

Dead Sea Warming and the Origin of Salt Giants

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Peer review status:

This manuscript submitted to EarthArXiv is the accepted version of the following article:

Guillerm, E., Lowenstein, T. K., Gardien, V., Bärenbold, F., Bouffard, D., Brauer, A., & Caupin, F. (2026). Dead Sea warming and the origin of salt giants. *Geophysical Research Letters*, 53, e2026GL124167.

DOI: <https://doi.org/10.1029/2026GL124167>

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27 **Key Points:**

- 28 • Physical model combining heat and mass transfers in hypersaline waterbodies
- 29 • The model predicts extreme warming and shrinkage of the Dead Sea and of a fully
30 restricted eastern Mediterranean Sea
- 31 • Positive feedback loop between warming and water loss allows precipitation of halite
32 and potash salts under non-extreme climates

Abstract

Episodically in Earth's history, marine basins became hydrologically restricted, forming "salt giants," yet the mechanisms driving their formation remain debated. The modern Dead Sea, undergoing restriction from anthropogenic inflow diversion, shows rapid lake-level decline and salt precipitation. We present a physical model coupling energy and mass fluxes in hypersaline waterbodies. The model reproduces the observed $\sim 3^\circ\text{C}$ Dead Sea water-column warming since 1979. By 2600, the Dead Sea will drop ~ 180 m, and warm by $\sim 10^\circ\text{C}$ to $\sim 20^\circ\text{C}$ depending on global CO_2 emissions. A fully restricted eastern Mediterranean under modern climate conditions would undergo 20°C warming and kilometer-scale drawdown within a few millennia. Once isolated, large basins enter a positive feedback loop between warming and water loss that drives precipitation of halite and potash salts without requiring hot, arid climates. Because paleobrine warming tracks brine shrinkage, vertical paleotemperature trends in evaporites may record drawdown rather than paleoclimate.

Plain Language Summary

Why did enormous "salt giants" form in Earth's history? These vast evaporite deposits are commonly attributed to extremely hot and arid climates, yet the mechanisms behind their formation remain poorly understood. Using the modern Dead Sea as natural analogue for basin isolation, we develop a model that couples water balance and heat exchange in hypersaline systems. The model reproduces recent Dead Sea warming and shows that once a large basin becomes isolated from the ocean, warming and water-level decline reinforce each other through self-amplifying feedbacks. Applied to an eastern Mediterranean basin disconnected from the ocean, this mechanism generates extreme drawdown and formation of highly soluble evaporites without requiring a hot and dry climate. Because brine warming and water loss go

hand in hand, the vertical temperature history preserved in ancient salt deposits may reveal the collapse of the sea that formed them, rather than the climate it once experienced.

1 Introduction

Salt giants are million-cubic-kilometer evaporite deposits that formed episodically throughout the Phanerozoic (Hay et al., 2006). Their formation is hotly debated. Among the major points of contention are the degree of isolation from the ocean and the amount of drawdown. For the most recent salt giant, formed during the Messinian Salinity Crisis in the Mediterranean Basin (5.5 Ma) (Krijgsman et al., 1999; Roveri et al., 2014), scenarios range from partial connection and limited drawdown to disconnection and near-complete desiccation (Roveri et al., 2025; Ryan, 2023). Mass budget models assuming climate-independent evaporation suggest that massive evaporite deposits can form irrespective of ocean connection and drawdown (Aloisi et al., 2024).

Another point of contention is the environmental conditions required for salt-giant formation. Paleothermometry studies of ancient evaporites revealed unusually high paleobrine temperatures (Benison & Goldstein, 1999; Wang & Lowenstein, 2017; Zambito & Benison, 2013; Zhang et al., 2015; X. Zhao et al., 2022; Y. Zhao et al., 2014) and upsection warming (Braitsch, 1964), pointing to hot or warming climates. Furthermore, the occurrence in many evaporite deposits of highly soluble salts, especially halite and potash salts, has been interpreted as evidence for arid climates (Chaboureaud et al., 2012; Kinsman, 1976; Schreiber & El Tabakh, 2000; Warren, 2010). The apparent scarcity of such hot–arid climate conditions has led some studies to invoke non-evaporative drivers of salt-giant formation, e.g. hydrothermal processes (Chaboureaud et al., 2012; Debure et al., 2019; Hovland et al., 2006).

Understanding whether halite and potash salts require truly arid conditions hinges on H_2O activity (a_{H_2O}). a_{H_2O} is a thermodynamic quantity that measures how much the chemical potential of water in solution differs from pure water, and decreases with brine concentration. Precipitation of highly soluble salts only occurs for low values of a_{H_2O} . a_{H_2O} also influences evaporation: evaporation rate is proportional to the water–air vapor pressure difference, $a_{H_2O} P_{\text{vap,sat}}(T_s) - RH P_{\text{vap,sat}}(T_a)$, where RH is the relative humidity of the overlying air, T_s

84 and T_a are the temperatures of water surface and air, respectively, and $P_{\text{vap,sat}}$ is saturated vapor
85 pressure (Salhotra et al., 1985). According to this relation, in a brine that concentrates through
86 evaporation, evaporation rate decreases with $a_{\text{H}_2\text{O}}$, and becomes null when $a_{\text{H}_2\text{O}} P_{\text{vap,sat}}(T_s)$
87 equals $RH P_{\text{vap,sat}}(T_a)$. In a system with identical water and air temperatures, this equality
88 occurs for $a_{\text{H}_2\text{O}} = RH$. This equality is the underlying assumption for the arid-climate origin of
89 halite and potash salts. However, still according to the water–air vapor-pressure difference
90 relation, when water is warmer than the overlying air, evaporation can be sustained even when
91 $a_{\text{H}_2\text{O}}$ is below atmospheric RH . As, according to the Clausius-Clapeyron relation, $P_{\text{vap,sat}}$
92 increases by ~7% per additional degree Celsius, warm water relative to the overlying air can
93 enhance evaporation considerably (d’Ans, 1947; Oroud, 2019). Amplification of evaporation via
94 the water–air temperature difference, hereafter termed Clausius-Clapeyron (CC) amplification,
95 has not yet been applied to the genesis of salt giants.

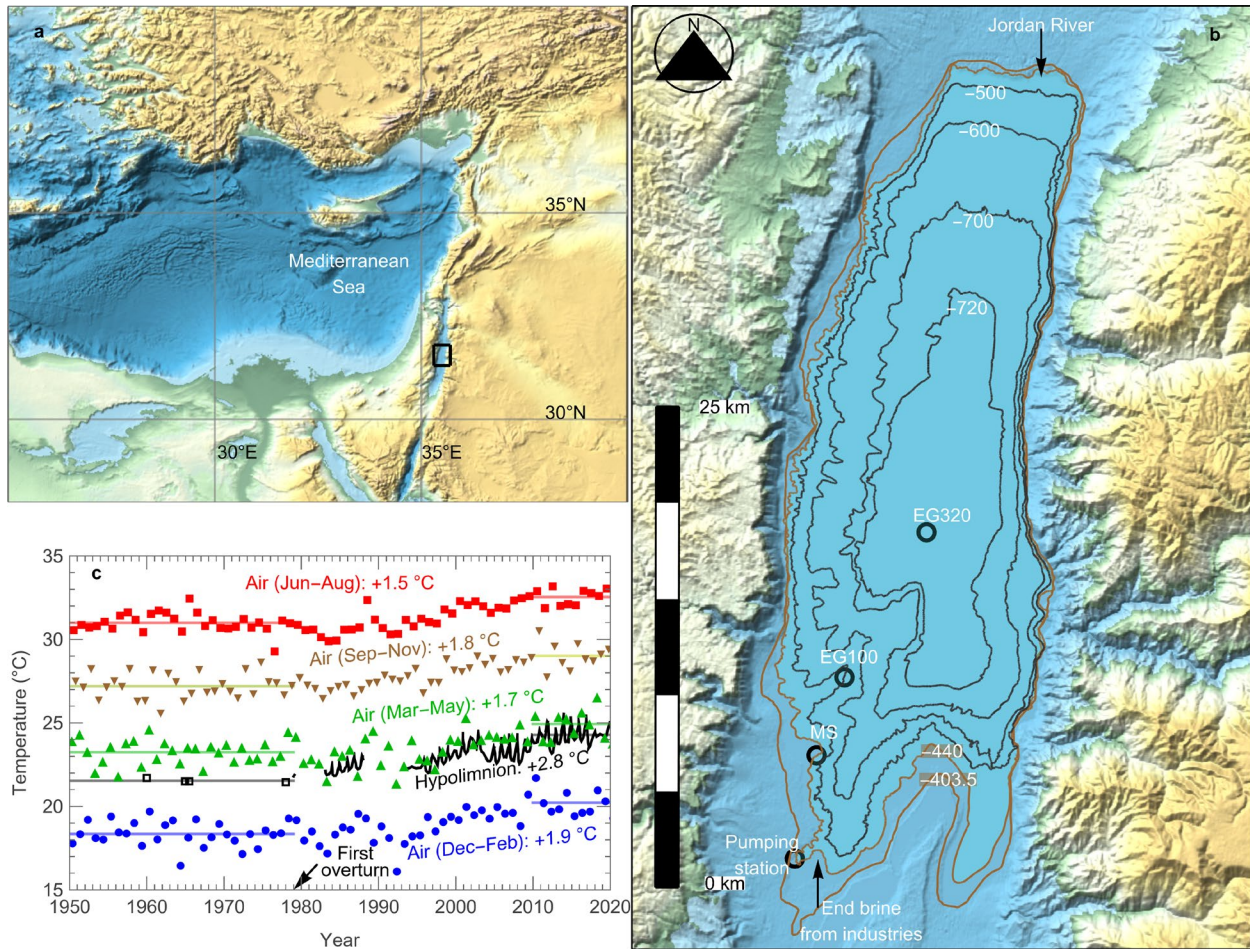


Figure 1. Geographic, hydrographic and climatic settings of the Dead Sea. *a*, Eastern Mediterranean map; Dead Sea area (black rectangle) enlarged in *b*. *b*, -403.5 and -440 m asl represent lake level in 1985 and 2025, respectively. Circles: stations mentioned in the text. *c*, Evolution of air and hypolimnion temperatures in the Dead Sea (source: see Text S5). Warming is calculated as temperature difference between 2010–2019 and 1950–1978.

As the only halite-saturated deep lake on Earth (Sirota et al., 2016), the Dead Sea (Fig. 1a,b) is a unique natural laboratory for studying the hypersaline waterbodies that formed salt giants (Meiburg & Lensky, 2025). Since 1979, when the lake switched from meromixis to monomixis (i.e. from a permanent to a seasonal stratification with one annual mixing) and became halite-saturated (Steinhorn, 1983; Steinhorn et al., 1979), the Dead Sea has experienced extreme water warming. In the 4 decades that followed, the temperature of the upper water layer—the epilimnion—rose at a rate of $\sim 0.5\text{--}0.6\text{ }^{\circ}\text{C}/\text{decade}$ (Arnon et al., 2016; Kishcha et al., 2018; Stanhill, 1990), a warming rate comparable to that of the air (Fig. 1c) and well above the

regional lake surface water warming rate (~ 0.35 °C/decade) (Tong et al., 2023). Even more striking, the temperature of the deep water layer—the hypolimnion—rose by 2.8 °C (Fig. 1c), hence among the fastest-warming lacustrine deep waters in the world (Pilla et al., 2020).

The causes of this rapid warming remain unresolved. Several studies estimated surface fluxes and storage of heat in the Dead Sea (Lensky et al., 2005; Oroud, 2023; Stanhill, 1990, 1994) but covered only short time intervals of the late 20th century and/or assumed stationary climate. However, several key factors affecting heat fluxes have changed significantly since the 1970s: lake level has dropped by ~ 40 m (Fig. S1), air temperature has increased by ~ 1.8 °C, RH peaked in the 1980s–1990s and has declined since, brine α_{H_2O} has dropped by ~ 0.03 (Fig. S3), and the lake experienced two short returns to meromixis since 1979 following exceptional floods.

One of the peculiarities of the Dead Sea heat budget is the large magnitude of diapycnal (i.e. vertical) fluxes of heat from the epilimnion to the hypolimnion, due to enhancement by double-diffusive (DD) salt fingering (Anati & Stiller, 1991; Arnon et al., 2016). DD salt fingering results from the characteristic summer stratification of deep monomictic hypersaline lakes, whereby the warm, salty epilimnion overlies the cooler, slightly fresher hypolimnion. As heat diffuses faster than salt, sinking salt fingers lose buoyancy and continue downward, transporting heat and salt across the interface (Radko, 2013). The consequence of these fluxes on the long-term temperature evolution of the Dead Sea have not been investigated.

To resolve the causes of Dead Sea warming, and to evaluate the long-term role of evolving diapycnal fluxes, climate and water level, we construct a physically-based model of deep hypersaline lakes. The model solves coupled epilimnion–hypolimnion heat budgets across monomictic and meromictic regimes, with diapycnal exchange resolved into separate double-diffusive, turbulent and molecular-diffusive terms. We calibrate the model on a short (2012–2015) instrumental record and validate it against four decades (1979–2019) of observations, an order-of-magnitude extension in time that lets the model be applied with confidence beyond the observational period. We run sensitivity tests to investigate the mechanisms behind the trends in water temperature and lake level. We then test two hypothetical waterbodies: a future Dead Sea under sustained greenhouse gas-driven warming and total inflow restriction, and a fully-disconnected eastern Mediterranean Sea. We evaluate how CC amplification,

diapycnal fluxes, water level change and air warming interact and whether these mechanisms can reproduce the paleotemperatures and mineral assemblages of the salt-giant record without invoking extreme aridity or a hydrothermal origin.

2 Methods

We explain here the general structure of the model, and further information can be found in Texts S1–5, Figs S1–3 and Tables S1–3.

The model has three modes: *monomictic stratified season*, *monomictic mixed season* and *meromictic*.

In *monomictic stratified season* mode, the model calculates the temperature of the epilimnion (T_e) and hypolimnion (T_h) by solving the ordinary differential equations

$$\frac{dT_e}{dt} = \frac{A_{DS} J_{surf} - A_h J_{D,T}}{V_e C_{p,w}} \quad (\text{Equation 1})$$

and

$$\frac{dT_h}{dt} = \frac{A_h J_{D,T}}{V_h C_{p,w}} \quad (\text{Equation 2})$$

J_{surf} is the net heat flux at the air-water interface; $J_{D,T}$ is the effective diffusion heat flux from the epilimnion to the hypolimnion, including DD, turbulent and molecular diffusive terms; V_e and V_h are the volume of the epilimnion and hypolimnion, respectively; A_{DS} and A_h are the area of the Dead Sea surface and of the thermocline, respectively; $C_{p,w}$ is the heat capacity of Dead Sea water; and t is time. Eqs. 1,2 are solved from the onset of stratification in March 15 until the overturn triggered by equality of the water-layer temperatures.

In *monomictic mixed season* mode, the model calculates the temperature of the mixed waterbody (T_{DS}) by solving the ordinary differential equation

$$\frac{dT_{DS}}{dt} = \frac{A_{DS} J_{surf}}{V_{DS} C_{p,w}}, \quad (\text{Equation 3})$$

where V_{DS} is the volume of the mixed waterbody. Eq. 3 is solved from the overturn until March 15.

In *meromictic* mode, the model solves Eqs. 1,2 as in the *monomictic stratified season* mode but the diapycnal heat flux is restricted to molecular diffusion.

In order to calibrate the parameters controlling the diapycnal heat flux, we use monitored water temperatures from a limited period: 2012–2015 (Arnon et al., 2016). This allows using monitored data outside the calibration period for model validation, as described in Section 3.1.

3 Results and Discussion

3.1 Model validation

To evaluate model performance, we run a baseline simulation of the Dead Sea. The model parameters are taken from the calibration (Section 2), but the starting point is now 1979. Using processed observation data as input (Text S5), we run the simulation until 2019. Meromixis is prescribed, according to surface water density and lake level observations, from November 1, 1979 to March 15, 1982 and from January 15, 1992 to March 15, 1996. Lake level is prescribed with the measured values (Fig. S1); by proceeding this way, we constrain water balance without relying on observation data of water fluxes, which are scant in the Dead Sea.

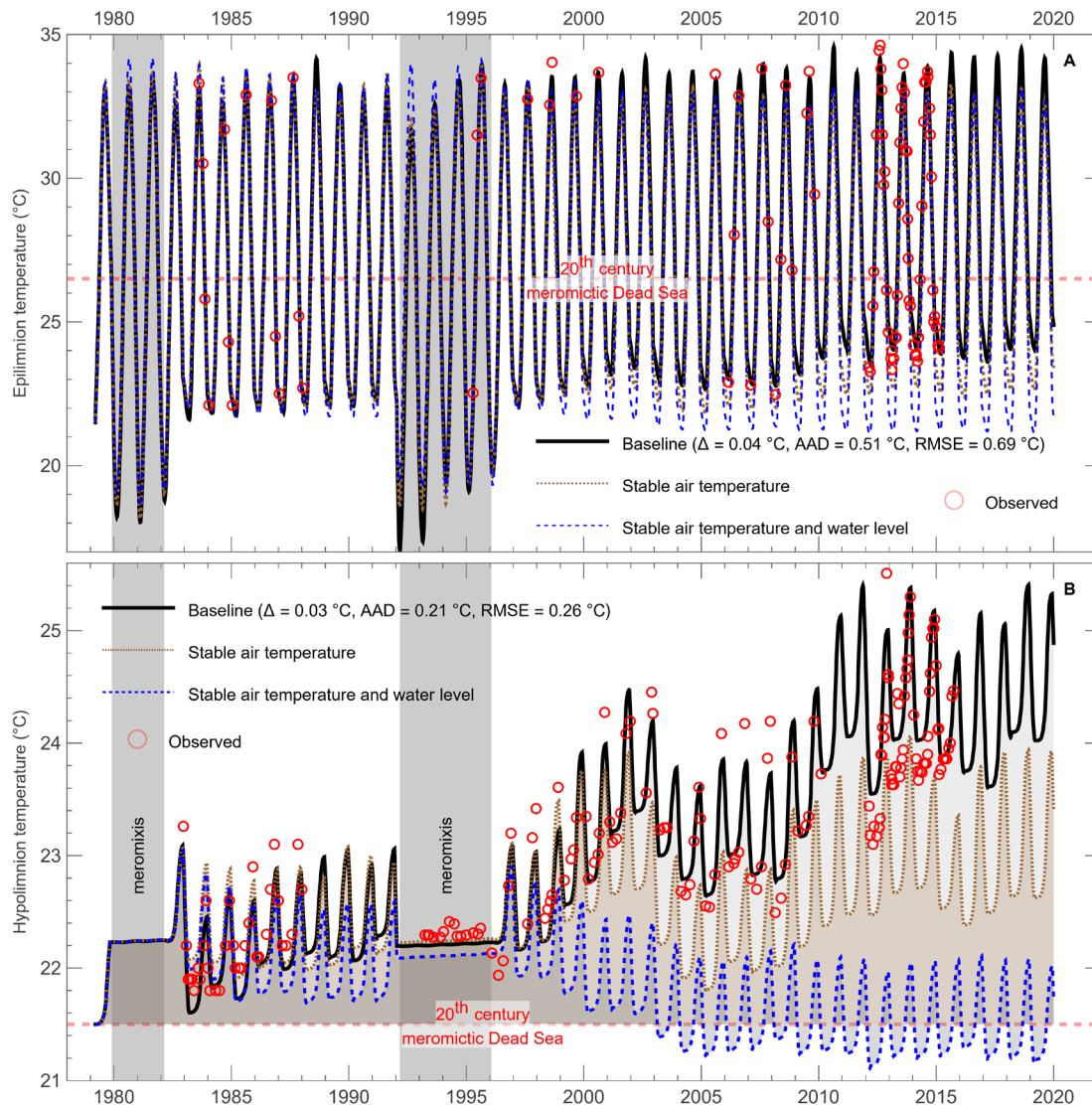


Figure 2. Epilimnion (A) and hypolimnion (B) temperatures of the Dead Sea in the baseline and sensitivity simulations against measurements. Epilimnion and hypolimnion temperature measurements are from water depth 7–15 m and ≥ 50 m, respectively (Text S5). Agreement between baseline simulation and measurements is indicated by mean bias (Δ), average absolute deviation (AAD) and root mean square error (RMSE).

Epilimnion and hypolimnion temperatures in the baseline simulation are in excellent agreement with observations (Fig. 2, Table 1). Statistical measures yield little bias and deviation between model and data. Simulated warming from the start of monomixis to the 2010s is in line with observations. Moreover, the model accurately captures the contrasting dynamical responses of

epilimnetic and hypolimnetic temperatures: sinusoidal and sawtooth patterns respectively during monomixis, and amplified and muted thermal variability respectively during meromixis (Figs. 2,S2). The annual overturn, which is a side product of the model, occurs around late November–December, consistent with observations (Fig. S4); it occurs earlier towards the end of the simulation, as expected from the excess warming of the hypolimnion relative to the epilimnion. Modeled net air–water heat flux also agrees closely with observations (Fig. S5).

Overall, the strong agreement of the baseline simulation with observations over a validation period more than 10 times longer than the calibration period, supports model reliability and justifies its application in sensitivity and projection simulations.

Table 1 – Summary of simulation results.

Simulation	End hypolimnion temperature (°C)*	Hypolimnion warming (°C)**	End epilimnion temperature (°C)*	Epilimnion warming (°C)**	End lake level (m asl)	Level change (m)
Dead Sea, observations (1979–2019)	24.3	2.8	28.2	1.7	-434.4	-34.1
Dead Sea, baseline simulation (1979–2019)	24.3	2.8	28.1	1.6	-434.4***	-34.1***
Dead Sea, sensitivity simulations (1979–2019)						
Thermocline depth +20%	24.5	3.0	28.2	1.7	-434.4***	-34.1***
Thermocline thickness -20%	24.8	3.3	28.2	1.7	-434.4***	-34.1***
No air warming	23.0	1.5	26.8	0.3	-434.4***	-34.1***
No lake level decline	22.8	1.3	27.6	1.1	-400.3***	0.0***
No air warming, no lake level decline	21.5	0.0	26.3	-0.2	-400.3***	0.0***
Projection simulations						
Dead Sea, high-emission scenario	41.1	19.6	46.3	19.8	-579.4	-179.1
Dead Sea, medium-emission scenario	36.0	14.5	41.1	14.6	-580.3	-180.0

Isolated Eastern Mediterranean Sea	41.1	16.9	46.4	18.8	-2894.9	-2494.9
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*Average of the last 10 years.

**Difference between last 10 years and initial state.

***Prescribed lake level.

3.2 Sensitivity simulations

In addition to the baseline, we run various sensitivity simulations, all starting in 1979, with all model parameters and input but one or two identical to the baseline simulations. Table 1 shows how the end values in 2019 are affected by the changes.

The sensitivity simulations with 20% deeper or thinner thermocline (Fig. S6) yield hypolimnion temperatures higher than in the baseline simulation and observations and exhibit a degraded agreement with observed hypolimnion temperatures. This suggests that thermocline depth and thickness, whose values in the model are based on observations in 2012 (Text S1, Table S1), have not significantly varied over 1979–2019.

To assess the combined impact of air warming and lake level decline, we run a sensitivity simulation with no air warming and no lake level decline. Compared to the baseline, air temperature is held constant at the 1950–1978 average annual cycle. Moreover, lake level is fixed at its 1979 value, hence constant volumes of the water layers, constant $a_{\text{H}_2\text{O}}$ (0.674) and suppressed DD heat flux.

Epilimnion and hypolimnion mean annual temperatures (Fig. 2) remain close to the temperatures of the upper and deep layers, respectively, of the 20th-century meromictic Dead Sea. Note that we attribute the 0.5 °C hypolimnion cooling from the 1980s to the 2010s to the decrease in RH (Fig. S3), which enhances evaporative cooling. The absence of long-term warming of the water layers in this sensitivity simulation confirms that this trend has been driven by air warming and lake level decline.

To isolate the respective contributions of air warming and lake level decline, we conducted two additional sensitivity simulations. Compared to the baseline, either air temperature was held constant at the 1950–1978 average annual cycle, or lake level was fixed at the 1979 value.

In the simulation with stable air temperature, the epilimnion and hypolimnion temperatures (Fig. 2) exhibit warming trends less pronounced than in the baseline simulation. Comparison of the two simulations reveals that, by the 2010s, air warming contributed 1.3 °C to epilimnion and hypolimnion warmings. Comparison with the simulation with no air warming and no lake level decline reveals that, by the 2010s, lake level decline contributed 0.5 °C to epilimnion warming and 1.5 °C to hypolimnion warming. These values are confirmed by the simulation with fixed lake level (Fig. S7).

We first explore the mechanism by which lake level decline induces water warming during monomictic conditions. For the hypolimnion, two main processes are involved. During the winter mixed season, lower $\alpha_{\text{H}_2\text{O}}$ limits evaporative cooling. During the stratified season, increased salinity difference and volume ratio between the epilimnion and hypolimnion amplifies the warming effect of diapycnal fluxes. For the epilimnion, net cooling occurs during the stratified season due to enhanced diapycnal fluxes, but this is more than offset by net warming during the winter mixed season due to $\alpha_{\text{H}_2\text{O}}$ reduction, therefore lake level decline raises the annual average temperature of surface waters.

We now consider the impact of air warming on water temperature. For +1.8 °C of air warming on annual average, our sensitivity simulations reveal a warming of 1.3 °C in each water layer, hence a warming rate of 0.72 °C per 1 °C of air warming. The epilimnion response aligns with the global lake averages (Tong et al., 2023). Conversely, the hypolimnion response contrasts with the more complex, more indirect, and much weaker deep water–atmosphere coupling in deep freshwater lakes (Livingstone, 1993; Pilla et al., 2020), as best illustrated by the absence of recent hypolimnion warming in lake Kinneret (Rimmer et al., 2011), a deep warm monomictic freshwater lake close to the Dead Sea.

Two processes can explain the strong hypolimnion response to air warming in the Dead Sea.

First, compared to other lakes, diapycnal fluxes during the stratified period are enhanced by

double diffusion. This process transfers heat from the epilimnion to the hypolimnion and thereby enhances the deep-water–atmosphere connection. Second and most importantly, we suggest the long mixed period (3–4 months), with strong convection due to the large positive water–air temperature difference that supports surface cooling (Anati & Stiller, 1991), provides a strong deep water–atmosphere connection. The results of our simulations in which only the temperature of the air of one month is fixed (Text S6, Fig. S8) show that ~90% of air warming-driven hypolimnion warming occurs in November–March, supporting the major control of winter mixing on the deep water–atmosphere connection.

Given the amplified lake temperature response to ongoing level decline and air warming as demonstrated by our simulations, the question arises: how will the Dead Sea evolve in the coming centuries with ongoing water deficit and global warming?

3.3 Dead Sea projections

To anticipate the future evolution of the Dead Sea, we run two projection simulations until 2600 AD, accounting for greenhouse gas-driven air warming and assuming full hydrological isolation and uninterrupted monomixis. The input in these simulations differs from the baseline as follows. RH , wind speed and insolation remain stable at their 1950–1978 average annual cycle. α_{H_2O} is dynamically computed using the equations of Zilberman et al. (2017) that relate α_{H_2O} to lake level along the paths of dilution and evaporation of the modern waterbody. The annual air temperature oscillation follows the 1950–1978 average, while the annual mean increases due to anthropogenic air warming and lapse rate. In the “high-emission” projection, greenhouse gas-driven air warming rate is $+0.045\text{ }^{\circ}\text{C yr}^{-1}$, i.e. the average rate in 1979–2019, reproducing approximately the regional expression of the “pessimistic” scenario SSP3 7.0 of the IPCC (2021). We introduce a cap of $+10\text{ }^{\circ}\text{C}$ relative to 1950–1978 to test the effect of a halt in anthropogenic air warming. The “medium-emission” projection uses half the rate ($+0.023\text{ }^{\circ}\text{C/yr}$) and cap ($+5\text{ }^{\circ}\text{C}$) of the high-emission projection. In all projection simulations we solve for water level by equating the derivative of water level and the opposite of evaporation rate. This equation is an approximation, which we discuss in Text S7. We check that diapycnal heat fluxes

275 remain in the baseline range; in the opposite case, the assumption on thermocline thickness
276 would potentially break down (Fig. S11).

277 According to the projection simulations, the Dead Sea will undergo massive warming whatever
278 the emission scenario (Fig. 3A, Fig. S9, Table 1). In the high- and medium-emission scenarios,
279 water temperatures will rise at nearly double and triple the rate of air temperature until 2200,
280 respectively, and continue rising after 2200 despite the end of air warming. These water
281 warming rates suggest that lake level decline will remain a major driver of water warming
282 alongside air warming, contributing ~ 10 °C of water warming. This is mainly due to the
283 reduction of evaporative cooling linked to the decrease in $a_{\text{H}_2\text{O}}$. This strong warming effect of
284 reduced $a_{\text{H}_2\text{O}}$ in the simulations is supported by observations in the hypersaline ponds
285 surrounding the Dead Sea. There, a clear $a_{\text{H}_2\text{O}}$ –water temperature inverse relationship is
286 observed, and summer water temperatures in the range ~ 40 – 50 °C have been measured in the
287 most concentrated brines (~ 6 – 16 °C above warmest-month mean temperature) (Oroud, 1995)
288 (Fig. S10).

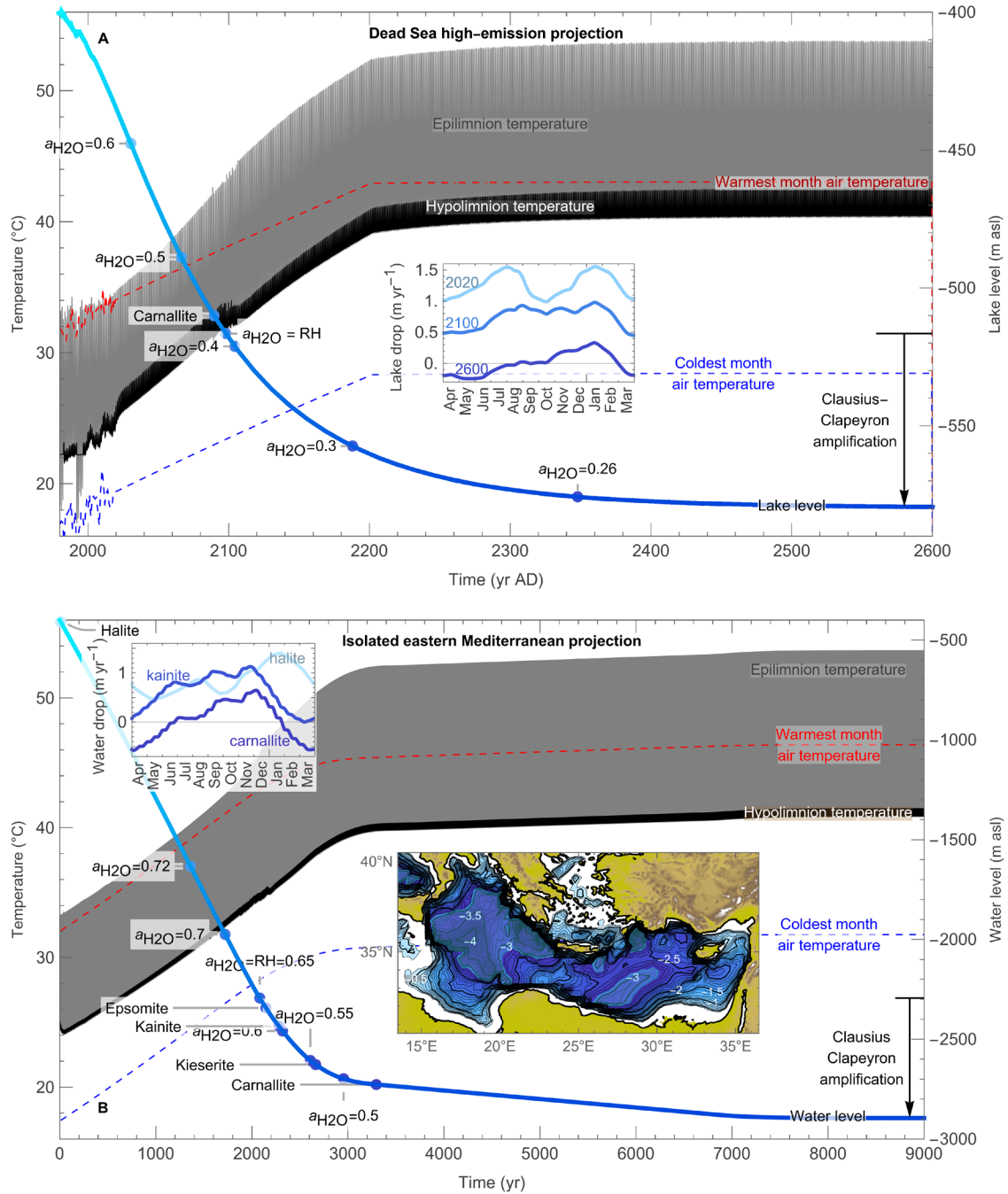


Figure 3. Water temperature and level projections for fully-restricted (A) Dead Sea in a scenario of high CO₂ emissions and (B) eastern Mediterranean Sea. (A) Baseline simulation is shown for the period 1979–2019. (B) In the map, elevation contours (in km asl) are shown up to the simulation's initial level, -0.4 km asl. Blue semi-opaque surfaces with blue contour at -2895 m asl show extent of final waterbody. (A,B) Discrete values of $a_{\text{H}_2\text{O}}$ and first saturation of

minerals help track the evolution of the evaporation process. Inset shows water level drop rate at simulation times indicated by time in years or by newly saturated mineral.

Still according to the Dead Sea projection simulations, the lake level drop will considerably exceed previous estimates. The lake level will reach -517 m asl when $a_{\text{H}_2\text{O}} = RH = 0.41$, in close agreement with previously estimated equilibrium lake level under no inflow and no potash production assumptions (Krumgalz et al., 2000; Zilberman et al., 2017). However, in our projections the lake will further decline to a lower equilibrium level of ~ -580 m asl, when $a_{\text{H}_2\text{O}} < RH - 0.15$, whatever the CO_2 -emission scenario. This lower equilibrium lake level stems from CC amplification of evaporation. CC amplification is particularly evident winter, as the annual maximum in simulated evaporation reflects particularly warm surface waters relative to the air. We identify a positive feedback loop of brine warming and shrinkage: water warming induces CC amplification of evaporation, which decreases $a_{\text{H}_2\text{O}}$, thereby reducing evaporative cooling and leading to more water warming. In deep brine bodies, this positive feedback loop is further amplified by diapycnal fluxes, which contribute more hypolimnion warming as summer evaporation rate is high and hypolimnion volume decreases. This feedback loop accelerates and extends waterbody drawdown, which raises a broader question: did similar thermal-evaporative feedbacks occur in ancient restricted seas that formed salt giants?

3.4 Warming and shrinkage of isolated seas

Building on the findings from the Dead Sea, we apply our modeling approach to simulate the eastern Mediterranean Sea under total hydrological restriction. The simulation is meant to explore how a large marine basin evolves if fully isolated from the ocean.

The simulation differs from the Dead Sea projections as follows. It begins with a brine-filled basin at -400 m asl, just below the depth of the Strait of Sicily that separates eastern and western Mediterranean basins, and uses a basin hypsometry derived from our digital elevation model (Fig. S1). The brine composition starts at first halite saturation of seawater—thus assuming a preliminary phase of partial sea restriction and brine concentration increase (see Aloisi et al., 2024)—and evolves with water volume as dictated by a chemical equilibrium simulation of seawater evaporation (Text S2). Air temperature follows the Dead Sea's 1950–

1978 annual cycle, adjusted with lapse rate. Latitude (34 °N), *RH* (65%), wind speed (6 m s⁻¹), and clearness index (60%) are set at modern eastern Mediterranean mean annual values. The waterbody is monomictic throughout the simulation.

Looking first at the heat budget, the simulated fully-restricted eastern Mediterranean Sea undergoes a warming of ~20 °C within ~8000 years, comparable in magnitude to the Dead Sea high-emission projection (Fig. 3B, Table 1). Part of this water warming originates from +14 °C of lapse-rate-driven air warming; this massive effect of lapse rate was not observed in the Dead Sea simulations owing to the different order of magnitude of water-level fall. The rest is the result of $\alpha_{\text{H}_2\text{O}}$ reduction and decreasing hypolimnion volume, like in the Dead Sea, in particular after 1500 years when the drop of the $\alpha_{\text{H}_2\text{O}}$ accelerates.

Looking then at the mass budget, the simulated fully-restricted eastern Mediterranean Sea drops by 2500 m in ~8000 years. CC amplification exacerbates drawdown like in the Dead Sea—here by an additional ~600 m. Moreover, CC amplification allows the precipitation of minerals that would have otherwise remained undersaturated, including potash salts (carnallite, kainite).

Our model suggests that the occurrence of potash salts, thick halite and high brine paleotemperatures, observed in many ancient evaporite deposits, are compatible with non-extreme climate states. Halite and potash-salt precipitations are simulated in the eastern Mediterranean despite relatively high *RH* (65%). High brine temperatures are simulated in the Dead Sea and eastern Mediterranean despite relatively mild ocean-level air temperatures. Neither hot and dry climate conditions, nor a hydrothermal origin, are necessarily required to explain the salt-giant record.

This reframing extends further: instead of low *RH*, the occurrence of potash salts can indicate warm paleobrine relative to the air, as CC amplification enables reaching $\alpha_{\text{H}_2\text{O}}$ lower than *RH*. In turn, instead of a hot ocean-level air, high paleobrine temperatures can indicate massive waterbody shrinkage, as concentration through evaporation reduces latent cooling. The warming effect of waterbody shrinkage is even greater in deep basins, where kilometeric drawdown generates lapse rate-driven air warming that is efficiently transferred across the waterbody via diapycnal fluxes and winter mixing. Given these expected trends, we propose to

use stratigraphic changes in reconstructed brine paleotemperature from fluid inclusions in halite as quantitative diagnostics of drawdown (Arnuk et al., 2024; Brall et al., 2022; Guillerm et al., 2020; Olson et al., 2023). The sensitivity of this paleothermometer to changes in water column height is further reinforced by the pressure-dependence of fluid inclusion density, which is quantified by physical models (Guillerm et al., 2025). Under this view, evaporite deposits that record upsection warming and increasingly soluble mineral assemblages may be archiving not intense climate warming, but the terminal collapse of the sea that left them behind.

Acknowledgments

We thank Nadav Lensky for fruitful discussions. We thank the reviewers, whose suggested revisions improved the robustness of our interpretations and better constrained their uncertainties. The authors acknowledge the following fundings: European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 101029939 (EG, TKL, AB); National Agency for Research in France, grant agreement No 2AZ52ACLIMS-Gardien (VG).

Open Research

The code of the model and data analysis, written in Wolfram Language, is available in the Wolfram Notebook Archive at <https://www.notebookarchive.org/2025-10-akyxqrn> (Guillerm, 2025). Input and output data of the simulations are available at the GFZ data repository at <https://doi.org/10.5880/gfz.avxh.2026.003> (Guillerm et al., 2026).

Conflict of Interest Disclosure

The authors declare there are no conflicts of interest for this manuscript.

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