Dead Sea seasonal stratification: metalimnion sharpening and the role of Double Diffusive diapycnal flux in a hypersaline lake
Arnon Ali 1,2,3, Lensky Nadav G.1 and Selker John S.3

1 Geological Survey of Israel, Jerusalem, Israel. 2 Department of Geography and Environment, Bar Ilan University, Ramat Gan, Israel. 3 Oregon State University, Oregon, USA

* Corresponding author’s email: ali.arnon@gmail.com

Introduction
The Dead Sea is a terminal hypersaline holomictic lake; it is thermally stratified during the 8 months of warm season, despite salinity increase due to evaporation. Saltier and warmer epilimnion enables salt fingering Double Diffusive (DD) flux across the metalimnion, located at depth of ~25 m. The negative water balance of the Dead Sea (evaporation >> inflows + rains) continuously concentrates the lake. Salt precipitation (or dissolution) depends on the combined effects of salt concentration and seasonal heating of the lake (green and red curves), through the degree of salt saturation. In different from “regular” lakes, in a hypersaline lake determination of the degree of halite saturation is needed to quantify DD flux.

The presented work:
(i) Quantifies the DD flux and distinguished it from halite precipitation processes.
(ii) Explores the expected sharpening of the metalimnion with DD diapycnal flux.
(iii) Reveals a unique salt fingering mechanism including localized precipitation of halite along the metalimnion’s bottom.

Thermohaline evolution of the hypersaline lake and diapycnal fluxes

Basic conditions for salt fingering Double Diffusion during warm season (warm saline brine over cold, less saline brine).

Salinity decline from mid-summer despite continuous evaporation (=inflows).

Synchronous under-saturation of the epilimnion.

Halite precipitation out of the epilimnion does not exist.

A different sink of salt from the epilimnion is required.

Ongoing crystallization in the hypolimnion during summer, without cooling, requires a source of salt.

Double Diffusion diapycnal flux

Metalimnion sharpening associated with Double Diffusion flux
High Resolution thermal observations

Efficient heat flux
An abrupt increase in temperature in the hypolimnion synchronous with stairs merging in the metalimnion

Sharpening:
- Metalimnion thinning: merge-up of the location (depth) of the top and bottom of the metalimnion.
- Rising of maximum temperature depth gradients (dT/dZ).
- Rising temperature depth curvature extrema (d²T/dZ²).

Methods
Monthly profiles and laboratory measurements (2012-2014):
- CTD casts with a SBE19 profiler (temperature, turbidity).
- Water sampling (Niskin bottles).
- Density and salinity measurements.
- Determination of degree of halite saturation of brine samples in the laboratory.
- Measurements of halite crystallization rate in situ measurements on a vertical cable in the lake.

High resolution temperature profiling for dynamics of thermal stratification study:
- Distributed Temperature Sensing (DTS) using optical fibers
- 9 cm vertical spacing
- Time resolution of 5 minutes for 7 months.

Stratification in the hyper-saline Dead Sea- unique mechanism of halite crystal nucleation out of DD fingers

Conclusions
- Diapycnal fluxes of salt and heat from the bottom of the epilimnion to the hypolimnion are necessary to close the salt balance of both layers during stratification time.
- Sharpening of the metalimnion and staircases development are synchronous with the increasing diapycnal flux (calculated based on the salt balance) indicating Double Diffusive salt fingering flux. Maximum DD flux efficiency in the Dead Sea is reached during peak summer to mid-fall.
- Evaluated DD fluxes during late summer are ~1-2 kg/m²/day. The DD salt flux across the epilimnion exceeds the “salt flux” due to evaporation (>>inflows).
- A unique DD salt fingering mechanism in a hypersaline lake is associated with salt precipitation in the descending fingers.