Non linear internal tides, turbulent mixing in the continental shelf of South Brittany

Yannis Cuypers, Pascale Bouruet Aubertot, Pascal Lazure, Antonio Lourenço, Michel Lunven, Marc Sourriceau, and Lourdes Velo-Suarez

IFREMER Dyneco-Physed Dyneco-EP
LOCEAN (UMR - Université Pierre et Marie Curie)

The Per2Tong campaign objectives

Programme Expérimental de Recherche de soliTON
et
plancTON dans le golfe de Gascogne
South Brittany (Bay of Biscay) June 28-July 13 2010

- Characterizing nonlinear internal tides, high frequency waves, turbulent dissipation and mixing in coastal waters

- Impact of these nonlinear processes on the phytoplankton and nutrient distribution in the pycnocline, notably on the stability of fine phytoplankton layers

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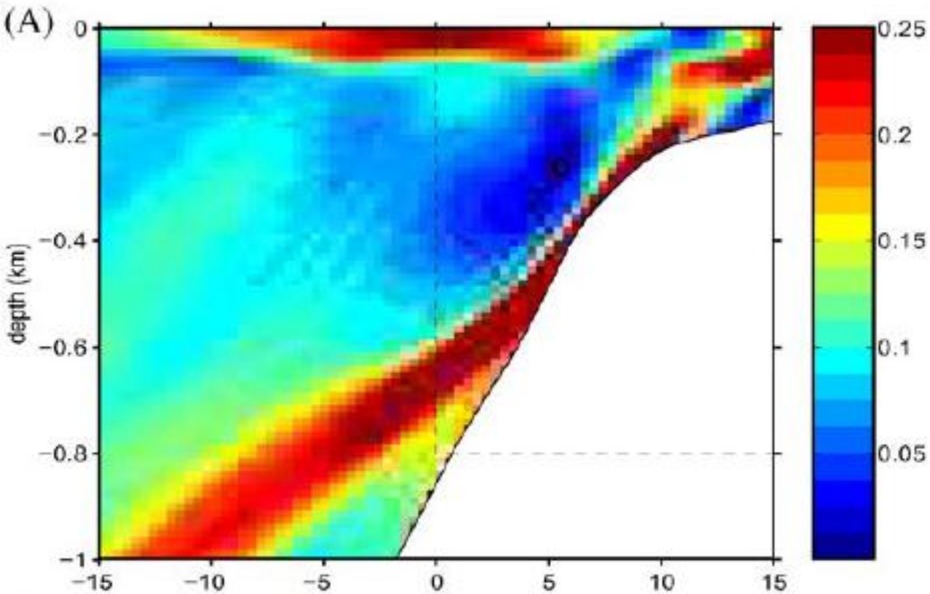
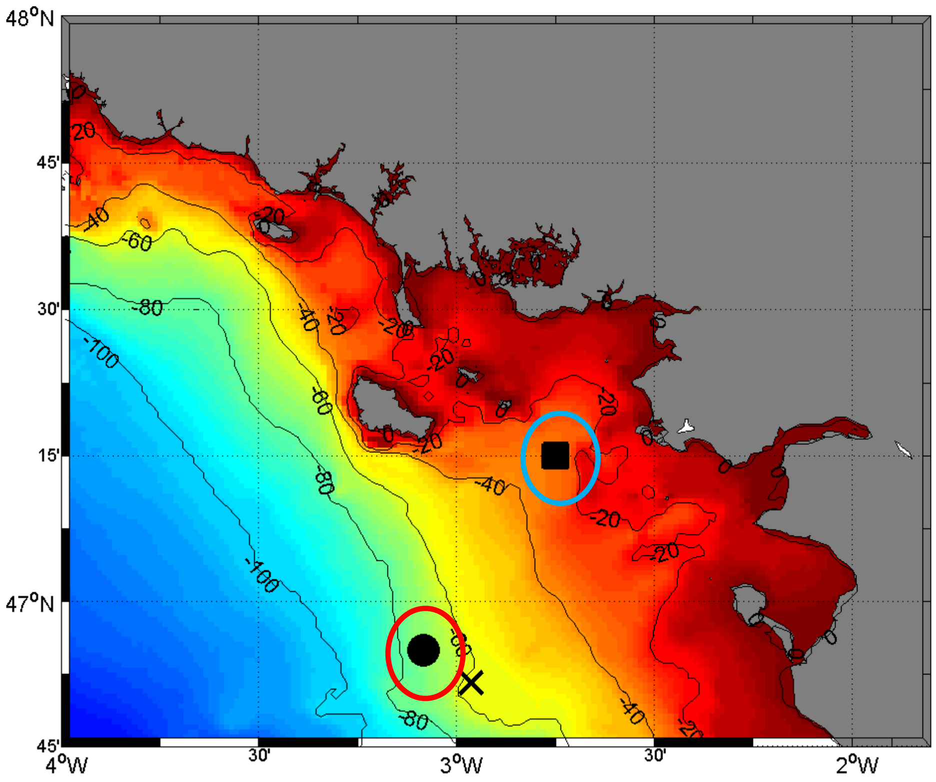
Internal tide generation in the bay of Biscay

Gerkema (2001) idealized linear model
modulus of velocity (m/s) (Semi Diurnal tide)



- One of the strongest spot of internal tide (IT) generation in the world
- Conversion of barotropic to baroclinc tide at the shelf break
- Propagation in deep sea => observation and modelling of nonlinear tides and solitary waves (New and Pingree 1998, Gerkema 2001)
- Propagation and nonlinear evolution on the shelf to the coast ?

Per2tong high frequency moorings



- **Belle île mooring** (70 m depth)

-ADCP 600khz. Δz=0.5m, Δt =1min

-7 NKE CTD sensors (9, 15, 20, 25, 30, 34, 35) m and Δt =1mn

-4 RBR high frequency temperature sensors) Δt =1s , at depths:

(10, 15, 20 and 25 m)

- **Croisic mooring** (35 m depth)

-ADCP 600khz. Δz=0.5m, Δt =1min

-5 NKE CTD sensors at depth

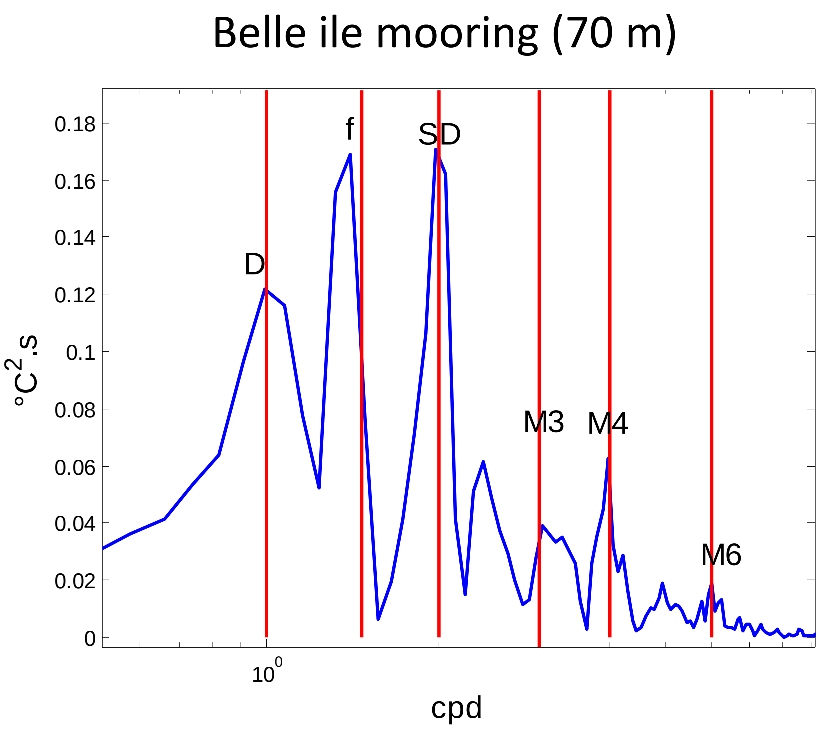
(33, 24, 15, 10, 6) m, Δt =1mn

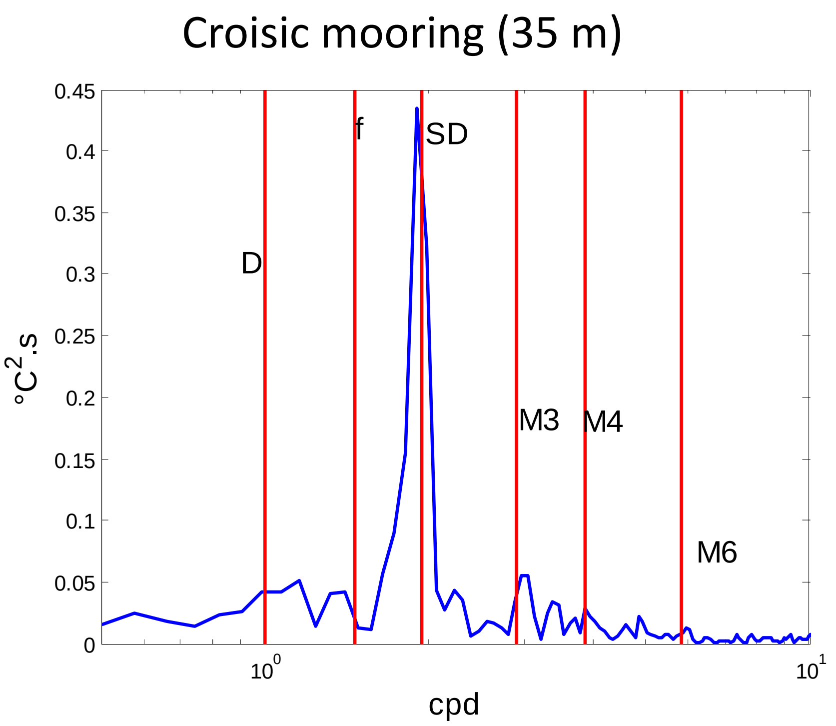
-4 RBR high frequency Δt =1s temperature sensors , at depths:

(10, 15, 20 and 25 m)

Frequency content of internal wave field

- Spectral analysis from 15 m depth high frequency temperature sensor



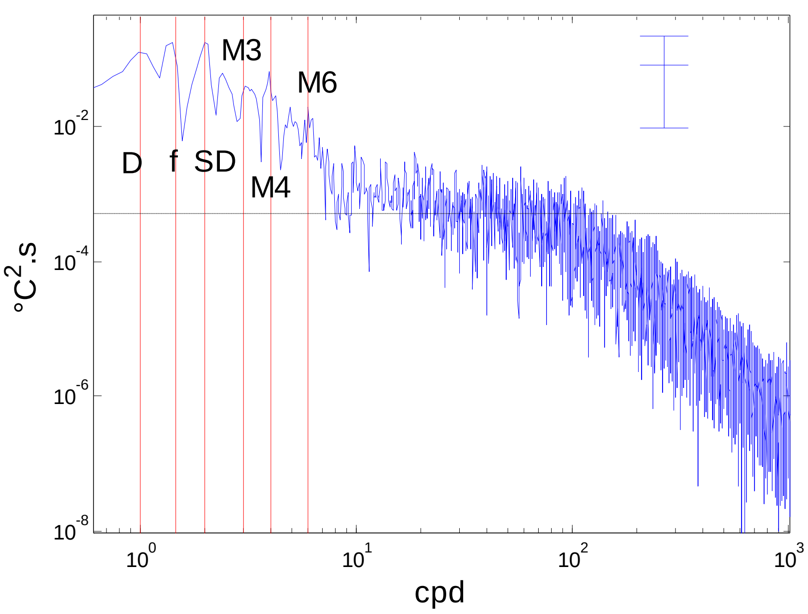


- Signal variance is dominated by low frequency tidal harmonics (~12h, 8h , 6h, 4h)
- Also a strong signature of the inertial and diurnal frequency at the Belle île mooring

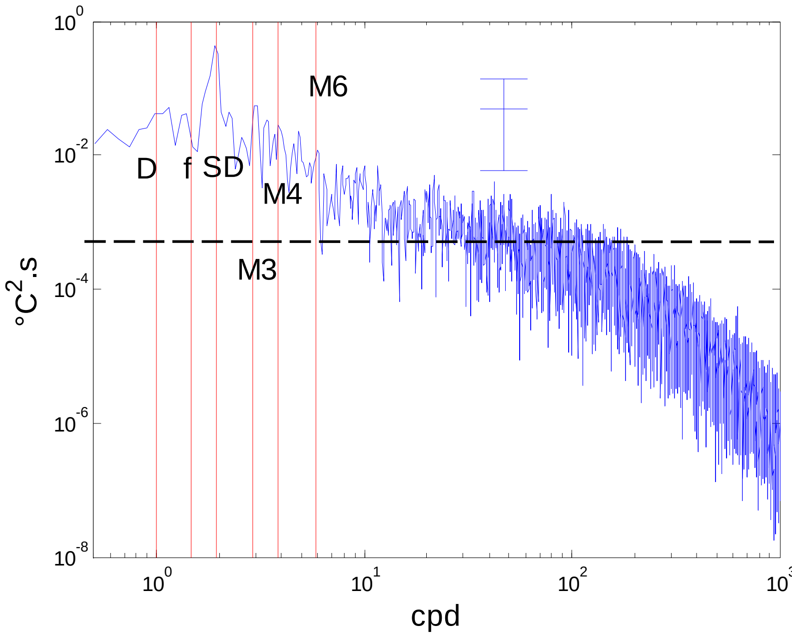
Frequency content of internal waves field

- Spectral analysis from 15 m depth high frequency temperature sensor

Belle ile mooring (70 m)



Croisic mooring (35 m)



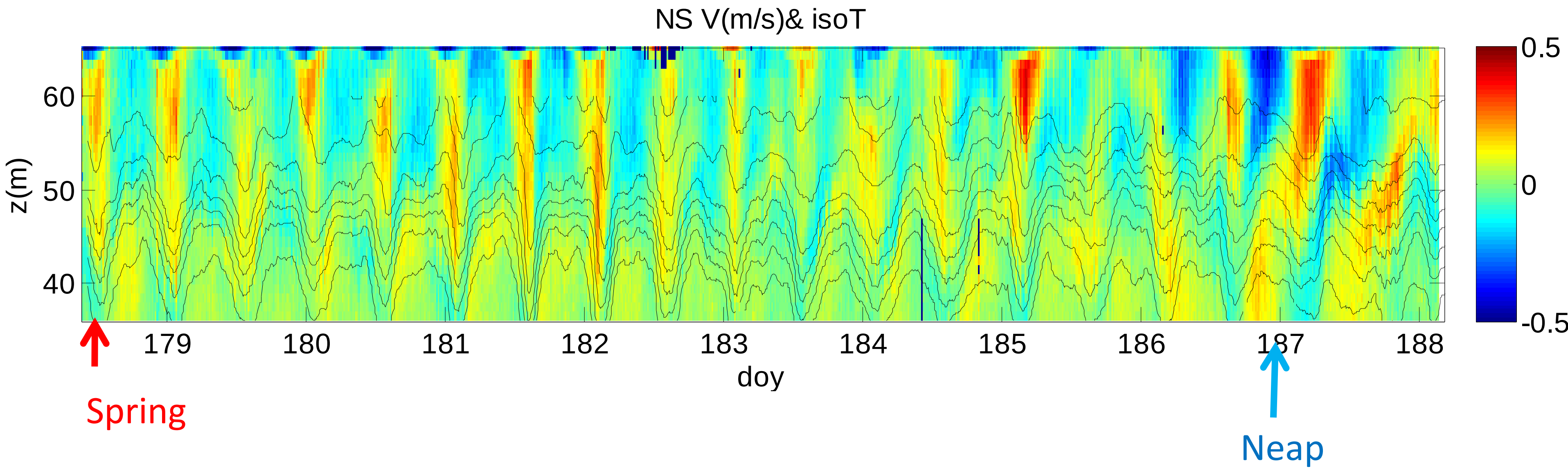
▪At high internal waves frequencies ($f_{inertial}$<< freq<N) the spectral slope is nearly flat

⇒extremely rugged signal strong contribution of high frequency waves

⇒far from classical ($freq^{-2}$) decrease generally observed in deep sea

Mooring Belle île (70m depth)

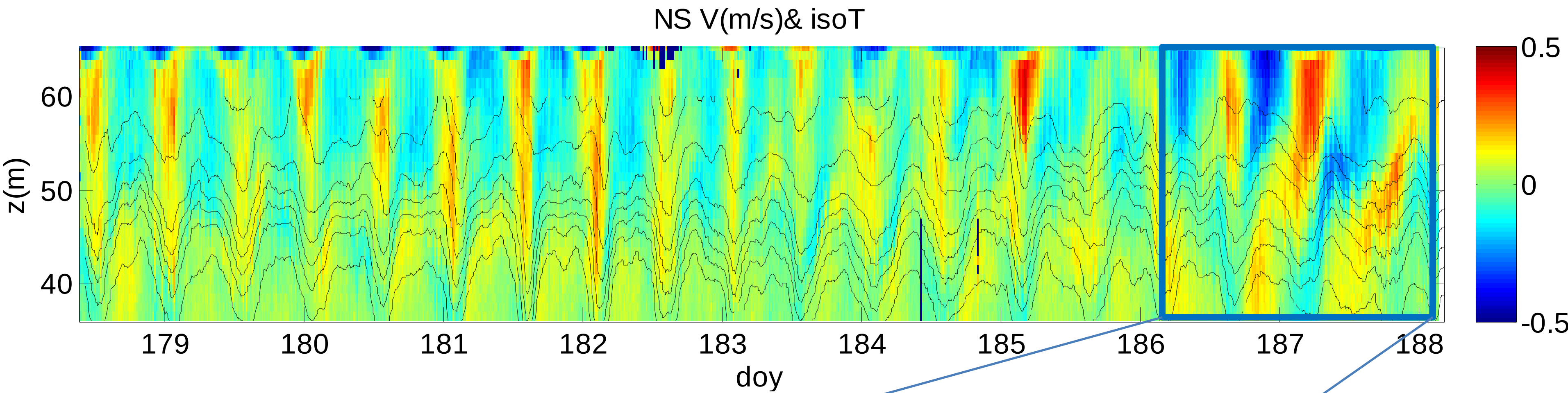
Isotherm contours (2H running average) and Meridional current (m/s)



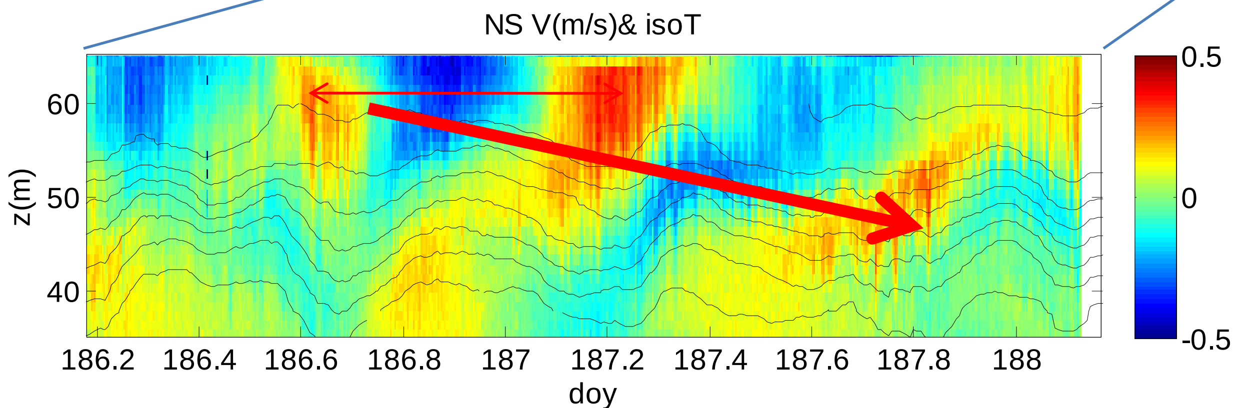
- Dominant Semi Diurnal (SD) cycle

Mooring Belle île (70m depth)

Isotherm contours (2H running average) and Meridional current (m/s)

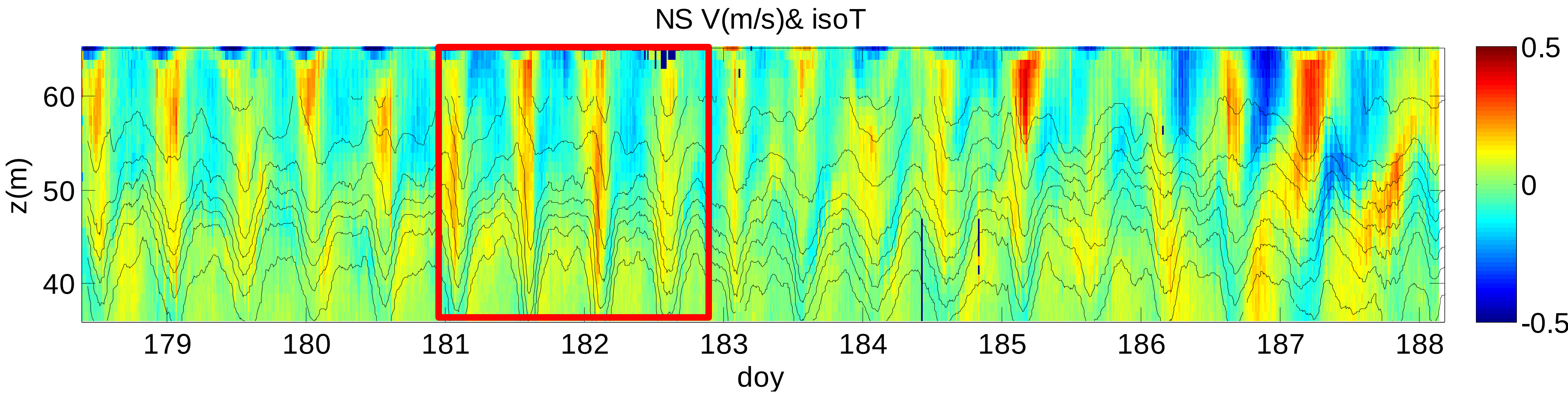


Near inertial waves with upward phase propagation and downward energy propagation) (wind generated)



Mooring Belle île (70m depth)

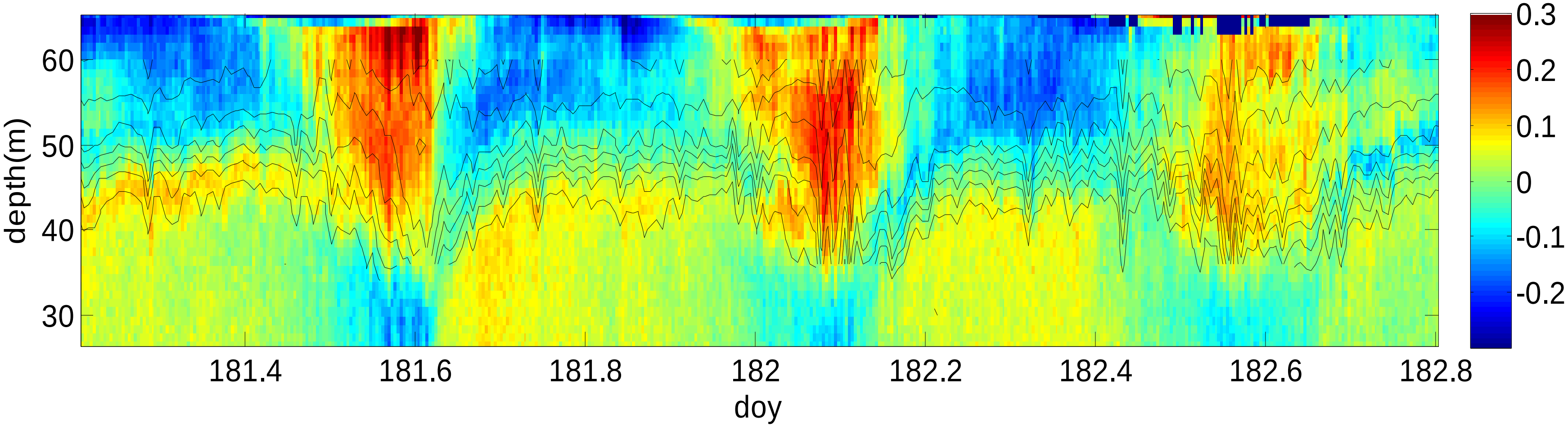
Isotherm contours (2H running average) and Meridional current (m/s)



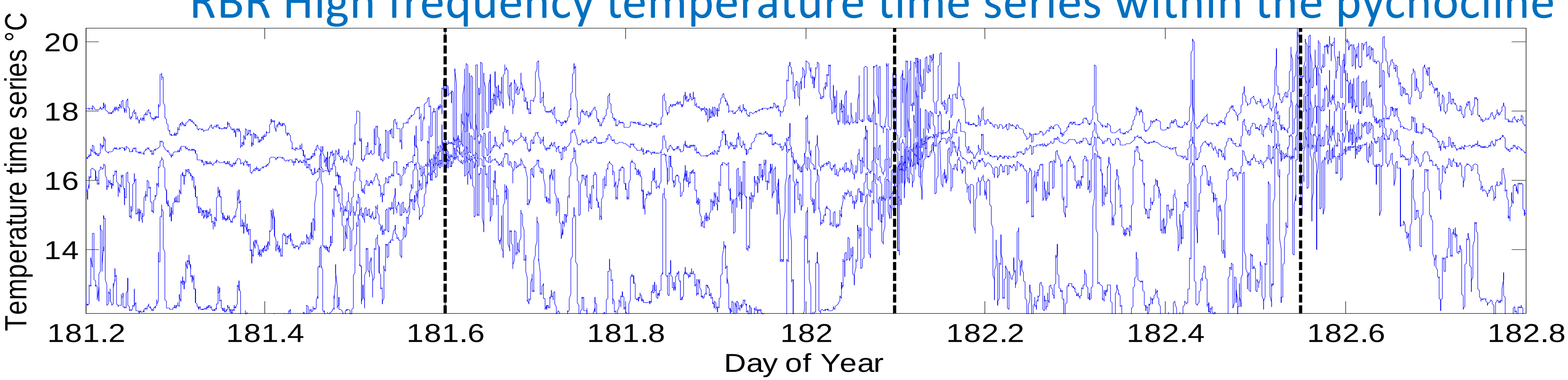
Strong non linear Semi Diurnal signal

Non linear SD Itide

Isotherm contours and Meridional current (m/s)

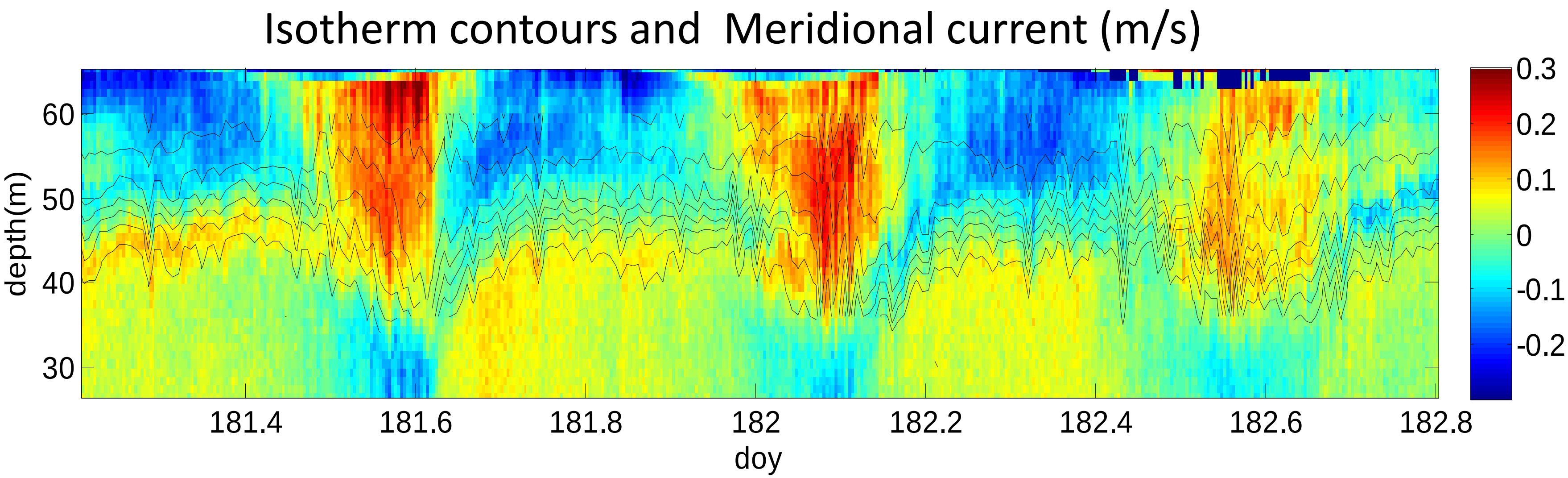


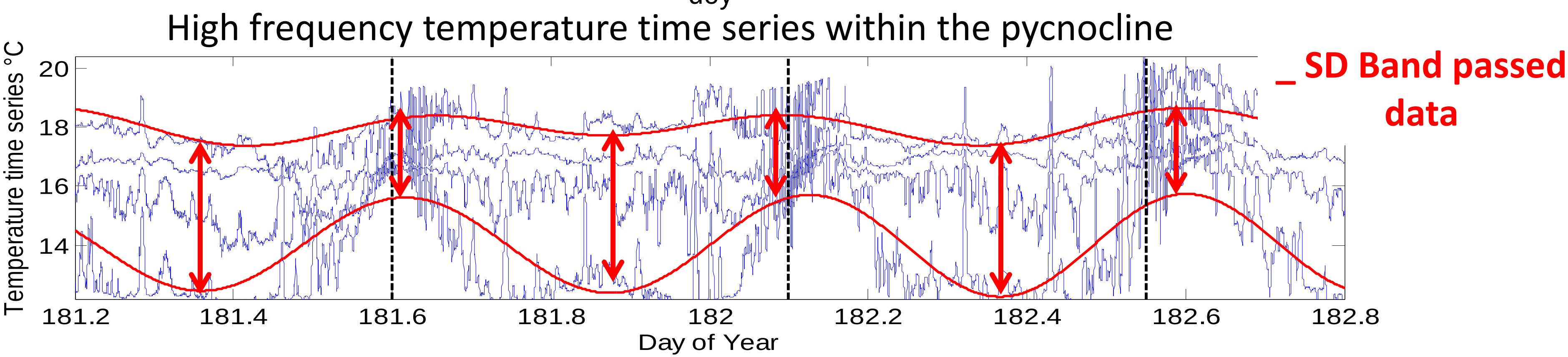
RBR High frequency temperature time series within the pycnocline



- Non linear Front with strong baroclinic velocity structure
- Generation of high frequency waves packets

Internal tide vertical structure





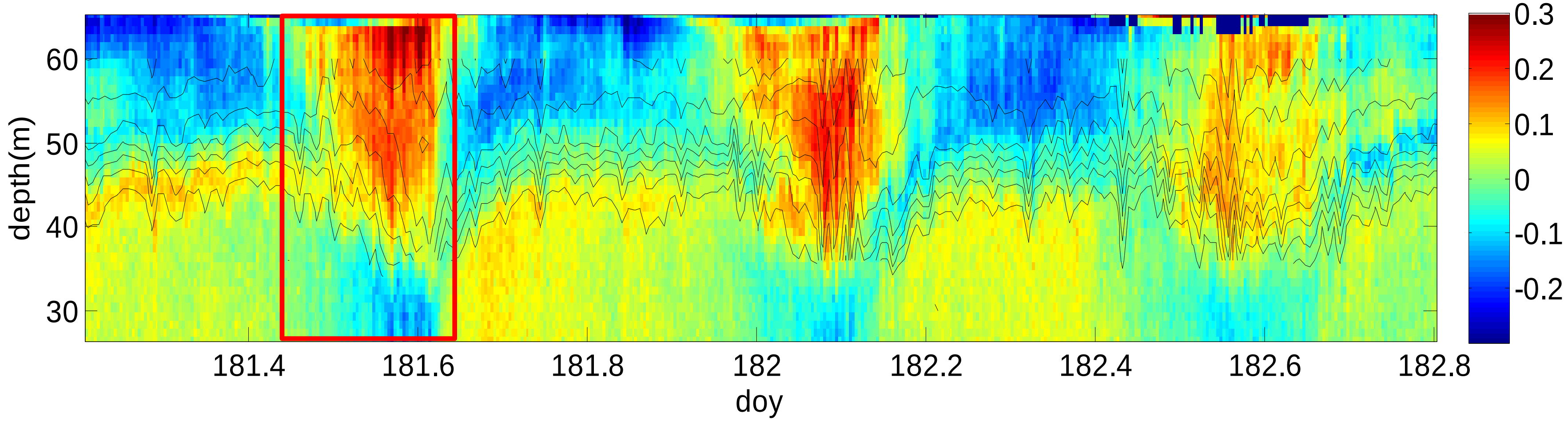
- Isotherm splitting (temperature converging) is associated with the Non linear Front

- Fine jet current structure in the thermocline is preceeding the front

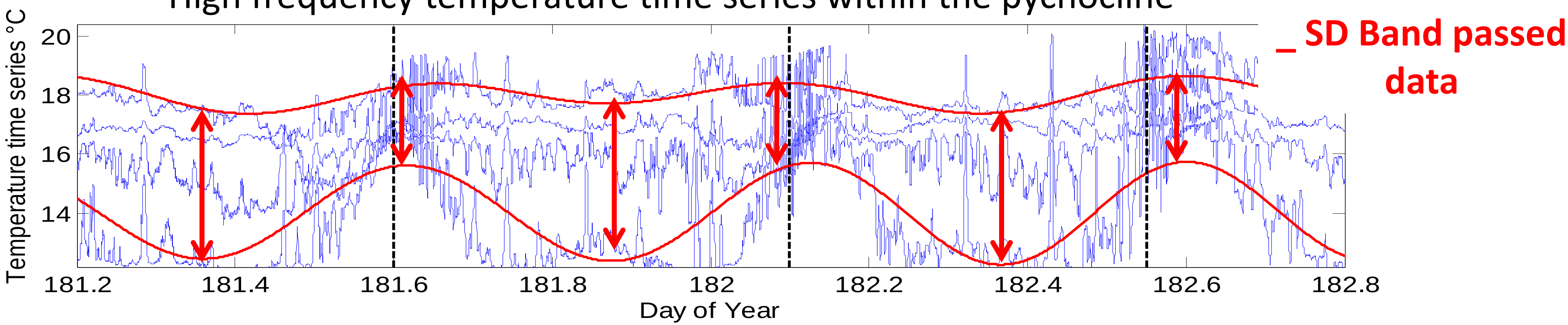
=> Several vertical modes are contributing to the signal , unexpected from regional model results (HYCOM)), may be enabled by the loose pycnoline profile in 2010

Internal tide vertical structure

Isotherm contours (2H running average) and Meridional current (m/s)



High frequency temperature time series within the pycnocline



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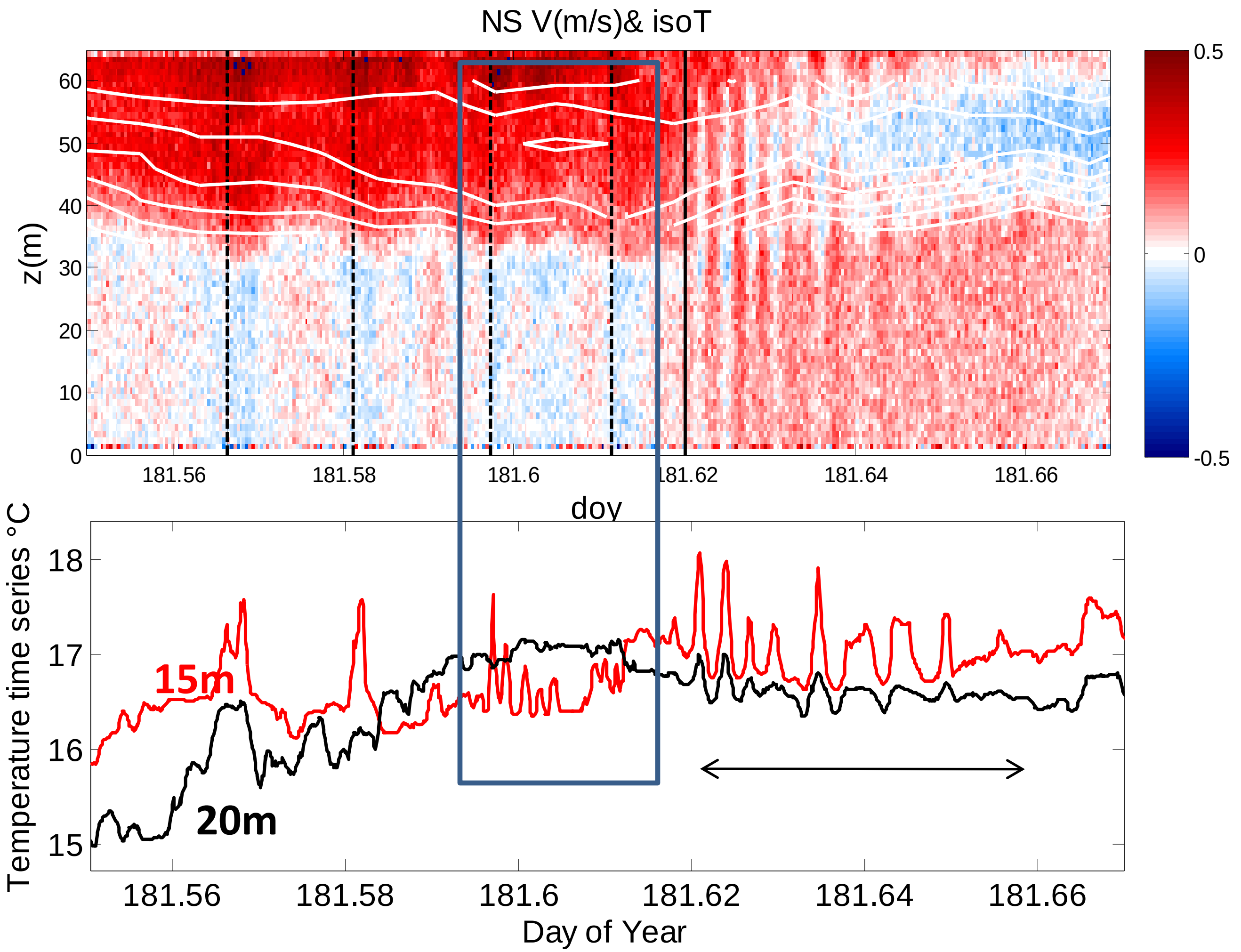
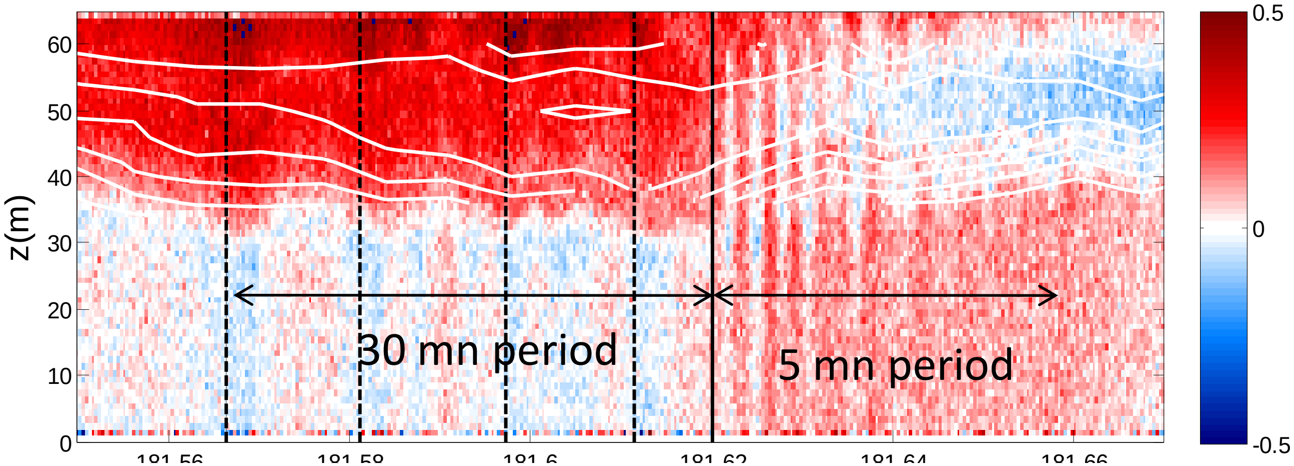
High frequency waves and mixing



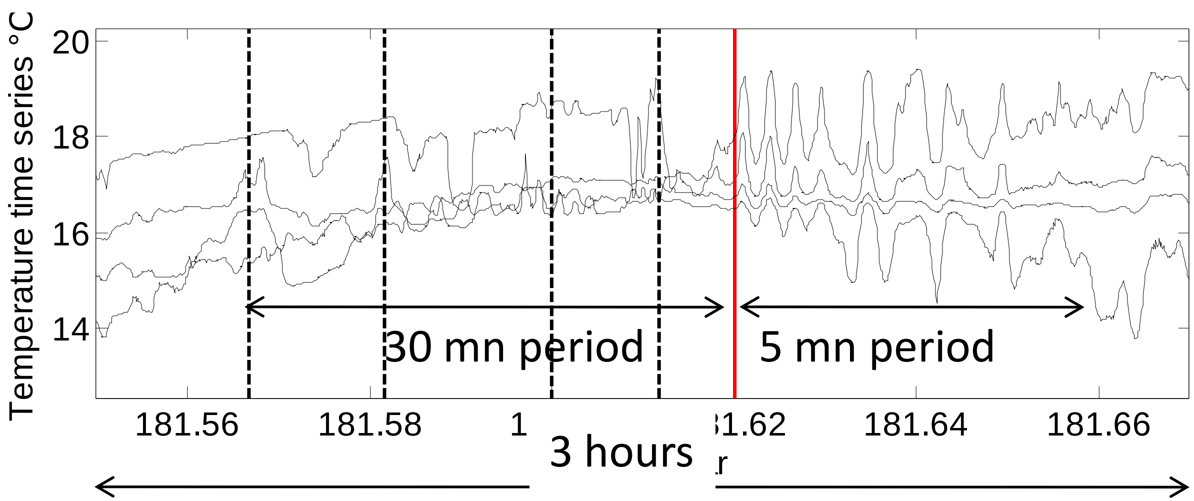
- Strong mixing event within the pycnocline over more than 5 m associated with strain and decrease of stratification

High frequency waves and mixing

Isotherm contours and Meridional current (m/s)

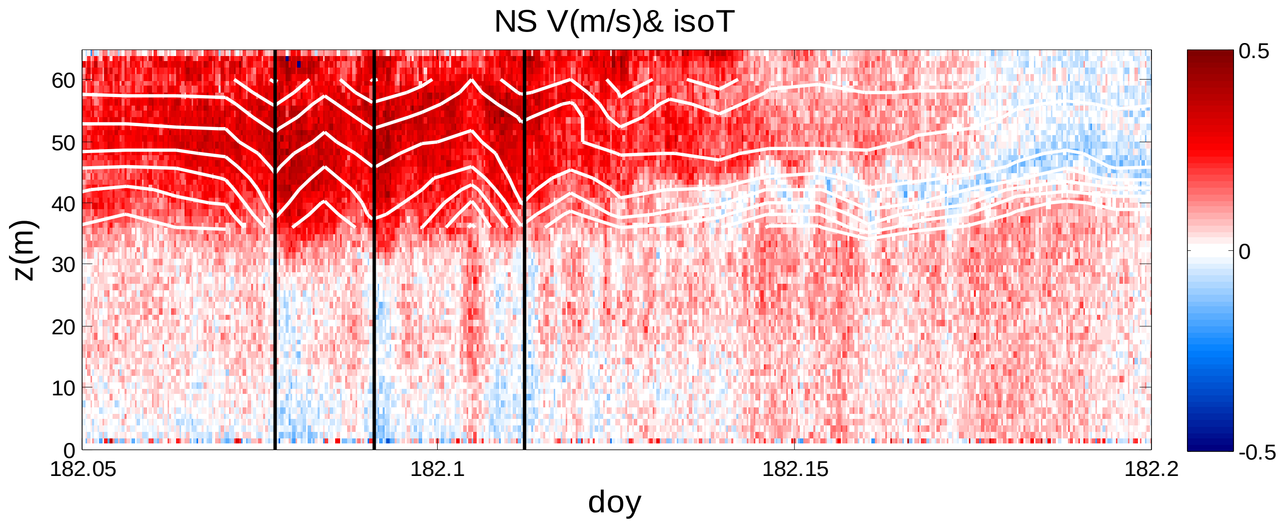


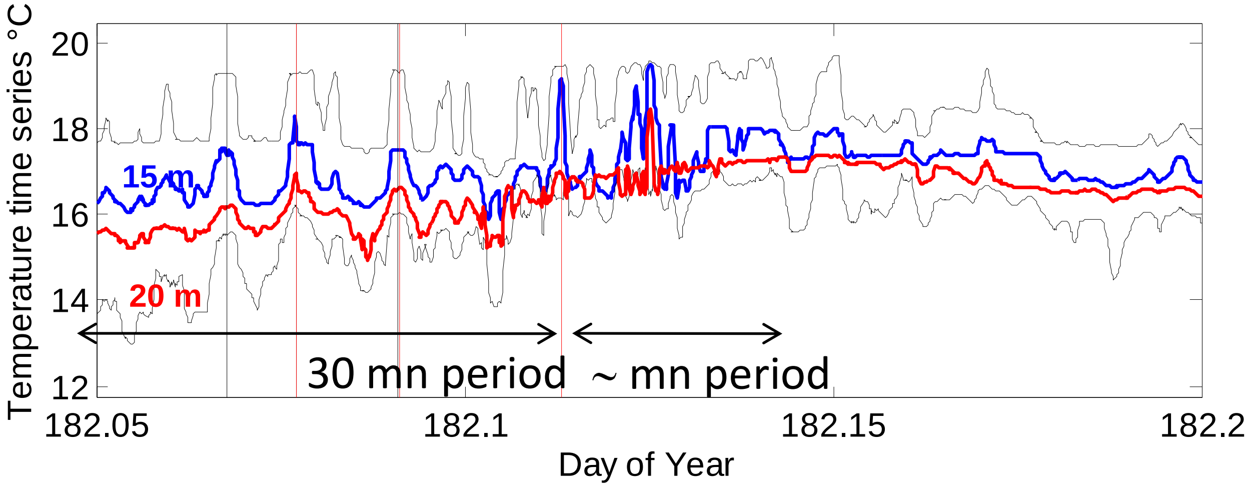
High frequency temperature time series within the pycnocline



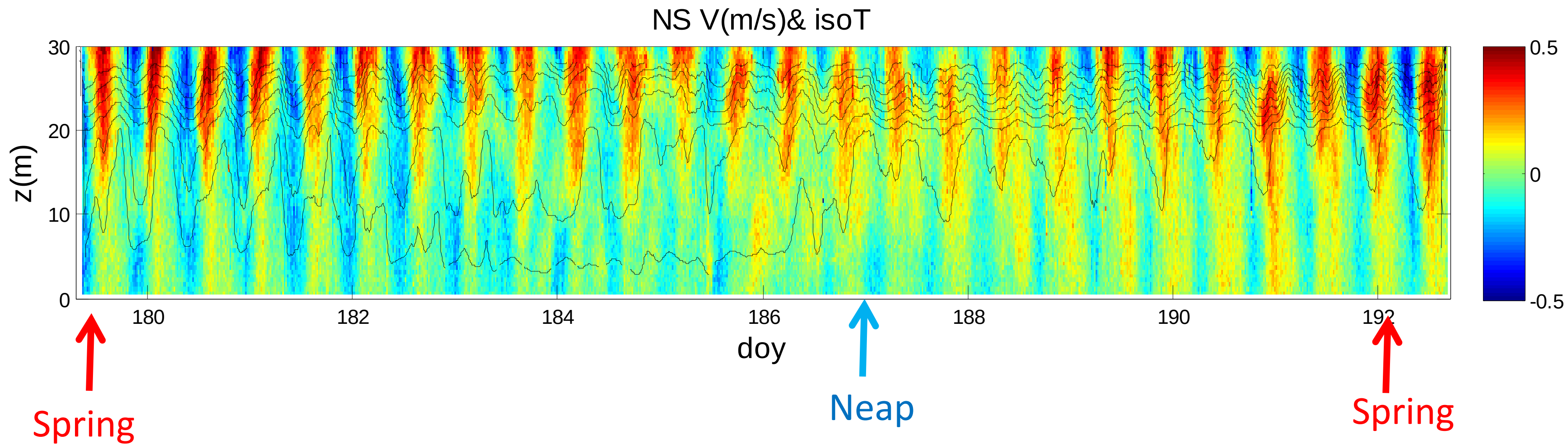
- High frequency waves 20-30 mn period during abrupt fall and stretching in the thermocline
- HFW with 5mn period following the mixing event and abrupt reversal of currents

One M2 cycle later





Mooring Croisic (35m depth)



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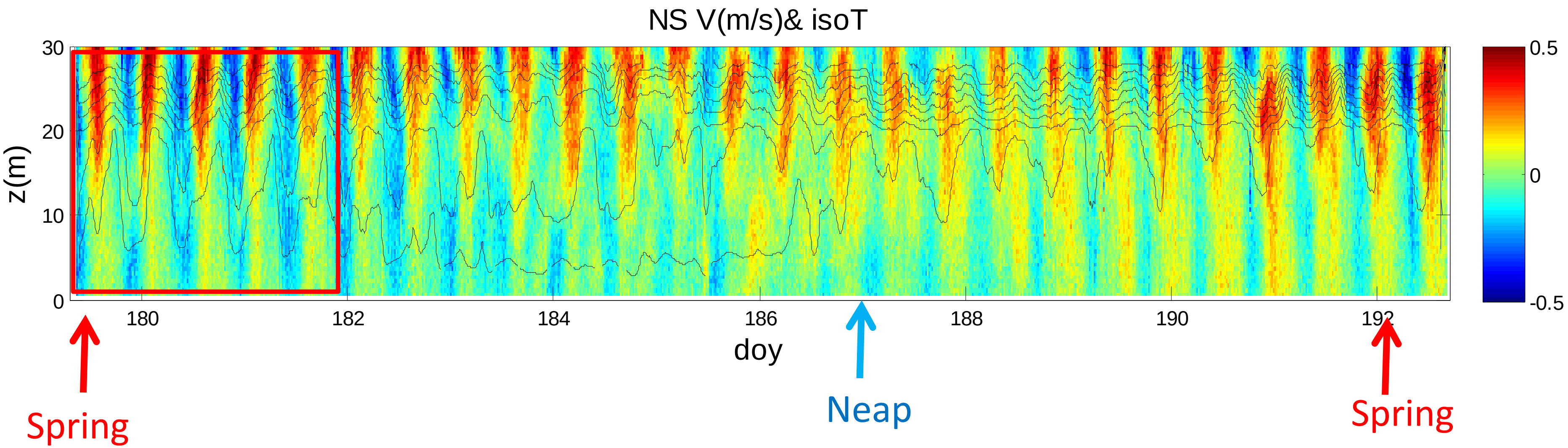
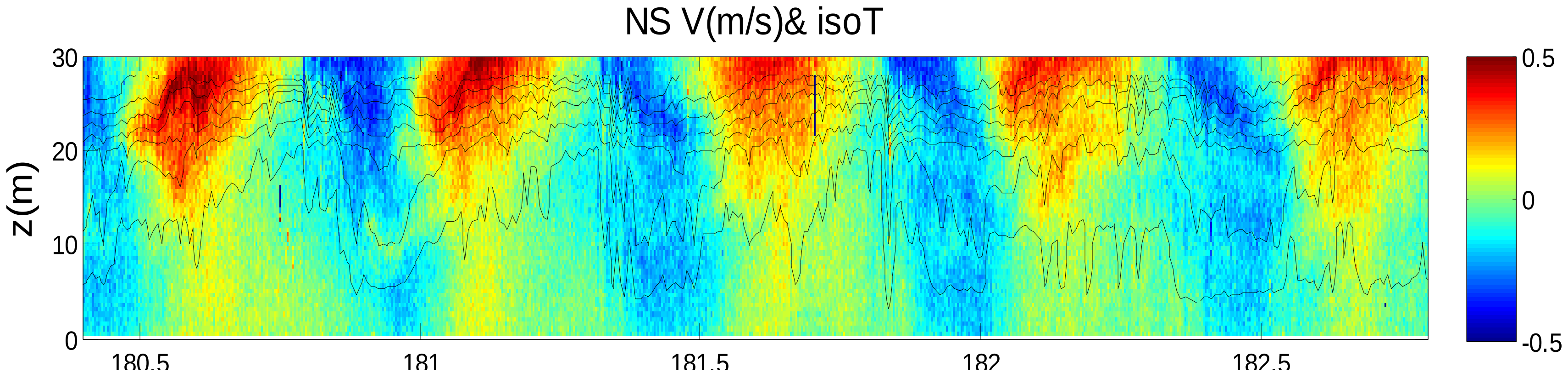
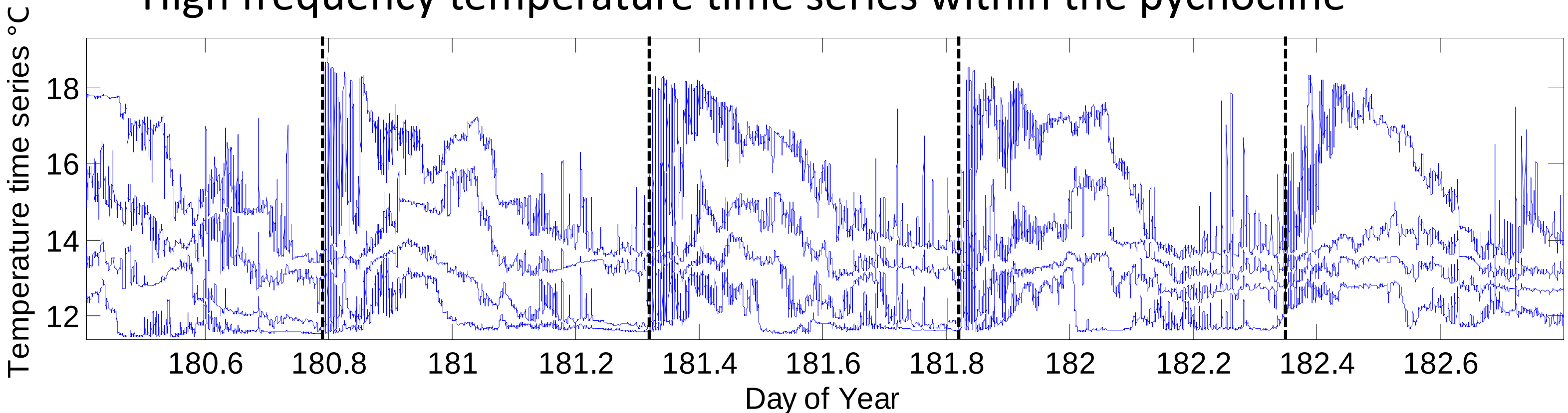


- Strong Non linear internal tides identified mostly during first Spring cycle

Strong non linear SD tides



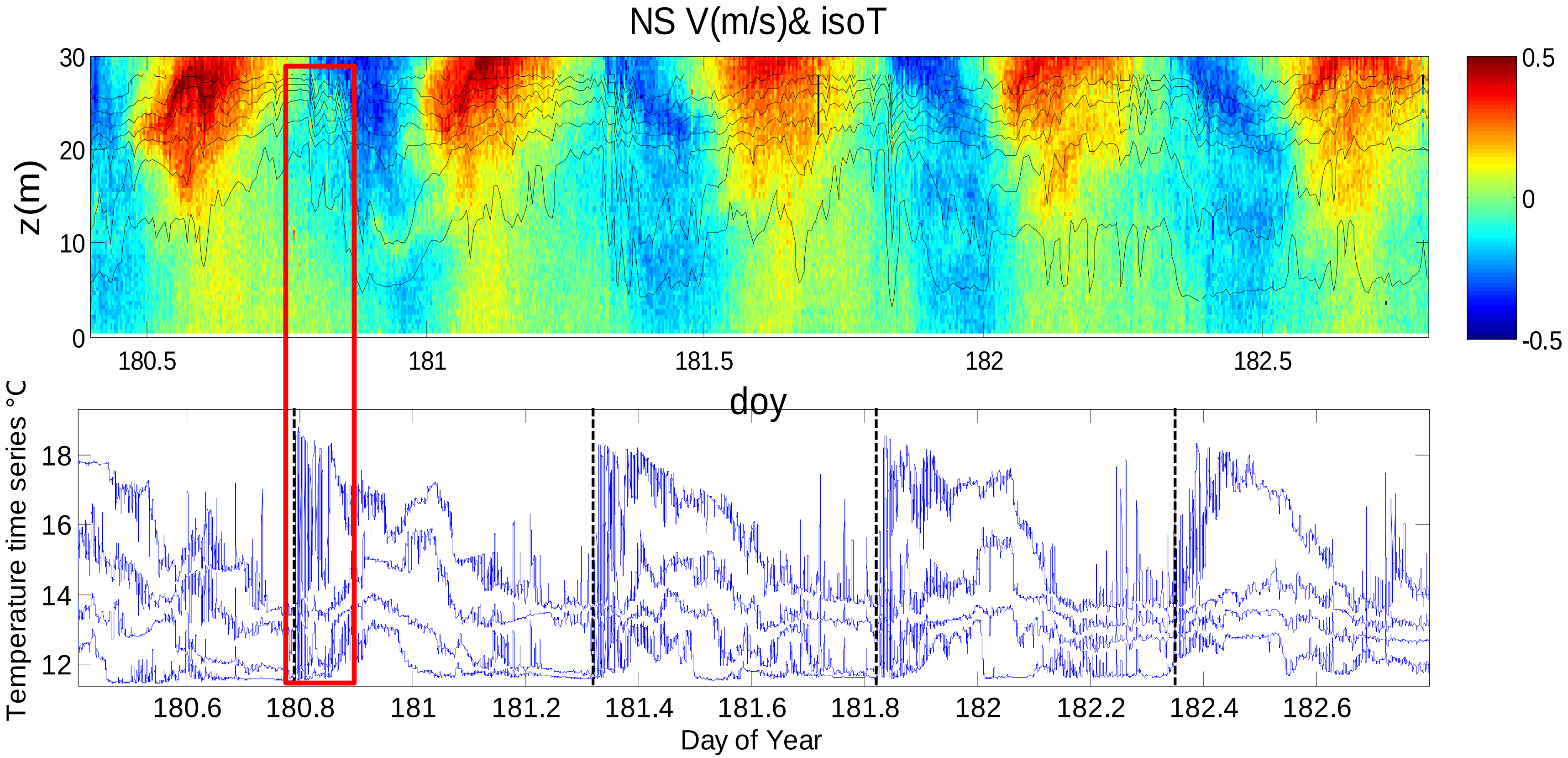
High frequency temperature time series within the pycnocline



- Non linear Front, gradual rise and abrupt fall of isotherm

- Generation of high frequency wave packets

Strong non linear SD tides



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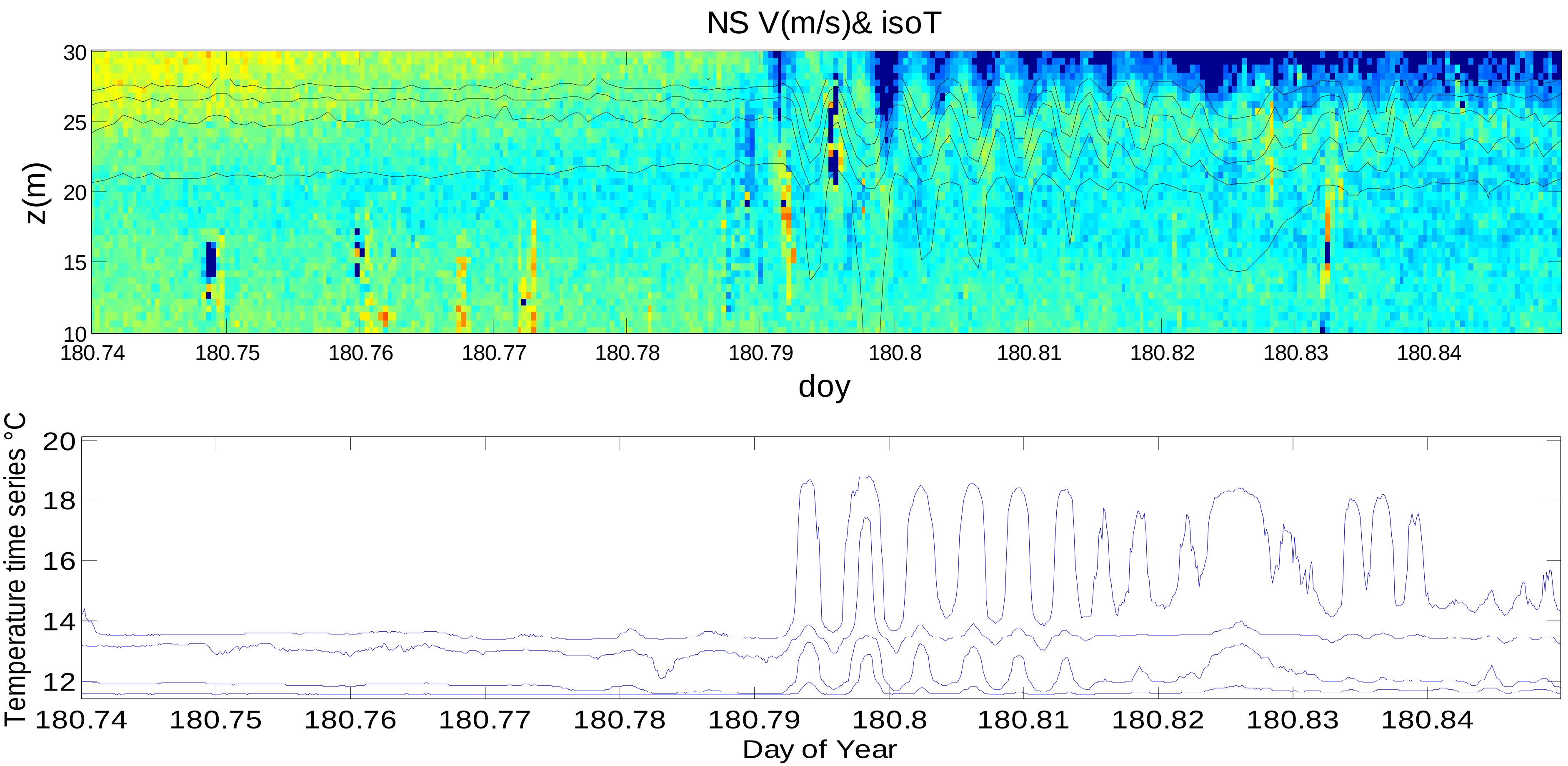
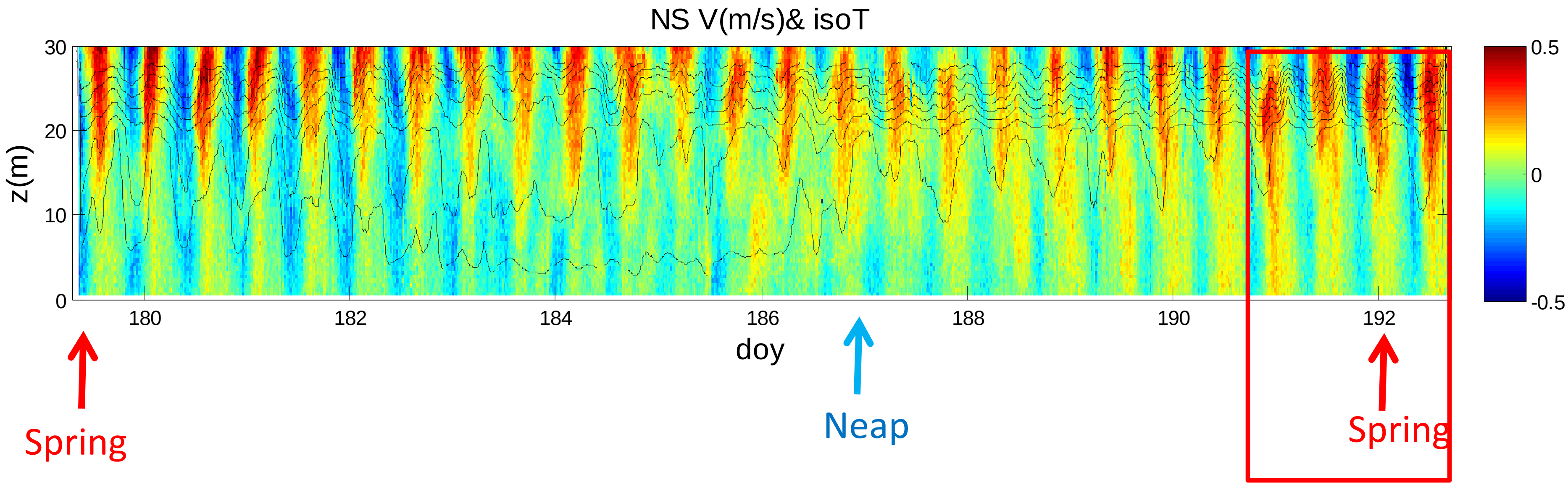
Solitary waves sequence

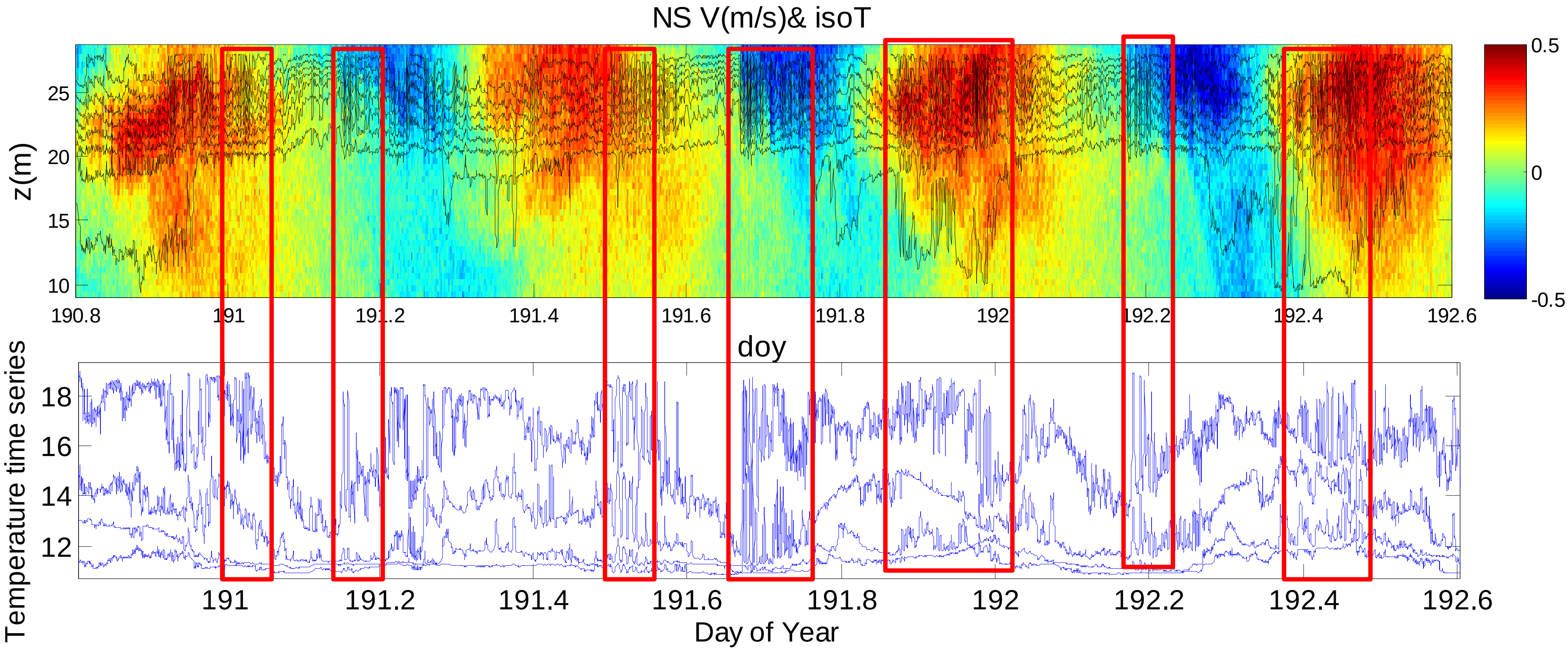


- Rank ordered sequence of solitary waves
- Korteweg de Vries mechanism (i-e nonlinear nonhydrostatic effect balance?)

Non linear SD Itide during 2nd spring tide



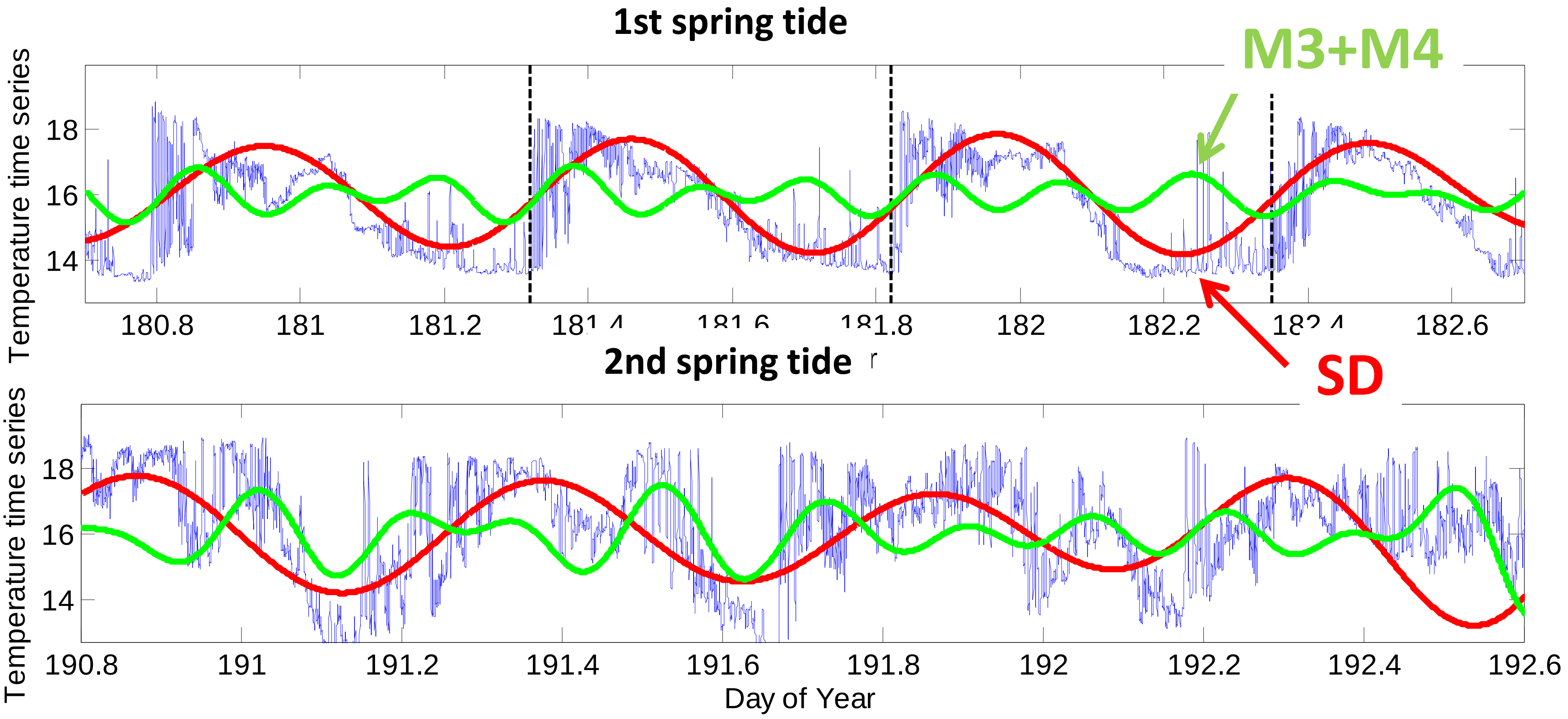
Non linear SD internal tide during 2nd spring tide



- Less marked internal fronts at the SD period
- high frequency waves generated at higher tidal harmonics periods

Comparison 1st spring tide /2nd spring tide

High frequency temperature time serie within the thermocline (15m depth)



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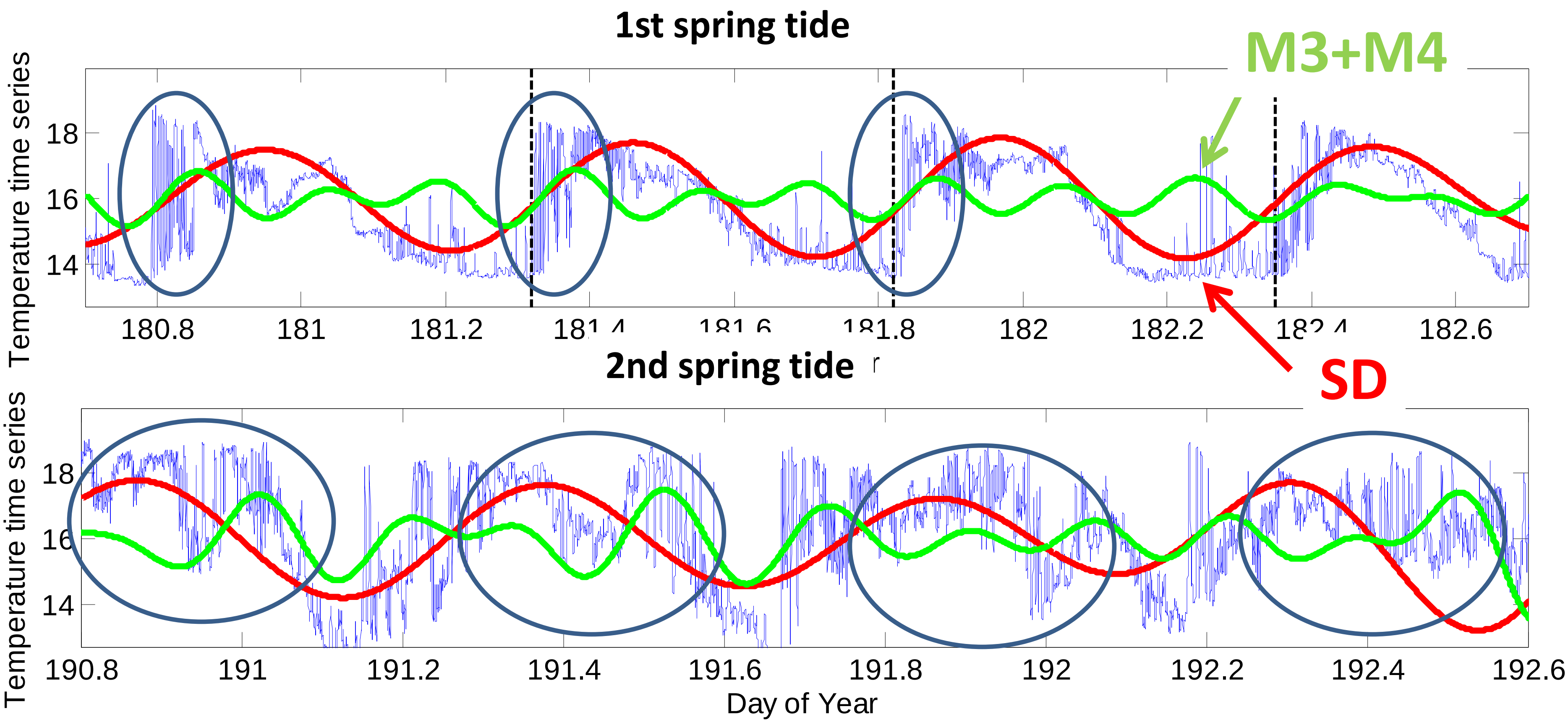
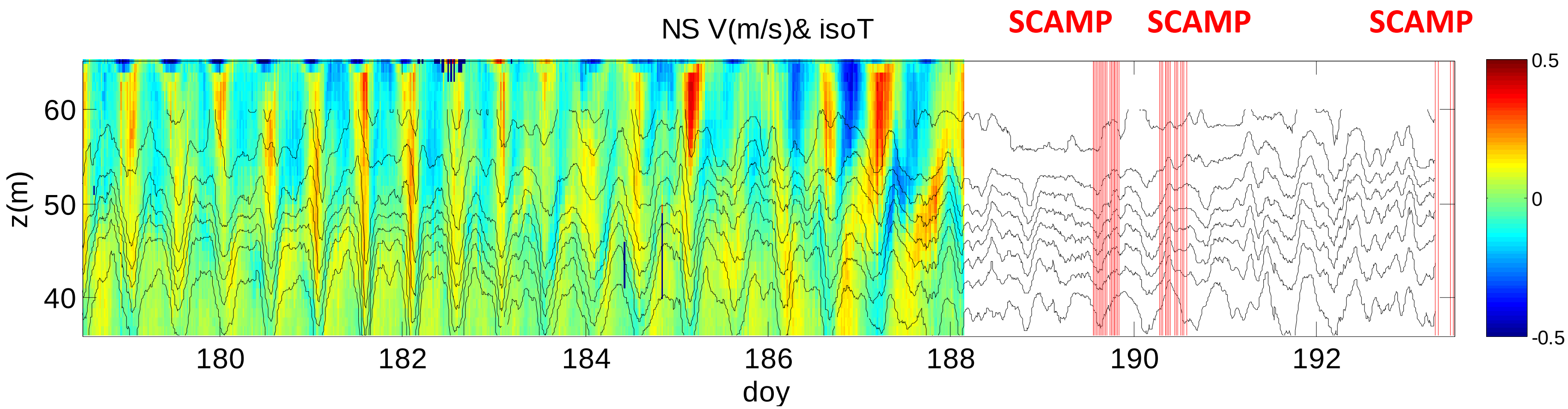


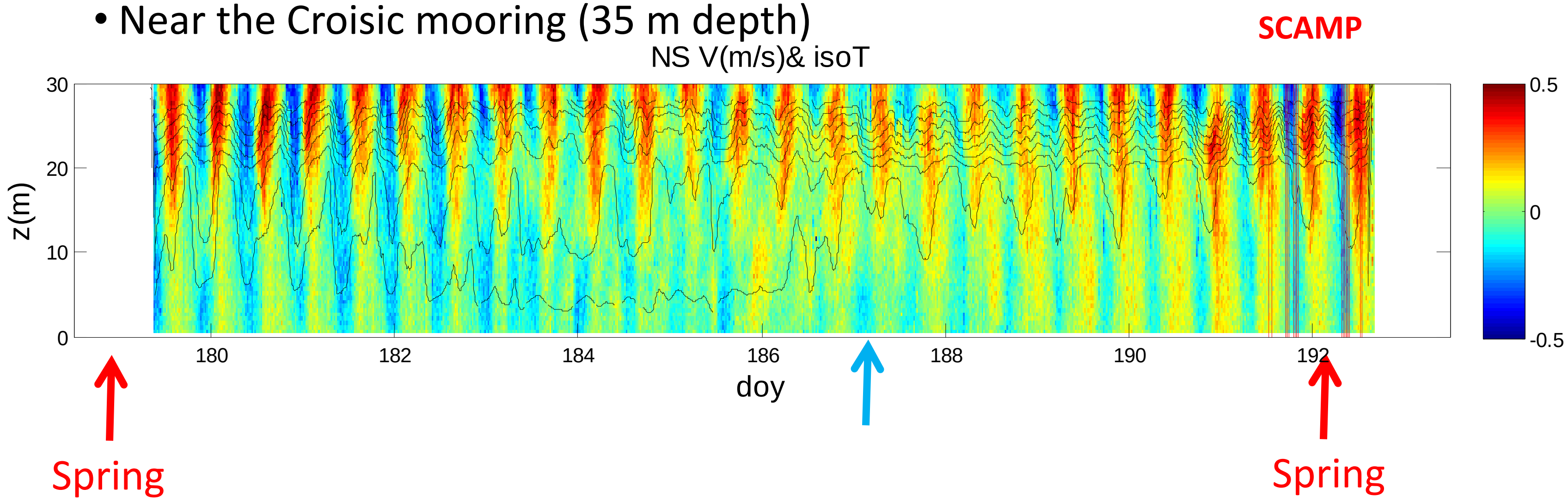
- During First spring tide SD (M2+S2) and higher harmonics (M3,M4) sum up to generate a very steep front and relatively high amplitude solitary waves
- During 2nd spring tide SD and M3,M4 are out of phase, each tidal harmonic generate frontal structure with high frequency waves of smaller amplitude

Dissipation from SCAMP temperature microstructure measurements

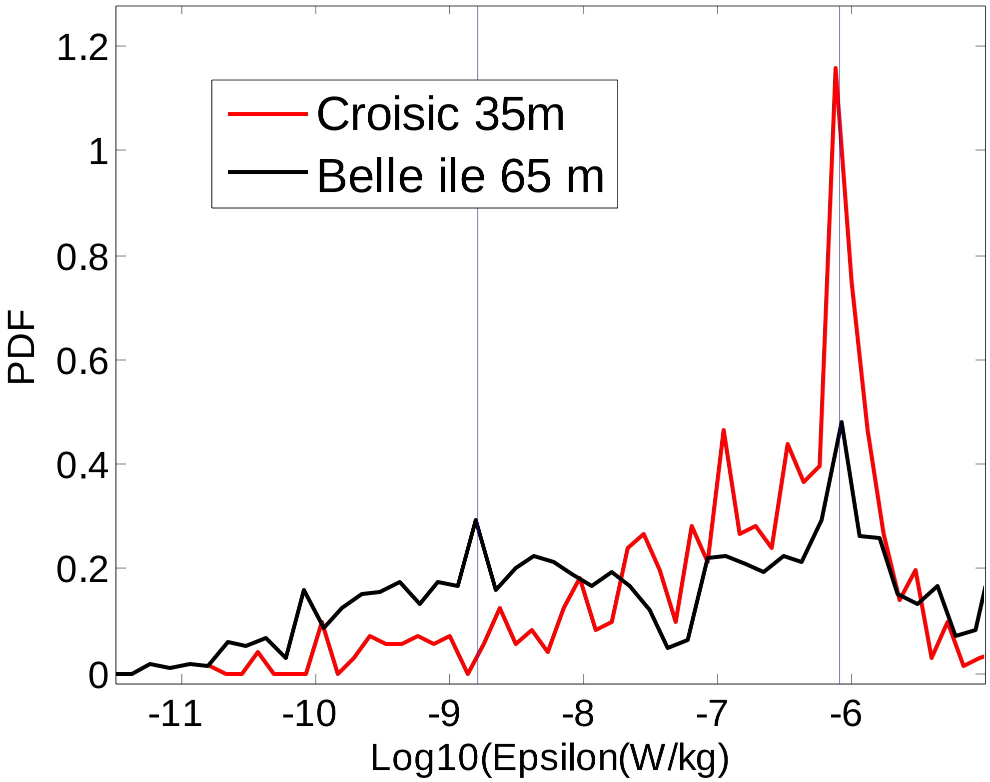
- Near the Belle ile mooring (70 m depth)



- Near the Croisic mooring (35 m depth)

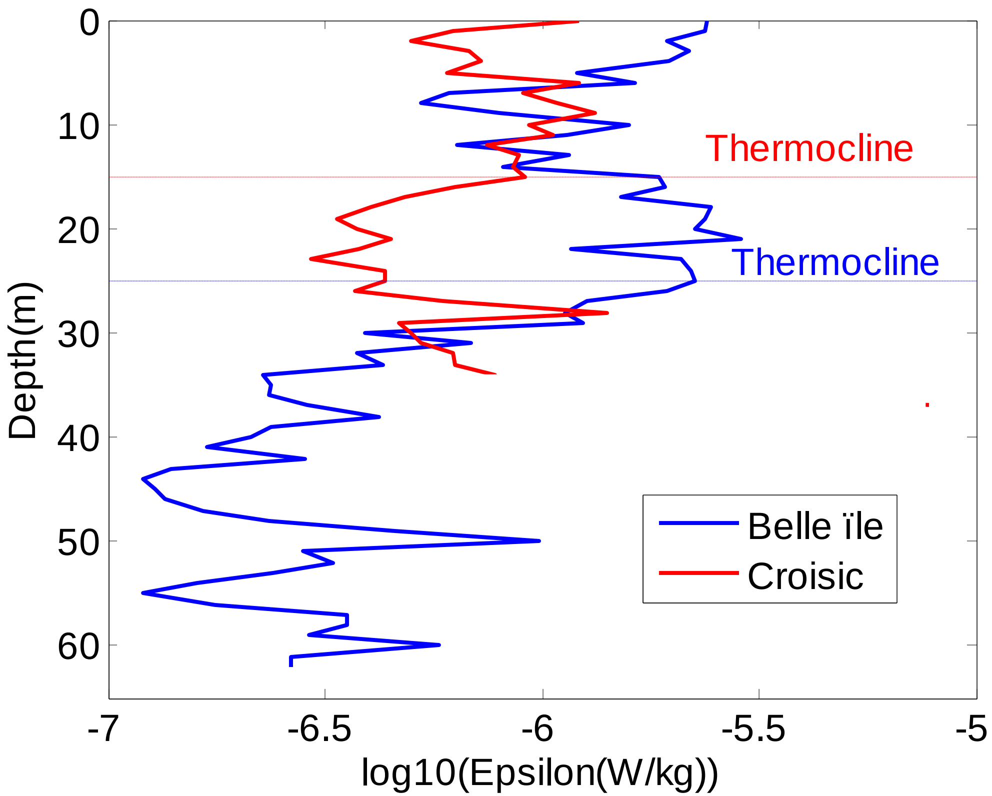


Dissipation PDF



- Very strong dissipation with a mode value of nearly 10^{-6} W/kg for both locations
- Measurements near Belle île show a second peak at weaker dissipation of 10^{-9} W/kg

Dissipation depth averaged profile



•Intensification of dissipation at the top of the thermocline notably at belle île where strong strain and overturnings where observed

•Surface and bottom intensification

Conclusion

•Strong non linear tides where oberved, with frontal structure and generation of high frequency waves packet:

•At the deeper mooring (Belle île) large strain and overturnings where observed in the thermocline. Coherent with microstructure measurements showing high dissipation in the thermocline

•During the stronger events high frequency waves at two frequencies where observed at 20-30 mn within the frontal structure and at 5 mn immediately following the front .
Different nature of these HF waves? influence of the strong change in background stratification and shear?

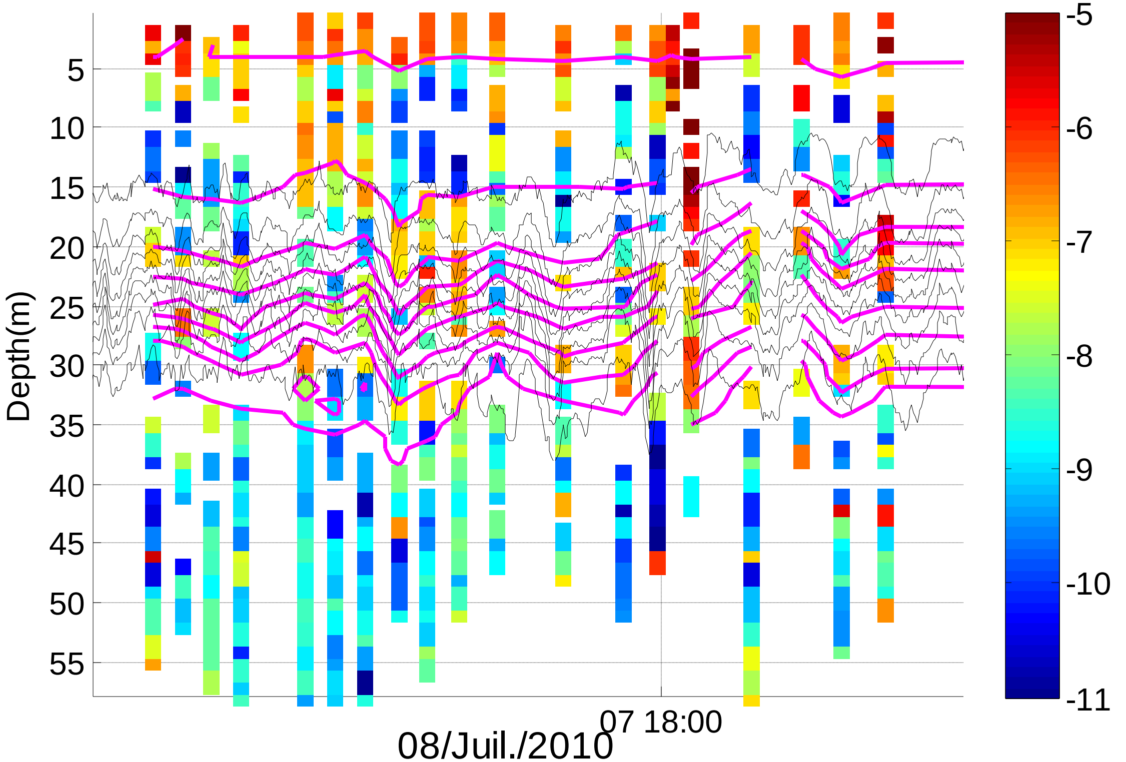
•At the shallow mooring , larger frontal structure and higher amplitude frequency waves where associated with in phase SD and higher M3, M4 tidal harmonics

Perspectives

- Modelling high frequency waves generation=>first attempt with KDV equation.

- Characterizing turbulent dissipation and mixing as a function of background internal wave field and particlulary the influence of high frequency waves

- Characterizing the impact of these processes on phytoplankton distribution and notably on the stability of fine layers.



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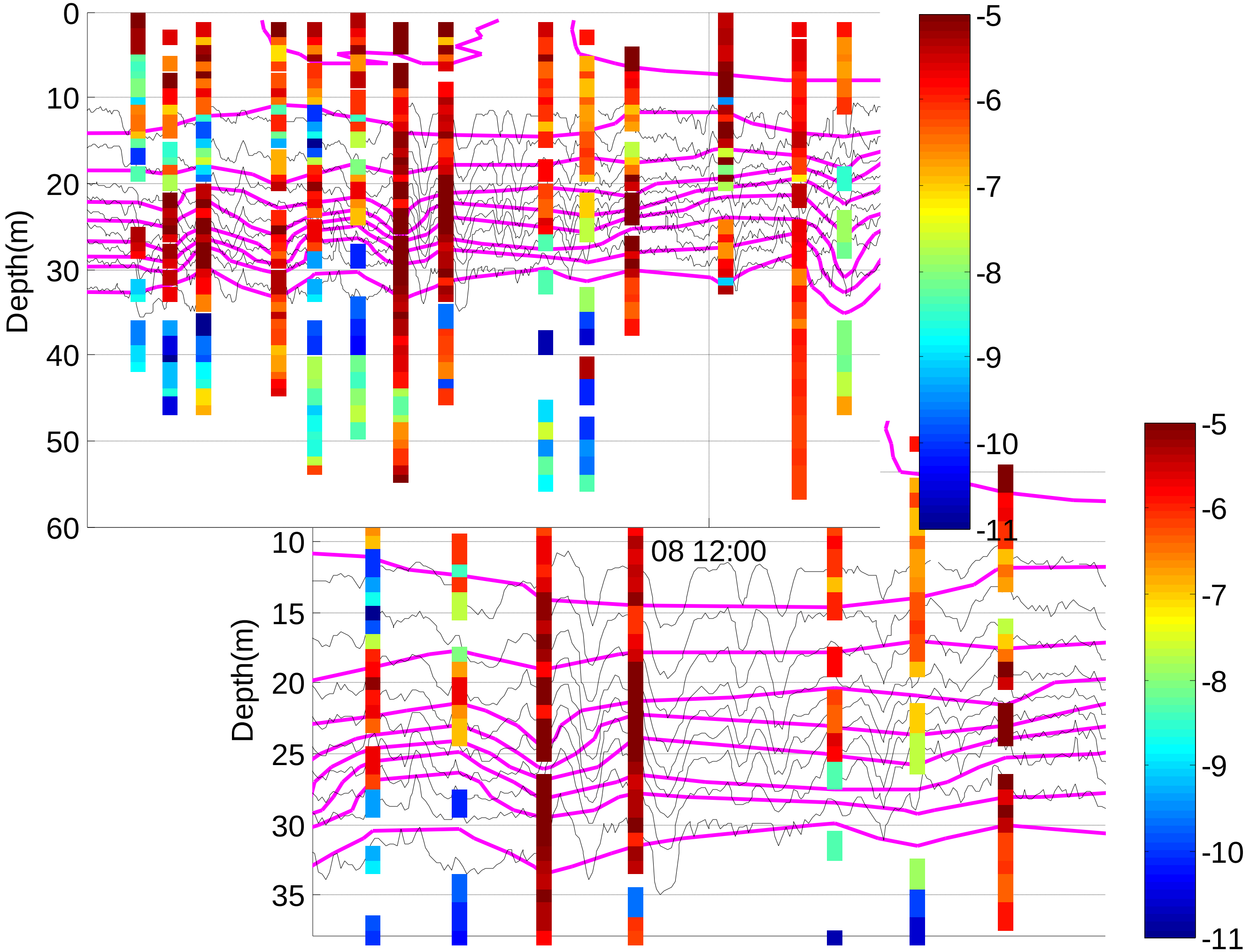

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