ARTIFICIAL NEURAL NETWORKS AS A SUPPORTING TOOL FOR SOLVING METEOROLOGICAL AND AIR QUALITY MEASUREMENT/MODELING PROBLEMS - AN APPLICATION FOR LONG TIME SERIES OF LONG WAVE MEASUREMENT CORRECTION

Primož Mlakar[1], Marija Zlata Božnar[1], Amauri P. Oliveira[2] and Jacyra Soares[2]

[1]AMES d.o.o., Slovenia
[2]Group of Micrometeorology, Department of Atmospheric Sciences, University of São Paulo,

INTRODUCTION

Meteorological and air pollution modeling are based on measurements. There are many situations when the modelers should face unperfected measurement data making the modeling less effective, unreliable or even impossible. The data problem can be due to the device malfunctioning, lack of proper sensor calibration or even due to unsuitably planned measuring parameters. However, some of the data problem can be corrected later.

This paper presents the synthetic series of longwave radiation, corrected for dome emission effects on pyrgeometer model PIR from Eppley, based on neural network called multilayer perceptron (MLP). It is assumed that the dome emission effects on the flux are a nonlinear function of other measured meteorological parameters and estimated using MLP with non-linear transfer function (Rumelhart et al. 1986; Lawrence 1991). About 3-month long measurements of longwave radiation flux, dome and case temperatures, global solar radiation, air temperature and relative humidity are enough to train the neural network algorithm and correct longwave radiation measurements.

A difficulty measuring longwave radiation flux is that the temperature compensated pyrgeometer neglects the dome emission. According to Fairall et al. (1998) the exclusive use of the manufacturer's instruction can lead to errors in the total flux up to 5% (~ 20 W m^{-2}). This error can be a serious problem when the longwave radiation flux is used, for instance, to perform energy balances or to recover surface temperatures.

To apply the MLP parameters, developed in this work, is necessary having only accessible meteorological parameters (global solar radiation, air temperature and relative humidity) simultaneously to atmospheric longwave radiation measurements corrected only by manufacturer recommendations.

This work also describes the seasonal evolution of the radiation balance at the surface of São Paulo city considering atmospheric long wave radiation corrected by neural network and solar radiation.

METEOROLOGICAL DATA SET

Downward longwave atmospheric radiation at surface has been regularly measured in São Paulo City, Brazil, since January 1998. The measurements are taken on a platform located at the building top of "Instituto de Astronomia, Geofísica e Ciências Atmosféricas da Universidade de São Paulo" at the University Campus, in São Paulo western side, at 744 m above MSL ($23^0$33'35"S; $46^0$43'55"W), with a sampling frequency of 0.2 Hz (12 min^{-1}) and stored at 5 minutes intervals. Simultaneously it is also measured, at the surface level: (i) global solar radiation, (ii) air temperature and (iii) relative humidity.

The longwave atmospheric emission has been measured using a Precision Infrared Radiometer from Eppley Inc., model PIR. This instrument performs hemispherical, broadband, infrared radiative flux measurements, using thermopile temperature difference. Its composite transmission window is about 4-50 μm. The model PIR pyrgeometer comes with a battery-powered resistance network that provides a voltage that expresses the radiative flux contribution due to the case temperature.

Extra channels for measuring case and dome temperatures become available only in October 2003. Prior 15 October 2003, measurements of longwave radiation with the PIR pyrgeometer followed only the manufacturer recommendations.

Global solar irradiance is measured by a pyranometer model 8-48, built by Eppley Lab. Inc. This sensor is calibrated periodically using as secondary standard a spectral precision pyranometer model 2, from Eppley (Oliveira et al. 2002). The air temperature and relative humidity were estimated using a pair of thermistor and capacitive sensors from Vaisalla. The hourly values of wind velocity, used in this work, were measured at the same site during 8 January to 30 April 2004 (83 days or 1992 hours) with a cup anemometer from DAVIS Weather Monitor II. All data measured at the platform was checked and questionable data was removed (Oliveira et al. 2002).

This dataset has already been used to estimate hourly values of diffuse solar radiation at the surface in São Paulo City, Brazil, using perceptron neural network technique (Soares et al., 2004).

RESULTS

In this work the neural network technique is applied to correct the pyrgeometer data collected without correction of the dome emission effects. The database was analyzed and the most relevant parameters for the MLP construction to be used as neural network input were: (i) observed longwave radiation, (ii) global solar radiation, (iii) air temperature, (iv) relative humidity and (v) local time. The standard back propagation algorithm was used with learning rate 0.5 and momentum 0.9. Previous works show that this selection of parameters leads to a quick and effective learning (Mlakar and Božnar 1997; Božnar and Mlakar 1998).

The *training set* (learning and optimization dataset) employs data measured in the period from 15 October 2003 to 7 January 2004, corresponding to 73 days (1752 hours). The *optimization data set* was based on randomly selected 10% of patterns from the original training set and it was used during the training process to periodically test the MLP performance as the “unknown” data set to determine the MLP’s generalization capabilities. The final network was the one that gave the smallest error on the optimization data set and not on the training set. The *testing set* used for check the validity of the generated series was taken from 8 January to 30 April 2004, comprising 89 days of continuous measurements of longwave radiation (2136 hours).

The longwave radiation measurements, corrected only by manufacturer recommendations, will be called hereafter as *observed* longwave radiation and indicated by LW_{Obs} . The longwave radiation measurements with the additional corrections, as proposed by Fairall et al. (1998), hereafter will be indicated by $LW_{Fairall}$ and called *corrected* longwave radiation.

Figure 1a displays, as an example, the hourly values of longwave radiations observed and corrected using Fairall et al. (1998) during 29 February and 1 March 2004 (year days 60 and 61). As expected, the major differences occur when the solar heating is more intense. The discrepancy between the observed and corrected longwave emission from the atmosphere is superior to 10% of the daytime observed emission value (Fig. 1b).

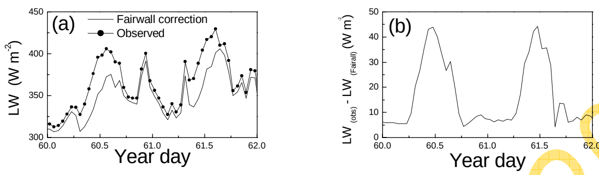

Fig.1; Diurnal evolution of hourly values of longwave radiations (a) corrected using Fairall et al. (1998) and applying only the manufacturer correction (Observed) and (b) the difference between them. Year days 60 and 61 corresponds to 29 February and 1 March 2004.

During daytime, in general, the dome temperature is considerably greater than the case temperature indicating an important dome emission (Fig. 2). During nighttime, very often, the dome is slightly warmer than the case and, as consequence, the dome emission is not zero (Fig. 1b).

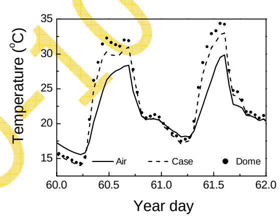

Fig. 2; Diurnal evolution of hourly values of air (continuous line), case (dashed line) and dome (dot) temperatures.

The resemblance between the longwave value curves obtained from multilayer perceptron neural network output and using Fairall correction (Fig. 3a) indicates that the neural network generated data is able to reproduce the corrected longwave measurements.

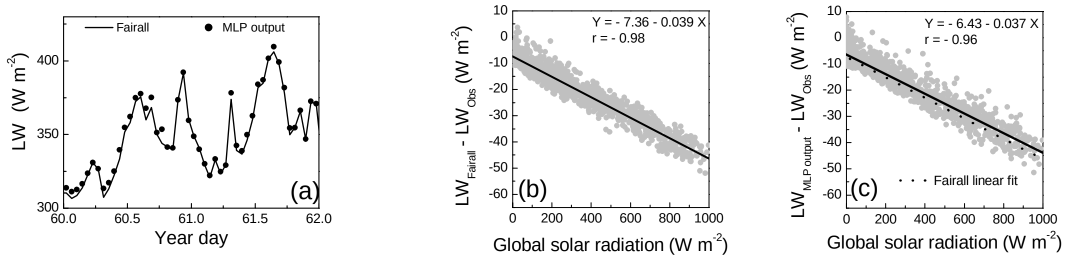

Fig. 3; (a) Hourly values of longwave radiations obtained as multilayer perceptron (MLP) neural network output (dot) and using Fairall et al. (1988) correction (continuous line). Dispersion diagrams between hourly values of global solar radiation and (b) Fairall-Observed longwave radiation difference and (c) MLP output-Observed longwave radiation difference. Continuous lines correspond to the curve fitted by least squares method. The correspondent linear equation and the correlation coefficient (r) are also indicated. The dotted line in (c) corresponds to the linear fit obtained in (b).

The dispersion diagrams between the longwave radiation corrections estimated by Fairall and from MLP show that the MLP network (Fig. 3c) follows the dependence with the global solar radiation presented by the Fairall method (Fig. 3b). The slope of the linearly fitted curve with the additional corrections proposed by Fairall (-0.039 W m^{-2}) is similar to the MLP (-0.037 W m^{-2}) Seasonal variation of the radiation flux components. The amplitude of solar radiation at the top of the atmosphere in December (Fig. 4a) corresponds to approximately twice the amplitude in June (Fig. 4b).

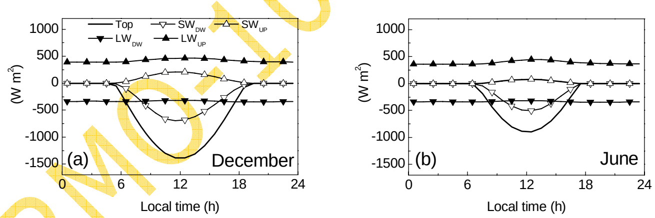

Fig. 4; Diurnal evolution of monthly averaged radiation balance components at the surface. Solar radiation at the top of the atmosphere (Top), longwave radiation emitted from the atmosphere (LW_{UP}) and from the surface (LW_{DW}), global shortwave radiation (SW_{DW}) and reflected shortwave radiation (SW_{UP}).

Monthly average hourly values of longwave radiation emitted from the atmosphere have similar amplitudes during December (Fig. 4a) and June (Fig. 4b). The amplitude of the longwave emission from the surface follows, as expected, the diurnal evolution of the surface temperature (not shown here).

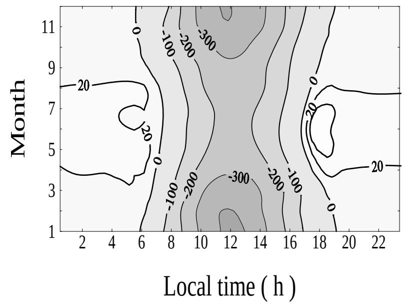

Fig. 6; Diurnal evolution of monthly averaged hourly values of net radiation at the surface.

The longwave components have a similar trend in both months. However, in December (Fig. 4a) the net radiation at the surface indicated very small positive values during nigthtime, comparatively to June (Fig. 4b). The seasonal evolution of net radiation in São Paulo is indicated in Figure 6.

CONCLUSION

This paper presents a methodology for generating synthetic series of longwave radiation, corrected for dome emission effects on pyrgeometer model PIR from Eppley, based on neural network called multilayer perceptron.

The longwave radiation values generated by the MLP were very similar to the Fairall values, assumed here as the reference approach to correct dome emission effects in pyrgeometers model PIR from Eppley.

The good performance of the MLP neutral network indicates that the temperature effect on downward longwave atmospheric radiation, measured at the surface with a pyrgeometer Eppley, can be corrected using only about 3-month long data set.

The corrected atmospheric longwave radiation allows estimating the radiation balance at São Paulo city. The diurnal evolution of monthly averaged values of net radiation at the surface indicates large positives values (50 Wm^{-2}) during winter months at nighttime and large negative values during daytime in the summer (-500 W m^{-2}).

REFERENCES

Božnar, M. and P. Mlakar, 1998: Improvement of air pollution forecasting models using feature determination and pattern selection strategies. Gryning, Sven-Erik (Ed.), Chaumerliac, Nadine. In *Air pollution modeling and its application XII*, (NATO challenges of modern society). New York; London: Plenum Press, 725-726.

Fairall C. W., P. O. G. Persson, E. F. Bradley, R. E. Payne and S. P. Anderson, 1998: A New Look at Calibration and Use of Eppley Precision Infrared Radiometers. Part I: Theory and Application. *J. Atmos. Oceanic Technol.***, 15**, 1229-1242.

Lawrence, J., 1991: Data preparation for a neural network. *Artificial Intelligence Expert* November, 34-41.

Mlakar, P. and M. Božnar, 1997: Perceptron neural network - based model predicts air pollution. Adeli, H. (ed.). Intelligent Information Systems IIS'97, Grand Bahama Island, Bahamas, December 8-10, 1997. *Proceedings. Los Alamitos, California, USA: IEEE Computer Society*, 345-349.

Oliveira, A. P., J. F. Escobedo, A. J. Machado and J. Soares, 2002: Diurnal evolution of solar radiation at the surface in the City of São Paulo: seasonal variation and modeling. *Theor. Appl. Climatol.*, **71(3-4)**, 231-249.

Rumelhart, D. E., G. E. Hilton and R. J.Williams, 1986: Learning internal representation by error propagation. *In Parallel Distributed Processing: Explorations in the Nicrostructure of Cognition.* Eds D.E. Rumelhart and J.L. McClelland, **1**, MIT Press, Cambridge, MA.

Soares, J., A. P. Oliveira, M. Z. Božnar, P. Mlakar, J. F. Escobedo and A. J. Machado, 2004: Modeling Hourly Diffuse Solar-Radiation in the City of São Paulo using a Neural-Network Technique, *Appl. Energy*, **79**, 201-214.