Parameterization of surface solar radiation and its applications

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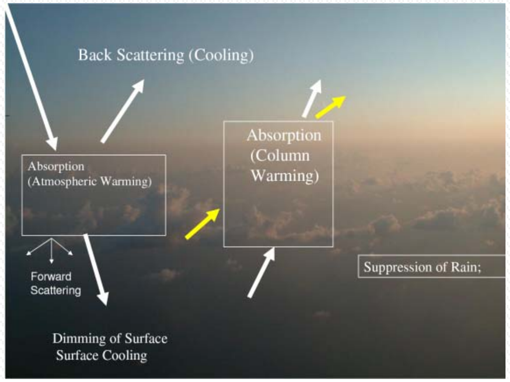
Motivation

- Surface solar radiation ($E_{g\downarrow}$) is a key parameter that plays an important role in climate and solar energy
- Aerosol is one of important modulator of surface solar radiation via its scattering and absorption (direct) and acting as CCN (indirect)
- Modeling of surface solar radiation is required for evaluation of aerosol direct radiative effect (ADRE) and derivation of aerosol optical depth (τ_a) from surface solar radiation measurements



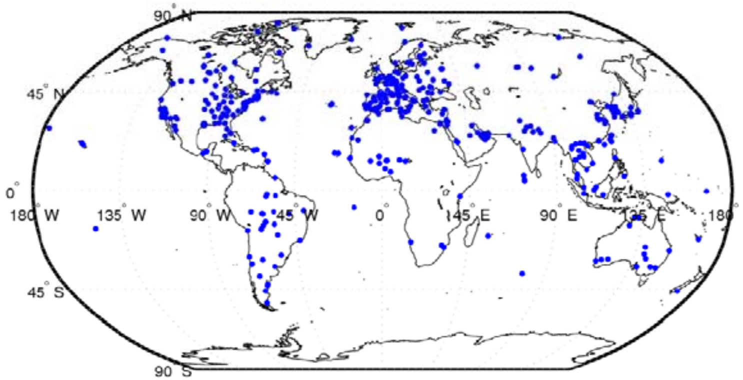
Motivation

- ADRE = $E_{g\downarrow} - E^{o}_{g\downarrow}$, $E_{g\downarrow}$ can be measured by pyranometer, so the key issue is to obtain the second term.
- $E^{o}_{g\downarrow}$ means the expected $E_{g\downarrow}$ for zero τ_a that can be calculated from radiative transfer model. This method is impacted by modeling errors (not only from RT algorithm but also from input errors). Furthermore, modeling error is independent on measurement errors, so large ADRE error might be derived.
- Generally, $E^{o}_{g\downarrow}$ is derived from $E_{g\downarrow}$ measurement by extrapolation.

Objective

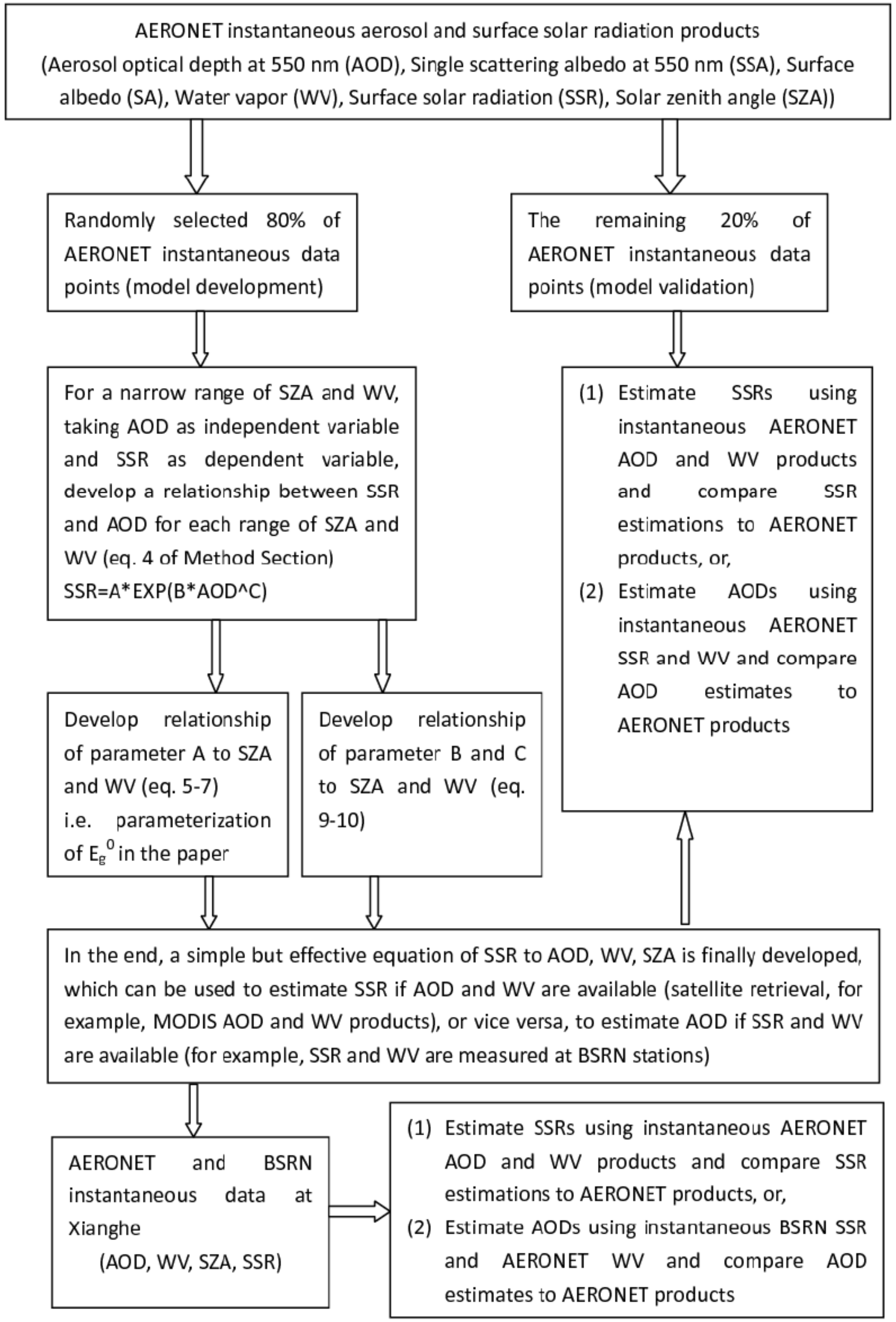
- To estimate a simple but effective parameterization for $E_{g\downarrow}$
- Compare this method against previous methods
- Discuss its potential applications

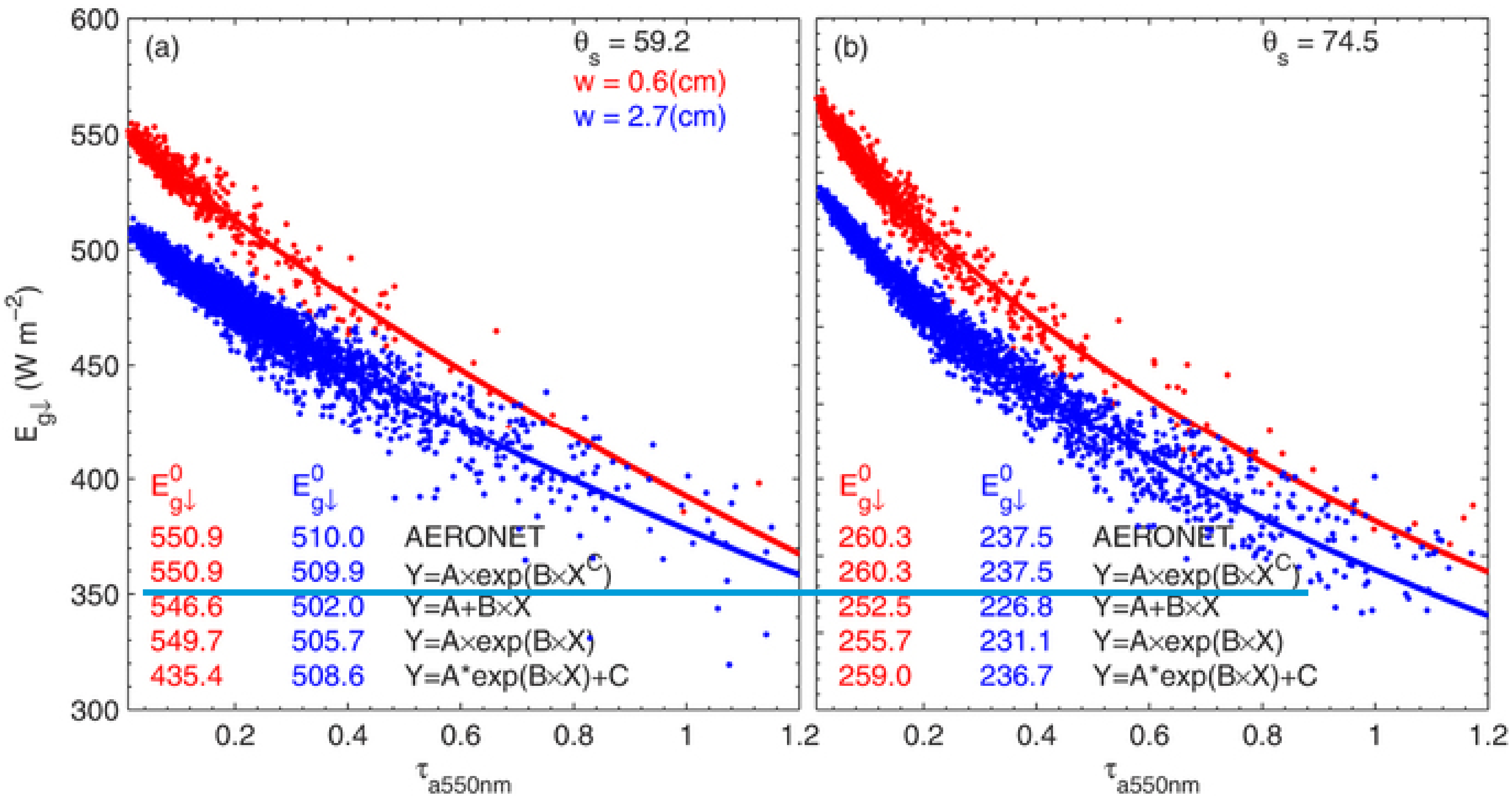
Data



- AERONET aerosol optical properties and $E_g{\downarrow}$ data across the world (τ_a , single scattering albedo (ω_{550nm}), surface albedo, water vapor, $E_g{\downarrow}$ and $E^o_g{\downarrow}$)
- The AERONET products were used because they cover different aerosol types ($0 < \tau_a < 3.0$; $0.65 < \omega_{550nm} < 1.0$; $-0.2 < \alpha_{440\_870nm} < 2.5$, that means a robust method can be established. Furthermore, the availability of $E^o_g{\downarrow}$ data provides a benchmark for the evaluation of the parameterizations.
- Nearly one million data points are available from AERONET website, I randomly select 80% of data points to develop the parameterization and the remaining 20% were used as test data.

Method


AERONET instantaneous aerosol and surface solar radiation products (Aerosol optical depth at 550 nm (AOD), Single scattering albedo at 550 nm (SSA), Surface albedo (SA), Water vapor (WV), Surface solar radiation (SSR), Solar zenith angle (SZA))
Randomly selected 80% of AERONET instantaneous data points (model development)
The remaining 20% of AERONET instantaneous data points (model validation)
For a narrow range of SZA and WV, taking AOD as independent variable and SSR as dependent variable, develop a relationship between SSR and AOD for each range of SZA and WV (eq. 4 of Method Section) SSR=A*EXP(B*AOD^C)
(1) Estimate SSRs using instantaneous AERONET AOD and WV products and compare SSR estimations to AERONET products, or,
(2) Estimate AODs using instantaneous AERONET SSR and WV and compare AOD estimates to AERONET products
Develop relationship of parameter A to SZA and WV (eq. 5-7) i.e. parameterization of E_g^0 in the paper
Develop relationship of parameter B and C to SZA and WV (eq. 9-10)
In the end, a simple but effective equation of SSR to AOD, WV, SZA is finally developed, which can be used to estimate SSR if AOD and WV are available (satellite retrieval, for example, MODIS AOD and WV products), or vice versa, to estimate AOD if SSR and WV are available (for example, SSR and WV are measured at BSRN stations)
AERONET and BSRN instantaneous data at Xianghe (AOD, WV, SZA, SSR)
(1) Estimate SSRs using instantaneous AERONET AOD and WV products and compare SSR estimations to AERONET products, or,
(2) Estimate AODs using instantaneous BSRN SSR and AERONET WV and compare AOD estimates to AERONET products



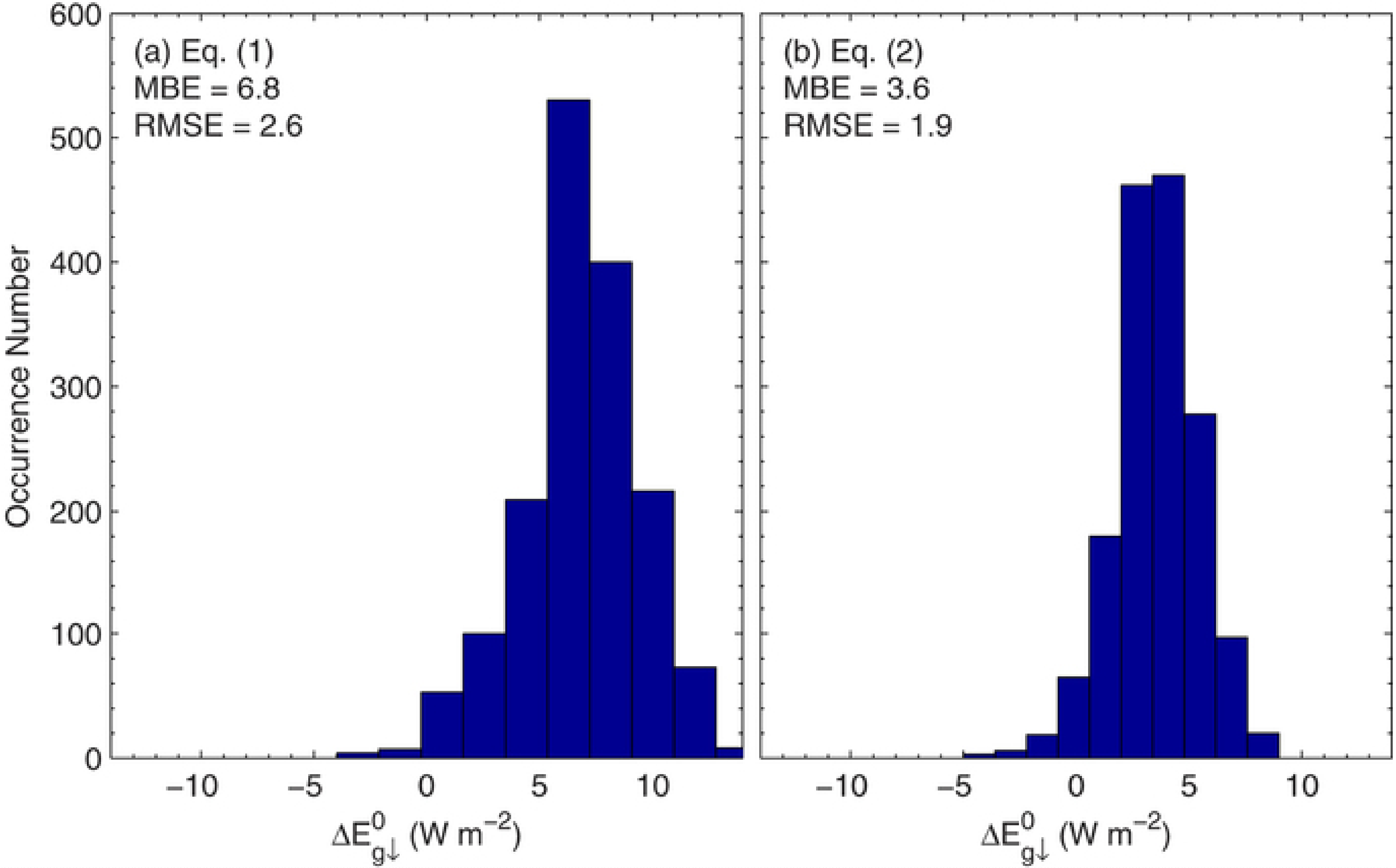
$$E_{g\downarrow} = A + B \times \tau_a$$

$$E_{g\downarrow} = A \times \exp(B \times \tau_a^C)$$

$$E_{g\downarrow} = A \times \exp(B \times \tau_a)$$

$$E_{g\downarrow} = A \times \exp(B \times \tau_a) + C$$

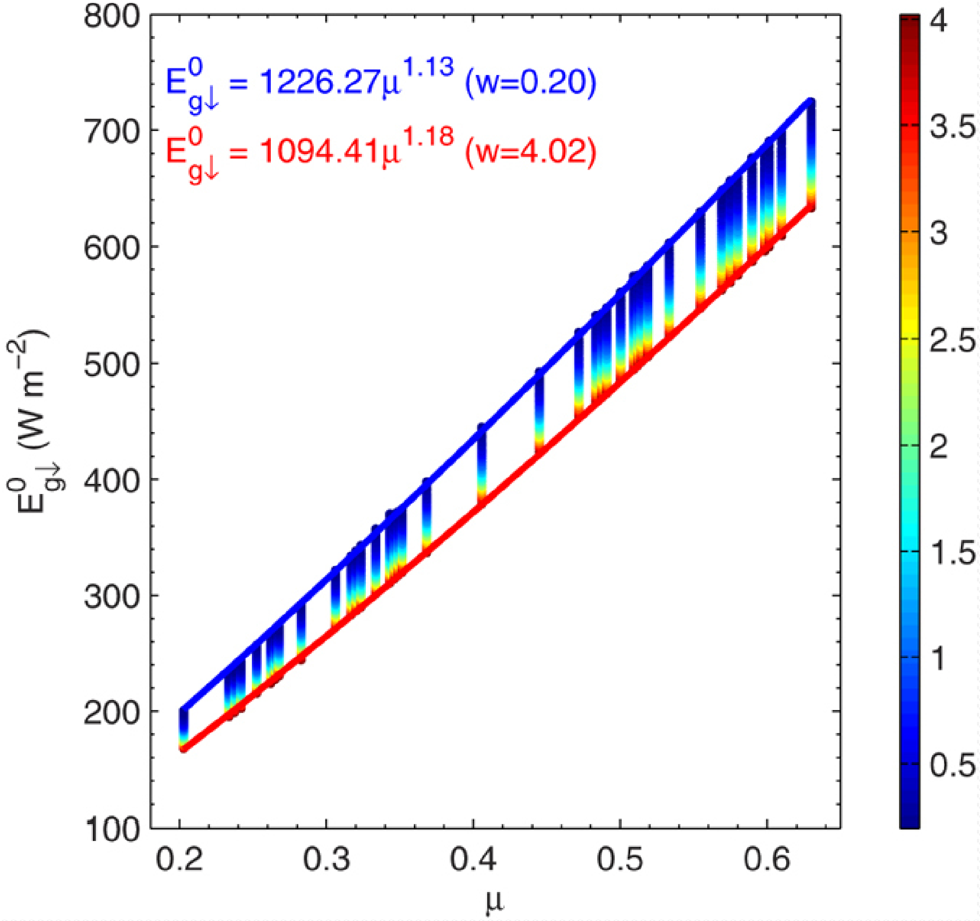
The relationship between $E_{g\downarrow}$ and τ_a for a specified solar zenith angle and water vapor content



Previous methods overestimate $E^o_{g\downarrow}$, indicating improvements are required

$$E_{g}\downarrow = A \times \exp(B \times \tau_{a}^{C})$$

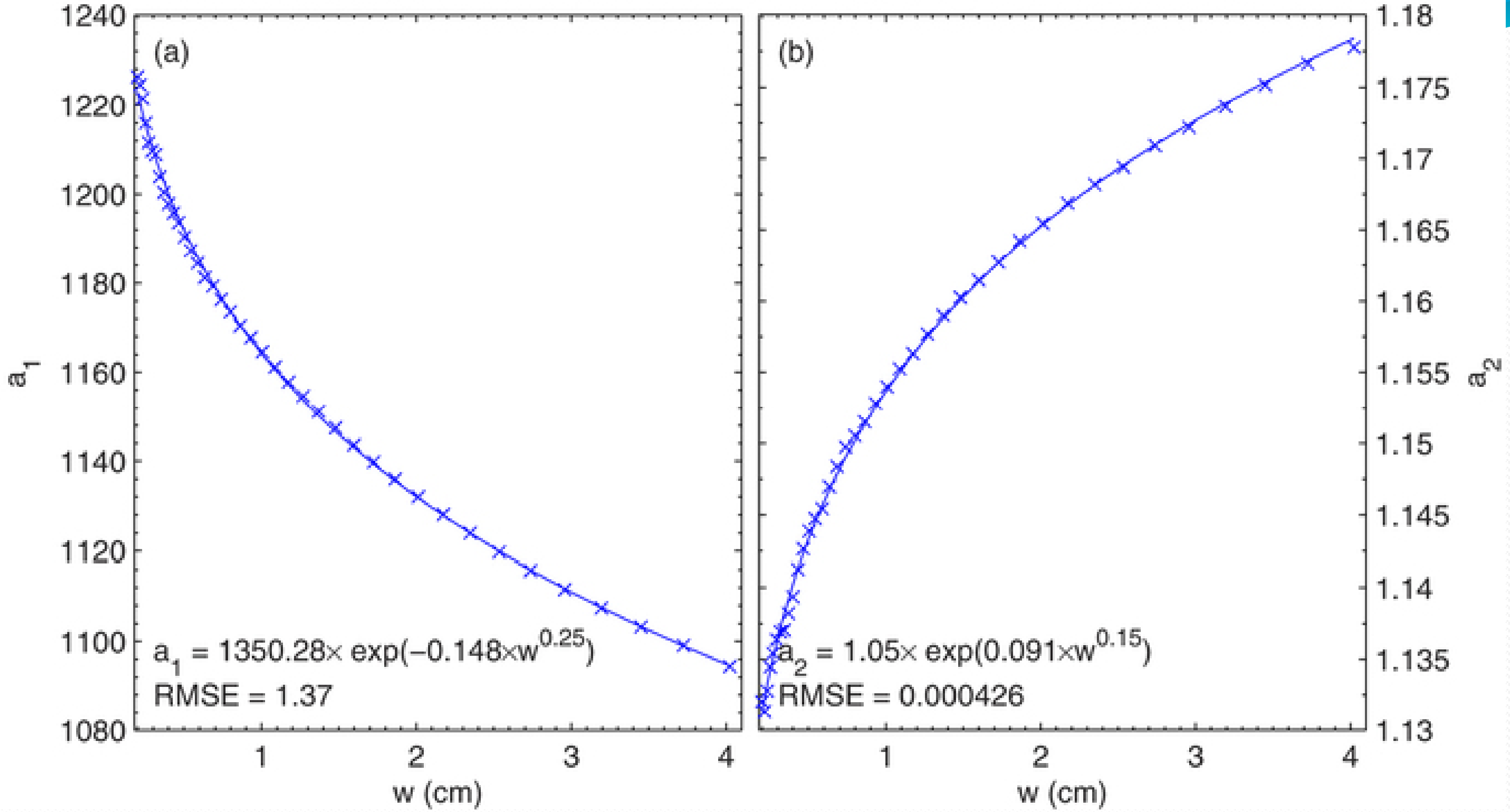
- This new equation works much better than previous equations
- Parameters A, B, C varies with solar zenith angle, water vapor content, therefore, they are parameterized as function of solar zenith angle and water vapor content



- A means $E^o_{g\downarrow}$
- It closely related to solar zenith angle and water vapor content
- For a specified water vapor content,

$$A_{\theta_s} = a_1 \times \mu^{a_2}$$

$$E_{g\downarrow} = A \times \exp(B \times \tau_a^C)$$

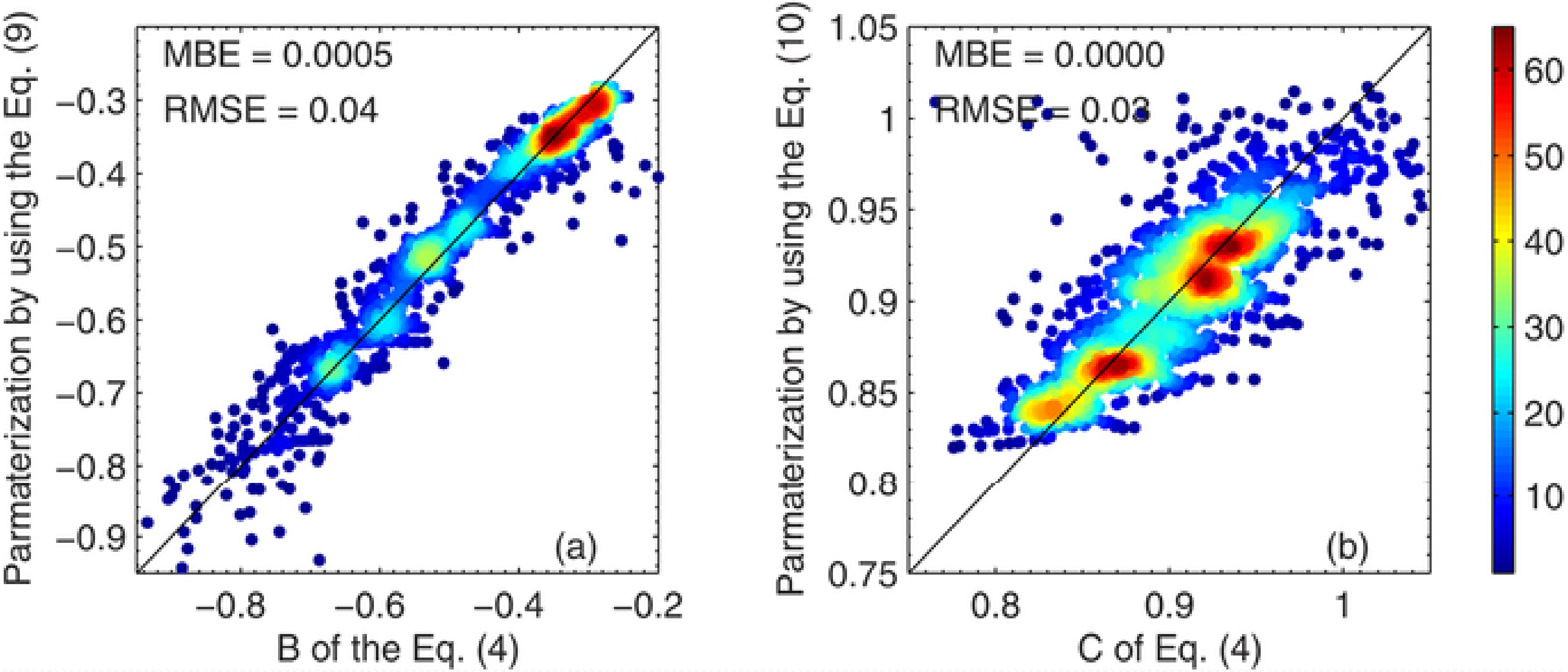


- Parameters a1 and a2 show close relationship to water vapor content.
- Therefore, $E^{o}_{g\downarrow}$ is parameterized as a function of solar zenith angle and water vapor content.

$$A = (1350.3 \times \exp(-0.148 \times w^{0.25})) \times \mu^{(1.05\times \exp(0.091\times w^{0.15}))}$$

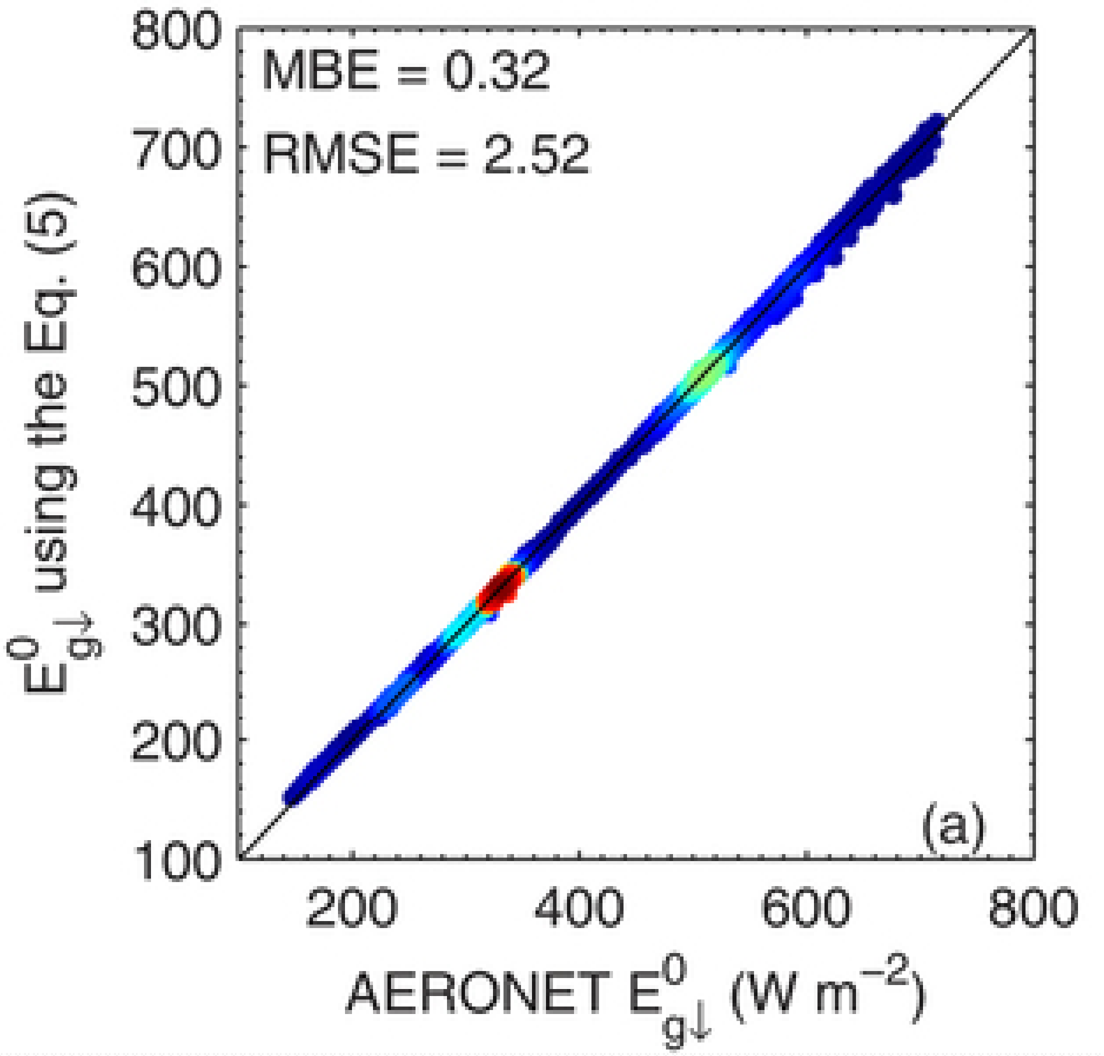
$$B = (-0.0024 \times w^{-2.105} - 0.188) \times \mu^{-0.879}$$

$$C = 1.295 \times \mu + 0.019 \times w^{-0.955} + 0.759$$

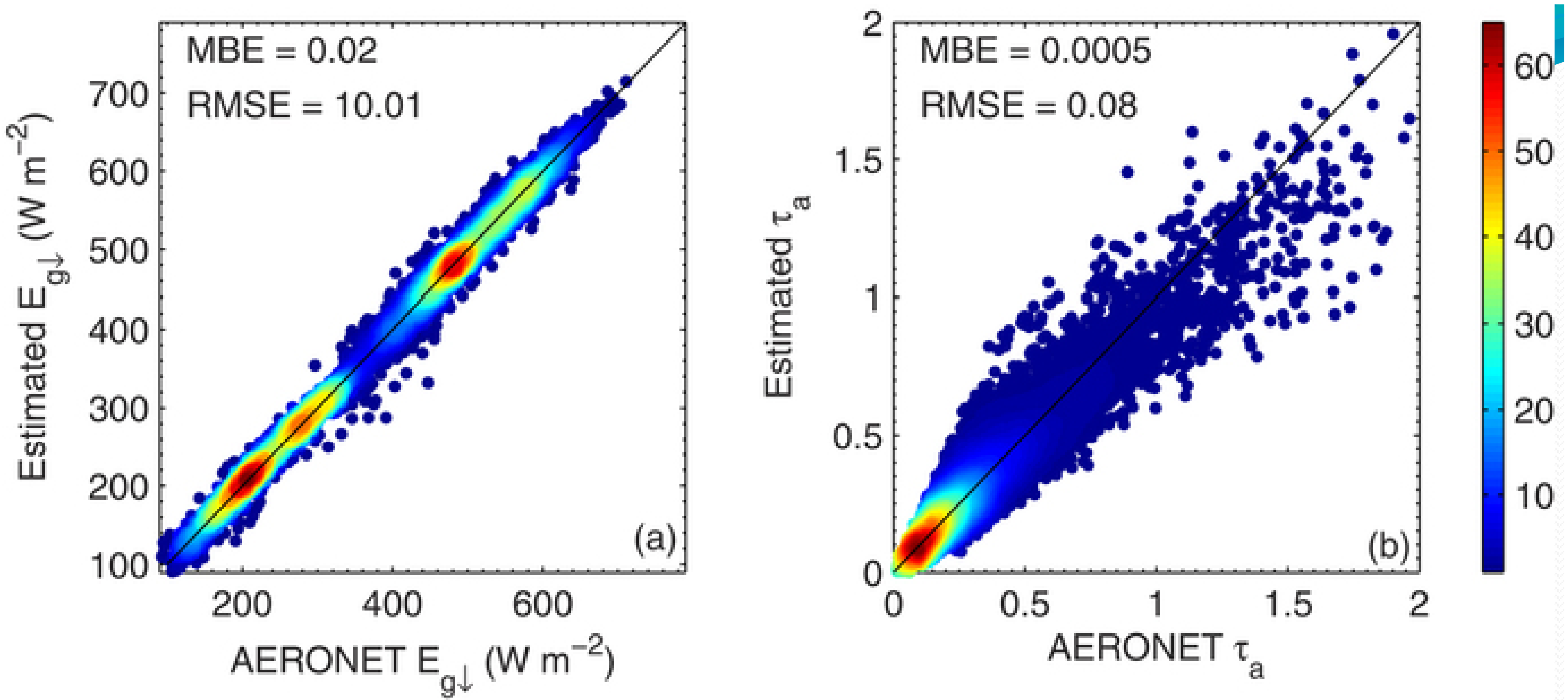


Evaluation of parameterization of B and C, two parameters in

$$E_{g\downarrow} = A \times \exp(B \times \tau_a^{C})$$

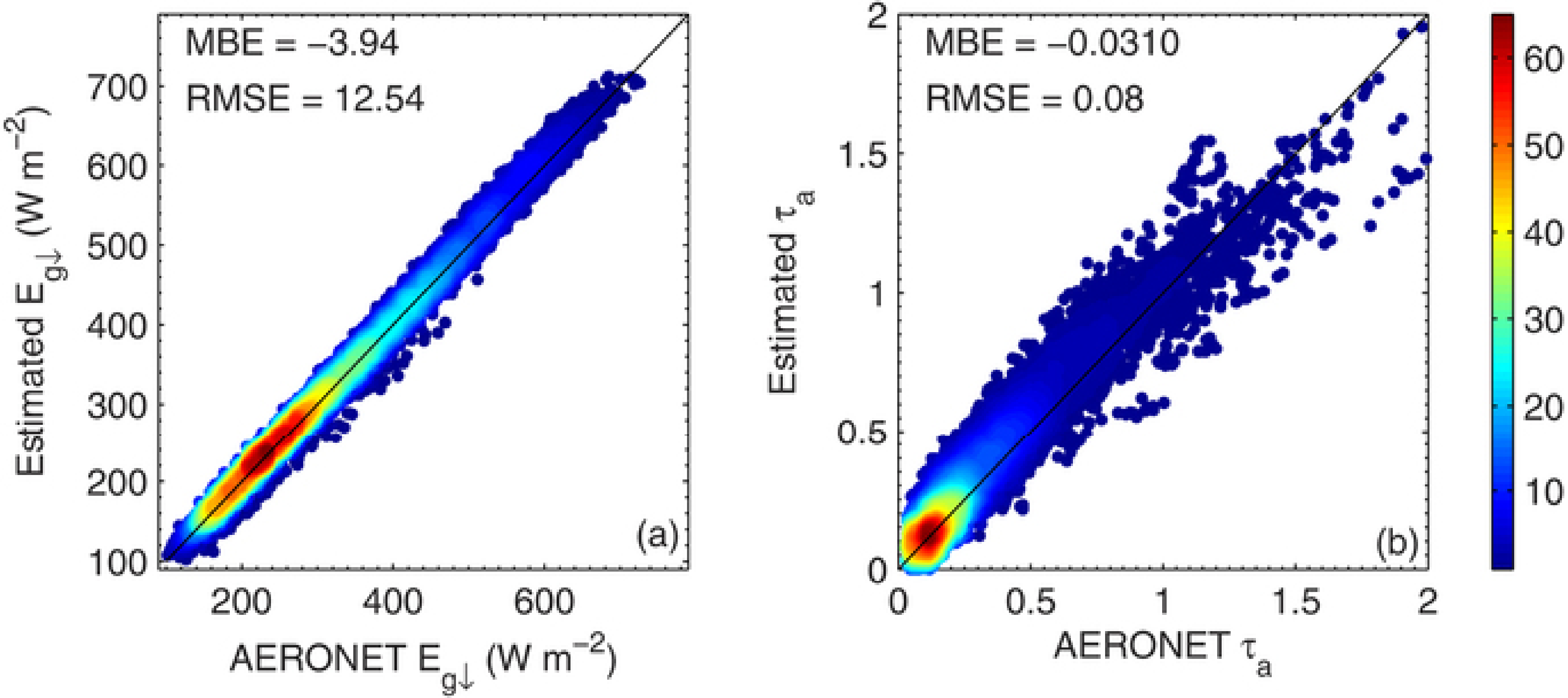


- Evaluation of $E^o_{g\downarrow}$ and ADRE by comparison of the parameterization against AERONET products
- Mean Bias Error is about 0.32, that is one order of magnitude smaller than estimations by previous methods.



- Evaluation of $E_{g\downarrow}$ and τ_a by comparison of the parameterization against AERONET products.
- Mean Bias Error of $E_{g\downarrow}$ and τ_a are 0.02 and 0.0005, respectively.

$$E_{g\downarrow} = A \times \exp(B \times \tau_a^C)$$

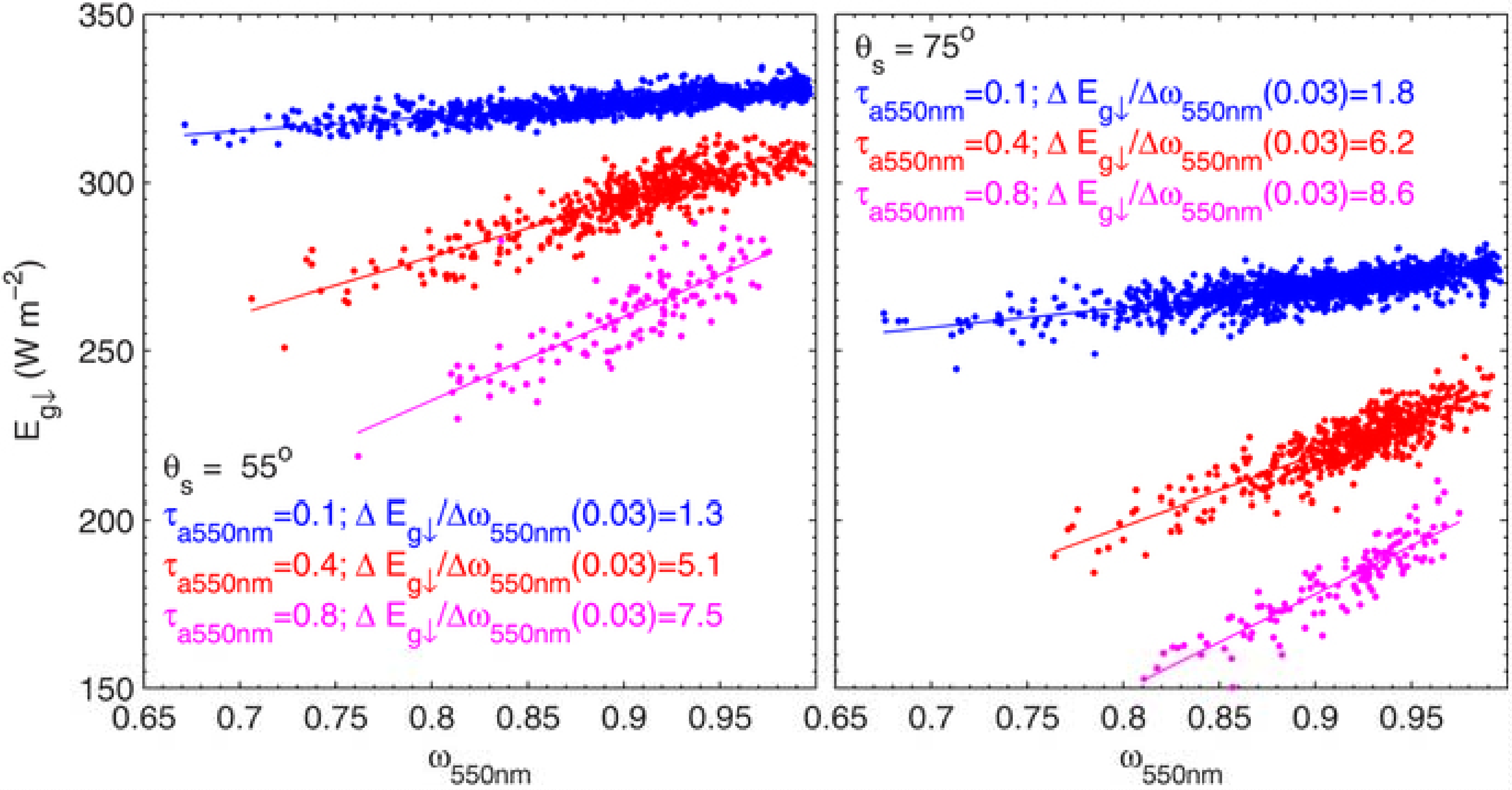


Comparison of BSRN surface solar radiation and estimation from AERONET aerosol optical depth at Xianghe station.

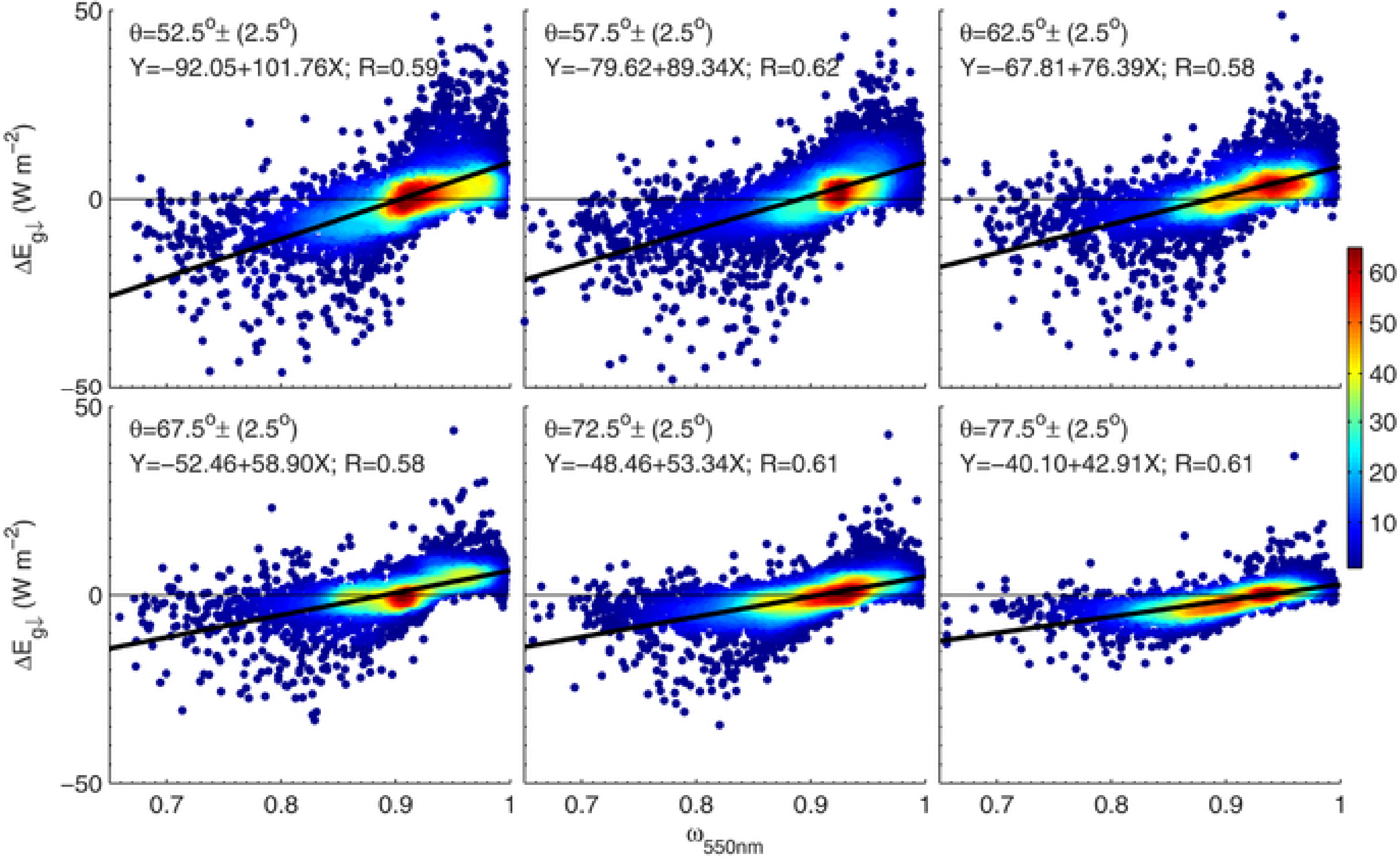
Comparison of AERONET aerosol optical depth and estimation from BSRN surface solar radiation at Xianghe station.

$$E_{g\downarrow} = A \times \exp(B \times \tau_a^C)$$

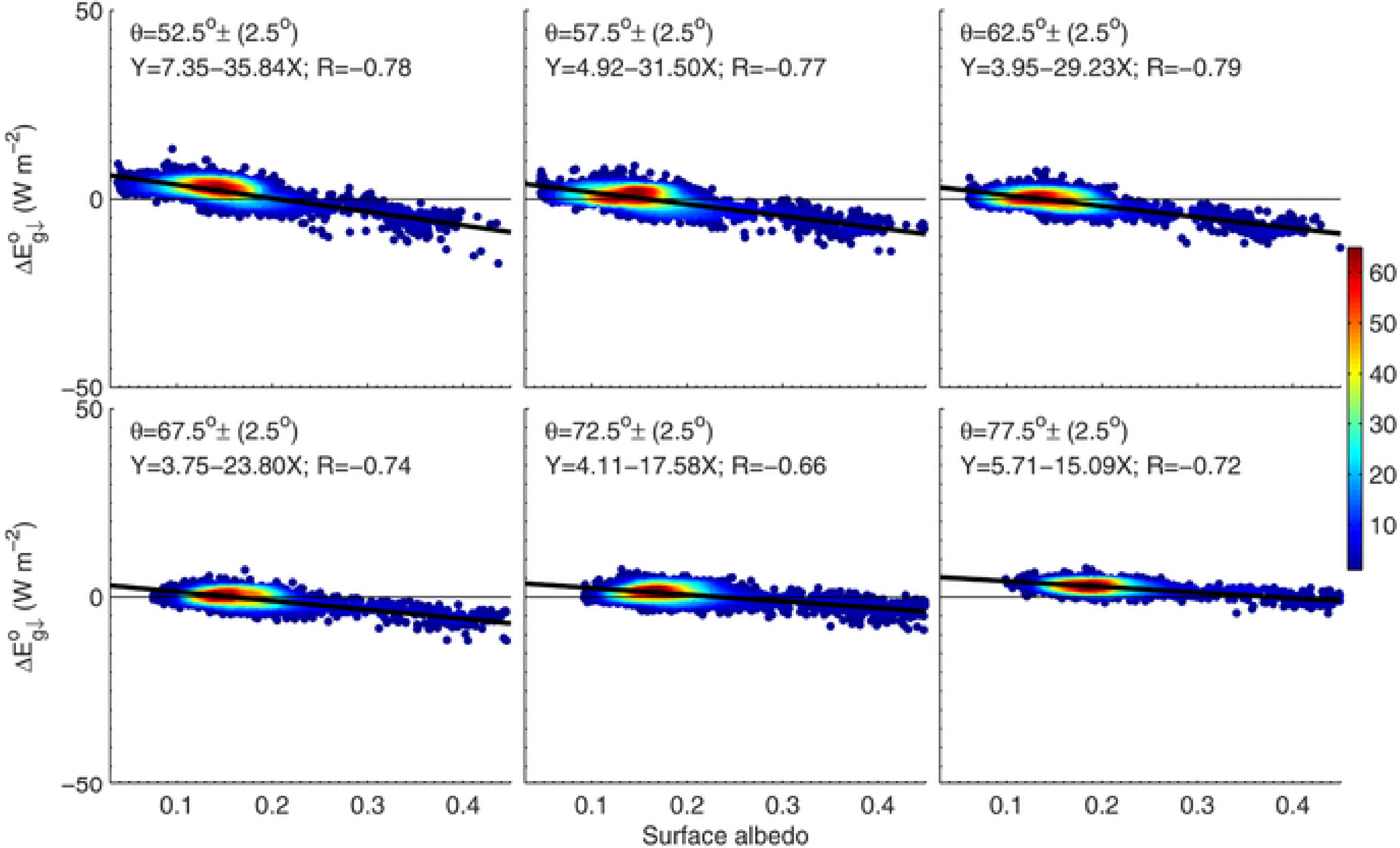
Uncertainty analysis



Aerosol absorption plays an important role that needs further study



- Potential effect of aerosol absorption is clearly shown by the uncertainty analysis



- Potential effect of surface albedo is clearly shown by the uncertainty analysis

Summary

- A simple but effective parameterization of surface solar radiation is introduced.
- This method can be used to estimate surface solar radiation if aerosol optical depth is available or vice versa.
- Estimation of aerosol radiative effects on surface solar radiation is greatly improved.

Limitation and perspective

- Aerosol absorption should be considered in order to improve the performance of the parameterization. The analysis might be performed based on measurements from a specified aerosol types, for example, dust in Africa and biomass burning aerosols in Amazon etc.
- Only data for solar zenith angle larger than 50 degree are available from the AERONET retrievals products, further analysis using AERONET and BSRN data is expected to be able to produce a more robust parameterization of surface solar radiation for a wider range of the solar zenith angle.

Thank you for your attention!

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