

Moonstruck in the deep ocean

Hans van Haren*

For centuries it has been known that near the sea surface plankton migrates vertically with sun and lunar rhythms, in order to avoid predation. A recent, 1.5 years long record of acoustic Doppler current profiler (ADCP)-data from the Canary Basin (North-Atlantic Ocean) reflects vertical zooplankton migration between 800 and 1400 m. This record clearly distinguishes 3 major periodicities of down- and up-going motions: a daily, a seasonal and, most intriguingly, a monthly cycle. Largest daily excursions occur during full moon, but they are observed at depths well below the zone of moon- (and only very weak sun-) light penetration. As no physical (internal wave), geochemical or sinking food mechanism can trigger the deep daily and monthly cycles, it may be that an entrained biorhythm running precise internal biochemical clocks controls the vertical migration.

Acoustic backscattering is a well-developed and useful tool to qualitatively detect, e.g., suspended material and fish in the ocean. Acoustic scattering off suspended material has been successfully exploited for estimation of 3-D ocean currents, resulting in acoustic Doppler current profilers (ADCPs) now commonly used by physical oceanographers. However, occasionally an ADCP shows (daily) periodic variations in the vertical current component w and in 'relative acoustic backscatter echo intensity' dI in the upper ocean. Such daily variations are considered a contamination of the ADCP's [physics] signals, as they cannot be related to any ocean dynamics. Marine biologists established using towed nets that such daily variations were not associated with horizontal currents, but with vertically migrating zooplankton. Although the obvious reasons

for such daily near-surface migration were food and [avoiding of] predation, the real trigger seemed variation of light.

A new 1.5 years long hourly record sampled by NIOZ-oceanographers shows that ADCP data can be useful to study such vertical motions deep below the photic zone. The record was obtained so deep, around 1000 m, that sunlight is more than 10 million times smaller than near the surface. This already demands extremely sensitive photo-receptors in zooplankton to trigger its migration. During full-moon, the same low light level is found at even shallower 100-150 m and moonlight is impossible to detect at 1000 m.

Yet, the present time-series clearly show a seasonal cycle with values 10 times above the winter minimum observed

during late summer/autumn (Fig. 1a). This cycle has no correspondence with temperature and, therefore, cannot be associated with possible variations in suspended matter due to water mass changes. Superposed on the seasonal cycle are monthly and daily (Fig. 1b) period variations, persistent throughout the year but most visible in late winter/spring (Fig. 2a). Minimum daily variations occur during new moon when, in general, echo intensity has large value. However, a spring-neap cycle, the fortnightly beat of dominant lunar and solar semidiurnal tides, is not observed. These daily and monthly cycles are also observed in vertical current data (Fig. 2b), with directly observed hourly mean vertical velocity amplitudes of $|w| = 0.025 \pm 0.01 \text{ m s}^{-1}$ ($\sim 2000 \text{ m day}^{-1}$). As the migrations last about 2-3 hours one-way, it typically covers several 100 m in the

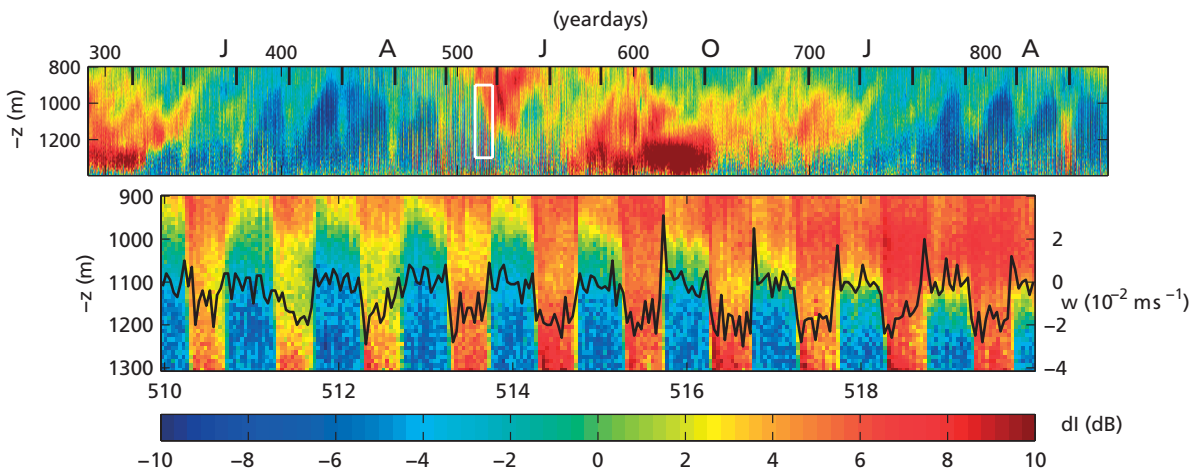


Fig. 1. (top) Entire 19 months ADCP time series of relative echo intensity. The heavy vertical ticks indicate times of new moon. (bottom) Detail from rectangle in top-panel, with w from 1250 m superimposed (black graph, scale to the right).

* Corresponding author: hansvh@nioz.nl

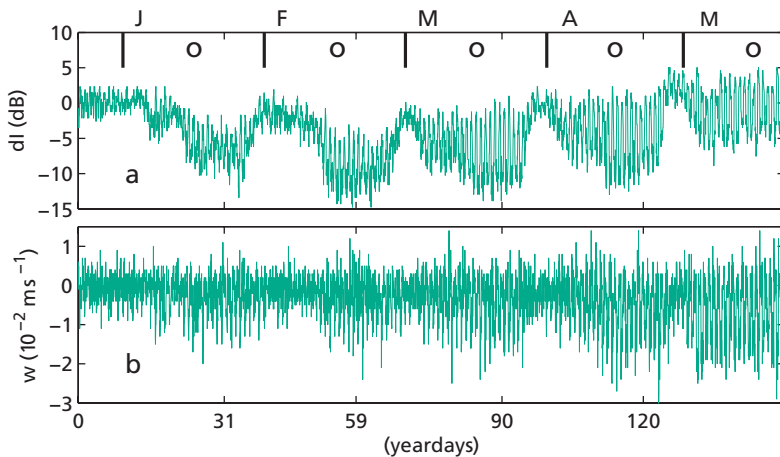


Fig. 2. Winter-spring detail at 1100 m. a. Relative echo intensity. The heavy vertical ticks indicate times of new moon, the circles full moon. b. Vertical current.

vertical, as observed. It is also observed that the variation in length of day between winter and summer is precisely followed by the periodic plankton motions at great depth.

The observed variations in vertical current and echo intensity cannot be triggered by internal waves. Under the assumption that the present observations do describe vertical zooplankton migration, we speculate how this plankton is

capable of following the sun's periodicity, daily and seasonal, and especially also the moon's periodicity, at such great resting depths of 1300 m or more, where (moon)light intensity is just too not present. Are the zooplankton moon-struck?

It seems that the deep daily-monthly migrations are most likely related with a biorhythm that is perhaps originally induced by [sun and moon] light variations on species living higher up in the

water column prior to moving to greater depths at later life stages, as, e.g., occurs for the copepod *Calanus cristatus*. One could argue, using the observation of precise seasonal variation of the daily cycle, that the gene-controlled internal clocks are reset daily, as in many terrestrial organisms, when reaching relatively shallow depths where sunlight just barely penetrates. However, the observed 'zooplankton' are at their greatest depth during daytime and their clocks definitely cannot be reset to follow the moonlight cycle, which suggests large memory persistence in time. Some memory persistence of such biorhythms has been established in laboratory experiments for shallow (tidal) water species and for day-night rhythms. The present data suggest such precise persistence at much larger depths, where life occurs in the dark and yet triggered by light variations far above.