IACETH
Institute of Atmospheric and Climate Science
Swiss Federal Institute of Technology Zürich

contact:
Jan.Henneberger@env.ethz.ch

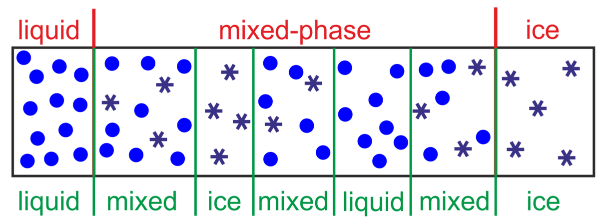
Mixed-phase Cloud Measurements in a High Alpine Environment using Digital In-line Holography

J. Henneberger[1], J. P. Fugal[2], and U. Lohmann[1]
[1]ETH Zürich, Institute for Atmospheric and Climate Science, Zürich, Switzerland
[2]Johannes-Gutenberg-Universität Mainz, Institute for Atmospheric Science, Mainz, Germany

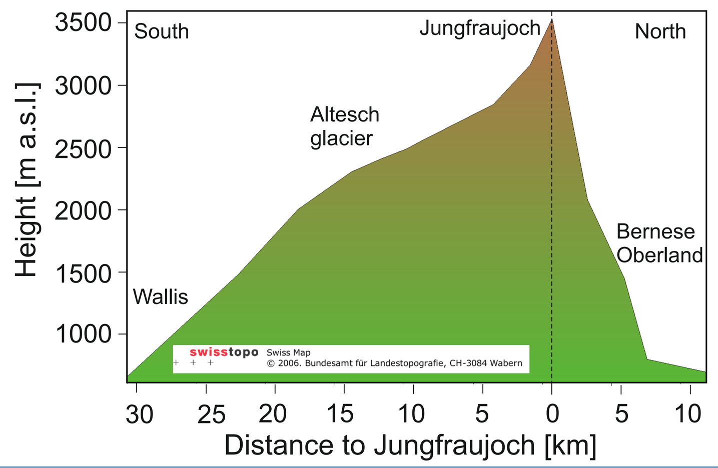
Motivation

Importance of microphysical studies of mixed-phase clouds:

- Aerosol-cloud interactions are the most uncertain of all forcing agents.
- Level of understanding of mixed-phase clouds (MPC) is low because of their complicated structure, dynamics, and heterogeneous ice nucleation.
- Retrieval methods of satellite and ground based remote sensing depend on cloud phase and ice crystal habits.
- Airborne ice crystal concentration measurements have large uncertainties due to shattering.
- Direct measurements of small scale cloud properties are needed for an accurate representation in global and regional climate models.



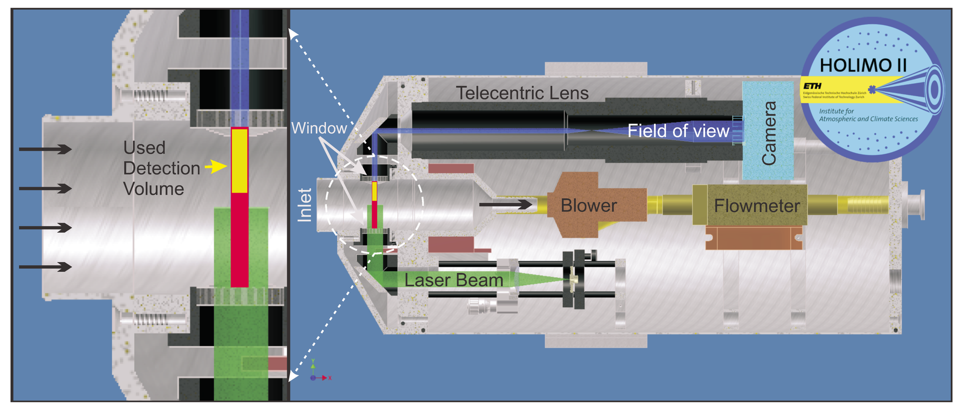
The classification of a cloud phase in liquid, mixed-phase or ice cloud depends on the spatial resolution of the measurement.



Height profile of the Jungfraujoch (JFJ) in south-north direction. The profile is taken starting at the Wallis valley, following the Aletsch glacier to the JFJ, and descending to the Weisse Lütschine valley near

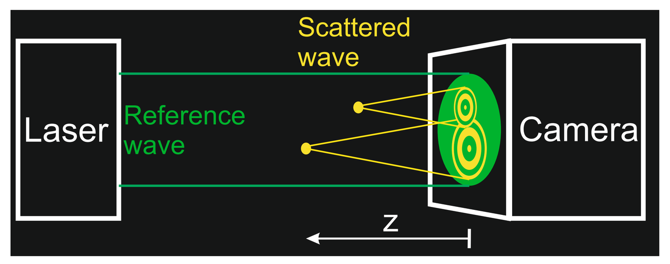
HOLIMO II - HOLographic Imager for Microscopic Objects II

- The measurements were done with a newly developed field instrument HOLIMO II (HOLographic Imager for Microscopic Objects II) (Henneberger et al., 2013).
- HOLIMO II uses digital in-line holography to in-situ image ensembles of cloud particles within a well defined sample volume.



Horizontal cross-section of the HOLIMO II inlet

Experimental setup during CLACE 2013 campaign with HOLIMO II on the platform from the University of Manchester.



Principle of digital in-line holography.

$$U(\vec{\rho};z) = \mathcal{F}^{-1}\{\mathcal{F}\,[U_R\, I(\vec{\rho};0)]\, H(\vec{v}_r;z)\}$$

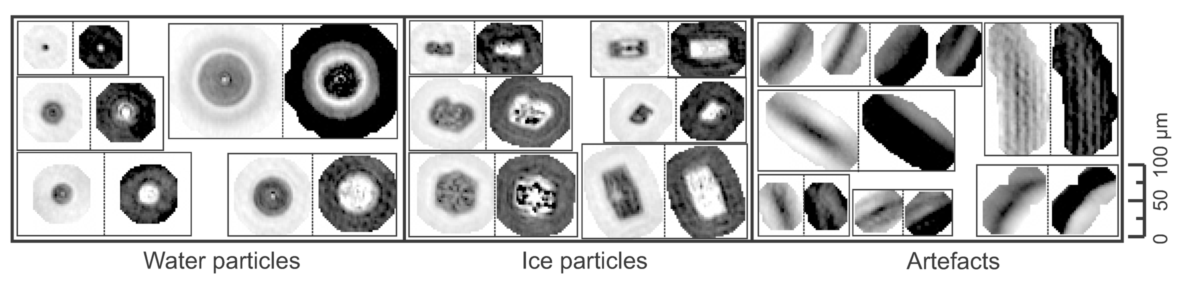
z = longitudinal coordinate
$\vec{\rho}$ = transversal coordinates
$\vec{v}_r$ = transversal frequencies
$\mathcal{F}$ = Fourier transformation
$H(\vec{v}_r; z_2 - z_1)$ = filtering kernel
$U(\vec{\rho};z)$ = complex wavefront

Detection volume: 4.1 mm x 3.2 mm x 19 mm = 0.25 cm^3
Sample volume rate: 0.25 cm^3 x 33 frames s^{-1} = 8.3 $cm^3\,s^{-1}$
Object detectable: 6 – 250 µm
Phase distinction: > 20 µm

Data analysis with HOLOSUITE

A supervised learning algorithm was trained to classify cloud particles based on their shape as circular water droplets, non-circular ice crystals or falsely detected artifacts.

HOLOSUITE: GNU General Public License (Fugal et al., 2009)



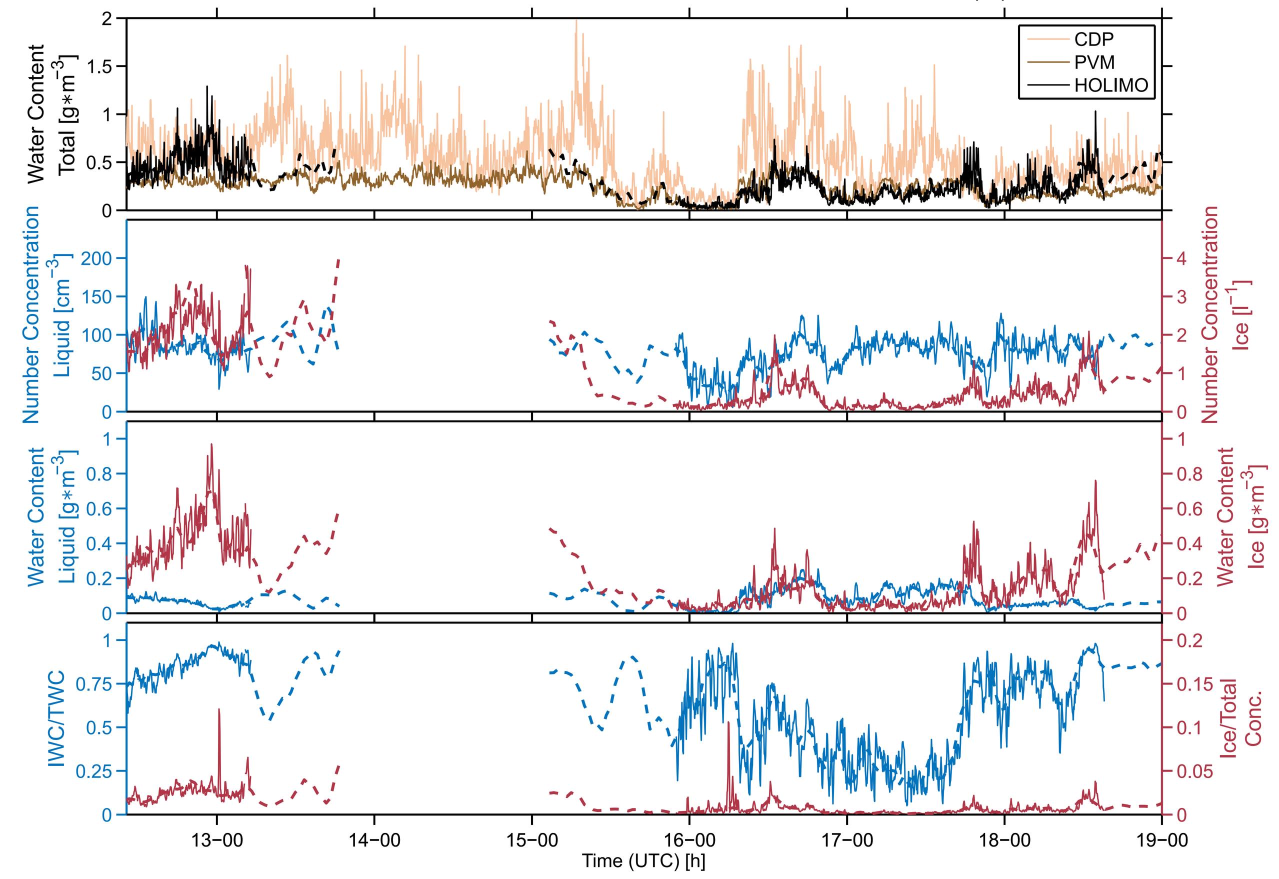
Example images of measured particles. For each particle the amplitude image (left side) and the phase image (right side) is shown.

Measurements of mixed-phase clouds

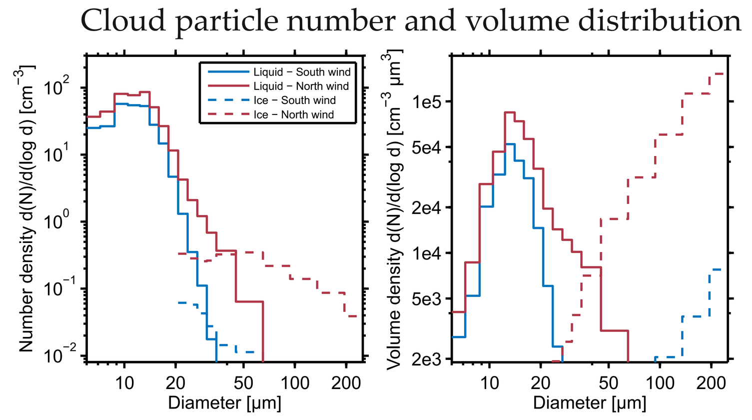
- Mountain-top field measurements from the high altitude research station Jungfraujoch, Switzerland
- Altitude: 3580 m a.s.l
- Campaigns at April 2012 and January/February 2013 (CLACE 2013) are presented.
- 16 cloud cases with in total 1800 100-s intervals were analyzed (50 h).
- Cloud criteria: TWC > 10 mg m^{-3}

	Unit	25%	Mean	75%
Liquid number conc.	cm^{-3}	21	62	86
Ice number conc.	cm^{-3}	0.018	0.40	0.45
LWC	mg m^{-3}	17	53	73
IWC	mg m^{-3}	4.5	122	170
Liquid mean diameter	µm	9.4	11	12
Ice mean diameter	µm	51	63	76

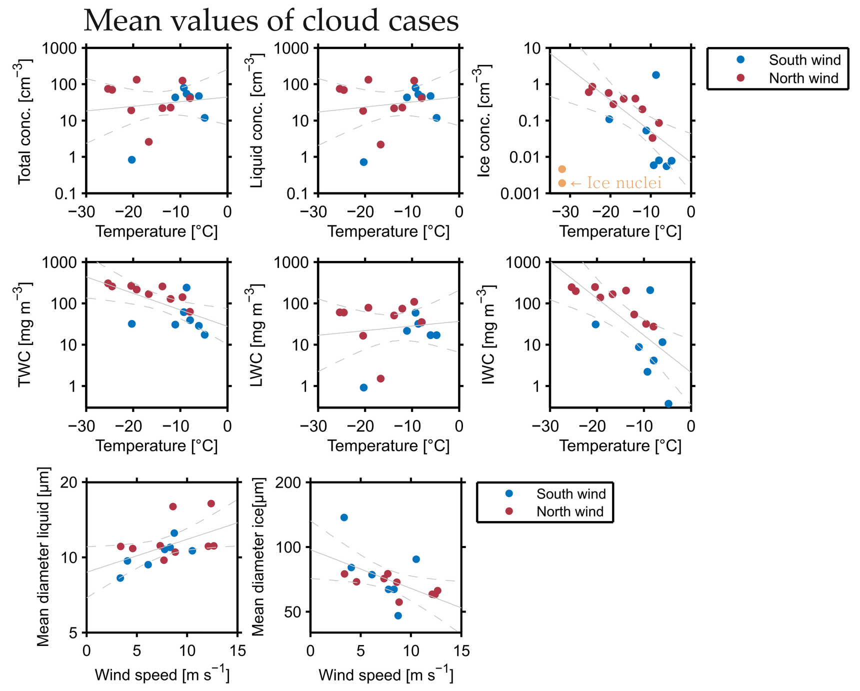
Time series from the 7/2/2013 case.



Cloud particle number and volume distribution



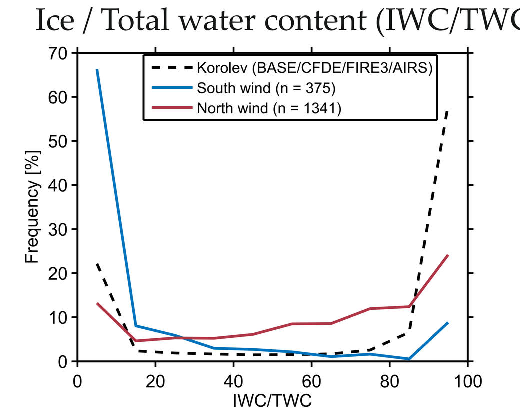
Mean values of cloud cases



During northerly winds ...

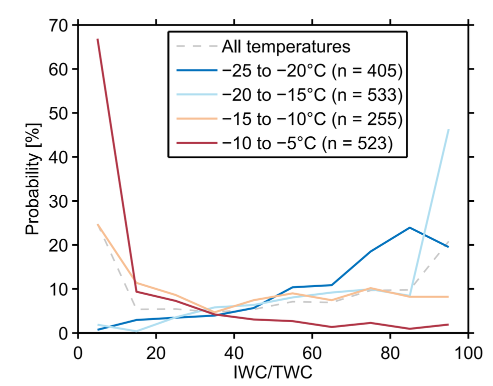
... higher concentrations and water contents.
... more intermediate IWC/TWC fractions.
⇨Stabilization of the MPC due to stronger. orographic lifting.

Ice / Total water content (IWC/TWC)



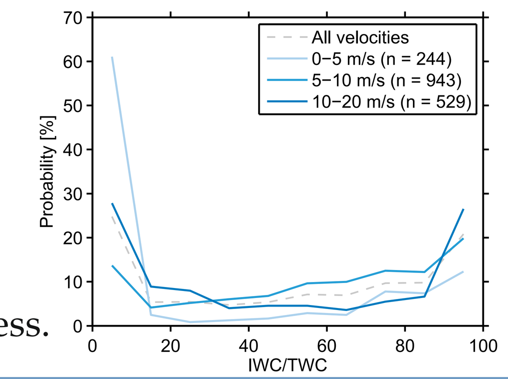
At colder temperatures ...

... higher ice crystal concentrations.
⇨More ice nuclei (IN) available, but still more ice crystals than measursed IN (PINC, Yvonne Boose).
... larger ice water and total water content.
⇨Different from Korolev et. al, 2003.
... larger IWC/TWC fractions.



At higher wind speeds ...

... larger water droplets.
... smaller ice crystals.
... larger IWC/TWC fractions.
⇨Less time for the Wegener-Bergeron-Findeisen prozess.



(Henneberger et al, 2014, in preperation)

Conclusions

- Successful development of HOLIMO II, a single cloud particle imager, which is using digital-inline holography.
- Implementation of a classification algorithm to distinguish liquid particle from ice crystals by their shapes.
- Caused by the topography of the Jungfraujoch, two main wind regimes with distinguished cloud properties were observed.
- During northerly wind mixed-phase clouds at the Jungfraujoch were stabilized due to orographic lifting.
- Ice crystal concentrations two magnitude higher than available ice nuclei concentrations

Outlook

- Inter-comparison of CLACE 2013 measurements with other in-situ cloud instruments. (University of Manchester)
- Implementation of an ice crystal habit classification algorithm. Comparision to Radar data (EPFL - LTE, Alexis Berne)
- Relate HOLIMO II in-situ measurements to turbulence and ice nuclei measurements (ETH, Yvonne Boose) .
- Simulating the Jungfraujoch region using a regional climate model to study the influence of the updraft velocity on the microphysical cloud properties (ETH, Olga Henneberg).
- Build an in-situ cloud measurements system on a cable car system to measure vertical profiles of MPCs (ETH, Alexander Beck).

References

- **Henneberger, J., Fugal, J. P., Stetzer, O., and Lohmann, U.: HOLIMO II: a digital holographic instrument for ground-based in-situ observations of microphysical properties of mixed-phase clouds, Atmos. Meas. Tech., 6, 2975-2987, 2013.**
- **Henneberger, J., Fugal, J. P., Farrington, R., and Lohmann, U.: Mountain-top measurements of the microphysical properties of mixed-phase clouds with the holographic imager HOLIMO II, Atmos. Chem. Phys, 2014 (in preperation).**
- Fugal, J. P., Schulz, T. J., and Shaw, R. A.: Practical methods for automated reconstruction and characterization of particles in digital in-line holograms, Meas. Sci. Technol., 20, 2009.
- Korolev, A. V., Isaac, G. A., Cober, S. G., Strapp, J. W., and Hallett, J.: Microphysical characterization of mixed-phase clouds, Q. J. Roy. Meteor. Soc., 129, 39–65, 2003.

Acknowledgements

- We thank Matthew Beals for his major contribution to the development of the HOLOSUITE software.
- We thank Martin Gallagher, Paul Conolly, Keith Bower, Robert Farrington and Gary Lloyd from the University of Manchester for the support during the CLACE2013 campaign and the CDP and PVM data.
- We thank the International Foundation High Altitude Research Station Jungfraujoch and Gornergrat (HFSJG) for the opportunity to perform experiments on the Jungfraujoch.
- This work was supported by MeteoSwiss within the Global Atmosphere Watch (GAW) program of the World Meteorological Organization.

IACETH
Institute of Atmospheric and Climate Science
Swiss Federal Institute of Technology Zürich