

Brief Note

Conversion function between the Linke turbidity and the atmospheric water vapor and aerosol content

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Abstract

This technical note presents a conversion function between the widely used Linke turbidity coefficient T_L , the atmospheric water vapor and urban aerosol content. It takes into account the altitude of the application site.

The function is based on radiative transfer calculations and validated with the help of an independent clear sky model. Its precision is around 0.12 units of T_L .

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1. Introduction

In the field of solar radiation modelisation, the clear sky irradiance components are the main normalization functions. In order to evaluate them, for example by the mean of radiative transfer models (RTM), the atmospheric aerosol and water vapor content has to be known; these two parameters have the greatest influence on the transmittance. If the water vapor can be retrieved from ground or satellite measurements, it is not so easy for the turbidity.

Up to now, the most popular quantification of the turbidity is the Linke coefficient (Linke, 1922; Kasten, 1996; Ineichen and Perez, 2002). It takes into account both the atmospheric aerosol and water vapor content and cannot be used as is in the radiative transfer models. To circumvent this difficulty, the present technical note describes a conversion function between the aerosol optical depth, the water vapor column and the Linke turbidity; it is based on two different radiative transfer and clear sky models.

2. Conversion function

In a previous work, Ineichen (2006) developed a simple physical relation between these three parameters for the purpose of clear sky model comparison and validation and based on the following developments.

From numerically integrated spectral simulations done with the radiative transfer model Modtran (Berk et al., 1989), Molineaux et al. (1998) obtained for the broadband optical depth of a clean and dry atmosphere (fictitious atmosphere that comprises only the effects of Rayleigh scattering and absorption by the atmosphere gases other than the water vapor, including a 343 Dobson ozone content) the following expression:

$$A_{\text{cda}} = -0.101 + 0.235 * M^{-0.16}$$

and the broadband water vapors optical depth:

$$A_w = 0.112 * M^{-0.55} * w^{0.34},$$

where w is the integrated precipitable water vapor content of the atmosphere expressed in cm and M the optical air mass. The precision of these fits is better than 1% when compared with Modtran simulations in the range

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$1 < M < 5$, water vapor up to 5 cm and at sea level. The influence of the stratospheric ozone content is deemed as negligible on Δ_{cda} in the present application (Molineaux et al., 1998). Then, using the Kasten pyrheliometric formula (1996), the Linke turbidity at $M \cong 2$ can be written:

$$T_{L2}(\Delta_a, w) = -(9.4 + 0.9 * M) * (\Delta_{\text{cda}} + \Delta_w + \Delta_a),$$

where Δ_a is the broadband aerosol optical depth. When not known, and this is often the case, it can be evaluated from the spectral aerosol optical depth:

- from Molineaux et al. (1998) $\Delta_a \sim \text{aod}_{700}$, this equivalence is only slightly influenced by the air mass,
- or with the help of the empirical Bird and Huldstrom (1980) approximation based on the attenuation at two wavelengths commonly used by meteorological networks: $\Delta_a = 0.2758 * \text{aod}_{380} + 0.35 * \text{aod}_{500}$,

where aod_λ is the aerosol optical depth at the considered wave length λ . The extension of the Linke turbidity coefficient to other values of the air mass was published by Ineichen and Perez (2002).

In order to extend its validity to higher atmospheric water vapor content and to introduce altitude dependence, a new formulation is proposed. It is based on a new clear sky model developed by Mueller et al. (2004) derived from LibRadtran (Mayer et al., 1997) radiative transfer calculations: the Solis scheme. It is fully compatible with the above formulation within the specified limits.

To develop it, radiative transfer calculations are conducted for 550 nm aerosol optical depth values from 0 to 0.6, water vapor column values from 0.2 to 10 cm, altitudes from 0 to 7000 m and urban aerosol type.

The Linke turbidity values T_{L2} are then calculated from the beam irradiance obtained with the Solis model and the help of Kasten pyrheliometric formula. The conversion function is then a multivariable best fit on the radiative transfer calculation results and has the following form:

$$T_{L2}(\text{aod}_{550}, w, p/p_o) = 3.91 * \exp(0.689p_o/p) * \text{aod}_{550} + 0.376 * \ln(w) + [2 + 0.54 * (p_o/p) - 0.5 * (p_o/p)^2 + 0.16 * (p_o/p)^3]$$

where p is the atmospheric pressure at the considered altitude, p_o the sea level atmospheric pressure and aod_{550} the aerosol optical depth at 550 nm.

The coherence with the previous model is verified on Fig. 1 where the Linke turbidity is compared for the two formulations, at sea level and for $M = 2$. The agreement is very good for turbidity values up to 4 and satisfying for higher values, with a negligible bias between the two formulations.

The Linke turbidity values obtained with the above empirical regression are compared to the values retrieved from the radiative transfer beam irradiance for the complete range of parameters. This is illustrated on

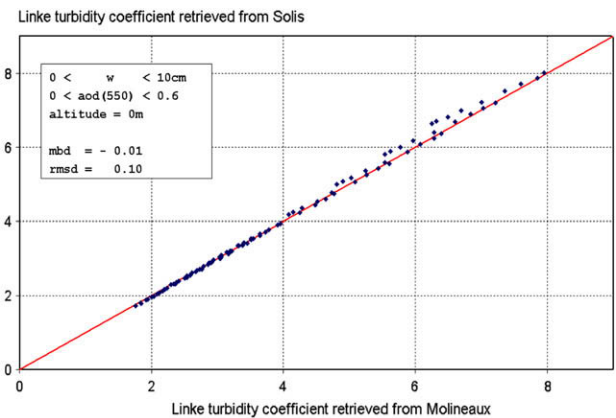


Fig. 1. Comparison of the Linke Turbidity coefficient evaluated through two independent clear sky models.

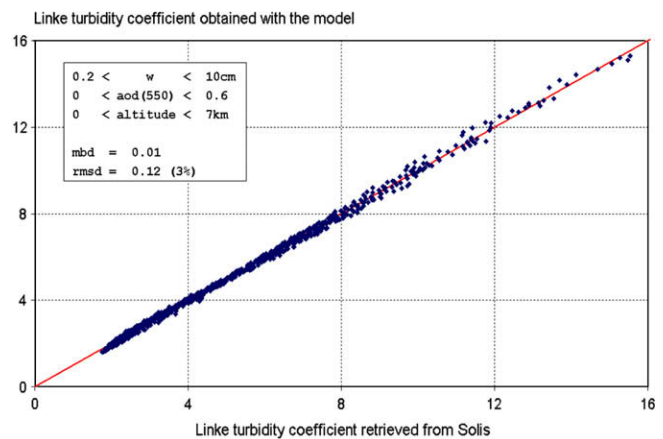


Fig. 2. Modelled Linke turbidity T_L coefficient versus the corresponding value evaluated from RTM calculations.

Fig. 2 where the modeled Linke turbidity are plotted versus the RTM calculated values for $M = 2$.

It can be seen on Fig. 2 that the correspondence is very good for Linke turbidity up to 8. Keeping in mind that the definition of T_L is the number of clean and dry atmospheres producing the same attenuation than the considered atmospheric conditions, turbidity values higher than 8 correspond to non zero altitudes. Over the complete range, the mean bias difference between RTM calculations and the empirical regression is negligible and the dispersion of the regression is around 3% (or 0.12 in absolute value of T_L).

This regression was obtained from RTM calculation with urban aerosol type. When conducting RTM calculations with rural aerosol type, and comparing them with the proposed regression over the whole range of input parameters, a dispersion of 2% is observed, with a maximum deviation of 4% on T_L .

Another commonly used turbidity parameter is the Angstrom coefficient β . It is related to the optical depth by the Angstrom relation with the α Angstrom coefficient which is representative of the aerosol size. Various correlations

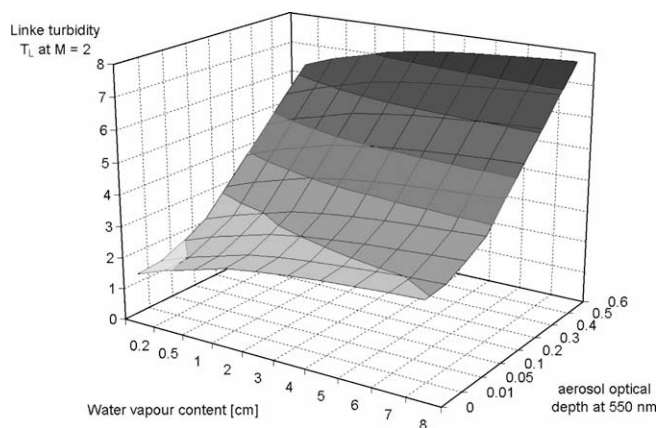


Fig. 3. Linke Turbidity T_L at air mass = 2 versus the aerosol optical depth and the atmospheric water vapour content at sea level.

between the Angstrom parameters and the Linke turbidity coefficient can be found in the literature (Dogniaux, 1976; Jacovides, 1997; Jamali et al., 2002; Katz, 1982; Mächler, 1983), etc. The simplest model taking into account the same parameters than the present correlation is from Dogniaux. Compared to the RTM calculations, the Dogniaux formulation gives values 10% lower, with a 6% standard deviation over the whole range of input parameters. Cucumo et al. (1999) drew similar conclusions.

T_L obtained from the conversion function is represented on Fig. 3 versus the atmospheric water vapor content and aerosol optical depth at 550 nm, at sea level and for an air mass $M = 2$.

The inverse function can be used to convert the Linke turbidity T_L to the aerosol optical depth. When dealing with other air mass than $M = 2$, the new formulation for the Linke turbidity defined by Ineichen and Perez (2002) should be used.

3. Conclusion

A conversion function between the Linke turbidity coefficient, the atmospheric water vapor content and the urban aerosol optical depth is developed, taking into account the altitude of the site. The range of validity of the function

covers the majority of the possible situations. The multiregression developed with the help of the Solis clear sky model is validated with an independent model at sea level.

Compared to RTM calculations, the overall performance of the function is better than 3% with a negligible bias.

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