Biases in GCM shortwave radiation introduced by cloud fraction and overlap assumptions

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Assumptions/approximations in GCM cloud radiation parameterizations

- Cloud fraction captures the zero order fluctuation of the subgrid optical properties. Two underlying assumptions:

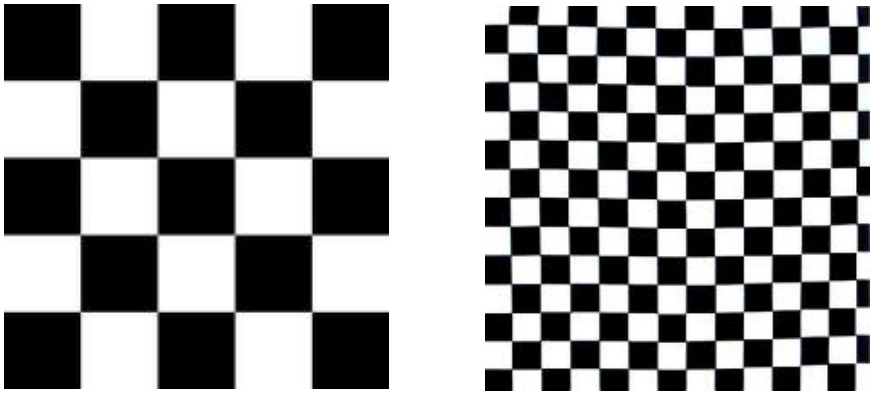
- Plane-parallel (PP) assumption ignores cloud internal variability. Overestimation of cloud albedo by 10-20% (to compensate this bias, one needs to reduce the cloud water mass by 20-40%)

- The lurking Independent Column Approximation (ICA), no net horizontal transport (interaction) between clouds and the environment.

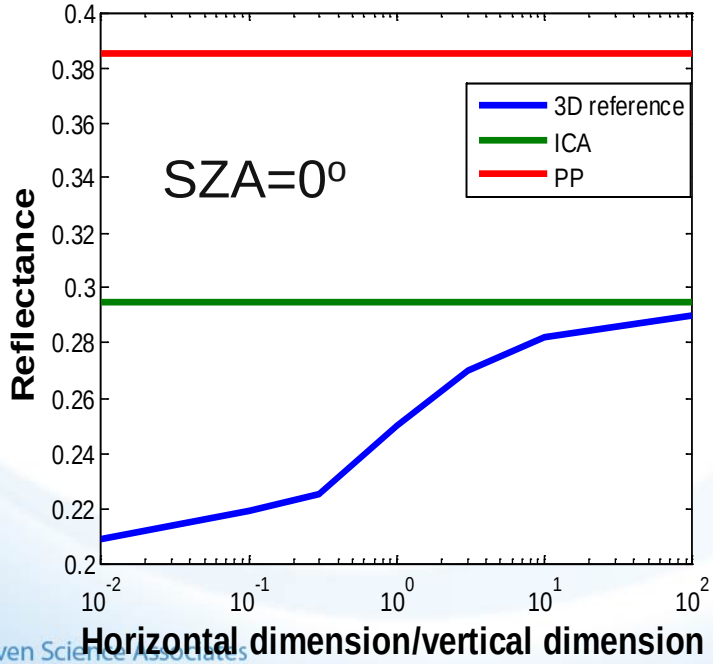
$$R = (1-a)*R_{clear} + a*R_{cloud}, \quad T = (1-a)T_{clear} + a*T_{cloud}$$

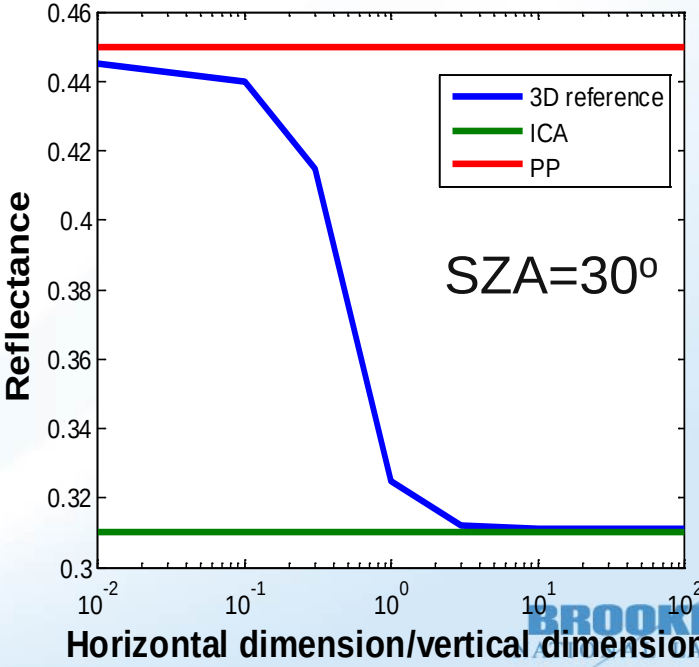
- Vertical overlap parameterizes cloud vertical heterogeneity.

PP and ICA biases are highly sensitive to scales



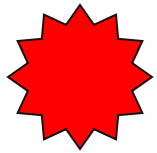
Optical thickness of cloudy and clear regions is 18 and 0.001; cloud fraction is 0.5; single scattering albedo is 1; and asymmetry parameter is 0.85.



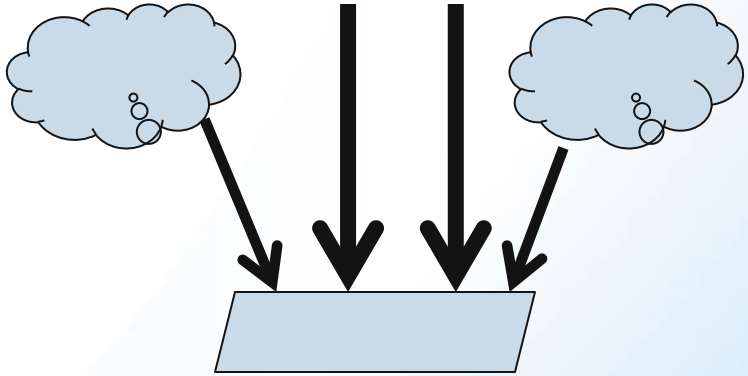


The 3D (true) reflectance can be anywhere

- True (3D) albedo always smaller than PP albedo: $R_{3D}<R_{PP}$



- $R_{3D}>R_{ICA}$
  - Solar zenith angle >25^o
  - Relatively large cloud fraction (>0.7)



- $R_{3D}<R_{ICA}$
  - Solar zenith angle <25^o
  - Relatively small cloud fraction (<0.7)

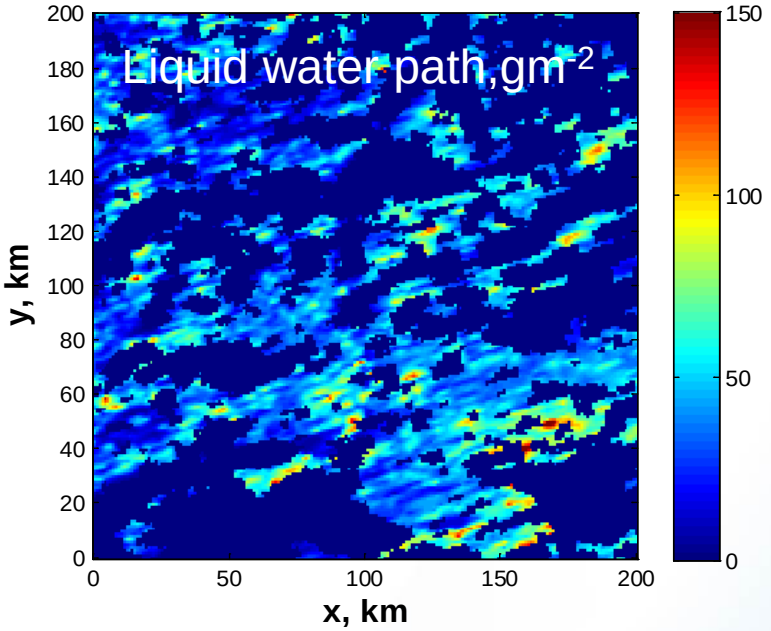
- For the binary cloud representation, the ICA and PP biases do not cancel for certain conditions.

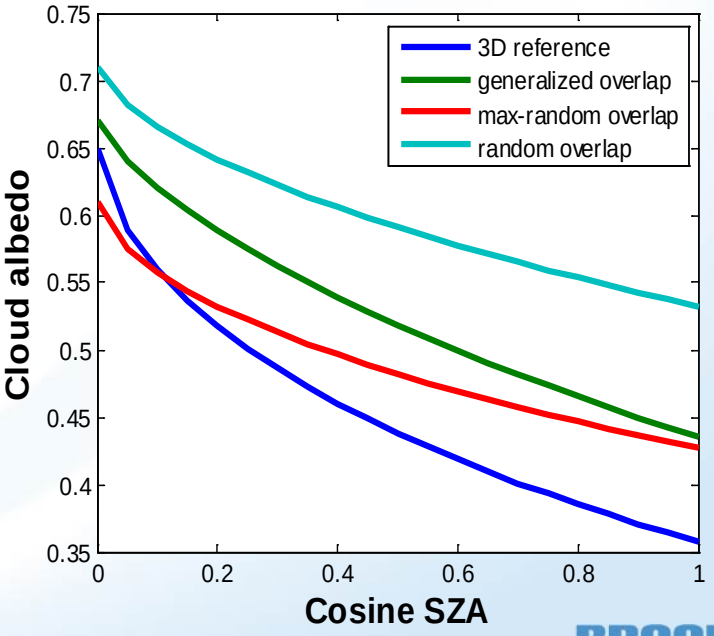
Overlap assumption

- Cloud overlap inherits the problems of cloud fraction, i.e., inability to include the correlation of cloud properties at different levels.

- Due to various sources of compensating errors (ICA, PP, etc.), using exact overlap often results in less accurate flux calculations.

Cloud fraction and overlap should not be examined together not disjointedly.





Summary

- The underlying IPA assumption when using cloud fraction in climate models can result in overestimation or underestimation of grid-average albedo depending on sun angle, cloud fraction, cloud heterogeneity, etc. But underestimation is more often.

- PP assumption overestimates cloud albedo, and this overestimation often partially cancels with the bias introduced by the IPA for cases with relative large cloud fraction.

- Exact vertical overlap does not necessarily improve the radiation calculations due to the complicated compensating errors.