Wind Sea and Swell Waves in the Nordic Seas

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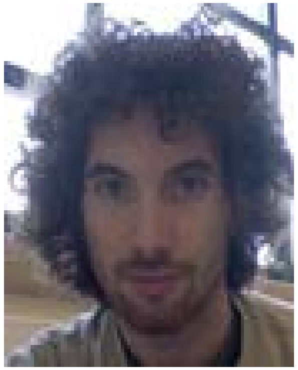
Co - authors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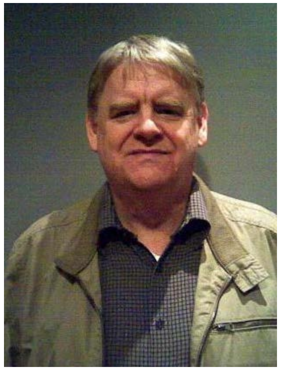
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The Norwegian Meteorological Institute (met.no)

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CENTEC-Portugal

Outline

- Motivation
- Data and methodology
- Conclusions
- Results
- "... Something (almost) completely different!"

Motivation – main issues

Wind Sea and Swell Waves in the Nordic Seas (Norwegian, North, and Barents Sea)

- Waves modulate several processes at the ocean surface... these processes are sea state dependent, and we need to know the state of the wave field to better understand them.
- The impact of swell waves on the lower MABL.
- Qualitative approach in describing the wave climate pattern (e.g. same H_s... different wind sea vs. swell combinations).
- How do wind seas and swells play together in costal areas and marginal seas, where fetches are limited and sheltering takes place? What are the differences compared to the open ocean?
(Apply the global recipe (Semedo et al. 2011) to a regional area).

Conclusions

Wind Sea and Swell Waves in the Nordic Seas

- The wind sea vs. swell balance in the Nordic Seas (Norwegian, Barents, and North Seas) is different from the open Ocean, particularly in the North Sea.

- Fetch dimensions, sheltering effects, and storm track play an important and decisive role in this balance.

- Swell is less prevalent and has a less energy weight in the area, compared to the open Ocean.

- Decadal variation of H_s is the low fetch area (in the North Sea) is mostly locally driven.

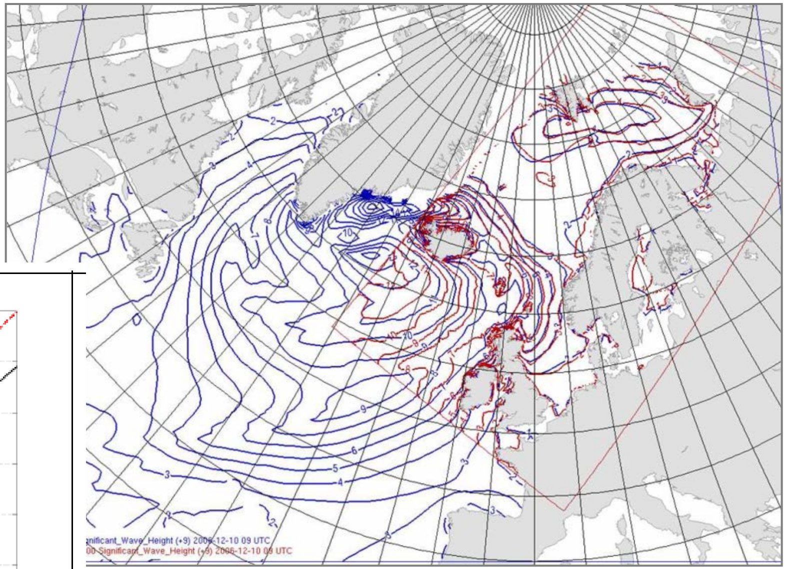
- The swell propagating effect (energy, swell prevalence, and long term variation) is stronger in the Norwegian Sea.

Data – NORA10 Reanalysis (1958 – 2001)

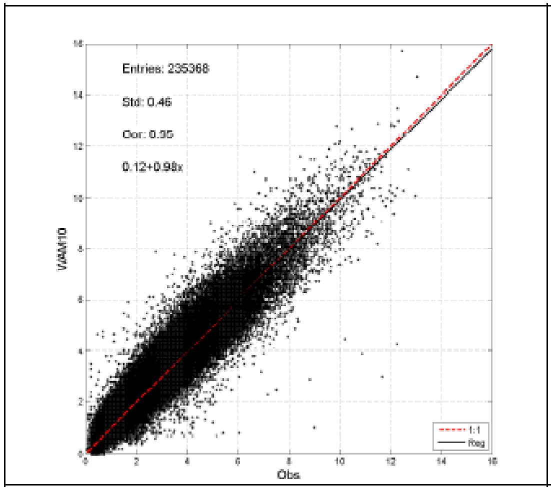
- 3-hourly atmospheric and wave high resolution regional reanalysis for the Nordic Seas produced by met.no.

- Downscaling of ERA-40 and ECMWF operational analyses (here we use only the 1958-2001 period corresponding to ERA-40).

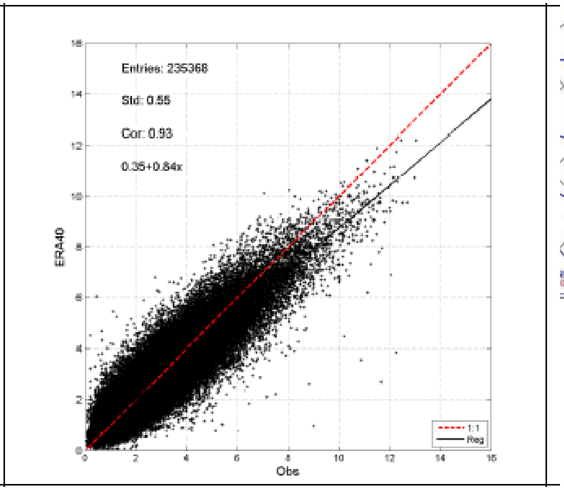
- Extensive improvement on the quality of the wave parameters compared to ERA-40.



(Reistad et al. 2009)



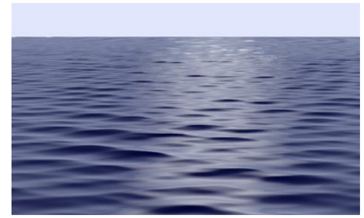
Hs obs. vs NORA10



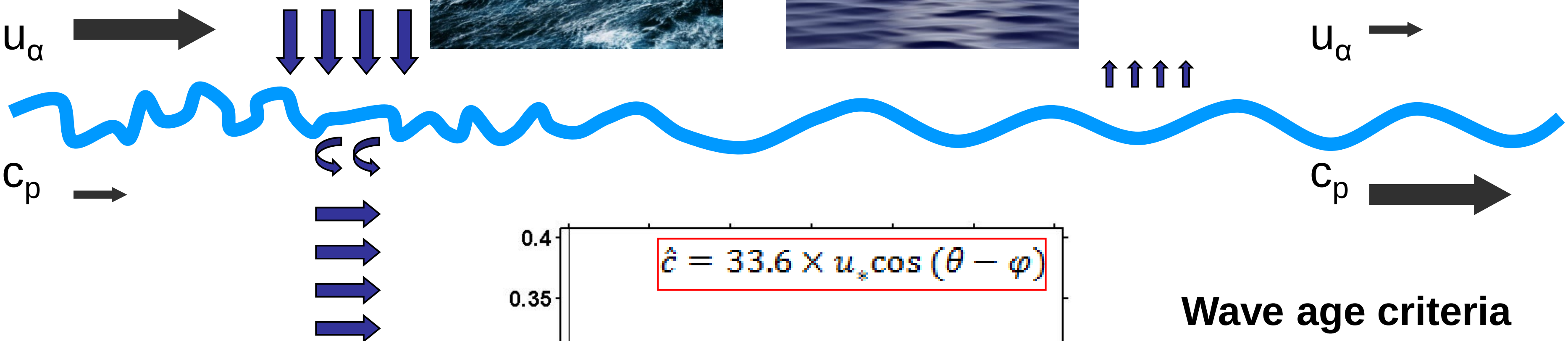
Hs obs. vs ERA-40

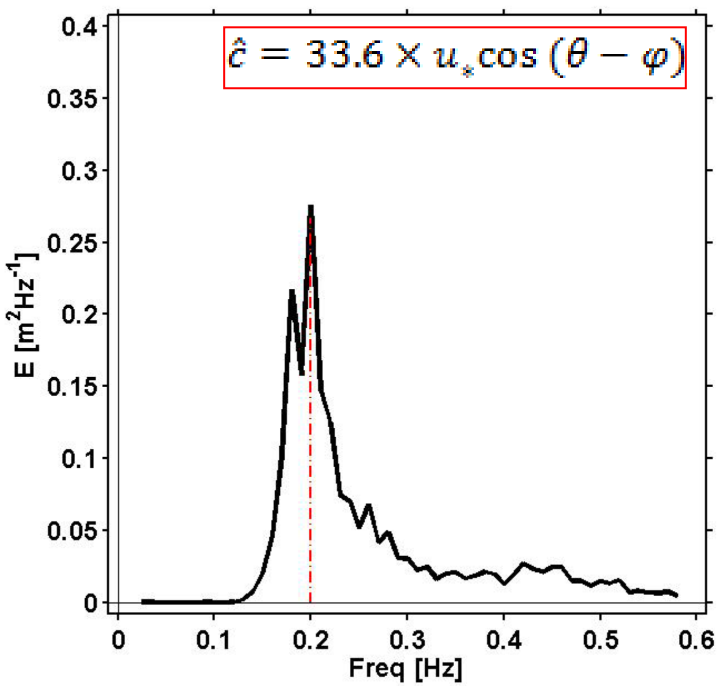
Wave spectral partition – the wave age

Wind sea



Swell





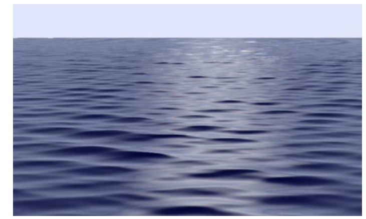
Wave age criteria

$\frac{c_p}{U_{10}} < 1.2$ — **Wind sea**

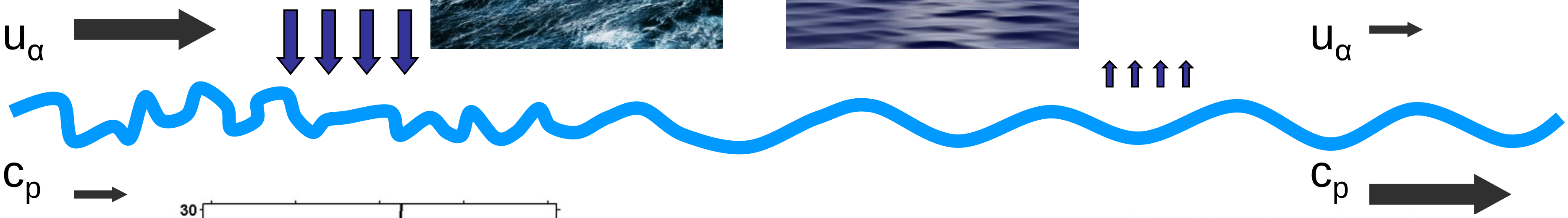
$\frac{c_p}{U_{10}} > 1.2$ — **Swell**

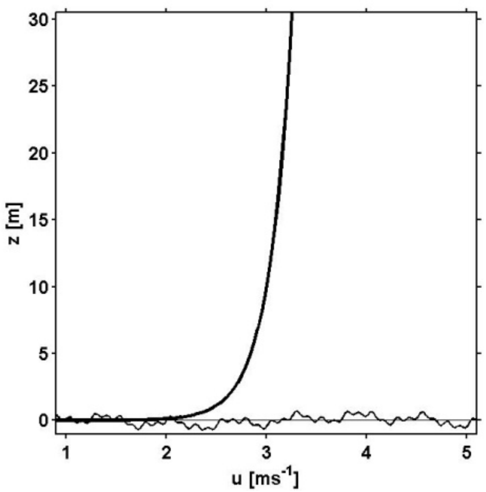
Swell modulation of the lower MABL

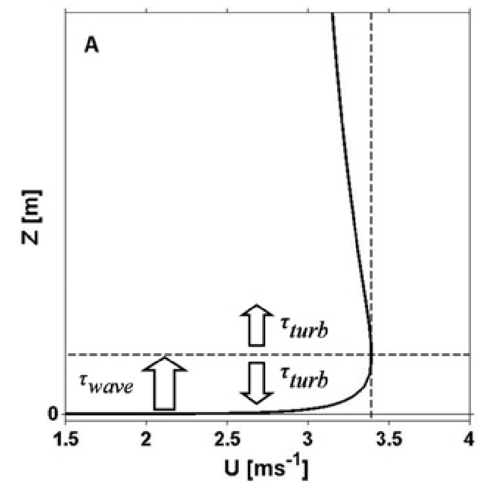
Wind sea



Swell







Low level wind speed anomaly:

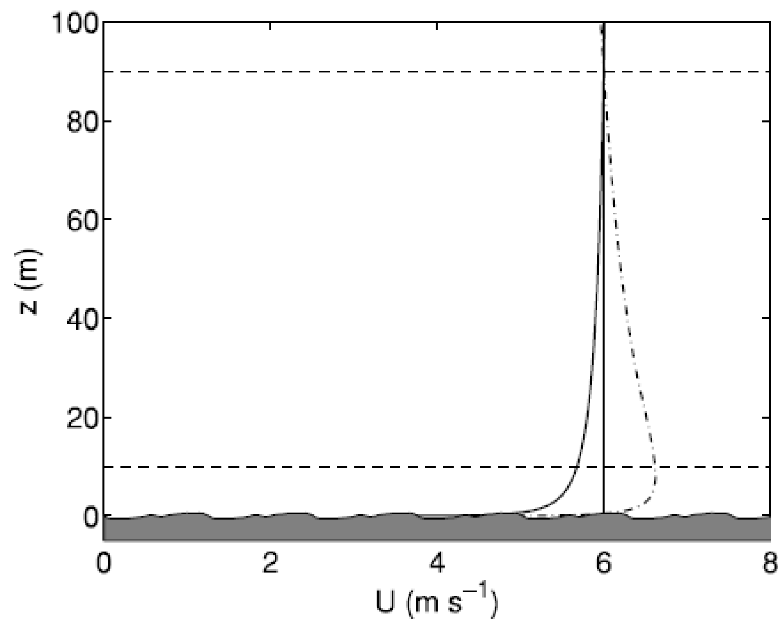
-Low level jet

"Wave-driven wind"

- Linked to swell attenuation

(Semedo et al. 2009)

Swell modulation of the lower MABL



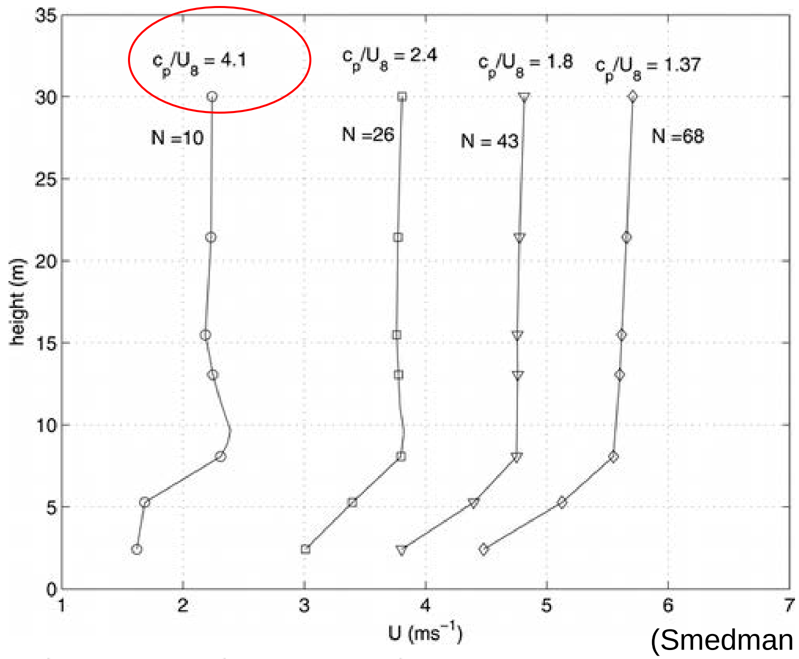
<u>In (strongly) swell dominated wave fields (very high wave age):</u>

- **Waves modulate the turbulence structure of the lower MABL;**
- **Monin-Obukhov similarity theory is not valid;**
- **The drag coefficient changes (different formulations for wind sea and swell conditions); and**
- **The net momentum flux can reverse (upwards).**

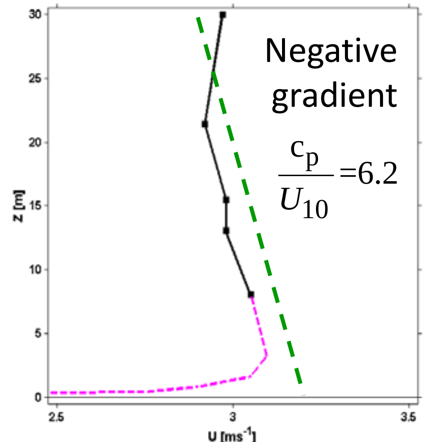
Swell modulation of the lower MABL

BASE - Baltic Sea Swell Experiment

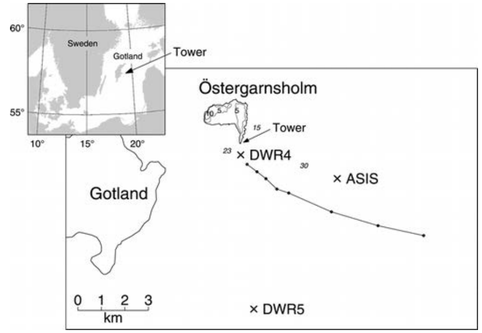
Tower+ASIS



(Smedman et al. 2009)

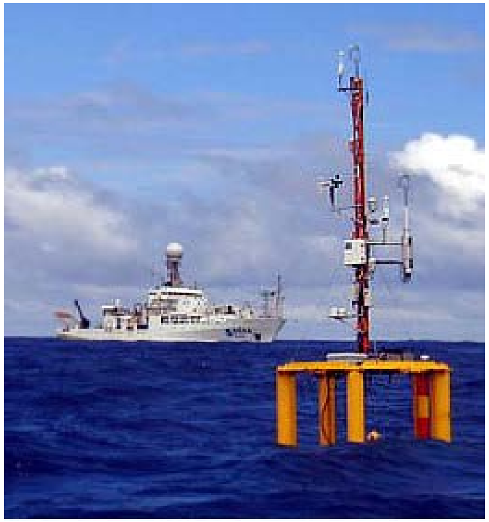


(Semedo et al. 2009)



(Guo Lársen, 2003)

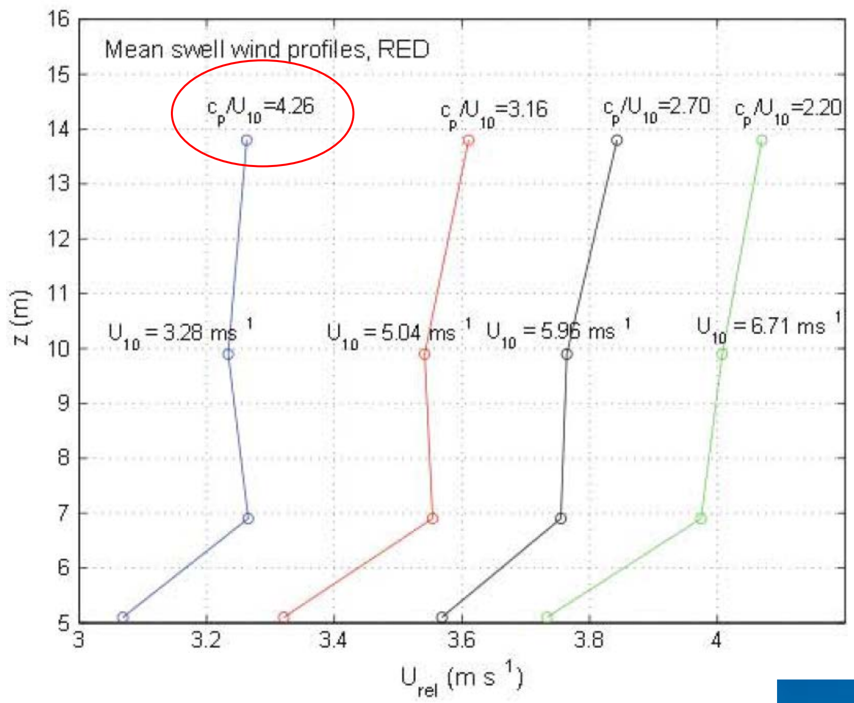
Östergarnsholm



(photos: Andreas Fridvall)

Swell modulation of the lower MABL

RED (rough evaporation duct) Experiment

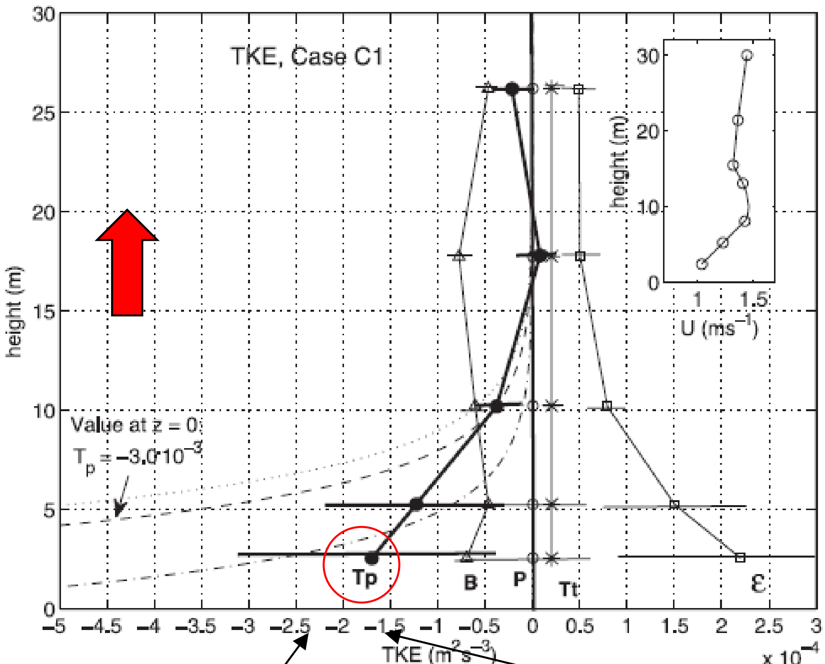


(Högström et al. 2013)

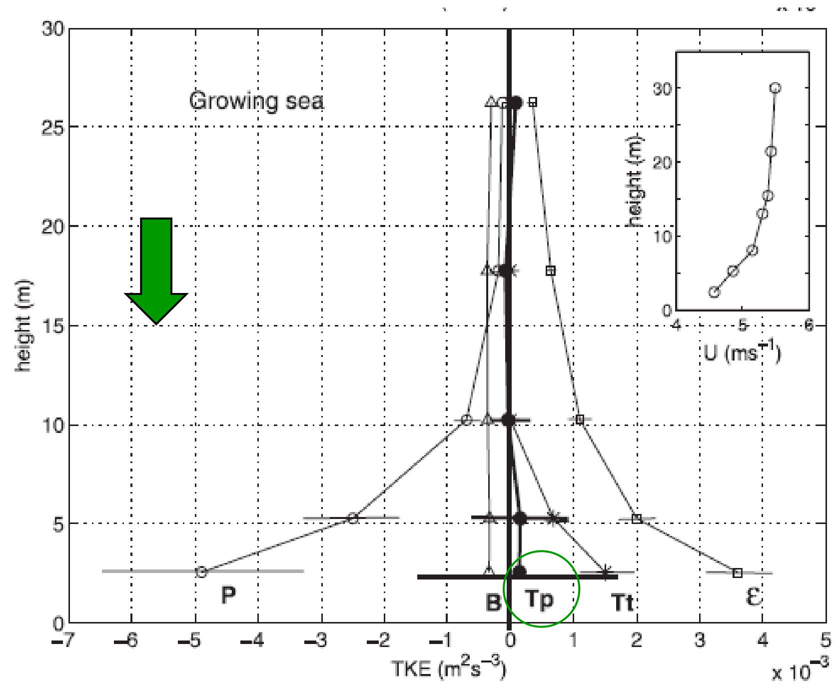
(photos: Tihomir Hristov)

Swell modulation of the lower MABL

Swell



Wind sea



(Semedo et al. 2009)

$$\tau_{tot} = \tau_{turb} + \tau_{wave}$$

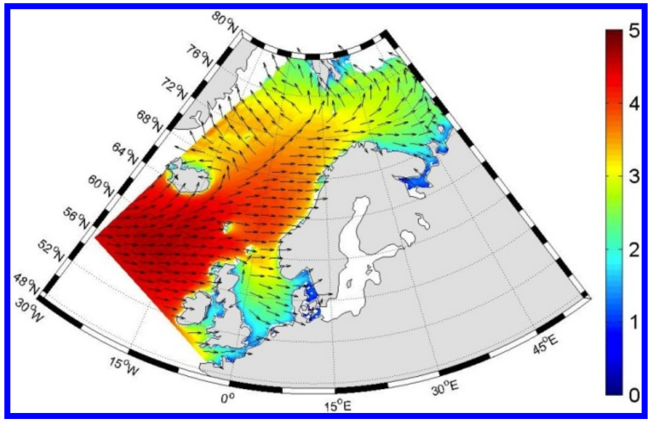
>0 (+)

<0 (-)

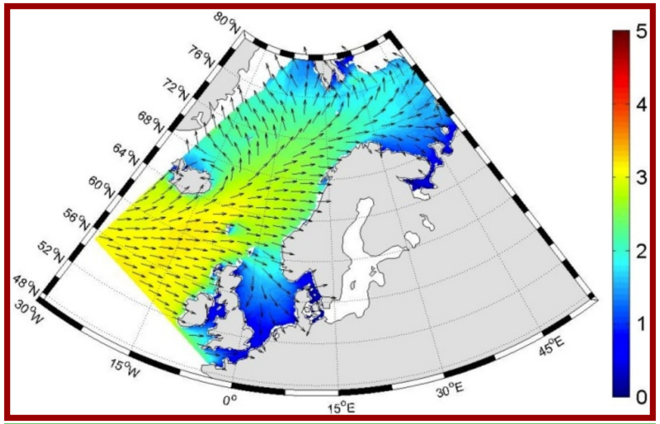
T_p – Pressure transport term

DJF – seasonal mean SWH and U10

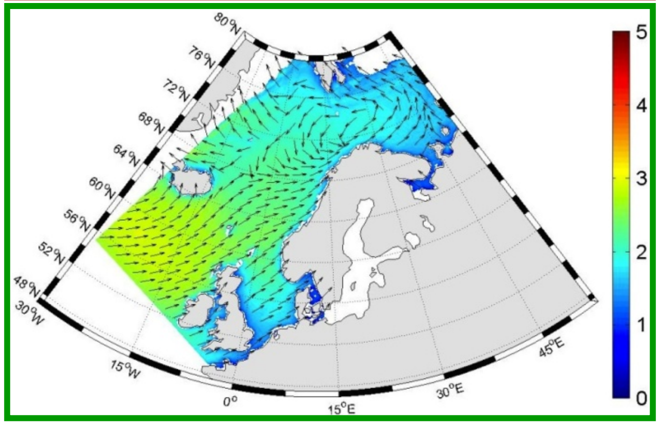
Hs



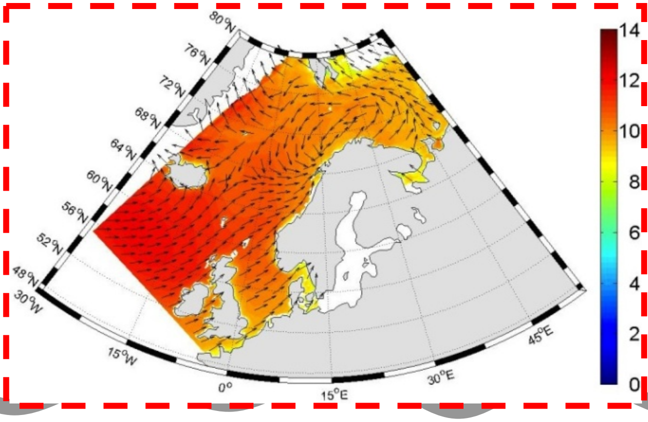
Swell



Sea



u10



Winter (total), Hs and swell and wind sea significant wave heights means.

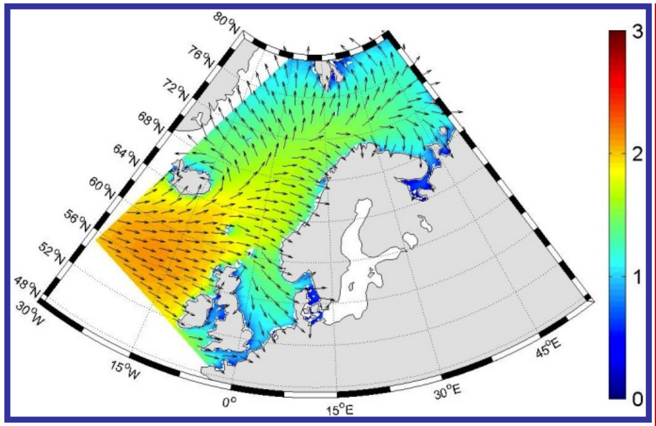
Swell > wind sea (comparable in some areas, though)... Except in the **North Sea**.

North Sea:

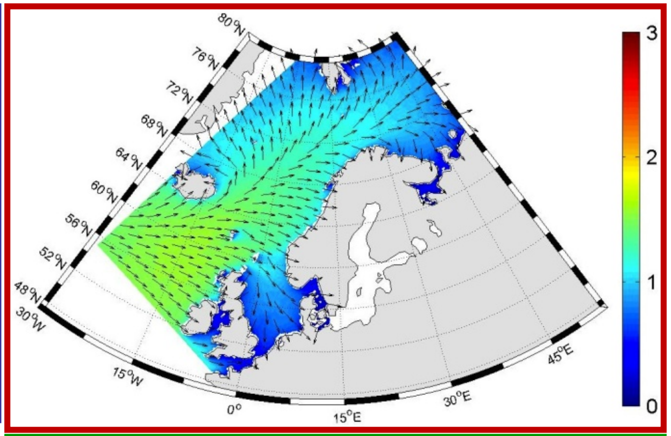
- Higher wind seas
- ~Δ90º difference in direction

JJA – seasonal mean SWH and U10

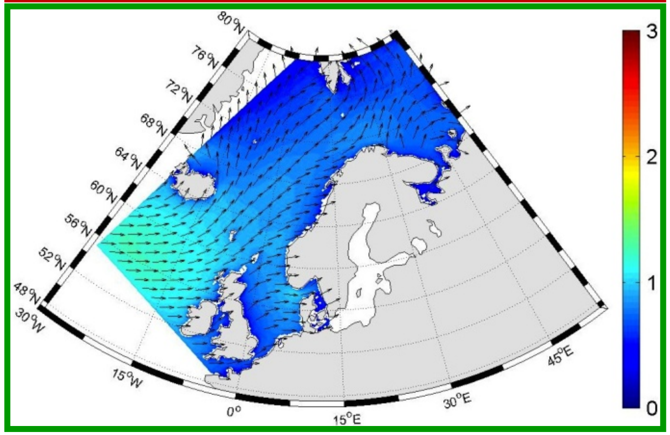
Hs



Swell



Sea



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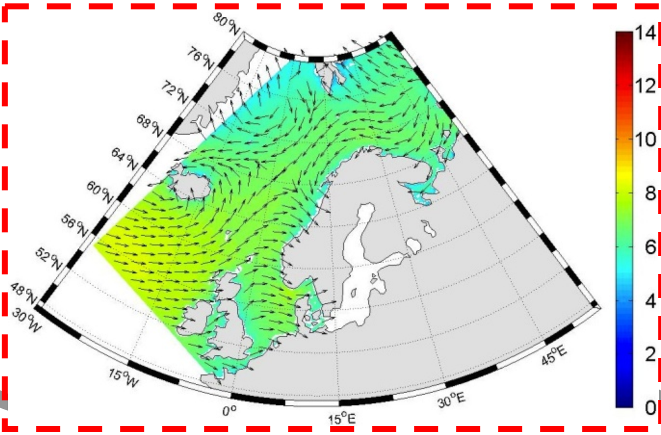


Summer (total) Hs and swell and wind sea significant wave heights means.

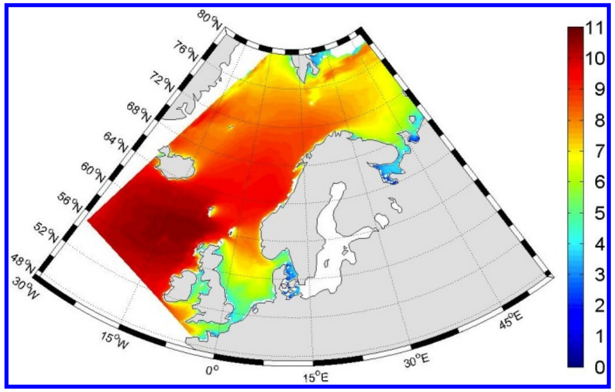
Swell > wind sea...

North Sea:

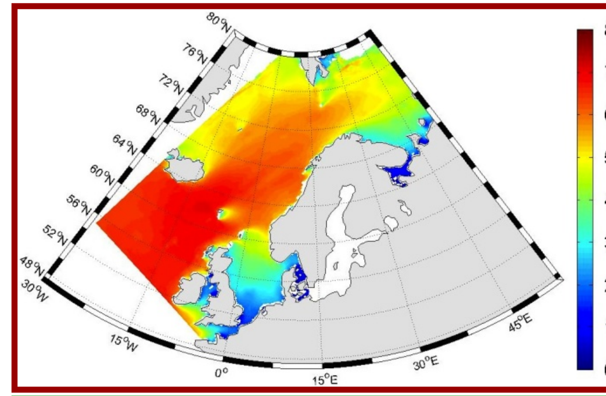
- Wind sea ~ swell heights
- ~Δ90º difference in direction

DJF – 99% percentile

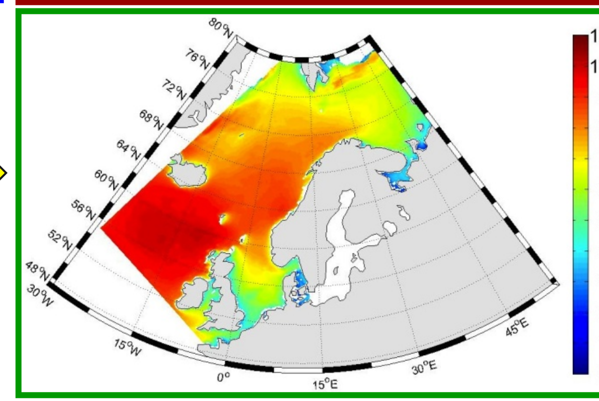
Hs



Swell



Sea



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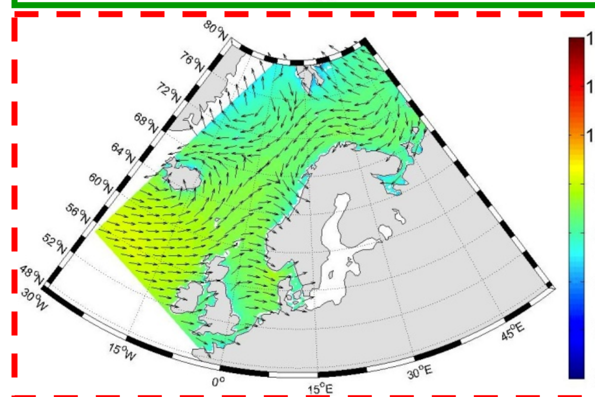


Winter 99% percentile of (total) Hs and swell and wind sea significant wave heights.

Extreme waves in winter are dominated by wind seas.

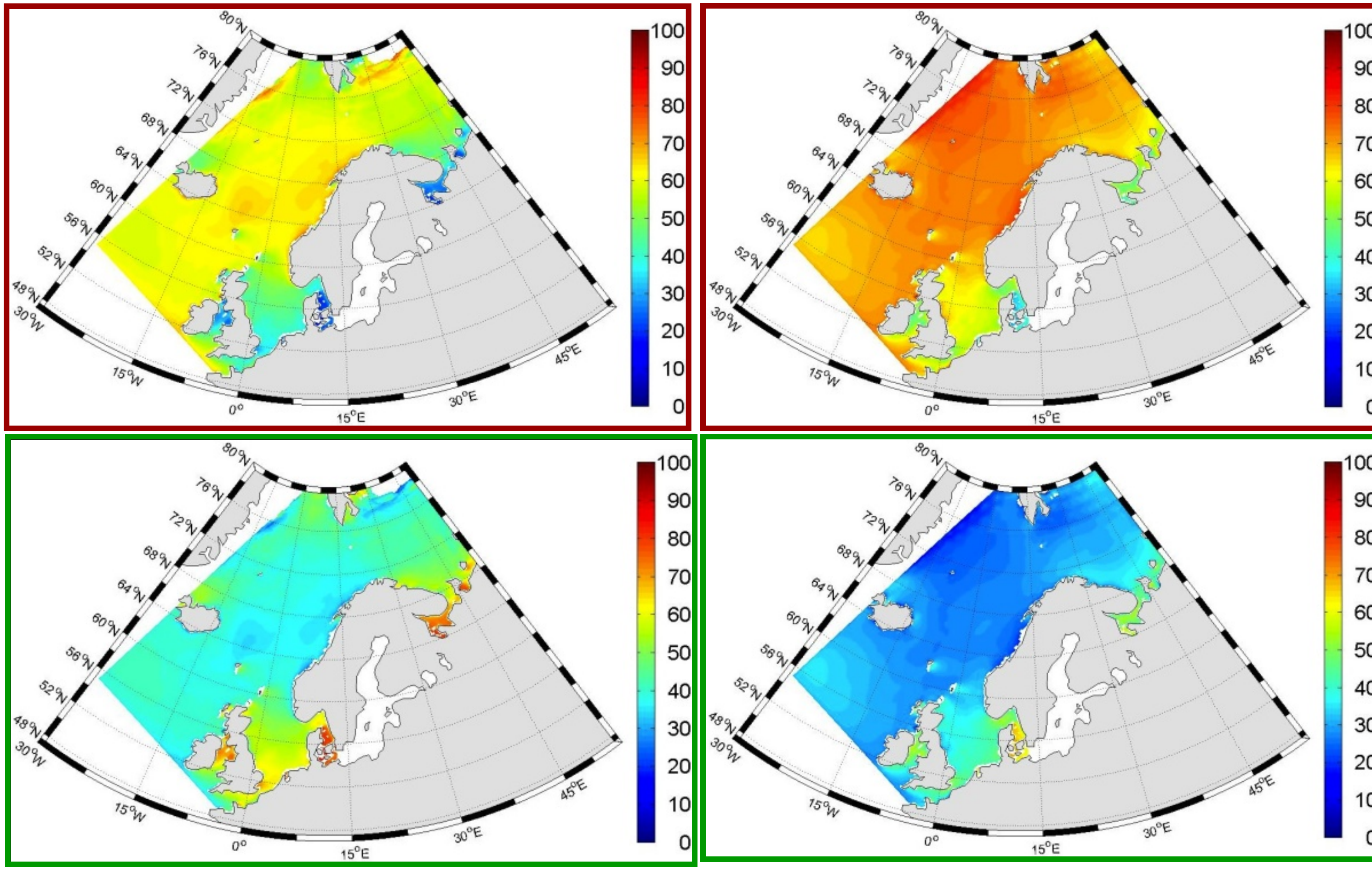
Largest diference in the **North Sea**.

DJF and JJA wind sea and swell energy weight

DJF **JJA**

W_s Swell

W_w Sea



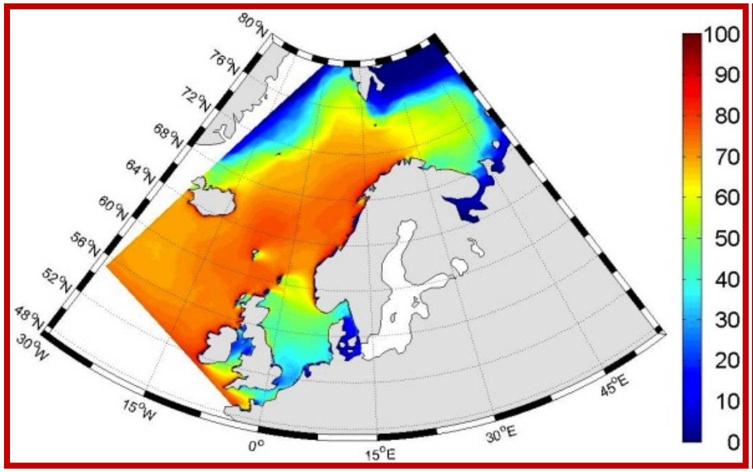
$W_s = E_s(f)/E_{tot}(f)$

$W_w = 1 - W_s = E_w(f)/E_{tot}(f)$

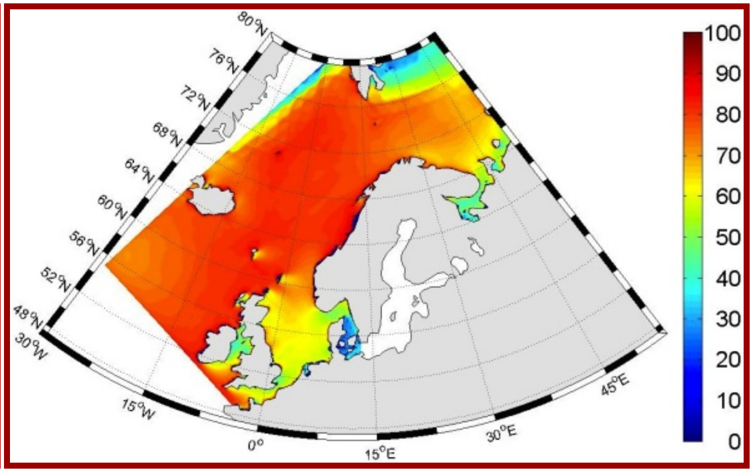
Swell carries more energy, except in the **North Sea**, in DJF!

DJF and JJA swell probability $[P(c_p/u_{10})>1.2)]$

DJF



JJA



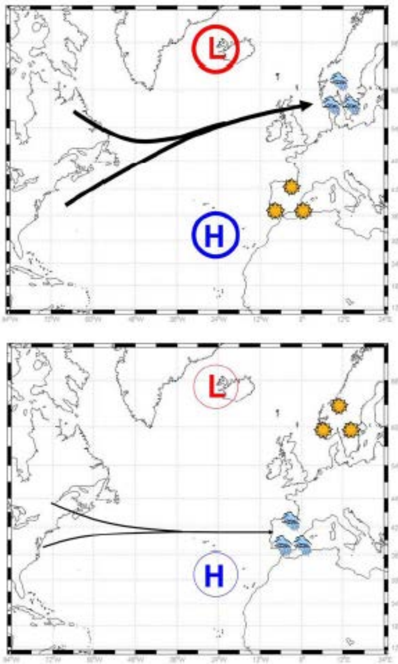
How “swellish” are the Nordic Seas?

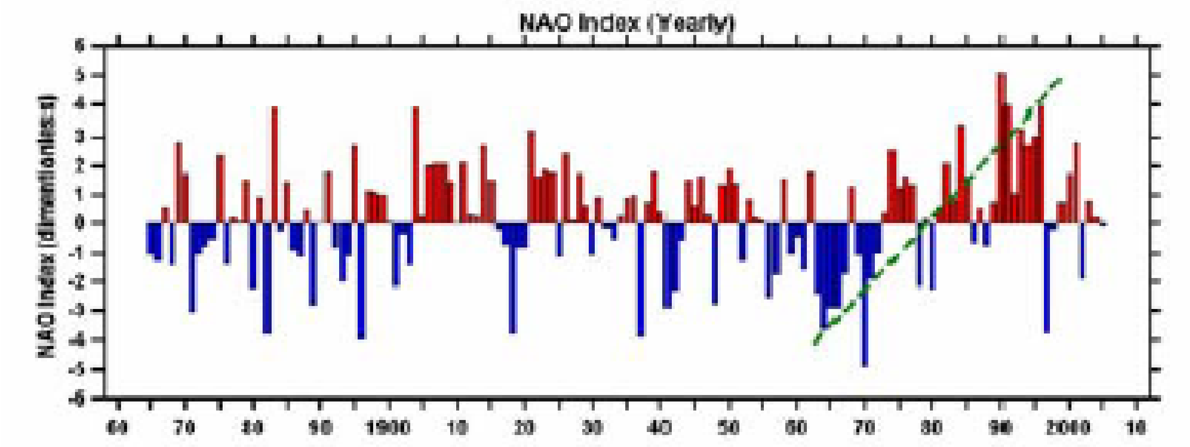
Taking into account that the wave age is an assessment of the swell domination, the probability of having a higher wave age than 1.2 can answer that question.

Swell prevails... But less than in the open ocean.

North sea: wind sea is more prevalent than swell in DJF (low fetch effect).

(Large scale) atmosferic forcing of wind sea and swell

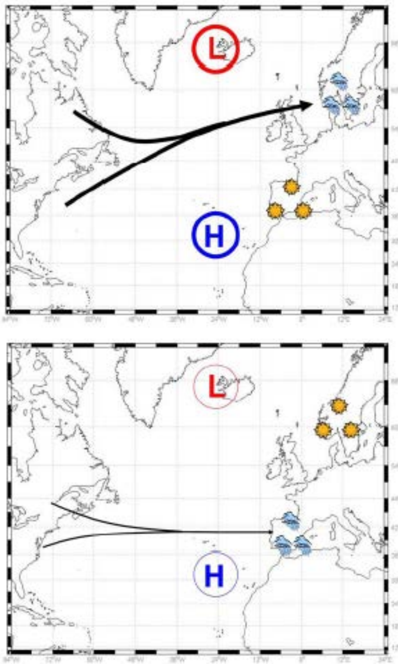


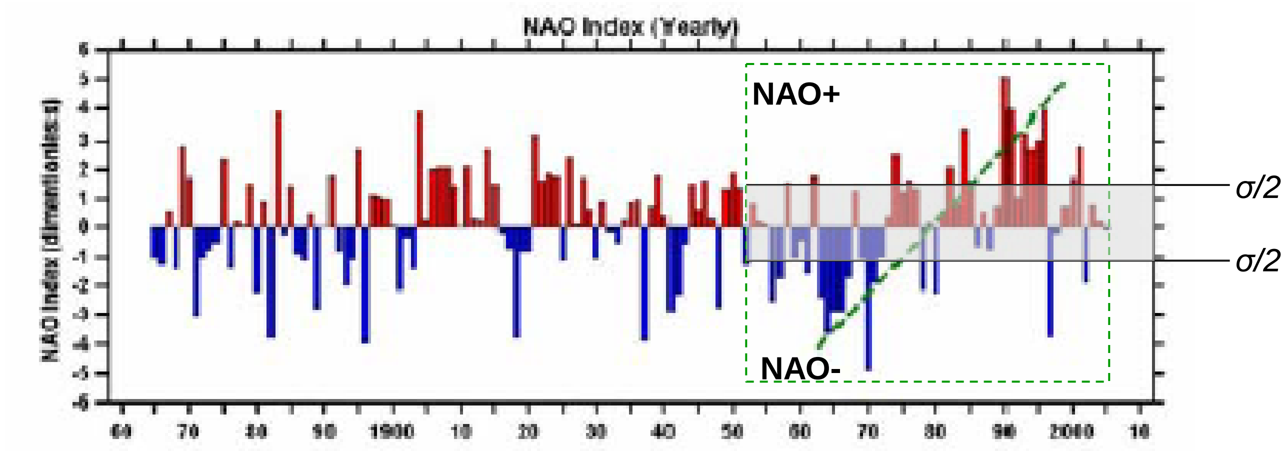


North Atlantic Oscillation

Considering the shape of the Nordic Seas **what is the role of storm tracking** and large scale atmospheric forcing in the wind sea and swell climates in the area?

(Large scale) atmosferic forcing of wind sea and swell





North Atlantic Oscillation

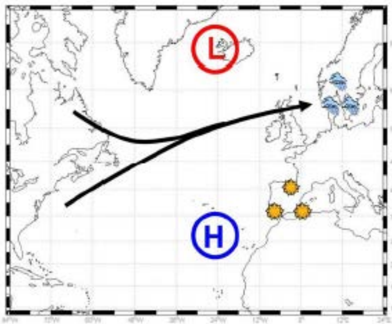
Positive and negative NAO regimes:

NAO+

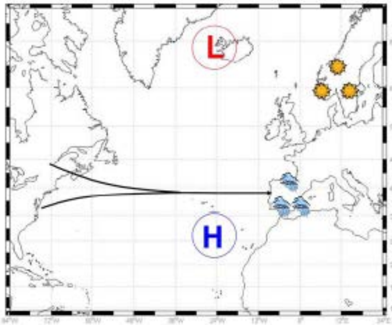
NAO-

DJF NAO+ and NAO- wave climate in the Nordic Seas

NAO+



NAO-

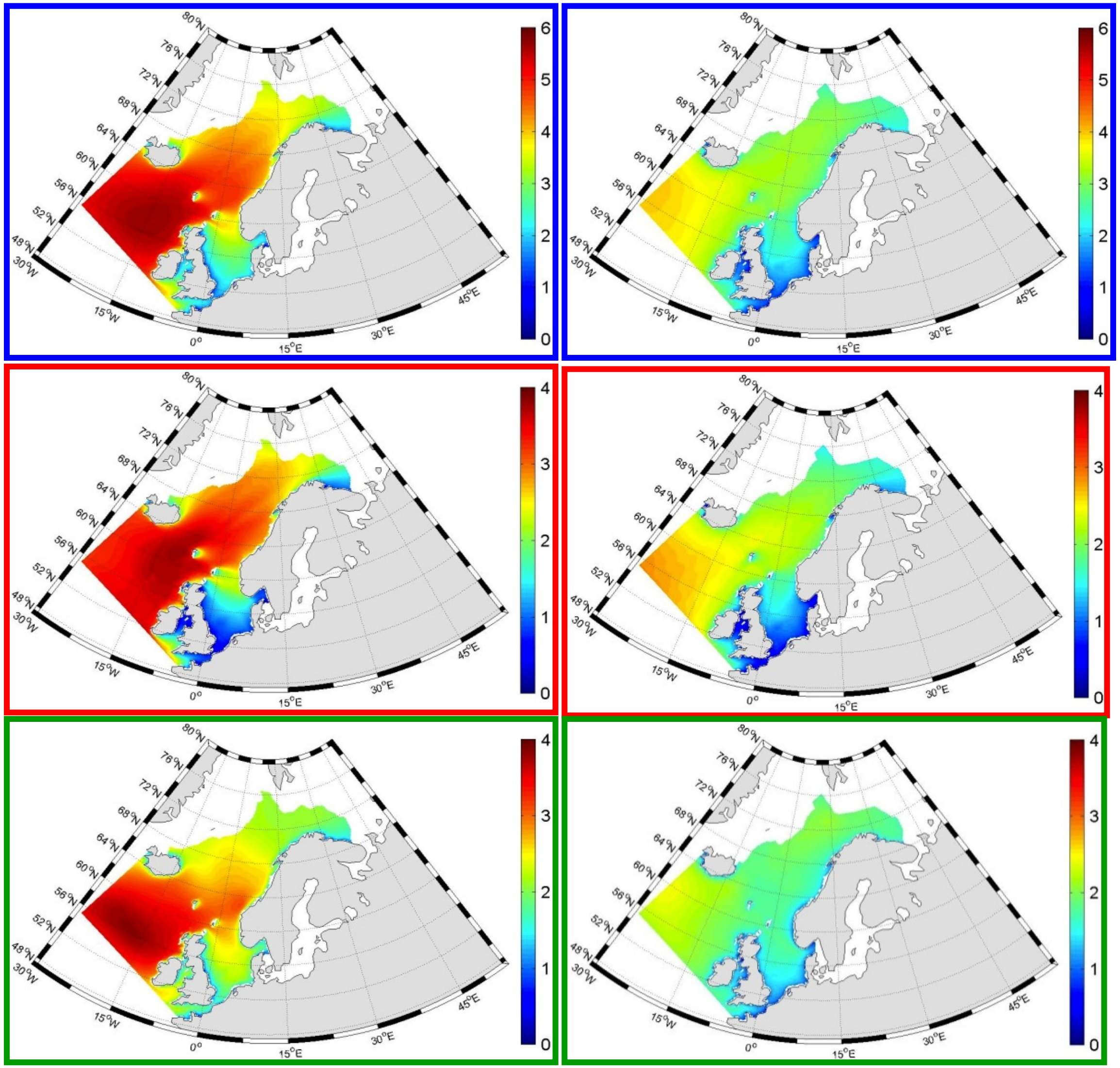


NAO+ | NAO-

Hs

Swell

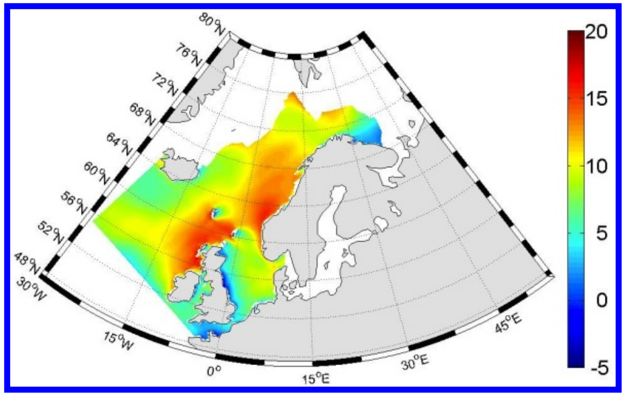
Sea



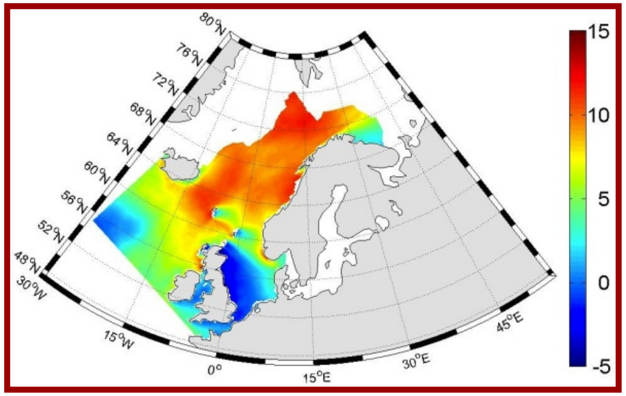
Color scale varies between panels!

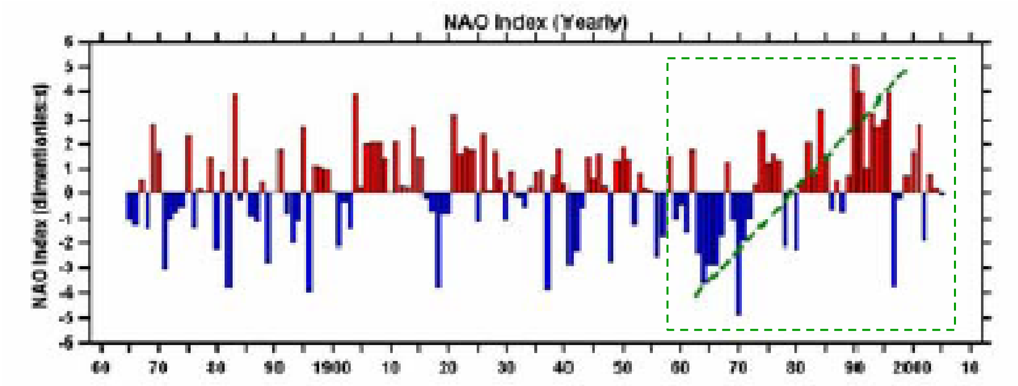
DJF decadal trends (cm/decade) for 1958-2001

Hs

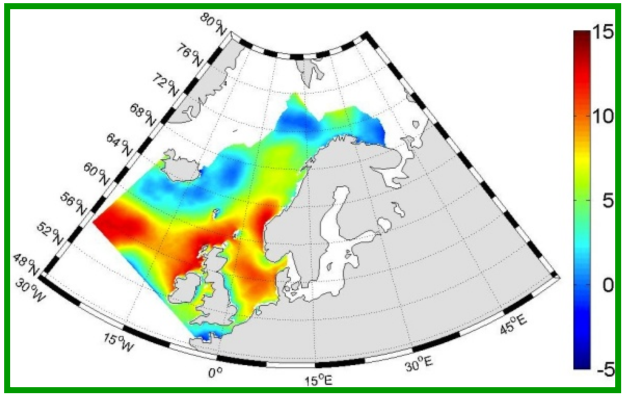


Swell





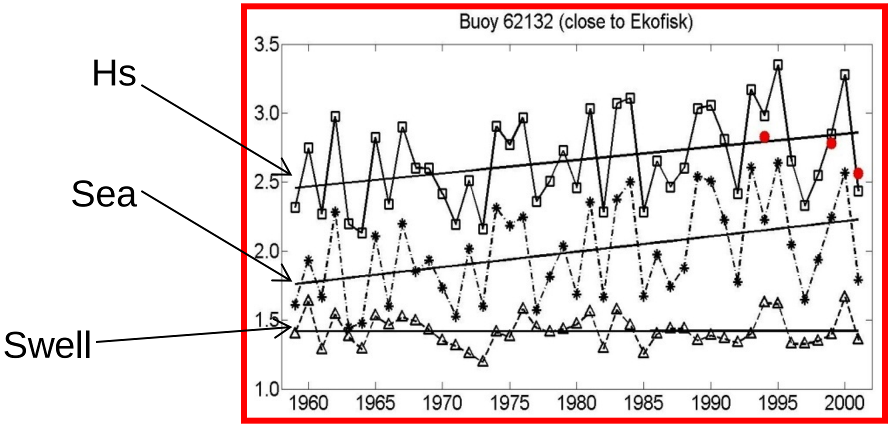
Sea

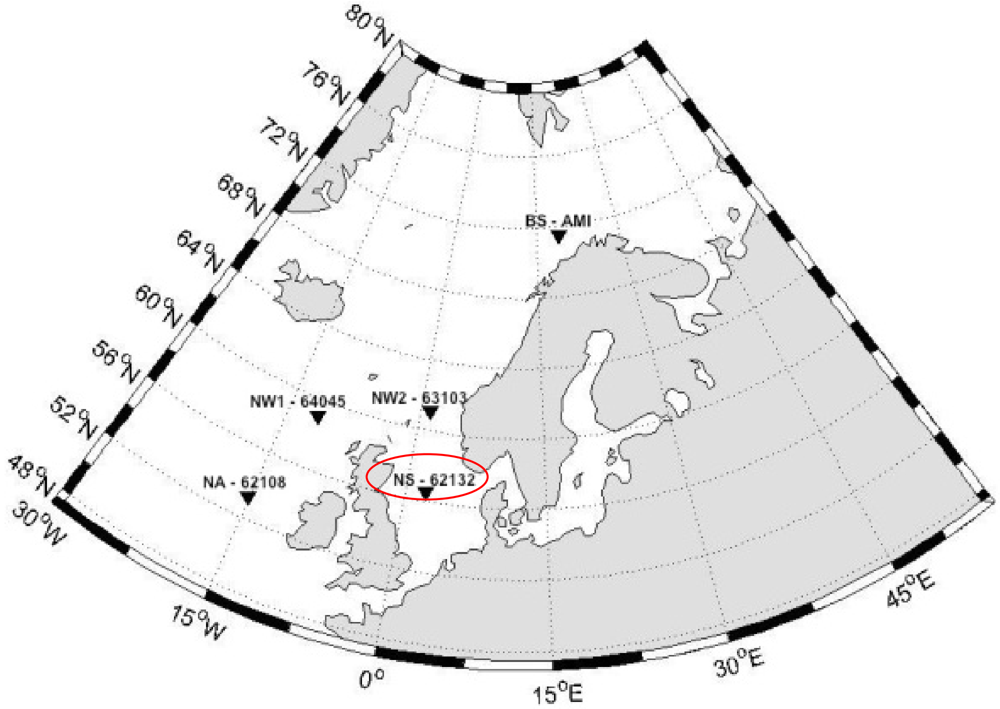


What is the **propagated effect of swell** in the Hs trends dring the studied period?

DJF decadal trends (cm/decade) for 1958-2001

Winter (total) Hs and swell and wind sea significant wave heights decadal trends.





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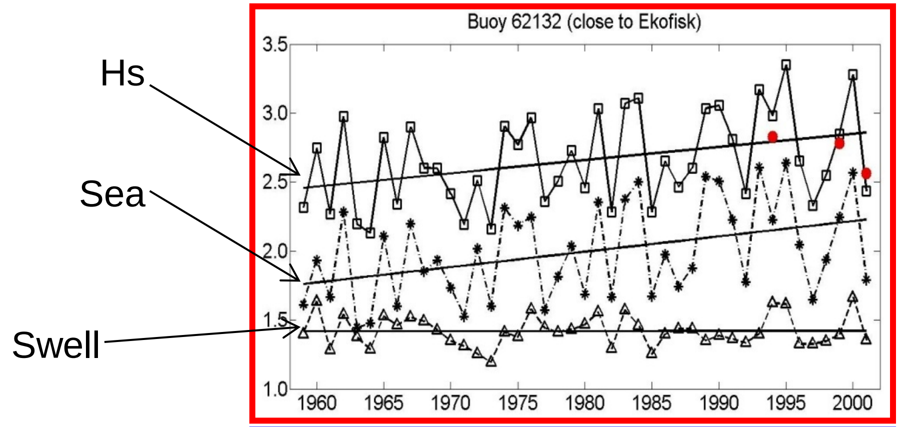
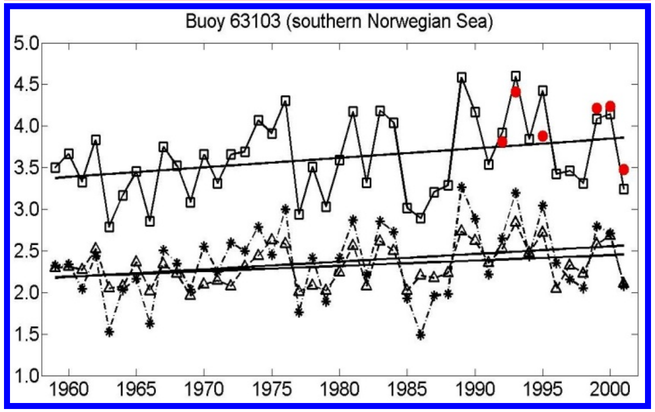
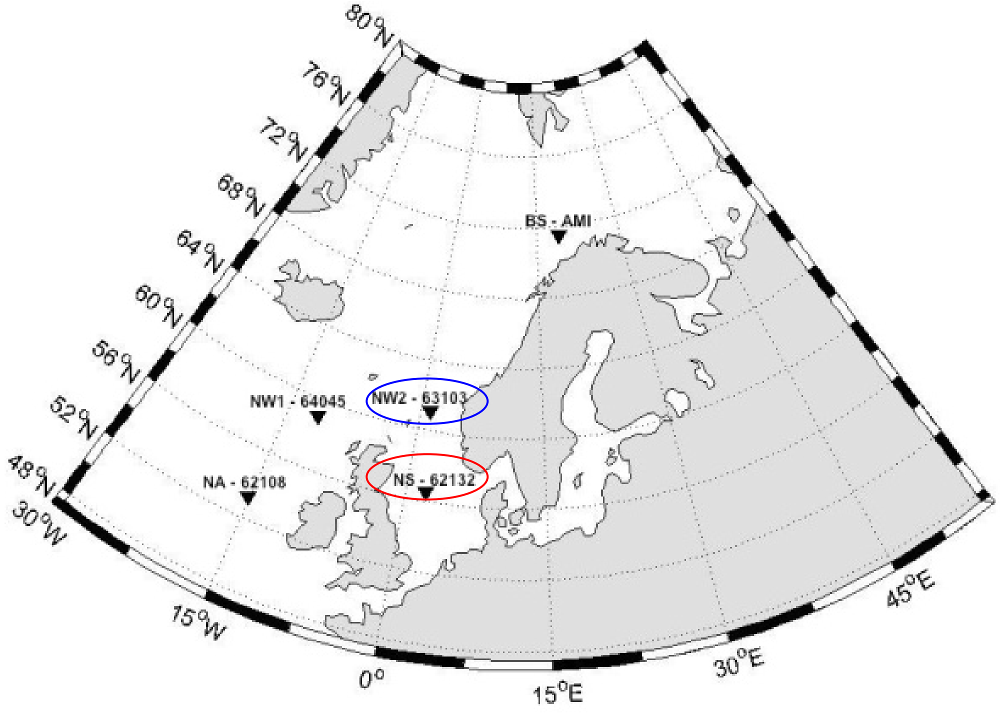
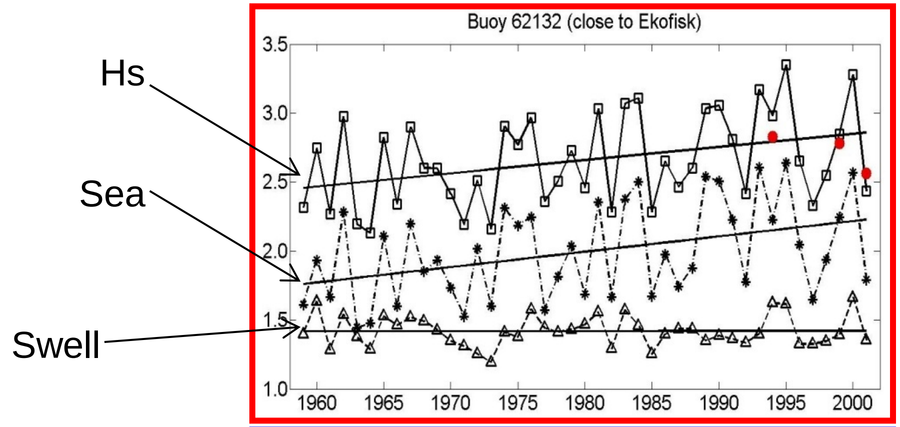


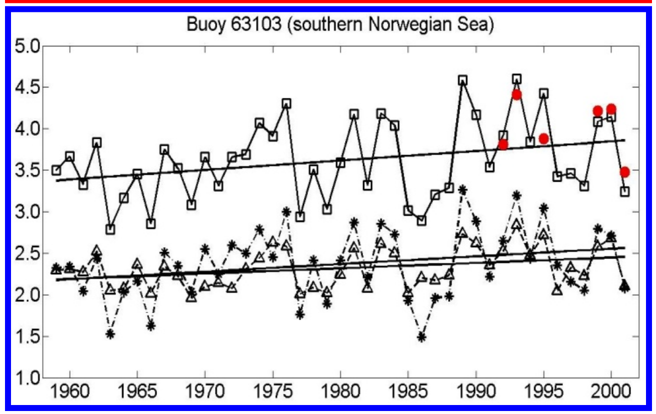


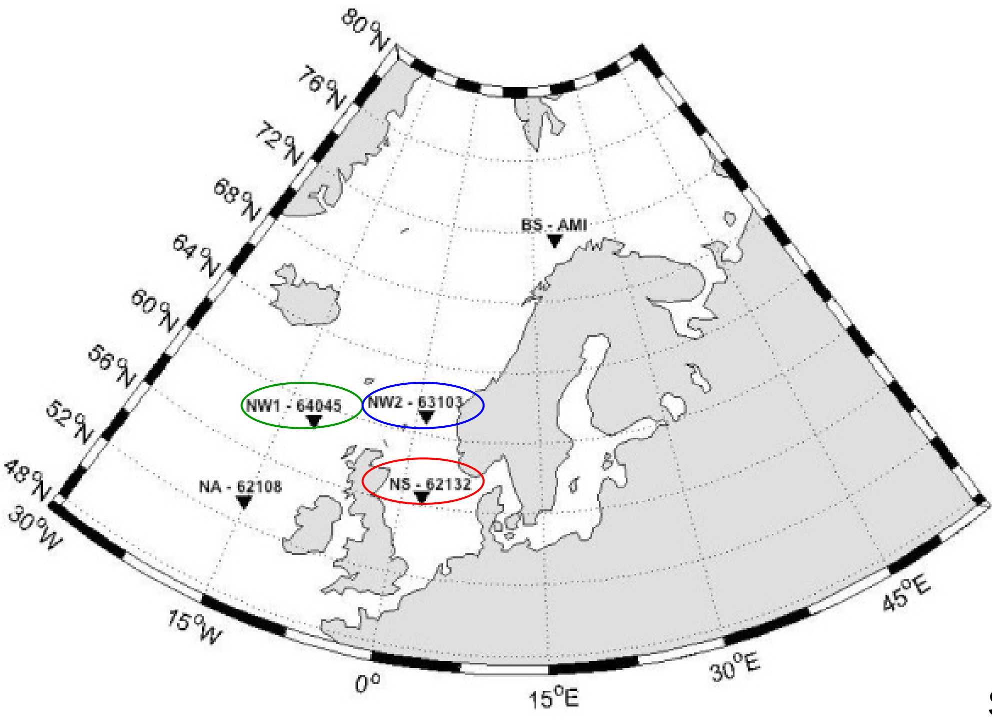


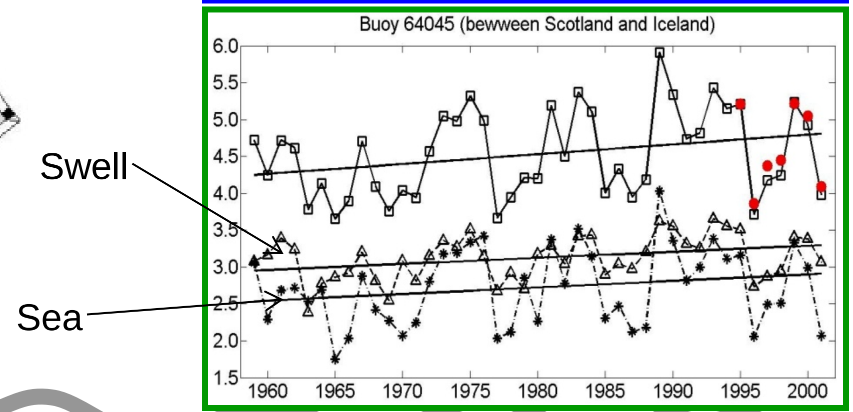
DJF decadal trends (cm/decade) for 1958-2001

Winter (total) Hs and swell and wind sea significant wave heights decadal trends.



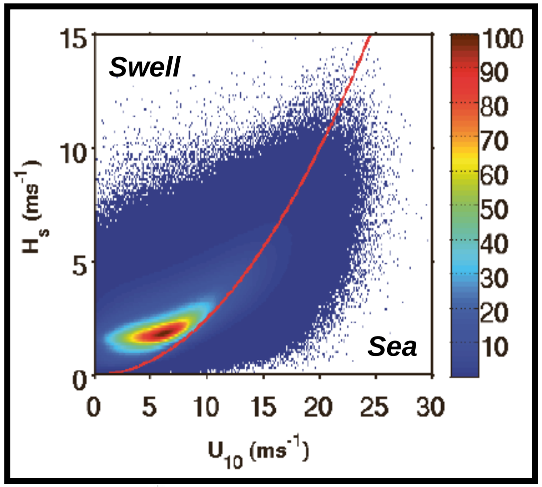




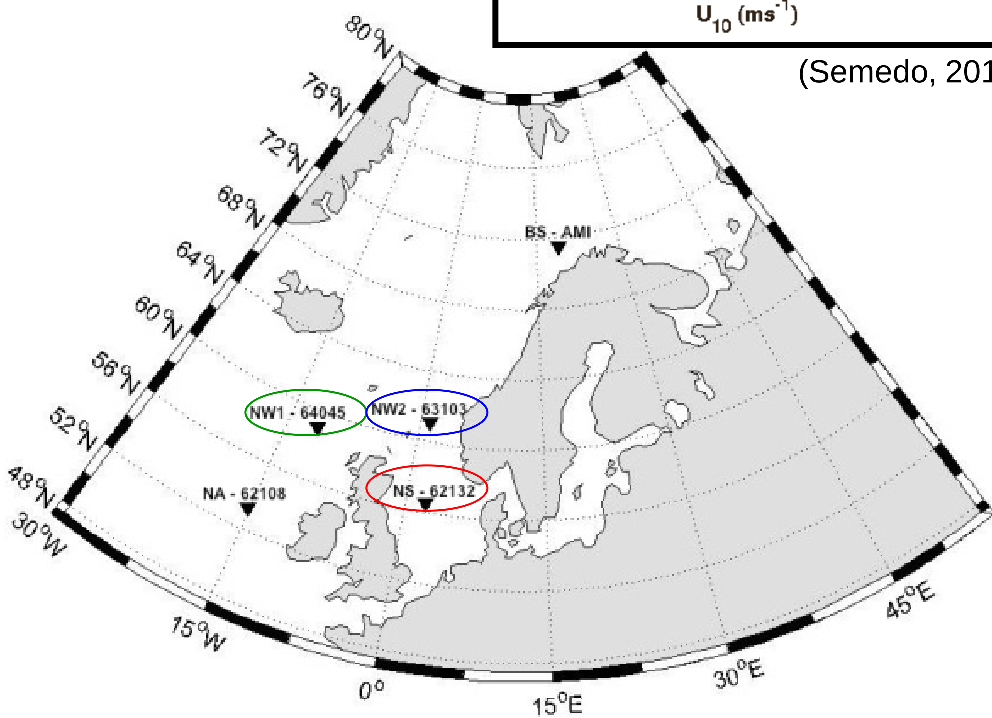


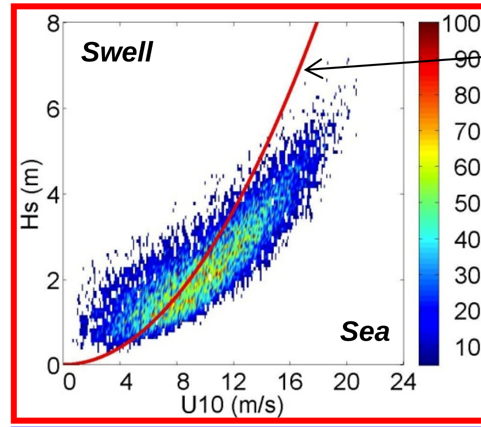
DJF Hs and u10 scatter plots

Global ocean from ERA-40

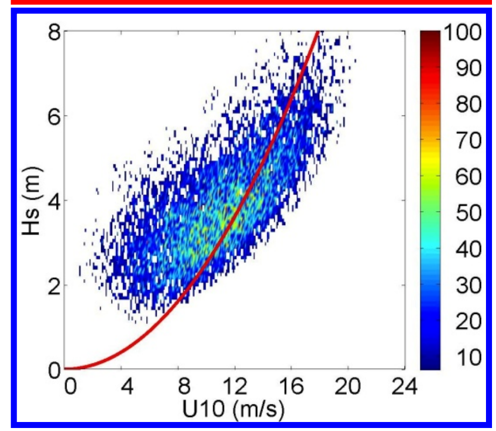


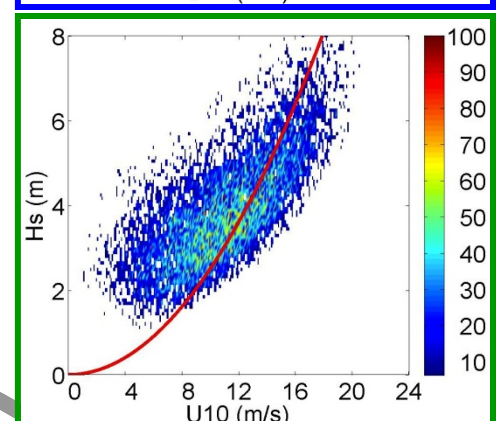
(Semedo, 2010)



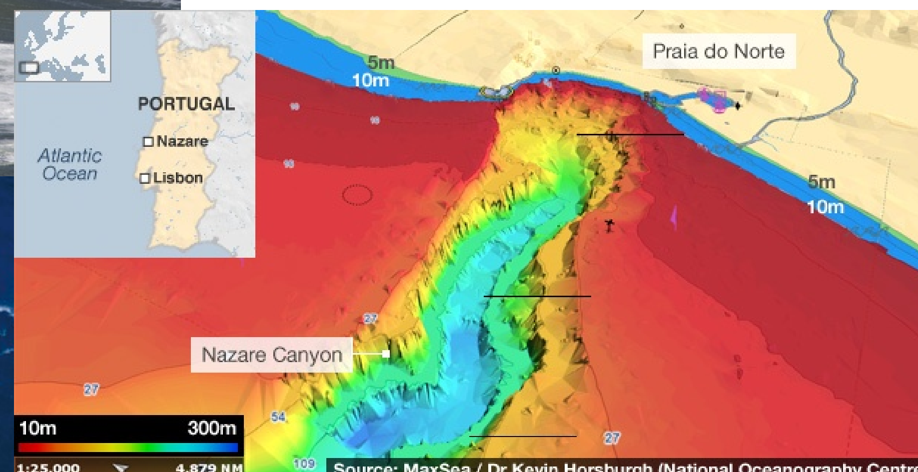


$$H_s = 0.025U_{10}^2$$





Riding mountains outside Nazaré (Portugal´s west coast)



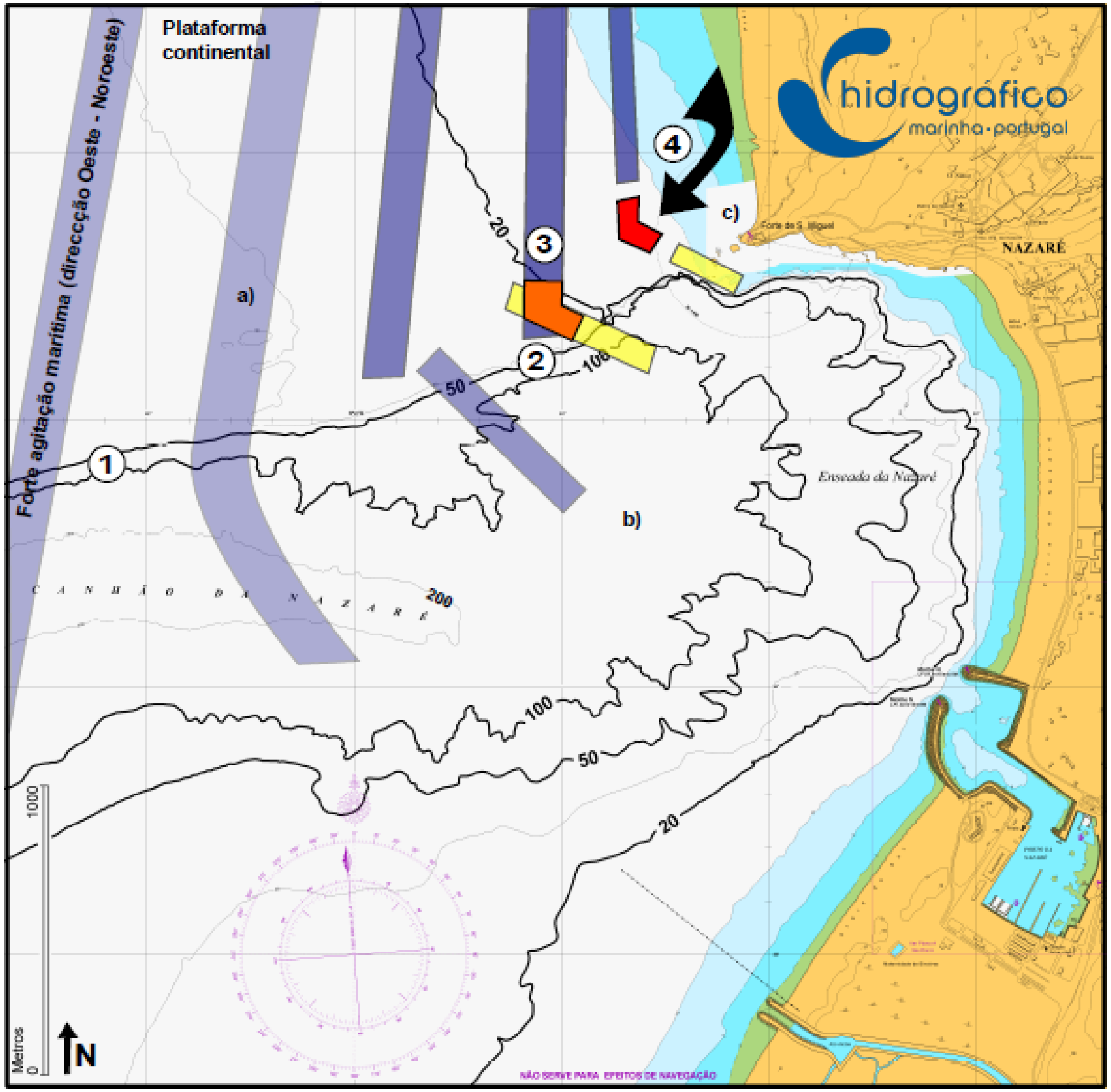
Garret Macnnamara

Movie

First record: 90 ft wave (2011)
Second record: 111 ft (this week)

Wave induced currents:

http://youtu.be/g2HRglsE9kU



a) Frentes de onda; b) Cabeceira do canhão submarino da Nazaré; c) Praia do Norte

Onda de 30 metros na Nazaré. Como a podemos explicar ?

EMPOLAMENTO DA ONDA NA APROXIMAÇÃO À PRAIA DO NORTE

Com a chegada à região costeira de Portugal continental de ondulação forte proveniente dos quadrantes Oeste / Noroeste, verifica-se:

1 Refracção da onda por diferença de profundidades entre a plataforma continental e o canhão. Este efeito leva à mudança de direcção da onda sobre o canhão (onde a onda viaja mais rápido).

2 Galgamento de um degrau topográfico (desnível vertical do fundo). A rápida redução de profundidade origina o empolamento da onda (redução do seu comprimento de onda e a amplificação da sua altura). Este efeito ocorre também de forma gradual com a aproximação da onda à costa.

3 Interferência positiva entre a onda proveniente do canhão e a onda que atravessa a plataforma continental norte. Este efeito promove novo empolamento no ponto de intersecção destas duas ondas.

4 Deriva Litoral. A ondulação promove uma corrente junto à praia que escoa de norte para sul e que inflecte no cabo para o mar. Esta corrente é reforçada pelo empilhamento de água na enseada, a norte do cabo, que flui na mesma direcção e que intercepta a onda no sentido contrário à sua propagação. Este processo contribui adicionalmente para o empolamento da onda.

O efeito combinado destes processos aumenta significativamente a altura da onda, que pode alcançar assim valores muito superiores aos registados ao largo. Estas ondas rebentam quando a sua altura ultrapassa aproximadamente a profundidade local.

Conclusions

Thank you! Comments? Questions?

Wind Sea and Swell Waves in the Nordic Seas

- The wind sea vs. swell balance in the Nordic Seas (Norwegian, Barents, and North Seas) is different from the open Ocean, particularly in the North Sea.
- Fetch dimensions, sheltering effect, and storm track play an important and decisive role in this balance.
- Swell in less prevalent and has a less energy weight in the area, also compared to the open Ocean.
- Decadal variation of H_s is the low fetch area (in the North Sea) is mostly locally driven.
- The swell propagating effect (energy, swell prevalence, and long term variation) is stronger in the Norwegian Sea.