DISSIP : Dynamique de la marée Interne SouS Inertielle et Processus de dissipation

Yannis Cuypers[1], Pascale Bouruet Aubertot[1], Anda Vladoiu[1], Noé Lahaye[2], Jonathan Gula[2], Guillaume Roullet[2], Clement Rousset[1], Bruno Ferron[2], Fréderic Vivier[1].
LOCEAN-IPSL, Sorbonne University (UPMC, Univ Paris 06)-CNRS-IRD-MNHN, Paris, France
2 Univ. Brest, CNRS, IRD, Ifremer, Laboratoire d'Océanographie Physique et Spatiale (LOPS), IUEM, Brest, France

Journées GMMC Toulon 12-14 juin 2019

Abstract

The LEFE/CNRS DISSIP project (2018-2020) aims at characterizing the sub inertial internal tides dynamics that is for the most part M2 internal tides generated poleward of 74.5 (N/S) and K1 internal tide generated poleward of 30 °(N/ S). Sub inertial internal tide SiIT can not propagate freely in the ocean interior it is trapped at the bottom topography where it will either dissipate or propagate as topographic waves. SiIT has been shown to represent locally an important source of mixing for instance in the Kuril archipelago (Tanaka 2010) or in the Yermak plateau (Fer et al) 2016. At the global scale GCM have shown that as much as 30% of the diurnal tides was generated above its critical latitude (Muller 2013). Using linear wave theory and vertical normal mode decomposition Falahat and Nycander (2015), FN 15 hereafter were able to provide global maps of the sub inertial tide energy, yet their computation was restricted to a small topography assumption and required an hypothesis for a typical dissipation time scale. The DISSIP project uses available simulations and rich data set from previous projects (ANR OPTIMISM, LEFE/ STEP LEFE/GRAVILUCK ANR LUCKYSCALES) in 3 contrasted regions:

- An arctic fjord in Svalbard, where the high frequency variability is dominated by the ou la SIIT M2.
- The Sicily strait a turbulent hot spot in the Mediterranean sea where a large part of teh variability is associated with the SIIT.
- The Lucky Strike region of the Mid Atlantic ridge, which has constituted in the past years a natural laboratory for the observation of the internal tides dissipation (Polzin et al 1997, Pasquet et al 2016).

We show here the structure of the SiIT for these 3 sites from data and/or model and provide some comparisons with the FN15 parameterization and underline some limitations, we also show some preliminary results regarding idealized simulations which shall allow to get some further insights of the bottom trapped generation process and to improve the parameterization of bottom trapped internal tides .

3 contrasted sites for the Sub Inertial internal tides

Sicily strait	Lucky Strike	Storfjord Svalbard
H≅500m	H≅3000 m	H≅100m
Lat=37°24'N	Lat=31°-43°N	Lat=77°-78°N
$\omega_D = 0.82f$	$\omega_D = 0.74 - 0.84\ f$	$\omega_{M2} = 0.985f$
$R_\omega \cong$ 30km	$R_\omega \cong$ 60km	$R_\omega \cong$ 20km

$R_\omega \cong \frac{NH}{\sqrt{f^2-\omega^2}}$ pseudo Rossby radius

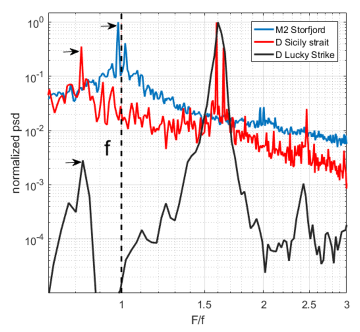
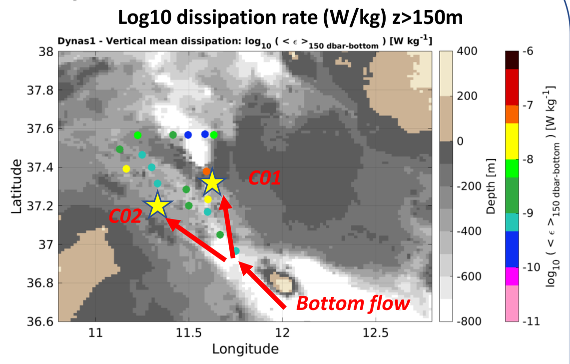


***Figure** Normalized Kinetic energy spectrum for the 3 sites The sub-inertial component is indicated by an arrow*

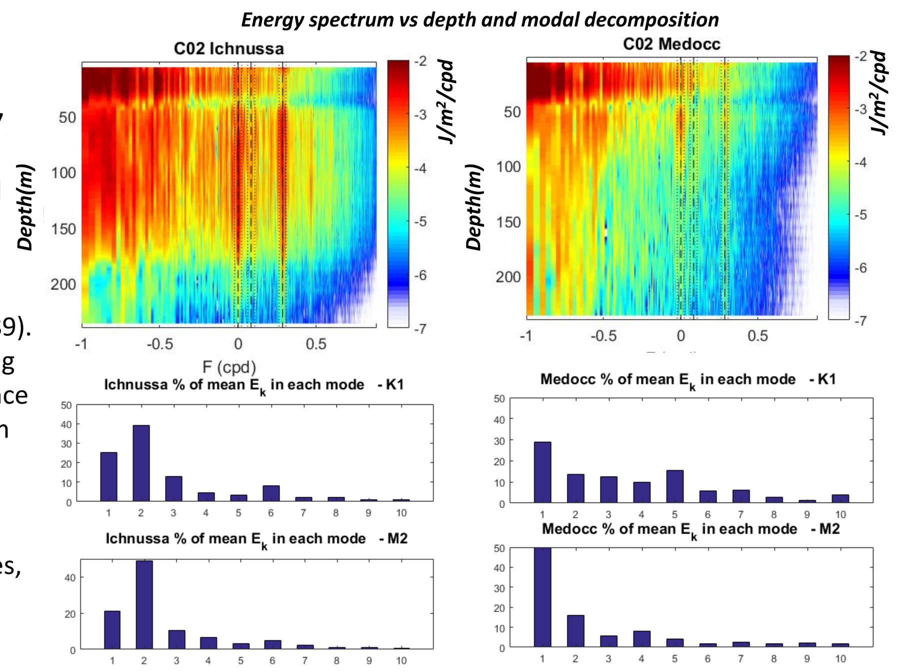
Sub-Inertial diurnal internal tide in the Sicily strait

Long term monitoring along two passages North and South (collaboration ISMAR) JERICHO NEXT DYNAS project
-C01mooring (500m) ADCP Δz=16m , Δt=2h
16 /11/2012-01/04/2014 and 05/18-03/19
-C02 mooring (550m) avec ADCP Δz=4m , Δt=2h
16 /11/2012-07/08/2015 and 05/18-03/19
Field campaign CTD/LADCP microstructure (turbulence):VENUS 7 /06/2013, ICHNUSSA 18/10/2013, MEDOCC 2-6/04/2014, EMSO 28/06/2014, DYNAS 1 &2 May 2018 sept 2018

Log10 dissipation rate (W/kg) z>150m



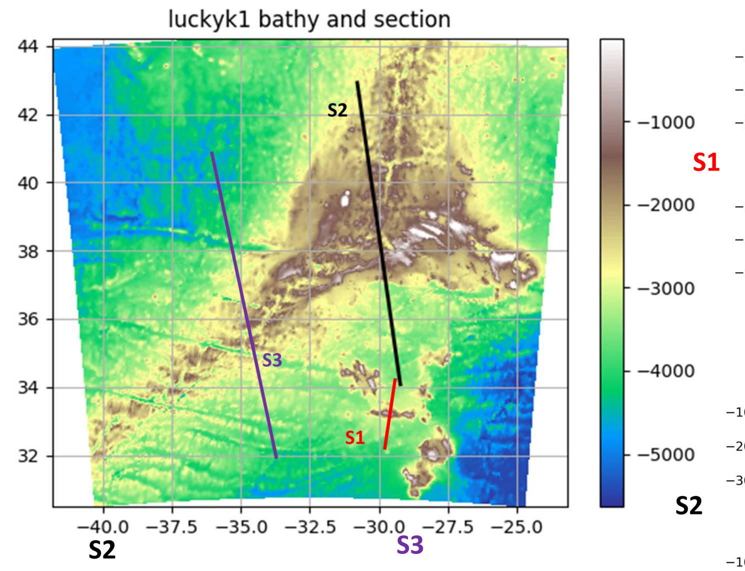
Energy spectrum vs depth and modal decomposition

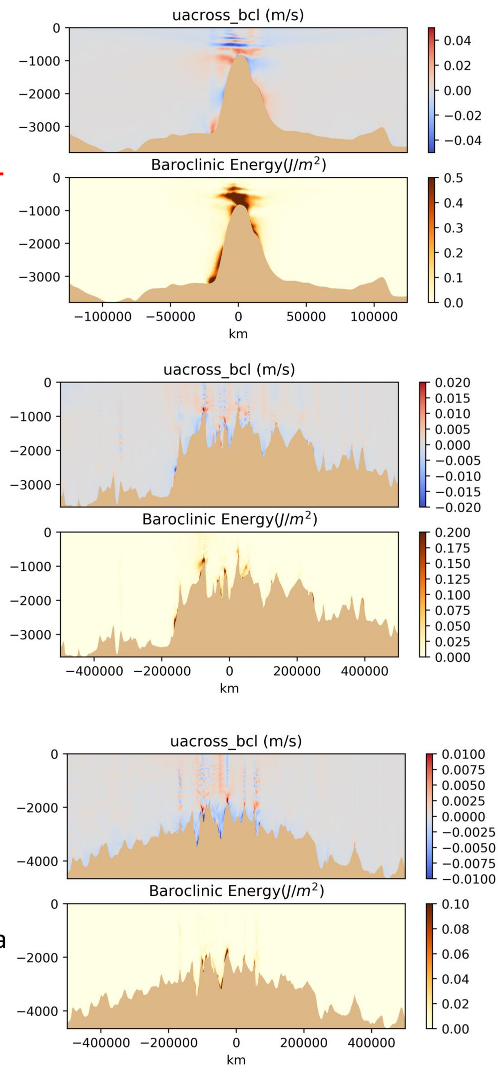


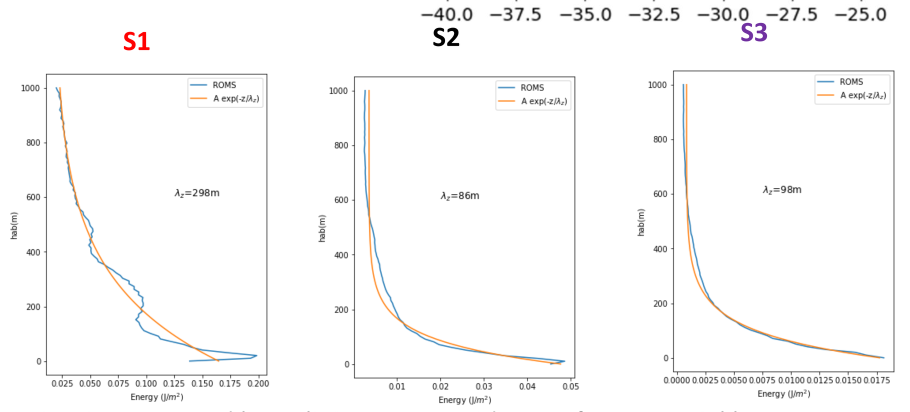
- Sicily strait is hot spot of dissipation (Ferron et al, 2017 Vladoiu et al 2018).
- Evidence of enhanced diurnal K1 internal tide suggesting propagation and resonance along the Talbot bank as suggested by Artale et al (1989).
- Internal tides enhanced during autumn (Ichnussa), no evidence of bottom trapping, maximum energy is found in the pycnocline.
- K1 internal tides are characterized by higher modes, than M2=>Higher dissipation expected

Lucky Strike: High resolution simulation of the sub-inertial K1 tidal component

High resolution ROMS simulation with 80 sigma vertical levels , 1/128° forced by K1 component and no circulation. Details on 3 sections crossing rough topographic features (S1, S2, S3) .



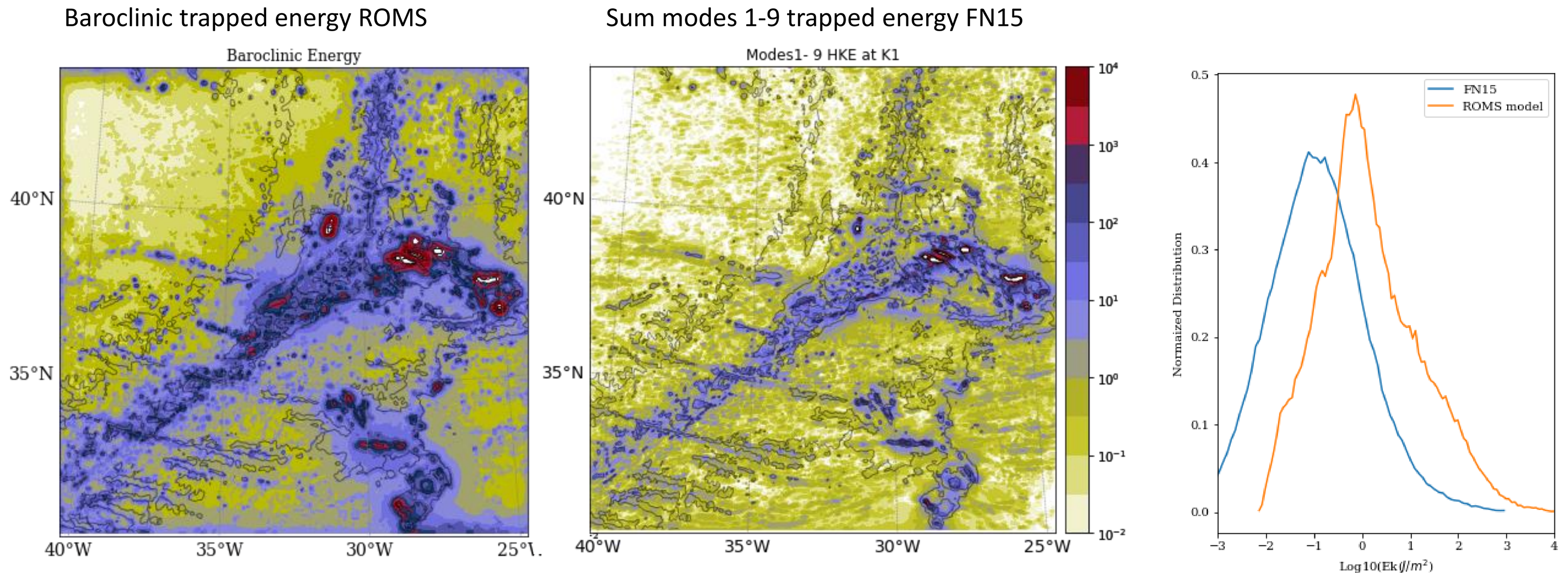




Section averaged baroclinic energy, evidence of exponential bottom trapping over up to a few hundreds of m above the bottom, smaller scale topography of S2 and S3 associated with faster decrease, consistent with $\exp(-kR_\omega\tilde{z})$ form (k horizontal wavelength, with $R_\omega \cong \frac{NH}{\sqrt{f^2-\omega^2}}$ (pseudo Rossby radius)

Lucky strike: K1 Internal tide energy: prediction from FN15

Baroclinic trapped energy ROMS   Sum modes 1-9 trapped energy FN15



FN15 formulation: linear wave theory and vertical normal-mode decomposition in an ocean of finite depth in the weak topography assumption => map of the baroclinc sub-inertial energy:

$$E(x,y,t) = \frac{1}{2}\rho_0 \int_{-H}^{0} (u^2+v^2+N^{-2}b^2)\,dz$$
$$= \frac{1}{2}\rho_0 \sum_{n=1}^{\infty} \frac{c_n}{|f|}(u_n^2+v_n^2+c_n^{-2}p_n^2),$$

Each vertical mode n is characterized by an energy trapped horizontally with a typical scale equal to the pseudo Rossby radius $R_n = \frac{c_n}{\sqrt{f^2-\omega^2}}$ (c_n vertical mode speed)

The structure of FN15 is correct but there is a clear gap in the energy level: what are the important missing processes?

- Non linearity
- Non–weak topography
- Dissipation
- 3D resonance of horizontally propagating bottom trapped waves

=> Idealized simulations are needed

Références

- **FN15** Falahat, S., & Nycander, J. (2015). On the generation of bottom-trapped internal tides. Journal of Physical Oceanography, 45(2), 526-545.
- Fer, I., Müller, M., & Peterson, A. K. (2015). Tidal forcing, energetics, and mixing near the Yermak Plateau. Ocean Sci., 11, 287–304.
- Ferron, B. , P. Bouruet Aubertot , Y. Cuypers , K. Schroeder, and M. Borghini, 2016: Dissipation rates, mixing, geothermal heating and the overturning circulation of the Western Mediterranean Basin, in rev for Geophys. Res. Lett.
- Müller, M. (2013). On the space and Time dependence of barotropic to baroclinic tidal energy conversion. Ocean Modelling, 72, 242252.
- Tanaka, Y., Hibiya, T., Niwa, Y., & Iwamae, N. (2010). Numerical study of K1 internal tides in the Kuril straits. Journal of Geophysical Research: Oceans, 115**(C9).**
- Vladoiu, A., Bouruet-Aubertot, P., Cuypers, Y., Ferron, B., Schroeder, K., Borghini, M., ... & Ismail, S. B. (2018). Turbulence in the Sicily Channel from microstructure measurements. Deep Sea Research Part I: Oceanographic Research Papers, 137, 97-112.

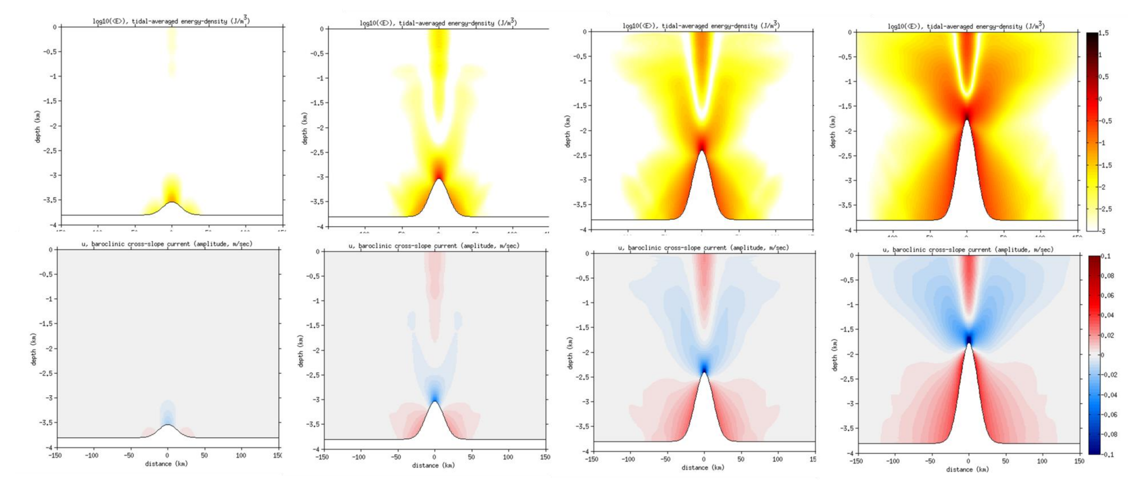
Trapped K1 tides around a gaussian ridge comparison between FN15 and idealized internal tides model

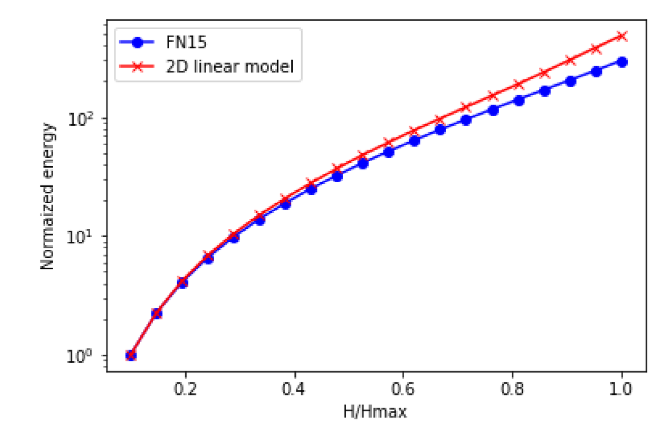
2D Linear model

We use Theo Gerkema 2D model (Gerkema 2002) which is linear but not restricted to the weak topography approximation for a gaussian ridge fitted to the S1 ridge section. We let the height of the ridge vary between 0.1Hmax and Hmax, where Hmax=2662m is the fitted gaussian height and compute the baroclinic energy for FN15 and the 2D linear model.

We observe a rapidly increasing baroclinic energy with increasing ridge height (for constant barotropic flux). We observe that FN15 energy follows closely the 2D tidal up to H=0.5Hmax.

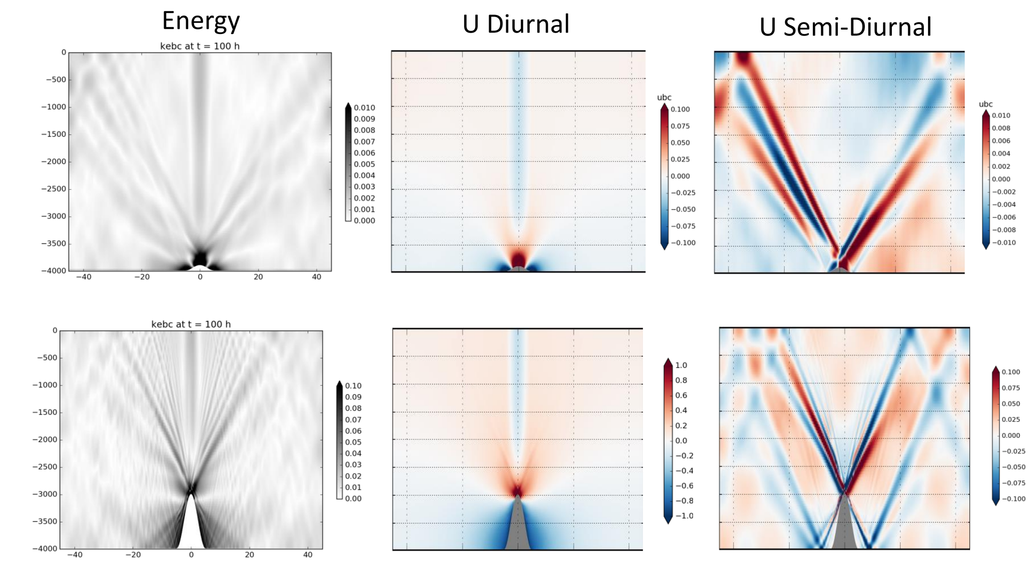
=>The weak topgraphy assumption does not appear to represent a major issue

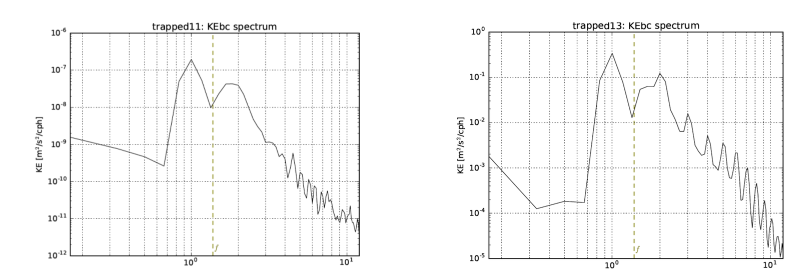




2D non linear model using CROCO code (work in progress)

A first serie of nearly invisicd fully non linear simulations at the K1 frequency was undertaken with a 1cm/s barotropic flow and open boundary conditions, a part of the energy is transfered to higher harmonics (Semi-Diurnal, Quarter diurnal) the transfer increase with the ratio H/Hmax and nonlinearity.
Next simulations will investigate the impact of the dissipation and height H/Hmax, ratio $R_\omega = \frac{NH}{\sqrt{f^2-\omega^2}}$ and will be compared with FN15. The final step will be to investigate the resonance of trapped waves in 3D configuration.





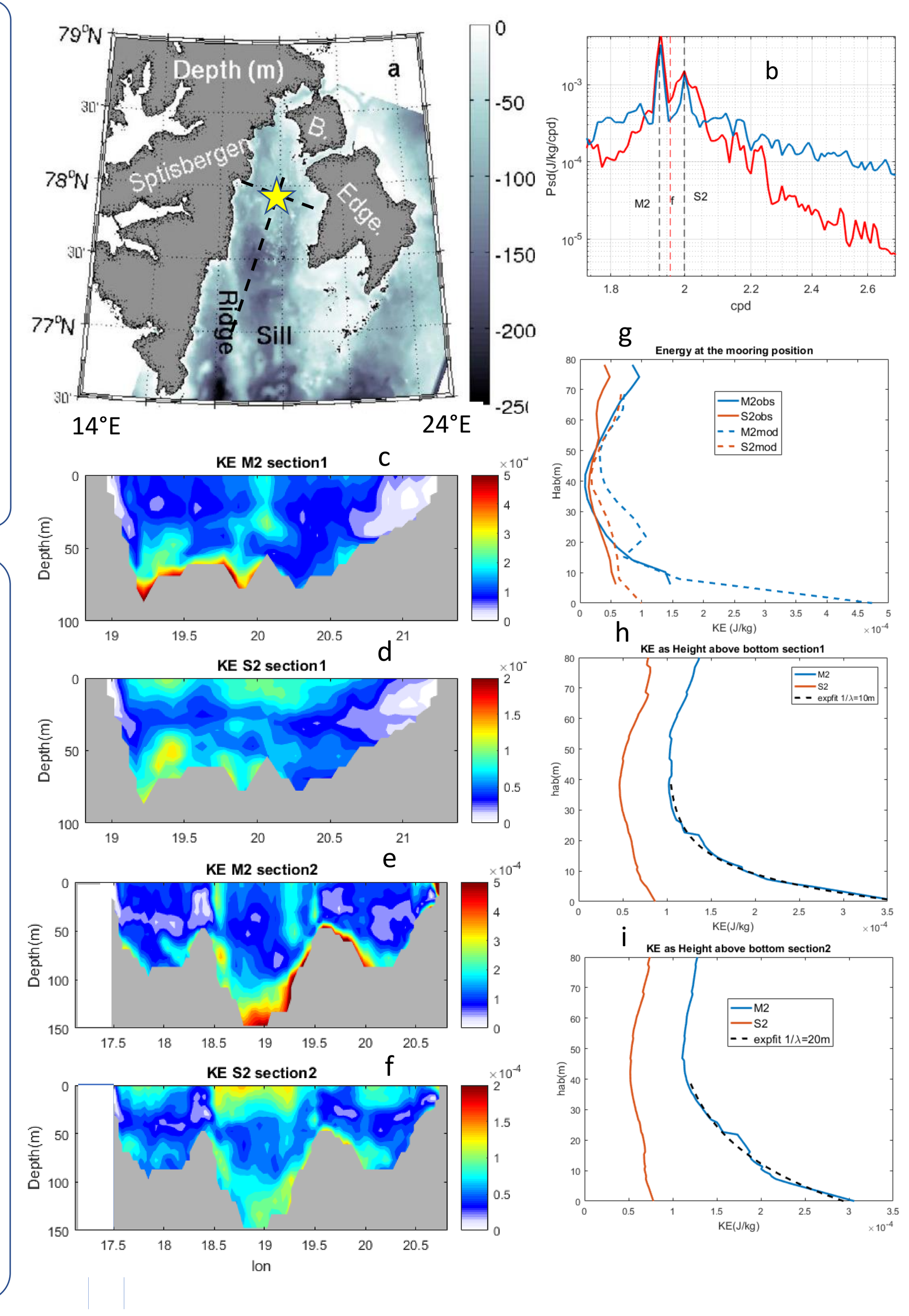
Sub-inertial internal tides in the Storfjord Svalabard

Dataset: Mooring in the northern part (Fig.6a) (87 m) ADCP: Δz=4m, Δt=12mn from august 2011 to august 2013, T,every 5 m S every 25 m.

Model NEMO 1/36° 75 vertical levels (Rousset et al 2016). Tidal forcing and for the atmosphere, ice dynamics LIM3.

One year analysis: Aug 2011-Aug 2012 : good agreement for the baroclinic energy at M2 between data and mooring (b), qualitative agreement for the baroclinic energy profile for M2 and S2 (g).

Bottom trapping of the M2 sub-inertial tide (c,e) with a 10-20 m decay scale over the 2 sections, no trapping of the super-inertial internal tide S2 (d,f).



Conclusions

We have shown preliminary results from observations and/or simulations regarding sub-inertial internal tides energy level and spatial structure in 3 contrasted regions in terms of depth, sub-inertial internal tide intensity and ratio ω/f .

- The simulation (ROMS 1/128° K1 forced only) analyzed over Lucky Strike section show the trapping of K1 internal tide energy with an exponenatial decay over rough topographic features with typical vertical and horizontal scales of ~100s m and ~10kms respectively, consistent with the linear theory. The GCM formulation of FN15 is tested to estimate the baroclinic energy and shows an overall good agreement for the spatial structure but a strong underestimation of the mean energy level. Idealized simulations are in progress to better understand the generation and dissipation mechanism of the sub-inertial tides and improve its parameterization for GCM.
- In-situ observations in the Sicily strait shows enhanced trapped diurnal internal tide with relatively strong dissipation rate along the slope suggesting resonance process along the Talbot bank. No bottom trapping is observed. Analysis of the NEMO eNATL60 (1/60°) model runs hourly output is under progress to get further insight this process.
- Analysis of the Storfjord simulations NEM0 1/36° shows bottom trapping of the M2 sub inertial internal tide which is the dominant high frequency signal in this region. Model runs are in relatively good agreement with observations at the mooring position. Work is in progress regarding the impact on the dissipation rate in the model and in the observations

3 sites contrastés pour la Marée Interne Sous Inertielle

Detroit de Sicile	Secteur Lucky Strike	Storfjord Svalbard
H≅500m	H≅3000 m	H≅100m
Lat=37°24'N	Lat=31°-43°N	Lat=77°-78°N
$\omega_D = 0.82f$	$\omega_D = 0.74 - 0.84\,f$	$\omega_{M2} = 0.985f$
$R_\omega \cong 30$km	$R_\omega \cong 60$km	$R_\omega \cong 20$km

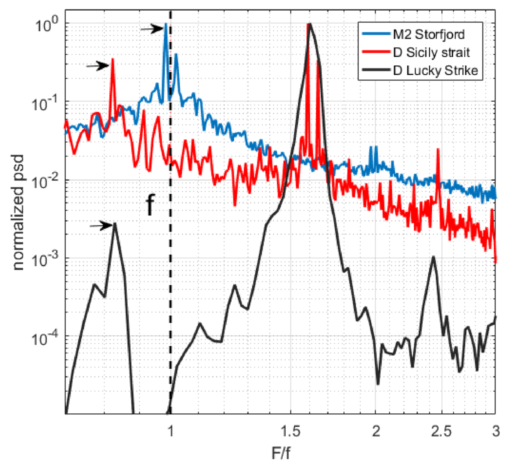
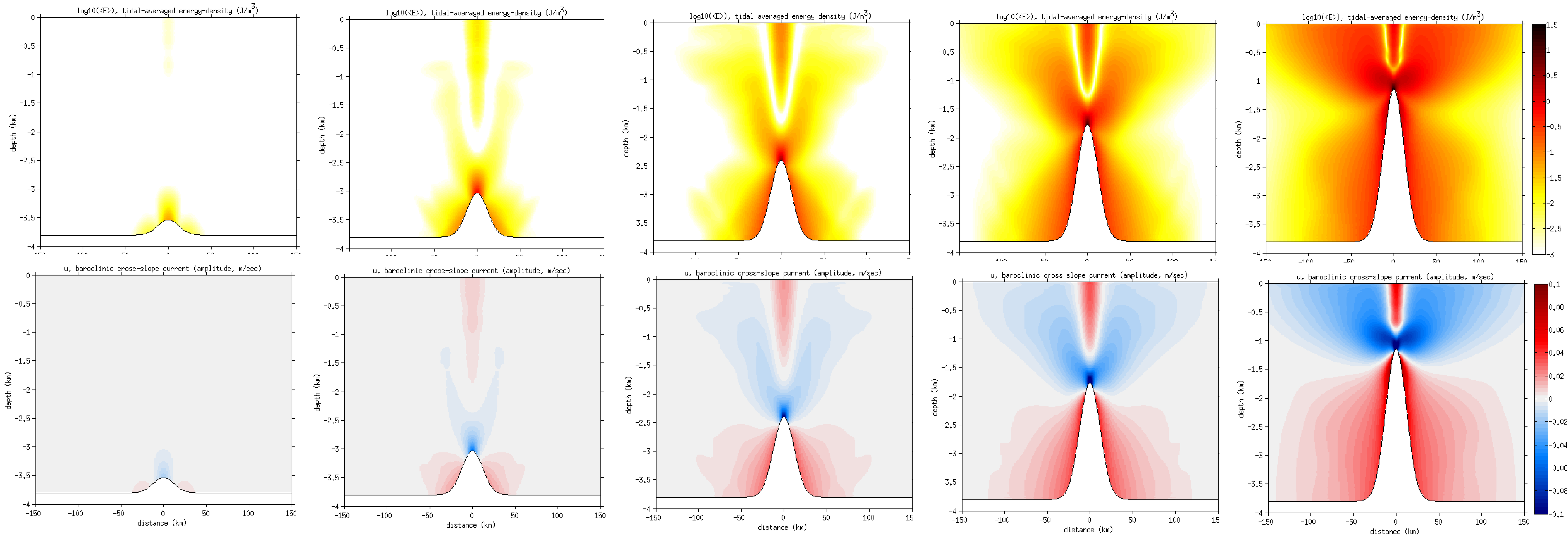
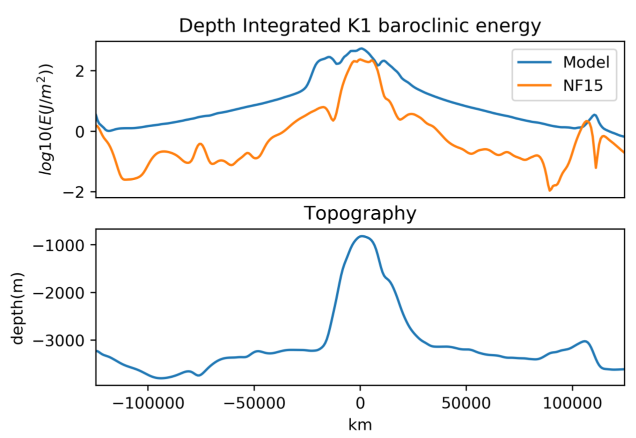
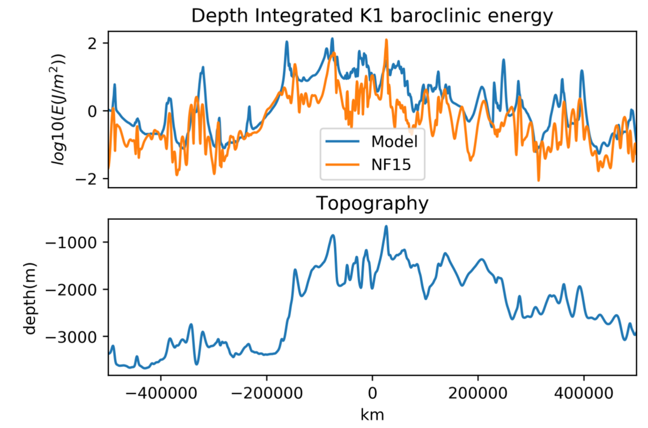
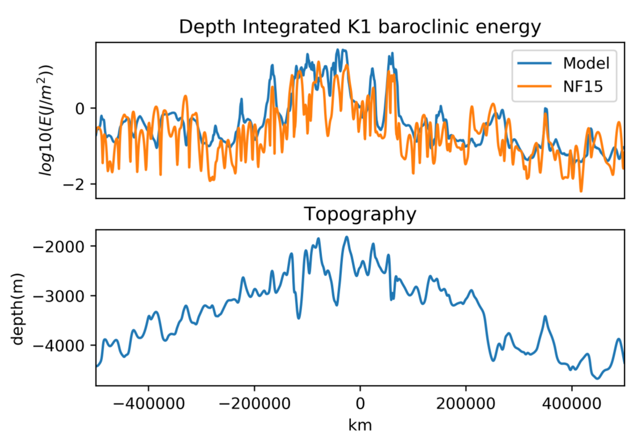


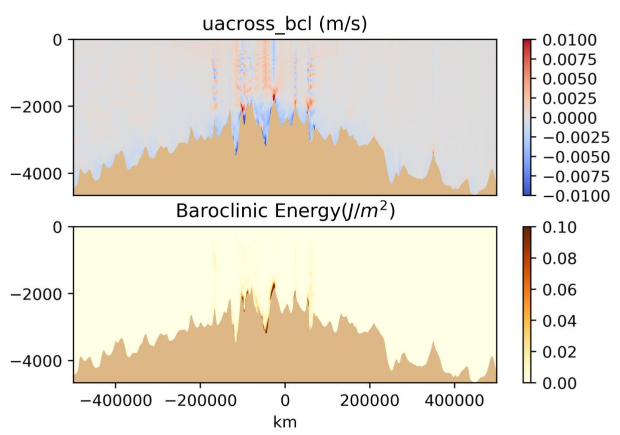
Figure 2 *Spectres d'energie cinétique barocline normalisés pour chacun des 3 sites. La composant sous inertielle étudiée est indiquée par une flèche*

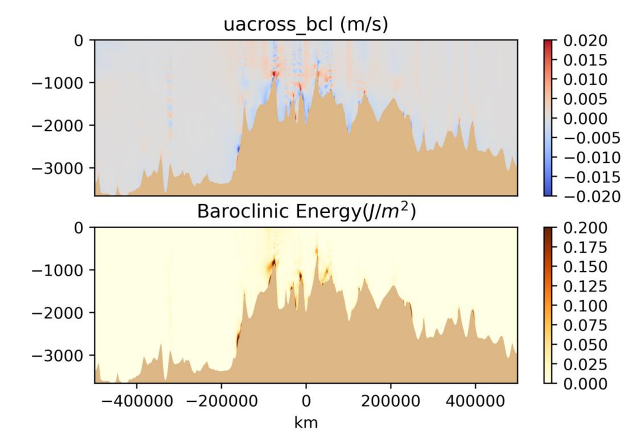


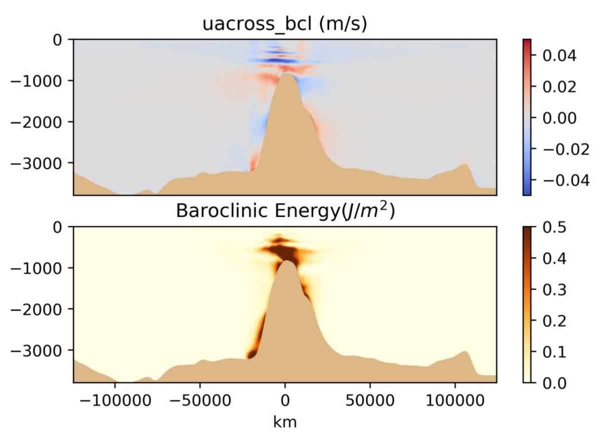


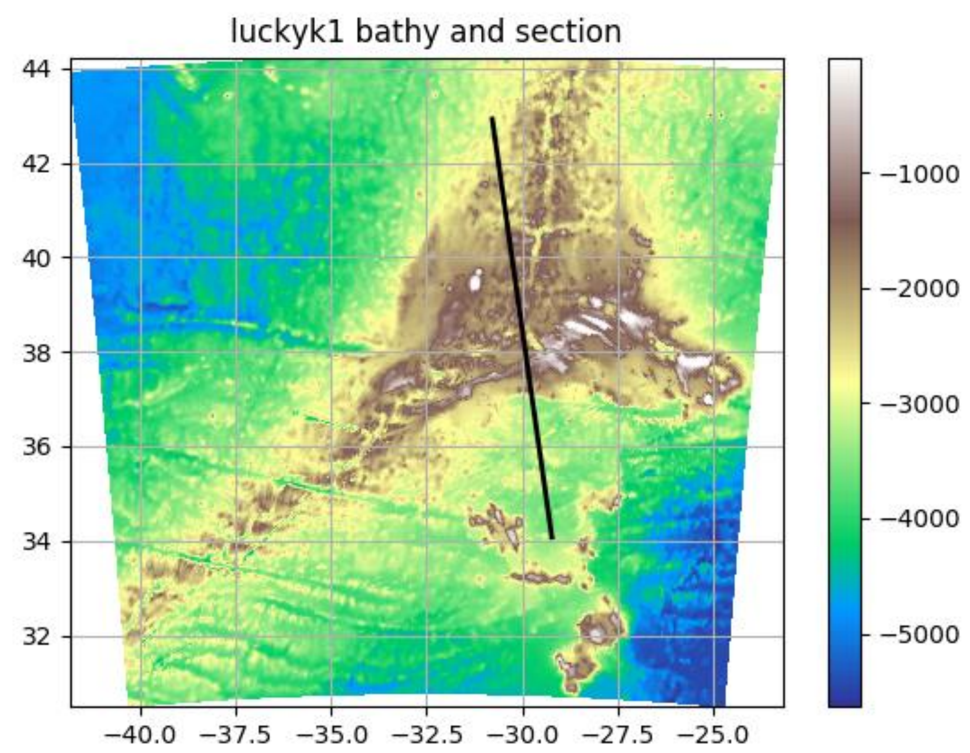











luckyk1 bathy and section
44
42
40
38
36
34
32
−40.0
−37.5
−35.0
−32.5
−30.0
−27.5
−25.0
−1000
−2000
−3000
−4000
−5000