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Article

Keywords:

Posted Date: October 20th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-11385025/v1>

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Additional Declarations: There is **NO** Competing Interest.

Explaining and anticipating global temperature surges by tracking heat

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Abstract

Earth’s energy imbalance (EEI) and El Niño heat release from the subsurface tropical Pacific play a critical role in the variability of the near-surface climate system. An unusually large increase in EEI followed by El Niño heat release caused the record global temperatures of 2023 and 2024, and both drivers were elevated again in 2026. Here we show that a heat budget built on these two drivers effectively explains observed global temperature throughout the Argo era, and yields a one-year outlook conditioned on the current El Niño state. We find that the two-year temperature decline from the peak at the end of 2023 was driven mainly by subsurface heat uptake, which reversed to heat release by mid-2026. The heat uptake was not enough to cool global temperature to the level before 2023, leaving global temperature substantially higher, and additional heat from EEI in early 2026 and the developing El Niño is projected to raise it further. If the El Niño heat release from the subsurface follows the 1997/98 path, the El Niño-year (July 2026–June 2027) global average temperature could reach 1.80 ± 0.06 K above the 1850–1900 baseline, 0.25 K above the record.

Main text

Global temperature stands at the 1.5 K warming level that the Paris Agreement pursues: the annual mean of 2024 exceeded 1.5 K above the 1850–1900 baseline for the first time^{1,2}. Two physical drivers of global temperature therefore warrant attention, both of which acted in concert in the record years 2023 and 2024³. The first is the release of heat from the tropical-Pacific subsurface to the surface at the transition from a multi-year La Niña to a strong El Niño^{4–6}. The second is Earth’s energy imbalance (EEI), whose positive trend^{7–13} is accelerating the warming of the climate system^{14,15}. The superposition of these drivers caused an exceptional heat surge in the near-surface ocean and atmosphere in 2023/24³. Both drivers were elevated again in 2026, reminiscent of 2023

(Fig. 1b,c and Fig. 2). The elevated net radiation is concentrated at low latitudes, with the 30°S–30°N belt, which occupies only half of Earth’s area, accounting for 80% of the global-mean anomaly in 2022/23 and 87% in 2025/26 (Fig. 2). In both episodes the EEI anomaly is dominated by reduced shortwave reflection. Most of this shortwave gain is associated with clouds, but increased longwave emission partly offsets the cloud-related gain, leaving comparable net contributions from cloud and clear-sky changes (Extended Data Fig. 1).

Many previous studies have assessed the influence of El Niño and of global warming on global mean surface temperature (GMST) by regression on Niño indices^{16–18}, and such regressions also provide forecasts of the coming year’s GMST^{4,16}. Recently, a heat-budget analysis with EEI and the El Niño release of subsurface heat as the drivers was shown to explain the exceptional warmth of 2023/24³. This study analyzed the heat budget of the atmosphere and the upper 100 m of the ocean, together referred to as the near-surface reservoir. The heat content of this reservoir is the sum of the atmospheric energy and the upper-100 m ocean heat content (OHC). Heat budget analysis quantifies the contributions of individual drivers even when they are correlated, as is the case for EEI and El Niño^{6,19,20}. Their analysis, however, was applied to only three El Niño events over one-year periods, and did not show how the diagnosed variations of the near-surface heat translate into GMST.

Here we propose a monitoring framework and apply it throughout the past two decades to quantify how EEI and the vertical ocean heat exchange of El Niño and La Niña drive changes in near-surface heat content, which is tightly correlated with GMST. This framework allows us to decompose past changes in heat content into contributions of specific drivers, and to develop an outlook for near-surface heat content over the coming year, from which we estimate GMST.

Applied to the developing 2026/27 El Niño, this framework demonstrates how tracking heat through the climate system can provide a physically based outlook for near-term GMST.

Heat budget and its decomposition

The central quantity of the framework is the near-surface heat ($A+O_{100}$), the sum of the global atmospheric energy anomaly, A , and the global 0–100 m near-surface OHC anomaly, O_{100} (Methods). By combining the atmospheric energy and the upper-100 m OHC together, we do not need to directly estimate the air–sea heat flux, whose uncertainty is large^{21,22}. This near-surface energy co-varies with GMST ($r = 0.966$; Fig. 1d), and therefore the framework can be used to understand past and future GMST changes. For every month after a start month t_0 , the closed energy budget gives the change of ($A+O_{100}$) from its value at t_0 as the sum of three terms (Methods equation (2)). These terms are the heat exchanged with the tropical-Pacific subsurface layer at 100–300 m depth (Methods), representing vertical heat redistribution associated with the El Niño–Southern Oscillation (ENSO)^{23,24}; the time integral of EEI, accumulating excess energy received from space; and the integrated background heat taken up by the other reservoirs, including the deep ocean, land, and cryosphere. An increase in the subsurface heat-release term indicates heat release, whereas a decrease indicates heat uptake. To take into account the acceleration of Earth’s heat uptake^{14,25,26}, the background uptake is fitted as a linear function of time (Methods). This background uptake primarily represents heat storage in the ocean deeper than 100 m, where most of the excess energy associated with EEI accumulates^{27–31}.

The budget closes across the Argo era from the start month $t_0 =$ January 2008. The resulting reconstruction tracks the observed level of ($A+O_{100}$) over the 18 years with a correlation of 0.992, a root-mean-square error (RMSE) of 3.0 ZJ, and a variance explained fraction (VARF; Methods) of

98% (Fig. 3a; per-product reconstructions in Extended Data Fig. 2). This tight closure means that the evolution of the near-surface heat can be understood as the sum of the contributions of the three terms. Net radiation exceeding background heat uptake accounts for the long-term increase in near-surface heat.

The decomposition explains both the 2023/24 surge and the subsequent decline. The record-high heat in 2023/24 resulted from the combined effects of tropical-Pacific subsurface heat release and radiative input exceeding background heat uptake, consistent with Minobe et al.³. After the 2023/24 peak, near-surface heat declined steadily in 2024 and 2025. Although background uptake continued, its integral was exceeded by the integral of net radiation (Fig. 3d), so the decline mainly reflected heat uptake by the tropical-Pacific subsurface. This uptake was comparable to that following the 2015/16 El Niño, but followed a much larger release. Consequently, subsurface OHC did not recover to its pre-surge level, as it had after earlier events (Fig. 3b–d). The subsequent subsurface heat uptake therefore only partly offset the preceding release, leaving excess heat in the near-surface reservoir. This elevated near-surface heat content provides an important initial condition for the outlook for the developing El Niño below.

One-year outlook

We construct a one-year outlook by evaluating equation (2), starting in August 2026. The initial value of near-surface heat on the left-hand side is taken from observations. The EEI is estimated from its linear trend, the background uptake from the linear increase determined above, and the subsurface release from scenarios about its future evolution (Methods).

We consider two scenarios: the first is based on the largest observed subsurface heat release, and the second is an idealized case with no further release. Because El Niño heat release is

quantified using tropical-Pacific subsurface OHC, we can use observations dating back to 1995, following completion of the TAO mooring array³². Of the eight El Niño events since 1995, seven have a distinct heat-release peak (Fig. 4). The largest one-year release is 52 ZJ (48 ZJ after applying a three-month running mean), observed in 1997/98. In the first scenario, the one-year release matches this amount, with the release peak set to January 2027 (Methods). In the second scenario, subsurface heat content is fixed at its August 2026 value to assess how much warming can occur without further heat from the subsurface ocean.

The two projected trajectories of near-surface heat, ($A+O_{100}$), reach maxima of 94 and 72 ZJ (Fig. 5a), corresponding to GMST values of 1.94 and 1.74 K relative to the 1850–1900 baseline, respectively (Fig. 5c). Both values exceed the previous monthly record of 1.62 K. The record is thus projected to be broken even if the tropical-Pacific subsurface releases no further heat. Without further release, near-surface heat rises monotonically, because net radiation exceeds the background heat uptake, reaching its maximum at the end of the outlook period in July 2027. The 1997/98-based outlook reaches its maximum in February 2027, one month after the January peak in subsurface heat release. How warm 2026/27 becomes therefore depends mainly on how much heat the tropical-Pacific subsurface releases.

To assess the dependence of the 1997/98-based outlook on issue month, we also compute outlooks using observational records truncated at the end of March, April, May, June or July 2026, refitting the EEI trend and background heat uptake for each month. Across the six issue months from March to August, the projected monthly GMST maximum varies by less than 0.04 K, much less than the projection uncertainty (Extended Data Fig. 3). Assessing how likely this outlook is to materialize requires guidance from El Niño forecasts, which can change substantially with the issue month. For example, NOAA/CPC’s probability of a very strong El Niño rose from at most 25% in

April to 100% in October. Nevertheless, the stability of the outlook across issue months makes it a useful reference for interpreting the implications of these evolving forecasts for future GMST. It is also interesting to note that the March outlook also closely follows GMST estimated from the subsequently observed near-surface heat through the end of the record.

Annual-mean outlooks

The calendar-year 2026 mean GMST is projected to exceed the 2024 record by 0.02–0.05 K across the two scenarios (Fig. 6). More importantly, 2026 is the onset year of the El Niño, as 2023 was, and both projections exceed the 2023 mean value by 0.10–0.13 K, suggesting that GMST during the present event may be higher than during the 2023/24 event.

We also examine the projected 12-month mean GMST from July to June^{4,16}, a period referred to here as an El Niño year. This period may capture the influence of El Niño better than a calendar year because El Niño typically peaks in boreal winter. The outlook for the 2026/27 El Niño year with no further release gives a mean GMST of 1.69 K relative to the 1850–1900 baseline, clearly exceeding the 2023/24 record of 1.55 K. With heat release following 1997/98, the projected mean GMST reaches 1.80 K, exceeding the previous record by 0.25 K. Consequently, the present framework suggests a new GMST record for the 2026/27 El Niño year, with a substantial margin if subsurface heat release is comparable to that during 1997/98.

Implications for climate monitoring and model evaluation

The framework offers a transparent physics-based form of climate monitoring. Because it rests on a heat budget, changes in near-surface heat can be decomposed into the contributions from EEI, tropical-Pacific subsurface heat exchange, and background heat uptake. Through the observed

relationship between near-surface heat and GMST, this decomposition also helps explain global temperature variations. Updated regularly and incorporated into climate assessments, the decomposition would help a wide audience, including policymakers, understand the variations of GMST and how they are related to the net radiation that the Earth receives and El Niño-La Niña cycles. The outlook adds a forward-looking perspective, providing valuable advance warning of projected variations and extremes of near-term GMST.

The closure of the heat budget underlines the importance of the observing networks. CERES for TOA radiation³³ and Argo for the global ocean³⁴ provide essential information for the heat budget, and the TAO/TRITON moorings³² extend the record of subsurface heat release back to 1995, before Argo. The moorings remain important even in the Argo era: withholding their observations from assimilation degrades analyses of the equatorial thermocline and forecasts of El Niño^{35,36}. Our results highlight the importance of sustaining the global observing system, including CERES, Argo and the TAO array, to explain changes in near-surface heat and inform outlooks for global temperature.

It is also important to assess whether state-of-the-art climate models capture the relationships among EEI, tropical-Pacific subsurface heat exchange, near-surface heat and GMST. With global temperatures now close to the Paris Agreement's 1.5 °C level, accurately representing these processes is important for understanding and predicting year-to-year variation, including in model-based forecasts³⁷. Previous studies have examined climate-model output for the OHC variability associated with El Niño³⁸, the trend and variability of EEI³⁹⁻⁴¹, and the relation between the two⁴². In particular, Tsuchida et al.⁶ reported that climate models reproduce a surge in EEI during the transition from a multi-year La Niña to an El Niño, as observed in 2023/24 and again in 2025/26. These studies, together with our findings, indicate that it is important to assess how well

models capture the combined contributions of EEI and tropical-Pacific subsurface heat exchange to near-surface heat and GMST. Moreover, El Niño events in climate models have been evaluated mainly using sea-surface-temperature indices^{43,44}, whereas evaluating them also in terms of subsurface heat exchange would help clarify how El Niño interacts with EEI to shape near-surface heat and GMST. By tracking heat through the climate system, the present framework connects the diagnosis of past temperature variations with an outlook for near-term GMST. Improving our ability to trace where heat goes, within and between the ocean and atmosphere, will be essential to understanding and anticipating changes in surface climate.

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Methods

Data

The following monthly data are used. TOA radiation is from CERES-EBAF Edition 4.2.1 (March 2000–July 2026; ref. ³³; see also ref. ⁴⁵). OHC is computed for the 0–100 m, 0–300 m and 0–2000 m layers, both globally and over the tropical Pacific (100°E–80°W, 20°S–20°N), from three products: ORAS5⁴⁶, EN4 v. 4.2.2⁴⁷, and the Institute of Atmospheric Physics (IAP) ocean analysis v. 4.2⁴⁸, all used through August 2026, the latest month available across all three products at the time of analysis (October 2026). For EN4 we use the mean of its four bias-correction variants. OHC is derived with the TEOS-10 gsw toolkit from potential temperature and salinity for ORAS5 and EN4, while IAP provides layer OHC directly. The heat-budget analysis begins in January 2008, following the Argo array’s attainment of its design target of 3000 floats in November 2007³⁴. Atmospheric energy, the sum of vertically integrated internal, latent, and potential energy, is calculated from ERA5⁴⁹; kinetic energy is neglected because its variability is much smaller than that of OHC^{3,50}. Anomalies are computed relative to the 2005–2024 climatology.

El Niño events are identified from the Relative Oceanic Niño Index (RONI) of NOAA/CPC, the Niño-3.4 index with the tropical (20°S–20°N) mean removed and a scale adjustment applied⁵¹, on a 1991–2020 base period. The El Niño and La Niña periods follow the NOAA/CPC operational criterion applied to that index. For Extended Data Fig. 4 we also use Niño-3, Niño-4 and relative versions of these indices, which we calculate from ERSSTv6^{52,53} following the procedure used by NOAA/CPC.

GMST, the blend of land near-surface air temperature and sea-surface temperature in which warming levels are conventionally expressed, is the mean of three products: Berkeley Earth⁵⁴, HadCRUT5⁵⁵ and NOAA GlobalTemp v6.1⁵⁶, all used through August 2026. Anomalies are calculated with respect to the 2005–2024 monthly climatology of each product. To express the outlook relative to 1850–1900, the difference between the 2005–2024 and 1850–1900 means, averaged over the three products, is added to these anomalies.

Time windows for 2022/23 and 2025/26 episodes

The time windows used for Fig. 2 and Extended Data Fig. 1 are chosen objectively for each driver (EEI for Fig. 2a,b; tropical-Pacific 100–300 m OHC for Fig. 2c,d). We calculate five-month running means for EEI and three-month running means for the three-product mean OHC from the unsmoothed monthly anomalies. For each driver, we identify the maximum running-mean value in each of the two periods: 2022–2023 and 2025–2026 (through July 2026 for EEI and August 2026 for OHC). The consecutive months contributing to each maximum define the time window for that episode. The OHC windows match the three-month smoothing used throughout, while the longer EEI windows capture elevated EEI lasting several months, because EEI enters the budget as a time integral.

The near-surface heat budget

The diagnostic extends the event analyses of Minobe et al.³ to a continuous monthly time series. Over any interval, conservation of energy requires that the change in the total energy of the climate system equals the time integral of the net TOA radiation,

$$(A + O_{total} + L + I)(t) - (A + O_{total} + L + I)(t_0) = \int_{t_0}^t R dt' \quad (1)$$

where A is the global atmospheric energy, O_{total} the global full-depth OHC, L the land heat content, I the energy stored in ice and snow, and R the globally integrated net TOA radiation, obtained by multiplying EEI by Earth's surface area.

We split the ocean into the near-surface layer O_{100} (0–100 m), a subsurface layer O_{sub} , and the remaining ocean O_{rest} , and isolate the near-surface heat ($A+O_{100}$) on the left-hand side. This gives the reconstruction that is the main diagnostic of this work,

$$(A + O_{100})(t) - (A + O_{100})(t_0) = -[O_{sub}(t) - O_{sub}(t_0)] + \int_{t_0}^t R dt' - \int_{t_0}^t c dt' \quad (2)$$

The background uptake rate $c(t)$ accounts for the rate of change of ($O_{rest} + L + I$) together with any closure residual, including contributions of geothermal heating⁵⁷ and the smaller anthropogenic heat release⁵⁸, whose year-to-year variations are far below the uncertainty of the radiative integral. The seasonal cycle is removed from every variable entering equation (2), relative to 2005–2024. For R the mean-retained anomaly³ is used: the conventional anomaly plus the mean over the reference period, which retains the mean values over one or more complete years while removing the seasonal cycle.

The background uptake rate is fitted as a linear function, $c(t) = C_0 + \dot{C}(t - t_0)$ in equation (2), separately for each OHC product, given the documented inter-product differences in ocean heat uptake and its acceleration⁵⁹. The fitted rate of increase is $\dot{C} = +0.59 \text{ ZJ yr}^{-2}$ (+0.53 to +0.70 across products), equivalent to about 0.37 W m^{-2} per decade, so that $c(t)$ rises from about 7 ZJ yr^{-1} in 2008 to about 18 ZJ yr^{-1} in 2026 (Extended Data Fig. 2b), consistent with reported accelerations of

ocean warming^{14,25,26}. The skill metrics are the reconstruction RMSE and the fraction of variance explained, $VARF = 100 \left(1 - \overline{(\hat{y} - y)^2} / \overline{(y - \bar{y})^2} \right)$, where an overbar denotes an average over the evaluation period, y is the observed ($A + O_{100}$) anomaly, and $\hat{y}$ is its reconstruction from equation (2).

Choice of subsurface reservoir

We test two candidates for O_{sub} , the global 100–2000 m layer and the tropical-Pacific 100–300 m layer, the latter of which takes up and releases heat over the ENSO cycle. For each product, $c(t)$ is fitted as described above.

The tropical-Pacific 100–300 m layer yields lower reconstruction errors and more consistent results across products than the global 100–2000 m layer (Extended Data Fig. 2). This is consistent with previous studies reporting that the signal-to-noise ratio of OHC decreases below 300 m^{60,61}. We therefore adopt the tropical-Pacific 100–300 m layer as O_{sub} , which primarily represents the subsurface-to-surface heat exchange associated with the El Niño/La Niña cycle with very little long-term trend (Fig. 1c), while O_{100} and the background uptake represent the long-term ocean heat uptake.

Because tropical-Pacific subsurface OHC represents the influence of El Niño in our heat-budget framework, we compare its relationship with GMST against those of conventional SST-based El Niño indices. Correlations between the Niño indices and GMST peak when the indices lead GMST by three months, reaching 0.68 for Niño-3 and Niño-3.4 (Extended Data Fig. 4). At this lag, these correlations exceed those for subsurface OHC, suggesting that Niño-3 and Niño-3.4 may be better predictors of GMST three months ahead. The OHC products, however, have higher maximum correlations of 0.72–0.74 at zero lag. Although SST is itself a component of GMST, heat

content in the subsurface 100–300 m layer has a slightly stronger relationship with GMST than the SST-based Niño indices do. This finding supports the usefulness of subsurface OHC for relating El Niño to GMST within the heat-budget framework.

Outlook for the coming year

The outlook (Fig. 5) is obtained by integrating equation (2) from August 2026 (referred to as the reference month and denoted by t_1), the latest month available across all three OHC products, over the following twelve months to August 2027. Applying a centred three-month running mean gives the displayed outlook through July 2027. Beyond a year the spread of plausible ENSO outcomes grows too wide to be informative. We use the background heat uptake described above and estimate future EEI by extrapolating a linear trend fitted to the monthly mean-retained anomalies of observed EEI.

For the subsurface release, the least-constrained input, we consider two scenarios. In one, future monthly heat release is based on the observed release during 1997/98, with one-year heat release for 2026/27 being the same as that in 1997/98. Because part of this one-year heat release has already been observed and its value differs from that in 1997, we adjust future heat release using a rescaling constant, α :

$$O_{sub}^{max}(t) - O_{sub}^{max}(t_1) = \alpha [O_{sub}(t - \Delta) - O_{sub}(t_1 - \Delta)] \quad (for\ t > t_1) \quad (3)$$

where the superscript “max” denotes the assumption based on the largest observed release, and Δ is the 29-year time shift from 1997 to 2026. The constant α is determined so that the one-year heat release between January 1997 and January 1998 (Fig. 4) is reproduced in this scenario between January 2026 and January 2027 for each OHC product. For simplicity, the three-month running

mean is not used to estimate this constant. The other scenario is no further heat release ($O_{sub}^{min}(t) = O_{sub}^{min}(t_1), t > t_1$), allowing us to assess how near-surface heat and GMST could evolve without additional heat from the subsurface ocean.

Uncertainty

The uncertainties for the past budget analysis and future outlook are expressed as ± 1 standard deviation (s.d.), and are estimated as follows. The uncertainty of the historical budget in equation (2) is estimated from radiation and ocean terms. The uncertainty of the radiation is estimated using a $\pm 0.3 \text{ W m}^{-2}$ uncertainty on the monthly global-mean net flux, the scale of the Terra–Aqua difference, with the monthly errors taken as independent³. The uncertainty of the ocean terms is the standard deviation across the three OHC products; for the reconstruction we evaluate the ocean terms of equation (2) separately for each product and take the spread across the three. The total uncertainty is estimated by combining the uncertainties of the radiative integral and the ocean terms in quadrature. The uncertainty of the atmospheric energy is neglected, because it is expected to be smaller than the standard deviation of the atmospheric-energy anomaly (1.9 ZJ). Even if it were as large as that standard deviation, the uncertainty of the reconstruction (4.9 ZJ on average in Fig. 3a) would increase by only 7%.

The uncertainty of the outlook (Fig. 5) combines four contributions, each a function of the number of months (k) since the outlook reference month (t_1). First, uncertainty of the initial state, σ_{ini} , is given by the spread of the observed $(A+O_{100})(t_1)$ across the three products and is constant through the outlook. Second, the uncertainty of the EEI integral, σ_{EEI} , accounts for uncertainty in the extrapolated linear trend and in the residuals around it. Third, the uncertainty of the background uptake, σ_{upt} , combines two parts in quadrature. One is the closure error of the budget, σ_{clo} , which is

estimated by the RMSE between the reconstruction, essentially given by equation (2) from a starting month, s , instead of t_0 , $(A + O_{100})_s^{rec}$, and the corresponding observations across all available start months:

$$\sigma_{clo}^2(k) = \frac{1}{N-k} \sum_{s=t_0}^{N-k-1+t_0} [(\langle (A + O_{100})^{obs}(s+k) \rangle - \langle (A + O_{100})_s^{rec}(s+k) \rangle)^2], \quad (4)$$

where N is the number of months of the three-month running-mean (denoted by $\langle \rangle$) series from January 2008 to June 2026. The other is the standard deviation across the three OHC products of the time-integrated background uptake, after applying the three-month running mean. Fourth, the uncertainty of the subsurface heat release, $\sigma_{sub}(k)$, is the s.d. across the OHC products of the subsurface heat release for the 1997/98-based scenario, and is zero for the scenario with no further heat release.

The four contributions are assumed to be independent and are combined in quadrature,

$$\sigma_{AO}^2(k) = \sigma_{ini}^2 + \sigma_{EEI}^2(k) + \sigma_{upt}^2(k) + \sigma_{sub}^2(k). \quad (5)$$

At the projected maximum of near-surface heat for the 1997/98 scenario (February 2027), σ_{AO} is 7.7 ZJ with contributions, in descending order, of σ_{ini} , σ_{sub} , σ_{upt} , and σ_{EEI} (4.8, 3.6, 3.5, and 3.2 ZJ). Conversion to monthly GMST through the regression slope a adds the residual s.d. of that fit, σ_{conv} , in quadrature,

$$\sigma_{GMST}^2(k) = a^2 \sigma_{AO}^2(k) + \sigma_{conv}^2 \quad (6)$$

giving an uncertainty of 0.09 K at the projected GMST maximum.

For the 12-month means shown in Fig. 6, observed monthly GMST is used where available and projected values thereafter. Uncertainty in the observed months is neglected. For the projected

months, equation (6) includes uncertainty in the predicted near-surface heat, expressed in GMST units through the regression slope, and the scatter of observed GMST around the regression line. For the first term, we sum the monthly standard deviations, assuming only one independent value across all projected months. For the second, we estimate the uncertainty of the sum assuming one independent value per three projected months, based on the estimated decorrelation timescale. We combine these two uncertainties in quadrature and divide by 12 to obtain the uncertainty of the 12-month mean.

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466 Data availability

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468 [means?tab=overview](https://cds.climate.copernicus.eu/datasets/reanalysis-era5-pressure-levels-monthly-means?tab=overview)

469 ORAS5, [https://www.ecmwf.int/en/elibrary/80763-ocean5-ecmwf-ocean-reanalysis-system-and-its-](https://www.ecmwf.int/en/elibrary/80763-ocean5-ecmwf-ocean-reanalysis-system-and-its-real-time-analysis-component)
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479 ENSO strength forecast,

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481 Berkeley Earth, <https://berkeleyearth.org/data/>

482 HadCRUT5, <https://www.metoffice.gov.uk/hadobs/hadcrut5>

483 NOAAGlobalTemp, <https://www.ncei.noaa.gov/products/land-based-station/noaa-global-temp>

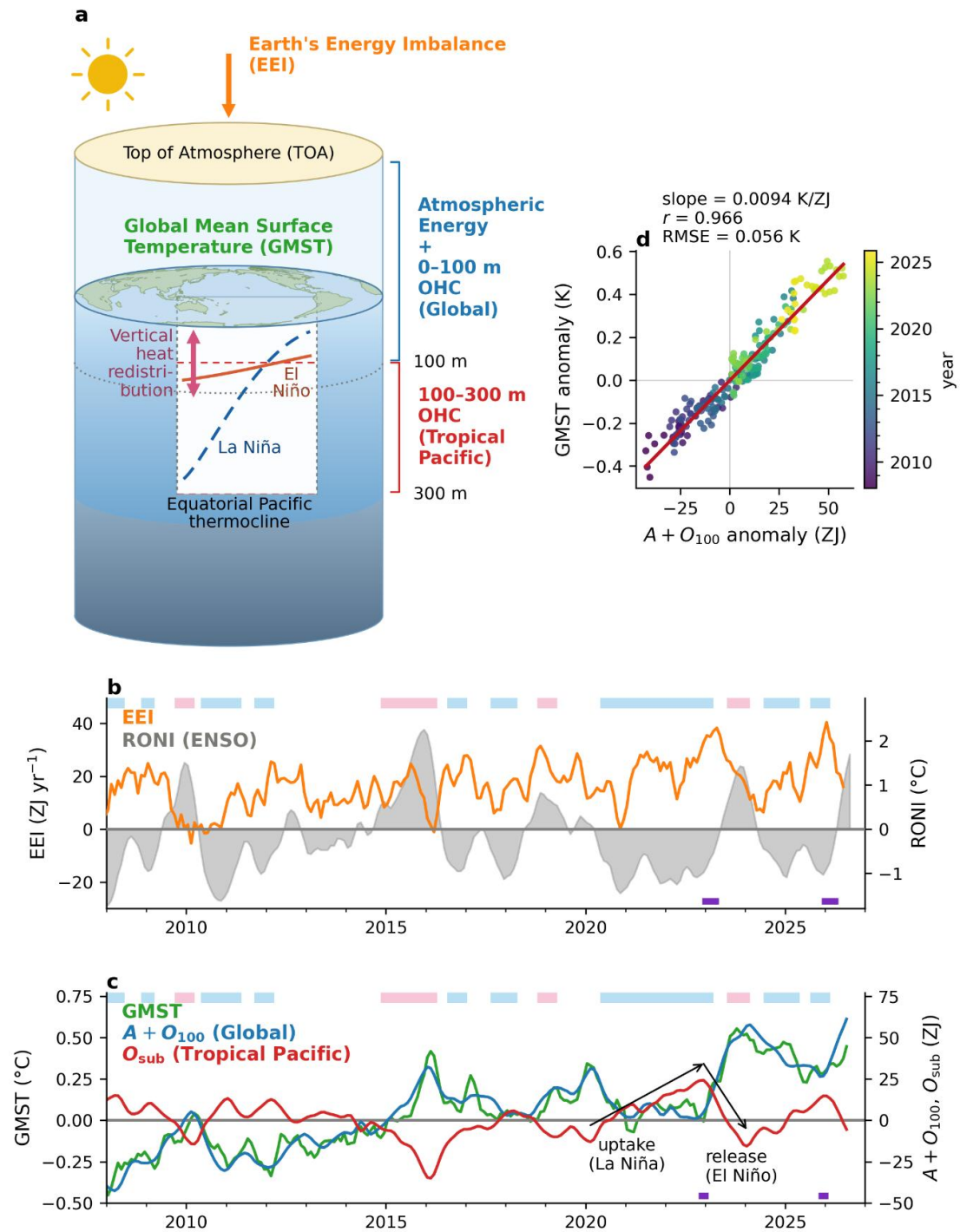
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485 Code availability

486 All code is available upon reasonable request to the corresponding author. The Python scripts that
487 reproduce the figures, together with the derived data series they read, will be deposited in Zenodo
488 upon publication.

489

490 Figures with captions



491

Fig. 1 | The near-surface heat reservoir, its drivers and its link to global surface temperature.

a, Schematic of the framework; the inset shows the equatorial Pacific thermocline tilting between El Niño (solid) and La Niña (dashed), redistributing heat across the 100 m level between the tropical-Pacific 100–300 m reservoir and the surface. **b**, EEI (orange, left axis) and the Relative Oceanic Niño Index (RONI; grey shading, right axis). **c**, GMST anomaly (green, left axis), globally integrated $A+O_{100}$ (blue) and the tropical-Pacific 100–300 m OHC (O_{sub} ; red, right axis). Arrows on the red curve mark the subsurface heat uptake during the 2020–2023 multi-year La Niña, and the heat release that followed into the El Niño. In **b,c**, the pink and blue bars along the top mark El Niño and La Niña periods. The OHC series in **c** are the three-product means (ORAS5, IAP and EN4.2); the purple bars at the bottom mark the episode windows mapped in Fig. 2. **d**, Regression of GMST against the near-surface heat: scatter of the GMST anomaly against $A+O_{100}$ over the Argo era (2008–2025; 3-month running means), coloured by year. The red line is the least-squares fit.

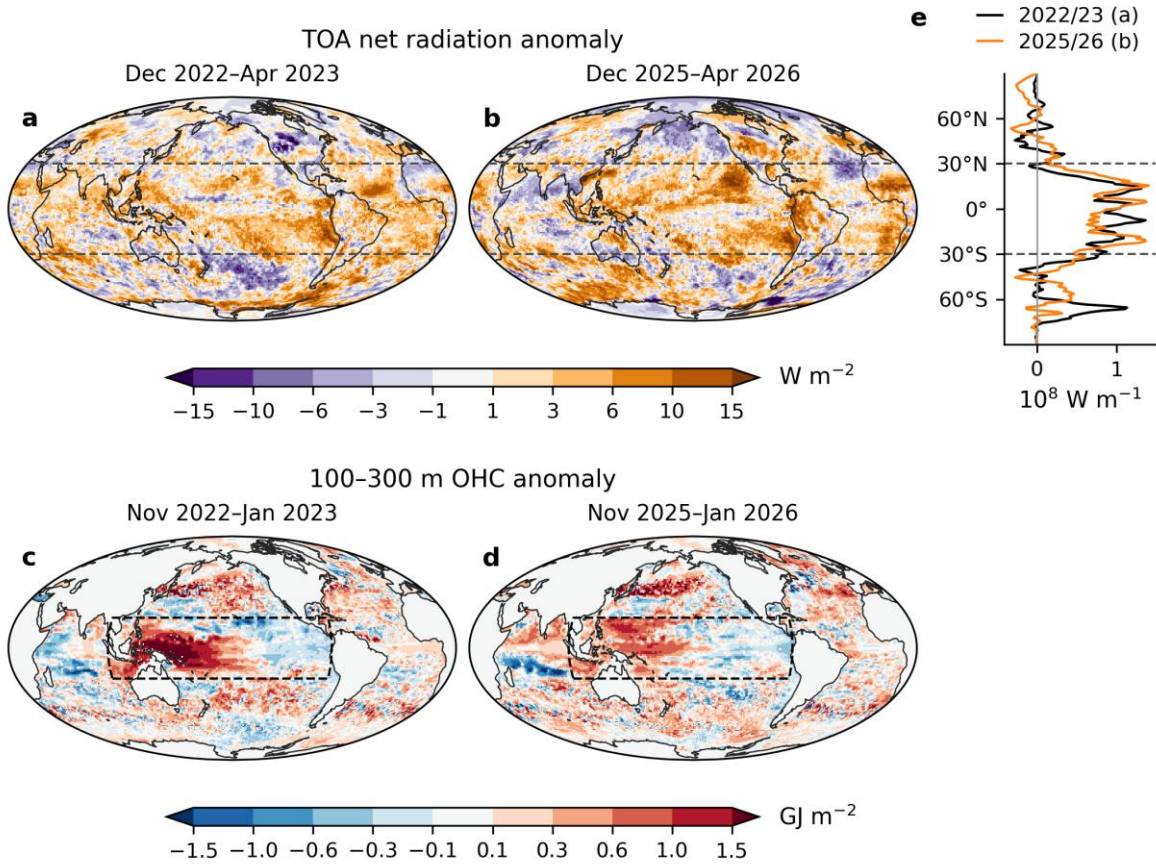


Fig. 2 | The 2022/23 and 2025/26 episodes in Earth's energy imbalance and subsurface ocean heat. **a,b**, TOA net-radiation (EEI) anomaly and **c,d**, 100–300 m OHC (ORAS5) anomaly, each averaged over time windows (**a**, Dec 2022–Apr 2023; **b**, Dec 2025–Apr 2026; **c**, Nov 2022–Jan 2023; **d**, Nov 2025–Jan 2026). The dashed box in **c,d** outlines the tropical-Pacific subsurface reservoir (100°E–80°W, 20°S–20°N). **e**, Zonal integral of the EEI anomaly of **a** (black) and **b** (orange); the dashed lines mark 30°S and 30°N, as in **a,b**.

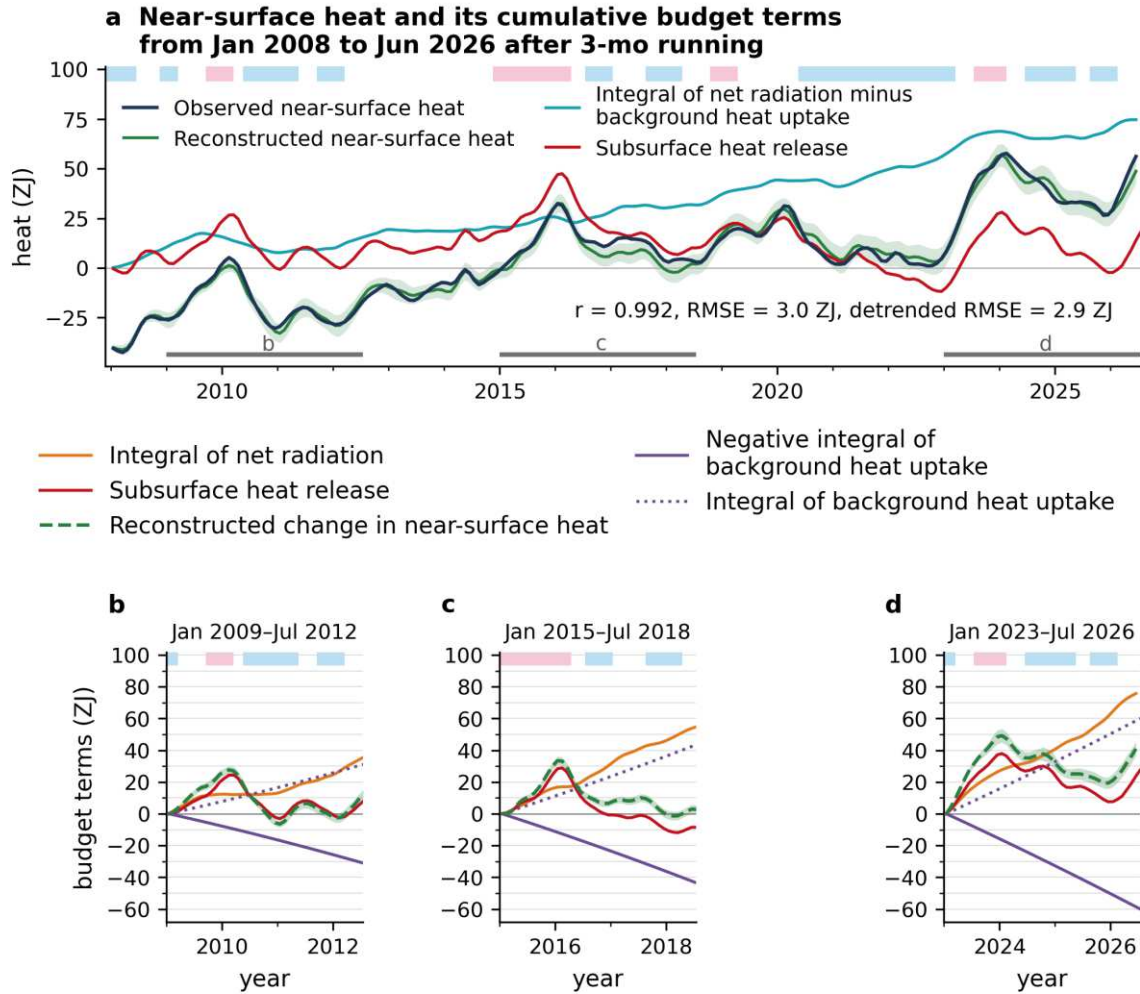
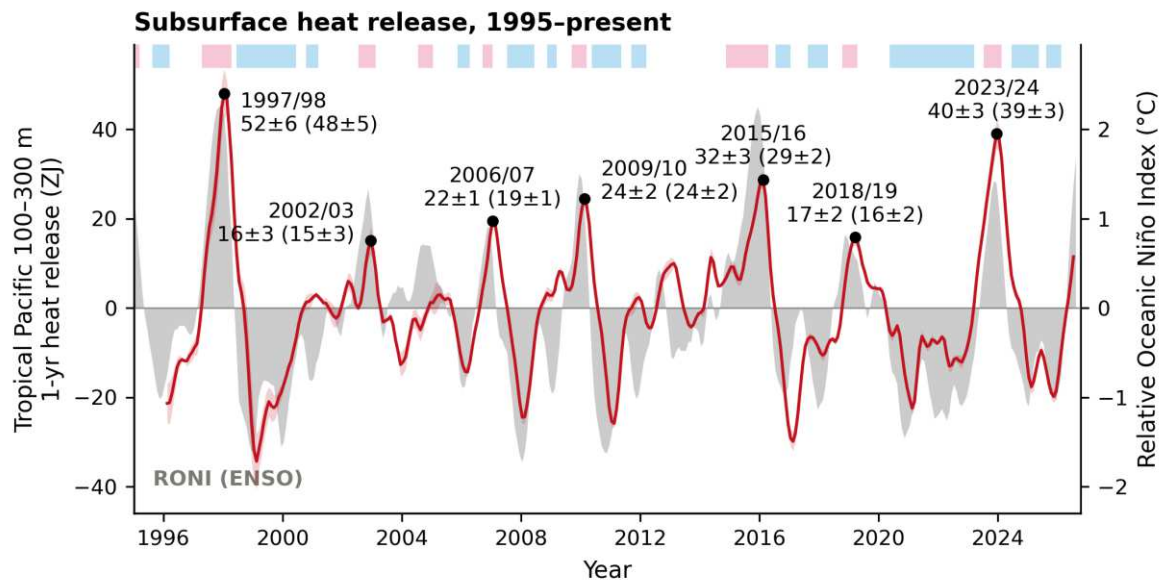


Fig. 3 | Near-surface heat budget. Time series are 3-month running means of monthly anomalies relative to the 2005–2024 climatology, in ZJ (1 ZJ = 10^{21} J). **a**, Observed (dark blue) and reconstructed (green) $A+O_{100}$. The integral of net radiation minus background heat uptake (light blue) is $\int_{t_0}^t R dt' - \int_{t_0}^t c dt'$, and subsurface heat release (red) is $-[O_{sub}(t) - O_{sub}(t_0)]$, with $t_0 =$ January 2008. The reconstruction equals the initial observed heat content plus these two contributions. Grey bars mark the time periods of **b–d**. **b–d**, Budget terms over three windows beginning in January 2009, 2015, and 2023, respectively, with each start month denoted by s :

519 integral of net radiation (orange), $\int_s^t R \, dt'$; subsurface heat release (red), $-[O_{sub}(t) - O_{sub}(s)]$;
 520 and negative integral of background heat uptake (solid purple), $-\int_s^t c \, dt'$. Their sum gives the
 521 reconstructed change in near-surface heat (dashed green). The dotted purple line shows the positive
 522 integral of background heat uptake for comparison with the radiative integral. Pink and blue bars
 523 along the top of each panel mark El Niño and La Niña periods as in Fig. 1. Green shading shows ± 1
 524 standard deviation (s.d.) uncertainty of the reconstruction. The uncertainty of the observed $A+O_{100}$
 525 in **a** is about one third of that of the reconstruction (4.9 ZJ on average), and the uncertainty of each
 526 term in **b–d** is less than 4 ZJ.

527



528

529 **Fig. 4 | Tropical-Pacific subsurface heat release since 1995.** The one-year subsurface heat
530 release, $O_{sub}(t - 1yr) - O_{sub}(t)$, for the tropical-Pacific 100–300 m layer, 1995 to the present
531 (three-product mean; red shading, inter-product spread). Release peaks are the largest local maxima
532 of at least 3 ZJ in the three-product mean, occurring between two months before and five months
533 after each El Niño RONI maximum. Positive values denote heat released upward to the near-surface
534 reservoir. Black dots mark the seven El Niño release peaks identified since 1995, annotated with the
535 peak value and the inter-product spread. The numbers outside and inside parentheses for each peak
536 are the one-year subsurface heat release without and with the three-month running mean,
537 respectively. The running means are also used for the dots and the curve. Grey shading is the RONI
538 (right axis), and the pink and blue bars along the top are the El Niño and La Niña periods defined
539 from it as in Fig. 1b,c.

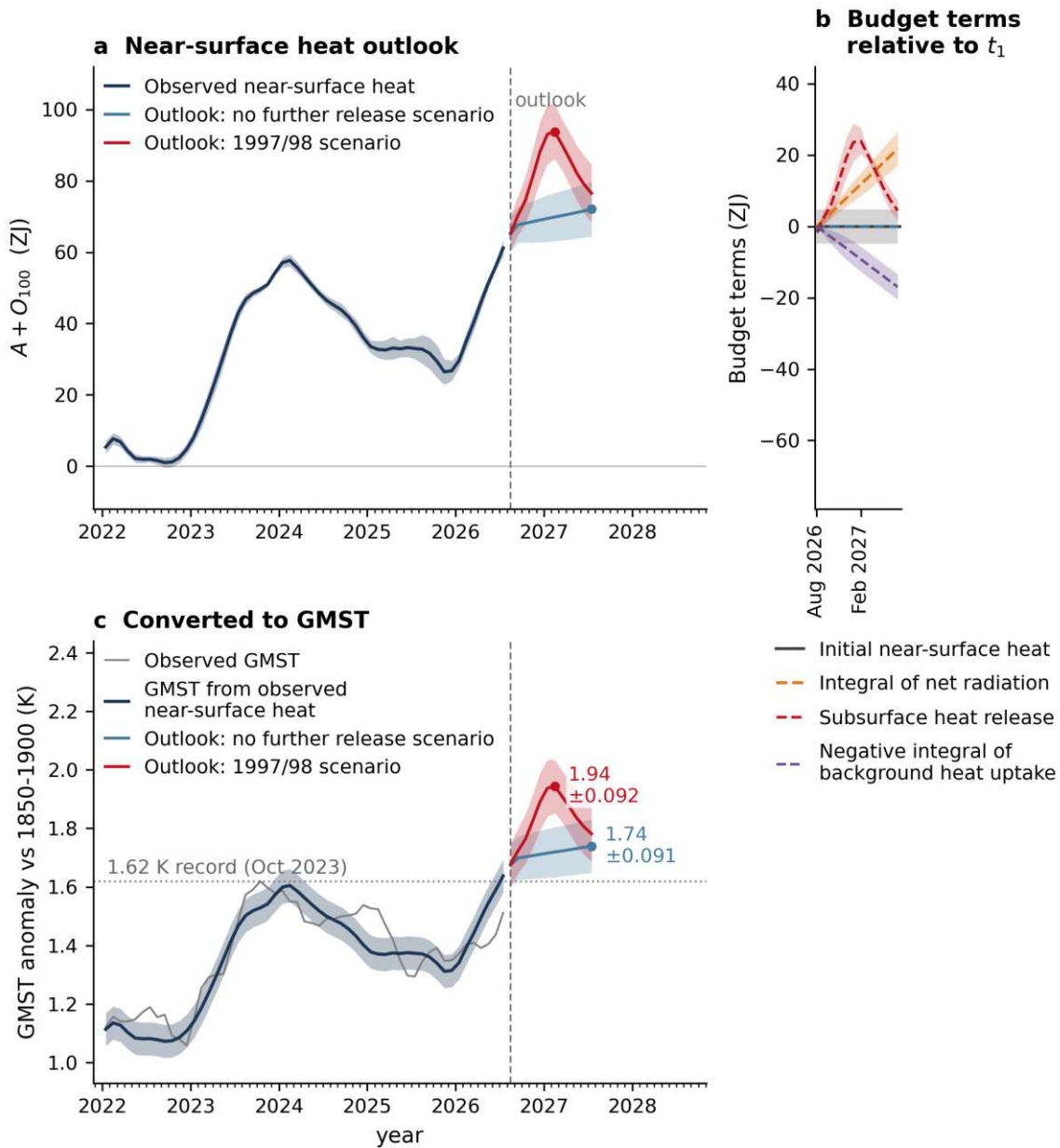
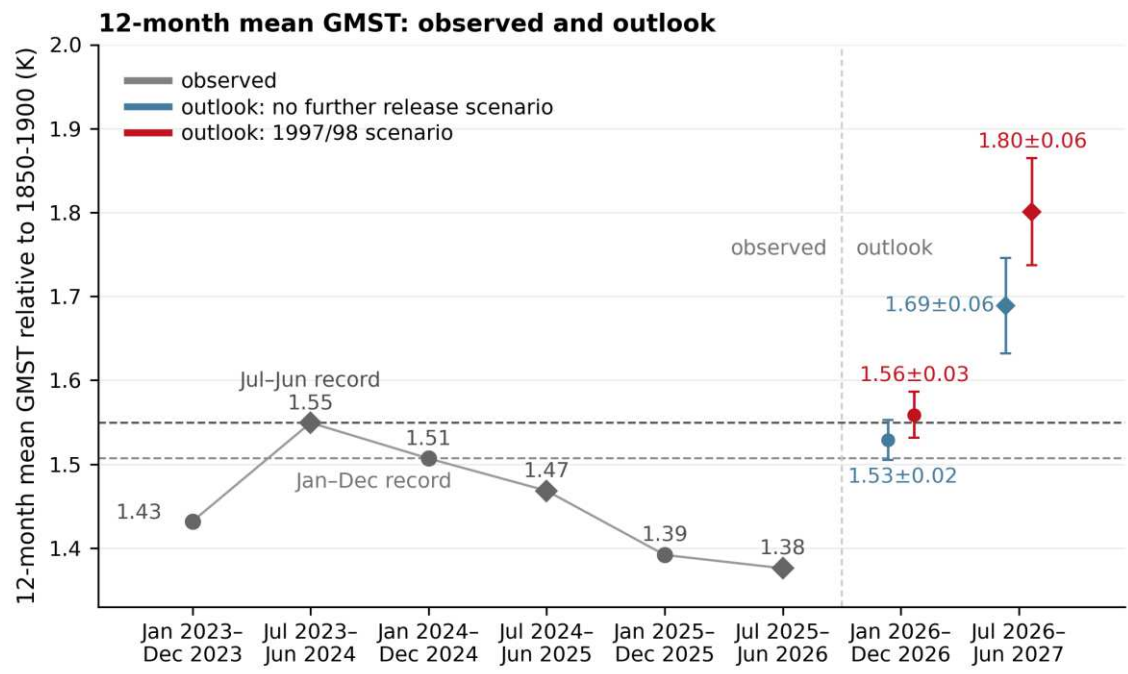


Fig. 5 | One-year outlook for the near-surface heat and GMST. **a**, One-year outlook for $A+O_{100}$. Following the observed series (dark blue, as in Fig. 3a), coloured lines are the projected trajectories for the two release scenarios. Filled circles mark each trajectory's maximum. Shading shows ± 1 s.d.: the inter-product spread for observed near-surface heat and the combined projection

uncertainty for each outlook. In **a** and **c** the vertical dashed line marks the outlook reference month,
 $t_1 = \text{August 2026}$. **b**, Budget terms expressed as changes from t_1 and drawn on the same vertical
scale as **a**: integral of net radiation (orange), $\int_{t_1}^t R dt'$; subsurface heat release (red for the 1997/98
scenario), $-[O_{sub}(t) - O_{sub}(t_1)]$; and negative integral of background heat uptake (purple),
 $-\int_{t_1}^t c dt'$. The grey line represents the initial near-surface heat in **a**, shown at zero here. Shading
shows the uncertainty of the initial state, projected radiative integral, subsurface release and
background uptake, respectively. **c**, The outlook as GMST on the 1850–1900 baseline: $A+O_{100}$
converted by the Argo-era regression (Fig. 1d). Observed GMST (grey) is the mean of three
products. Shading around GMST converted from observed near-surface heat (dark blue) shows the
regression residual standard deviation; outlook shading also includes the projected heat uncertainty.

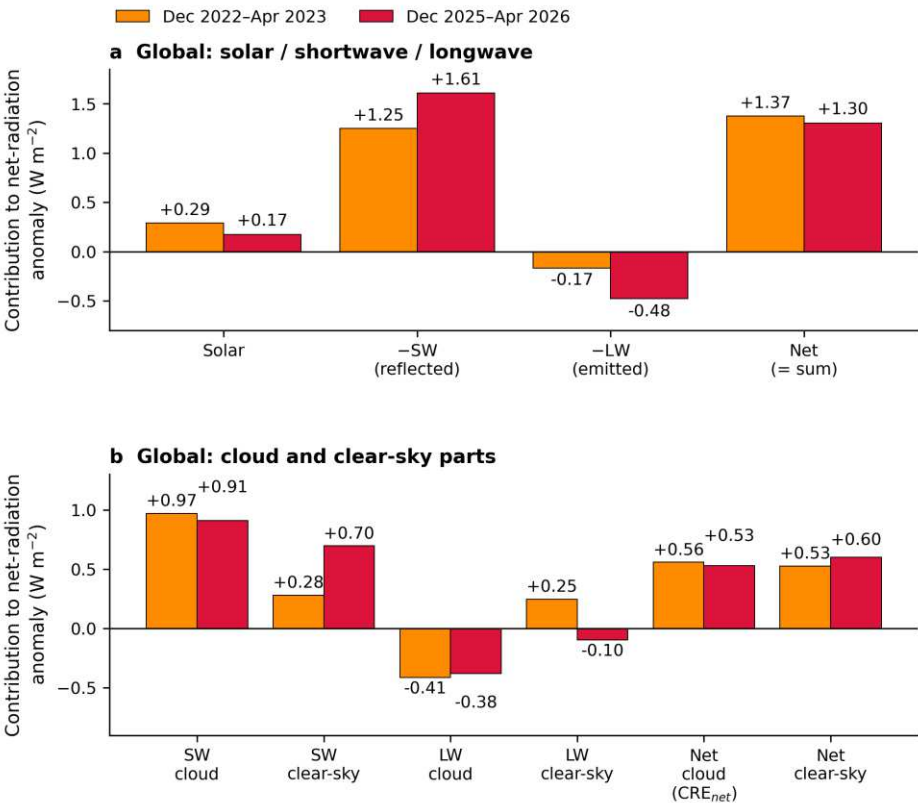
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557 **Fig. 6 | Twelve-month mean GMST: observed and outlook.** Observed 12-month mean GMST
558 relative to 1850–1900, alternating calendar years (circles, Jan–Dec) and El Niño years (diamonds,
559 Jul–Jun) from 2023 to 2025/26, followed by the outlook for calendar year 2026 and for the 2026/27
560 El Niño year under the two scenarios (blue: no further heat release, red: 1997/98 heat release) with
561 error bars indicating ± 1 s.d. projection uncertainty. Horizontal dashed lines mark the calendar-year
562 record and the El Niño-year record. The vertical dotted line separates observed means from the
563 outlook, issued at the August 2026 outlook reference time.

Extended Data

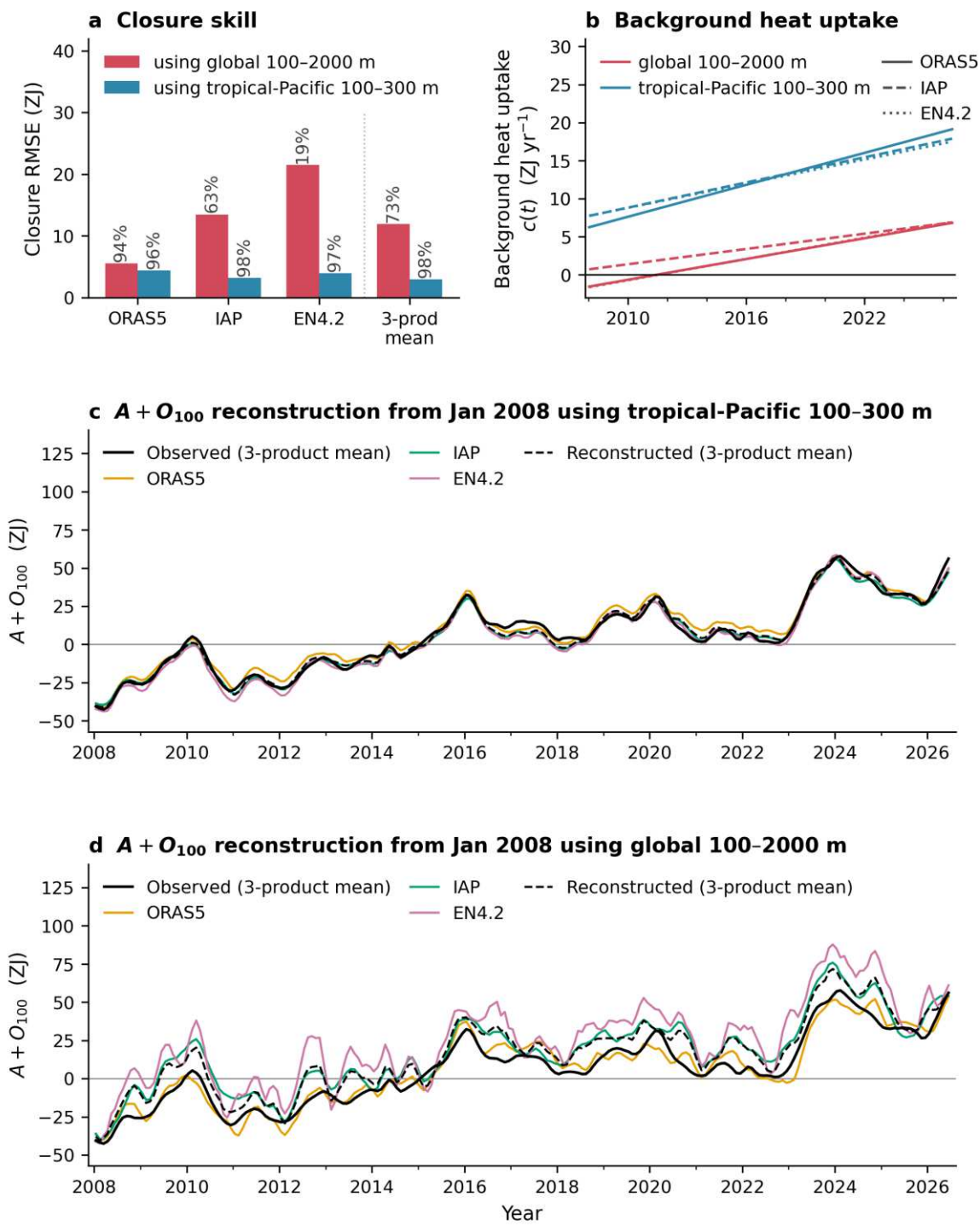


Extended Data Fig. 1 | Decomposition of the elevated EEI in the 2022/23 and 2025/26

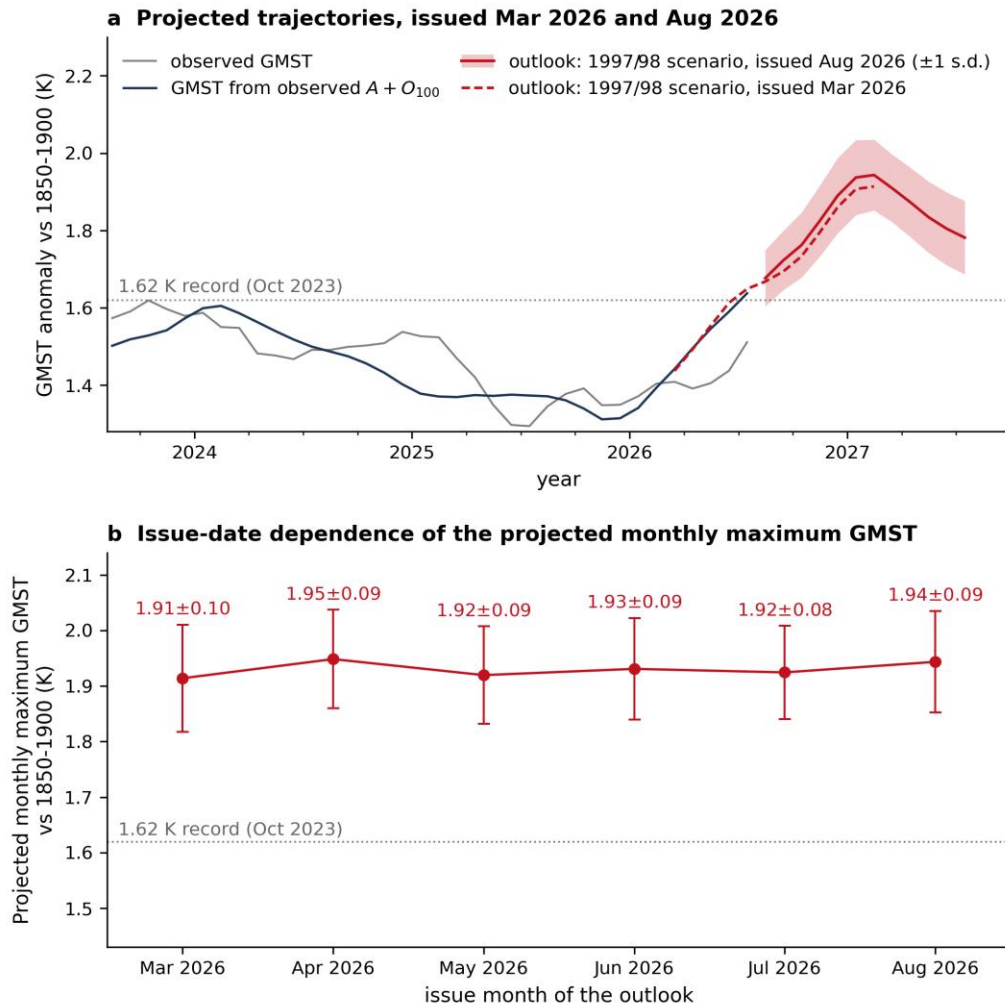
windows. a, Contributions to the global TOA net-radiation anomaly (W m^{-2}) from incoming solar radiation, reflected shortwave ($-\text{SW}$) and emitted longwave ($-\text{LW}$), averaged over the same five-month windows as Fig. 2a,b (December–April; climatology 2005–2024; CERES-EBAF).

Downward fluxes are defined as positive, and the sum of the three contributions gives the net

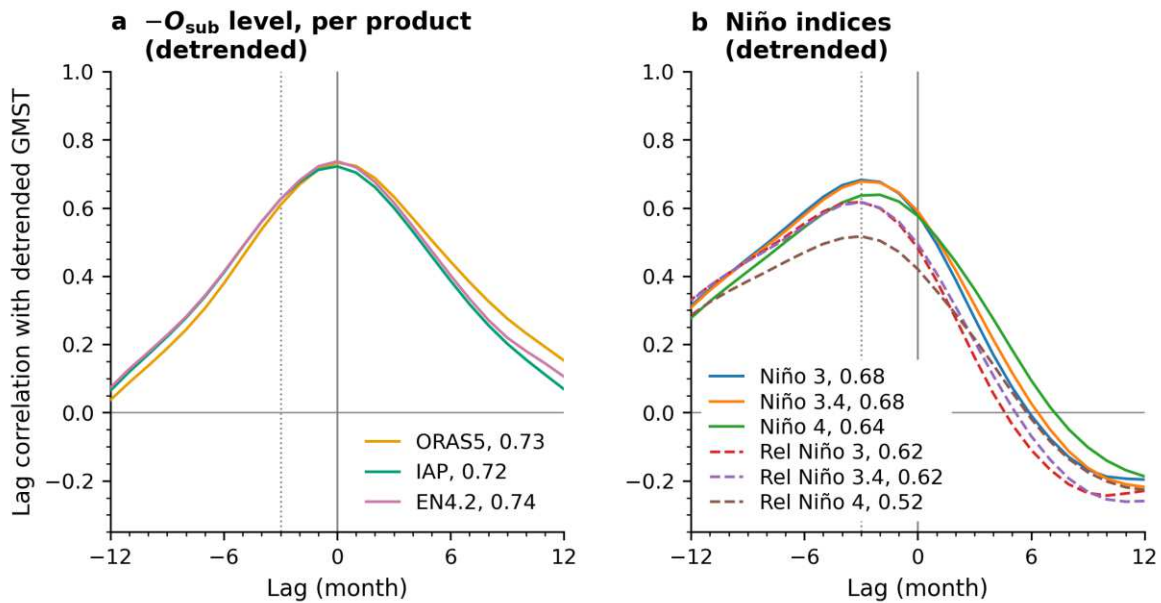
anomaly. **b**, Decomposition of the shortwave and longwave contributions into a cloud part (all-sky minus clear-sky) and a clear-sky part; CRE_{net} is the sum of the two cloud parts, that is, the net cloud contribution.



Extended Data Fig. 2 | Choice of the subsurface reservoir. Comparison of the two candidate definitions of the subsurface layer O_{sub} , the global 100–2000 m layer (red) and the tropical-Pacific 100–300 m layer (blue), for each of the three OHC products and for their three-product mean, over the evaluation period (January 2008 to June 2026). **a**, Skill of the reconstruction: RMSE, with the variance-explained fraction (VARF) annotated above each bar; each product’s reconstruction is evaluated against its own observed series, and the mean of the three reconstructions against the observed three-product mean. **b**, The fitted background uptake $c(t)$. **c,d**, Observed $A+O_{100}$ (black; three-product mean) and the reconstructions obtained from each product separately (coloured curves), taking O_{sub} as the tropical-Pacific 100–300 m layer (**c**) and as the global 100–2000 m layer (**d**). The black dashed line is the mean of the three reconstructions.



Extended Data Fig. 3 | Dependence of the outlook on the issue date. **a**, Projected GMST for the 1997/98 heat-release scenario issued in March 2026 (dashed, no shading) and August 2026 (solid, with ± 1 s.d. shading), with observed GMST (grey) and GMST converted from the observed $A + O_{100}$ (dark blue) as in Fig. 5c. **b**, Maximum monthly projected GMST for the 1997/98 release scenario at six issue months with error bars indicating the projection uncertainty. For all issue months, maximum values occur in February 2027. Dotted lines mark the previous record of monthly GMST. Earlier issue months are excluded because their outlooks do not extend to the February 2027 peak after three-month smoothing.



Extended Data Fig. 4 | Lag correlation of GMST with the subsurface reservoir and with Niño indices. a,b, Lag correlation between GMST and two groups of tropical-Pacific predictors over 1995–2025, using three-month running means of anomalies with linear trends removed. Lags range from –12 to +12 months in monthly steps: negative lags indicate that the predictor leads GMST. Solid and dotted vertical lines mark lags of 0 and –3 months, respectively. **a,** The sign-reversed tropical-Pacific 100–300 m subsurface OHC, $-O_{\text{sub}}$, for each of the three OHC products. **b,** Six Niño indices: Niño-3, Niño-3.4, Niño-4 and their warming-adjusted relative counterparts.