Aviation-induced changes in cirrus cloud properties over Europe: Investigation with CALIPSO lidar measurements

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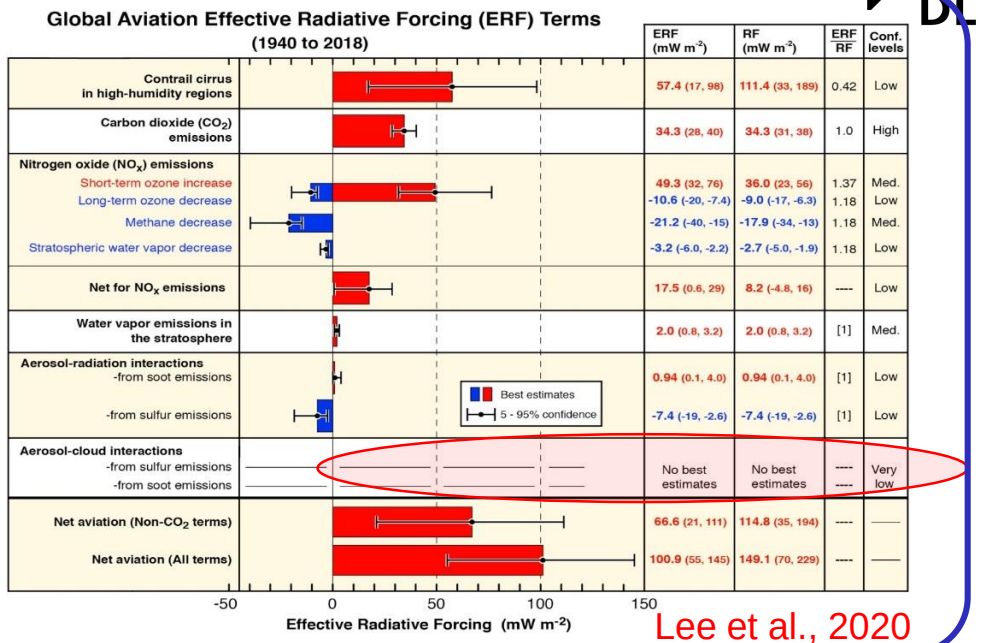
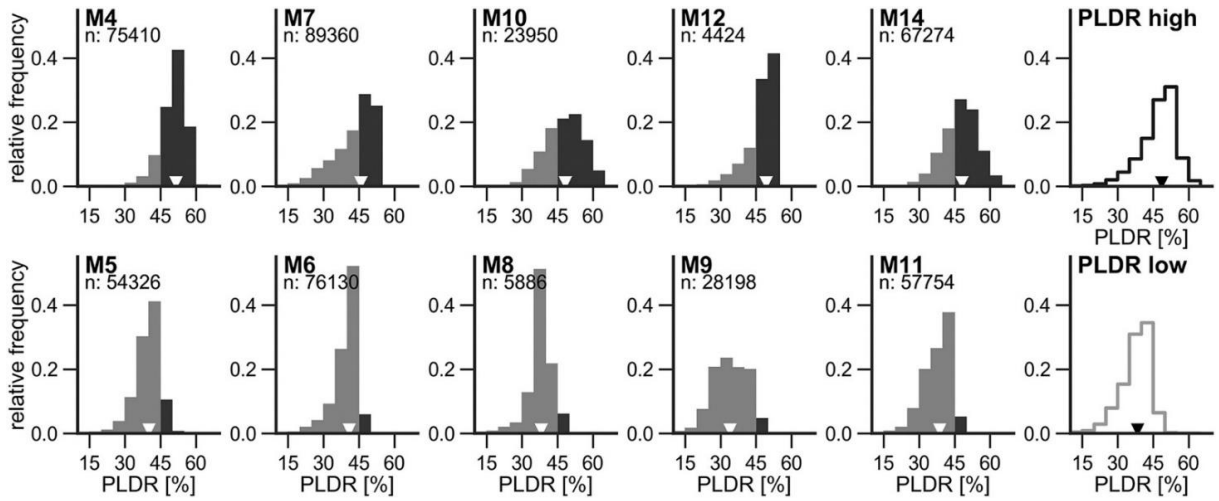
Motivation: Climate forcing from global aviation emissions and cloudiness

- Aviation contributes to global warming;
- Contrails > 50% of the climate impact of aviation;
- Low-level understanding of the aviation-induced aerosol-cloud interaction;

  → No best estimate!
- Radiative effects of cirrus depend on the size, shape, and complexity of ice crystals, indicated by particle linear depolarization ratios (PLDR);



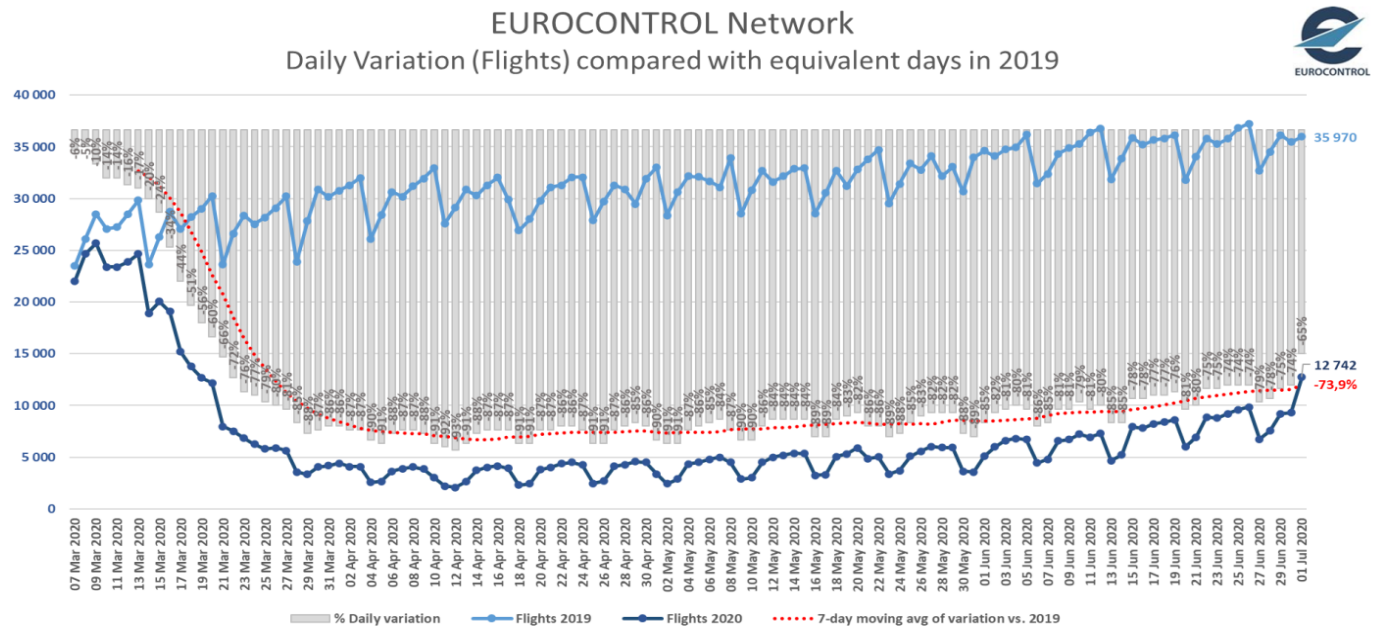
Lee et al., 2020



- Specific clouds with either high or low values of PLDR;
- Enhanced PLDR for clouds formed in the high air traffic regions;
- Lower PLDR in the pristine regions;

Urbanek et al., 2018

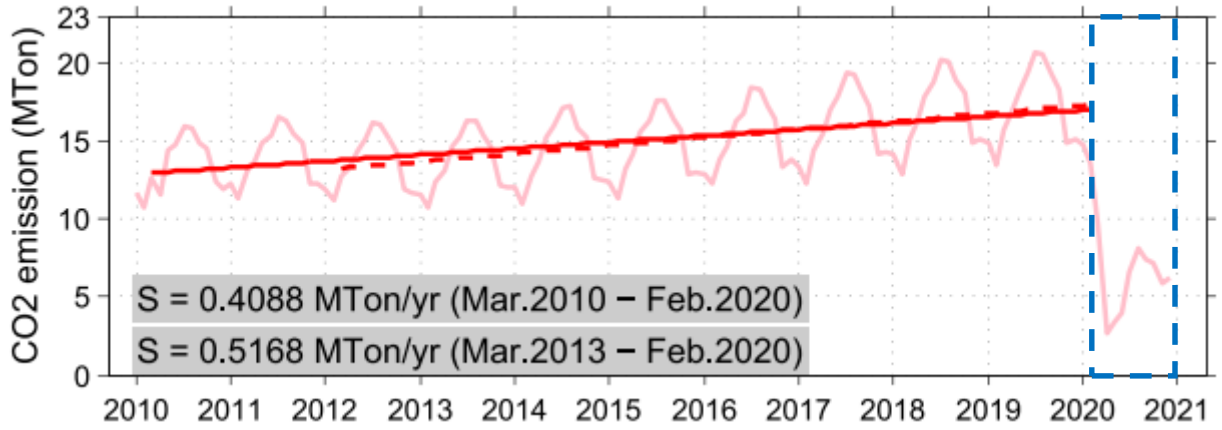
Aviation changes over Europe: Research questions



⇒ Due to COVID-19, the civil air traffic in Europe was strongly reduced: up to 90% reduction in April 2020 vs 2019;

⇒ A unique condition to study the air traffic impact on cirrus cloud properties;

Aviation in Europe (incl. 42 countries and regions)

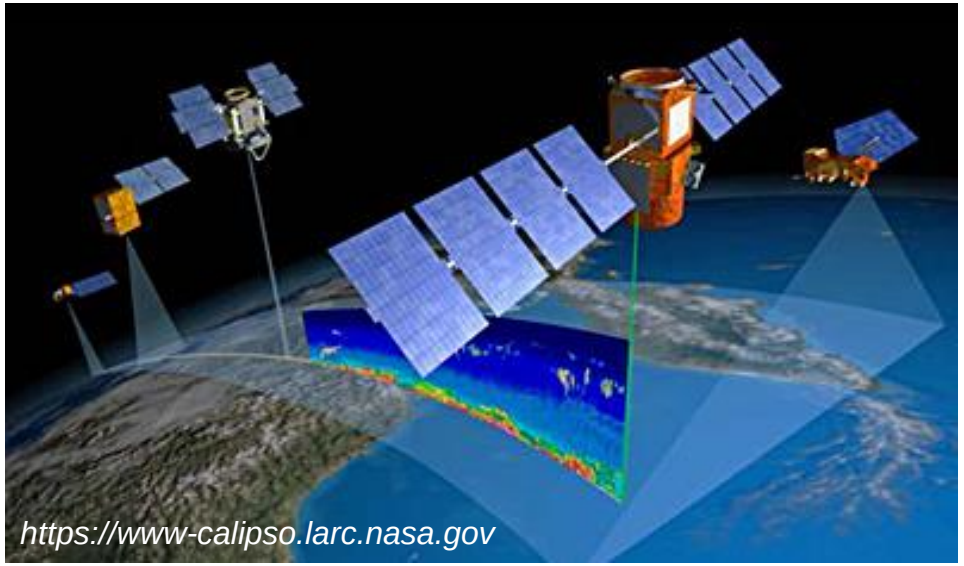


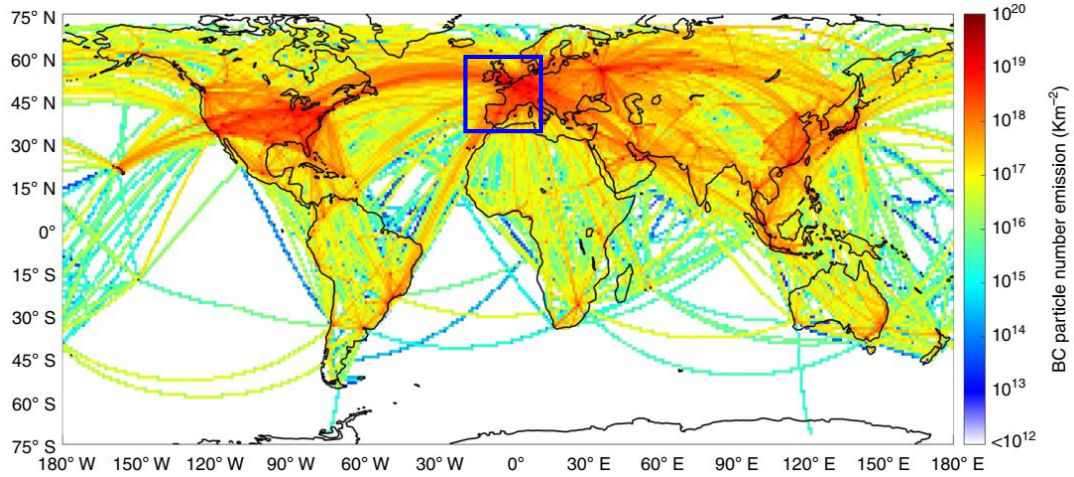
Research questions:

I. Do we see changes in cirrus PLDR in connection with the COVID-19-caused aviation reduction?

II. Do we see a trend in PLDR before the COVID-19 period and potential correlations with aviation?

Measurements from spaceborne lidar on CALIPSO





Zhang et al., 2019

CALIOP:

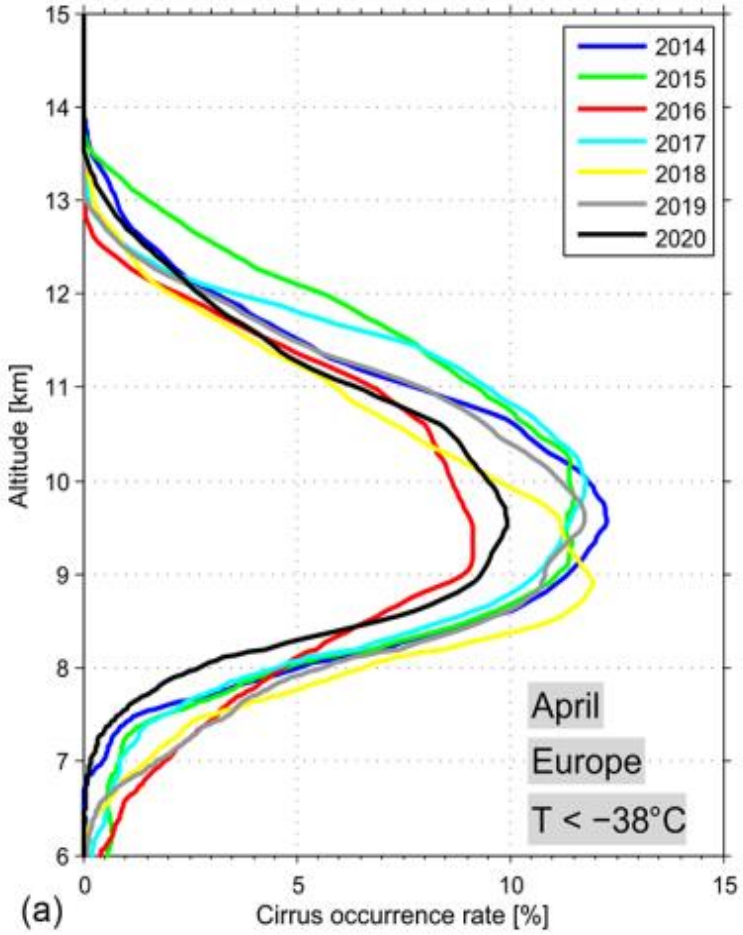
- At 532nm and 1064nm;
- Polarization sensitive at 532nm;
- Level-2 cloud profile products:
  - Horizontal resolution 5km
  - Vertical solution of 60m
- Particle linear depolarization ratio PLDR;

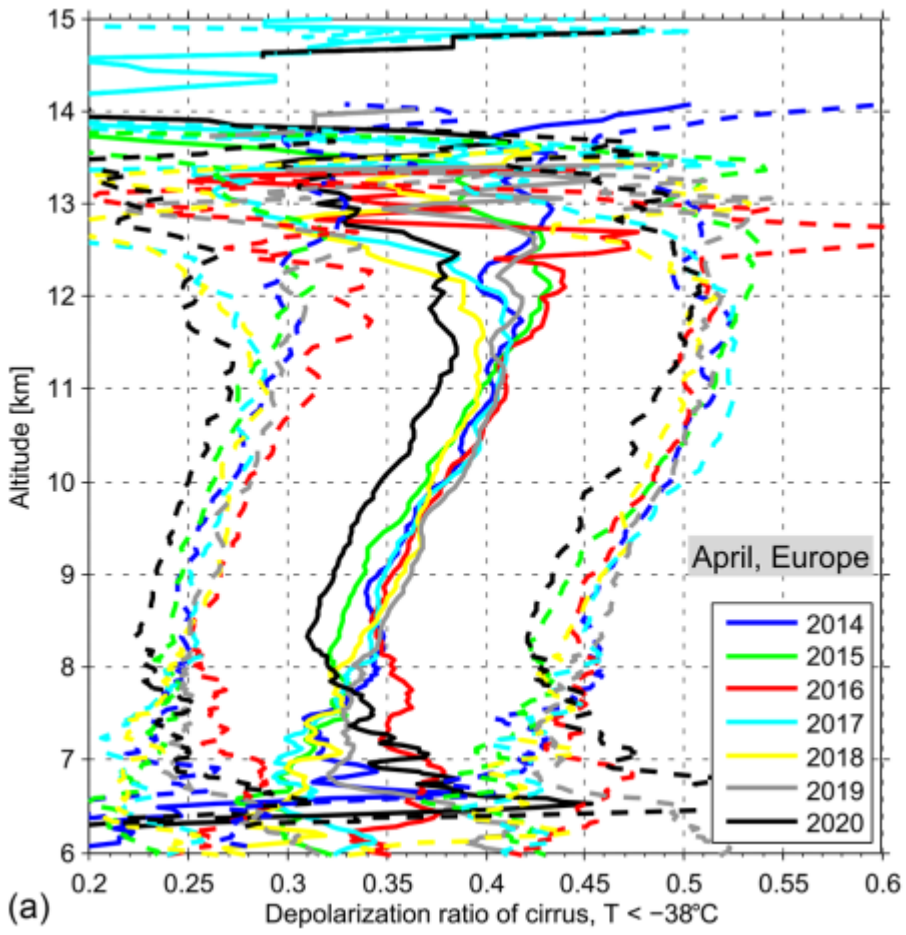
Measurement:

- Atlantic – Central Europe: 35–60°N; 15°W–15°E;
- Ice clouds with T < 238 K;
- Periods:
  - April of the years 2014 – 2020;
  - Monthly PLDR in the last 10 years; 2010–2020;

I. Do we see changes in cirrus PLDR in connection with the COVID-19-caused aviation reduction?

Changes in cirrus cloud properties over Europe (in April)





Li and Groß, 2021

⇒ Cirrus cloud formation with maxima in 9-10 km;

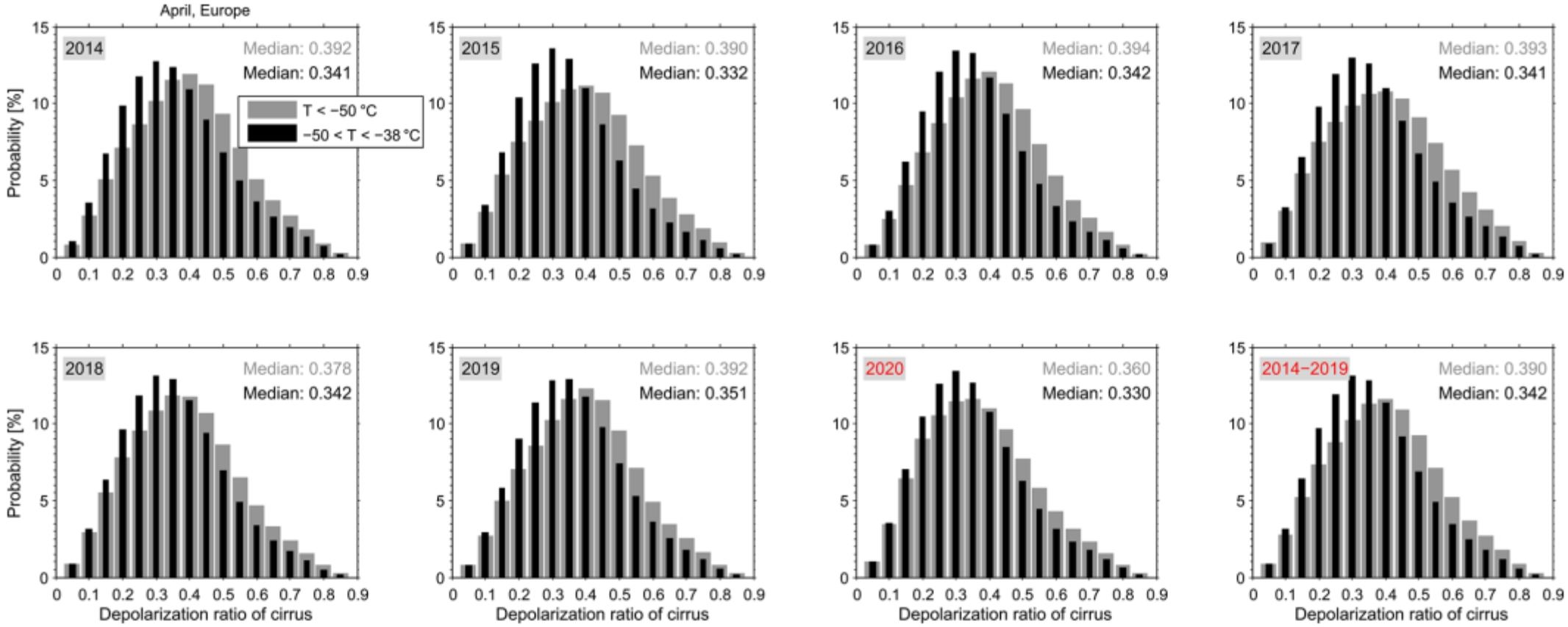
⇒ **ORs in 2020 smaller** than others (exc 2016: due to warmer and drier airmasses);

⇒ **PLDR increase** with altitudes for all cases;

⇒ Enhanced PLDR in 2016 compared with 2020, although smaller occurrence in 2016;

⇒ **Reduced PLDR** (along the altitudes) in 2020 for altitude range from ~8 to 12 km (aviation hgt);

Distributions of cirrus cloud PLDR: Temp dependence



Li and Groß, 2021, ACP

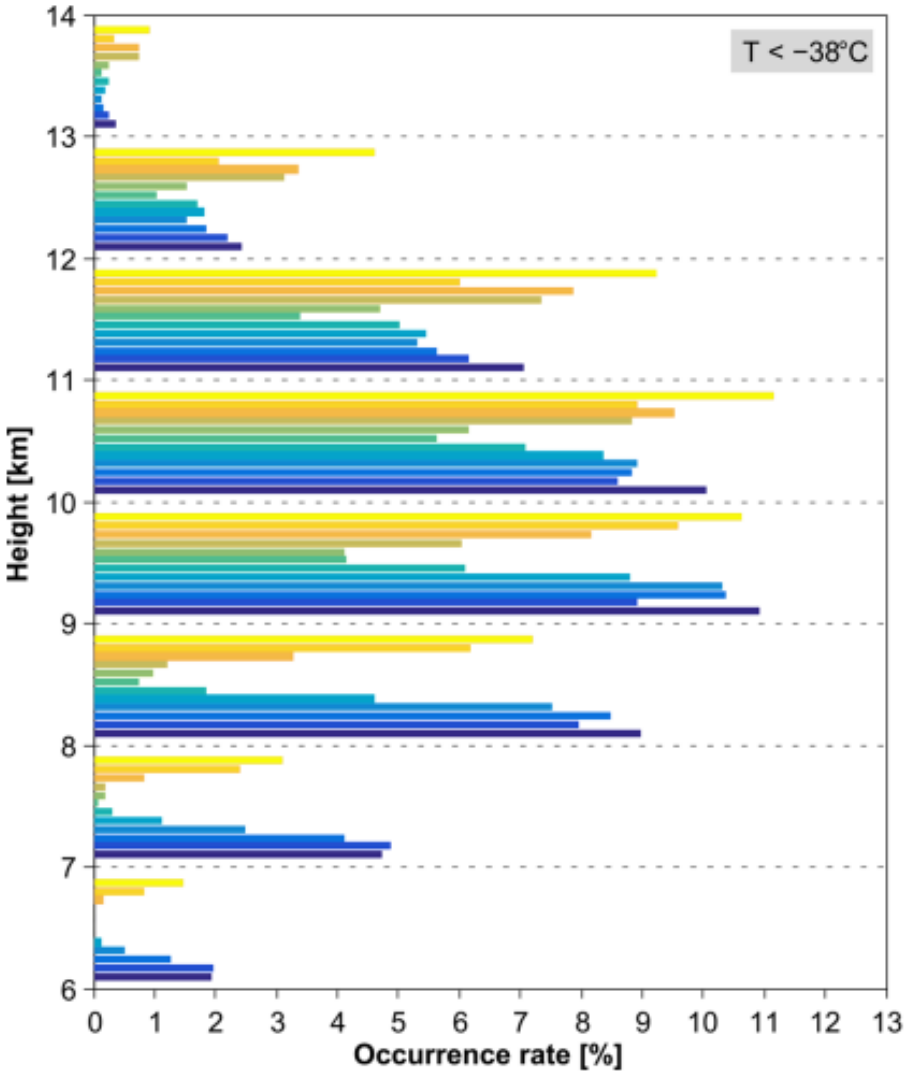
⇒ PLDR are larger at lower temperatures (< -50ºC) than higher temperatures;

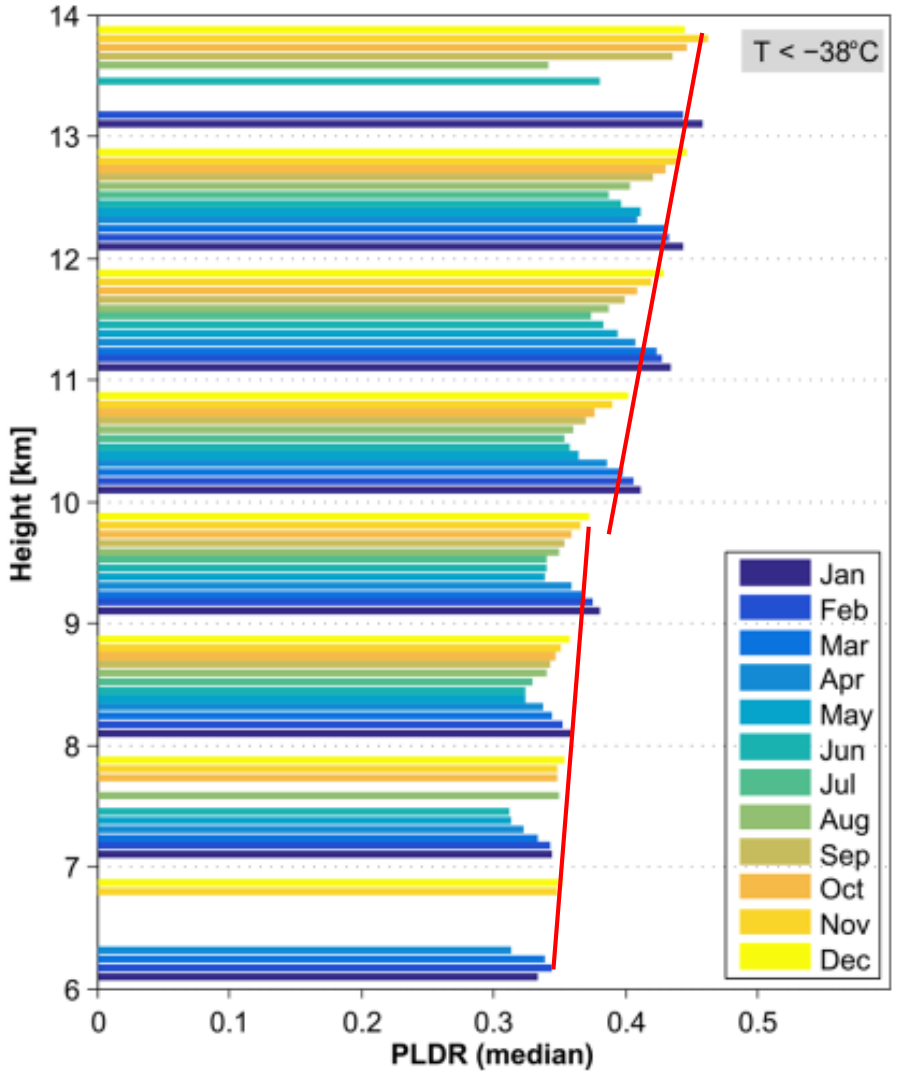
⇒ Smaller PLDR were found in April 2020 than in other years;

⇒ Contrail and Contrail-induced cirrus characterized with higher PLDR form at lower temperatures;

II. Do we see a trend in PLDR before the COVID-19 period and potential correlations with aviation?

Seasonal cycle in OR and PLDR of cirrus cloud





⇒ Seasonality in both params in all 1-km altitude bin;

⇒ Stronger seasonality in OR in lower altitudes;

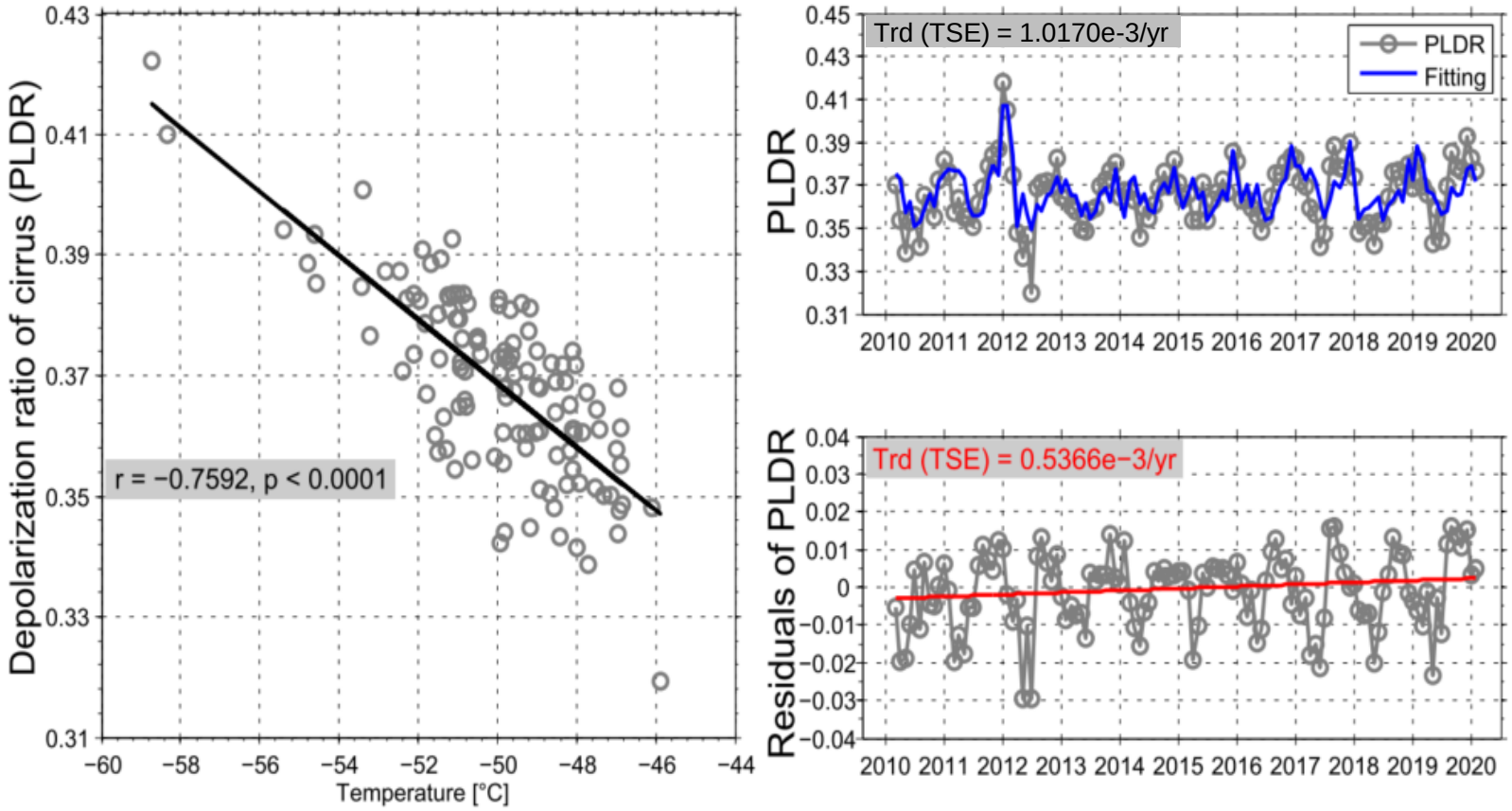
⇒ Cirrus mostly in high altitudes in summer due to lower temps;

⇒ PLDR increase with altitudes in each month;

⇒ PLDR increases stronger in higher altitudes;

Li and Groß, 2022, ACP

Long-term study of cirrus clouds: Temp dependence



⇒ PLDR strongly increase with decreasing T (in c);

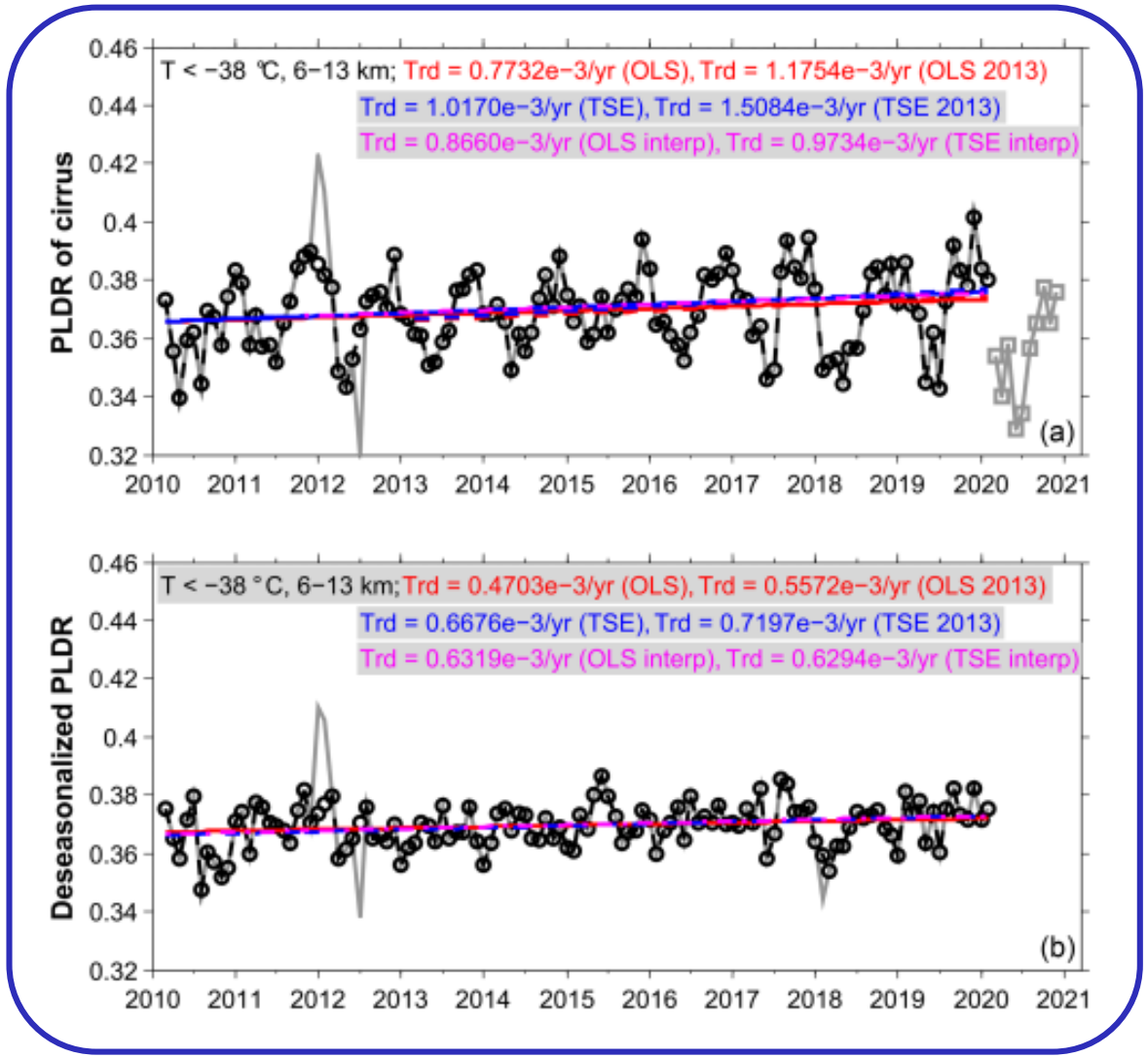
⇒ **An increasing trend in PLDR** (monthly medians) in the 10 years before COVID;

⇒ Stronger since 2013;

⇒ The residuals (after removing the regressed contribution of T) increase in the last 10 years;

⇒ **Other factors** contribute to the long-term trend in cirrus cloud properties than temperatures?

Long-term study of cirrus clouds and aviation impact



⇒ Monthly PLDR medians show an increasing trend in the 10 years before COVID-19;

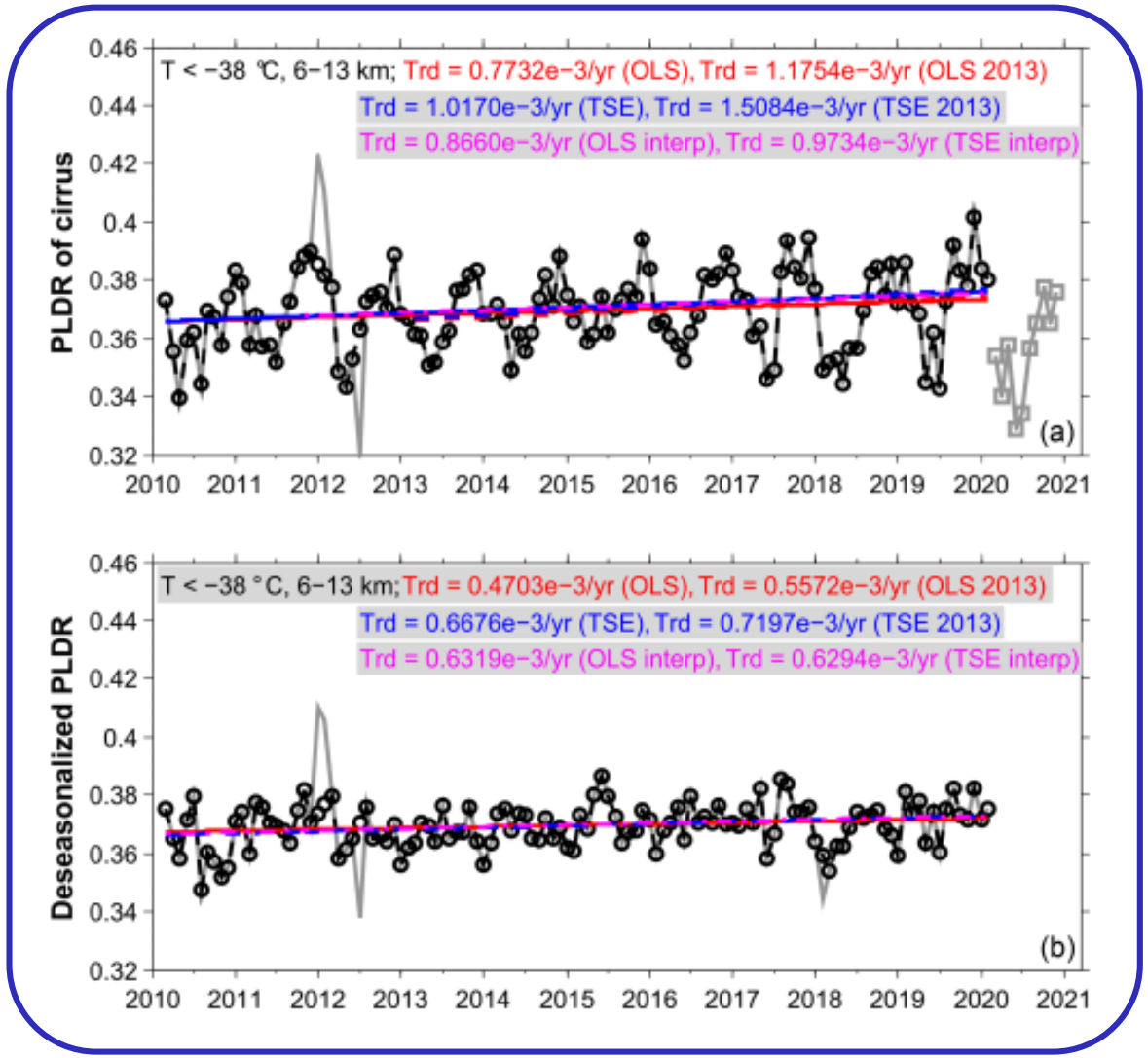
⇒ Reduced PLDR during COVID-19;

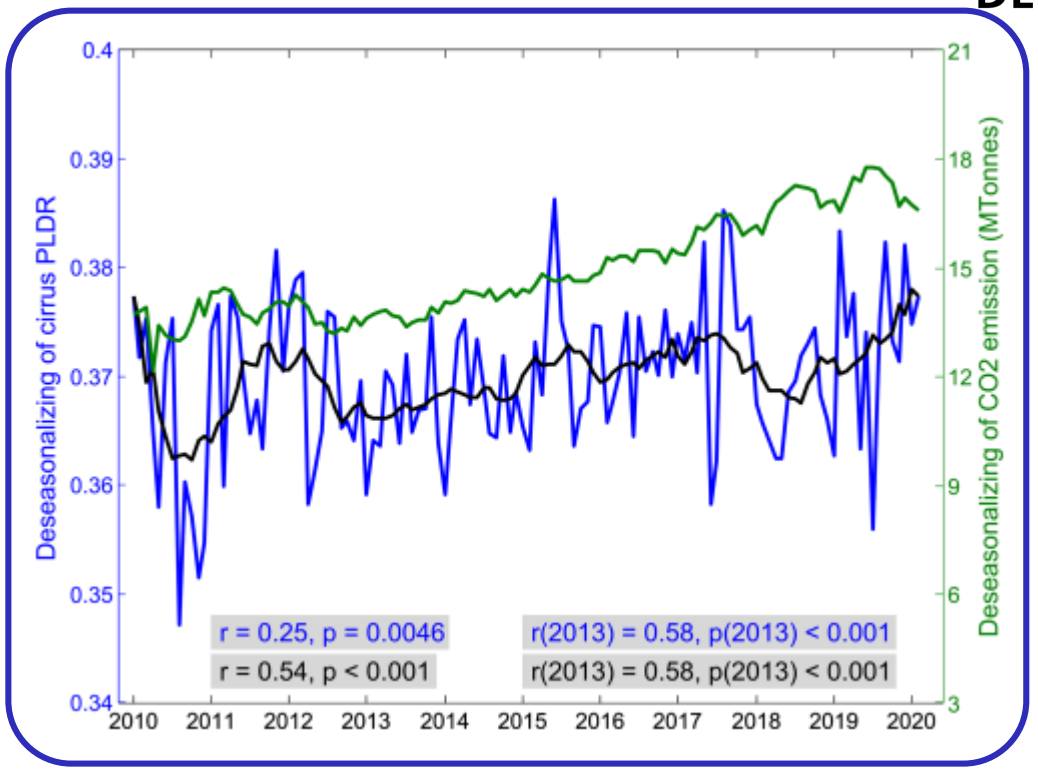
⇒ Clear seasonality in PLDR; Impacts on trend?

⇒ Deseasonalized timeseries of monthly PLDR medians: increasing trend with significance;

Li and Groß, 2022, ACP

Long-term study of cirrus clouds and aviation impact





⇒ Besides the outliers, an increasing trend recognized in both, especially from 2013;

⇒ Close correlation between PLDR and CO2 emissions from aviation (r=0.54, p<0.001);

Li and Groß, 2022, ACP

Summary and outlook

- A strong reduction in cirrus PLDR in April 2020 was detected in the typical aviation cruising altitudes, which is corresponding to the aviation reduction due to the COVID-19;
- An extended study with 10-year observations of cirrus clouds before COVID-19;
  - PLDR show seasonality with the largest values in winter and smallest in summer;
  - A significant increasing trend in PLDR values as well as in the deseasonalized timeseries of them in the last 10 years (2010-2020) before COVID-19;
  - A close correlation between PLDR and CO2 emission from aviation at a high CL;

⇒ Aviation-induced changes in cirrus cloud properties (PLDR) can be detected from the lidar measurements with CALIPSO. The physical mechanisms for the findings will be further investigated with airborne measurements during the Cirrus-HL and HALO-AC3 campaigns;

⇒ The upcoming **EarthCARE** mission (launched on 28.05.2024) will further strengthen our understanding of cirrus clouds;

Thank you for your attention!