DACAPO-PESO: REMOTE SENSING AND IN-SITU OBSERVATIONS IN SUB-ANTARCTICA (53° S,71° W) TO ENHANCE THE UNDERSTANDING OF AEROSOL-MOISTURE-CLOUD-PRECIPITATION INTERACTION

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Europa fördert Sachsen. ESF

Diese Maßnahme wird mitfinanziert durch Steuermittel auf Grundlage des von den Abgeordneten des Sächsischen Landtags beschlossenen Haushaltes.

OUTLINE

1. **DACAPO-PESO – Why measure at the Southern tip of Patagonia?**

2. Contrasting mixed-phase cloud statistics in Southern and Northern Hemisphere

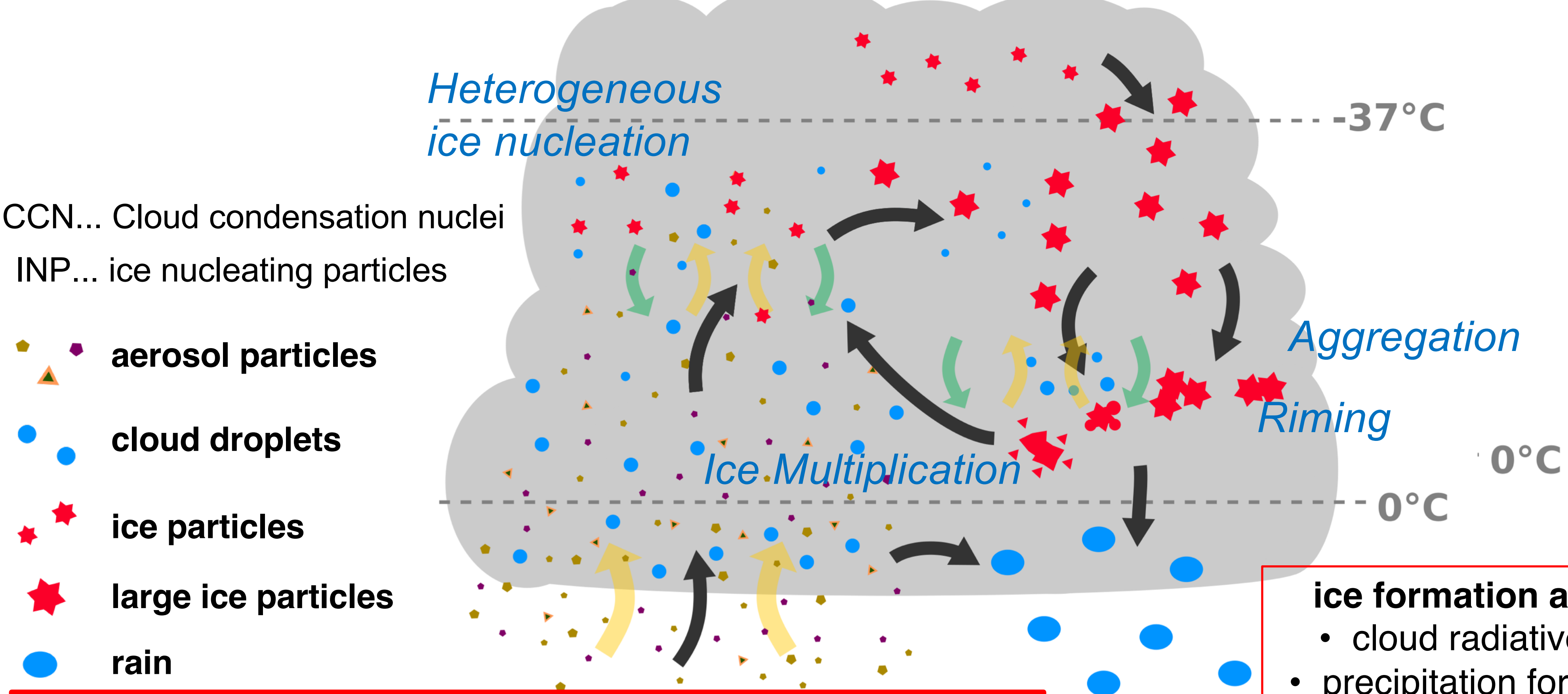
3. Developing methods to identify differences in thick mixed-phase clouds between SH and NH

DACAPO-PESO

THE ROLE OF AEROSOL IN MIXED-PHASE CLOUD PROCESSES

CCN... Cloud condensation nuclei

INP... ice nucleating particles

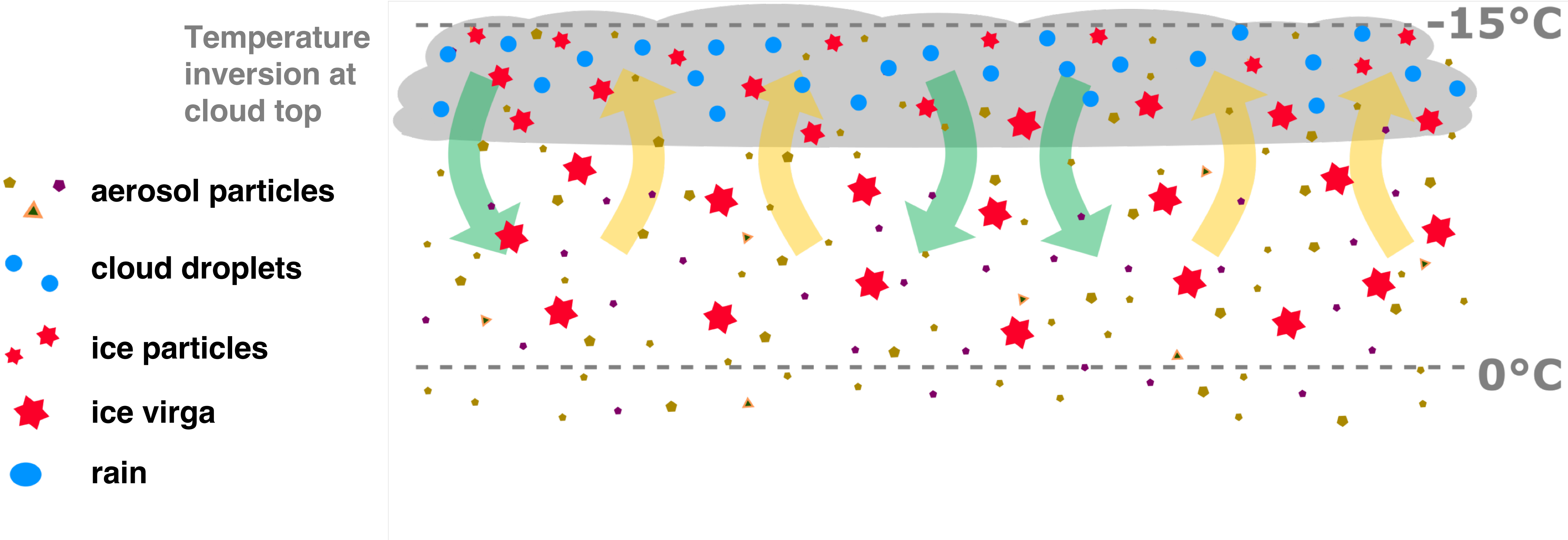


ice formation affects:
- cloud radiative prop.
- precipitation formation
- cloud lifetime

But how can we pin down potential aerosol effects?

BUT HOW CAN WE PIN DOWN POTENTIAL AEROSOL EFFECTS?

(1) Pick <u>shallow</u> (< 300 m thick) mixed-phase clouds as natural laboratory to constrain (thermo-)dynamics, ice multiplication, riming and aggregation



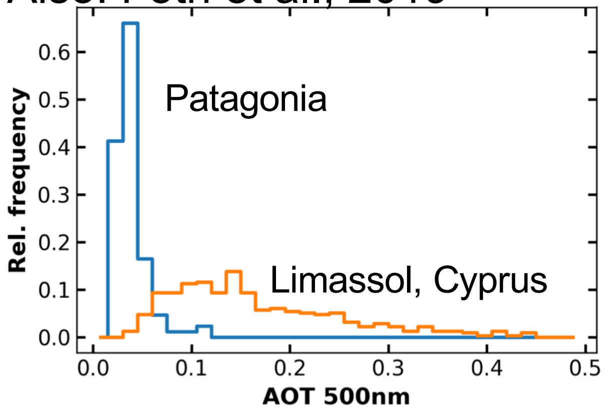
BUT HOW CAN WE PIN DOWN POTENTIAL AEROSOL EFFECTS?

Mean concentration of CCN:

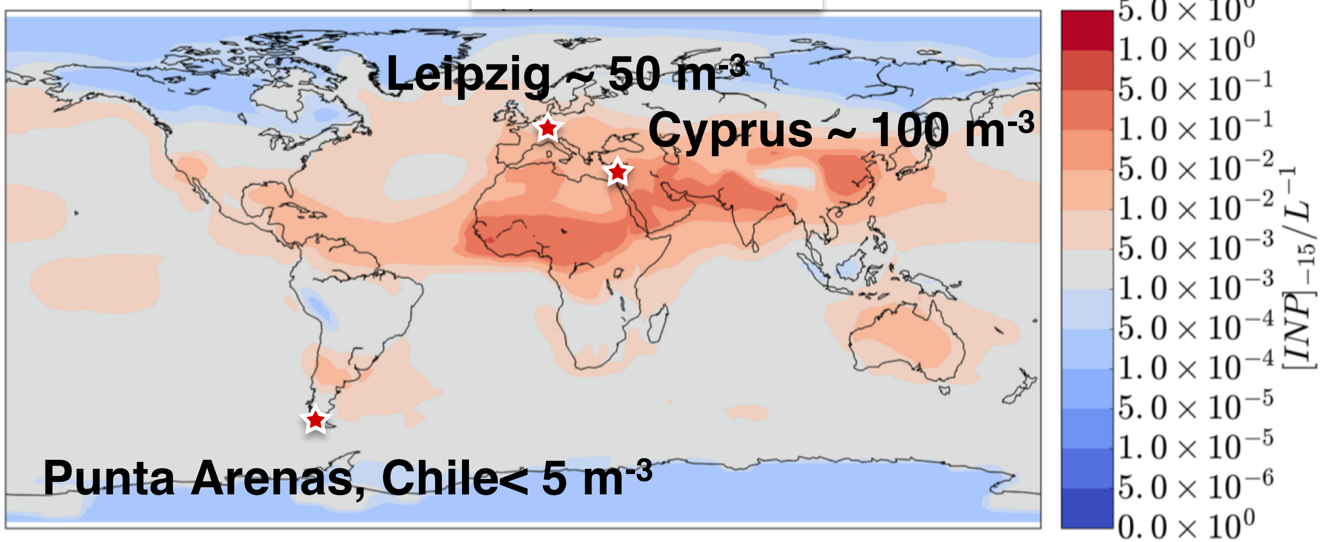
- Large differences in SH and NH
- ~ factor of 10-20 more in NH (Hamilton et al., 2014)

Statistics of AOT:

- Much lower values in mid lat of SH
- Also: Foth et al., 2019



Mean concentration of INP at ground
for -15°C (dust and marine biogenic)



Vergara-Temprado et al., 2017

Sub-Antarctic region (e.g., Punta Arenas, Chile): very low concentration of CCN and INP
→ ideal place for studying atmosphere & clouds in generally very low aerosol loads

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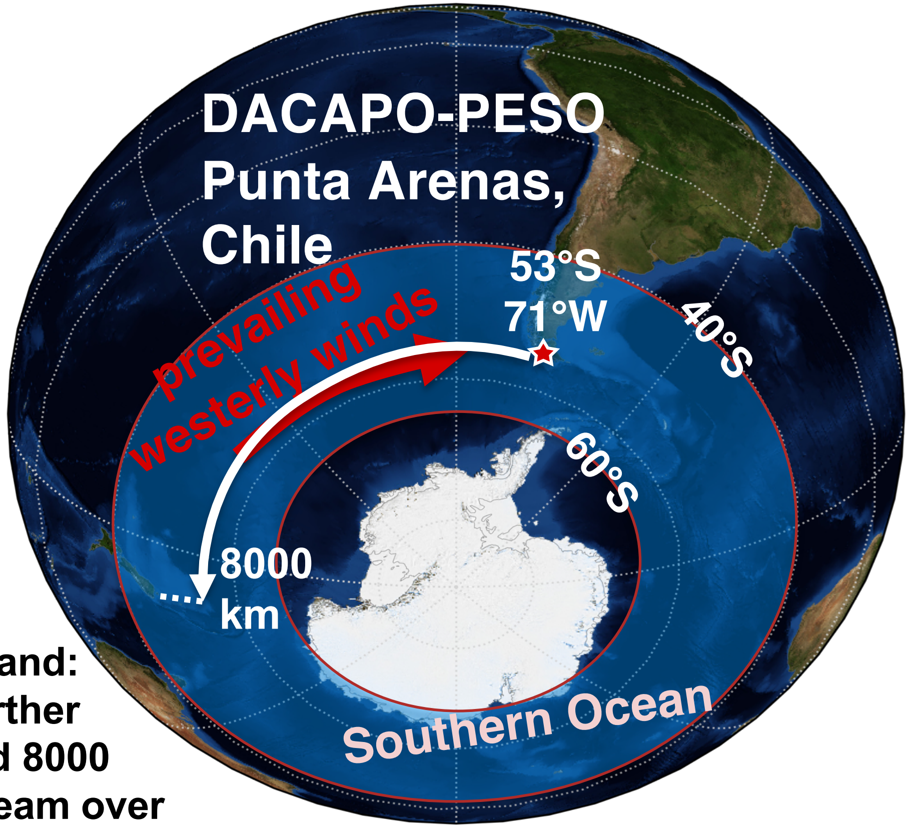


New Zealand:
7° lat. further North and 8000 km upstream over Southern Ocean

DACAPO PESO

Dynamics, **A**erosol, **C**loud and **P**recipitation **O**bservations in the **P**ristine **E**nvironment of the **S**outhern **O**cean

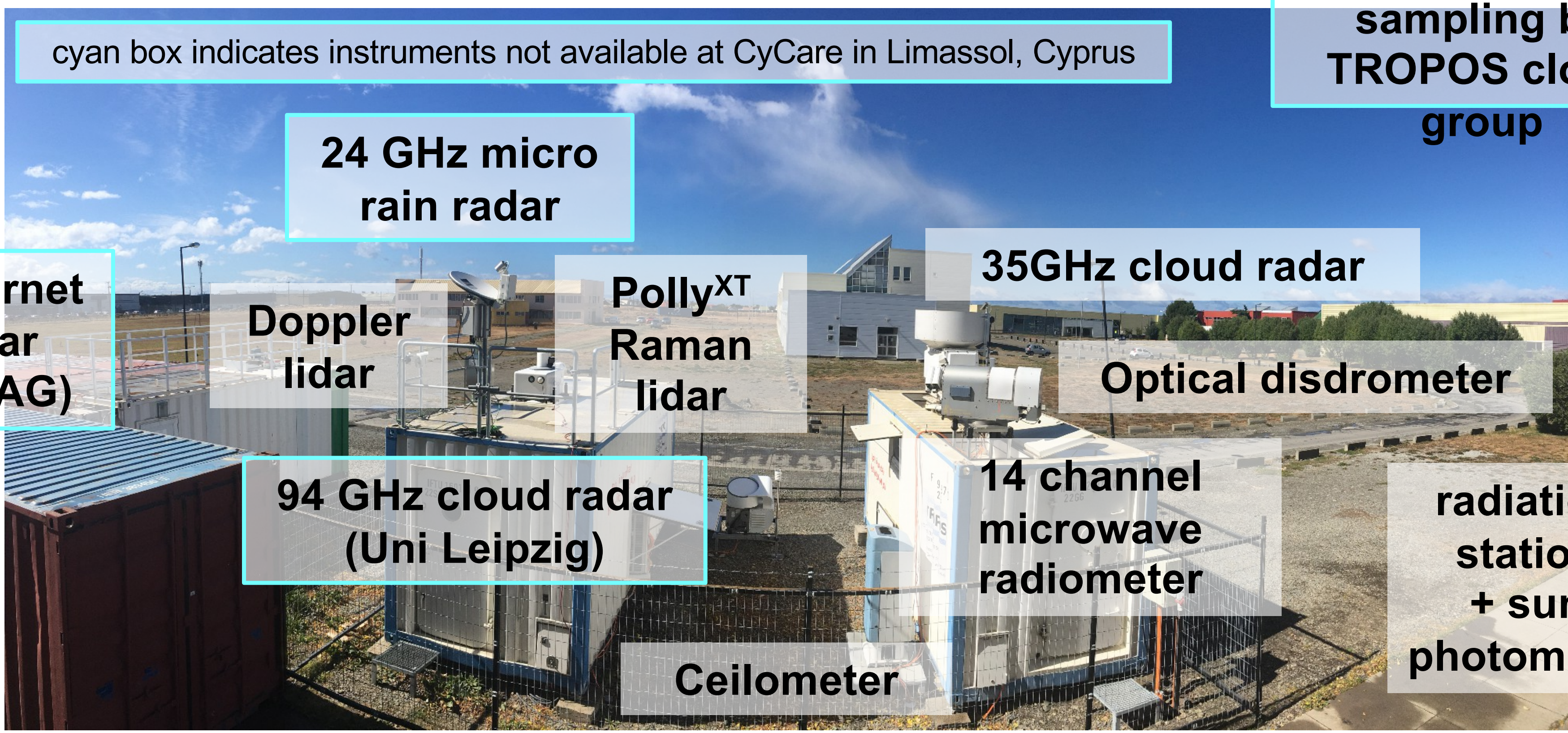
https://dacapo.tropos.de

LACROS: Leipzig Aerosol and Cloud Remote Observation System

Dynamics, Aerosol, Cloud and Precipitation Observations in the Pristine Environment of the Southern Ocean

measurements in Punta Arenas: Nov 2018 – summer 2020

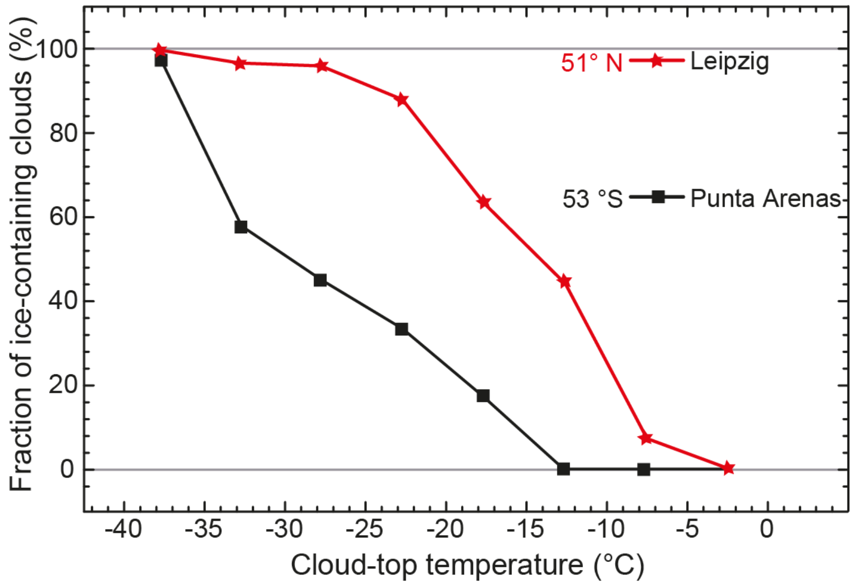
upwind in-situ sampling by TROPOS cloud group



LIDAR OBS. OF REGIONAL DIFFERENCES IN ICE FORMATION EFFICIENCY

- Derive cloud-top height and thermodynamic phase from long-term **lidar** datasets

Variability in ice formation explainable by differences in background aerosol load?!



Ansmann et al., 2009; Seifert et al., 2010; Kanitz et al., 2011; Seifert et al., 2015

Objective: Quantify the lidar-observed contrasts with synergistic ground-based instrumentation

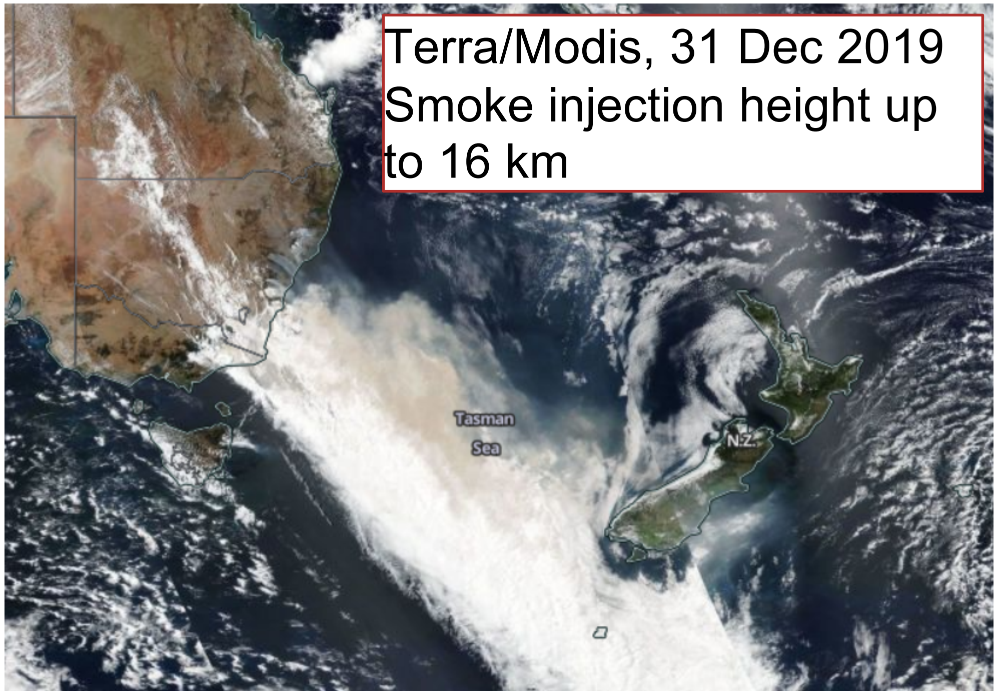
OUTLINE

1. **DACAPO-PESO – Why measure at the Southern tip of Patagonia?**
   a) **Australian Smoke – Interruption of pristine conditions from Nov 19 – Jan 20**
   b) **Atmospheric Rivers**
   c) **Continuous profiling of liquid cloud microphysics for aerosol-cloud-interaction studies**
2. Contrasting mixed-phase cloud statistics in Southern and Northern Hemisphere
3. Developing methods to identify differences in thick mixed-phase clouds between SH and NH

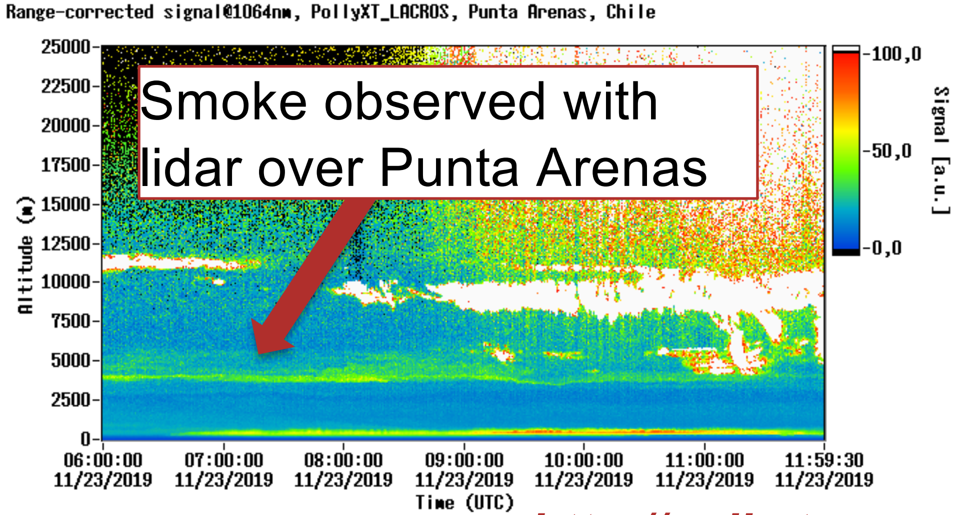
See also: Ohneiser et al: https://meetingorganizer.copernicus.org/EGU2020/EGU2020-5140.html

INTERRUPTION OF PRISTINE CONDITIONS FROM NOV 19, 2019

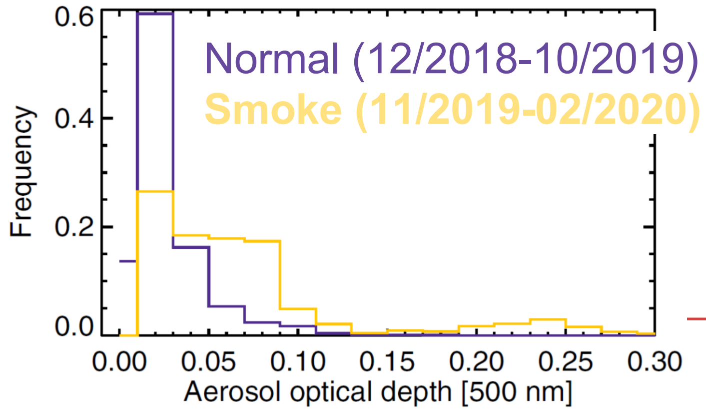
Record Australian wildfires produced unprecedented long-lasting tropospheric and stratospheric pollution over Punta Arenas



https://go.nasa.gov/3f9VRFq



http://polly.tropos.de



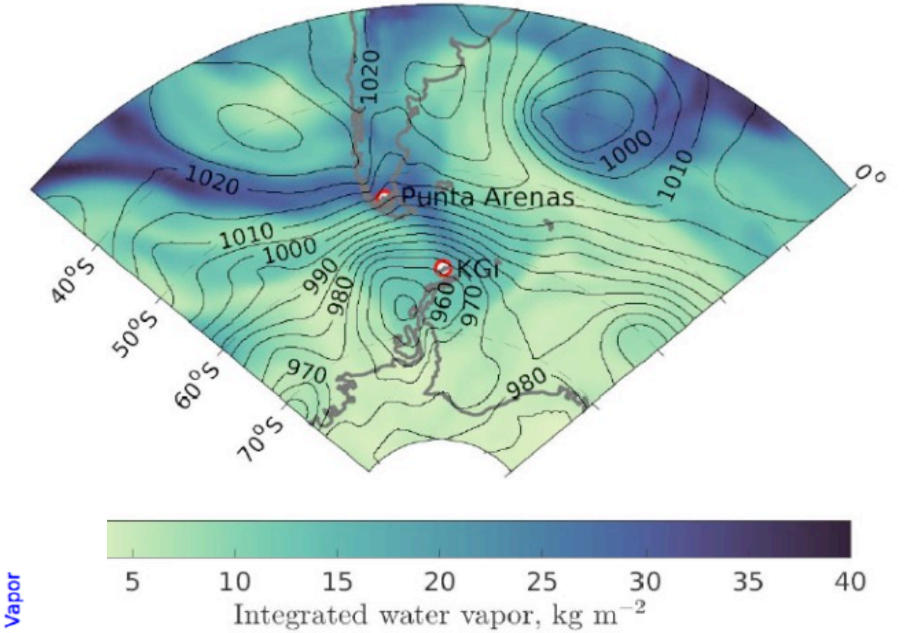
500-nm AOD@Punta Arenas

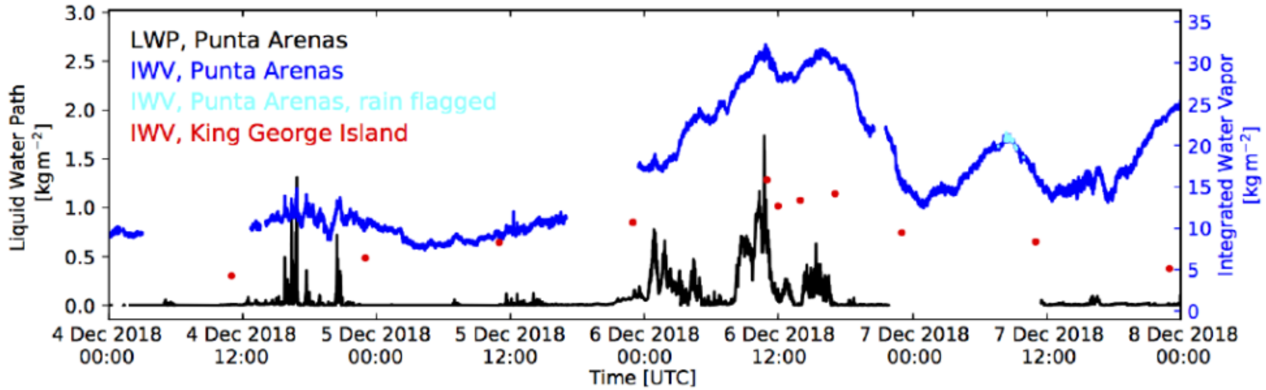
https://aeronet.gsfc.nasa.gov

See also: Gorodetskaya et al: https://meetingorganizer.copernicus.org/EGU2020/EGU2020-20313.html

ATMOSPHERIC RIVER EVENTS OVER PUNTA ARENAS

- Contribution of DACAPO-PESO to studies of atmospheric rivers
- Strong event observed from 6-8 Dec. 2018
- Contribution under review for BAMS (*Bromwich et al., 2020*)

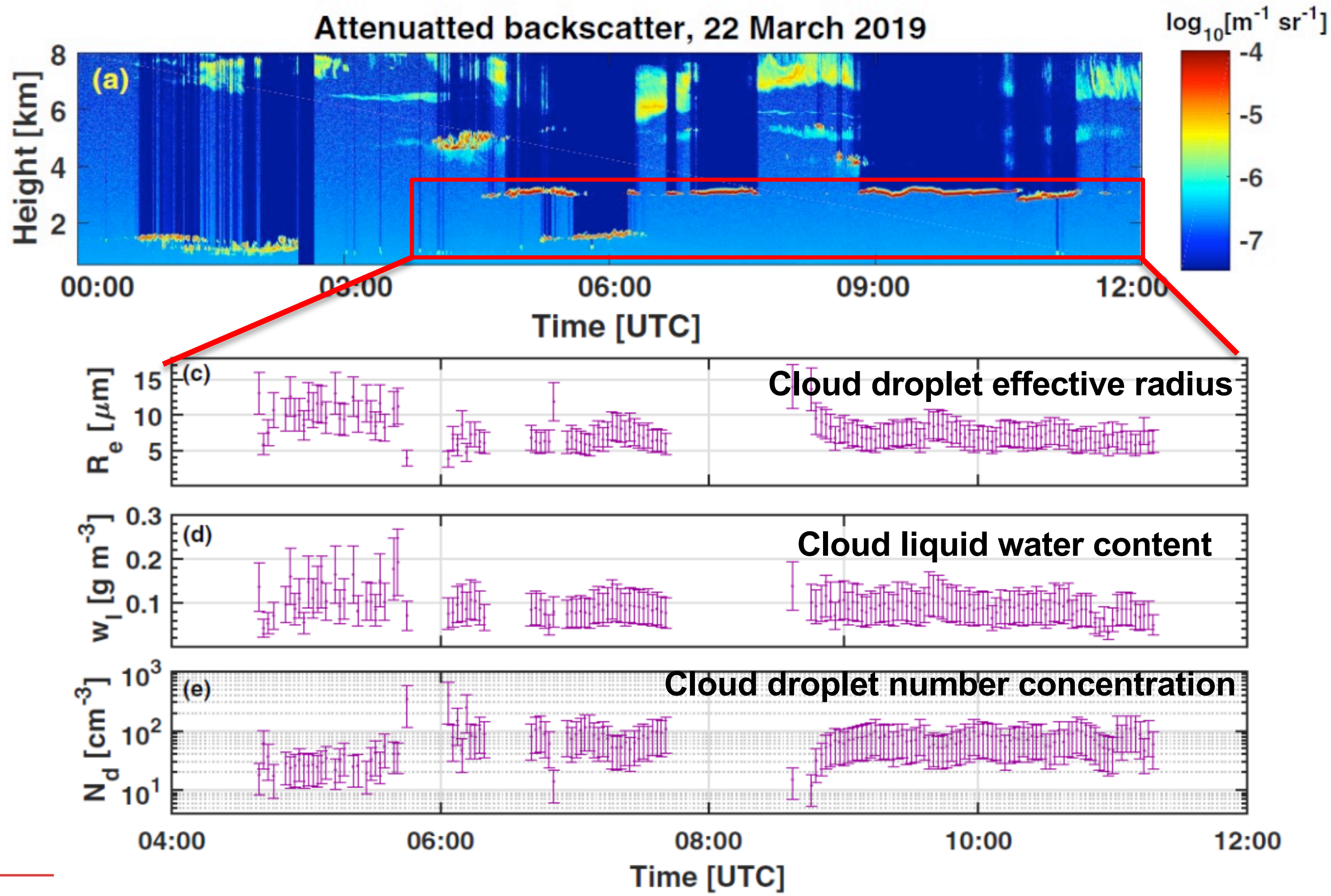




- Up to 30 kg m^{-2} over Punta Arenas
- Up to 15 kg m^{-2} over Antarctic King George Island

LIQUID CLOUD MICROPHYSICAL PROPERTIES FROM LIDAR OBS.

- **Dual-field-of-view lidar** (Polly^{XT}) observations provide **microphysical parameters of liquid water layers**. The same lidar instrument also provides aerosol optical properties, which permits **studies of aerosol-cloud interaction**
- **Resolution:** 7.5 m vertical; 30 s temporally; day- and nighttime



(Jimenez et al., 2020, in prep. for AMTD)

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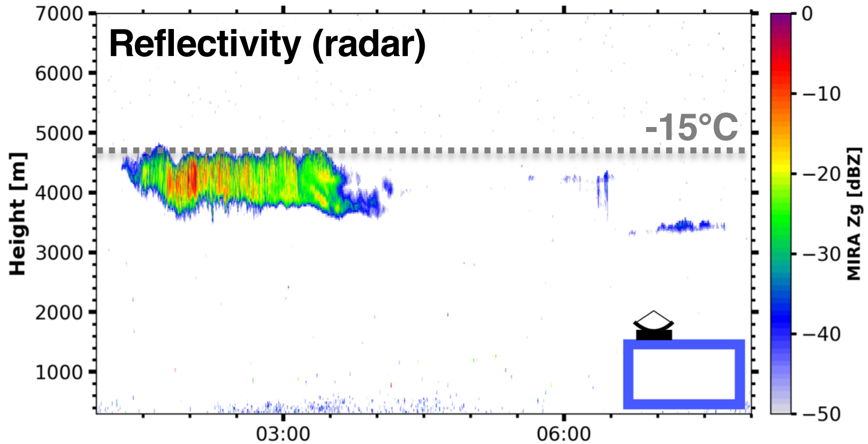
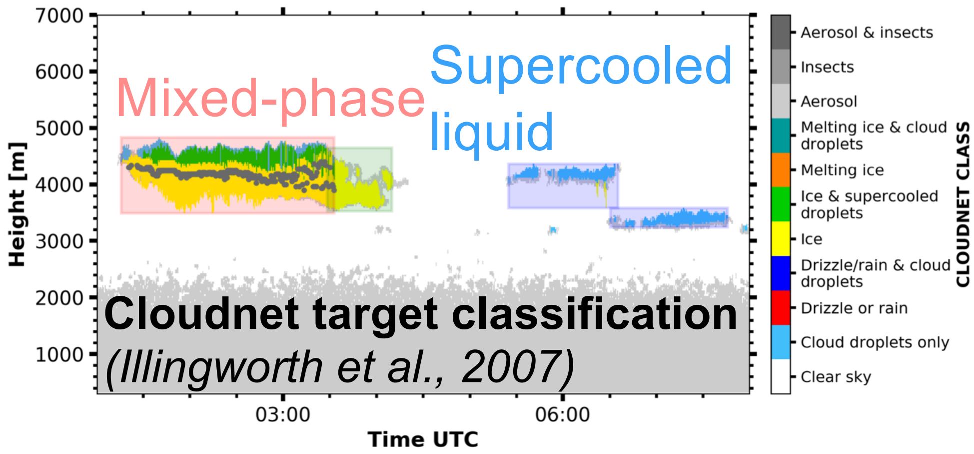
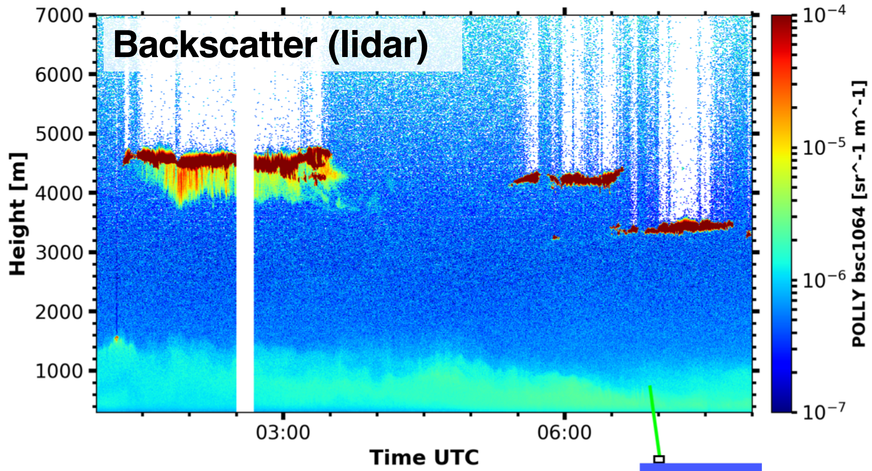
Deriving properties of mixed-phase and supercooled liquid clouds observed in Punta Arenas, 28 Nov 2018





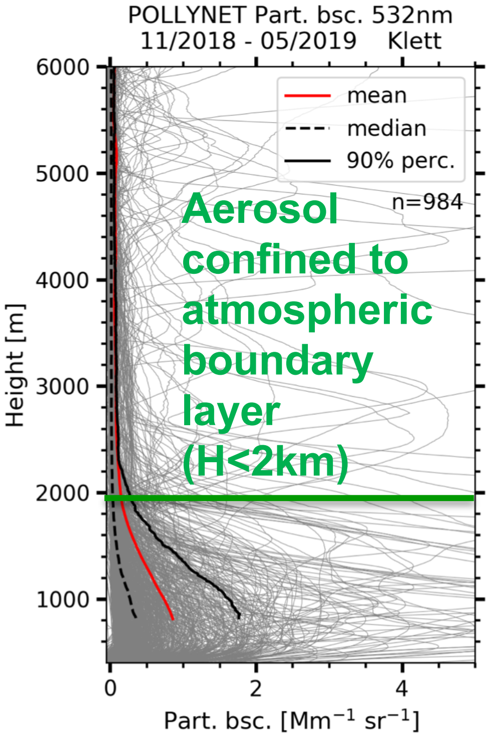


Example:
liquid layer:
median thickness 311 m
median LWP 40 g m^{-2}

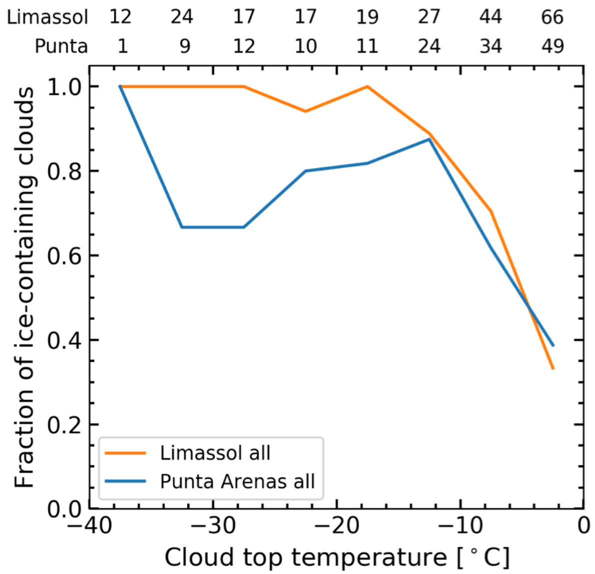
median IWC below liquid layer base:
2.23e-06 kg m^{-3}
(Hogan et al., 2006)

Next:
create **statistics** based on all **shallow** mixed-phase and supercooled liquid clouds observed at Limassol and Punta Arenas

Rough filtering for aerosol influenced cloud layers
→ Backscatter profiles from Raman lidar @ Punta Arenas



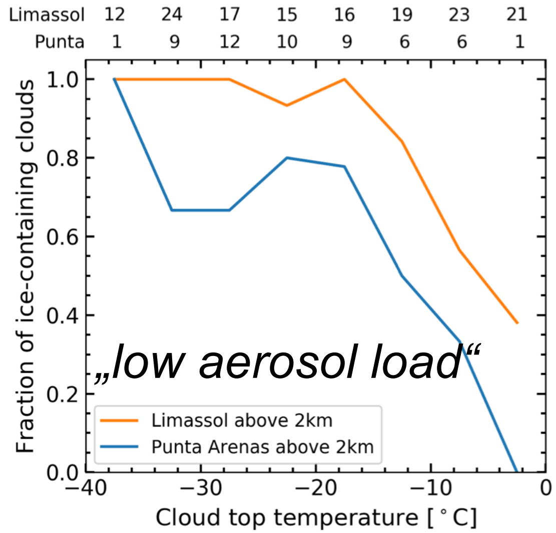
lidar + radar



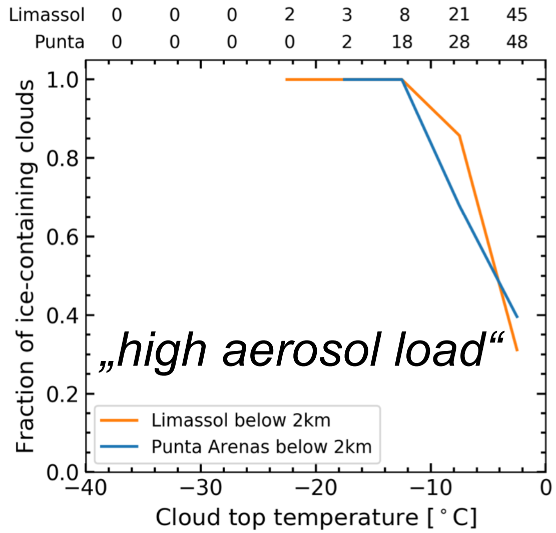
(CCT)

preliminary results

cloud base above 2 km



cloud base below 2 km



Quantification of differences in amount of produced cloud ice

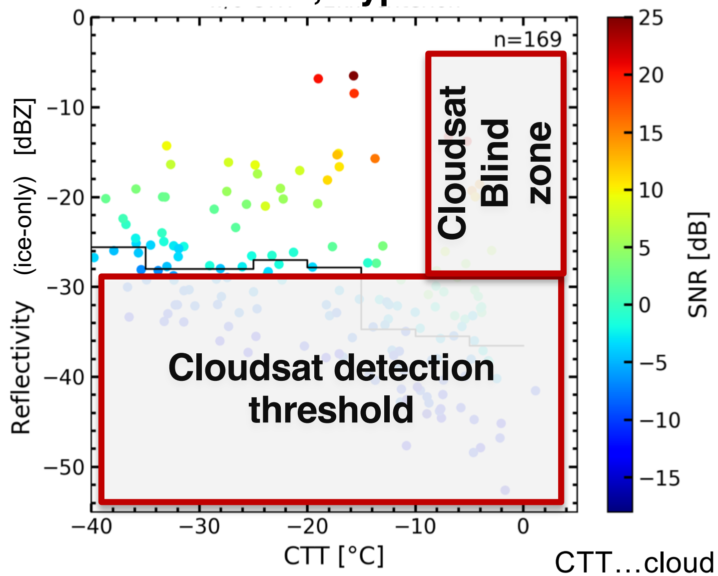
- Comparison of radar reflectivity in the ice-only part of the mixed-phase clouds
- Higher reflectivities observed at Limassol, Cyprus

→ Implication that also the ice water content is higher at Limassol (*Hogan et al., 2006*)

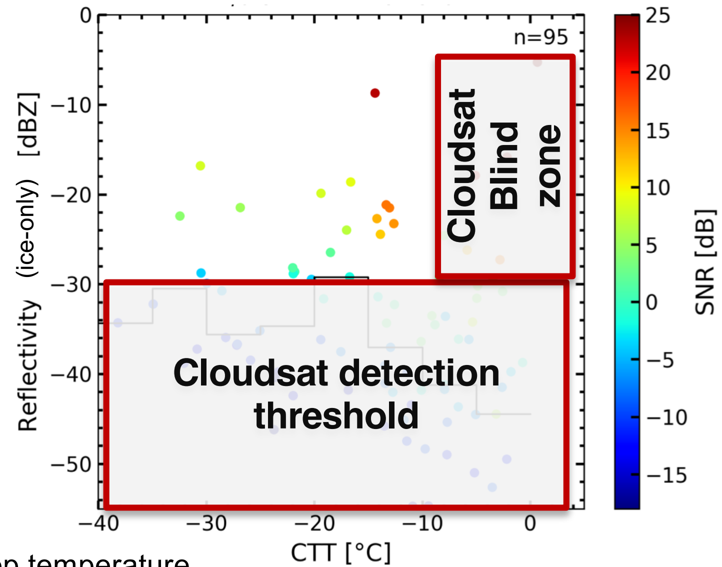
- Similar behaviour as found in A-Train study of *Zhang et al., 2018, ACP*
- Further work needed to harmonize sampling and sensitivity characteristics of ground-based and A-Train observations

preliminary results

Limassol, Cyprus

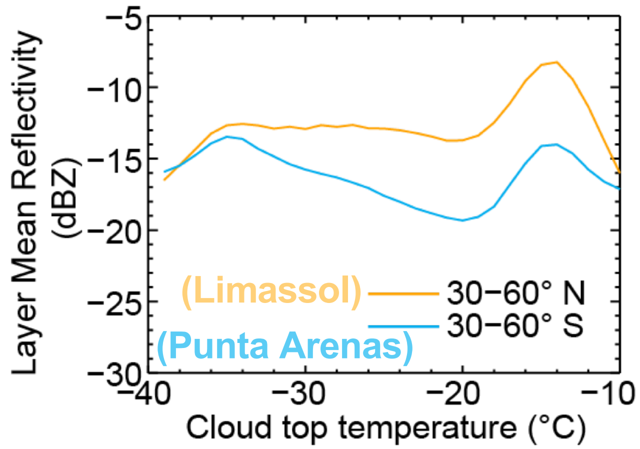


Punta Arenas, Chile



CTT…cloud top temperature

A-Train based statistics



(*Zhang et al., 2018,* figure adapted)

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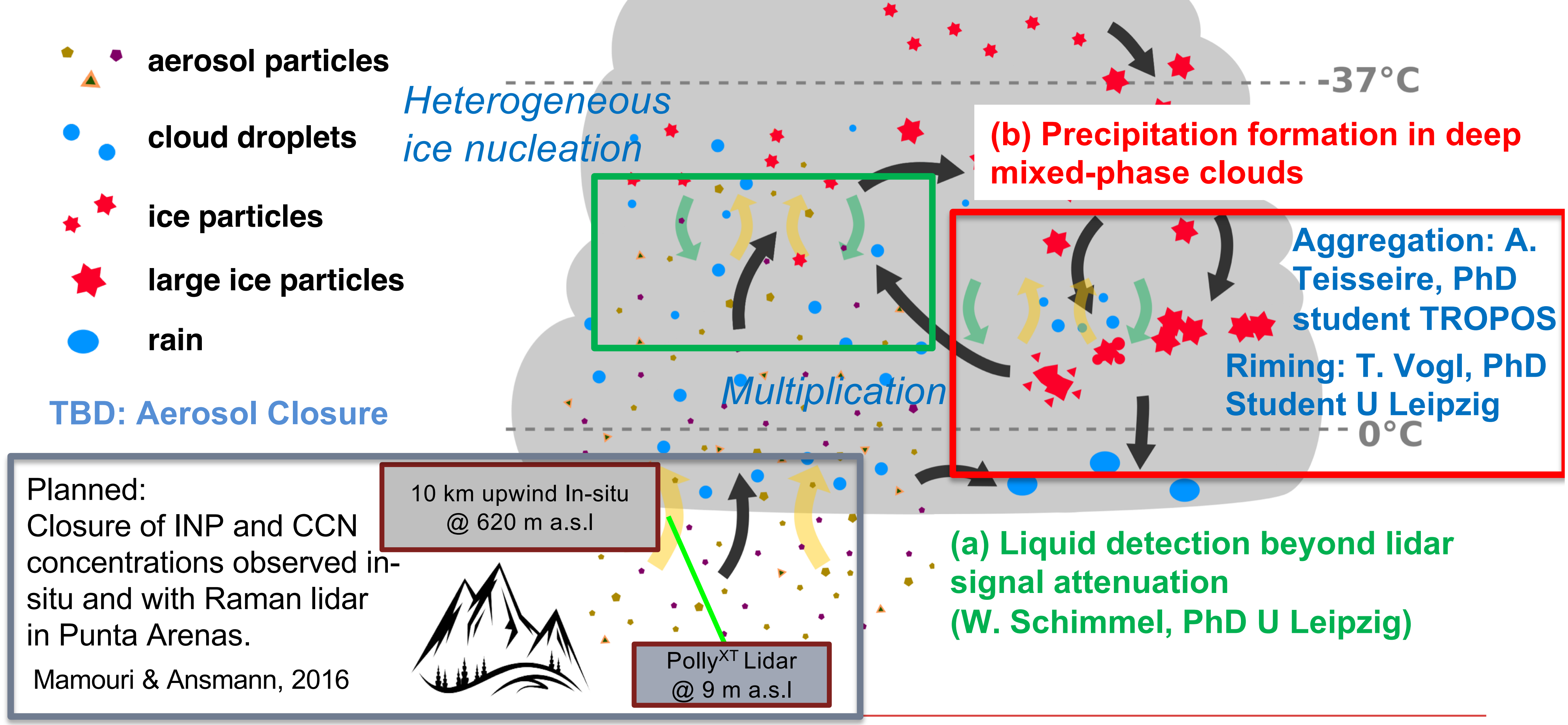
3. **Developing methods to identify differences in thick mixed-phase clouds between SH and NH**
   a) **Detecting supercooled liquid layers beyond full lidar signal attenuation**
   b) **Determining influence of INP- and CCN load on precipitation formation and microphysical particle growth processes (riming, aggregation)**

DEVELOPING METHODS TO CHARACTERIZE THICK MIXED-PHASE CLOUDS



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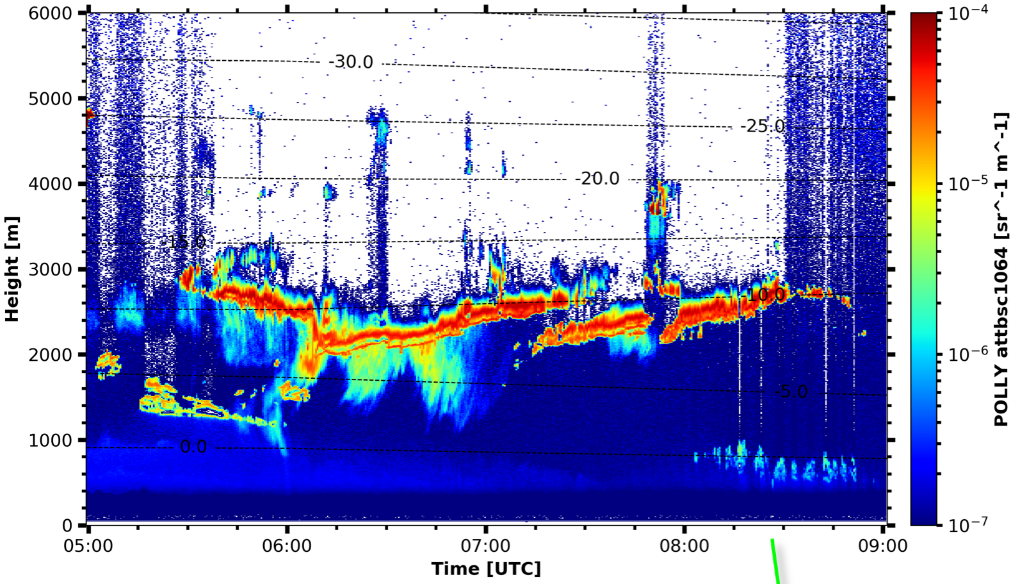
GROUND-BASED LIDAR & RADAR – SYNERGY

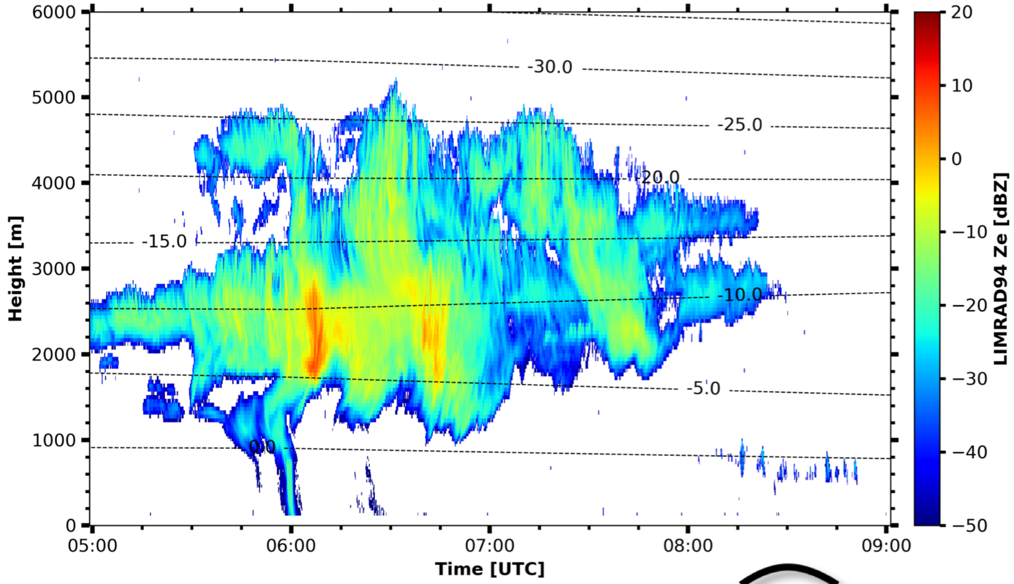
(1) Liquid detection beyond lidar signal attenuation (W. Schimmel, PhD U Leipzig)

Punta Arenas, Chile: 1st August 2019

Raman Lidar Attenuated Backscatter Coefficient β @1064nm



Doppler Cloud Radar Reflectivity Z_e @94GHz



$$\beta \sim N, D^2$$

$$Z_e \sim N, D^6$$

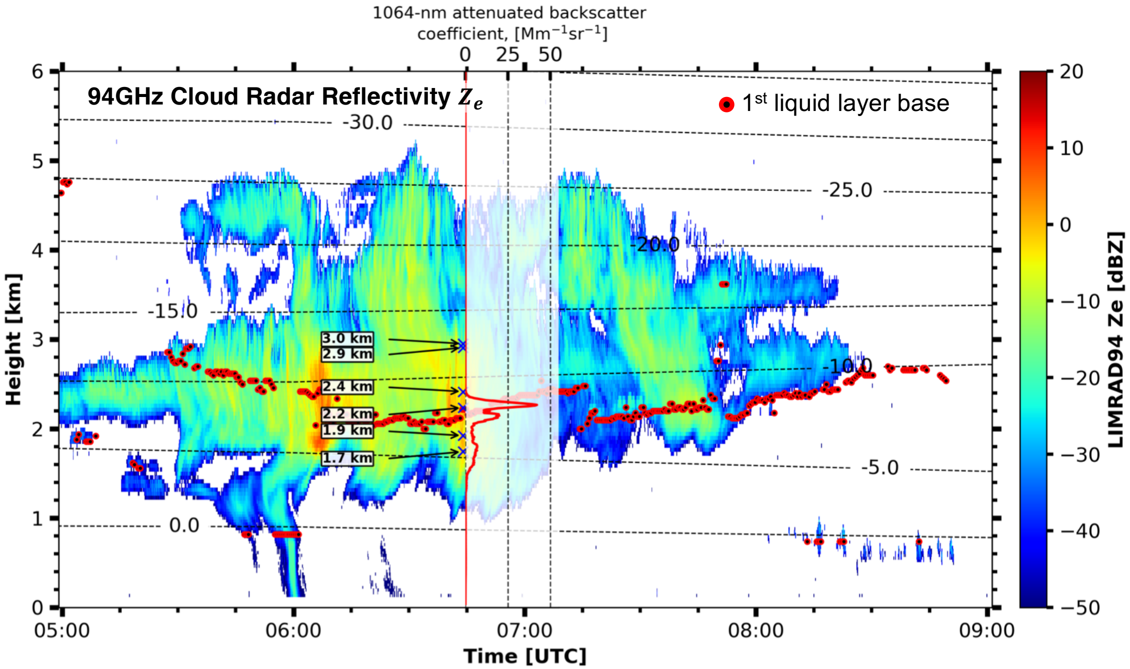
- sensitive to numerous small liquid droplets
- full signal attenuation at optical depth ~ 3

- most sensitive to few large ice crystals
- signal penetrates entire cloud depth

DACAPO-PESO

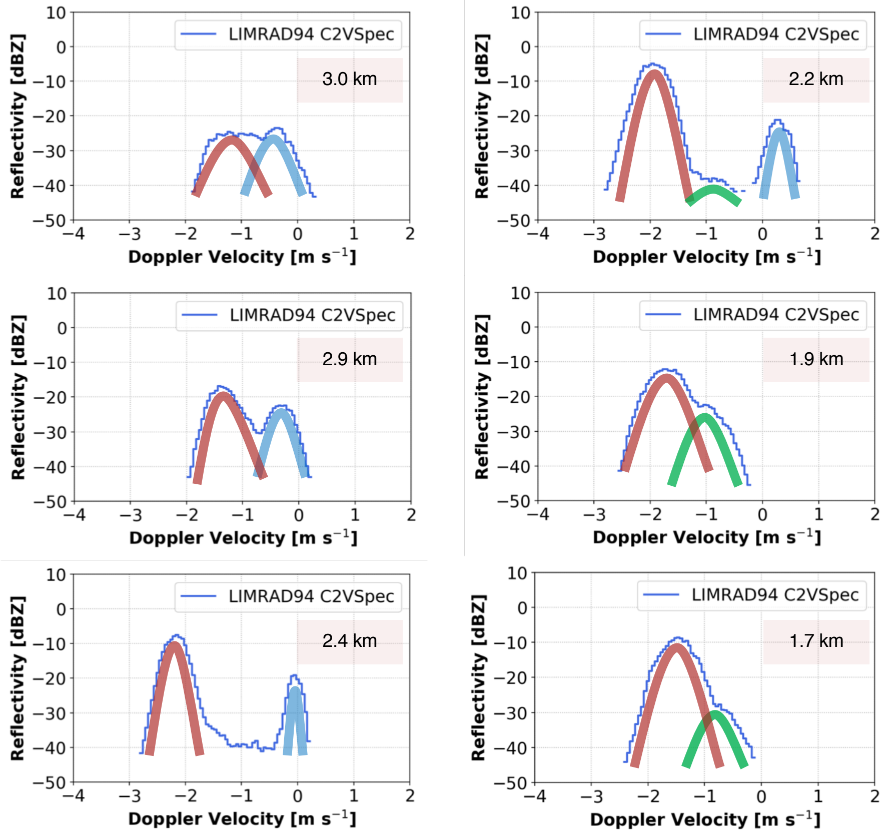
CLOUD RADAR DOPPLER SPECTRA, REFLECTIVITY AND LIDAR ATTENUATED BACKSCATTER

Punta Arenas, Chile: 1st August 2019 at 6:44 UTC



complete lidar signal attenuation at 2.4 km indicating supercooled liquid layer

ice crystals - liquid droplets - new ice formation



FEATURE EXTRACTION OF CLOUD RADAR OBSERVATIONS

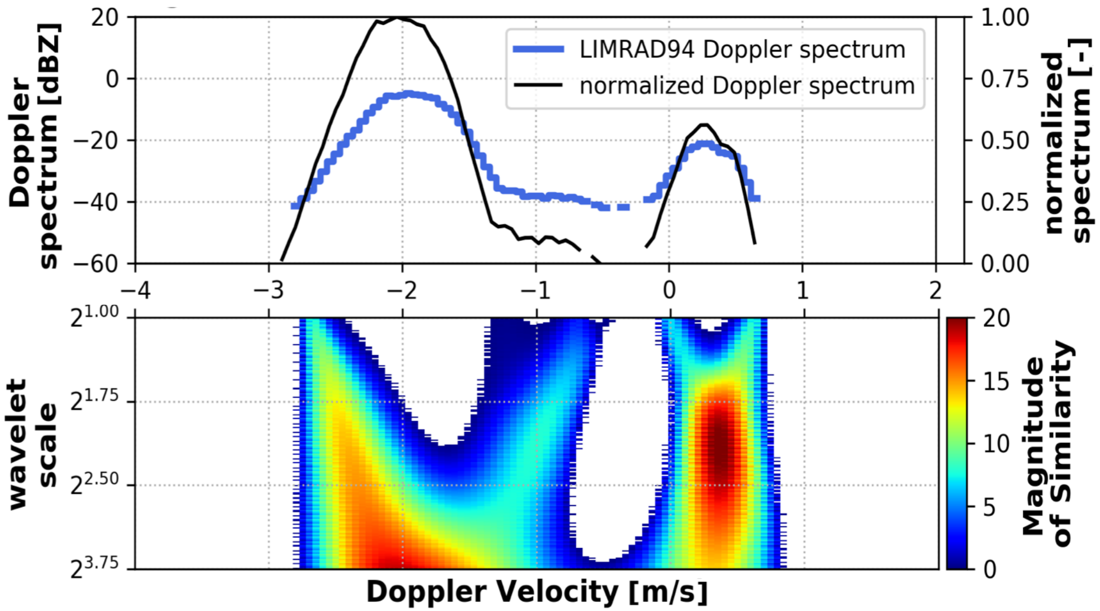
Doppler Spectra & Continuous Wavelet Transformation

Preprocessing:

- removing artifacts (non-hydrometeor signals)
- replace missing values by sensitivity limit
- de-aliase Doppler spectra

<u>preliminary</u> Resulting Samples:

- use N spectra enclosing a Cloudnet grid cell, with time-res.: 30 sec and range-res.: 30 m
- dimension:
  - Number of Doppler bins, e.g. $n_{Dbin} = 256$
  - Number of wavelet scales, e.g. $n_{scl} = 32$
  - Number of channels, e.g. $n_{ch} = 6$
- novel approach, based on Luke et al. 2010
- The number of channels depends on the feature extraction method and cloud radar time- and range-resolution.



Punta Arenas, Chile: 1st August 2019, 6:44 UTC at 2236 m altitude

The Deep Learning based Hydrometeor Classifier

Observations

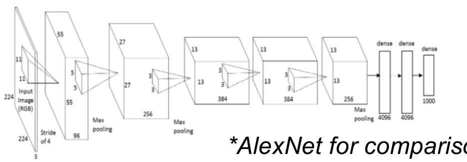
raw data batches

Preprocessor

processed batches

Observations from DACAPO-PESO 27th Nov 2018 till 27th Sep 2019, in Punta-Arenas, Chile.

Automatically selecting Cloudnet time-range cell labels for training data using the detection status flag, indicating good radar and lidar echos.



AlexNet for comparison

Convolutional Neural Network Classifier

Architecture:

- n convolutional layer, $ReLU$ activation, pooling and batch normalization
- m dense layer are added, $ReLU$ activation
- output layer has n_c nodes/classes followed by soft(arg)max

Chen et al., 2016, Goodfellow et al., 2011

Training, Predictions & Validation

Implementation using the Python3 version of Keras and TensorFlow2,

Abadi et al., 2016.

Pre-processing, training and validation is done on a GPU Workstation co-founded by ESF.

Processing Specifications:

- Dual Intel Xeon (Gold 6154) 18-Core
- 4 x NVIDIA Quadro RTX 8000

Allowing to search through a large hyperparameter space.

Hydrometeor Classification

DACAPO-PESO

FIRST CLASSIFICATION RESULTS

Cloudnet Target Classification (Illingworth et al., 2007)

- requires ground-based cloud radar, ceilometer and microwave radiometer
- reliable classification below complete lidar signal attenuation
- 1 ice & supercooled liquid in a layer between 2.5 - 3 km altitude (-8 to -14C)
- 2 cloud droplets only after 8 UTC

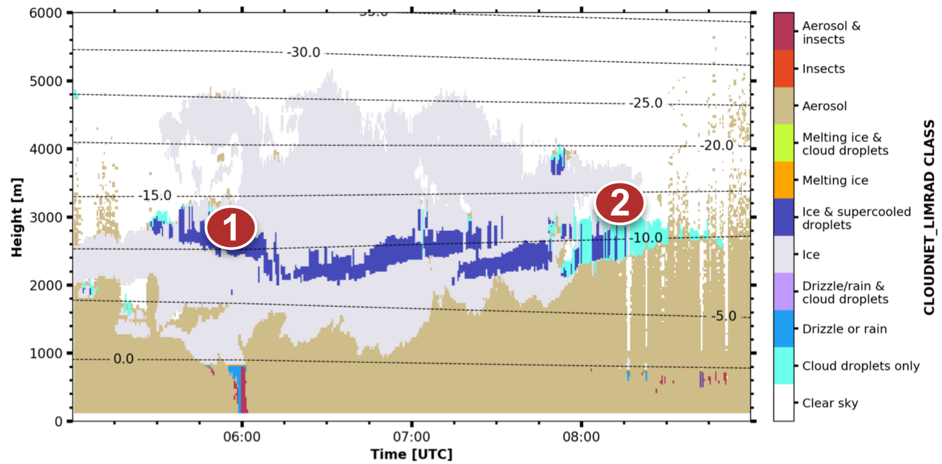
preliminary radar-spectrum-only Convolutional Artificial network (ANN) cloud phase classifier

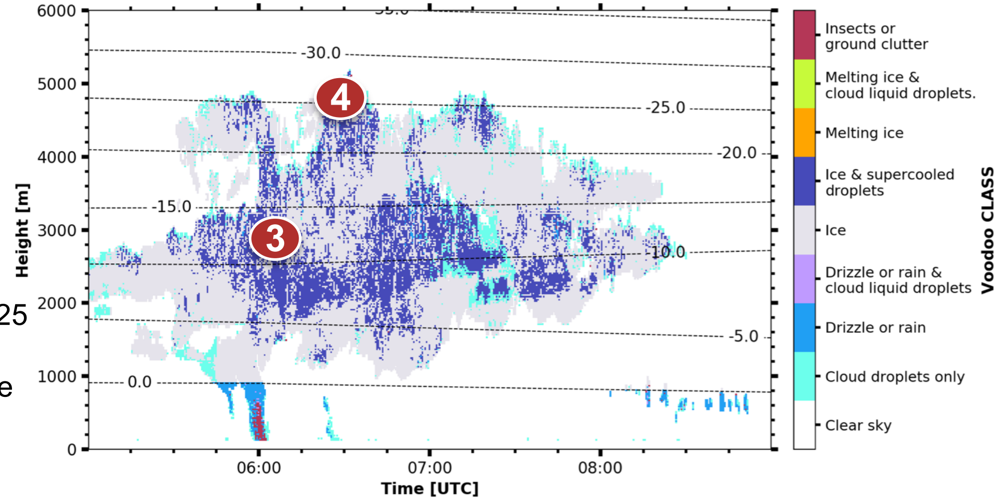
- goal: prediction of supercooled liquid beyond complete lidar attenuation
- requires cloud radar Doppler spectra with minimum resolution of 30 seconds (time)
  and 30 meters (range)
- 3 classifier was able to predict the mixed-phase layer as detected by the Raman lidar
- 4 additional supercooled liquid layer (SCL) at 4.5 km altitude (cloud top temp = -25 C) classified

→ Existence of SCL seems plausible for ice occurrence below at these temperature ice formation happens mostly via liquid-dependent heterogeneous freezing (Westbrook and Illingworth, 2011)

→ ANN classifier outperforms Cloudnet target classification beyond lidar signal attenuation

Punta Arenas, Chile: 1st August 2019 at 5-9 UTC





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   a) Detecting supercooled liquid layers beyond full lidar signal attenuation

   ↓

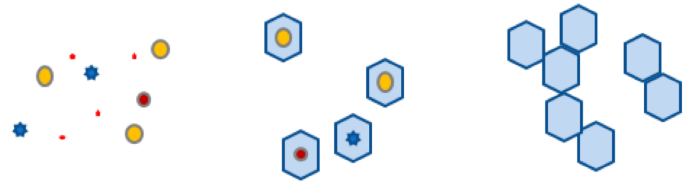
   Liquid identified by ANN is first indicator of possible microphysical growth process

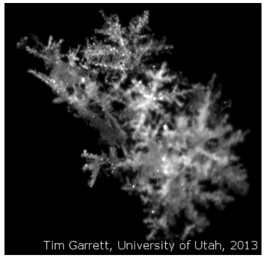
   ↓

   b) Determining influence of INP- and CCN load on precipitation formation and microphysical particle growth processes (riming, aggregation)

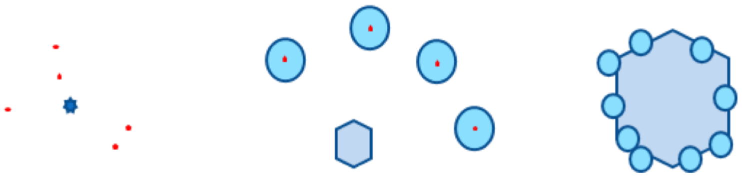
Hypothesis : Microphysical growth processes in mixed-phase clouds are susceptible to aerosol perturbations

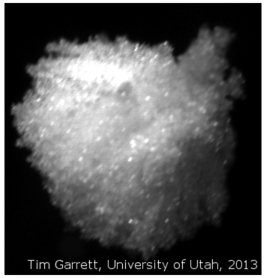
1. High aerosol loads and high INP concentrations → higher ice crystal concentrations → ***more aggregation***





2. Low aerosol loads and scarcity of INP → thicker/ more persistent supercooled liquid layers → ***more riming***





Legend :

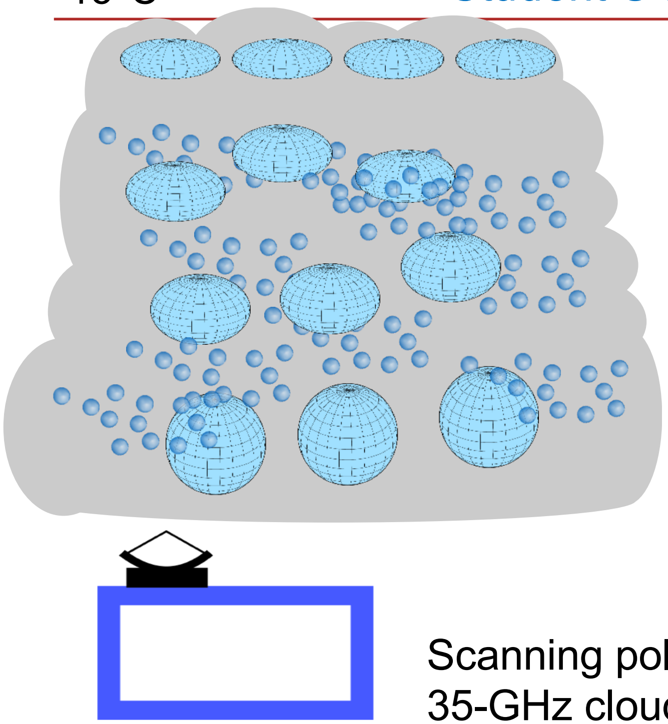
- Aerosol particles
- Droplets
- Rain
- Ice particle

Observing the vertical structure of the particle shape in mixed-phase clouds to identify the contributions of riming or aggregation

Low INP → Less pristine ice crystals, more droplets
→ **Riming** more likely

Riming: T. Vogl, PhD Student U Leipzig

-15°C



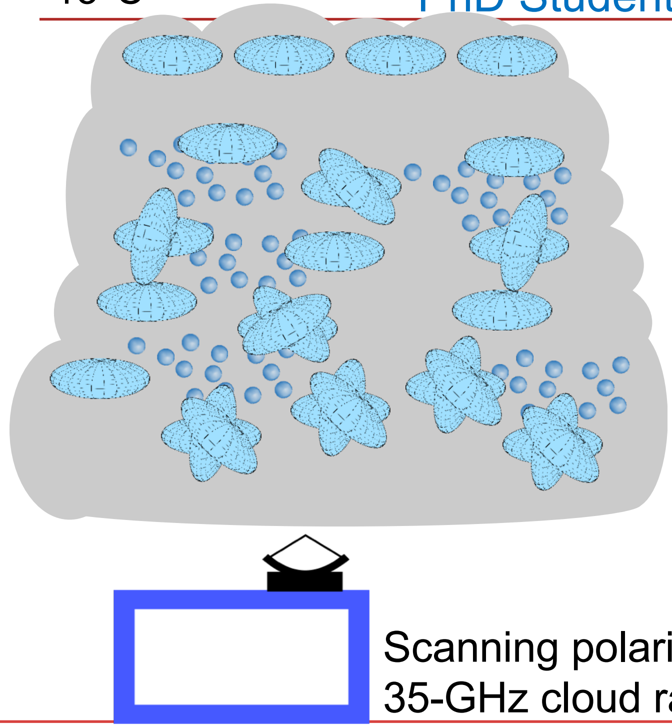
Steady increase of rimed, more-spherical crystals + Strong increase in fall velocity

Scanning polarimetric (SLDR) 35-GHz cloud radar

High INP → More pristine ice crystals, less droplets
→ **Aggregation** more likely

Aggregation: A. Teissiere, PhD Student U TROPOS

-15°C



Steady increase of aggregated, more-spherical crystals + Small increase in fall velocity

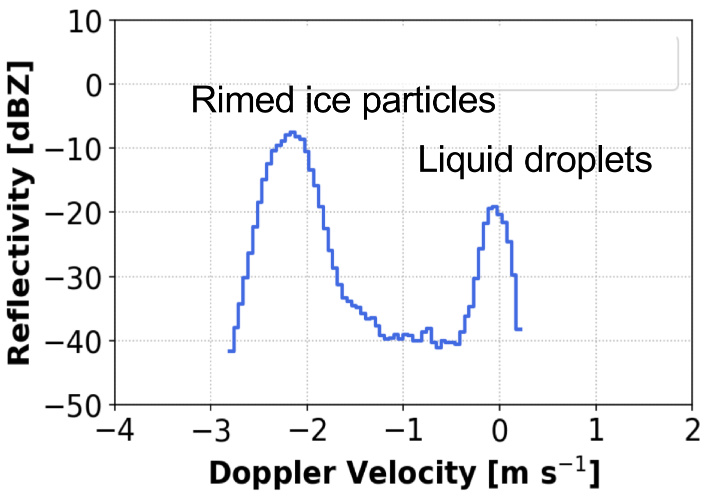
Scanning polarimetric (SLDR) 35-GHz cloud radar

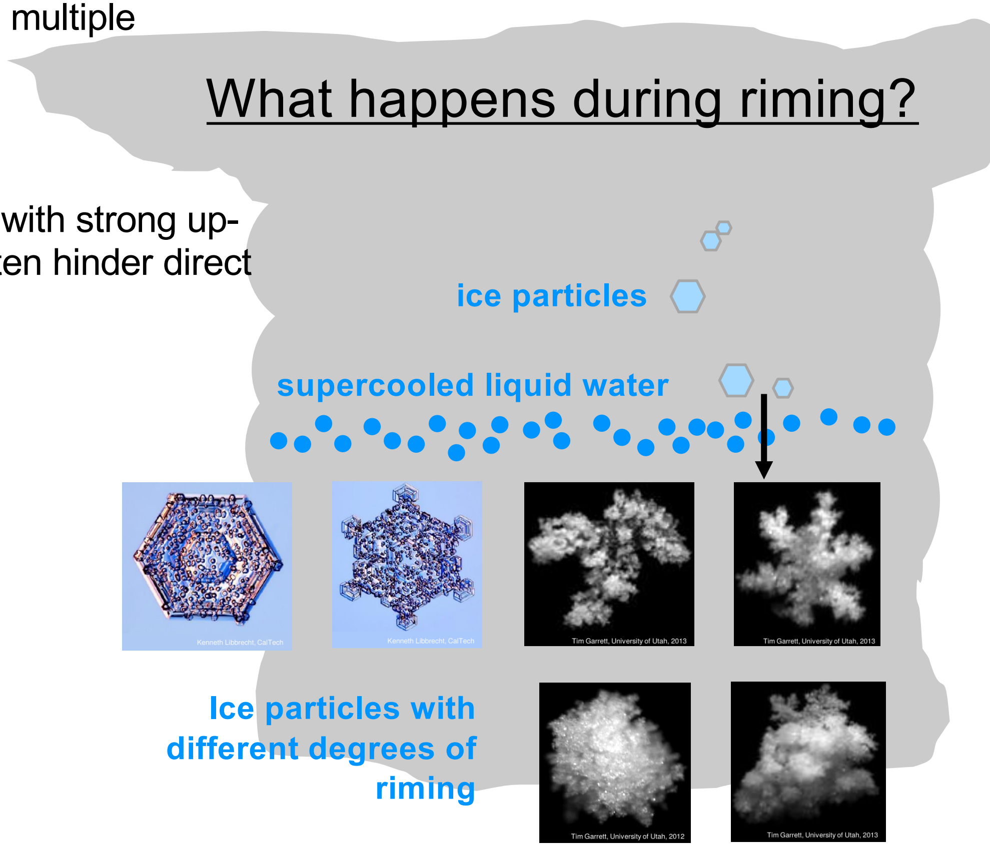
PRECIPITATION FORMATION: DETECTION OF RIMING USING CLOUD RADAR DOPPLER SPECTRA

- Multiple peaks in cloud radar Doppler spectra (see below) indicate multiple hydrometeor types in the same radar volume

→ Radar spectrum <u>width</u> increases

- Riming: ice particle fall velocity increases… but orographic waves with strong up- and downdraft regions at Punta Arenas (in lee of end of Andes) often hinder direct use of Doppler velocity absolute values





DETECTION OF RIMING USING CLOUD RADAR DOPPLER SPECTRA

Finding peaks in cloud radar Doppler spectra using supervised machine learning

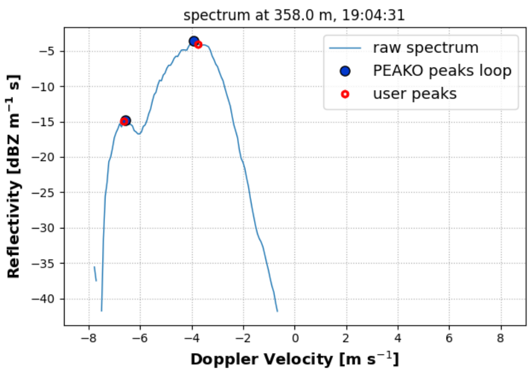
- PEAKO algorithm presented in Kalesse et al. (2019), AMT

```
~$ pip install pyPEAKO
```

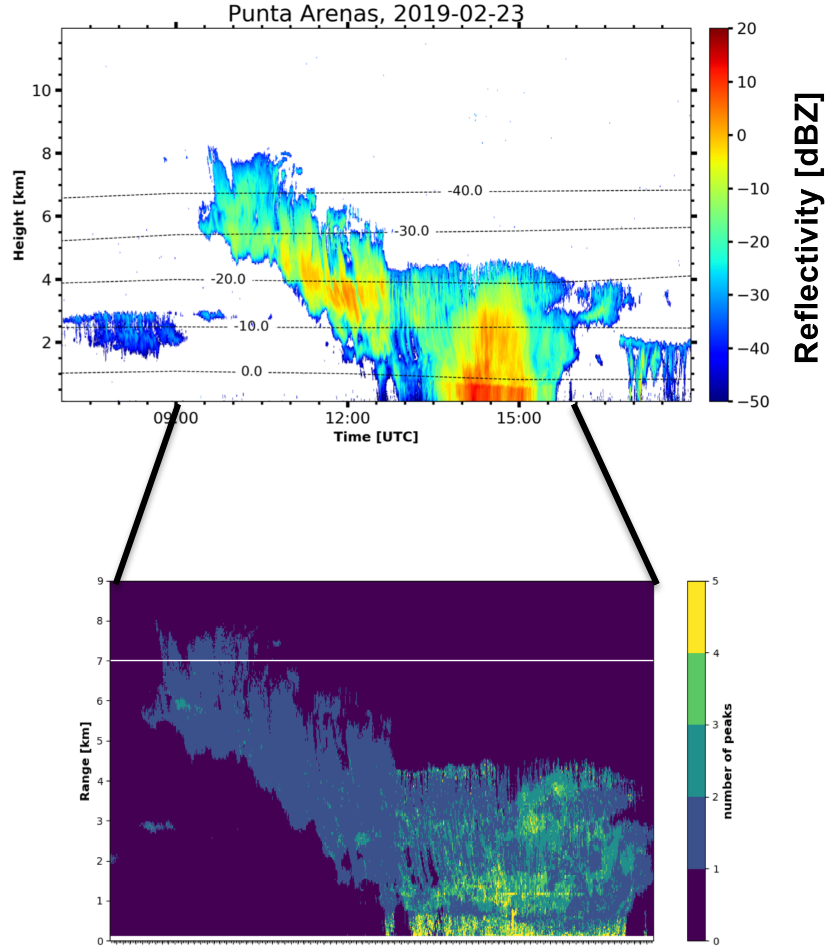
- Pre-release available on PyPI

https://pypi.org/project/pyPEAKO/

- Creating training data: (human) user-marked peaks in Doppler spectra



applicable to all Doppler cloud radars → try it yourselves! ☺

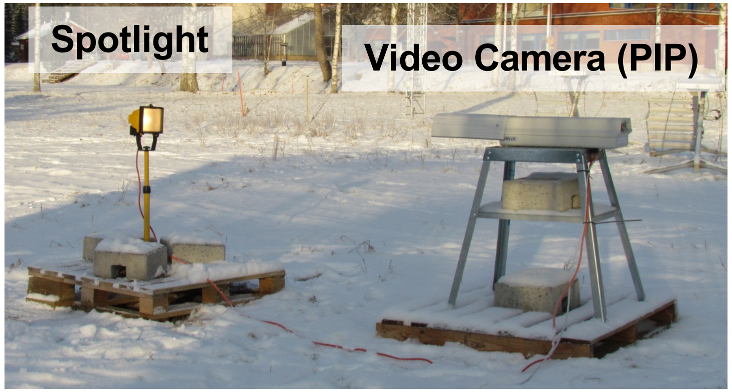


DETECTION OF RIMING USING CLOUD RADAR DOPPLER SPECTRA

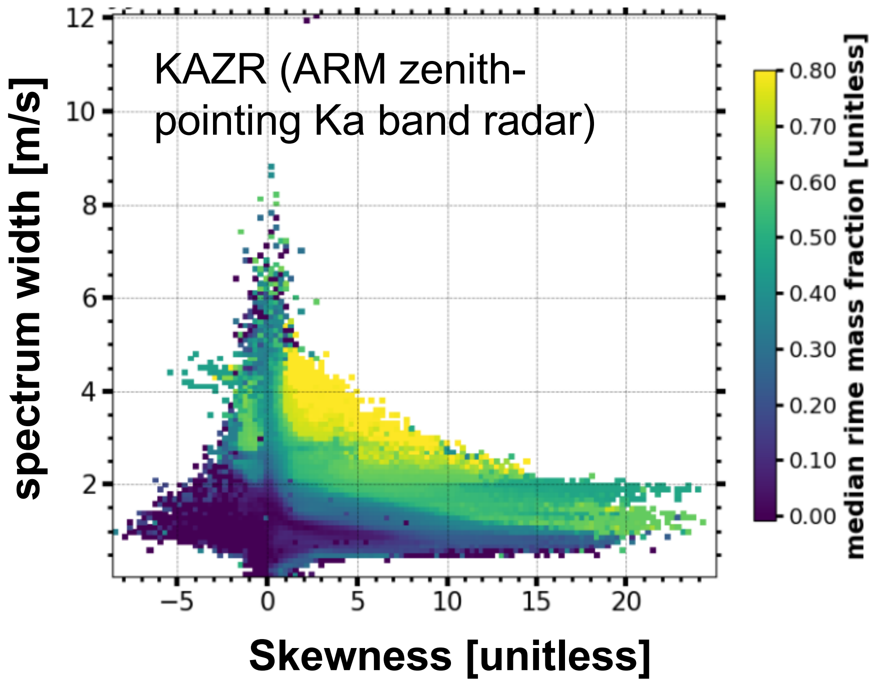
Developing a riming 'flag' based on spectrum width and skewness

- Objective: detect riming in conditions influenced by orographic waves without using absolute values of mean Doppler velocity
- Starting point: combine ground-based remote-sensing data set of ARM BAECC experiment (Hyytiälä, Finland, 2014) with in-situ data
  - → Possibility to derive rime mass fraction (Moisseev et al., 2017)

Particle-image-package (PIP) in Hyytiälä at BAECC field experiment

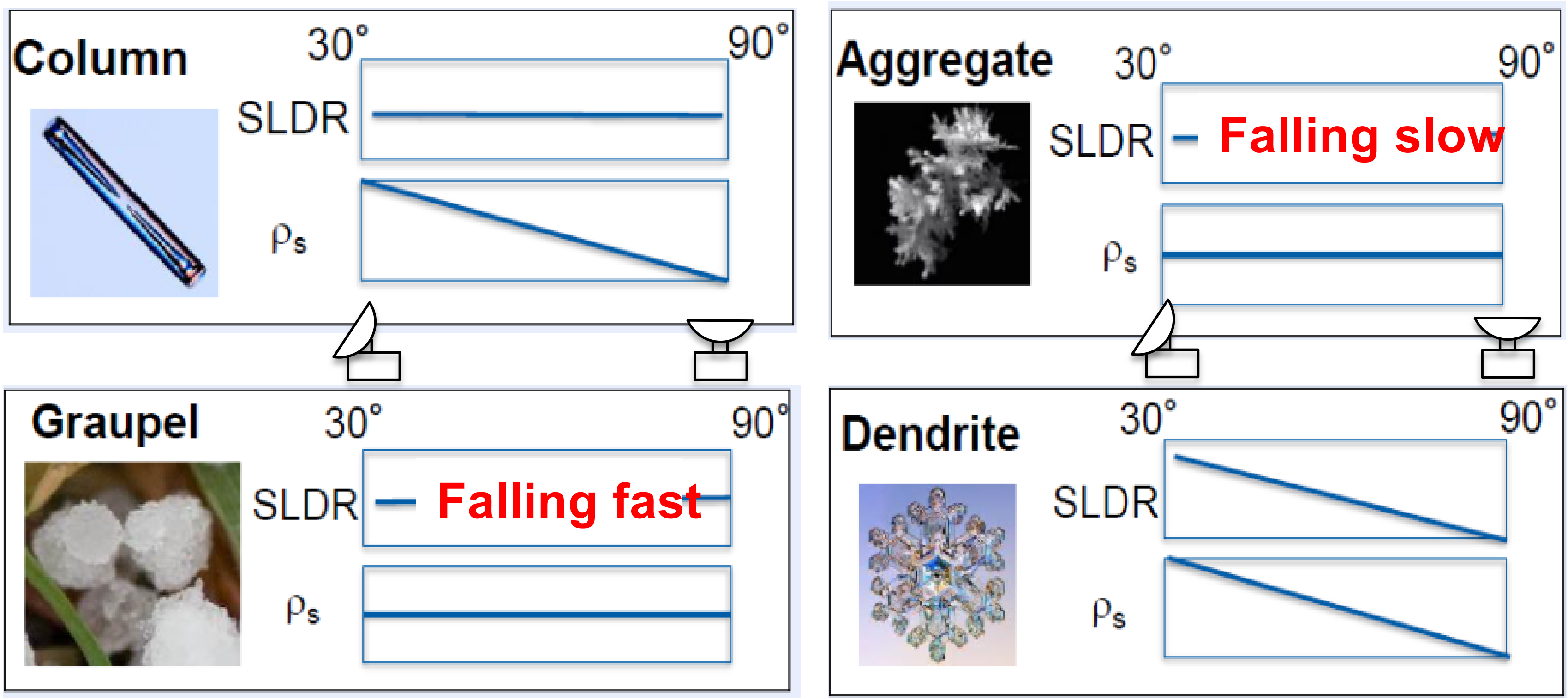


Spectra with both high skewness and high spectrum width have a high rime mass fraction → next step (future work): application to Punta Arenas data set

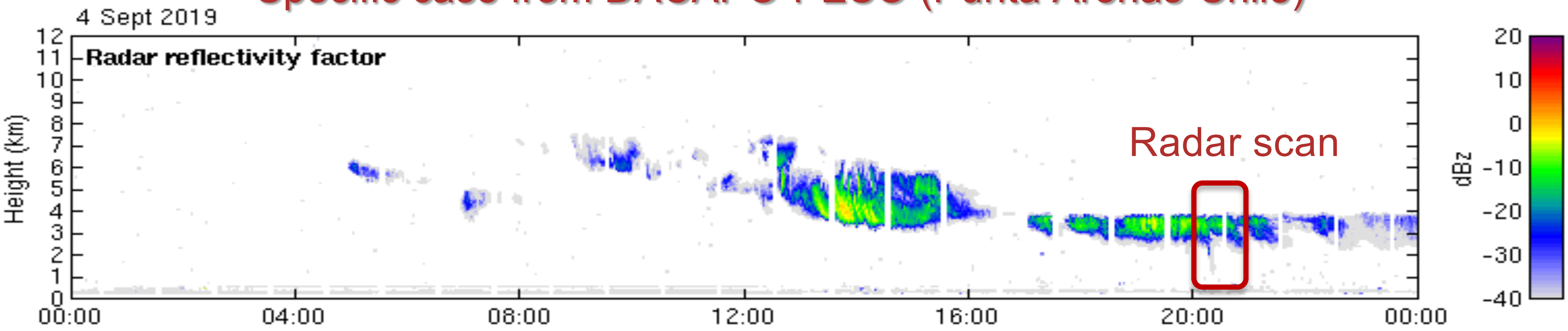


Ice physical properties from cloud radar

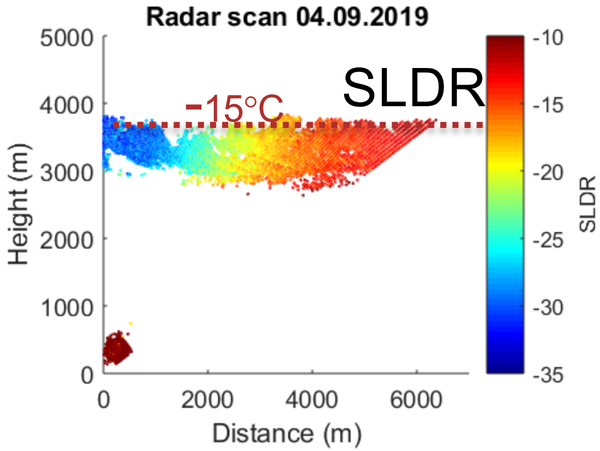
Unique relationship between: slanted LDR, ρ_{cx}, antenna elevation angle and particle shape

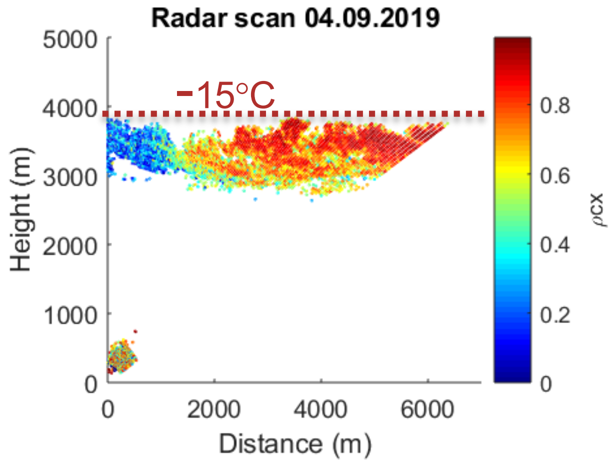


Specific case from DACAPO-PESO (Punta Arenas-Chile)



Range-height indicator (RHI scan) of SLDR and correlation coefficient

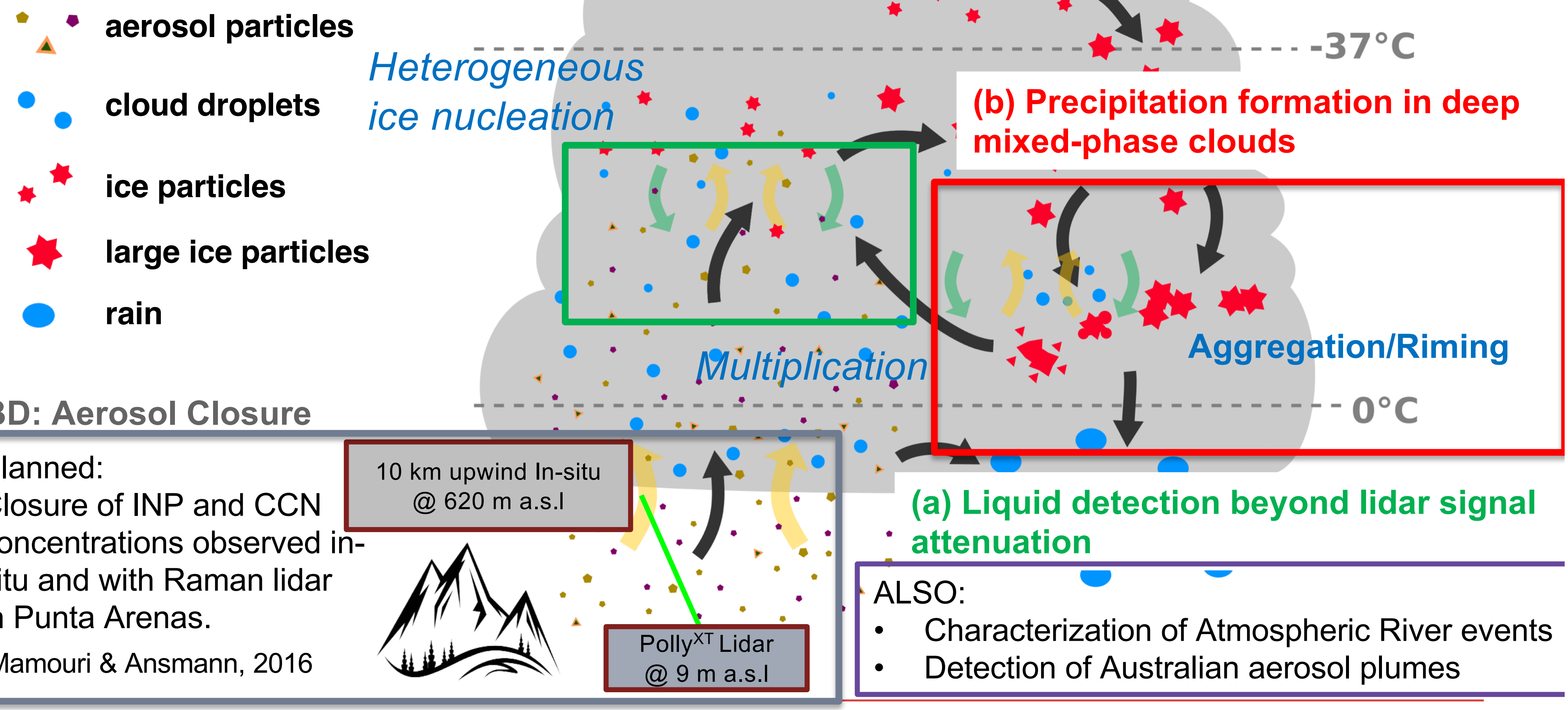




- → Dendritic particles!
- → The vertically resolved observations enable the retrieval of the vertical gradient of the particle shape

DACAPO-PESO

SUMMARY: SYNERGISTIC OBSERVATIONS AND NEW RETRIEVAL TECHNIQUES WILL HELP TO BETTER UNDERSTAND ATMOSPHERE & CLOUDS IN SUB-ANTARCTICA



TBD: Aerosol Closure

Planned:
Closure of INP and CCN concentrations observed in-situ and with Raman lidar in Punta Arenas.

Mamouri & Ansmann, 2016

ALSO:

- Characterization of Atmospheric River events
- Detection of Australian aerosol plumes

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