



Modelling and simulation of sea ice dynamics Part I: Context and objectives

Jérôme Weiss Institut des Sciences de la Terre, CNRS

with

V. Dansereau, M. Rabatel, F. Gimbert, L. Girard, D. Marsan, P. Rampal,

E. Schulson, H. Stern, P. Saramito, S. Labbé,..

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TEN SIGNS OF A WARMING WORLD



Arctic sea ice

- > Small thickness (~meter) + Large extent (10⁶ km²) = Large variability
- > Thermodynamic processes (freeze/melt) <</p>
- > Dynamic processes (drift/deformation)



Role of sea ice in the climate system

Sea ice controls air – sea exchanges of heat and momentum (winter)



Highly non-linear dependance!!

Role of sea ice in the climate system

> Sea ice is also a summertime insulator:



Concentration and extent

September minimum extent





From satellite microwave imagery, since 1979

➤- 50% in 42 years for the September ice extent

➤ - 10% in 42 years for the winter ice extent (March)

Concentration and extent

2012 September minimum extent



Sea ice thickness

Source: Lindsay and Schweiger, 2015

From various sources:

- Submarine upward-looking sonars
- Satellite and airborne lidars
- Airborne electro-magnetic measurements



- 65% in 37 years for ice thickness
- 85% in 37 years for september sea ice

Arctic warming

ARCTIC WARMING



The albedo feedback



Climate modelling: ice thickness

(Rampal et al., JGR, 2011)



> Arctic sea ice thinning 4 times faster than forecast





Trajectories of passive tracers (analogy with turbulence)



Drift acceleration

(Rampal et al., JGR, 2009)



> + 9.0% (±1.9%) per decade for the average ice velocity

Strain-rate



"Proxy" of the strain-rate:

 $L \times t$

Increasing strain rates

(Rampal et al., JGR, 2009)



> + 50% (±10%) per decade for the average ice deformation rate !

Drift acceleration

(Rampal et al., JGR, 2009)



No trend on modelled sea ice speed
Neglect an increasing sea ice export

Drift acceleration: the cause ?

The result of a more fractured/fragmented, and so weaker sea ice cover ?

Sea ice mechanics: A multi-scale problem



How to model such multi-scale complexity ?

Sea ice dynamics

(in operational, regional and coupled climate models)

Sea ice considered as a deformable **continuum**

(a « fluid mechanics » approach)



A Maxwell - EB model Dansereau et al., The Cryosphere, **10**, 2016

• Constitutive relationship (rheology):





Coupling with damage mechanics

$$\eta = \eta(d)$$
$$E = E(d)$$
$$\lambda = \lambda(d)$$



Waves/ice interactions in the Marginal Ice Zone



