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Simulations and observations of cloud contributions to RO refractivity biases

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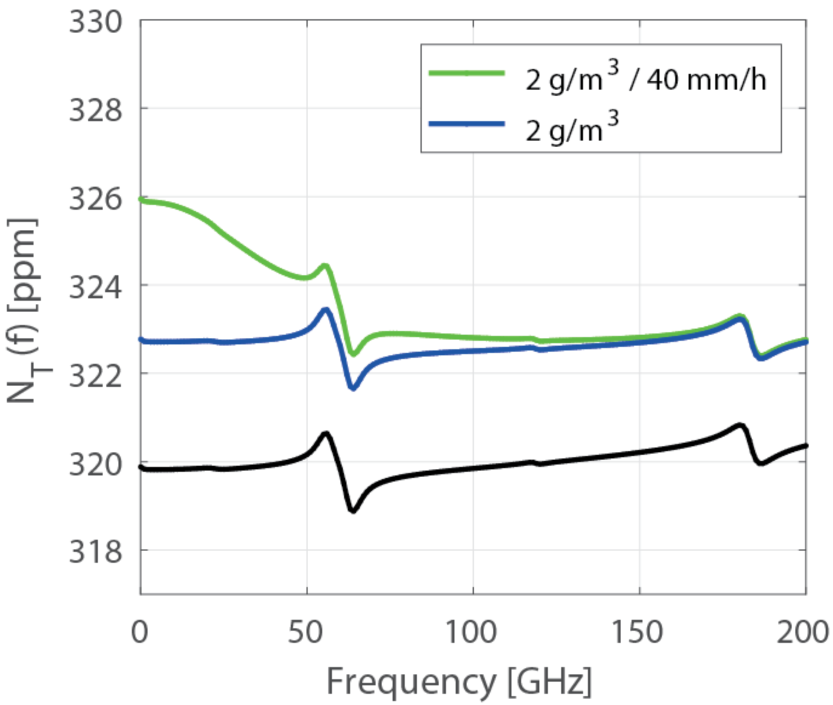
Refractivity and Clouds

Dispersive (frequency-dependent) refractivity:

$$N_T(f) = N_0 + N'(f) + jN''(f)$$

$$N_0 = 77.6\frac{P}{T} + 3.73 \times 10^5 \frac{e}{T^2} + N_S$$

where N_S is scattering by particles (**cloud water**, **rain**)



Clouds characterisation in NWM:

- liquid water content (*LWC*)
- ice water content (*IWC*)

$$N_{L,I} = \frac{3}{2} \times 10^6 \left[\frac{\varepsilon_{L,I} - 1}{\varepsilon_{L,I} + 1}\right] \frac{M_{L,I}}{\rho_{L,I}}$$

$$N_L \approx 1.45\, LWC$$
$$N_I \approx 0.69\, IWC$$

- liquid water path (*LWP*)
- ice water path (*IWP*)

$$LWP = \int_{z=0}^{\infty} \rho_t Q_L dz$$

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Motivation

Anchor observations:

- RO data enter NWM without bias correction

Quality control:

- Observation minus Background (O-B)

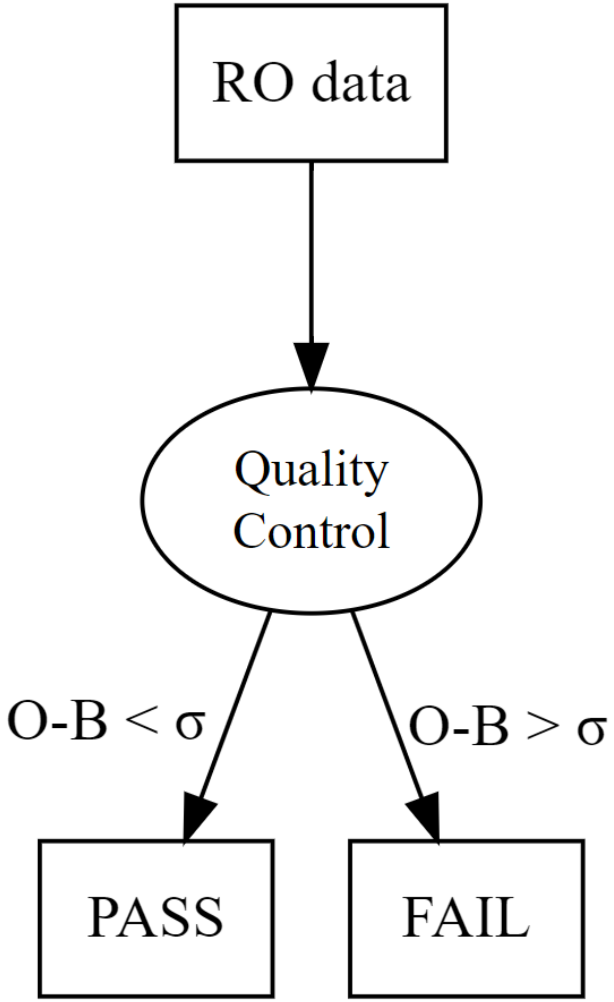
σ threshold based on observation error

***N errors (Healy et al., 2005)*:**

- 1.1% at 4 km to 0.25% at 10 km

***α errors (Healy and Thepaut, 2006)*:**

- 10% at surface to 1% at 10 km



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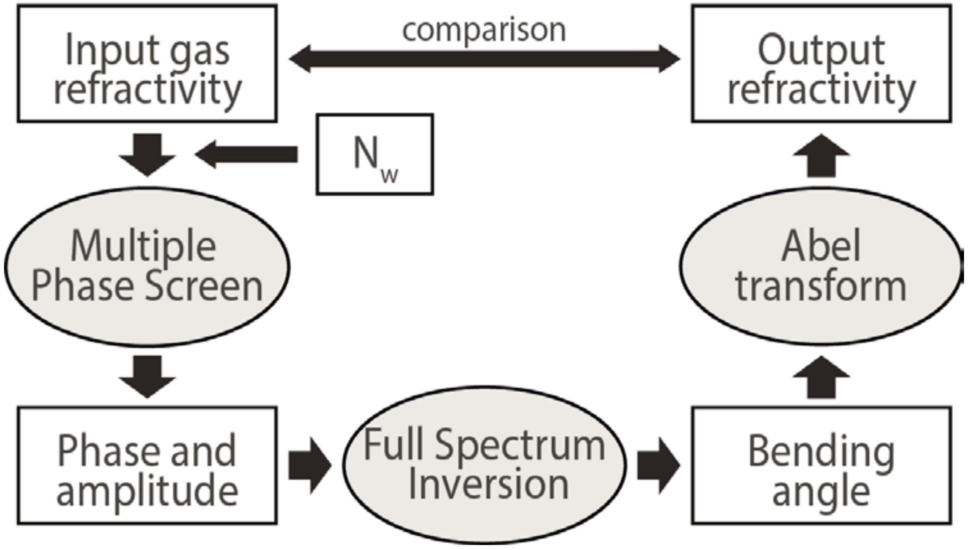
Methodology

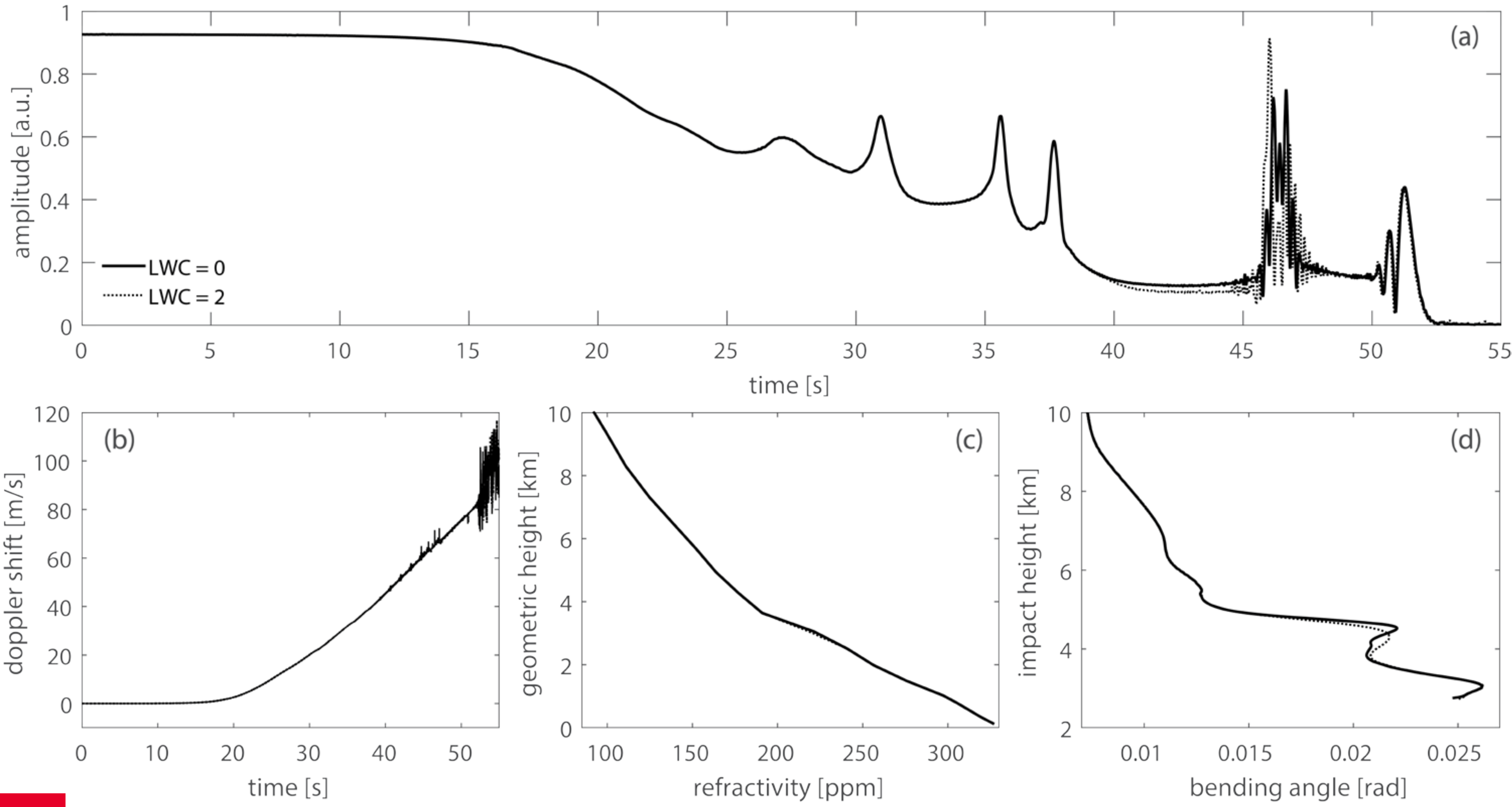
Background model:

- GFS forecasts
- +03 timestep
- 0.5º x 0.5º resolution
- 4/day model cycle

- yearly dataset (2016)
- end-to-end simulations
- multiple phase screen
- 1D/2D atmosphere



Example of Simulation Result



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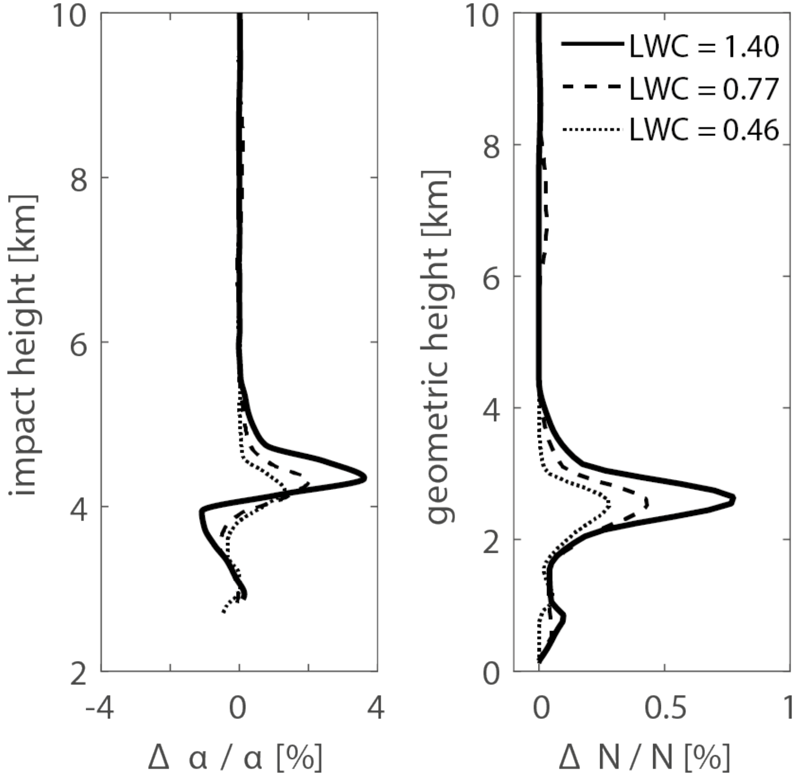
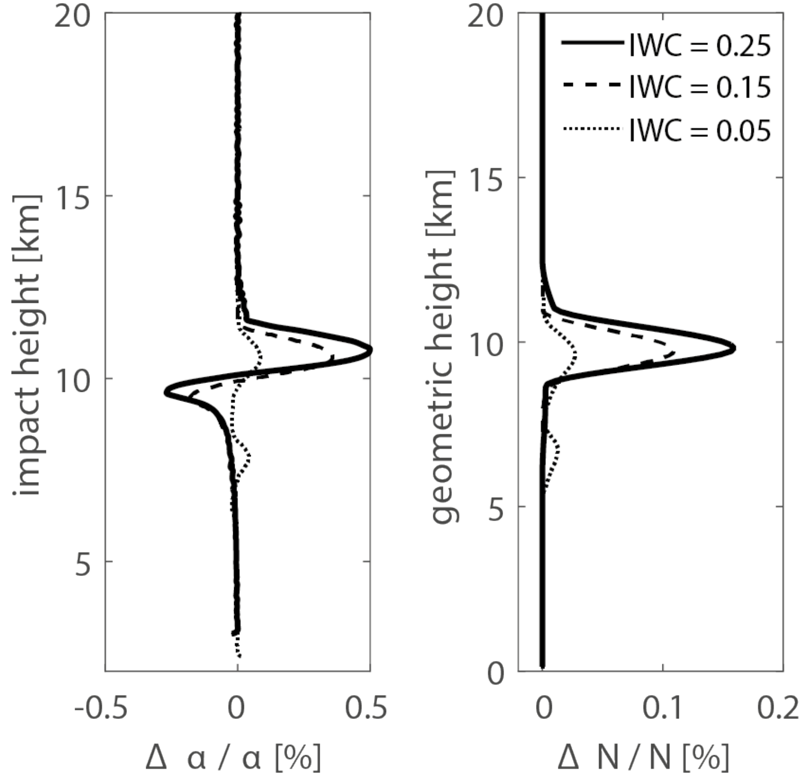
Simulation Results: LWC vs. IWC

LWC:



IWC:



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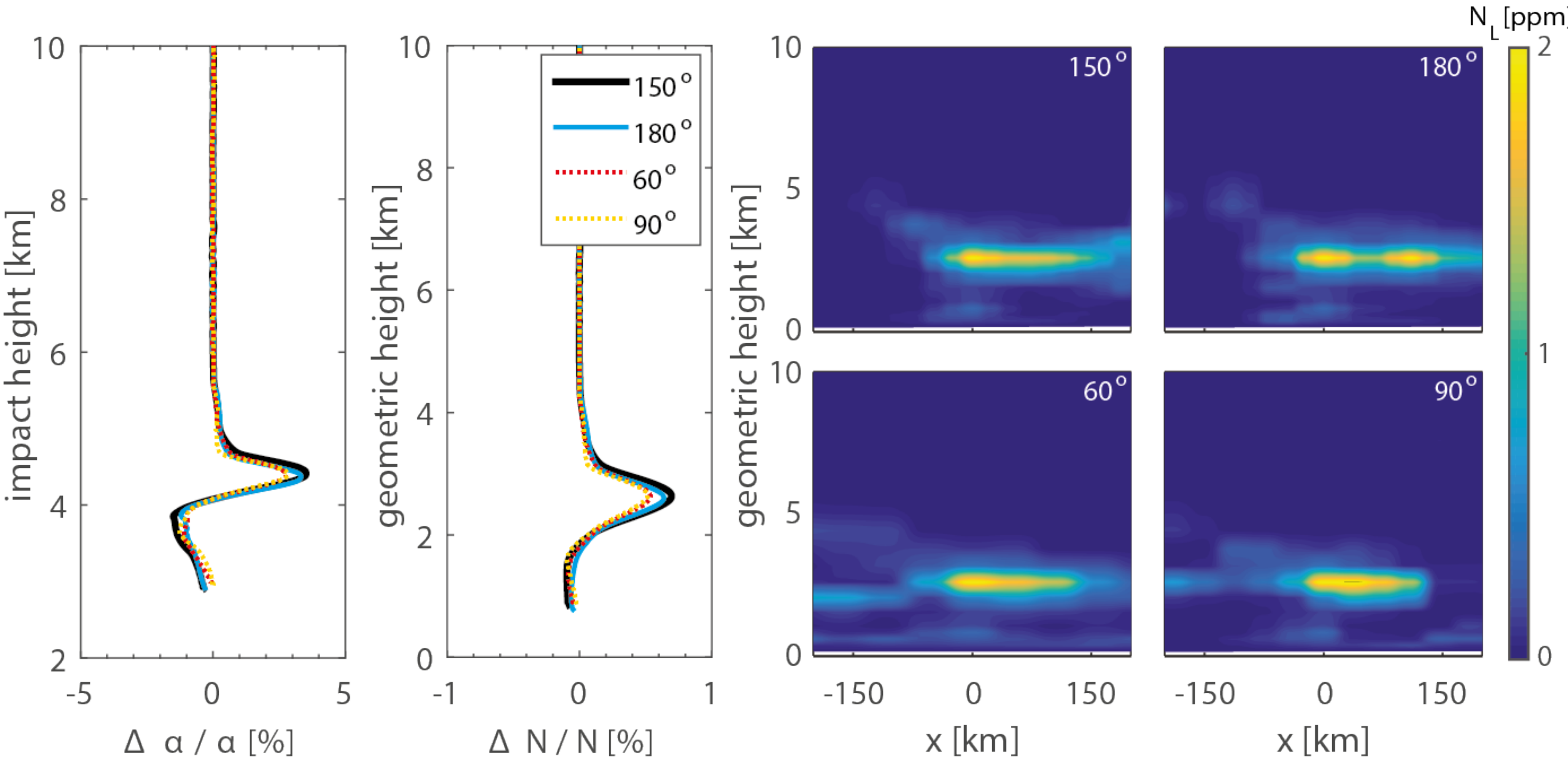
Horizontal Inhomogeneities



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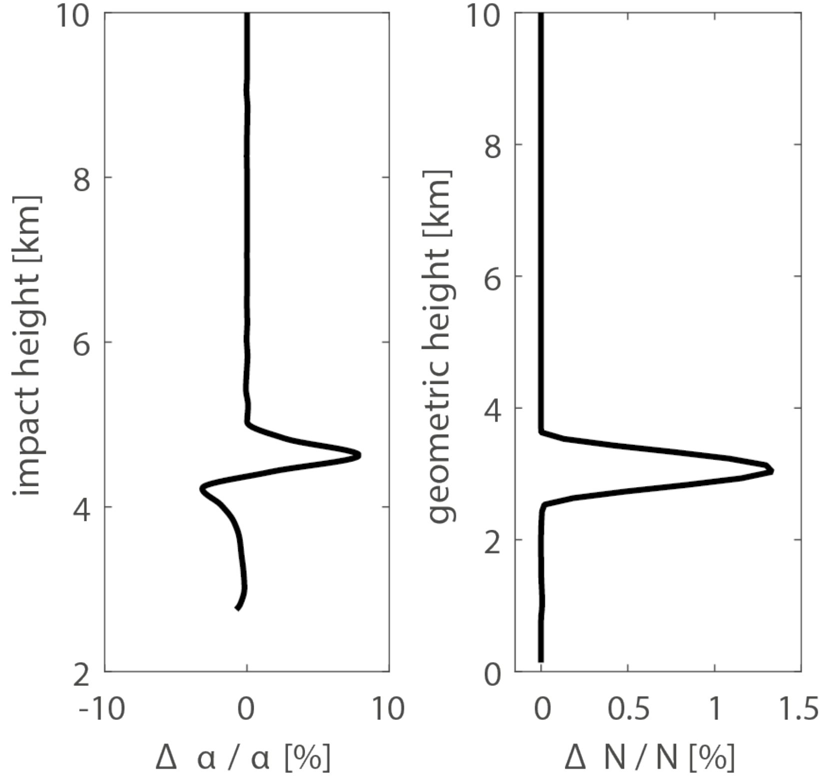
Simulation Results: LWC vs. LWP

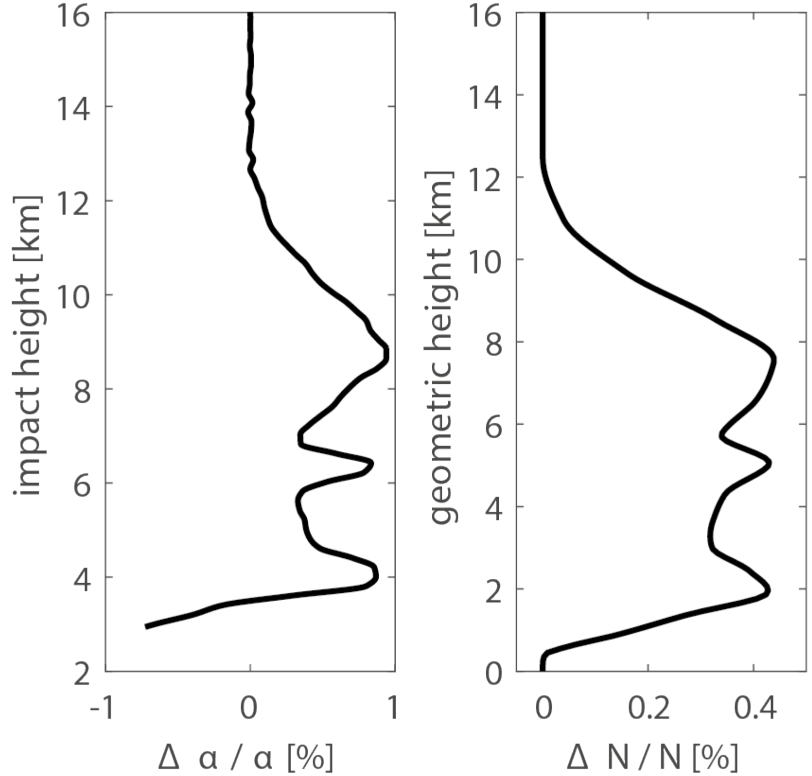
Large LWC, small LWP:

- *LWC = 2 g/m³*
- *LWP = 1.2 kg/m²*



Small LWC, large LWP:

- *LWC = 0.9 g/m³*
- *LWP = 4.3 kg/m²*



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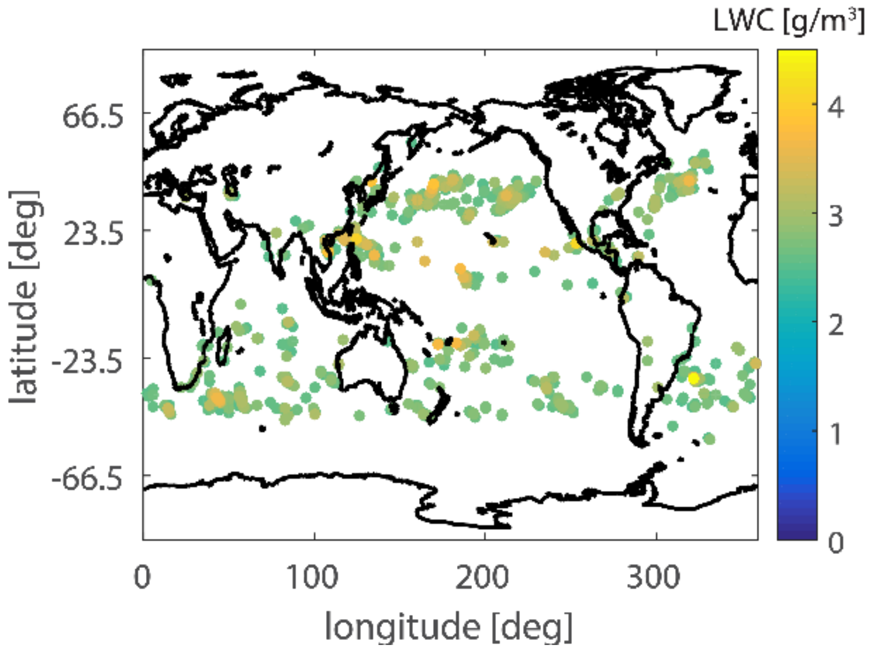
Spatial Distribution of Clouds

LIQUID



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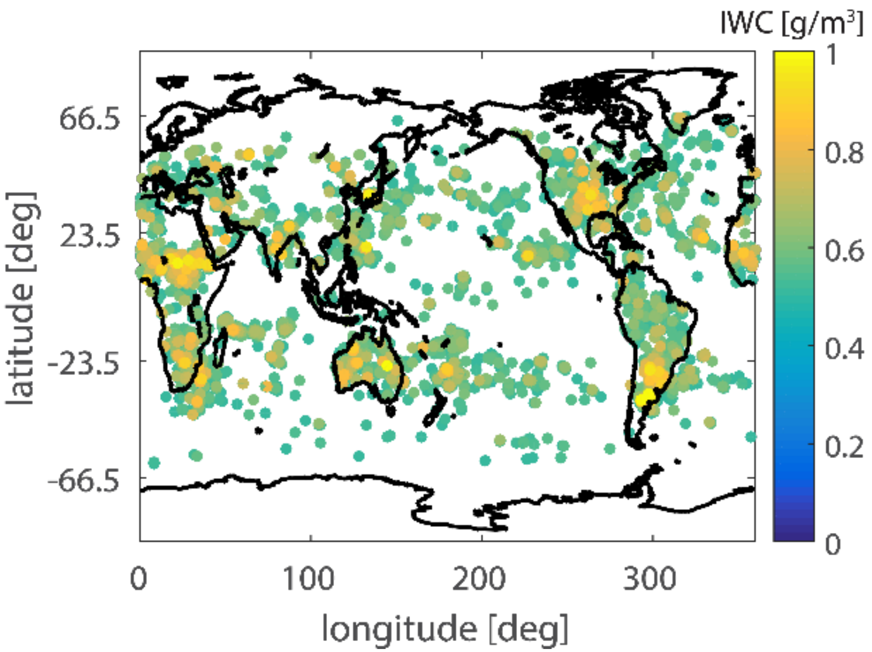

LWC: over wa … er lands

	Latitudinal Zone		
Hemisphere	Tropical	Subtropical	Temperate
LWC > 2.5 g/m^3			
Northern	143	105	192
Southern	66	121	179
IWC > 0.5 g/m^3			
Northern	1054	484	773
Southern	823	851	265

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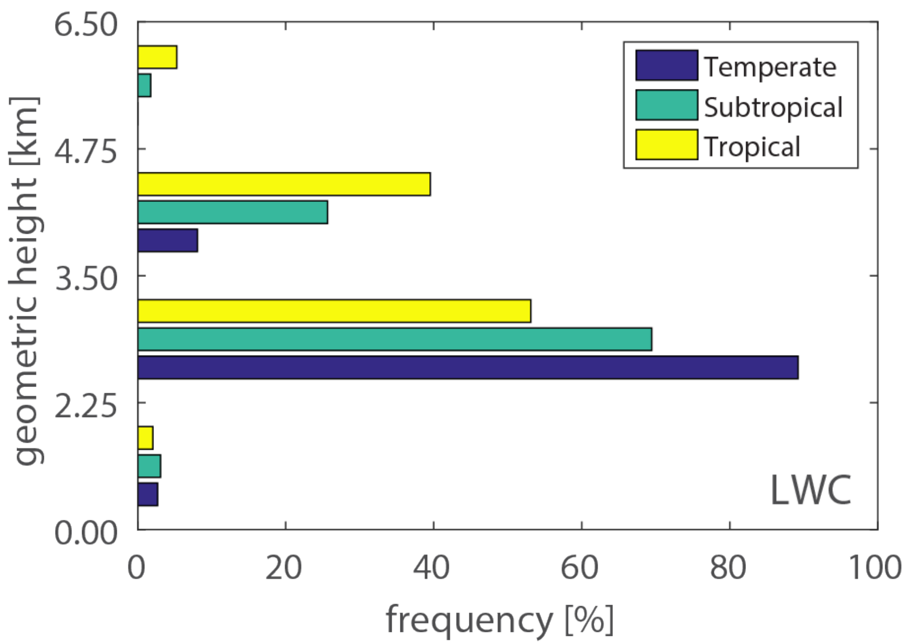
Vertical Distribution of Clouds

LIQUID



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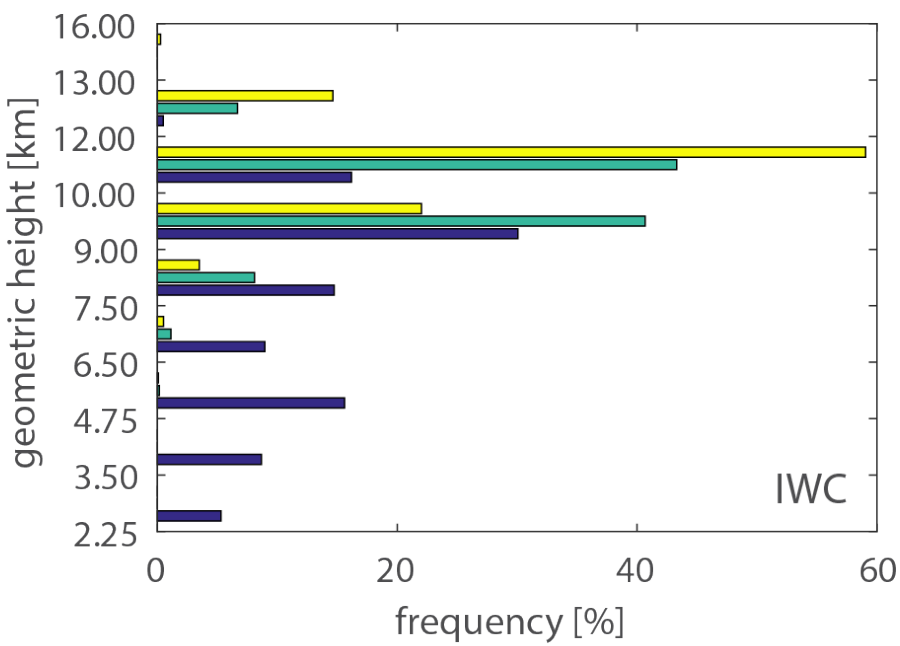
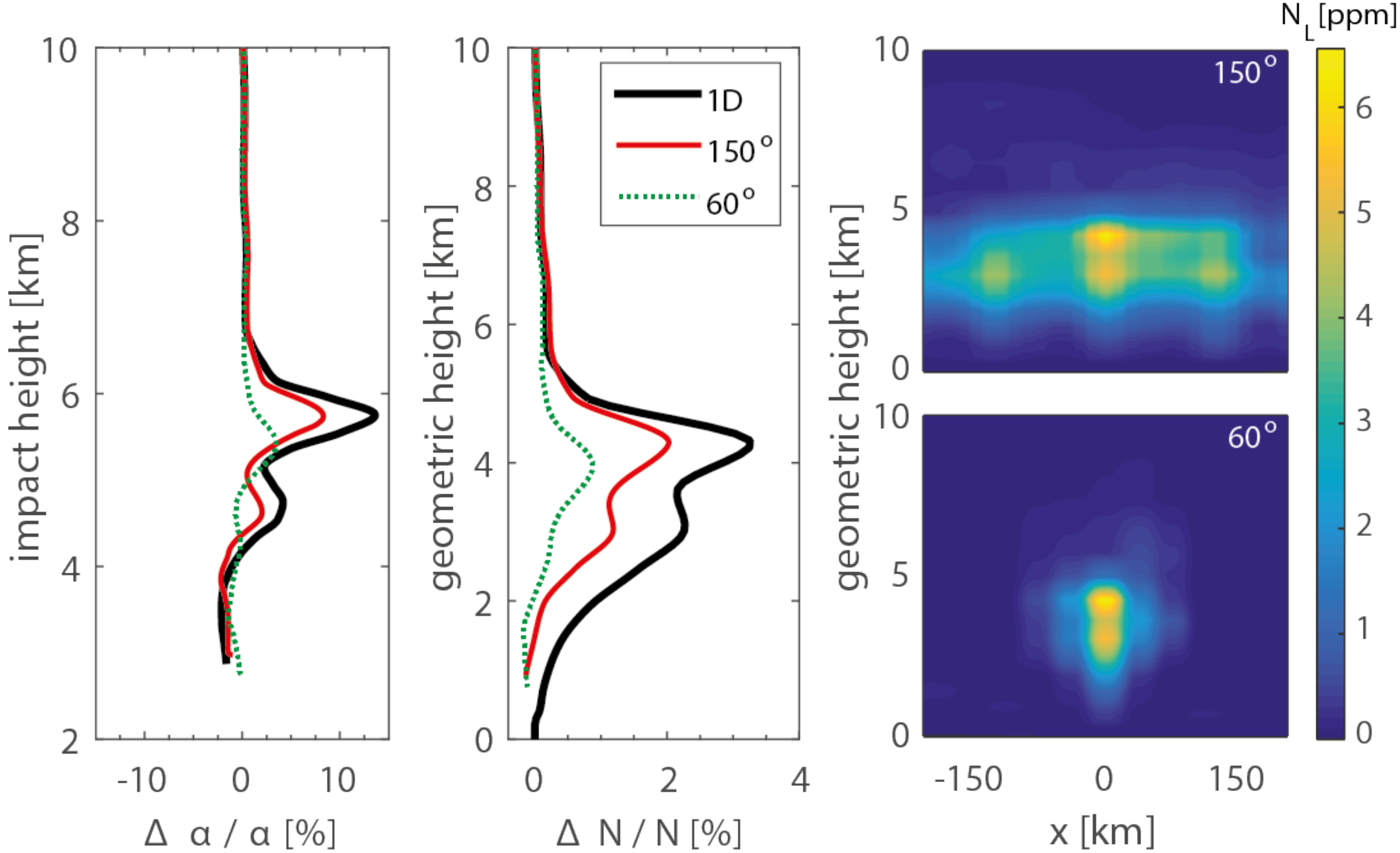


LWC: over water bodies
altitude ~4 km

IWC: over lands
altitude 10-12 km (UTLS)

Liquid Clouds - “Worst Case”

***N* observation error (Healy et al. 2005):** **1.1% at 4 km**



LWC = 4 g/m³

2-d structure: 1-2%

1-d structure: ~4%

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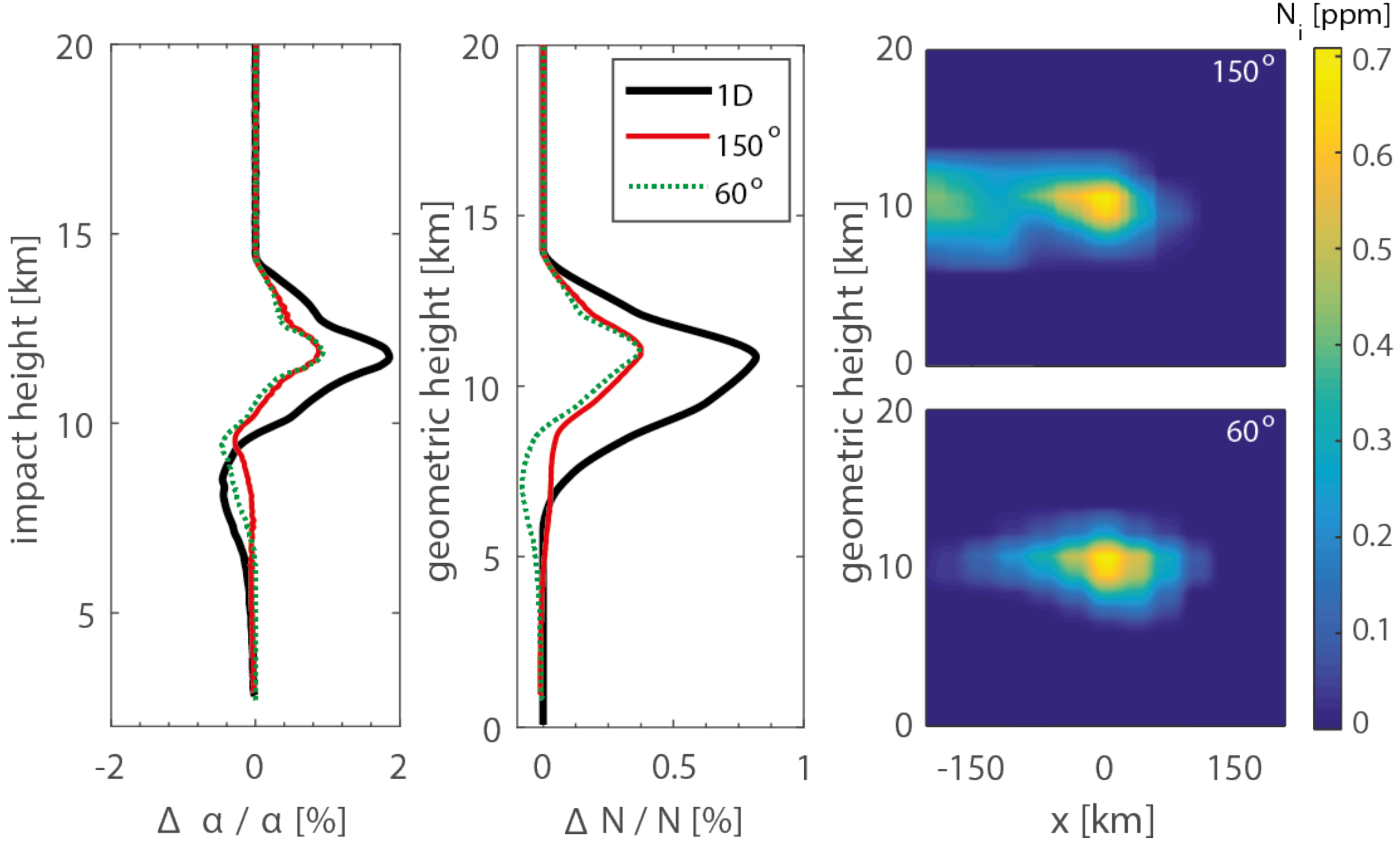
Ice Clouds - "Worst Case"

***N* observation error (Healy et al. 2005):** **0.25% at 10 km**



IWC = 1 g/m³

2-d structure: ~0.5%

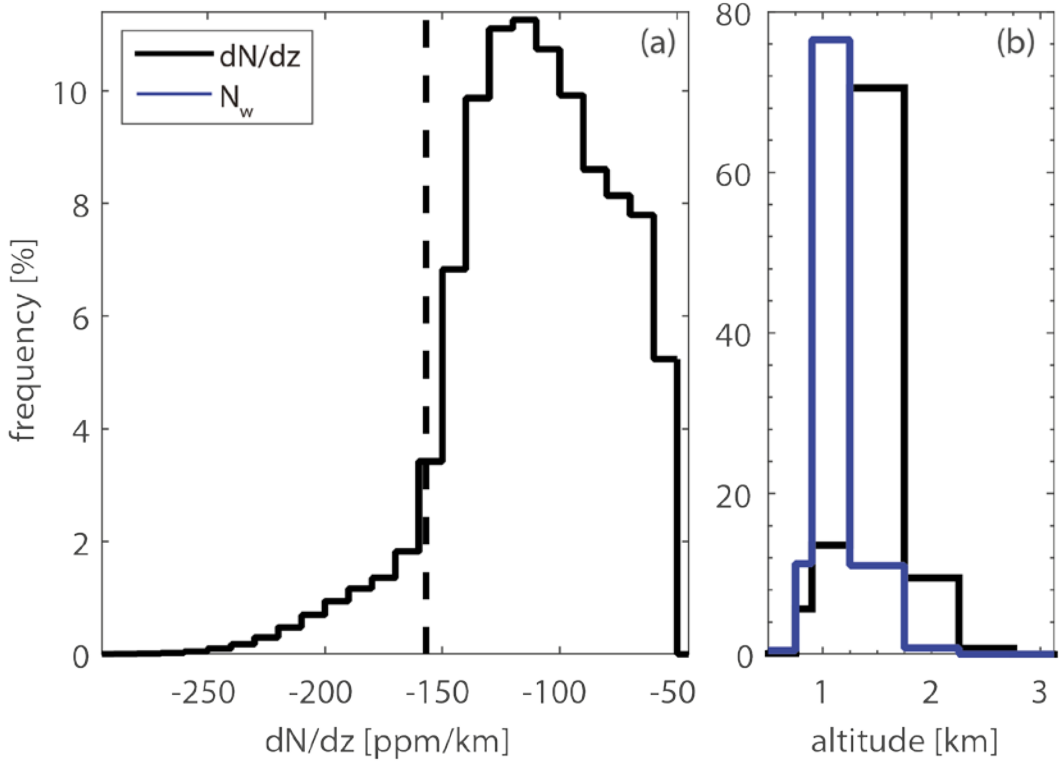
1-d structure: ~1%

Superrefractions and PBL Clouds

Yearly analysis for 2016:

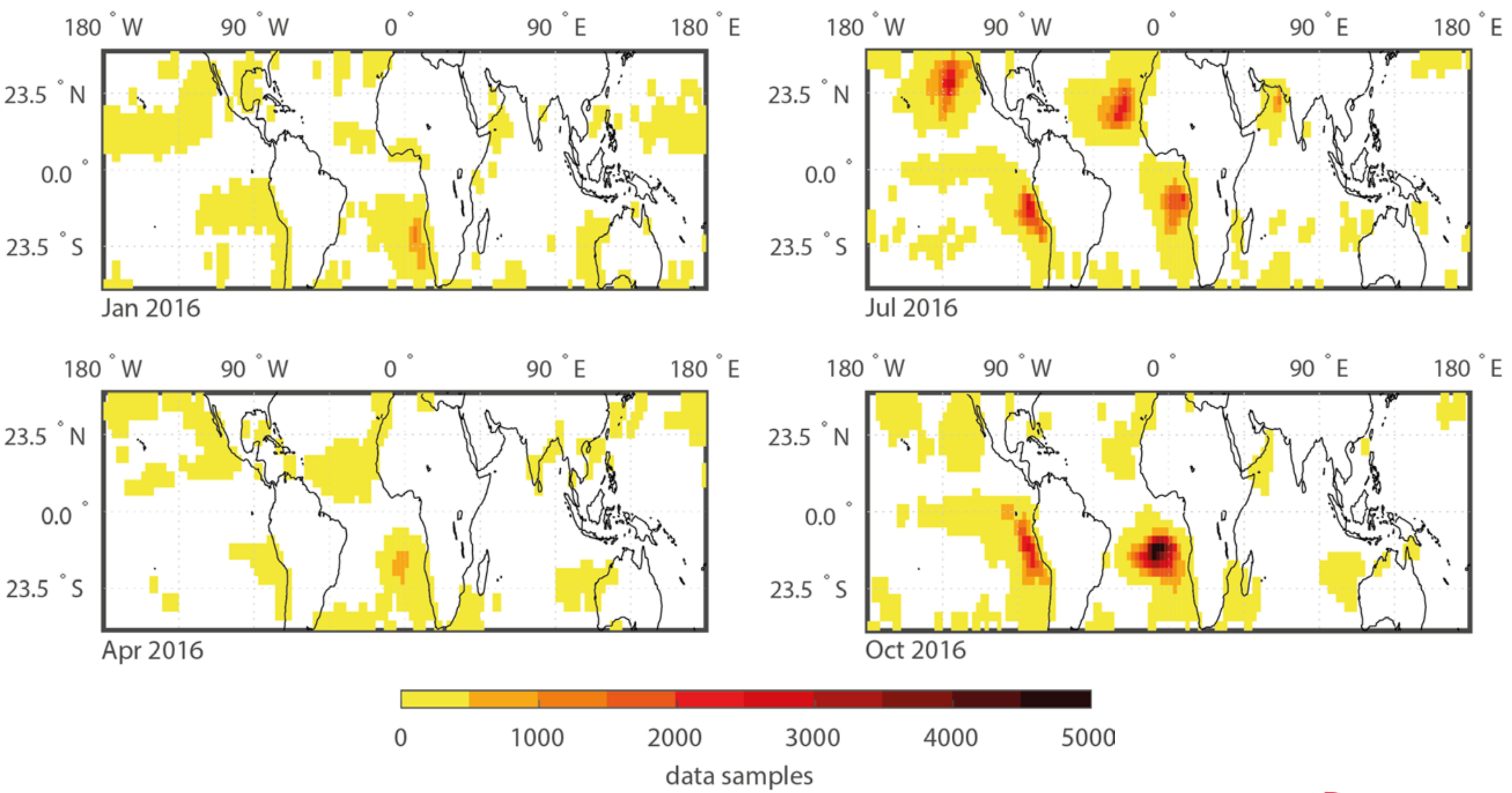
a) frequency distribution of refractivity gradients (*dN/dz*)

b) altitudes for min(*dN/dz*) and altitudes for max(N_w)

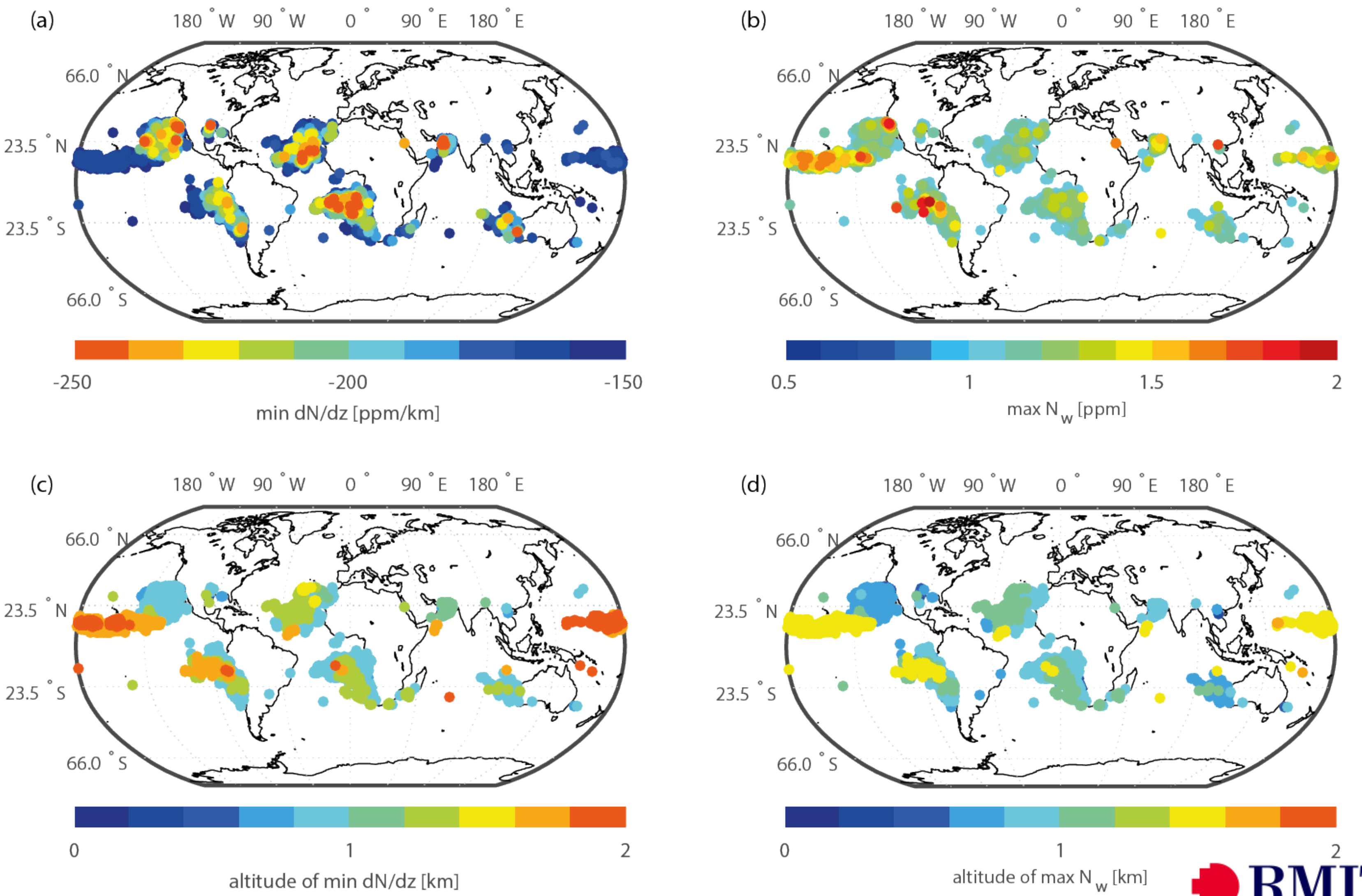


Distribution of PBL Clouds

Gridded 2.5º x 2.5º monthly data



Superrefractions with $N_w \geq 1$ ppm



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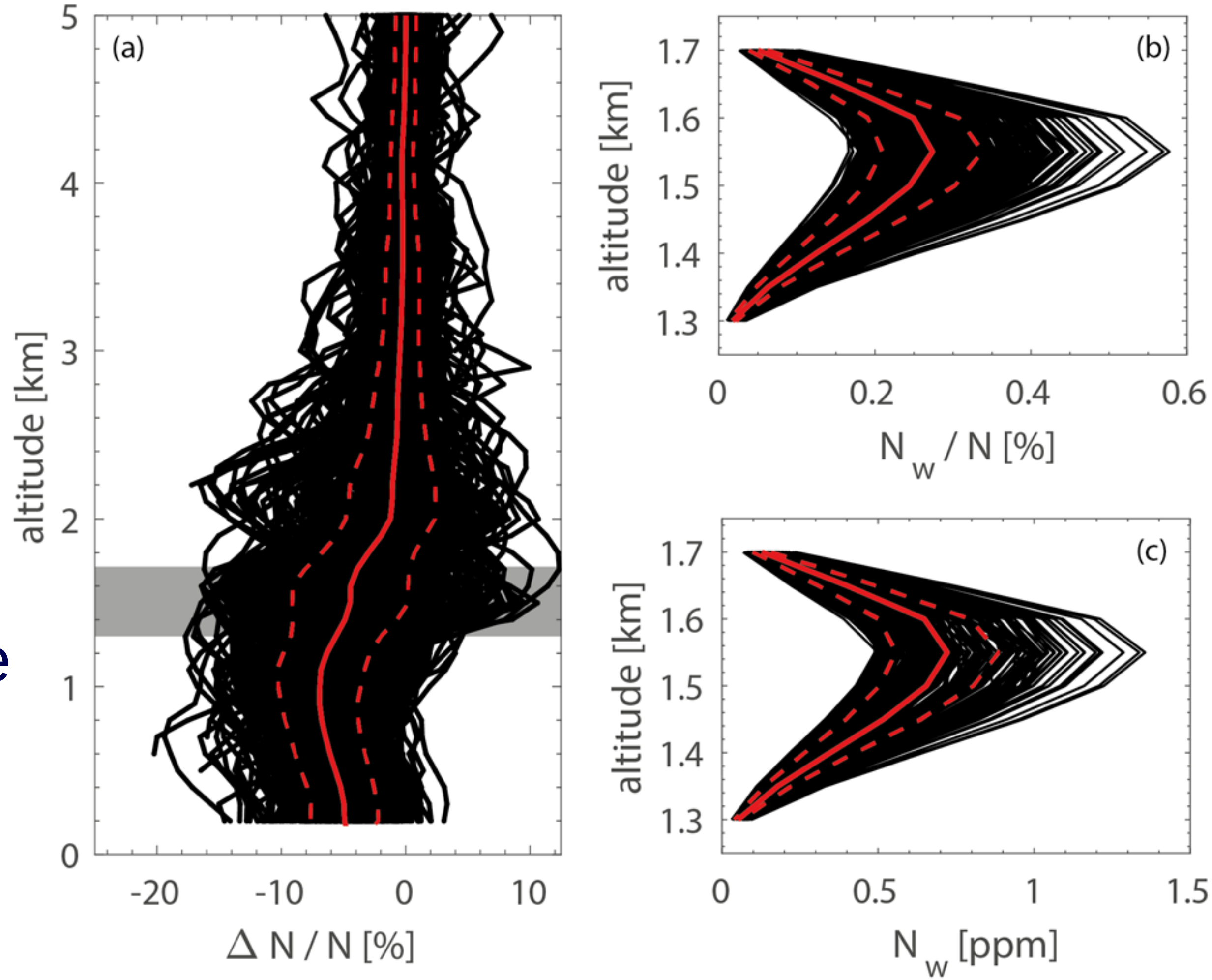
Pacific Region, Jan 2016

- atmPrf refractivity
- collocation with GFS N-profiles

- PBL clouds higher in the troposphere
- vertically extensive N-bias



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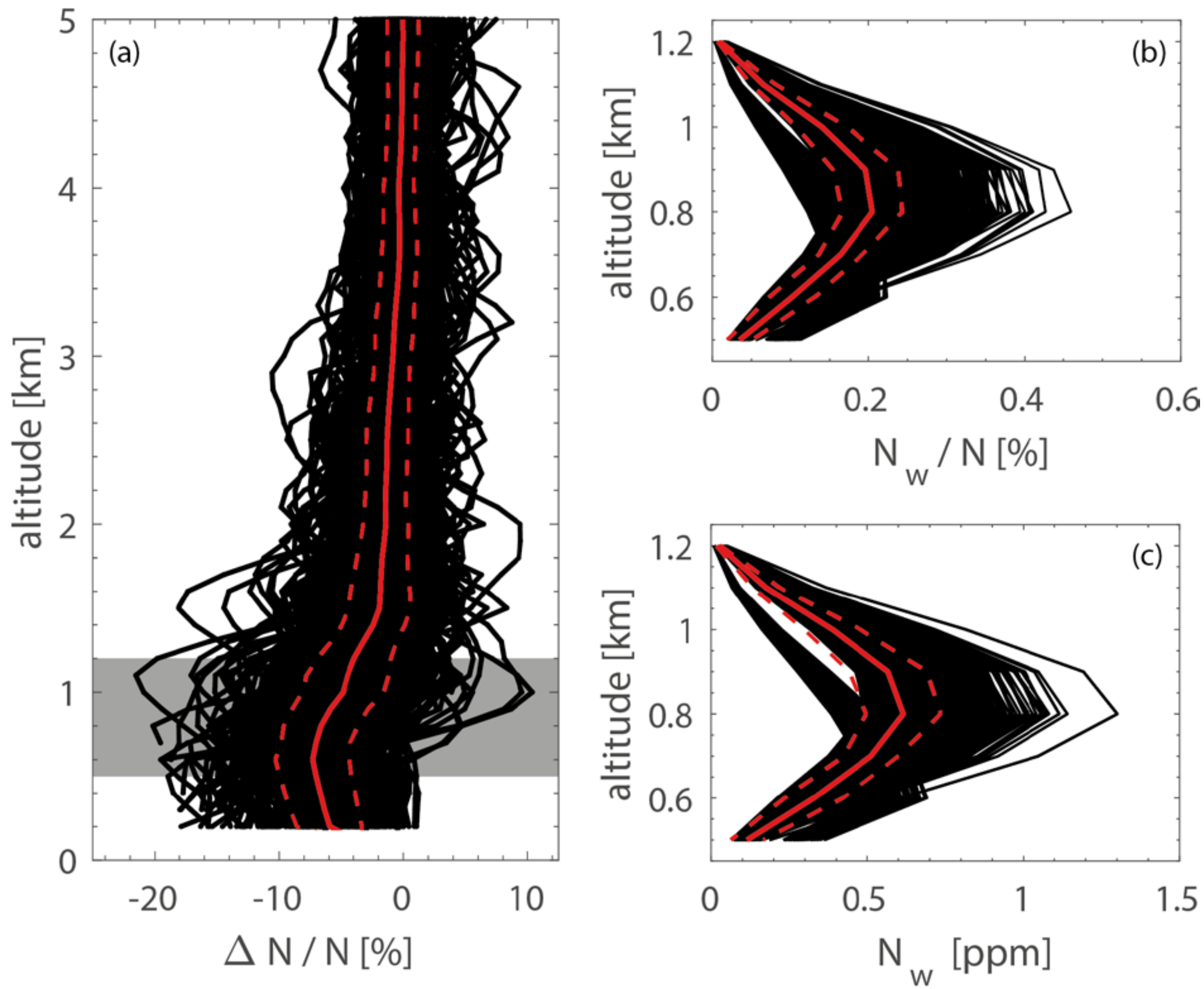
Atlantic Region, SON 2016

- atmPrf refractivity
- collocation with GFS N-profiles
- PBL clouds low in the troposphere
- less vertically extensive N-bias



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Summary

1. Clouds contributions can reach and exceed observation errors.
2. Liquid clouds dominate at 4 km.
3. Ice clouds affect the core region of GPSRO in the UTLS.
4. PBL clouds associated with negative N-bias.

References:

Hordyniec P. (2018). *Simulation of liquid water and ice contributions to bending angle profiles in the radio occultation technique*. Advances in Space Research. 62(5), pp. 1075-1089, doi: 10.1016/j.asr.2018.06.026

Hordyniec P., Norman R., Rohm W., Huang C.-Y., Le Marshall J. (2019). *Effects of liquid clouds on GPS radio occultation profiles in superrefractions*. Earth and Space Science, doi: 10.1029/2019EA000721.

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Thank you for your attention

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