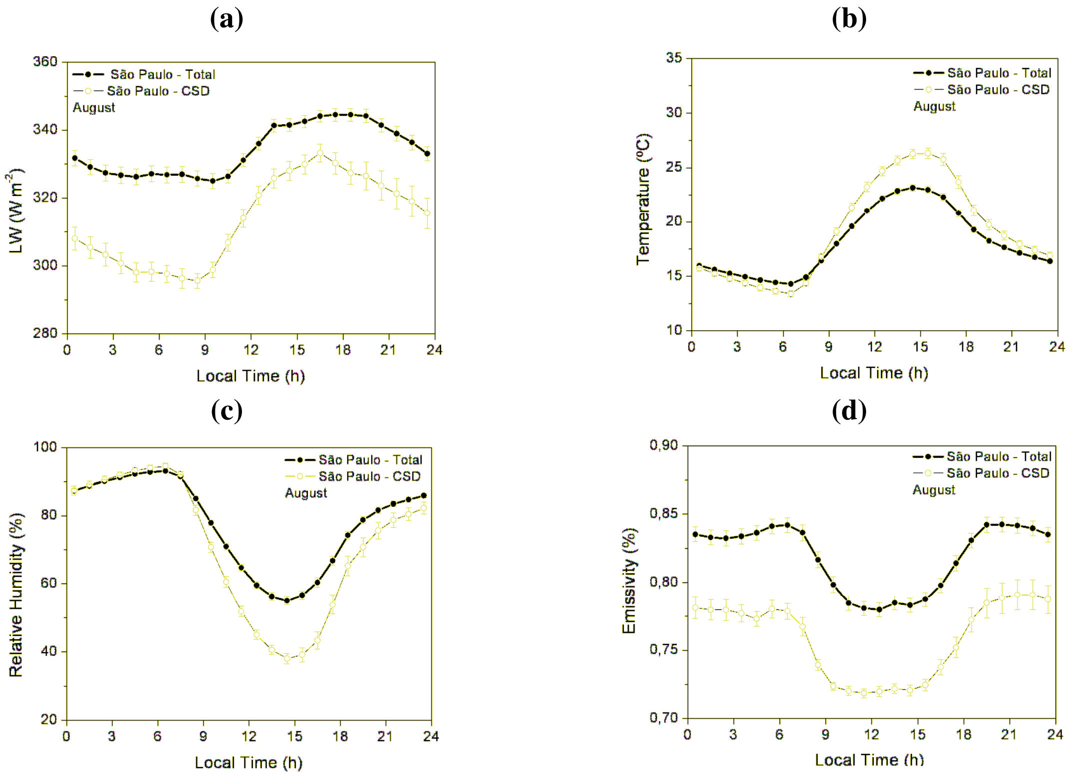

Figure 2. Diurnal evolution of **(a)** LW, (b) Temperature, **(c)** Relative humidity, **(d)** atmospheric emissivity at the surface. Monthly-average values based on entire dataset (from 1997 to 2006) are indicated by **Total**. Monthly-average values based only on clear sky days observations are indicated by **CSD**.

Figure 3 indicates that the hourly values of atmospheric emissivity at the surface are correlated to the hourly values of air temperature and relative humidity during clear sky days. Therefore, to develop empirical expressions to estimate the atmospheric emissivity at the surface in MRSP is necessary to take into consideration explicitly temperature and relative humidity. These results corroborate with the conclusion of Bárbaro *et al.* (2008) that Brunt empirical expression can be applied to estimate LW in the MRSP.

Another important conclusion is that in the presence of clouds the diurnal evolution of the monthly-average hourly values of the atmospheric emissivity at the surface follows the evolution of the emissivity in clear sky days. Therefore, to estimate LW regardless the sky condition in RMSP one can used the clear sky estimates obtained by Brunt formula and corrected by a constant factor to obtain the LW. In the case of August, the factor is about 1.08 (Fig. 2d). All these findings will be investigated in a future work.

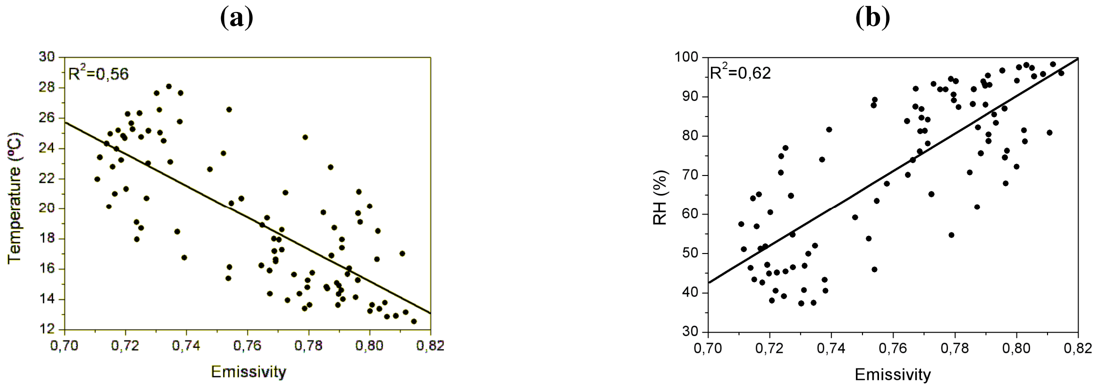

Figure 3. Dispersion diagram between atmospheric emissivity and **(a)** air temperature **(b)** relative humidity.

3. IMPACT OF POLLUTION

To investigate the impact of air pollution on the seasonal evolution of LW in the MRSP, it will be analyzed in this section the seasonal evolution of the particulate matter (PM_{10}). The São Paulo State Environmental Agency (CETESB), using Beta Attenuator Method (CETESB, 2004), measures hourly values of PM_{10} at the surface.

In this work it was selected two stations C. César and Lapa. These stations are located respectively at 6 and 4 km far from micrometeorological platform of IAG USP where LW measurements are carried out. The data used to evaluate the monthly-average values of PM_{10}, corresponds to 9 years of continuous observations from 1997 to 2005. The seasonal evolutions of monthly averaged daily values of PM_{10} are indicated in Figure 4.

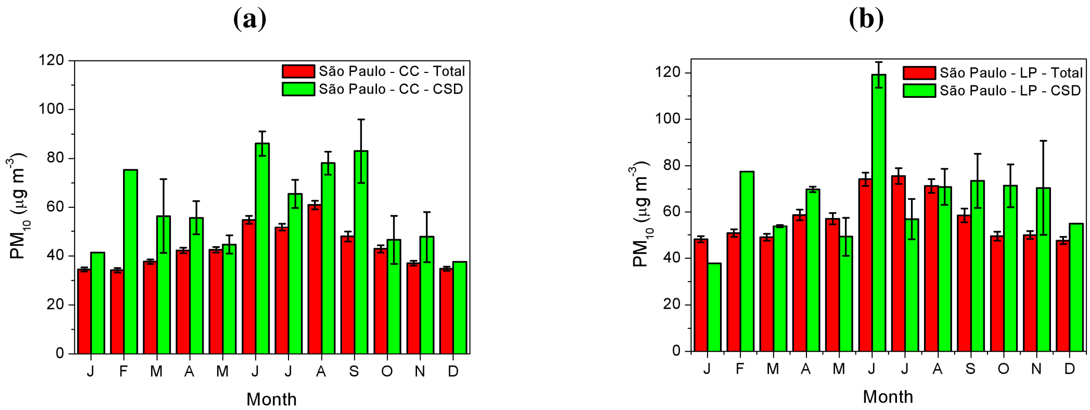

Figure 4. Seasonal evolution of monthly average daily values of PM_{10} observed at the surface in the city of São Paulo at CETESB monitoring network stations **(a)** Cerqueira Cesar (CC) and **(b)** Lapa (LP), from 1997 to 2005. Monthly-average values based on entire dataset (1997-2005) are indicated by **Total**. Monthly-averaged values based only clear sky are indicated by **CSD**.

Daily values of PM_{10} are higher during winter in both stations even when only clear sky days are considered. The largest daily values, 120 µg m^{-3}, occur at Lapa in June for clear sky days (Fig. 4.b). The seasonal evolutions of PM_{10} in these two stations are correlated, indicating that the high level of this pollutant is a regional feature of the MRSP during all months of the year.

Based on this fact, this work uses the PM_{10} observed in Cerqueira Cesar as representative of the PM_{10} concentration in the area where measurements of LW radiation was carried. Figure 5a show the diurnal evolution of monthly average hourly values of PM_{10} for MRSP during August. In Figure 5a the highest concentrations of PM10 are observed during clear sky conditions.

As indicated in the previous section, the emissivity of atmosphere at the surface shows a diurnal evolution that seems to be strong correlated with air temperature and relative humidity. However, no statically significant correlation was found (R^2=0.22, R is the linear correlation index) between emissivity and PM_{10} concentration observed simultaneously during clear sky conditions (Fig. 4b). The question is why particulate matter is correlated to direct solar radiation in RMSP at local (Oliveira *et al.,* 2002) and regional scale (Codato *et al.,* 2008) but it is not correlated to the emissivity of the atmosphere.

(a) **(b)**

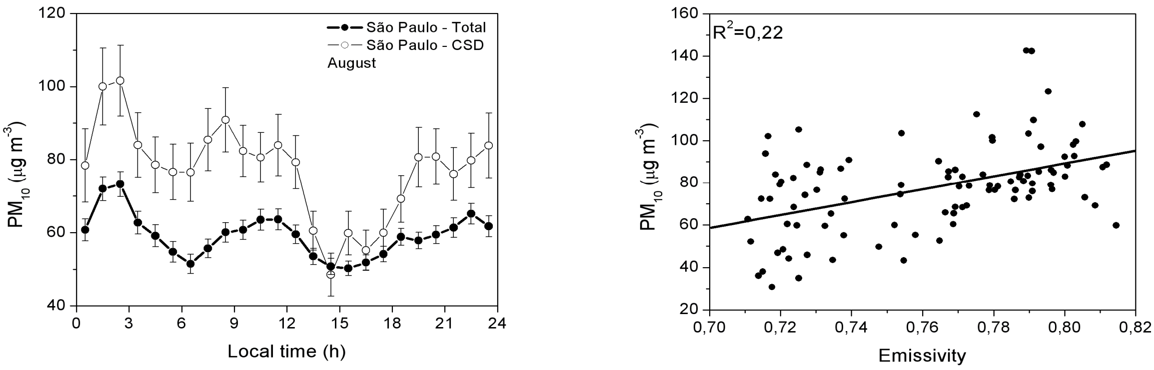

Figure 5. (a) Diurnal evolution of PM_{10} in August. **(b)** Dispersion diagram between atmospheric emissivity at the surface and PM10. Hourly values observed during clear sky days in August from 1997-2006 in RMSP.

One way to characterize the radiometric properties of the aerosol in the MRSP is by using the aerosol index (AI) estimated from satellite measurements (Torres *et al.*, 1998). This technique has been used to show that the dust from Sahara is correlated with negative anomalies of sea surface temperature (Lau and Kim, 2007). In Figure 6 is showed the time evolution of daily values of PM_{10} in Cerqueira Cesar and Lapa, accumulated rain and AI index, observed during summer (Fig. 6a) and winter (Fig. 6b). Rain cleans the atmosphere and reduces the concentration of PM_{10}, therefore the aerosol present in the atmosphere must reflect the local sources. However, there is no clear pattern relating AI and PM_{10} concentration, principally in the summer time. Sometimes AI is positive, indicating that the aerosol is scattering radiation. Other times, AI is negative, indicating that the aerosol present in RMSP is absorbing radiation.

(a) **(b)**

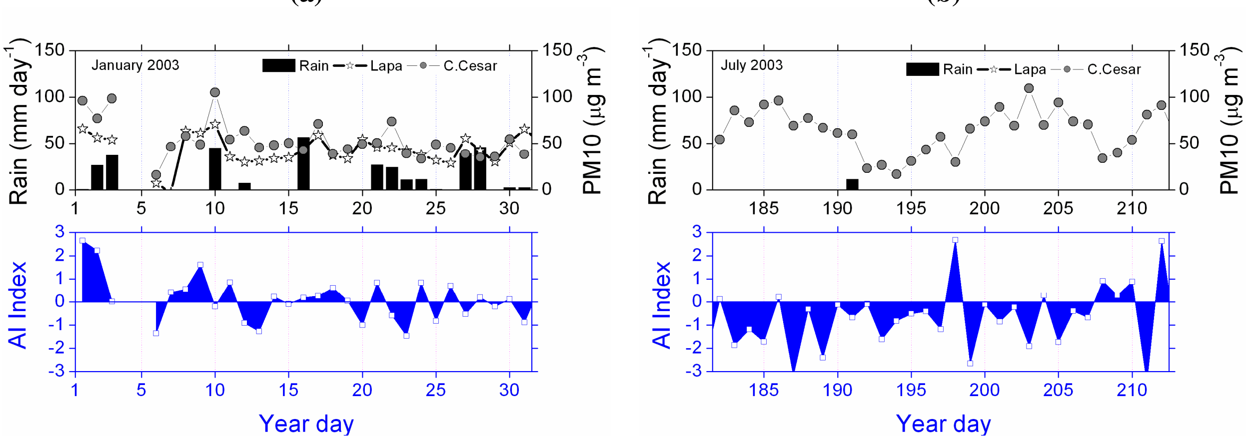

Figure 6. Time evolution of PM, accumulated rain and AI index observed in (a) Summer (January) (b) Winter (July). Daily values based on observation carried out in 2003.

The histogram of AI index for summer (Fig. 7a) and winter (Fig. 7b) indicates that during winter the aerosol in the MRSP absorbs more than scatter radiation. During summer, the aerosol present in the atmosphere both absorbs and scatters radiation.

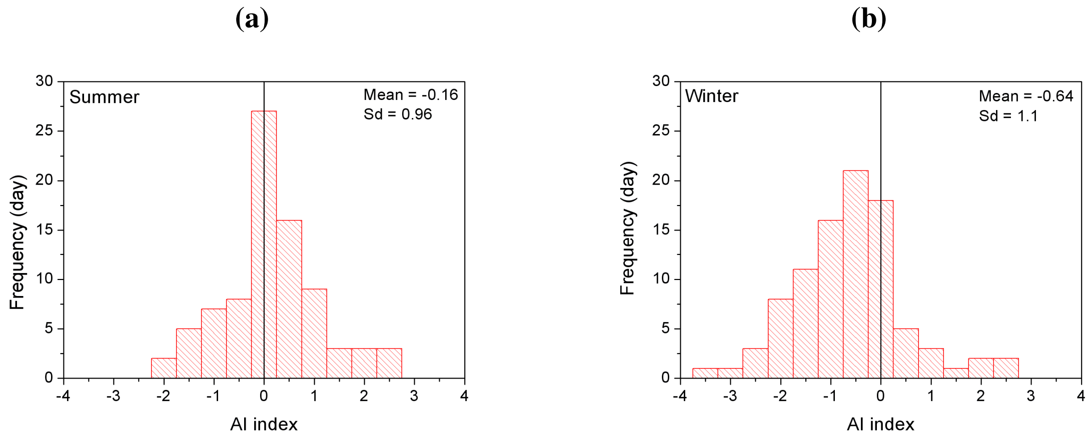

Figure 7. Histogram of AI index during (a) Summer (b) Winter of 2003 for the MRSP.

4. CONCLUSION

The main objective of this work is to describe the seasonal evolution of LW in the city of São Paulo. During summer and daytime, the LW observed shows a maximum. This pattern reflects the local climate patterns of temperature, moisture, cloud and air pollution. The temperature and relative humidity diurnal evolutions for clear sky days does not differ much of the mean behavior, when clouds are included in the statistics. The LW and respective atmospheric emissivity diurnal cycle, shows a seasonal variation that is determined by temperature and relative humidity evolutions at the surface. The presence of clouds intensifies the monthly-average atmospheric emissivity at the surface in about 8 %. When cloud effect is removed, the LW shows a strong correlation to air temperature and relative humidity. The impact of pollution was analyzed, indicating that the PM_{10} daily values are high during all the year, even when only clear sky days are considered. No statistically significant correlation was found between particulate matter concentration and atmospheric emissivity, but the AI index indicates that during the winter the aerosol in the MRSP absorbs more than scatter radiation.

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