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Aerosol properties obtained from broadband measurements of direct solar radiation during cloudless days

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Abstract. Anthropogenic and natural aerosols are important atmospheric constituents that can significantly reduce, by scattering and absorption, the solar radiation reaching the Earth's surface. This impact depends on the aerosols properties, namely the optical Depth (AOD), the exponent (α) and the coefficient (β) of Angstrom. These three parameters are first estimated by fitting the direct solar radiation measurements recorded on clear days with the Iqbal C model. The retrieval of τ and β using data collected in Tamanrasset, Southern Algeria, are in good agreement with those of retrieved by AERONET at the same time and location. However, α exponent comparison is not satisfactory, we have therefore developed an Artificial Neural Network method (ANN) to better estimate it. The ANN created was first learned from β and α obtained from AERONET. We then used β from the Iqbal C model with the ANN and obtain good estimate of α with R^2 of 60% compared to the Angstrom exponent from AERONET. We will first give in this presentation an overview of the Iqbal C model, then present the data used and the processing method, and finally discuss the main results of this study.

Introduction

Aerosols play an important role in the radiative transfer through the Earth's atmosphere. Indeed, the presence of aerosols contributes to atmospheric turbidity, which affects significantly the solar radiation reaching the ground. The most commonly used coefficients to express its effects are the Angstrom coefficient β , the Linke turbidity factor T_L and the Unsworth-Monteith turbidity coefficient TUM [1-3]. The Aerosol Optical Depth (AOD) expressed by the Angstrom turbidity formula, which takes into account the number and size of the particles in the atmosphere, is given by the following Equation [4]:

$$AOD = \beta \times \lambda^{-\alpha} \quad (1)$$

where λ is the wavelength expressed in micrometers, α is the Angstrom exponent and β is the Angstrom coefficient.

The Angstrom exponent is a reliable index of the size distribution of aerosols. It is a good indicator of the dominant size of the atmospheric particles [5, 6]. This coefficient varies between 0 and 4. When the aerosol particles are very small, of the order of the air molecules, α takes the value of 4, and it is close to 0 for large particle. The use of these parameters to study the properties of aerosols is interesting on renewable energies

Theoretical background

The Aerosols Optical Depth τ , the Angstrom turbidity β and the Angstrom exponent α are obtained by fitting measurements (I_d) of the solar radiation with a model on which it depends. It is based on empirical representations of the radiative transfer equations taking into account the absorption and diffusion effects of aerosols, water vapor, ozone and other gases, and Rayleigh diffusion. We will use the two models described below.

The Iqbal Model

This model is described in Iqbal [7]. The beam irradiance (I_d) according to this model under clear sky conditions is given as follows:

$$I_d = 0.9751 E_0 I_0 \tau_r \tau_o \tau_w \tau_a \quad (2)$$

The Bird model

This model is widely used to estimate the solar radiation on the ground under clear sky conditions [8]. The direct solar radiation (I_d) measured on the ground is given by [8]:

$$I_d = 0.9662 I_0 E_0 \tau_r \tau_o \tau_w \tau_a \quad (3)$$

I_0 and E_0 are the total solar irradiance and the correction factor of the earth-sun distance, respectively.

τ_o , τ_w , τ_r and τ_a are the Ozone, Gas, Water, Rayleigh and Aerosols scattering transmittances, respectively.

Results and discussion

The first step is to estimate the AOD using the Iqbal model from the (i) global solar radiation and the (ii) direct solar radiation recorded in clear sky conditions at Tamanrasset during the period 2007 and 2011 with a radiometric station.

The results of the fitting method are compared to AOD measurements obtained from the photometer of AERONET [9] on the same site. The AOD estimated from Iqbal clear sky model is based on Angstrom formula (Equation 1) (see Figure 1).

Figure 2 shows the AOD obtained by the model with measurements of the global and direct components superposed to the one obtained from AERONET. It is observed that the results obtained from the fit with direct solar radiation are better than those obtained with global solar radiation with a correlation R of 0.85 and 0.48 respectively. This is due probably to the fact that AOD measurements with the photometer are obtained from the direct solar flux.

	AOD	rmse	nrmse	mape	mbe	Nmbe	R
Bird model		0,14	12,61	20,73	-0,10	-9,50	0,82
Iqbal model		0,10	10,61	12,35	-0,07	-6,93	0,85
Iqbal model using visibility equation		0,22	23,20	44,21	-0,21	-22,34	0,71

Table 1. Comparison between AOD measured by AERONET and AOD estimated from the models using the direct solar radiation

We note that the results with the Iqbal model agree better with the AOD daily variations of AERONET than those obtained with the Bird model. The statistical analysis between AOD measured with AERONET and AOD estimated with the Iqbal and Bird models using direct solar radiation gives a correlation R of 0.85 and 0.82 respectively, a rmse of 10.61 and 12.61, a mape of 12.35% and 20.73% and a mbe of -0.07 and -0.10 (see Table 1).

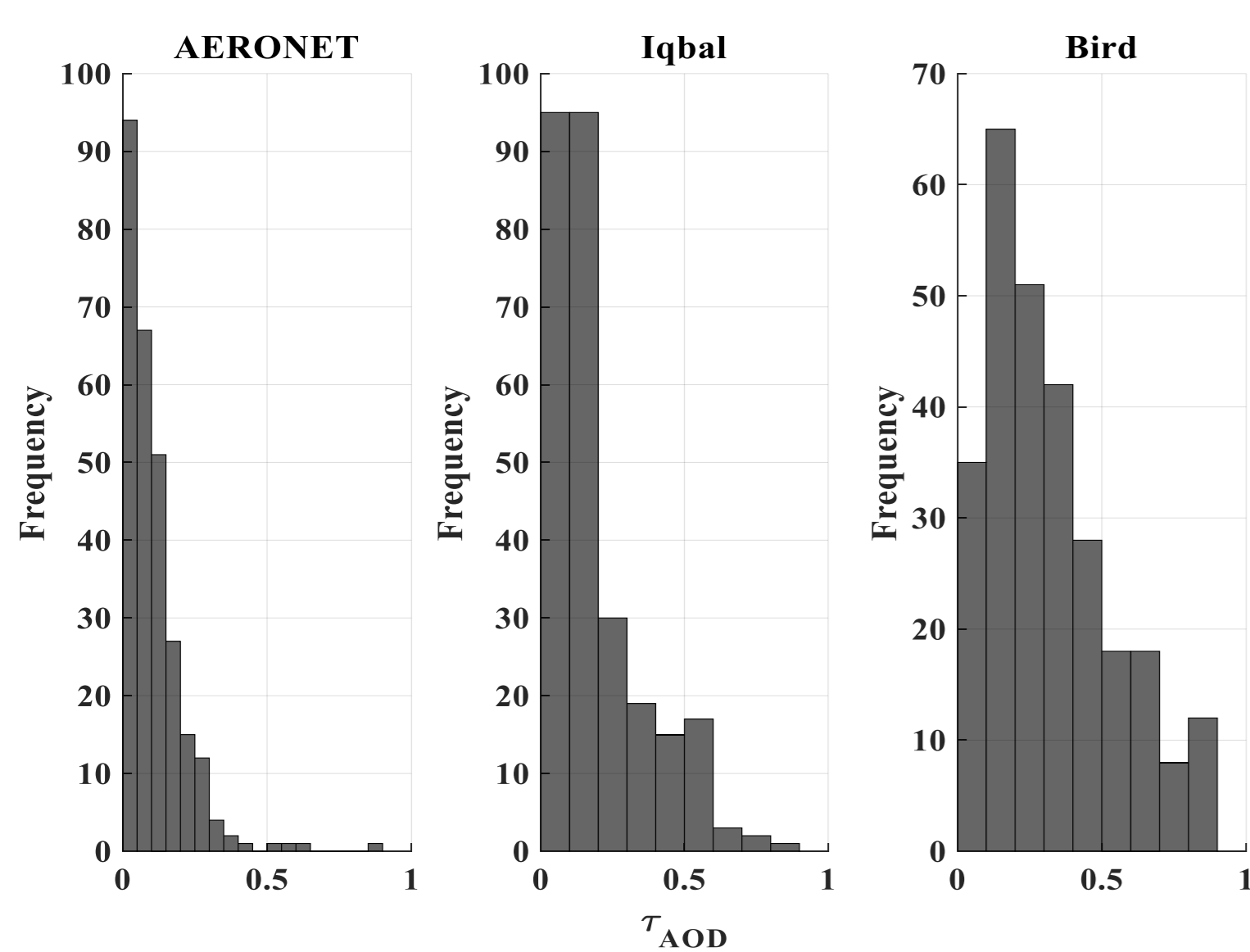


Fig. 3 AOD histograms

The results also show that the AOD obtained from the models has other clearly visible differences on its value histograms (see Figure 3). Indeed, we observe that the AOD obtained from the Iqbal model is closer to that obtained from AERONET, which emphasizes what is observed in Figure 2. The AERONET, Iqbal and Bird models give 98.55%, 91.69% and 79.78% respectively of the AOD values less than 0.5.

The monthly average of the AOD obtained using the two models (red curve) and of AERONET (black curve) is illustrated in Figure 4. We note that the AOD obtained with the models presents a maximum during the June which is confirmed by the results obtained from AERONET. It also presents a second maximum during the month of March which is clearly visible in the results obtained with the Iqbal model.

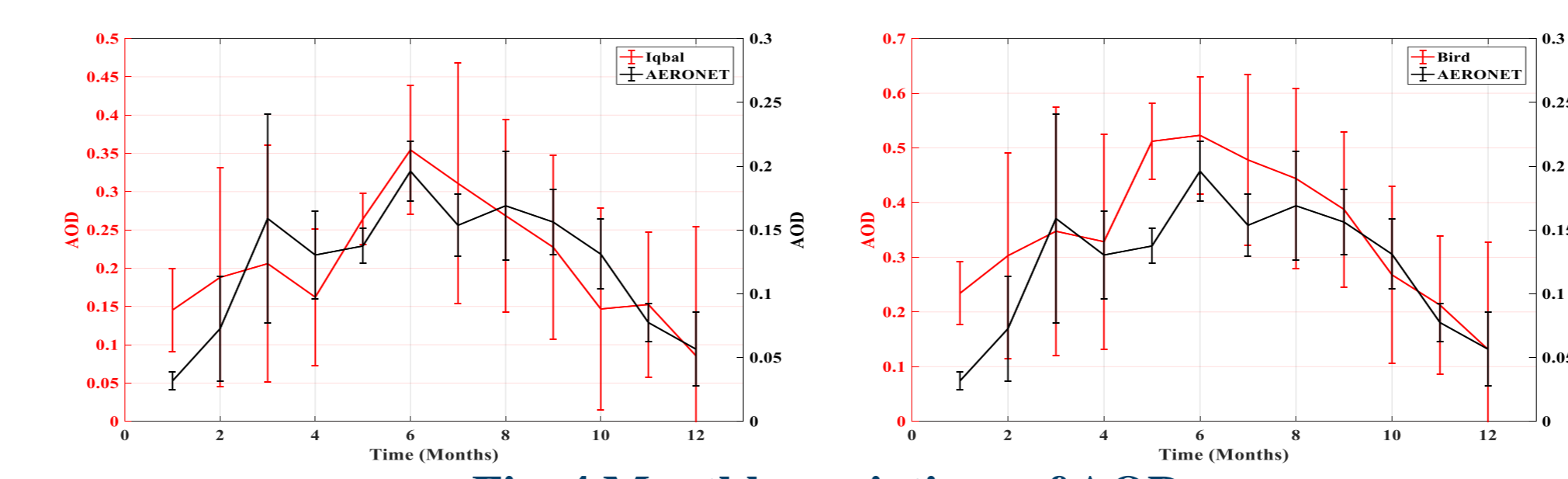


Fig. 4 Monthly variations of AOD

The second step is to compare the Angstrom turbidity obtained from the regression using the two models and those obtained from the photometer. Figure 5 shows the daily variation of β . The results obtained from the Iqbal model fitting the direct solar radiation are more significant than those obtained with the Bird model. The correlation factor R are respectively 0.84 and 0.80.

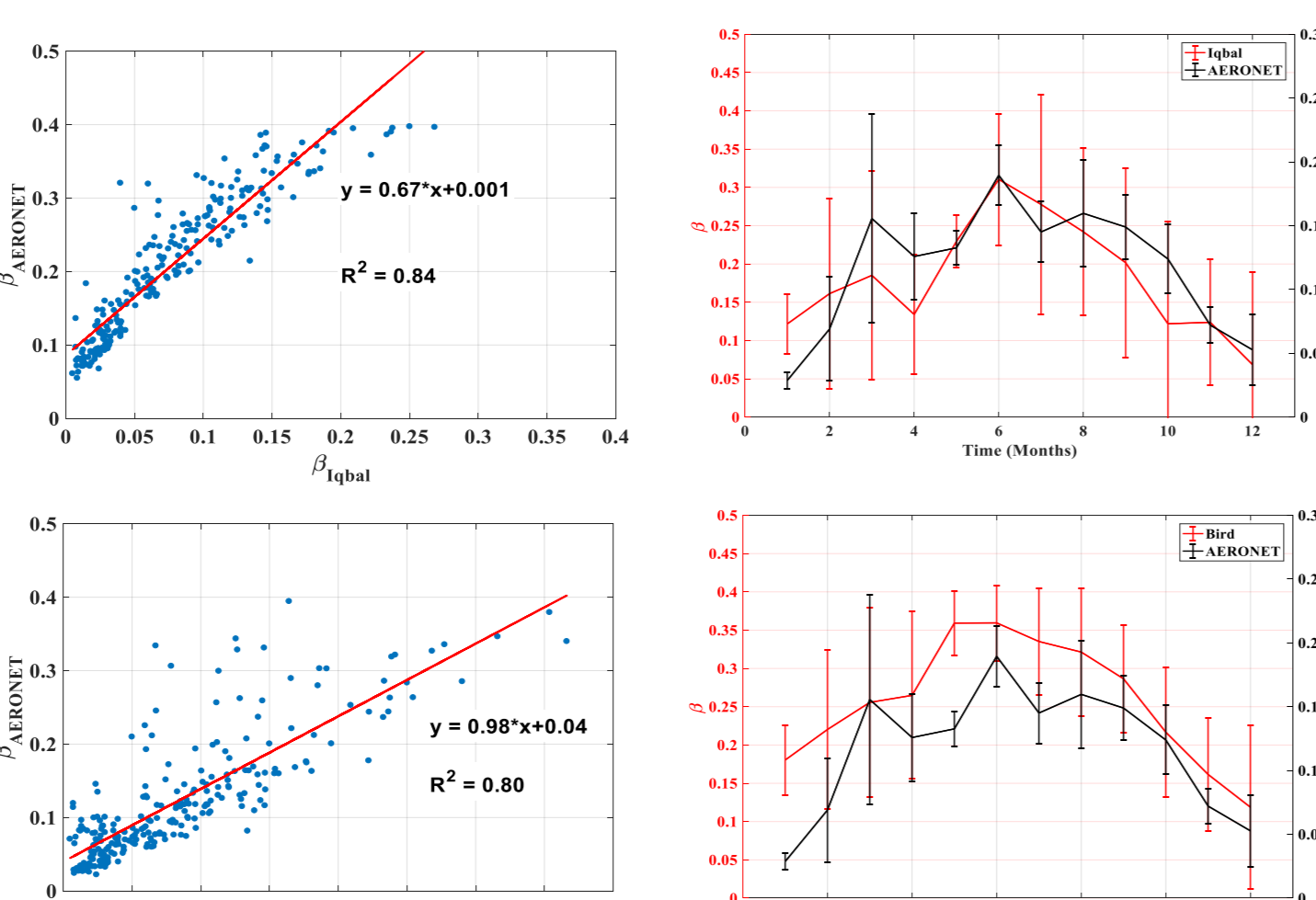


Figure 6 shows the estimated Angstrom exponent (α) from the 2 clear sky models used. We note that the Angstrom exponent obtained with the Iqbal model has the same trend as that of AERONET compared to what is obtained with the Bird model. Its values are however more sensitive than those of AERONET. This is due to the complexity and reliability of the adjustment method for estimating the five parameters on which the Iqbal model depends.

At this stage, the results require correction to be more significant and this leads us to use and exploit some unsupervised predicted algorithms which is the Artificial Neural Network (ANN).

The ANN used in our present work is based on Multilayer Perceptron (MLP), the most common type used of neural networks. MLP consists of the input layer, output layer, and one or more hidden layers [10]. Each layer of MLP includes one or more neurons directionally linked with the neurons from the previous and the next layer. Figure 7 represents a 3-layer perceptron with three inputs, two outputs, and a hidden layer of five neurons.

The ANN is first trained with AERONET data and then used to process our measurements. Figure 8 shows the predicted Angstrom exponent (α) (red line) using β estimated from Iqbal model superposed to the measured by AERONET (black line). We observe that the predicted Angstrom exponent has the same trend with Angstrom exponent measured by AERONET with a correlation R of 60%.

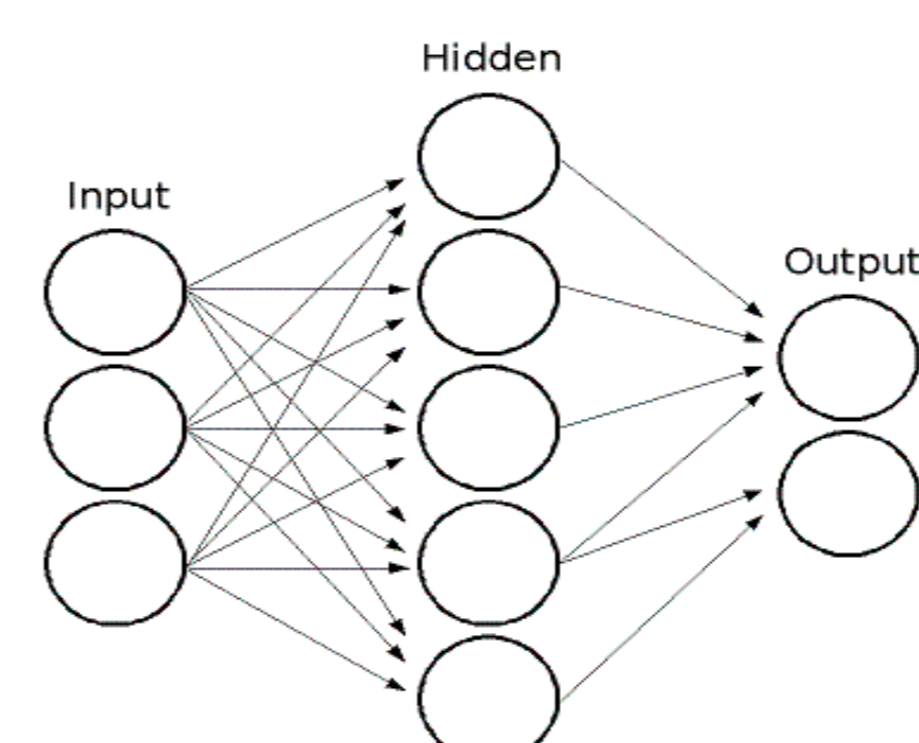


Fig. 7 3-layer perceptron with 3 inputs, 2 outputs and a hidden layer

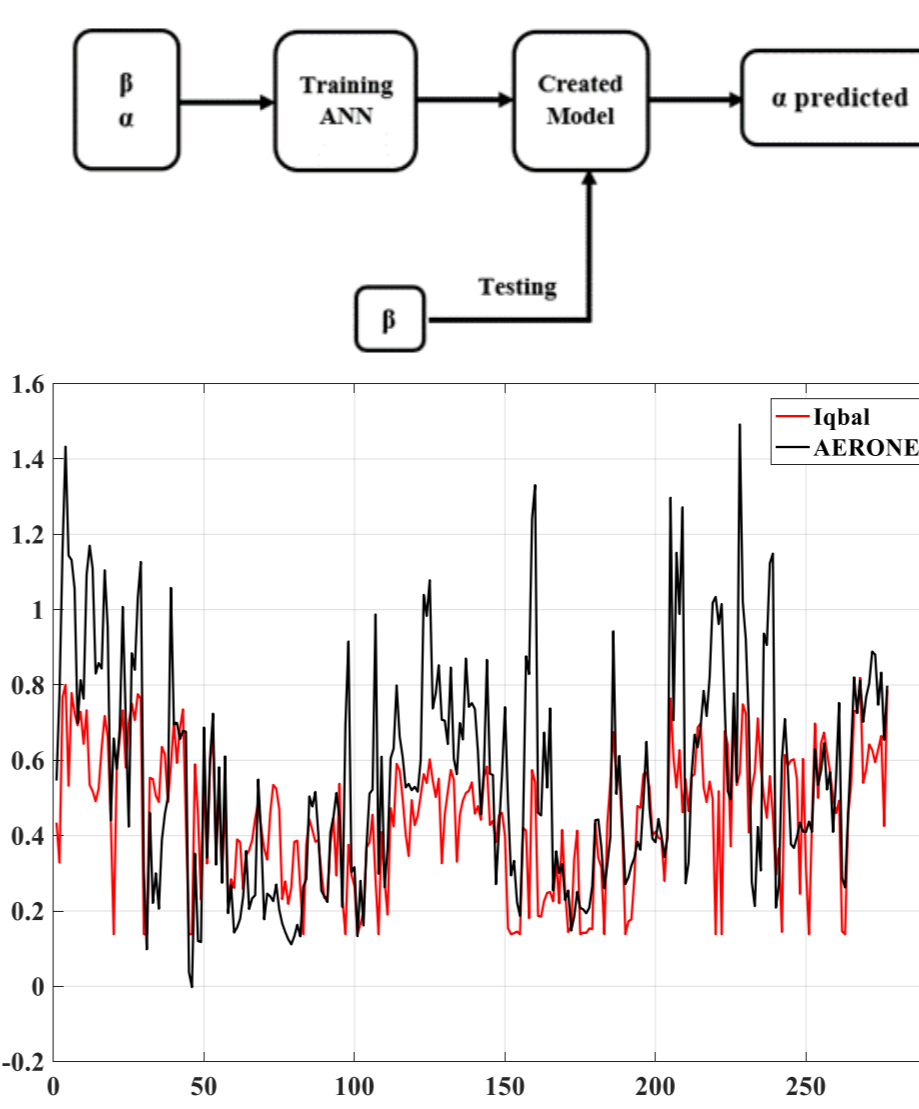


Fig. 8 daily alpha variations with AERONET and ANN

Conclusion

We compared the aerosols optical depth τ , the Angstrom turbidity β and the Angstrom exponent α obtained from AERONET with those estimated with two models of solar radiation in clear sky, the Iqbal and Bird models. The data used with these models were recorded during the period 2005-2009 in Tamanrasset, in the south of Algeria, with a radiometric station on the ground. We used several parameters to quantify the comparison between them the mean square error (rmse), the normalized mean square error (nrmse), the mean absolute percentage error (mape), the dependence of the model error (mbe) and the standardized error dependence model (nmbe). We found that we obtained the best results with the Iqbal model to estimate both τ and β . The Angstrom exponent α was less well estimated with the inversion method and the model. We then used a new method based on neural networks that we trained with AERONET data. New estimates of the Angstrom exponent with the ANN method showed that the results are very close to those of AERONET with the same temporal trend during the period analyzed.

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