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Meso- and small-scale vertical motions in the deep Western Mediterranean

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ABSTRACT

Acoustic reflections on particles larger than a few mm are compared with optical background data of bioluminescence at the ANTARES neutrino telescope site in the deep North-western Mediterranean Sea. Periodic increases of these data are associated with increases in horizontal and downward vertical currents. The observations provide unique knowledge of some oceanographic processes in the Mediterranean. Several periodicities are distinguished: seasonal, with large increase during spring, 20-day, which is associated with a meandering continental boundary current, 1–17.6 h, evidencing deep internal waves.

1. Introduction

The ANTARES neutrino telescope stands to about 600 m from the bottom in 2475 m water depth at the foot of the continental slope in the North-western Mediterranean Sea (Fig. 1a). A so-called Mini Instrumentation Line equipped with four light-sensitive Optical Modules (MILOM) and with a single downward-looking 300 kHz Acoustic Doppler Current Profiler (ADCP) was deployed in spring 2005 (Fig. 1b) [1]. In subsequent years, more lines were added until full completion of 900 optical sensors and two ADCPs [2].

An ADCP estimates water current in all three Cartesian components: East–West, North–South, vertical, [u,v,w], and acoustic echo amplitudes I. At ANTARES, estimates are made every 2.5 m over 125 m, sampling data every 240 s, and every 60 s on a different line from December 2008 onwards. An ADCP relies on the reflection from ‘particles’ larger than 0.003 m at 300 kHz. It is thus sensitive to suspended flocs of material and especially to zooplankton and larger animals. It is not sensitive to bacteria or phytoplankton, which are smaller than a few mm. Here we compare ADCP-data with background ‘baseline’ optical data. At low levels OM-data are dominated by ^{40}K radio-active disintegration and bacterial bioluminescence. At high levels they are dominated by light-emitting species other than bacteria and phytoplankton. Thus, OMs are expected to provide timeseries of data that are different from those of ADCP's echo, except when both are mainly influenced by bioluminescent animals.

The focus is on observed optical and acoustic variations with time and on the oceanographic processes that govern these, specifically on the relation between near-surface, atmospheric, processes and the deep-sea via vertical motions (subsidence). Three processes are distinguished in the area: (i) seasonal dense-water formation following the drying and cooling of warm near-surface waters in winter, (ii) associated boundary current meanders and eddies that vary on timescales O (10 days), (iii) internal waves that range between inertial periods, locally 17.6 h, and buoyancy periods, between about 1 and 8 h depending on the vertical density stratification.

2. Mesoscale subsidence

The ADCP measured vertical currents down to $w = -0.03\,\mathrm{m\,s^{-1}}$ in the spring of 2006. Mean values of about $-0.01\,\mathrm{m\,s^{-1}}$ or $-1000\,\mathrm{m\,day^{-1}}$ persisted for days, up to a week (Fig. 2). In amplitude, these values are at least 10-times larger than typical sinking speeds [3]. The w are accompanied by an I increase of a factor of about 10 and by $|U| > 0.35\,\mathrm{m\,s^{-1}}$. They coincide with saturation of OM-readings, which is due to high levels of bioluminescence. Although the severe winter of 2006 was favourable for deep dense-water formation that can cause such w [4], the presently observed 20-day periodic episodes of high I, high OM-data and large negative w continuing into the summer are not direct evidence of this process. It is hypothesized that the deep ANTARES-observations can be extrapolated to the surface. Then, the main process for moving material across the 2500-m water column within a few days is local convection [5], initially triggered by deep-water formation, but persistently governed by small- and mesoscale meanders, including a bipolar vortex, linked

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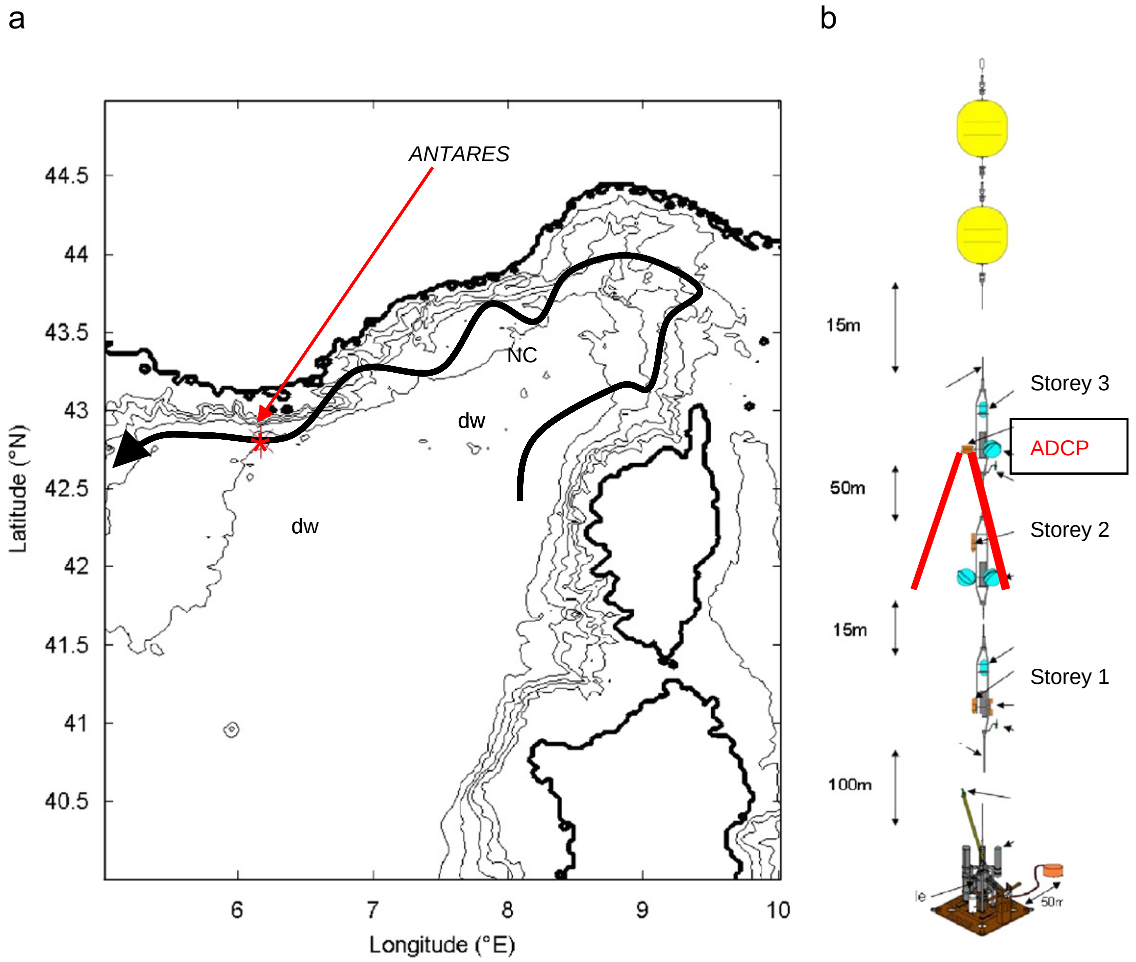

Fig. 1. (a) ANTARES site * just south of Toulon, France, with a sketch of the Northern Current NC (meandering solid line) and areas of dense-water formation (dw). Isobaths every 500 m between [−500, −2500] m. (b) Sketch of MILOM mooring.

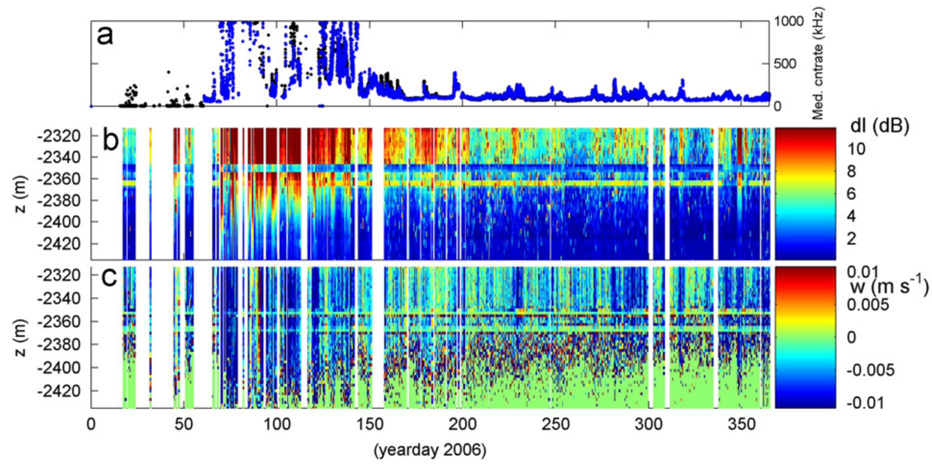

Fig. 2. Yearlong time series. (a) Optical baseline data observed on MILOM line (black) and additional line (blue). (b, c) Raw ADCP data. Vertical white lines indicate no data due to transmission interrupt. The horizontal lines near 2350 and 2365 m are direct sound reflections off storeys 2 and 1, respectively. (b) Beam 1 relative echo amplitude, limited between [0, 12] dB. (c) Vertical current, limited between [−0.01, 0.01] m s^{-1} for display purposes. Good current data reach about 2390 m, but deeper between days 70 and 100 when echos are large. Time is yeardays 2006. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

with instabilities in the ‘Northern Current’ flowing along the continental slope (Fig. 1a) [6]. The data are not generated by short-term cascading through canyons, which only occur in winter [7,8].

These observations demonstrate the capabilities of the ANTARES-telescope to register and monitor oceanographic phenomena that have not been studied before in detail. It could be used as warning system for events such as deep dense-water

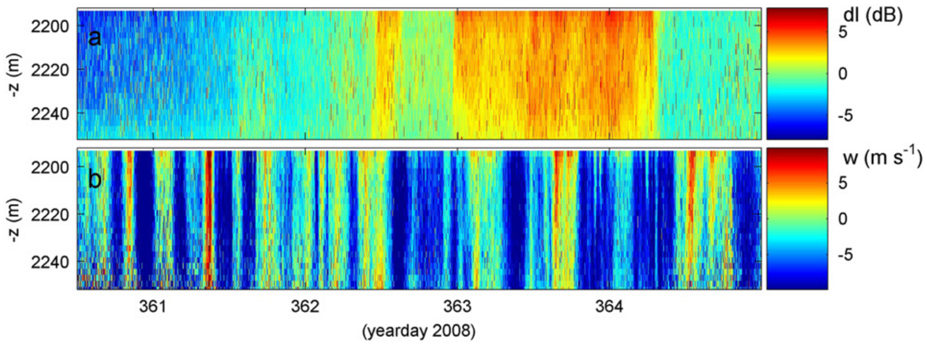

Fig. 3. Five days detail of raw-ADCP data from late 2008. (a) Relative echo amplitude. (b) Vertical current dominated by downward motions and by both near-inertial and near-buoyancy frequency internal waves.

formation, which occur irregularly once every 5–8 years. These events are important for the replenishment of fresh materials to the deep Mediterranean Sea, and oceans in general.

3. Internal waves

Large downward *w* are accompanied by short-term 'noise-like' rapid motions, having typical amplitudes O(0.01 m s^{-1}) (Fig. 3). These are not instrumental noise, but measurements of waves in the deep interior that are supported by the vertical density stratification. Generally, such 'internal waves' can exist between the inertial frequency, mainly as horizontal circular motions of 17.6 h period at ANTARES, and the buoyancy frequency, mainly as vertical motions. The former waves can propagate even in purely homogeneous waters with more vertical motions, which are rare in the ocean but which occur in the deep Mediterranean [9]. There, typical buoyancy periods are 4–8 h. However, as an aftermath of newly formed deep dense water, near-bottom stratification may increase by a factor of 10 [10], so that the buoyancy period shortens to about 1 h, as observed in *w* (Fig. 3b). Such high-frequency internal waves have not been observed before in the deep Mediterranean.

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