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Ice Cloud Particle Roughness Inferred from Satellite Polarimetric Observations

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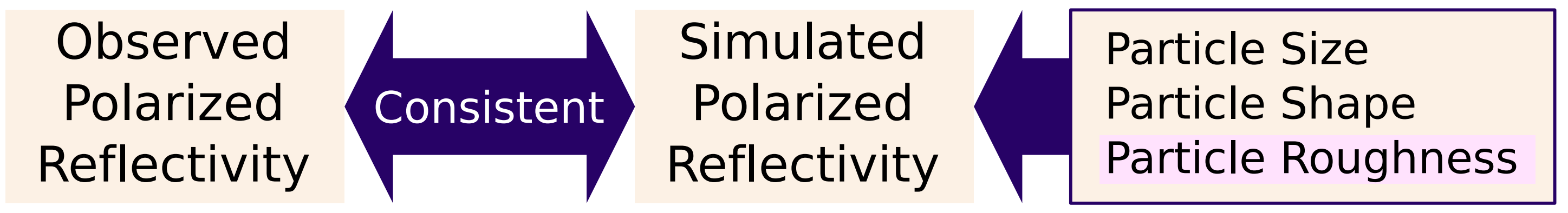
Abstract

We expand upon satellite polarimetric observation to infer ice cloud particle roughness. The particle roughness in this study is a surrogate for a variety of imperfection that break symmetry in smooth hexagonal column aggregate ice particle. Our inference method based on two steps of inversion is applied to the data from Polarization & Anisotropy of Reflectances for Atmospheric Sciences coupled with Observations from a Lidar (PARASOL) sensor. The result indicates that a severely roughened particle most closely matches the observation from PARASOL. The inferred roughness in tropics and extratropics were nearly identical.

1. Background and Strategy

The ice particle roughness is applied in scattering modeling to mimic the imperfection within an ice particle. Although previous studies indicate that the particle roughness improves the consistency between modeled and observed polarized reflectivities, the optimal degree of roughness remains unclear.



Observed Polarized Reflectivity

Consistent

Simulated Polarized Reflectivity

Particle Size
Particle Shape
Particle Roughness

Fig. 1. Required consistency between observation and simulation.

The standard approach to guarantee the consistency in polarized reflectivity is to compare observation and simulation, assuming multiple degrees of roughness [Baran and C-.Labonnote 2006, Cole et al. 2014]. In this study, we focused on two major problems of the approach to improve the accuracy of the inference.

Problems

1 The parameter space (σ^2) is discrete and non-linear to the polarized reflectivity; the impact of an observational error is difficult to quantify.

2 The variation of a cloud top height is not taken into account; this may result in the latitudinal bias of cloud properties.

Keys of our Strategy

① We investigated the impact of surface roughness on P12 element of Mueller matrices to construct the parameter space approximately linear to the measurement space.

② We utilized the reflectivities from multiple channels to infer the cloud top height and the cloud reflectivity, then inferred the cloud property based on the reflectivity.

Fig. 2. Problems of the standard approach and our strategy against them.

2. Roughness and P_{12}

An empirical orthogonal function (EOF) analysis is conducted with P12 elements of Mueller matrices for the aggregate of solid column particle assuming multiple roughness parameters. The EOF analysis is applied in the scattering angle between 60° and 170°.

Two EOFs are sufficient to reconstruct P12 elements.

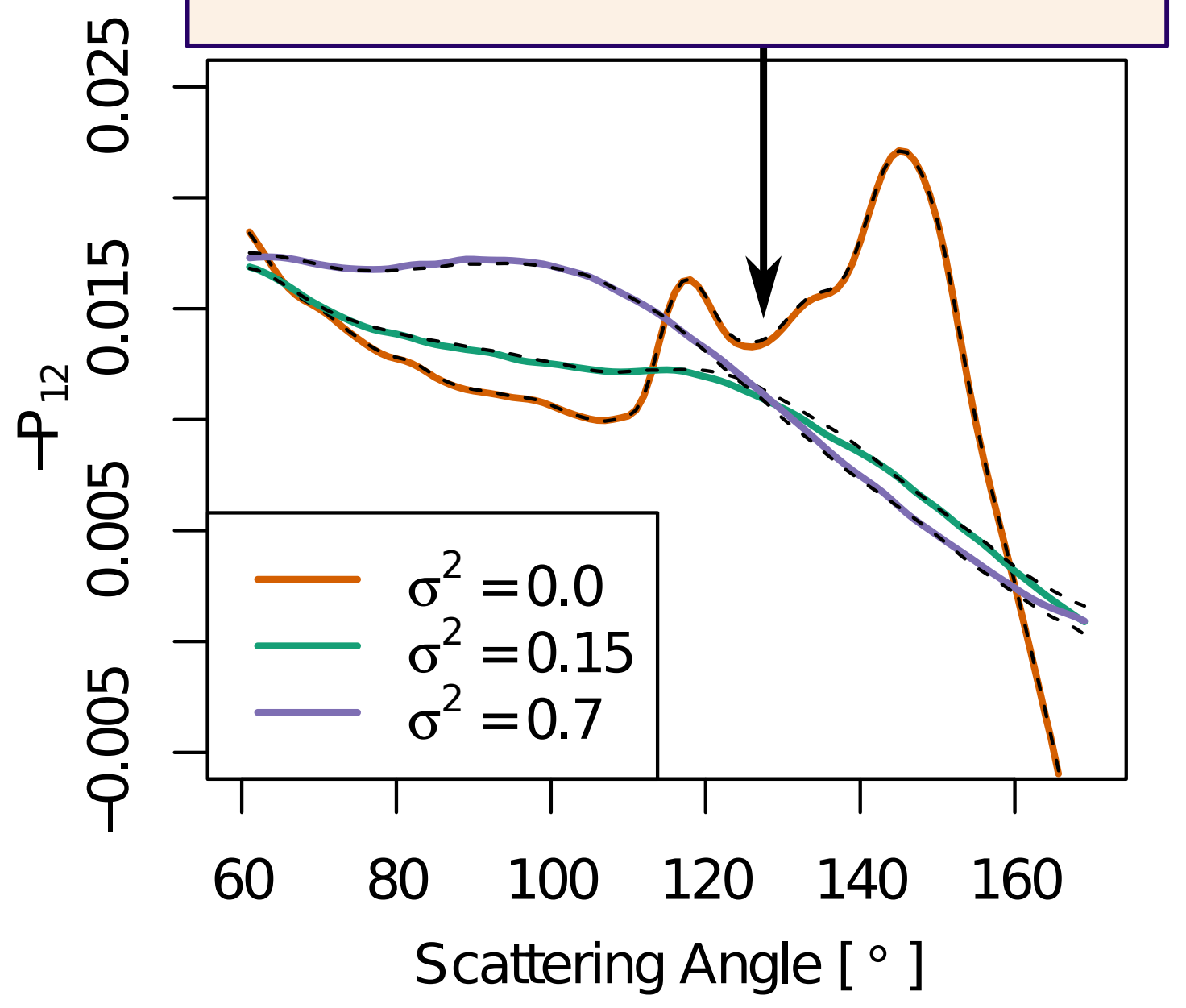


Fig. 3. Reconstruction of P12 elements (dot line) with two EOFs.

The first EOF shows strong hexagonal column-feature and the second EOF shows a bulge in side scattering.

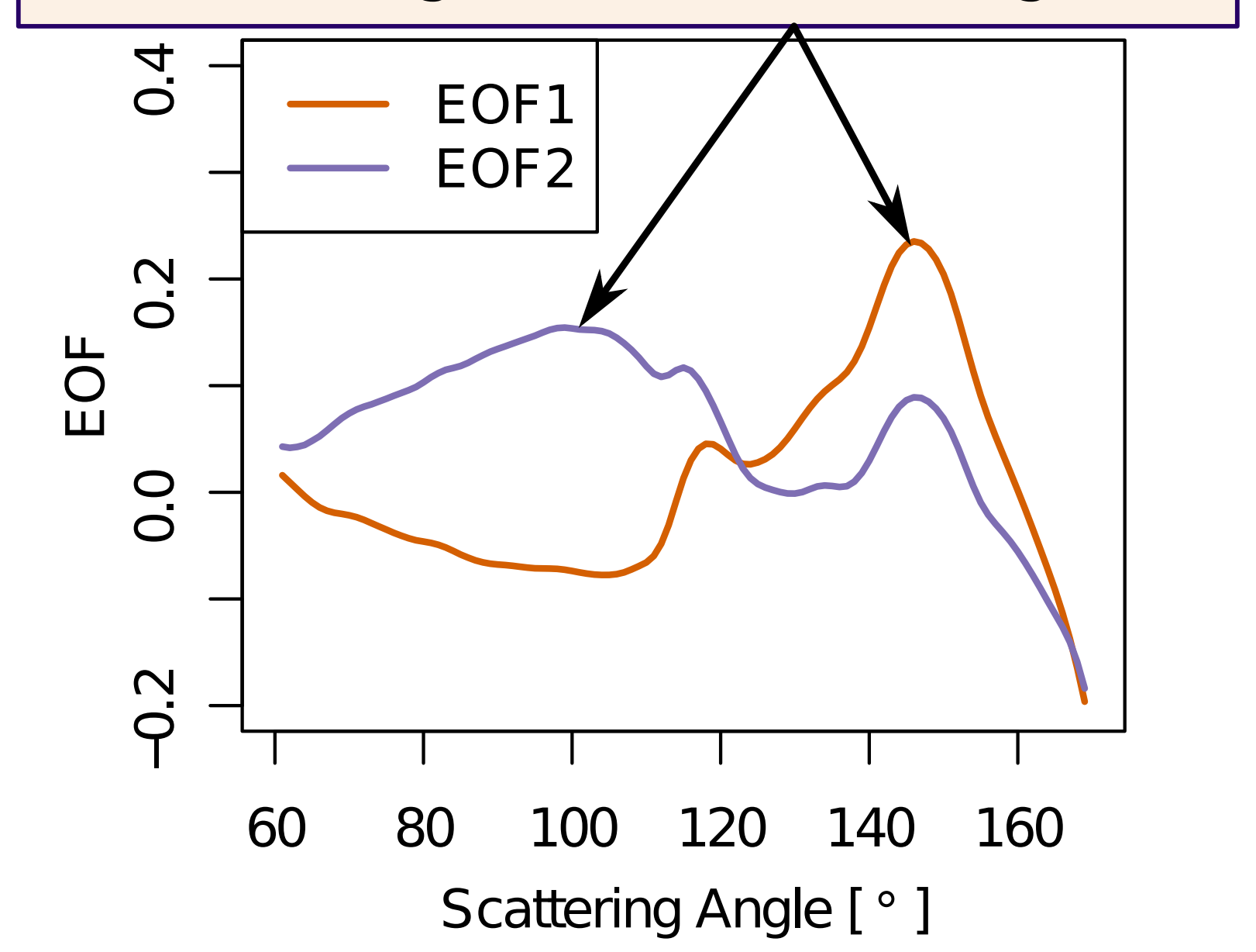


Fig. 4. Shapes of first two EOFs.

Effective roughness

The logarithm of roughness parameter σ^2 is linear to the EOF1 score.

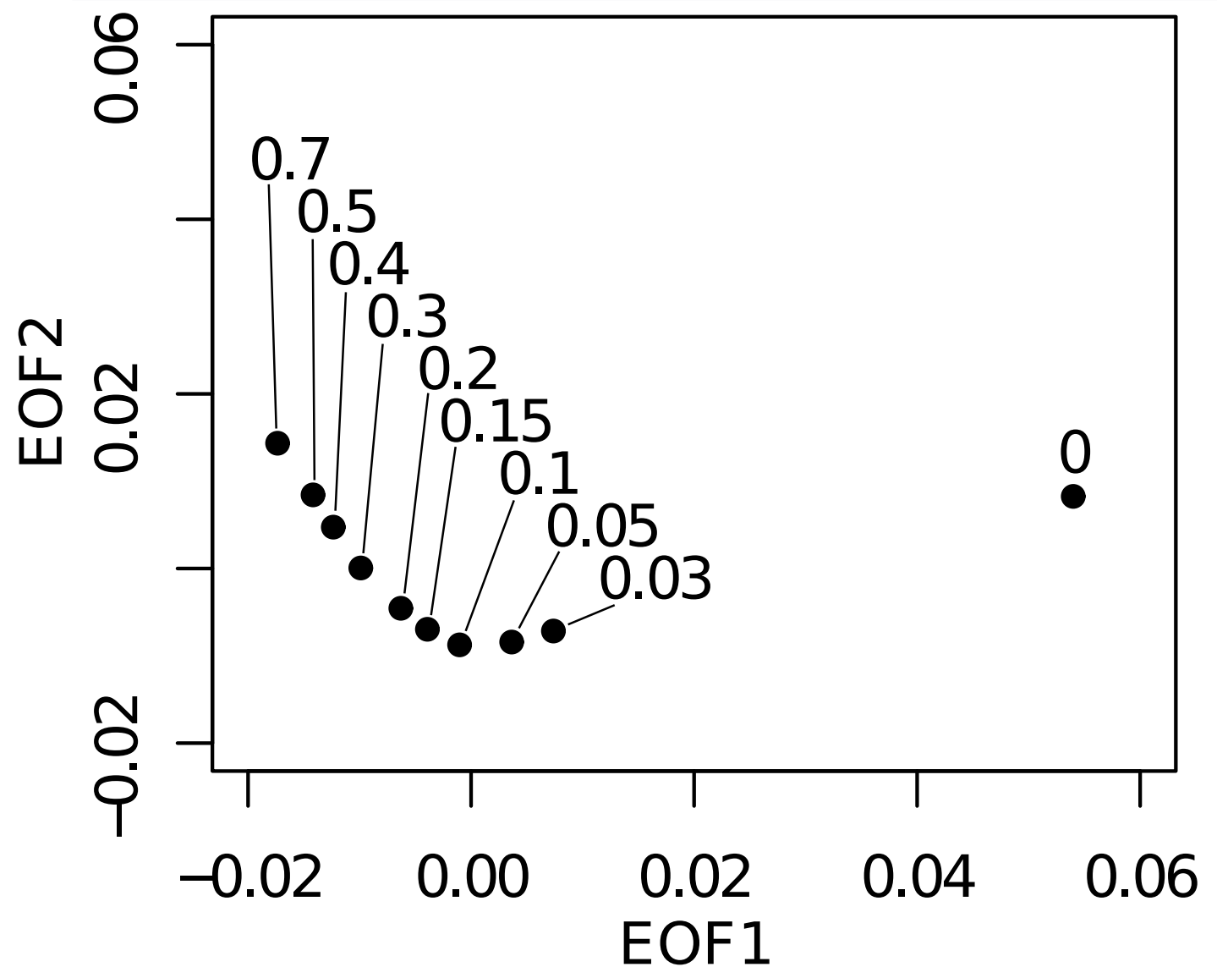


Fig. 5. EOF scores for different σ^2.

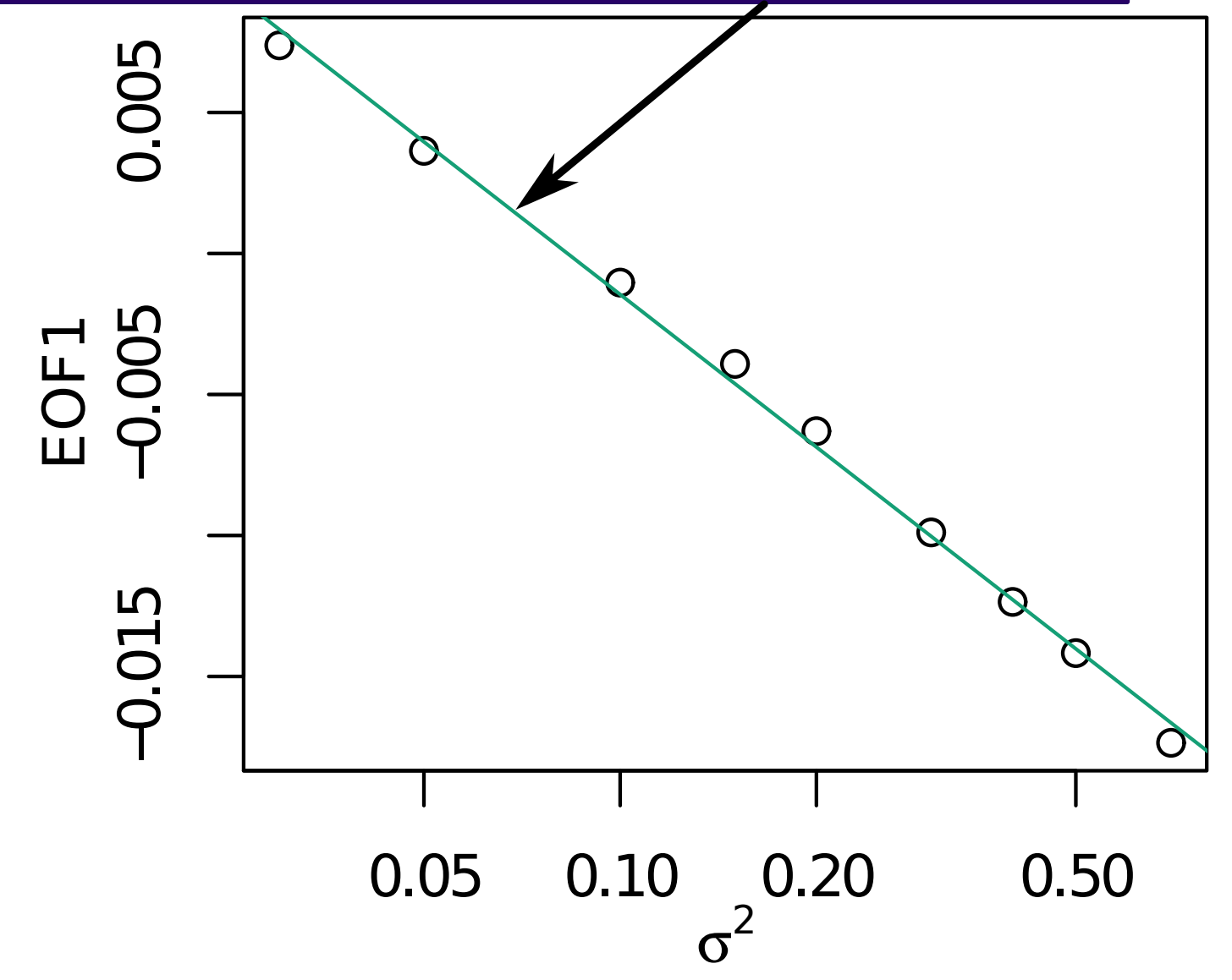
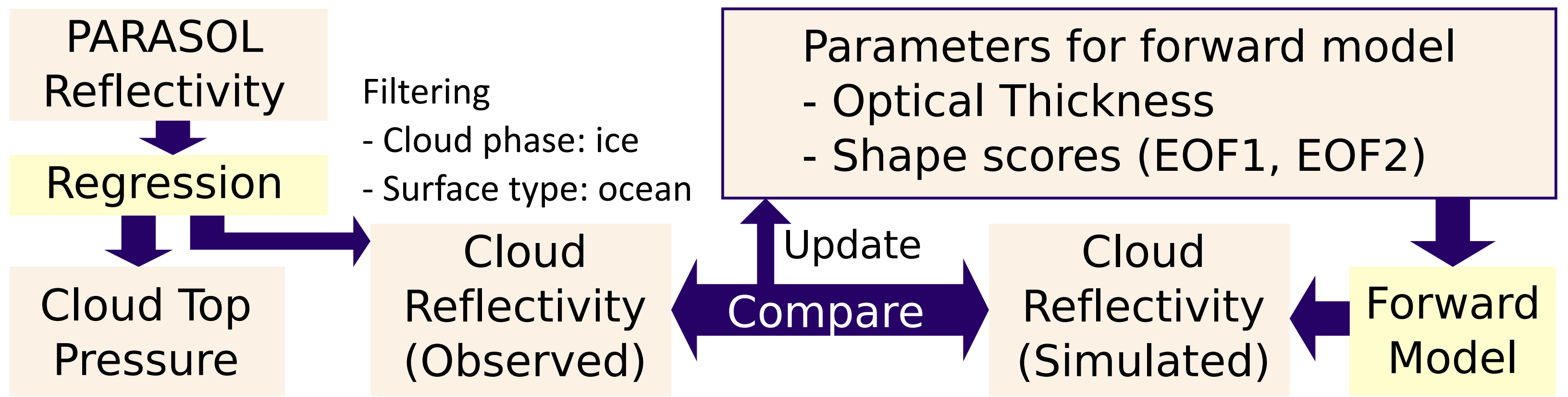


Fig. 6. EOF1 is linear to σ^2.

3. Inference Method



PARASOL Reflectivity

Regression

Filtering
- Cloud phase: ice
- Surface type: ocean

Cloud Top Pressure

Cloud Reflectivity (Observed)

Update

Compare

Parameters for forward model
- Optical Thickness
- Shape scores (EOF1, EOF2)

Cloud Reflectivity (Simulated)

Forward Model

Fig. 7. Particle roughness inference scheme.

PARASOL polarized reflectivities from three visible and infrared channels are utilized in a regression to separate cloud reflection out of Rayleigh scattering. The obtained cloud reflectivity is compared with the simulation to update input parameters by iteration.

4. Particle Roughness

The inference method is applied to a month (September, 2005) of PARASOL data over the Western Pacific (115E-150W).

EOF1 maxima is at about -0.02, corresponding to σ^2=1.0.

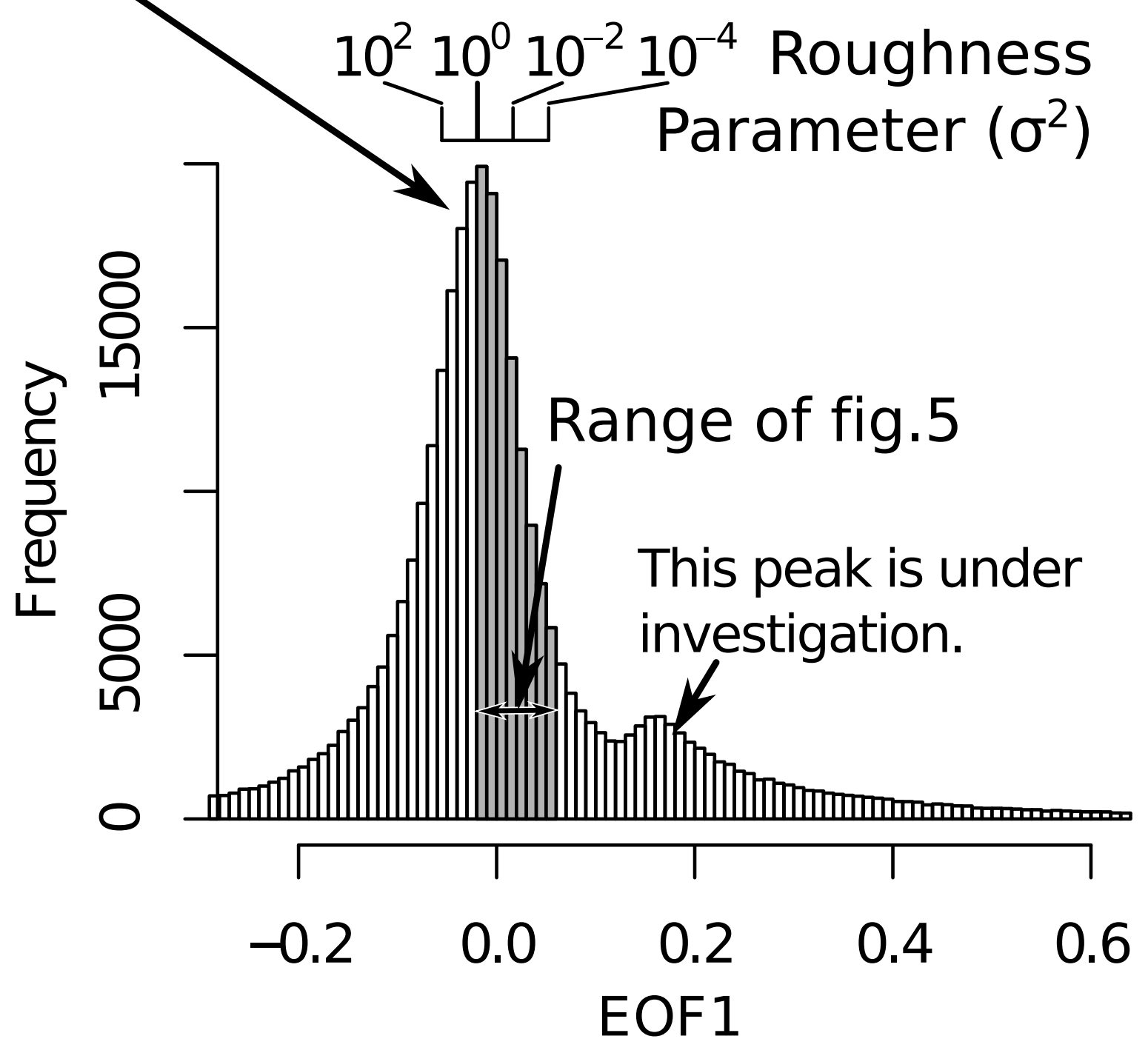


Fig. 8. Histogram of EOF1 (inferred particle roughness). The data between 5% and 95% percentiles are plotted.

EOF1 distributions in tropics and extratropics are nearly identical except the maximum at 0.18.

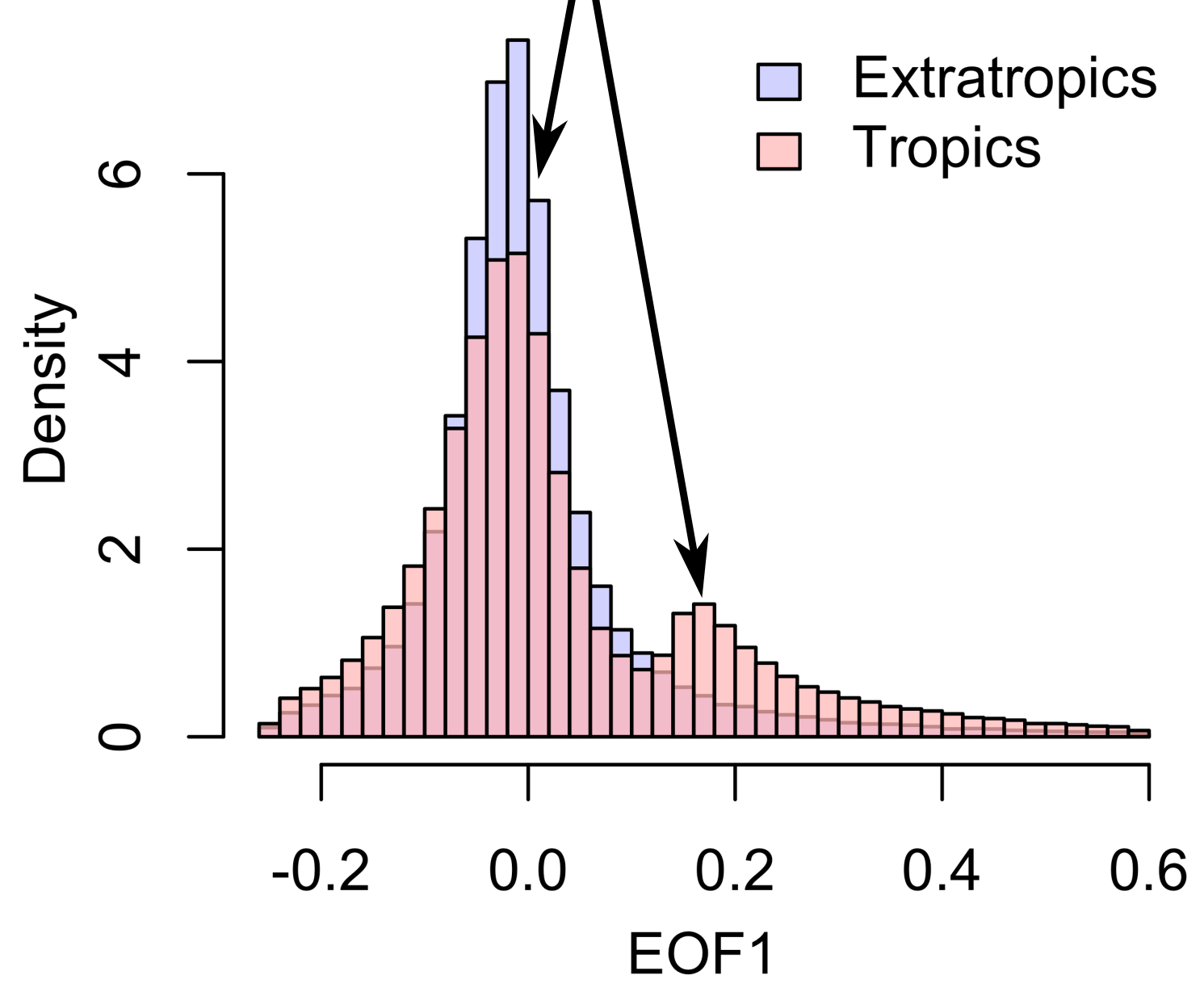


Fig. 9. Comparison of distributions in tropics and extratropics.

5. Summary and Discussion

- **Two coefficients to the first two EOFs of P12 elements are sufficient to represent the impact of roughness on the aggregate of column habit.**
  - EOF1 and EOF2 showed different intensity of hexagonal column-feature.
  - EOF1 score is linear to the logarithm of roughness parameter (σ^2).

- **The effective roughness (EOF1) distribution favored roughened particle.**
  - The maxima corresponded to the roughness parameter of σ^2=1.0.
  - There was a maximum about EOF1=0.18, which is under investigation.

- **The maxima and widths of EOF1 distributions are nearly the same for tropics and extratropics, but further investigation is needed.**
  - This supports the use of a single ice particle model in global satellite data analysis for thick ice clouds.
  - Further investigation is needed, as the inference method has different sensitivity and accuracy in different latitudes.

References and Acknowledgments

- Baran and C.-Labonnote (2006), *J. Quant. Spectrosc. Radiat. Transf.*, **100**, 41-54
- Cole, Yang, Baum, Riedi, and C.-Labonnote (2014), *Atmos. Chem. Phys.*, **14**, 3739-3750.

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