Measuring sea states

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Short course on ocean waves

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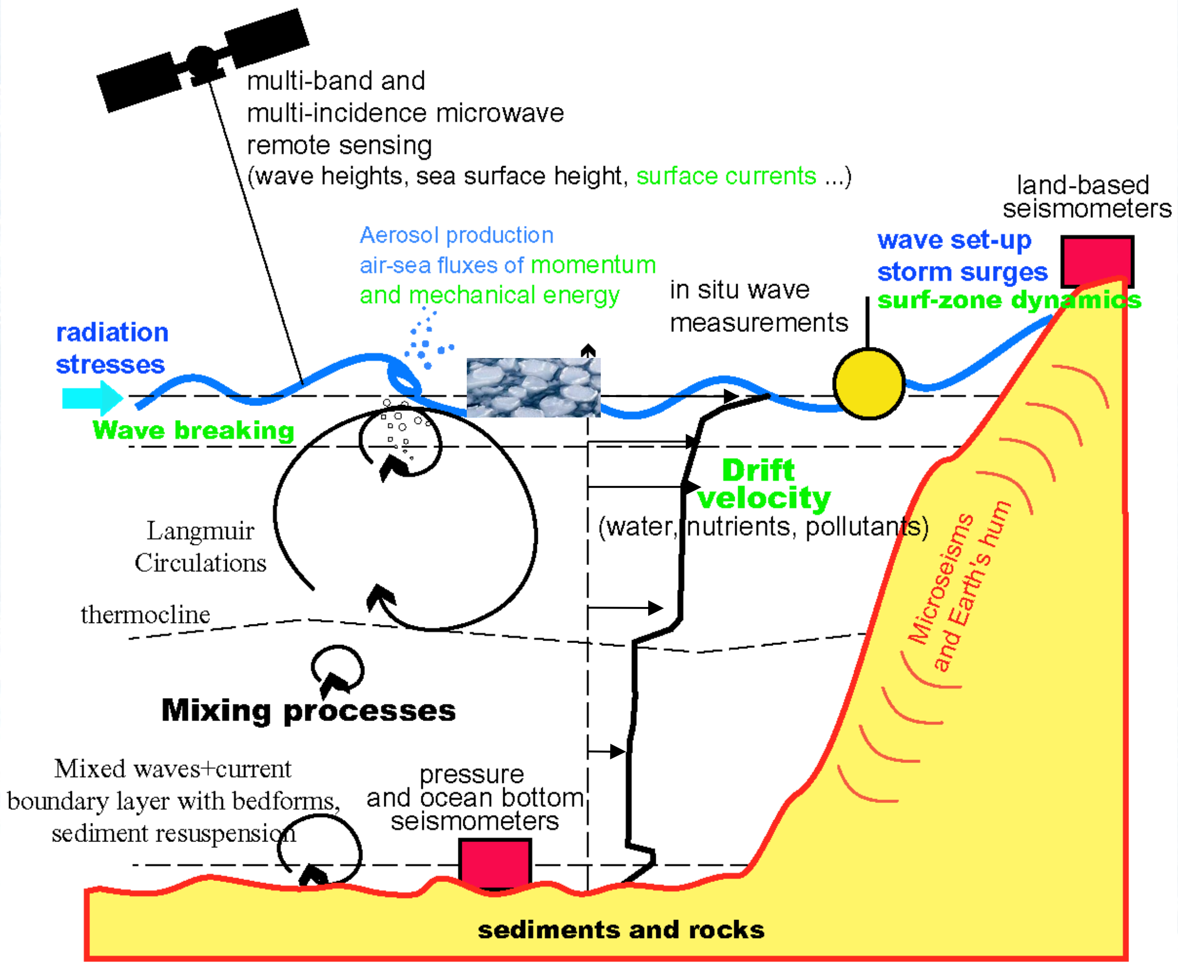
Why waves? A key rôle at Earth System interfaces…

- air-sea
  - Land-sea
  - Ocean-ice
- ocean-crust

+ engineering...



Outline

1. measuring waves with buoys
2. Other in situ sensors
3. Stereo-video
4. Satellite remote sensing

Material : « Waves in geosciences », chapter 3

http://tinyurl.com/wavesgeo

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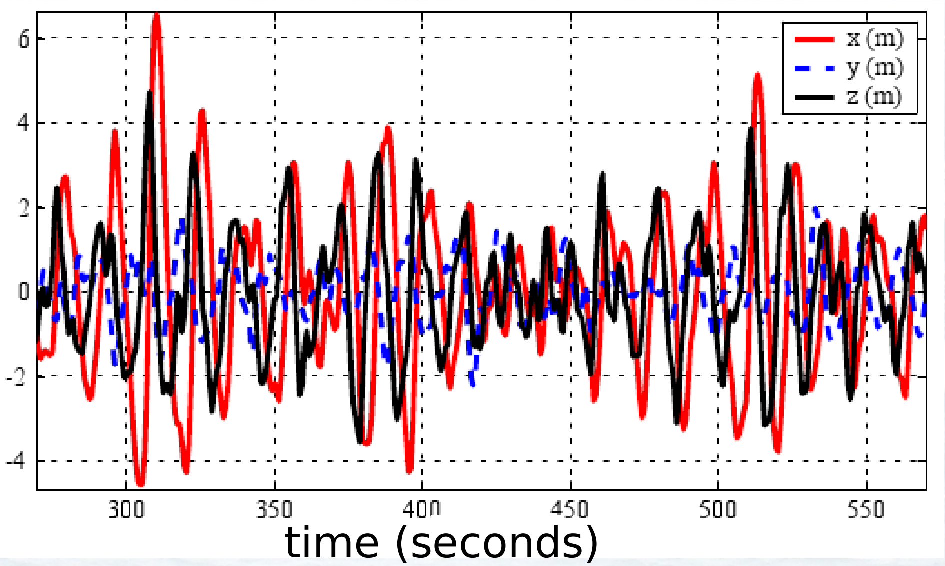
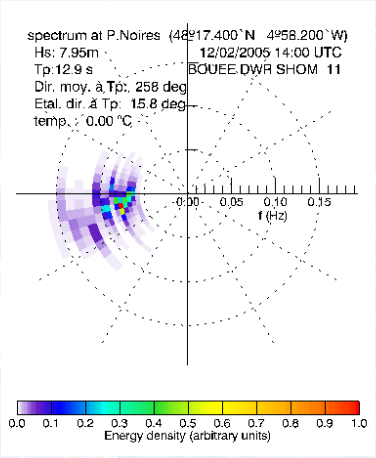
Measuring waves with buoys

Measuring $E\left(f,\theta\right)$?

A datawell buoy

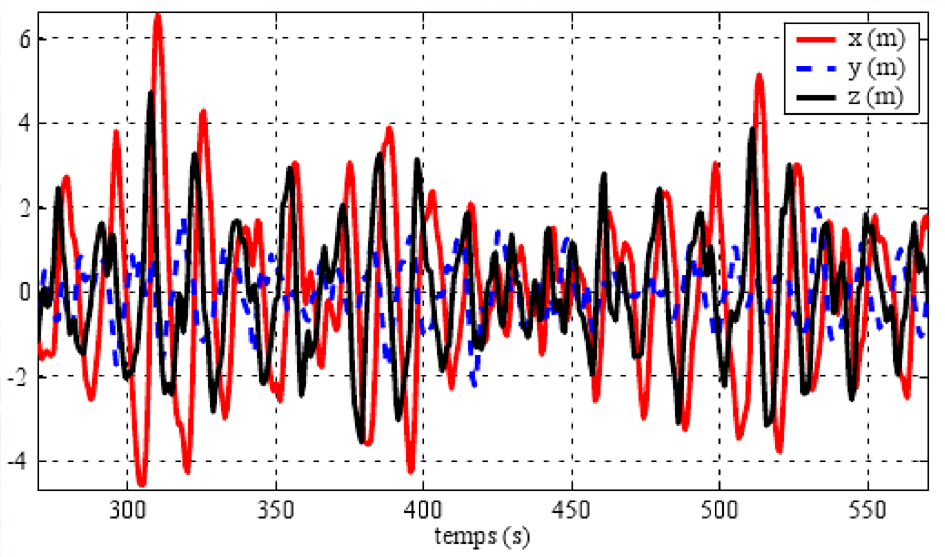




Corresponding $E\left(f,\theta\right)$ Using MEM (Maximum Entropy Method)

How does it work ?

Measuring $E(f,\theta)$?



Directional buoy → 3 time series :
x, y and z displacements

E(f) is spectrum of z : Czz(f)
Spectrum of x : Cxx(f)
Spectrum of y : Cyy(f)

Now we can also « mix » x, y and z to make co-spectra :
Cxz(f)
Cyz(f)
Cxy(f)

Co-spectra are the specta of the correlations, they have an amplitude and a phase

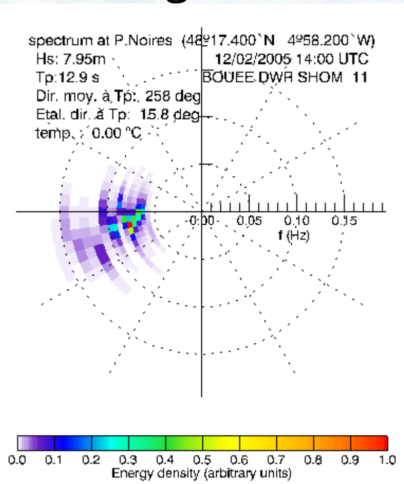
Measuring $E(f,\theta)$?

So we have 6 parameters for each frequency.
1. the « check ratio » : (Cxx + Cyy)/Czz = 1/tanh^2(kD) for linear waves

5 define the directional distribution : the « first 5 »

E(f), a1(f), b1(f), a2(f), b2(f) ... or equivalently
E(f), th1(f), sth1(f), th2(f), sth2(f)

How do you get 36 numbers (or more) from just 5 ? ...
... statistical estimator.
- Most widely used : Max. Entropy Method (Lygre & Krogstad, 1986)
  - Makes the narrowest peaks that fit the data
  - Is able to detect 2 peaks at same frequency



First 5 or just 3 ?

Making a cheap buoy is very easy :
A GPS receiver gives velocity data (u,v), which provide two spectra and a co-spectrum : Cuu, Cvv, Cuv. This yields E(f) and a2 and b2.

But good GPS can produce all first 5... and does not have to be expensive : https://spoondrift.co/

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Other in situ sensors

From elevation to other parameters... and back : modulation transfer functions (MTFs)

Using linear wave theory, we can use $E\left(f,\theta\right)$ to determine other properties : velocities, slopes, pressure ...

Conversely, spectra of other properties – when dominated by linear waves – can be used to estimate $E\left(f,\theta\right)$

$$A = \boxed{M}\zeta \quad \rightarrow \quad E_A(f,\theta) = |M|^2 E(f,\theta)$$

$$\zeta = a\cos\Theta,$$

$$\mathbf{u} = a\boxed{\frac{\mathbf{k}}{k}\sigma\frac{\cosh\left(kz+kh\right)}{\sinh\left(kD\right)}}\cos\Theta,$$

$$w = a\sigma\frac{\sinh\left(kz+kh\right)}{\sinh\left(kD\right)}\sin\Theta,$$

$$p = \overline{p}^H + \boxed{\rho_w g}a\boxed{\frac{\cosh\left(kz+kh\right)}{\cosh\left(kD\right)}}\cos\Theta$$

without currents currents :

$$\sigma^2 = gk\tanh\left(kD\right)$$

Warning : current effects

$E(f,\theta)$, as estimated from buoy data,

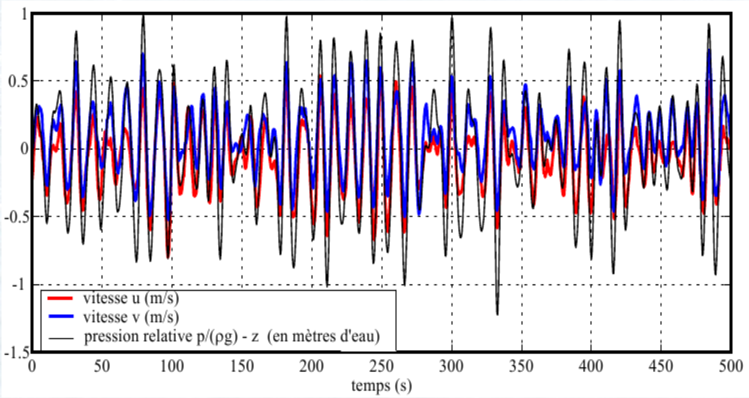
is different from $F(f_r,\theta)$ coming out of WAVEWATCH,

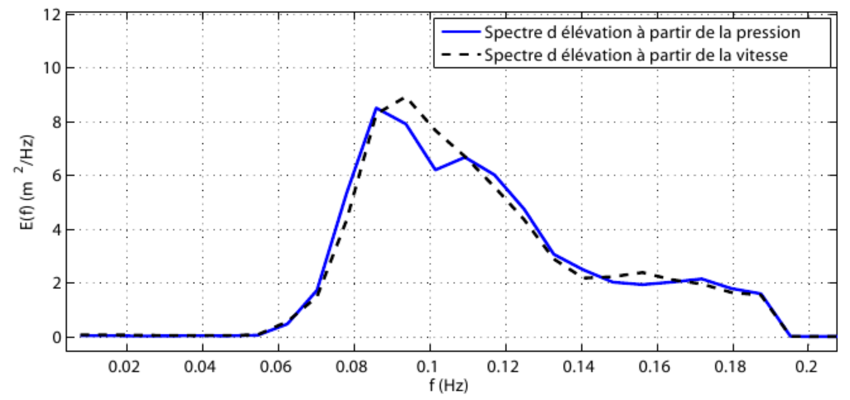
because $\omega = \sigma + \mathbf{k}\cdot\mathbf{U}$

ω = 2 pi / f σ = 2 pi /f_r

Measuring $E\left(f,\theta\right)$?

Using bottom pressure and velocity : again 6 spectra + co-spectra





$$\mathbf{u} = a\boxed{\frac{\mathbf{k}}{k}\sigma\frac{\cosh\left(kz+kh\right)}{\sinh\left(kD\right)}}\cos\Theta$$

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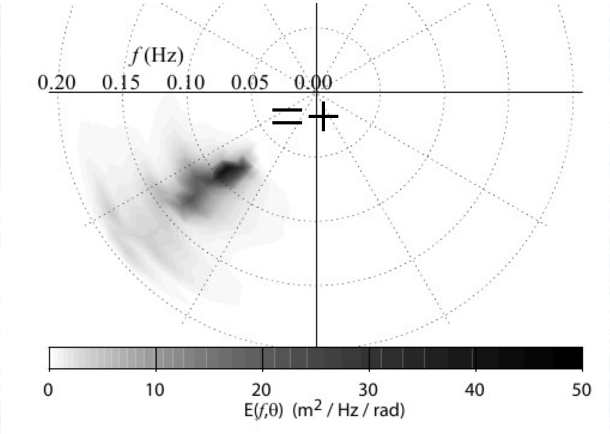

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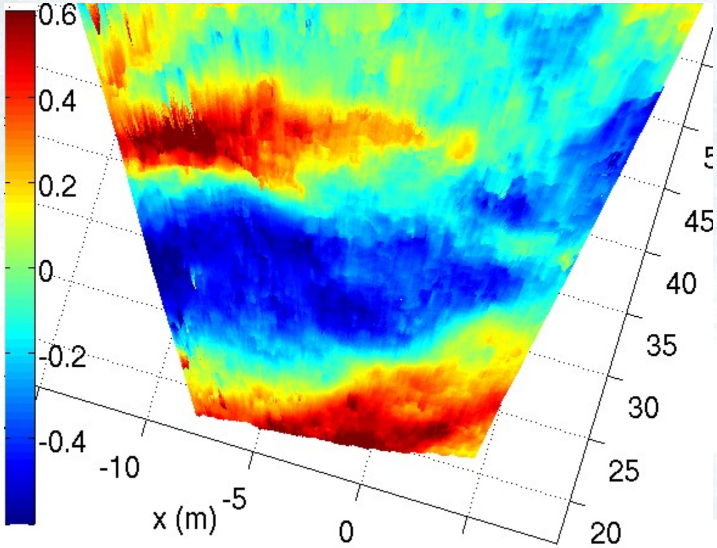
Stereo video

Measuring with cameras

See Benetazzo et al. (2012,2016)
Fedele et al. (2013)

It is becoming much easier …



Surface elevation

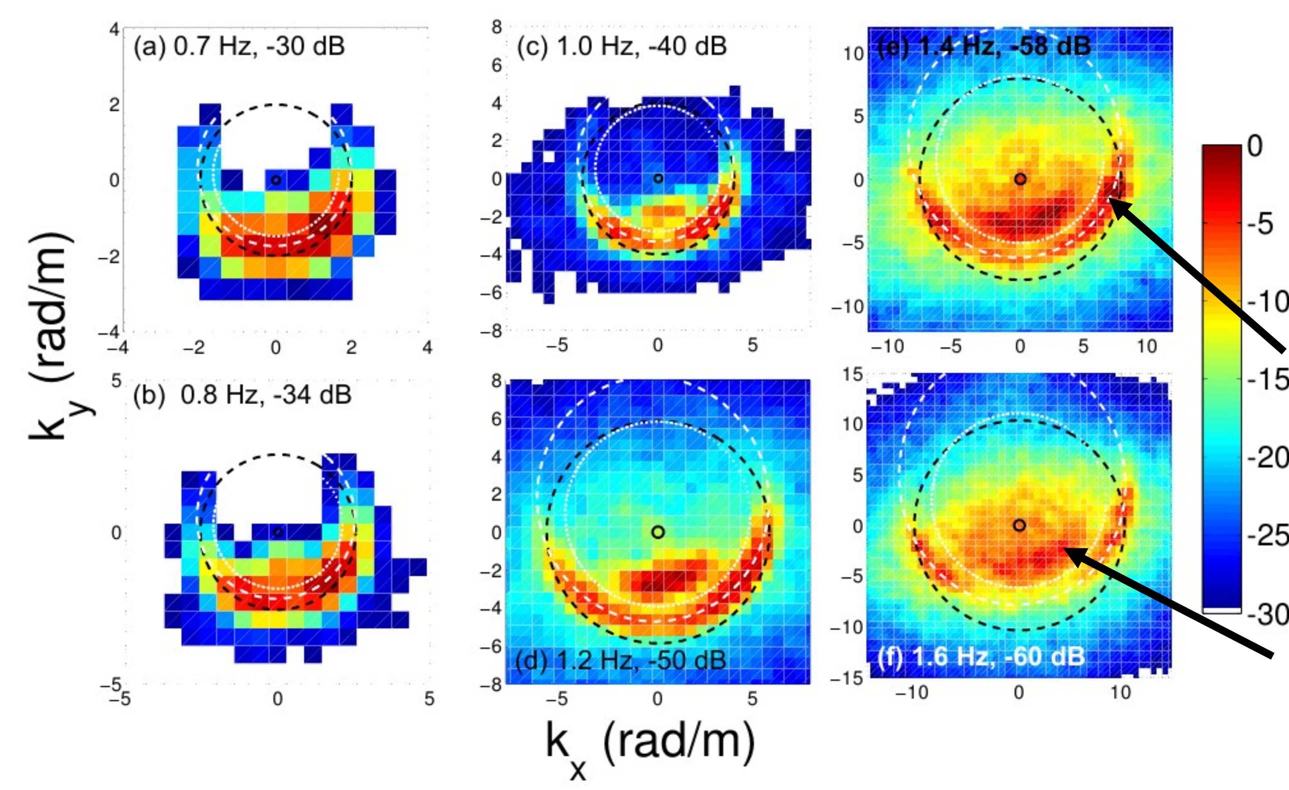
One of the two images in the stereo pair

Measuring with cameras

3 → 2 : Dispersive properties of ocean waves :

only true for **linear waves** in **homogeneous media**

Examples of cuts through 3D spectrum (Leckler et al. JPO 2015)



Free components (linear)

Bound components (locally forced)

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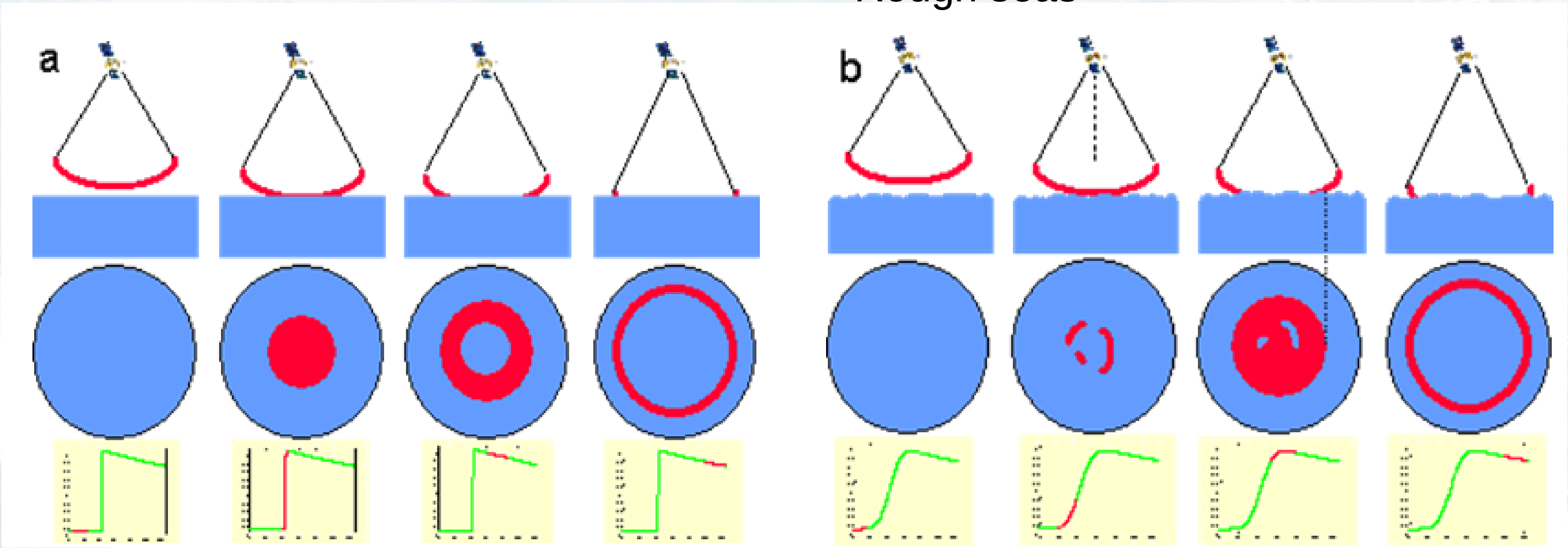
Satellite remote sensing

Satellite altimetry for waves : principles

Satellite altimeters do not resolve the waves → no spectrum
They, measure
1) distribution of elevations → **Hs** and mean sea level
2) backscattered power (NRCS)
→ slope variance = mean square slope (**mss**)
3) other data: radiometer → winds & whitecaps

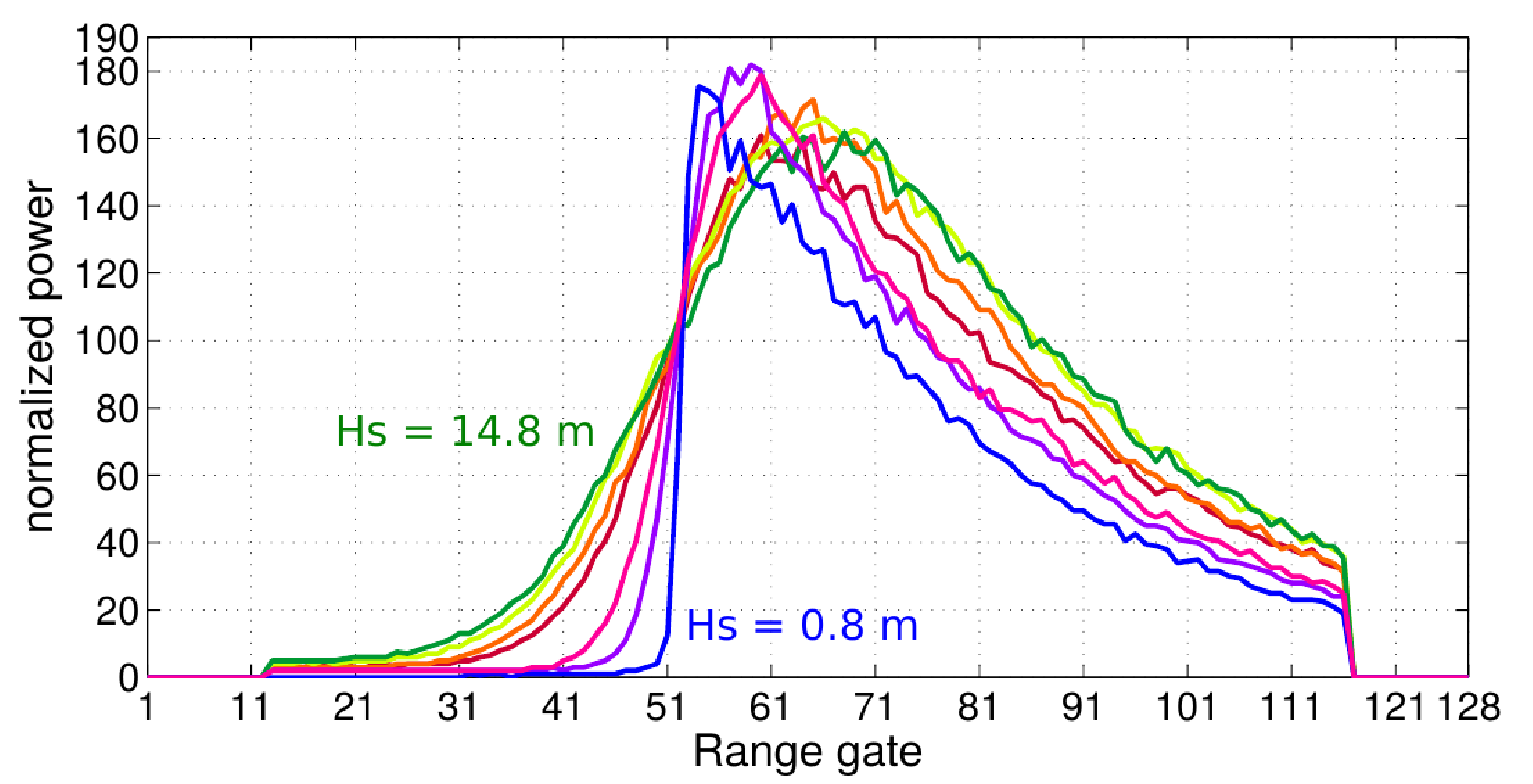
Calm seas

Rough seas



Satellite altimetry for waves : principles

Here are example of Ka-band waveforms from SARAL-Altika

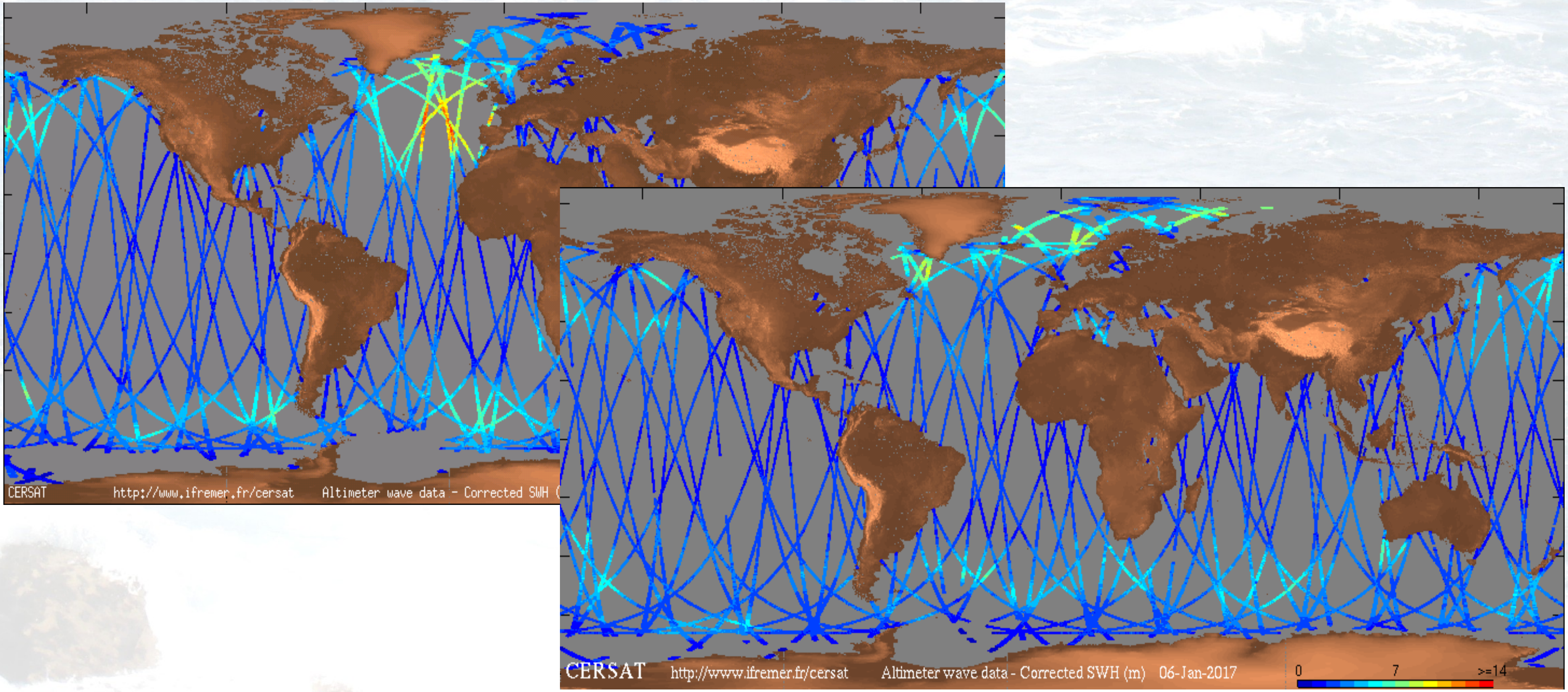


Satellite altimetry: sampling

Continuous measurements since 1993. Not all the ocean is covered.

Here : 1 day of ground tracks for 6 Jan 2014 and 6 Jan 2017.
Over 1 month, each 0.5*0.5 degree cell of the ocean is visited

ftp://ftp.ifremer.fr/ifremer/cersat/products/swath/altimeters/waves/

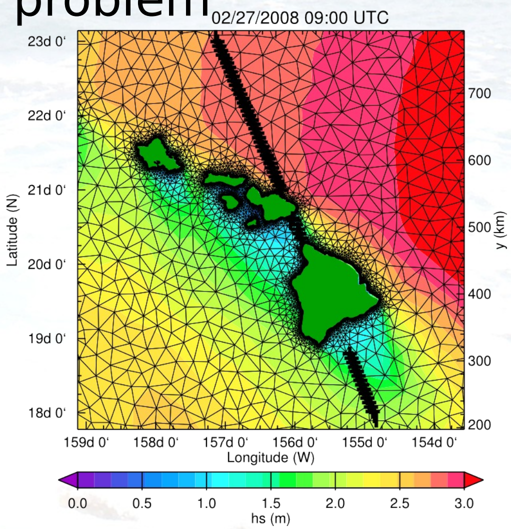


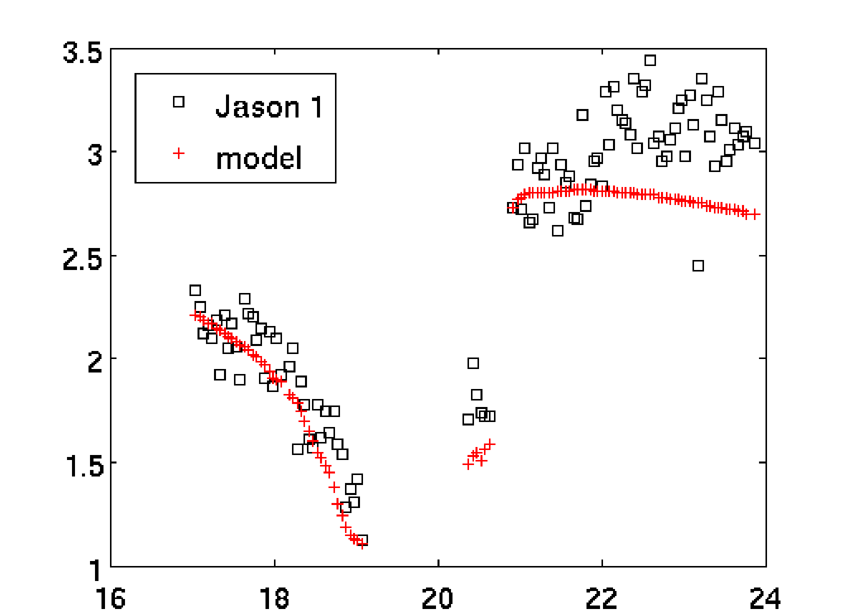
Satellite altimetry: issues

- not accurate for Hs < 1 m
  (SARAL is better : Ka -band, see Sepulveda & al. 2015)
- issues close to shore (~ 20 km)
- data looks reasonable up to Hs = 20.1 m (Hanafin et al., BAMS 2012), but little direct validation for Hs > 12 m.

- improving quality with new satellite missions, but problems of consistency in time (especially for mss)
  → calibrated databases (e.g. **Ifremer** database, ESA CCI+)

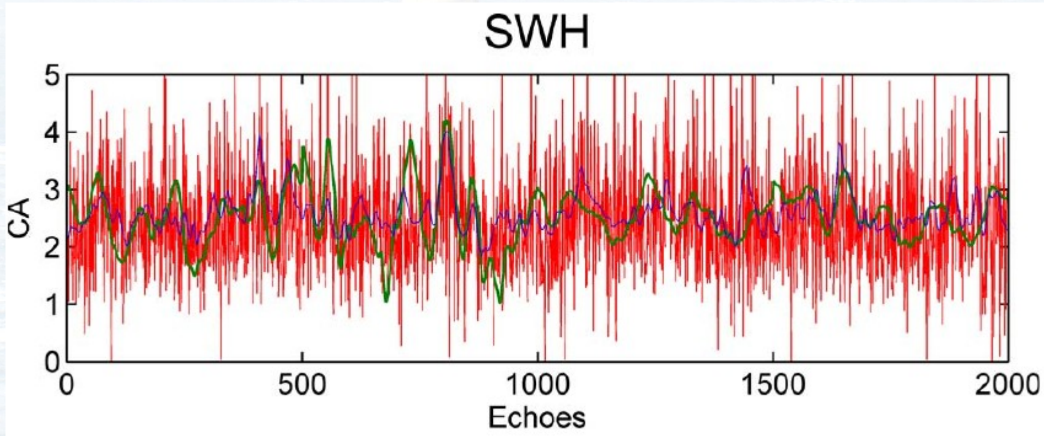
- 1 Hz data is still very noisy :
Processing problem



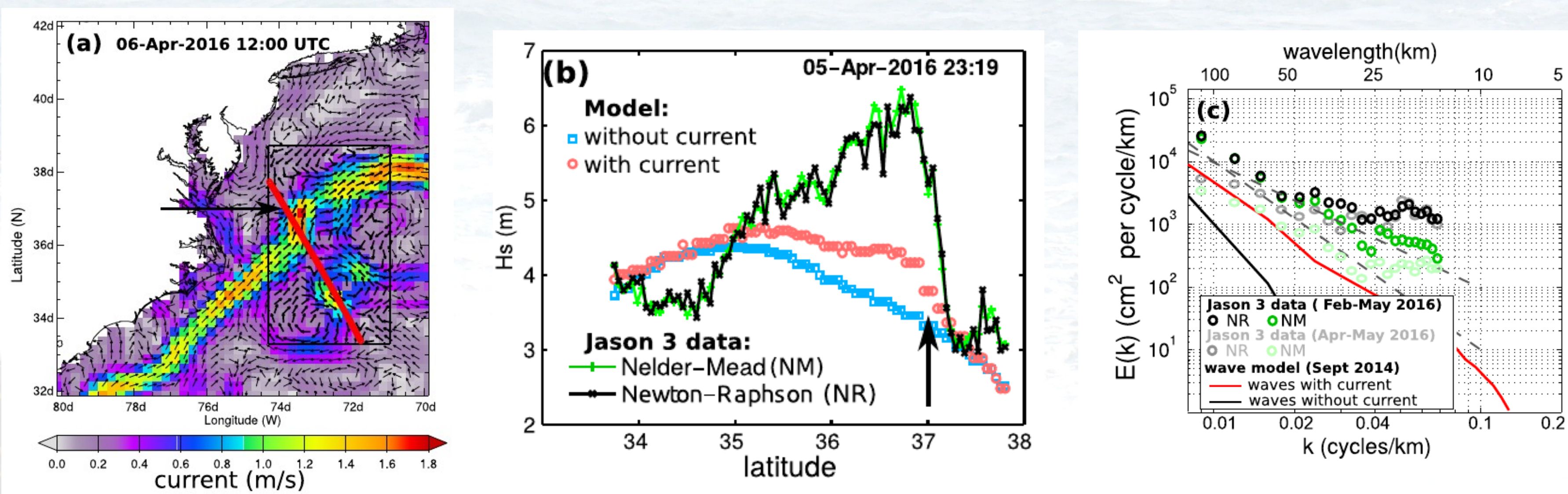


Satellite altimetry: issues

- Better processing ('retracking') is possible : e.g. Halimi et al. (2016)



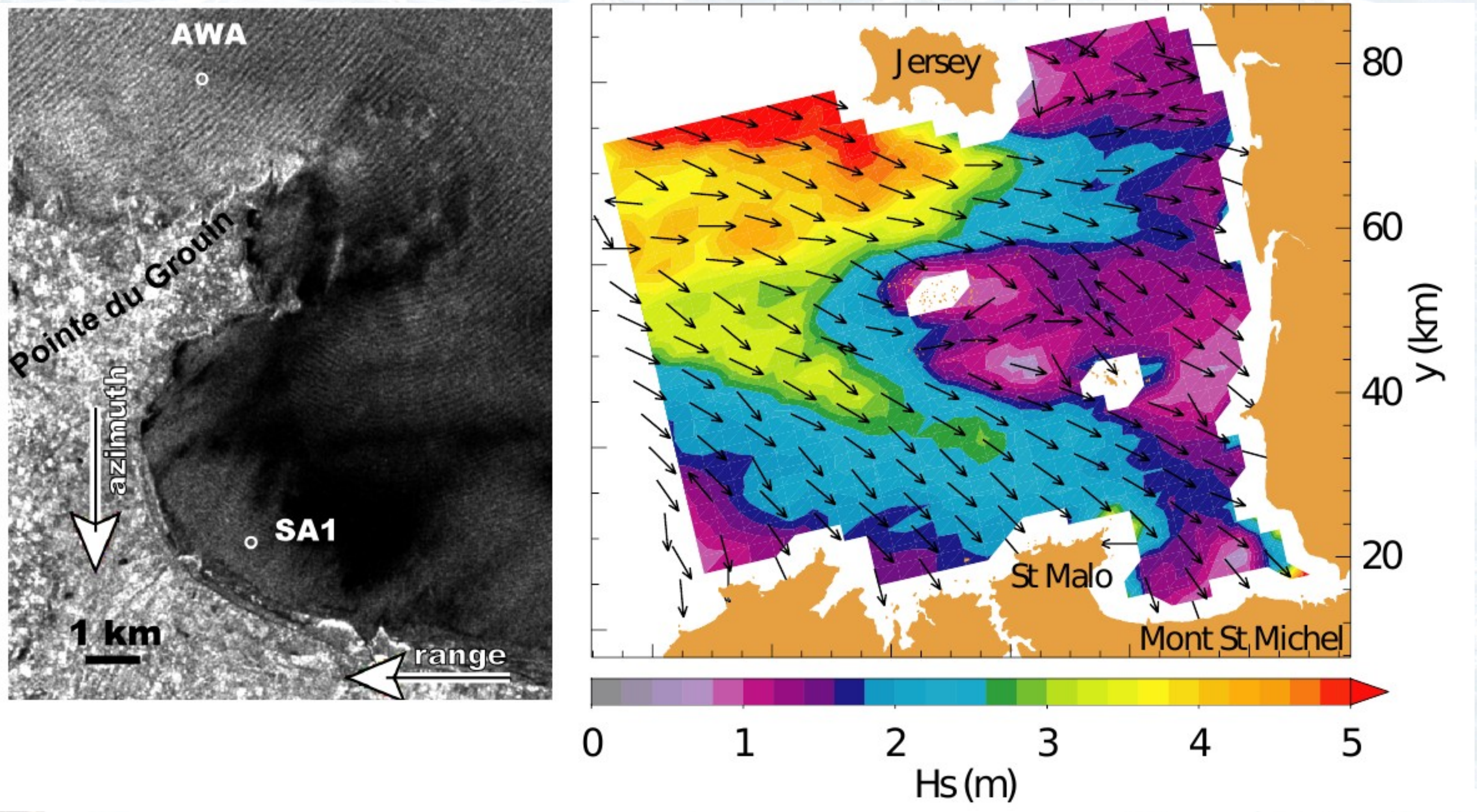
- important for wave-current interactions (e.g. Ardhuin et al. 2017),



SARs and CFOSAT

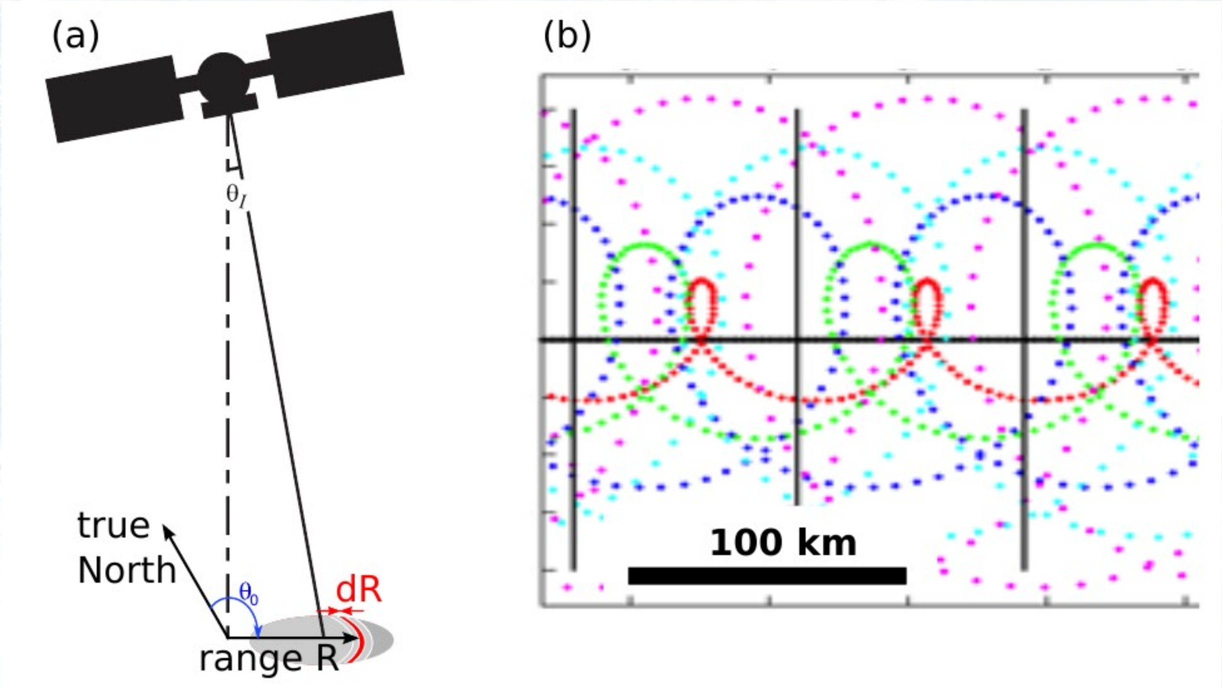
To get spectra, we need resolution in range...

Example of SAR scene (Collard et al. 2005),



SARs and CFOSAT

To get spectra, we need resolution in range… but not necessarily in azimuth (Jackson et al. 1985, Hauser et al. 2017). This will be used with CFOSAT. Launch in August 2018.



Summary

1) Buoys do not measure a full **2D spectrum**, but only 5 parameters at each freq.

2) linear wave theory gives simple **transfer function** from, e.g. bottom pressure to surface elevation : this is why you can (or can't) measure waves with a bottom pressure recorder.

3) Altimeters provide robust estimates of Hs from 1 to 20 m.
Also gives mss → (Hs, mss) can be used for proxy of wind, mean period …

4) Measuring spectra from space : SARs or the future SWIM instrument on CFOSAT. (and we have proposed a follow-on to ESA for EE9 : SKIM).