Lidar and RAdar Synergy for ICE retrievals (LIRAS – ICE)

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[1] Harz University
[2] TROPOS

LMU Munich, 03 September 2025

Leibniz Institute for Tropospheric Research

Hochschule Harz
Hochschule für angewandte Wissenschaften

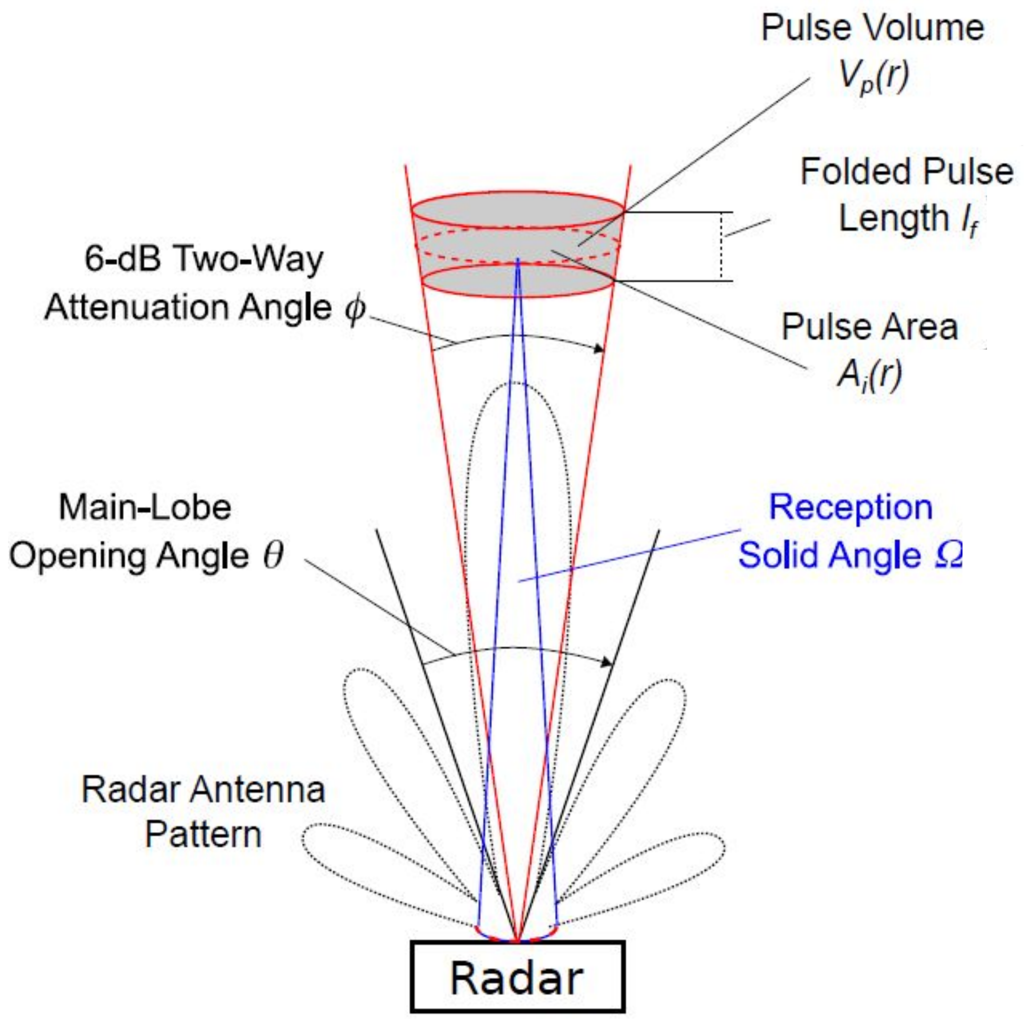
What exactly is “Harz University”?

Hochschule Harz, Wernigerode

Curricula:

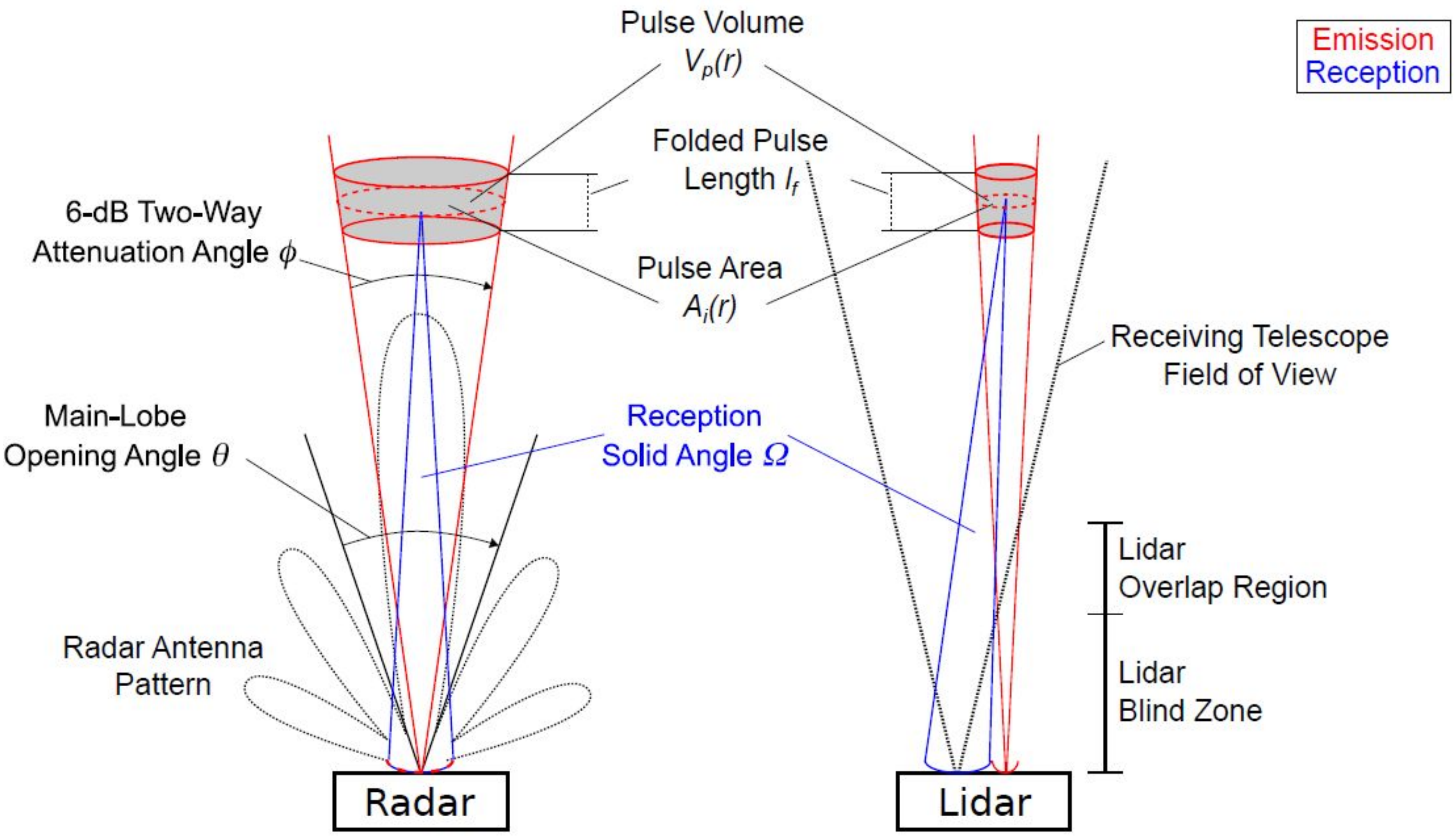
- Informatics
- Data Science
- AI Engineering

Analytic Lidar/Radar Synthesis



[Bühl, 2015]

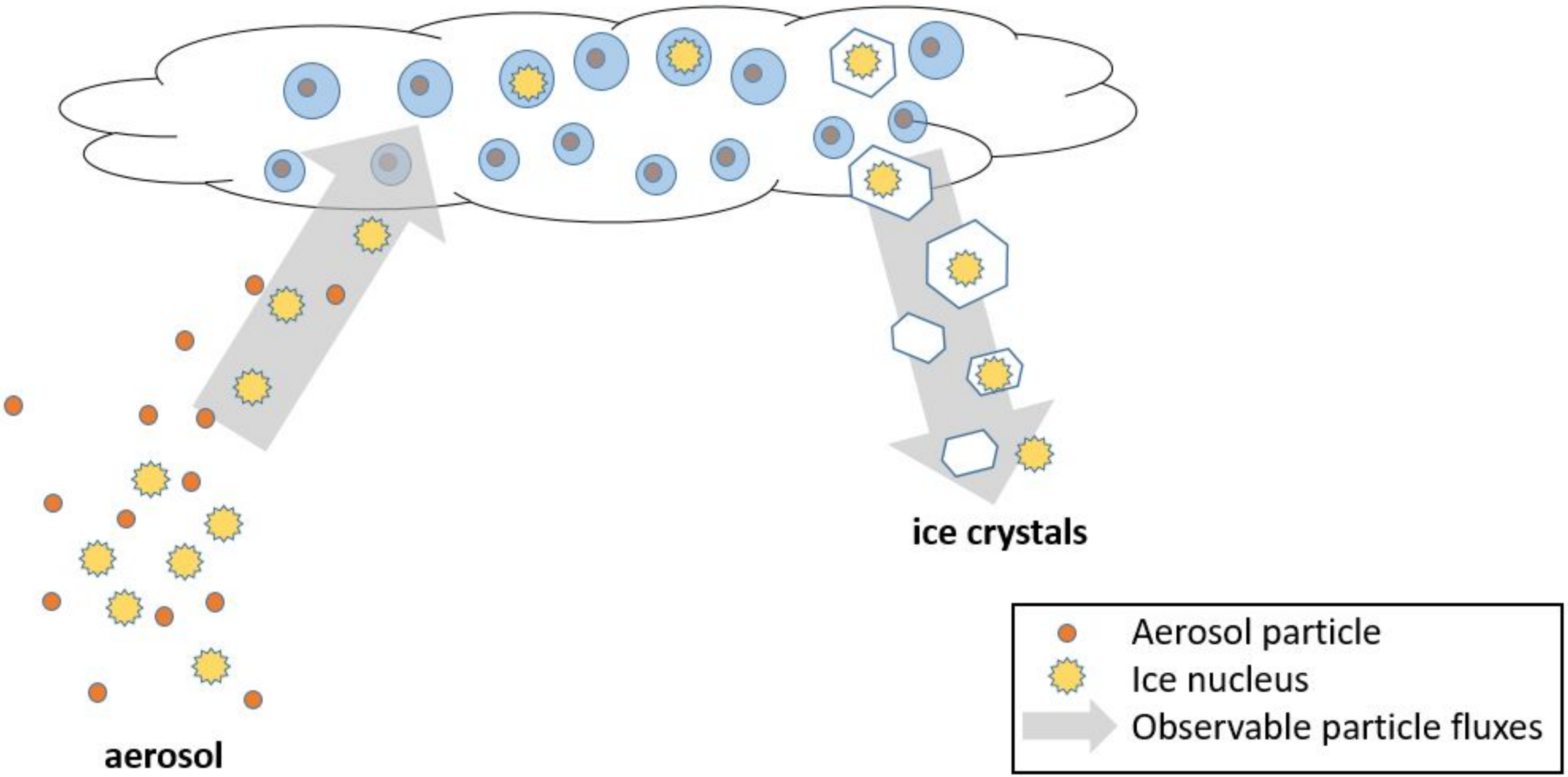
Analytic Lidar/Radar Synthesis



$$P_c(r) = P_0 l_f A_t O(r) B(r) T^2(r) \frac{1}{r^2}$$

[Bühl, 2015]

Are we looking at the right quantities?



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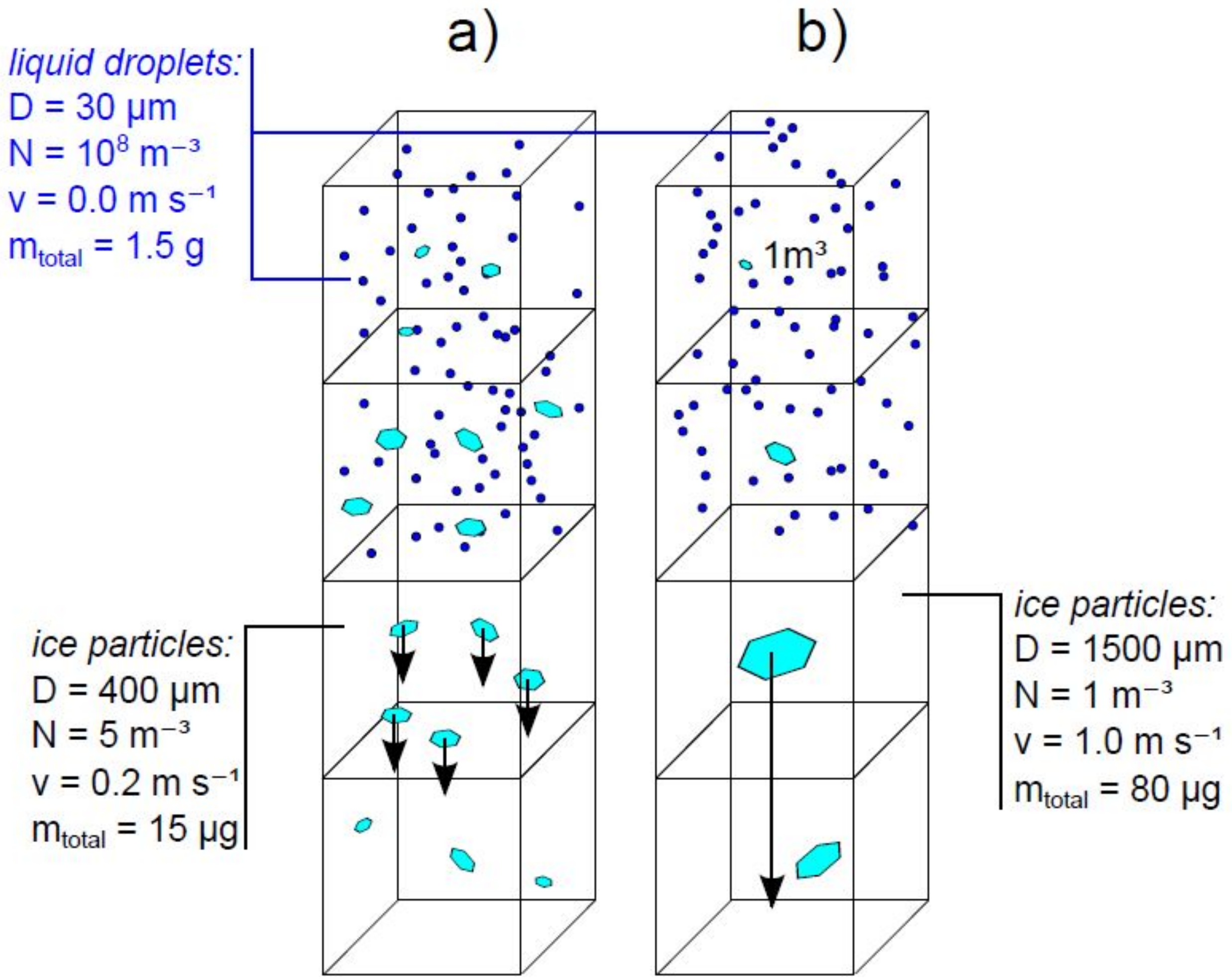


Flux:

$$F = 1.0\, m^{-2} s^{-1}$$

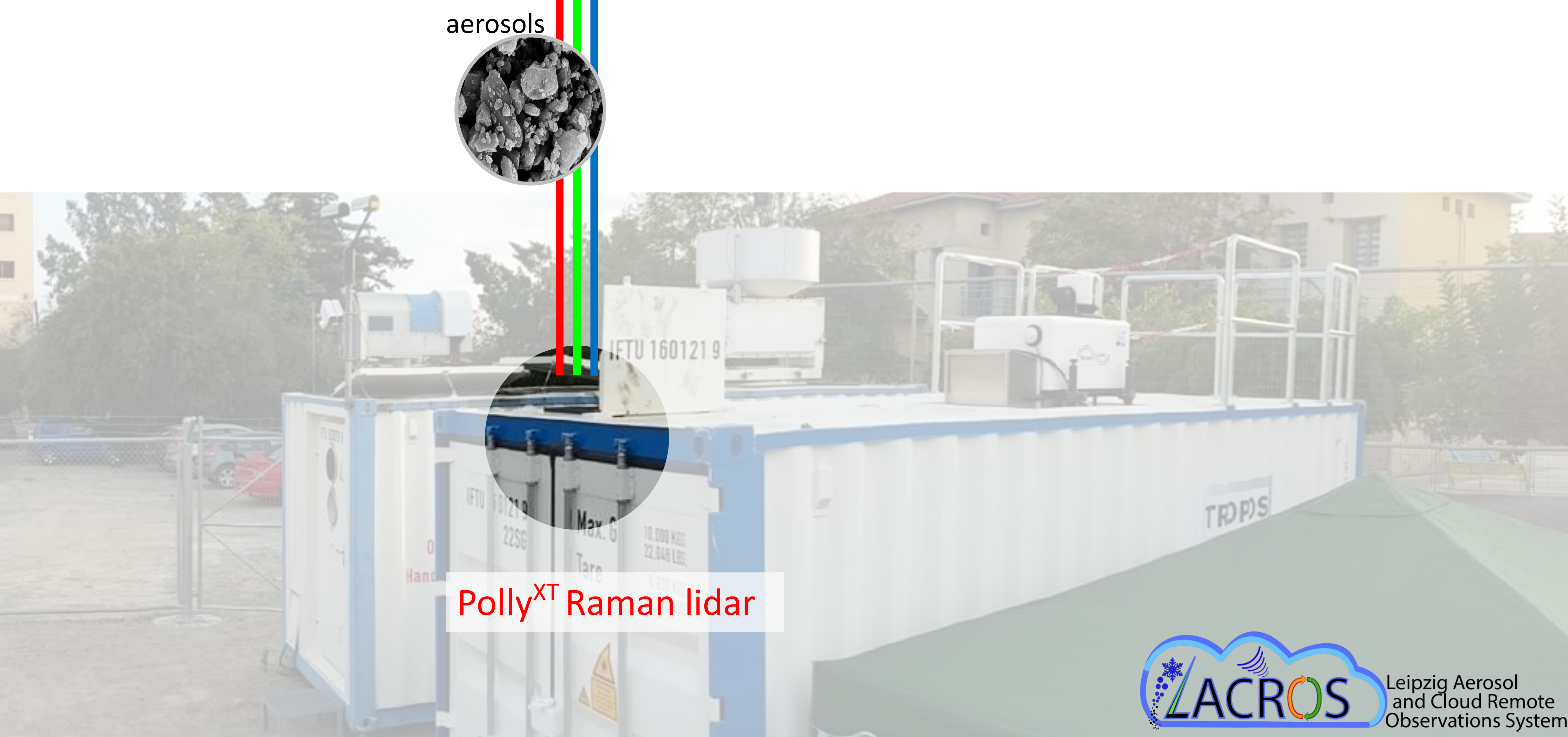
[Bühl, 2015]

In the field: Investigating aerosol-cloud-dynamics interaction with LACROS

Leipzig Aerosol and Cloud Remote Observations System

@ Limassol, Cyprus

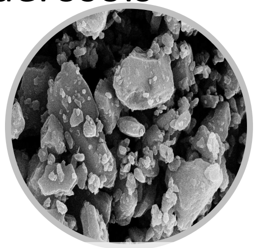
Investigating aerosol-cloud-dynamics interaction with LACROS



LACROS
Leipzig Aerosol and Cloud Remote Observations System

Investigating aerosol-cloud-dynamics interaction with LACROS

aerosols

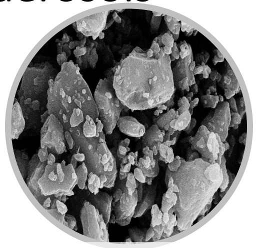


clouds

LACROS
Leipzig Aerosol
and Cloud Remote
Observations System

Investigating aerosol-cloud-dynamics interaction with LACROS

aerosols

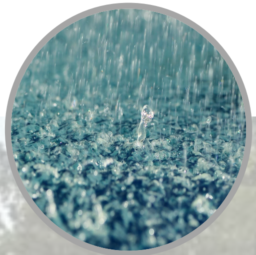


clouds

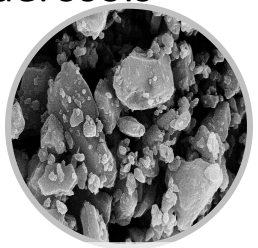
dynamics

Investigating aerosol-cloud-dynamics interaction with LACROS

precipitation



aerosols



clouds

dynamics

Leipzig Aerosol and Cloud Remote Observations System

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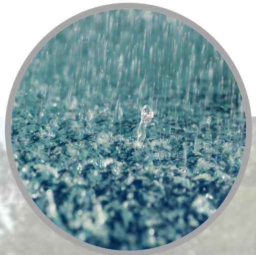
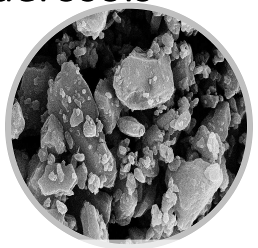


atmospheric
water content

aerosols



clouds

dynamics

LACROS
Leipzig Aerosol
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Investigating aerosol-cloud-dynamics interaction with LACROS

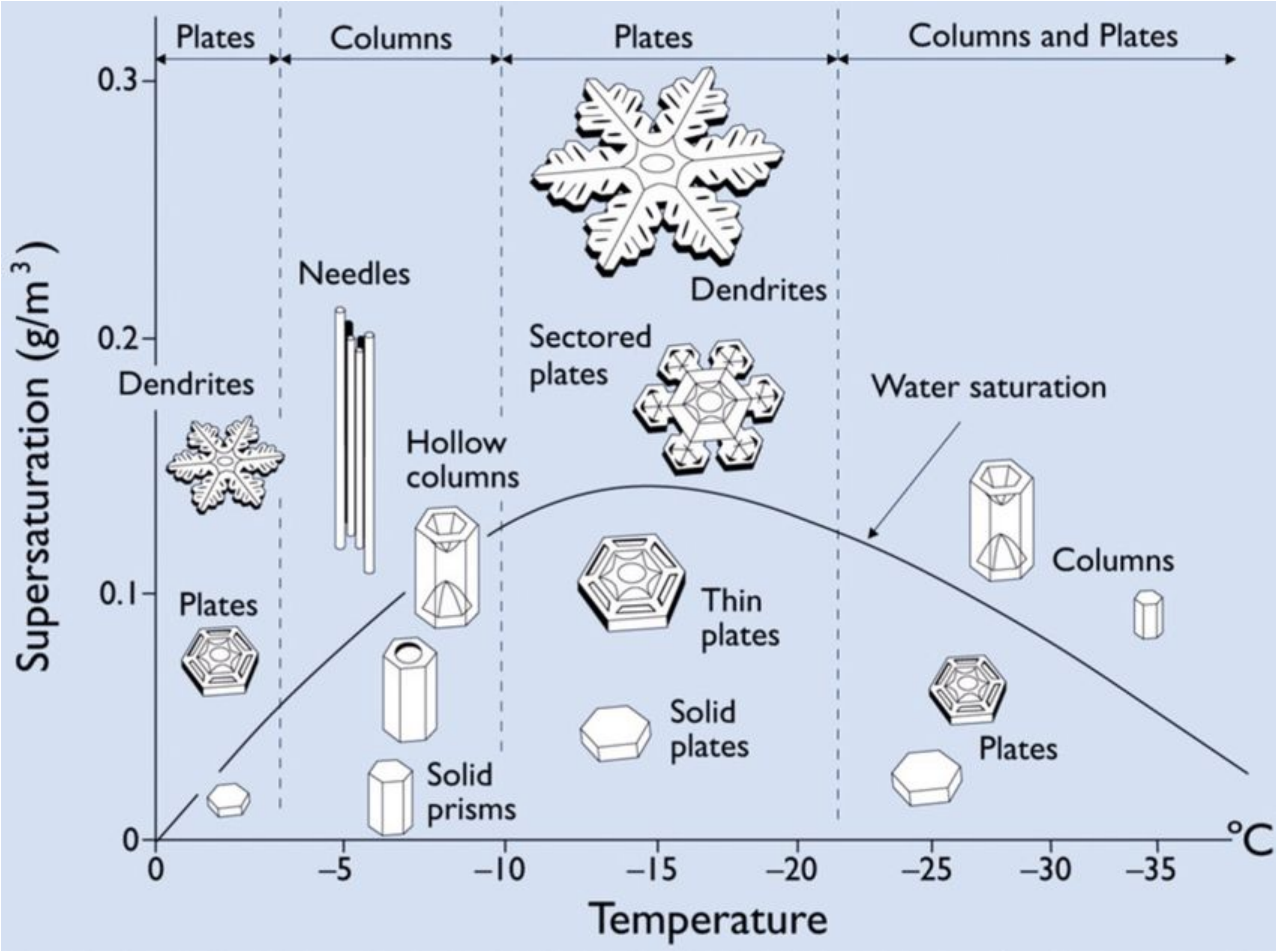
Ice crystals…

[MPG]

AI ice crystals…

[Leonardo AI Phoenix Model]

Ice crystals…

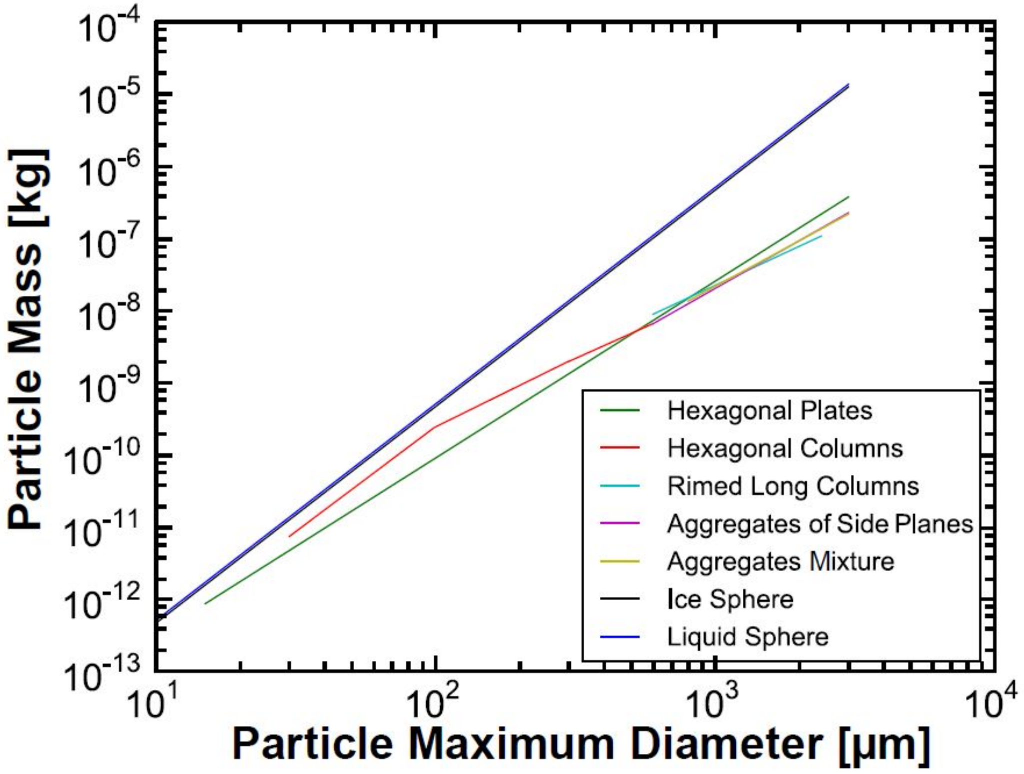


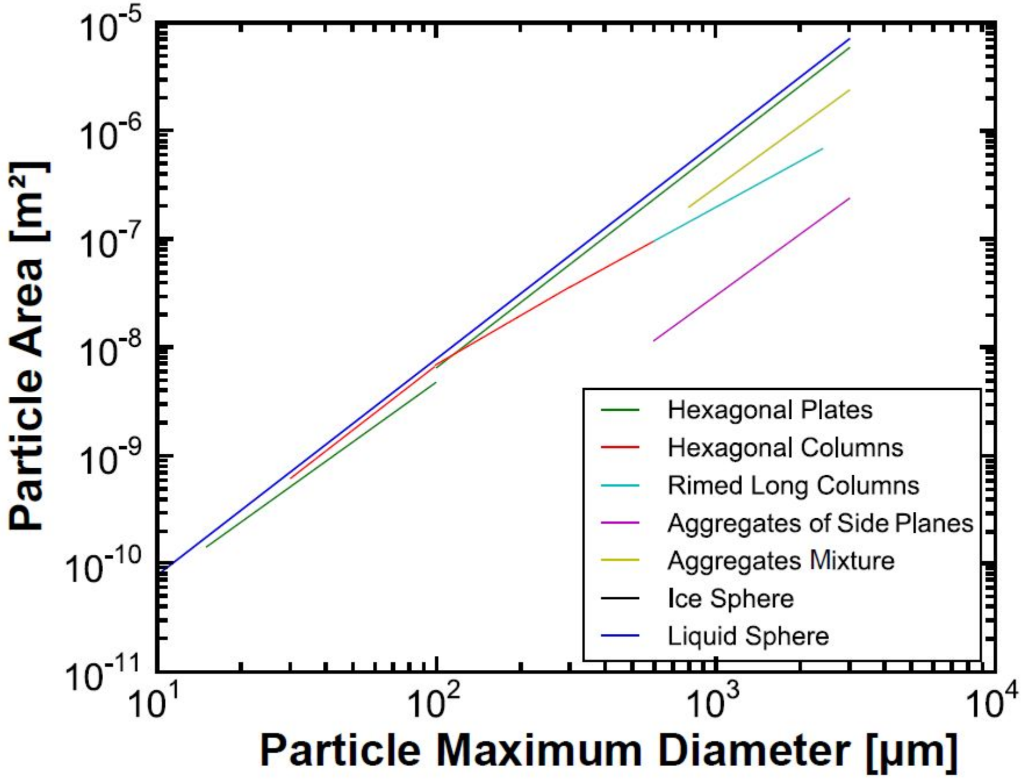
[???]

How to parameterize cloud particles?

$$A_p(D_m) = aD_m^b$$
$$m_p(D_m) = cD_m^d$$

…get *a*, *b*, *c* and *d* section wise from experiments…



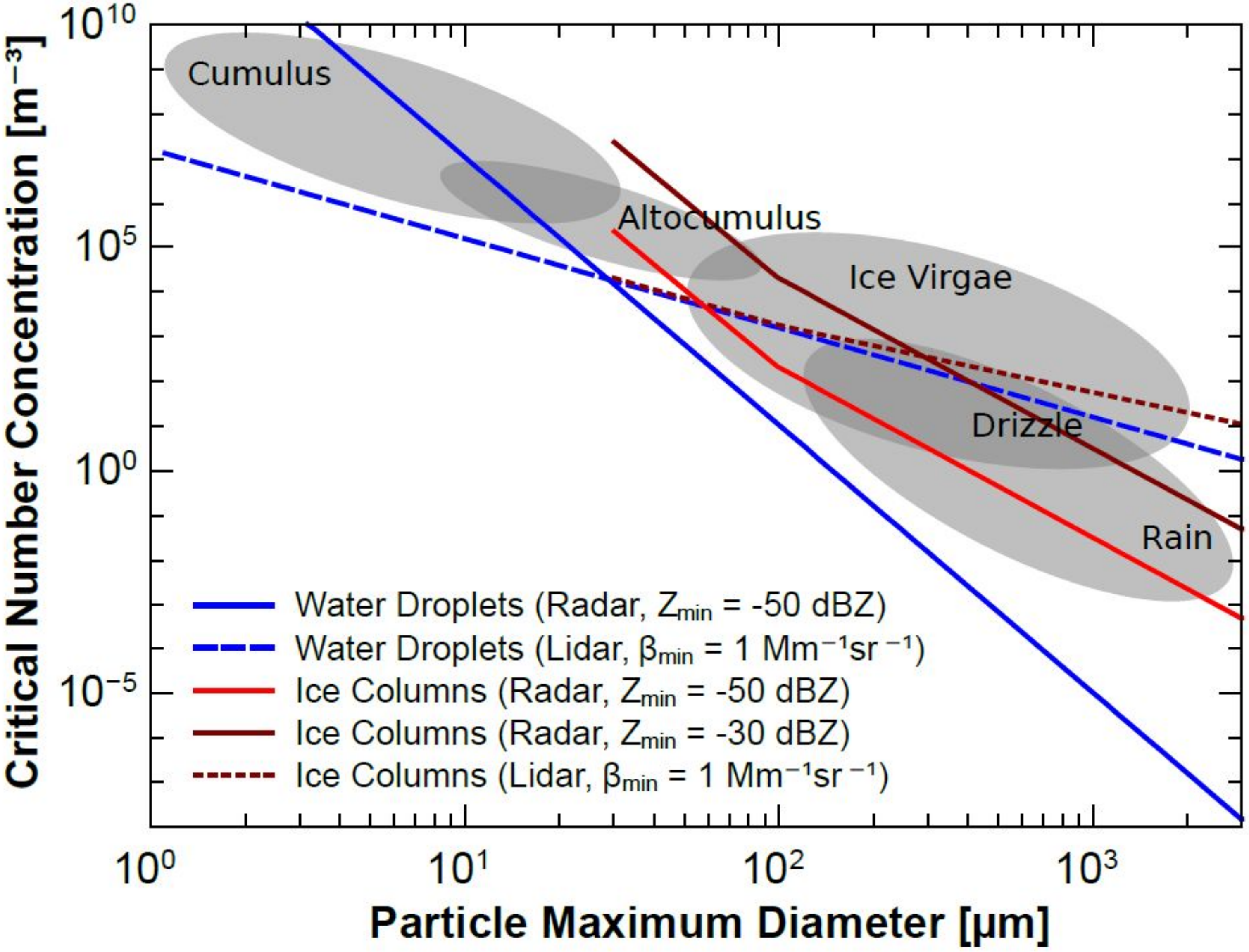


$Z \sim K\, m^2$

$E = \alpha = 2\, A_p$

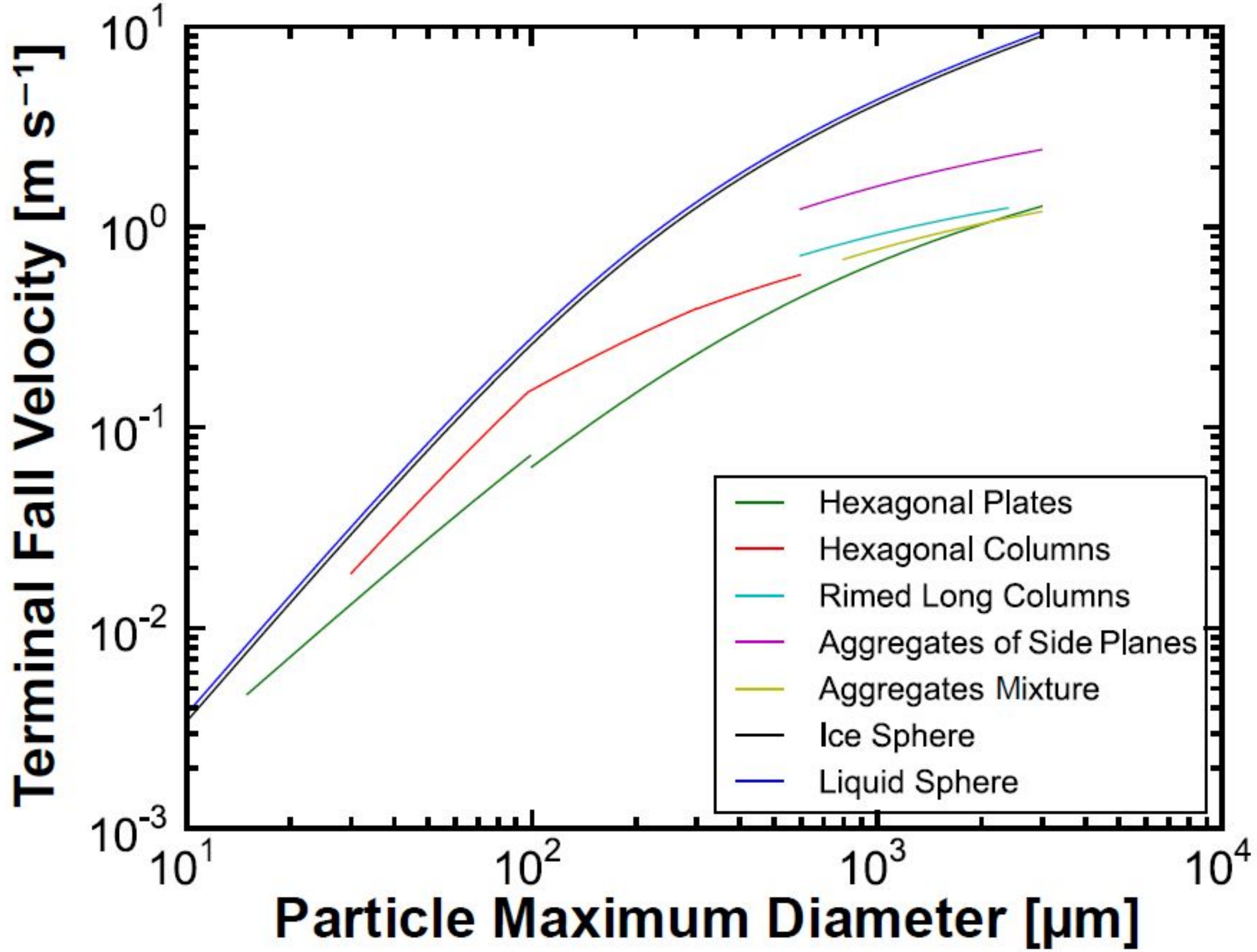
[Bühl, 2015]

How to parameterize cloud particles?



[Bühl, 2015]

Cloud particle's terminal fall velocity



$$v_t = \frac{\eta_{\mathrm{air}} \mathrm{Re}}{\rho_{\mathrm{air}} D_m}$$

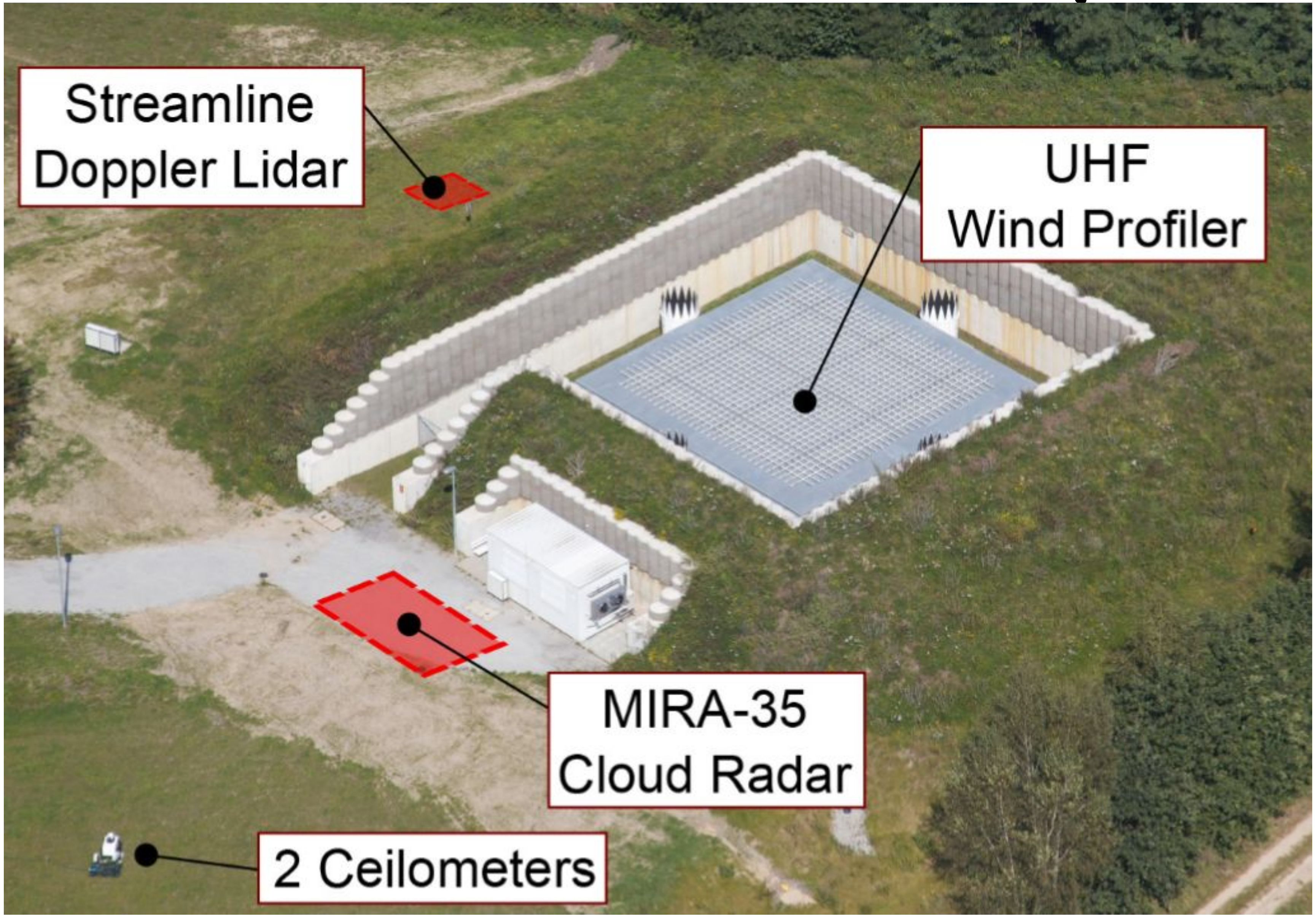
$$\mathrm{Re} = \frac{\gamma_0^2}{4}\left[\left(1 + \frac{4\sqrt{X^*}}{\gamma_0^2\sqrt{\gamma_1}}\right)^{0.5} - 1\right]^2$$

$$X^* = \frac{8 m_p g \rho_{\mathrm{air}}}{\pi \eta_{\mathrm{air}} A_r^{(1-k)}}$$

Many different flow characteristics at play!
(laminar, transition, turbulent)

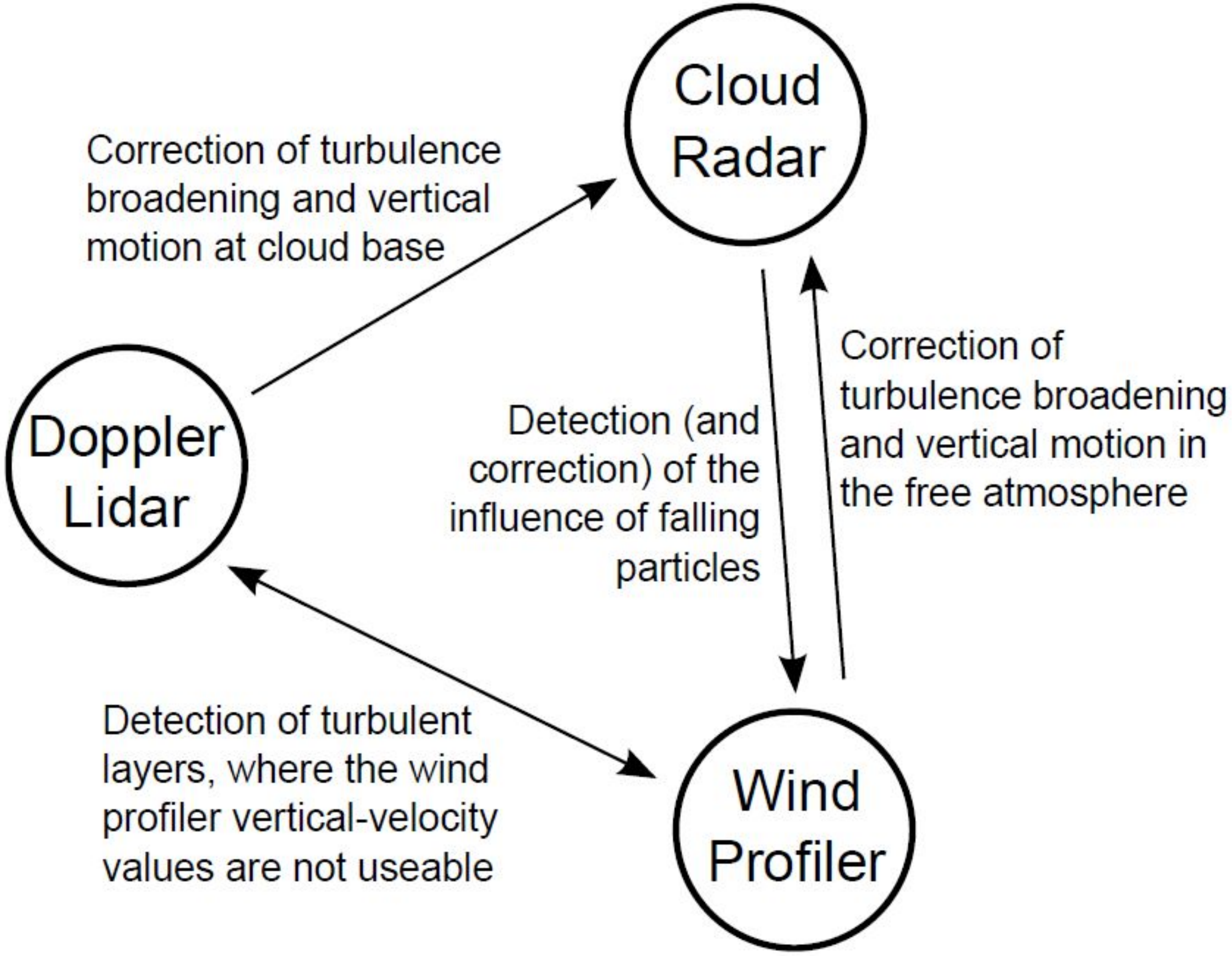
[Bühl, 2015]

How do we measure v_t?



[Buehl et al. , 2015]

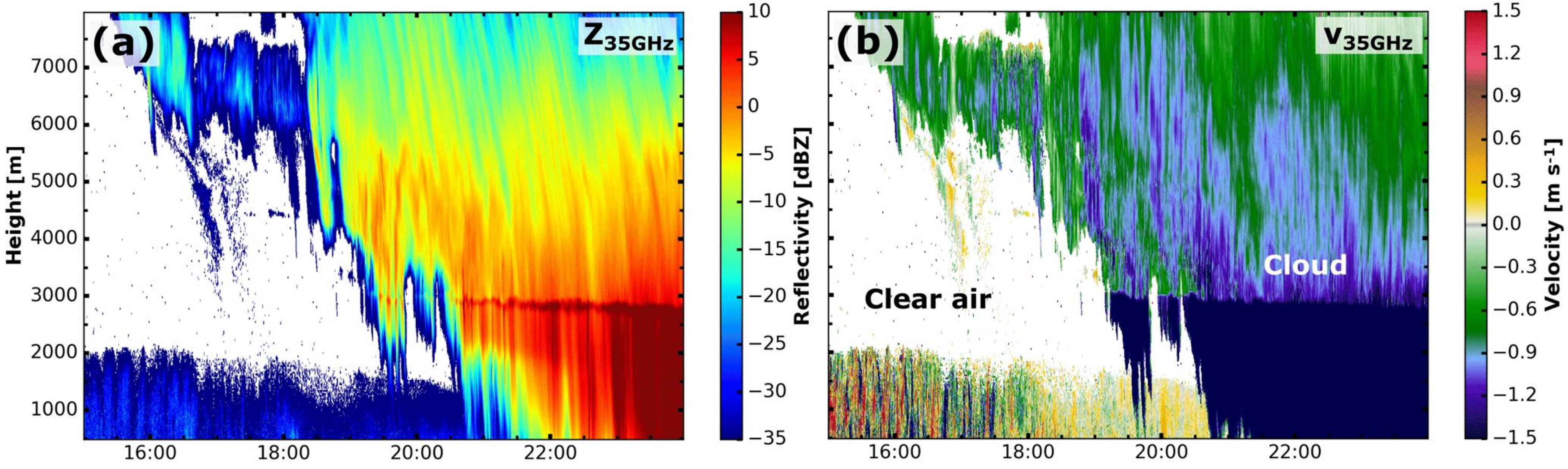
Direct conversion of radar spectra into particle size distributions



[Bühl, 2015]

How do we measure v_t?

Cloud Radar

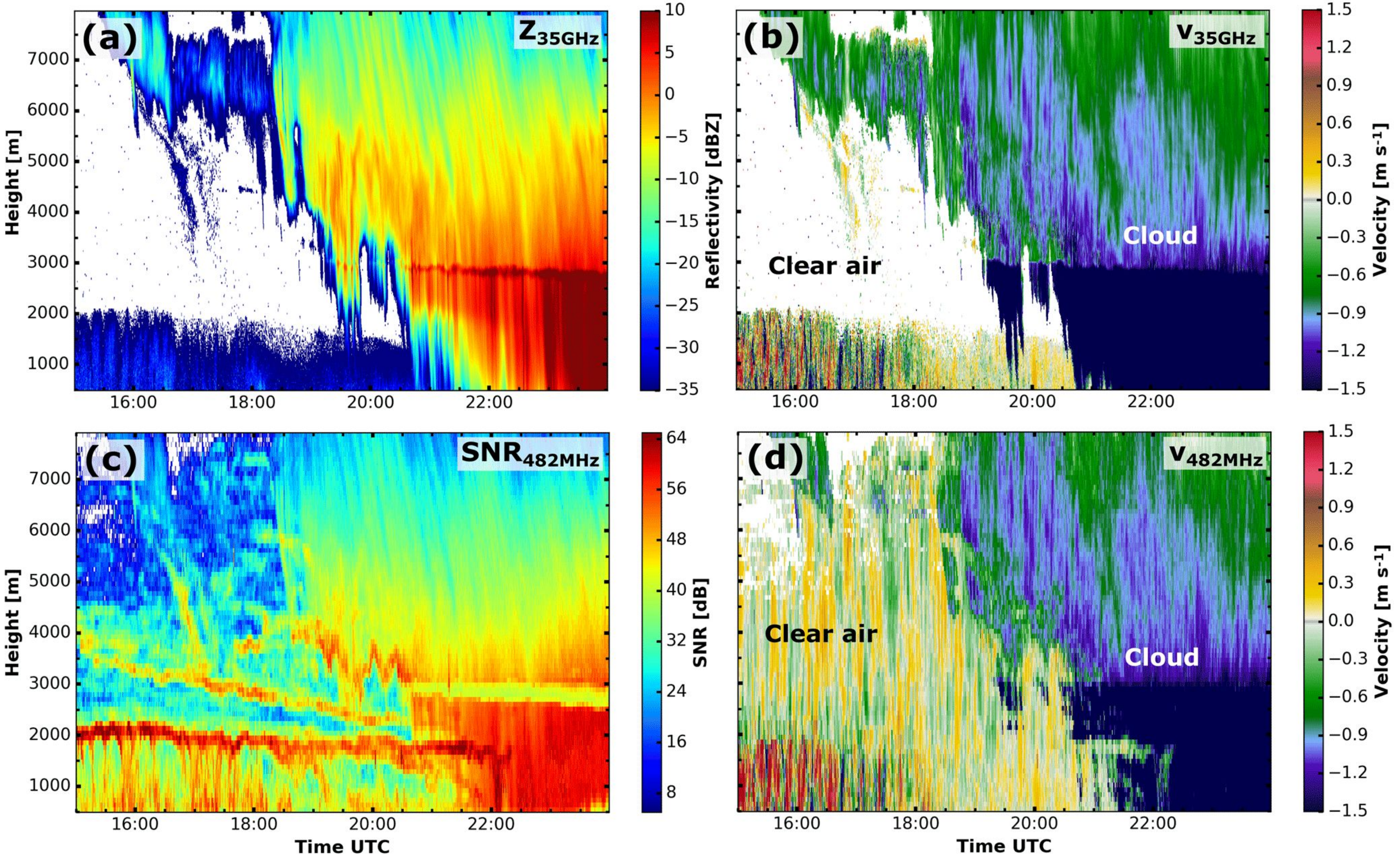


[Radenz , 2020]

How do we measure v_t?

Cloud Radar

Wind Profiler



[Radenz , 2020]

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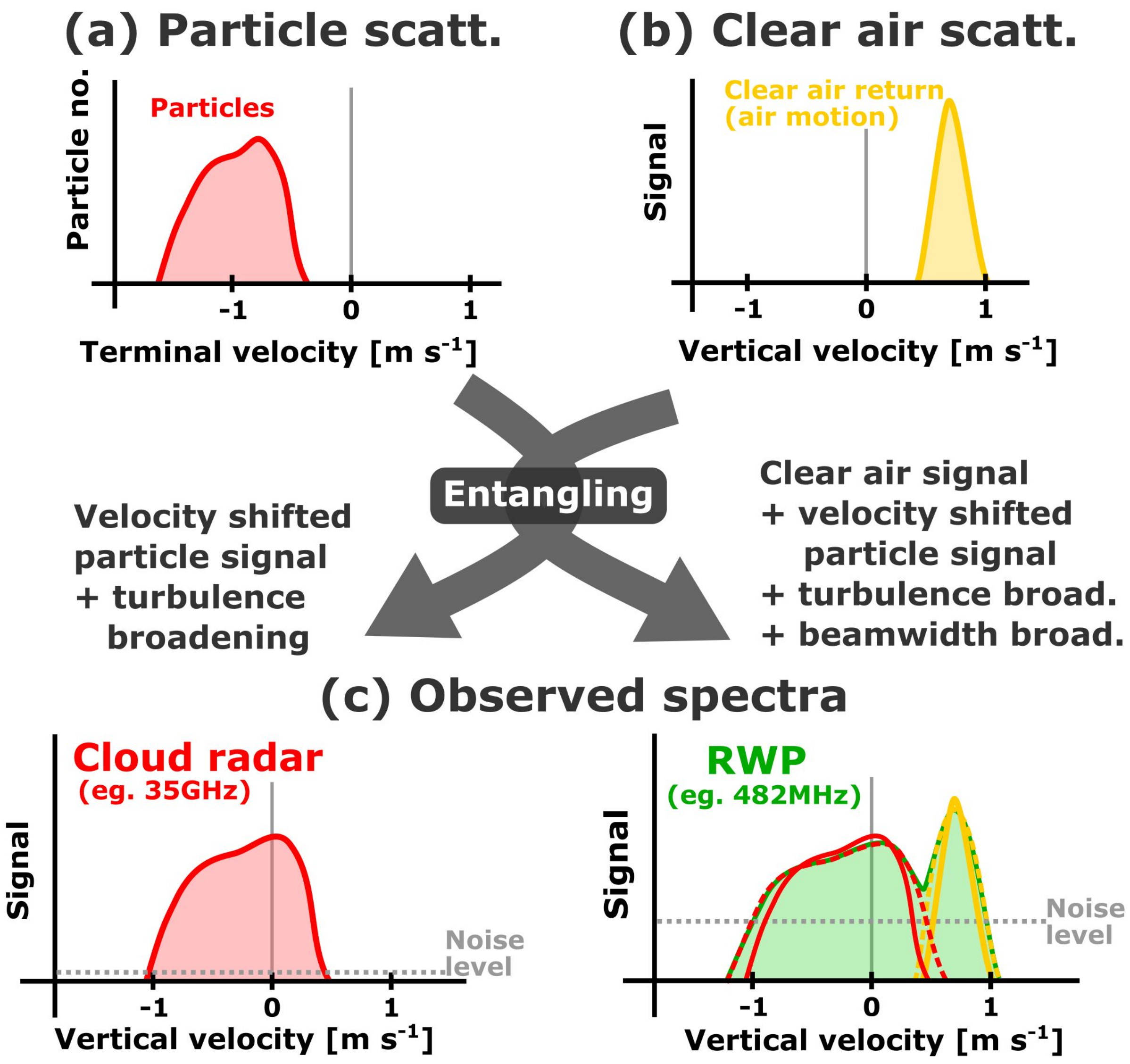

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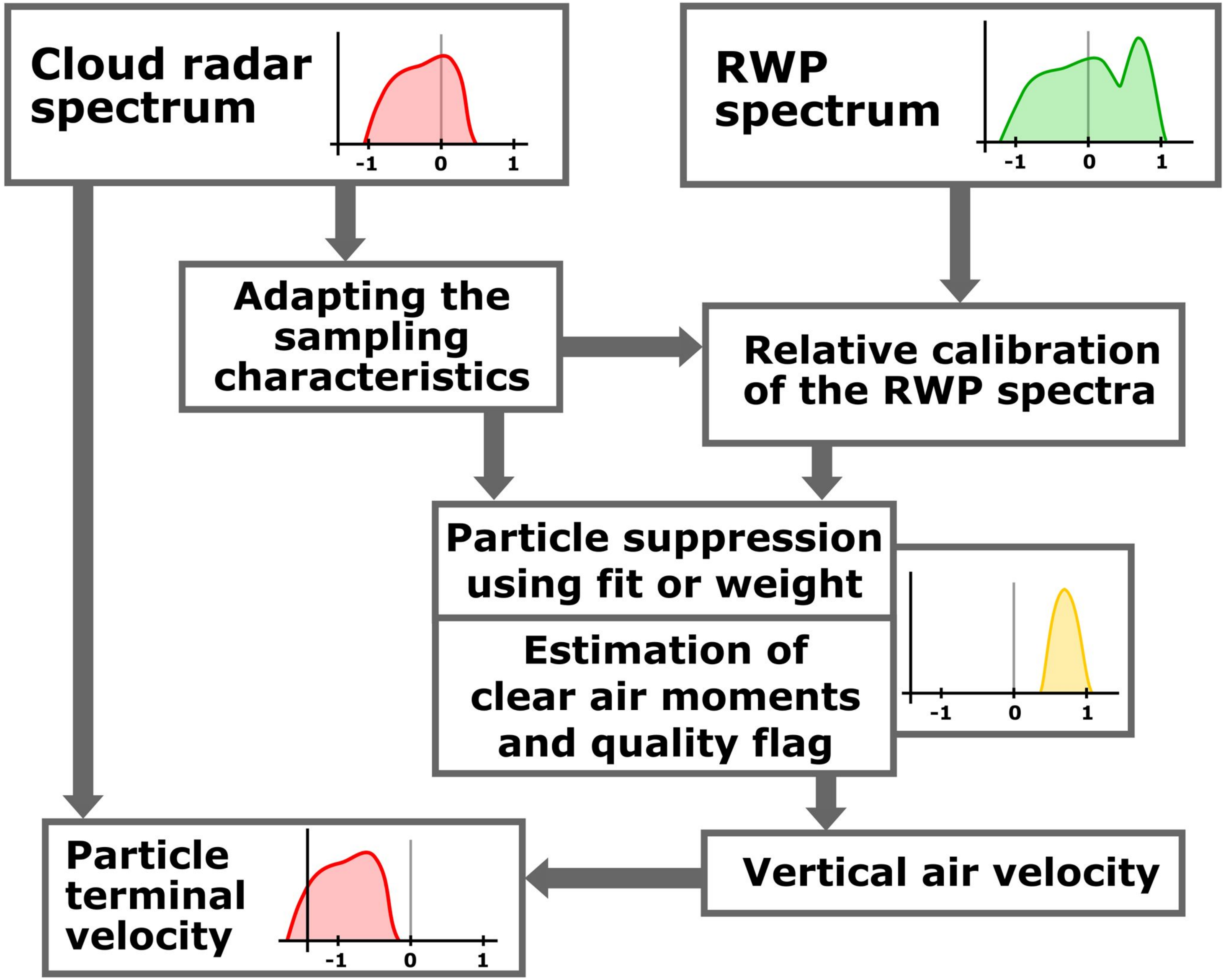

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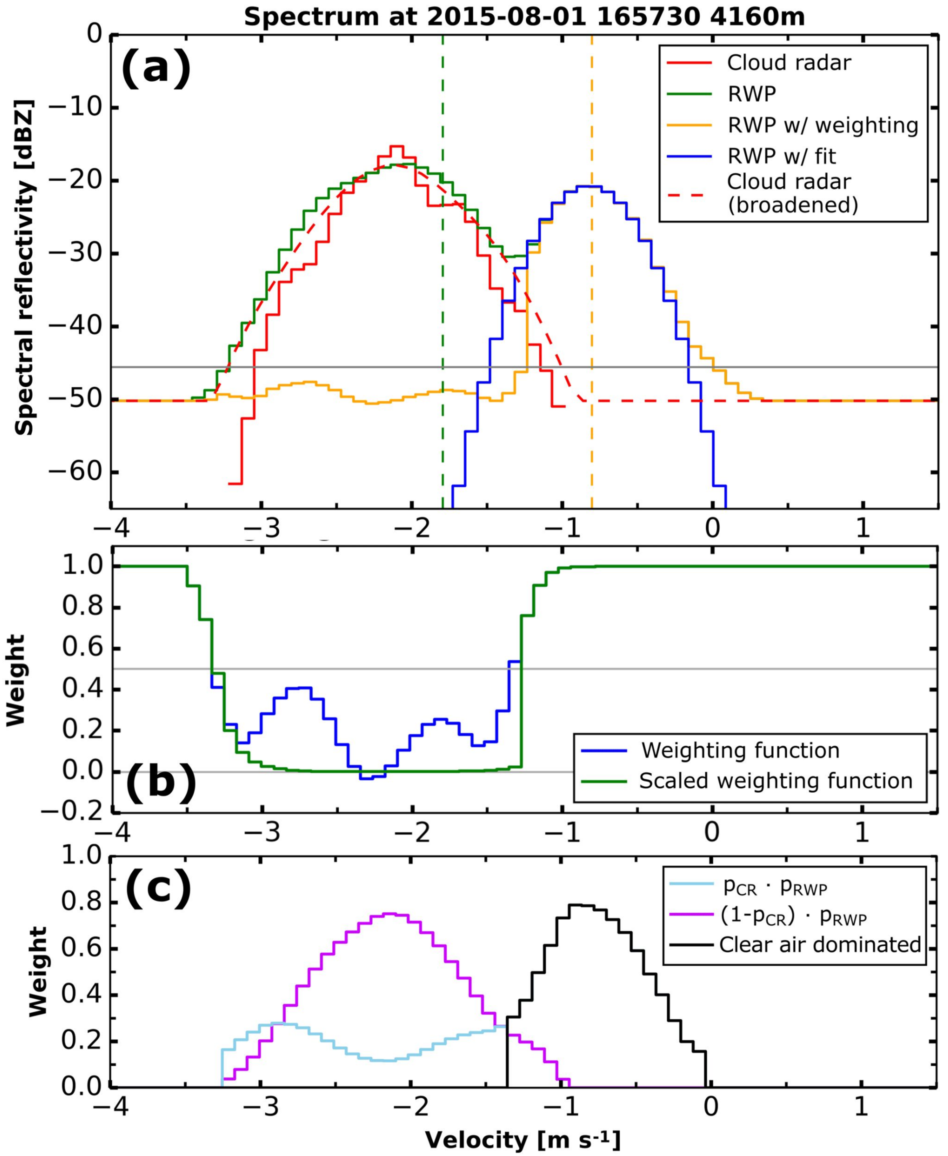

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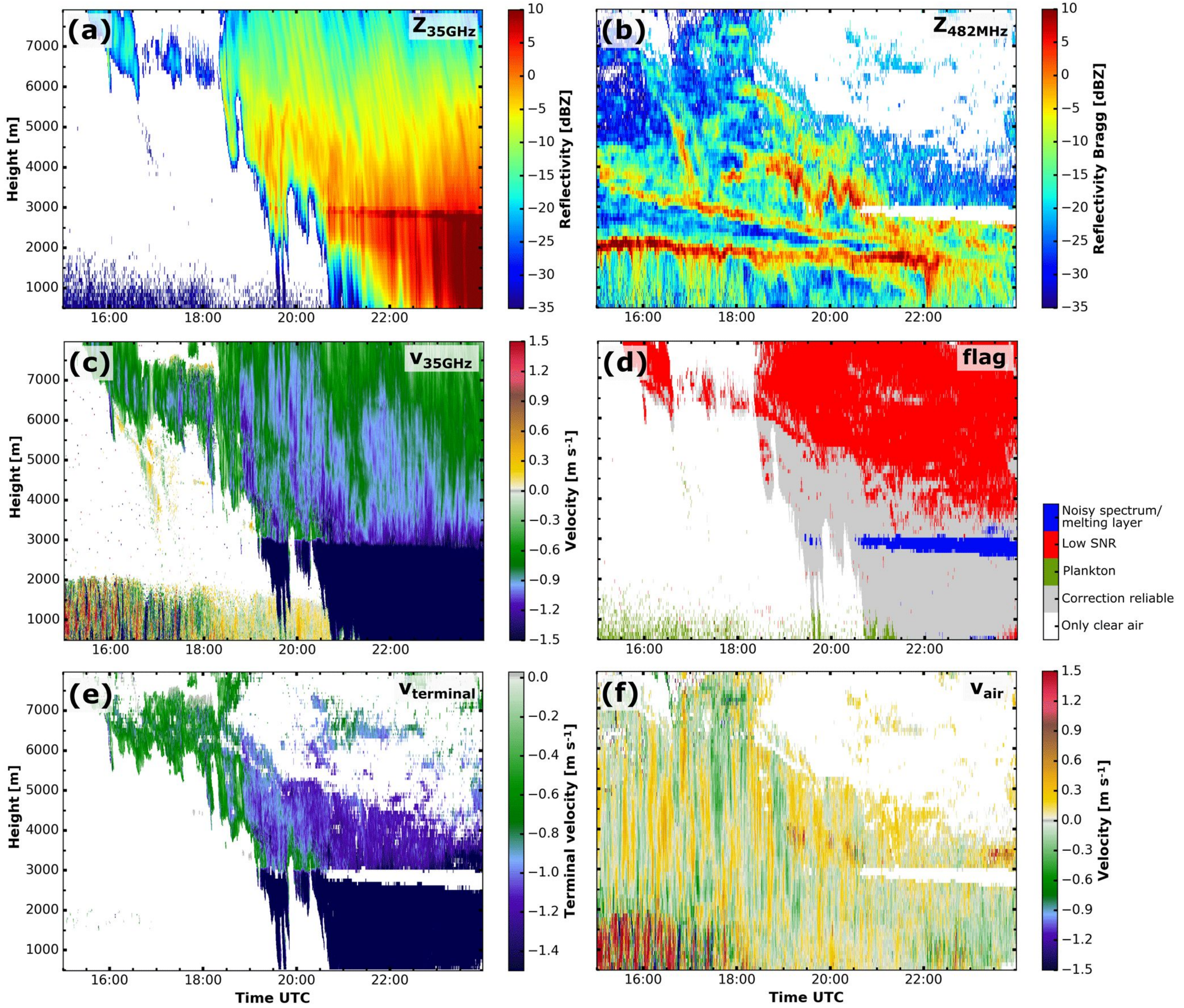

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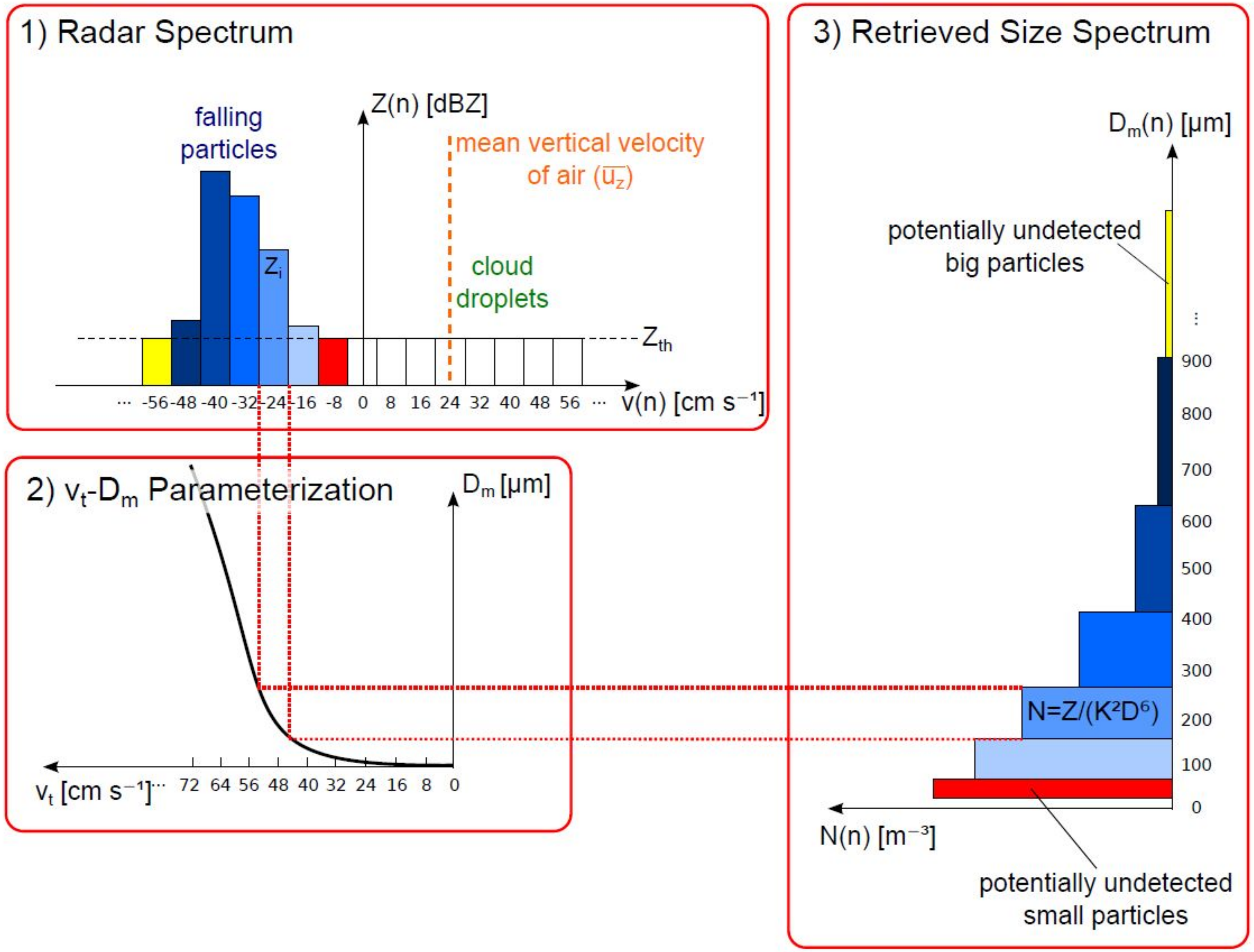
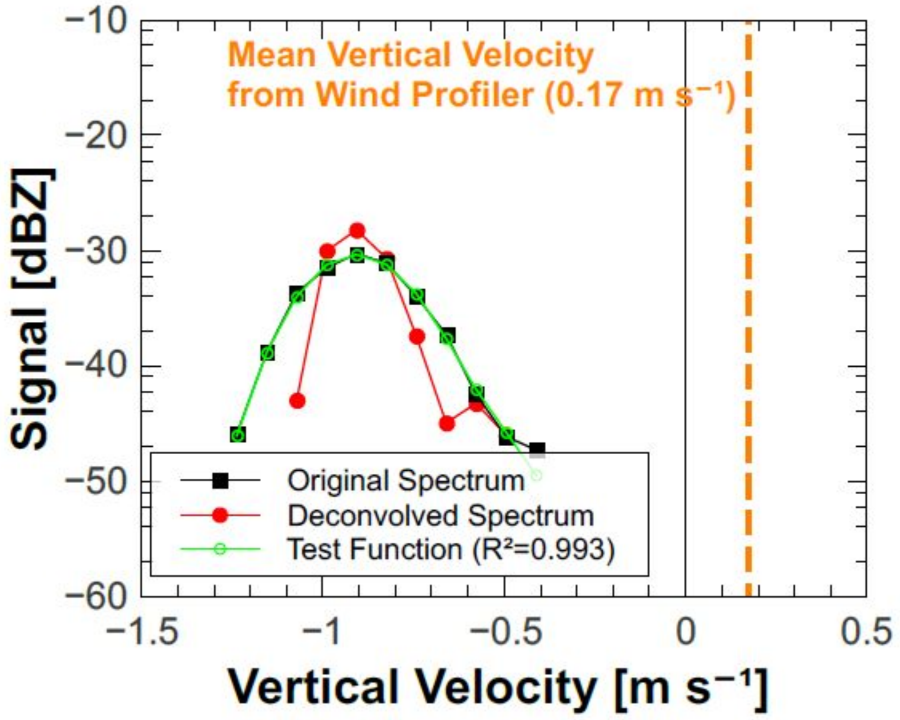
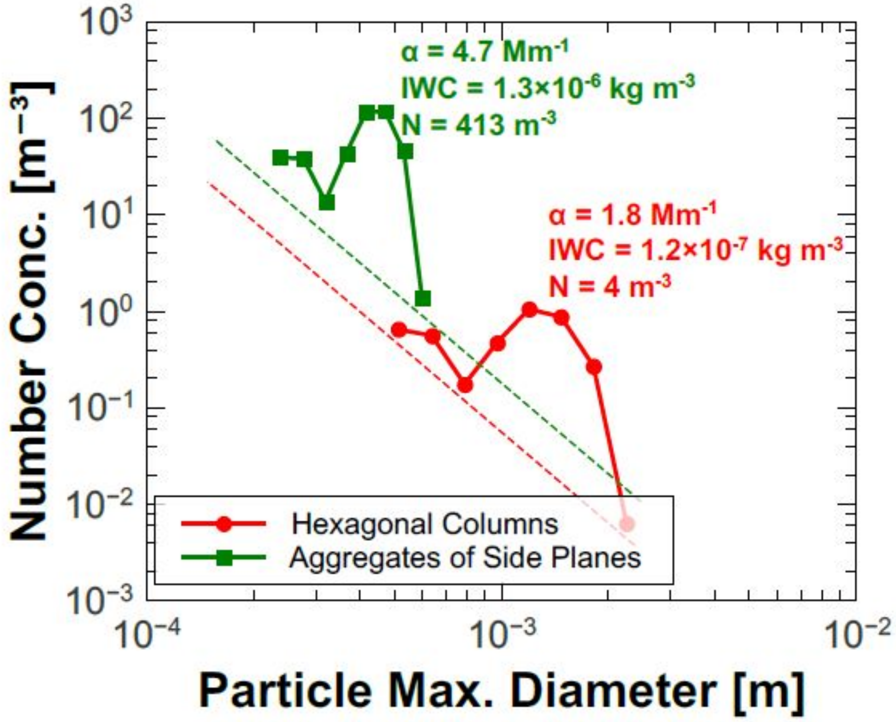
Direct conversion of radar spectra into particle size distributions



[Bühl, 2015]

Direct conversion of radar spectra into particle size distributions

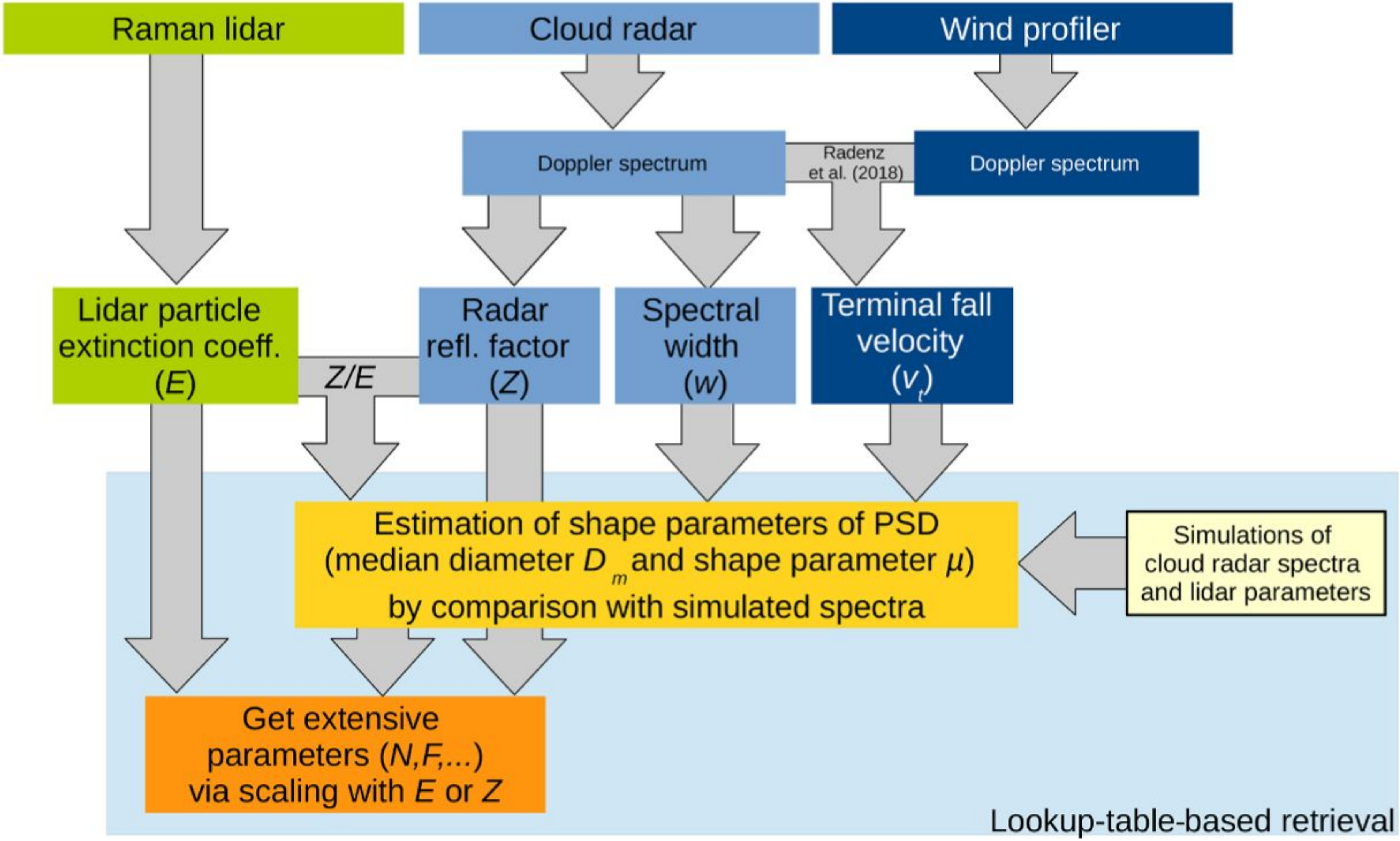




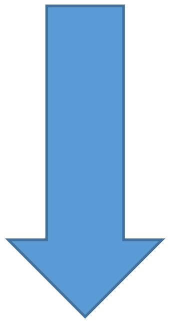
[Bühl, 2015]

Toward LIRAS-ICE…

Algorithm flow chart



input vector



output vector

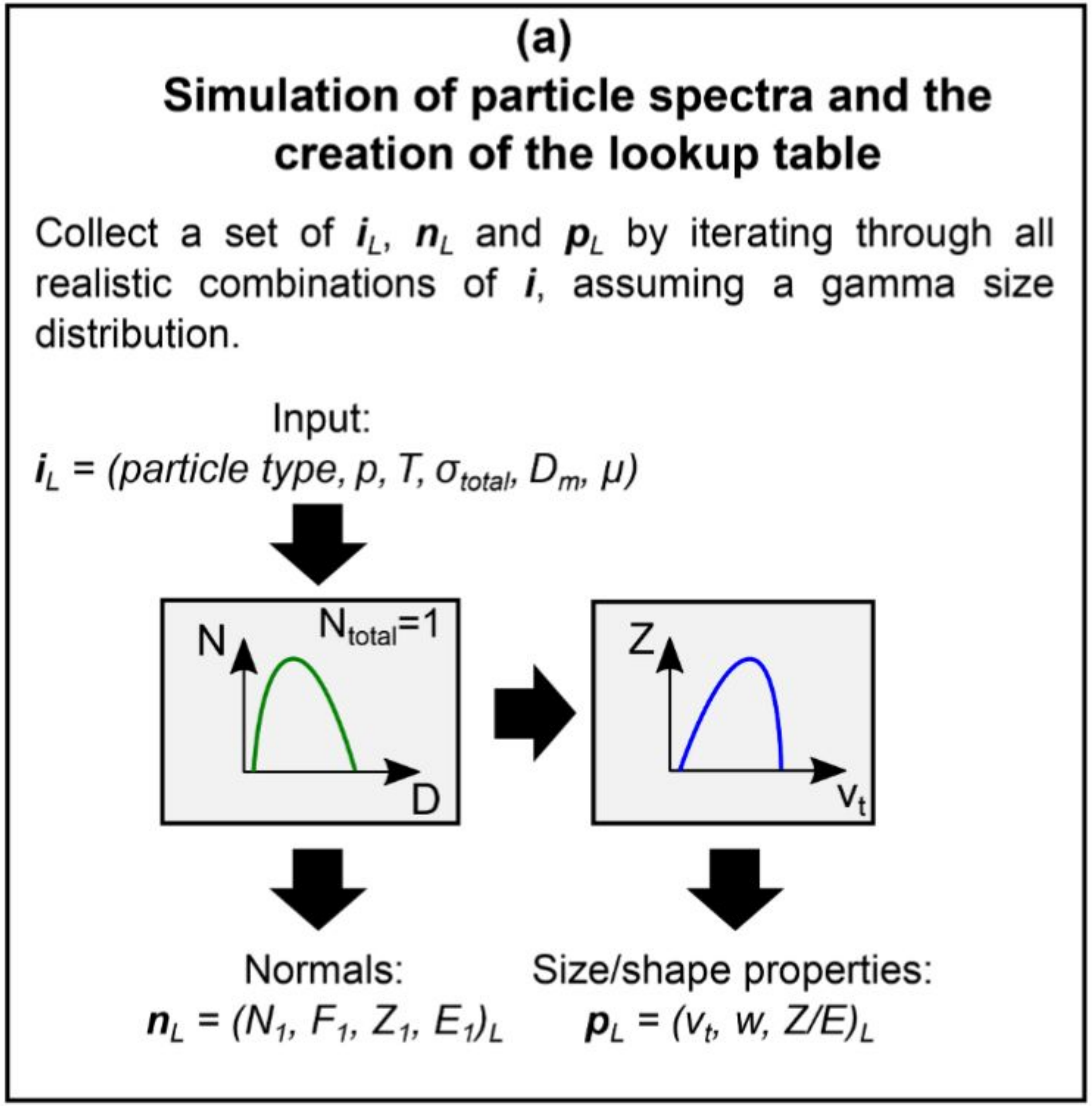
[Bühl, 2019]

Forward simulation of lidar and radar measurements

Parameter	Range low	Range high	Step size	Unit
p	50	1050	50	hPa
T	180	270	10	K
σ_{total}	0.05	0.5	0.1	$\mathrm{m\,s^{-1}}$
D_{m}	1×10^{-5}	5×10^{-3}	25×10^{-6}	m
μ	1	61	1	–

=> Forward modeling and lookup table of observables (v_t, Z, E, …)

[Bühl, 2019]



***i* :** **Input parameters**

***n* :** **Normalized extensive parameters**

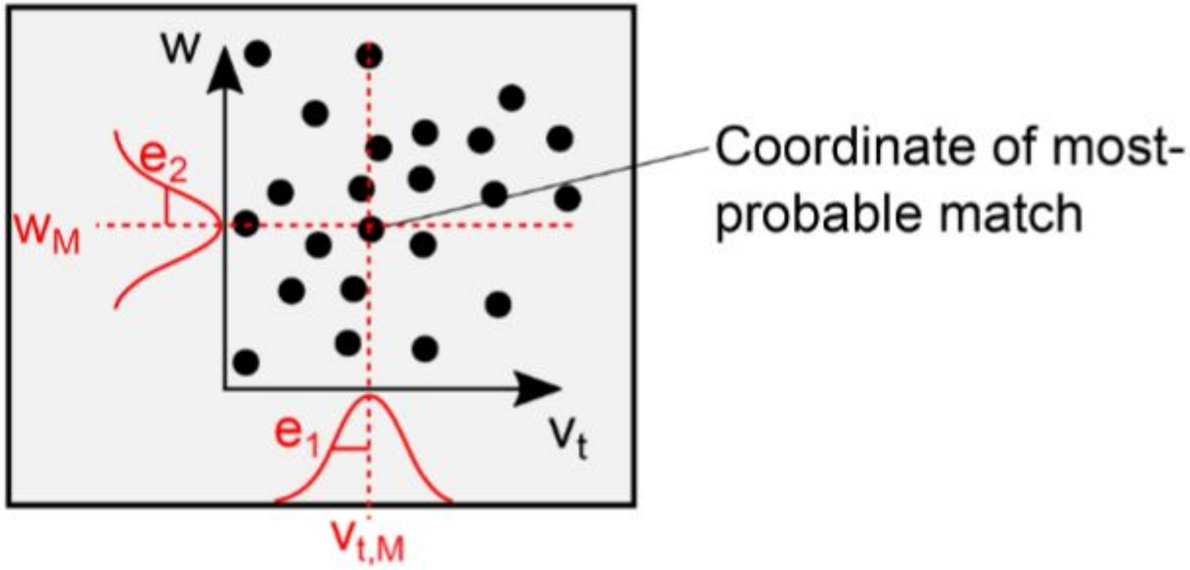
***p* :** **Intensive parameters (particle properties)**

[Bühl, 2019]

(b)

Look up a result

Create space with a combination of the coordinates (here: v_t, and w) and fill with the corresponding vectors $\boldsymbol{n}_L$ and $\boldsymbol{i}_L$.
Calculate the distribution of the matching probability in (v_t , w) space against vector $\boldsymbol{m}=(v_{t,M}\ ,\ w_M)$ measured with errors.



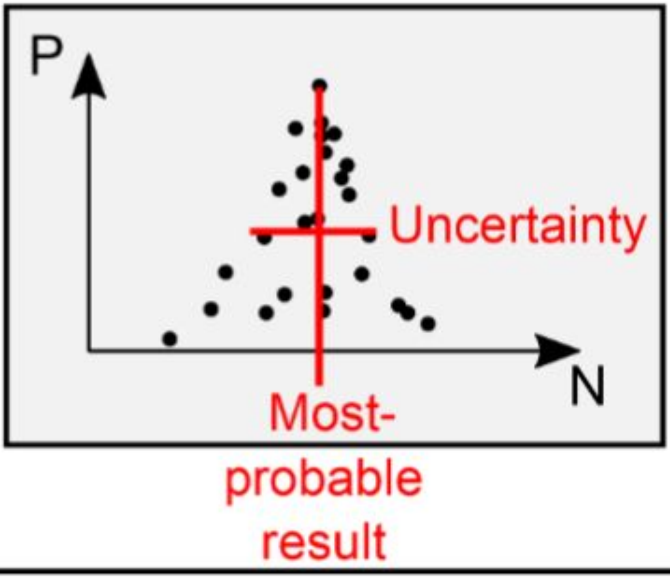
e: **Errors of input parameters**

[Bühl, 2019]

(c)
Scale normal vectors and combine with P

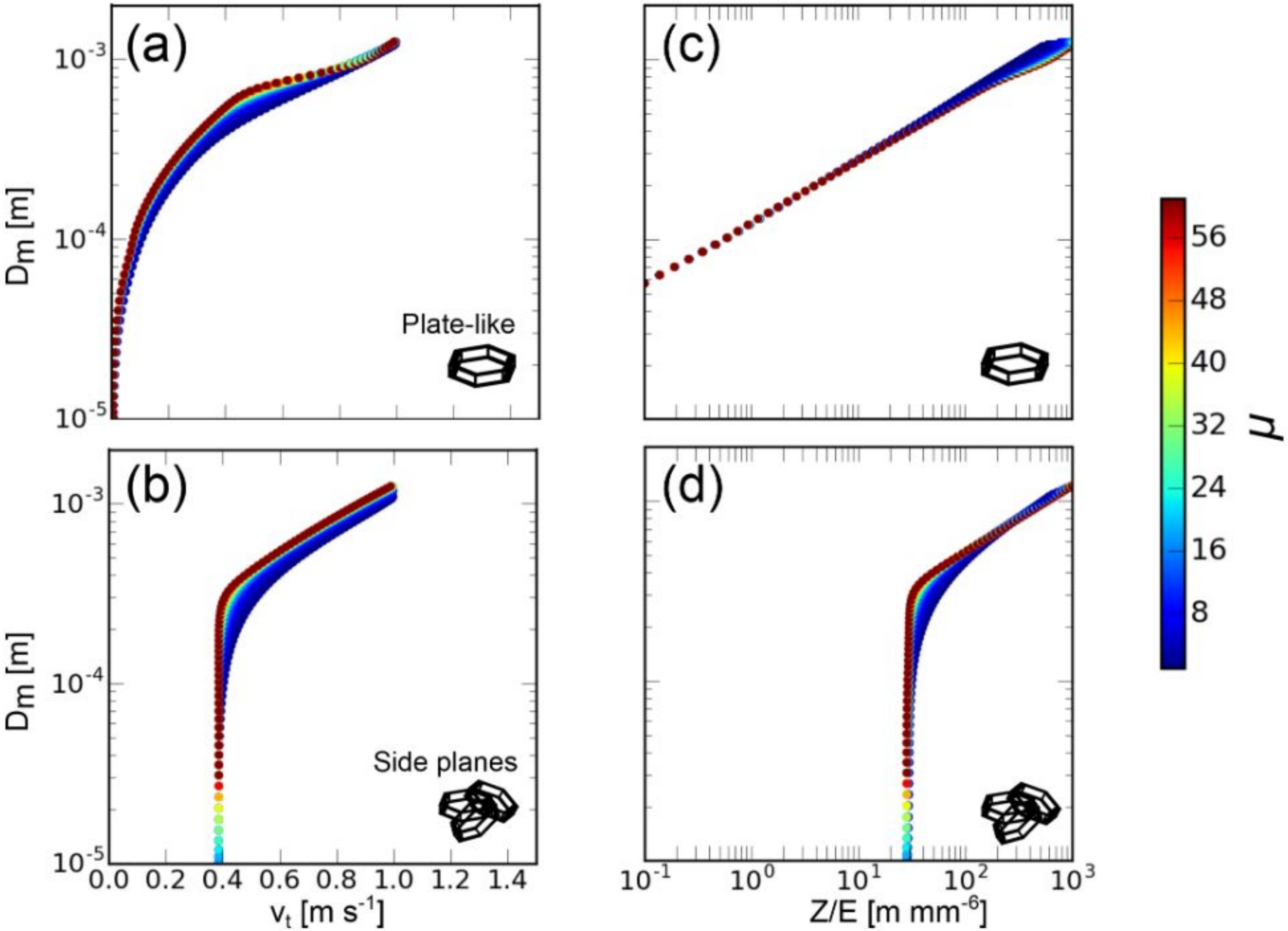
Retrieve vectors $\boldsymbol{r}_L$ of extensive properties by scaling each normal vector of the lookup table with measured Z_M and the simulated Z_1 so that $\boldsymbol{r}_L = \boldsymbol{n}_L\,(Z_M / Z_1)$.

Plot an element of all vectors $\boldsymbol{r}_L$ vs matching probability P (example for number concentration).



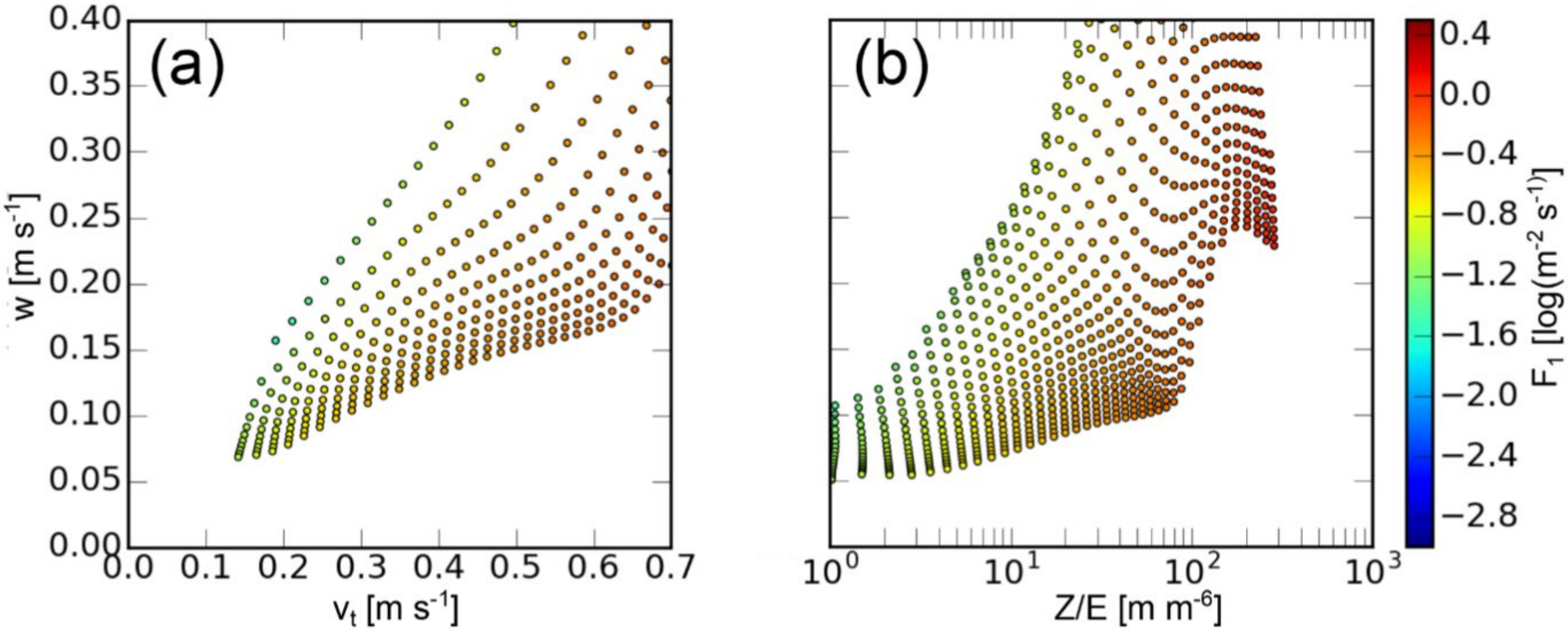
[Bühl, 2019]

Forward simulation of lidar and radar measurements – equivalence of v_t and Z/E



[Bühl, 2019]

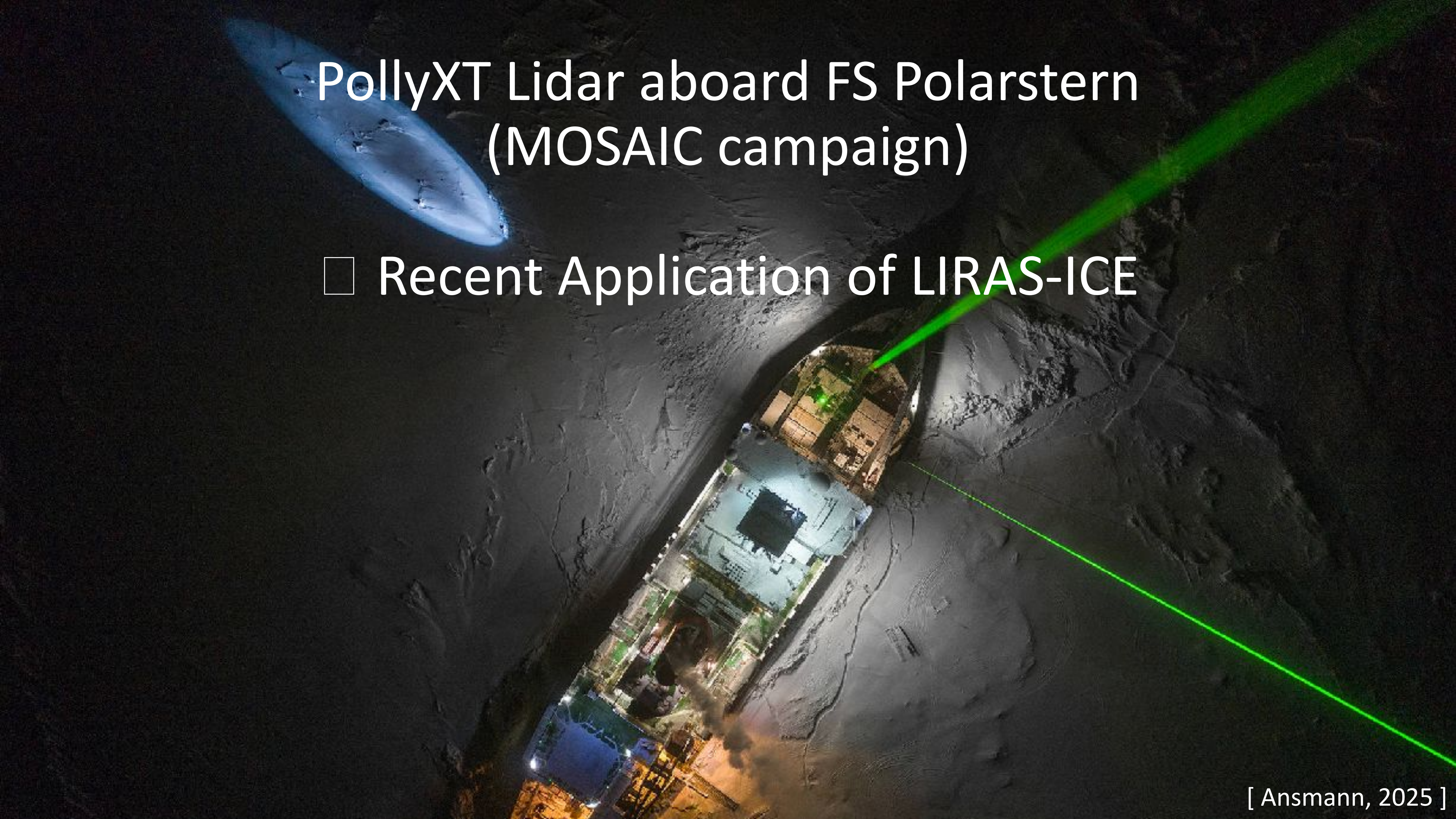
Forward simulation of lidar and radar measurements



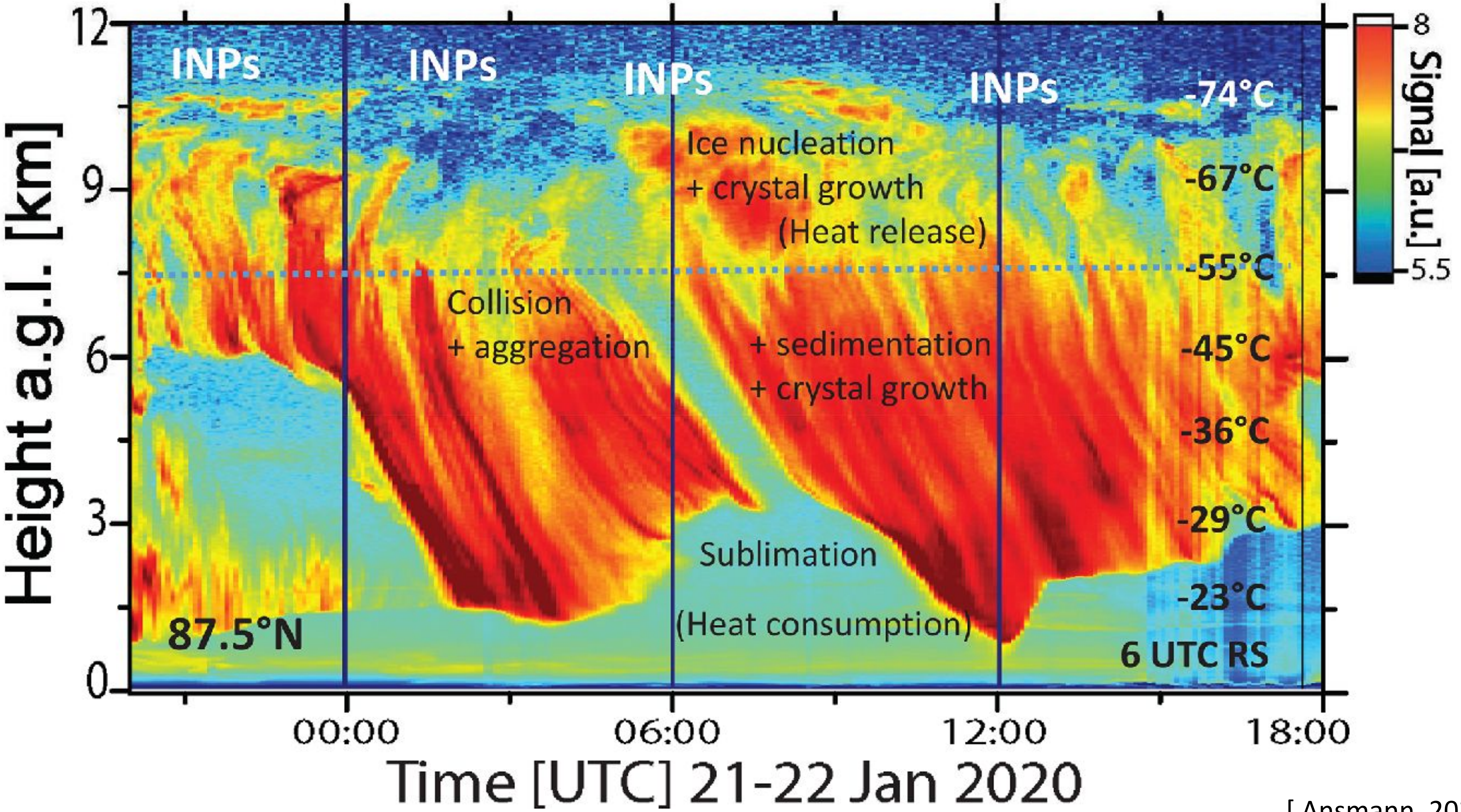
[Bühl, 2019]

PollyXT Lidar aboard FS Polarstern (MOSAIC campaign)

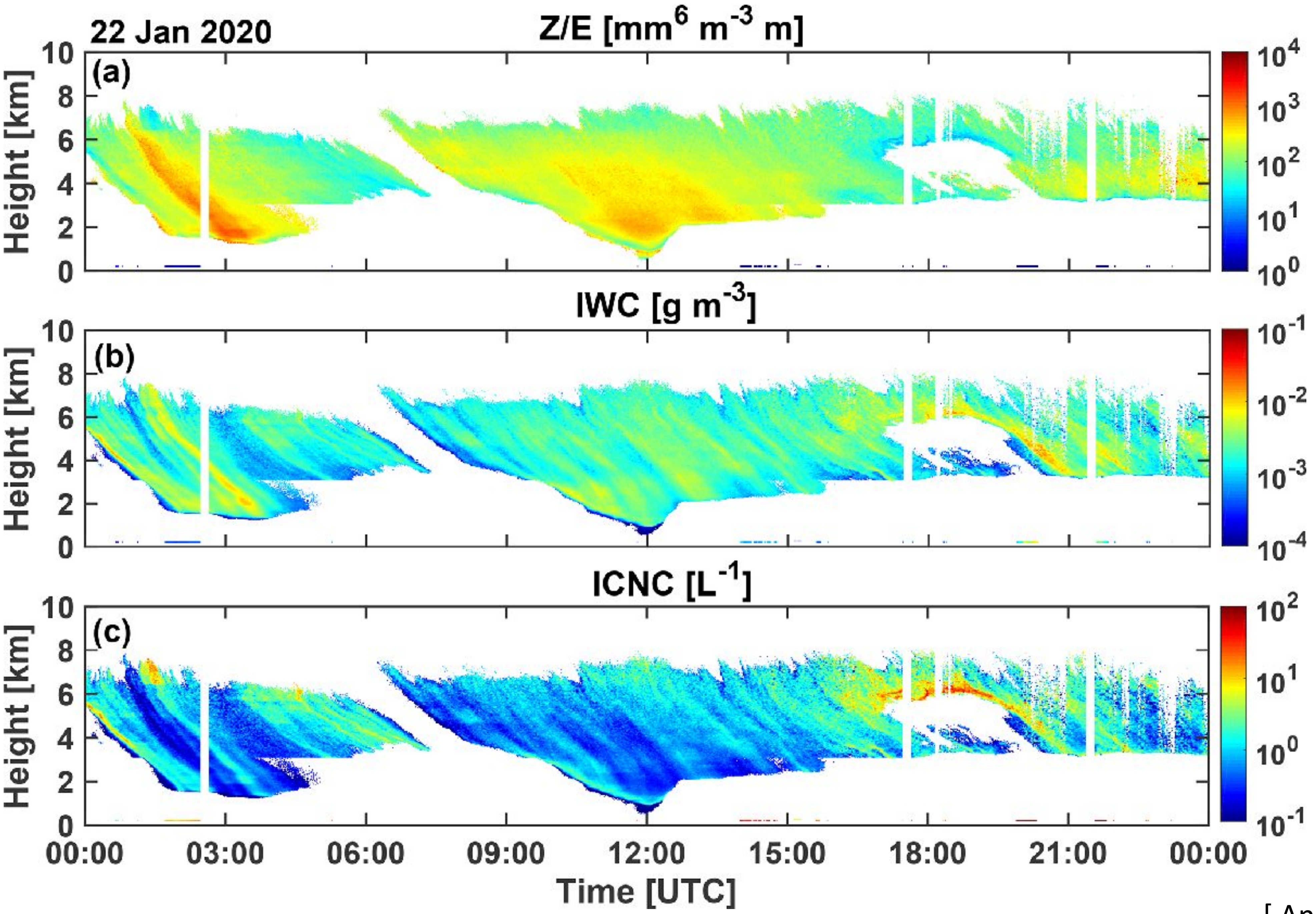
 Recent Application of LIRAS-ICE



[Ansmann, 2025]



[Ansmann, 2025]



[Ansmann, 2025]