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Is the MLB parameterization accurate enough to describe dependency of solar radiation with solar zenithal angle?

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1. Context

A new direct method, Heliosat-4, is currently being developed by the MINES ParisTech and the German Aerospace Center (DLR), aiming at estimating surface downwelling solar irradiance (SSI). This method is structured in two parts:

- ✓ Clear-sky module based on the radiative transfer model (RTM) libRadtran;
- ✓ Cloud-ground module (Oumbe et al. 2009).

However, running a RTM for clear-sky module intensively in real time is computer resources and time consuming. Therefore, it will be very beneficial to use parameterization to reduce the number of runs of RTM.

In this study, we test one published parameterization: Modified Lambert-Beer (MLB) (Muller et al. 2004), for the dependency of solar radiation with solar zenithal angle (SZA) for 32 spectral bands (Kato et al. 1999) and broadband.

MLB: dependency with solar zenithal angle θ_s:

$$E_\lambda^{MLB}(z_n, \theta_s) = E_{TOA,\lambda}(\theta_s) * MLB_\lambda(z_n, \theta_s)$$

$$MLB_\lambda(z_n, \theta_s) = \exp\left(\frac{-\tau_\lambda(z_n)}{\cos(\theta_s)^{a_\lambda(z_n)}}\right)$$

$E_{TOA,\lambda}(\theta_s)$ is the irradiance received by a horizontal plane at the top of atmosphere for the wavelength λ and the SZA θ_s. $\tau_\lambda(z_n)$ and $a_\lambda(z_n)$ are evaluated from the irradiances at two different solar zenithal angles.

Oumbe, A., Blanc, Ph., Ranchin, T., Schroedter-Homscheidt, M., and Wald, L.: A new method for estimating solar energy resource. In Proceedings of the ISRSE 33, held in Stresa, Italy, 4-9 May 2009. Published by Joint Research Center, Ispra, Italy, USBKey, paper 773, 2009.

Mueller, R., Dagestad, K.F., Ineichen, P., Schroedter, M., Cros, S., Dumortier, D., Kuhlemann, R., Olseth, J.A., Piernavieja, G., Reise, C., Wald, L., and Heinnemann, D.: Rethinking satellite based solar irradiance modelling - The SOLIS clear sky module, Remote Sensing of Environment, 91(2), 160-174, 2004.

Kato, S., Ackerman, T., Mather, J., and Clothiaux, E.: The k-distribution method and correlated-k approximation for shortwave radiative transfer model. Journal of Quantitative Spectroscopy & Radiative Transfer, 62, 109-121, 1999.

2. Tests based on a Monte-Carlo technique

We use a Monte-Carlo technique to randomly select 1000 sets within the 6D-space defined by the 6 most influent inputs of the libRadtran:

- ✓ Aerosol optical thickness;
- ✓ Aerosol type;
- ✓ Aerosol Angstrom coefficient;
- ✓ Total column water vapor content (kg/m²);
- ✓ Total column ozone content (Dobson);
- ✓ Atmospheric profile for different types of atmosphere.

For each 6-tuple, libRadtran is run for

- ✓ 11 altitudes of the ground surface: from 0 to 3 km by step of 0.5 km, and from 3 km to 8 km by step of 1 km;
- ✓ 22 SZAs: from 0 to 75 by step of 5 , from 75 to 87.5 by step of 2.5 + 89.9 ;
- ✓ 2 ground albedoes: 0 and 0.5.

For a given 6-tuple and a given altitude, the SSI values at the fitting angles are used to compute the fitting parameters of the MLB. Then, the MLB function is used to compute the SSI for the other SZAs, and these estimated SSIs are compared to the reference SSIs.

Definition of clearness index KT:

KT is defined as the ratio of the solar radiation (global, direct or diffuse) measured at the ground level to the total solar radiation at the top of the atmosphere.

$$KT_\lambda(z_n, \theta_s) = E_\lambda(z_n, \theta_s) / E_{TOA,\lambda}(\theta_s)$$

3. MLB with fitting angles: 0 and 60

Between 0 and 60 , the MLB performs very well for direct and global *KT*, and thus for diffuse *KT*: bias, RMSE and P95* are very low.

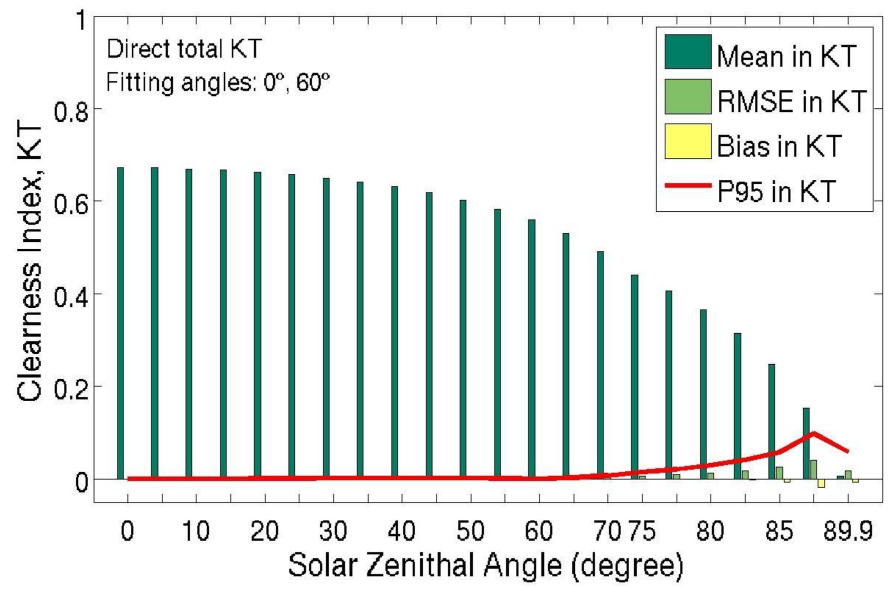
For SZA greater than 60 , the errors for both global and direct *KT* increase rapidly.

The error in global *KT* for SZA greater than 60 is much greater than for direct *KT*.

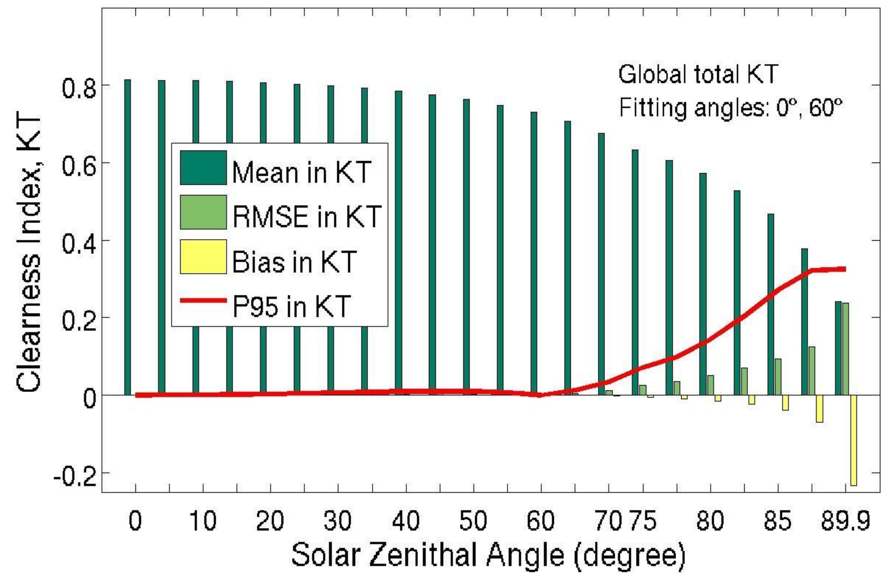
Accordingly, the error in diffuse *KT* is large. The MLB function tends to underestimate the diffuse SSI, and therefore the global SSI, at large SZA.

** Percentile 95%: 95% of the time, the errors is below the value of P95.*

Direct KT:



Global KT:

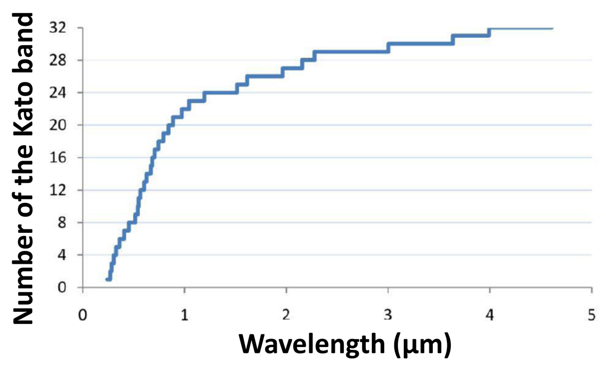


4. 5-Piecewise MLB

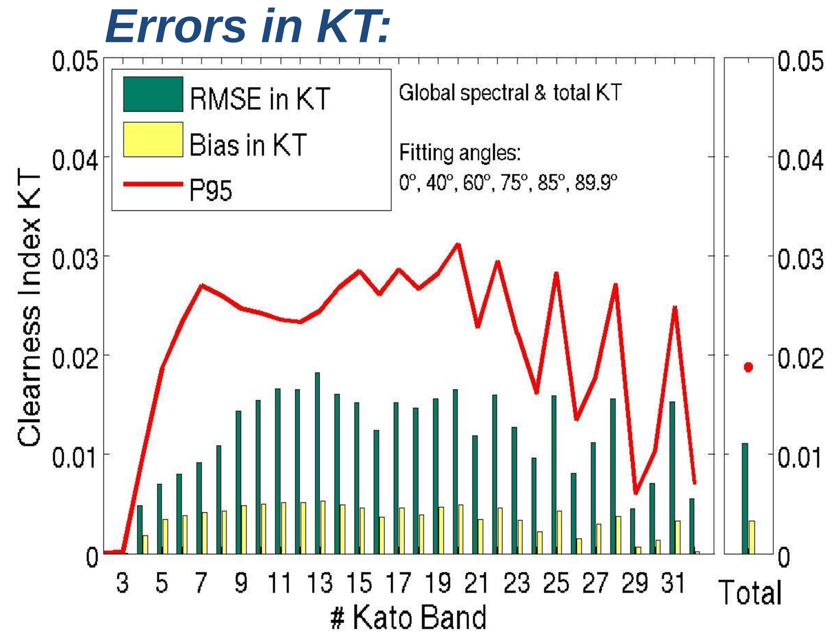
In order to reduce errors for large SZA, we have proposed in a previous study a parameterization made of four MLBs whose parameters are assessed for four intervals (0 , 60), (60 , 75), (75 , 85), and (85 , 89.9). But this 4-piecewise MLB does not satisfy the criteria of P95 < 10 W/m2 for global total irradiance. Therefore, we propose a 5-piecewise MLB in adding another fitting angle at 40 .

This five-piecewise MLB shows satisfactory performances which meets our criteria based on requirement analysis of articles and WMO guide for global total SSI: bias < 3 W/m2 and P95 < 10 W/m2.

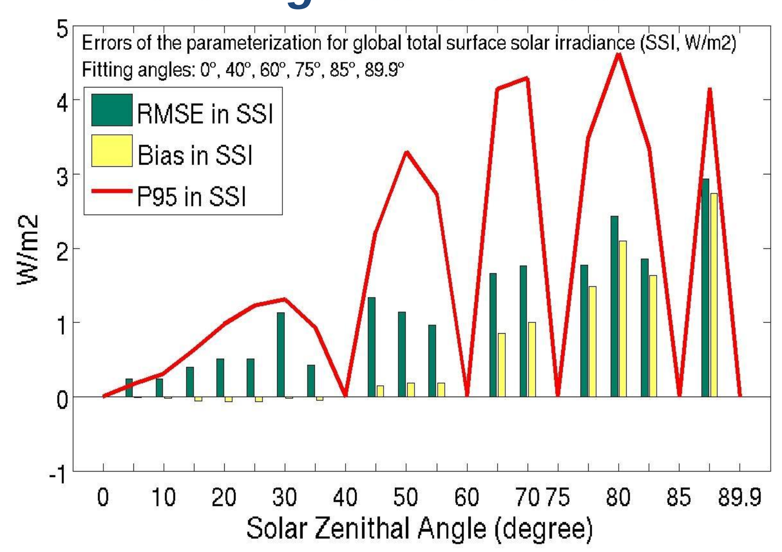
Kato bands:



Errors in KT:



Errors in global total SSI:

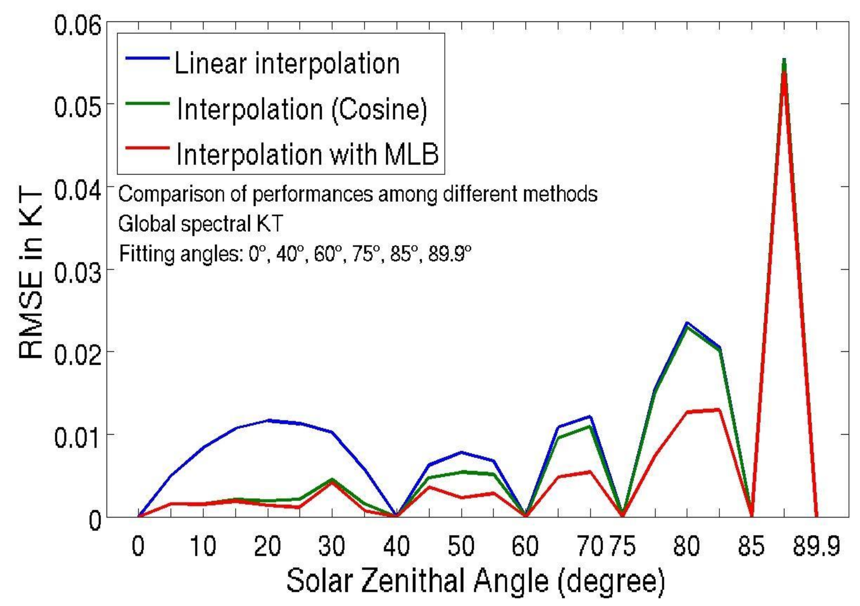


5. Comparison with "standard" interpolation techniques

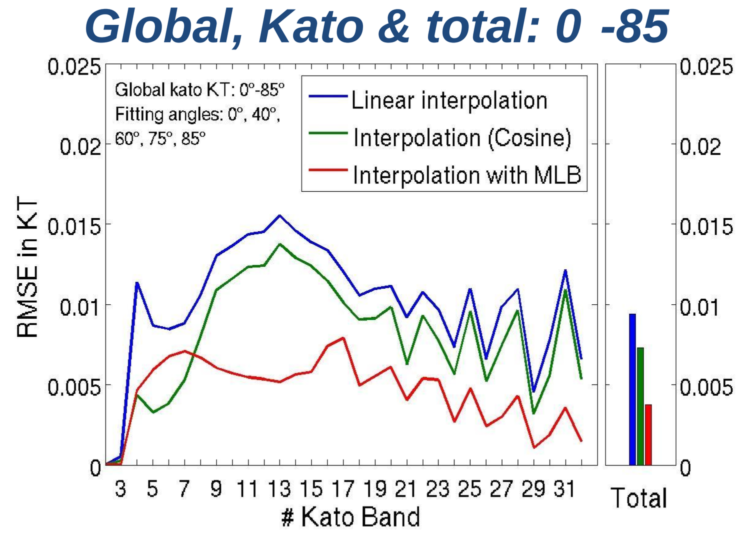
5-piecewise MLB largely outperforms the linear interpolation and a cosine-kernel interpolation for SZA less than 85 .

The performance of 5-piecewise MLB is higher for direct irradiance than for global and diffuse irradiance.

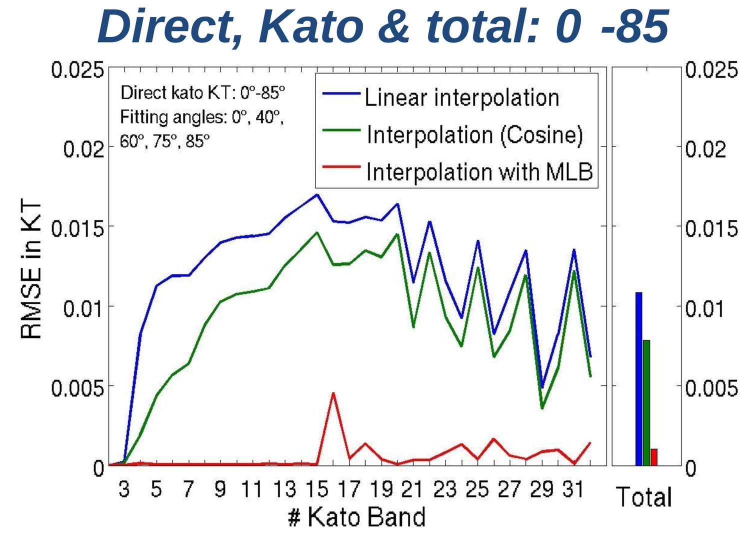
Global, Kato: 0 -89.9



Global, Kato & total: 0 -85



Direct, Kato & total: 0 -85



6. Conclusion

We find that the MLB parameterisation is efficient for all wavelengths, provided the solar zenithal angle (SZA) ranges between 0 and 60 . However, errors are large for SZA greater than 60 .

The MLB function has a solid physical sense for the direct irradiance, and very good performances can be achieved. It is less physically sound for the diffuse irradiance and performances are lower for the diffuse and global irradiances.

A 4-piecewise MLB has been proposed in our previous study, but it does not satisfy the criteria of P95 when ground albedo is greater than 0.1. Therefore, we have proposed a 5-piecewise MLB by adding another fitting angle at 40 .

We observe that this 5-piecewise MLB demonstrates satisfactory performances and could be used accurately in the Heliosat-4 method to reduce the number of runs of the RTM.

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macc Monitoring atmospheric composition & climate