Analysis of the Composition of Clouds with Extended Polarization Techniques, ACCEPT

Alexander Myagkov

- **Introduction and motivation**

  Mixed-phase clouds are frequently observed in the atmospheric temperature range between -40 and 0 °C where water droplets and ice crystals can coexist. The composition of these mixed-phase clouds, i.e., the partitioning of liquid water and ice, plays a crucial role in the formation of precipitation and in the cloud radiative effect. The passage of crystals through layers of super-cooled liquid water affects ice crystal growth and shape. Thus, to observe the evolution of the microphysical properties of ice crystals through mixed-phase layers, knowledge about their size, mass, and shape is required. The proposed project aims at improving techniques for phase detection and estimation of crystal shape at all stages, from the cloud formation to the precipitation of ice particles. Information about the shape of ice crystals is a prerequisite for the determination of size and mass of ice crystals, because the shape determines the relationship between measured particle fall velocity and the unknown particle size.

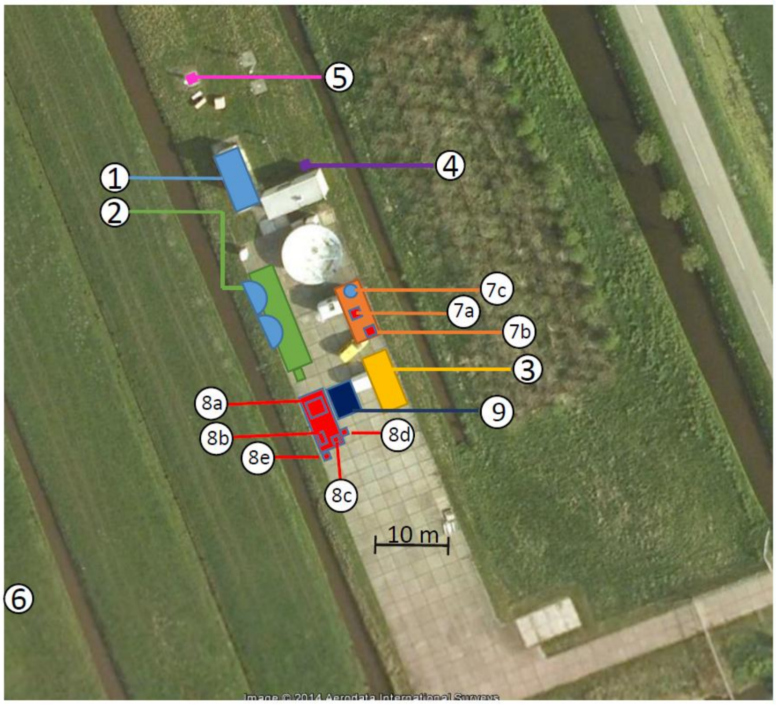
  At the CESAR observatory, the 3-GHz radar TARA is operated to retrieve particle shape of large precipitation particles. At this frequency, the signal is not contaminated by scattering from super-cooled water droplets and is not attenuated, providing direct information on ice crystal properties even for optically thick clouds. However, at such a frequency, freshly formed, small particles cannot be detected. Additionally, the zenith-pointing lidar CAELI provides polarization measurements which allow the detection of liquid layers up to heights where the lidar beam is extinguished.

  At TROPOS, Leipzig, Germany a new technique was developed in cooperation with METEK GmbH, Elmshorn, Germany, to investigate the shape of ice crystals with a cloud radar operating in so-called STSR (Simultaneous Transmit Simultaneous Receive) mode at a wavelength of 35 GHz. Observations at the much shorter wavelength allow to estimate the shape of even freshly formed, small ice particles in optically thin clouds but suffer from attenuation and sensitivity to liquid water that affect the radar output for optically thicker clouds. In addition, co-located measurements of the off-zenith pointing polarization-lidar Polly-XT of TROPOS will be exploited to detect layers of horizontally aligned planar crystals, causing specular reflections which affect only the signal measured with the zenith-pointing CAELI.

- **Scientific objectives**

  Within the proposed TNA project the recording of a dataset will be realized that enables to retrieve the ice crystal microphysical properties in a large size range from micrometer- to cm-scales based on the multi-frequency complementarity provided by the unique, novel set of instruments. The dataset obtained during the ACCEPT campaign will allow to focus on the following main questions:

  1. How do atmospheric temperature and humidity affect the shape and size of ice crystals?
  2. How do the microphysical properties of ice crystals change in multi-layered mixed-phase cloud systems?
  3. Do increased concentrations of ice nuclei have a measurable impact on ice crystal microphysical properties (shape and size)?
  4. Under which atmospheric conditions does aggregation and riming occur?



CESAR Equipment
1: 35-GHz cloud radar
2: TARA 3-GHz radar
3: CAELI
4: Leosphere 355-nm lidar
5: Microwave radiometer
6: 1-GHz wind profiler

TROPOS *Equipment*
7: OCEANET Container
7a: Polly^{XT} lidar
7b: All-Sky camera
7c: Vaisala RS92 radiosonde station

8: LACROS Container
8a: STSR-mode 35-GHz Mira
8b: Microwave radiometer HATPRO
8c: Optical disdrometer OTT Parsivel^2
8d: Ceilometer Jenoptik CHM15kx
8e: HALO Streamline Doppler lidar

9: LDR-mode 35-GHz Mira

Figure 1: List of instruments and site setup during the ACCEPT campaign.

5. In addition, the inter-calibration of the three deployed radar systems will be evaluated.

The scope of the TransNational Access was to enable the installation of the TROPOS instrumentation at CESAR observatory. Experts are required to implement the hardware at a field site and to ensure its proper operation.

- **Reason for choosing station**
  Main reason for choosing CESAR observatory for the study, is that it is well equipped with a broad range of atmospheric remote sensing instruments. Fundamental requirements for the ACCEPT campaign were the zenith-pointed lidar CAELI, the 3-GHz radar TARA, a 1-GHz wind profiler, and the microwave radiometer. CESAR observatory provides sufficient spatial, electrical, and telecommunication resources for the installation of additional remote-sensing instrumentation with a total power consumption of approximately 10 kW. Because radar and lidar instruments are already operated at CESAR observatory, the permits required to operate such instruments could be easily obtained. In addition, the location of Cabauw in the flat terrain of the Netherlands provides suitable conditions for scan experiments which would not be possible in mountainous or forested areas.

- **Method and experimental set-up**
  The list of instruments as well as the experimental setup during the ACCEPT campaign is shown in Figure 1. Two scanning instruments were operated during the campaign. TARA was pointed towards west at a fixed elevation angle of 45°. The STSR-mode cloud radar of TROPOS was continuously performing different scan patterns that allowed to measure the effects of particle shapes on the polarimetric measurements (elevation scans between 30° and 150°), the horizontal wind components (conical scans from 0 to 360° azimuth at fixed elevation angles), and the inter-calibration of the different radar systems (45° elevation into the same azimuth direction as TARA; 90° elevation for initer-calibration with the other zenith-pointed instruments).

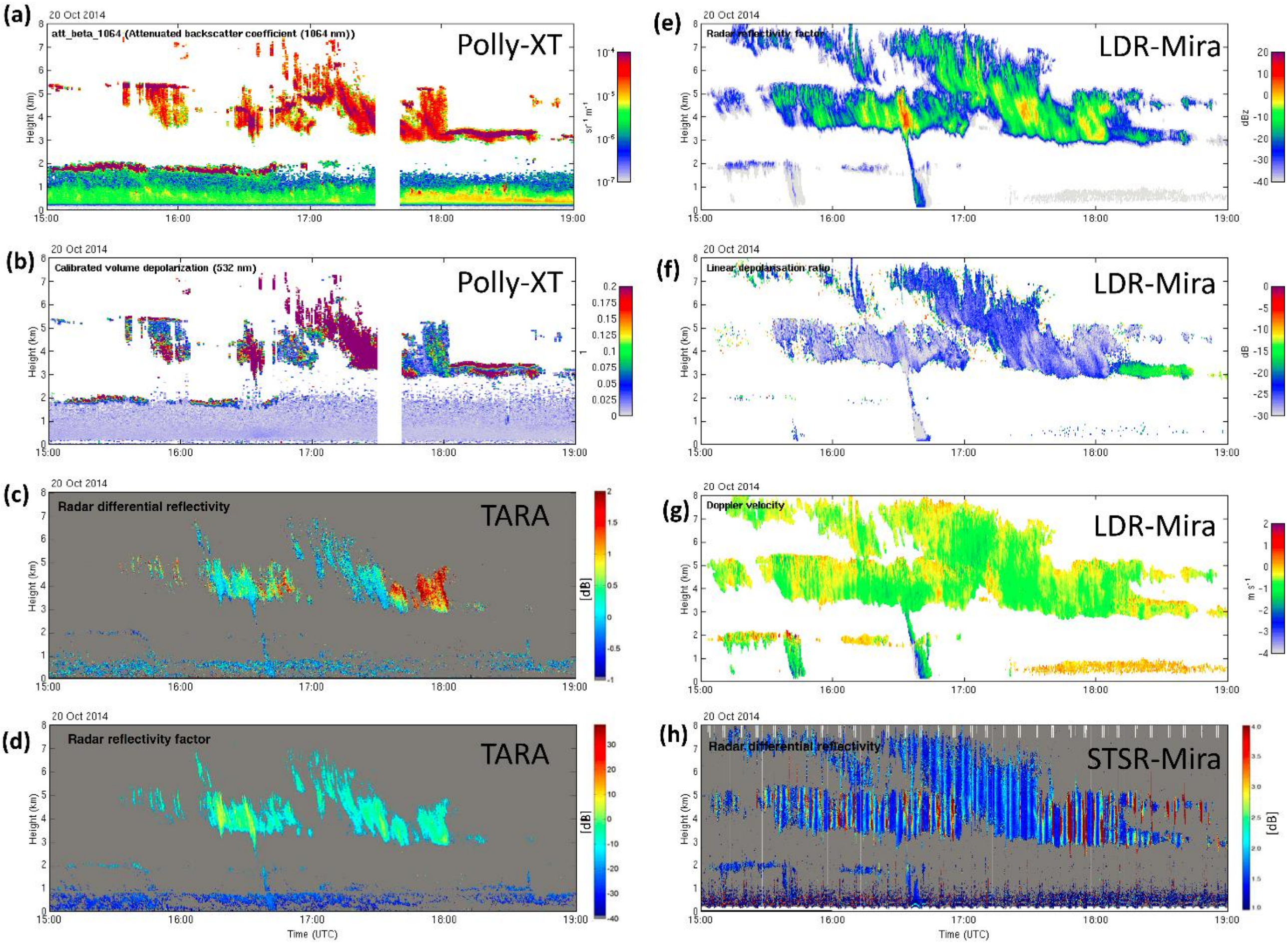


Figure 2 : Combined measurements of a mixed-phase cloud system with the lidar Polly-XT (a,b), 3-GHz radar Tara (c,d), LDR-mode cloud radar Mira (e-g), and STSR-mode cloud radar Mira (h) on 20 October 2014 from 1500 to 1900 UTC.

- **Preliminary results and conclusions**

  In the frame of ACCEPT continuous measurements of virtually all available instruments were performed from 01 October to 18 November. From this dataset more than 100 cases of ice formation in well-defined cloud layers were documented. The measurements show a clear relationship between the temperature and humidity of ice crystal formation and the observed polarimetric properties of the cloud hydrometeors. A selection of the available measurement parameters is presented in Figure 2 that shows the observation of a complex mixed-phase cloud system on 20 October 2014, 1500-1900 UTC. It can be seen that the observed parameters change as a function of altitude of formation. E.g., from Fig. 2(b) it can be seen that hydrometeors that formed at heights of around 5 km produce very low lidar linear volume depolarization ratios. Hydrometeors that formed at greater or at lower heights show high values of the volume depolarization ratio. There is a correlation of these regions of low and high volume depolarization to the respective parameters observed with Tara and the Mira systems. For regions were the volume depolarization ratio is low, Tara and STSR-mode cloud radar observe high values of differential reflectivity whereas the LDR-mode Mira observes rather low depolarization ratios. In turn, regions in which Polly-XT observed large volume depolarization ratios, differential reflectivity observed with Tara and STSR-Mira were low, but the LDR-Mira observed high values of linear depolarization ratio. Consequently, the measurements of the different instruments clearly indicate the presence of different types of hydrometeors during the time of observation of the cloud system. In addition, and more importantly, the measurements can also be used to derive information on the microphysical properties of the cloud particles.

- Outcome and future studies
  The commitment of the 4 experts engaged in the underlying TNA made it possible to obtain a continuous high-quality, multi-instrument dataset during the ACCEPT campaign.
  The in-depth analysis of the ACCEPT dataset will be realized by Phd students that will work on the data during a two-year period after the campaign. It is envisaged to produce a publication for each of the 5 scientific questions specified above.
- References
  None.