Wind waves as a source of noise in the Earth system: opportunities for monitoring the stratosphere

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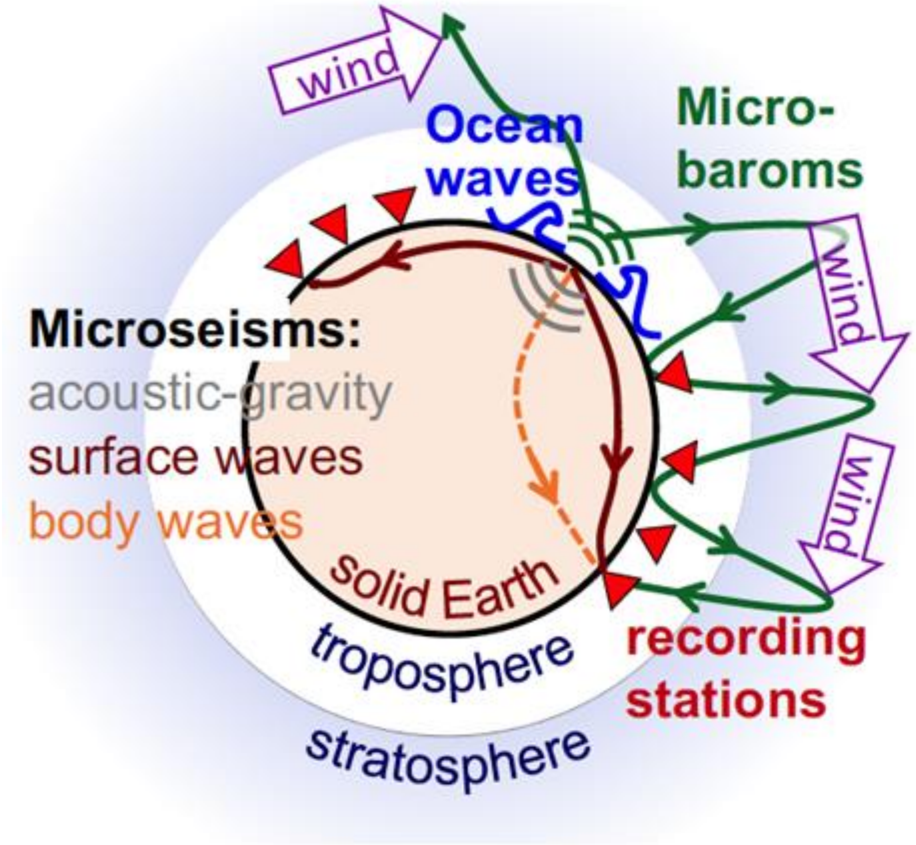
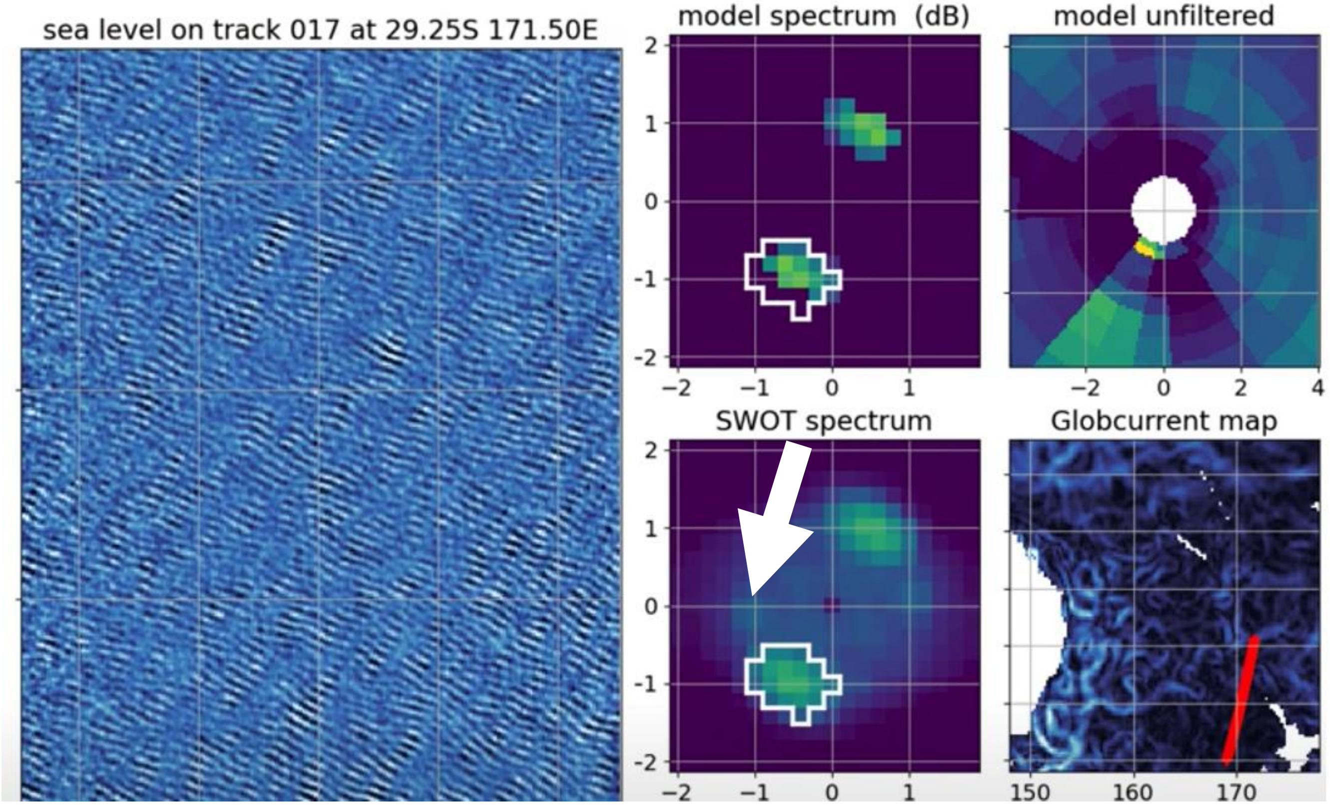


STRATSOUND project schematic

… and challenges for wave observation & wave modelling



SWOT sea level data. June 11, 2023

Outline

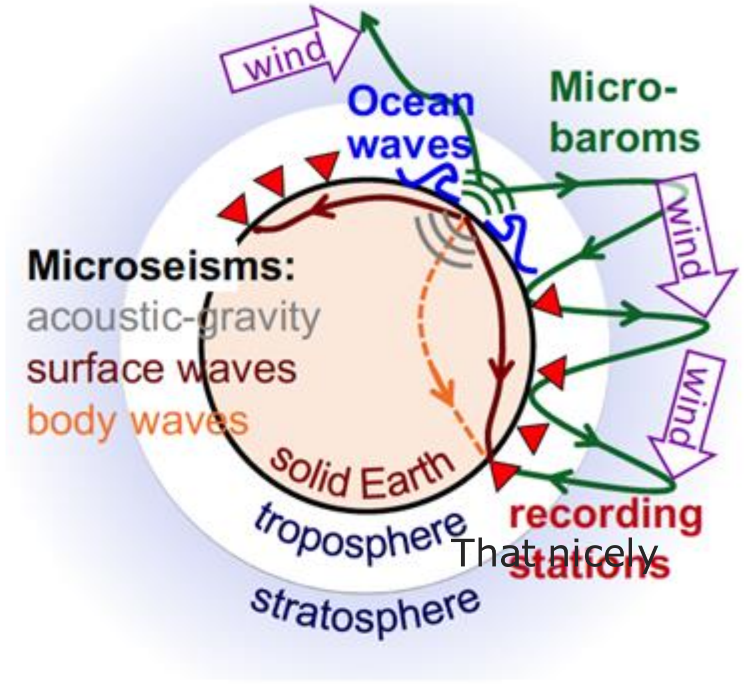
1. context: the STRATSOUND project

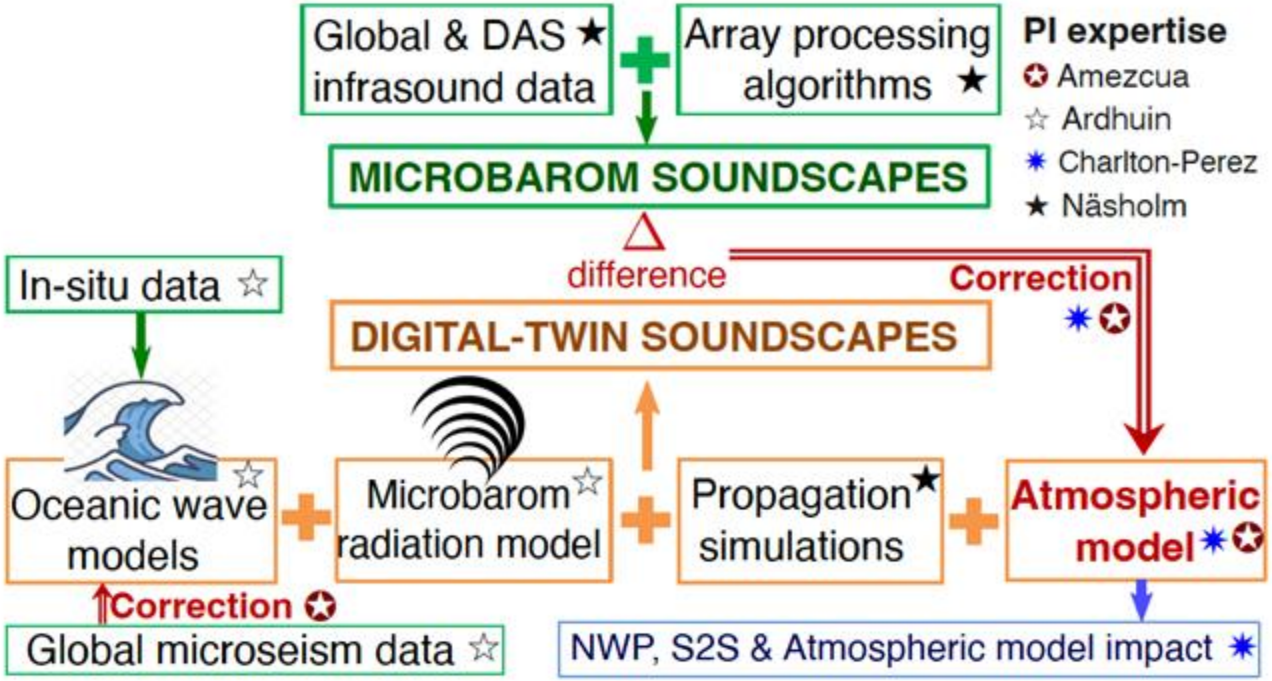
2. 2nd order wave properties and noise generation

3. spectral tail and energy balance

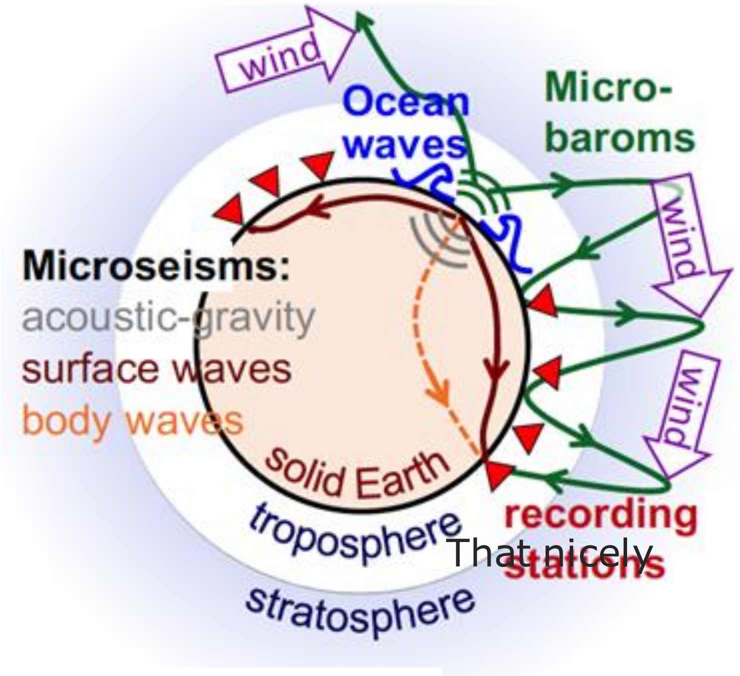
4. low frequency noise and coastal + iceberg reflection or scattering

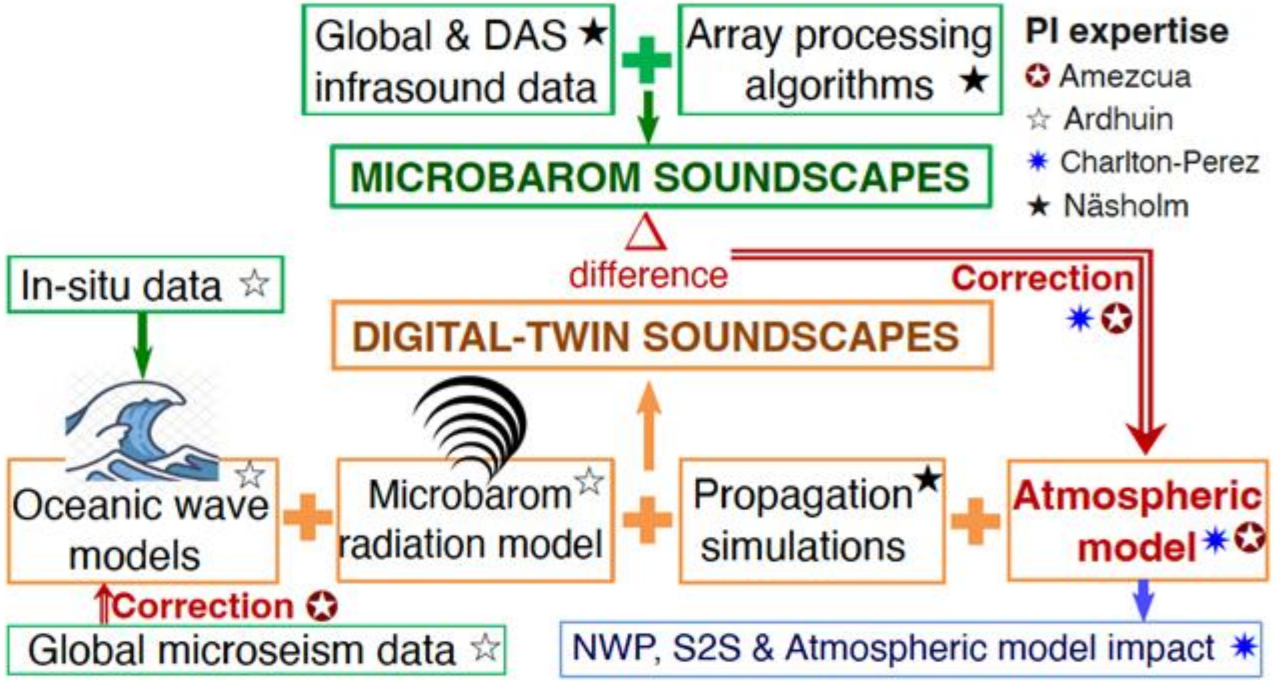
1. context: the STRATSOUND project

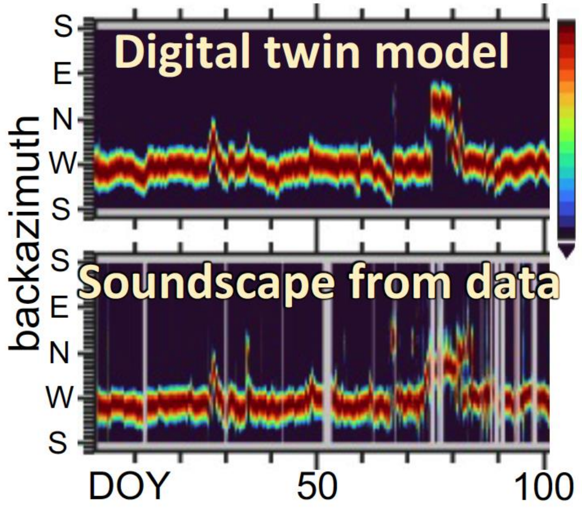


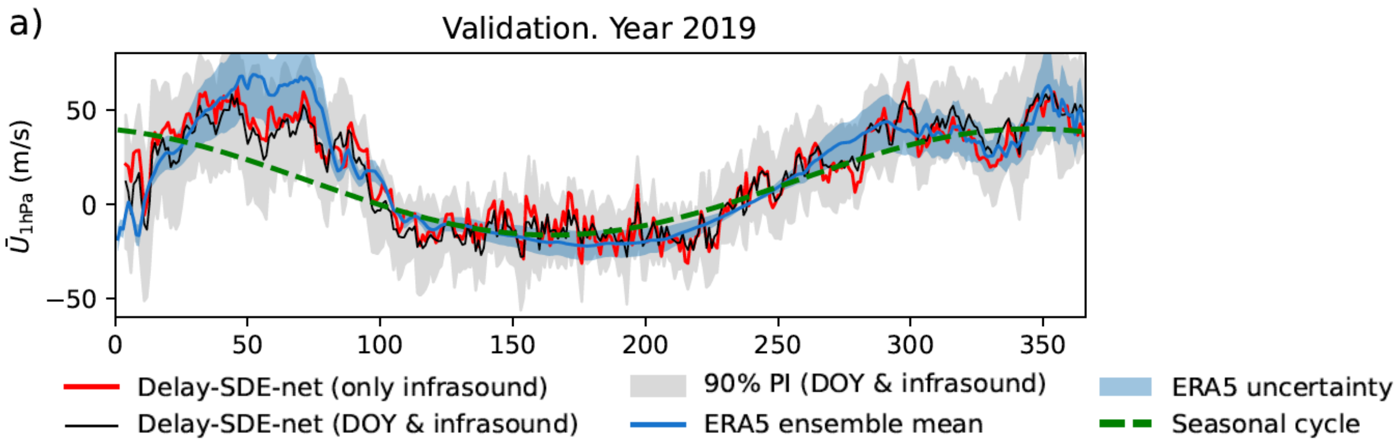


1. context: the STRATSOUND project





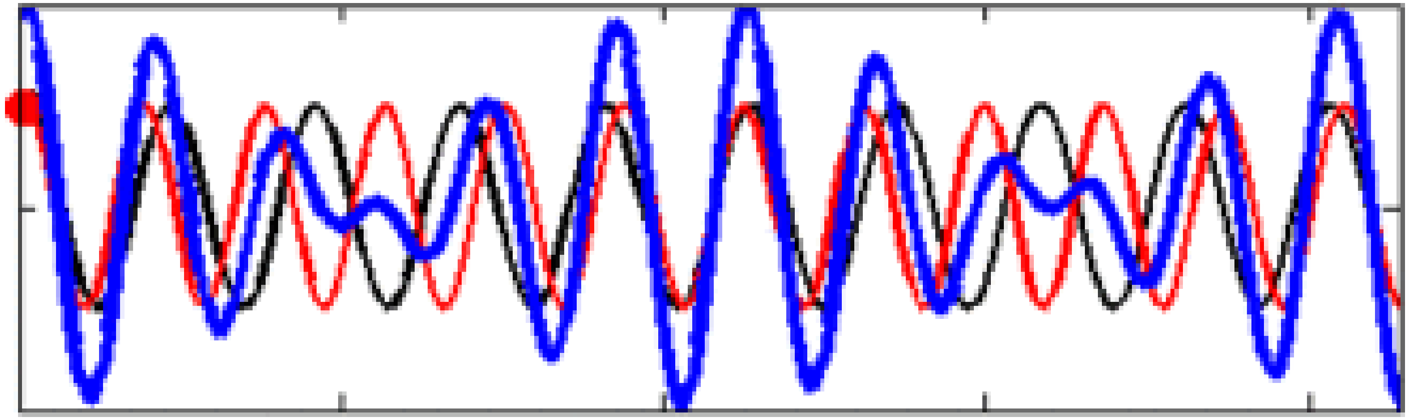




Vorobeva et al. (QJRMS, in press)

2. 2^{nd} order wave spectrum and noise generation

The superposition of waves gives wave groups …



There are two ways to see this surface elevation with $K = k_1 - k_2$, and $k = (k_1 + k_2)/2$
$\Omega = \sigma_1 - \sigma_2$

$$\zeta = a \cos(k_1 x - \sigma_1 t) + a \cos(k_2 x - \sigma_2 t) = 2a \cos[0.5 (K x - \Omega t)] \cos(kx - \sigma t)$$
$$= \mathbf{A(x,t)} \times \cos(kx - \sigma t)$$

(by the way, satellite altimeters measure wave groups … De Carlo & al. JGR 2023 …)

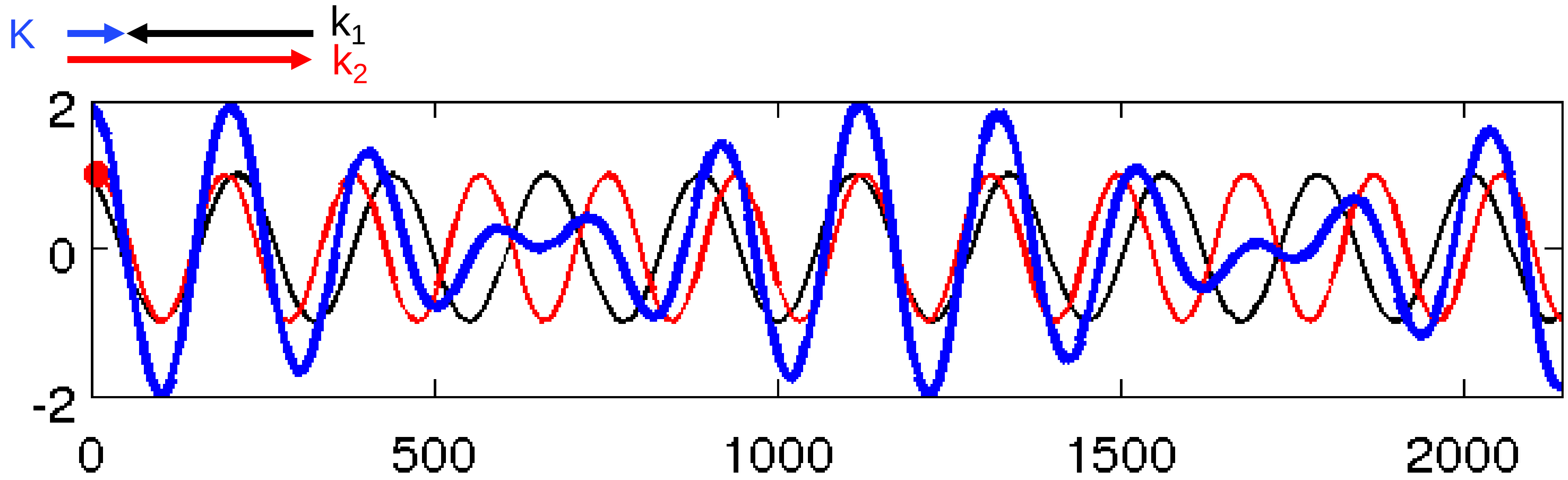
The envelope phase nicely travels at the group speed $Cg = \Delta\sigma / \Delta k$
What if the waves travel in opposite directions?

2. 2^{nd} order wave spectrum and noise generation

What if the waves travel in opposite directions?

Now $\Omega=\sigma_1+\sigma_2 \sim 2\sigma$
Speed of groups: $2\sigma/K$

and K=can be anything… including very close to 0: supersonic wave groups!



And because waves are weakly non-linear we get some second order pattern, a resonant forcing (equivalent surface pressure ~ u²) for seismic and acoustic waves

(Miche 1944, Longuet-Higgins 1950, Hasselmann 1963)

NB: for waves in intermediate / shallow water, be carefull with the bottom

(Ardhuin & Herbers JFM 2013)

2. 2^{nd} order wave spectrum and noise generation

The power spectral density of the « equivalent surface pressure », is (Hasselmann 1963)

$$F_{p2,\mathrm{surf}}(\mathbf{K} \simeq 0, f_s) \simeq \rho_w^2 g^2 f_s \int_0^{\pi} E(f,\theta)E(f,\theta+\pi)\,\mathrm{d}\theta.$$

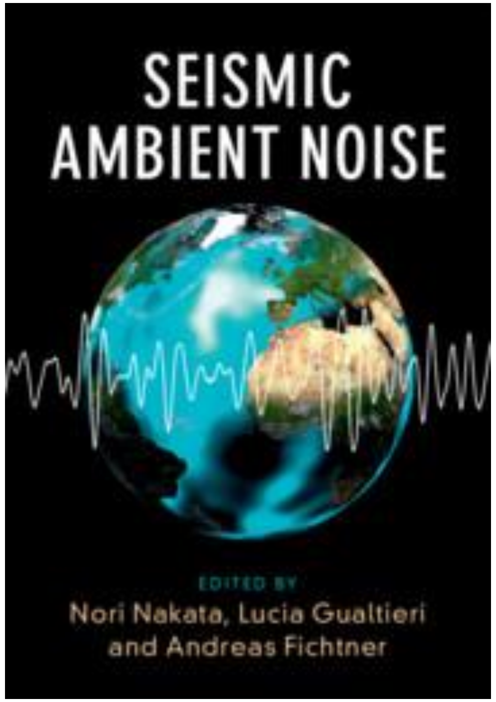
With units of $Pa^2\ m^2\ s$, and fs = 2 f.

E(f,θ) is the directional wave spectrum that can be observed (with stereo video systems) or modeled with WAM or WAVEWATCH III

This expression is valid for all K << k(f) : Fp2 is white around K=0.

Another way to write it: **$Fp2(fs)= \rho\ g^2 f\ E^2(f)\ I(f)$** (Farrell & Munk 2009)

$= \rho\ g^2 f \int E^2(f,\theta)\ H(f,\theta) d\theta$ (Ardhuin & al. 2021)



ocean is **coupled** to the atmosphere ➞ microbaroms

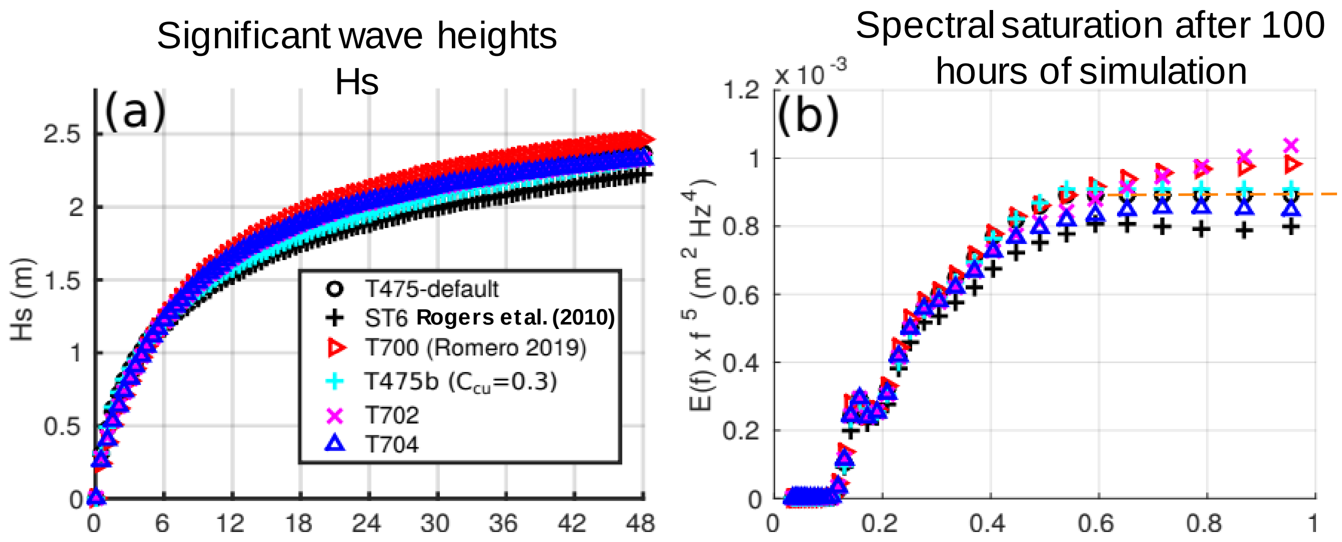
microbaroms propagate through stratosphere ➞ stratospheric monitoring

More details: De Carlo et al. (GJI 2021)

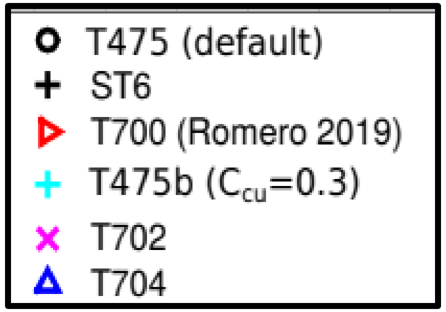
3. Spectral tail and energy balance: how good is your I(f)?

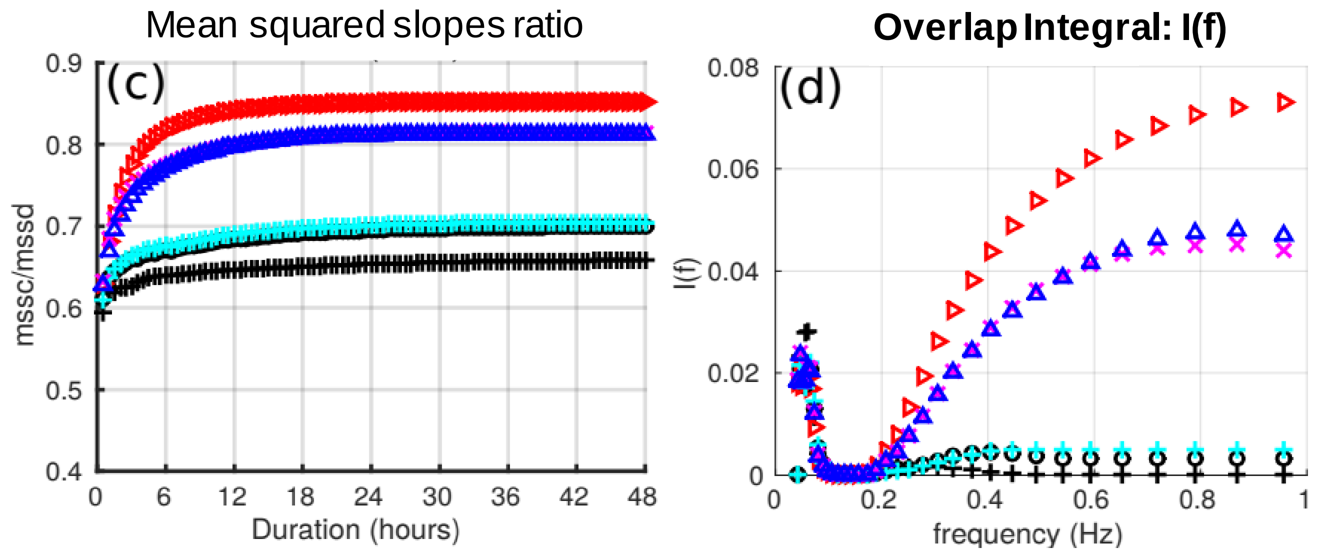
(alternative slide title: the ECMWF model is 1 order of magnitude off)

Impact of dissipation parameterization: **IDEALIZED TESTS (uniform ocean)**



Effect of the imposed tail





The Overlap Integral :

$$I(f) = \int_0^{2\pi} M(f,\theta)M(f,\theta+\pi)\mathrm{d}\theta.$$

Directional distribution of wave energy:

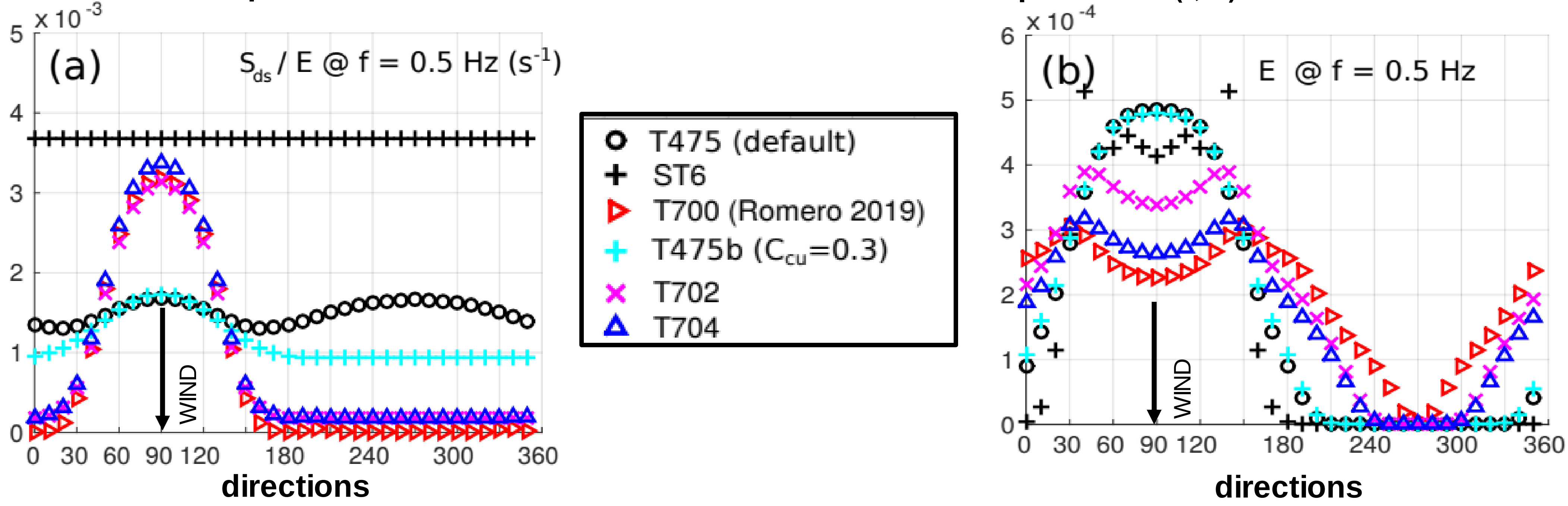
$$M(f,\theta) = E(f,\theta)/E(f)$$

2023

3. Spectral tail and energy balance: why does Romero (2019) work?

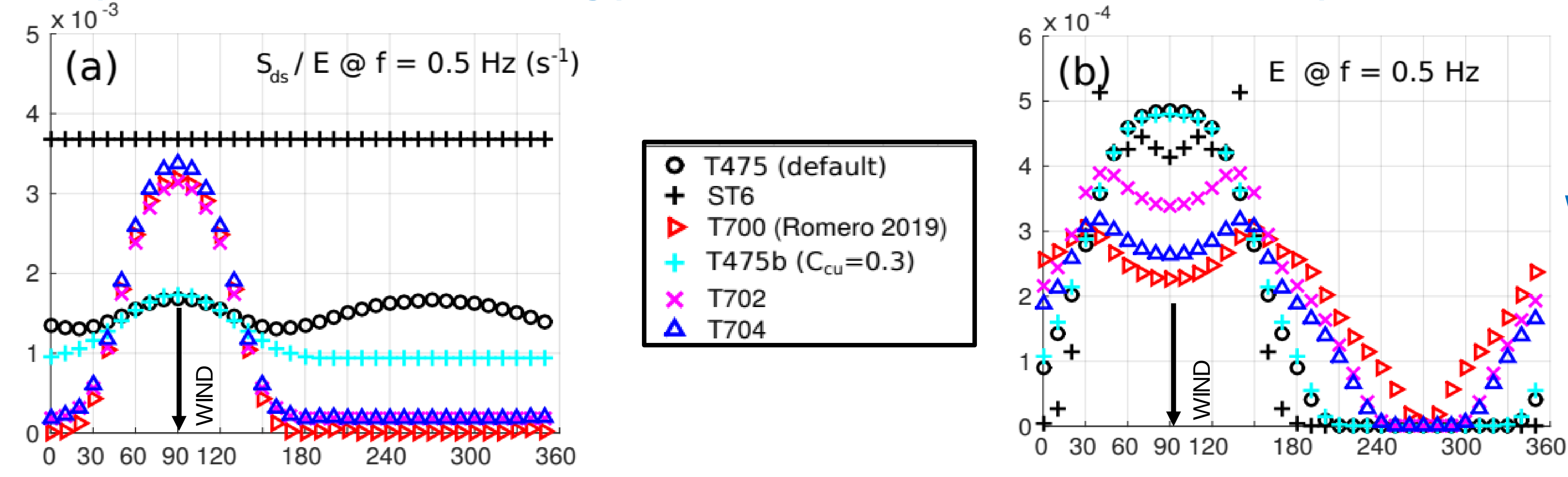
main novelty of Romero (2019): highly anisotropic dissipation → very different directional spectra

Normalized dissipation Sds/E | **spectrum E(f, θ)**

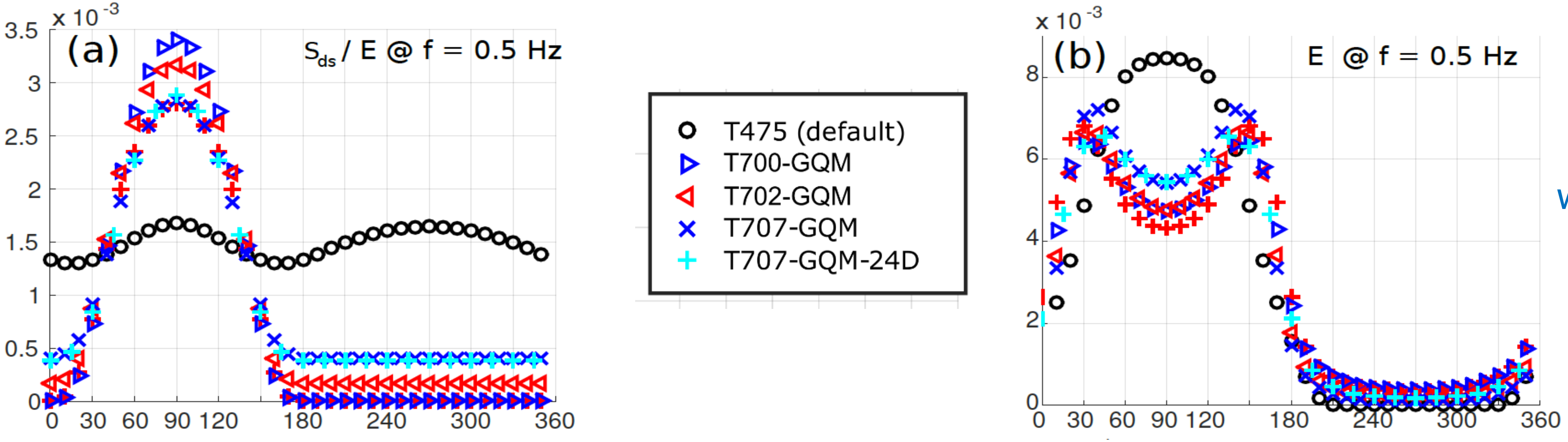


Results after 30 hours of simulation, with a constant wind speed of 10 m/s blowing in direction 90°.

3. Spectral tail and energy balance: time to move away from DIA



with DIA

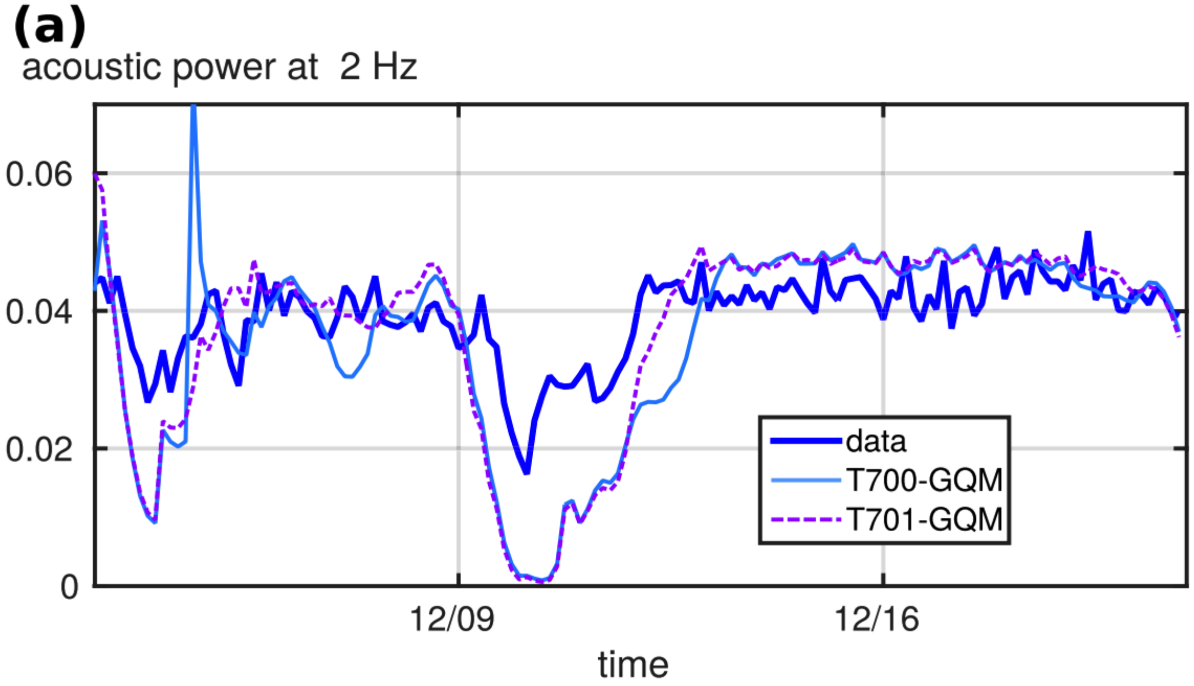


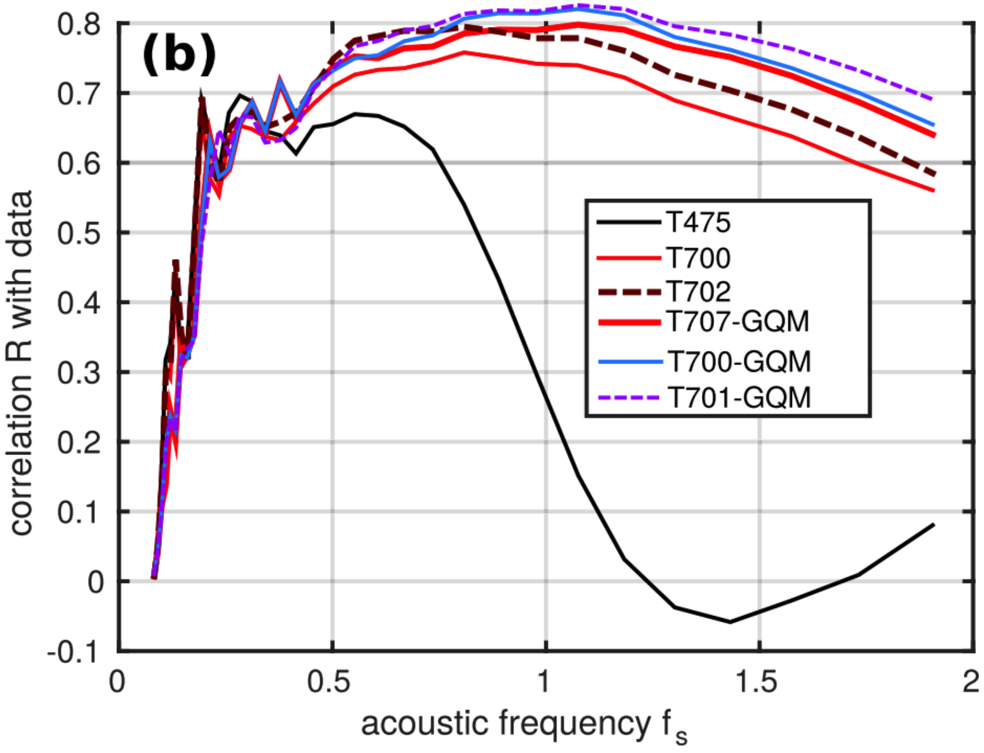
with GQM

3. Spectral tail and energy balance: time to move away from DIA

We can use underwater acoustic data to adjust wave model parameterizations:

- example of a bug in Romero (2019), as discussed by Alday & Ardhuin (JGR 2023)



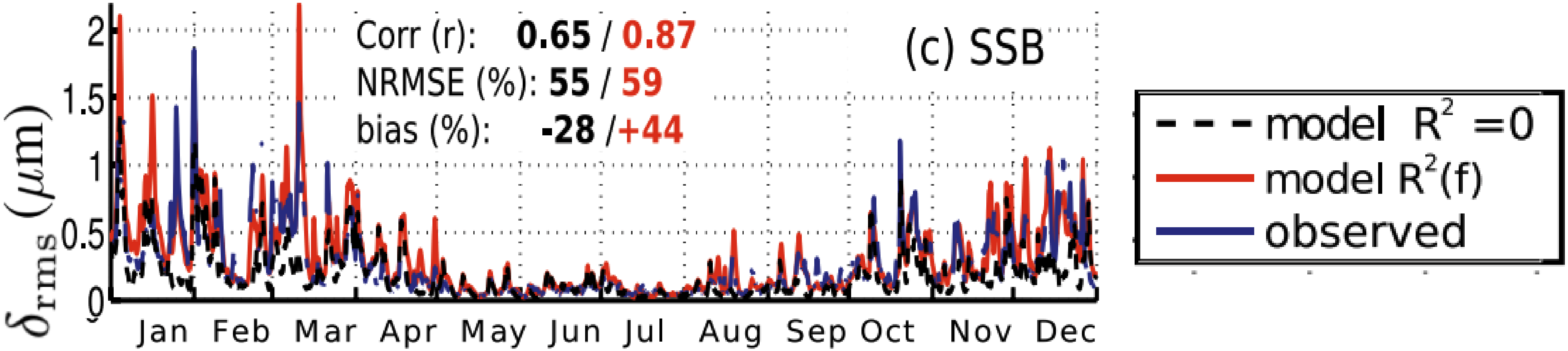


- work proposed for STRATSOUND: calibrate the amplitude of the 2nd order pressure.
NB: we can look at much higher frequencies than just 2 Hz.

4. Low frequency noise and reflection at coast / icebergs

For f < 0.06 Hz, most signals seem to be associated with wave reflections… which we **do not know very well**.

example of modeled microseism amplitude (Ardhuin et al. JGR 2011): in France (SSB)



Or should I say ***did not* know very well** (Ardhuin et al. work in progress)

4. reflection at coast / icebergs: enters the SWOT satellite

SWOT is a joint NASA-CNES mission
With contribution from UKSA & Canada

SWOT carries a Synthetic Apeture Radar interferometer (KaRIN)

Working in X-track mode:
Interferometric phase gives SSH (**and phase noise gives SWH**)

SWOT measures across a 120 km swath (with a nadir gap: 2 sub-swaths)

SWOT data is now public!

Different "products" :

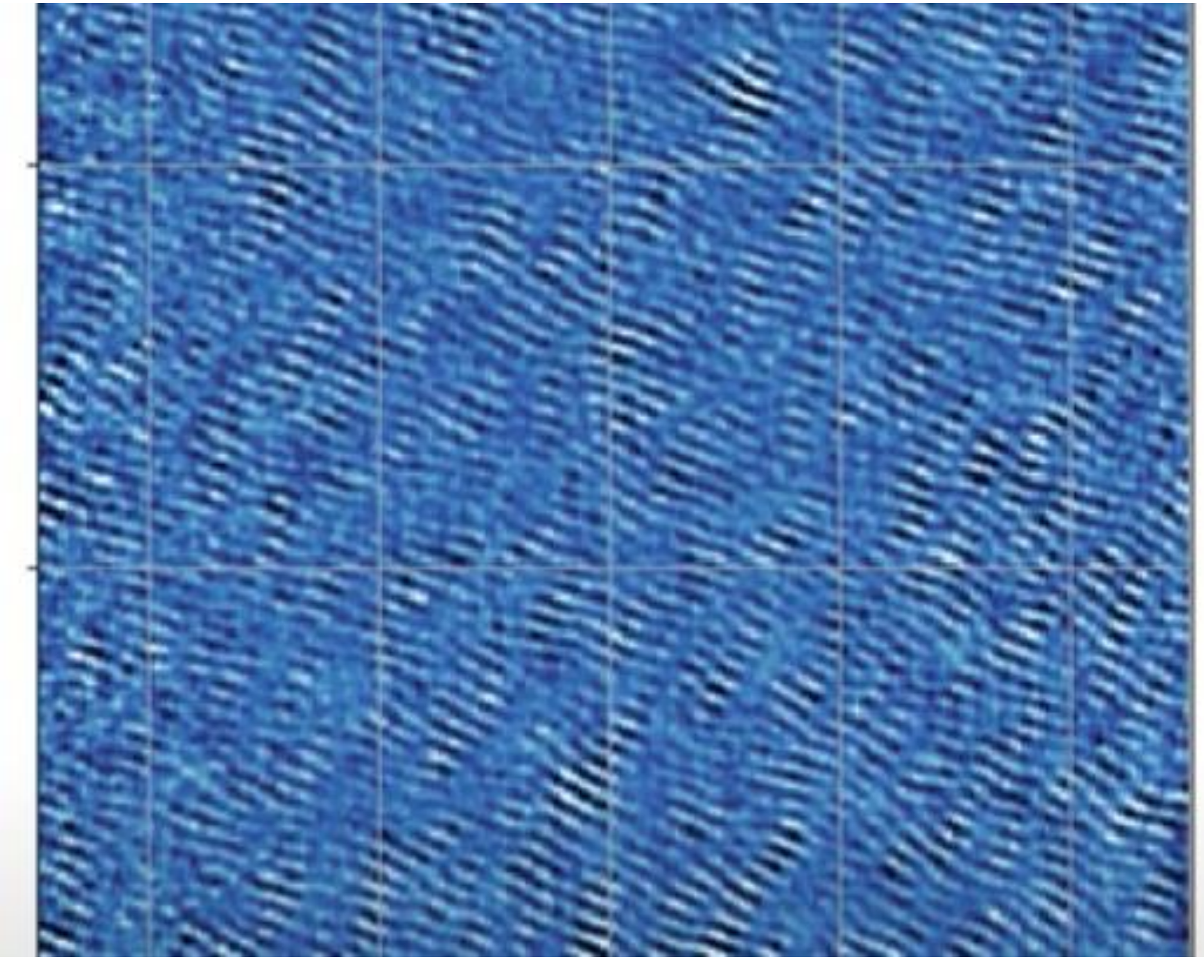
Global coverage ("Ocean" part of the mission) with "Low Res." data
- SSH at 2 km resolution
- Unsmoothed 250 m posting (filter has a 500 m width … but …)

High Res (HR) data in a land+coast+ a few other bits mask

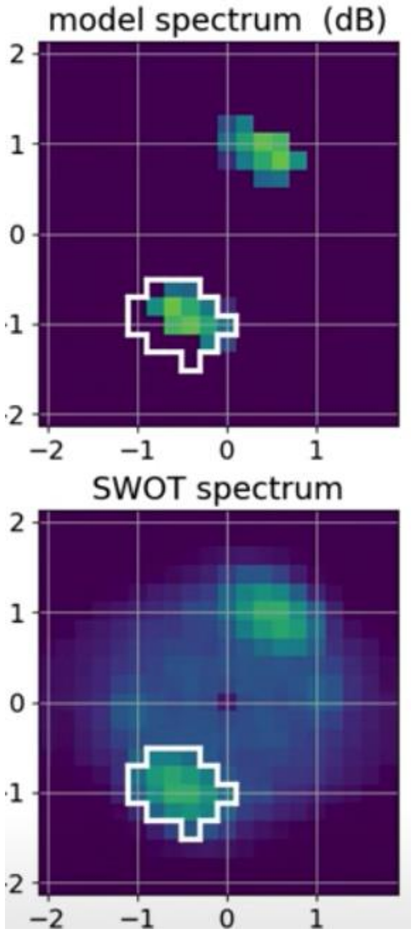
4. reflection at coast / icebergs: enters the SWOT satellite

SWOT measures waves with very large wavelength (here L = 900 m)

and very small height
- main swell: Hs = 23 cm
- side swell: Hs = 3 cm



40 km



4. reflection at coast / icebergs: enters the SWOT satellite

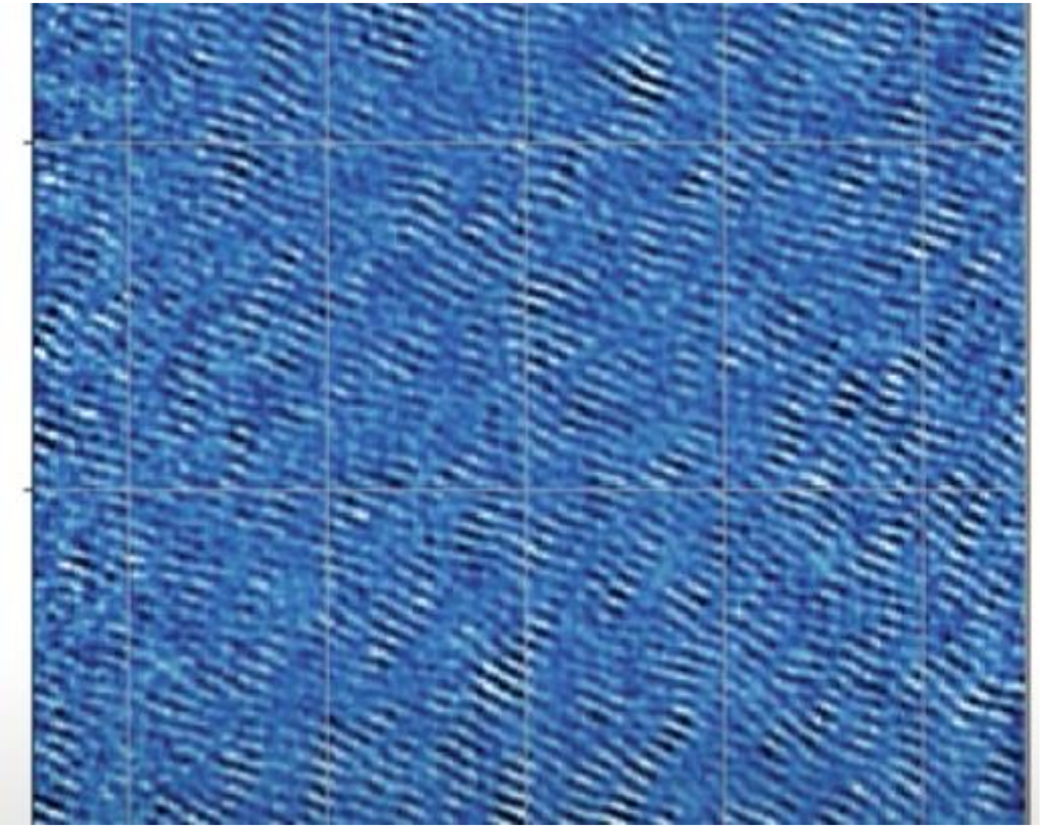


Figure 2. Captain Korent Joel, one of the last traditional navigators in the Marshall Islands, explains the wave concepts modeled within indigenous teaching devices and demonstrates how he detects the wave patterns by feeling how they alter the motion of an outrigger sailing canoe.

Genz et al. (2009)

- side swell: Hs = 3 cm

- side swell: Hs = 3 cm
- Where is that coming from?

https://youtu.be/YQTUR_3gMs8?si=nH5-J2tuuDqB2q1d&t=77

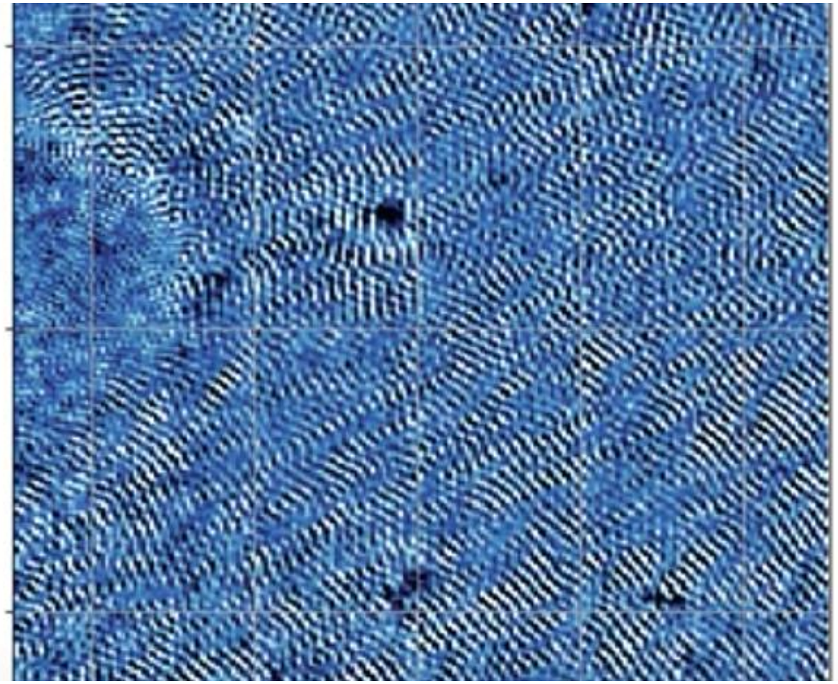
Summary

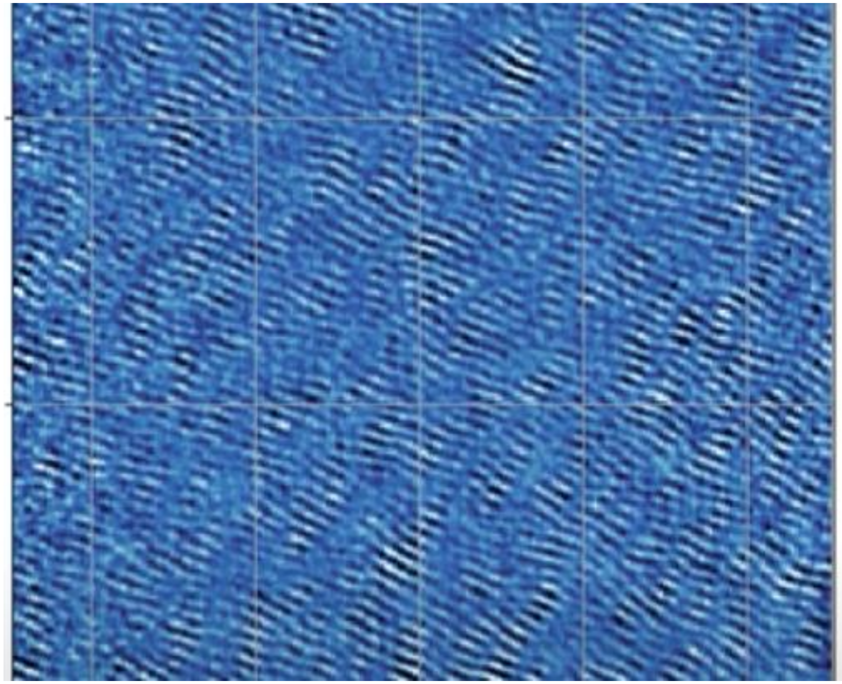
2nd order wave spectrum can be very sensitive to spectrum shape

- Overlap integral I(f) :

  - Big events usually OK
    (around 0.1 Hz , 0.2 Hz aco
  - HF can be fixed (not good in
  - low freq.: reflection must be

- Skewness ?
- correlation elevation-mss ?





Better sources of microseism / microbaroms, what for?

- Inverting wave model parameters (Alday & Ardhuin 2023)
- Improving on stratospheric wind retrievals (proposed STRATSOUND
- Wave events/climate back to the 1890s? (various ongoing efforts)

SWOT is measuring ocean waves in unprecedented detail

- We can revist propagation effects & energy balance near storms
(maybe in storms too ..)

The ocean wears denim: the swell fabric woven by storm Fabrice June 6 to 19, 2023

https://youtube.com/playlist?list=PLm1sPhvTQhOxMjglmUjAyB28bSM45C2eQ&si=AEWJ4Z7U6OjQP1_e

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3. from wave groups to skewness