Modelling ocean waves and sea ice in the Polar Oceans

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Outline

- ***Motivation:***

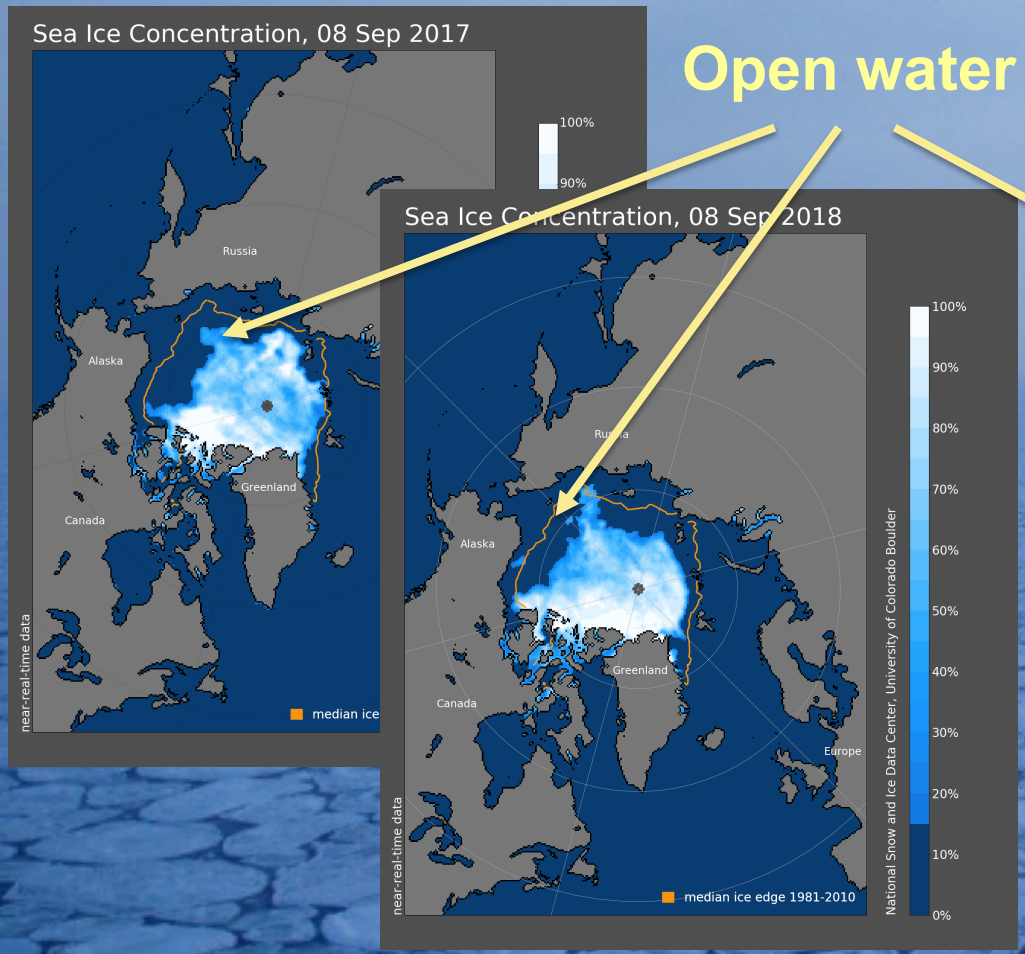
  (1) less Arctic ice - means waves in the Arctic Ocean
  (2) Southern Ocean: wider Marginal Ice Zone (MIZ)
  (3) fragmented ice - higher atmosphere-ocean fluxes
  (4) need for better ESM/climate projections & forecasts

- ***Methods:*** ice-ocean-waves models; mixing, ice drift, waves & ice fragmentation observations

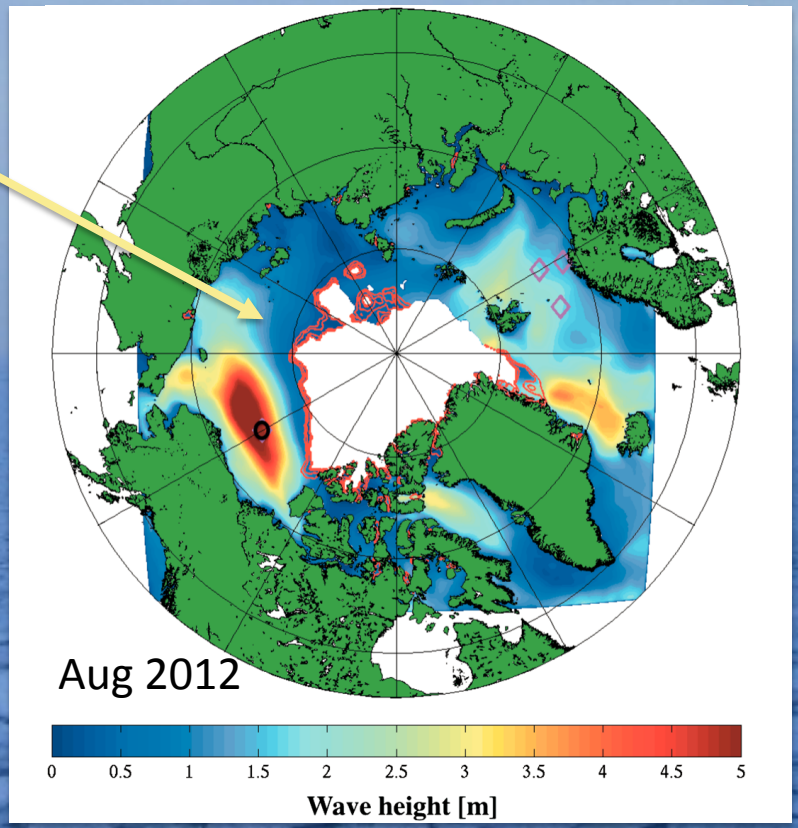
- ***Analysis:*** waves impact on ice/ocean & ice edge dynamics

- ***Outlook:*** waves-in-sea ice in NEMO & forecasting

Ice decline - means higher waves



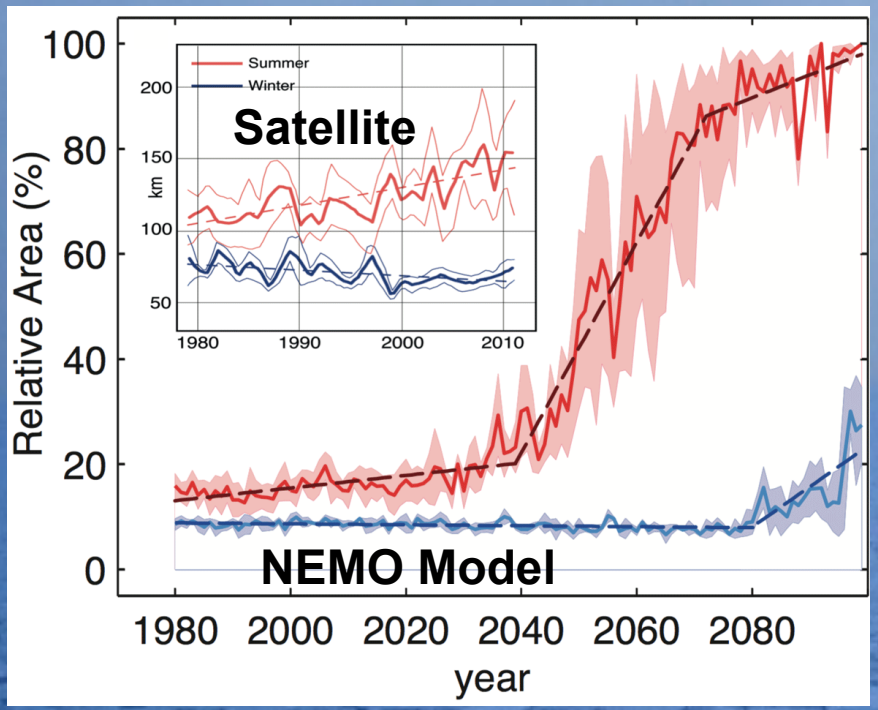
Open water

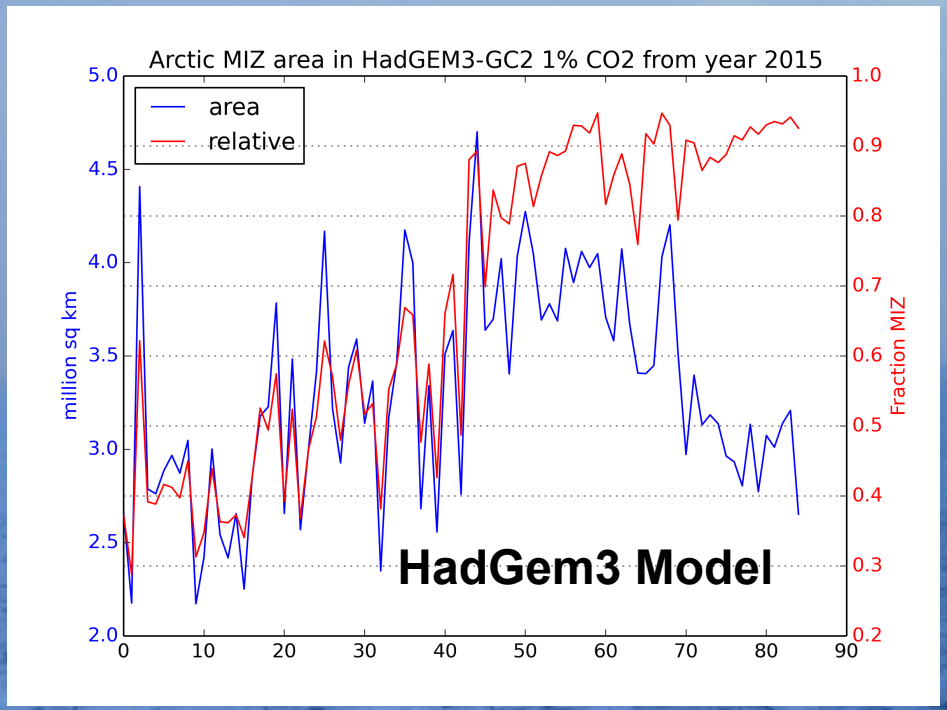


Thomson et al., NGO (2014)

Observed and projected Arctic MIZ

Marginal Ice Zone relative area = *Amiz/Aice*100*





Aksenov et al., JMPO 2017

Courtesy Ed Blockley (UKMO)

Summer Marginal Ice Zone (MIZ) increases

Winter Marginal Ice Zone (MIZ) decrease until the 2080s, then increases

Mature pancake formation by collision of floes

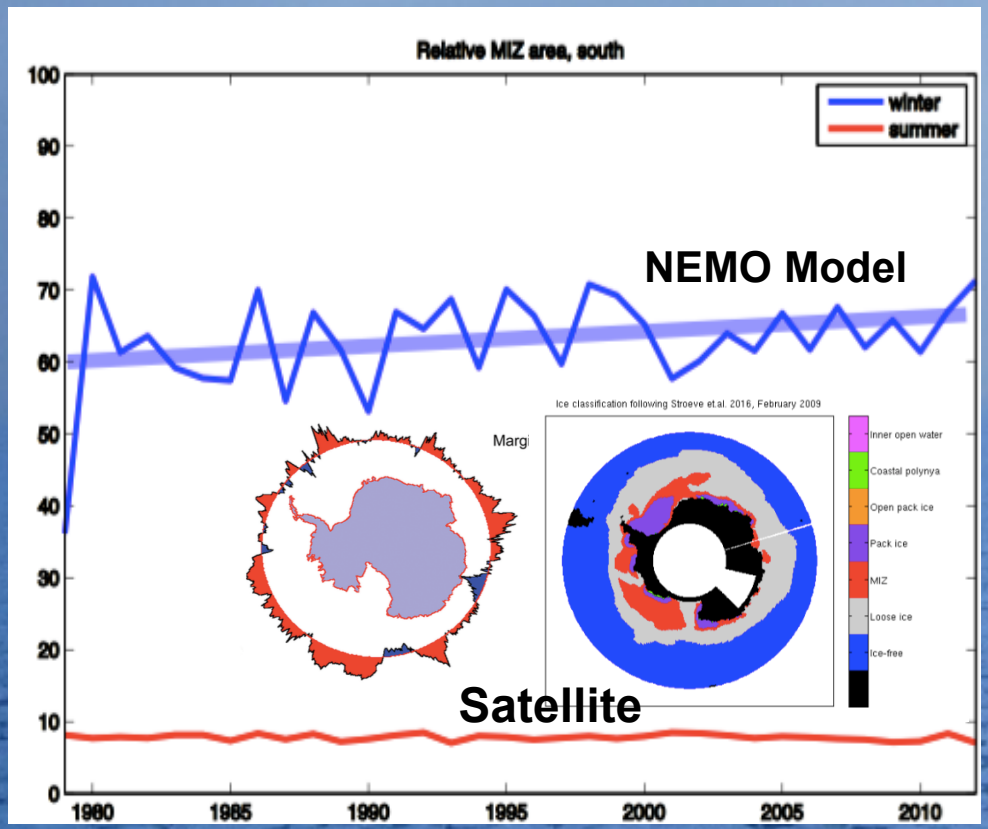
Shen et al., 2001

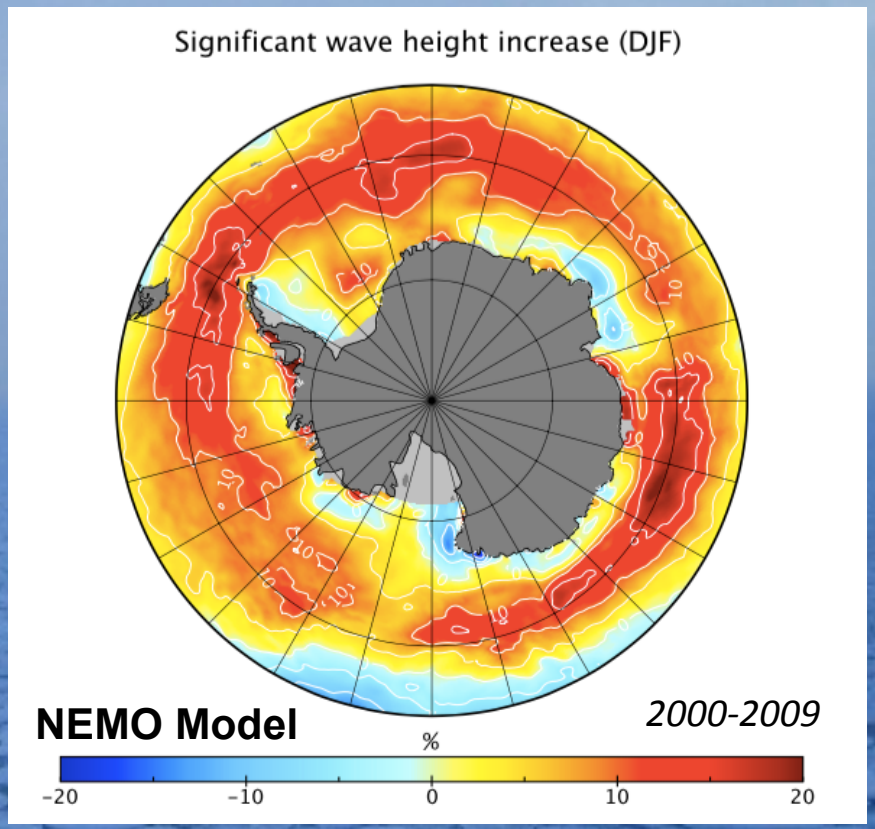
Ice Breaking by Waves

St Lawrence Estuary, Canada: video from Dany Dumont

MIZ & Waves in the Southern Ocean

Summer MIZ in SO is of ca. 60%; waves are up by 20%





Stroeve et al. TC., 2016 & Hosekova (in prep.)

Aksenov et al. Mar.Pol., 2017

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Ice & waves in Marginal Ice Zone

1. Sea ice fragmentation due to waves & wave attenuation by ice (H_{ice}, A_{ice} & L_f)

2. Ice rheolgy in MIZ and pack ice & and impact on ocean

3. Ice termodynamics: ice thickness & concentration change (H_{ice}, A_{ice})

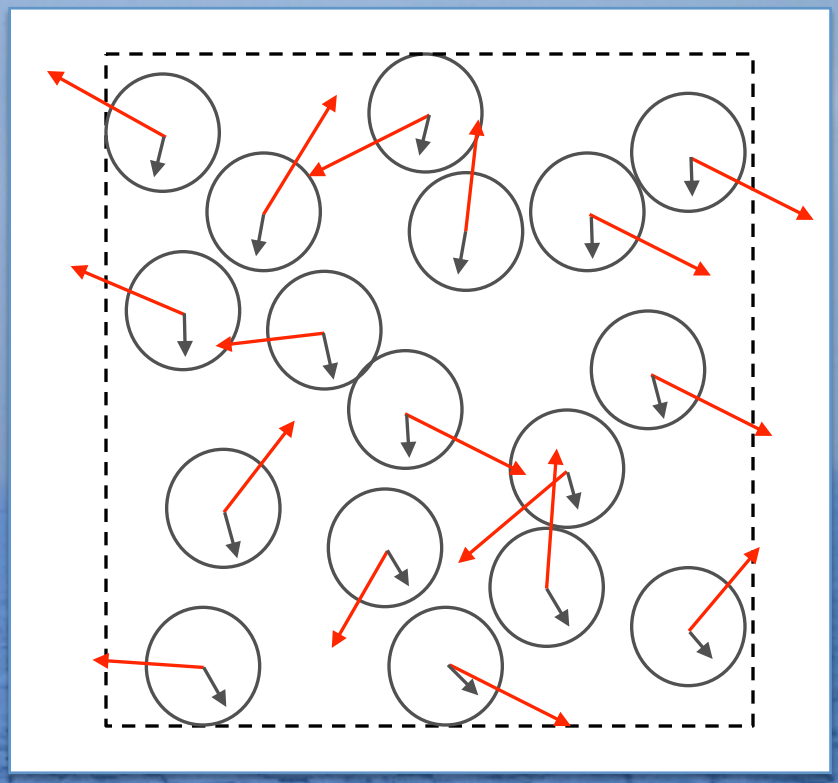
4. Ice floes sizes evolution $L_f(x,y,t)$

Model: 1° & 1/4° NEMO-CICE

- Global NEMO-CICE
- Waves information from ECWAM
- Sea ice Break up and Floe Size Distribution Evolution
- New mixing accounting from waves
- New sea ice combined granular-EVP rheology for Marginal Ice Zone
- Form drag formulation, including floe size effects

How do we model MIZ Rheology?

Photo Credit: Martin Vancoppenolle



Combined MIZ and pack ice rheology (circular floes) accounts for turbulent motion of ice floes ($v = v_{mean} + v'$) and ice break by waves.

Seamless Combined Collisional & Elastic-Viscous-Plastic (EVP) Rheology

$$m\frac{\partial \mathbf{u}}{\partial t} = \nabla \cdot \sigma + \tau_a + \tau_o - mg\nabla H - \mathbf{k} \times mf\mathbf{u}$$

- Combined rheology (Shen 1986; Feltham, 2005)
  - Used for pack ice and MIZ
  - The natural switch between EVP/anisotropic and collisional regimes is set by velocity fluctuation magnitude U_c (Kinetic Energy of Ice Drift Pulsations $G_t \sim U_c^2$)

$$\sigma_{ij} = 2(\eta^{EVP} + \eta^{COL})\varepsilon_{ij} + ((\zeta^{EVP} + \zeta^{COL}) - (\eta^{EVP} + \eta^{COL}))\varepsilon_{kk}\delta_{ij} - \frac{1}{2}(P^{EVP} + P^{COL})\delta_{ij}$$

Kinetic Energy of ice drift pulsations

- Measure of floe kinetic energy pulsations
- Sources: air and ocean interfacial stress fluctuations (*F*)
- Sinks: floe rubbing and collisions and losses to internal ice stresses (*Γ*) and (*σ : grad u*)
- split into advection/diffusive parts (*q*) and sources/sinks

$$m\frac{\partial}{\partial t}G_T + mu \cdot \nabla G_T = -\nabla \cdot q + F - \sigma^T : \nabla u - \Gamma$$ +A^2/P^2*H/h

tendency advection diffusion

Wave surge

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Marginal Ice Zone: Ocean Mixing & Roughness

How it is done now in NEMO?

- Calculate from significant wave height
  - $z_0 = 1.3\ H_s$
  - Wind based parameterisations calculate H_s from wind
  - Presence of sea ice is ignored

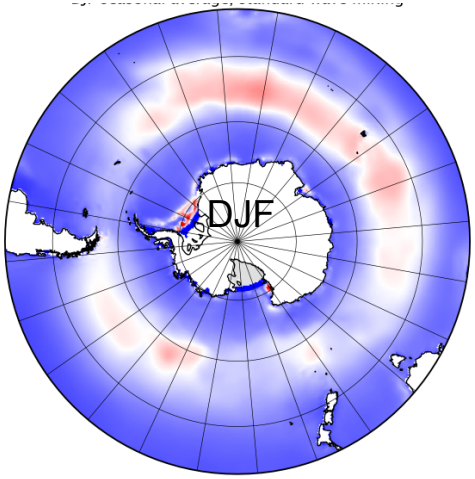
New development

- Use significant wave height (H_s) modified by the ice cover
- Still ignoring the roughness length of the sea ice cover itself (future extension)

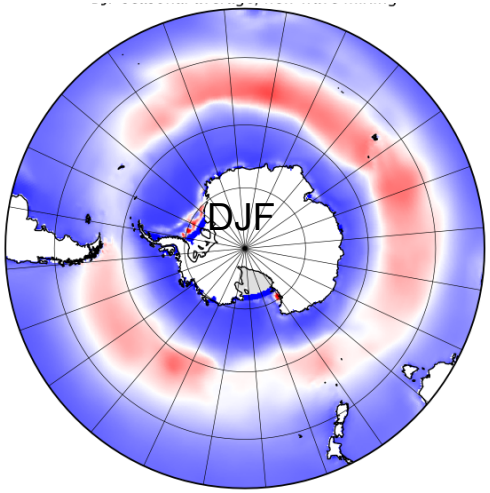
Effect on the mixed layer depth, Antarctic

Model

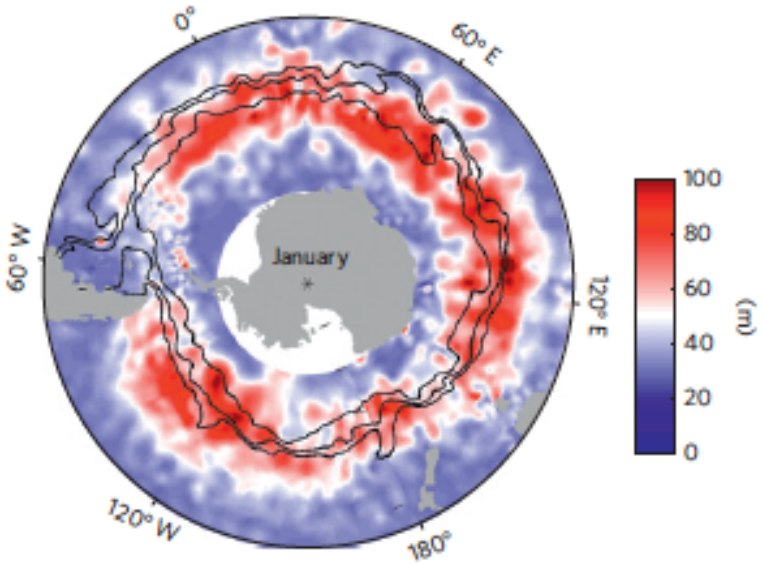
standard



new



Observations



Shallow bias in summer mixed layer depth improved

Summary & Outlook

- Changes in sea ice effect wave climate in Polar Seas
- Fundamentals of Ice-waves coupled modelling

  (I) Ice break up by waves

  (II) New rheology: seamless combined with EVP via ice drift KE
- Impact of wave mixing on sea ice & ocean

- What's next?
  - Full atmosphere-sea ice-ocean-waves coupling
  - Development: Combined thickness/floe size evolution
  - Revise mixing: ice roughness and breaking non- breaking waves
  - Pull through of the development in the new NEMO sea ice model SI3

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Thank you