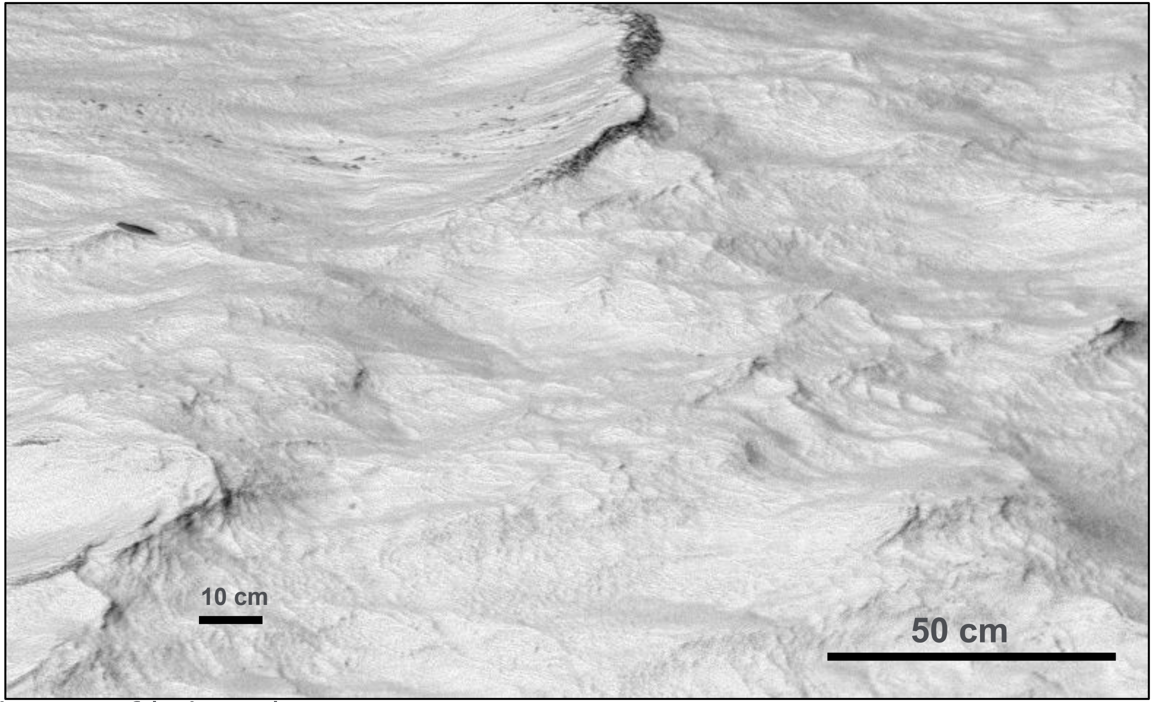
Wave observations and forecasts

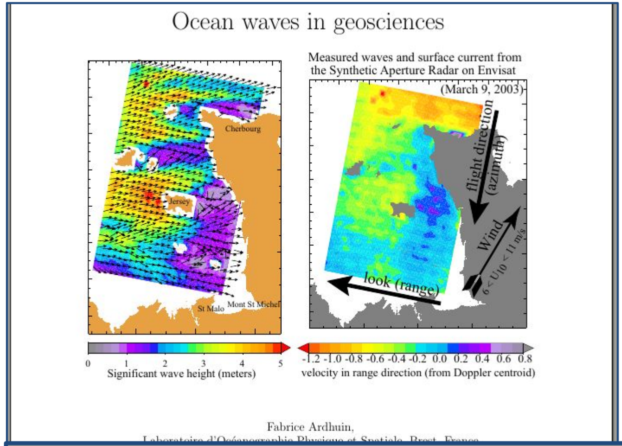
by Fabrice Ardhuin

Lab. for Ocean Phys. & Satelite remote sensing (LOPS), Univ. Brest, CNRS, IRD, Ifremer, Brest, France

For the DBCP Mediterranean Training Workshop on Ocean Observations and Data Applications



degree of light polarization
(BBWAVES 2015, P. Sutherland). wind ~ 7 m/s.




frontiers in Marine Science

REVIEW
published: 09 April 2019
doi: 10.3389/fmars.2019.00124

Check for updates

Observing Sea States

Fabrice Ardhuin[1*], Justin E. Stopa[2], Bertrand Chapron[1], Fabrice Collard[3], Romain Husson[4], Robert E. Jensen[5], Johnny Johannessen[6], Alexis Mouche[1], Marcello Passaro[7], Graham D. Quartly[8], Val Swail[9] and Ian Young[10]

Outline

- Wave parameters and buoy measurements
- Wave observations from satellites
- Numerical wave forecasting : forcings, parameterizations, numerical schemes

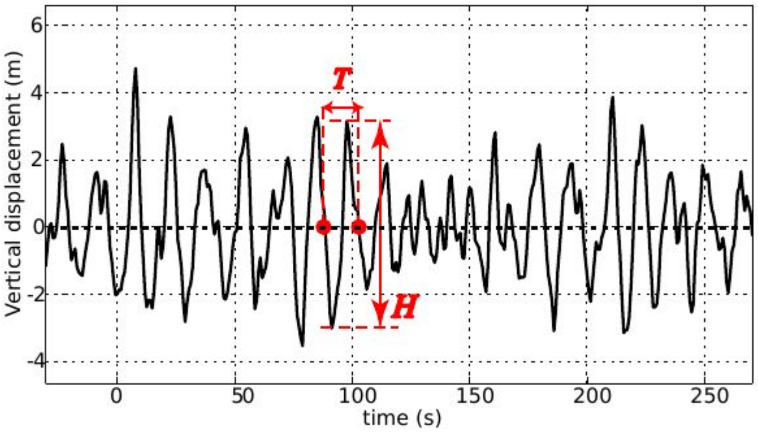
Storm Larisa, Porto Vecchio (Corsica) 11/03/2023
image: MeteoExpress

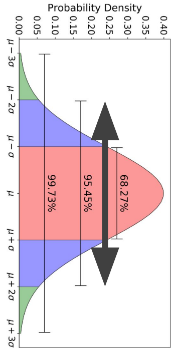
Wind event, NW Med. 2/03/2023
Sentinel 2 (Copernicus).

1. Wave parameters and buoy measurements: heights

- waves are associated to sea surface motions + motions in the water & air
- all motions can be related to the **surface elevation**

- The most simple quantity measured is **E** = **variance** of surface elevation (units : m²)
- or equivalently the **significant wave height** (SWH), here for a time series,





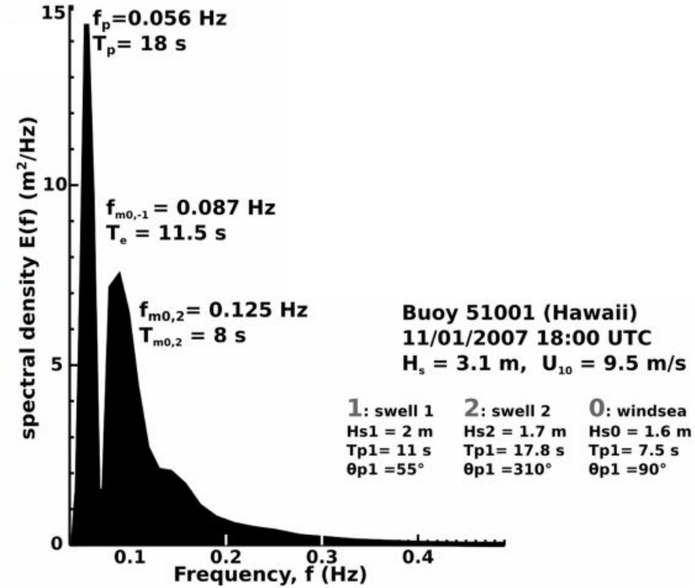
Hs = 4 √E (units : m)

Hs is a **statistical quantity**:
- random fluctuations depend on record length (these decrease like 1/√N)
- two nearby instruments give similar values

Hs has deterministic variations in space and time

1. Wave parameters and buoy measurements: periods

- Elevation time series are recorded by floating buoys
- Besides Hs, we can also measure the time scale or period T of the oscillations
- … and more generally the 1D wave spectrum E(f)



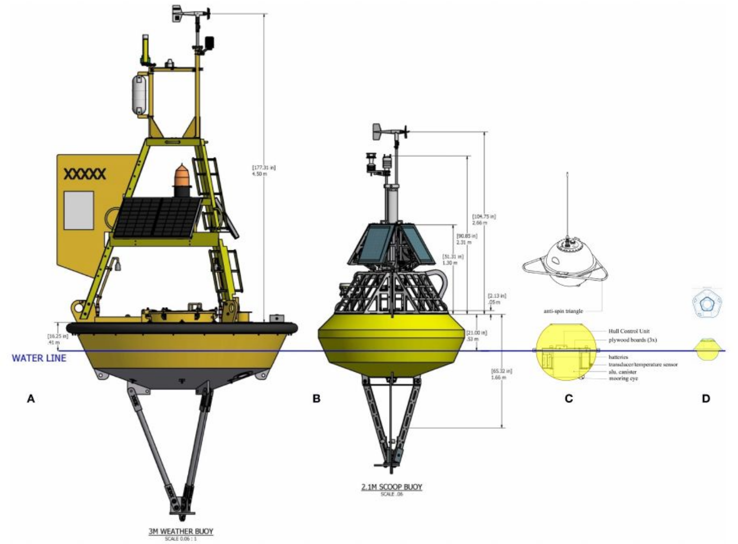
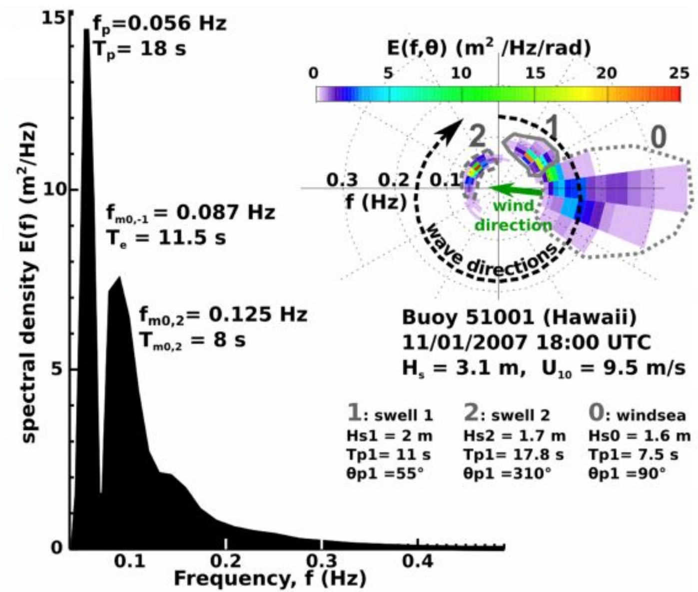


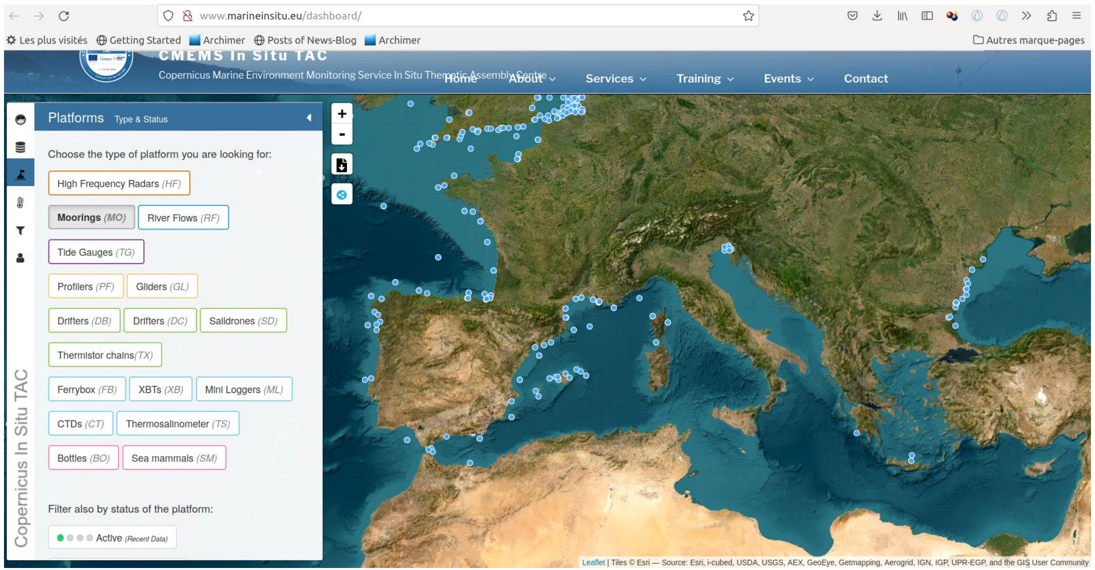
FIGURE 12 | Schematics of existing and planned super-structures of NDBC moored buoys measuring waves, (credit Eric Gay, NDBC). **(A)** is the standard design of 3-m discus buoys (Steele et al., 1992) pictured in **Figure 1A**, **(B)** is the new SCOOP design with a 2.1 m diameter that is replacing many buoys. The 3-m diameter SCOOP is pictured in **Figure 1B**. For reference, **(C)** is the schematic for the Mark 4 Datawell waverider with a 0.9 m hull diameter, drawn to scale, and **(D)** is the schematic of a Spotter buoy made by Spoondrift, following the developments of Herbers et al. (2012).

- Spectrum gives mean periods $T_{m0,2}$, $T_{m0,-1}$ …

1. Wave parameters and buoy measurements: directions

- 3-axis measurements (x,y,z) provides "first 5" moments of directional spectrum:
  for each frequency f we can tell the mean direction, spreading and 2 more parameters.



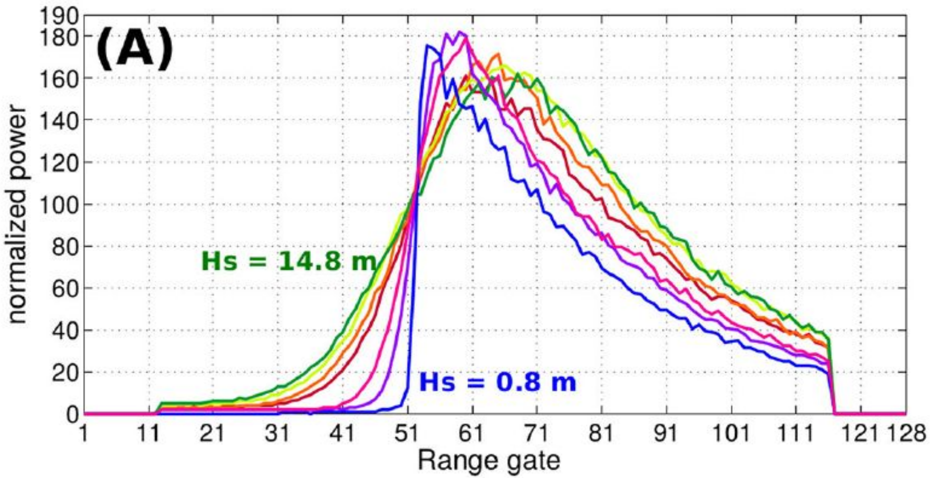


- Warning: buoys cannot give access to the full 2D spectrum

2. Wave observations from satellites: wave heights

- The “spread” of **altimeter** radar echoes from the ocean is a direct measurement of **Hs**
here are examples from SARAL:

waveforms



footprint

- Warning: radar “speckle noise” causes random fluctuations in Hs estimates, making values < 1.5 m very noisy.
- The effective footprint gets wider for larger wave heights.

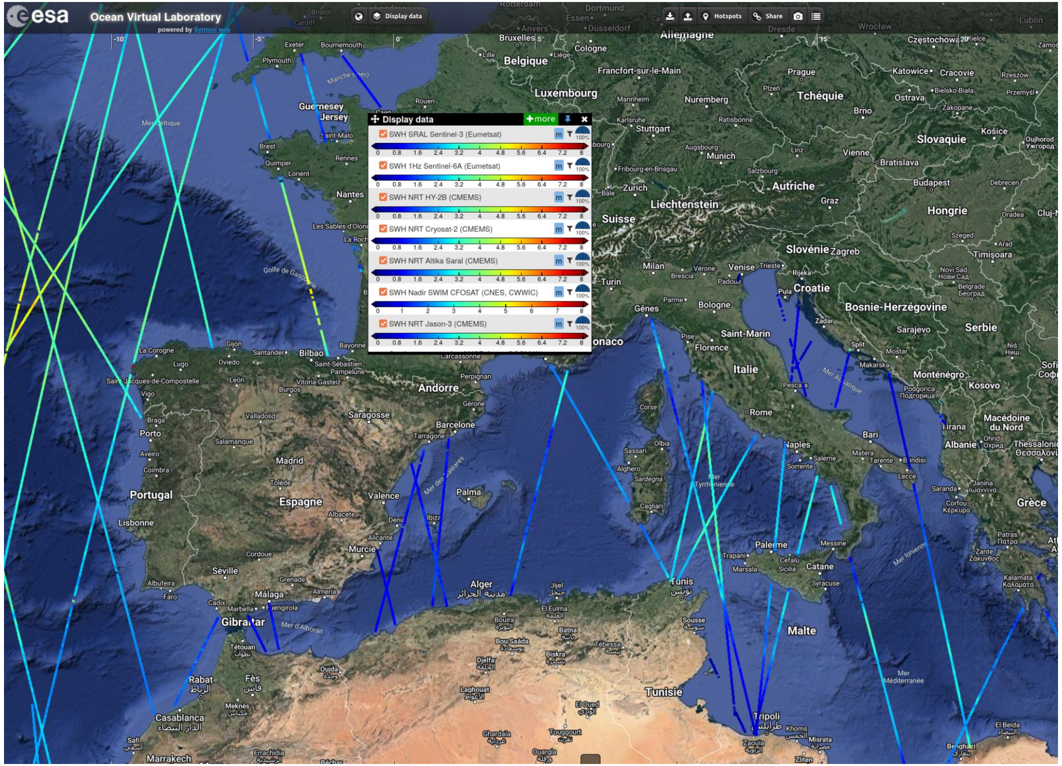
2. Wave observations from satellites: wave heights

- Satellite altimeters: global coverage
  + continuous data since 1992
  + high resolution (2-10 km)
  - revisit time can be long (missing events)
  - noisy at high resolution

https://odl.bzh/bzD4PcIJ

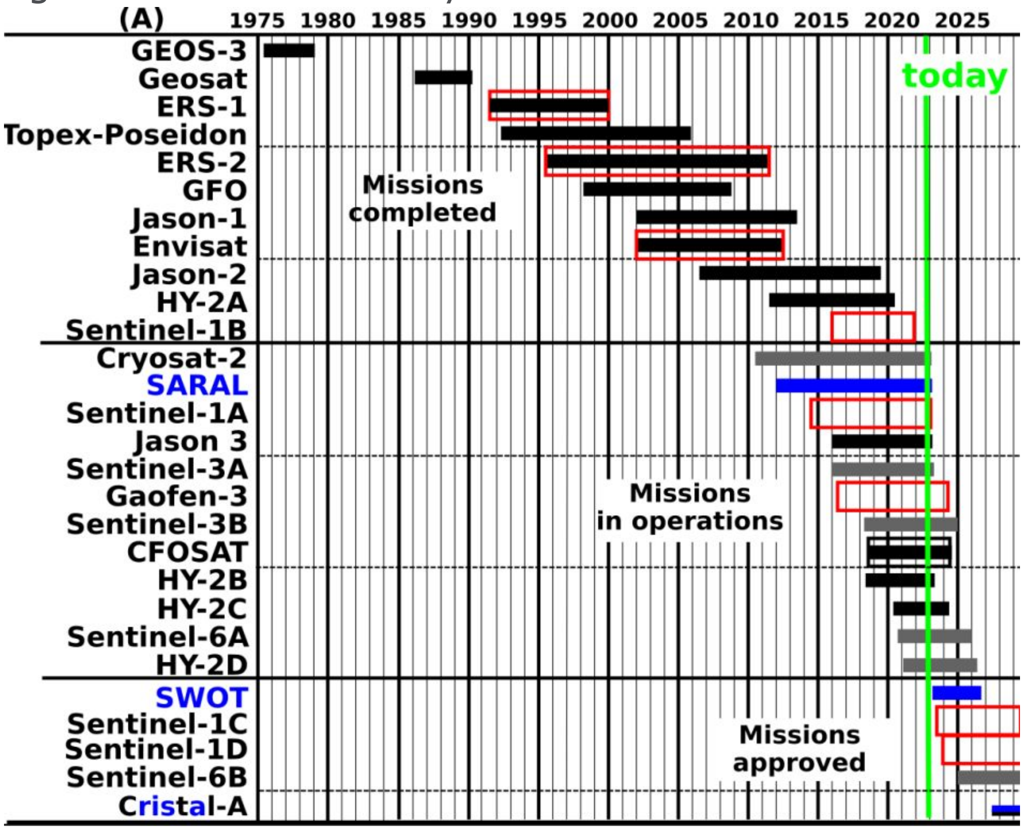
- recent reprocessing efforts:
  - reduced noise
  - data closer to coast
  - new processing (SARM vs LRM)

(See ESA Sea State CCI dataset)
… more work in progress



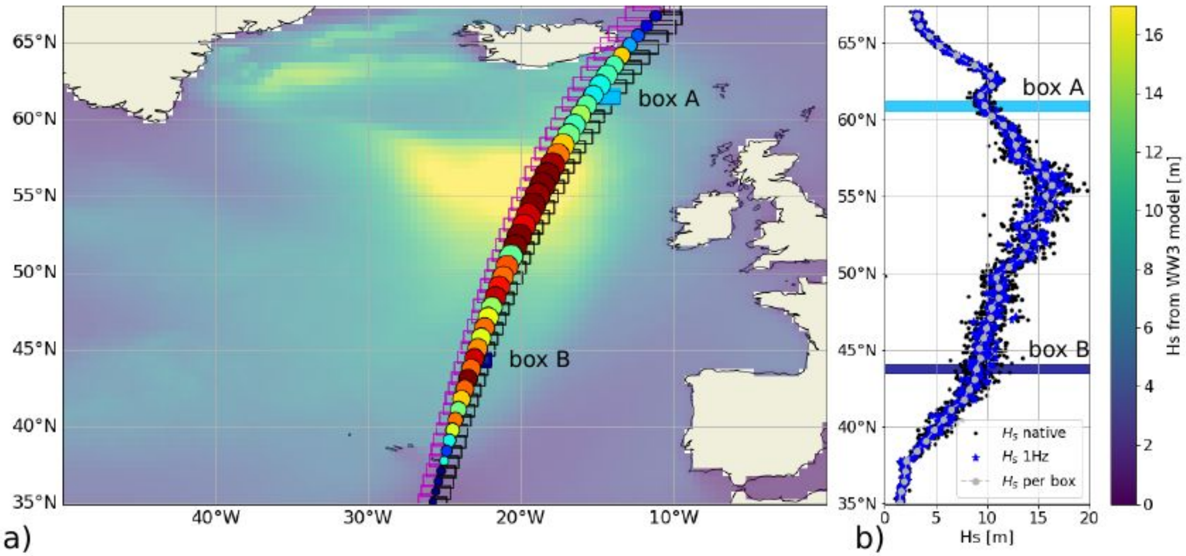
2. Wave observations from satellites: wave heights

- Now is the golden age of satellite altimetry

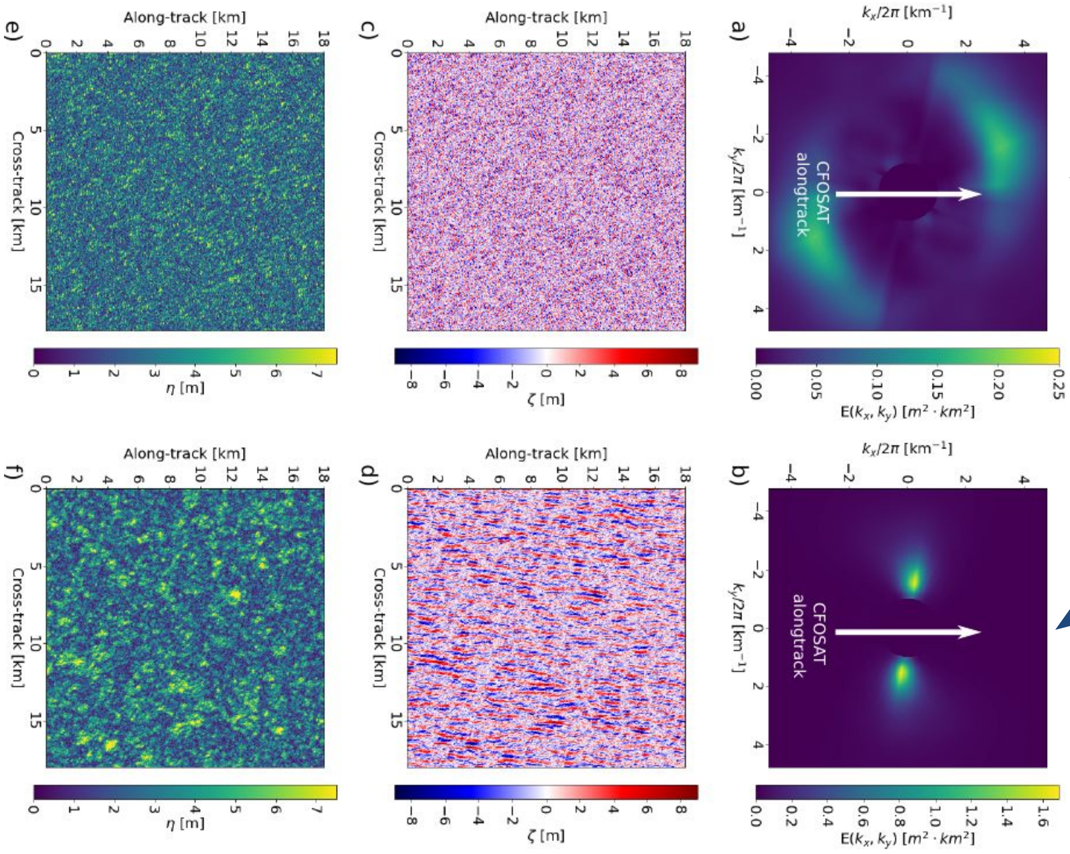


2. Wave observations from satellites: wave spectra

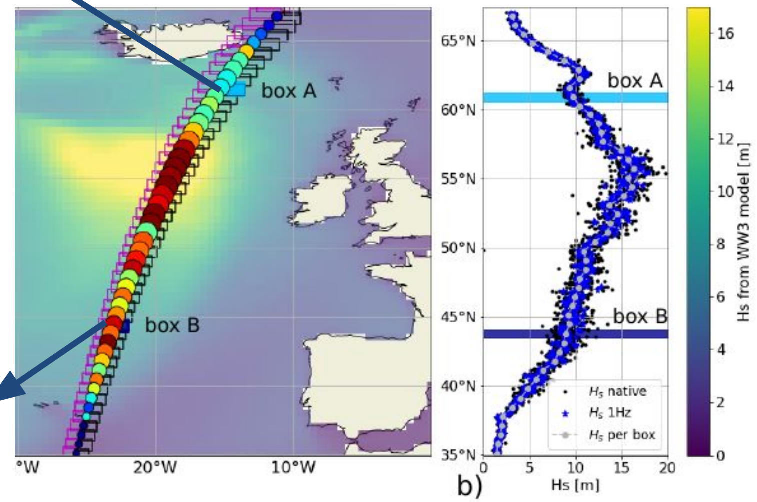
- Synthetic Aperture Radar (SAR) provides information on wavelengths (and thus periods) and directions: Sentinel 1, Gaofen 3 …
- The wave scatterometer SWIM on the China-France Ocean Satellite (CFOSAT) is able to measure shorter waves and a more complete spectrum (Hauser et al. 2018).
- We can use wave spectra to better understand Hs "noise" (De Carlo et al., in review):



2. Wave observations from satellites: wave spectra



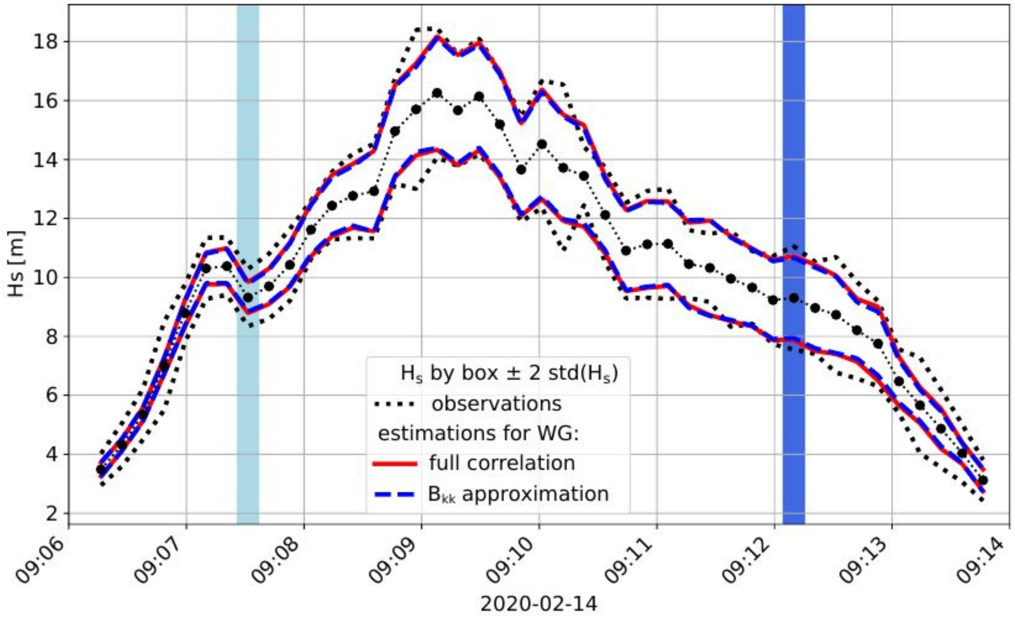
broad spectrum:
small-scale wave groups

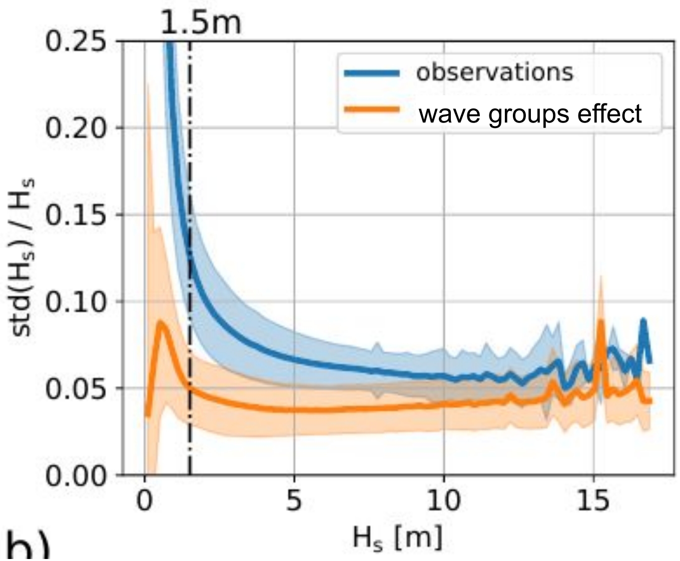


narrow spectrum:
large scale groups

2. Wave observations from satellites: wave spectra

- SWIM spectra used predict the “noise” of Hs in the SWIM altimeter
- wave groups are dominant source of “noise” for Hs > 10 (De Carlo et al., in review)
- radar noise (speckle) dominant source of true noise for Hs < 3 m .

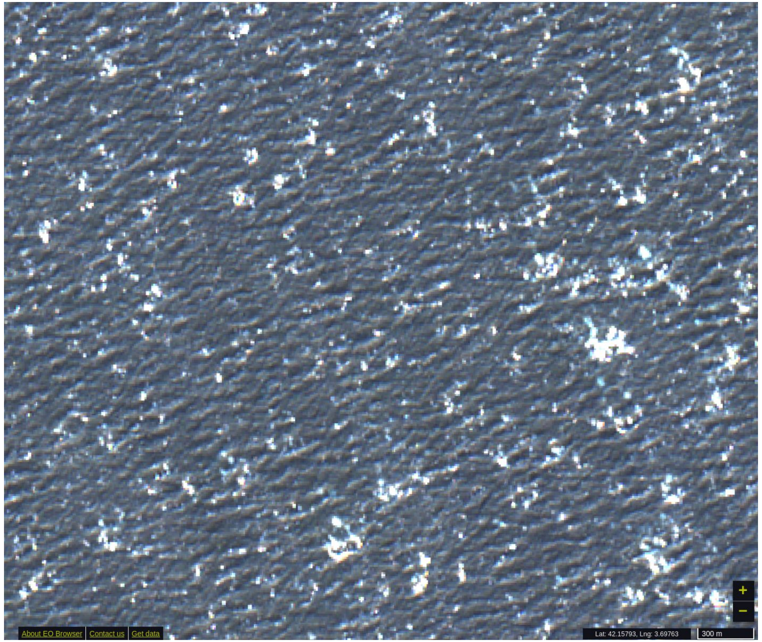




2. Wave observations from satellites: more coming

- Clear sky conditions make possible optical observations, here with Sentinel 2

https://sentinelshare.page.link/Mv9N



3. Numerical wave forecasting: principles

- Because (almost) all wave properties can be estimated from the 2D wave spectrum, wave models solve this equation for the evolution of the wave spectrum

$dE(f,\theta)/dt = S_{tot}(f,\theta)$: evolution of wave energy during propagation is given by a "source" function (actually a sink if negative)

Usually we decompose $S_{tot}(f,\theta) = S_{in}(f,\theta) + S_{nl}(f,\theta) + S_{ds}(f,\theta)$

S_{in}: linearized input, prop. to $E(f,\theta)$ and some function of u* … but warning, u* is generally a function of U_{10} and wave spectrum

S_{nl}: energy exchanges in spectrum, forward (oblique) & inverse cascades.

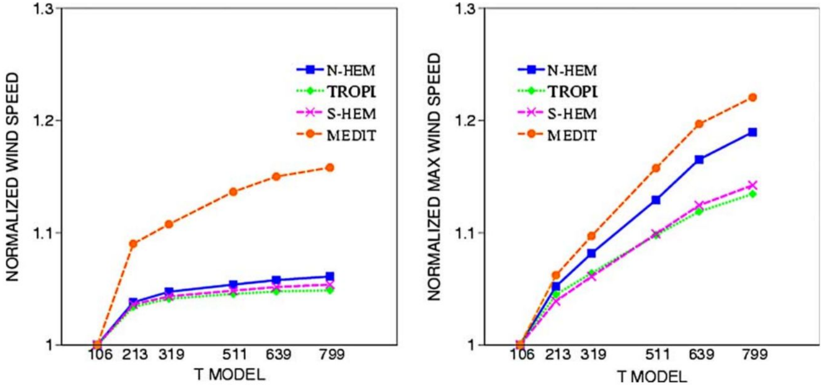
S_{ds}: dissipation … mostly due to wave breaking (whitecapping…)

- Model differences are caused by : forcing (wind),
  parameterizations of S_{in}, S_{nl}, S_{ds},
  data assimilation (spectra have longer lasting impact)
  numerics (spatial resolution, ….)

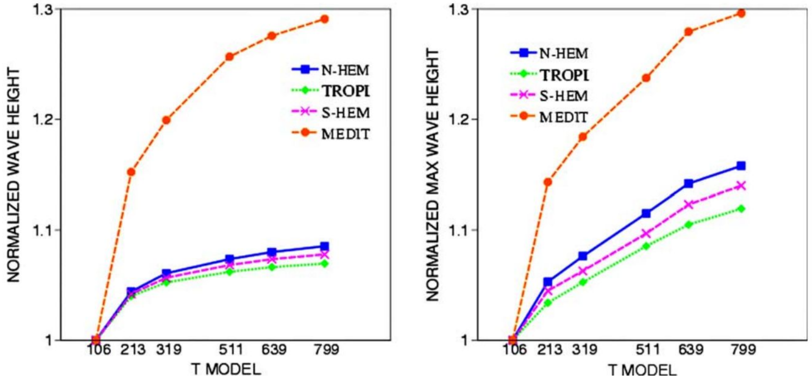
3. Numerical wave forecasting: forcing

- Waves are generated by the wind: it is very important to use accurate winds, which may require downscaling (especially around mountainous coasts). It used to be a very big problem

winds



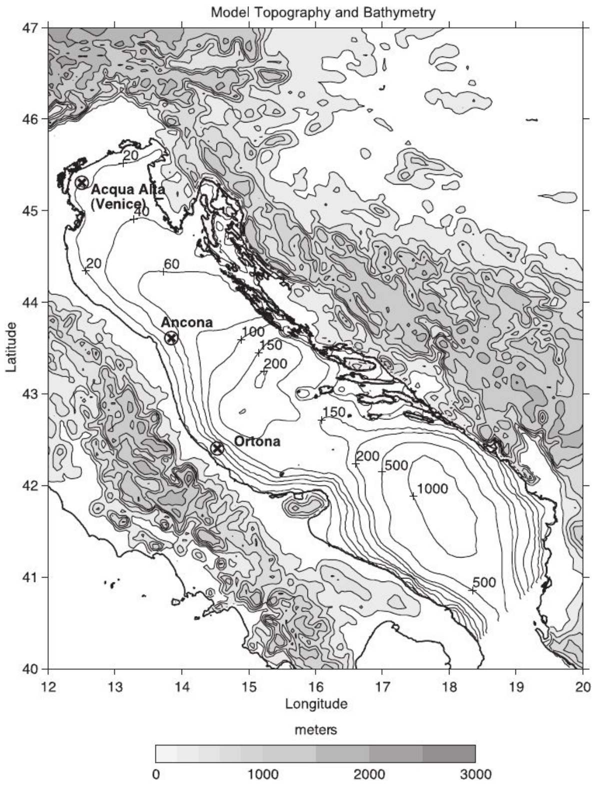
waves

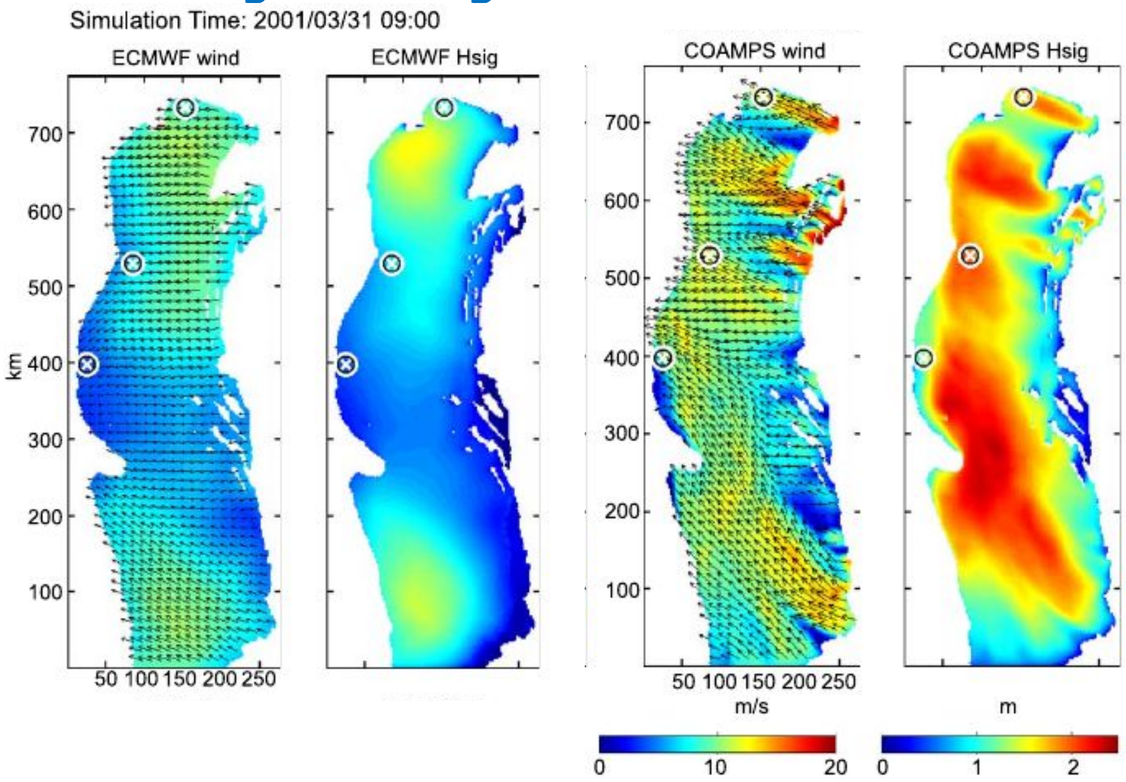


Cavaleri & Bertotti (2006)

- currents also influence waves … not so easy to measure at the proper resolution (< 30 km)

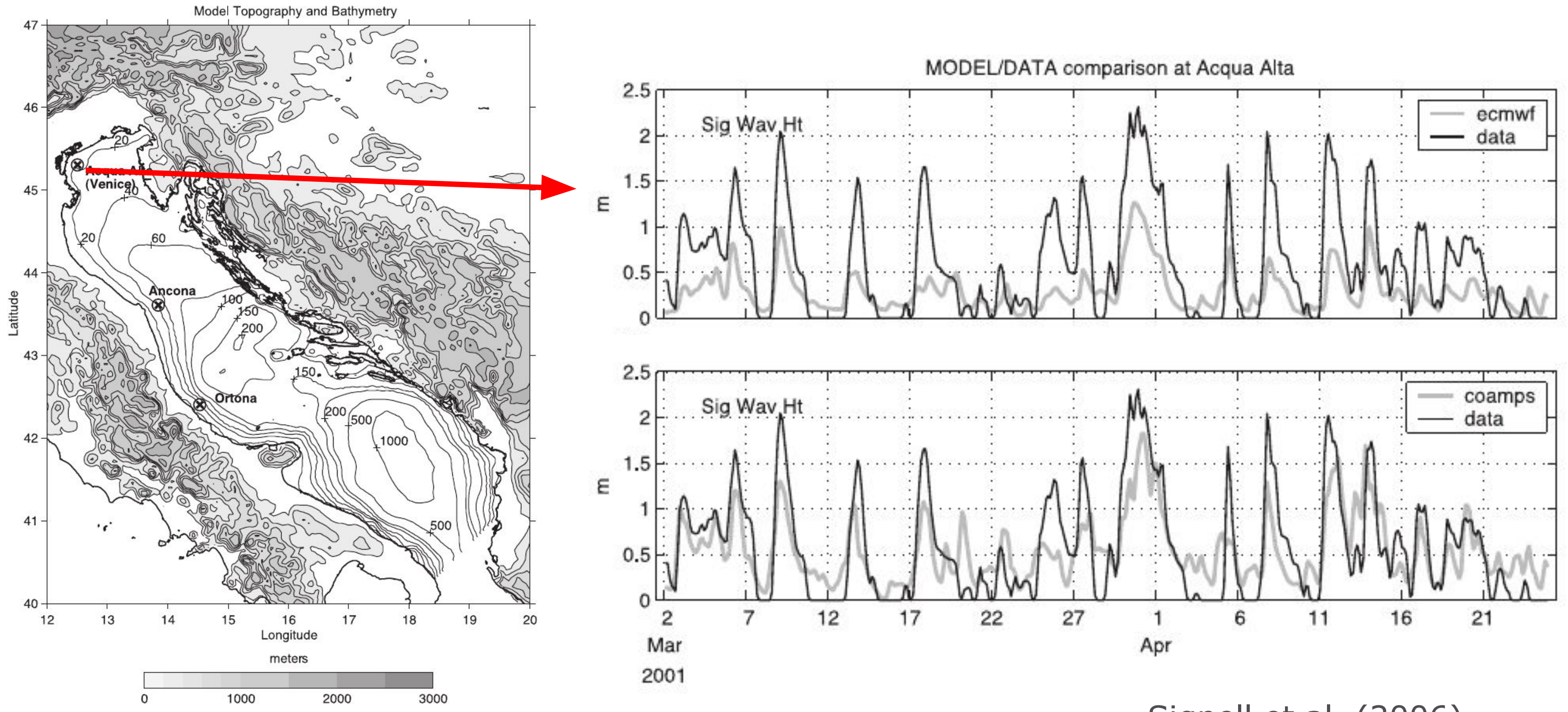
3. Numerical wave forecasting: forcing





Signell et al. (2006)

3. Numerical wave forecasting: forcing

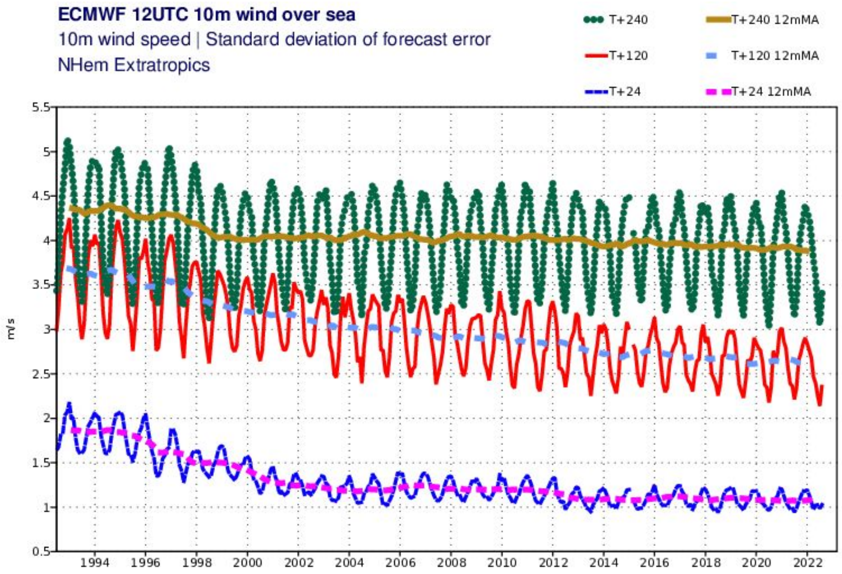


Signell et al. (2006)

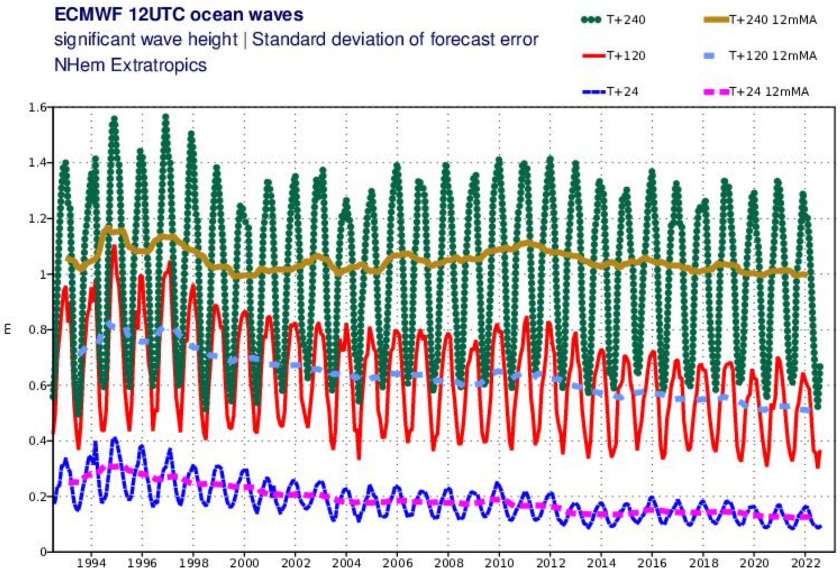
3. Numerical wave forecasting: forcing

- Wind forecasts are getting better all the time:

winds

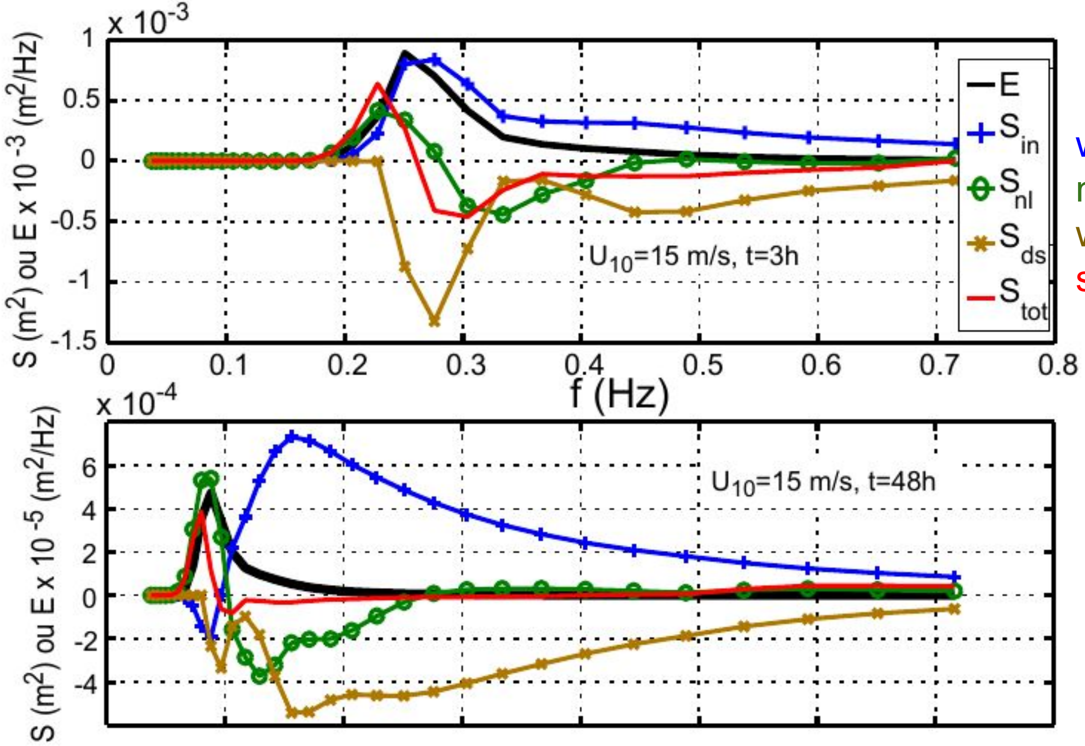


waves



3. Numerical wave forecasting: parameterizations

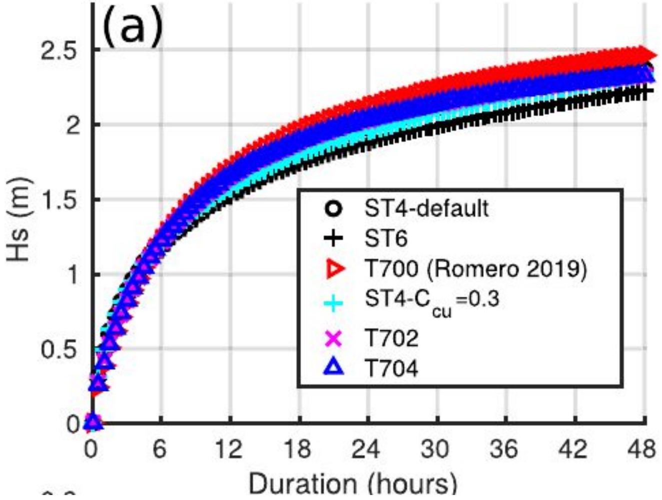
- Wave spectrum evolution is the result of propagation and energy balance
- All 3 dominant source terms in deep water are parameterized (with important errors)

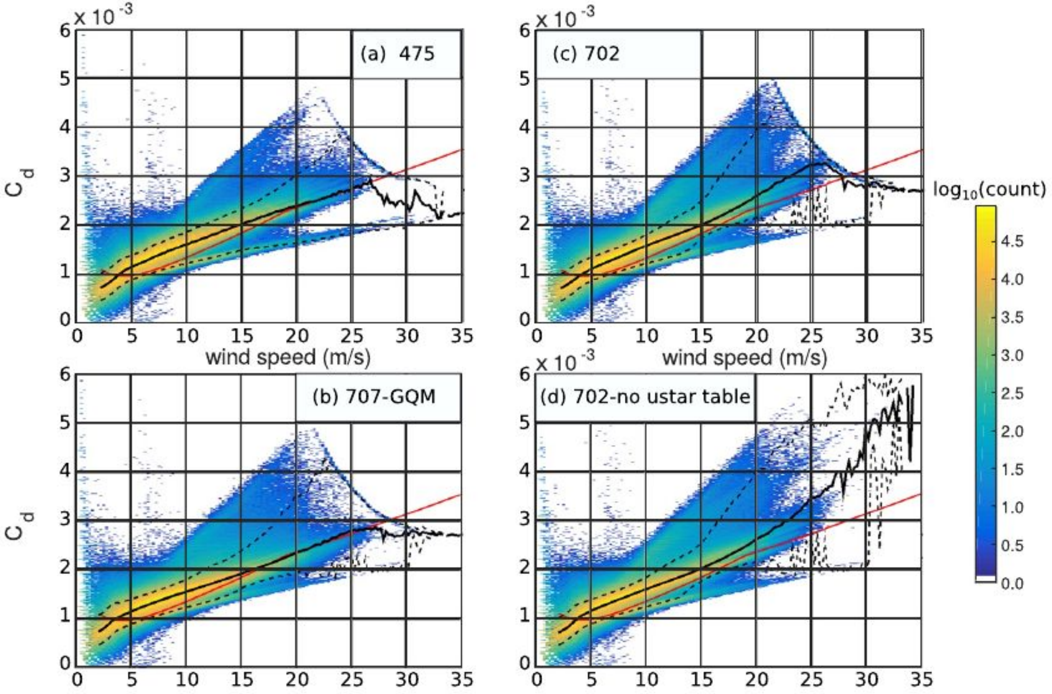


wind-wave generation
non-linear wave-wave scattering
wave dissipation (breaking …)
sum of all three: $dE/dt = S_{tot}$

3. Numerical wave forecasting: parameterizations

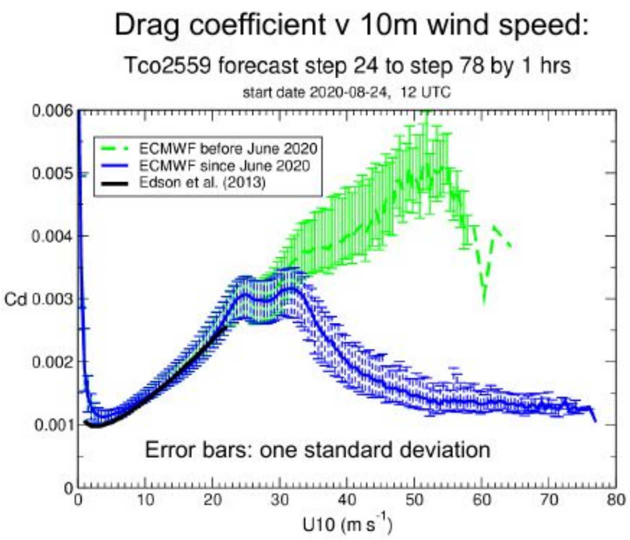
- Modern parameterizations (e.g. Ardhuin et al. 2010, Romero 2019 …) give similar wave heigts
- Many differences remain in the tail of the spectrum that determines the wind stress:
  here are examples that overestimate wind stress (Alday & Ardhuin 2023)





3. Numerical wave forecasting: parameterizations

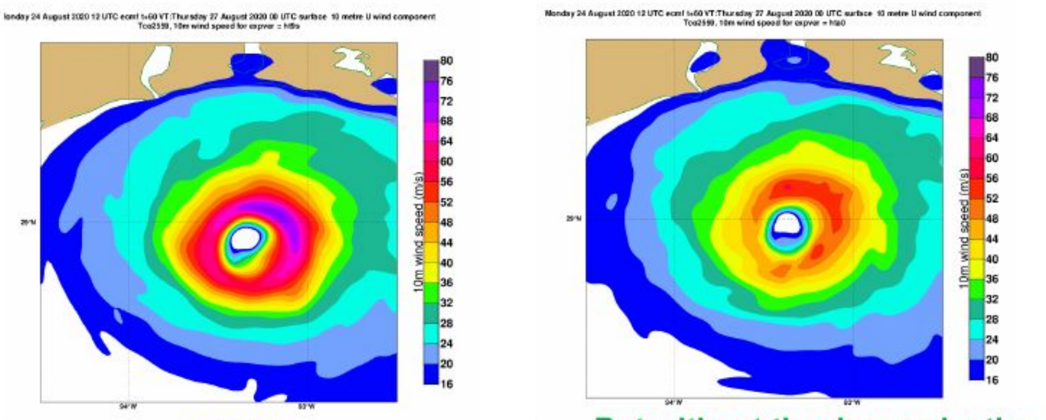
- Many differences remain in the tail of the spectrum that determines the wind stress: latest adjustments in ECMWF model (courtesy of J. Bidlot)



Majumdar et al. (2023) in review

ECMWF

10m wind speed, Hurricane Laura 27 August 2020



CY48R1

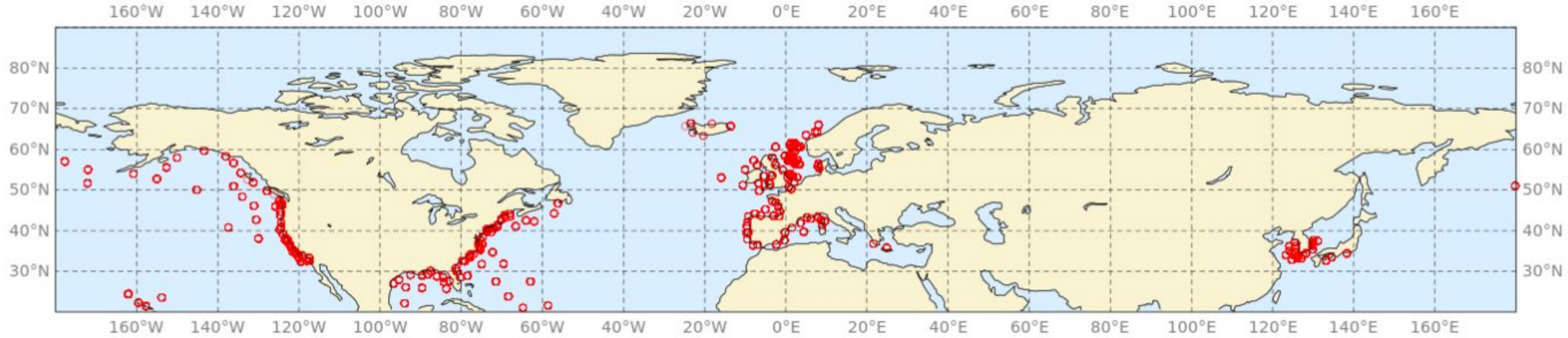
But without the drag reduction introduced in June 2020, it would not have been the case.

7

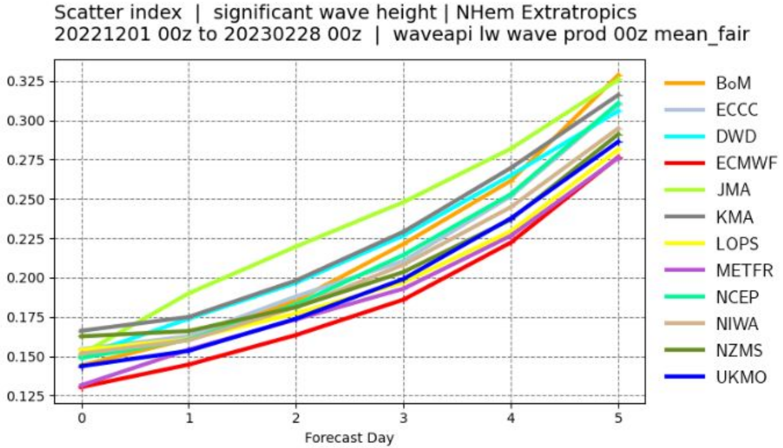
3. Numerical wave forecasting: model verification

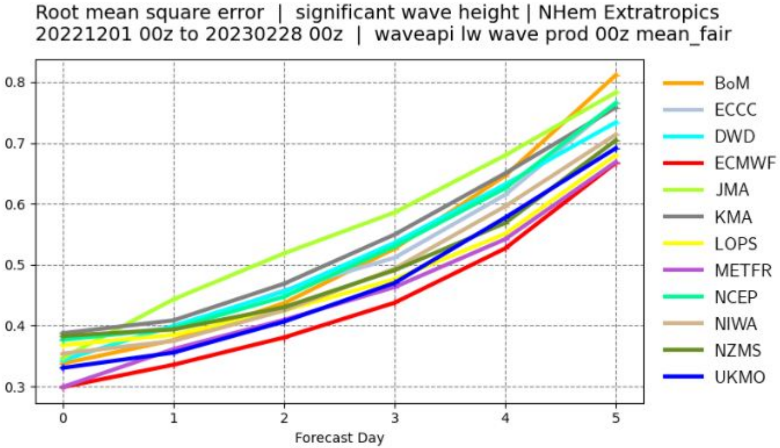
WMO verification:

wave heights (now uses only buoys)



https://confluence.ecmwf.int/display/WLW





Summary

reference wave observation using moored buoys

are confined to a few (often) coastal locations

→ ongoing efforts to use drifting buoys

Satellite altimeter data provides very accurate wave heights (for Hs > 1 m), sparse in time. Very important source of model validation

Spectra from satellite data are provided by SARs & CFOSAT's SWIM, but often restricted to long (swell) components

For most applications, including forecasts, models are the only source of data with the relevant time and space resolution.

Model validation / calibration is critical : errors are mostly caused by

- errors in forcing (winds & currents)
- inaccuracy in parameterizations (Sin, Snl, Sds)
- data assimilation can help for short time ranges