Ice fog and light snow measurements using a high resolution camera system

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Background

- Ice fog, diamond dust, and light snow
  - very small hydrometeors
  - form in cold weather
  - affect aviation operations
  - influence the local radiative budget
- Prediction difficult
  - limited knowledge of the microphysical properties
  - need to represent better in forecast and climate models
- Accurate measurements from ground-based instrumentation

Imaging of ice particles to complement other routine in-situ measurements: **newly developed ICI probe, aimed at measuring ice fog and light snow particles**.

Method / Instrument

Imaging of ice particles: Ice crystal imaging probe – **ICI**

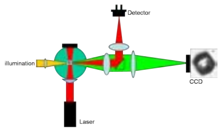
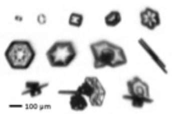


Diagram showing set-up used at FRAM-YK

Particle detection (red light path in diagram): laser beam and detect scattered light at 90°
- Collect scattered light through imaging objective lens
- Beam splitter directs light to detector



Set-up used at FRAM-YK

Top view of set-up used at FRAM-YK

Bright-field imaging: illumination from behind (yellow in diagram)
- Flashed LED illumination
- Imaging objective lens
- Straight through beam-splitter and tube lens to CCD camera (green light path in diagram)
- 4.2 μm/pixel
- FOV 4.32 mm X 3.24 mm

Inlet (not seen on above figure) and active air sampling at average snow fall speed.

Campaign

Ice fog in Yellowknife, part of:

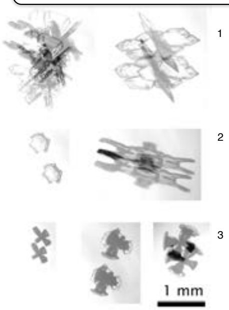
Fog Remote Sensing and Modeling – FRAM-YK
- Yellowknife, NWT, Canada
  - airport (62°28' N, 114°26' W)
- Winter of 2010-2011
- Goal of FRAM: Improve understanding and predictions of fog

In Yellowknife focus on cold weather
- microphysical properties
- effect on aviation
- radiative properties

- Large range of ground-based instruments used at campaign
  - meteorological sensors
  - precipitation sensors
  - optical array probe
  - and **ice crystal imaging (ICI)**

ICI installed at FRAM-YK campaign. Instrument in normal configuration with inlet.

Results



Fall speed

Tested fall speed measurements during a few days of the campaign.

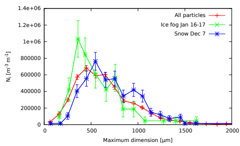
- Without inlet, no active flow, particles fall freely
- Two illuminating flashes during one exposure
- Measure distance travelled on image -> **speed**
- Size, area, shape, and orientation known from image

Images from fall speed measurements. Orientation and shape influence fall speed.
Examples from three shape classes are shown:
1 sideplanes; 2 plates and stellar; 3 bullet rosettes.

Results …

Size distributions

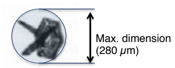
During campaign, ice particles detected in 343 hours.
Ice particles from 304 hours considered in analysis.
Mean size of 660 μm.
Average concentration (304 hours): 0.45 L^{-1}.



Size distribution of ice particles during the whole campaign (total conc. 0.45 L^{-1}), red curve.
Size distributions for two short-term events, ice fog (green, 0.11 L^{-1}) with mean size of 550 μm and light snow (blue, 0.95 L^{-1}) with mean size of 730 μm; these two events are scaled to the same total number as red, whole campaign.

Description of particles

Size (maximum dimension),
area,
area ratio.

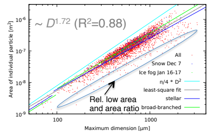


Area ratio 0.52

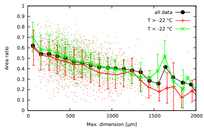
Ice particles with 'normal' area ratio.

Ice particles with relatively low area ratio, observed at temperatures around -12 to -20 °C.

Measured area



Area of individual particles plotted versus size (maximum dimension D). The data are fitted well by a area-dimensional power law (indicated on figure). For comparison, two area-dimensional power laws for stellar and broad-branched ice crystals from Pruppacher and Klett 1978.



Area ratio of all ice particles as function of particle size. A small difference can be noticed between colder and warmer particles. The latter, at $T > -23$ °C, include more particles with relatively low area ratio than the colder ice particles.

Acknowledgements and References

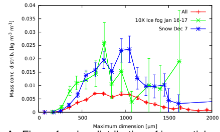
We like to thank the Swedish National Space Board, National Search And Rescue Secretariat (SAR) of Canada, and Environment Canada for funding this work.

Gultepe, I., et al. (2014), Ice fog in Arctic during FRAM-Ice Fog project: Aviation and nowcasting applications, Bull. Amer. Met. Soc., 95, 211–226, doi:10.1175/ BAMS-D-11-00071.1.
Gultepe, I., et al. (2015b), A review on ice fog: measurements and modeling, Atmos. Res., 151(SI), 2–19.

Results …

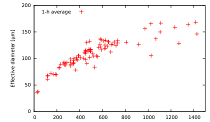
The effective diameter of an ensemble of ice particles is proportional to its total mass divided its total area.
We estimate mass of individual particles from their measured area and size using a parameterization by Baker and Lawson (Appl. Meteorol. Clim., 45,9, 2006).

Particle mass distribution



As Figure for size distribution of ice particles, but showing mass distributions.
Whole campaign (red, total conc. $6.7 \cdot 10^{-3}$ g m^{-3}), ice fog (green, $1.4 \cdot 10^{-3}$ g m^{-3}) scaled up 10x and light snow (blue, $18 \cdot 10^{-3}$ g m^{-3}).

Effective diameter



Ice particles effective diameter for 1-h periods. Used convention for effective diameter is by Foot (Q. J. R. Meteorol. Soc., 114, 479, 1988).

Conclusions and future work

ICI probe to measure small ice particles of ice fog and snow.

Measured particles betw. 0.1 and 1.5 mm.

Snow fall speed measurements demonstrated.

Lower size threshold lower than 100 μm by improved particle detection with forward scattering.

Multi-imaging ICI with two or more views of the same ice particle.

Snow fall speed measurements.

Summary

In this presentation, measurements collected by the ice crystal imaging (ICI) probe employed during FRAM (Fog Remote Sensing and Modeling) project for the Winter of 2010-2011 in Yellowknife, NWT, Canada are analysed to study small ice crystal impact on aviation operations. Ice fog, diamond dust, and light snow form during cold weather conditions and they affect aviation operations through visibility and deposition over the surfaces. In addition, these events influence the local heat budget through radiative cooling. Prediction of these hydrometeors using models is difficult because of limited knowledge of the microphysical properties at the small size ranges. These phenomena need to be better represented in forecast and climate models and this can only be done using accurate measurements from ground-based instrumentation. Imaging of ice particles' properties can complement other in-situ measurements being collected routinely.

The newly developed ICI probe, aimed at measuring ice fog and light snow particles, is presented here. The ICI probe samples ice particles through a vertical inlet, where a laser beam and photodetector detect ice crystals contained in the flow. The detected particles are then imaged with high optical resolution between 10 to 1000 micron size range. An illuminating LED flash and image capturing for measurements are triggered by the photodetector.

The results suggested that the majority of ice particles during the two-month long campaign were small with sizes between 300 µm and 800 µm. During ice fog events, the size distribution measured had a lower mode diameter of 300 µm compared to the overall campaign average with mode at 500 µm. In this presentation, challenges and issues related to small ice crystals are described and their importance for aviation operations and climate change are discussed.

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