

# Wave and stratification effects on Surface drift currents: A first analysis of HF radar data

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1: SHOM, 2: Ifremer, 3: TUD

# Motivations

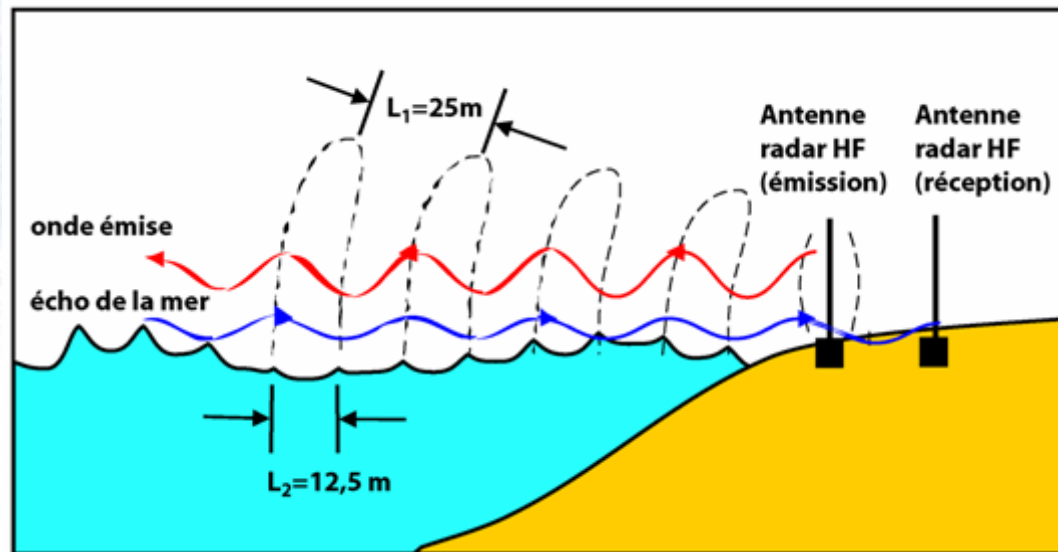
Understanding, observing and predicting *where « stuff » goes* in the ocean is one of the main objectives of operational oceanography. The present work is part of the effort on final products such as *« surface drift currents »*.

## Outline

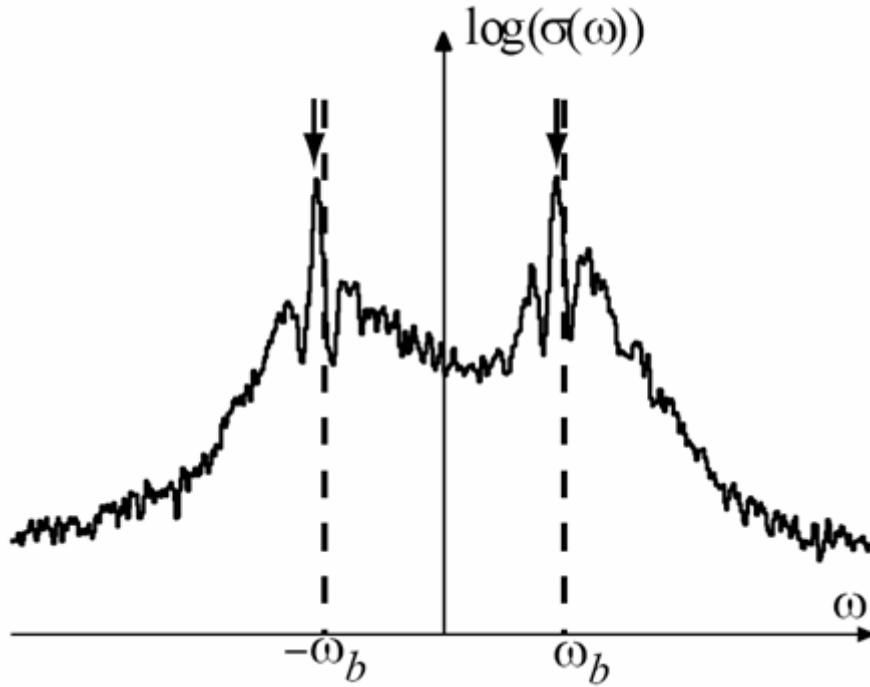
1. Nature of HF radar measurements
2. The HF radar data
3. Surface waves, drift and modelling
4. Interpretation of the data: beyond Ekman
5. Operational and scientific perspectives

# 1. HF radar measurements: basics

Although there are all sorts of waves on the ocean  
the radar is most sensitive to waves with wavelengths  $L_2$  half that of the radar  
( $L_1$ : given by radar frequency =  $C/f$ )  
that propagate to or away from the radar (Bragg waves in monostatic case)



# 1. HF radar measurements: basics



The 2 prominent peaks in the Doppler spectrum are due to Bragg waves (with wavelength  $L_2$ ) approaching and receding.

The **shift** from the linear wave phase speed is the « **current** » component  $U_R$  in the direction of the radar.

$$U_R = C - C_{\text{lin}}$$

# 1. HF radar measurements: velocities (1)

What is this « current »  $U_R$  ??? ... a bit of theory

$$U_R = C - C_{\text{lin}} = U_{Sf} + U_E$$

1

Kind of advection of the Bragg wave (of wavelength  $L_2$ )  
**by the other waves** (Weber and Barrick 1977, Broche et al. 1983)

$$U_{Sf} \simeq U_{ss}(f_B) \cdot \frac{k_B}{k_b} + 4\pi k_b \int_{f_B}^{\infty} \int_0^{2\pi} f \cos(\theta - \theta_B) E(f, \theta) d\theta df$$

Advection by the Stokes drift of the longer waves...

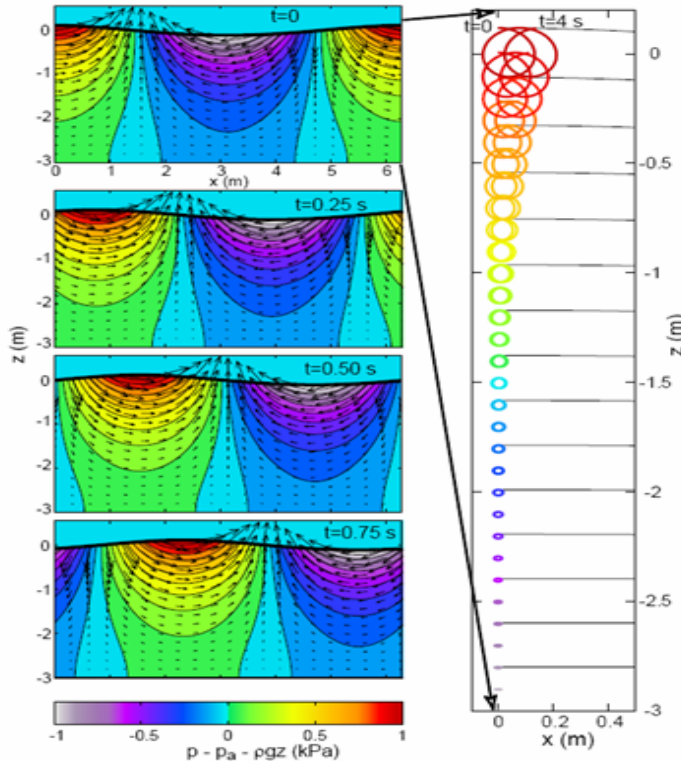
$$U_{ss}(f_c) = 4\pi \int_0^{f_c} \int_0^{2\pi} f k(f, \theta) E(f, \theta) df$$

...with also a correction coming from the smaller waves.

# 1. HF radar measurements: velocities (2)

What is this « current »  $U_R$  ??? ... a bit of theory

$$U_R = C - C_{lin} = U_{Sf} + U_E$$



2

Advection of the Bragg wave  $L_2$  by the Eulerian current (i.e. the mean current)

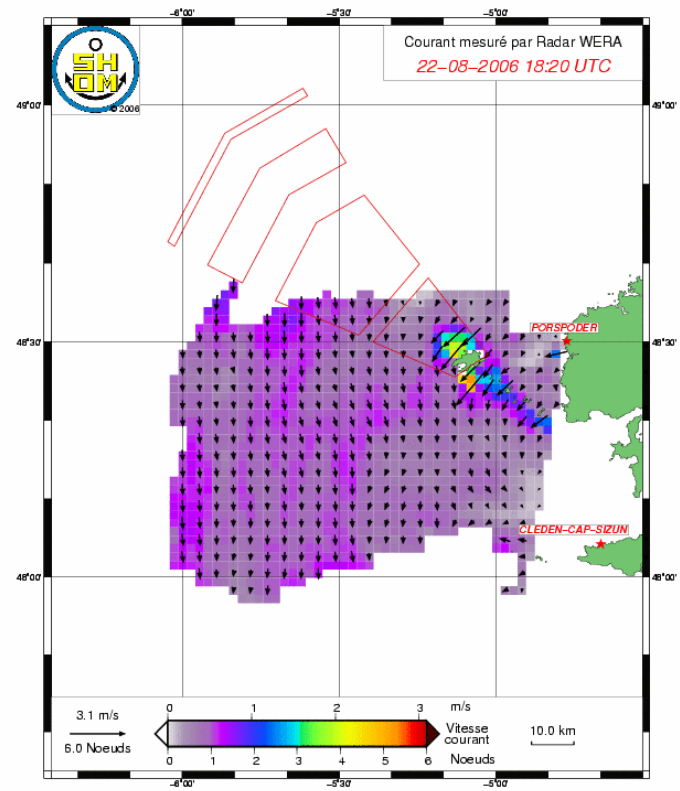
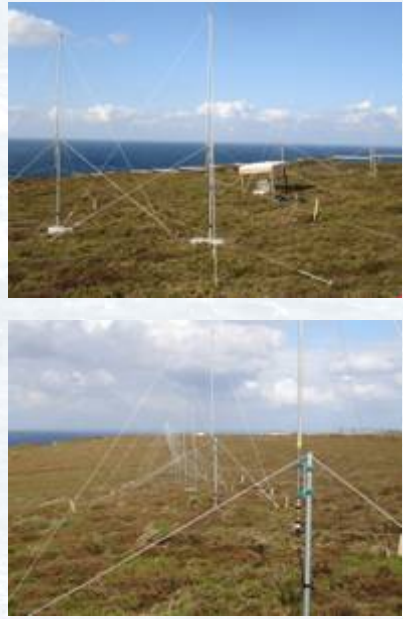
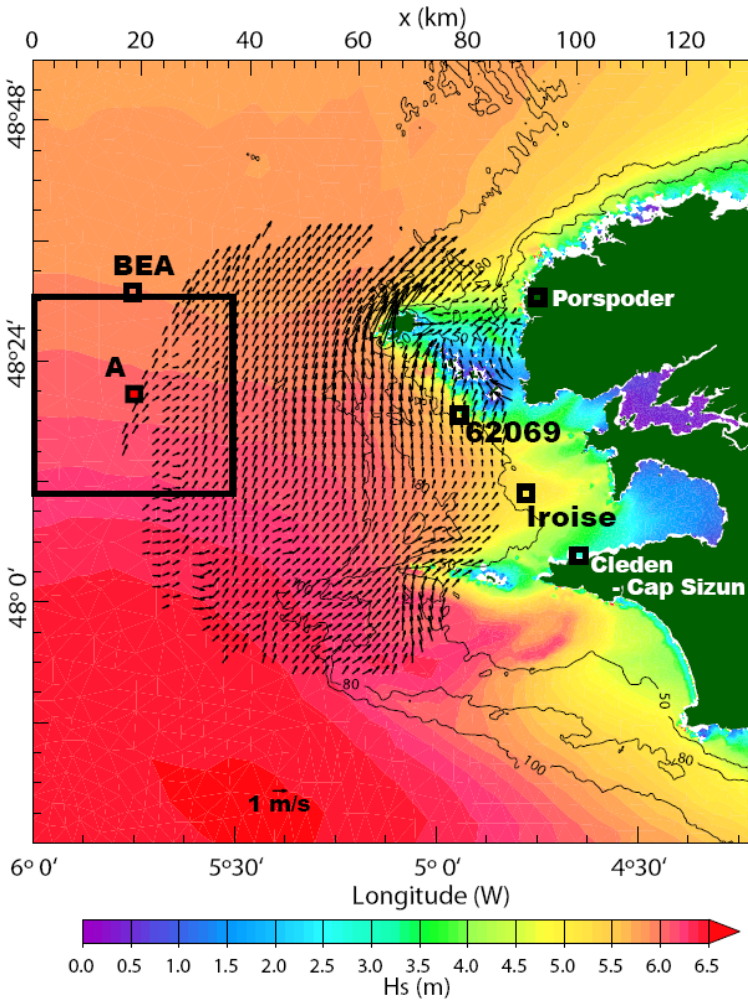
For linear waves Stewart & Joy (1974), and Kirby and Chen (1989), have shown that the **advection velocity  $U_E$**  of the Bragg wave is the Eulerian current profile weighted with the profile of the Stokes drift of the Bragg waves  $L_2$ . For our 12.4 MHz radar, this has a **median depth of 0.6 m.**

Pressure, velocity and drift for 2 s waves in 3 m depth:

For 0.33 Hz waves: space  $\times 2$ , and time  $\times \sqrt{2}$

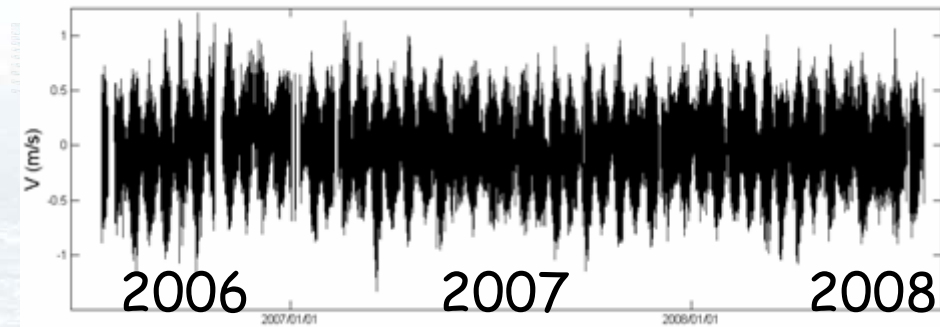
# 2. The HF radar data

Two WERA 12.4 MHz radar deployed at Porspoder and Cleden-Cap Sizun.  $L_2=12$  m

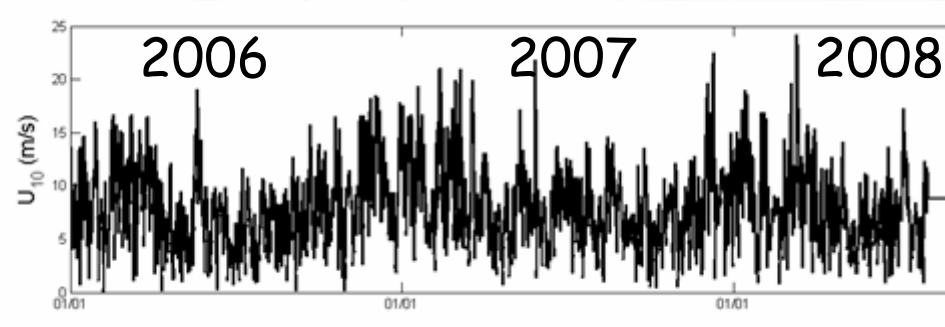


Operated for SHOM by Actimar SA, since July 2006: tide-dominated currents.

## 2. The HF radar data

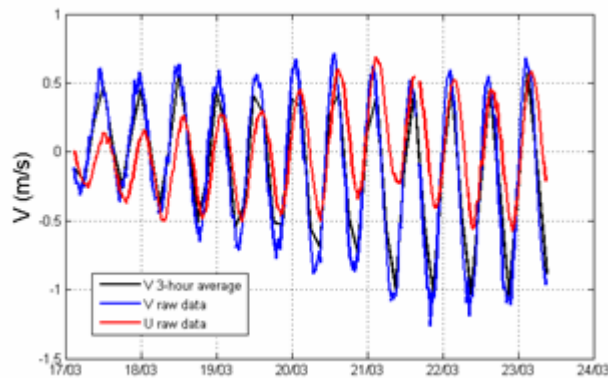


Full time series of current at point A

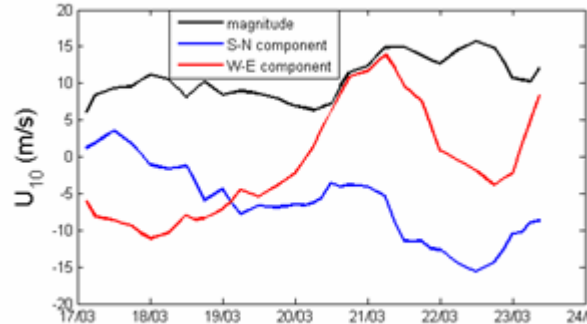


and wind (ECMWF)

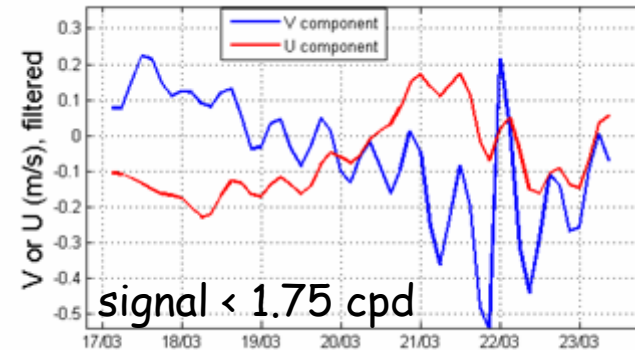
Usually tide-dominated ... but not always: see 20-23 March 2008  
 Inertial currents can as large as spring tidal currents (coeff. 85-95)



Full signal



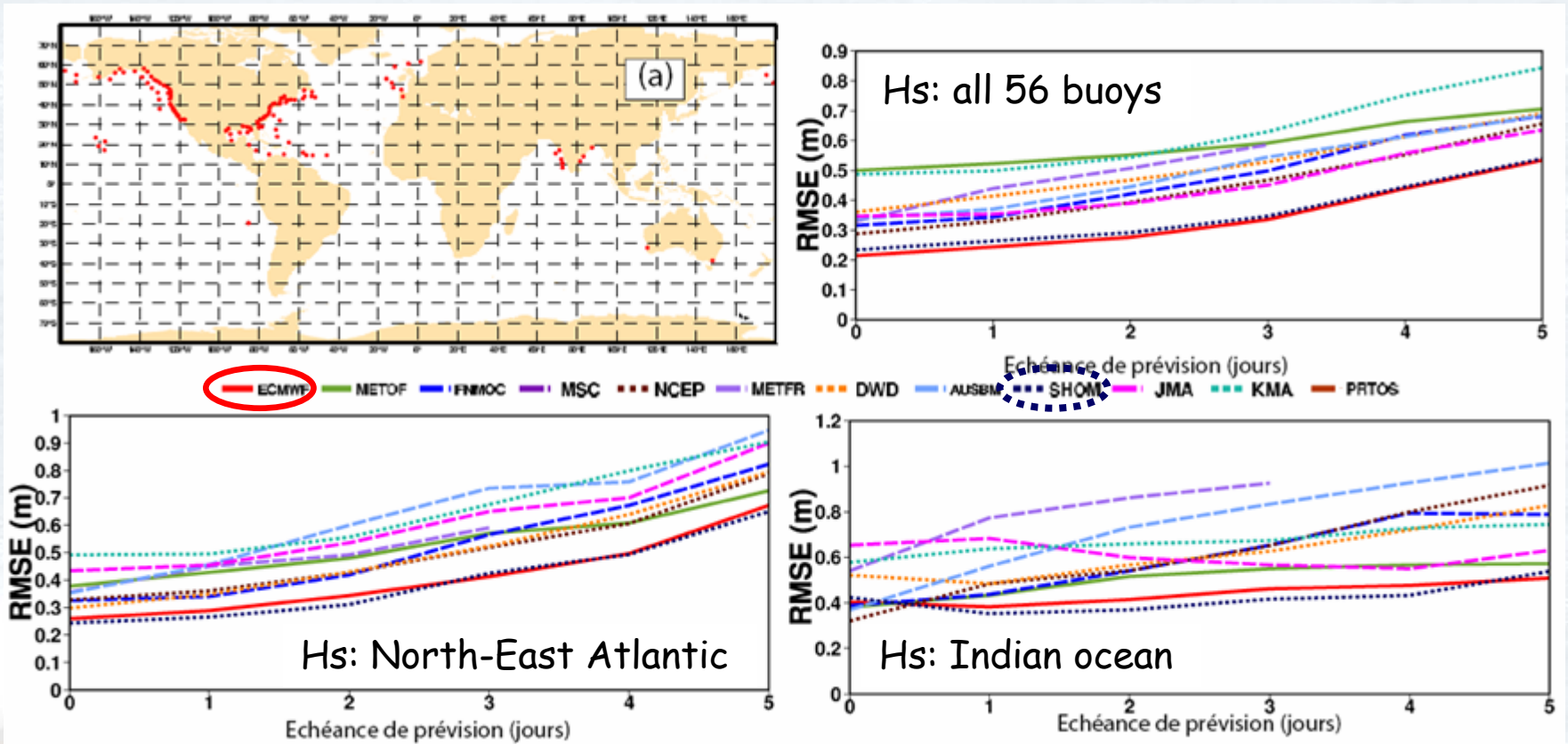
Wind



Inertial currents

# 3. Surface waves, drift, and modelling

Since May 2008, SHOM has been running the world's **most accurate wave model**<sup>(1)</sup> in terms of **Hs** and **Tz** ... according to ECMWF statistics computed for JCOMM (these results should be available soon on Previewer.org).  
 Google on « JCOMM verification » for the plots below ... and more.



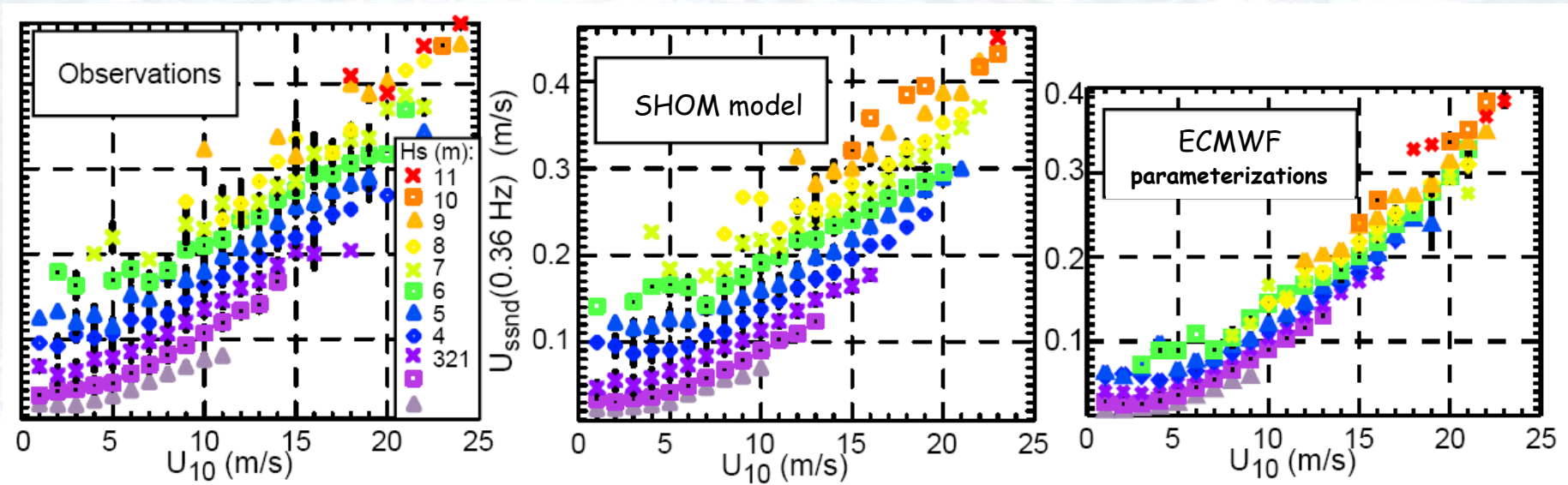
<sup>(1)</sup>: because ECMWF assimilate wave data and runs a model on a finer grid, their forecasting system is, in some areas, marginally more accurate than SHOM... but not the model itself.

# 3. Surface waves, drift, and modelling

Hs and Tz are nice ... but what about the surface Stokes drift  $U_{ss}$  ?

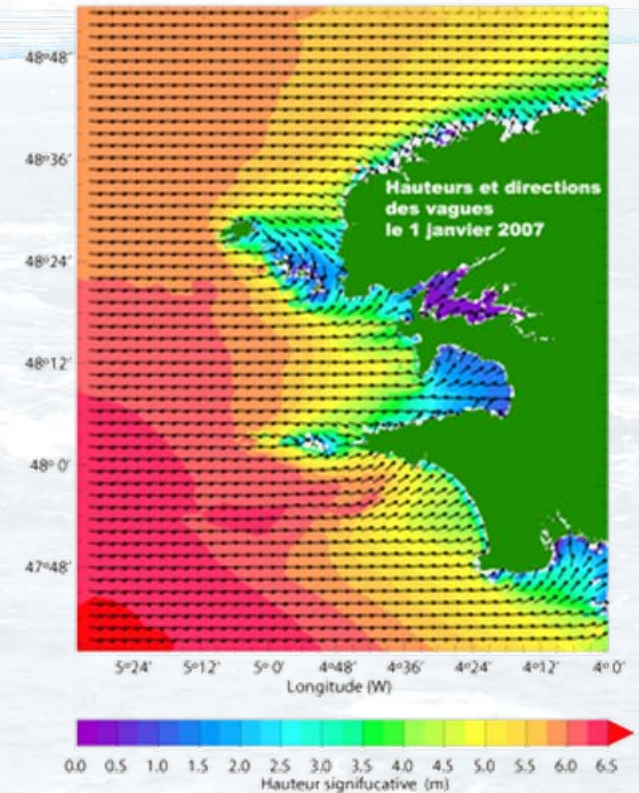
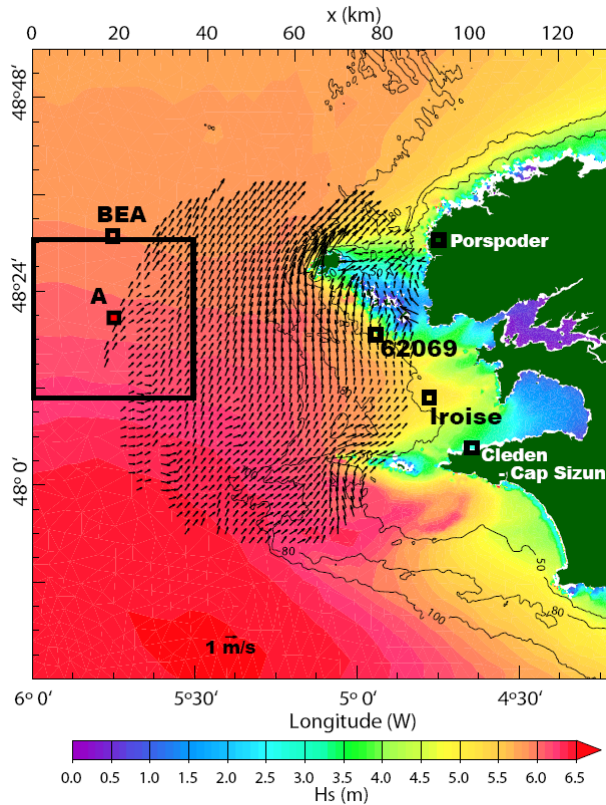
- $U_{ss}$  estimate requires spectral data ... and there is no permanent deep water Spectral data in the North-East Atlantic, excepts for Puertos del Estado buoys and ... since August 2008, buoy 62001 (Gascogne).

So we turn to a similar wave climate: North-East Pacific (buoy 46005):



The new parameterizations of wind input and dissipation in SHOM's model improve both the usual parameters  $H_s$ ,  $T_p$ ,  $T_z$  ... and also  $U_{ss}$

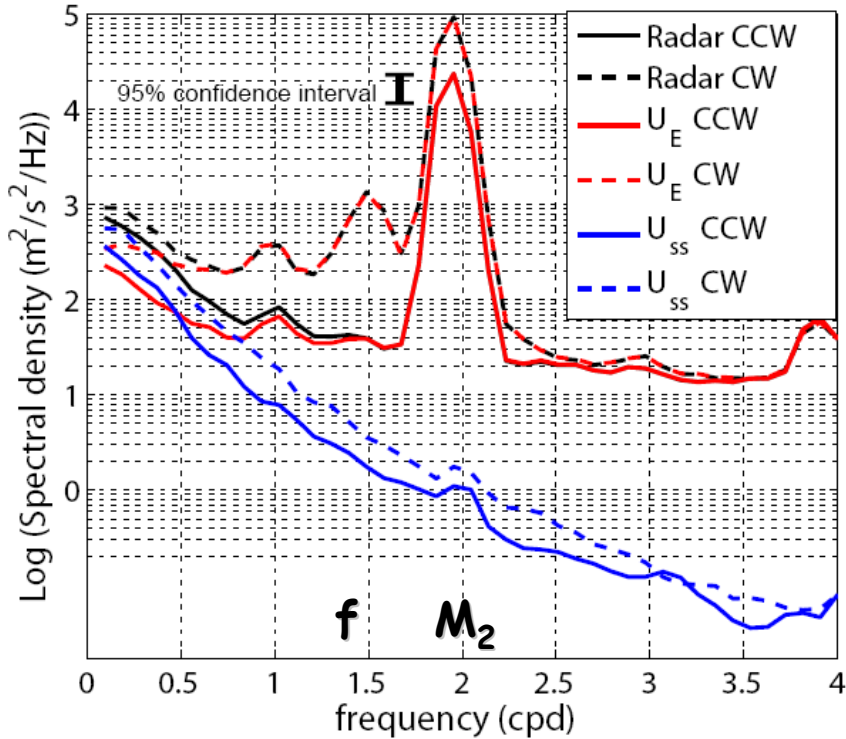
# 3. Surface waves, drift, and modelling



Estimation of  $U_{ss}$  at A: unstructured WAVEWATCH III (8400 wet nodes) nested into  $0.1^\circ$  Bay of Biscay, nested into  $0.5^\circ$  global. Partial validation at 62069 (Pierres Noires). Bias on  $U_{ss}$  (0.36 Hz) and  $U_{sf}$  expected to be less than 5% at A

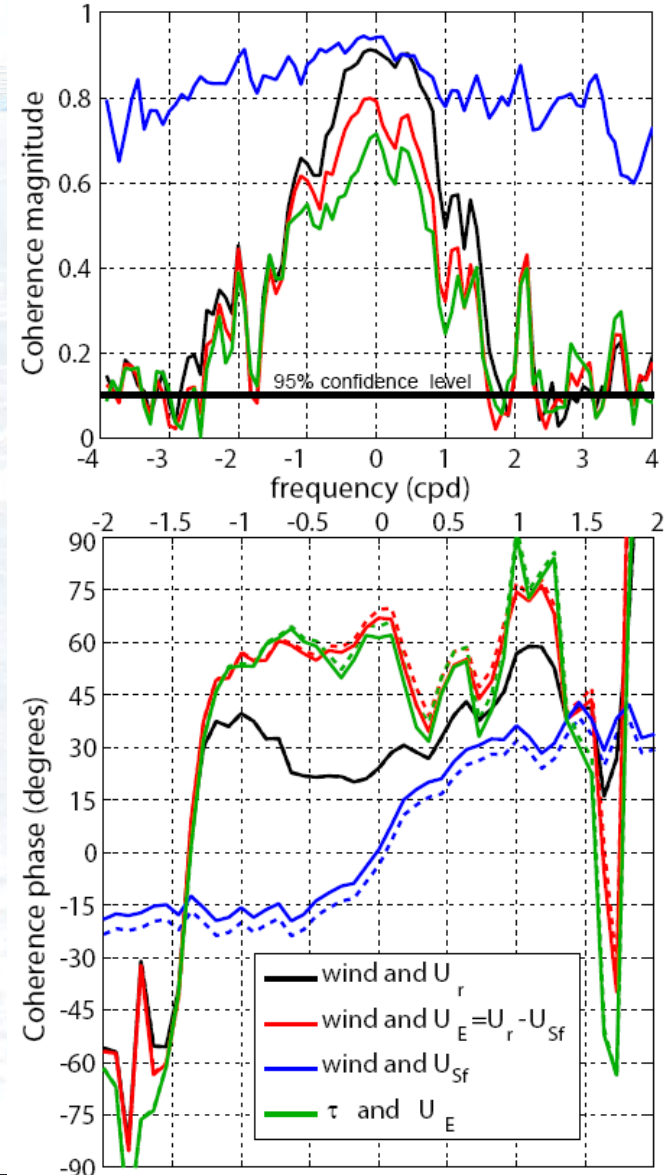
# 4. Interpretation of the data: beyond Ekman

$$\underline{U_R} = C - C_{lin} = \underline{U_{Sf}} + \underline{U_E}$$



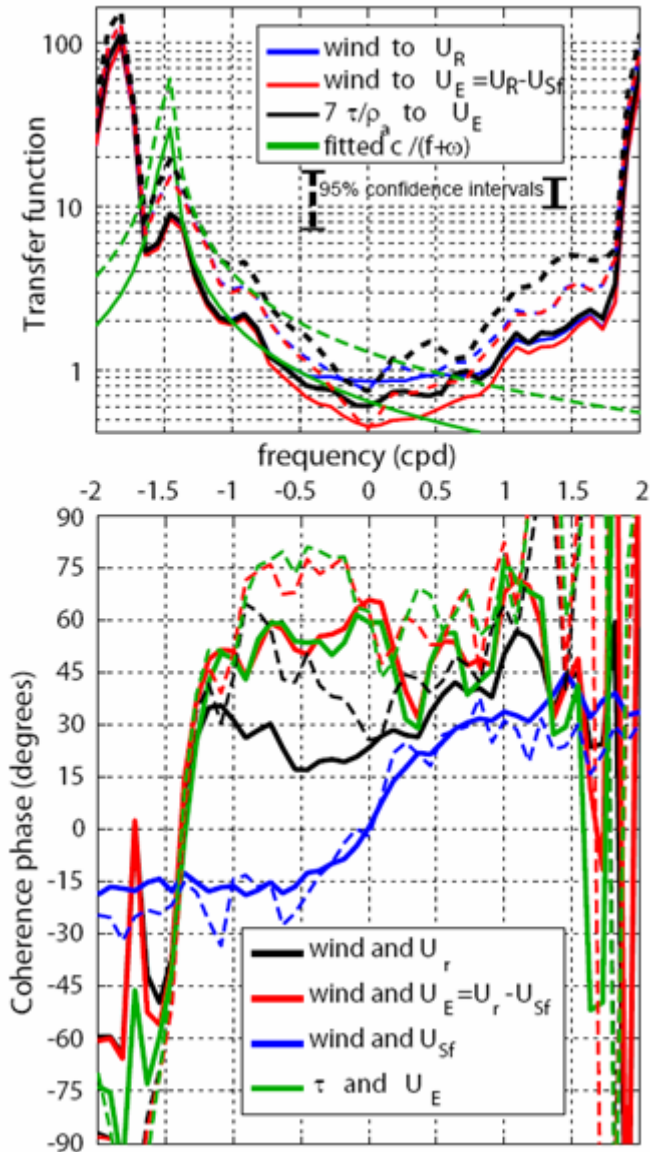
Spectra ...

and co-spectra ->



The Stokes part lags 1.5 hours to the wind.  
 The Eulerian part is generally 60° to the right of the wind.

## 4. Interpretation of the data: beyond Ekman



We separate into summer stratified (--) and winter homogeneous (—) water column using SST data.

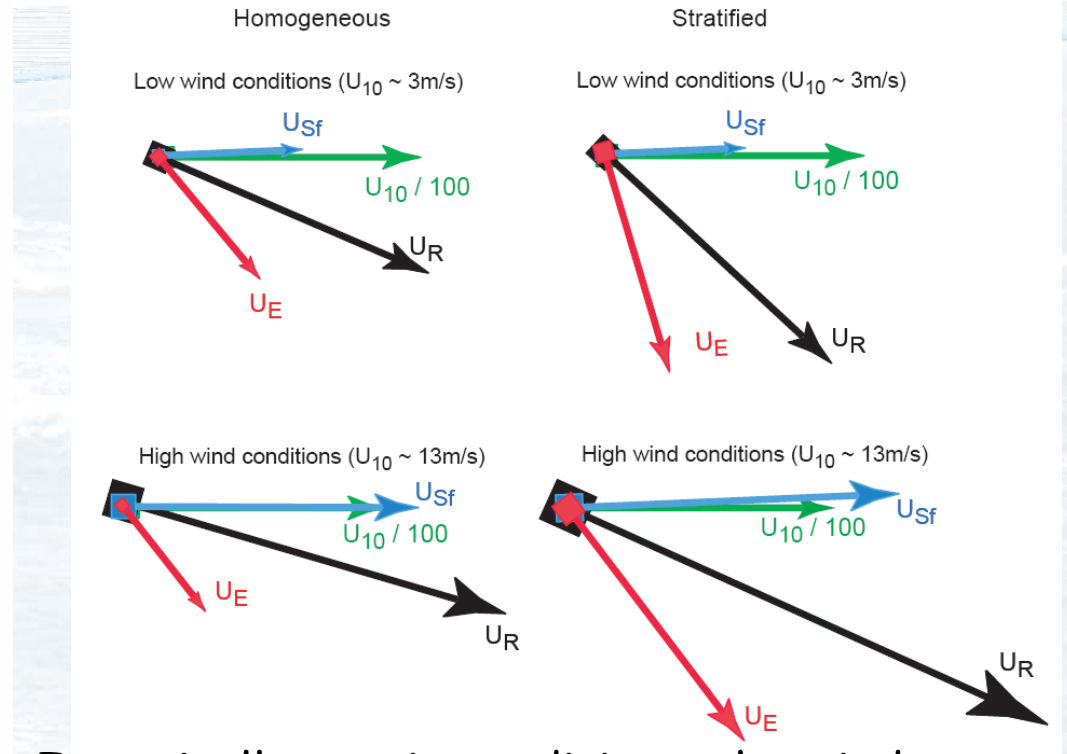
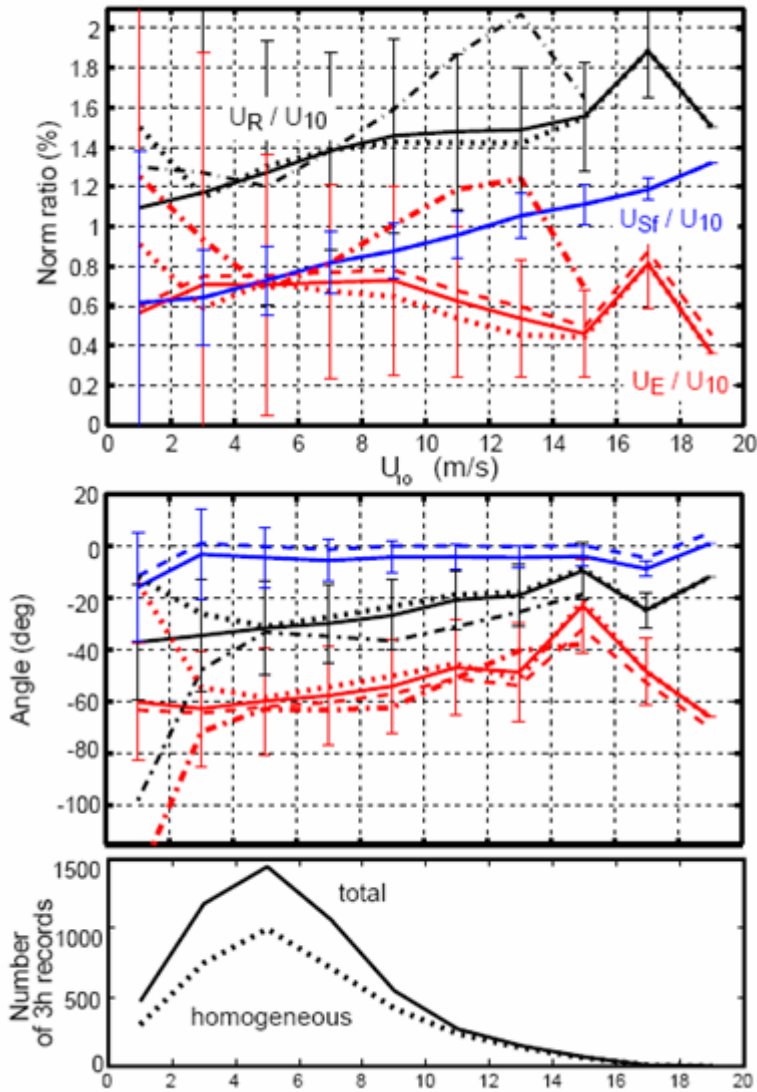
-> Eulerian surface current response twice as large in stratified conditions

-> Surface current even more to the right in stratified conditions

-> HF radar can probably be used to determine the mixed layer depth.

(See also Broche et al. 1983: forward model using Laplace's transform).

# 4. Interpretation of the data: beyond Ekman



In typical oceanic conditions, the wind induced surface currents are dominated by the wave Stokes drift  $U_{ss}$  (60%,  $\sim U_{10}^2$ )

The Eulerian current is weaker ( $\sim 0.5\% U_{10}$  only), except for stratified conditions (up to 1.2% of  $U_{10}$ )

# 5. Operational and scientific perspectives

The separation of surface current into wave-induced Stokes drift and Eulerian current is important both for:

**modelling** (coherence between strong mixing and large surface currents, important for transport of weakly buoyant material ... and for horizontal mixing and spreading)

**comparisons to observations** (ADCP, drifters, radars).

HF radar observations confirm numerical model results with strong wave-induced mixing (Rascle 2007):

**Stokes drift dominates wind-related surface currents in open ocean, Stratification enhances surface drift.**

Empirical « windage » relations used for search and rescue may be better replaced by a **transfer function** (Fourier or Laplace, see Millot & Crépon JPO 1981) using the full wind history.

Further work: spatial coherence of inertial motions