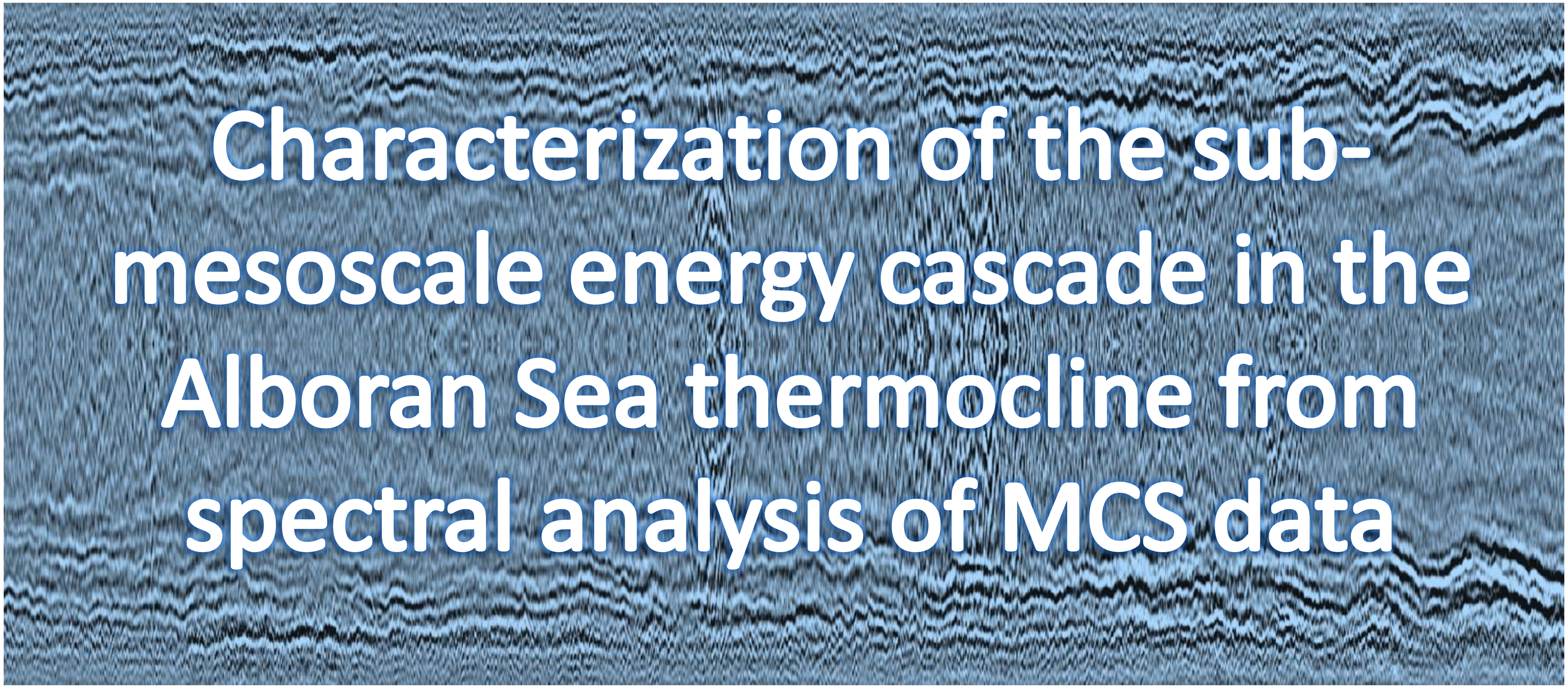


Characterization of the sub-mesoscale energy cascade in the Alboran Sea thermocline from spectral analysis of MCS data

Valentí Sallarès

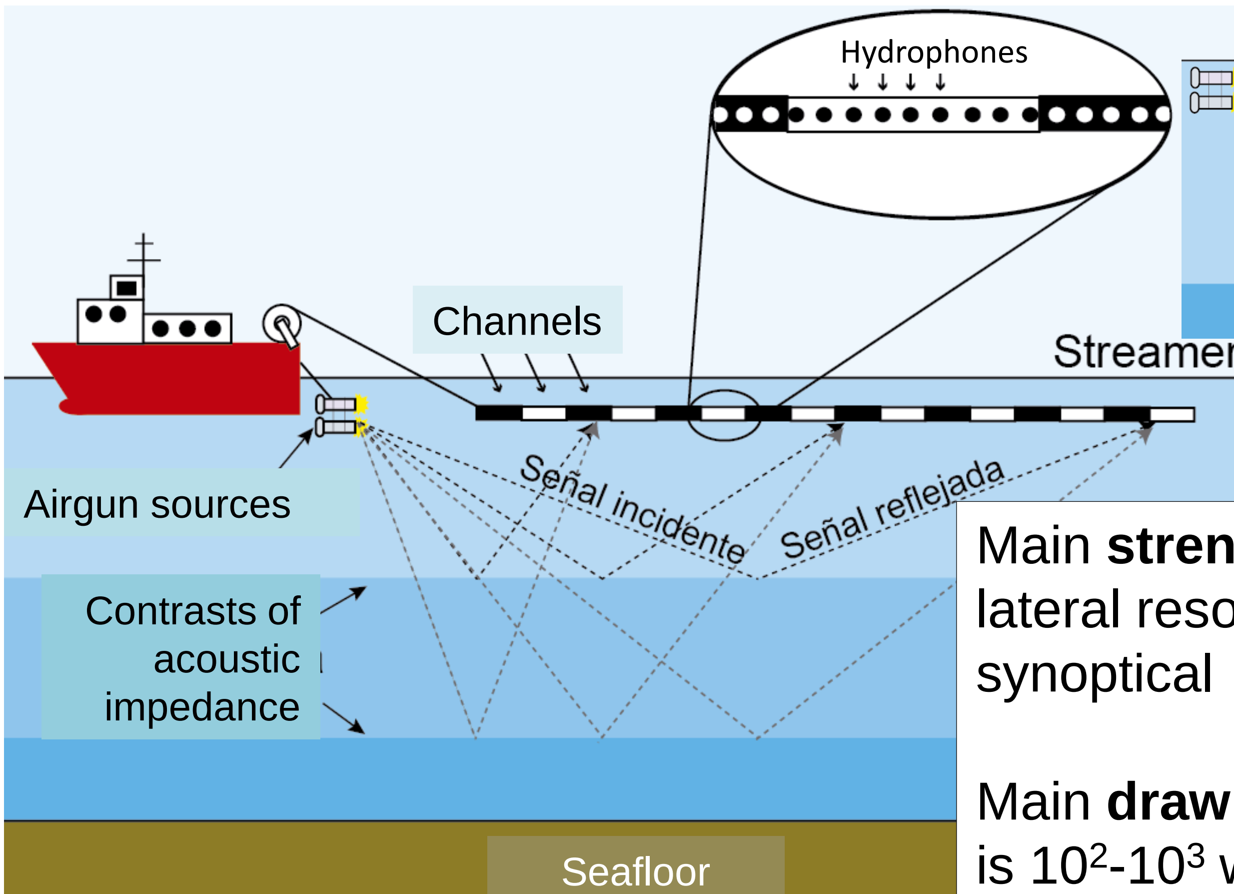
Jhon F. Mojica, Berta Biescas, Dirk Klaeschen

Outline

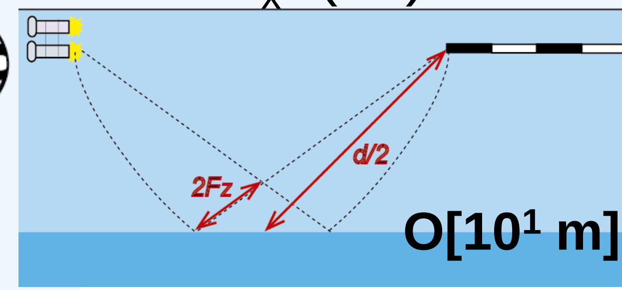
- Introduction
    - Seismic oceanography
    - Characterization of the sub-mesoscale energy cascade
- Motivation and objectives
- Data set
    - MCS data & acoustic reflectors tracking
    - k_x slope spectra of vertical reflector displacements
- Results
    - Interpretation of the obtained spectra
    - Implications concerning sub-mesoscale energy cascade
- Summary

Seismic oceanography

Study of the ocean's thermohaline finestructure using seismic/ acoustic methods (essentially **MCS**) [Holbrook et al., 2003]



$$2R_x = (\lambda d)^{1/2}$$



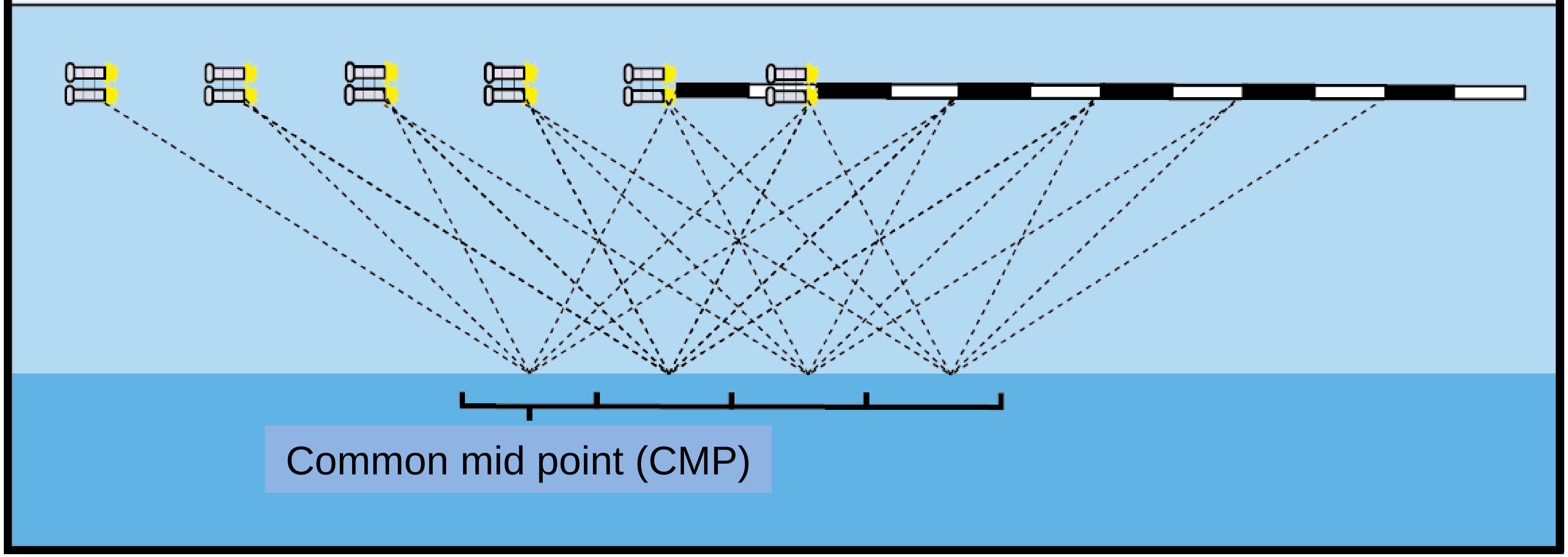
Main **strength**: unprecedented lateral resolution, close to synoptical

Main **drawback**: water reflectivity is 10^2-10^3 weaker than in solid Earth → noise is a major issue

Seismic oceanography

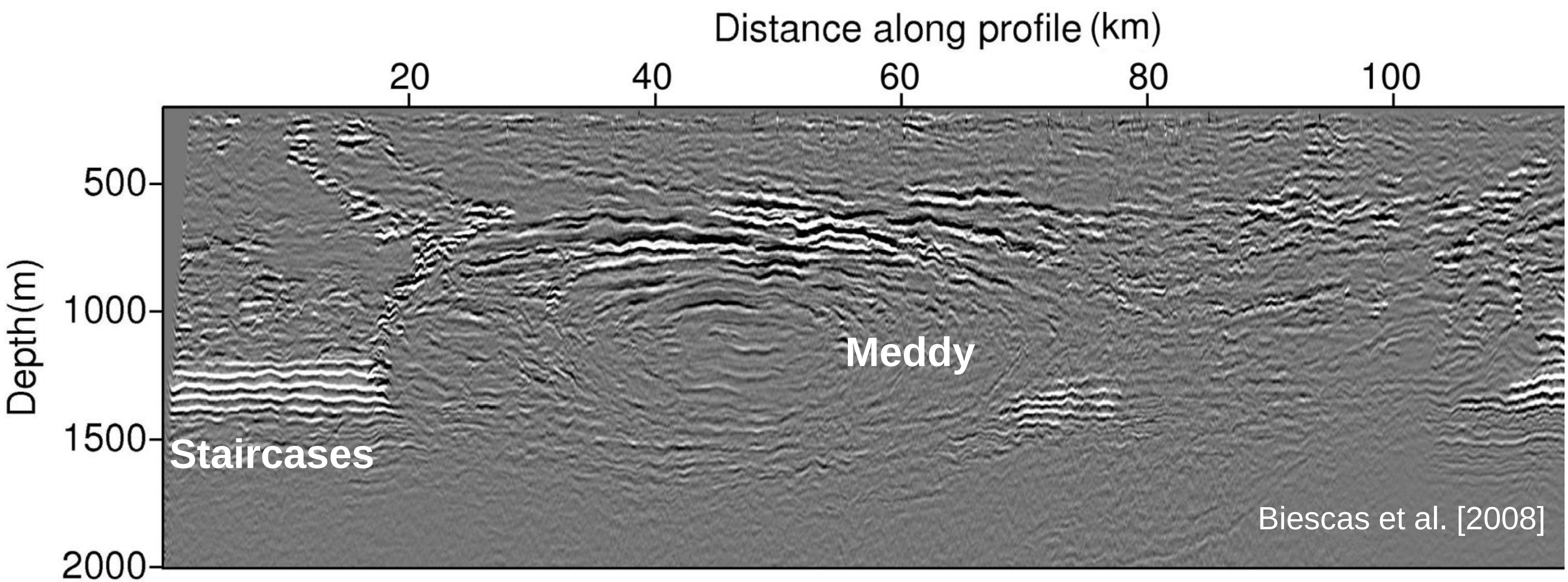
Study of the ocean's thermohaline finestructure using seismic/ acoustic methods (essentially **MCS**) [Holbrook et al., 2003]

Multi-channel system



Seismic oceanography

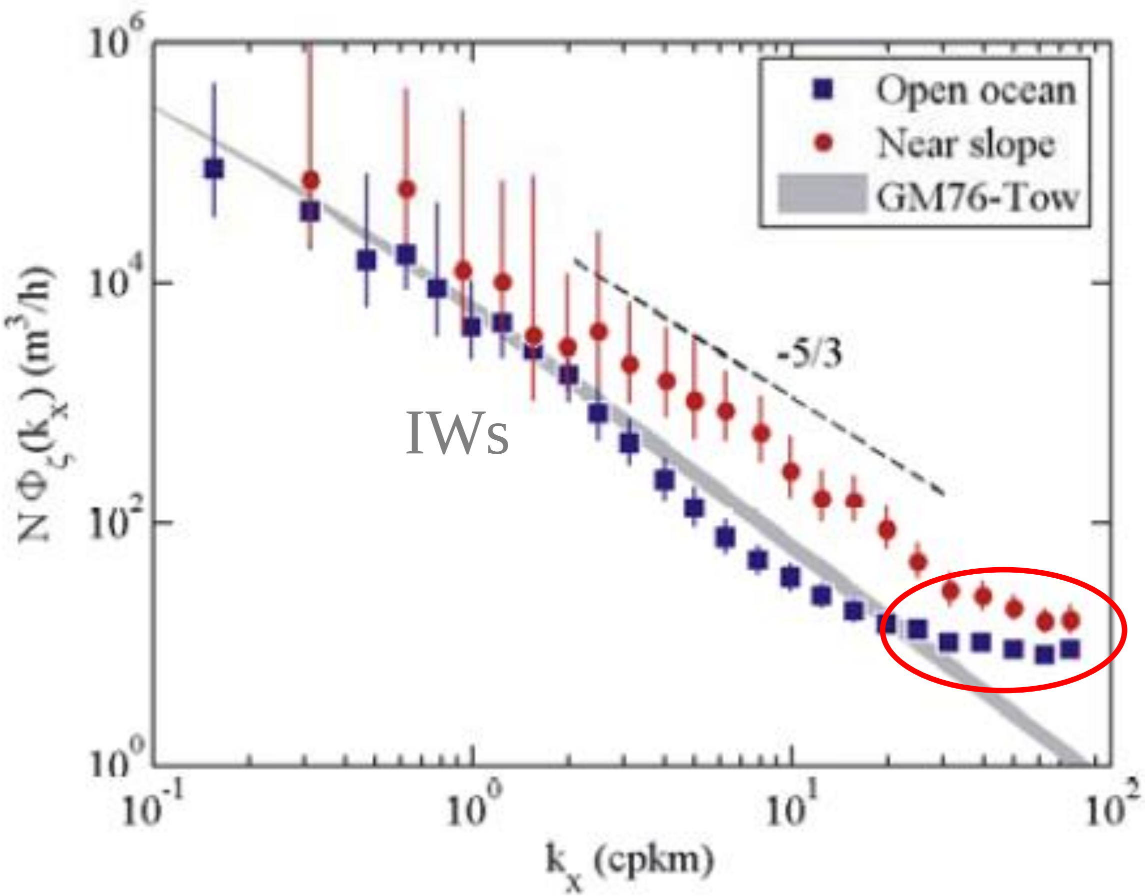
Study of the ocean's thermohaline finestructure using seismic/ acoustic methods (essentially **MCS**) [Holbrook et al., 2003]



Maps of acoustic reflectivity $\rightarrow$ correspondence between reflector position and thermohaline gradients (essentially V through T)

Seismic oceanography

Extract information on water dynamics by spectral analysis of acoustic reflector's vertical displacements [Holbrook and Fer, 2005]

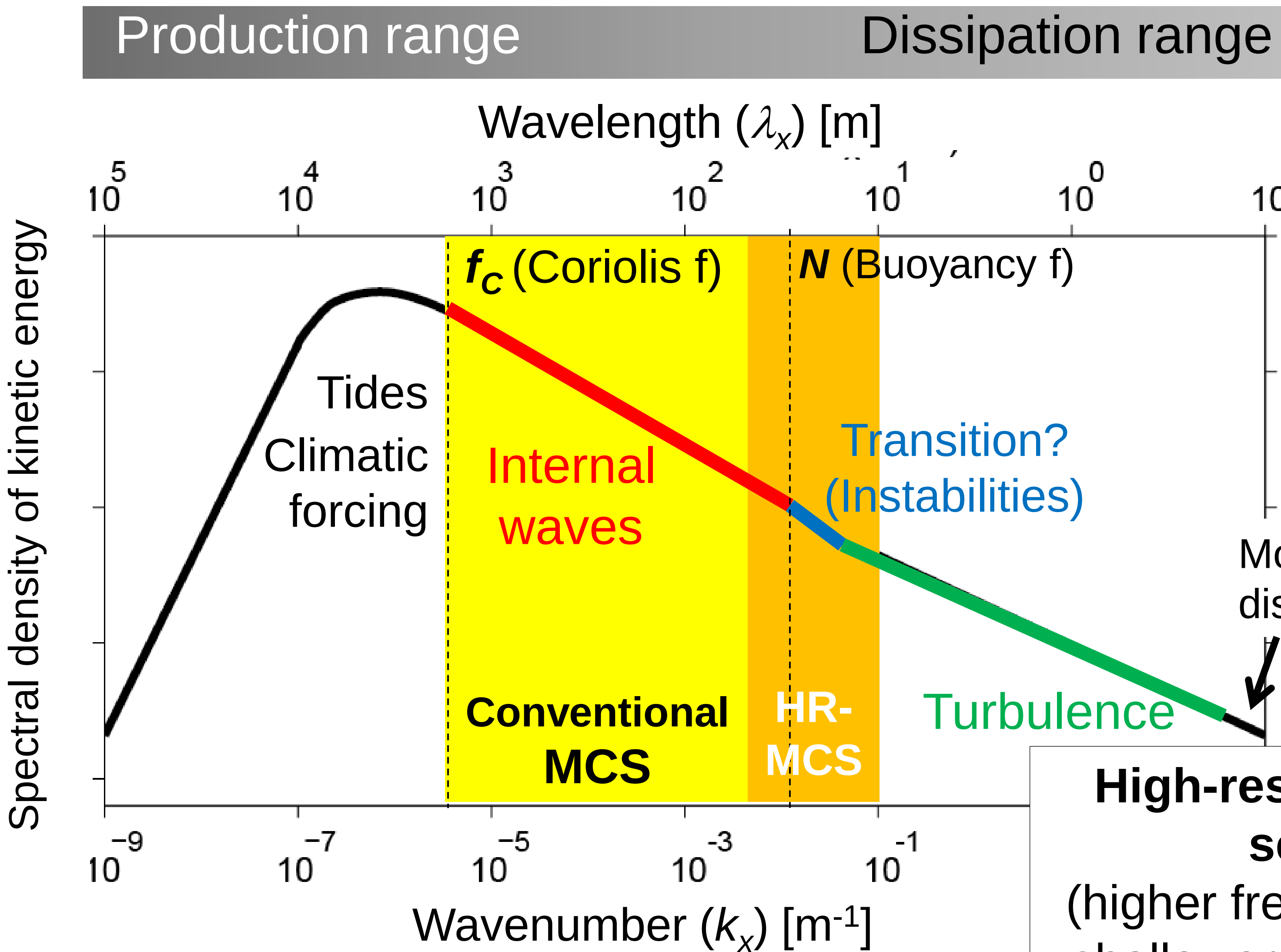


Deep targets (>400 m)

Low frequency sources (<80 Hz)

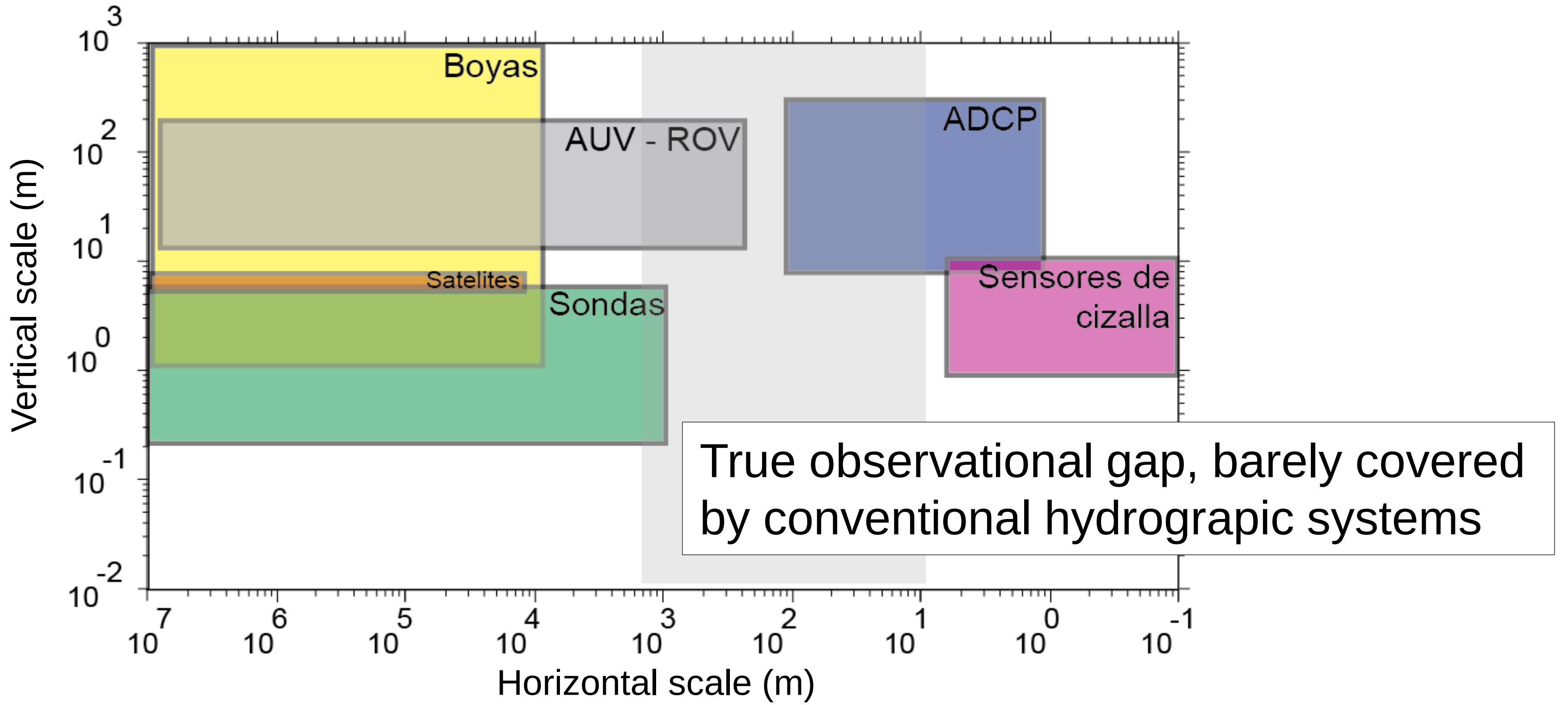
R_x≈50-100 m

Energy cascade at the submesoscale



High-resolution seismics
(higher frequency, shallower targets)

Motivation and objectives

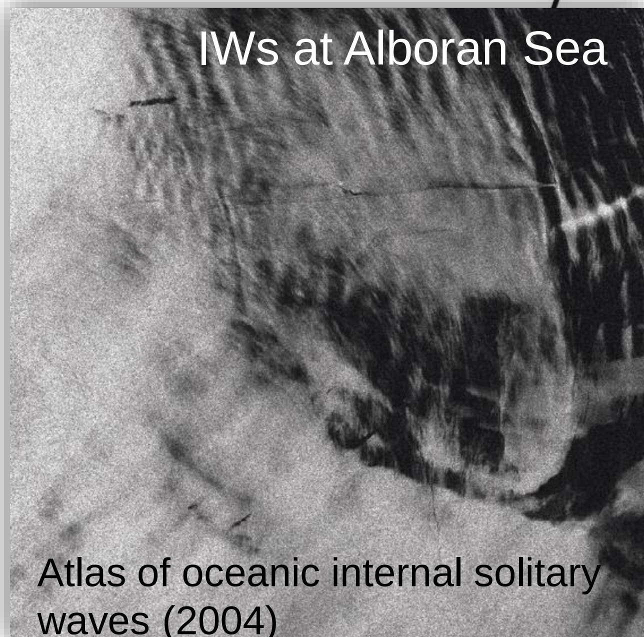


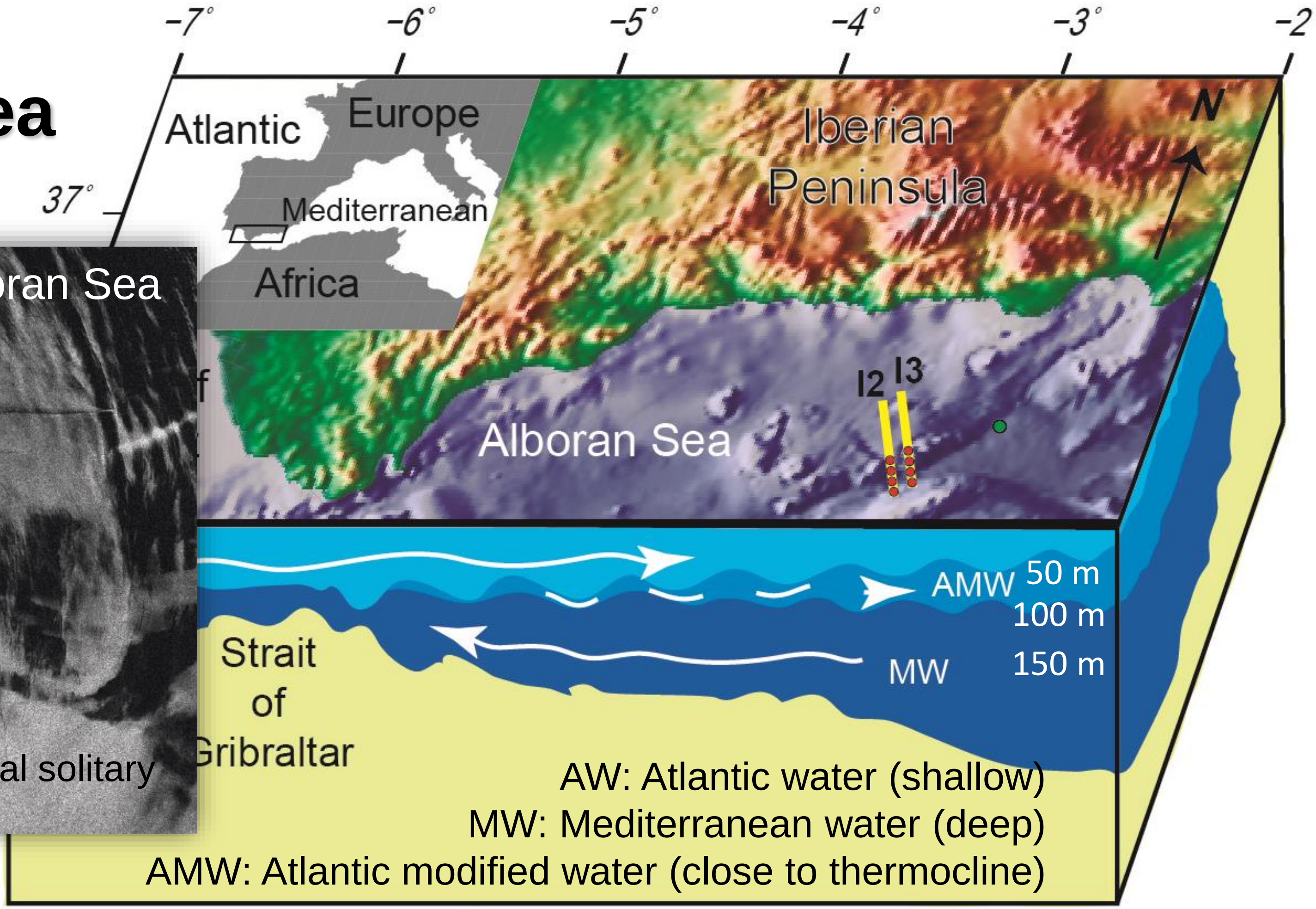
Explore the potential of **high resolution MCS data** to:

→ Cover observational gap at horizontal scales of ~10^3-10^1 m

→ Investigate transitional subrange of the energy cascade between internal waves and turbulence

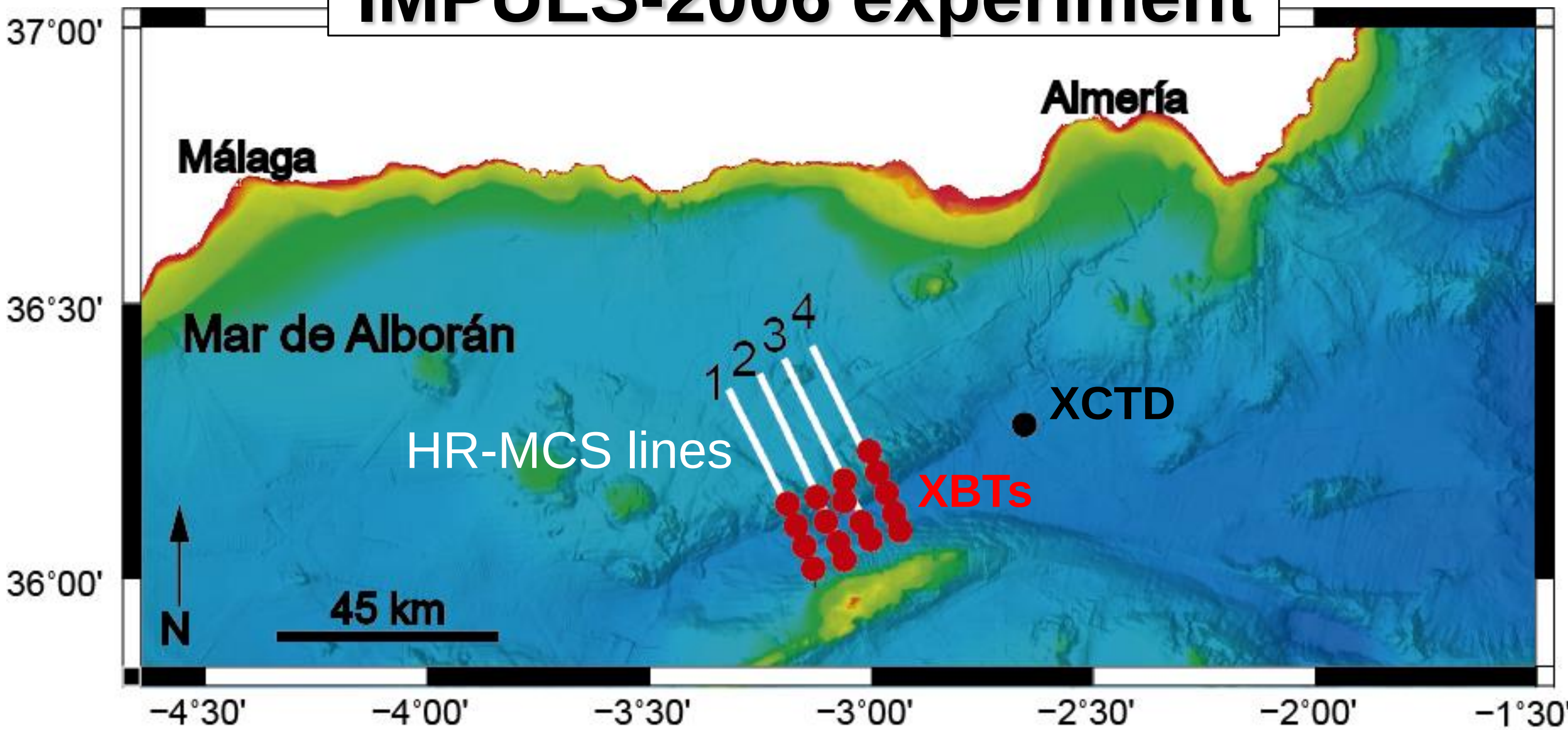
Alboran Sea





- Complex shallow thermohaline finestructure by mixing of AW and MW (AMW)
- IWs are generated at the Strait of Gibraltar
- Subject to continuous shear between outgoing MW and incoming AW

IMPULS-2006 experiment



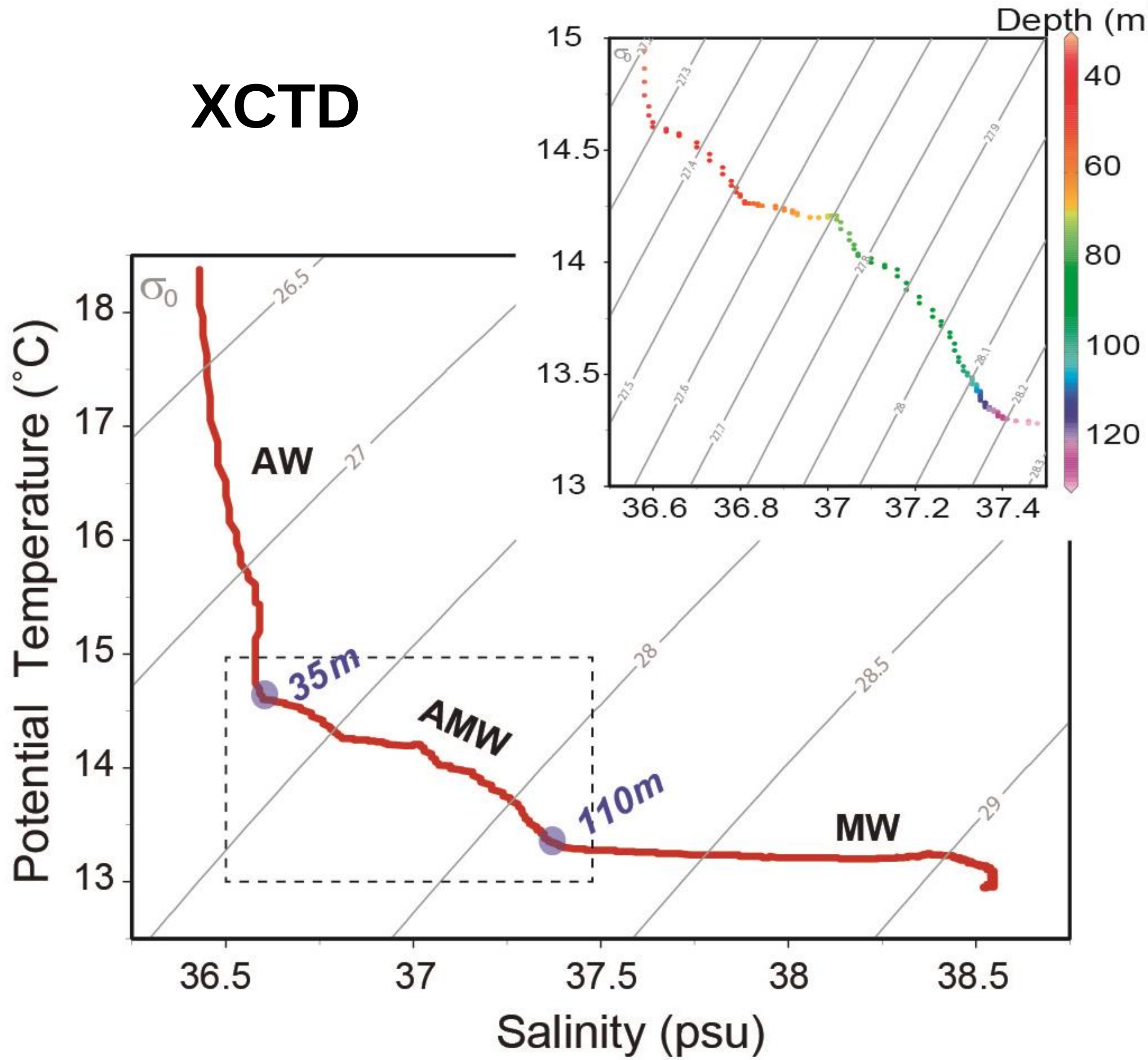
Originally intended for geological research, but also to explore potential for seismic oceanography (simultaneous XBT, XCTD)

HR-MCS system: Streamer of 300 m, 48 channels (6.25 m); source of 4.75 liters at 138 bars [40-240 Hz]

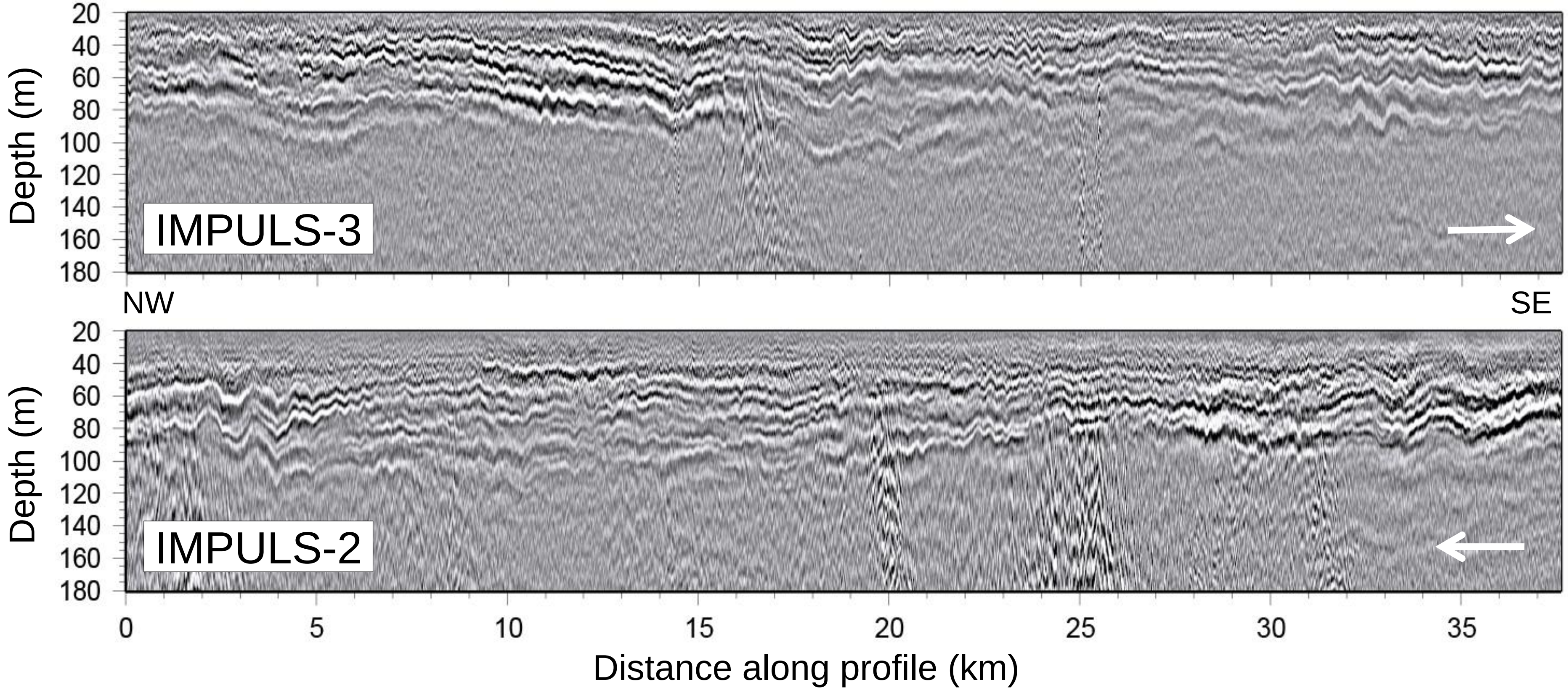
→ Nominal $R_x(75\ m)\approx 15\ m$

Alboran Sea

The thermohaline stratification created by the water exchange concentrated between 35 m and 110 m deep at the time of the HR-MCS acquisition (AMW)



HR-MCS data

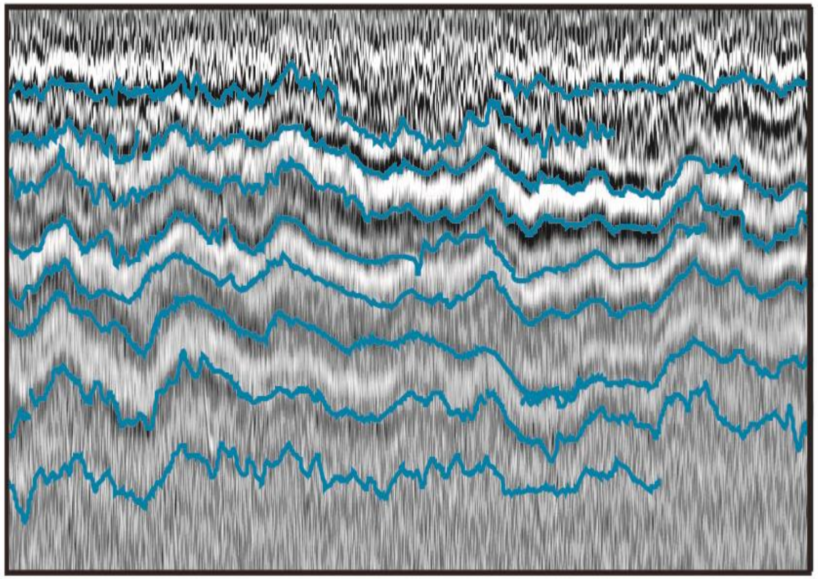


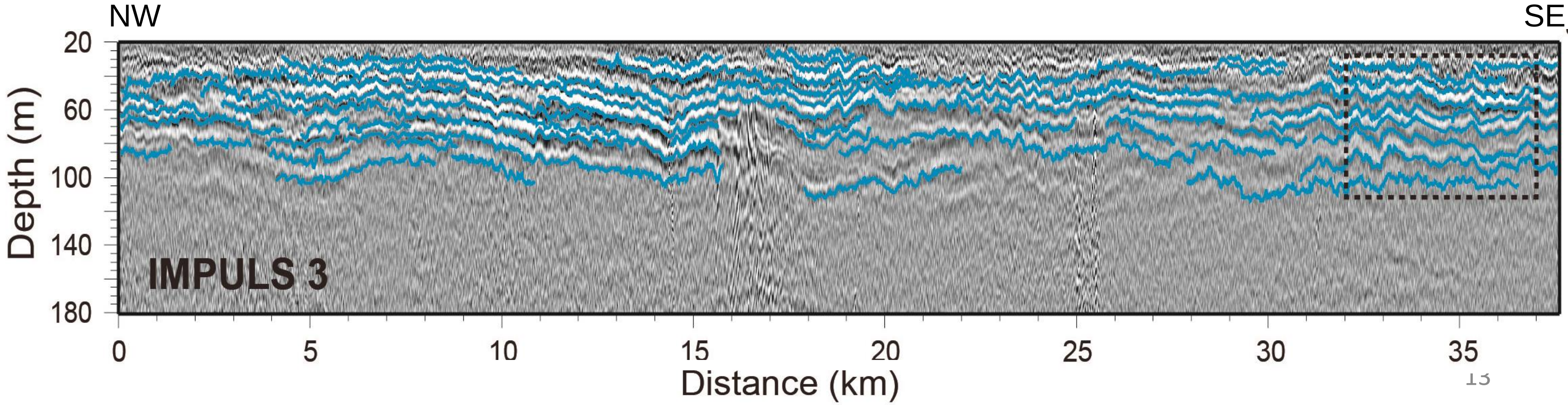
Processing flow : 2D geometry correction, CMP fold doubling, freq. filtering (40-240 Hz), amplitude correction, direct wave filtering, CMP sorting, PSTM, depth conversion with XBT-derived sound speed model

Reflector tracking

Automatic reflector tracking following a criteria of maximum cross-correlation between neighbouring traces. It must be above a threshold within a 10 ms time window (7,5 m)

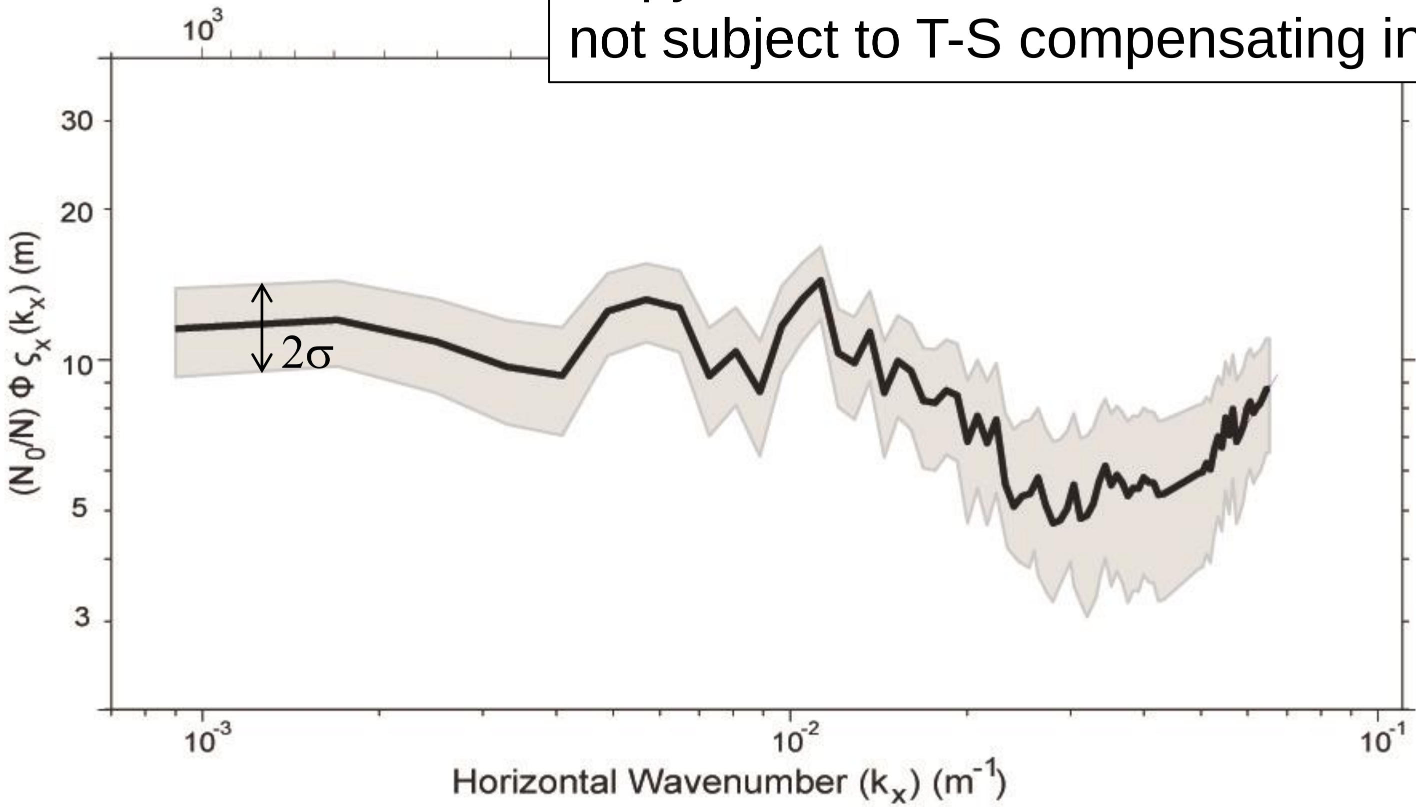
Reflectors >1200 m long → all contribute equally to the analyzed scale range





k_x slope spectra

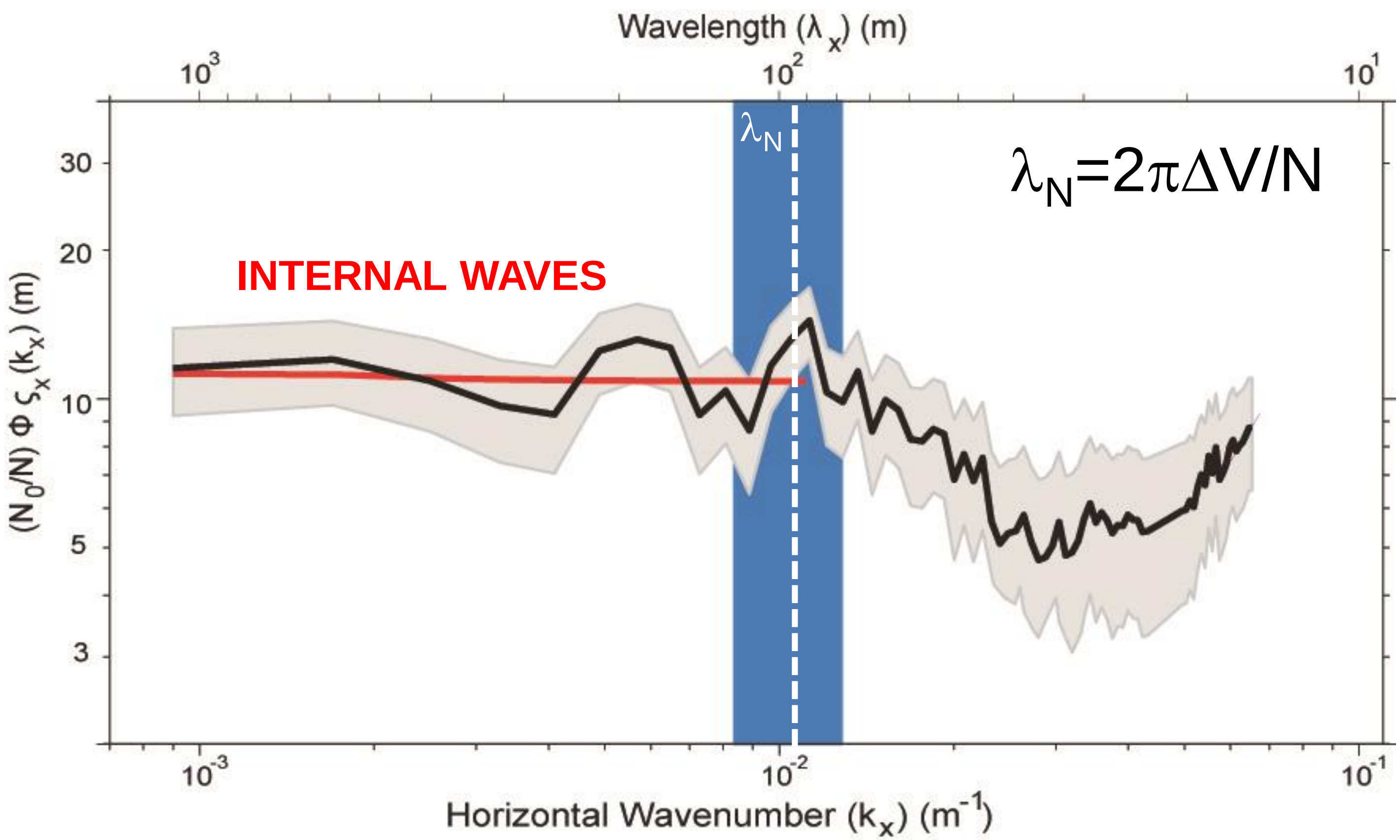
Key assumption: reflectors follow isopycnals $\rightarrow$ shown to be true in areas not subject to T-S compensating intrusions



Averaged spectrum of the117 reflectors tracked in the two profiles, multiplied by $(2\pi k_x)^2$ to emphasize slope variations, and scaled by the buoyancy frequency (N/N_0)

Results

$\lambda_x > 100$ m

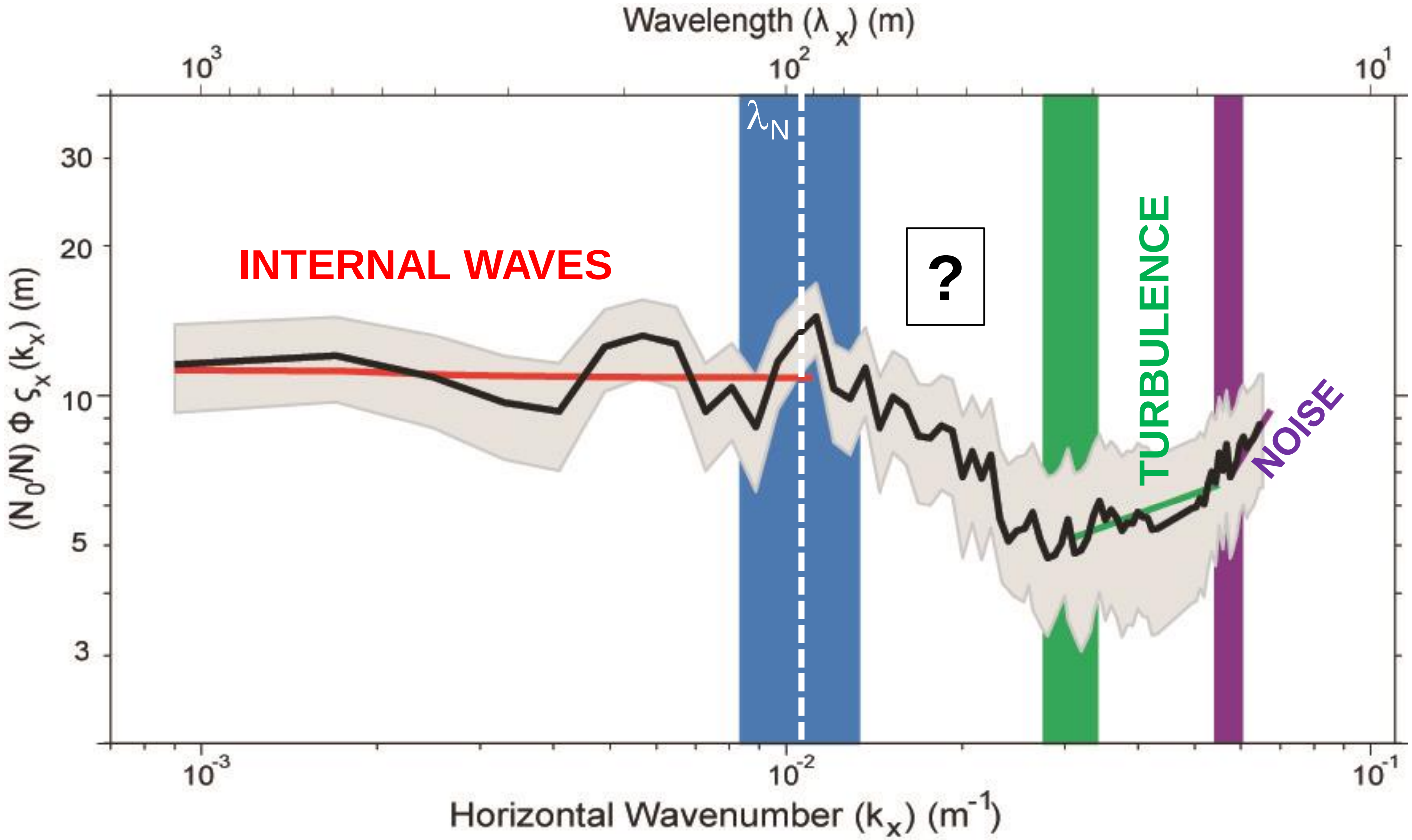


Spectral slope k_x^{-q} with q=2.05±0.06

GM79 predicts q=2 for internal waves (between f_C and N)

Results

33 m > λ_x > 16 m

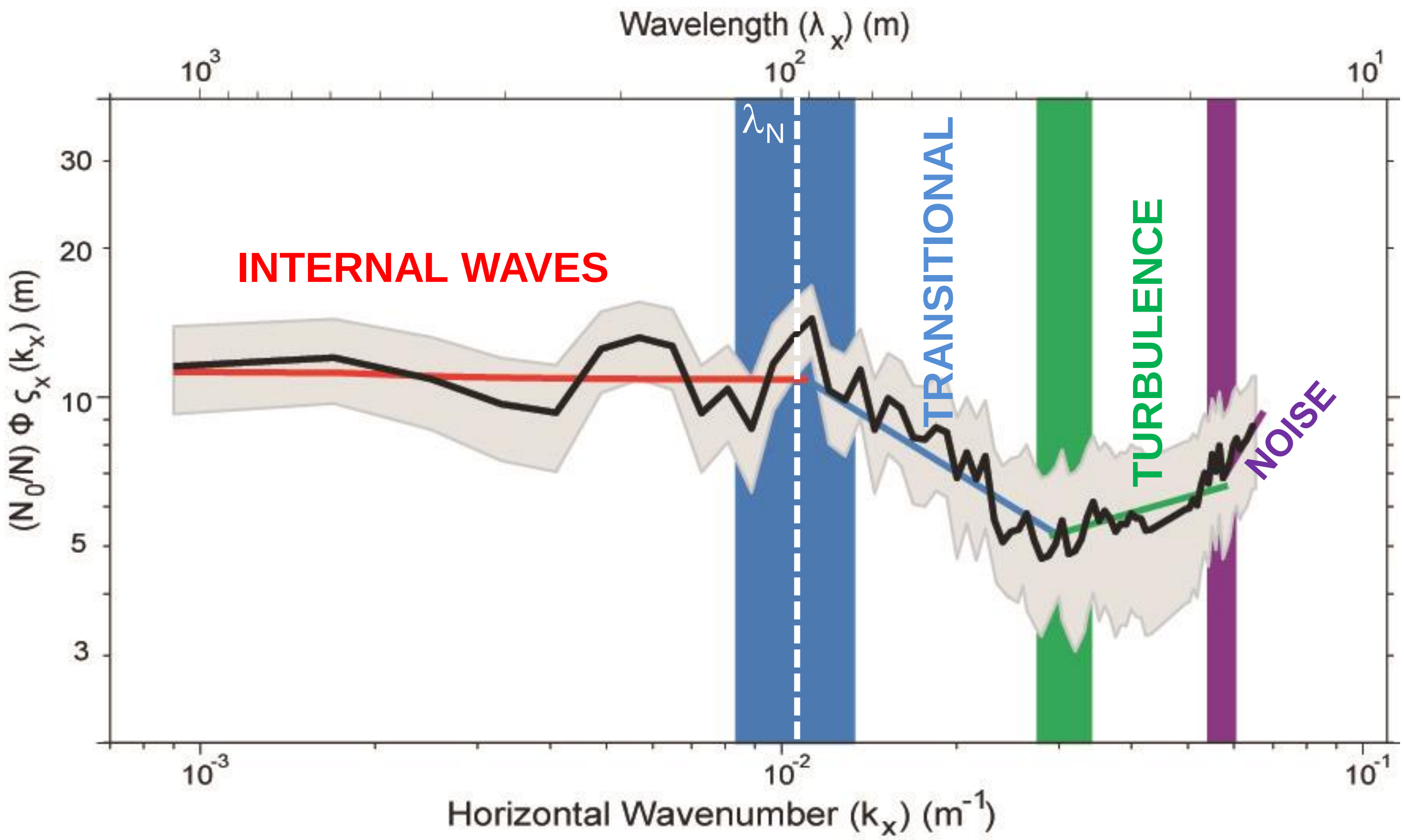


k_x^{-q} with q=1.64±0.21, in agreement with Batchelor59 for turbulence (q=5/3) → IW collapse

At λ_x<16 m (similar to R_x), q≈0, characteristic of white noise

Results

$100\ m > \lambda_x > 33\ m$



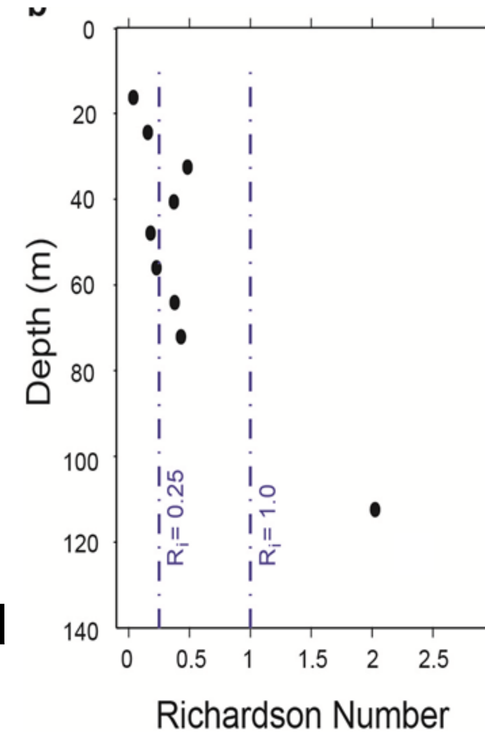
Transitional subrange characterized by q=2.8±0.2

→ Kelvin-Helmholtz shear instabilities? q=2.5-3.0 (Waite, 2011)

Kelvin-Helmholtz instabilities?

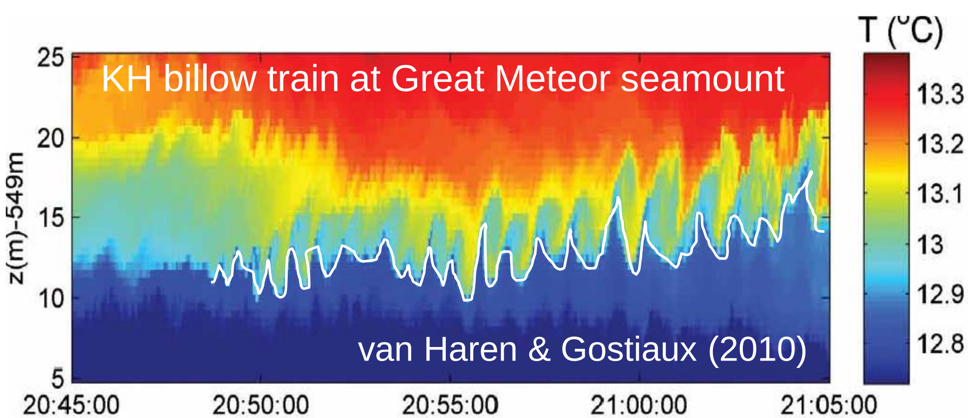
KH billows described in atmosphere and ocean

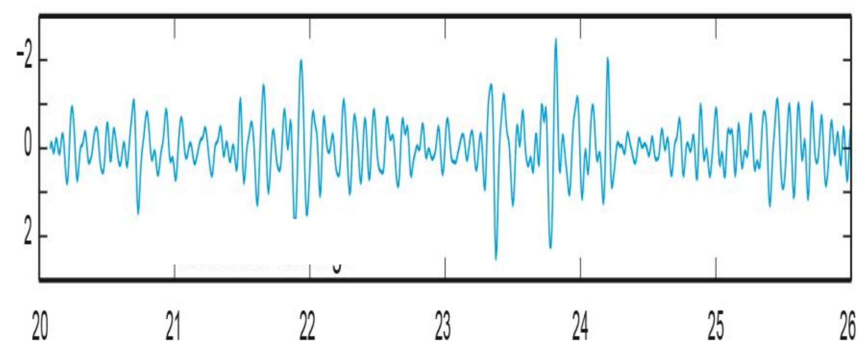
1) Develop in stratified systems when shearing is strong enough to bring $R_i=N^2/(\partial V/\partial z)^2<0.25$



2) Aspect ratio 7:1 bw thickness of sheared layer and wavelength of largest disturbances → 100/13≈7.6

3) Observations suggest average λ=50-75 m and A=1-5 m





Summary

- HR-MCS data help covering the observational gap that exists in the ocean at horizontal scales of 10^1-10^3 m

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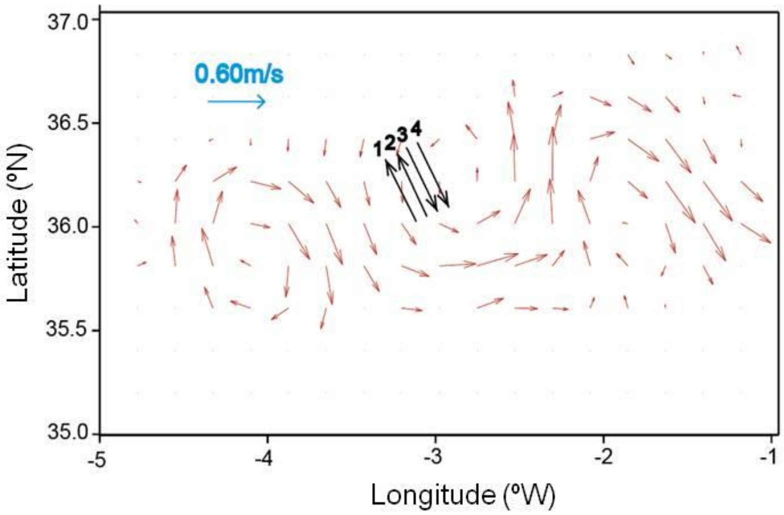
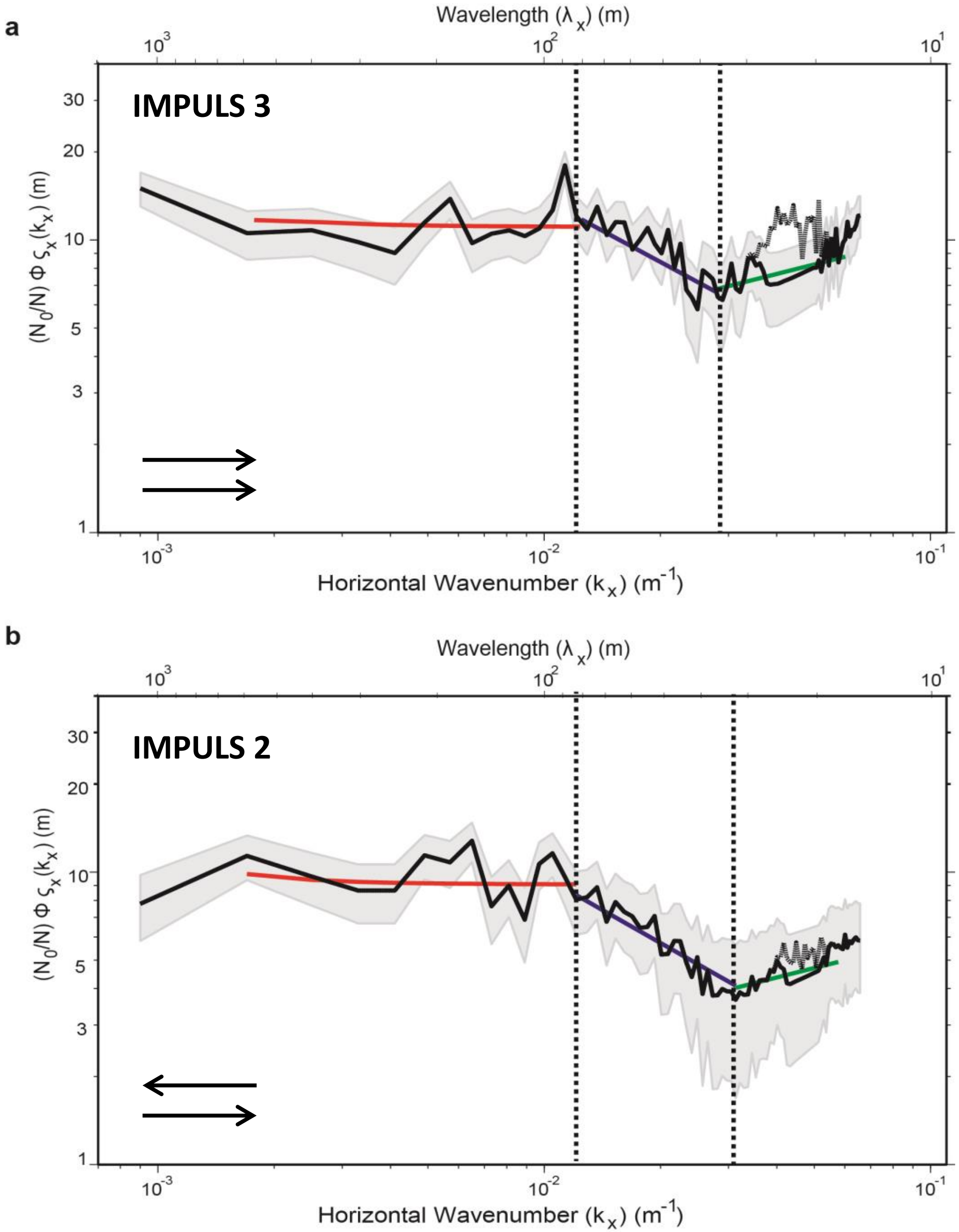
- HR-MCS data help covering the observational gap that exists in the ocean at horizontal scales of 10^1-10^3 m
- We found strong evidence that ocean dynamics at the Aboran Sea thermocline is dominated by internal waves at $\lambda_x > \lambda_N$, below which KH-type instabilities likely develop until they collapse giving rise to turbulence

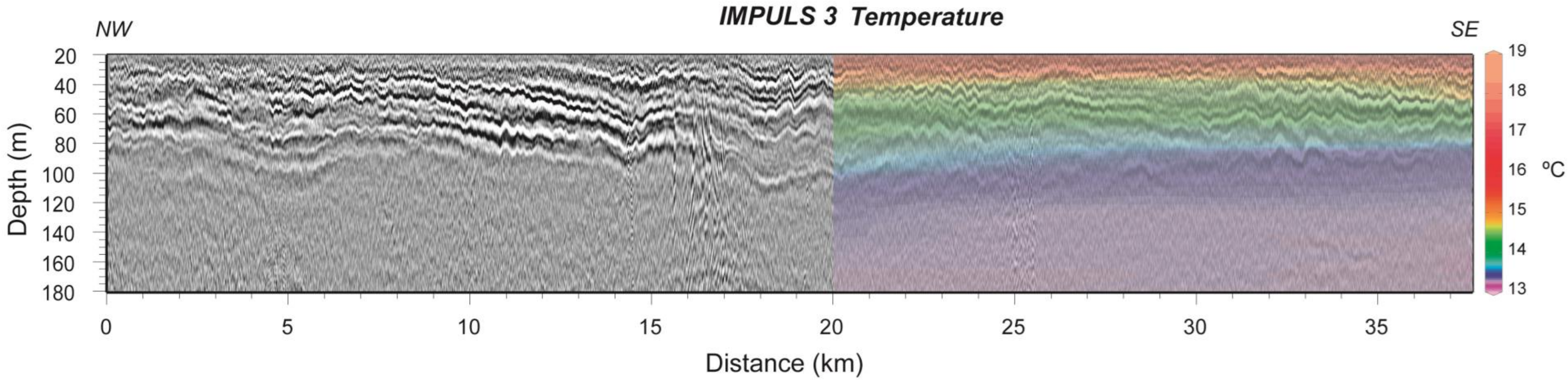
Summary

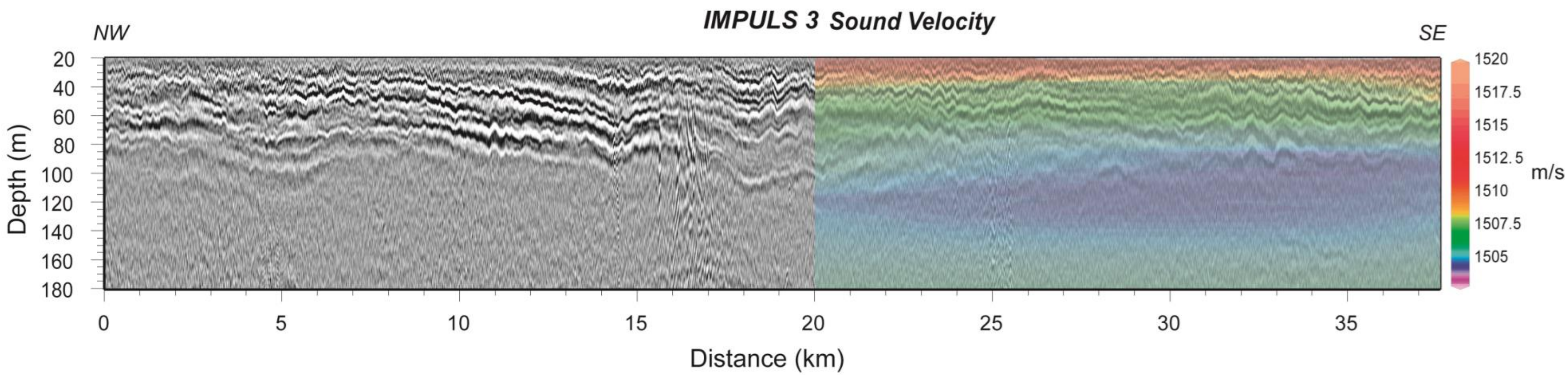
- HR-MCS data help covering the observational gap that exists in the ocean at horizontal scales of 10^1-10^3 m
- We found strong evidence that ocean dynamics at the Aboran Sea thermocline is dominated by internal waves at $\lambda_x > \lambda_N$, below which KH-type instabilities likely develop until they collapse giving rise to turbulence
- The availability of a system providing observations at the appropriate scales opens new perspectives to improve knowledge on small-scale mixing and dissipation

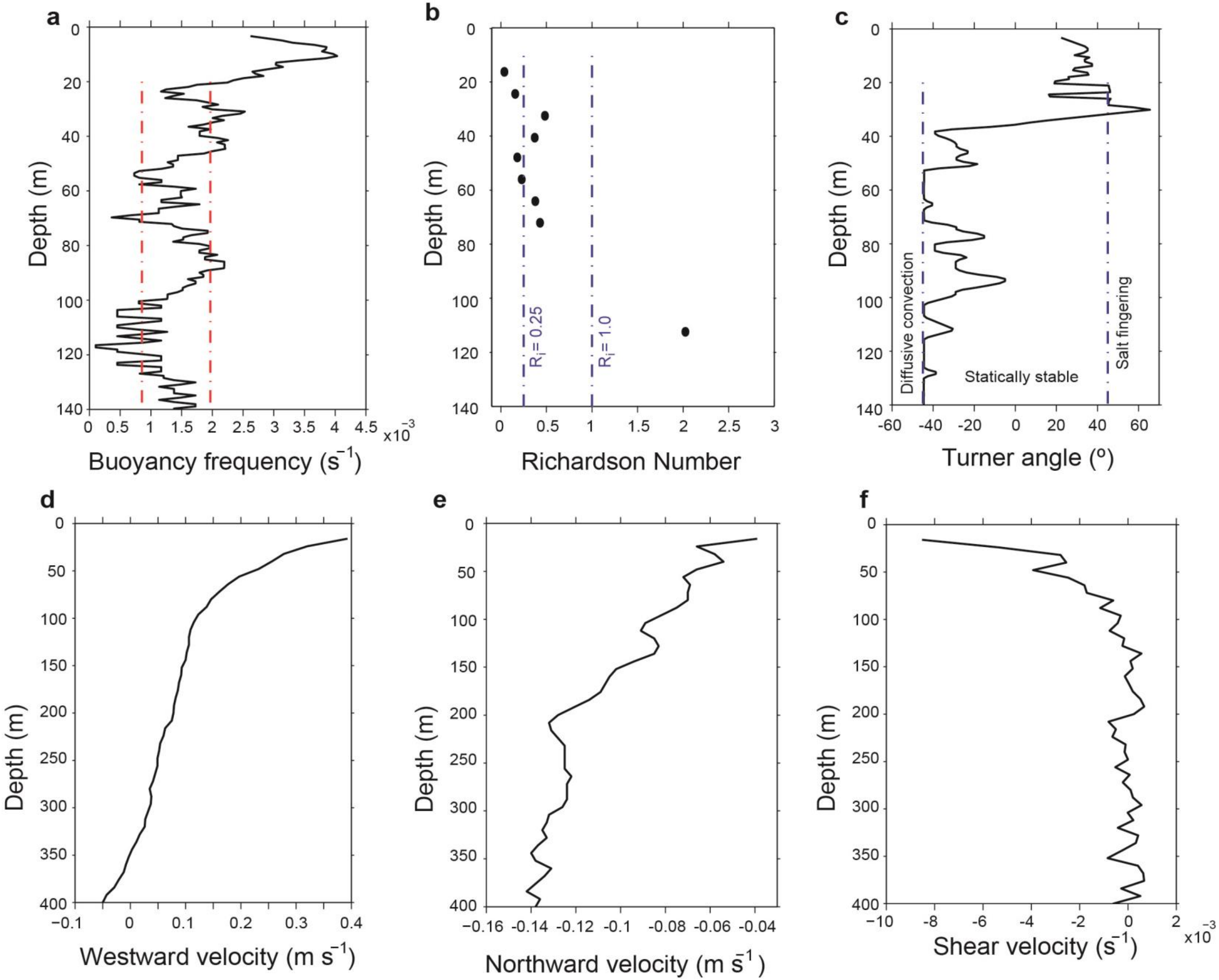
Thank you


0.60m/s
1
2
3
4
Latitude (ºN)
Longitude (ºW)
37.0
36.5
36.0
35.5
35.0
-5
-4
-3
-2
-1


a
IMPULS 3
Wavelength (λ_x) (m)
$(N_0/N)\,\Phi\,\varsigma_x(k_x)$ (m)
Horizontal Wavenumber (k_x) (m^{-1})
b
IMPULS 2
Wavelength (λ_x) (m)
$(N_0/N)\,\Phi\,\varsigma_x(k_x)$ (m)
Horizontal Wavenumber (k_x) (m^{-1})


IMPULS 3 Temperature
NW
SE
Depth (m)
20
40
60
80
100
120
140
160
180
0
5
10
15
20
25
30
35
Distance (km)
19
18
17
16
15
14
13
ºC


IMPULS 3 Sound Velocity
NW
SE
Depth (m)
20
40
60
80
100
120
140
160
180
0
5
10
15
20
25
30
35
Distance (km)
1520
1517.5
1515
1512. 5
1510
1507.5
1505
m/s


a
Depth (m)
Buoyancy frequency (s-1)
x10-3
b
Depth (m)
Ri = 0.25
Ri = 1.0
Richardson Number
c
Depth (m)
Diffusive convection
Statically stable
Salt fingering
Turner angle (º)
d
Depth (m)
Westward velocity (m s-1)
e
Depth (m)
Northward velocity (m s-1)
f
Depth (m)
Shear velocity (s-1)
x10-3