

A multi-thickness sea ice model accounting for sliding friction

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Talk structure

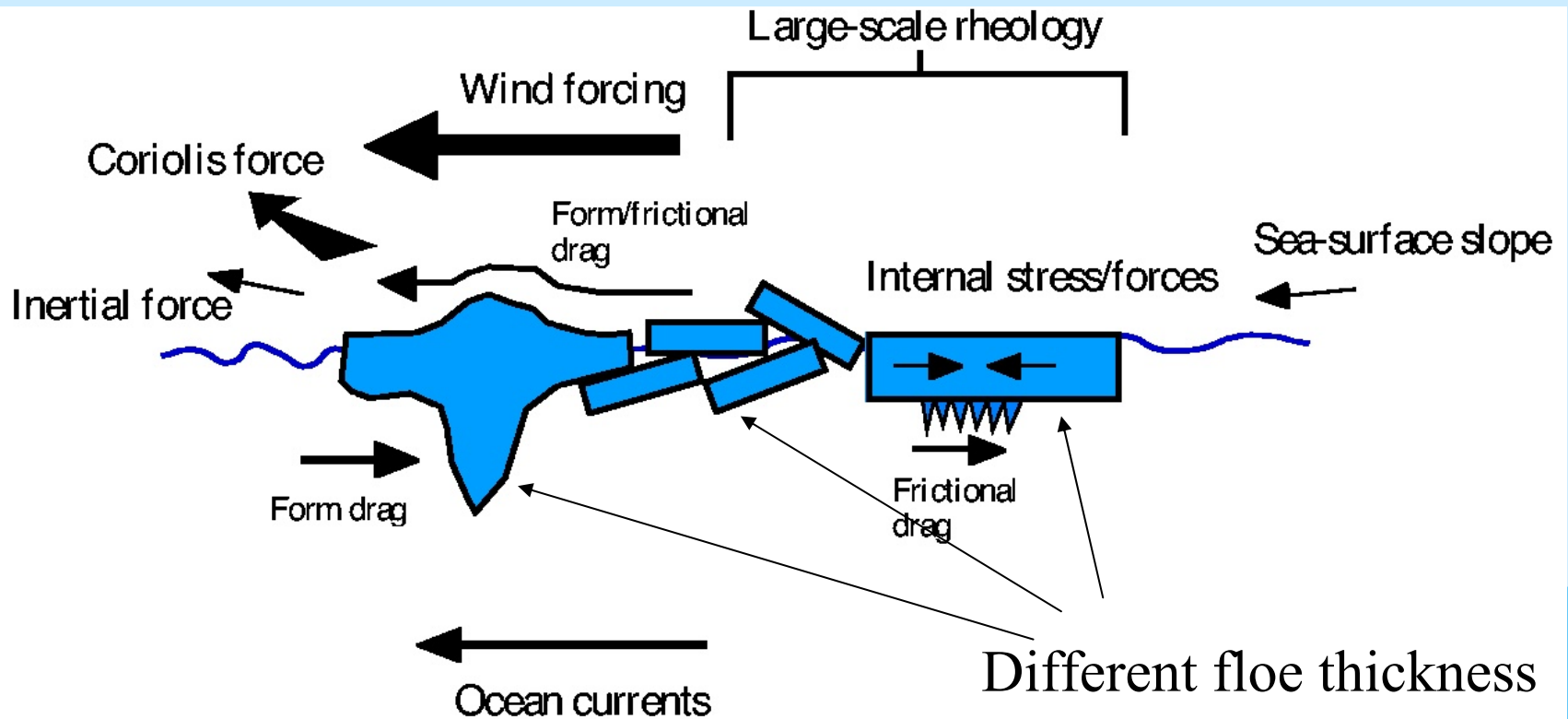
I. Background

II. Develop an improved model of multi-layer sea ice dynamics using latest theory

III. Incorporate it into the CICE code

IV. Simulate the Arctic

Ice thickness distribution function $g(h)$



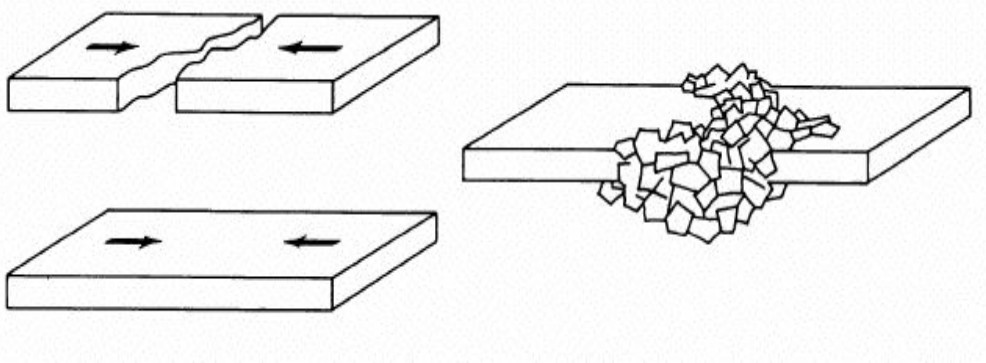
Fraction of floes of thicknesses, h , is described by
 $g(h)$

During deformation only $\approx 15\%$ sea ice ridges

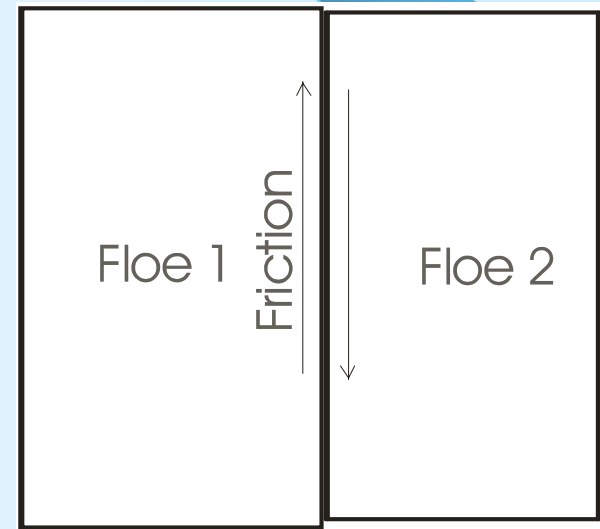
Sea ice stress contributions:

1. Pressure ridging:

Frictional motion of piling ice blocks

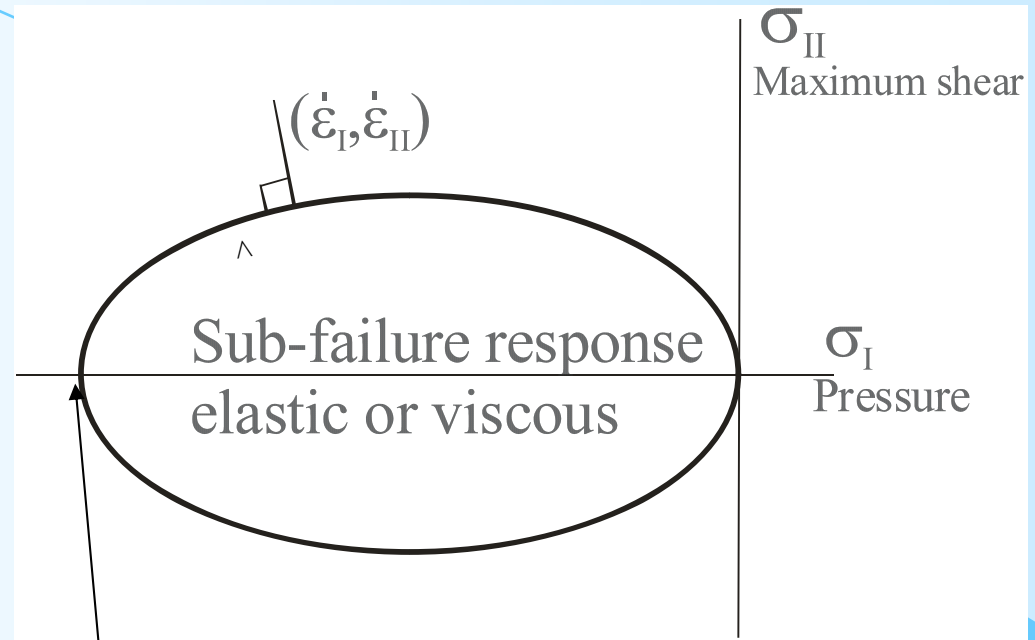


2. Inter-floe frictional sliding



Yield curve

Yield curve grows (hardens) or shrinks (weakens) if the ice thickness increases or decreases.



Ice strength

In two layer model (thick ice + thin ice) sea ice strength is approximated

$$P \propto h e^{-20(1-A)}$$

Mean thick ice thickness

Thick ice concentration

II. Develop an improved model of multi-layer sea ice dynamics using latest theory

Sea Ice Strength

In modern multi-layer models (Flato & Hibler, 1995):

Ridging Strength \Leftrightarrow Potential energy change

$$P \propto \int \omega h^2 dh$$

Ridging mode (loss+gain)

In reality (discrete simulation results; Hopkins, 1998):

Ridging Strength \Leftrightarrow Friction in ridge piling up

Ridge thickness $\propto h^{1/2} \Rightarrow$

$$P \propto \int \lambda h^{3/2} dh$$

Ridging rate (loss)

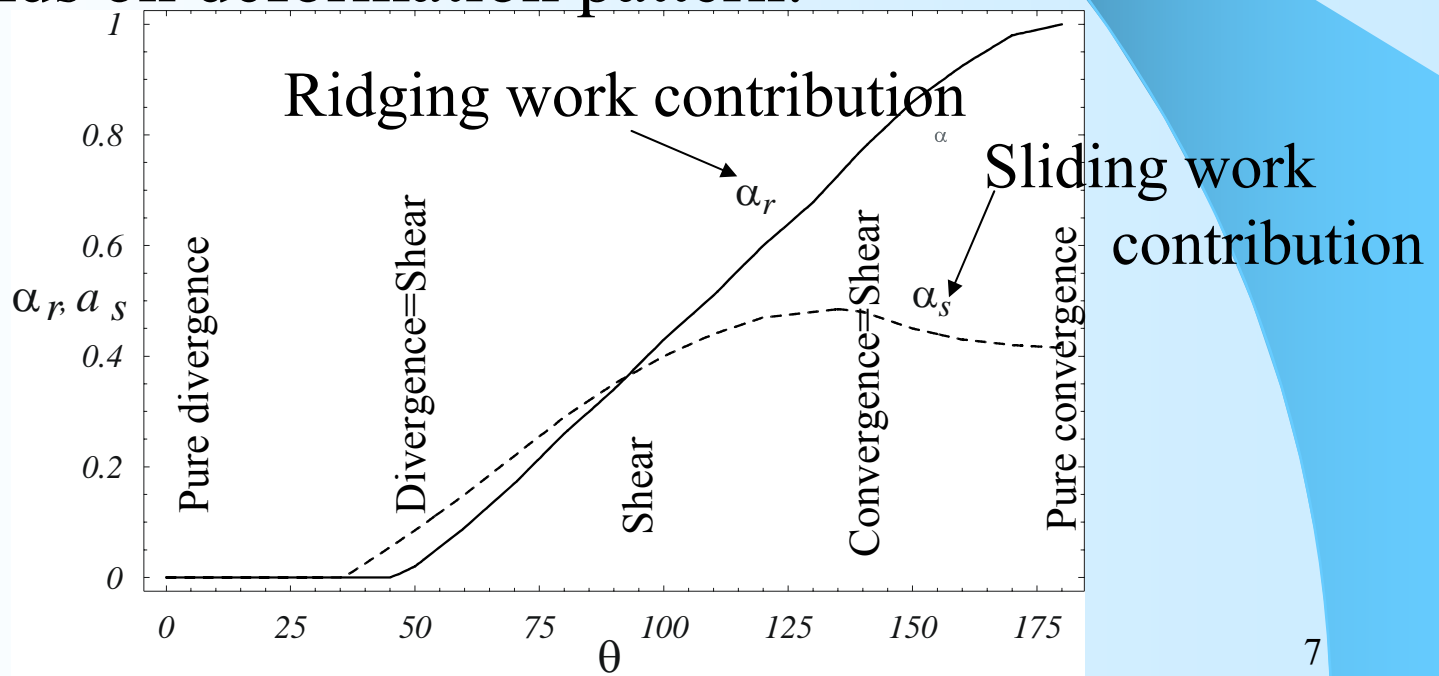
Ridging and Sliding Work

In modern multi-layer models (Flato & Hibler, 1995):

Their ratio is parameterized. No sliding in pure convergence.

In reality (simulation result, Ukita & Moritz, 2000):

It depends on deformation pattern:



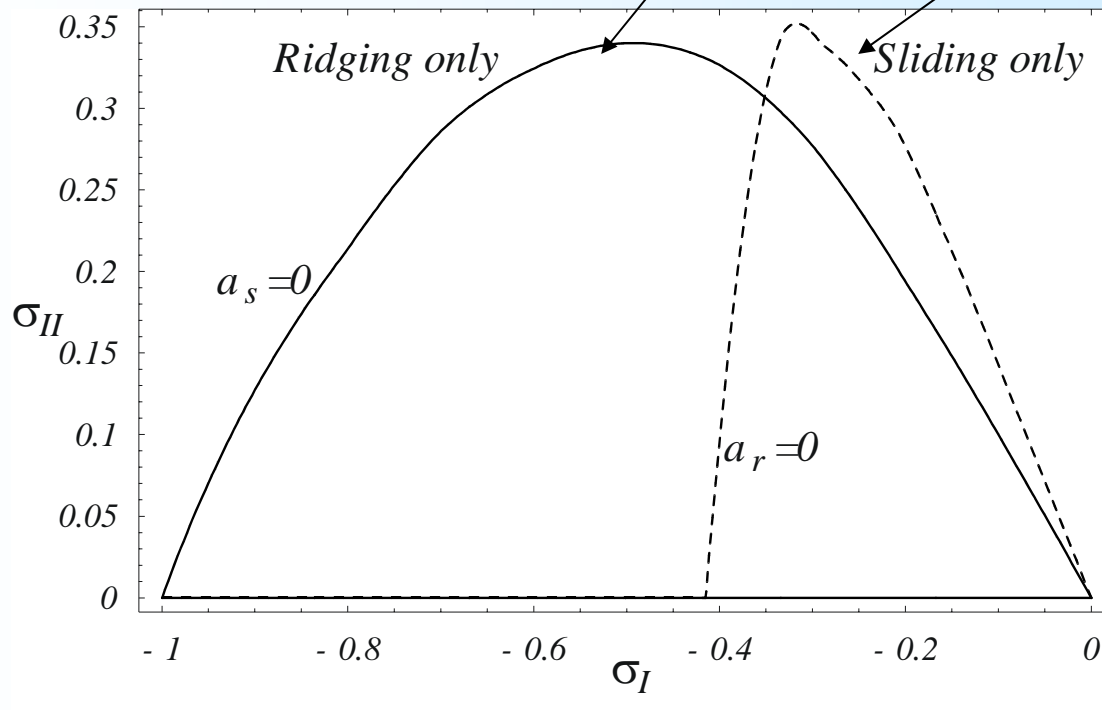
Incorporating more “reality” into sea ice models

- Use the $h^{3/2}$ law for the ridging ice strength
- Use the ridging and sliding strain-rate modes found by Ukita and Moritz for uniform thickness
- Account for the thickness difference by making use of sliding and opening participation functions that say that more sliding and opening occur in thinner ice.

Derived sea ice stress

Opening strength Ridging strength Sliding strength

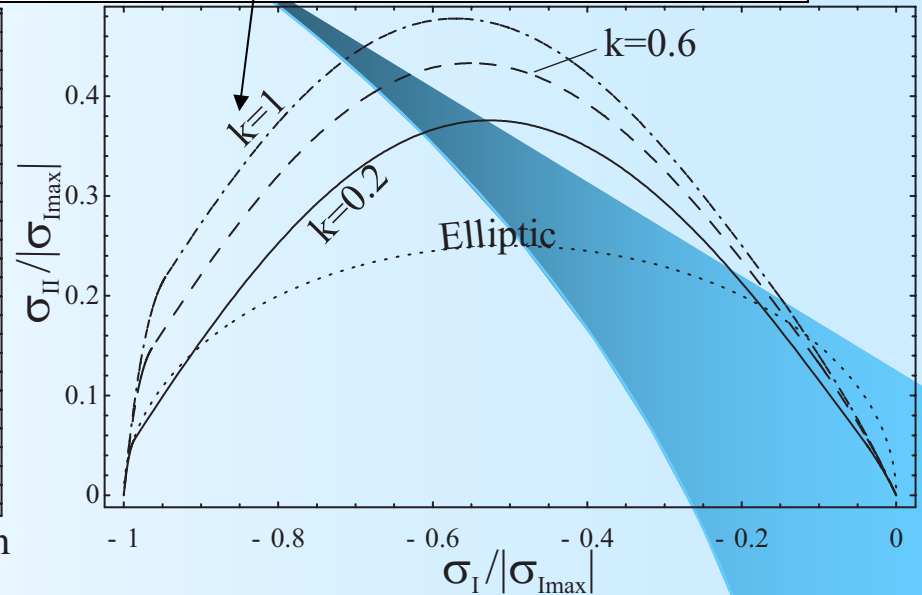
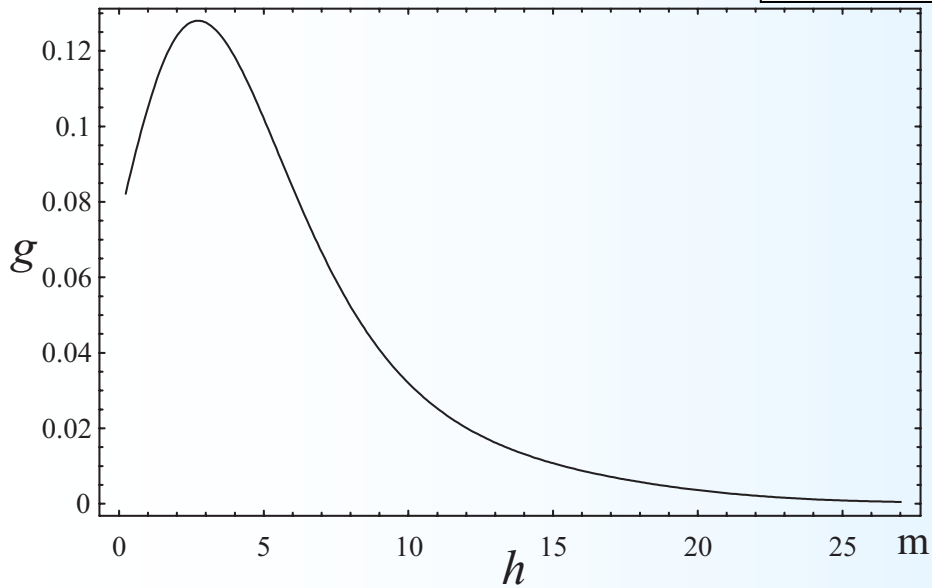
$$\boldsymbol{\sigma}(\dot{\boldsymbol{\epsilon}}) = P_o \mathbf{1} + (P_r + P_o) \boldsymbol{\sigma}_r(\dot{\boldsymbol{\epsilon}}) + P_s \boldsymbol{\sigma}_s(\dot{\boldsymbol{\epsilon}})$$



Composite yield curve shape

For submarine-measured ice thickness distribution:

$k = \text{importance of sliding to ridging}$



Smoothed ice thickness distribution for regions A and B (Wadhams, 1992)

Normalised yield curves for regions A and B (Wadhams, 1992)

III. Incorporate it into the CICE code

Incorporation into the Elastic Viscous Plastic model

EVP model is tied to Hibler's rheology through Δ and e

$$\frac{\partial \boldsymbol{\sigma}_{ij}}{\partial t} + \frac{1}{T_{ij}} e^2 \boldsymbol{\sigma}_{ij} = f_{ij}(\Delta, \dot{\boldsymbol{\epsilon}})$$

Ellipse aspect ratio
Relaxation time

General plastic rheology form, including our new model:

$$\boldsymbol{\sigma} = \nu(\dot{\boldsymbol{\epsilon}}_I, \dot{\boldsymbol{\epsilon}}_{II}) \mathbf{1} + \eta(\dot{\boldsymbol{\epsilon}}_I, \dot{\boldsymbol{\epsilon}}_{II}) \dot{\boldsymbol{\epsilon}}^*$$

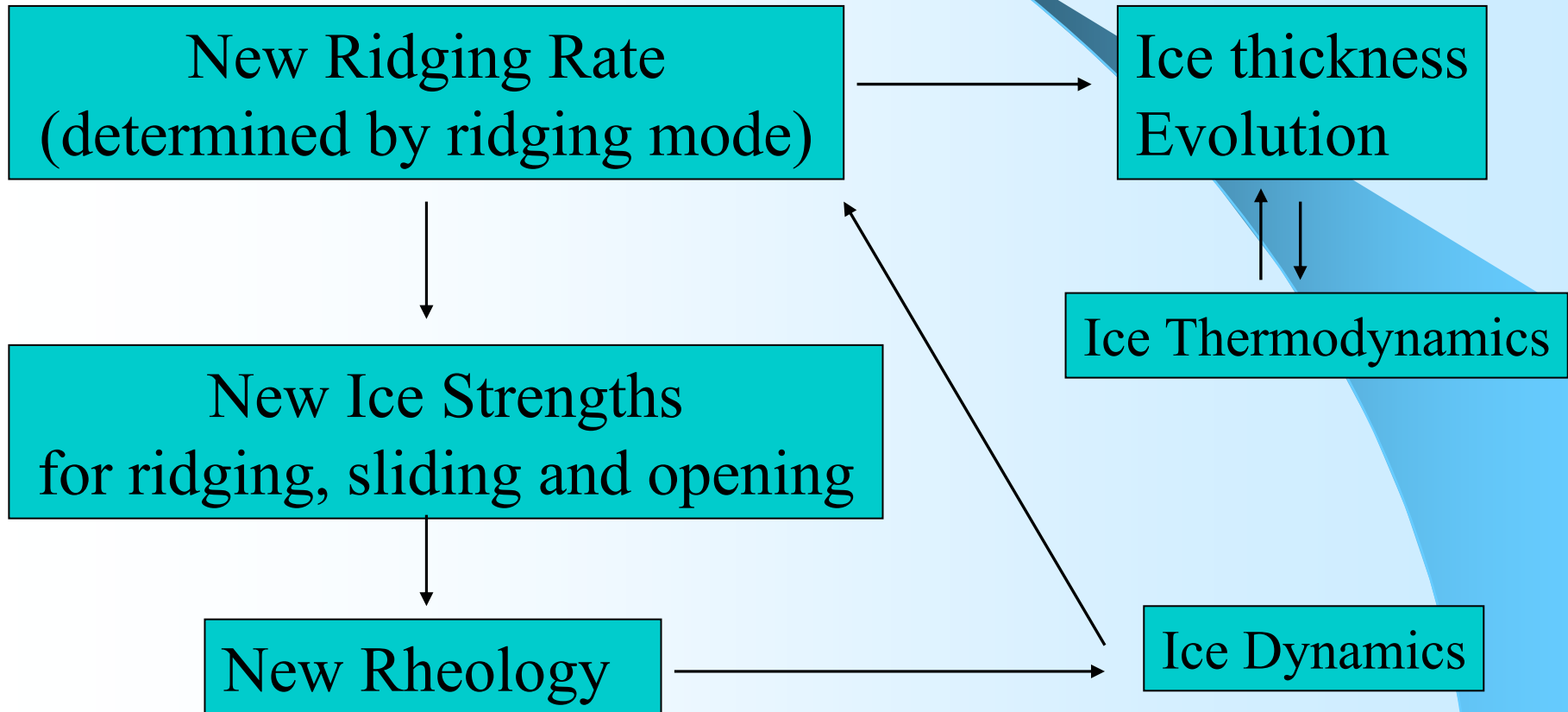
Modified EVP model for general rheology:

$$T \frac{\partial \boldsymbol{\sigma}}{\partial t} + \boldsymbol{\sigma} = \nu(\dot{\boldsymbol{\epsilon}}_I, \dot{\boldsymbol{\epsilon}}_{II}) \mathbf{1} + \eta(\dot{\boldsymbol{\epsilon}}_I, \dot{\boldsymbol{\epsilon}}_{II}) \dot{\boldsymbol{\epsilon}}^*$$

Modification in the CICE code components

NEW

AFFECTED



IV. Simulate the Arctic

Used ridging strengths

Present:

$$P_r \propto \int_0^{\infty} \lambda(h) h^{3/2} dh$$

Area loss

Rothrock:

$$P_r^R \propto \int_0^{\infty} \omega(h) h^2 dh$$

Area gain - loss

Hibler:

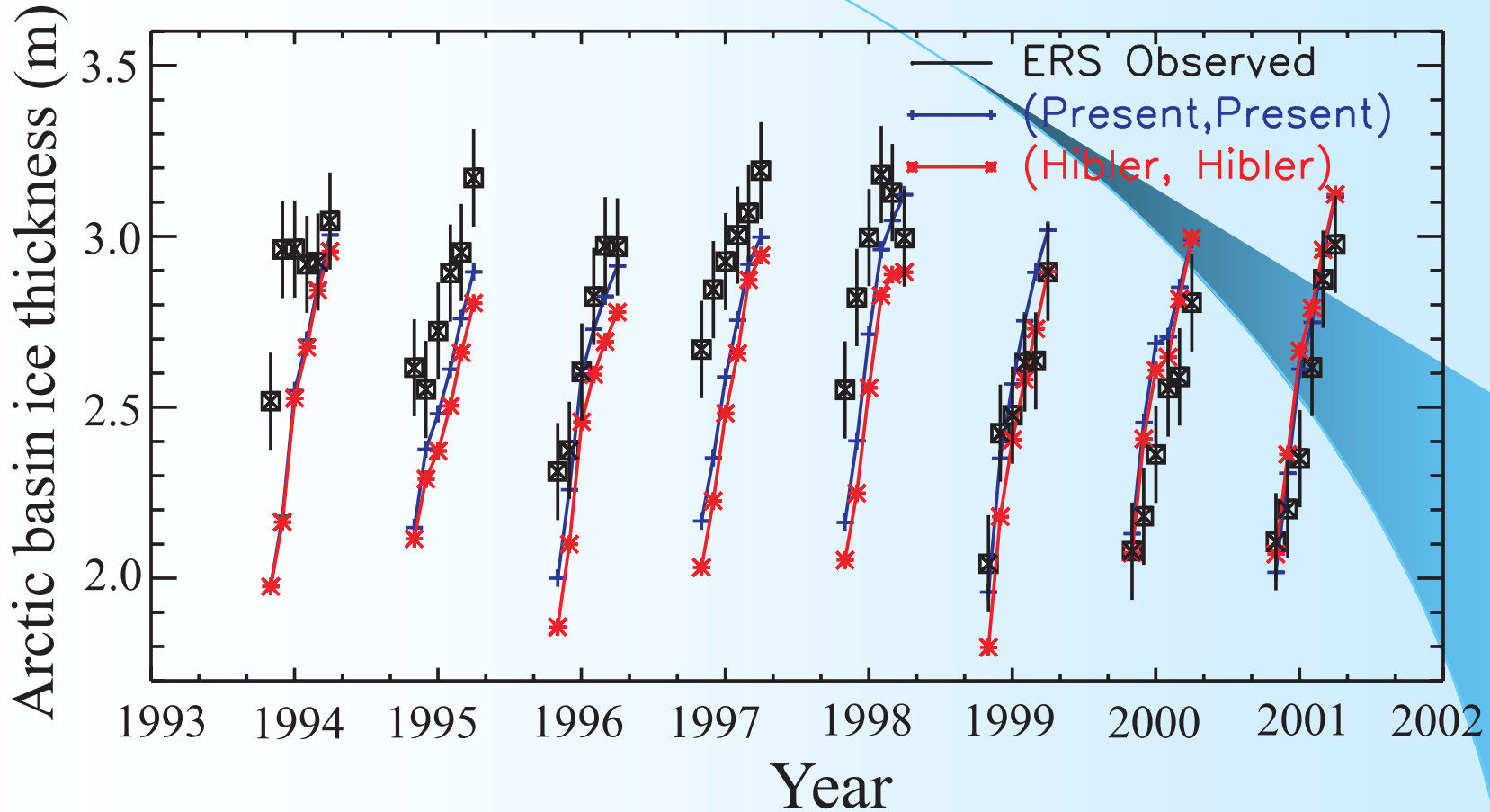
$$P_r^H \propto H e^{-20(1-C)}$$

Ice concentration

2.718281828459045235

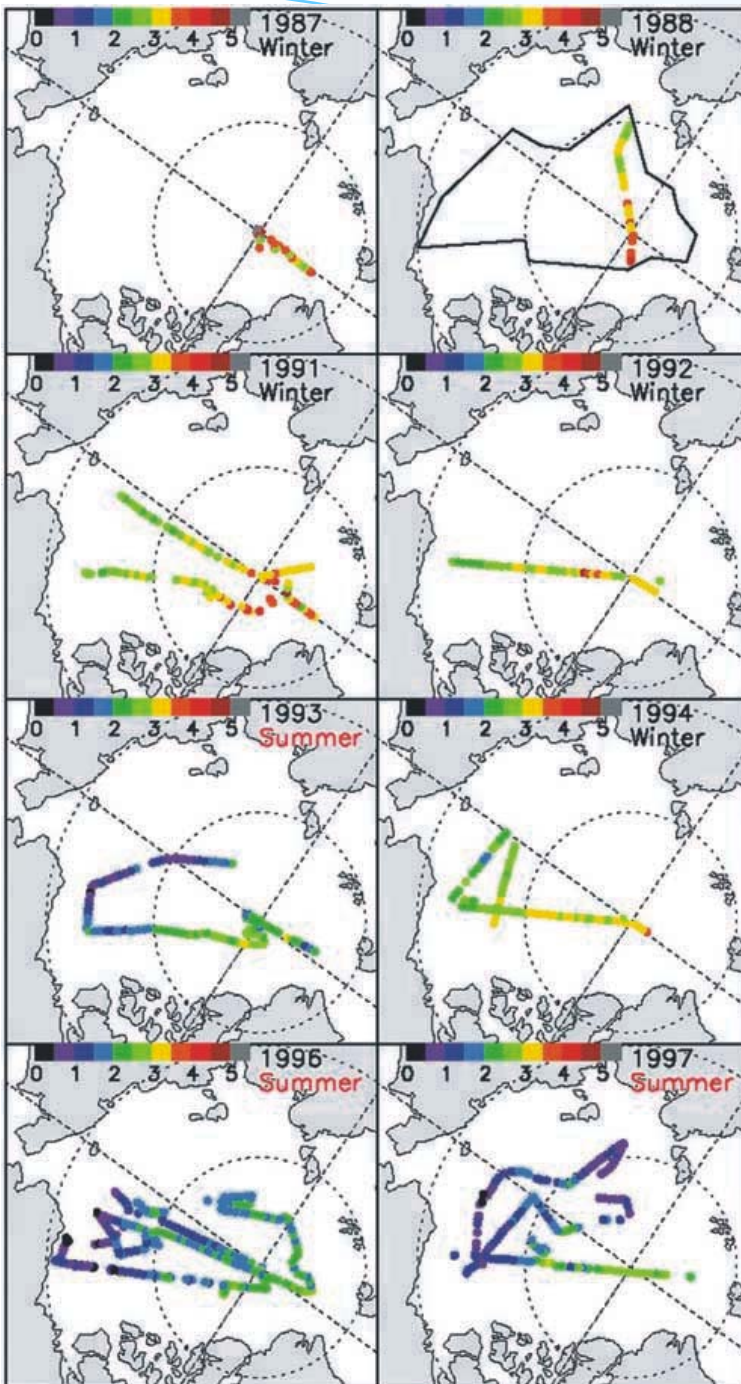
Mean thickness

Tuning



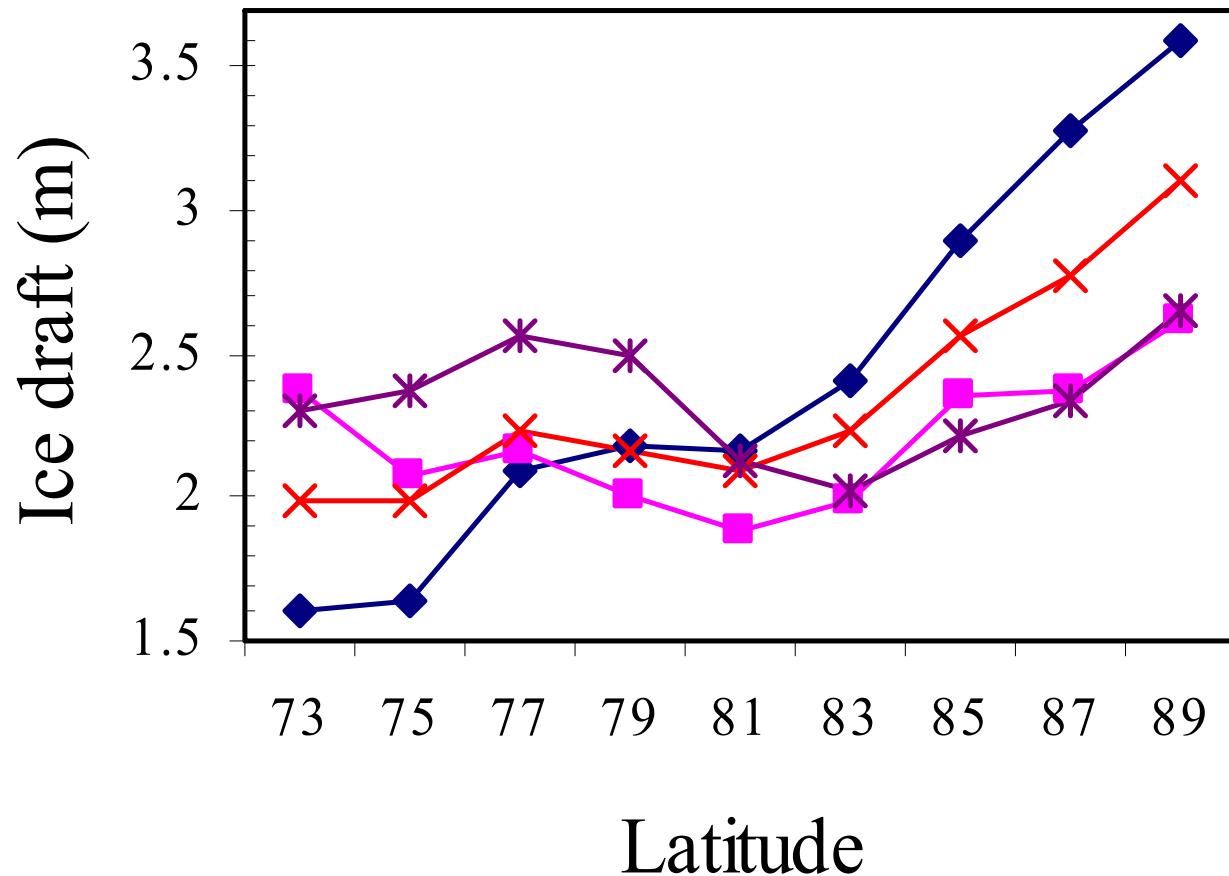
Comparison of the mean ice thickness in the Arctic given by the PRESENT and CICE model with the ERS derived. ERA-40 wind forcing data.

Comparisons with submarine ice drafts.



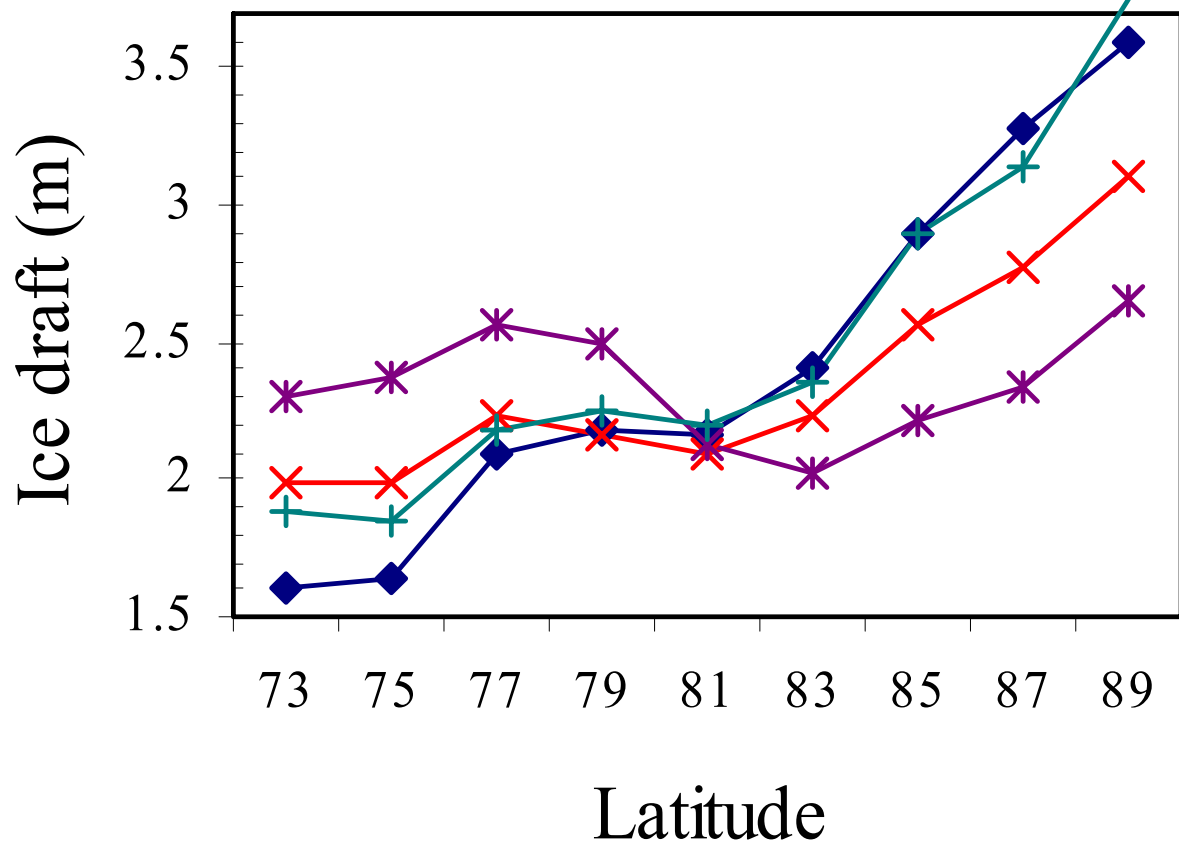
The observed ice draft (m) along eight submarine cruise tracks from 1987 to 1997.

Mean ice thickness along submarine cruises. 1. Comparison with data.



- ◆— Observation
- (Present, Present)
- ×— (Present, Hibler)
- *— (Hibler, Hibler)

Mean ice thickness along submarine cruises. 2. Comparison with Paul's model



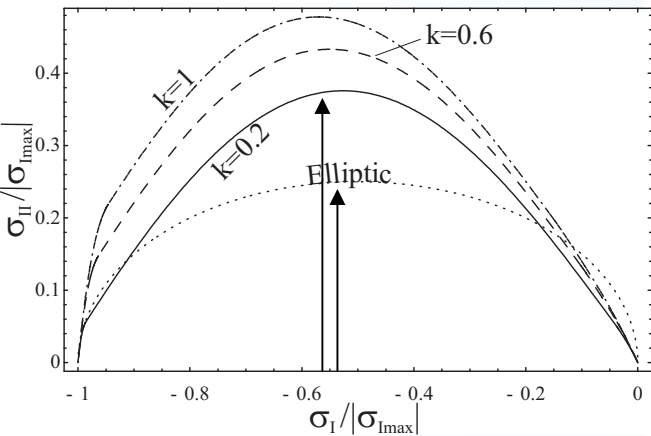
—◆— Observation

—×— (Present, Hibler)

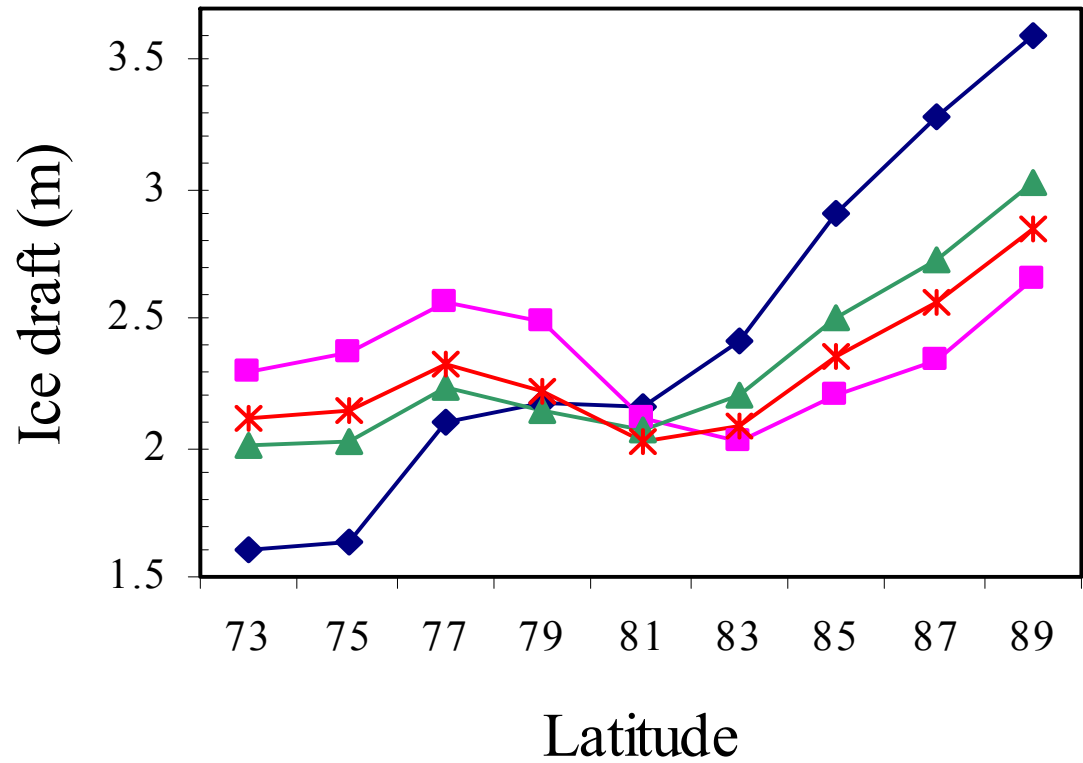
—*— (Hibler, Hibler)

—+— Paul's

Mean ice thickness along submarine cruises. 3. Shear stress effect.



Maximum shear stress



- ◆— Observations
- (Hibler, Hibler)
- ▲— (Present, Hibler), $k=0.2$
- *— (Present less shear, Hibler), $k=0.2$

Results

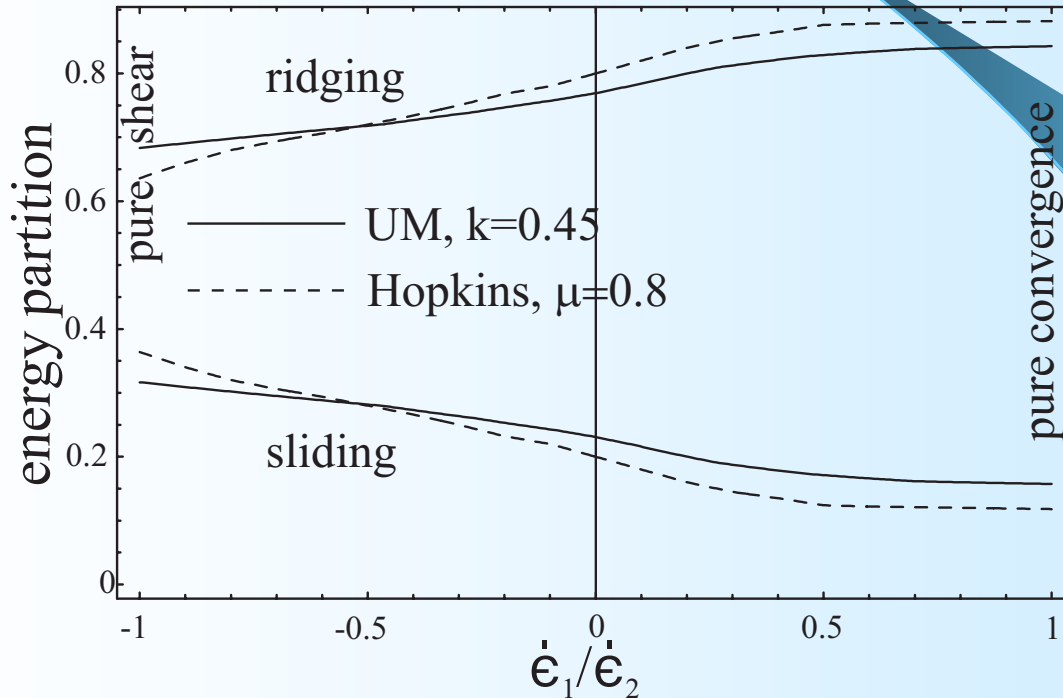
- I. A new isotropic model has been developed and incorporated into CICE that includes
 1. More realistic plastic strength of multi-layer sea ice.
 2. More realistic ridging rate.
- II. Ice thickness distribution is better than CICE-produced, worse than given by Paul's model.
- III. Improvement due to a better ridging rate expression.

Further work

- Issues with multi-layer ice strengths (e.g. Rothrock's)

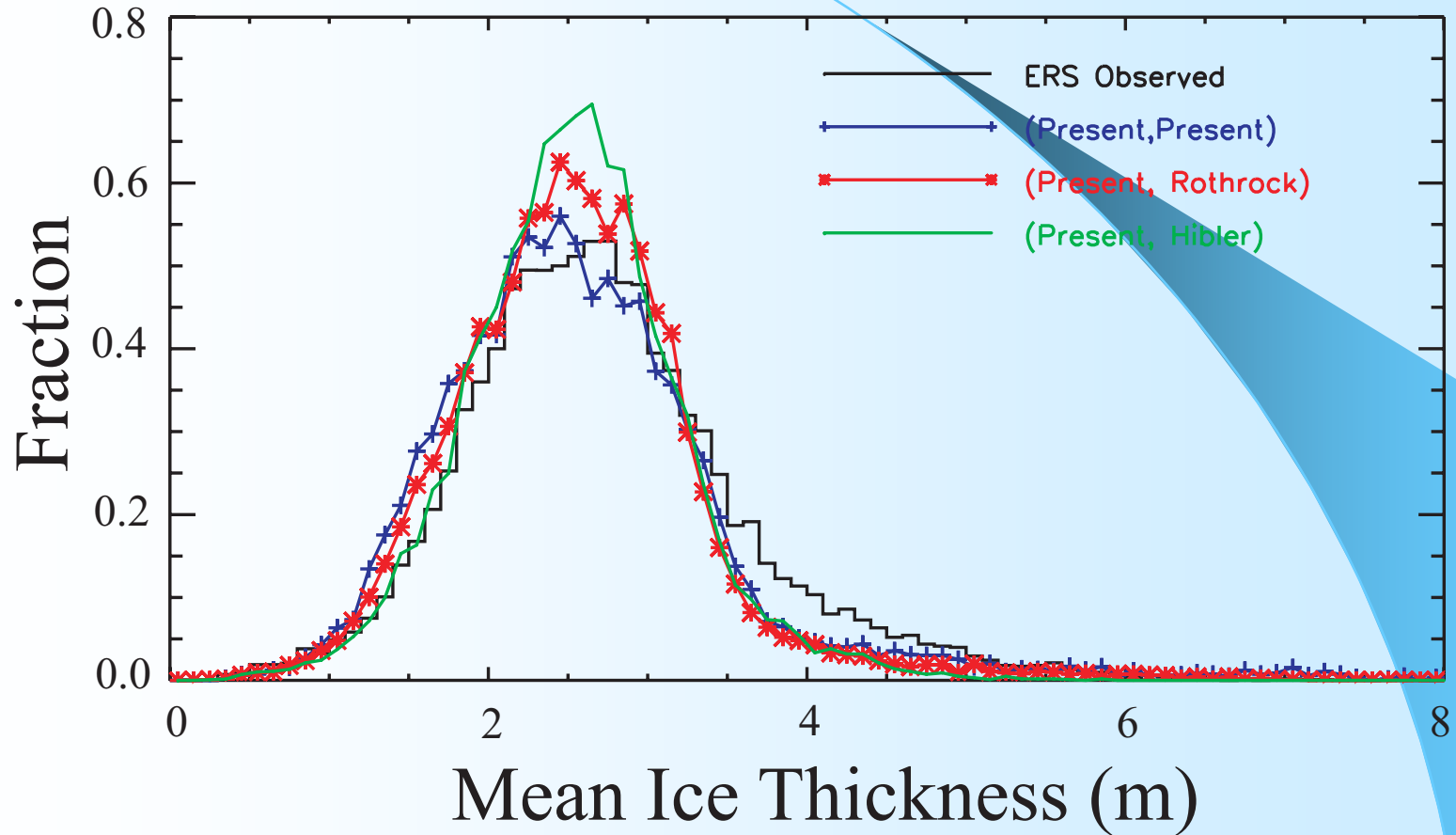
Sliding strength

$$P_s^* = k P_r^*$$

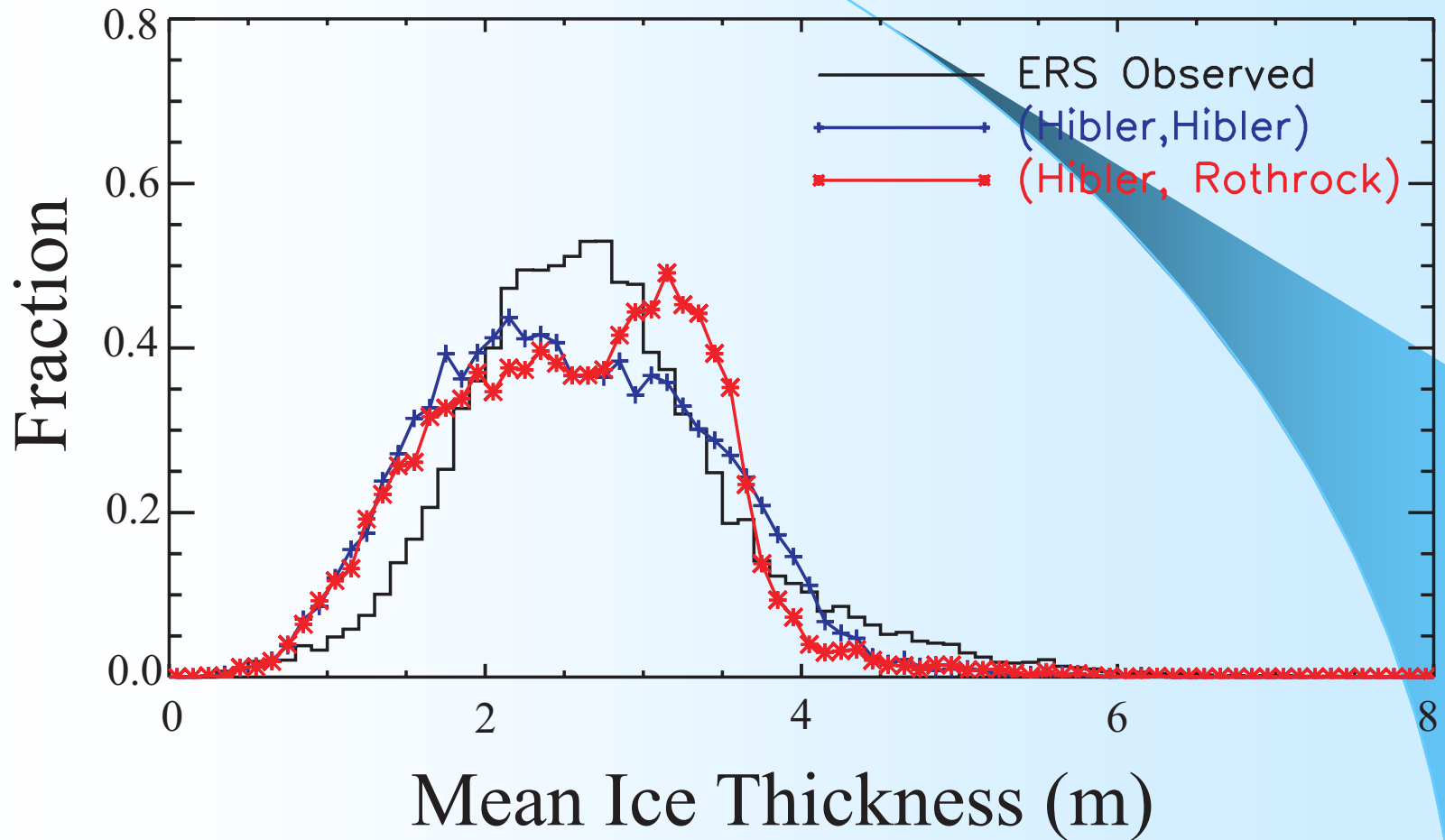


Energy partitions given by Ukita and Moritz's kinematic model and Hopkins' dynamic one.

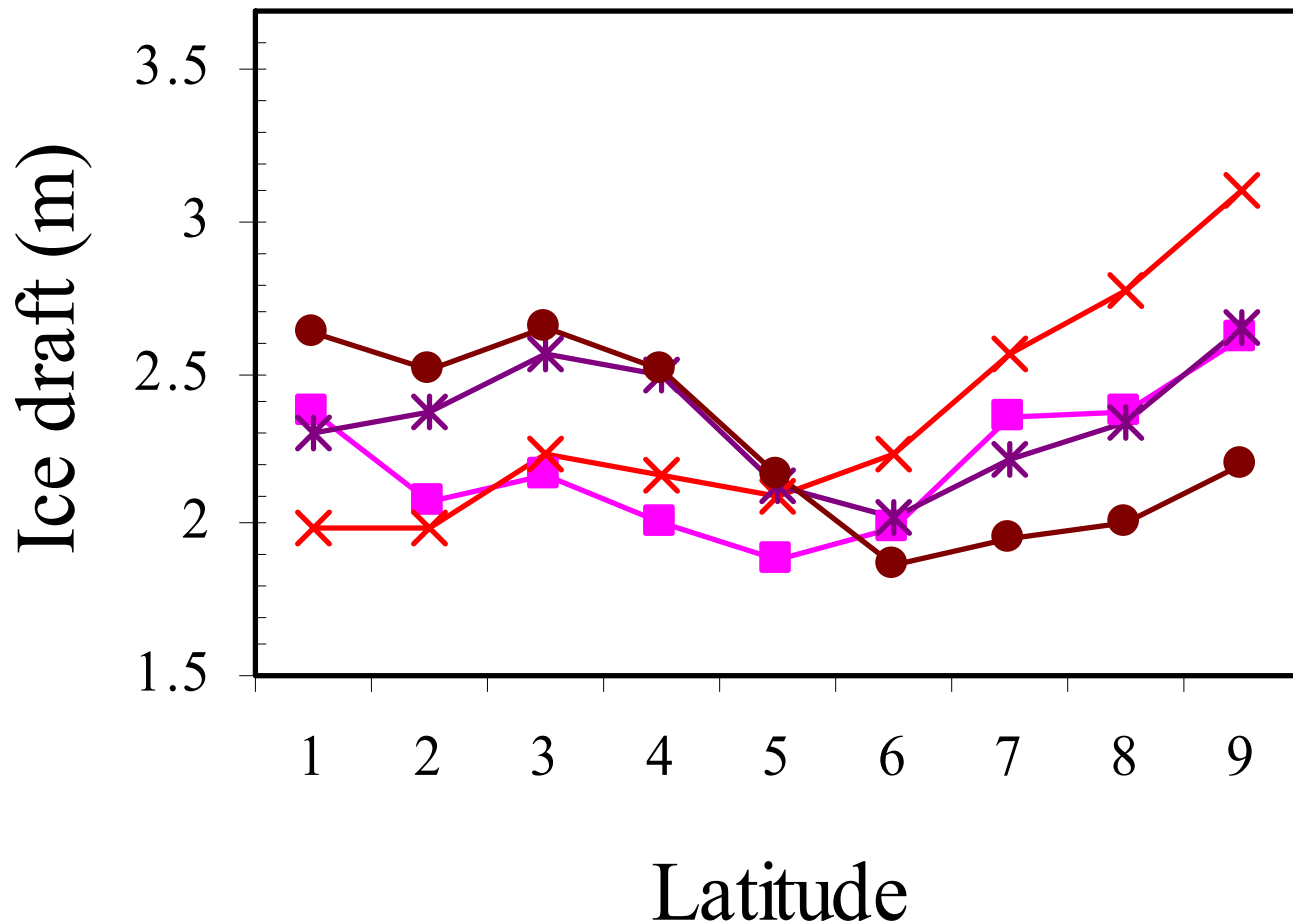
Areal fraction of mean ice thickness. Present rheology. ERS covered area.



Areal fraction of mean ice thickness. Hibler's rheology. ERS covered area.



Mean ice thickness along submarine crusies. 1. Ridging strength effect.



—■— (Present, Present)

—x— (Present, Hibler)

—*— (Hibler, Hibler)

—●— (Hibler, Rothrock)