# Breaking the ice using passive anti-icing coatings – Lessons learned from the Nordic TopNANO research project

Presented by **Agne Swerin**, SP Technical Research Institute of Sweden

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SP Technical Research Institute of Sweden

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Top-level Research Initiative

# TopNANO – ice accretion related to wind, airplanes and heat exchangers

- Need and potential for nanotechnology to increase energy efficiency and combat icing problems
- Description of TopNANO project – Nordic Top-level Research Initiative for applied nanotech
- Summary of project outcome
  - Superhydrophobicity – when it works and does not work for anti-icing
  - Ice adhesion on substrates with quasi-liquid layers
  - Methodology for studies of biological stain removal
  - Icing wind tunnel and new ice adhesion test
  - Scaled-up field tests at a wind park
  - Nordic platform for ice-related research and innovation

# Co-authors to this presentation


- **Mikael Järn and Kenth Johansson,** SP Technical Research Institute of Sweden
- **Joseph Iruthayaraj and Sergey Chernyy,** Aarhus University, Denmark
- **Per Claesson,** KTH Royal Institute of Technology, Stockholm, Sweden
- **Lasse Makkonen and Juha Nikkola,** VTT Technical Research Centre of Finland





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## Project and funding partners

- **Research partners in surface chemistry, coatings and ice physics**



With funding from

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# Project and funding partners

- **Companies from aircraft, wind power, heat-exchanger industry and coating companies**

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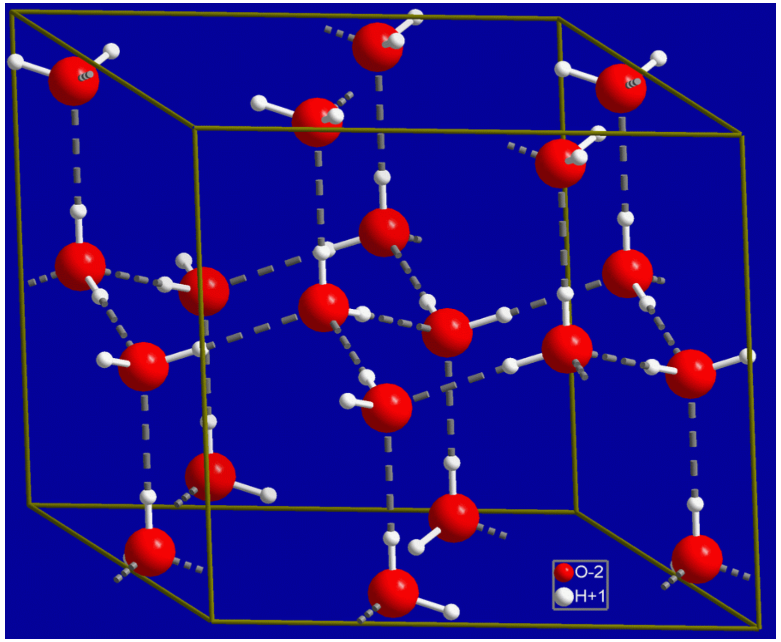
# Ice and frost formation – a nanotech area?

- Ice exists in fifteen different forms, the most usual is hexagonal
- Frost is formed directly from water vapor
- Ice is a nanostructured material
- Methodology to combat ice build-up is nanotechnology




$I_h$ – Hexagonal ice

# Icing – a complex problem

Different types of icing depending on the conditions

- **In-cloud icing**
  - Supercooled water droplets
  - Soft rime, hard rime, glaze
- **Precipitation**
  - Snow or rain
  - Freezing rain
  - Wet snow
- **Frost**
  - Water vapor solidifies on a cool surface

# Anti-icing and de-icing

De-icing: removal of ice

Anti-icing: prevention of ice accretion

- **Active**
  - Mechanical (de-icing)
  - Thermal (heating foils or hot air)
- **Passive**
  - Chemical
  - Surface coatings
- Thermal requires lots of energy and chemicals may be harmful for the environment
- Anti-icing coatings the ideal solution
- But… few commercial products available

# Deliverables

- Optimization of **surface chemistry and surface topography on the nanometer scale** to retard ice and condensation formation
- Effect of different **surface anchored functional groups**, polar uncharged and polar charged groups, on ice adhesion
- Develop **robust superhydrophobic** coating formulations

# Deliverables, cont'd

- Negative influence of **biological fluid stains** from impacted insects on wind turbines, aircraft wings and heat exchanger surfaces
- Novel **nanotech coatings for anti-freezing**
- New surface materials and **benchmarking** against the existing technology, in terms of cost, performance and LCA

# Deliverables, cont'd

- **Shorter and longer field tests** during the winter seasons
- Transfer to Nordic industries through direct industry-academia collaborations
- **Develop Nordic platform for deicing and anti-icing and proliferate to other sectors**
- **Industry partners at the end of the project have one concept validated under relevant conditions, two more validated in lab and another three concepts tested**

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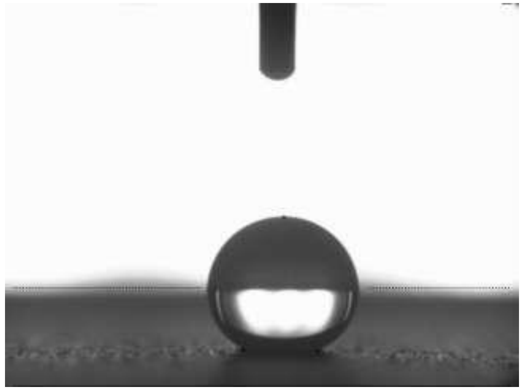
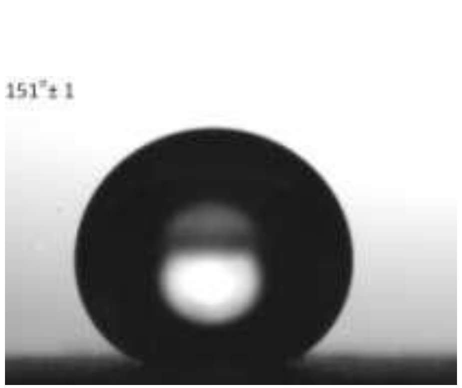
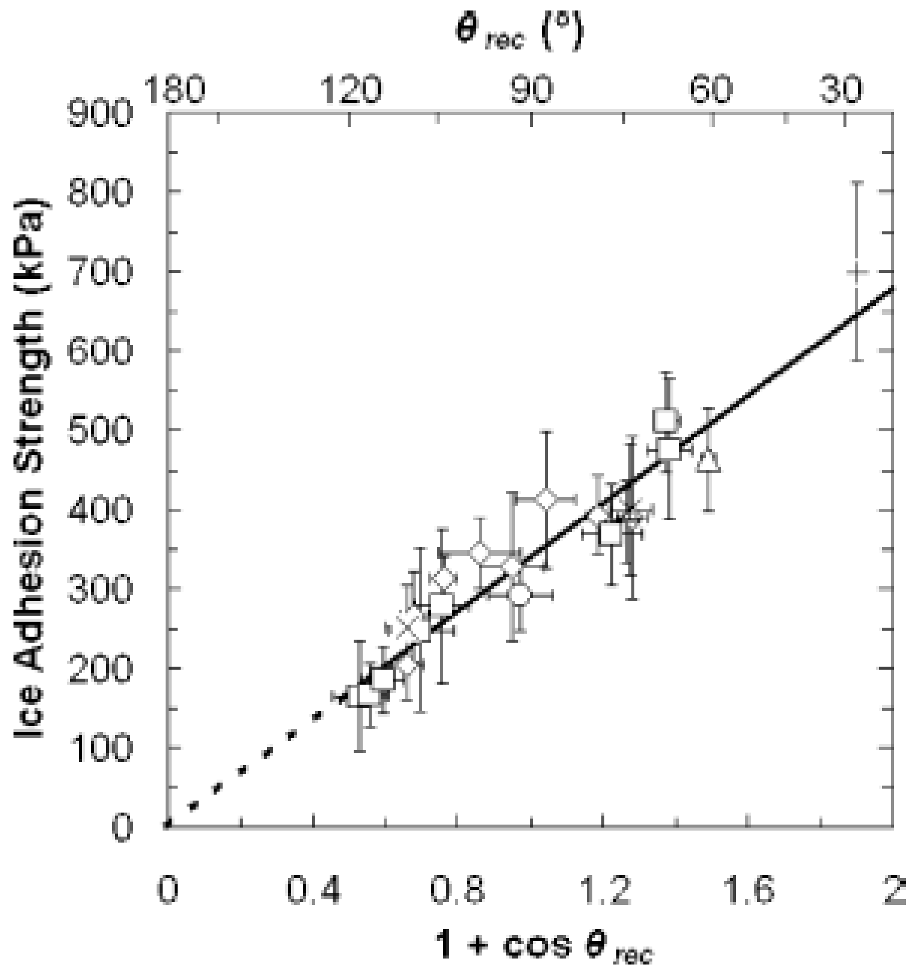
# Lead ideas to reduce ice formation

- Superhydrophobic surfaces
- Surfaces exposing chemical groups that  are water-structure breakers
- Understand on a molecular level **why** or **why not** these concepts work



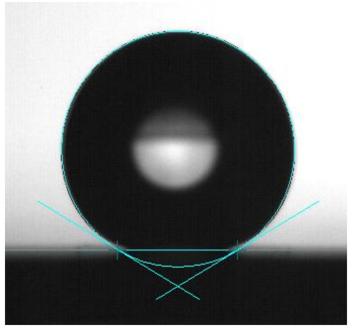


# The superhydrophobic track




*Meuler et al. (2010)*

- Preparation of superhydrophobic coatings
- Surface energy recovery after soiling
- Depends on the *receding* contact angle
  - Soiling a major issue
- Superhydrophobicity relies on surface chemistry and *topography*
  - Wear resistance crucial

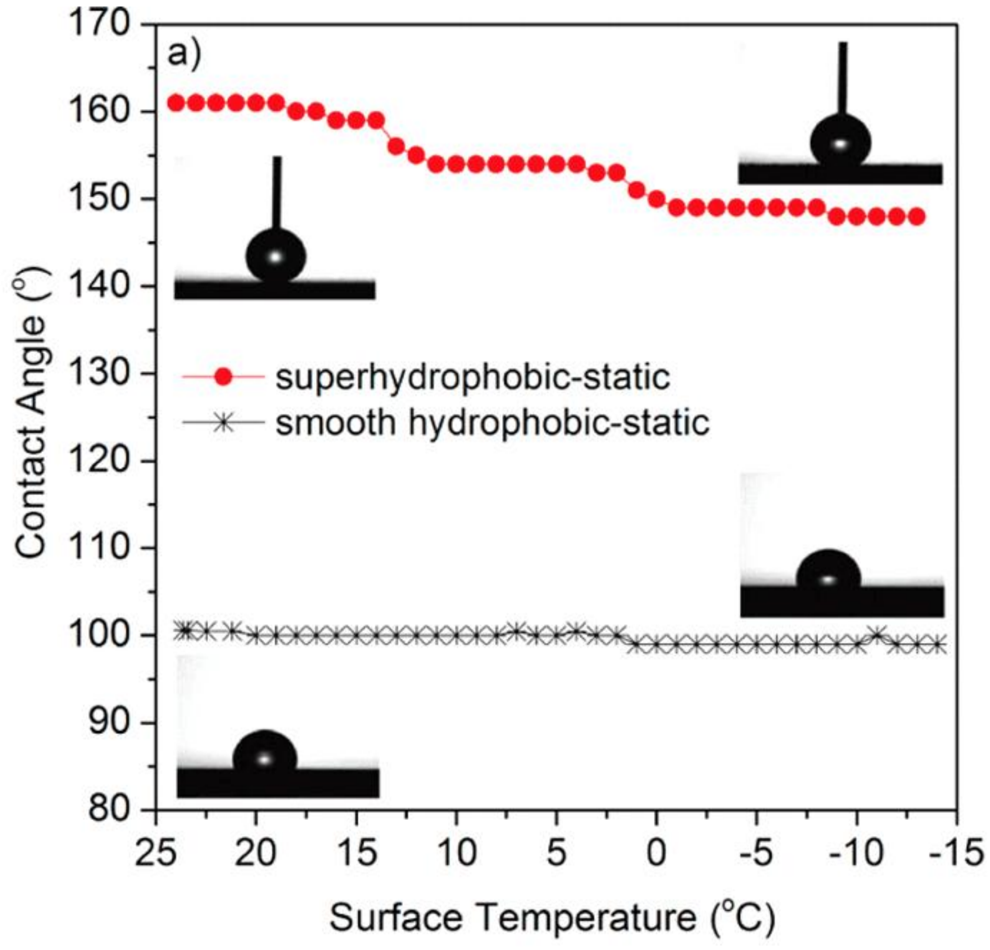


$$W_{adh} = \gamma_{LV}(1 + \cos\theta_{rec})$$

# Does a superhydrophobic surface retard droplet freezing?

- Surfaces with similar chemistry but different topography
- Water contact angles as function of temperature
- Water droplet freezing delay time
- Results explained by heterogeneous nucleation theory

# Contact angle as a function of temperature



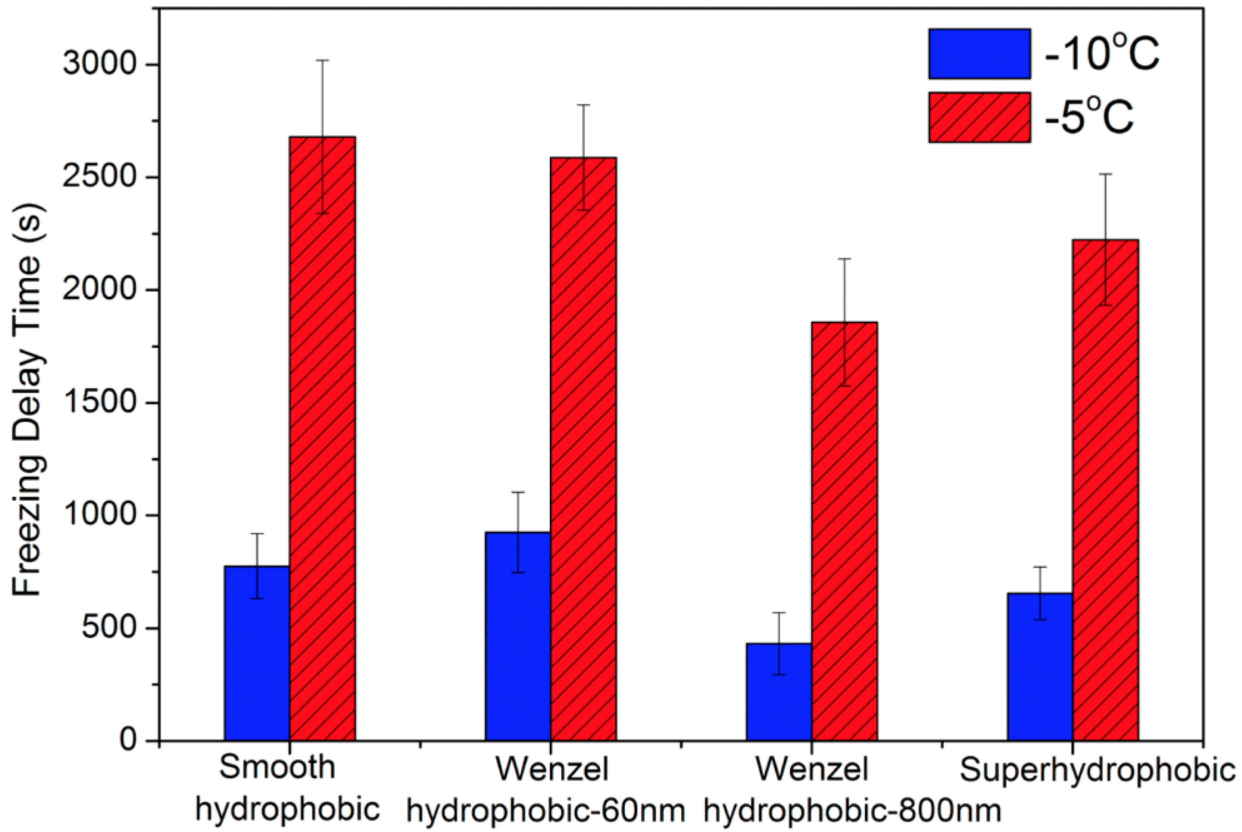

Water condensation and frost formation reduces contact angles on the superhydrophobic surface

Conclusion

- Contact angles measured at room temperature do not represent the wetting under supercooled conditions

*Heidari et al. (2010)*

# Freezing delay on different surfaces

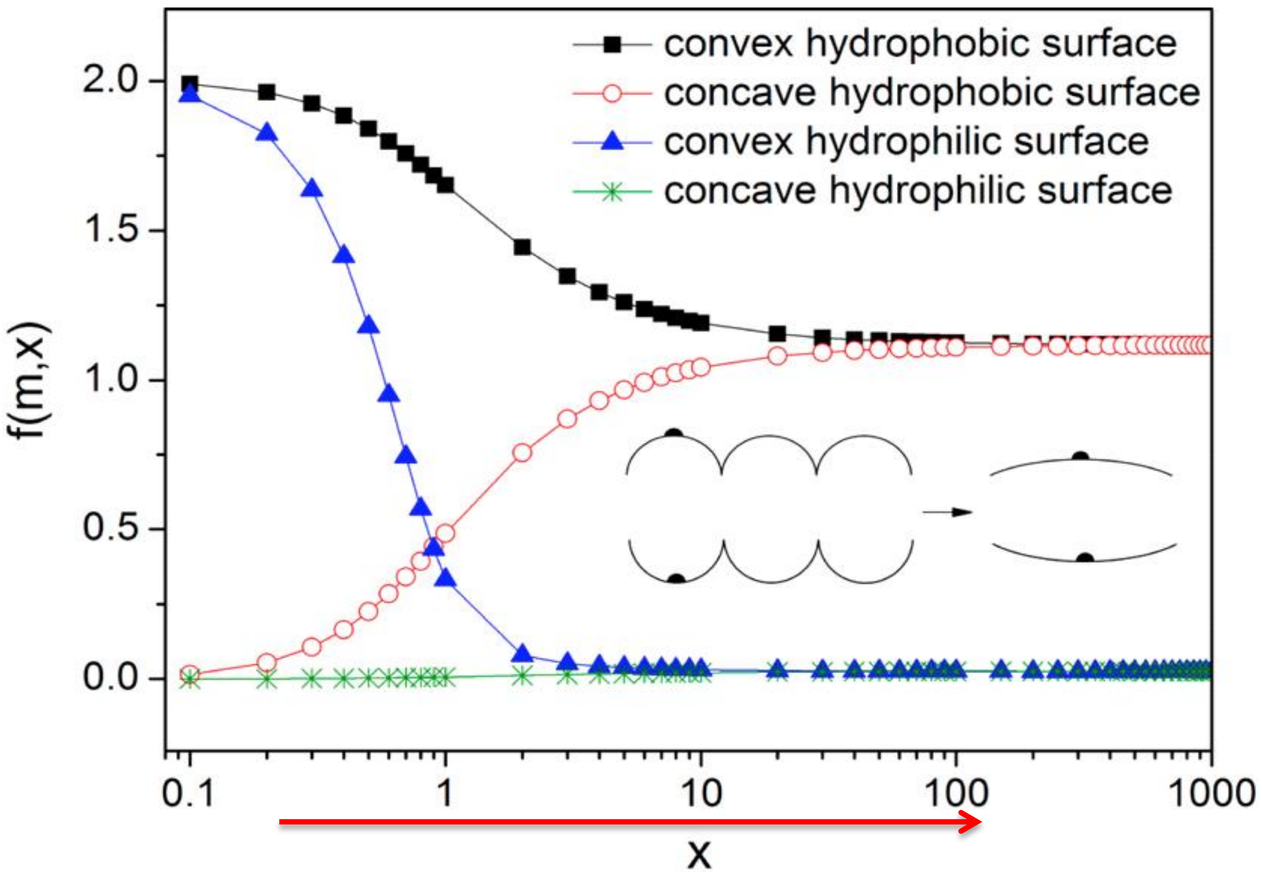



- **No benefit from a superhydrophobic surface, if anything a smooth surface is better!**

*Heidari et al. (2010)*

# The explanation – heterogeneous nucleation

Increasing energy barrier for ice nucleation




Increasing radius of surface features

X = r/r*

r = radius of surface feature

r* = critical ice nucleation radius ≈ 9 nm at -5 °C and about 4.5 nm at -10 °C

- Large surface features should not have any effect since r* is small
- All real surface has both concave and convex features
- Freezing occurs most readily in depressions (concave) and least readily on concave sites

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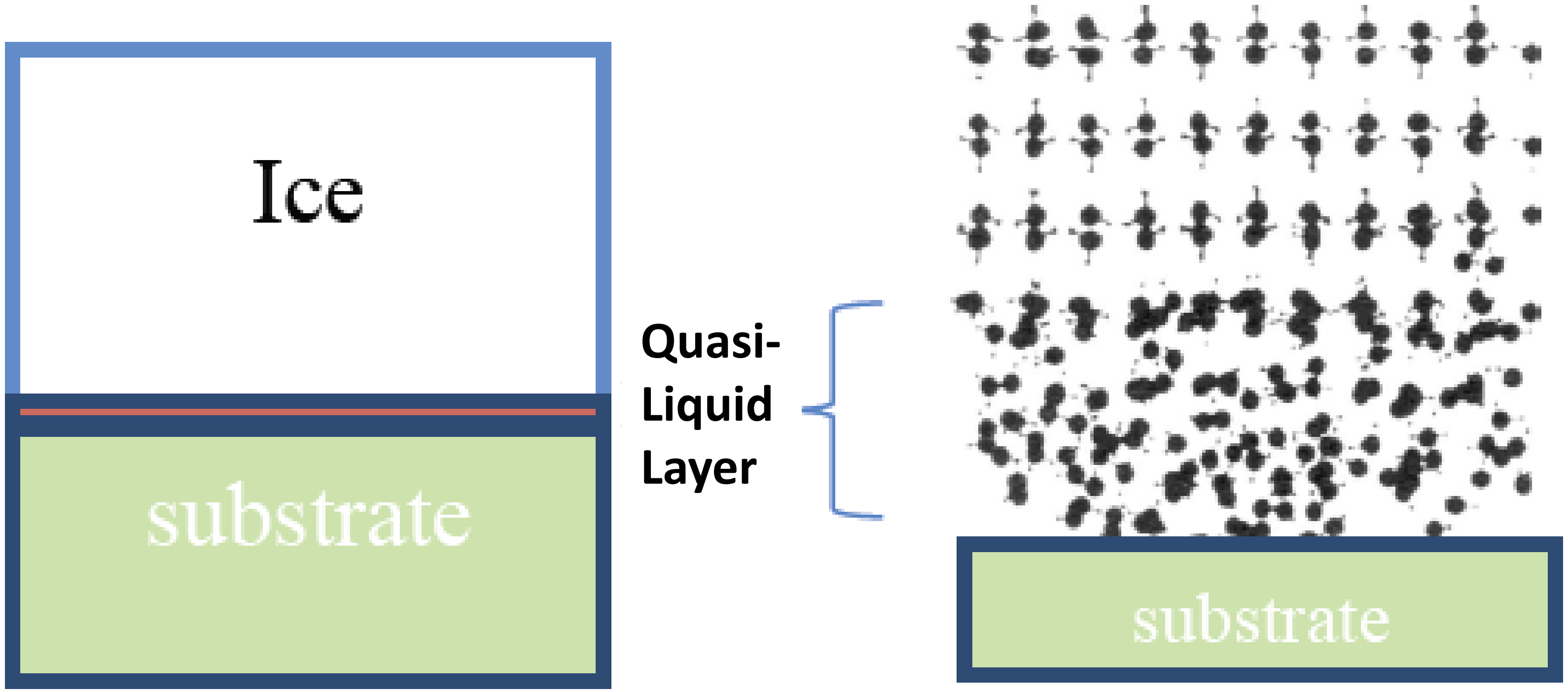
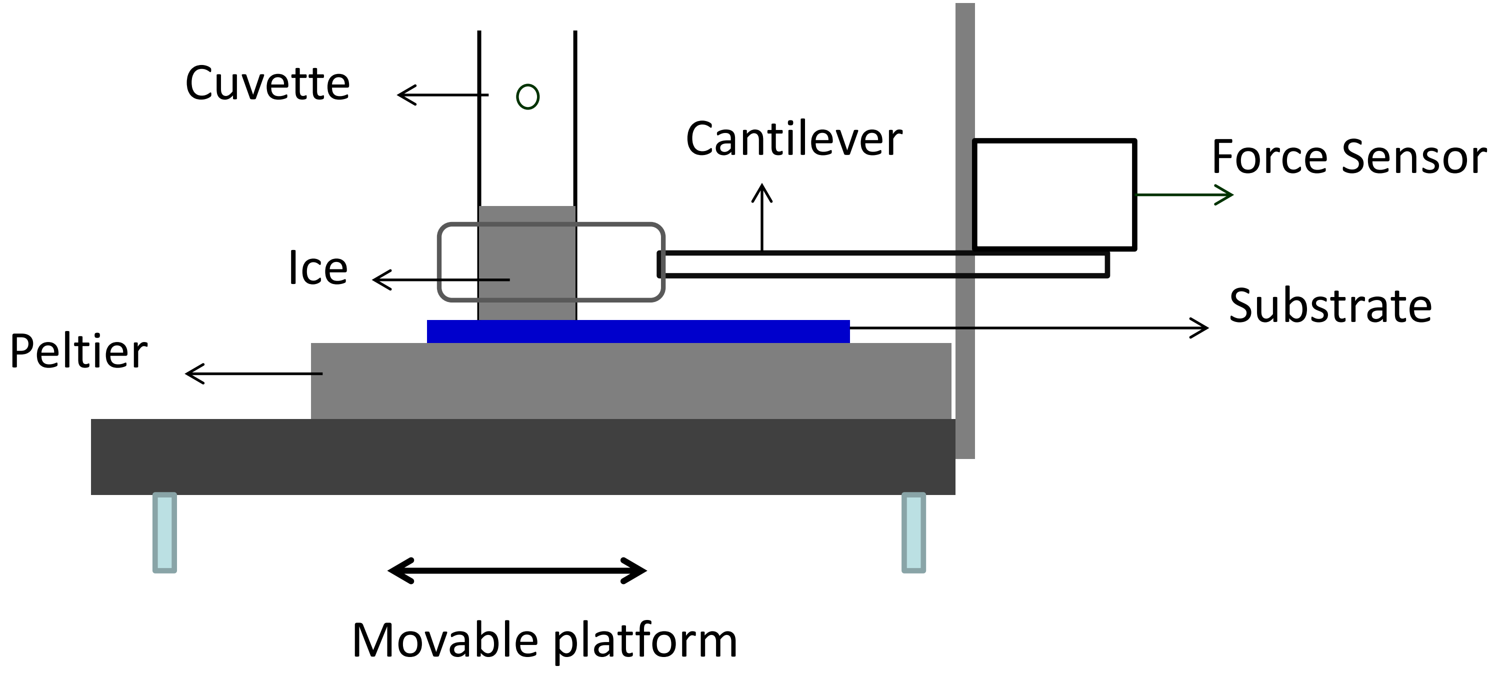
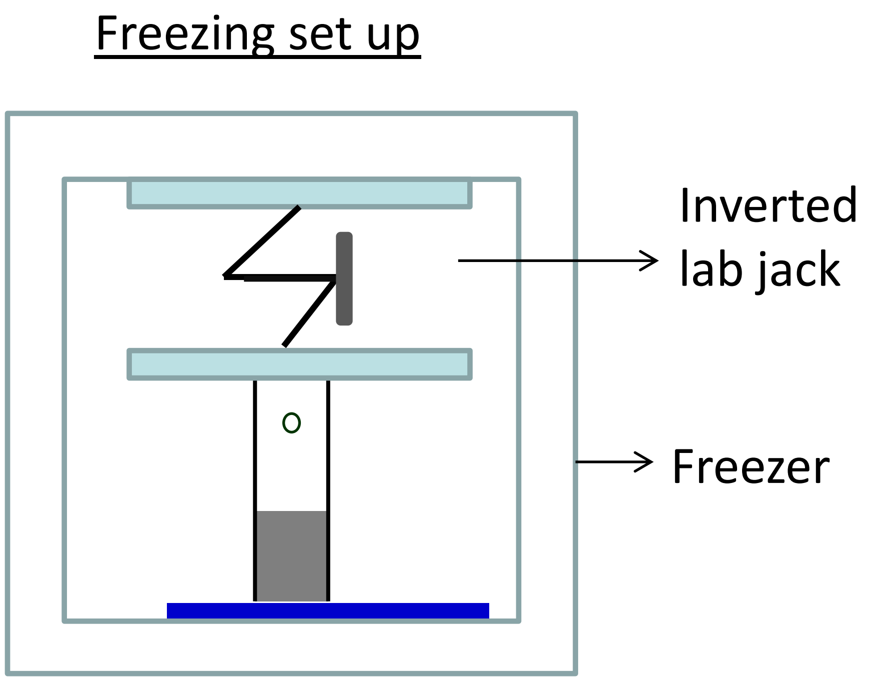
# Anti-icing coating

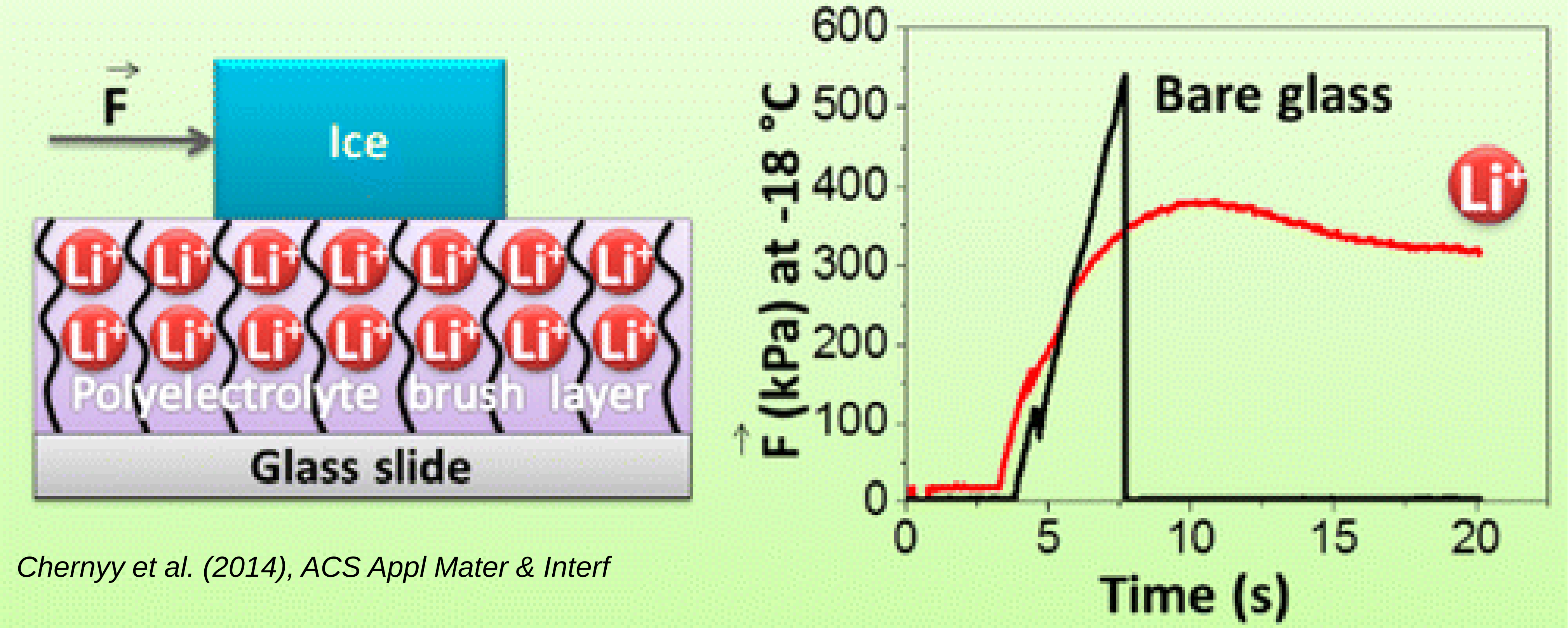
- Quasi liquid layer
- Hydrophilic polymers at the solid surface
- How does different ions influence ice adhesion?



# Ice adhesion measurements






- **Ice adhesion with counterion $Li^+$**
  - **40 % lower at -18 °C**
  - **70 % lower at -10 °C**
  - **Different type of failure**

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# Wind power – Field tests in two winters 2013 and 2014

- Surface modification of samples
- Surface characterization
- Mounting samples and monitoring
- Evaluation of samples post-winter

## Work flow

Coating development

In collaboration with companies

Characterization on the lab scale

Both coatings developed within the project and commercially available

Field tests

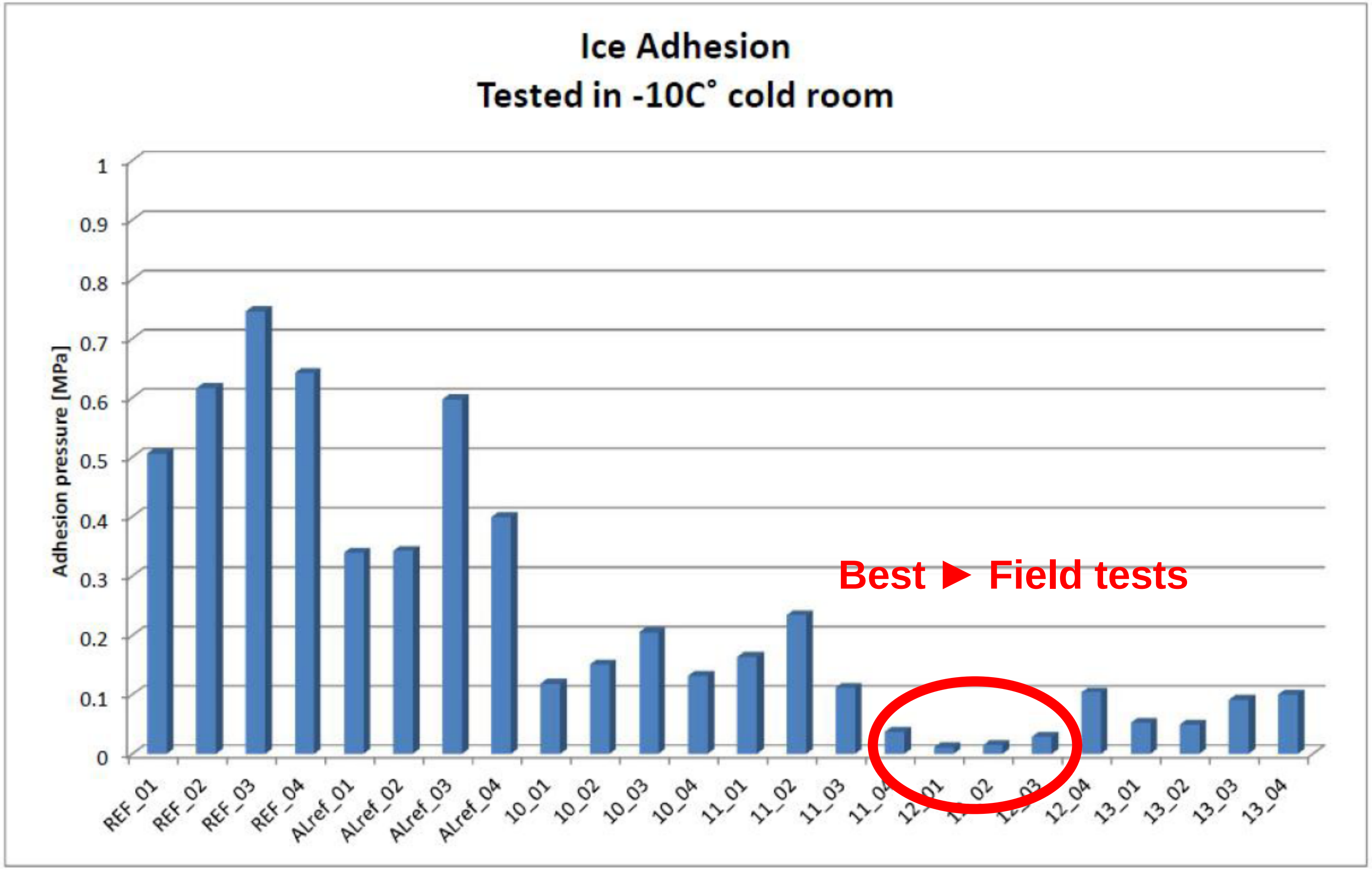
Subgroup wind/aircraft

At Vattenfall's wind power plant in Northern Sweden

Subgroup Heat exchanger

Tests at industrial partners' labs

# Best candidates from laboratory ice adhesion tests

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# Field tests at Vattenfall's wind power plant in Northern Sweden during two winters

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**Superhydrophobic coating #2**

Snapshots from water wetting experiments before and after field tests

**Before field tests – water runs off**

# Field tests at Vattenfall's wind power plant in Northern Sweden during two winters

**Superhydrophobic coating #2**

Snapshots from water wetting experiments before and after field tests

**Same sample after field tests – still good**

Front side - exposed

Back side

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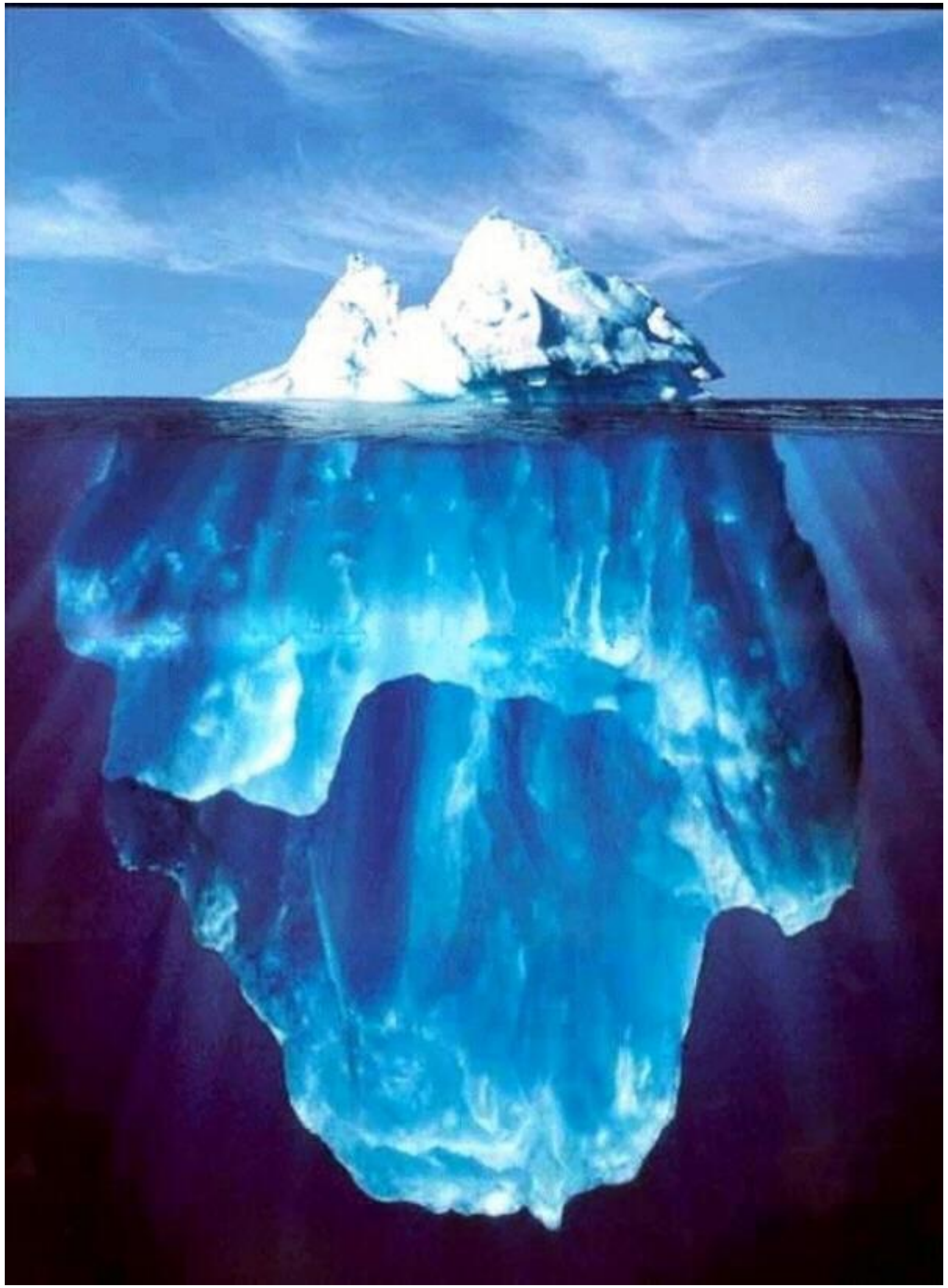
## Example of related projects

- ANTIS – Norwegian research council
  - Passive anti-icing coatings
- Micro-Deice – Swedish Energy agency
  - Active anti-icing
- Retrofit-Deice – KIC Innoenergy
  - Active anti-icing
- ICECONTROL – Eurostars
  - Anti-icing control on railroads



# TopNANO – project summary

## Main achievements

- Well-functioning consortium and research collaboration in the Nordic countries
- Strong engagement from industry: advice, samples/testing, field tests

# TopNANO – project summary

## Crucial elements for project success

- Strong industrial participation in project group
- Field tests and scaled-up tests for wind and heat exchanger applications

# TopNANO – project summary

## Take aways

- Established Nordic platform
- Broaden to other sectors (maritime, off-shore, transport, power transmission, etc.)
- Major public funding and industrial contracts
- Work through the network of TopNANO industrial companies.