Dynamics of the echo-reflecting layers in a deep lake: implementation of Acoustic Doppler Current Profiler (ADCP) for ecosystem analysis

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Abstract: *Echo intensity data and water current profiles were measured in Lake Kinneret (Israel) with an Acoustic Doppler Current Profiler (ADCP) moored at station H (10 m) and F (20 m) from January to March 2017, i.e. during the winter holomixis and period of winter-spring transient stratification. The collected information allow us to follow the dynamics of various echo-reflective layers. Concurrently with meteorological records and temperature dynamics measured with two thermistor chains installed at the same stations, we enable to acquire the impact of wind and transient stratification on development and dynamics of the near-bottom suspended sediments, near-surface wind-induced micro-bubble layer, and patches of gas-containing cyanobacterium Microcystis.*

Keywords: *Acoustic Current Doppler Profiler, echo intensity, echo-reflective layer, suspended sediment, microbubbles, cyanobacteria*

1. INTRODUCTION

Aquatic systems often contain various echo-reflective objects and layers of different origin, e.g. fish, zoo-, phyto-plankton, suspended particles, gas bubbles, etc. The traditional sampling methods (e.g. water collection, plankton net sampling) are unable to provide comprehensive information required for understanding the impact of physical and biological processes on spatiotemporal variability of these objects/layers in aquatic systems. This is why the dynamics and ecological role of such echo-reflective objects is still poorly understood. In this work we present the results of fields studies aimed on portraying the spatiotemporal dynamics of the main echo-reflective objects/layers in a large deep lake in response to external forcing during the time of holomixis and weak stratification. Particularly we studied the combined impact of physical and sedimentological processes on near-bed dynamics of suspended particulate matter, dynamics of near-surface clouds of micro-bubbles, and formation of patches of cyanobacteria.

2. MEASUREMENTS AND INSTRUMENTATION

Acoustic Doppler Current Profiler (ADCP). - We deployed the two upward-looking Teledyne RD ADCPs, which consist of four beams, convex configuration with a beam angle of 25° and one vertically oriented beam. Sentinel V50 has working frequency of 492 kHz and Sentinel V20 has working frequency of 983 kHz. These instruments were moored at water depth 19.8 m (Stn. F) and 9.8 m (Stn. H), respectively, from February to April 2017 (Fig. 1). Together with current velocities and echo intensity the instruments recorded heading, pitch, roll, pressure and temperature. The vertical bin size was 0.6 m and 0.3 m for V50 and V20, respectively, and 256 individual pings were recorded and averaged every 30 minutes (1.7 Hz ping rate) for both devices. The center of the first depth cell was 1.86 m for V50 and 0.83 m for V20. Velocity errors were up to 0.03 m s^{-1} for both instruments.

Thermistors chains. - Time series of temperature were recorded at different depths spreading throughout the entire water depth ranges at stns. F and H. Each thermistor chain was composed of a combination of RBRsolo (temperature sensor-data logger) and RBRduet T.D. (temperature and depth sensor-data logger), RBR Ltd., Canada. The thermistor chains were deployed in close proximity to ADCPs.

Meteorological data. - Meteorological data contained information on wind speed and direction, long- and short-wave solar radiation and air temperature. Wind speed, and wind direction were obtained from two Meteroeological Stations: the onshore Ginosar station (G) and offshore station A (courtesy of Y. Lechinsky and A. Rimmer) (Fig. 1).

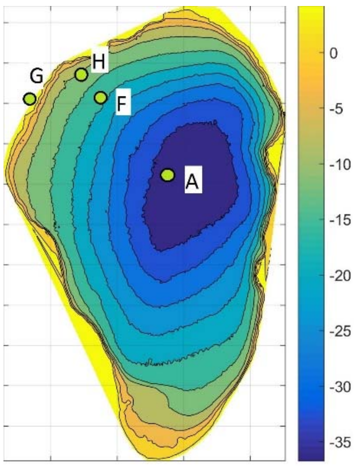

Figure 1. Bathymetric map of the Lake Kinneret with Stations A, F, H.

METHODS

MVBS computation. - The mean volume backscattering strength (MVBS) S_v (dB) was calculated from the recorded echo intensity *E* (counts) using sonar equation [1, 2]:

$$S_v = K_c(E - E_r) - P_{DBW} - L_{DBM} + 2\alpha_w R + 20\, log_{10} R + C \quad (1)$$

The first term on the right hand side of the eqn. 1 is the received and recorded signal intensity *E* [counts] minus the background electronic noise level E_r [counts] converted to dB by using the coefficient *Kc* [dB/count] provided by the manufacturer, E_r can be obtained in the lab or from remote profile regions where no backscatter signal can be expected. P_{DBW} [dB] is 10 $\log_{10}$ of the transmitted power [W] and hence describes the acoustic power transmitted into the water. L_{DBM} is 10 $\log_{10}$ of the transmit pulse length *P* [m] and characterizes the instantaneous ensonified thickness of water, where *P* is subject to the deployment configuration of the ADCP. The forth term on the right hand side of eqn. 1 characterizes the absorption of acoustic power by the water along the slant range to the scattering volume and back to the ADCP. Absorption is described using the acoustic absorption coefficient of clear water α_w [dB m^{-1}], which depends on the acoustic frequency, salinity, pressure and temperature.

The fifth term denotes the 2-way spreading of the conical acoustic beam. The slant range *R* [m] was calculated using [1, 2, 5]:

$$R = (B + |(P - D)/2| + N \cdot D + D/4)/cos\theta \quad (2)$$

where *B* [m] the blank distance adjacent to the transducers, *P* [m] is the transmit pulse length, *D* [m] the bin size, *N* the bin number and Θ is the angle of the transducers to the vertical (25° for slanted and 0° for vertical beam). *C* is a system constant delivered by the manufacturer (includes transducer and system noise characteristics of -139.18 dB and -135.49 dB for Sentinel V50 and Sentinel V20, respectively).

3. RESULTS

Thermal stratification. - Near-surface thermal stratification was episodically established in Lake Kinneret during winter and early spring. It characterizes by an increase of surface water temperature as early as in the middle of February 2017 (Figure 2b). At the end of March the stratification becomes permanent. At the time of strong wind ($\geq$ 5 m s^{-1}) the mixing in the upper water layer (up to water depth of 11 m) became prominent.

Near-bed dynamics of suspended particulate matter. - Appearance of strong near-bottom backscatter layer was the most distinct phenomenon detected at shallower stn. H. It was caused either by direct resuspension of particulate matter at the station location, or by lateral particle transfer from the shallower areas, or by transport from the watershed. At the same time, much lower near-bed backscatter strength at deeper stn. F suggests that no resuspension occurred in the neighborhood of this location.

Patches of cyanobacterium Microcystis. - Many cyanobacteria can regulate cell and colony buoyancy and form the near-surface blue-green scum of several inches thick [3]. *Microcystis* colonies are less transparent than water, therefore absorbing more solar energy and thus transferring heat to the ambient water, increasing its temperature. The enhancement of ambient temperature may in turn an increase in *Microcystis* growth rate [4].

An upper- and mid-water echo-reflecting layer showed distinct near-diurnal variability during the period of development of winter-spring bloom of gas-containing cyanobacteria. It seems that the observed changes in thickness and intensity of this layer could be associated with vertical migration of the cyanobacterium *Microcystis* in response to development/vanishing of thermal stratification in response to interactions between wind and heat forces. The migration of the echo-reflective layer during nighttime in the absence of strong wind (Fig. 3h) possibly pinpoints the subsidence of the cyanobacterium.

Micro-bubble cloud dynamics near the water surface. - The appearance of a thin but intense echo-reflective layer near the water surface (Fig. 2c, 2h) coincided with strong wind events ($\geq$ 7 m s^{-1}) and formation of surface waves. Breaking of the surface waves could form a surface layer full of the entrained air gas bubbles.

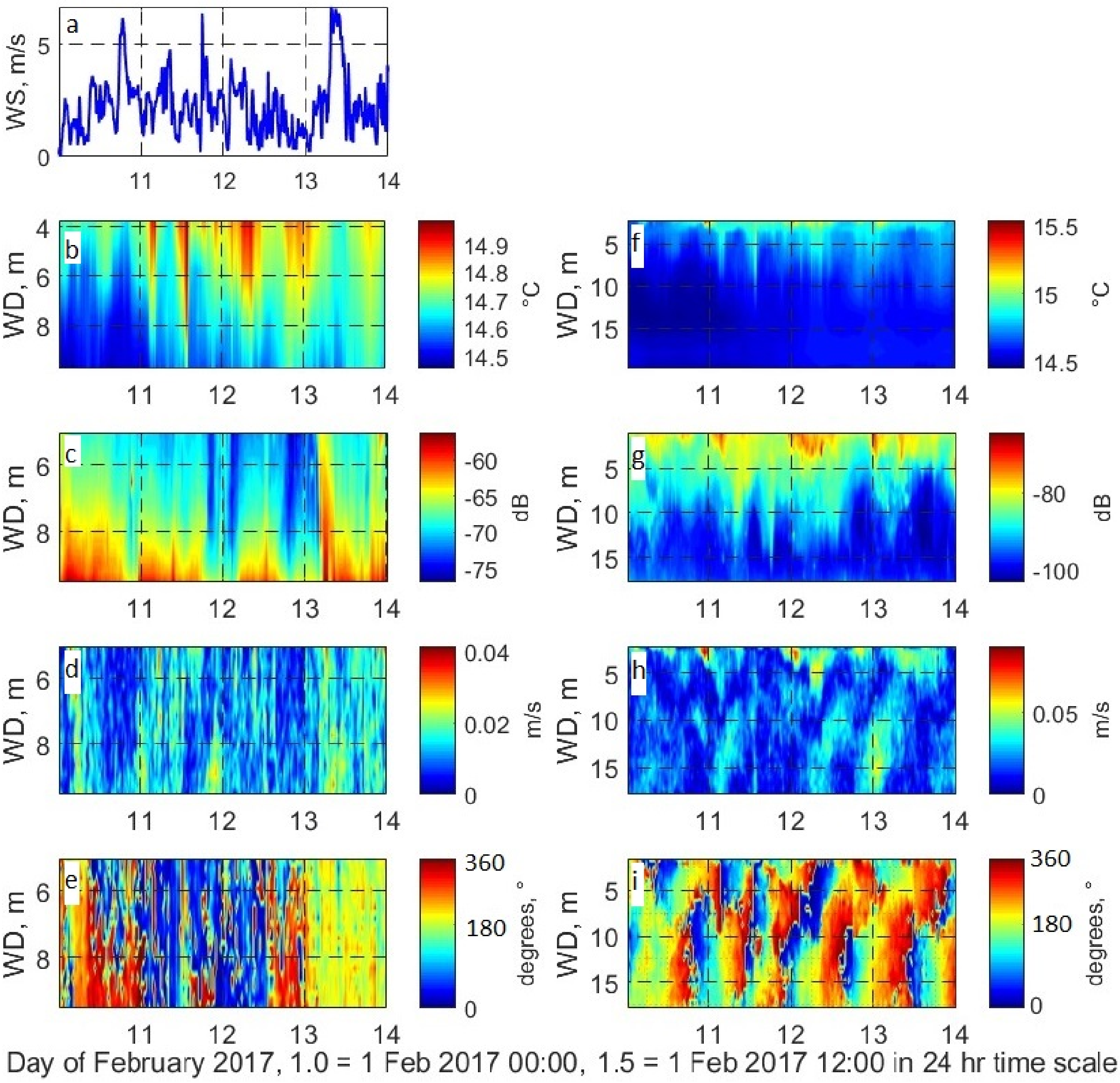

Fig. 2. Wind dynamics and spatiotemporal variability of water column variabilities between 10th and 14th of February, 2017. ***(a)*** *10-minute average of wind speed.* ***(b)*** *-* ***(e)*** - water column dynamics at stn. H; ***(f)*** *-* ***(i)*** - water column dynamics at stn. F. ***(b)*** and ***(f)*** *- water temperature;* ***(c)*** *and* ***(g)*** *- backscattering strength;* ***(d)*** *and* ***(h)*** *- current magnitude;* ***(e)*** ***and (i)*** *- current direction.*

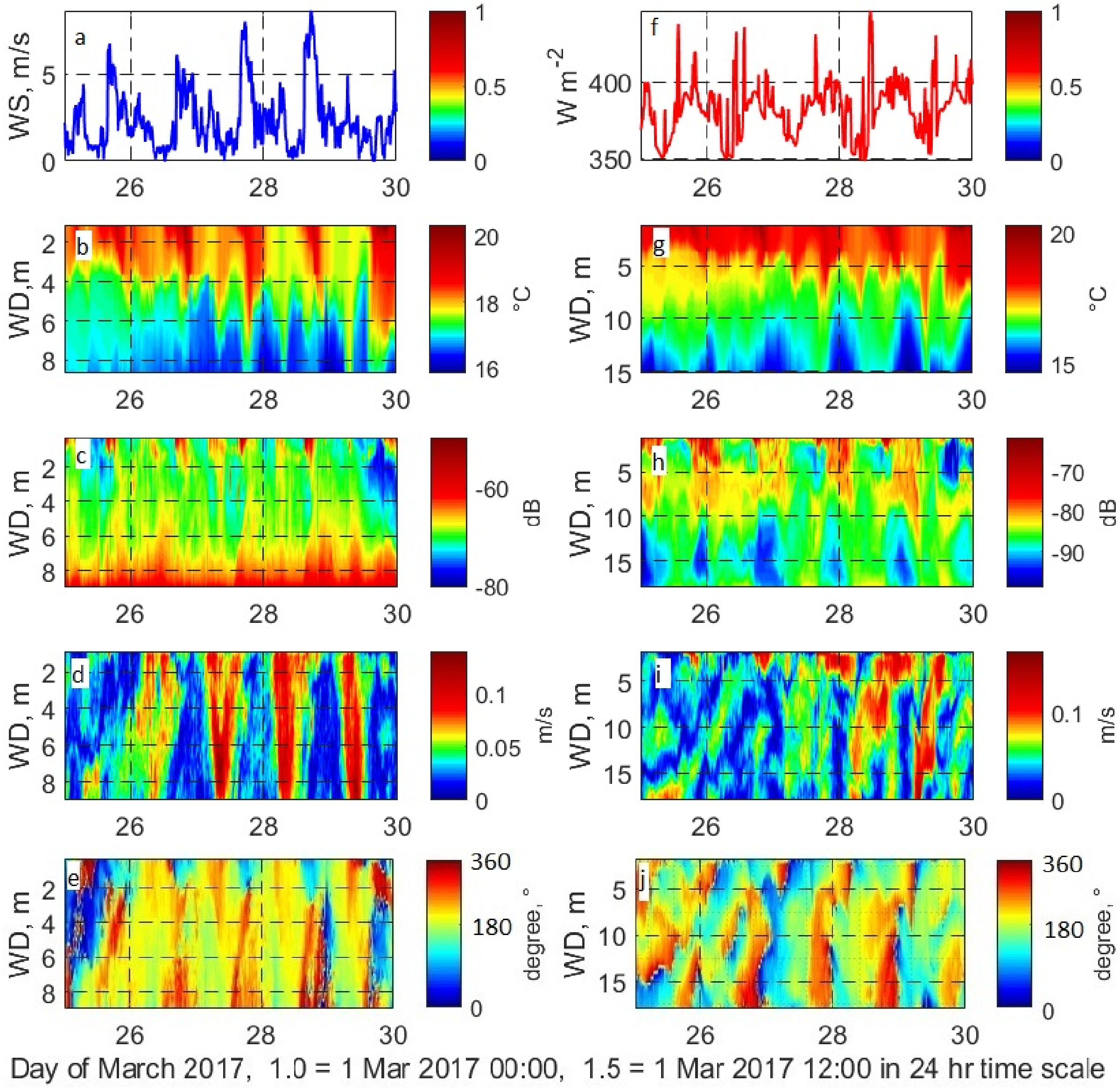

Fig. 3. Wind, long-wave solar radiation dynamics, and spatiotemporal variability of water column variabilities between 25th and 30th March, 2017. ***(a)*** *10-minute average of wind speed;* ***(f)*** *long-wave solar radiation.* ***(b)*** *-* ***(e)*** - water column dynamics at stn. H; ***(g)*** - ***(j)*** - water column dynamics at stn. F. ***(b)*** and ***(g)*** *- water temperature;* ***(c)*** *and* ***(h)*** *-backscattering strength;* ***(d)*** *and* ***(i)*** *- current magnitude;* ***(e)*** ***and (j)*** *- current direction.*

ACKNOWLADGEMENTS

This study was funded by grant no. 2033/15 from binational program of Israel Science Foundation and National Science Foundation of China (ISF-NSFC).

References

[1] **Deines, K.L.** (1999) Backscatter Estimations Using Broadband Acoustic Doppler Current Profilers. Application Note.RD Instruments, San Diego, U.S.A.

[2] **Lorke, A., Mcginnis, D. F., Spaak, P., & Wüest, A.** (2004). Acoustic observations of zooplankton in lakes using a Doppler current profiler. *Freshwater Biology*, *49*(10), 1280–1292. doi:10.1111/j.1365-2427.2004.01267.x

[3] **Crayton, M.** (2004). Toxic Cyanobacteria Blooms. *A Field Laboratory Guide. Office of Environmental Health Assessments*, 1-18.

[4] **Davis, T. W., Berry, D. L., Boyer, G. L., & Gobler, C. J.** (2009). The effects of temperature and nutrients on the growth and dynamics of toxic and non-toxic strains of Microcystis during cyanobacteria blooms. *Harmful Algae*, *8*(5), 715–725. doi:10.1016/j.hal.2009.02.004

[5] **Zhou, M., Nordhausen, W., & Huntley, M.** (1994). ADCP measurements of the distribution and abundance of euphasiids near the Antarctic Peninsula in winter, (October 2014). doi:10.1016/0967-0637(94)90106-6