Surface and Atmospheric Forcing by Anthropogenic Aerosols: Insights from a Model-Observation Intercomparison

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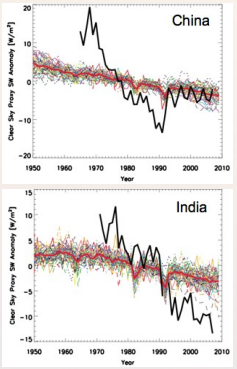
1 | Introduction



- Observations show a reduction in clear-sky surface solar radiation over South and East Asia since the 1950s [1, 2].
- Aerosols are the primary driver of the trend, and absorption by carbonaceous aerosols plays a particularly large role in the surface forcing in this region [1,3].
- CMIP5 models show a reduction of smaller magnitude than the observations, but similar to CMIP3 models, despite major changes to models' aerosol treatment between the two model generations [2,4].

Objective:

To use models' representation of trends in surface solar radiation and atmospheric absorption over Asia to understand and improve their aerosol treatment.

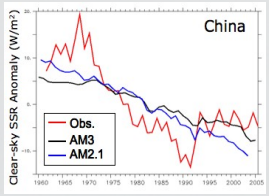
2 | Methods

- Compare the SSR trends in two generations of the GFDL AGCM, AM2.1 and AM3, using the models' standalone radiation code to isolate the contribution of various aerosol characteristics to the trend.

AM2.1 (CMIP3)
- Offline aerosols
Aerosol concentrations are not affected by the model's meteorology
- Externally mixed
Sulfate and black carbon (BC) aerosol particles exist independently

AM3 (CMIP5)
- Online aerosols
Aerosol emissions are transported and removed by the model's meteorology
- Internally mixed
Sulfate and BC aerosols exist within the same aerosol particle.

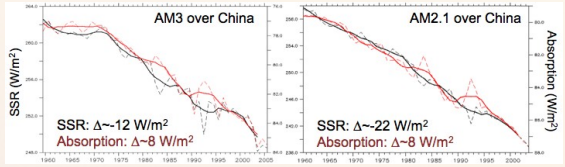
- AM2.1 and AM3 give similar trends in SSR over China, much like the CMIP3 and CMIP5 generations of other climate models.



How do aerosol characteristics lead to the similarities and differences in AM2.1 and AM3?

3 | Results

- **Absorption contributes strongly to the dimming trend in both models**



- Internal mixing leads to stronger absorption than external mixing, but AM2.1 has stronger absorption than AM3 when subjected to internal mixing.

- **Cancellation of Effects**
  - A reduction in the amount of aerosols from AM2.1 to AM3 counteracts the increased absorption from the transition to internal mixing in AM3, resulting in similar surface solar radiation trends in both models.

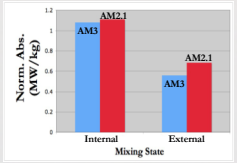
AM2.1	+	AM3	=	
More Aerosols ↑		Less Aerosols ↓		Similar trends in both models
External Mixing ↓		Internal Mixing ↑		

Are the aerosol amount and mixing state the only canceling terms? Are there others?

- **Normalized Absorption:** a means of isolating the contribution of different aerosol characteristics to the modeled absorption.

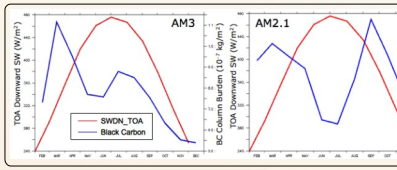
$$\text{Norm. Abs.} = \frac{\text{Absorption due to aerosol}}{\text{Total BC column burden}}$$

The aerosol column burden and mixing state are the leading order terms but other factors contribute to the modeled absorption.

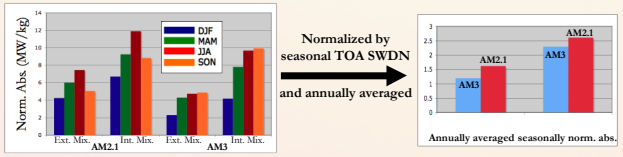


Other potential factors contributing to the modeled absorption

- ***Seasonality:*** **Seasonal cycle of aerosol vs. insolation**



The annual mean value of SSR and absorption is dependent on the coincidence of aerosol column burden and TOA insolation.

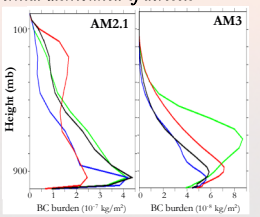


- Differing seasonality of the aerosol burden in AM2.1 and AM3 does not explain remaining differences between their modeled absorption and SSR.

- ***Hygroscopicity***

- Hygroscopic growth of aerosols can increase their interaction with radiation, and is dependent on mixing state and aerosol amount.
- Preliminary analysis suggests that hygroscopic growth increases absorption only in the presence of internal mixing.

- ***Vertical distribution of aerosols***



Vertically diffuse aerosols in AM2.1 vs. AM3 may influence interaction with downwelling shortwave radiation.

4 | Conclusions

- **AM2.1 and AM3 have similar trends in clear-sky surface solar radiation (SSR) over East Asia despite significantly different aerosol treatments.**
- **Aerosol absorption is a major contributor to reduced SSR in both AM2.1 and AM3, as in observations.**
- **Stronger absorption from AM3's internal mixing scheme is counteracted by weaker absorption from AM3's smaller aerosol burden—hence, similar trends in AM2.1 & AM3.**
- **Normalization of absorption by the aerosol column burden indicates that mixing state and aerosol burden are the leading order characteristics controlling the modeled absorption, but other factors still produce small differences between the models.**
- **Other factors may include the seasonality, hygroscopicity, and vertical distribution of aerosol.**

5 | Future Work

- The impact of the aerosol vertical distribution on SSR and absorption can be quantified by running the standalone radiation code using an aerosol climatology with AM2.1's aerosol burden but AM3's vertical distribution.
- Further analysis of the effect of hygroscopic growth will yield quantitative understanding of its contribution to the modeled absorption.

References

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4. Allen, R. J., J. R. Norris, and M. Wild. *J. Geophys Res.* (in preparation).

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