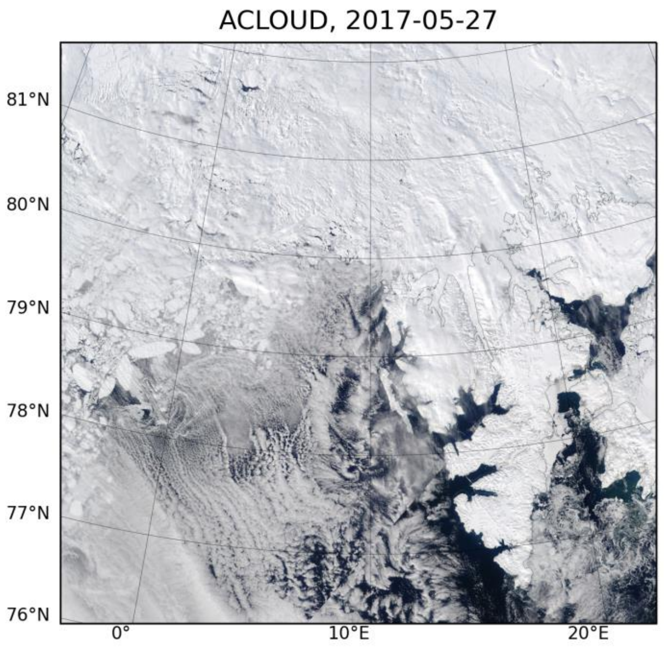
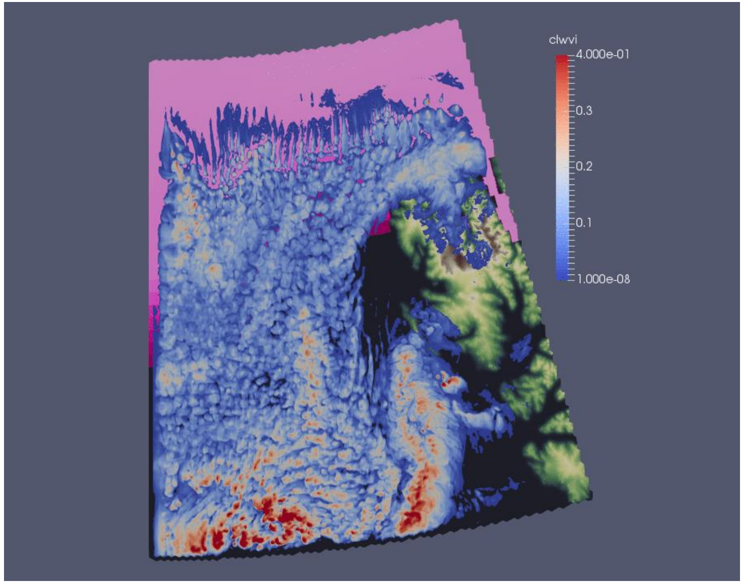
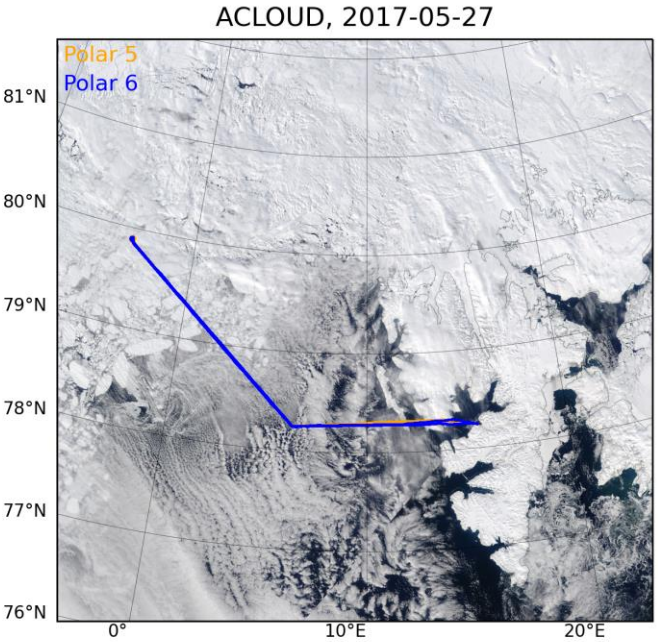
Passive and Active Microwave TRAnsfer (PAMTRA): a tool to simulate observations from space, air, and ground

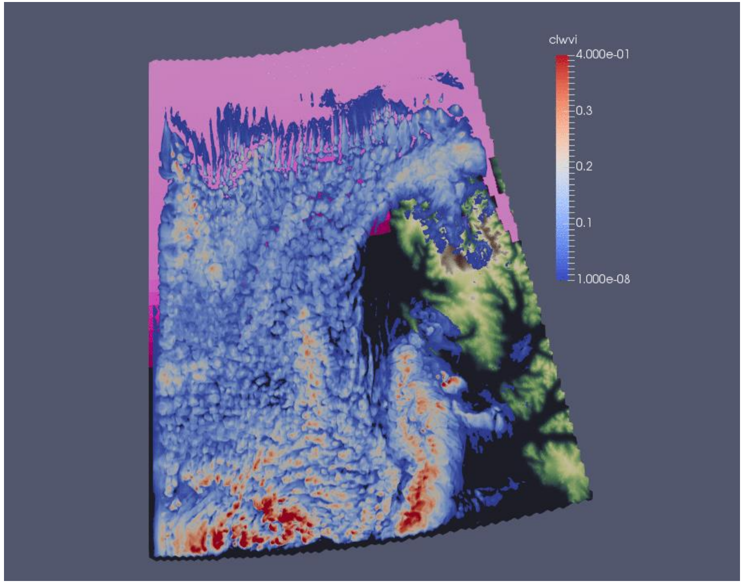
Mario Mech, Maximilian Maahn, Davide Ori, Pavlos Kollias, and Susanne Crewell



ICON-LEM by Schemann




ACLOUD, 2017-05-27
Polar 5
Polar 6
81°N
80°N
79°N
78°N
77°N
76°N
0°
10°E
20°E


clwvi
4.000e-01
0.3
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0.1
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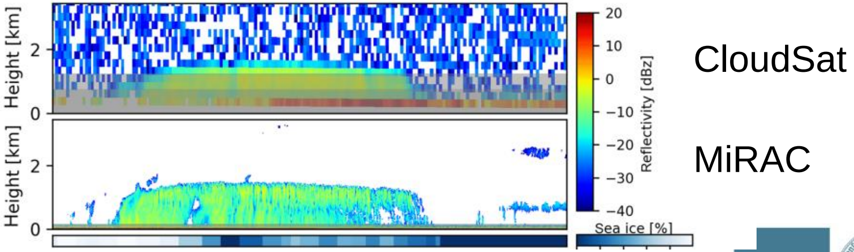

Height [km]
Height [km]
Reflectivity [dBz]
Sea ice [%]
CloudSat
MiRAC

There are already well established models. Why another model like PAMTRA?

- **User friendly** and easy to use
- **Consistency** between active and passive RT
- Unique choice of **scattering models**
- Unique treatment of **radar Doppler spectra**
- **Modularity** - possibility of integrating new scientific results and features and interfaces to models and instruments
- **Full control** of code design and future development

1 Accurate description of the hydrometeors and their particle size distribution

(Petty 2001, JAMC)

- Unlimited number of hydrometeors described by various properties (type, shape, size/velocity, mass/size, extend of psd, phase)
- Many implemented particle size distributions: from literature or as implemented in the models providing the atmospheric state
- 1 or 2 moment microphysical schemes
- Full bin size resolved microphysics from bin models or in-situ measurements

2 Exact description of (the gaseous absorption) and the single scattering properties of each particle

(Petty 2001, JAMC)

Absorption models:

- **Rosenkranz (2015)** (including recent modifications after Turner et al. (2009) and Liljegren et al. (2005)).
- **Liebe et al. (1993)** (MPM93)
- Recent models for super-cooled liquid (Kneifel et al., 2014; Cadeddu and Turner, 2011)

Single scattering properties:

- **Mie theory (1908)** spheres like cloud and rain droplets
- **T-Matrix method (Mishchenko and Travis 1994)** particles with symmetrie
- **DDA calculations from DBs (Liu 2008, Hong et. 2009)**
- **Self-Similar Rayleigh-Gans Approximation (SSRGA) (Hogan and Westbrook, 2014; Hogan et al., 2017)** for **active and passive**

3 Suitable and accurate method to solve the RT equation for the problem

(Petty 2001, JAMC)

passive

RT4 code of Evans et al. (1995) which applies the doubling and adding method: polarized brightness temperatures for frequencies between 1-800 GHz

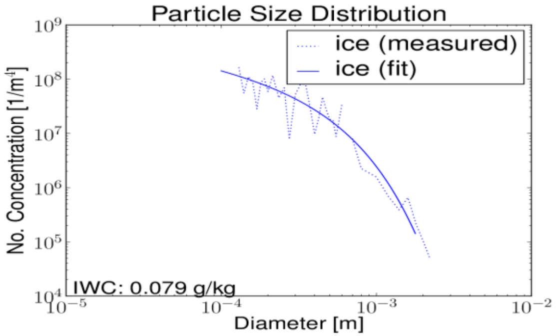
active

Radar Doppler spectra simulator based on methods by Kollias et al. (2011, 2014):

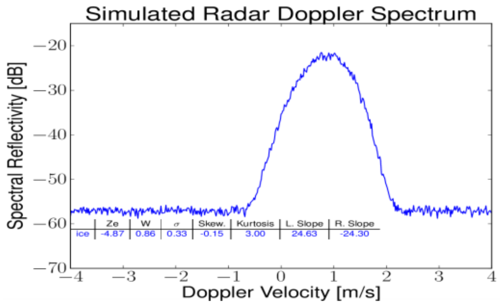
- Attenuation by gaseous and hydrometeors
- Radar reflectivity Ze
- Full Doppler spectrum and velocity
- Spectral width, skewness, kurtosis, and right and left slopes

Including instrument properties and turbulence

Derivation of the idealized Doppler spectrum



Forward operator



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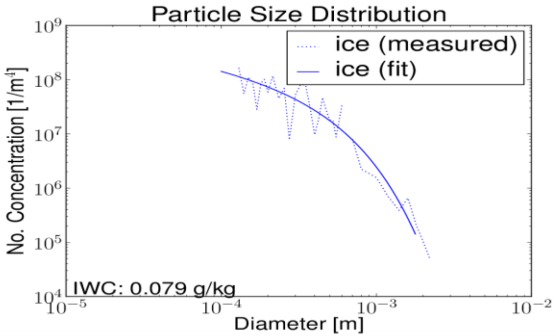
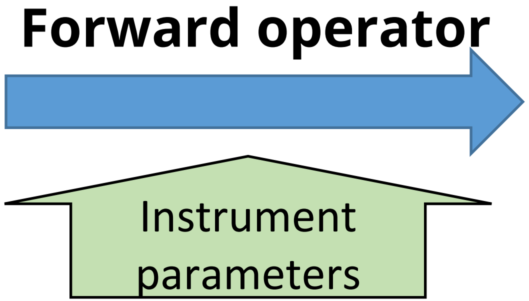
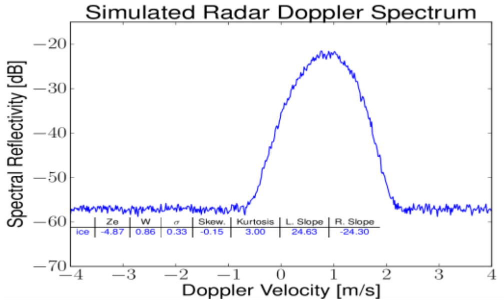
Including instrument properties and turbulence

Derivation of the idealized Doppler spectrum







Derivation of the non-idealized spectrum by applying the following perturbations:

- Attenuation
- Kinematic broadening (finite beam width, wind shear, turbulence)
- Vertical air motions
- Radar receiver noise
- Random noise effects
- Averaging

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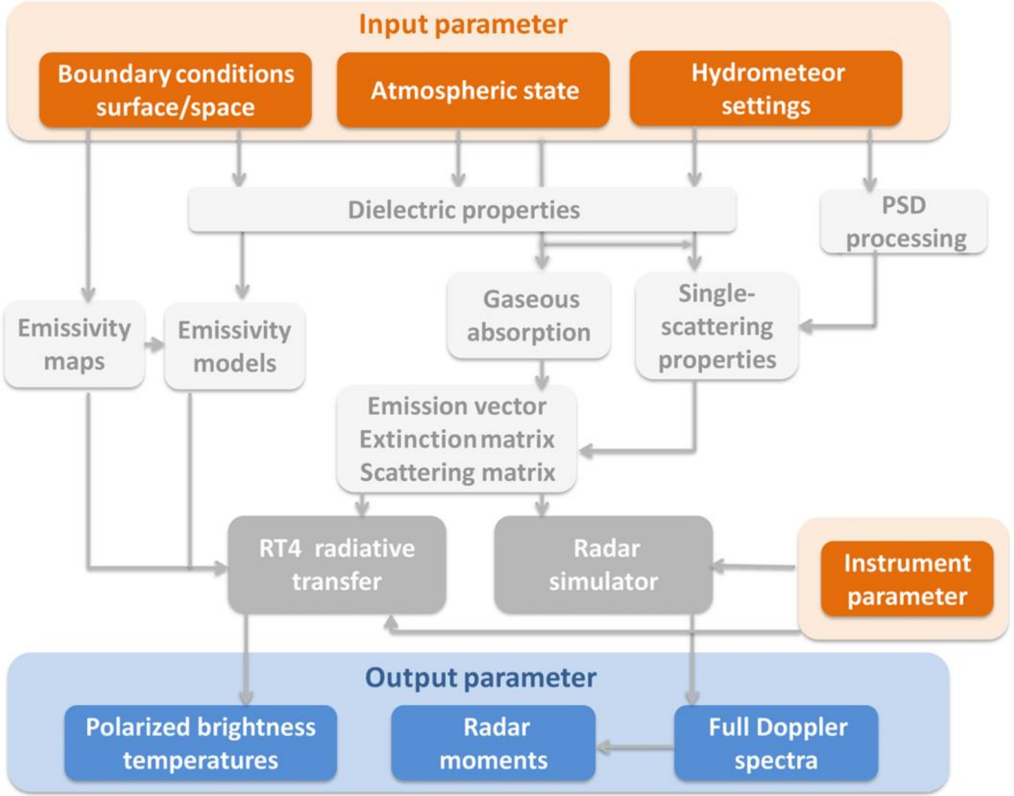

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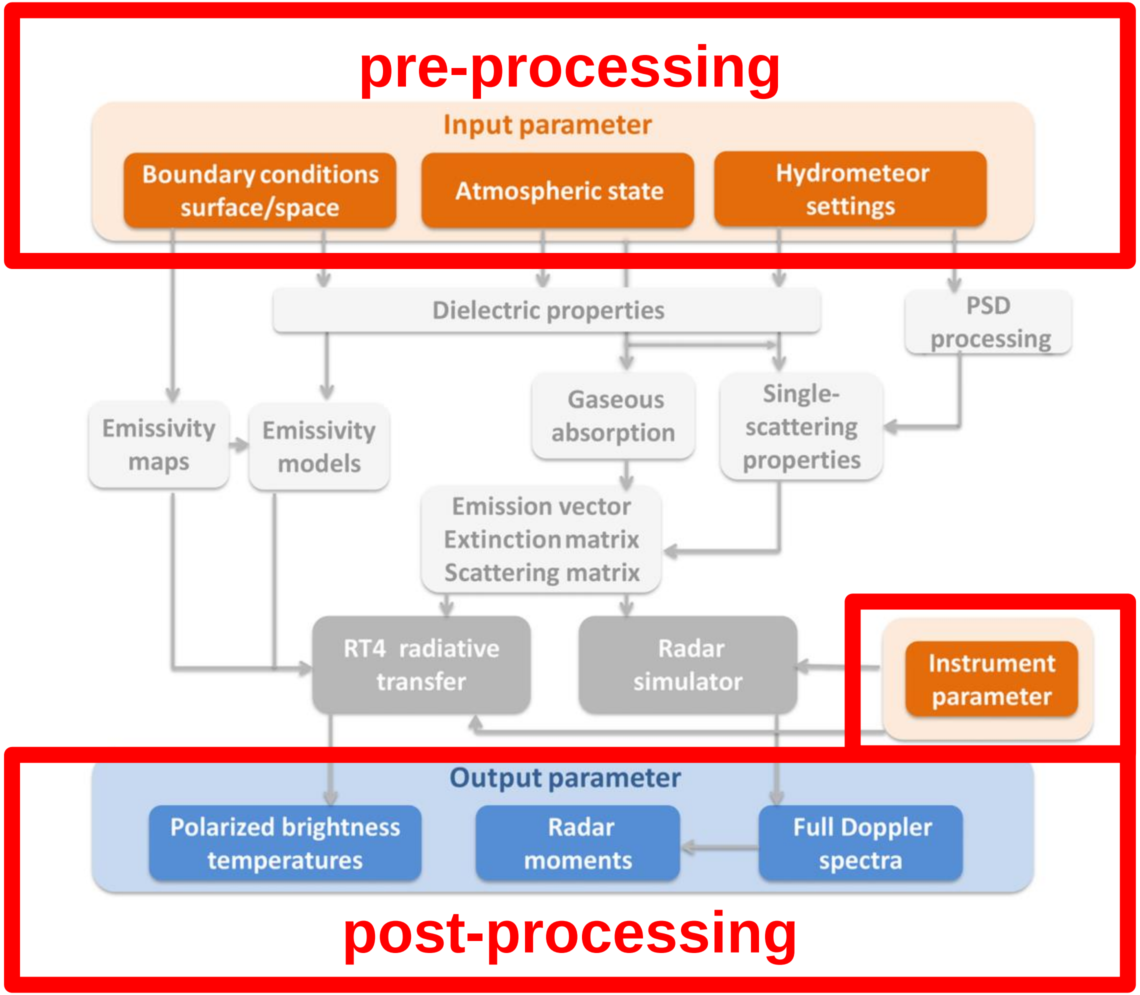

PyPamtra python shell

control

importers for various models and other output format

helper routines like slicing, regridding, profiles along satellite/flight path

parallelization of PAMTRA calculations

instrument geometry and convolution

file storage

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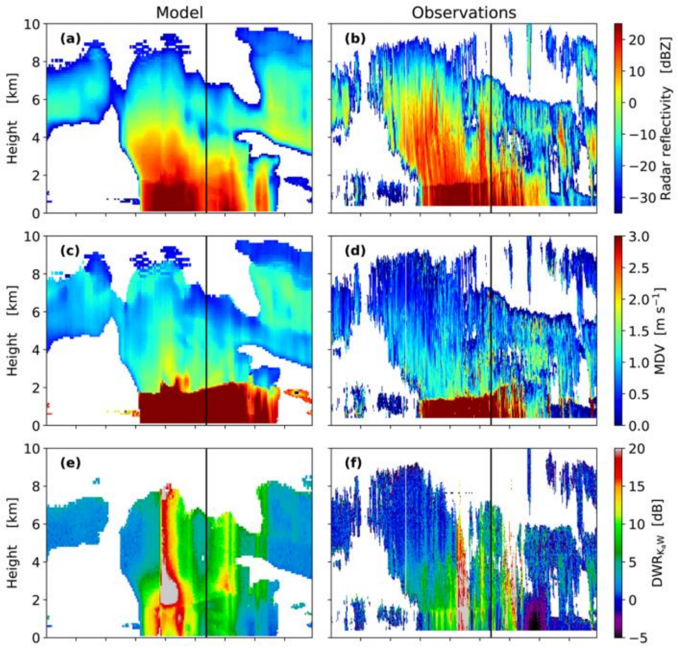
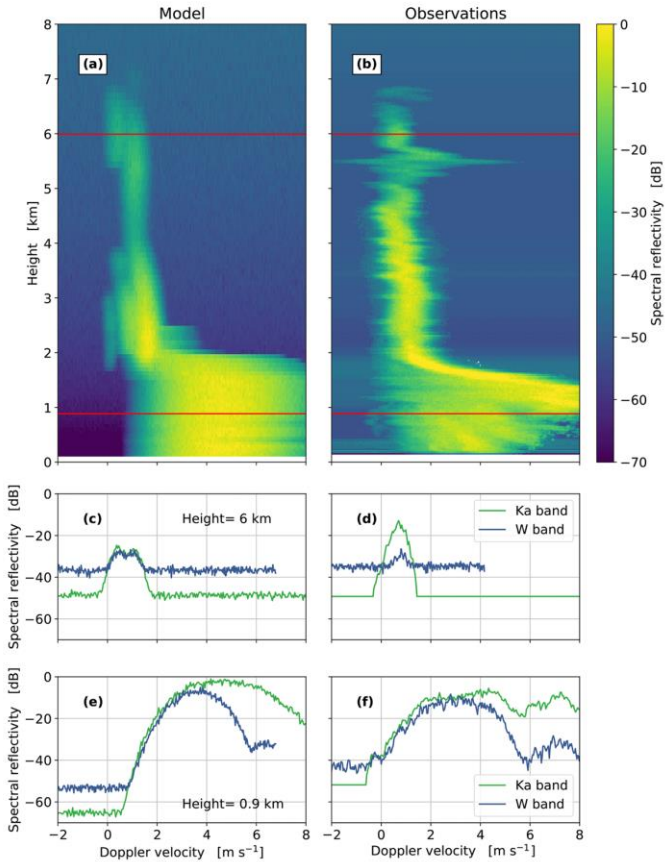
TRIPEx Multi-frequency Doppler: JOYCE vs ICON-LES

```
Setup: ICON importer (6 hyds - 2 mom);
       scattering Mie and SSRG;
       active full Doppler spectrum;
       routinely run for JOYCE (Germany)
       and AWIPEV (Ny-Ålesund, Svalbard)
```

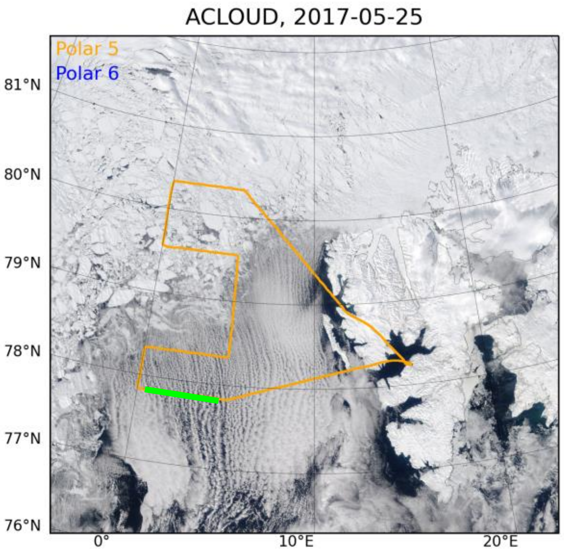


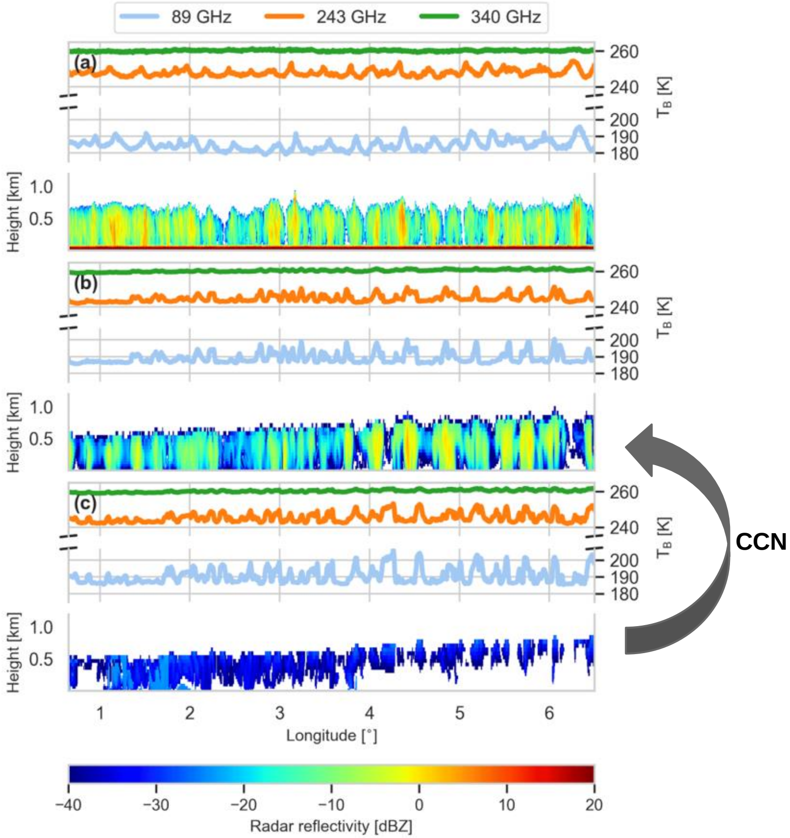


(Mech et al. 2020, GMD)

Airborne observation during ACLOUD: MiRAC vs ICON-LES

Setup:
ICON-LES importer (6 hyds);
scattering SSRG;
TESSEM2 surface emissivity;
active and passive simulations

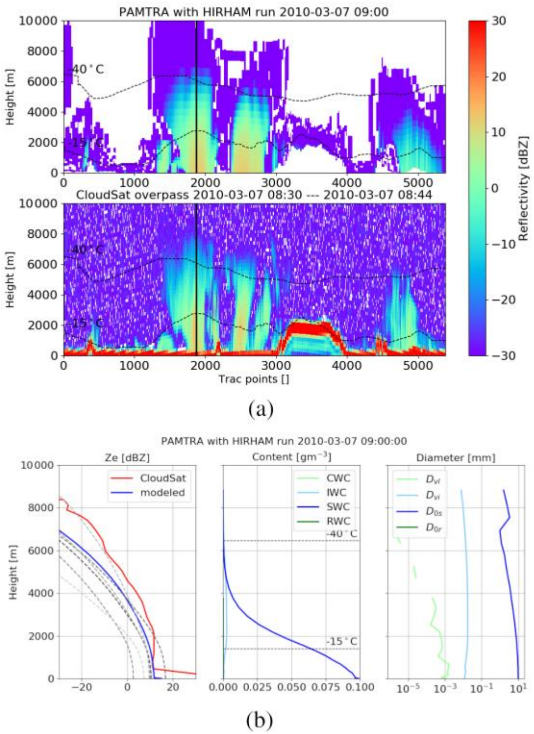


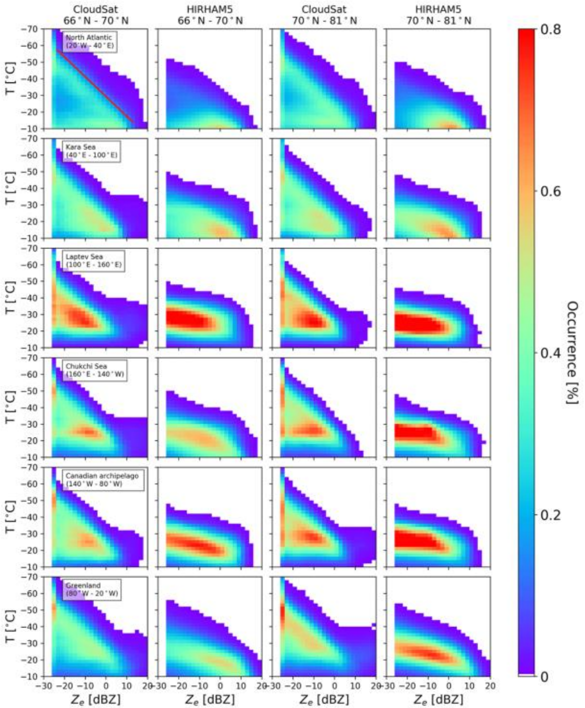


(Mech et al. 2020, GMD)

Distribution of Arctic snowfall: CloudSat vs HIRHAM

Setup:HIRHAM importer (4 hyds)(Data: Rinke (AC^3)); scattering Mie and SSRG; active; 5 years data simulated on Mistral - DKRZ





(von Lerber et al. 2022, ACP)

Outlook, online resources, documentation,...

- WarmWorld Easier): integration of PAMTRA as in-situ instrument simulatorPAMTRA2.0: Radar polarimetry, lidar simulator, additional importers, new methods for scattering, improved ice surface emissivity
- find model on GitHub: https://github.com/igmk/pamtra
- documentation: https://pamtra.readthedocs.io
- tutorial and examples: https://atmos.meteo.uni-koeln.de/~mech/pamtra.html
- PAMTRA user mailing list

PAMTRA 1.0: the Passive and Active Microwave radiative TRAnsfer tool for simulating radiometer and radar measurements of the cloudy atmosphere

Mario Mech, Maximilian Maahn, Stefan Kneifel, Davide Ori, Emiliano Orlandi, Pavlos Kollias, Vera Schemann, and Susanne Crewell

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PAMTRA: Passive and Active Microwave TRAnsfer tool

Flexible, modular, easy to use, and unique forward operator for the passive and active microwave region

Importers for a large variety of models under consideration of their hydrometeor/psd assumptions

State-of-the-art treatment of surface emissivity, gaseous absorption, and single scattering properties

Full radar Doppler spectrum and higher moments and 1D polarized brightness temperatures

Applied in many studies to evaluate CRMs by observations