

Solar radiative transport through anisotropic cumulus fields

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Goal

Investigate the degree to which cumulus cloud field anisotropy affects shortwave surface fluxes and the mechanisms by which this occurs.

Method

Perform Monte Carlo radiative transfer calculations on series of cloud scenes with increasing anisotropy but otherwise similar properties.

Compare results of full 3D computations to independent pixel approximation (IPA) and tilted independent pixel approximation (TIPA) results.

Test Scenes

Cloud scenes generated using the Evans and Wiscombe (2004) stochastic field generation program.

Input: Statistics of 12 LES cumulus cloud scenes

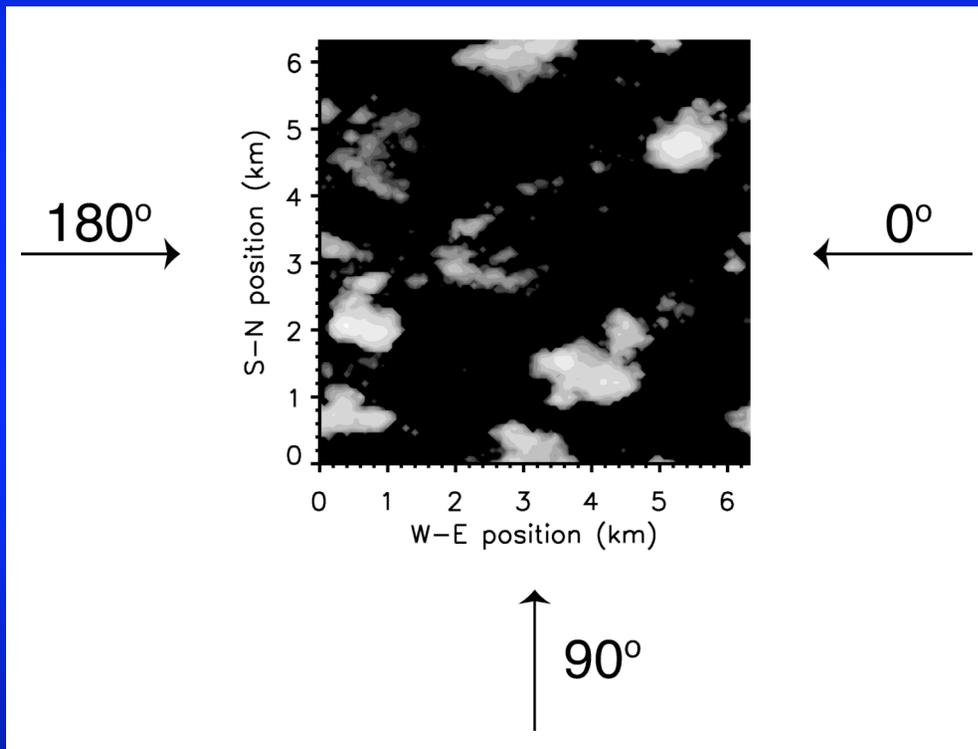
Output: Ensemble of 20 3D LWC distributions

For each member of the ensemble, create two series of fields in which anisotropy increases while the liquid water content distribution in each level and the correlation between the levels remains fixed.

Monte Carlo Setup

- Effective radii calculated from LWC with fixed drop number density (300 cm^{-3}) and lognormal distribution
- Droplet optical properties from Mie theory
- Broadband solar spectrum, RRTM band model (AER)
- Surface perfectly absorbing
- Solar zenith angles: 0° , 30° , 60°
- Azimuthal angles: 0° , 90° , 180° , and random

Azimuthal Angles

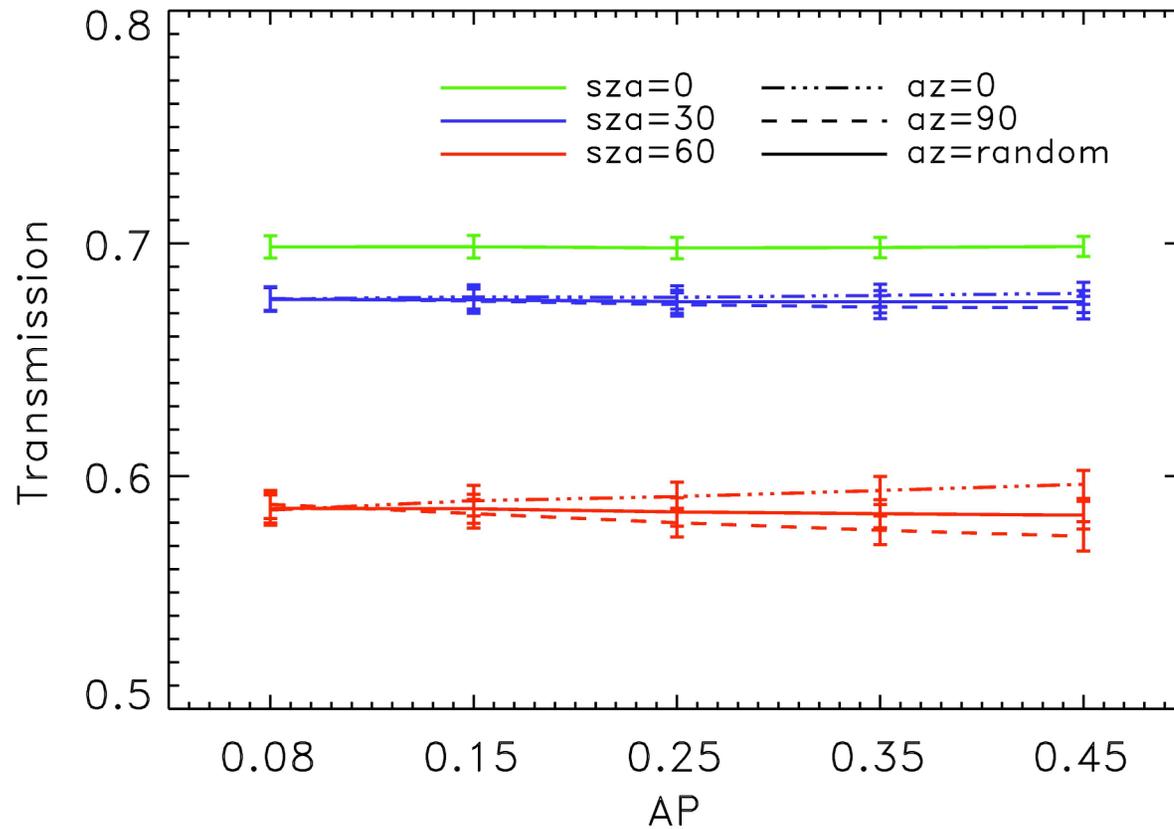


0° : parallel stretch axis
parallel tilt (towards)

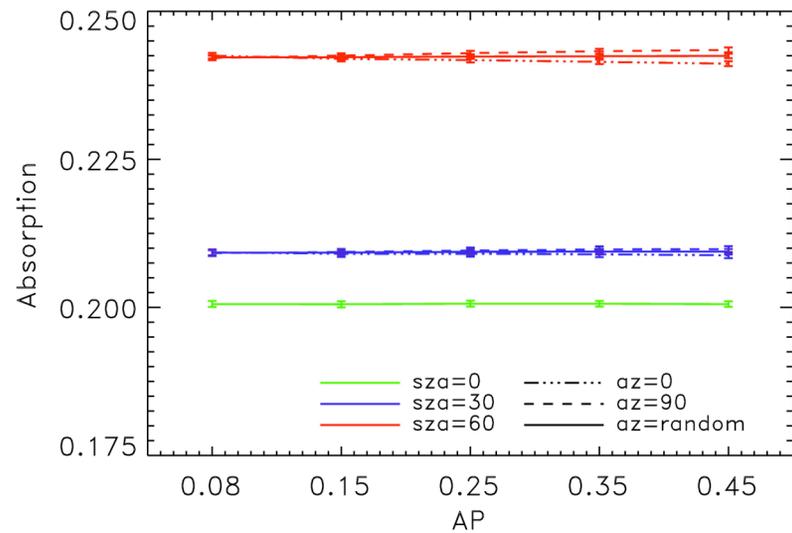
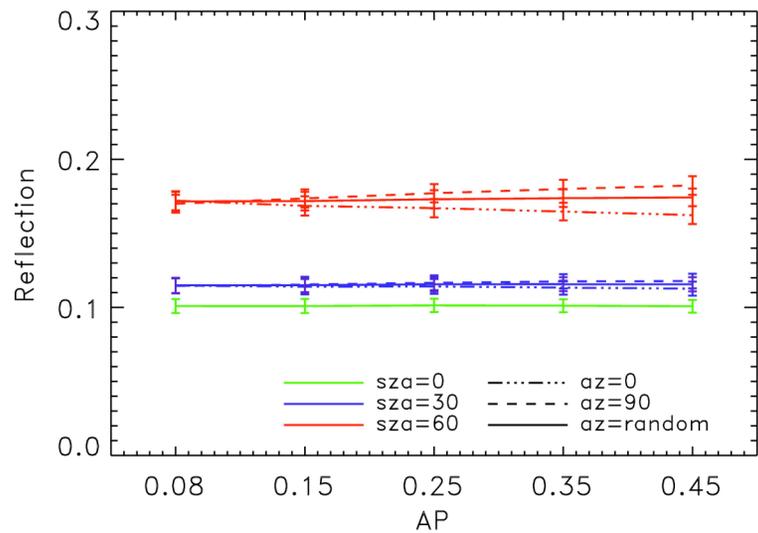
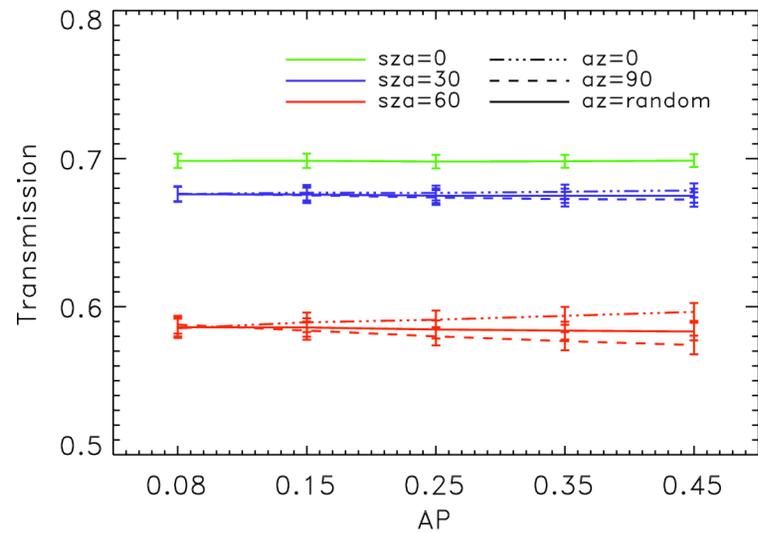
90° : broadside

180° : parallel stretch axis
parallel tilt (away)

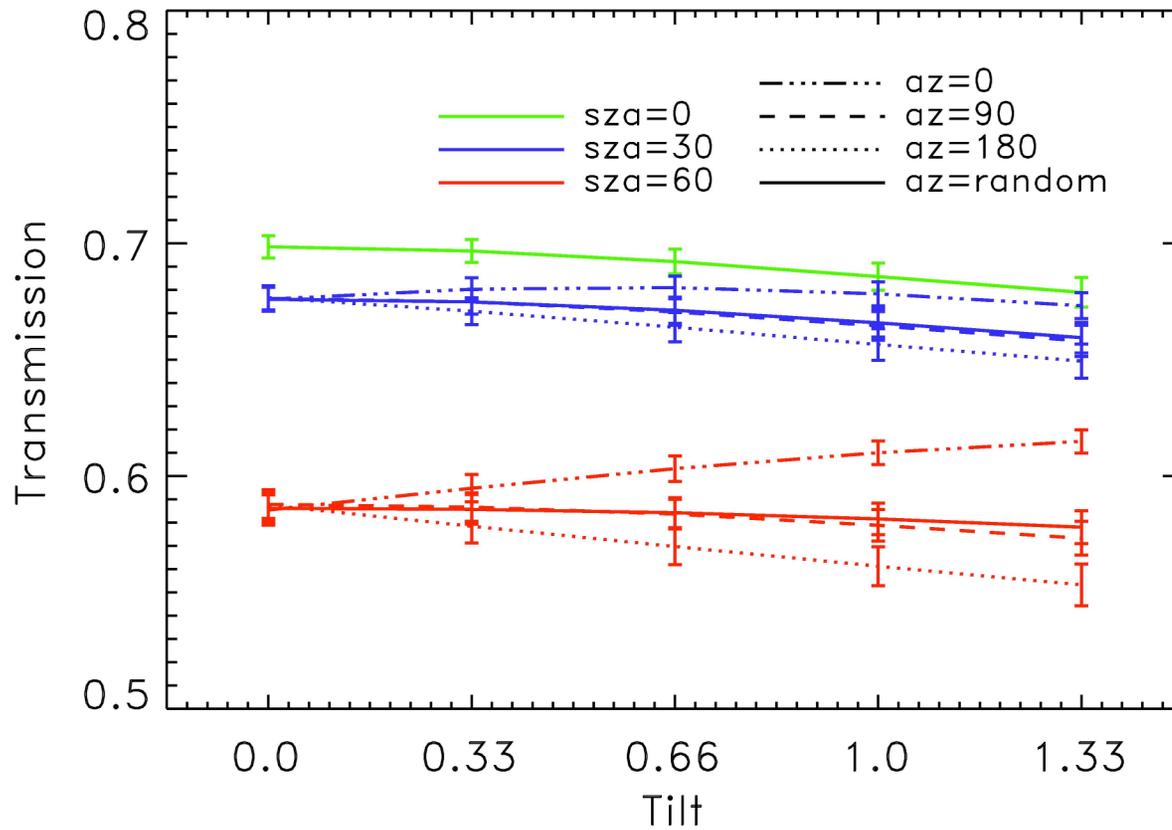
Effect of Stretch on Transmission



Stretch Results



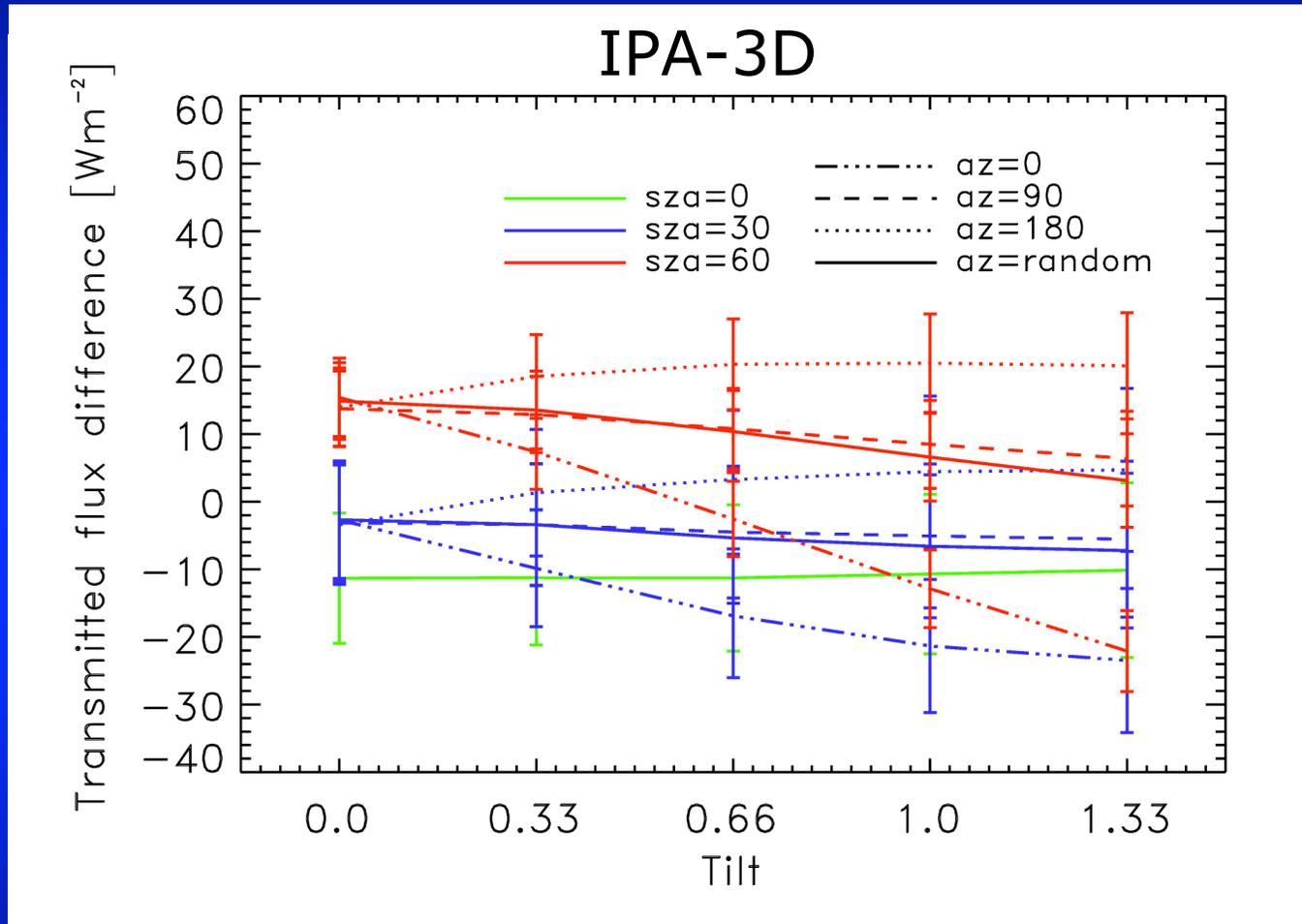
Effect of Tilt on Transmission



3D Effects

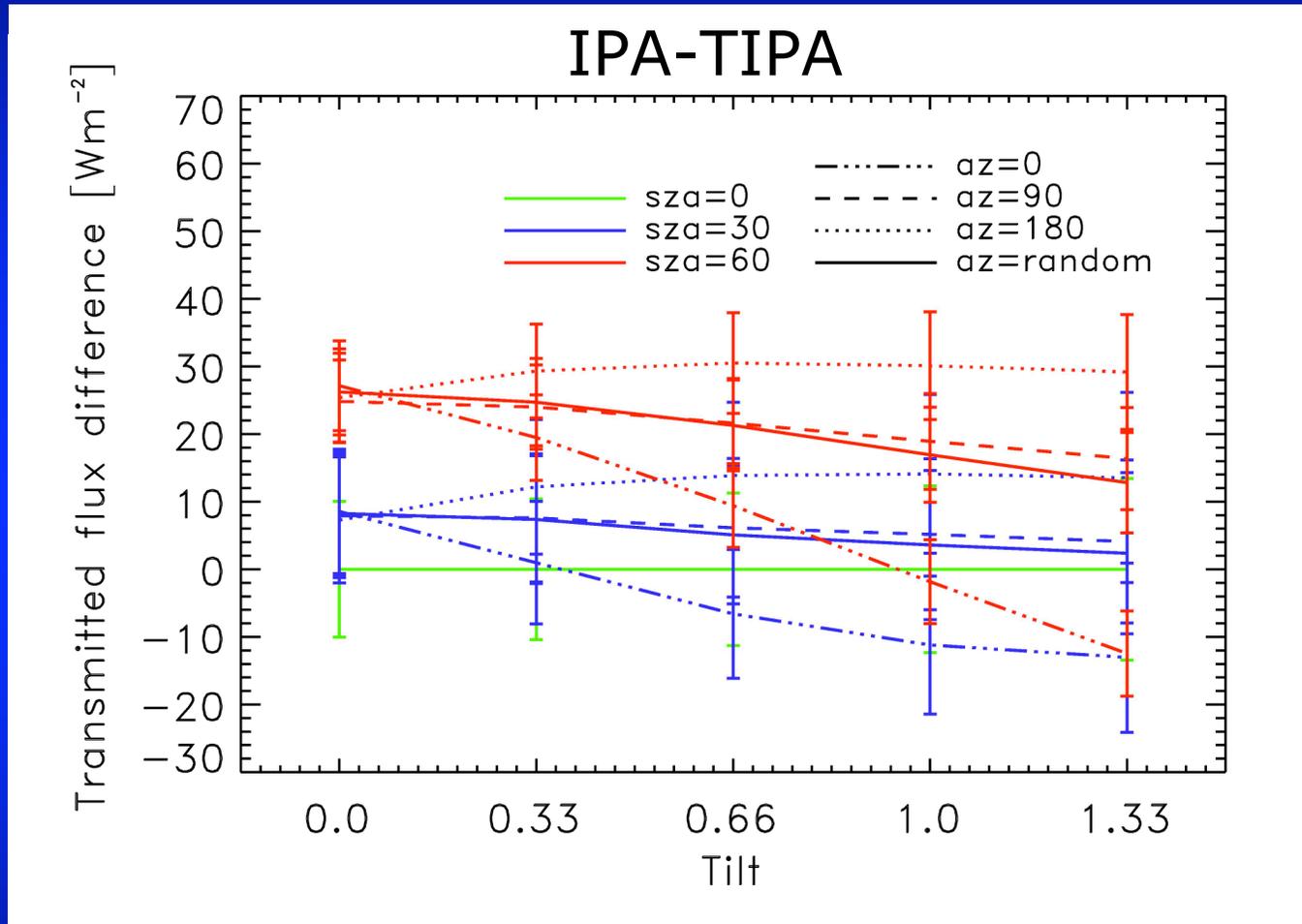
- “Horizontal” radiative transport -- propagation perpendicular to the angle of incidence.
 - Cloud geometry effects -- error due to sampling cloud in vertical direction.
- ➔ Can be distinguished by comparing IPA and TIPA results to full 3D computations.

Tilted Cases



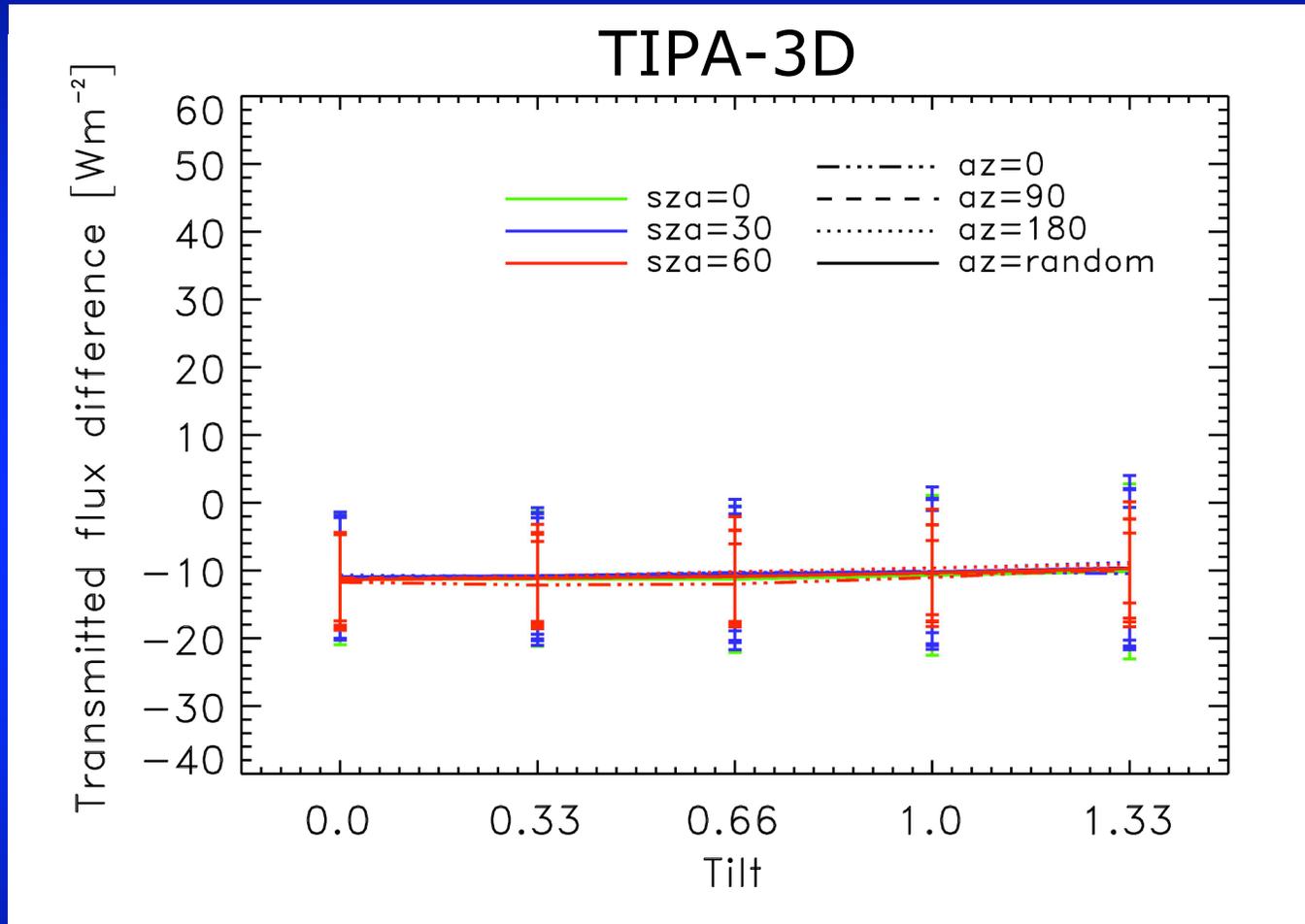
Neglect of all 3D effects causes large flux differences.

Tilted Cases



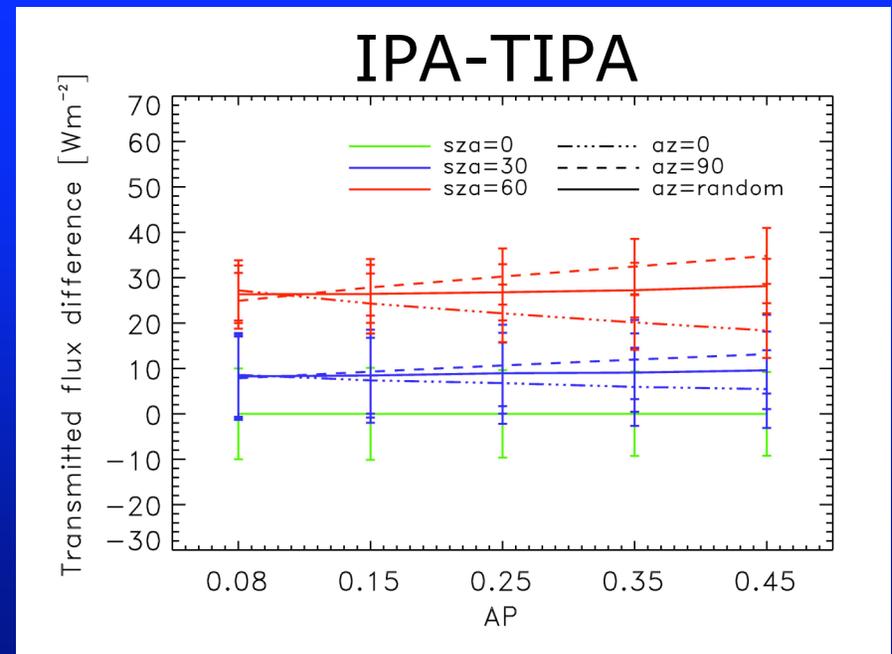
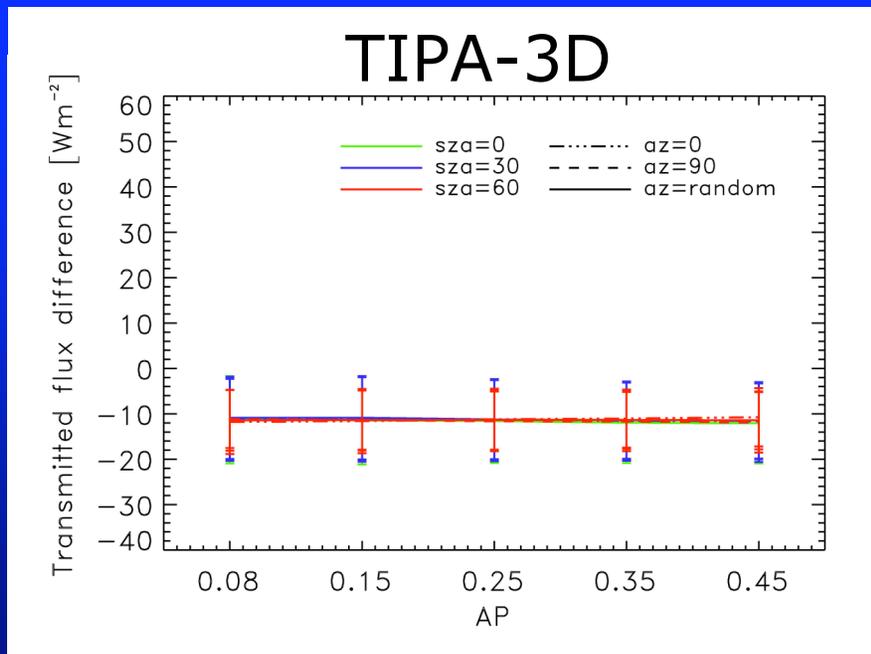
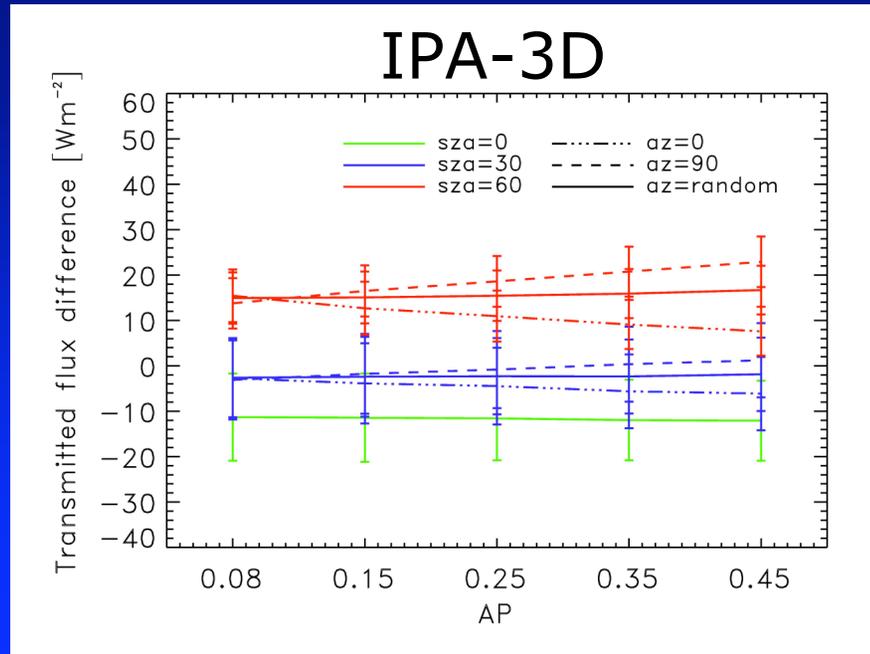
Error due to incorrect relative geometry can be large and of either sign.

Tilted Cases

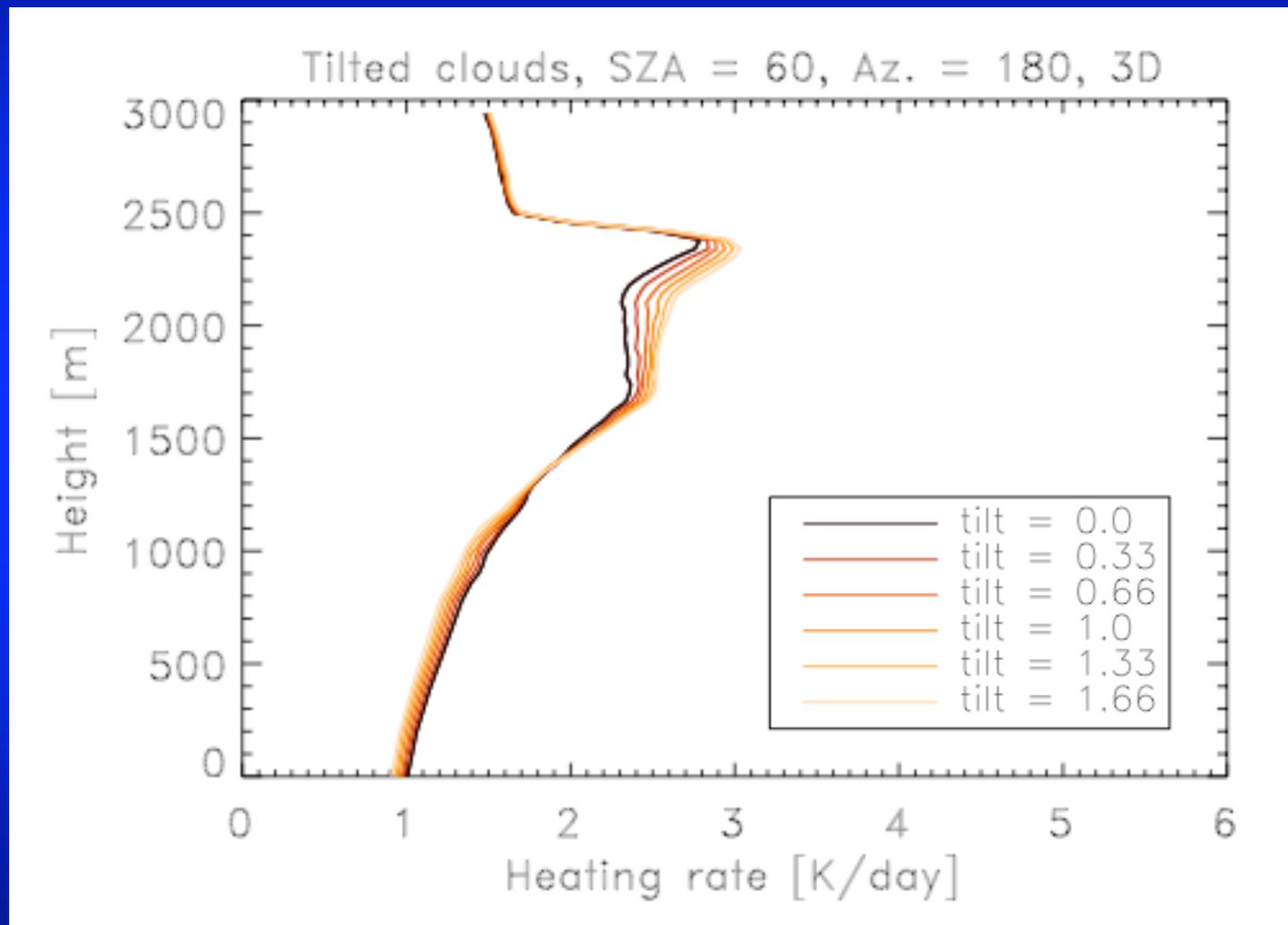


Error due to neglect of perpendicular transport is small and nearly independent of variations in scene geometry.

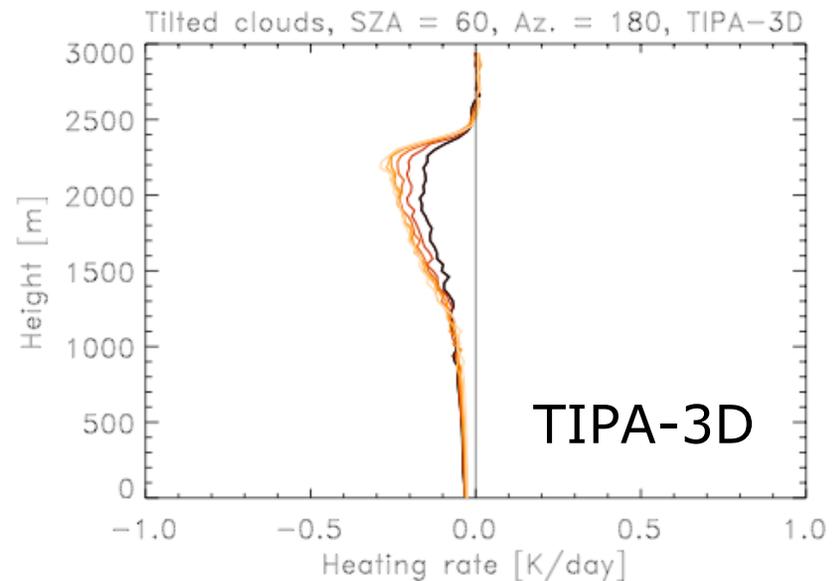
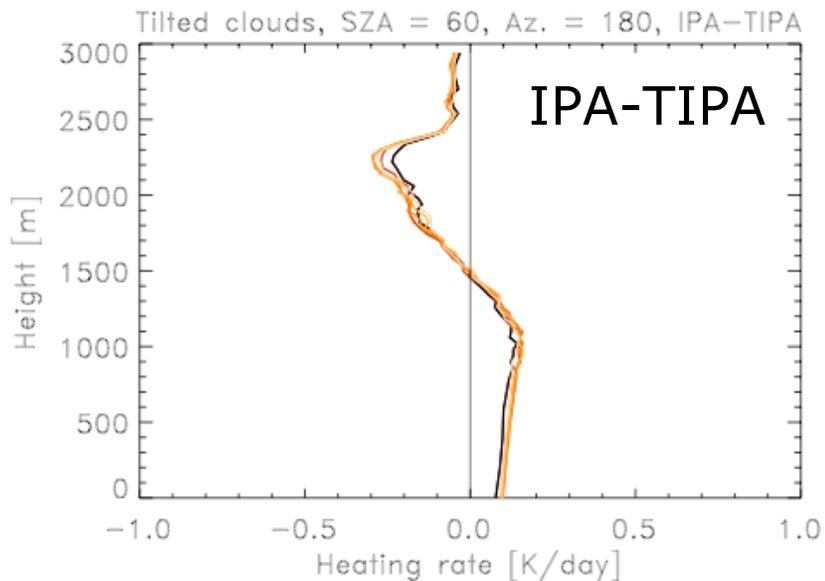
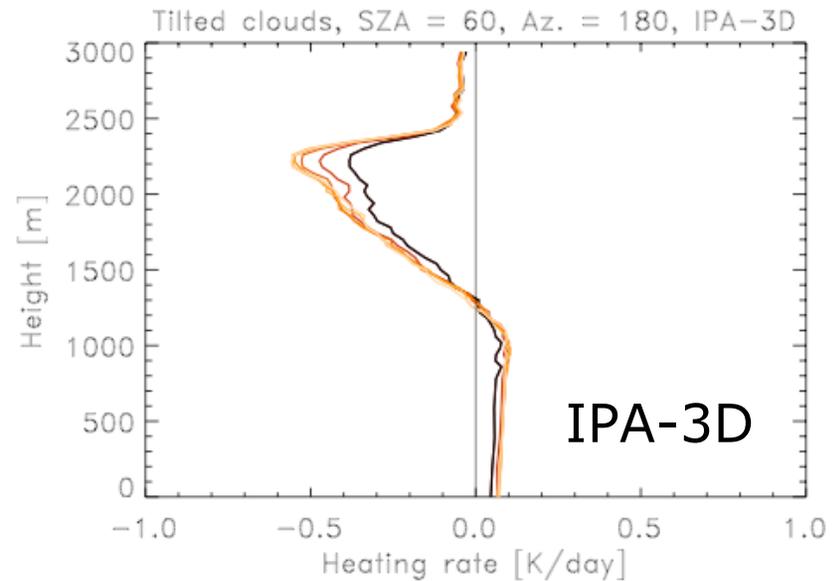
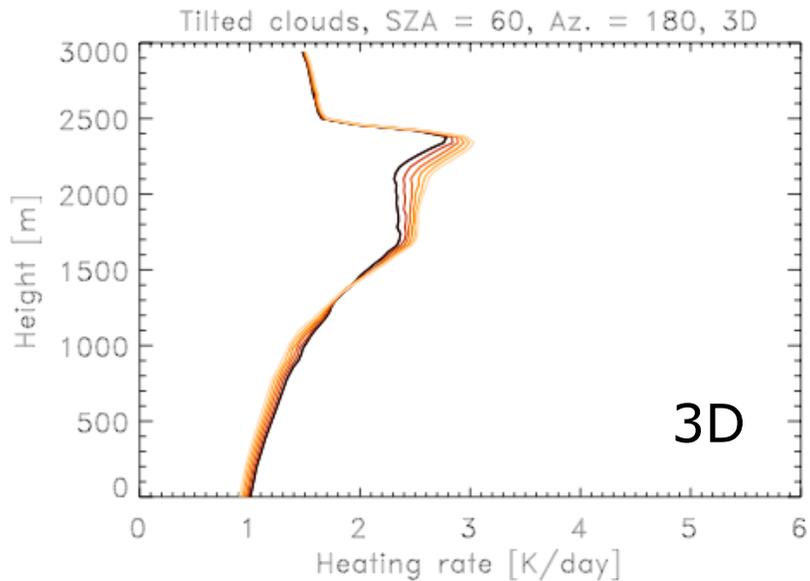
Stretched Cases



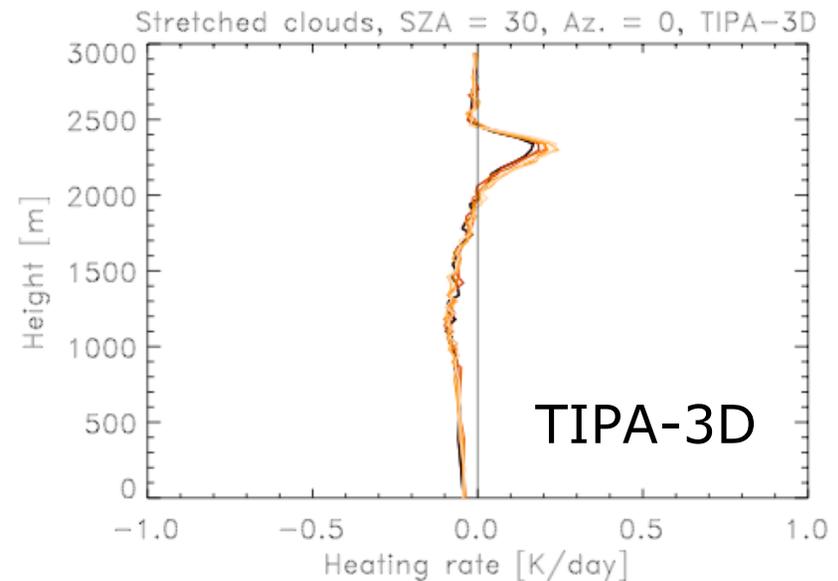
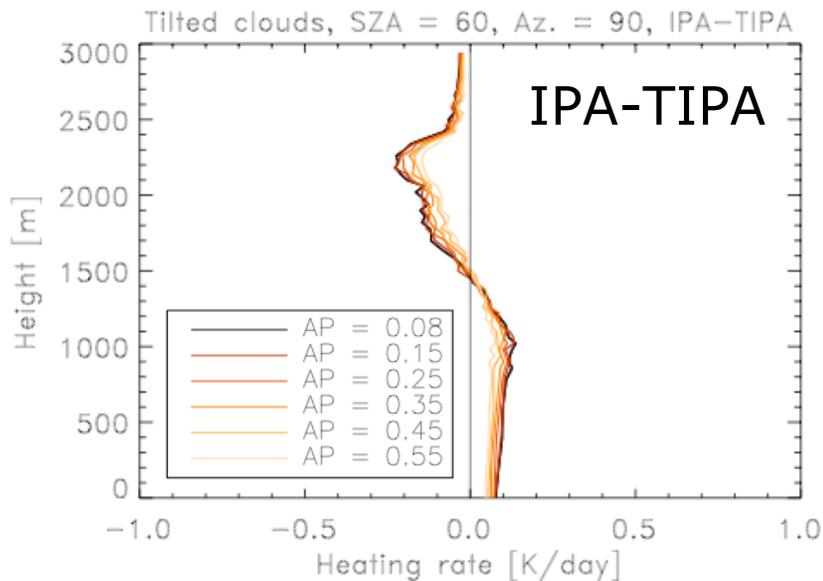
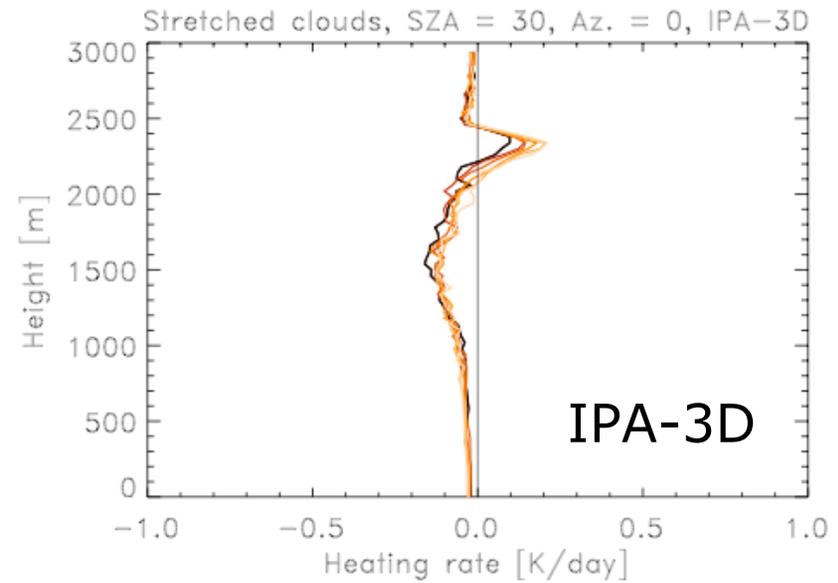
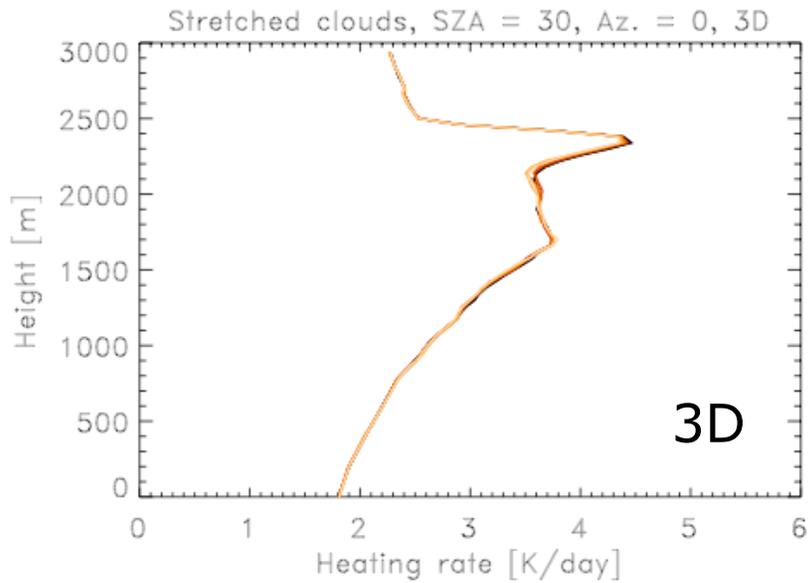
Domain-averaged Heating Rate Profiles



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Domain-averaged Heating Rate Profiles



Conclusions

- Horizontal anisotropy and vertical tilt of cumulus clouds have a significant effect on domain-averaged transmission, albedo, and absorption.
- Anisotropy effects depend strongly on solar geometry and are often nonzero even if averaged over a range of solar zenith and azimuth angles.
- Domain-averaged flux changes due to anisotropy are largely explained by changes in effective cloud fraction -- perpendicular transport is nearly constant.
- Perpendicular transport and effective cloud fraction effects on heating rate profiles can be of similar magnitudes.



Accounting for anisotropy effects on domain-averaged fluxes

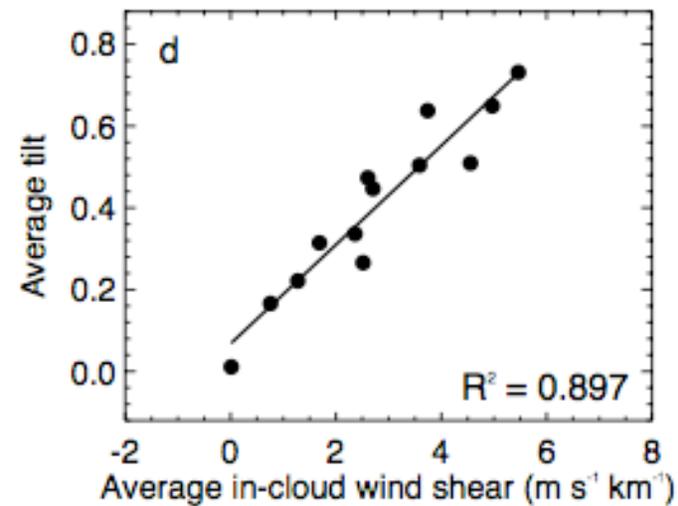
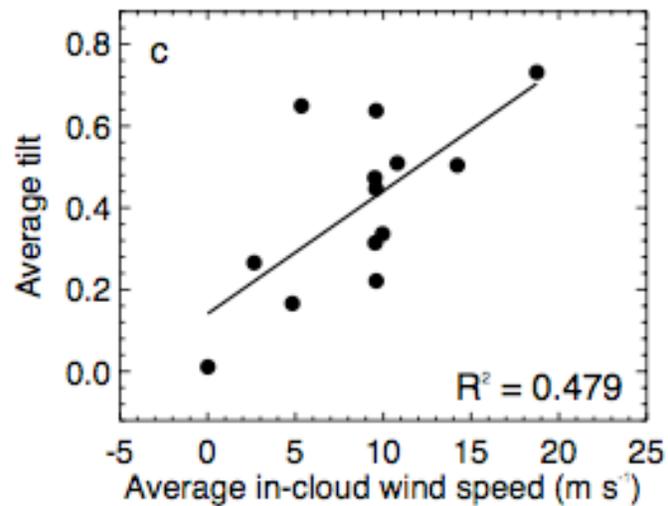
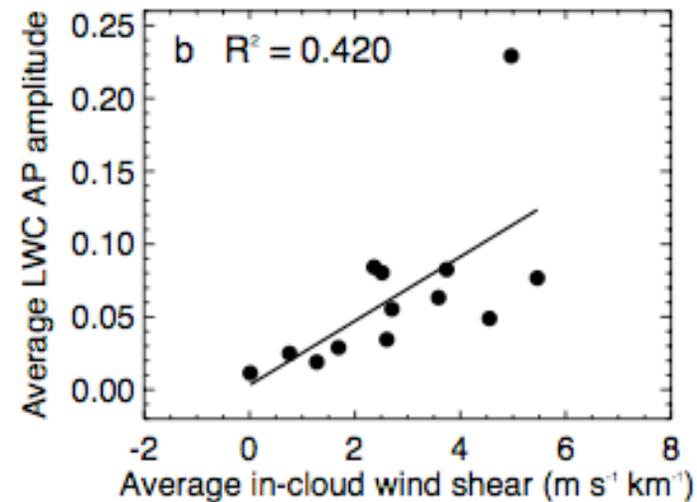
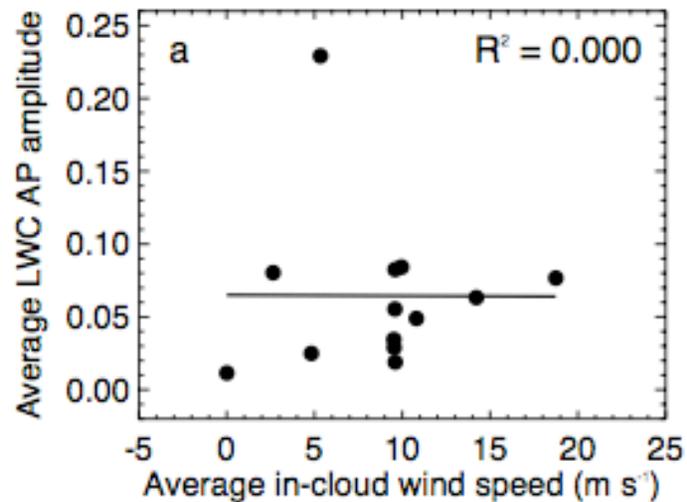
1) Use TIPA along with correction factor based on general cloud properties.

➔ Requires knowledge of 3D cloud structure.

2) Use LES results to derive relationships between dynamics and anisotropy.

Correct IPA results using anisotropy-flux relations.

Anisotropy-dynamics relations from LES studies

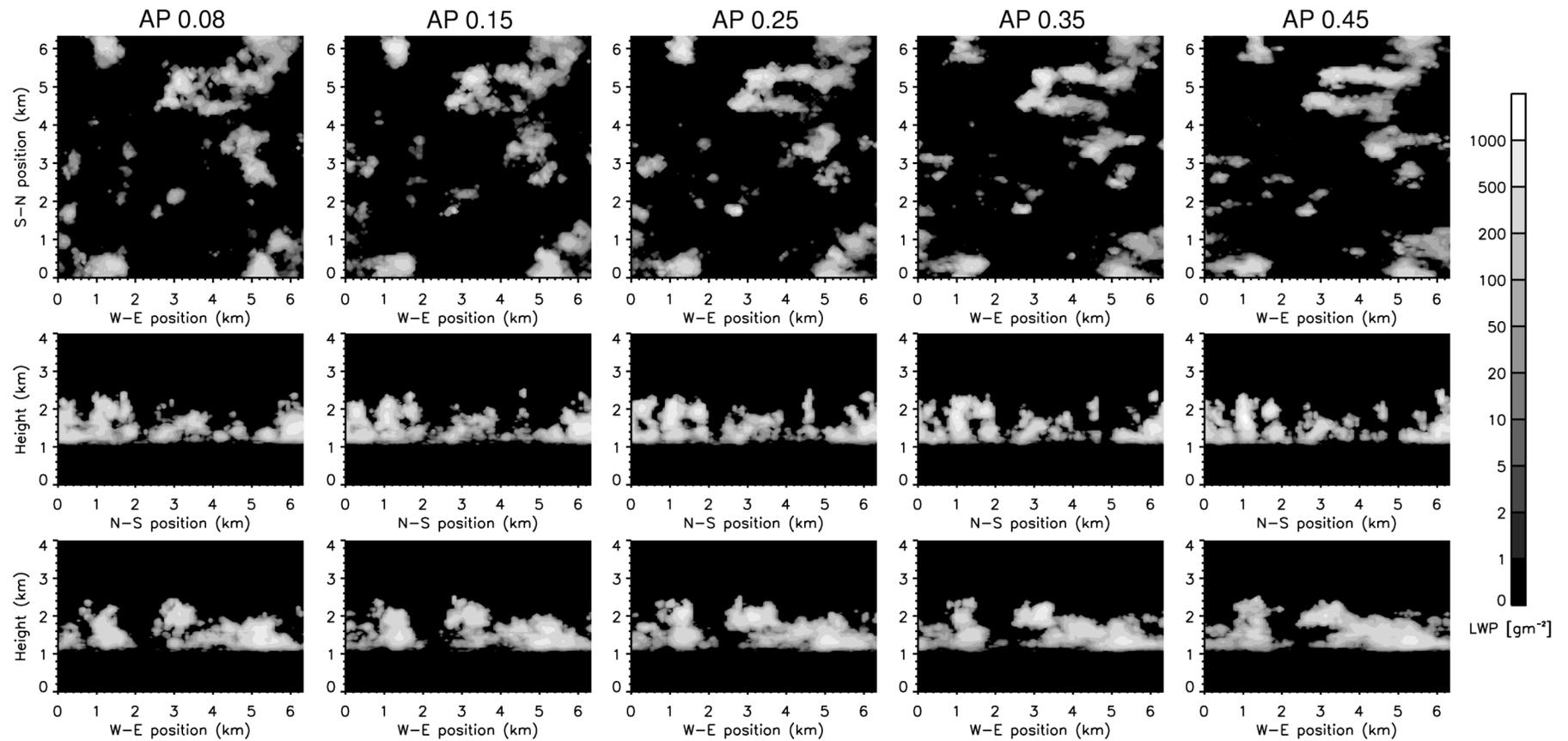


Parameterization of anisotropy effects on domain-averaged fluxes

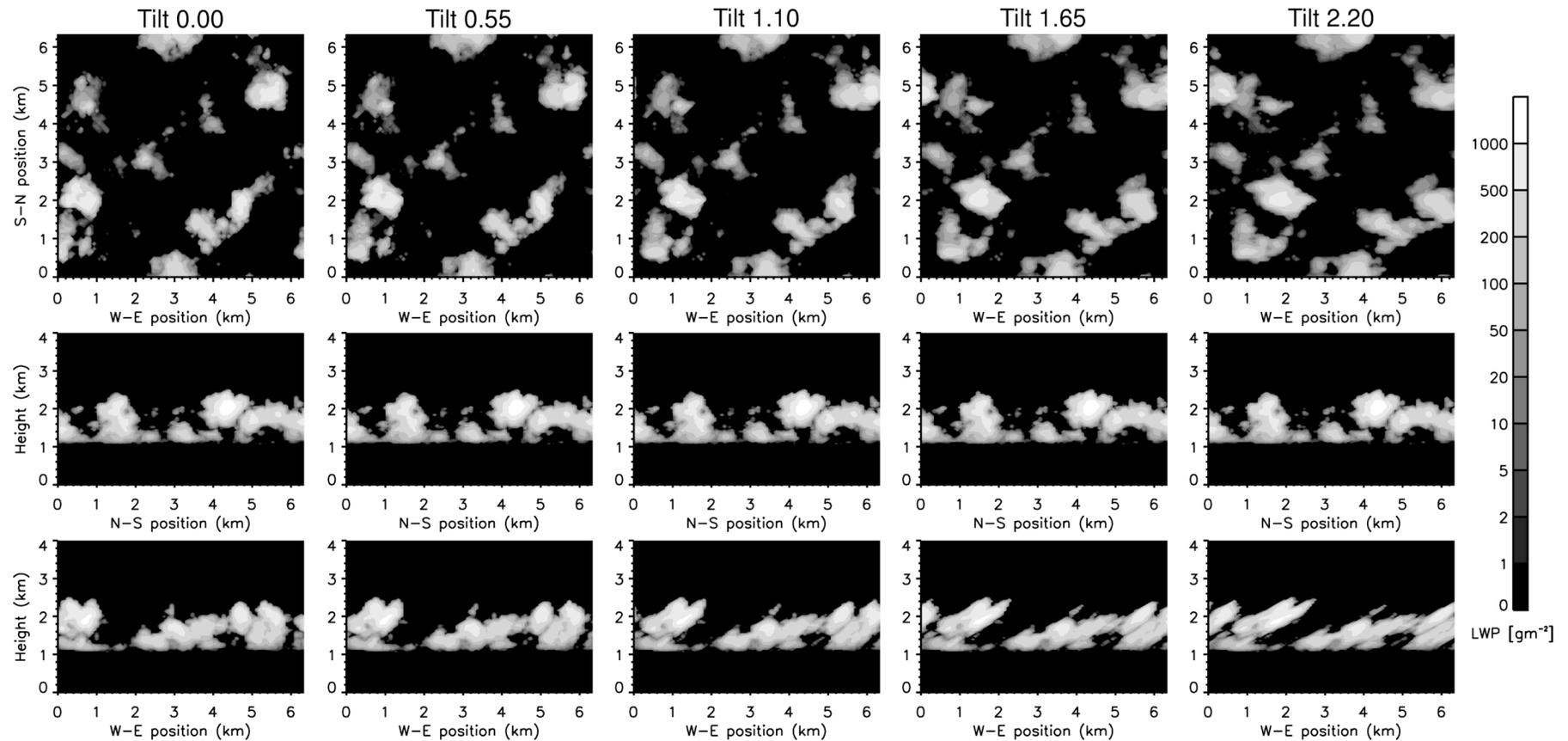
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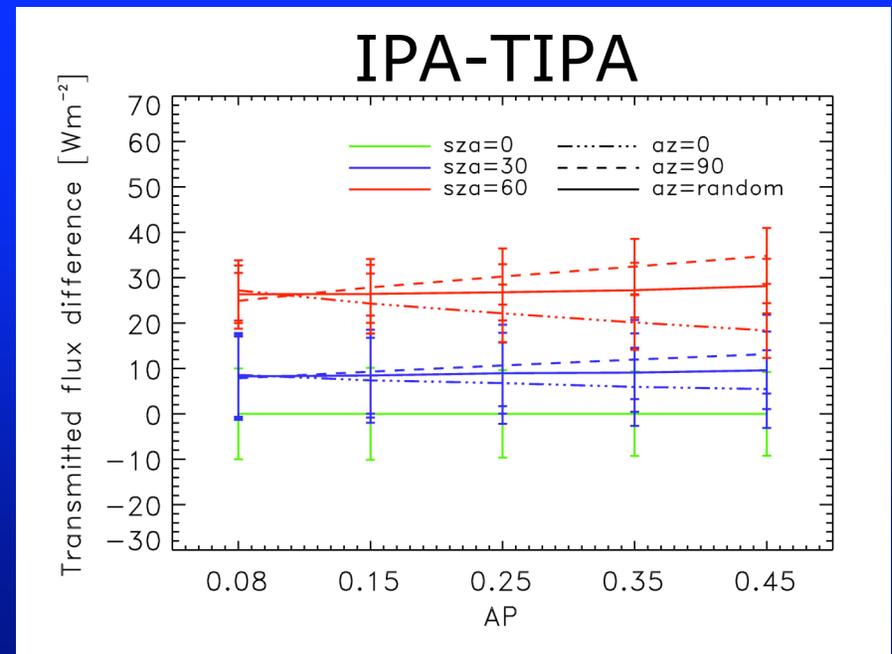
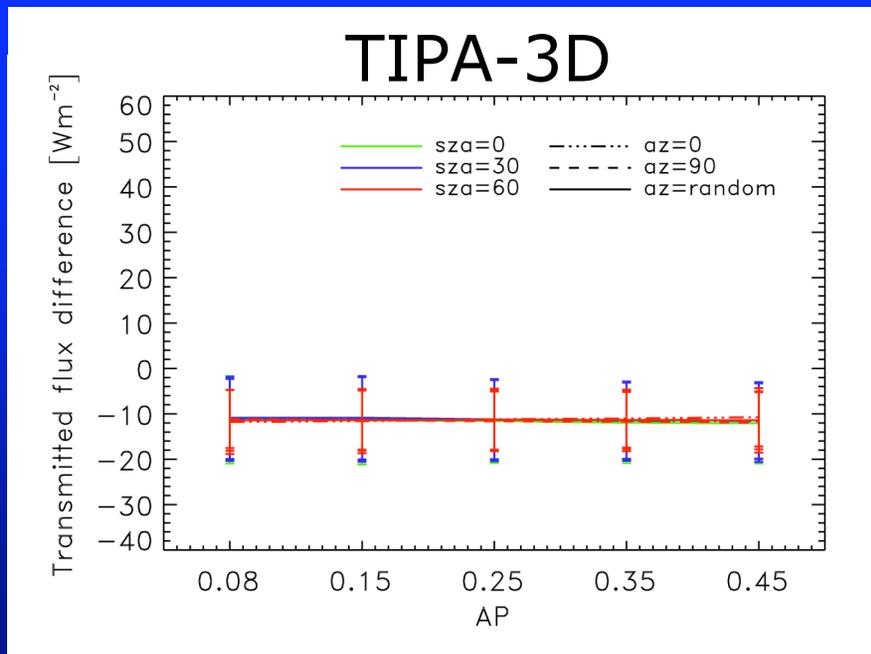
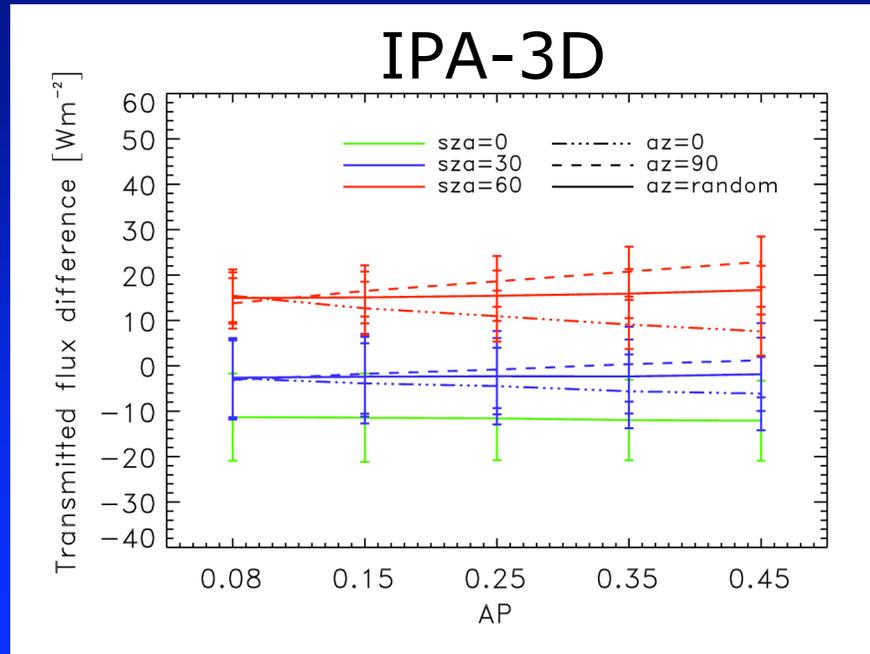
Examples: Stretch



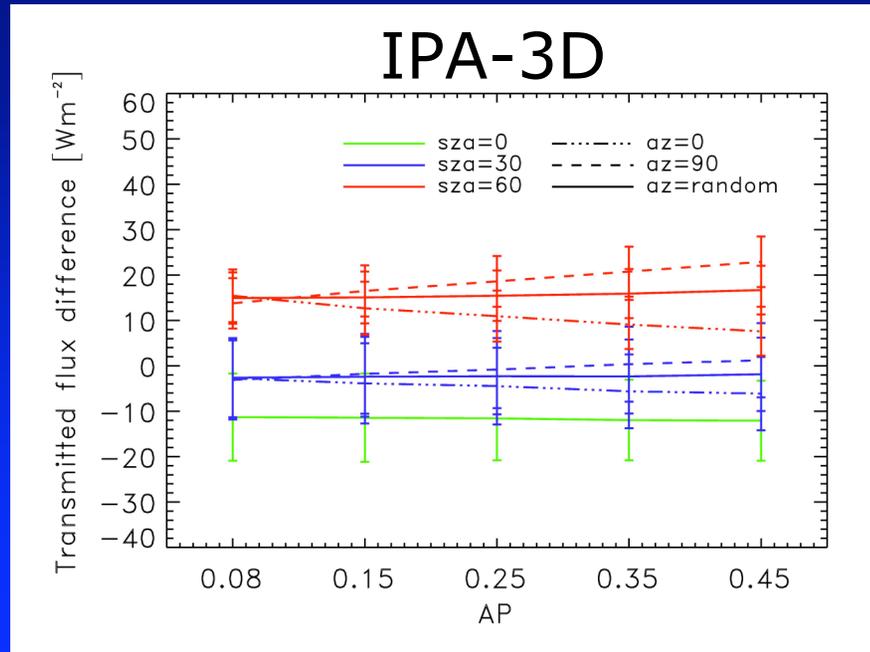
Examples: Tilt



Stretched cases



Stretched cases



Types of Anisotropy

1) Stretching (horizontal anisotropy):

- Elongation of individual cells or linear arrangement of cells
- Measured via anisotropy parameter (AP):
isotropic $0 \leq AP \leq 1$ linear

2) Tilt (vertical anisotropy):

- Horizontal displacement with height
- Measured in m/m (slope)

Anisotropy examples

Stretching



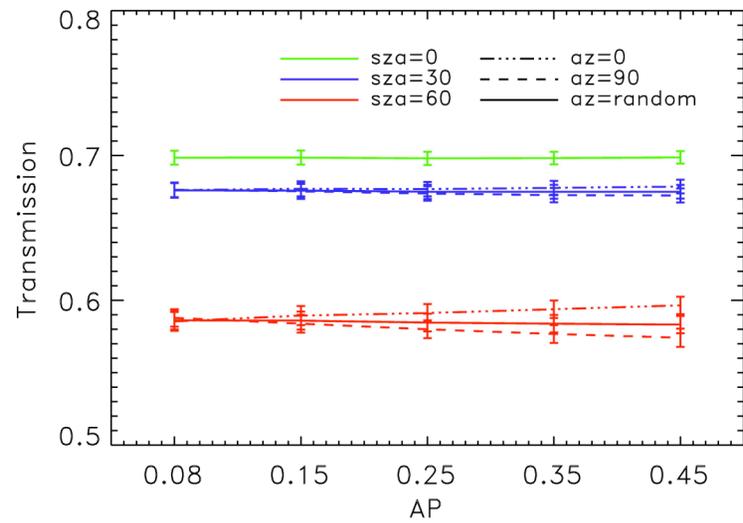
(Landsat Thematic Mapper, July 7, 1999)

Tilt

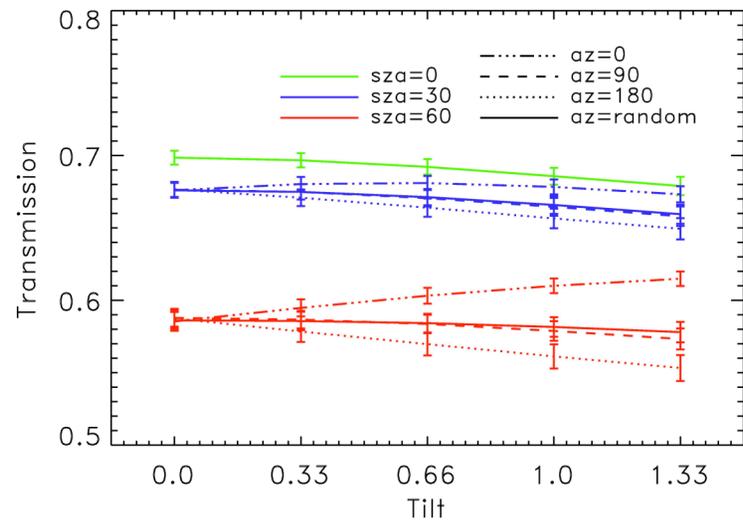


(Karlsruhe Wolkenatlas)

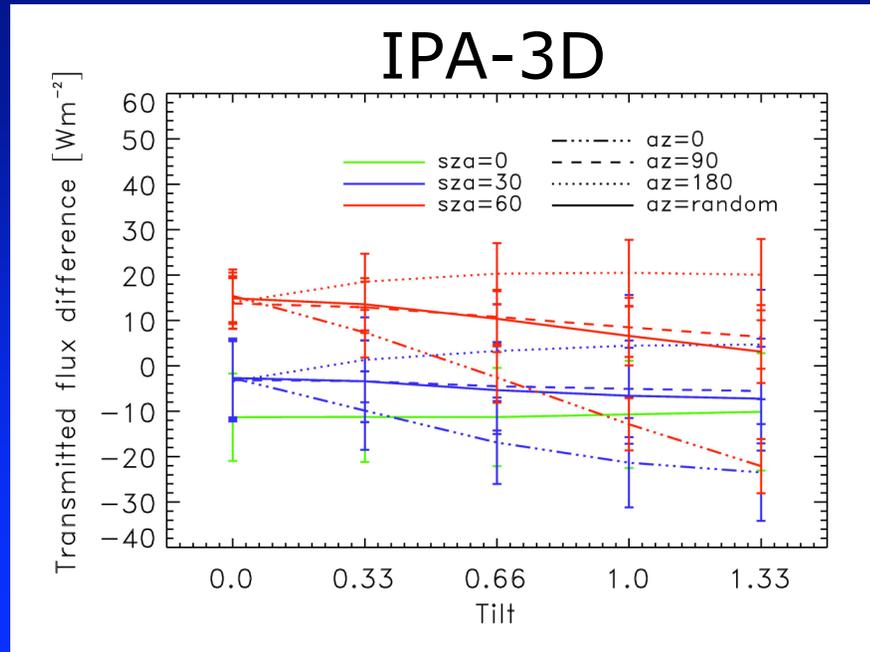
Stretch Results



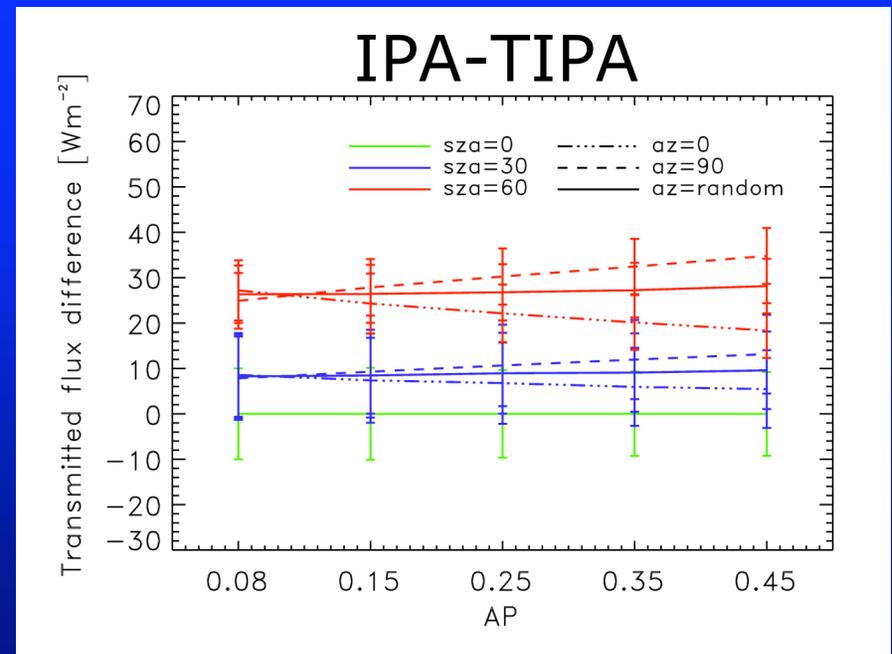
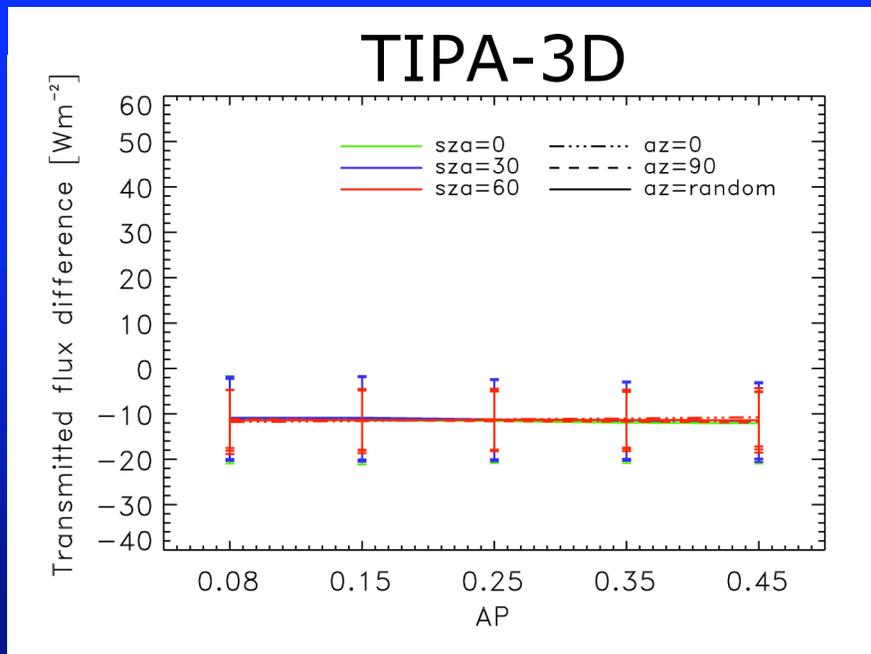
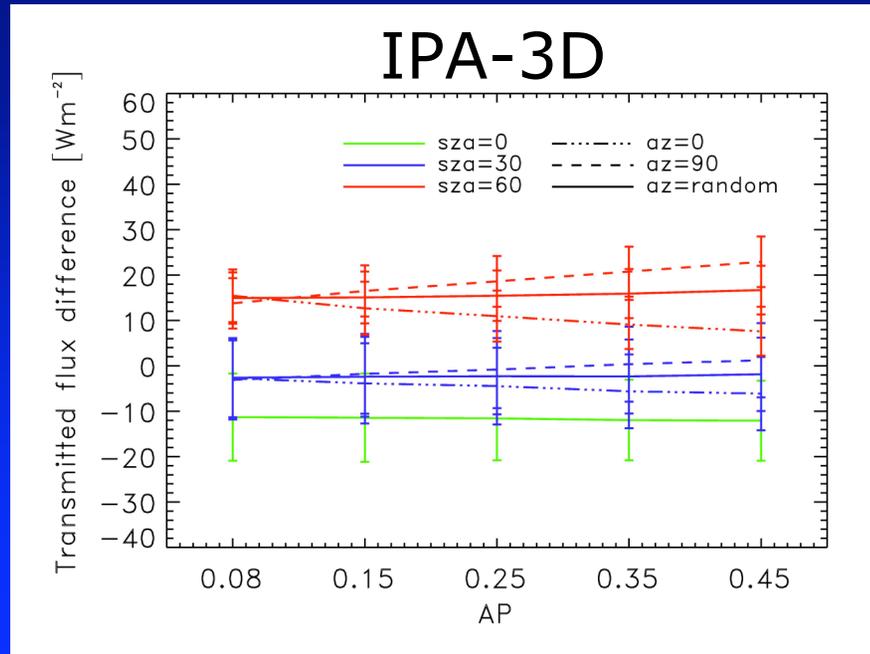
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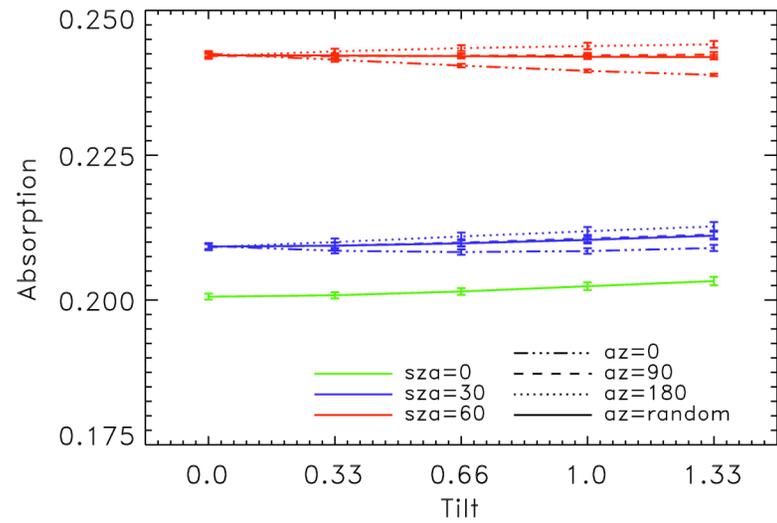
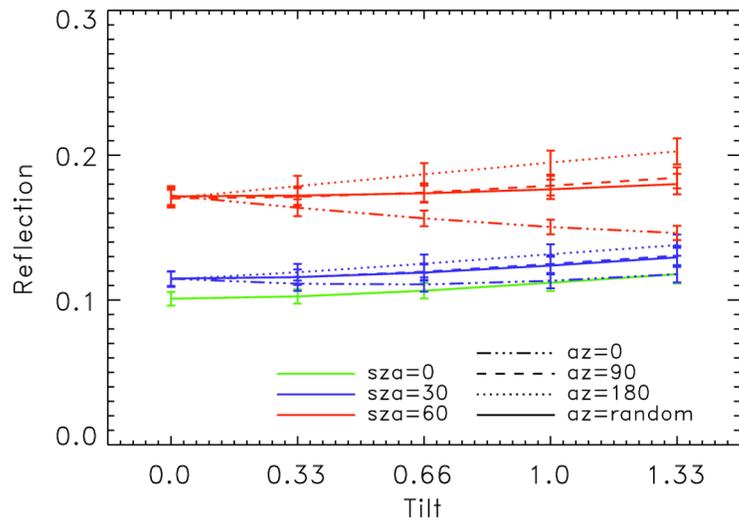
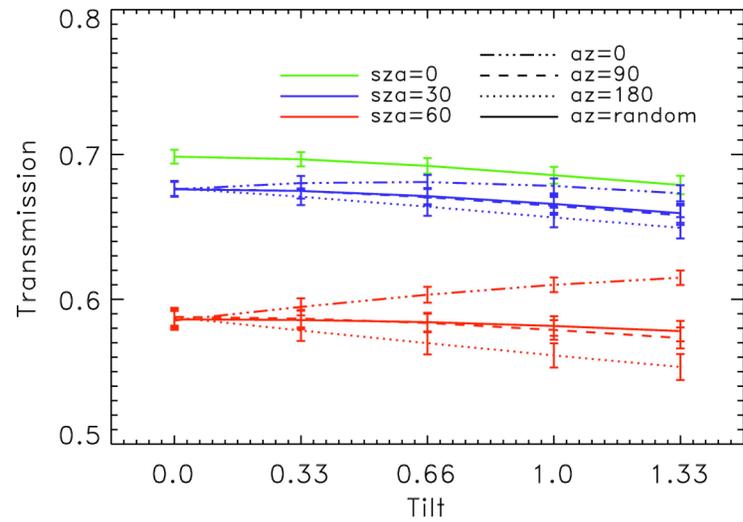
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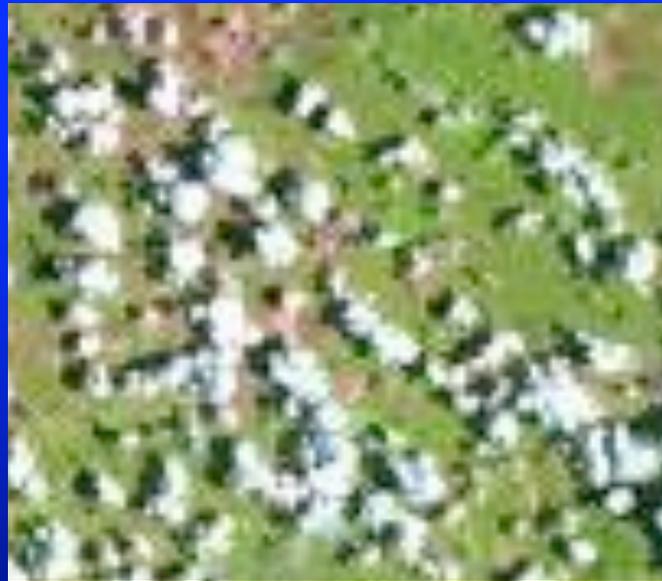
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