Towards Inclusion of sea ice attenuation in an operational wave model.

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Motivation

- ECMWF WAM does not treat sea ice explicitly. The model spectra for all sea points with sea ice cover (*ci*) larger than 30% are set to 0.
- Martin Doble had data from a buoy deployed in the Weddell Sea and was trying to reconstruct the low frequency wave conditions leading the ice break-up from ERA-interim spectra, only available where *ci* <30%.
- I told Martin that I could do better by using the model to advect the waves into the sea ice!
- We are now involved in the Office of Naval Research Department Research Initiative (DRI) Sea State and Boundary Layer Physics of the Emerging Arctic Ocean.

Methodology

- Quite some theoretical studies have been carried on the difficult subject of wave-sea ice interaction. The parameterisation of Kohout and Meylan (2008) based on the theory of multi-scattering by ice floes was recently applied to a sea ice model with an active ice model.
- We implemented the same parameterisation into a wave model. But without an ice model to replace the fixed arbitrary 30% threshold.
- We also need other physical mechanism for attenuation. We have implemented one.

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Conclusions

- Even though, we used a very crude approximation, we successfully reproduced the Weddell Sea data.
- The current parameterisation works as well as the default 30% threshold.
- It allows to start looking at the impact of wave-sea ice interaction on the coupled atmosphere/wave model with insights for the future fully coupled system.
- More work is needed …

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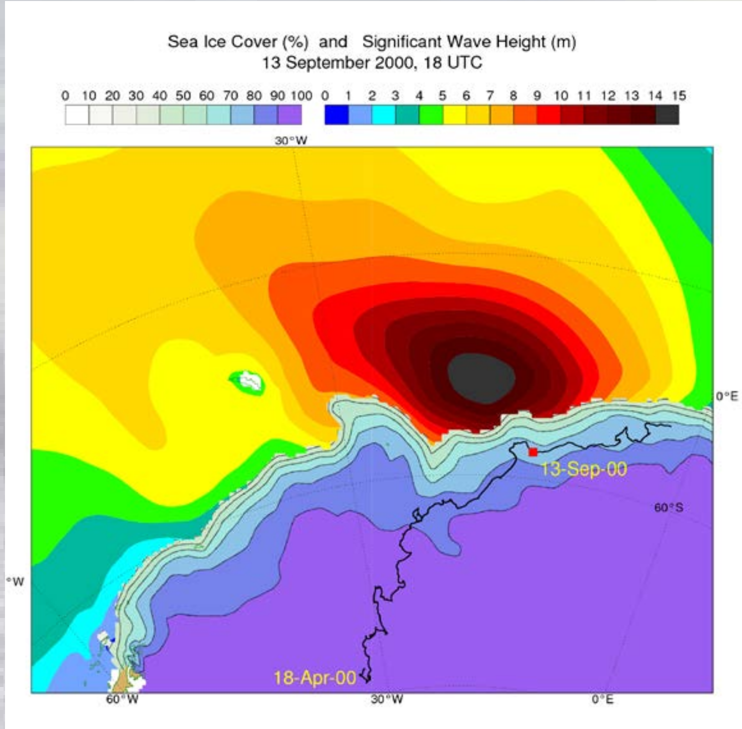
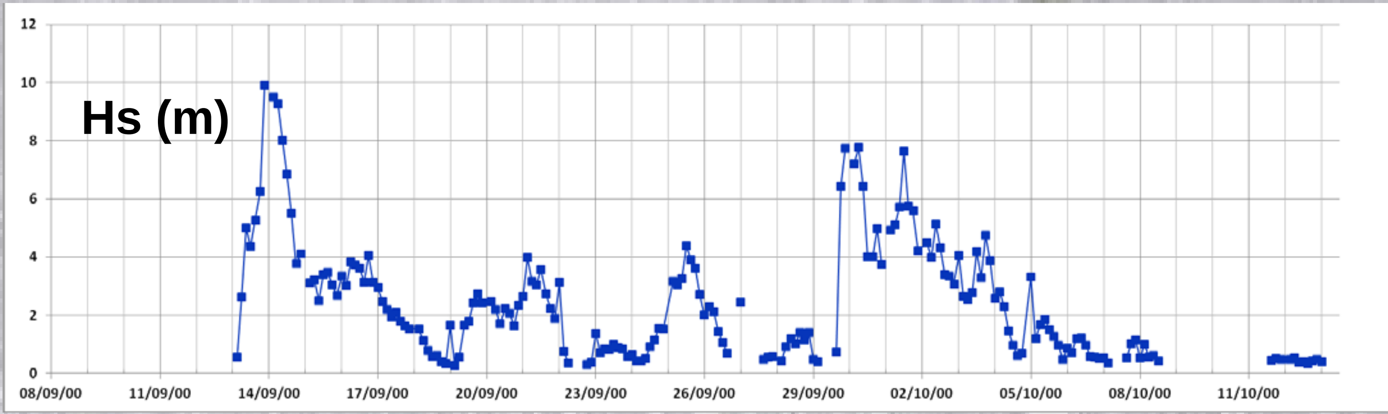
Situation leading to the break-up:

Pancake buoy



13th September 2000 18UTC



Sea ice attenuation:

Dumont et al. (JGR, 2011) applied the Kohout and Meylan (JGR 2008) wave scattering model to an ice model with parameterised waves spectra:

$$F(\mathbf{x}, f, \theta, t+\Delta t) = F(\mathbf{x}, f, \theta, t) \exp(-\alpha\, c_g \Delta t)$$

c_g : group speed $\quad$ Δt : model time step

$$\alpha = ci \frac{a}{\overline{D}}$$

ci : sea ice concentration

a: non dimensional attenuation, function(*ci*, ice thickness *h*)

$\overline{D}$: mean size of ice floes

assuming that ice floes will break up into ξ pieces : $\overline{D} = \dfrac{\sum_{m=0}^{M} (\xi^2 fr)^m \xi^{-m} D_{max}}{\sum_{m=0}^{M} (\xi^2 fr)^m}$

$$M = \log_\xi\left(\frac{D_{max}}{D_{min}}\right) \qquad D_{min} = 20\text{m} \qquad D_{max} = 200\text{m}$$

$\xi = 2 \qquad fr = 0.9$: ice floes fragility $\quad \longrightarrow \quad \overline{D} = 36\text{m}$

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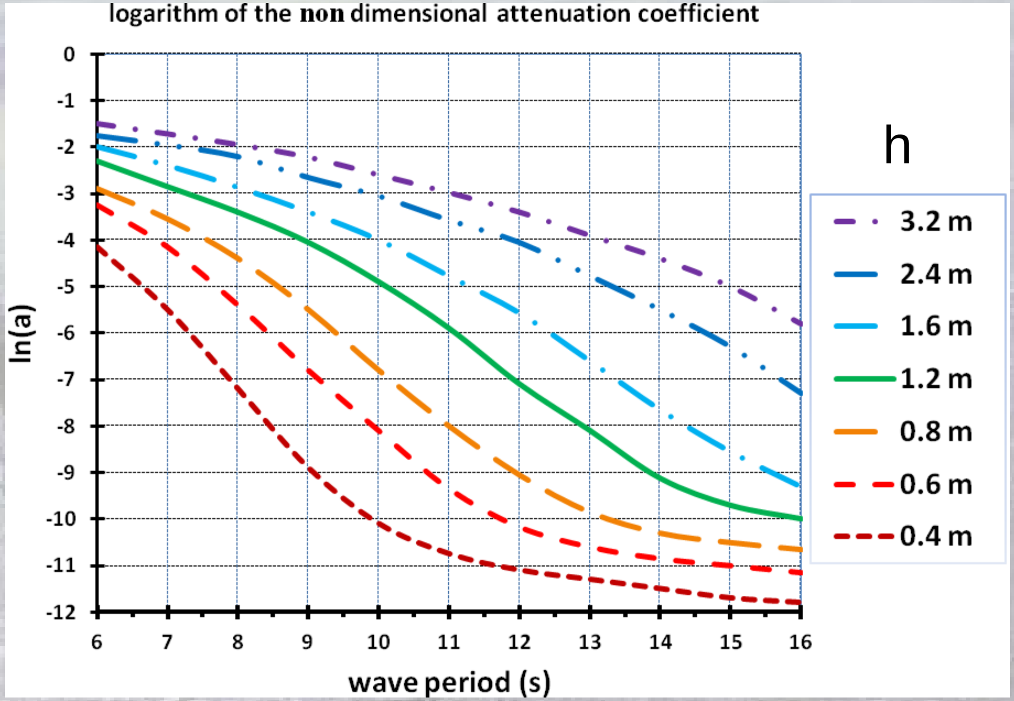
The Kohout and Meylan is based on elastic bedding of floes and does not contain other physics.

Sea ice attenuation:

$$\alpha = c i \frac{a}{D}$$

The non-dimensional attenuation coefficient “a” was found to depend only on wave period and sea ice thickness “h”



From Kohout and Meylan (JGR 2008)

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Sea ice attenuation:

Kohout et al. (Annals Glaciology 2011) added the attenuation due to the **bottom roughness of the ice floes** to account for wave energy loss in compact MIZ:

For the portion of the grid box covered by sea ice

$$F(\mathbf{x}, f, \theta, t+\Delta t) = F(\mathbf{x}, f, \theta, t)\exp(-\alpha\, c_g \Delta t)$$

c_g : group speed $\quad$ Δt : model time step

$$\alpha = C_d\, H\, k^2$$

H : wave height for each spectral component

k : wave number of each spectral component

C_d : ice - water drag coefficient

C_d : 1×10^{-3} to 35×10^{-3}

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Sea ice attenuation in ECWAM

So, we have a model for wave spectra but we do not (yet) have an operational sea ice model sea ice thickness “h”.

Could we instead parameterise “*h*” in term of *ci* ?

$$h = 0.2 + 0.4ci$$

For these reasons, we will also limit the applicability of this model to

$$ci \leq ci_{block}, \;\; 0.5 \leq ci_{block} \leq 0.8$$

For any values above this threshold, the wave energy is fully dissipated (other physical mechanisms are in play).

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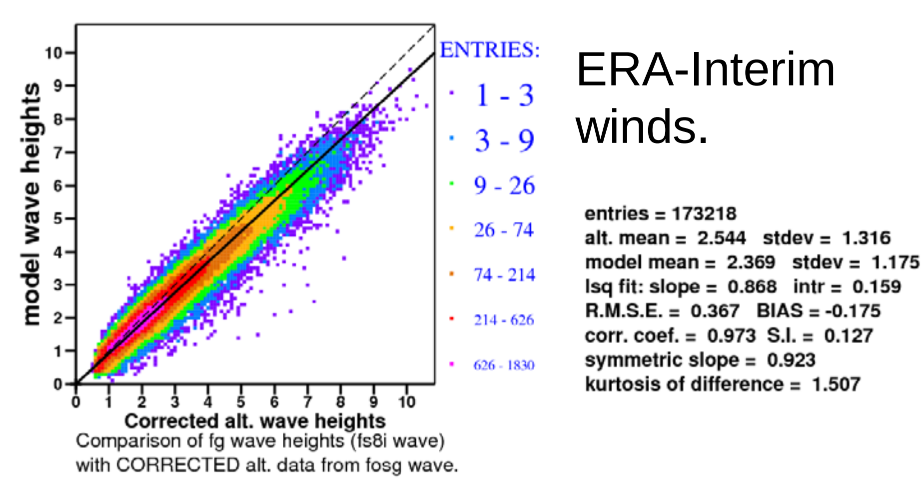
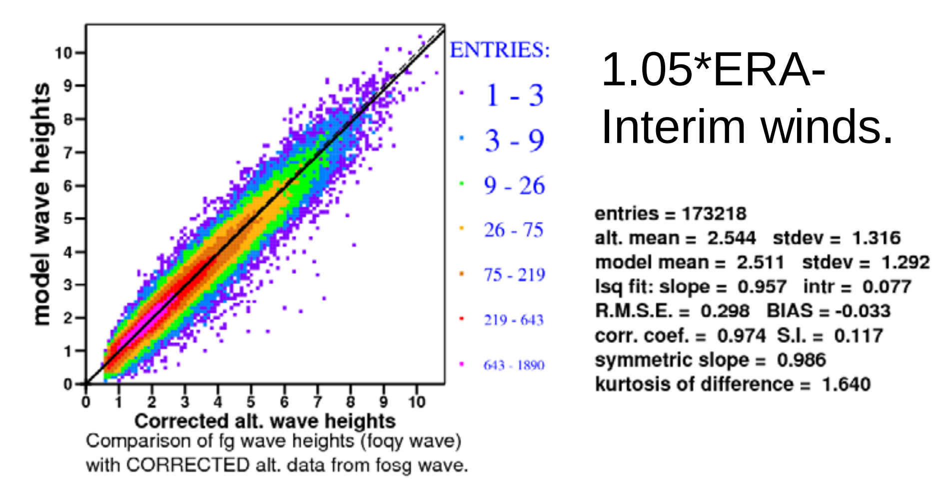
Model set-up:

The latest operational version (CY38r1) of the global stand alone ECWAM with a 28km grid with 36 directions, 36 frequencies, forced by ECMWF ERA-Interim winds boosted by 5% was run for 25 August 2000, 0 UTC to 13 October 2000, 0 UTC.





Global comparison with calibrated ERS-2 Hs

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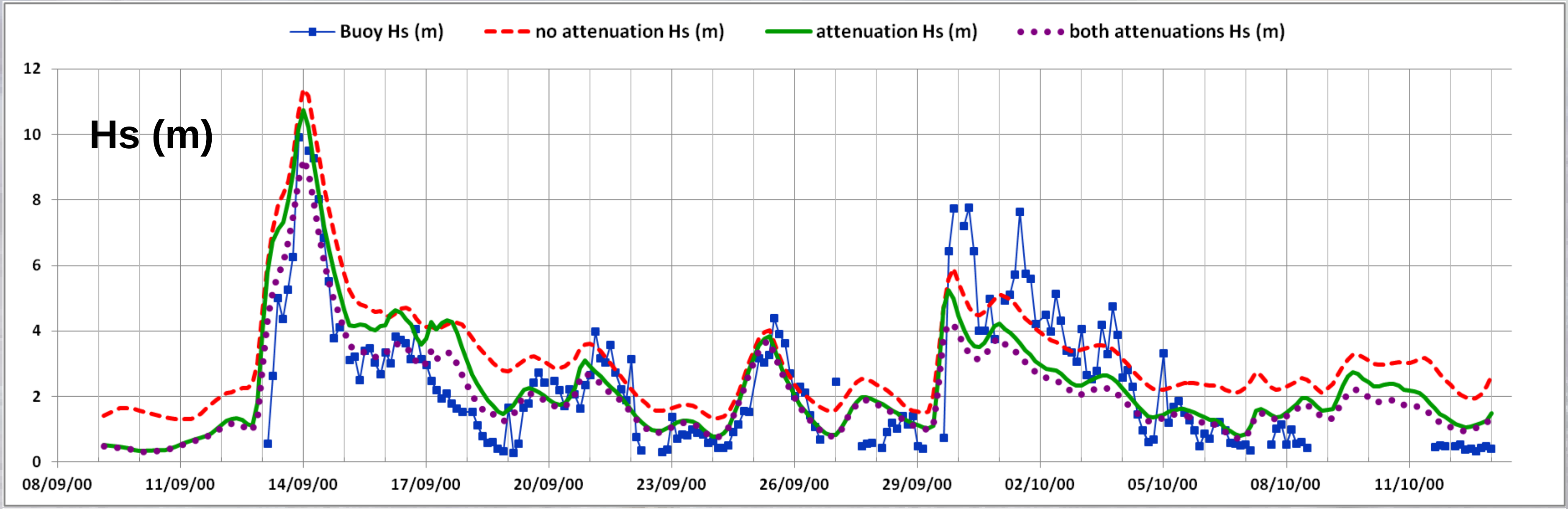
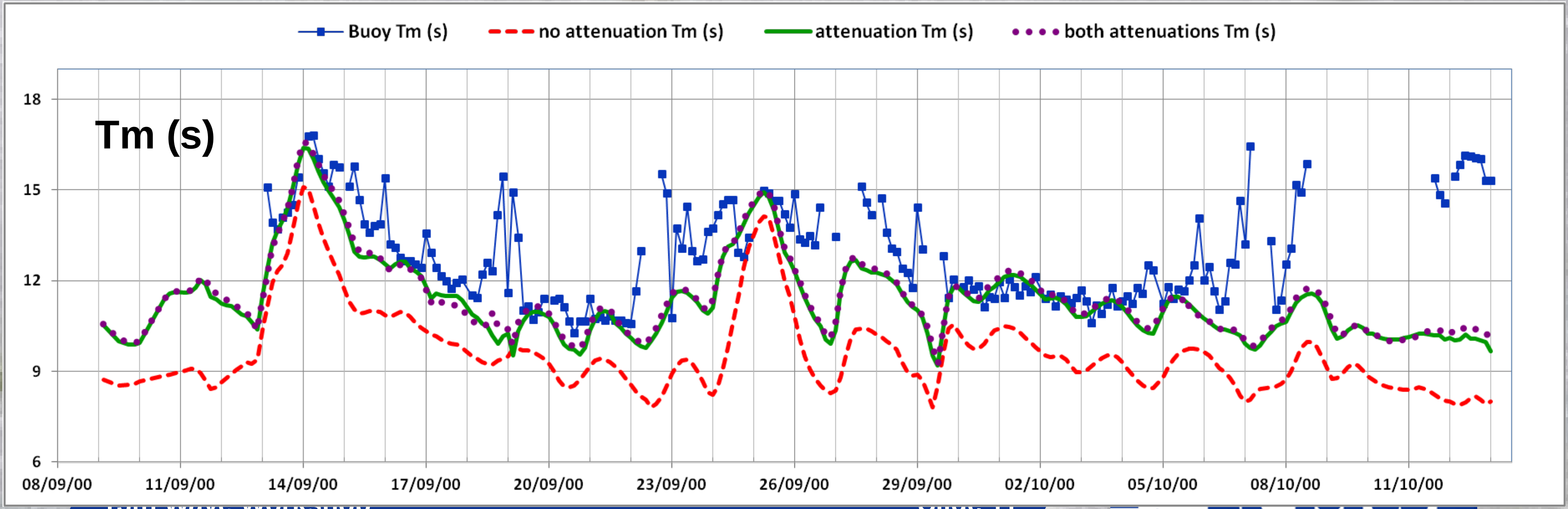
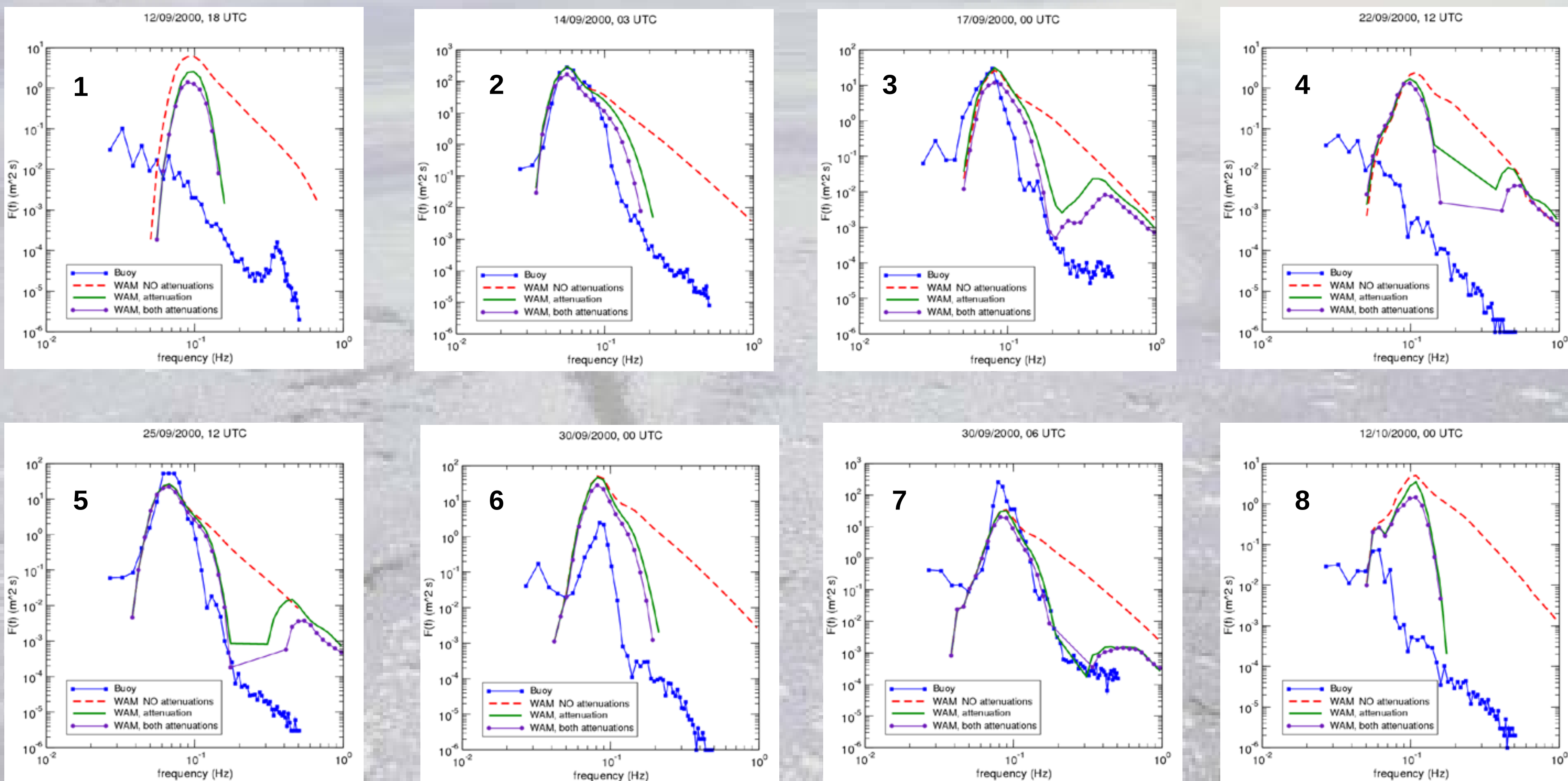
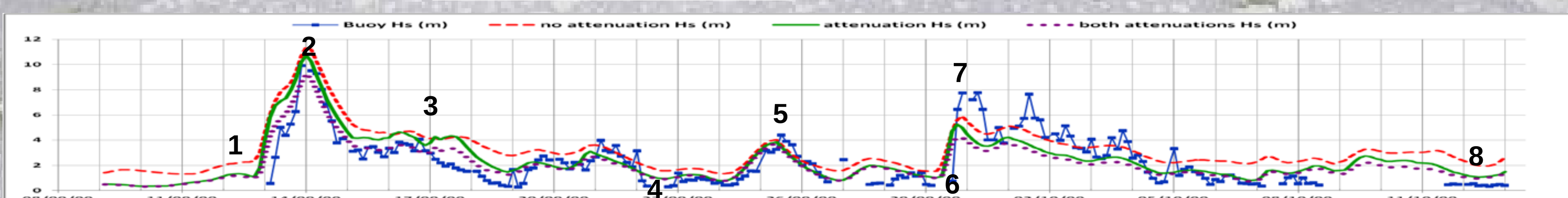
Sea ice attenuations in ECWAM





Sea ice damping modeling





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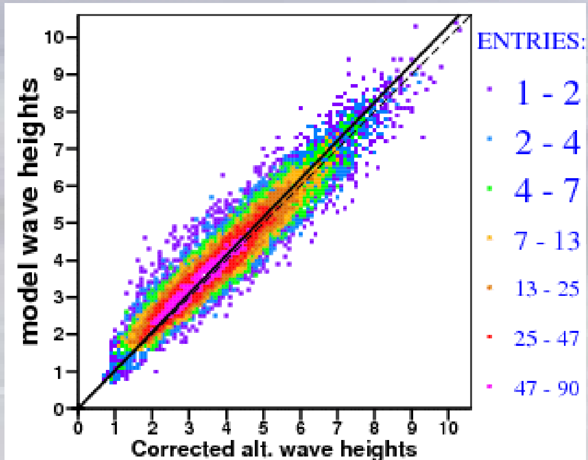
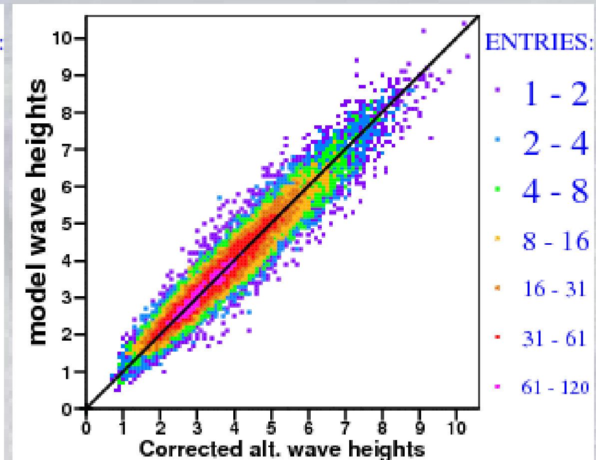
Comparison with calibrated ERS-2 altimeter Hs

No attenuations



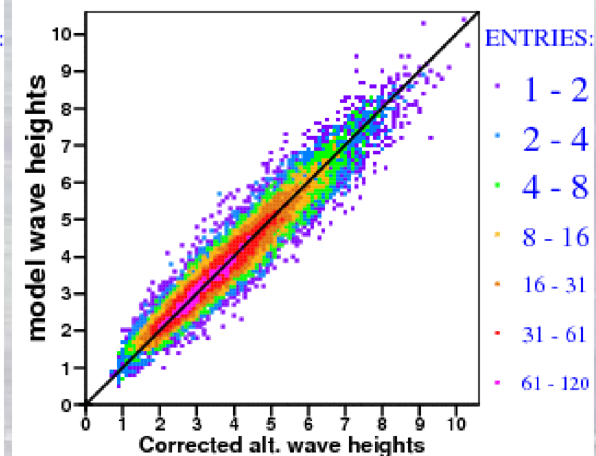
Comparison of fg wave heights (fru3 wave) with CORRECTED alt. data from fosg wave.

Attenuations



Comparison of fg wave heights (frw0 wave) with CORRECTED alt. data from fosg wave.

Full blocking for ci > 30%

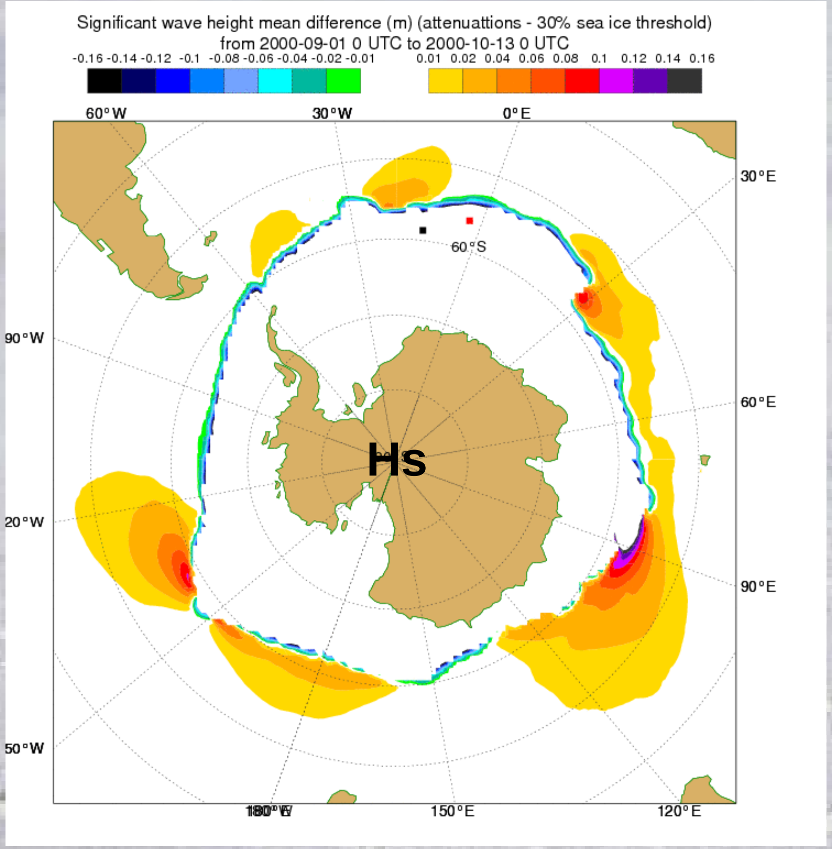


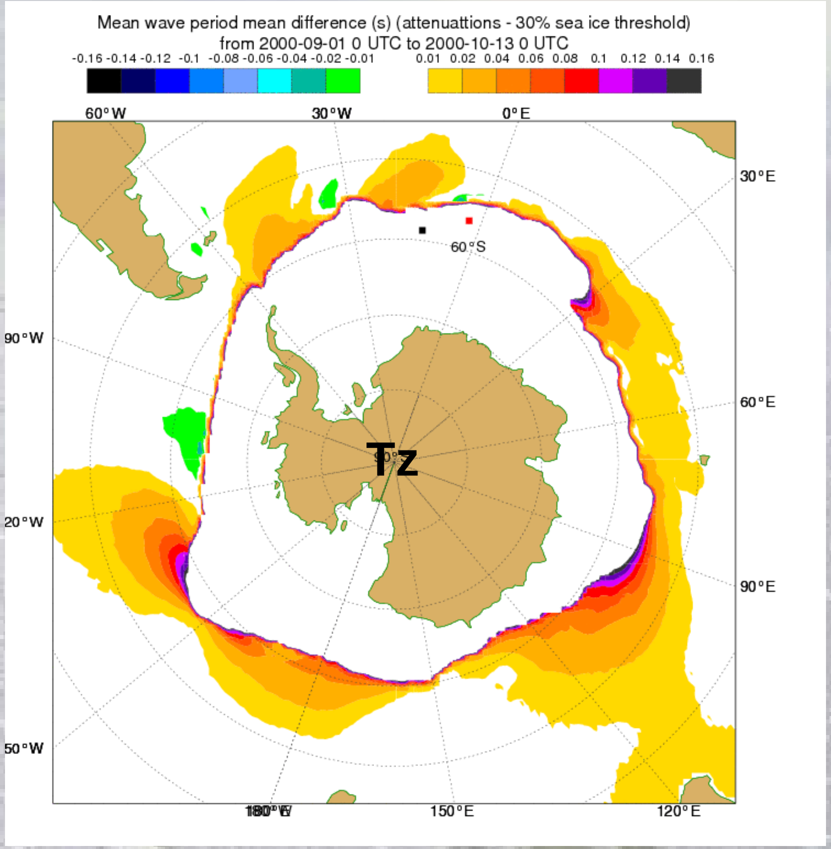
Comparison of fg wave heights (fru2 wave) with CORRECTED alt. data from fosg wave.

South of 50°S	No attenuations	attenuations	Full blocking
Bias (m)	0.150	0.011	0.014
Symmetric Slope	1.031	1.001	1.002
RMSE (m)	0.429	0.373	0.372
Scatter Index (%)	10.8	9.72	9.70
Correlation Coefficient	0.957	0.963	0.962

26 August 2000, 0 UTC to 29 September 2000, 0 UTC. 15074 collocations

Mean differences (attenuations – blocking 30% ci)





25 August 2000, 0 UTC to 12 October 2000, 18 UTC

Stand alone ECWAM, 28km grid, 36 directions, 36 frequencies, forced by ECMWF ERA-Interim winds boosted by 5%.

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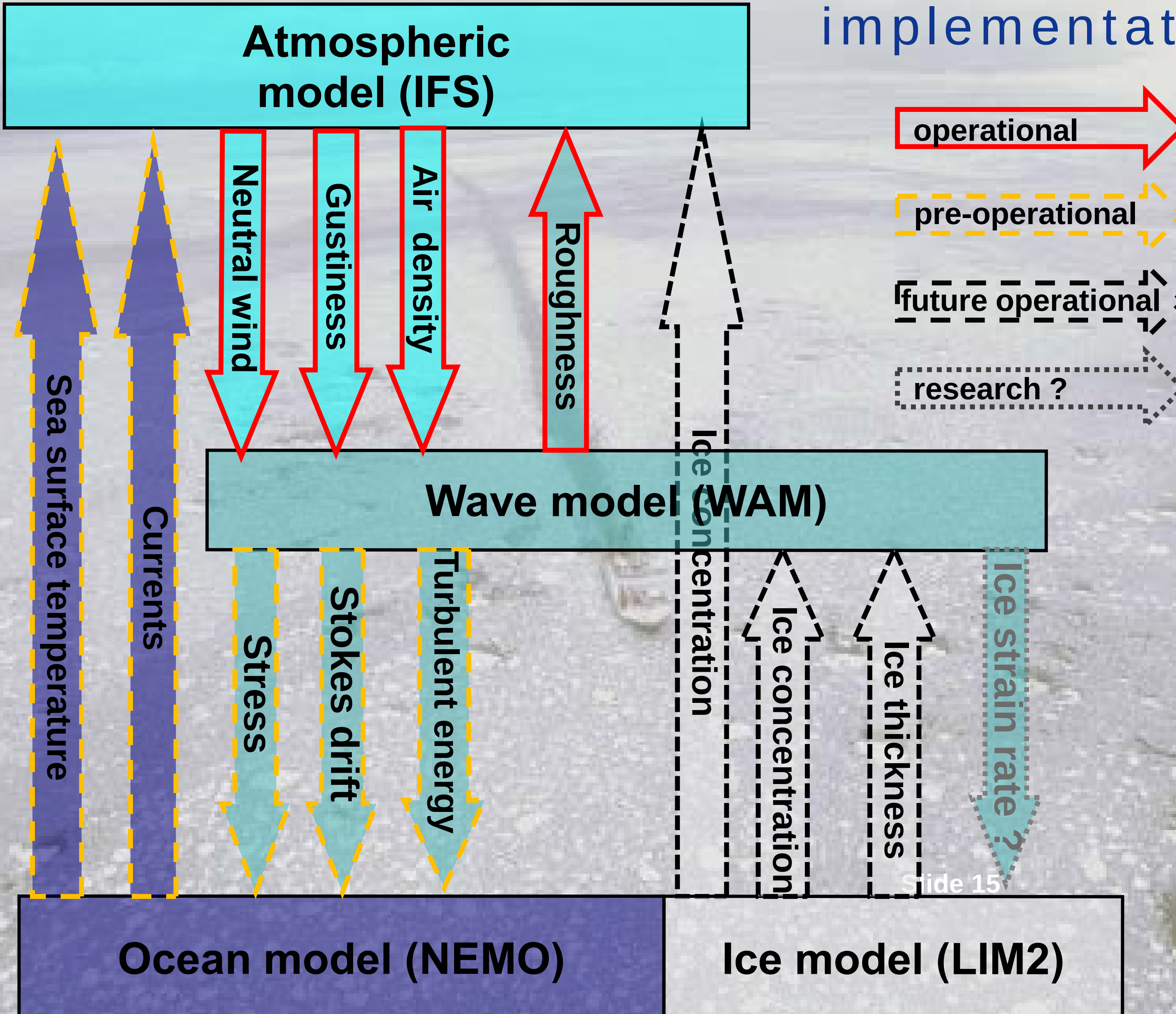
Operational implementation?



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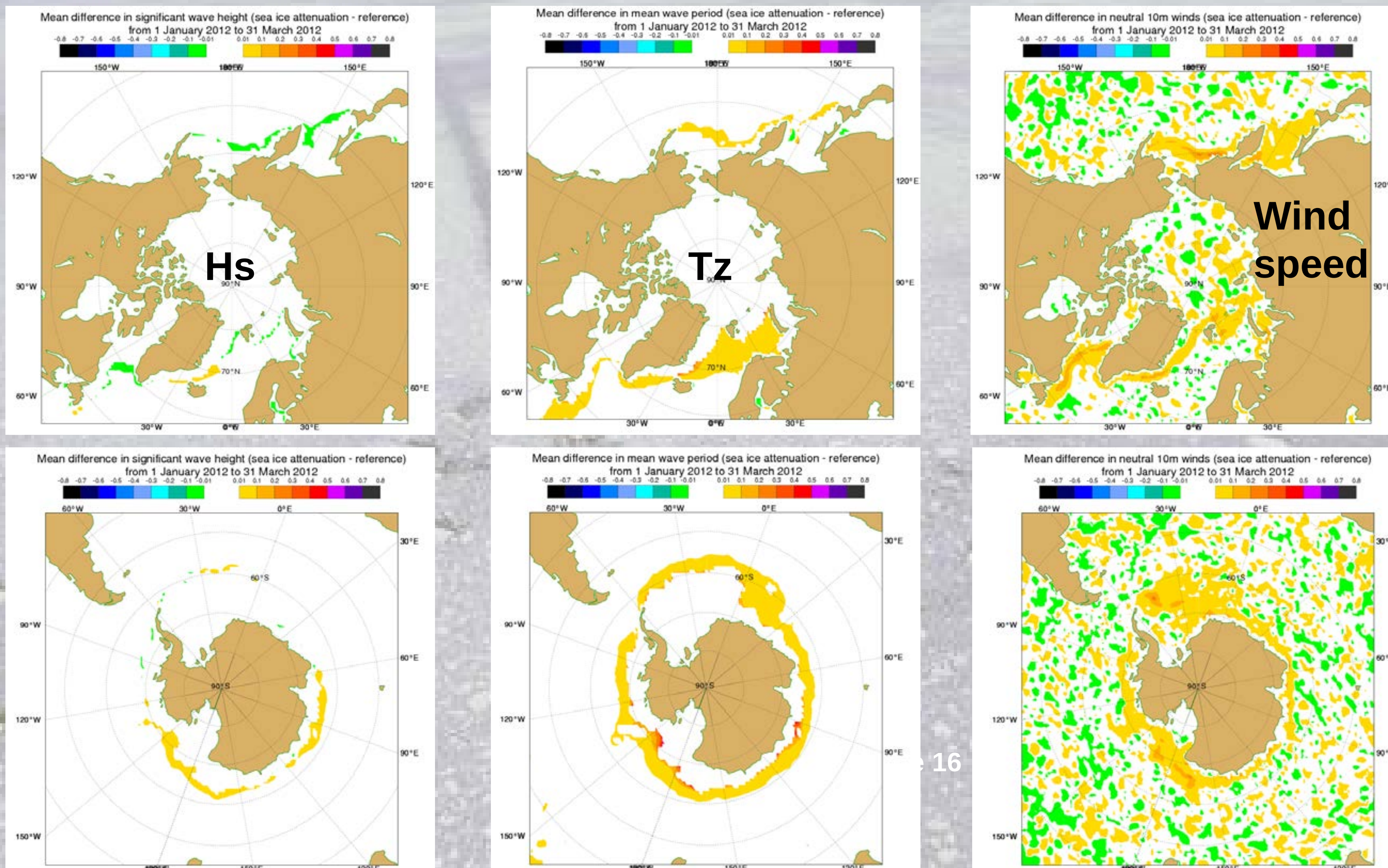
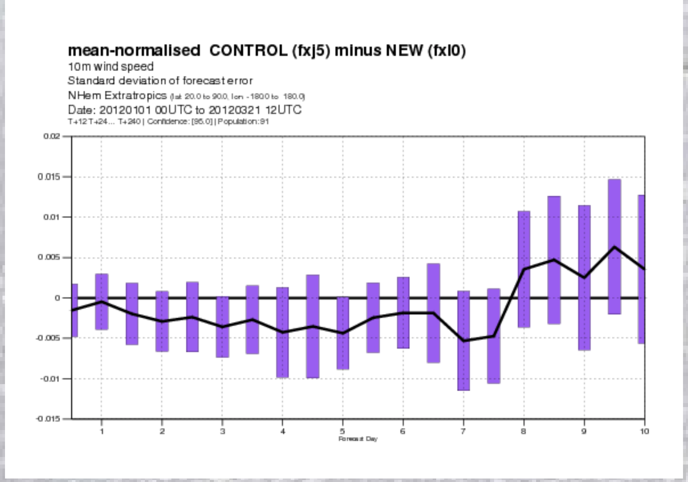
T511 coupled run: analysis difference

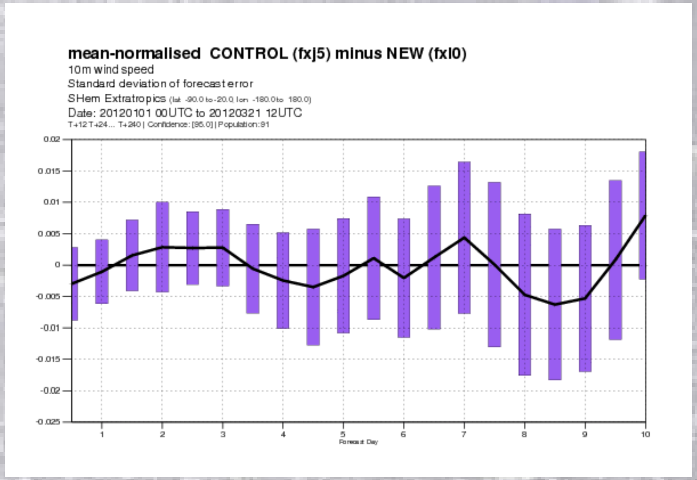
Sea ice attenuation - reference



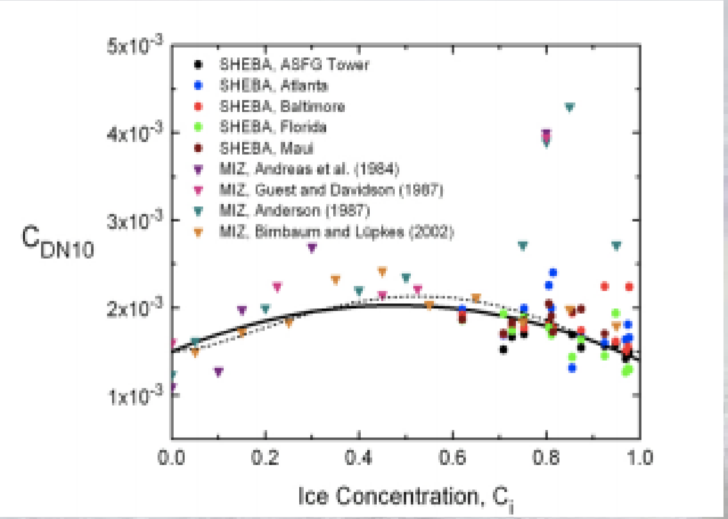
T511 coupled run: scores

	reference north of 40°N	Enhanced model north of 40°N	Reference south of 50°S	Enhanced model south of 50°S
Number of observations	72664	72664	141497	141497
BIAS (m)	-0.031	-0.034	0.041	0.045
RMSE (m)	0.421	0.419	0.347	0.351
Scatter Index	0.120	0.119	0.108	0.109
Correlation Coefficient	0.966	0.966	0.962	0.962

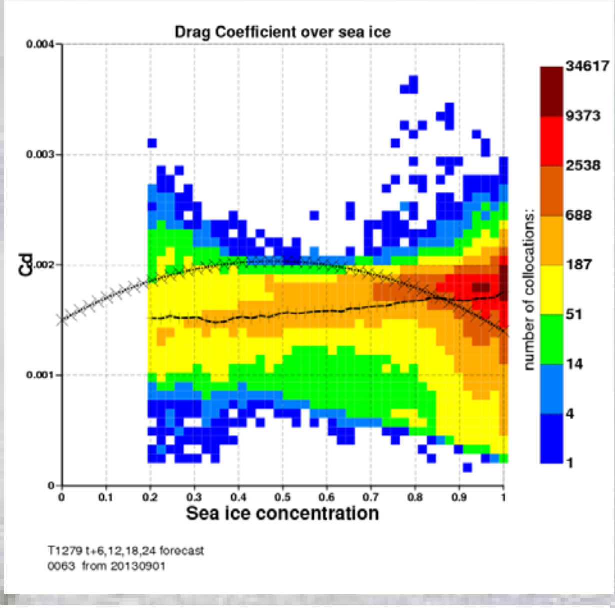




Operational implementation: issues

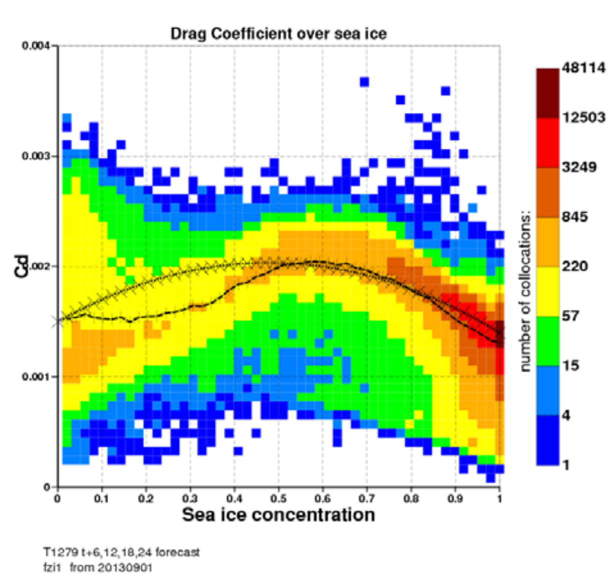


Cd as a function of ice concentration (Andreas et al. 2010)



Cd over sea ice
Operational forecast from 2013-09-01, t+6,12,18,24

cimin=20%
z_0=0.001
Full blocking ci>30%



Cd over sea ice forecast from 2013-09-01, t+6,12,18,24

cimin=2%
z_0=(ci)
Sea ice attenuation

Conclusions

- The simple sea ice attenuation parameterisation worked well for the ice break-up conditions of the Weddell Sea.
- When applied globally, the results are less convincing as sea ice conditions might well be quite different as those assumed in the model. Nevertheless, when limiting it to the ice edge, it is still a better representation of the wave conditions than a fixed threshold.
- Coupling issues need to be addressed.
- The scattering process should actually be modelled explicitly, and separate from other dissipative processes.

Thank You

Impact of waves on sea ice

Mean square strain in the ice: $$mssi = \int F(f) E^2 df$$

h_i ice thickness

$F(f)$ wave spectrum in the ice

$$E(f) = \frac{h_i k_{ice}^3}{2k}$$

k_{ice} wavenumber under the ice

k wavenumber open ocean

Dispersion relation under the ice: $$\omega^2 = \frac{M k_{ice}^5 + g k_{ice}}{\coth(k_{ice} D) + r h_i k_{ice}}$$ $$\omega = 2\pi f$$

$$M = \frac{Y_* h_i^3}{\rho_w 12 (1 - \nu^2)}$$

D water depth

$$r = \frac{\rho_{ice}}{\rho_w}$$ ice/water density ratio

$$\rho_{ice} = 922.5 \text{ kg m}^{-3}$$

$$\rho_{ice} = 1025 \text{ kg m}^{-3}$$

$Y_* = 5.510^9 \, Nm^{-2}$ Young's modulus

$\nu = 0.3$ Poisson's ratio

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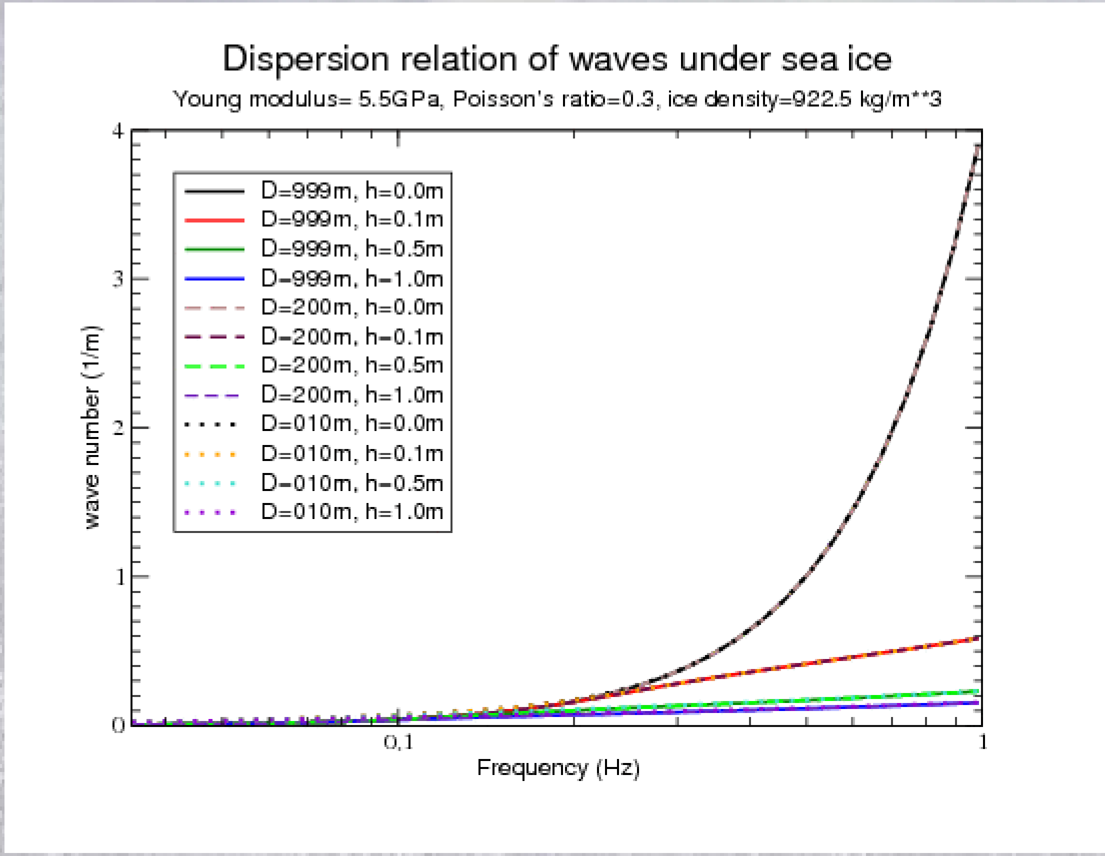
Impact of waves on sea ice

$$\omega^2 = \frac{Mk_{ice}^5 + gk_{ice}}{\coth(k_{ice}D) + rh_i k_{ice}} \qquad k_{ice} < k$$



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Impact of waves on sea ice

Probability that maximum strain from the waves exceeds a breaking strain: $\varepsilon_c = 5 \text{ x} 10^{-5}$

$$P_\varepsilon = P(E_s > \varepsilon_c) = \exp\left(-\frac{\varepsilon_c^2}{mssi}\right)$$

Assuming that breaking implies that the ice strength P^* is reduced.
P^* is replaced by an effective strength:

$$P_{eff} = \max\left[P^*(1 - P_\varepsilon), P^*_{\min}\right] \qquad P^*_{\min} \approx 5000 \text{ to } 40{,}000 \text{ Nm}^{-1}$$

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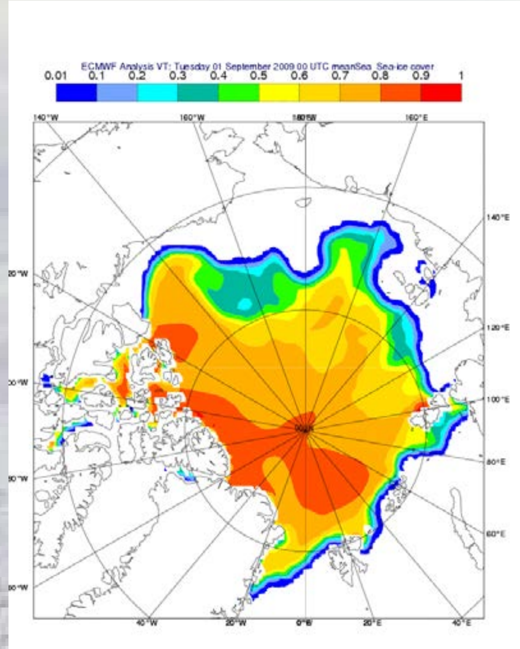
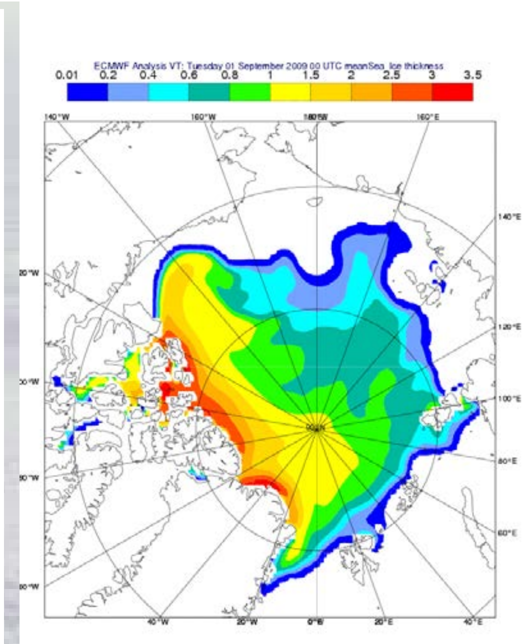
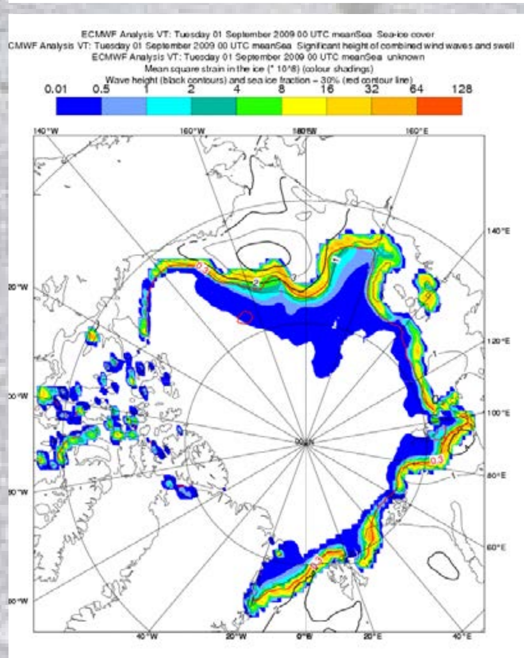
Ice concentration



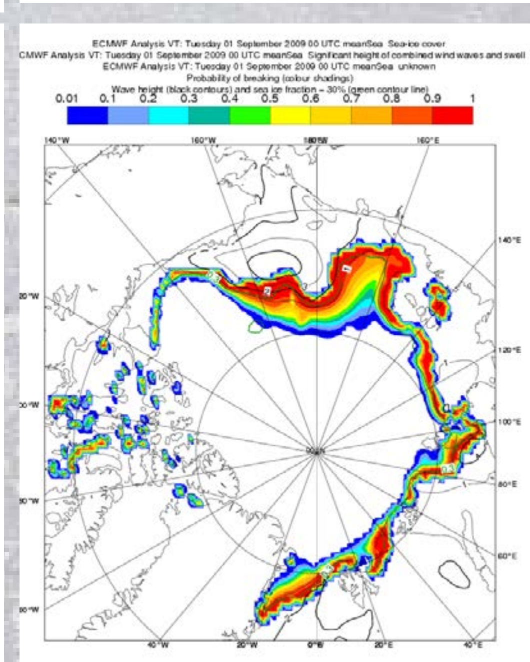
Ice thickness



Mean square strain in the ice



Probability of exceeding breaking strain in the ice



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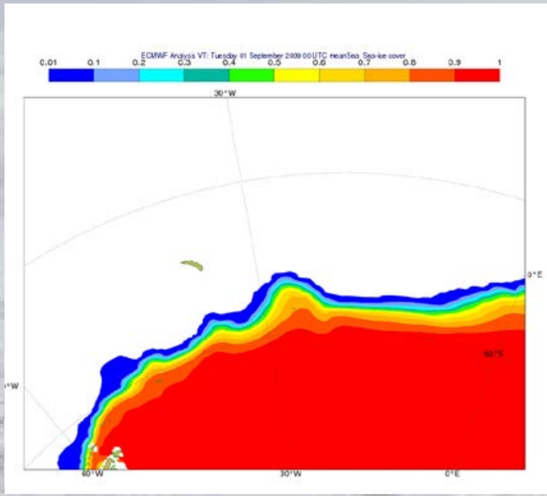
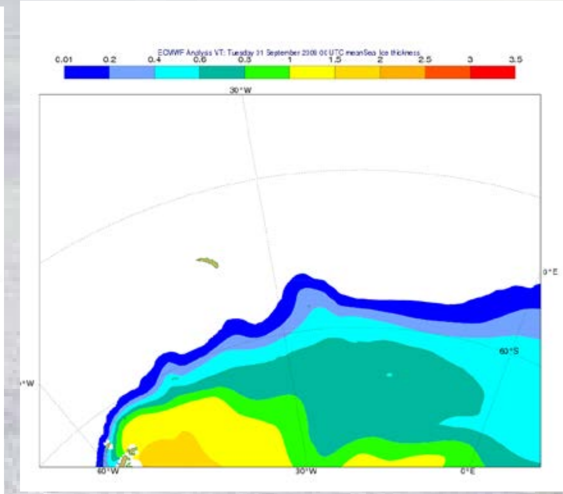
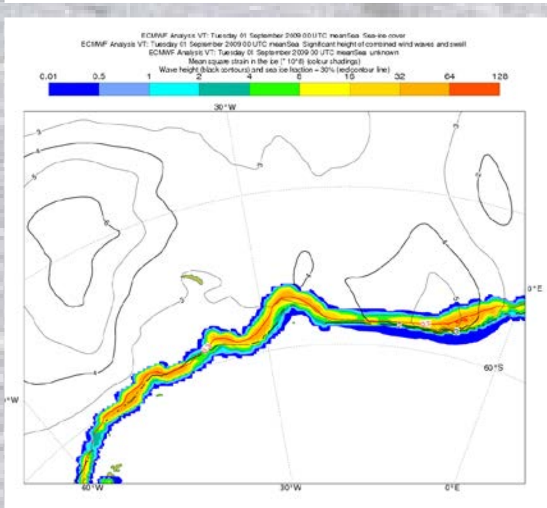
Ice concentration



Ice thickness



Mean square strain in the ice



Probability of exceeding breaking strain in the ice