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COMMENT

Comment on "Is there a paleolimnological explanation for 'walking on water' in the Sea of Galilee?"

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Abstract In a recent paper, Nof et al. (J Paleolimnol 35:417–439, 2006) suggest a physical mechanism which could account for the formation of ice on Lake Kinneret (Sea of Galilee) in northern Israel. Based on the sea surface temperature record of sediment cores from the Mediterranean Sea the authors argue that centennial-scale cold events had the potential to trigger local 'springs ice' formation on the lake in the past. Here, we demonstrate that a closer inspection of the paleoceanographic record in combination with correlation and regression analyses of meteorological data provides no evidence for such cold events in the lake region during the last 10,000 years. Thus, the formation of 'springs ice' on Lake Kinneret was unlikely at least since the beginning of the Neolithic.

Keywords 'Walking on water' · Lake Kinneret · Lake freezing · Atmosphere–ocean interaction · Northern Red Sea · Holocene

Nof et al. (2006, hereafter NMP) "sought a natural process that could perhaps explain the origin of the account that Jesus Christ walked on water" (NMP: 436). The possible explanation which NMP propose is based on the idea that one or more unusual local freezing events took place over small parts of Lake Kinneret (the Sea of Galilee located in northern Israel) during the last few thousand years. The ice which formed at the lake surface would have been thick enough to support human weight. A person standing on the ice might have appeared to a distant observer as if he was walking on water. Even though we highly appreciate any attempt to explain 'miracles' by simple physical processes, we found some major problems in the study of NMP.

Today, water temperatures in Lake Kinneret are everywhere above 14°C, at all depths and during the whole year. During the summer months, surface temperatures exceed 28°C and the lake becomes strongly stratified (ILEC 1999). According to the hypothesis proposed by NMP, the formation of ice at the lake's surface requires two crucial ingredients: (i) a mechanism for local density stratification in winter and (ii) a colder 'background climate', i.e. cold events over a period of order of 100 years or more.

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As to the first requirement, NMP argue that dense (warm and salty) springs along the western shore of Lake Kinneret may provide a haline stratification that acts as a barrier to convection. Utilizing the theory of plume dynamics along with a thermodynamic ice model, NMP show very convincingly that the springs-induced stratification may facilitate the local formation of ice ('springs ice') provided that the air above the lake is cold enough.

As to the second requirement—the existence of cold events in the Lake Kinneret region during the last few thousand years—NMP are, however, walking on thin ice. Since there are no paleotemperature records directly from Lake Kinneret [the existing reconstructions for biological productivity (Dubowski et al. 2003) and lake level (Hazan et al. 2005) provide no clues as to past changes in lake surface temperature], NMP use the alkenone records (alkenone unsaturation ratios reflect paleotemperatures at the sea surface) of two marine sediment cores from the Mediterranean Sea (Fig. 1): core BS 79–38 from the Tyrrhenian Sea (Cacho et al. 2001) and core RL 11 from the Ionian Sea (Emeis et al. 2000).

In their paleoceanographic evaluation, NMP assume that 2,000 years ago the climate was as warm as it is today. In this way, NMP obtain a sea surface temperature (SST) reduction (relative to today) of −2°C for about 1,500 years ago, and of −5°C for about 2,500 years ago from core RL 11. However, it seems more obvious to use the alkenone-derived temperature from surface sediments at the core location or the observed SST as a present-day benchmark [these two values are actually consistent as shown by Emeis et al. (2000)]. In so doing, we find

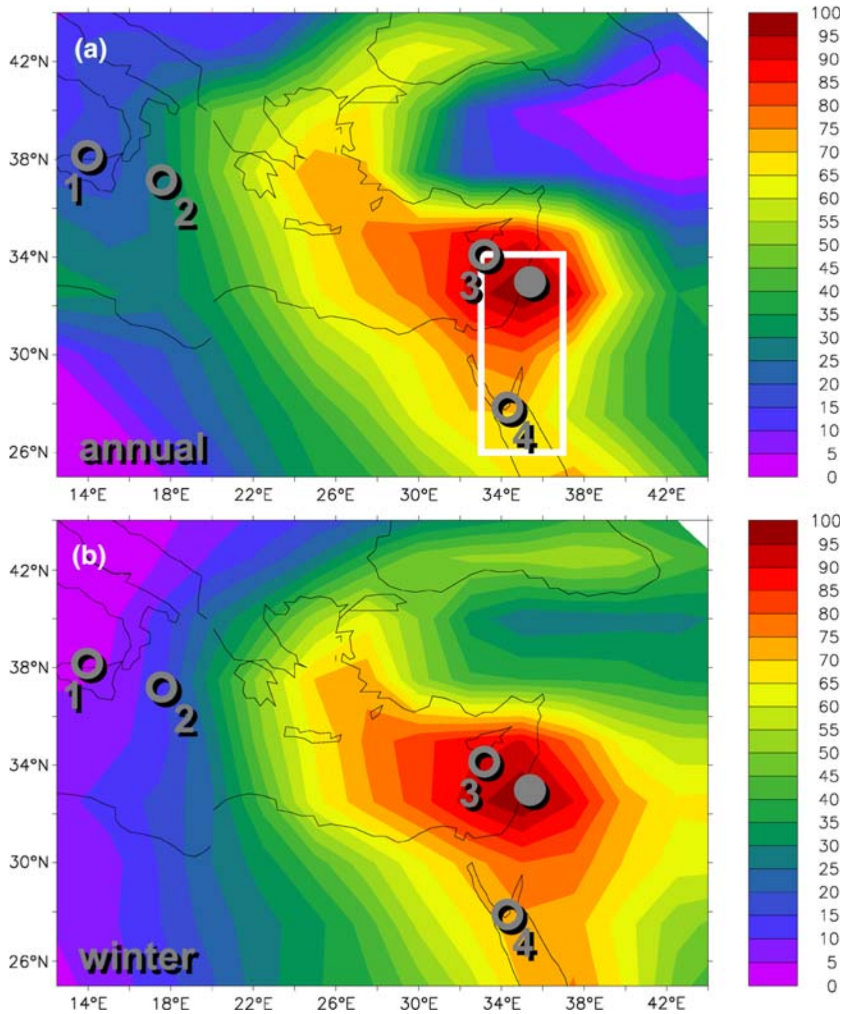

Fig. 1 **(a)** Squared linear correlation (i.e. the explained variance r^2) in % between annual-mean SAT and annual-mean SAT above Lake Kinneret for the period 1948–2005. The circles mark the locations of the marine sediment cores discussed in this paper: BS 79-38 (1), RL 11 (2), ODP Site 967 (3), and GeoB 5844-2 (4). The filled circle marks the location of Lake Kinneret. See text for the white frame. **(b)** As in (**a**) but for winter (December–March average) SAT

no cooling events greater than 0.5°C in the Ionian Sea during the past 10,000 years. We further note that the climatic situation 2,000 years ago (i.e. the 'Roman climate optimum') is subject to an ongoing debate, as is the case for the 'Medieval warm period' (was it warmer or colder than today?).

A third sediment core (ODP Site 967) from the Levantine Basin south of Cyprus is mentioned by NMP (Fig. 1). The authors argue, however, that the SST reconstruction from this site provides no reliable information about the paleoclimatic evolution of the eastern Mediterranean realm due to an overwhelming influence of relatively cold Nile river water. Therefore, they do not use the core from the Levantine Basin for their further evaluation. We are sceptical about the authors' argument, but note that the alkenone record of Site 967 shows always warmer-than-present conditions during the last ~7,000 years (Emeis et al. 2000).

NMP claim that "there are no cores closer to the lake—the only ones that are available do not extent more than 800 years before present" (NMP: 423). This is not correct. The closest alkenone-derived SST record—apart from ODP Site 967—comes from marine sediment core GeoB 5844-2 in the northernmost Red Sea and comprises the entire Holocene (Arz et al. 2003) (Fig. 1). Here, we argue that the SST record of core GeoB 5844-2 is a much better indicator for the paleoclimatic evolution in the Lake Kinneret region than the records considered by NMP, i.e. cores BS 79-38 (Tyrrhenian Sea) and RL 11 (Ionian Sea).

To examine how different geographical locations are climatically connected to each other, it is instructive to calculate the correlation of meteorological quantities utilizing data from the observational period. Using annual-mean values from the period 1948–2005 (NCEP reanalysis data on a 2.5° global grid provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at www.cdc.noaa.gov), we calculated the squared linear correlation (i.e. the coefficient of determination r^2 which reflects the explained variance) between the surface air temperature (SAT) above Lake Kinneret and all other locations (Fig. 1a). Correlations between Lake Kinneret and the sites of RL 11, BS 79-38 and GeoB 5844-2 are all positive. However, it turns out that only 27% (17%) of the annual temperature variance at Lake Kinneret is explained by temperature variations at site RL 11 (BS 79-38). The correlation is not much higher for longer timescales. Using 10-year running means instead of the annual temperature data (not shown), we find that 46% (38%) of the Lake Kinneret variance is explained by site RL 11 (BS 79-38). If we consider only the winter season (December–March), the pattern is similar, yielding an explained variance of 13% for site RL 11 and 5% for BS 79-38 (Fig. 1b). The latter value does not even represent a significant correlation at the 0.05 significance level. By contrast, the correlation between SAT above the northern Red Sea and Lake Kinneret is much higher. 70% of the annual-mean temperature variance at the lake is explained by variations at site GeoB 5844-2 (Fig. 1a). Using 10-year running means, the coefficient of determination between the two locations is 79% (not shown). The situation is similar (74%) when only the winter months are considered (Fig. 1b). The high SAT correlation between Lake Kinneret and the northern Red Sea is not too surprising, given that both sites are under the influence of the same northeast wind anomalies during cold winters (Rimbu et al. 2001, their Fig. 3).

It is unclear, of course, to which extent the correlations on annual and decadal timescales can be applied to longer timescales (i.e. centennial or millennial). However, there is no obvious reason to assume that the correlation patterns would shift dramatically. In particular, our simple statistical analysis challenges NMP's statement that "it is this SST [from core sites BS 79-38 and RL 11] which determines the air temperature above the lake" (NMP: 421).

The alkenone-derived SST record of GeoB 5844-2 in the northern Red Sea shows only relatively small variations over the past 10,000 years (Fig. 2). Relative to the present, temperature reductions do not exceed ~1°C during the entire period. What does an SST reduction of 1°C mean for the SAT of the overlying atmosphere? From a simple energy conservation equation, NMP calculate that the ratio of atmospheric temperature anomalies to SST anomalies can be as high as 4.0 (to their credit, they perform their final calculations for both a ratio of 1.5 and a ratio of 4.0). In their simple calculation, however, NMP ignore the fact that SAT and SST are closely coupled through vertical surface fluxes of longwave radiation, latent heat and sensible heat. In accordance

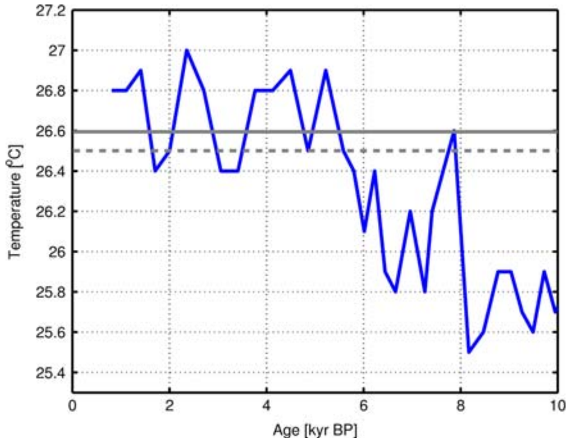

Fig. 2 Alkenone-derived paleo-SST in the northern Red Sea (core GeoB 5844-2) for the last 10,000 years (Arz et al. 2003). The solid horizontal line at 26.6°C marks the alkenone SST based on surface sediment samples from the northern Red Sea. The dashed horizontal line at 26.5°C marks the northern Red Sea SST 2000 years ago (according to the age model)

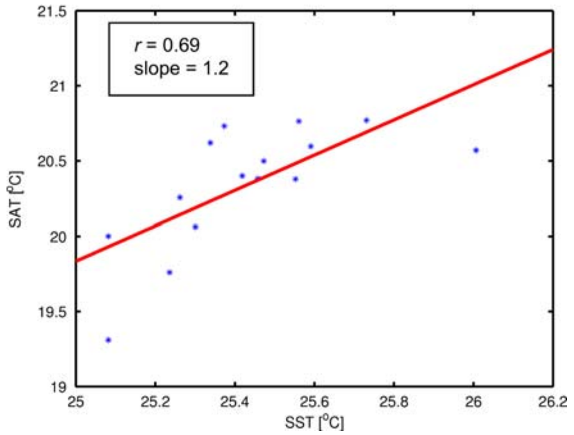

Fig. 3 Annual-mean SST (NCEP marine data for the period 1991–2005) at the location of core GeoB 5844-2 in the northern Red Sea versus annual-mean SAT (NCEP reanalysis data) over the Lake Kinneret/northern Red Sea region (spatial average over the area marked by the white frame in Fig. 1a). Linear regression analysis yields a slope of 1.2 ($r = 0.69$)

with the second law of thermodynamics, these fluxes should actually tend to equal the temperatures of the sea surface and the overlying air (e.g. Prange et al. 1997).

Here, we follow a different approach to obtain a functional relationship between SST and SAT reductions. We compare annual-mean SSTs (NCEP marine data on a 2° global grid provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.cdc.noaa.gov; temporal coverage is 1991–2005) at the core location of GeoB 5844-2 in the northern Red Sea with annual-mean SAT over the Lake Kinneret/northern Red Sea region (we have chosen an average over the area 33–37° E, 26–34° N which is marked by a white frame in Fig. 1a). As expected, both quantities are significantly correlated ($r = 0.69$). The linear regression slope is 1.2, i.e. a reduction of 1°C in northern Red Sea SST corresponds to a 1.2°C reduction in Lake Kinneret/northern Red Sea SAT (Fig. 3). Hence, the maximum Holocene SAT cooling in the lake region ~8,200 years ago (cf. Fig. 2) was probably not greater than ~1.2°C. According to the statistical model described by NMP, this "small cooling implies that the recurrence time for a springs ice is more than a 1,000 years—longer than the cooling event itself" (NMP: 423), rendering the formation of ice on Lake Kinneret during the past 10,000 years unlikely.

Aside any religious motivation, we think as paleoclimatologists that it is important to evaluate the paleoceanographic record with more care than it has been done by NMP. Based on the SST record of sediment cores in the Mediterranean far away from Lake Kinneret, NMP infer that there was "a large likelihood of springs ice occurring during events 1, 2 and 3 [1,500, 2,500, and 9,800 years ago]" (NMP: 436). A closer inspection of the paleoceanographic record along with simple correlation and regression analyses however reveals that springs ice formation on Lake Kinneret was unlikely during the Holocene. We cannot rule out that freezing of the lake occurred before this epoch. However, we consider it unlikely that the story of walking on water dates back to the Paleolithic period of the last Ice Age.

References

Arz HW, Lamy F, Pätzold J, Müller PJ, Prins M (2003) Mediterranean moisture source for an early-holocene humid period in the northern Red Sea. Science 300: 118–121

Cacho I, Grimalt JO, Canals M, Sbaffi L, Shackleton NJ, Schonfeld J, Zahn R (2001) Variability of the western Mediterranean Sea surface temperature during the last 25,000 years and its connection with the Northern Hemisphere climatic changes. Paleoceanogr 16:40–52

Dubowski Y, Erez J, Stiller M (2003) Isotopic paleolimnology of Lake Kinneret. Limnol Oceanogr 48:68–78

Emeis KC, Struck U, Schulz HM, Rosenberg R, Bernasconi S, Erlenkeuser H, Sakamoto T, Martinez-Ruiz F (2000) Temperature and salinity variations of Mediterranean Sea surface waters over the last 16,000 years from records of planktonic stable oxygen isotopes and alkenone unsaturation ratios. Palaeogeogr Palaeoclim Palaeoecol 158: 259–280

Hazan N, Stein M, Agnon A, Marco S, Nadel D, Negendank JFW, Schwab MJ, Neev D (2005) The late Quaternary limnological history of Lake Kinneret (Sea of Galilee), Israel. Quatern Res 63:60–77

ILEC (International Lake Environment Committee Foundation) (1999) World lakes database. http://www.ilec.or.jp, cited 1 Dec 2006

Nof D, McKeague I, Paldor N (2006) Is there a paleolimnological explanation for 'walking on water' in the Sea of Galilee? J Paleolimnol 35:417–439

Prange M, Lohmann G, Gerdes R (1997) Sensitivity of the thermohaline circulation for different climates – Investigations with a simple atmosphere-ocean model. Palaeoclim 2:71–99

Rimbu N, Lohmann G, Felis T, Pätzold J (2001) Arctic oscillation signature in a Red Sea coral. Geophys Res Lett 28:2959–2962