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CENTRE D'HYDRAULIQUE CANADIEN

CFD Applications Involving Floating Sea Ice

Mohamed Sayed

Canadian Hydraulics Centre

National Research Council

Ottawa, Ontario, Canada

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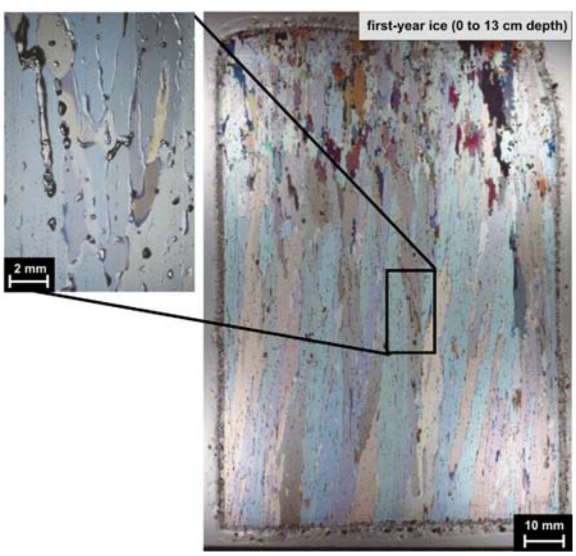
Sea Ice Structure and Types

(a) First-year ice:
Columnar-grained, maximum thickness ~ 2m
Salinity ~ 3%

(b) Multi-year ice:
Thickness > Floes 3 m to 7 m, max up to 20 m.
Low salinity, higher strength

Photos: courtesy M. Johnston

(a) **(b)**



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First-year Sea Ice

Photos: courtesy M. Johnston

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Ice Ridges

Photos: courtesy A. Barker

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Multiyear Sea Ice

Photos: courtesy M. Johnston

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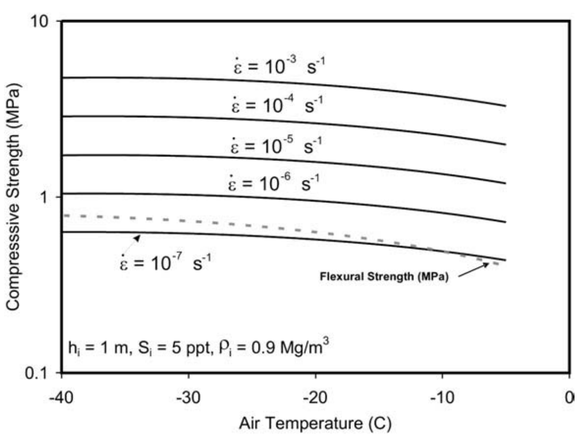
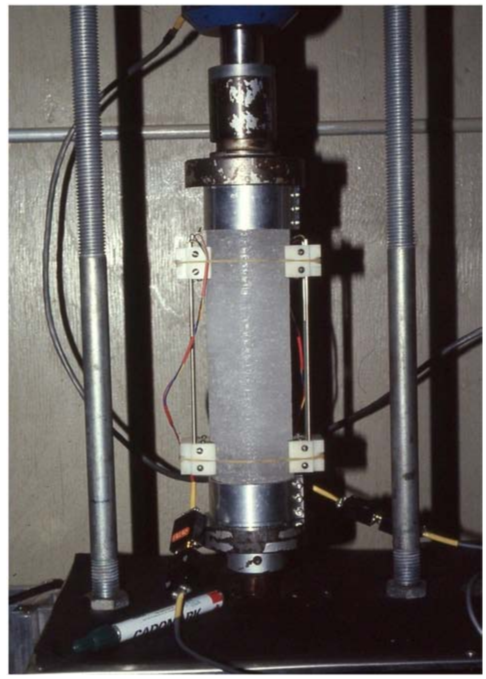
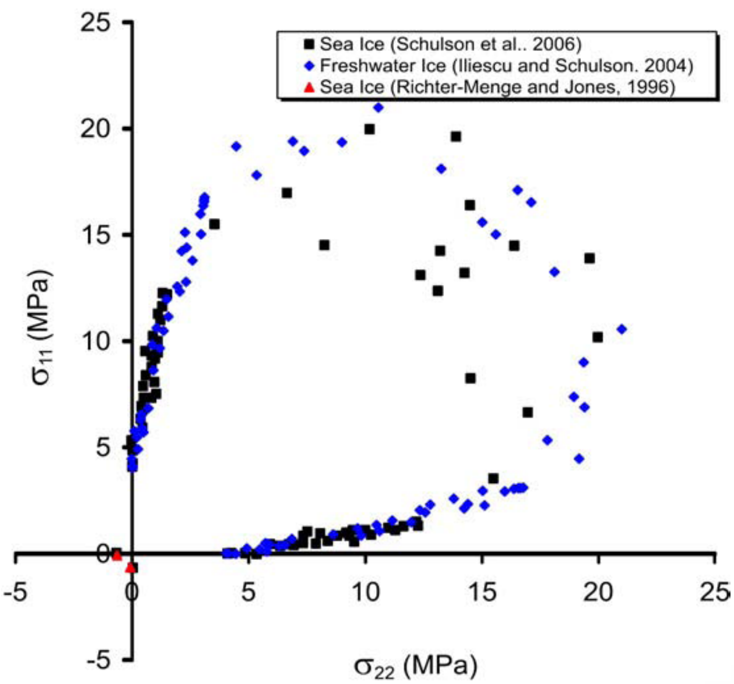
Strength of Sea Ice

Strength depends on temperature, salinity, structure, strain rate).

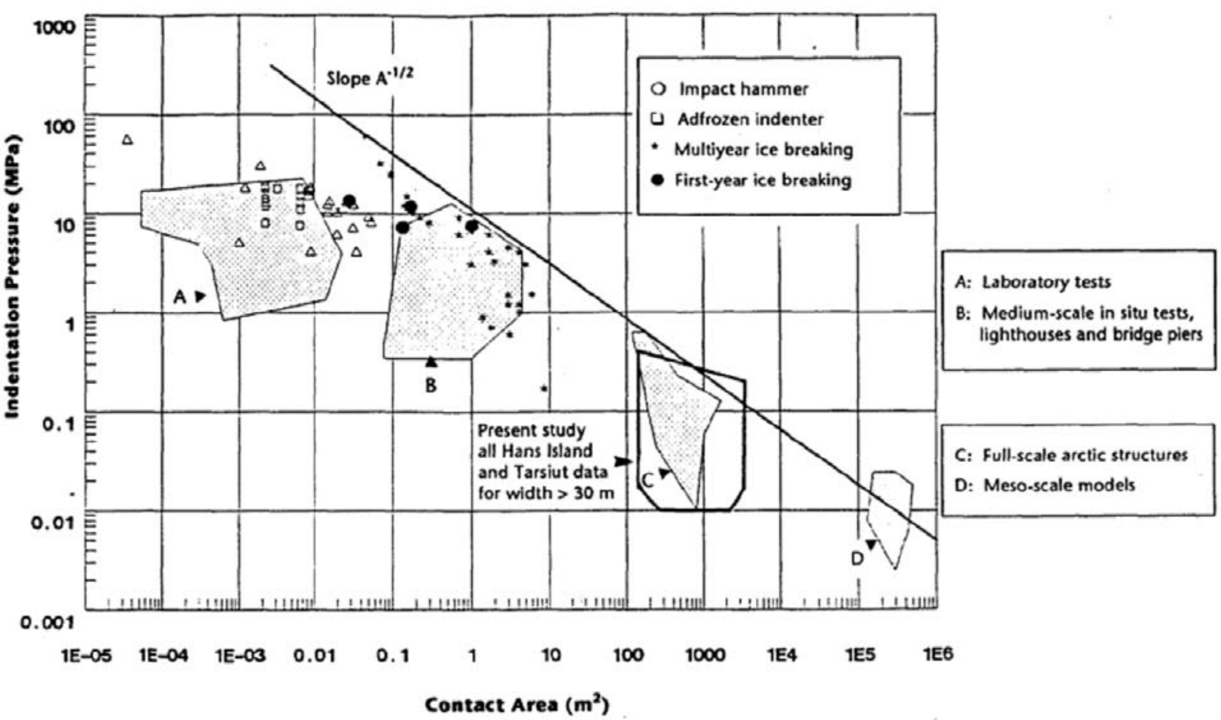






Timco & Weeks,
Cold Regions Sc & Tech,
Vol. 60, pp. 107-129

Length Scale Effect



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Applications

- Ice-structure interaction.
- Shipping.
- Meso-scale forecasting.

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Ice-Structure Interaction

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Failure Modes: Ridging and rubble Pile-up

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Ships In Ice I

Frobisher Bay, July 2008,

Courtesy Captain Vanthiel

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Ships In Ice II

East Coast of Canada, April 2007
Courtesy CCG and CIS

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Modeling Approach

Challenges

- Complex deformation modes and material properties
- Discontinuous behavior- ridging large cracks, open leads.
- Boundary conditions: moving free boundaries, structure's response.

Governing Equations

- Conservation of mass and linear momentum
- Constitutive equations (yield envelope)
- Forcing: wind and current drag, Coriolis force (for forecasting)
- Forecasting requires parameterization for thickness (ridging) evolution.

Governing Equations

- **Conservation of mass and momentum**

$$\frac{d\left(\rho_i\, c_i\right)}{d\,t} + \rho_i\, c_i\, \nabla \cdot \mathbf{u} = 0$$

$$\rho_i\; c_i \left[\frac{d\,\mathbf{u}}{d\,t}\right] = -\nabla \cdot \boldsymbol{\sigma} + \rho_i\; c_i\, \mathbf{g} + C_d\, c_i\; \rho_w \left|\mathbf{u}_\mathbf{w} - \mathbf{u}\right| \left(\mathbf{u}_\mathbf{w} - \mathbf{u}\right)$$

- **Constitutive equations**

$$\sigma_{ij} = p\,\delta_{ij} + \frac{A}{\Delta}\left(\dot{\varepsilon}_{ij} - \frac{1}{3}\dot{\varepsilon}_{kk}\,\delta_{ij}\right)$$

$$p = P^* \exp\left[-k\,\left(1 - c_i\right)\right]$$

Viscous Plastic approximation
A **is chosen to satisfy the yield condition**

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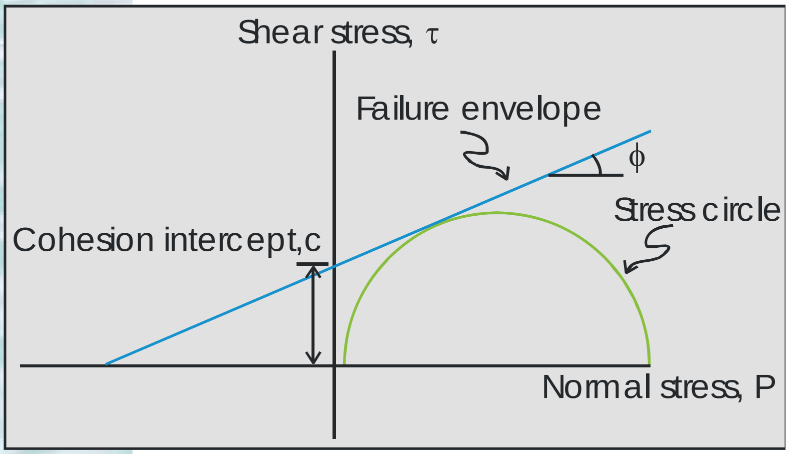
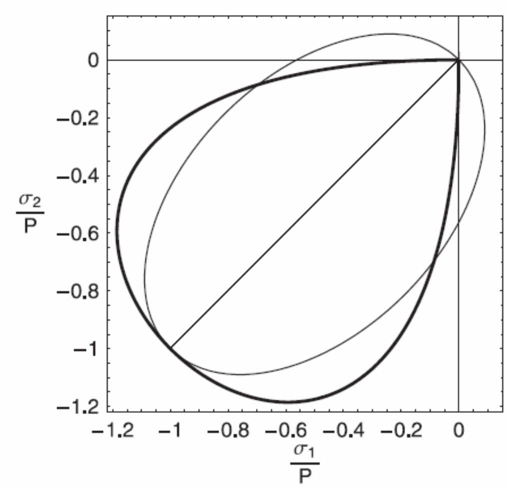
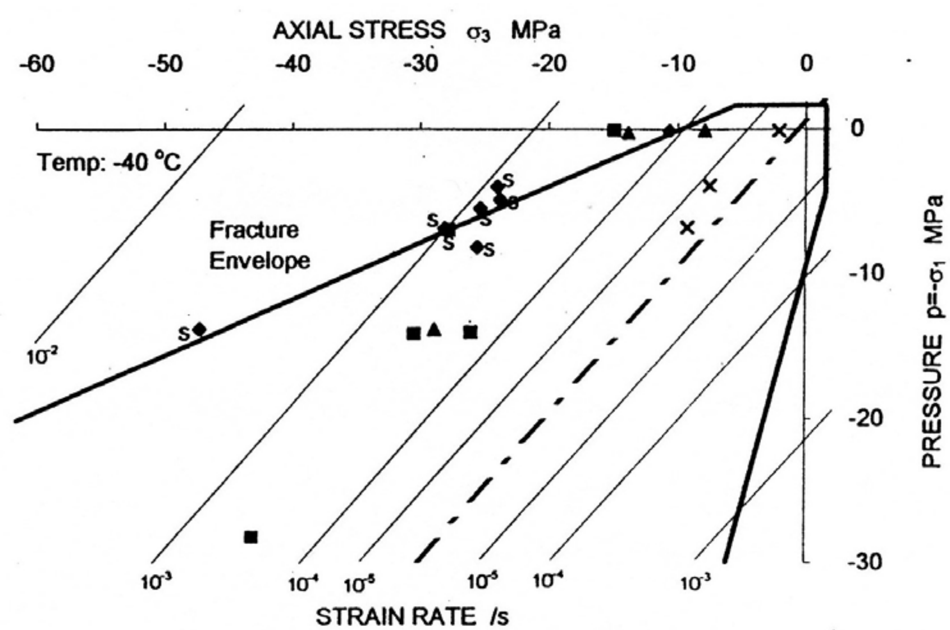
Examples of Yield Envelopes

Mohr- Coulomb yield envelope for ice rubble





Multi-year ice yield envelopes



EXAMPLES

The depth-averaged model

The Molikpaq
Multi-legged structure

The three-dimensional model

Ice pile-up against a slope

Stationary Ships

Meso-scale Forecasting

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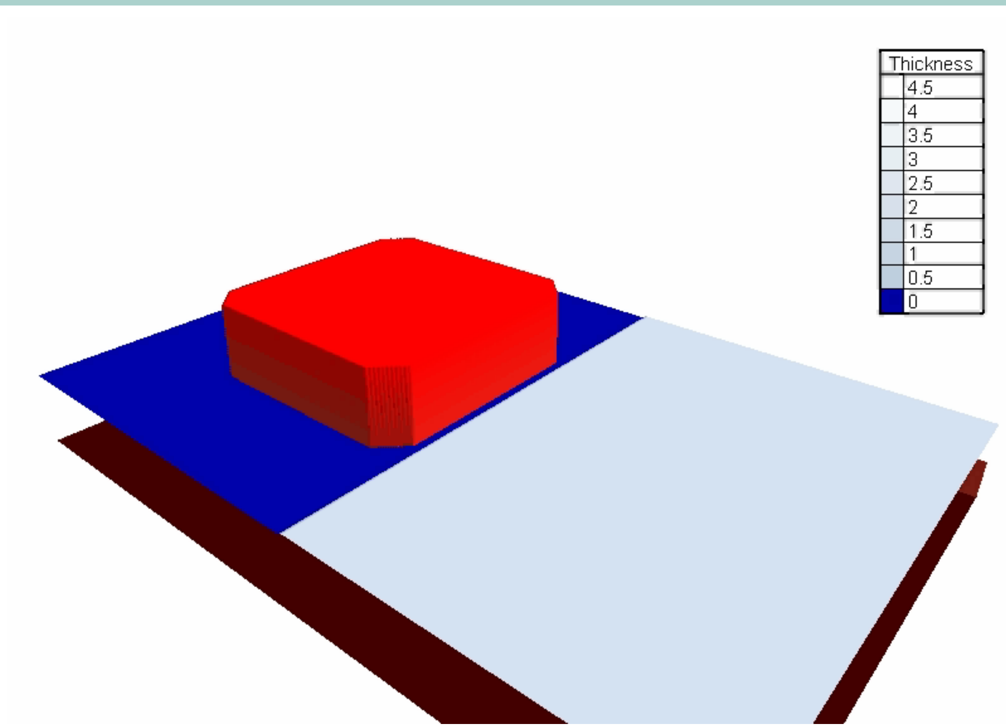
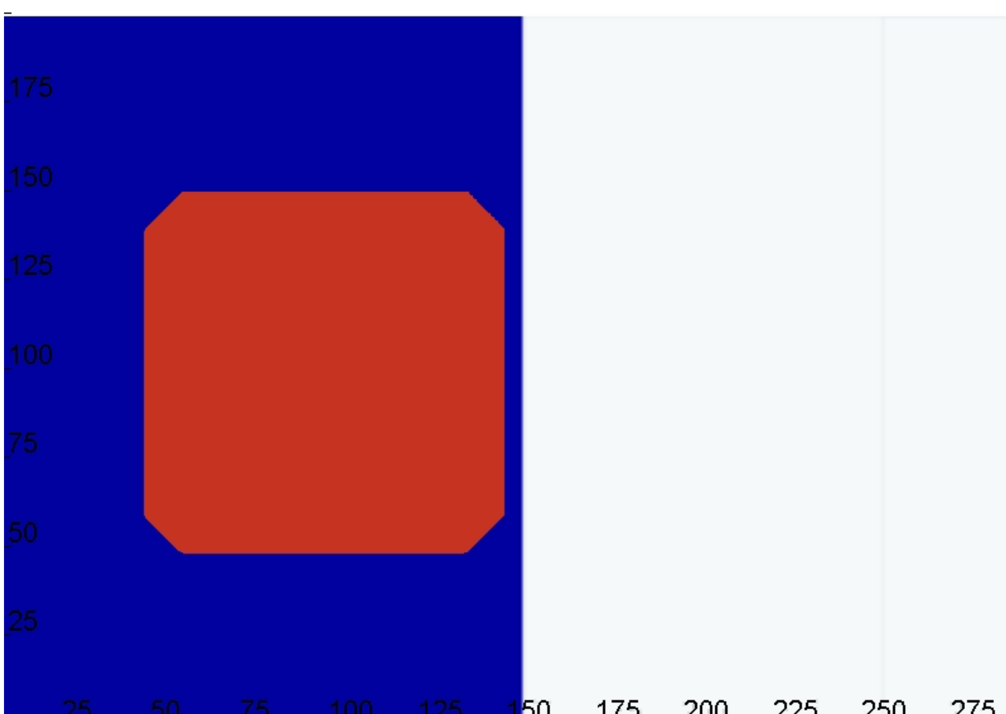
The Molikpaq





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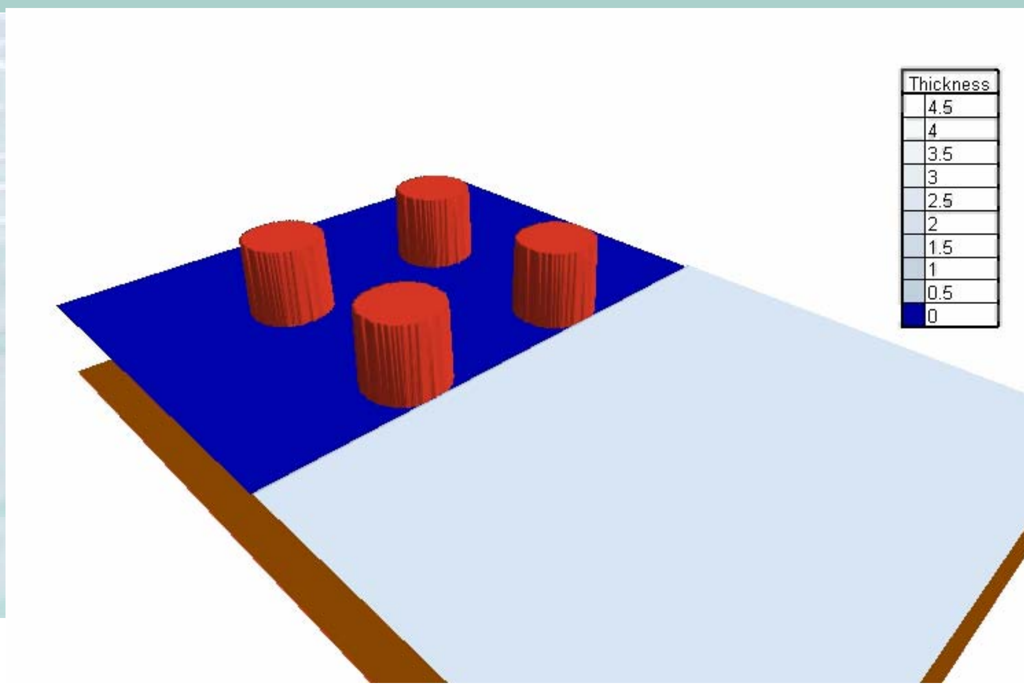
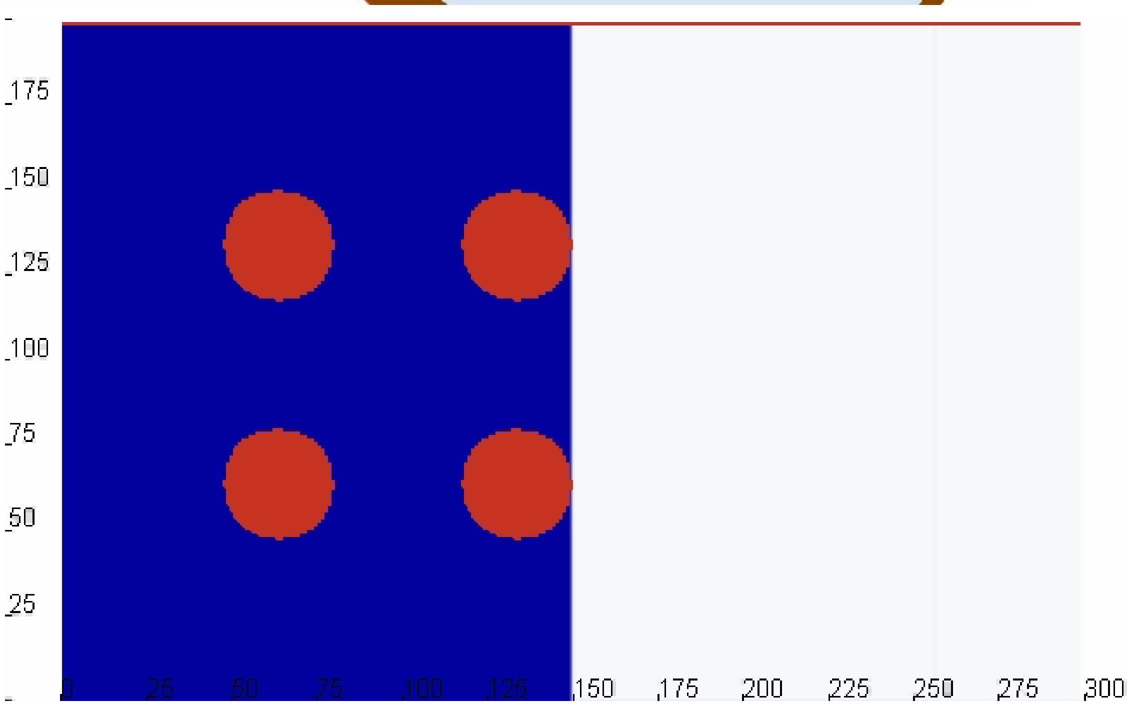
Multi-Legged Structures





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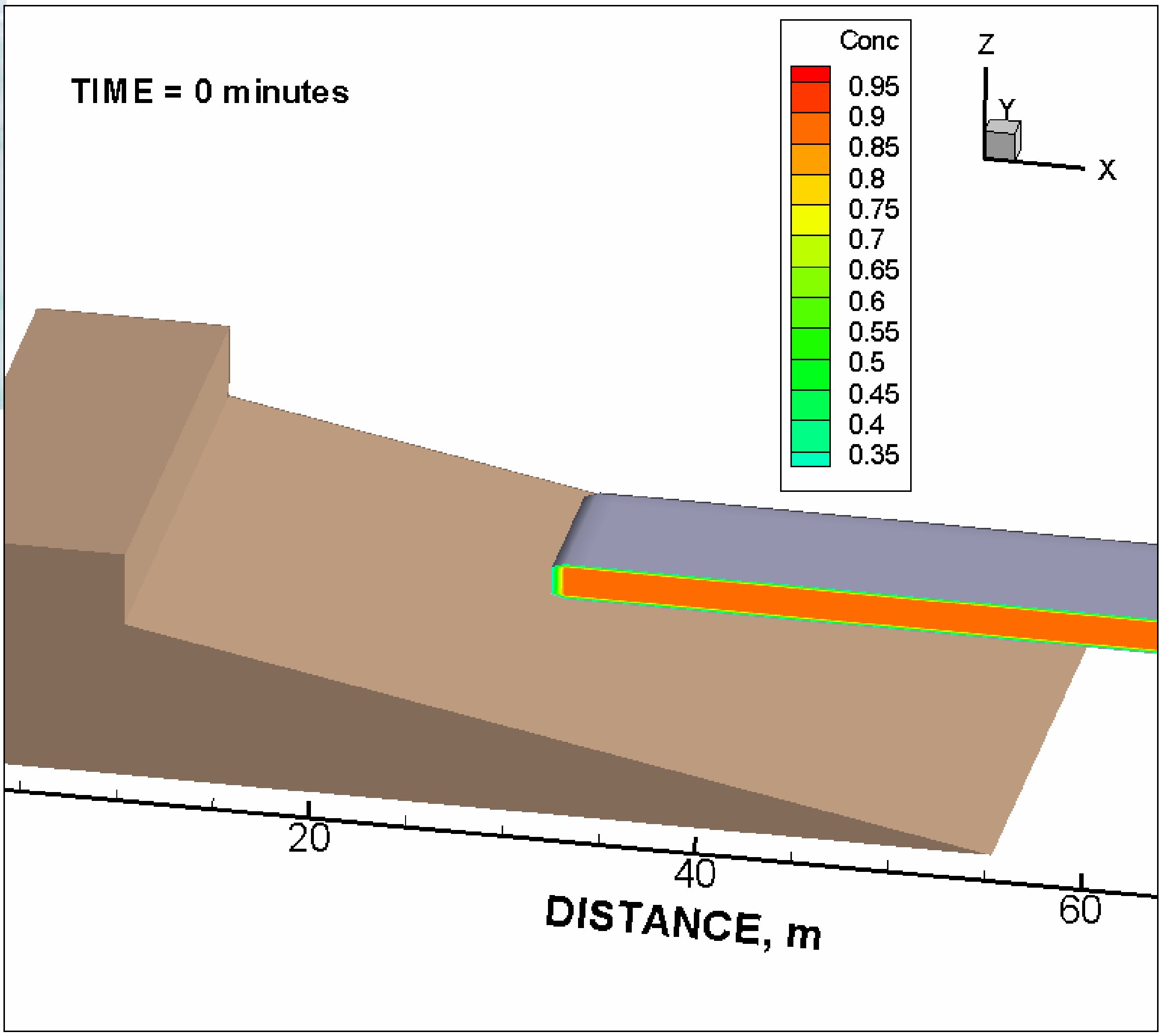
Ice Pile-up against a slope



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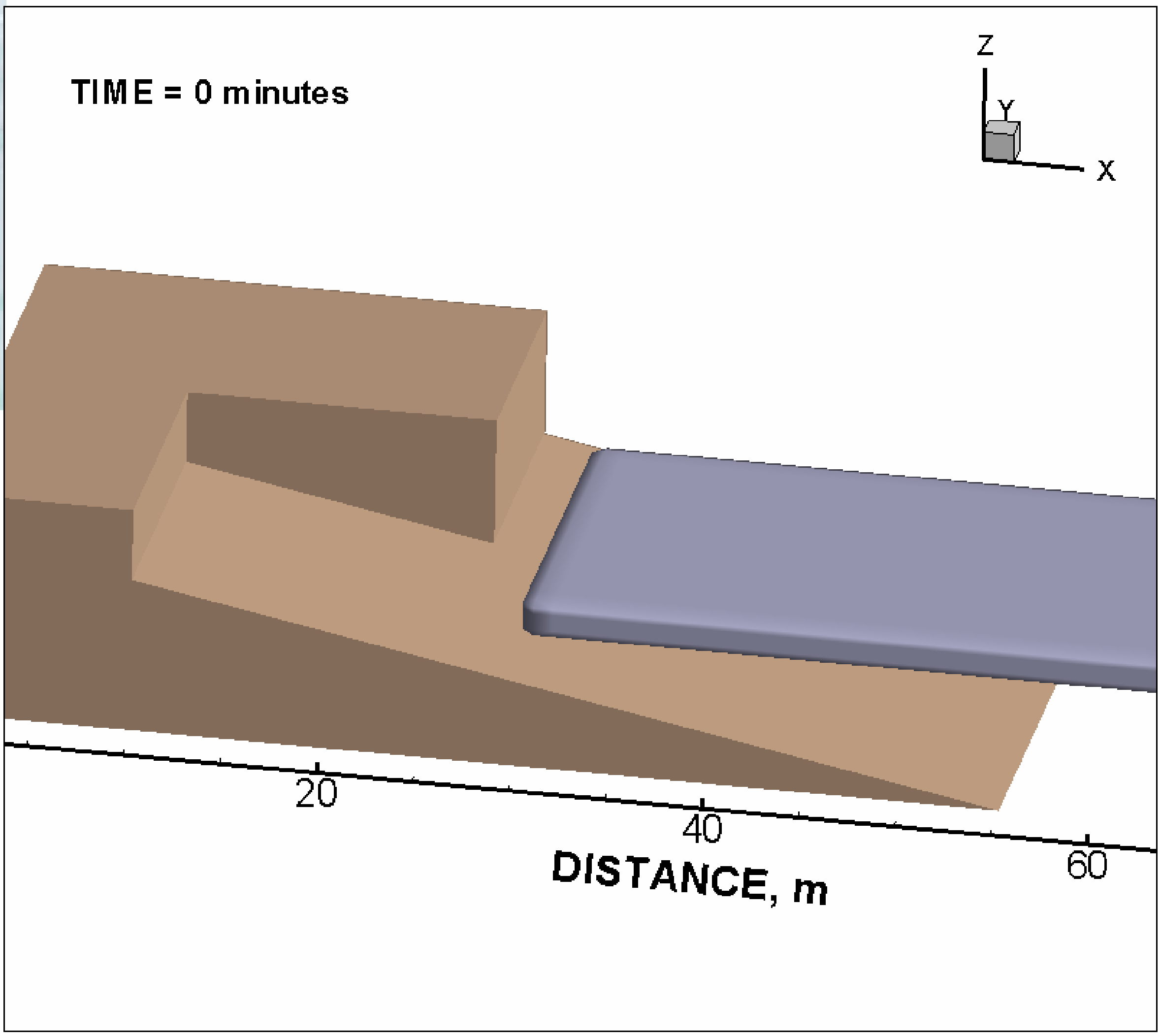
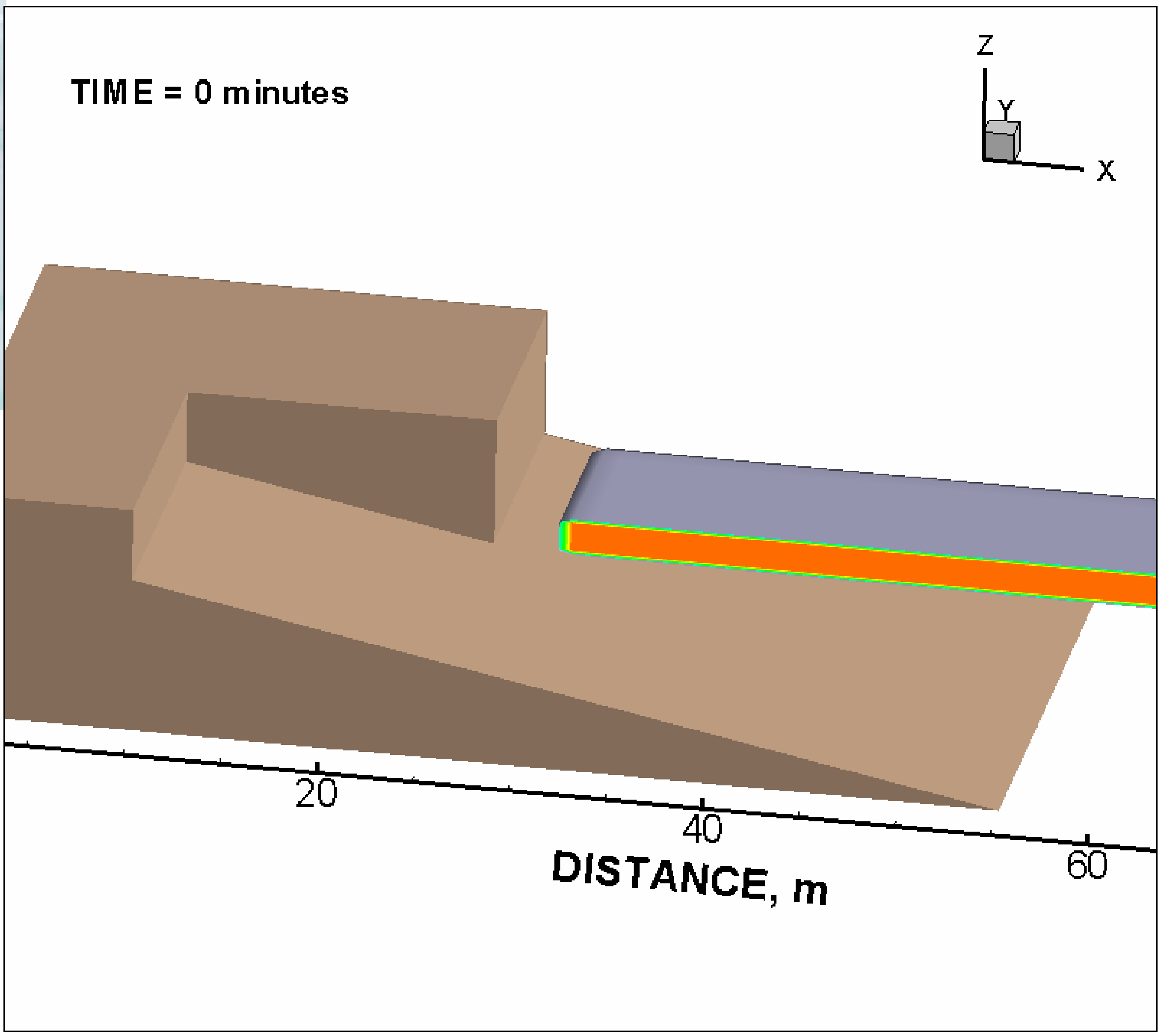
Ice pile-up over a corner



Ice pile-up over a corner II



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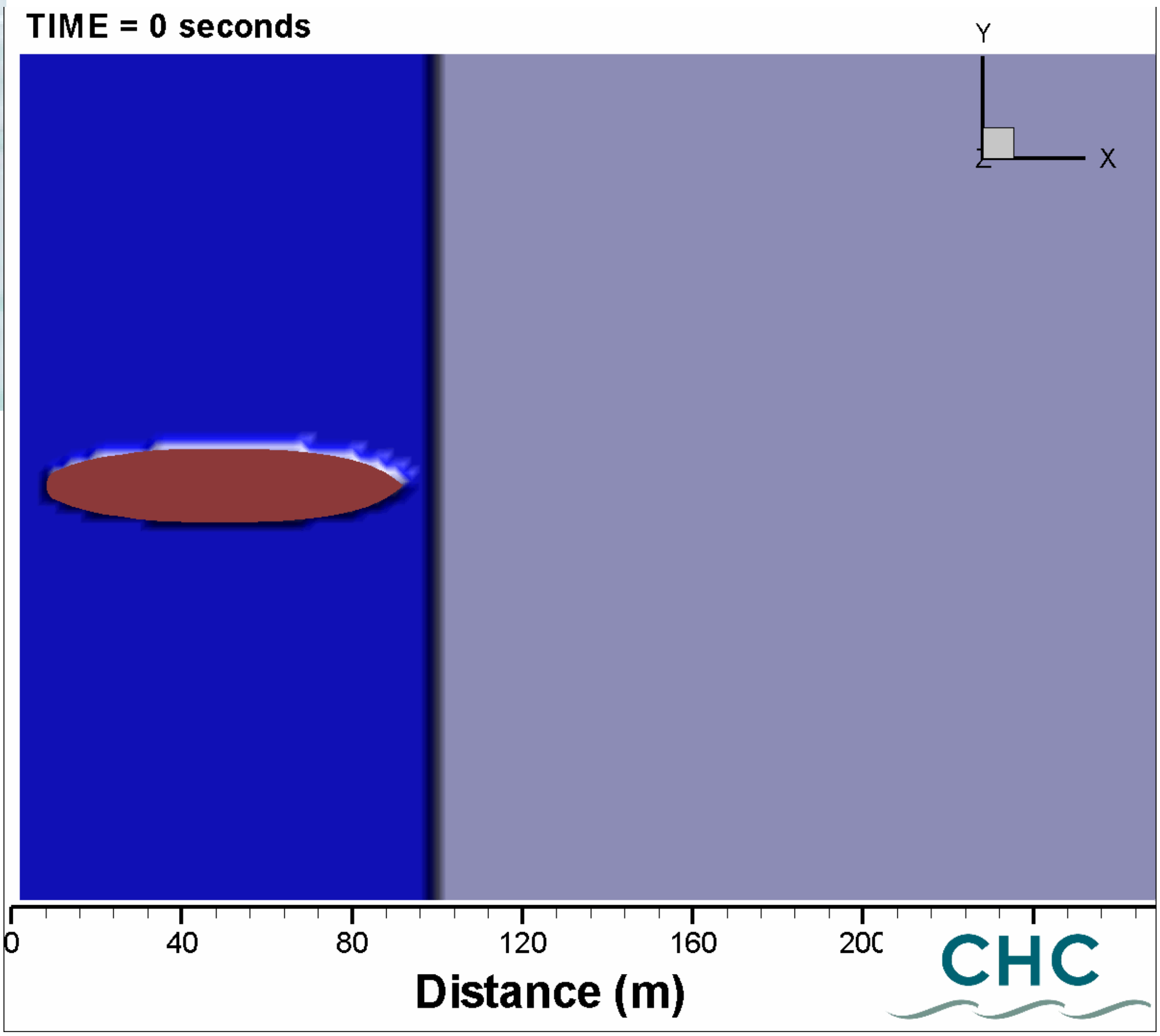
Stationary Ship



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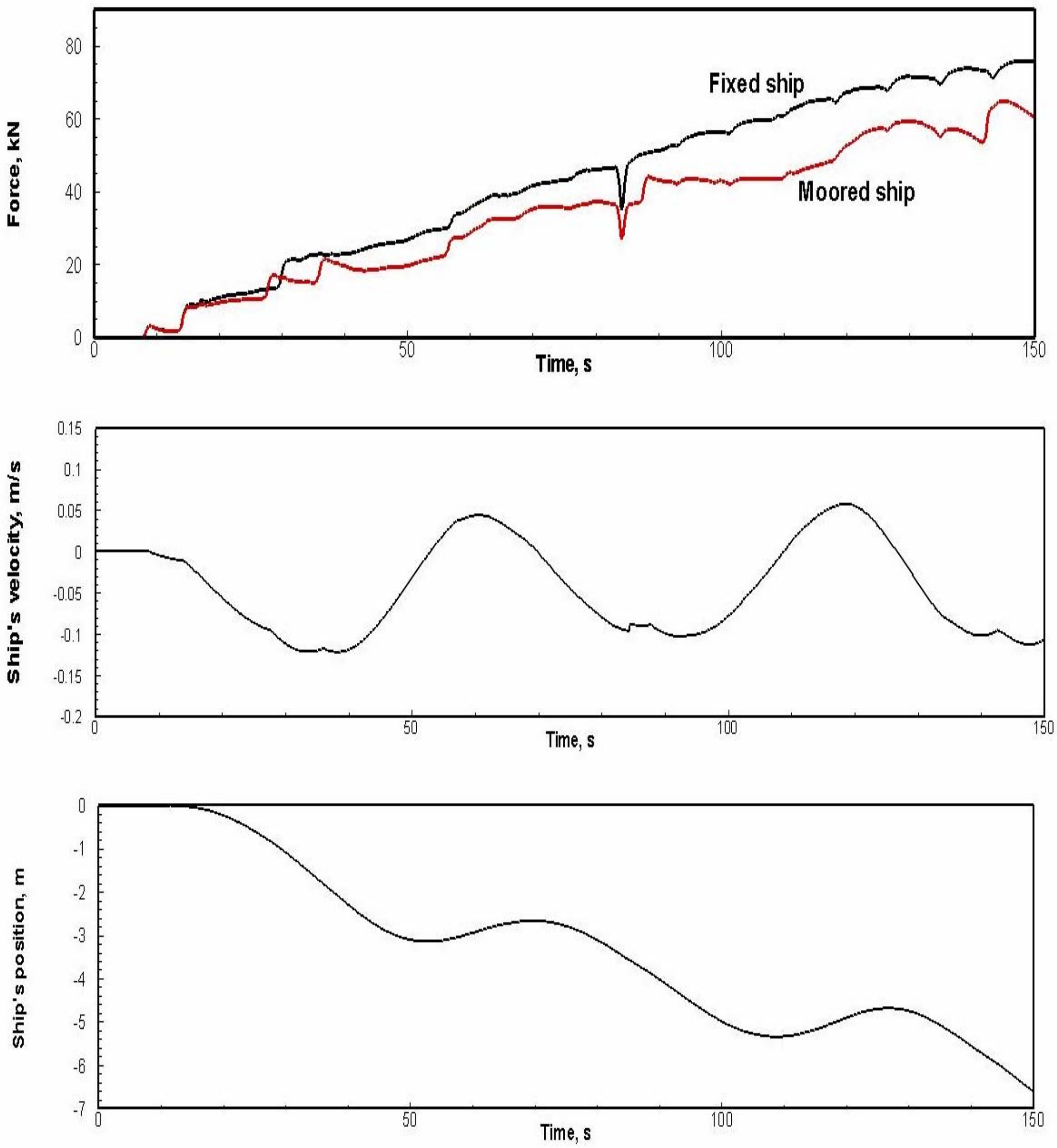
Forces on a Ship



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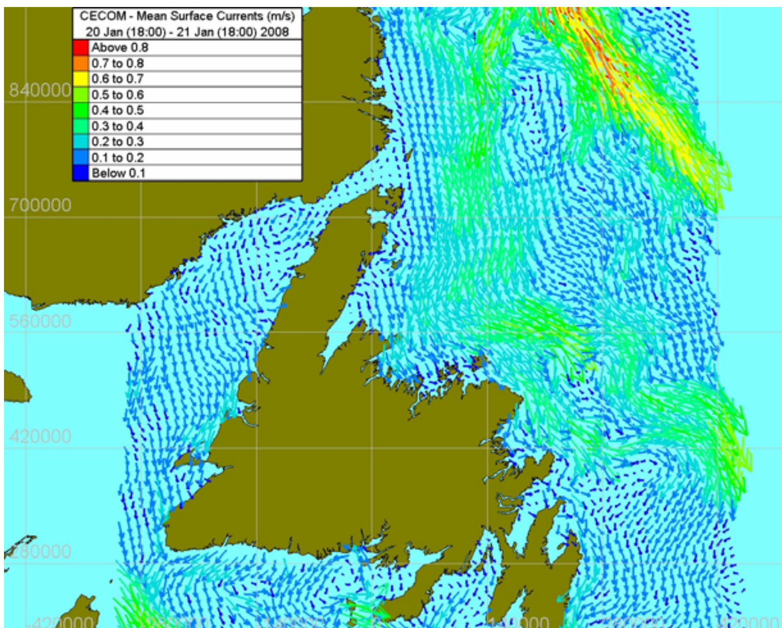
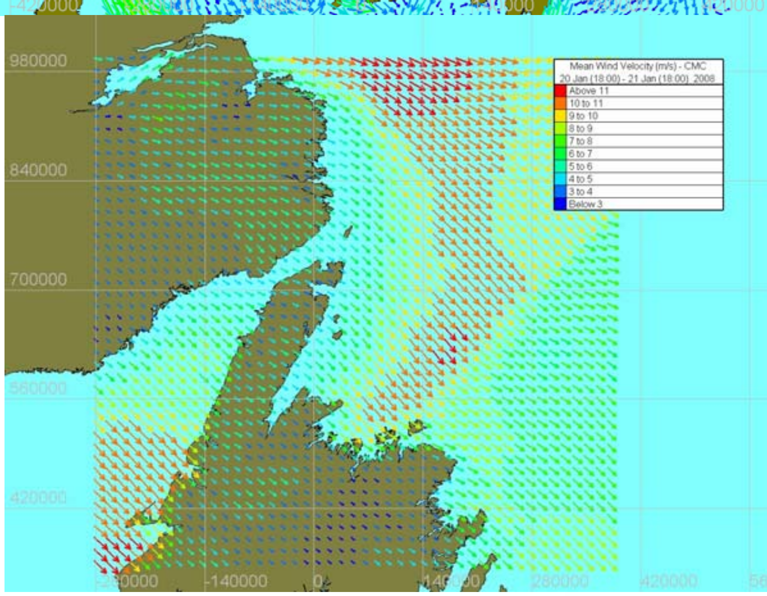
Ice Forecasting – Strait of Belle Isle

January 21-22, 2008.

Input water current and wind





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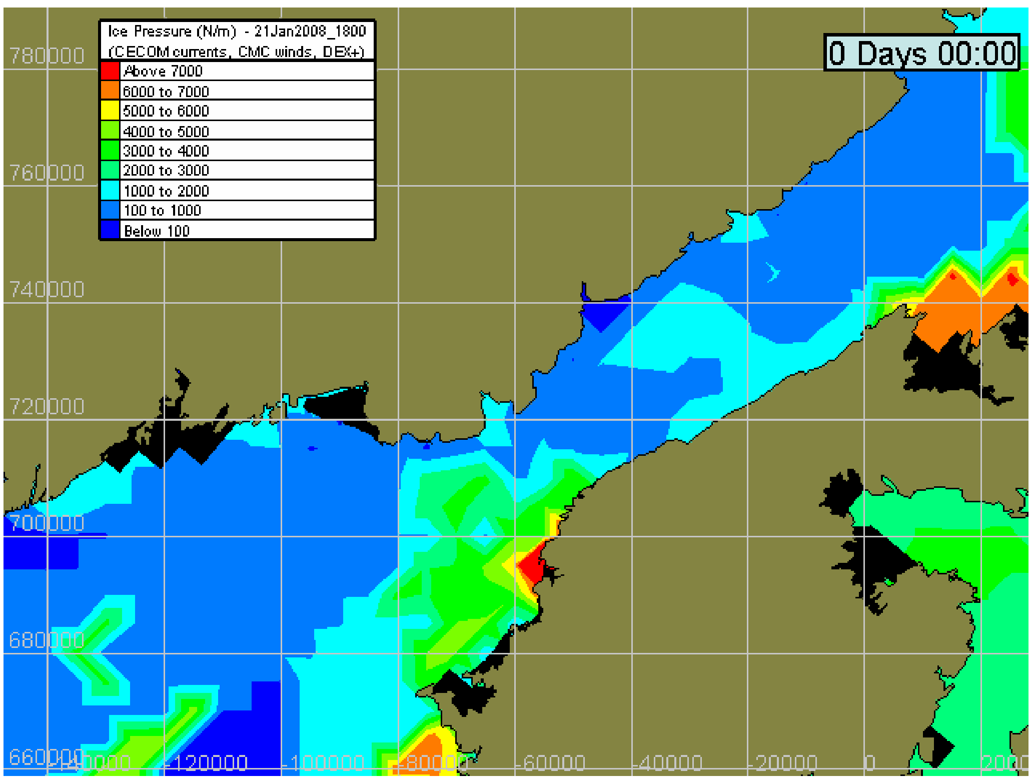
Pressure Build-up



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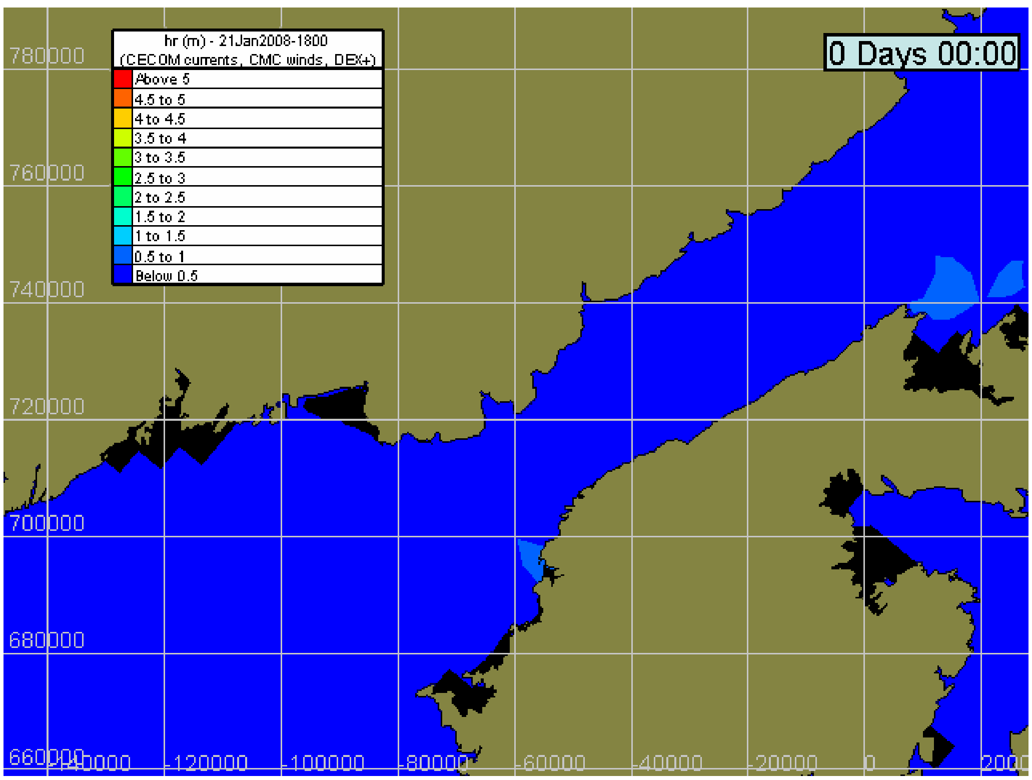
Evolution of Ridge Thickness



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Concluding Remarks

- Modeling the interaction between floating ice and structures is in its infancy has similarities with modeling granular flow problems.

- Modes of ice deformation present unique challenges – ridges, large cracks, open leads, rubble fields.

- Stresses and modes of deformation have strong dependence on the length scale.