

**Techniques de télédétection radar HF pour
l'étude de la dynamique océanique et
côtière:
performance, verrous technologiques,
enjeux scientifiques et sociétales**

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A tall, white, cylindrical radar mast stands on a sandy beach. The mast is supported by several thin cables extending to the ground. The background features a clear blue sky, a dark ocean with white-capped waves, and a sandy beach. In the distance, a small dark object, possibly a vehicle, is visible on the beach. The foreground is filled with dry, yellowish grass.

PLAN

Historique

Technique de la mesure

Réseaux radars dans le monde

Applications de la courantologie radar

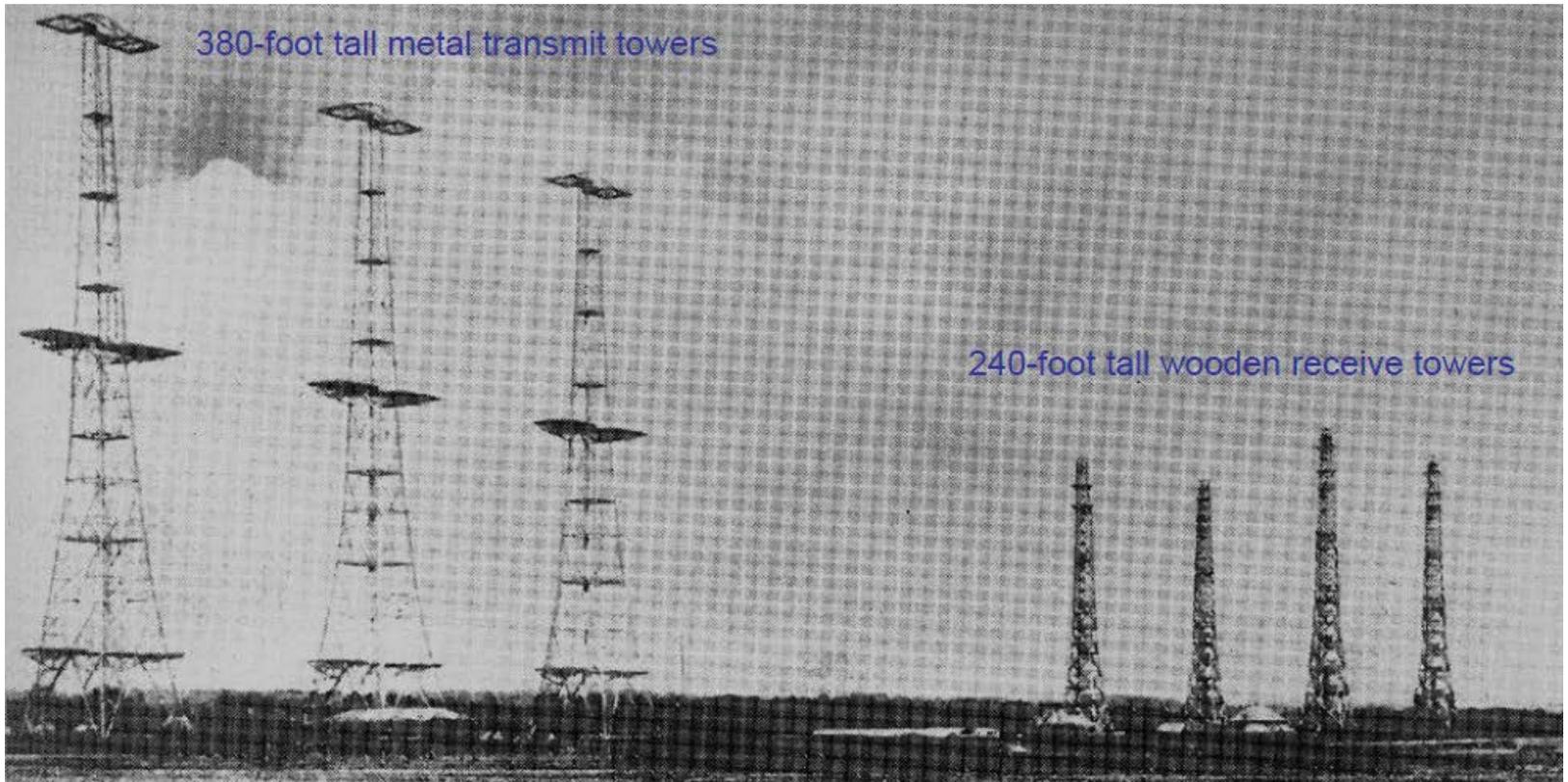
Réseaux français

Défis, projets

Communauté international et transmission de savoir

Technologie radar HF est elle nouvelle?

Installé en 1938 au R-U pour détecter les bombardiers allemands, le 25MHz "Chain Home" révèle un "Echo de mer" - dû au phénomène de résonance de Bragg, considéré comme bruitage



Crombie (1955)

Dominion Physical Laboratory, Lower Hutt,
New Zealand.

No. 4459 April 16, 1955

NATURE

681

THE INTERACTION OF HF/VHF RADIO WAVES WITH THE
SEA SURFACE AND ITS IMPLICATIONS

1970

Donald E. Barrick

The Electrical Engineering Department
The Ohio State University
Columbus, Ohio 43210

and

Battelle Memorial Institute
Columbus Laboratories
Columbus, Ohio 43201

Doppler Spectrum of Sea Echo at 13.56 Mc/s.

THE Doppler frequency shift of radio waves reflected from the sea surface at 13.56 Mc/s. has been recorded and a portion of a typical record is shown in Fig. 1. Such records show the following unexpected features: (a) the frequency of the principal component (as initially obtained by measurement of the length of individual cycles on the record) is surprisingly constant at about 0.38 c/s., irrespective of wind conditions and state of the sea; (b) the records show that the range of frequencies present is small. Spectrum analysis of the records made with an Admiralty wave analyser¹ confirmed these findings. Fig. 2 is a reproduction of a sample spectrum analysis which shows a large but narrow peak at a frequency of 0.38 c/s. accompanied by a smaller peak at a frequency of about 0.54 c/s.

A tentative explanation of these features can be offered if it is assumed that the sea waves act as diffraction gratings. It is known² that, under a given wind, sea waves of all lengths up to a maximum dependent on the wind velocity are generated. Of this multiplicity of waves, some travelling radially to the antenna will have a wave-length L and will reflect back a large signal when $L = \lambda/2$, λ being the radio wave-length. Since the velocity v of a sea wave of length L is given by $v = \sqrt{\frac{g}{2\pi} L}$, g being the acceleration due to gravity, then the Doppler shift Δf of this enhanced signal will be

$$\Delta f = \frac{2v}{\lambda} = \frac{2}{\lambda} \sqrt{\frac{g}{2\pi} \cdot \frac{\lambda}{2}} = \sqrt{\frac{g}{\pi} \cdot \frac{1}{\lambda}}$$

In the present case, $\lambda = 22.1$ m., $g = 9.81$ m./sec.², gives $\Delta f = 0.376$ c/s., agreeing closely with the value for $\Delta f = 0.38$ c/s. found from Fig. 2.

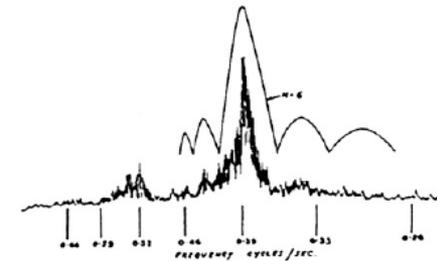


Fig. 2

It might also be expected that components of non-sinusoidal waves of wave-length $L = n\lambda/2$, n being an integer, travelling radially towards the antenna, would cause reinforcement and thus large reflected signals. These would then have Doppler shifts

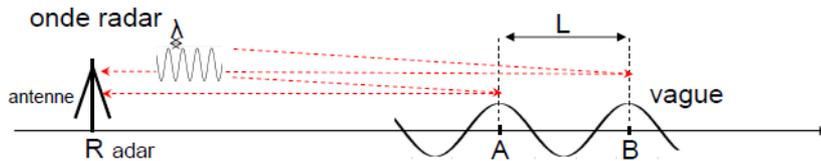
$$\Delta f = \sqrt{\frac{g}{\pi} \frac{n}{\lambda}}$$

The subsidiary peak in Fig. 2 at a frequency of 0.54 c/s. $\approx 0.38 \sqrt{2}$ thus suggests that this is due to waves having a length $L = \lambda$.

Both the peaks in Fig. 2 depart considerably from line spectra. At first sight this could be explained by considering that the relatively short waves of length $L \approx \lambda/2$ are superimposed on the crests of much longer waves and thus have velocities dependent on the lengths and heights of the larger waves. However, this would lead to a continuous spectrum, whereas in the neighbourhood of the larger peak in Fig. 2 there are small subsidiary maxima which on this argument would be unlikely to occur. An alternative explanation of the shape of the spectra is that the sea waves exist in short trains. The first-order ($n = 1$) diffraction patterns of short sea-wave gratings of variable spacing L have been calculated,

$$\text{and by the use of the relation } \Delta f = \frac{2}{\pi} \sqrt{\frac{g}{2\pi}} \cdot L$$

may be drawn as Doppler shift spectra. Superimposed on Fig. 2 is such a spectrum obtained for a grating containing six wave crests. The agreement is considered to be good. This may be of interest to oceanographers, since the explanation does not completely conform with accepted ideas of the behaviour of sea waves.



Phase du signal reçu par le radar provenant de la crête A : $\frac{2\pi}{\lambda} (RA + AR)$

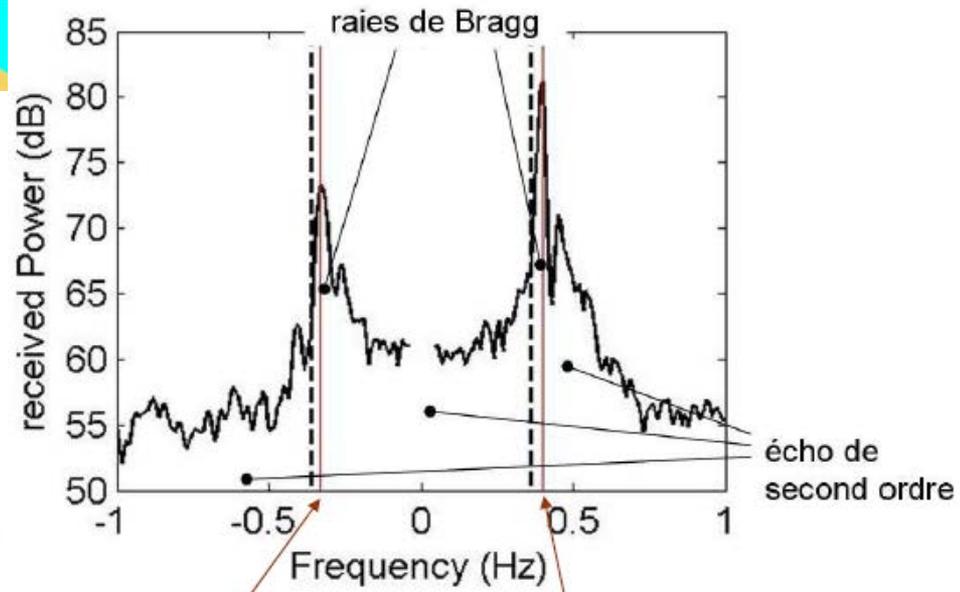
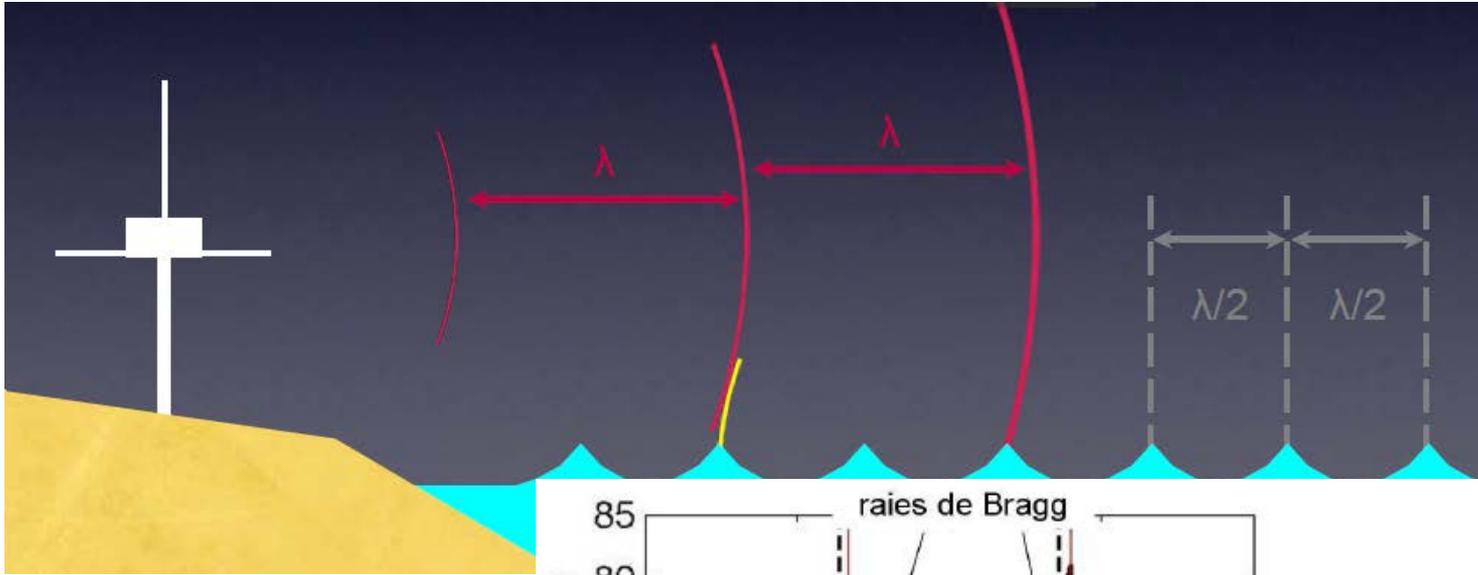
Phase du signal reçu par le radar provenant de la crête B : $\frac{2\pi}{\lambda} (RB + BR)$

Différence de phase : $\Delta\phi = \frac{2\pi}{\lambda} 2AB = \frac{4\pi}{\lambda} L$

Condition de résonance : $\Delta\phi = 2\pi \Rightarrow L = \frac{\lambda}{2}$ Vagues de Bragg

Seules les vagues à propagation RADIALE (// axe de visée) contribuent à ce mécanisme

Diffraction de Bragg, résonance, spectre Doppler



2 "raies" dans le spectre Doppler correspondant à la rétrodiffusion par les vagues de Bragg

$F_0 = 12.8 \text{ MHz}$

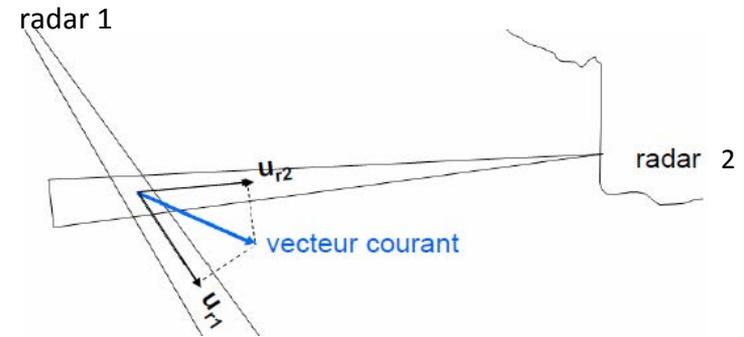
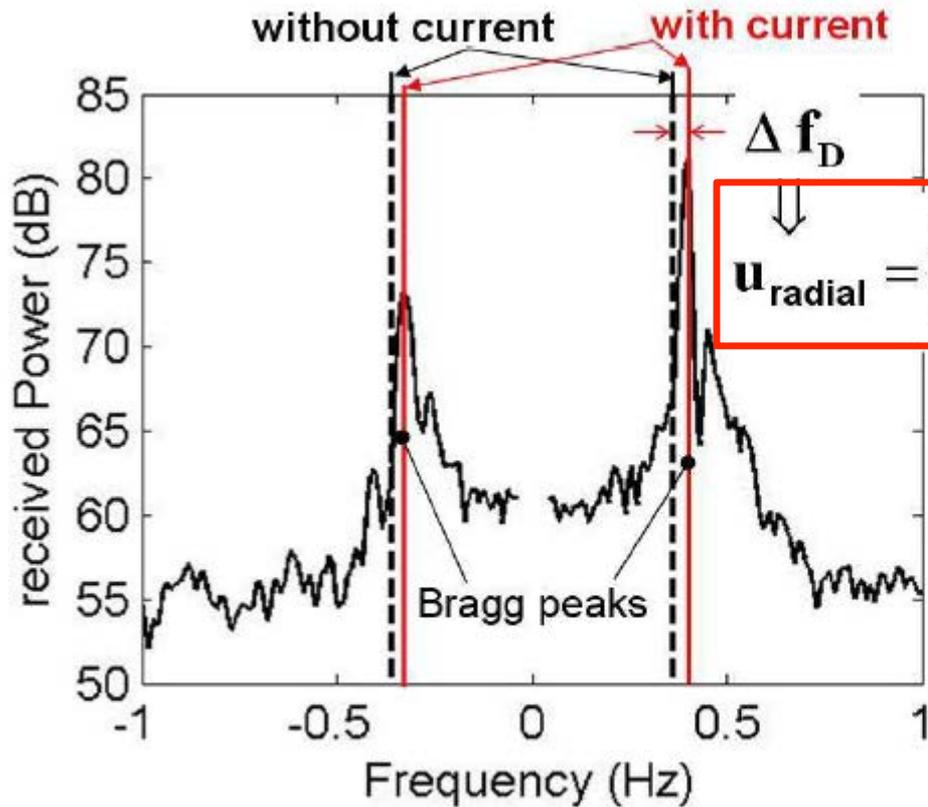
$f_B = -0.360 \text{ Hz}$

$f_B = +0.360 \text{ Hz}$

$f_B = 0.102\sqrt{F_0} \text{ (MHz)}$



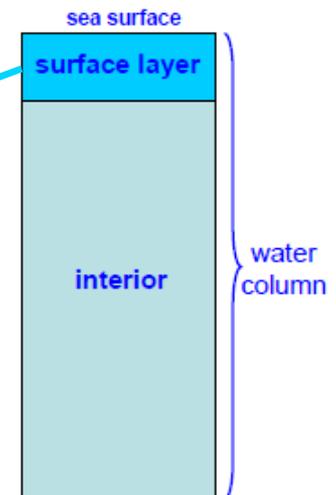
Mesure du courant – vitesse radiale



Le courant mesuré est égal à $4\pi/\lambda$ fois l'intégrale du profil de courant pondéré par $\exp(z \cdot 4\pi/\lambda)$

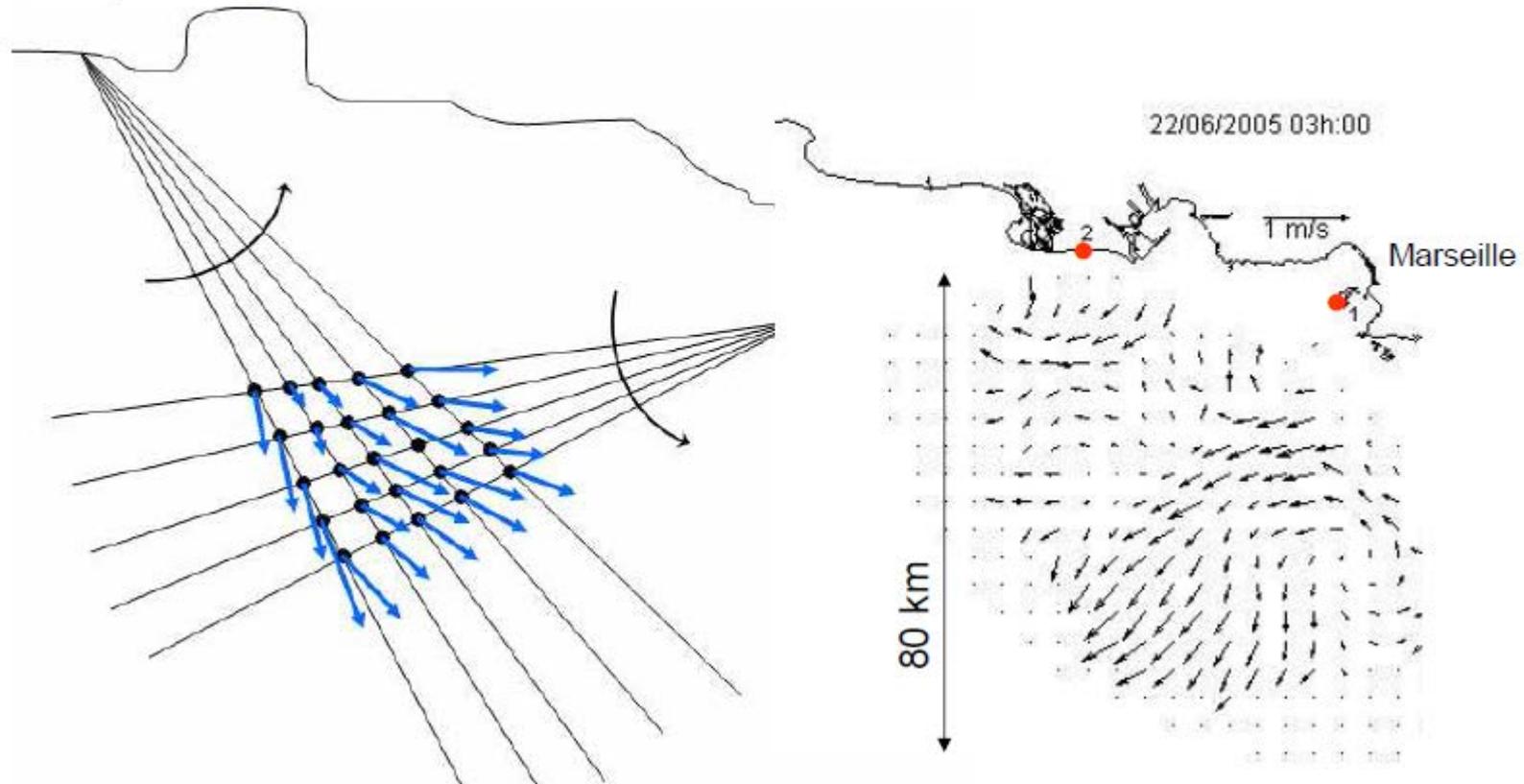
=> une bonne approximation de la « profondeur » de mesure est la valeur du courant à $\lambda/8 \pi$

- 4 MHz : 2.4 m
- 10 MHz : 1.2 m
- 30 MHz : 40 cm



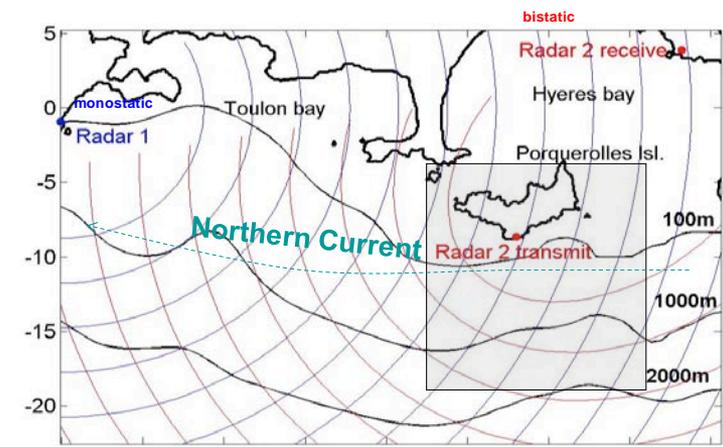
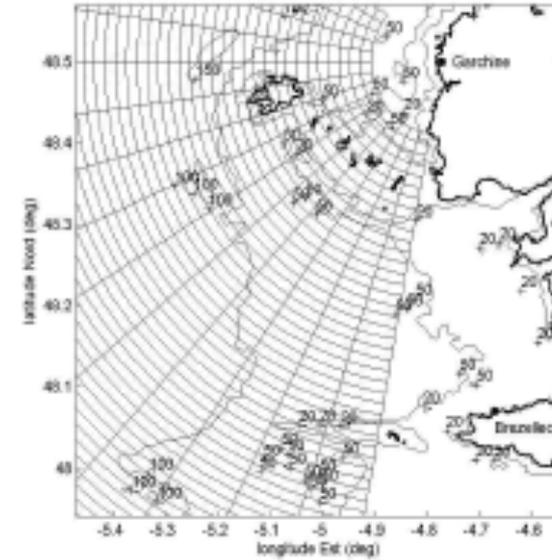
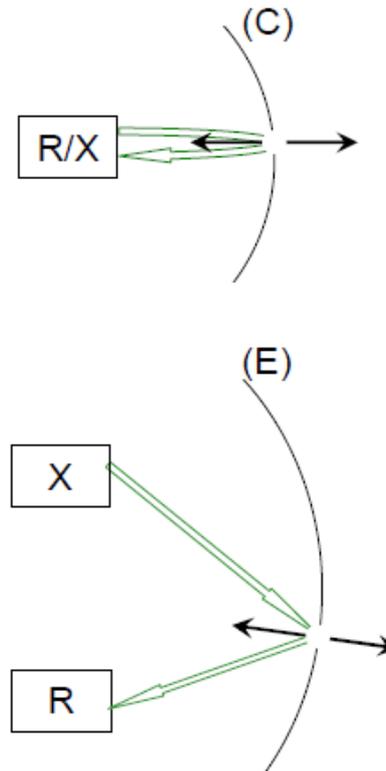
Cartographie des courants marins

Une carte de composantes radiales est obtenue par balayage en distance et en azimuth. Le croisement des données de 2 radars fournit la carte du courant vectoriel. Temps d'intégration: 10 à 20 minutes.



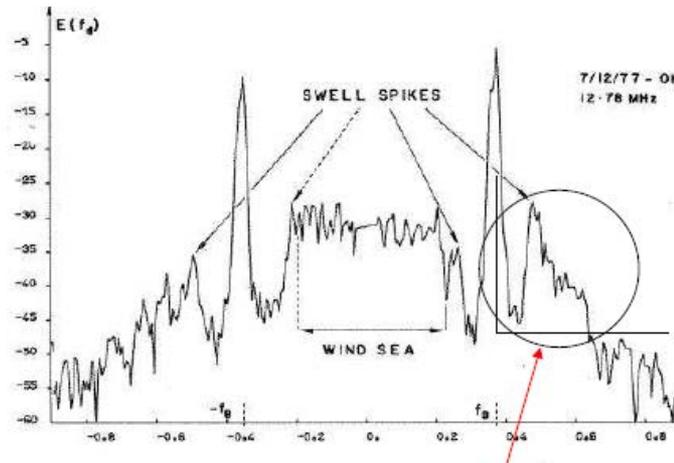
Monostatique - Bistatique

- **monostatisme**: les antennes d'émission et de réception sont au même point
 - les iso-range sont des cercles (C)
 - les vagues de Bragg sont à propagation radiale
- **bistatisme**: les antennes d'émission et de réception sont séparées
 - les iso-range sont des ellipses (E) dont les antennes R/X sont les foyers
 - les vagues de Bragg sont à propagation normale à ces ellipses

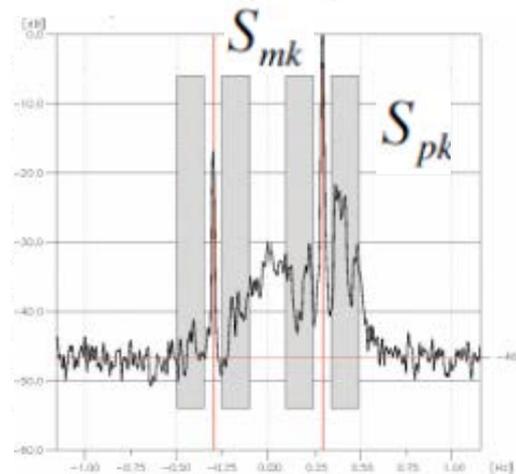


Spectre Doppler et spectre des vagues

Il existe une formule analytique non-linéaire reliant spectre Doppler et spectre directionnel des vagues *Barrick 1972 et +*



L'essence de cette théorie est que le spectre non-directionnel des vagues est reproduit de part et d'autre des raies de Bragg (à une fonction de pondération près) *Hasselmann 1971*



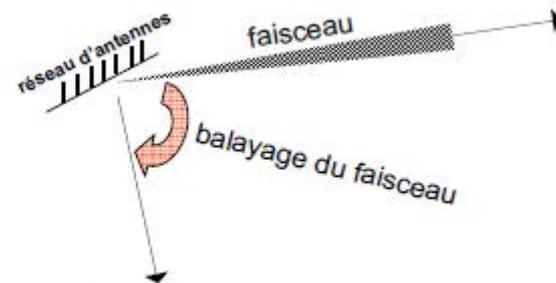
$$H_k = \alpha_k (S_{mk} + S_{pk})$$

Deux technologies

deux méthodes pour identifier la direction

balayage azimuthal

- formation de voie (beam forming)

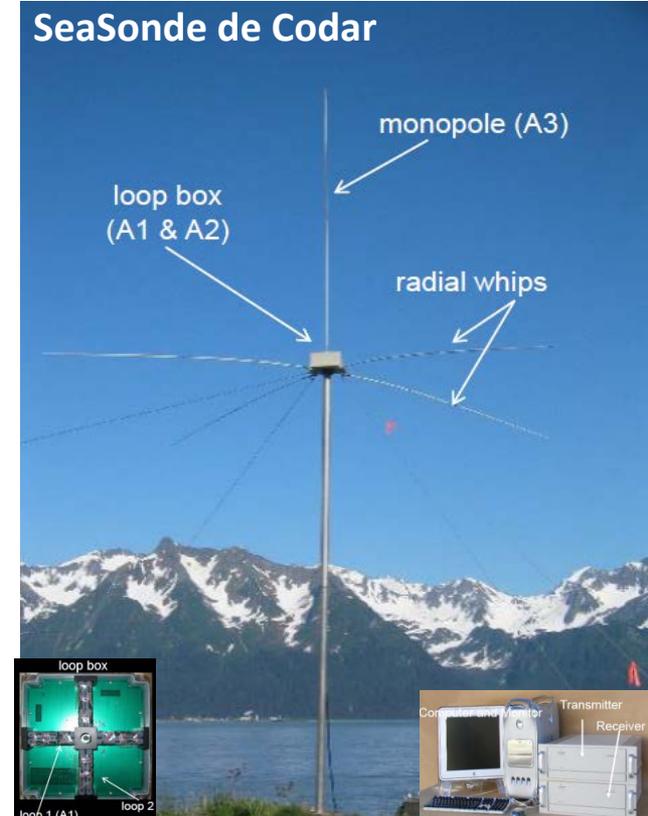
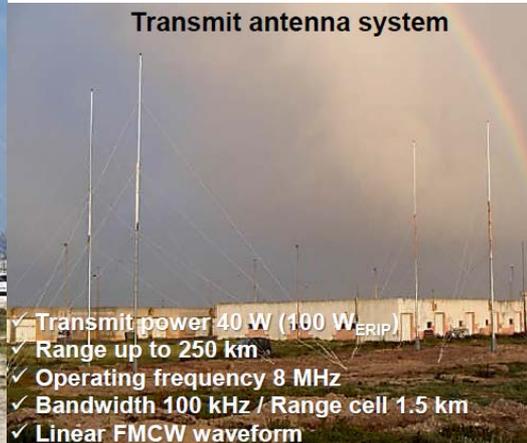


- principe goniométrique (direction finding)

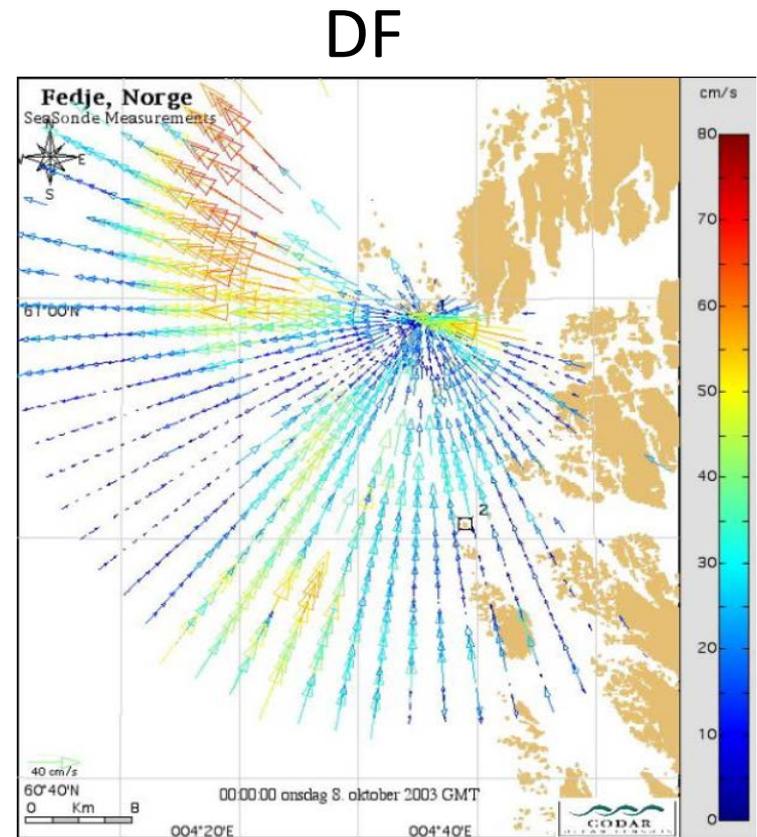
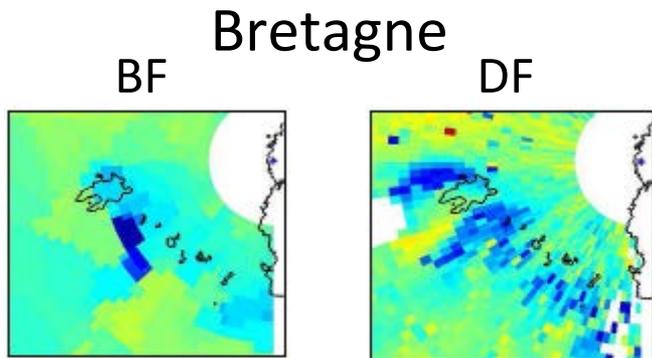
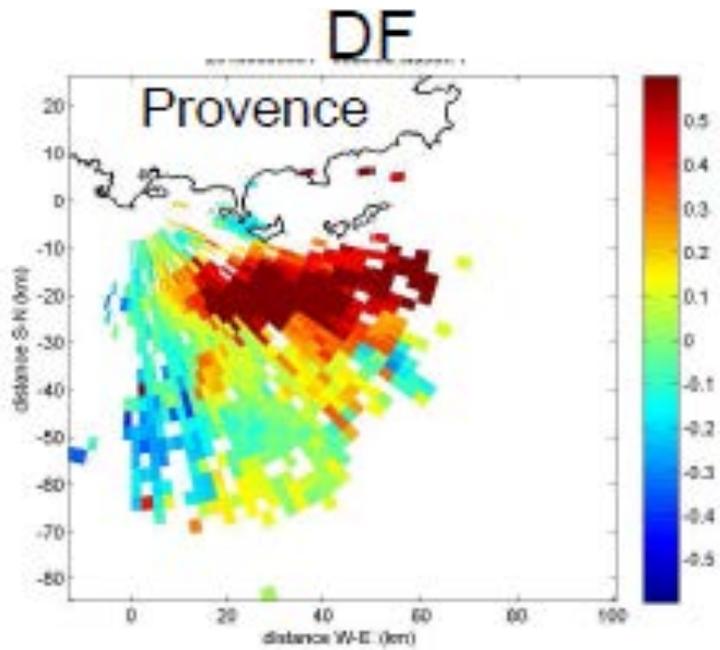
MUSIC processing (Schmidt, 1986)



WERA site at Figuera da Foz, PT

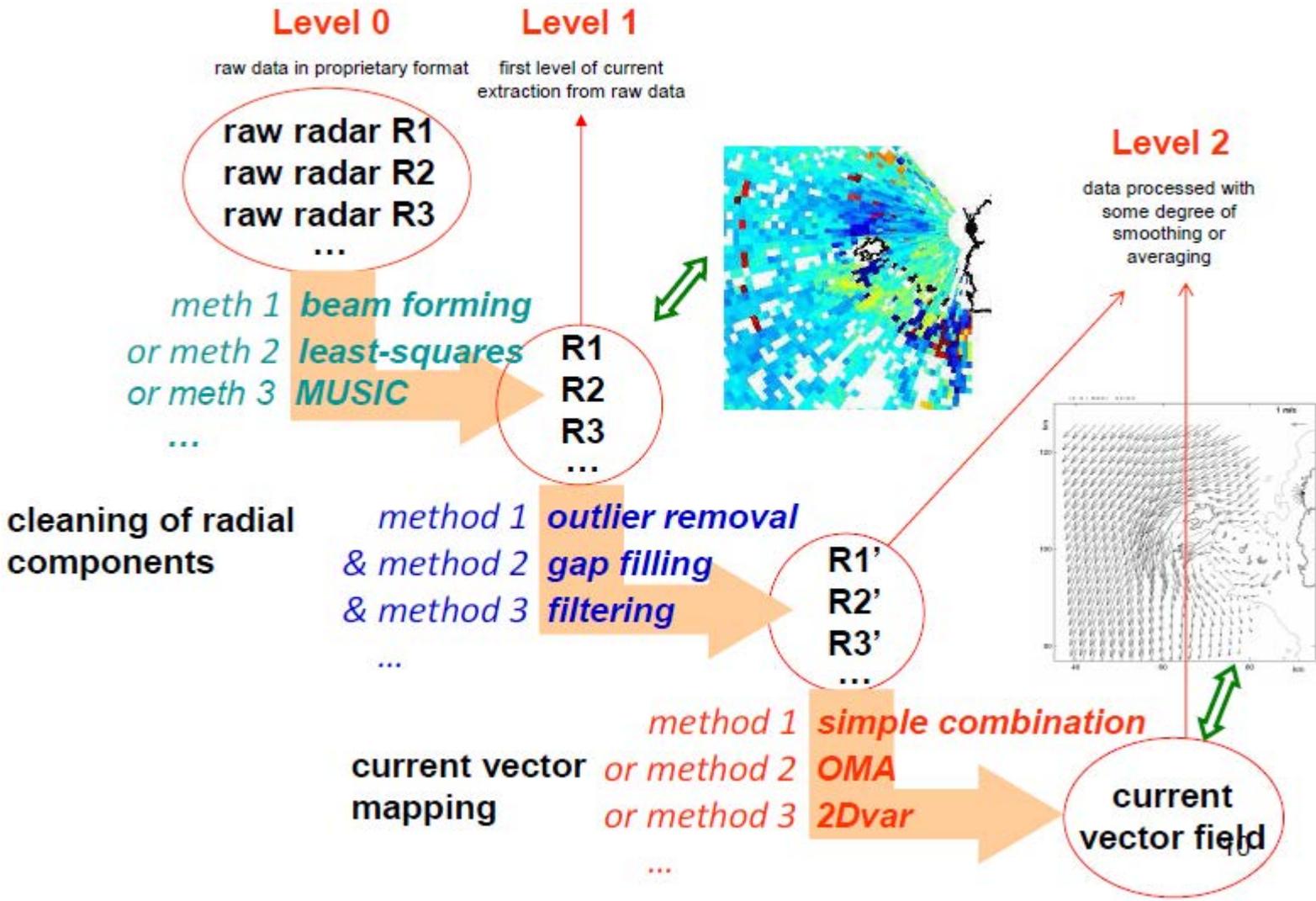


Vitesses radiales



Chaîne de traitement, qualité, types de produits

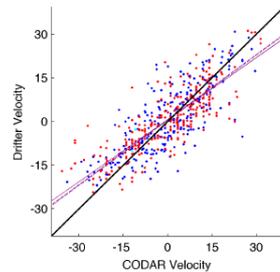
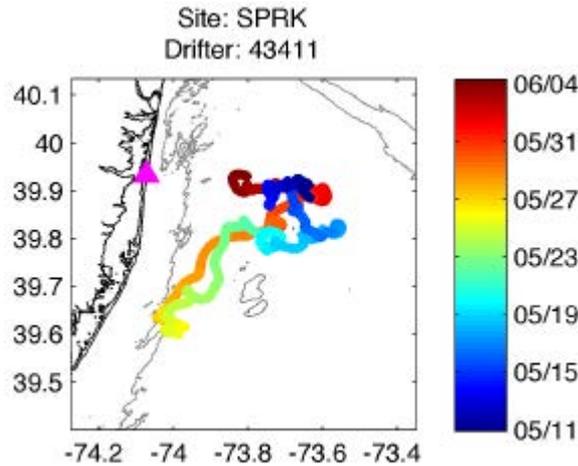
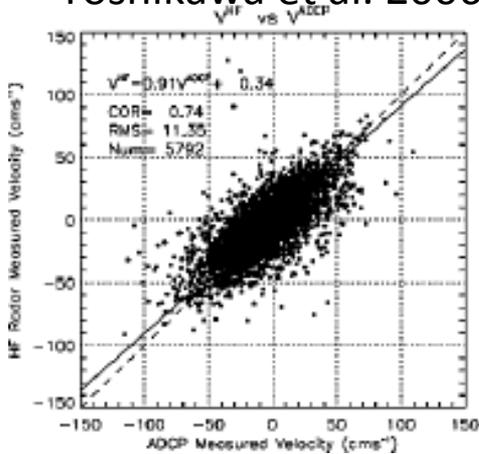
Ex.: protocol utilisé par ACORN (Aust Coas Oc Radar Network, Mal Heron, ROW 2009)



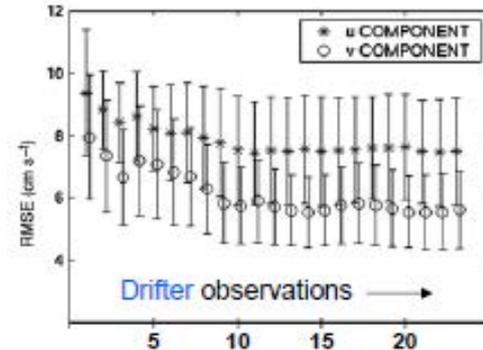
Estimation d'erreurs de la mesure

Comparaison courants-radar et courants-flotteurs

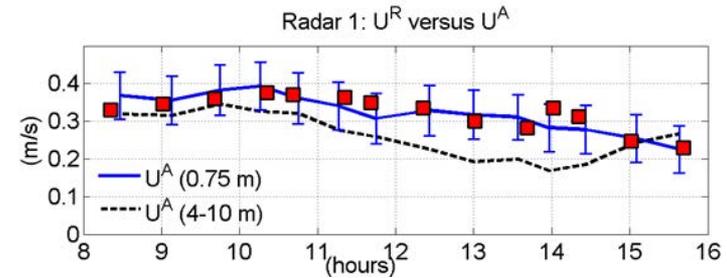
Yoshikawa et al. 2006



Ohlmann et al. 2007



Sentchev et al., 2016



Sources d'incertitude associée à la mesure :

- variations du courant dans la cellule (plusieurs km²)
- variations du courant pendant le temps d'intégration
- fluctuations du diagramme des antennes individuelles
- contribution due aux vagues (ce n'est pas une erreur...)
- profondeur de la mesure (ce n'est pas une erreur...)

RMSD: 0.02 – 0.15 m/s

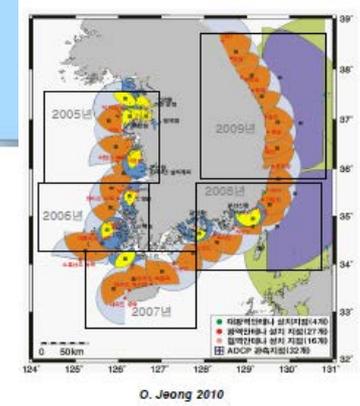
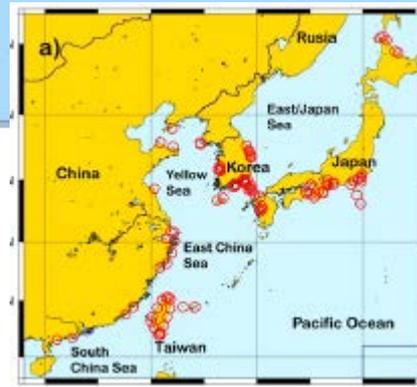
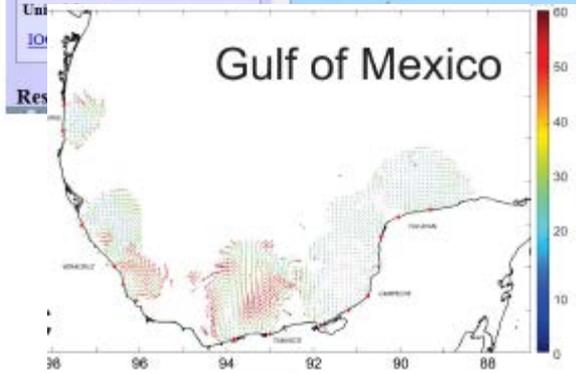


Réseaux radars actuels

Global HF Radar Network

Network Update

- >300 stations operating in
- 25 countries with
- 9 countries sharing surface current data



Réseaux radars actuels

CODAR Ocean Sensors

~ 80% du marché

*CODAR Corporate Headquarters
Mountain View, California 94043 USA
CODAR EUROPE Qualitas
Madrid, SPAIN*

Australia	8	4
Brazil		1
China		4
France	2+2	1(2)
India		10
Indonesia		2
Ireland		2
Israel		2
Italy		3
Japan		22
Jordania		1
Mexico		1

Le restant :

WERA & radars de laboratoire
ou d'institutions/organismes
divers

*Helzel Messtechnik GmbH
Kaltenkirchen, Germany*

Norway		2
Portugal		2
Russia		1
Korean	2	23
Spain		16
Taiwan		15
Thailand		6
Uae		2
Usa	10	115
Vietnam		3
	24	237

Il existe aussi des
systèmes RHF en
Chine et au Japon

Nombre de stations ORDRE DE GRANDEUR !

APPLICATIONS

Océanographie:

**courants et vagues, couplage avec la biologie,
qualité de l'eau, pêche, ...**

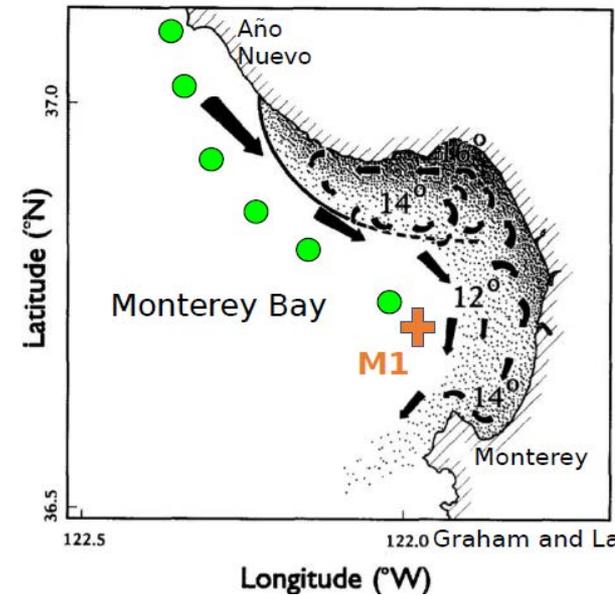
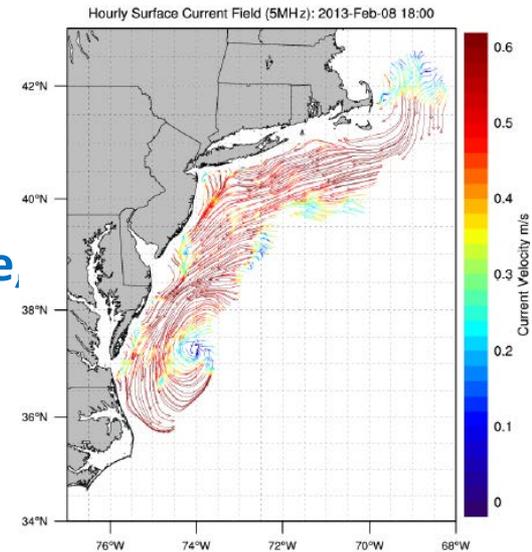
Recherche/sauvetage en mer

Suivi de pollution

Détection de bateaux à des grandes distances

Surveillance de tsunامي

Estimation de gisements d'énergies marines



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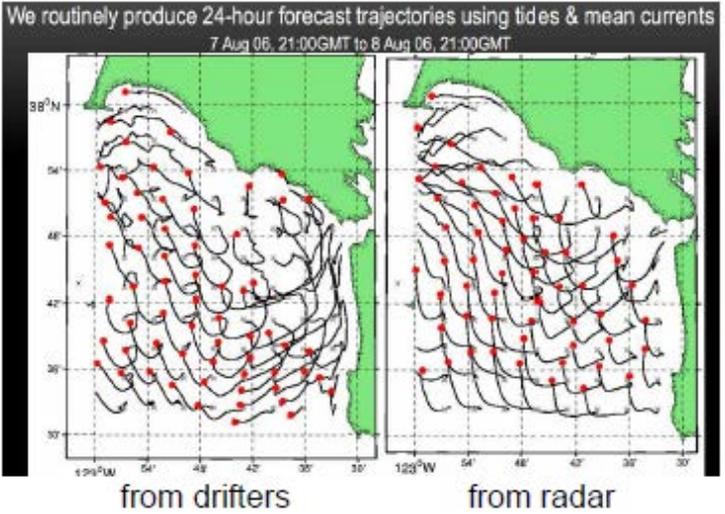
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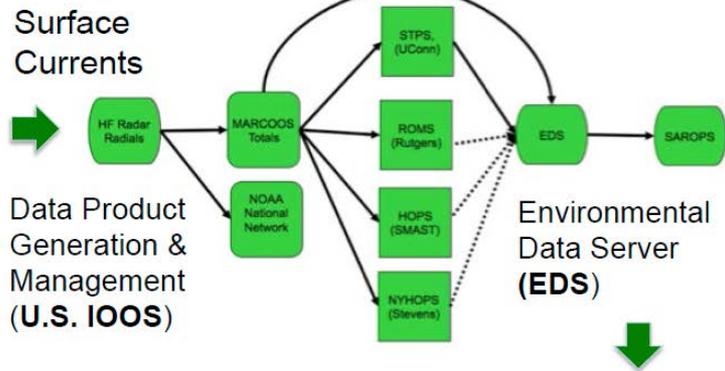
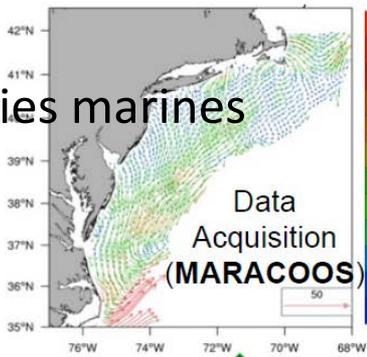
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Operational Use of HF Radar Surface Currents for Search And Rescue



Search And Rescue
Optimal Planning
System (SAROPS)



APPLICATIONS

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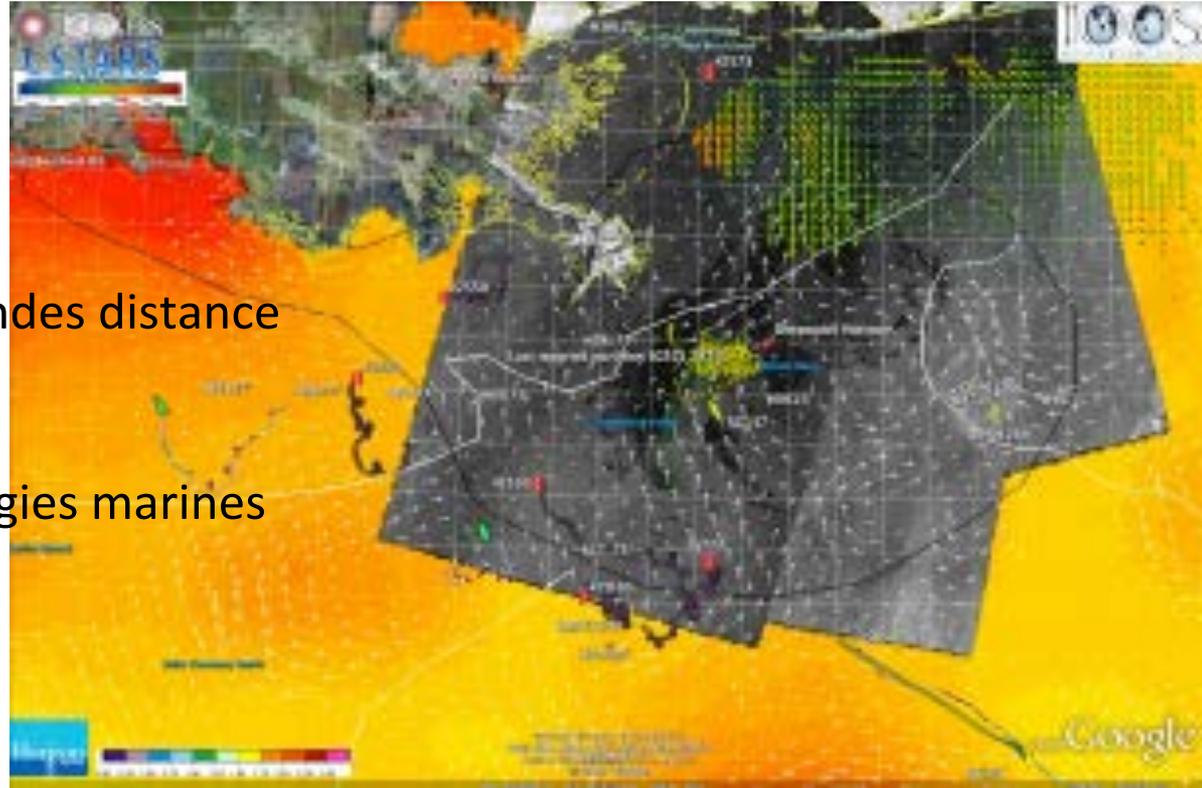
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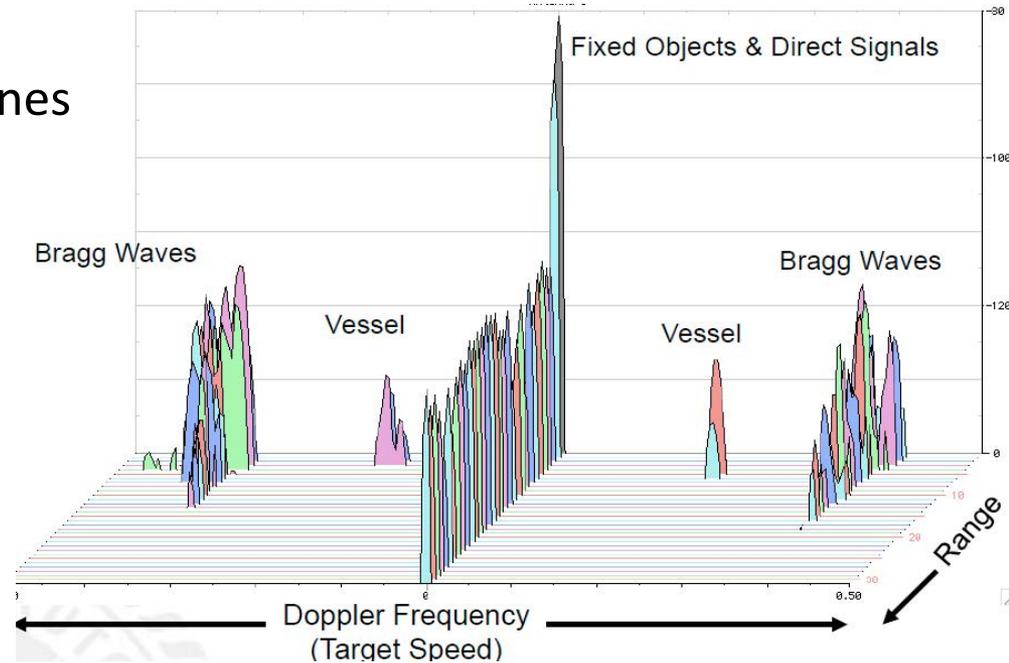
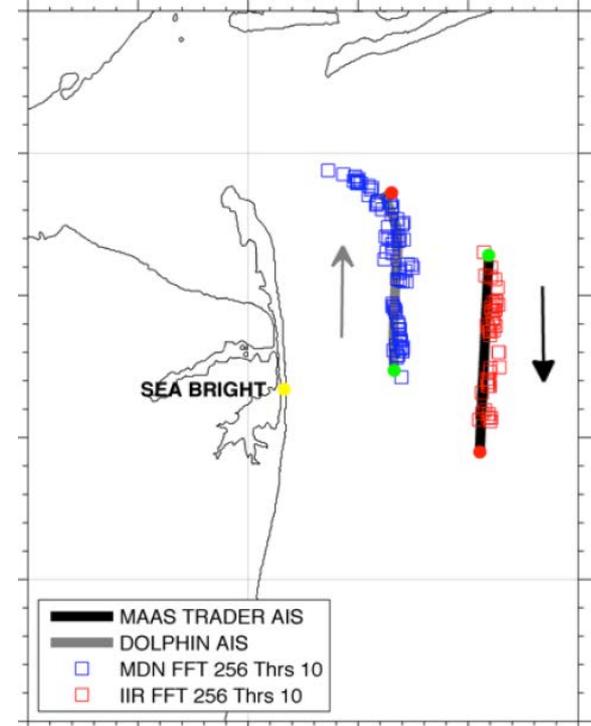
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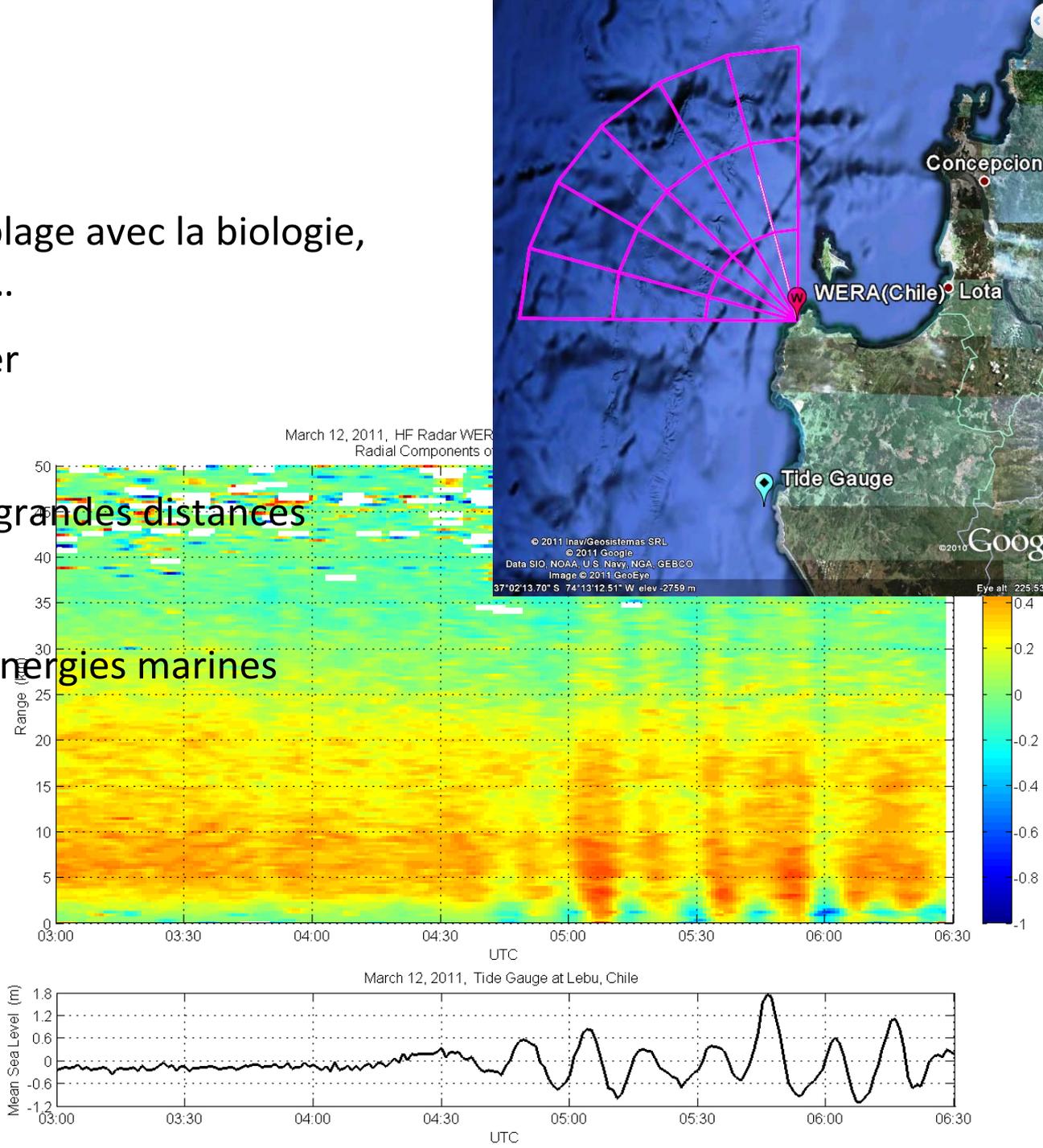
Recherche/sauvetage en mer

Suivi de pollution

Détection de bateaux à des grandes distances

Surveillance de tsunami

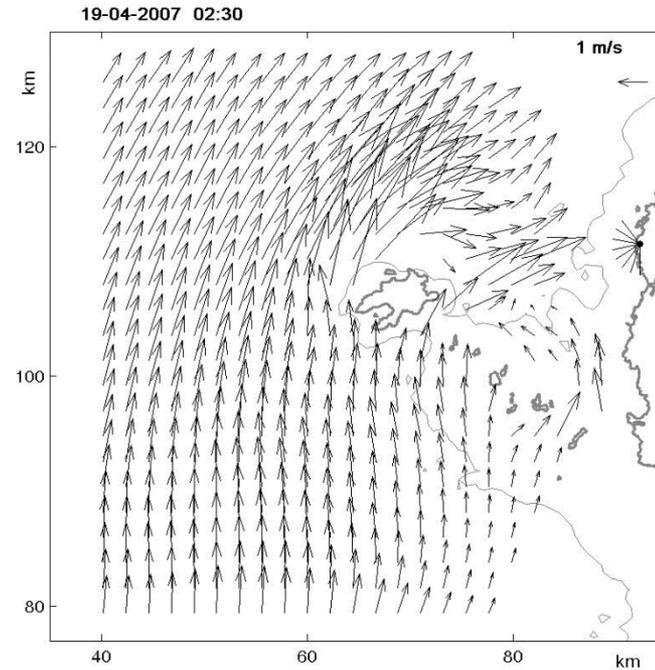
Estimation de gisements d'énergies marines



Réseaux français - Bretagne

Iroise radars: WERA's

- 12 MHz
- long time series (from 2006 to date)
- time resolution: 1/3 h
- resolution: 1.5 km along beam
- 2° in azimuth

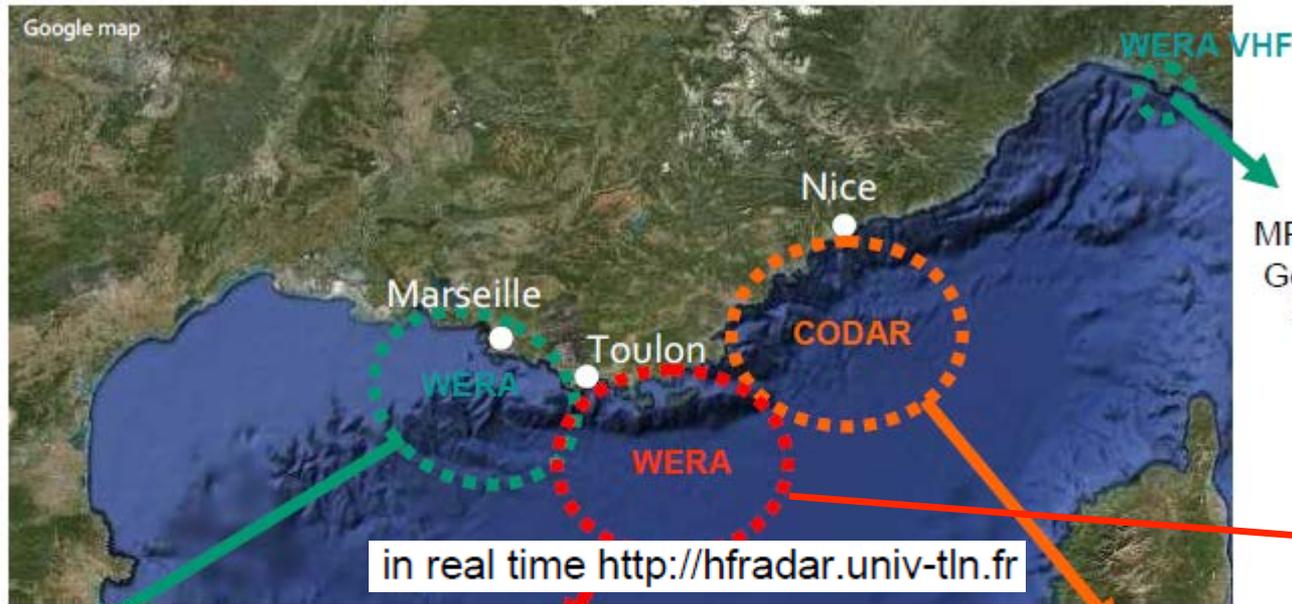


Réseaux français - Méditerranée

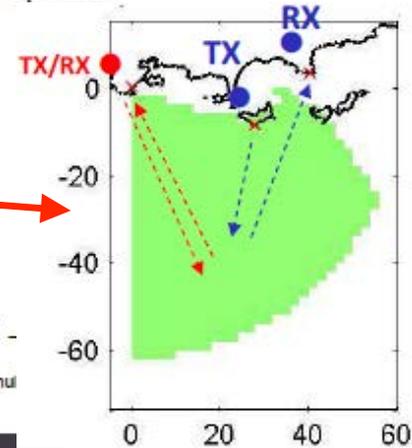
Passé

Présent

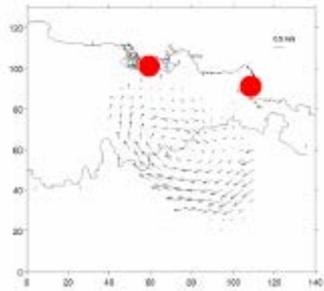
Futur



MREA 2007
Golfe de la Spezia



ECOLO - 2005 → 2007
Echanges CÔte Large

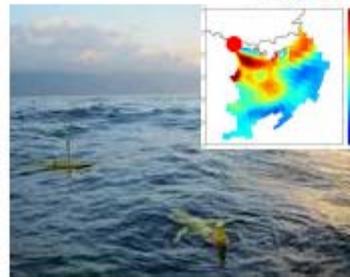


GIRAC - → 2012

Gestion Intégrée des Rejets d'Assainissement Côtiers

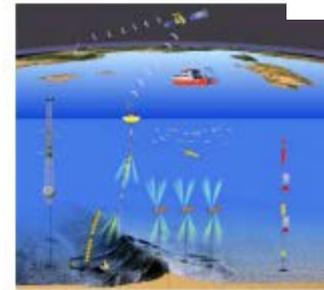
ECCOP - 2010 →
Etude de la Circulation Côtère Provençale

TOSCA - 2010 →
Tracking Oil Spills & Coastal Awareness network



MOOSE - 2012 -

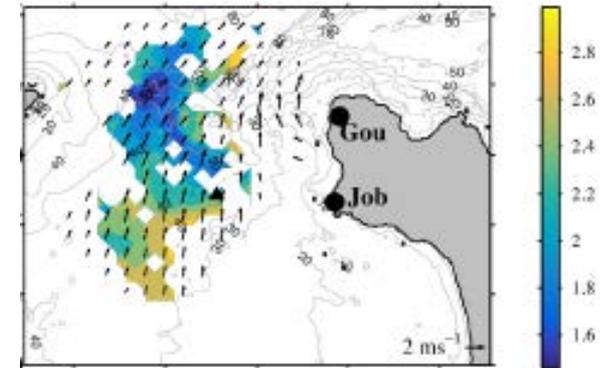
Mediterranean Ocean Observation mul Environment



Réseaux français - Cotentin



25 Jan - 1am (HW) – Vagues



The two sites have WERA phased-array radars, and are each composed of two TX arrays to transmit at 13 and 24 MHz, respectively, and one receiving array shared by the two frequencies.

	13 MHz	24 MHz
Bandwidth (kHz)	100	200
Range resolution (m)	~ 1500	~ 600
Azimuthal resolution (deg)	14	7
Grid spacing (m)	500 x 500	

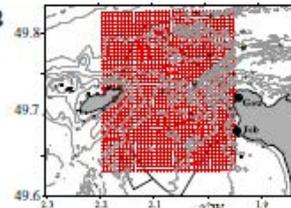
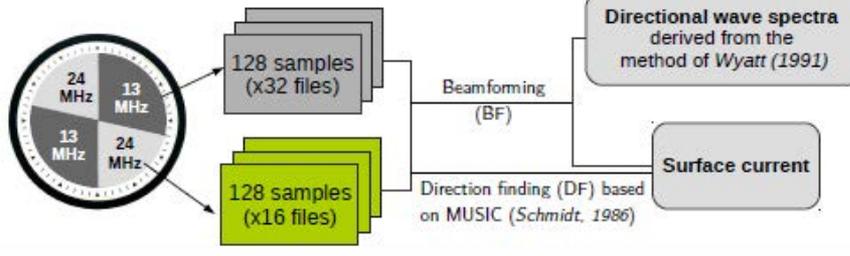
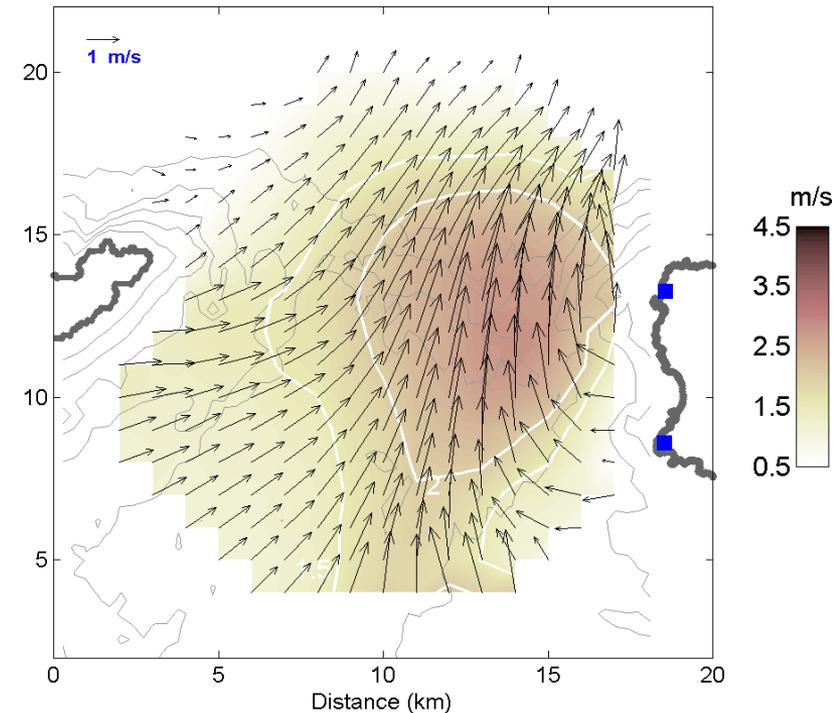


Fig 1. Radar sites, their coverage, and measuring grid (black dots). The model grid points used for comparison are shown in red.

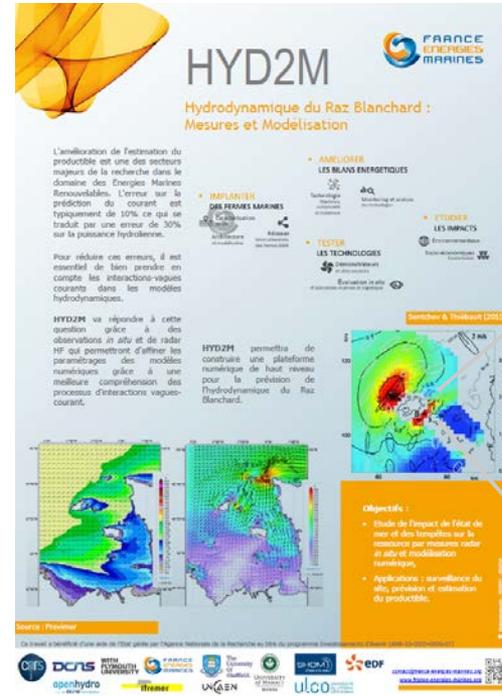
HF RADAR



Courants



Réseaux radars et les énergies marines

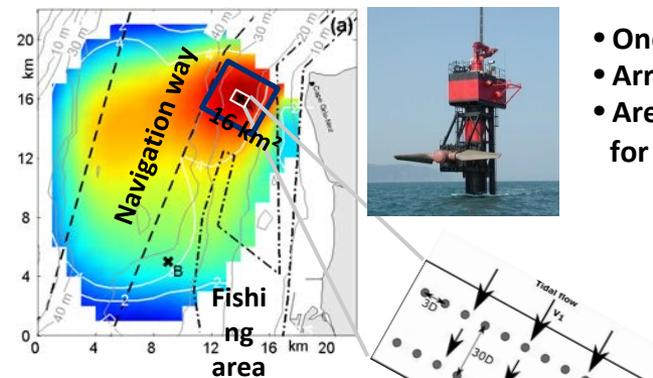


Fromveur

Array of 40: $P_{tec} = 50$ GWh



Détroit du PdC: potentiel d'én. tidale



- One MCT: $P_{tec} = 0.1$ GWh
- Array of 32: $P_{tec} = 2.5$ GWh
- Area of 16 km² is suitable for tidal harvesting.

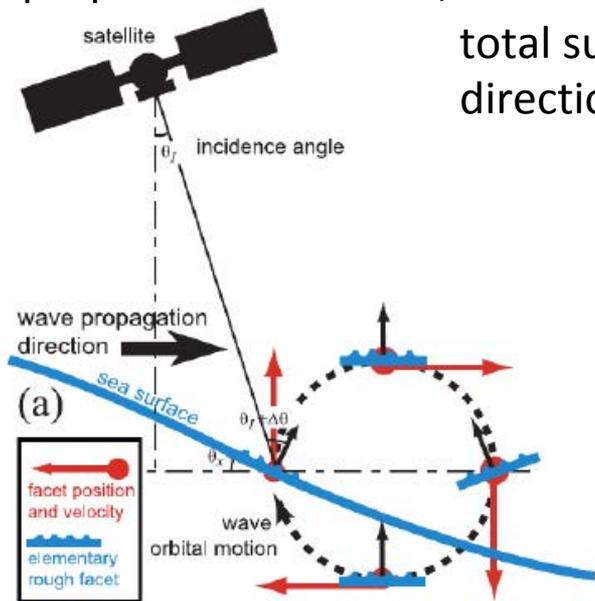
Méthodologie adoptée par l'Irlande, l'Ecosse, l'Australie

Future proche

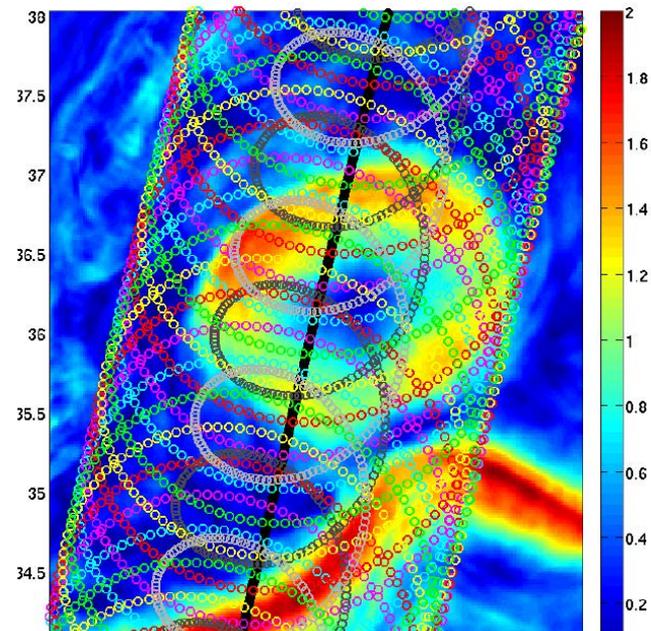
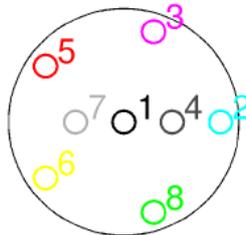
The **S**urface **K**inematics **M**ultiscale (**SKIM**)

proposal for ESA EE9, decision – end July 2019, PI Fabrice Ardhuin (LOPS)

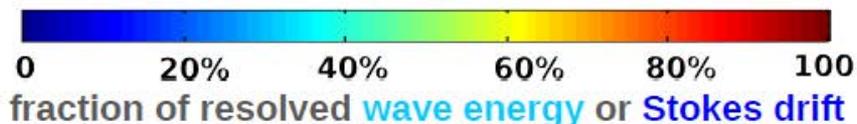
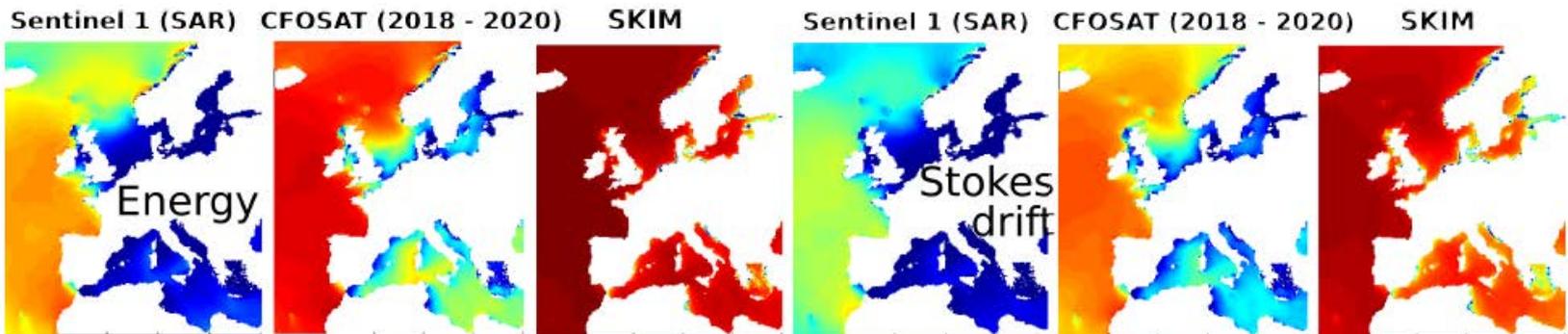
total surface current
directional ocean wave spectra



8 beams
Rotation ($T = 17.7$ s)
60 azimuths / beam (6° res)



SKIM will resolve **much shorter waves** (20 m) than Sentinels (~ 150 m) CFOSAT (70 m)

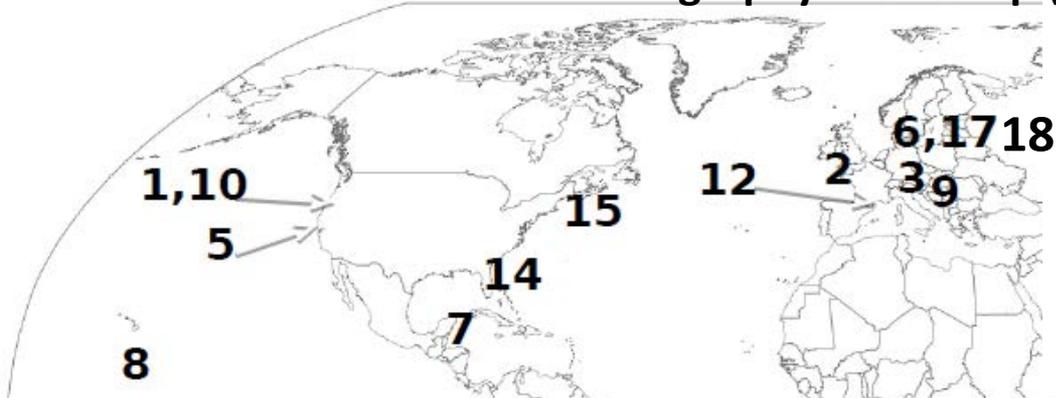


La communauté radar HF

Ocean Radar Conference for Asia (ORCA)



International Radiowave Oceanography Workshop (ROW)



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Remerciements à mes collègues français du LOG, MIO, Ifremer, Unicaen, LOPS ...
à mes collègues étrangers ...
à toi le public

Merçi

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