TNA PROJECT REPORT

1. Project Information

Proposal reference number	JN_CALL_2_13
Project Acronym (ID)	DYNAS
Title of the project	Dynamics and turbulence in the Sicily channel
Host Research Infrastructure	Sicily Channel Observatory (SiCO)
Starting date - End date	20/05/2018 - 04/04/2019
Name of Principal Investigator **Home Laboratory** **Address** **E-mail address**	Pascale Bouruet-Aubertot Université Pierre et Marie Curie (UPMC)- Laboratoire d'Océanographie et du Climat (LOCEAN) BP100- 4 Place Jussieu 75252 Paris Cedex 05, France pascale.bouruet-aubertot@sorbonne-universite.fr
User group members	Pascale Bouruet-Aubertot, Anda Vladoiu, Yannis Cuypers Sorbonne Université, France Bruno Ferron, Olivier Peden LOPS UMR 6527, France

2. Project objectives

The Sicily Strait is a key region crossed by different water masses exchanged between the Eastern and Western Mediterranean basins. It is also a very dynamical area characterized by meso and submesoscale processes with a strong variability and internal wave activity. Nevertheless the turbulence induced has been only characterized recently with the first in-situ microstructure measurements performed by our group during five cruises over two years (2013-2014) revealing that the Sicily channel is a hotspot for turbulence. Implementing additional measurements of temperature and conductivity along the mooring lines as well as high frequency velocity measurements close to the bottom will allow us to get insights on the impact of turbulence in local water mass transformation with indirect estimates from the mooring measurements provided that the inertial subrange is resolved (Lorke and Wüest, 2005). The ultimate ambitious goal is to get a vision on scale interactions with the quantification of energy transfers (bi-spectral analysis) and how they modulate the transport in the Sicily channel. Another related objective is to take benefit of the cruises to perform additional turbulence measurements along the main branches of the deep flow.

We plan also to use these observations for numerical model comparison and validation with improved parameterization in realistic numerical models and focus on the impact on internal tide mixing and nonlinear processes of higher frequencies. Also we may perform idealized numerical simulations with Daniel Bourgault's high resolution numerical model (Bourgault, D., and Kelley, D. E., 2004) along C01 section to help the interpretation of in-situ measurements.

The activity described in this report has received funding
from European Commission's H2020 Framework Programme
under JERICO-NEXT project, grant agreement No. 654410.

3. Main achievements and difficulties encountered

The aim of our participation to the two cruises was to perform additional microstructure measurements with the VMP in the Sicily channel and to deploy additional sensors (Fast temperature sensors, additional CTD sensor, high resolution 1200 kHZ ADCP) along the two mooring lines part of the Observatory. The two legs took place onboard Dalla Porta research vessel.

Leg1 (20-28/05/2018): the additional instruments were clamped on the mooring as scheduled under good weather conditions and 17 microstructure profiles were performed, half less than scheduled initially (see Leg1 cruise report)

Leg 2 (19-28/09/2018): because of bad weather conditions the ship had to remain most of the time in harbour and the work at sea was conducted during one day Sept.23rd, C01 mooring, which has surfaced a couple of weeks before the cruise and already recovered, was deployed without a few sensors whose connectors were broken and the maintenance of C02 mooring was performed. In the meantime, two VMP profiles were performed (see Leg2 cruise report).

Mooring CO1 was recovered by the Italian team in April 2019 but not mooring CO2 because of bad weather conditions. The remaining data from CO2 will be recovered in the following weeks and they will be transferred as soon as possible when the instruments will be sent back to LOCEAN and LOPS.

Most of the sensors worked well except a few ones because of battery deficiency.

To conclude this JERICO-NEXT project has been conducted successfully with a fairly good sampling of the water column at C01 and C02, except in the surface layer, and the microstructure measurements collected provide a real added value. The data collected are under process to get further insights on high frequency dynamical processes in the Sicily strait. This report is thus very preliminary but the analysis of the dataset collected is a long-term research work as detailed in the following.

4. Dissemination of the results

A poster presentation was shown last July at the JERICO-NEXT meeting in Brest.

The additional turbulence measurements collected during the two cruises will be integrated to the dataset of turbulence measurements presently under-process in a manuscript on the variability of mixing efficiency in the Western Mediterranean Sea, to be submitted within a month approximately ("Contrasted mixing efficiency in turbulent versus quiescent regions: insights from microstructure measurements in the Western Mediterranean Sea" Vladoiu et al, 2019, in preparation).

We plan to investigate the variability of the high frequency dynamics based on the mooring data and to publish these results as soon as possible.

In the meantime we plan to start to analyze hourly outputs from the NEMO numerical simulations at 1/60° from the NEMO eNATL60 experiment, with two configurations, with/without tidal forcing in collaboration with colleagues from IGE in Grenoble (**https://ocean-next.fr/expertise/natl60/**). The purpose of the manuscript will focus on the ability of the model to reproduce the high frequency dynamics and also estimate its relevance regarding the parameterization of turbulent mixing and to get some insights on the dynamics of the trapped diurnal internal tides.

The diurnal tide, which is sub-inertial at the Sicily channel, is evidenced from the mooring observations. This suggest a possible local resonance that we plan to further investigate and address the question of the parameterization of bottom trapped internal tides. This work is under present investigation (poster communication in Toulon, June, 2019, Cuypers et al).

Eventually, as scheduled, we plan to conduct non hydrostatic numerical simulations focused on the most turbulent constricted northern passage (C01 location) to help the interpretation of the measurements and the development of a parameterization, ideally this work should lead to a publication.

5. Technical and Scientific preliminary Outcomes

This document presents very preliminary results obtained from the datat collected during the DYNAS project. Two points are mentioned in the following : the turbulence measurements collected along the two deep flow branches and some spectral analysis performed focusing on high frequencies.

Turbulence measurements :

The only turbulence profiles collected prior to the project were obtained at C01 and C02. Turbulence profiles collected during DYNAS-Leg 1 provide for the first time an overview of the turbulence in the channel (Figure 1a and 1b) while the two profiles collected during DYNAS-Leg 2 support the findings from 4 previous cruises (Figure 1c), namely an intense dissipation in the lower layer at C01 (Vladoiu et al, 2018). Figure 1 shows the depth averaged dissipation rate in the 20-150dbar surface layer (left) and in the 150dbar-bottom layer (right). While subsurface dissipation rates are relatively homogeneous and moderately intense (~10^{-8} W.kg^{-1}), dissipation rates are contrasted at depth with enhanced turbulence at C01 and upstream. These measurements confirm that the deep flow branch passing through C01 is the most active one.

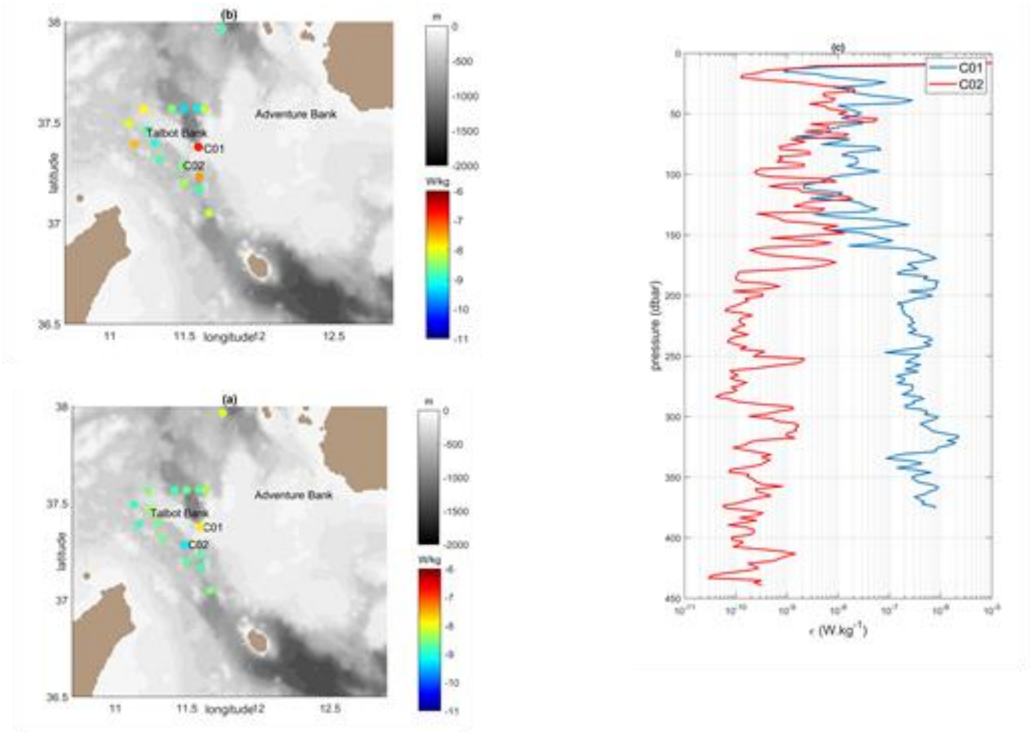

Figure 1 : Depth-averaged dissipation rate (log scale, W.kg-1) during DYNAS between 50 and 150dbar (a) and below 150 dbar (b); Dissipation rate (log scale) at C01 (blue) and C02 (red) collected during leg 2 (c).

<u>Dynamics at high frequencies : focus on tidal frequencies</u>

The ADCP, long range and short range, deployed at C01 was chosen to illustrate here the variability during late spring and summer 2018. The general features of the dynamics are well-known, with a meridional velocity larger in absolute value than the zonal velocity, a significant variability at temporal scales of a few weeks/days associated with the mesoscale dynamics and tidal fequency peaks. The inertial peak is remarkably non-existent while both semi-diurnal and diurnal tidal frequencies are observed (Figure 2). The absence of energy at near-inertial frequency in spite of the fairly strong atmospheric forcing suggests a dissipation mechanism coming into play in the surface layer. This point was not addressed in the absence of ADCP measurements in this surface layer. The semi-diurnal tidal constituent is on the other hand a main component of the dynamics as well as, to a lower extent, the diurnal constituent (Figures 2 and 3). The M2 constituent is especially large in the deep layer (Figure 3a) while the K1 constituent is intensified around 200m depth (Figure 3b). The relative contributions of these different constituents to dissipation may be estimated from the shear components taking benefit of the 0.5m fine vertical resolution of the 1200kHz, short range, ADCP. The time series of velocity and shear reveals a strong variability of these different components with events of strong shear (Figure 4) characterizing turbulent events. The question of the modulation of dissipation by internal tides will be further investigated based on the fine vertical resolution velocity measurements and estimates of the stratification. We also started to address this question based on high resolution simulations with explicit tidal forcing (Le Sommer et al, . The spatial structure of the depth-integrated tidal energy in the model displayed in Figure 5a shows regions of enhanced M2 tidal energy in the surroundings of C01 and C02, over Talbot Bank, that correlates well with enhanced depth-integrated dissipation rates. The diurnal tidal energy is as well significant as shown in Figure 5b, but with regions of enhanced energy further away from Talbot bank around Adventure Bank except for a small area in the vicinity of C01. We plan to investigate further the propagation and resonance of the diurnal tide based on these simulations as well on idealized simulations and address the hypothesis of either a bottom trapped internal tide or/and an internal Kelvin wave as already mentioned by Artale et al (1989). The structure of the sub-inertial diurnal internal tide from the mooring data may also provide insights on for the parameterization of sub-inertial internal tides.

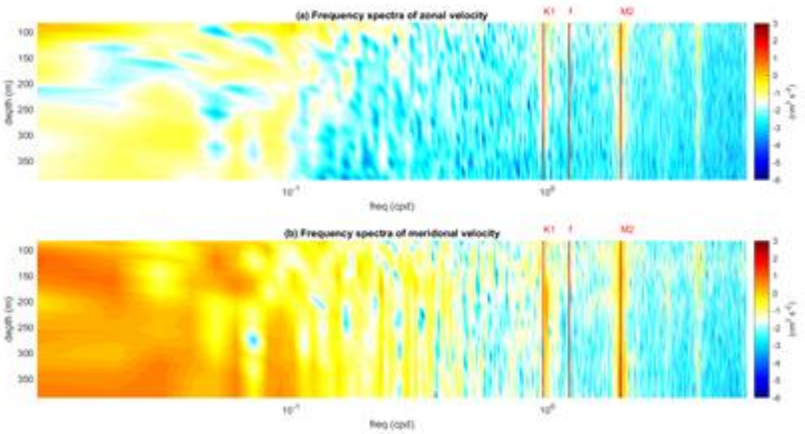

Figure 2 : Frequency spectra of zonal and meridional velocities as a function of frequency and depth inferred from the 75kHz long range ADCP with 16m bin vertical resolution at C01 mooring.

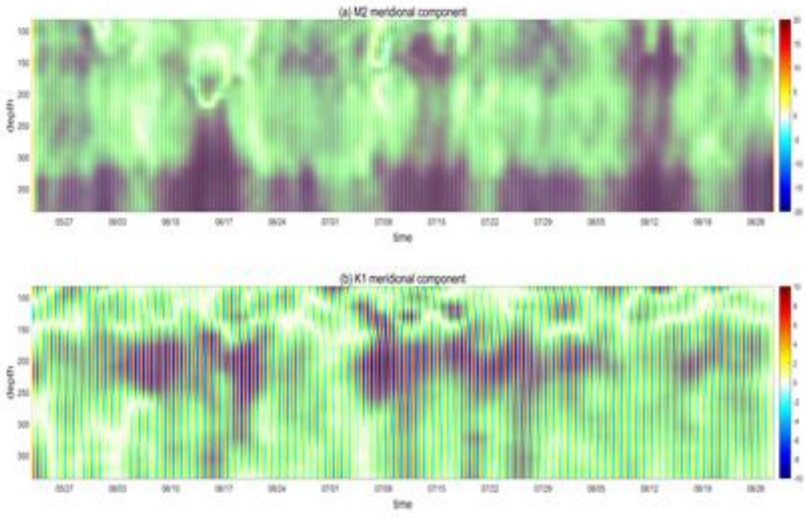

Figure 3: Meridional M2 velocity (a) as a function of time and depth at C01 from the long range ADCP; same in (b) but for the diurnal K1 meridional velocity.

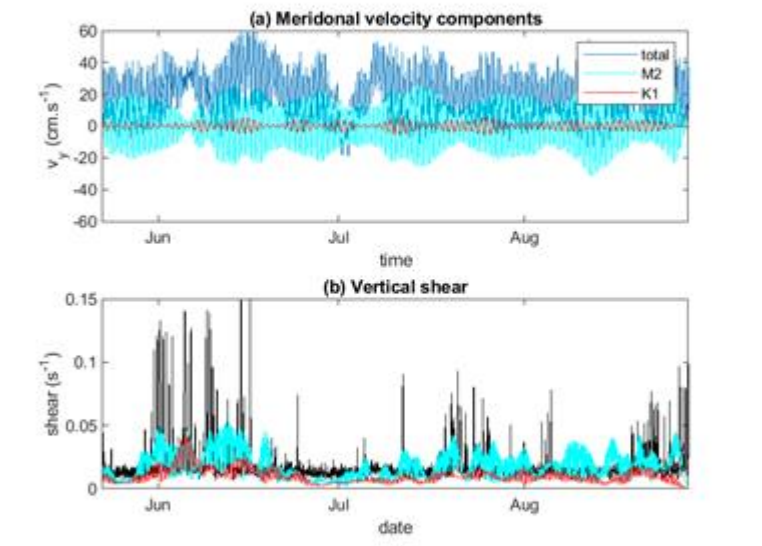

Figure 4 : Time series of depth-averaged meridional velocities (c) and of the vertical shear(d) from the short range 1200kHz ADCP with 0.5m bin vertical resolution at C01 mooring. The 3m depth-averaged velocities and shear are shown, the diurnal and semi-diurnal filtered signals are also displayed.

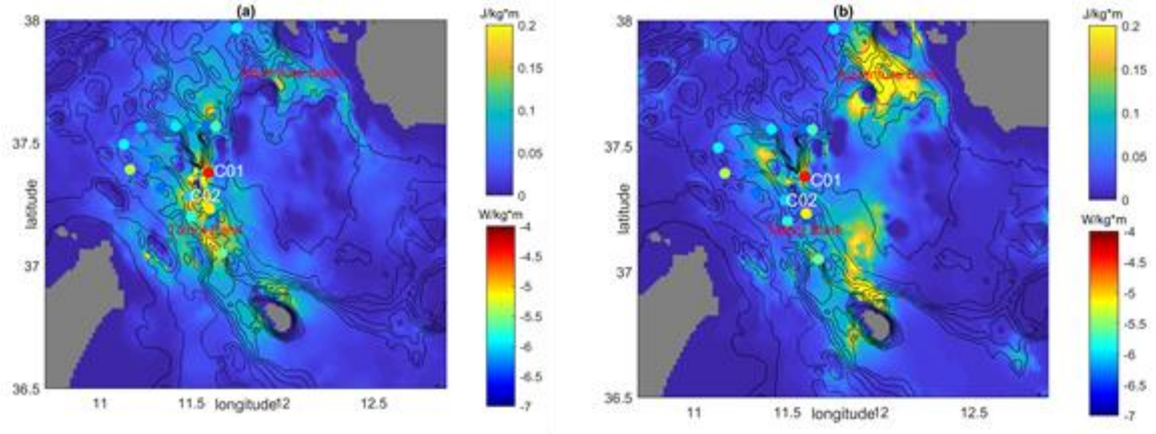

Figure 5 : (left) Map of simulated depth-integrated ([50m- bottom]) M2 tidal kinetic energy (colored map, upper colormap) and dissipation rate from DYNAS (colored circles, lower colorbar), (right) same but for the diurnal, K1, constituent. The simulations are from the NEMO eNATL60 configuration (1/60 degre resolution, 300 vertical levels, with explicit tides).

References:

- Artale, V., Provenzale, A., & Santoleri, R. (1989). Analysis of internal temperature oscillations of tidal period on the Sicilian continental shelf. *Continental Shelf Research*, *9*(10), 867-888.

- Bourgault, D., & Kelley, D. E. (2004). A laterally averaged nonhydrostatic ocean model. *Journal of Atmospheric and Oceanic Technology*, *21*(12), 1910-1924.

- Cuypers, Y., Bouruet-Aubertot, P., Vladoiu, A., Lahaye, N., Gula, J., Roullet, G., Rousset, C., Ferron, B., Vivier, F. (2019). Dynamique de la marée sous-inertielle et processus de dissipation. Journées GMMC Toulon, 12-14 Juin 2019.

-Le Sommer et al, Realistic SSH scenes for preparing SWOT: The NATL60 1/60° North Atlantic Ocean Simulations (**https://www.researchgate.net/profile/Laurent_Brodeau/publication/320621436_Realistic_SSH_scenes_for_preparing_SWOT_The_NATL60_160_North_Atlantic_Ocean_Simulations_160_North_Atlantic_Ocean_Simulations/links/59f1a540458515bfd07fcfb2/Realistic-SSH-scenes-for-preparing-SWOT-The-NATL60-1-60-North-Atlantic-Ocean-Simulations-1-60-North-Atlantic-Ocean-Simulations.pdf**)

- Lorke, A., & Wüest, A. (2005). Application of coherent ADCP for turbulence measurements in the bottom boundary layer. *Journal of Atmospheric and Oceanic Technology*, *22*(11), 1821-1828.

- 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.

SUBMITTED, 19 JUNE 2019; FINAL REVISION, 27 SEPTEMBER 2019