Investigation of the Directional Structure of Horizontal Cloud Inhomogeneities Derived from Ground-Based and Airborne Spectral Imaging and Cloud Resolving Models

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1 Introduction

- Clouds exhibit significant horizontal optical and microphysical inhomogeneities
- Directional, horizontal structure of cloud optical thickness (τ) fields investigated
- Fields of τ retrieved from spatial 2D spectral radiance fields (<10 m resolution)
- Two cloud types investigated [1]:
  - Cirrus obtained during CARRIBA (Clouds, Aerosol, Radiation, and tuRbulence in the trade wInd regime over Barbados)
  - Arctic stratus obtained during VERDI (VERtical Distribution of Ice in Arctic clouds)

How important are directional 2D cloud structures for the characterization of cloud inhomogeneities and how can they be parameterized?

2 Fields of Cloud Optical Thickness

Retrieved fields of τ from 2D fields of spectral radiance

4 ground-based cases of cirrus (Ci-01 to Ci-04)

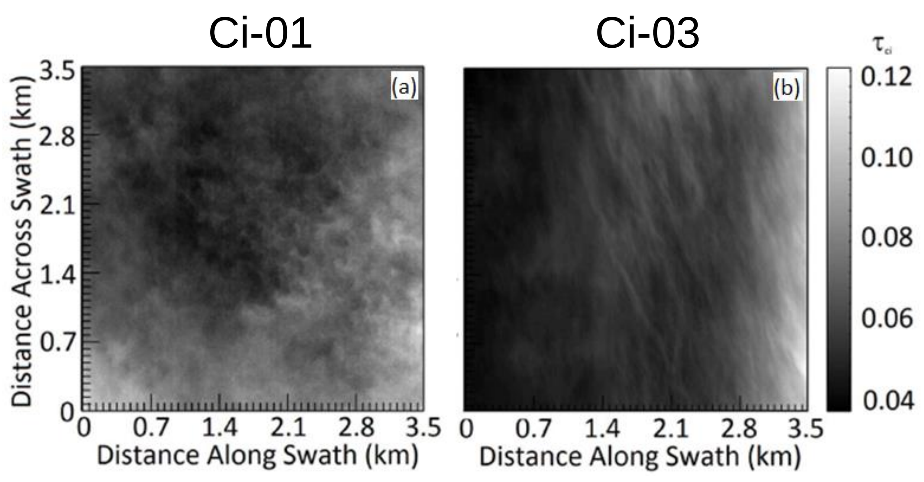

Fig. 1: Exemplary depicted fields of τ_{ci}. Cutouts from measurement case (a) Ci-01 and (b) Ci-03.

10 airborne cases of Arctic stratus (St-01 to St-10)

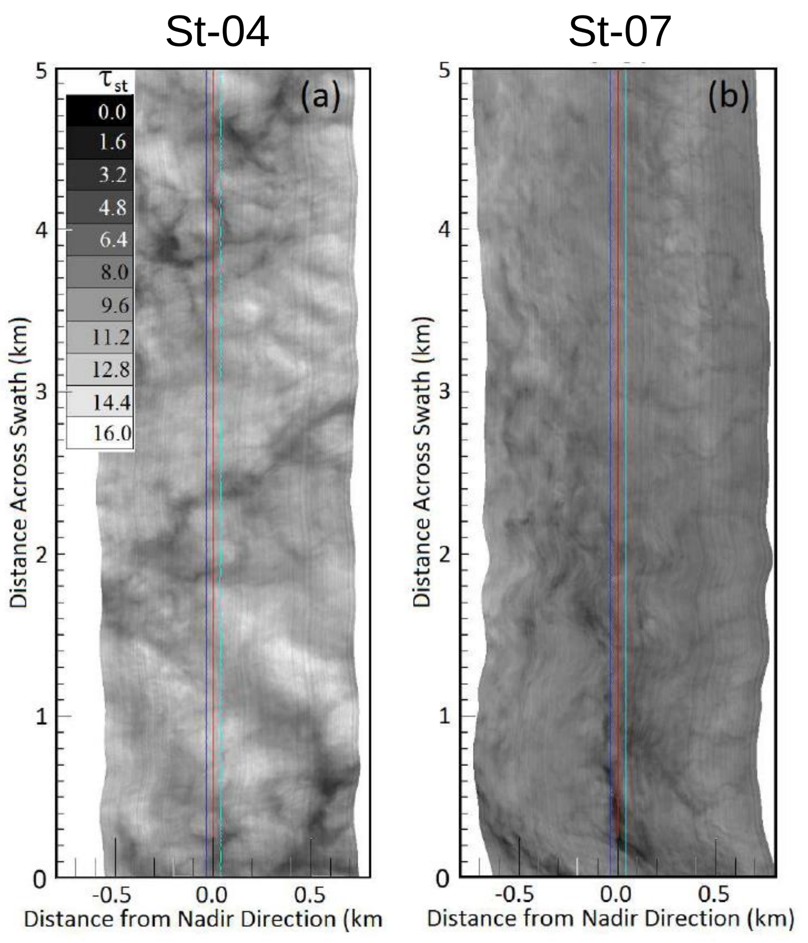

Fig. 2: Exemplary depicted fields of τ_{st}. Cutouts from measurement case (a) St-04 and (b) St-07.

Specifications:

	Cirrus	Stratus
Cloud type:	Cirrus	Stratus
Cloud top:	10-14 km	1 km
Origin:	Tropics	Arctic
Phase:	Ice	Liq. Wat.

3 Characterization of Cloud Inhomogeneity

Scalar 1D Inhomogeneity Parameters [2,3]

- Often applied to quantify cloud inhomogeneities
- Easy to calculate
- Not able to reproduce the 2D structure of cloud inhomogeneities
- Ratio of logarithmic to linear mean $\chi_\tau = \frac{\exp(\overline{\ln \tau})}{\bar{\tau}}$
- Ratio of standard deviation to mean $\rho_\tau = \frac{\sigma_\tau}{\bar{\tau}}$
- Standard deviation of logarithmic mean $S_\tau = \frac{\sqrt{\ln(\rho_\tau^2 + 1)}}{\ln 10}$

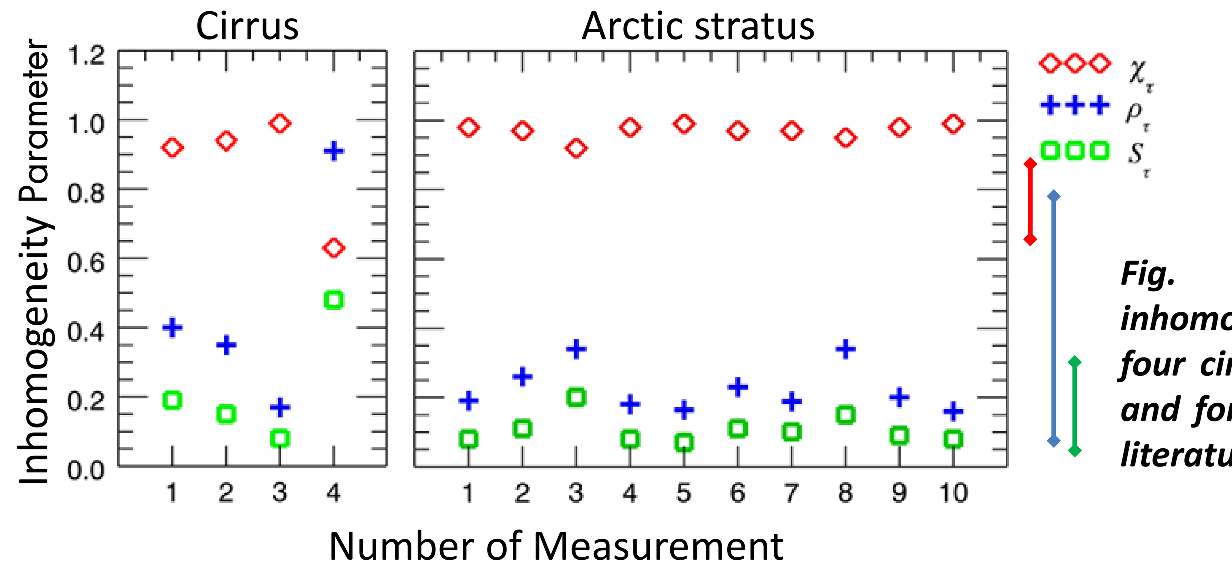

Fig. 3: Derived scalar 1D inhomogeneity parameters for the four cirrus/ ten Arctic stratus cases, and for comparison values from the literature (bars).

4 Size and Structure of Cloud Inhomogeneities

1D and 2D Spatial Autocorrelation Functions P_τ^2

- Investigation of the directional structure of cloud inhomogeneities
- Decorrelation length ξ_τ: Measure for size and structure of inhomogeneities

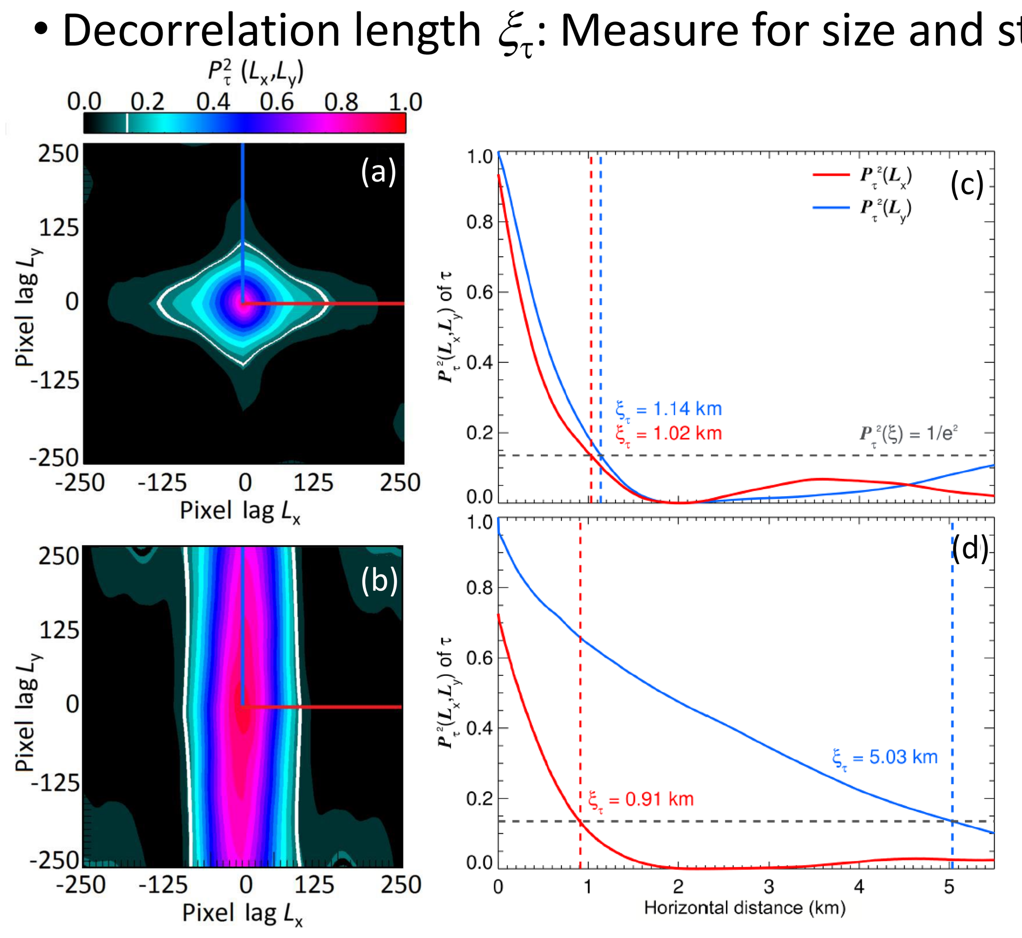

Fig. 4: Left panel: Calculated 2D spatial autocorrelation function of measurement case (a) Ci-01 and (b) Ci-03, displayed in Fig. 1. Right panel: 1D autocorrelation along illustrated lines in left panel.

Decorrelation length ξ_τ

$$P_\tau^2(\xi_\tau) = \frac{1}{e^2}$$

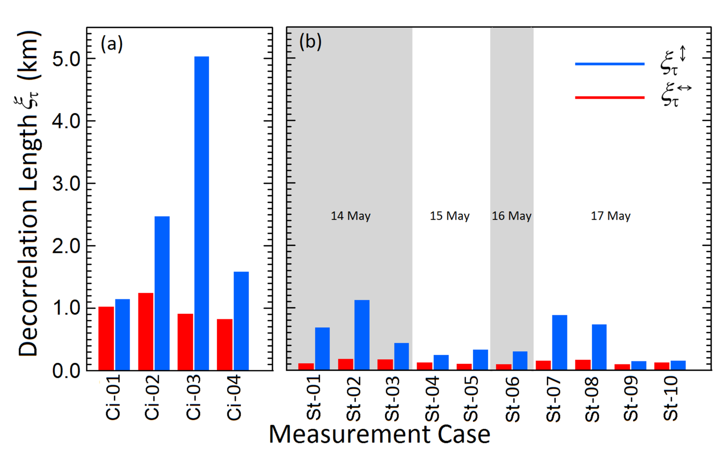

Fig. 5: Calculated decorrelation length ξ_τ along and across the predominant directional structure of the cloud inhomogeneities.

5 Comparison to Simulations

COSMO

- High resolution allows focus on clouds
- Idealized simulations:
  - 64 x 64 grid points
  - 100 m horizontal resolution
  - Periodic boundary conditions
  - 3D turbulence scheme
  - 12 min temporal resolution
  - 4 VERDI cases simulated

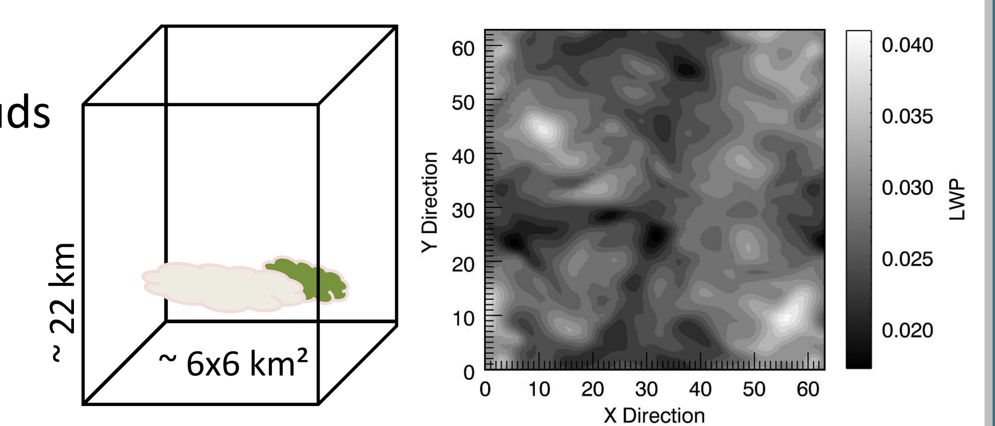

Fig. 6: Left panel: Model setup. Right panel: Simulated field of liquid water path (LWP) of Arctic stratus, based on measurement case from VERDI on 15 May 2012.

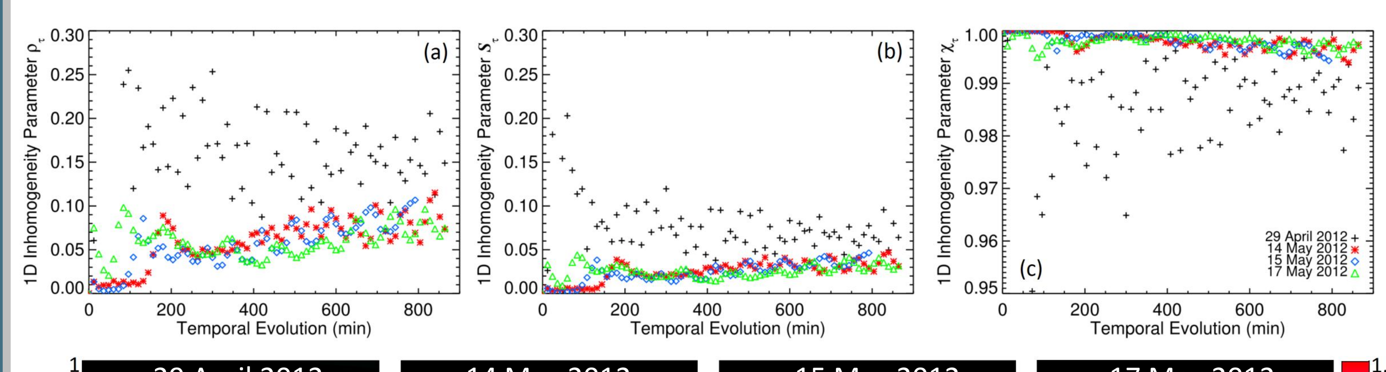

Fig. 7: Time series of 1D inhomogeneity parameters ρ, S, and χ for all simulated VERDI cases.

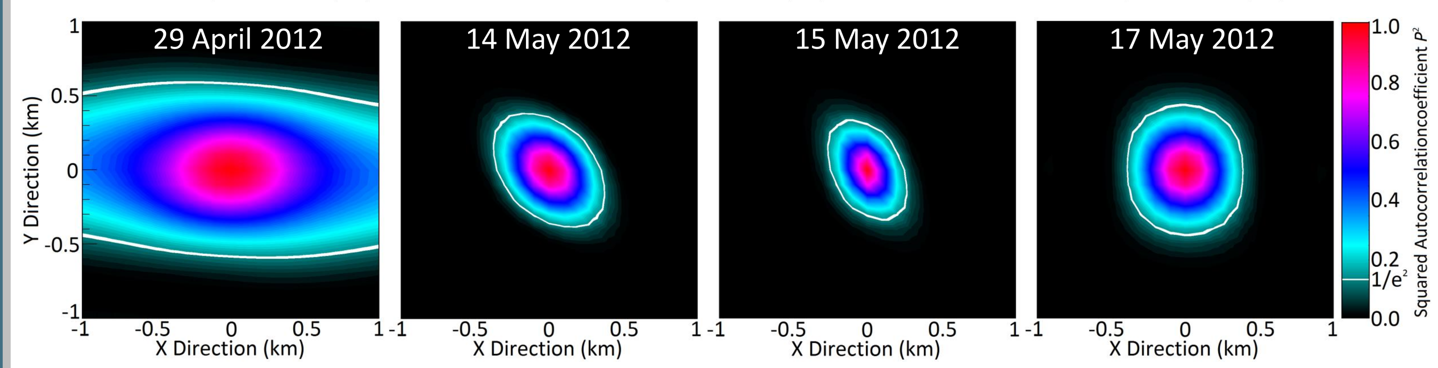

Fig. 8: Temporal averaged squared 2D autocorrelation coefficients for simulated VERDI cases. White line illustrates decorrelation length.

6 Summary & Outlook

- Directional structure of cloud inhomogeneities cannot be reproduced from 1D inhomogeneity parameters → misinterpretation possible using 1D observations (e.g. LIDAR)
- 2D analysis of the cloud structure helps to identify the directional, horizontal characteristics of cloud inhomogeneities
- Increasing cloud inhomogeneities in dependence of their temporal evolution

→ Investigations will be extended to more cases using COSMO (with longer temporal evolution) and upcoming 2D observations performed during ACLOUD

References

[1] **Schäfer, M.** and Bierwirth, E. and Ehrlich, A. and Jäkel, E. and Werner, F. and Wendisch, M., 2017: Directional, horizontal inhomogeneities of cloud optical thickness fields retrieved from ground-based and airborne spectral imaging, *Atmos. Chem. Phys.*, 17, 2359-2372, doi:10.5194/acp-17-2359-2017.

[2] **Zuidema, P.** and Evans, K., 1998: On the validity of the independent pixel approximation for boundary layer clouds observed during ASTEX, *J. Geophys. Res.*, 103, 6059-6074.

[3] **Oreopoulos, L.** and Cahalan, R. F., 2005: Cloud Inhomogeneity from MODIS, *J. Climate*, 18, 5110-5124.

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