

# 3-D Ice Accretion Code Workshop Code Developers Panel

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# General Comments

Identify the main objective of this exercise. Is one of the objectives to find the most accurate numerical model?

Comparison with experimental data and inter-code comparison has to be based on strong scientific and engineering foundations.

What lessons have been learned from the 2D exercise?

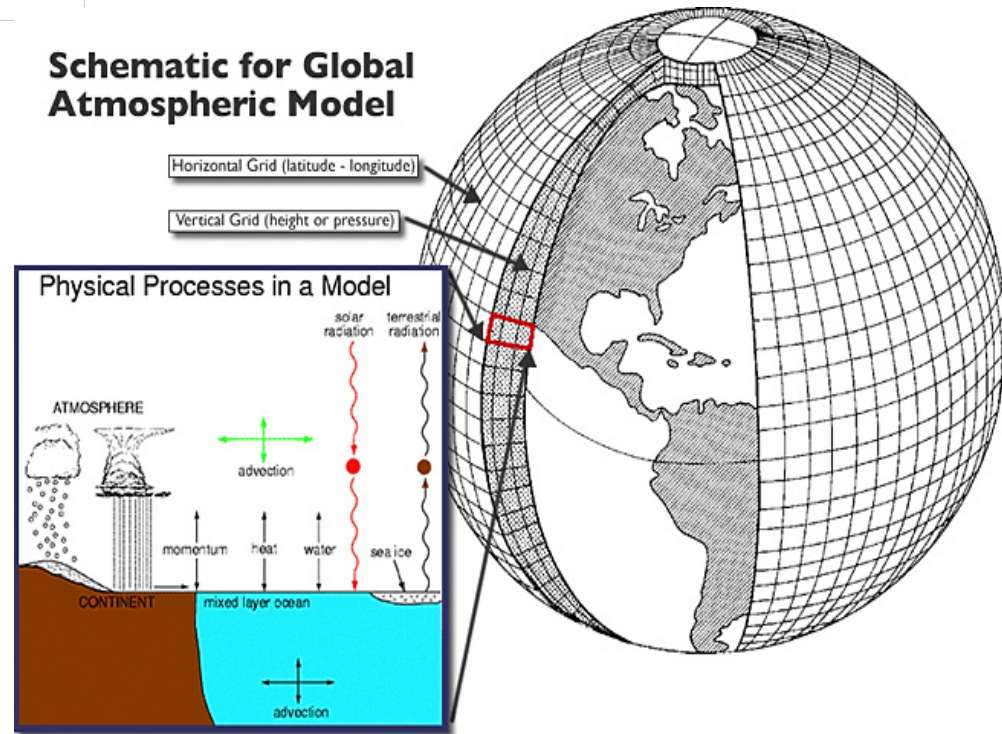
How did practitioners and code developers benefit from the 2D evaluation tests?

What necessary conditions have to be fulfilled to make this exercise meaningful?

- issues related to numerical models
- issues related to experimental data

# Similarities with General Circulation Models

- A GCM is a mathematical model of the general circulation of a planetary atmosphere and it is based on the Navier-Stokes equations with thermodynamic terms for various energy fluxes.
- GCMs are applied for weather forecasting and projecting climate change.
- Models are developed and tested for present conditions but also used for prediction of future and past climates.



In spite of numerical model deficiencies and issues with measurements, the models are widely used and accepted especially for weather forecasting.

# What are verifiable parameters?

What parameters should be used to compare/verify numerical solutions?

- 3D ice shape (how to quantify similarities)
- resulting changes of drag and lift coefficient
- total accretion mass
- aerodynamic and thermodynamic parameters
- ice roughness

Should one parameter or a combination of a few be used?

## Each module verification?

- Since the process of ice accretion consists of three general steps/modules (airflow, drop impingement, ice formation), should verification of each module be done separately?
- How to avoid propagation of errors from one module to another?
- Is module verification feasible and useful? Maybe inter-code comparison could be done but no comparison with experiments.
- Or maybe it does not matter that there are problems within the black box consisting of three modules, as long as the final prediction is correct.

# Ice roughness and its density

Ice roughness and its influence on heat transfer

- fit to experimental data versus analytical approach
- range of applicability of above approaches
- what is the difference between dealing with small-scale ice surface roughness and large-scale rough features (for example, lobster tails)?

What should be the formal measures for quantifying the macroscopic properties of complex ice accretion surfaces (lobes, feathers, lobster tails) and their variability?

Ice density and its influence on droplet interception and ice roughness

- can ice density be predicted?
- identify the cases when ice density is important

# Time-evolution

- To what extent should numerical models capture time evolution of the flow, drop trajectories and ice growth to give acceptable results?
- How many steps are needed to obtain desirable results? One-step, multi-step or maybe truly unsteady solution of all processes is needed.
- Should the number of steps depend on final ice thickness? Or maybe there is some other general criterion?

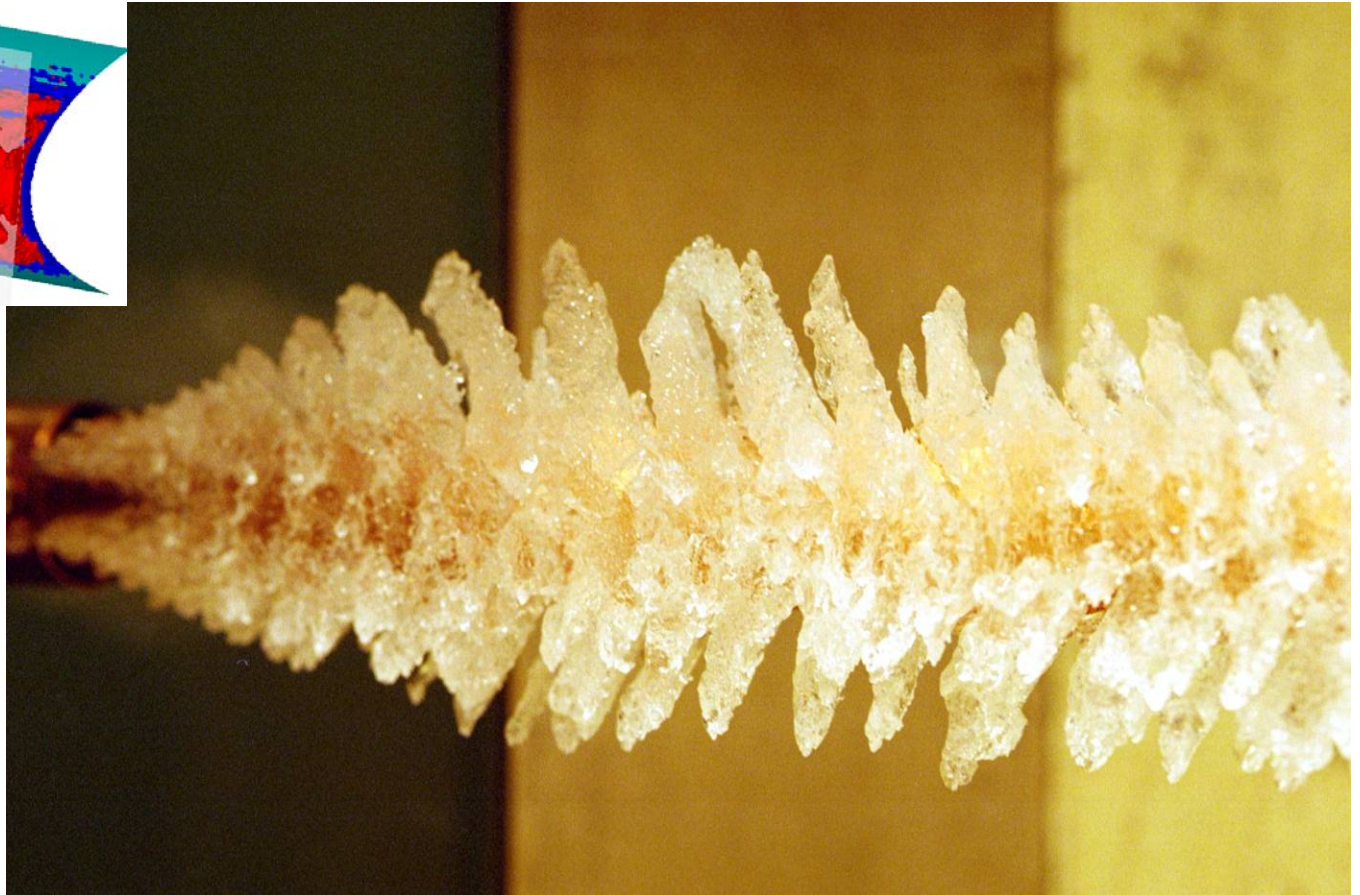
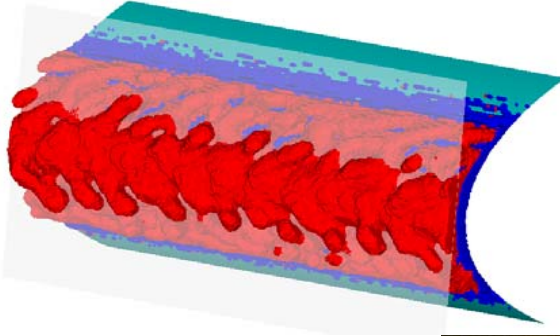
# Experimental verification

- Should wind tunnel or in-flight results be used?
- How is tunnel-to-tunnel ice accretion variability for a given set of conditions going to be addressed?
- What about tunnel repeatability and test section uniformity concerns?
- Experimental error should be identified. How are error bars of measurable input atmospheric parameters related to error bars for ice shape, total mass, or other measures of the resulting ice accretion?

## Closing Comments

- It would be valuable to develop some form of repository of 3D experimental and modelling data that all researchers in the field could contribute to and access.
- Greater attention should be paid to numerical modelling of icing removal by melting and shedding.
- We could benefit from reaching out to the icing on engineering structures community (wind turbines, power transmission and telecommunication equipment) linked with the International Workshop on Atmospheric Icing of Structures.

# Lobster Tails on Swept Wings



# Ice Accretion at Near-Freezing Temperatures

