Arctic sea ice modelling: introducing the Uvic model with the granular sea ice model

Jean-François Lemieux[1], Jan Sedláček[1], Bruno Tremblay[2],
David Holland[3] and Lawrence Mysak[1]

[1] McGill University, Montréal, Québec, Canada

[2] Lamont-Doherty Earth Observatory, New York, USA

[3] Courant Institute of Mathematical Sciences, New York, USA

Outline

- Description of the UVic model and the granular model

- Sea ice rheology in the granular sea ice model

- Research objectives

- Preliminary results

The UVic model version 2.6

- global with a resolution of 1.8° (lat) by 3.6° (long)

- oceanic component: MOM 2.2
  - 3D ocean with 19 unequally spaced levels

- the poles can be rotated to avoid the problem of grid convergence

- atmospheric component:
  - EMBM with moisture advection and dynamical feedbacks

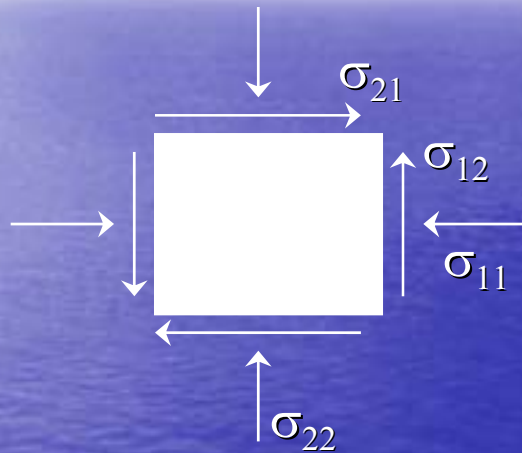Weaver et al. 2001

The granular sea ice model: the dynamics

- the major difference with other models is in the parameterization of the rheology term

- sea ice is treated as a slowly deforming granular material

- dilatancy effect included

$$- \rho_i h f (k \times u) + A(\tau_a - \tau_w) - \rho_i h g \nabla H_d + \nabla \cdot \sigma = 0$$

rheology
term

Tremblay and Mysak 1997

The granular sea ice model:
the rheology term

$$\sigma = \begin{bmatrix} \sigma_{11} & \sigma_{12} \\ \sigma_{21} & \sigma_{22} \end{bmatrix}$$

$$p = -\left(\frac{\sigma_{11} + \sigma_{22}}{2} \right)$$

$$q = \sqrt{\left(\frac{\sigma_{11} - \sigma_{22}}{2} \right)^2 + \sigma_{12}^2}$$

p and q are called the stress invariants

The granular sea ice model:
the failure criterion

Failure criterion: defines the transition between the rigid phase and the plastic phase
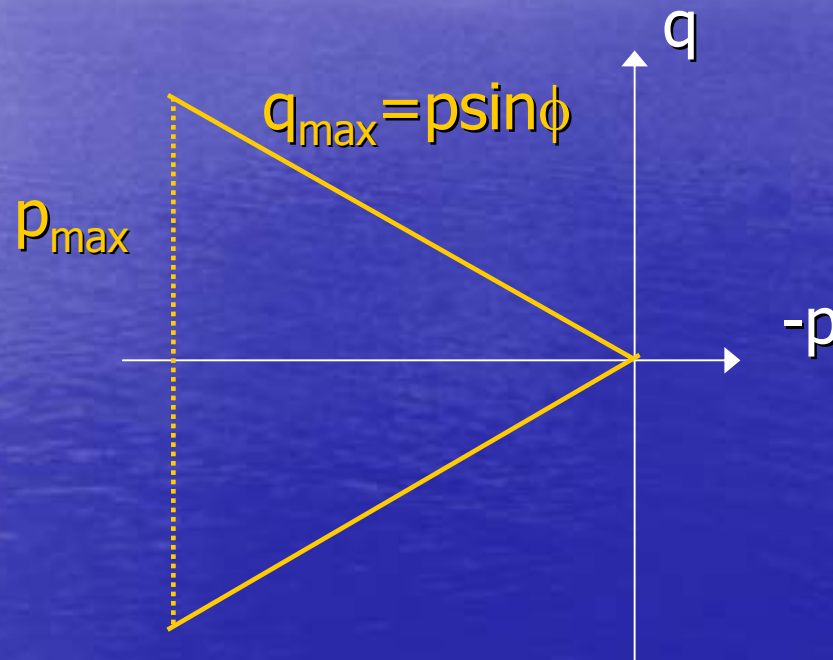
- failure in compression: $$p_{\max} = p^* h e^{-C(1-A)}$$ Hibler 1979

- failure in tension: free drift

- failure in shear: $$\tau_s = -\sigma_s \tan\phi \Rightarrow q_{\max} = p \sin\phi$$

  – Mohr-Coulomb failure criterion

The granular sea ice model:
the failure criterion

$$q_{max} = p\sin\phi$$

p_{max}

q

$-p$

The failure criterion in stress invariants space

The granular sea ice model: the rheology term

To close the system of equations, we can relate the stress tensor to the strain rates

$$\sigma = \begin{bmatrix} \sigma_{11} & \sigma_{12} \\ \sigma_{21} & \sigma_{22} \end{bmatrix}$$

$$\sigma_{ij} = -p\delta_{ij} - \eta\,\dot{\varepsilon}_{kk}\,\delta_{ij} + 2\eta\,\dot{\varepsilon}_{ij}$$

$$\eta = \min\left(\frac{p\sin\phi}{\sqrt{\left(\dot{\varepsilon}_{11} - \dot{\varepsilon}_{22}\right)^2 + 4\dot{\varepsilon}_{12}}}, \eta_{\max}\cos^2\varphi \right)$$
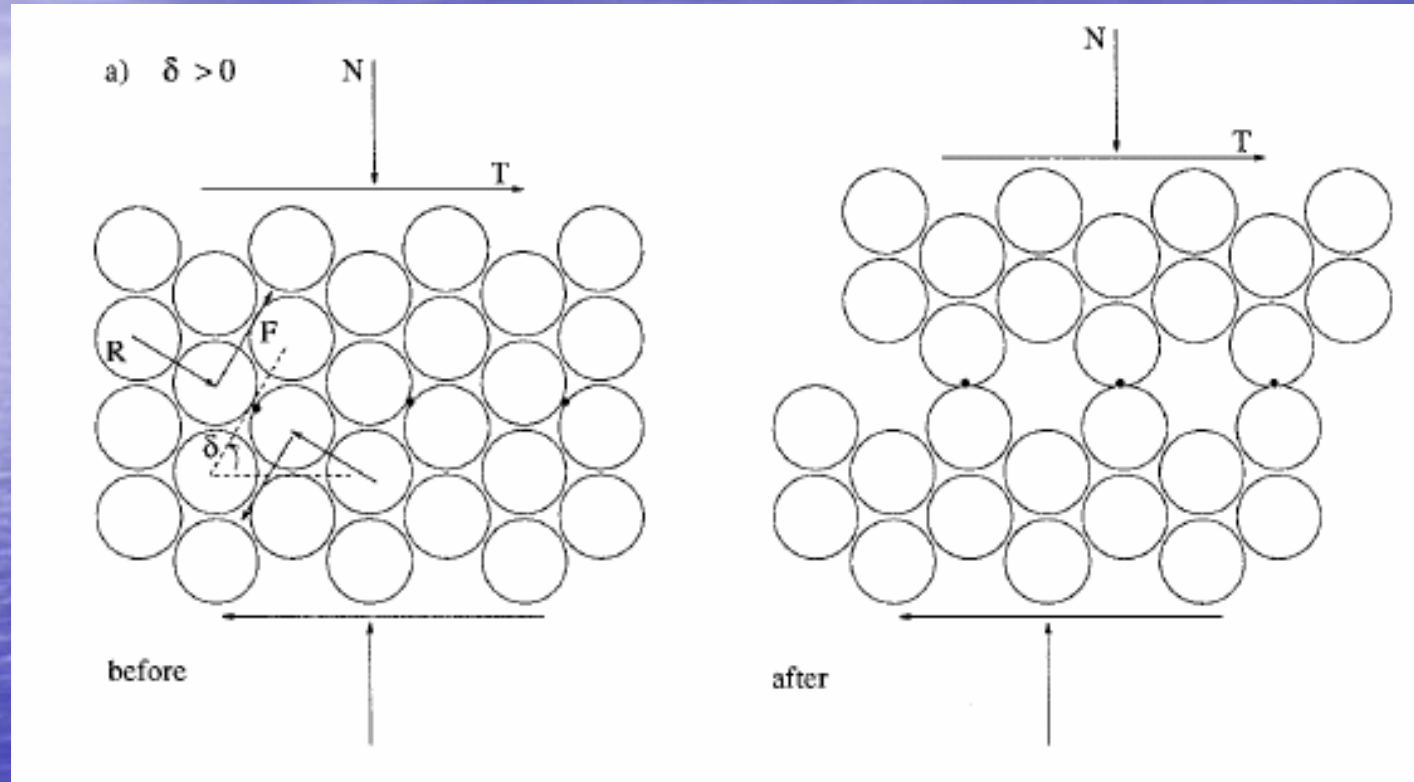
Tremblay and Mysak 1997

Numerical scheme:

free drift u,v
do k=1,#iterations
• pressure calculation and correction of u,v (Flato and Hibler 1992)
• η calculation and correction to u,v
enddo

The granular sea ice model:
# the dilatancy effect

Research objectives

- To convert the granular sea ice model to spherical coordinates √ **done**

- To couple the granular model to the UVic model √ **done**

- Validate the coupled model (compare with Arctic observations)

- Propose and implement improvements to the granular sea ice model

- Improve the numerical scheme of the granular sea ice model

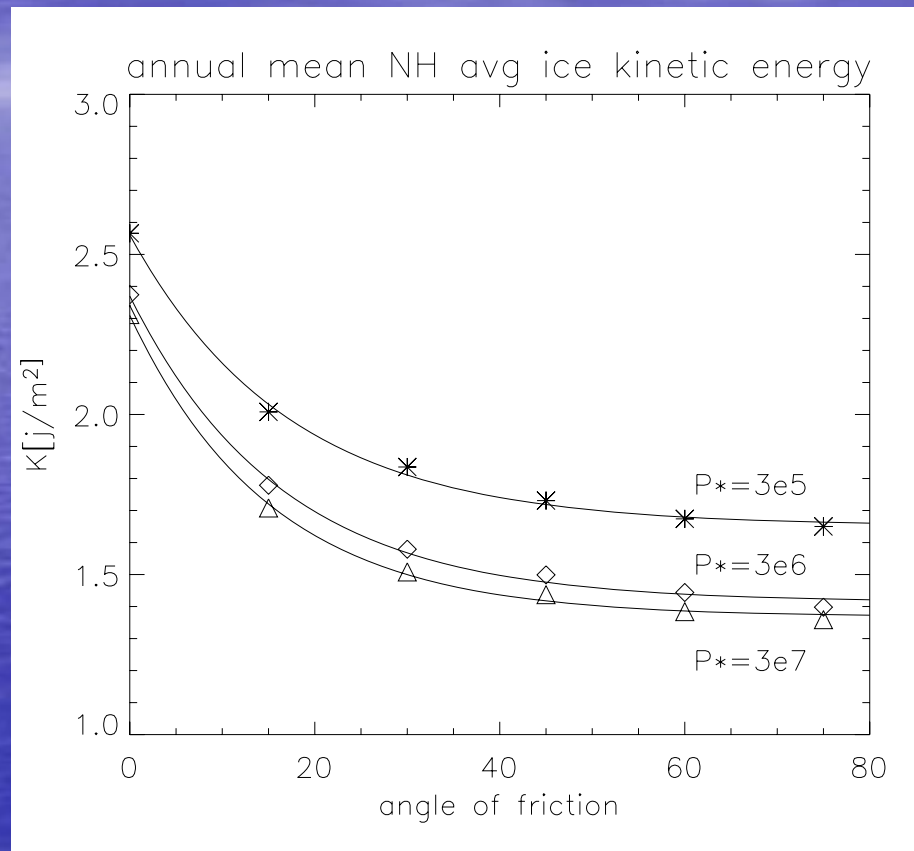# Preliminary results: η_{max} and the plastic phase
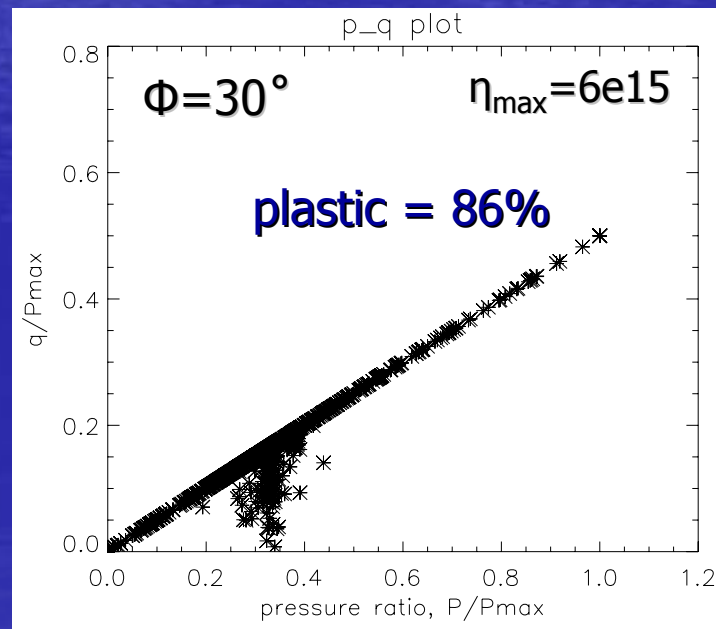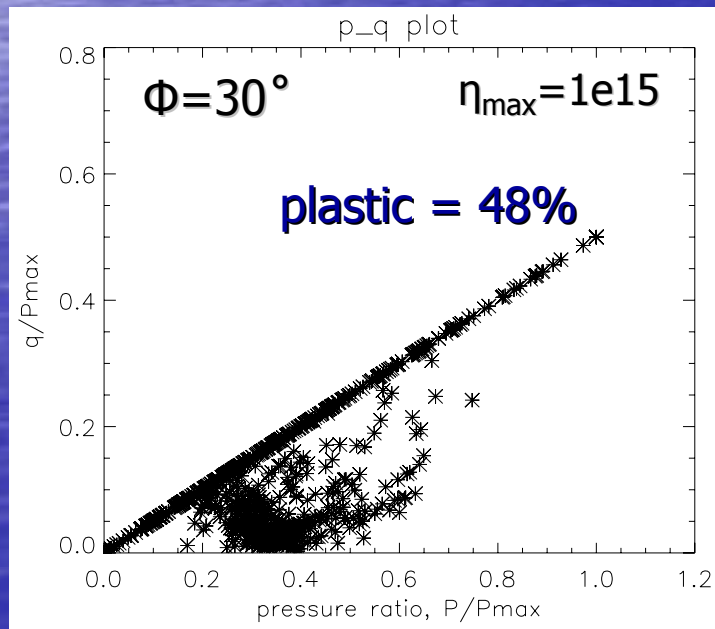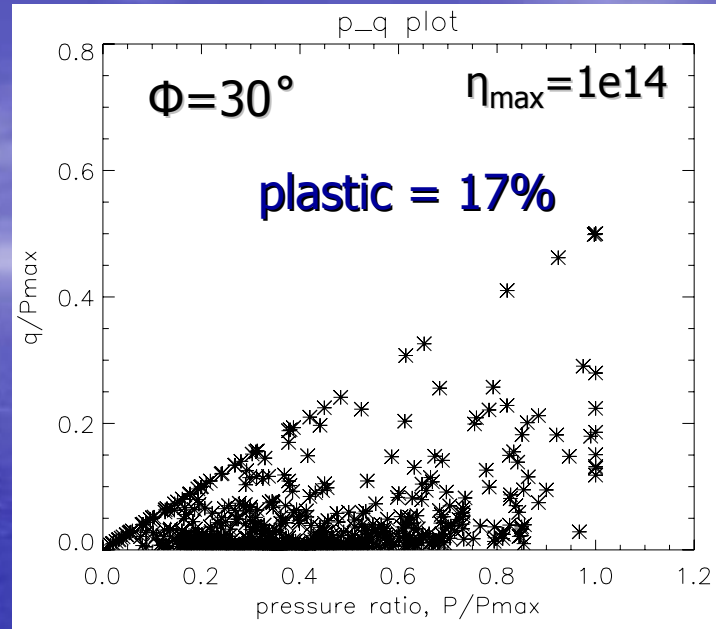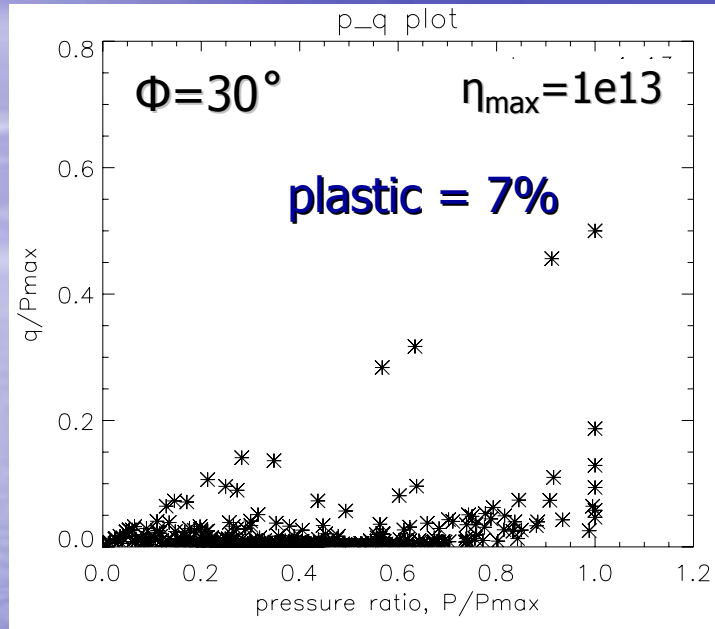
Preliminary results:
how many iterations are needed?
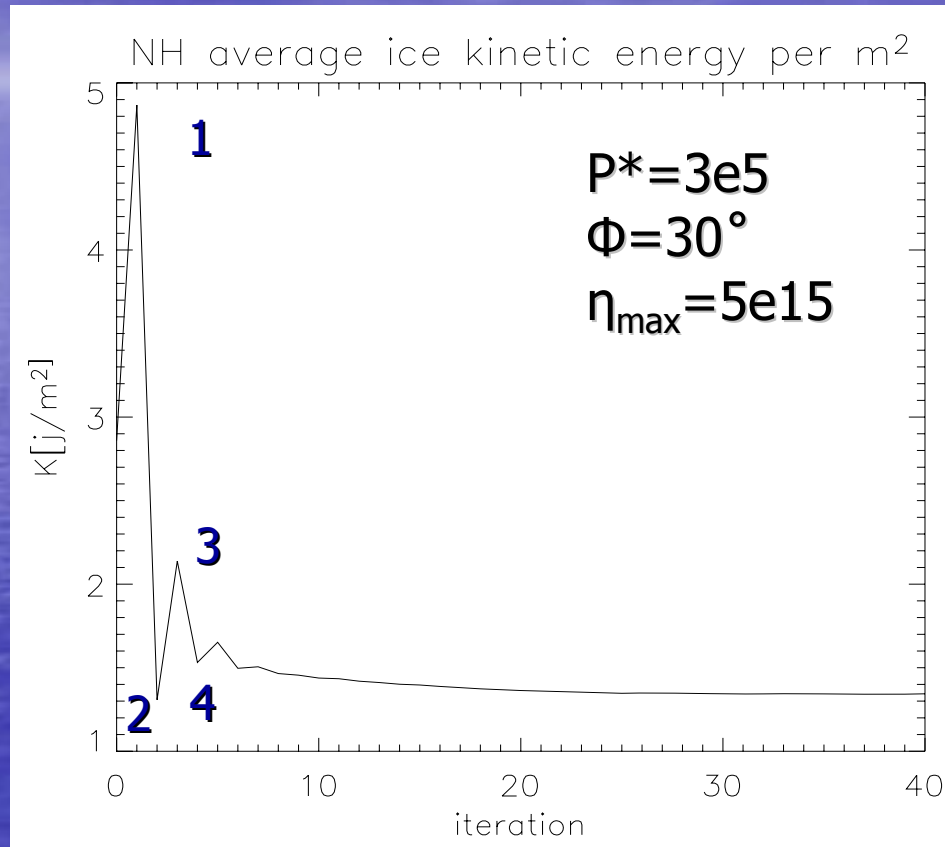
Preliminary results:
Annual mean NH average K as a function of P* and the angle of friction

annual mean NH avg ice kinetic energy

Summary

- The rigid and the plastic phases of sea ice are well represented by the model

- We should increase the number of iterations to allow the average kinetic energy to converge

- The annual mean average kinetic energy decreases as the ice strength and the angle of friction increase