# Supporting Information

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## SI Methods

**Correction for Acclimation Temperature.** Acclimation temperature affects the thermal-tolerance limits of ectotherms. If one is interested in cross-species comparisons of thermal tolerance with respect to extreme body temperatures in summer and winter, as is our goal here, then warm (summer) acclimation temperatures should be used for heat-tolerance assays, and the reverse for cold-tolerance assays. Unfortunately, many studies use somewhat arbitrary acclimation temperatures that are far from seasonal extremes. For example, cold-acclimation experiments are often run at 20–30 °C, for taxa from latitudes and elevations where operative temperatures in winter can approach 0 °C (Fig. S6).

To correct for acclimation temperatures within our dataset that were far from seasonal temperatures, we first fitted linear models for upper and lower thermal-tolerance limits (fitting separate models for each) as a function of acclimation temperature (Fig. S6). We included taxonomy as a random effect in these models to account for the nonrandom sampling structure across taxonomic groups but did not explore interactions among acclimation, latitude, and elevation, due to sample-size limitations. We next assumed that an "appropriate" acclimation temperature would be 5 °C less extreme than the maximum or minimum air temperature at each collection site: i.e., 5 °C cooler than extreme summer maximum and 5 °C warmer than extreme winter minimum (Fig. S6). We then used the slope coefficients from the models above to adjust each observed thermal-tolerance limit to that expected if the appropriate acclimation temperature had been used. We simply added or subtracted to the observed limit based how far the acclimation temperature was from the appropriate acclimation temperature and the slope from the above models; thus, we retained variability in the data, and studies with more appropriate acclimation temperatures were changed the least. This correction factor led to minor changes in $CT_{\max}$ (a decrease of 0.13 °C ± 1.96 SD), and to slightly greater changes in $CT_{\min}$ (a decrease of 2.61 °C ± 1.96 SD) (Fig. S6). Importantly, all model results using acclimation-corrected $CT_{\max}$ and $CT_{\min}$ were quantitatively similar to those in which raw $CT_{\max}$ and $CT_{\min}$ were used and acclimation temperature was included as a fixed effect (Table S4).

**Operative Body Temperatures.** Predicted steady-state temperatures ("operative temperatures," $T_{\mathrm{e}}$) of ectotherms in different microhabitats can be determined using physical models or manikins (1), or calculation via biophysical models (2, 3). For each ectotherm in our dataset, we used the biophysical modeling software "Niche Mapper" (3) to estimate $T_{\mathrm{e}}$ from a global dataset of temperatures (monthly means) of the daily maximum and minimum temperatures and relative humidities and daily average wind speed for 1961–1990, on a 10-degree spatial grid (www.cru.uea.ac.uk/cru/data). We estimated hourly $T_{\mathrm{e}}$ of a 5-g ectotherm (large insect or small vertebrate) whose midpoint was 1 cm above the ground, for the mean day of the warmest and coolest months (3). For each collection site (with specified latitude, longitude, and elevation), we simulated $T_{\mathrm{e}}$ of nonthermoregulating, lizard-shaped objects with 90% solar absorptivity in open habitats (full sun for maximum $T_e$) or full shade on the surface, or at fixed positions in the soil profile down to a depth of 200 cm (at the latter depth, $T_{\mathrm{e}}$ was assumed to remain stable at the annual average air temperature). The simulations were run assuming dry skin or wet skin over 100% of the skin surface area. From these simulations, we extracted the maximum and minimum hourly $T_e$ across all months for a given site, skin wetness, and microhabitat for our analyses. The model accounts for the effect of air pressure on convective heat exchange. We used modelled elevations based on the longitude and latitude of collection using a global digital elevation map. We then corrected for any difference between modelled and study-reported elevation using a lapse rate on $T_e$ and $T_a$ of 0.0055 °C/m elevation.

1. Bakken GS (1992) Measurement and application of operative and standard operative temperatures in ecology. *Integr Comp Biol* 32:194–216.
2. Kearney M, Porter W (2009) Mechanistic niche modelling: Combining physiological and spatial data to predict species' ranges. *Ecol Lett* 12(4):334–350.
3. Kearney M, Shine R, Porter WP (2009) The potential for behavioral thermoregulation to buffer "cold-blooded" animals against climate warming. *Proc Natl Acad Sci USA* 106(10):3835–3840.

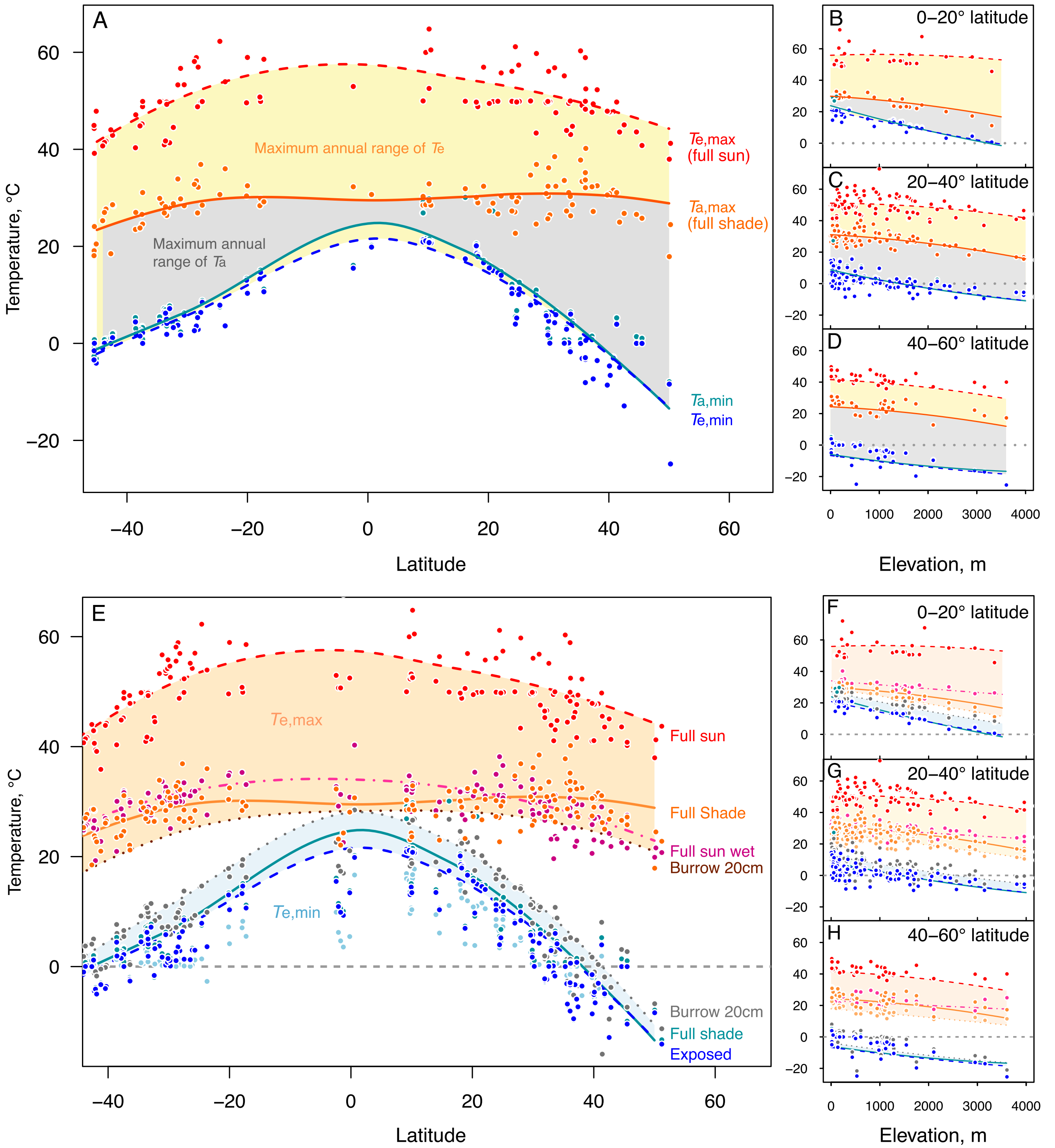


**Fig. S1.** Maximum and minimum hourly air temperatures ($T_a$) and operative temperatures in open habitats ($T_e$) at global collection sites (*A–D*), and the range of maximum and minimum operative temperatures in various microhabitats (*E–H*). (*A–D*) $T_a$ and $T_e$ are shown as a function of latitude (*A*) and elevation (*B–D*). Gray region shows range of hourly air temperatures across the year, and light yellow region shows range of extreme operative temperatures across the year. $T_e$ estimates are for dry-skinned ectotherms. (*E–H*) $T_e$ are shown as a function of latitude (*E*) and elevation (*F–H*). The light orange region shows the range of maximum hourly air temperatures across different habtats, and the light blue region shows the range of minimum operative temperatures across different habitats. In latitude panels (*A* and *E*), data are a subset from collection sites below 1,000 m elevation, and lines represent local regression (loess) curves. In elevation panels (*B–D* and *F–H*), data are subsets for indicated latitudes, and lines show best-fit regression coefficients from linear models.

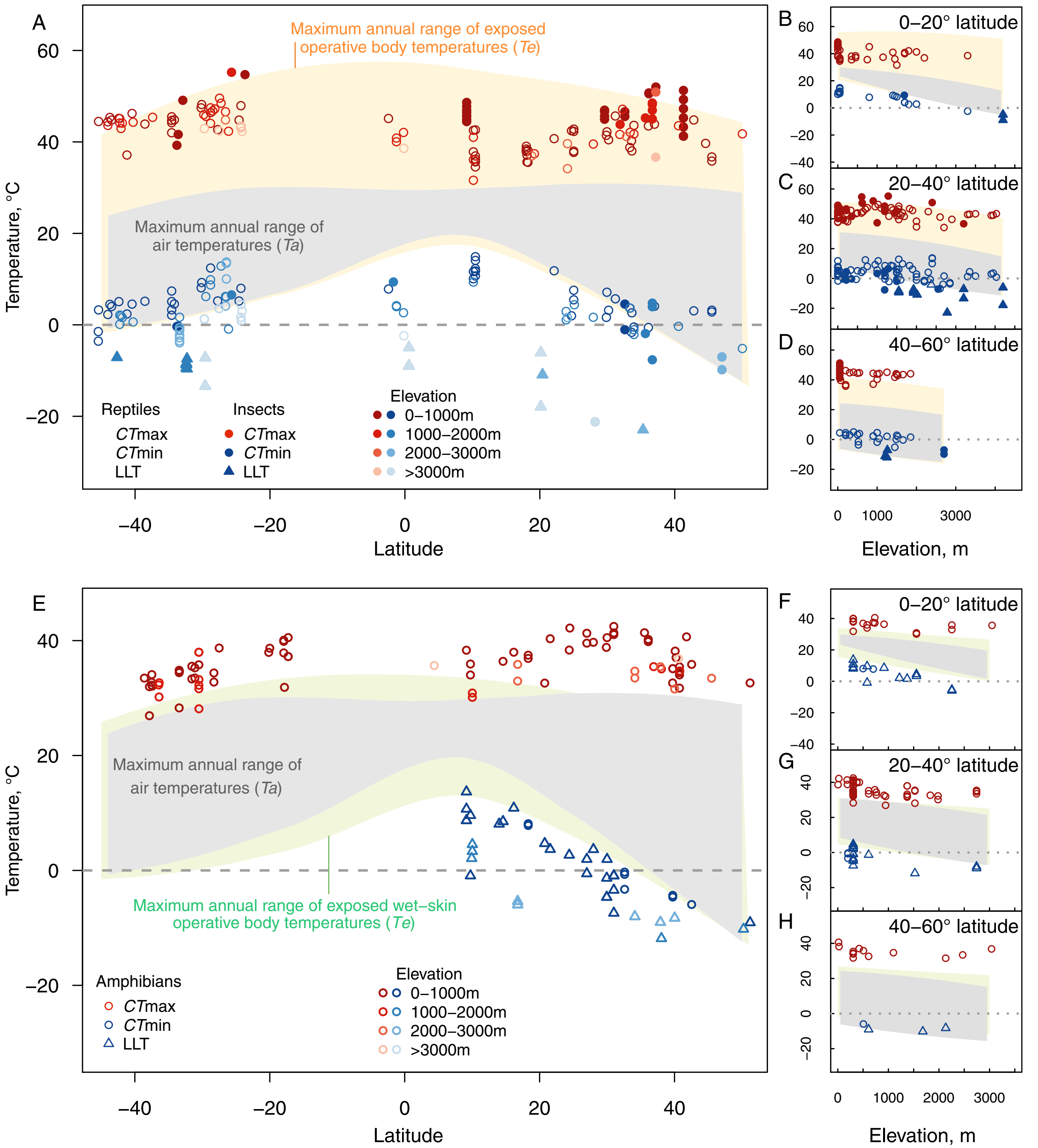


**Fig. S2.** Extreme air temperatures, operative temperatures in open habitats, and thermal tolerance limits of reptiles and insects as a function of latitude and elevation for dry-skinned ectotherms (*A–D*) and wet-skinned ectotherms (*E–H*). The gray region shows the range of hourly air temperatures across the year based on local regression through $T_{a,max}$ and $T_{a,min}$ data (Fig. S1). The light yellow region in *A–D* shows the range of dry-skin operative temperatures across the year in open habitats based on local regression through $T_{e,max}$ and $T_{e,min}$ estimates (Fig. S1). The light green region in *E–H* shows the range of wet-skin operative temperatures across the year in open habitats based on local regression through $T_{e,max}$ and $T_{e,min}$ estimates.

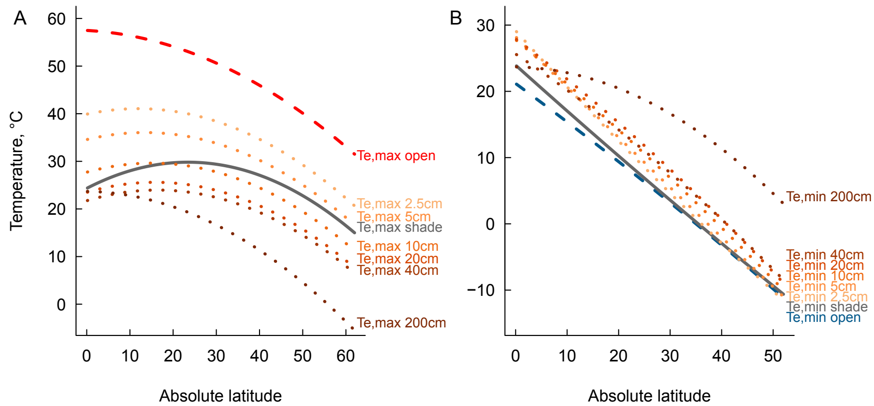


**Fig. S3.** Operative body temperatures ($T_e$) at different borrowing depths as a function of latitude during warm (*A*) and cold (*B*) seasonal extremes. Lines show best-fit relationships from linear models. Maximum and minimum $T_e$ in open habitats and air temperatures also shown for reference.

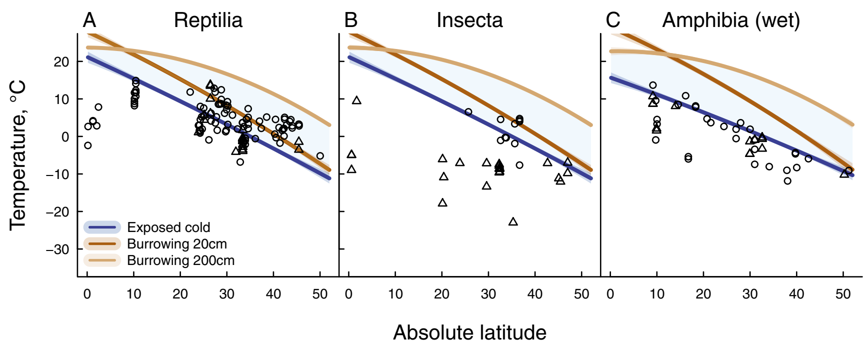


**Fig. S4.** The potential advantage of burrowing for maintaining operative body temperatures within tolerable cold limits. Curves bounding the light blue region show cold operative body temperatures at the surface and at 2 m depth as a function of latitude (at a fixed mean elevation of 800 m), based on linear models (Table S1) for reptiles (*A*), insects (*B*), and amphibians (*C*). $CT_{min}$ (black points) and lower lethal temperatures (black triangles) must be lower than operative body temperatures (within the light blue region) for cold survival; thus, burrowing provides one option for buffering cold extremes.

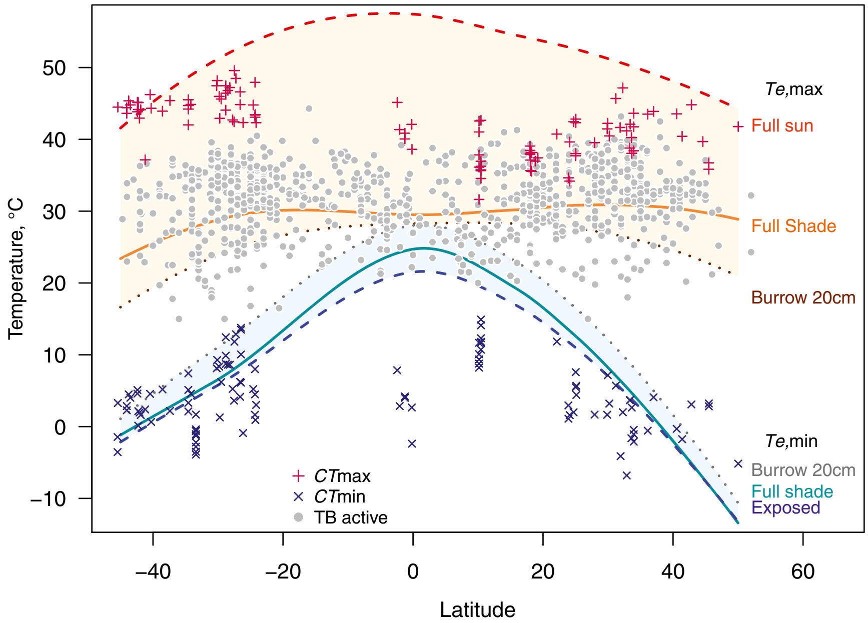


**Fig. S5.** Thermal tolerance limits ($CT_{max}$, $CT_{min}$), operative body-temperature extremes ($T_{e,max}$, $T_{e,min}$), and empirical body temperatures ($T_b$) of reptiles. $T_b$ data are for active reptiles, from Meiri et al. (1). $T_{e,max}$ and $T_{e,min}$ curves represent local regressions (loess) of $T_e$ estimates from collection sites below 2,000 m elevation as a function of latitude (see Fig. S4 for $T_e$ estimates by location).


1. Meiri S, et al. (2013) Are lizards feeling the heat? A tale of ecology and evolution under two temperatures. *Glob Ecol Biogeogr* 22:834–845.

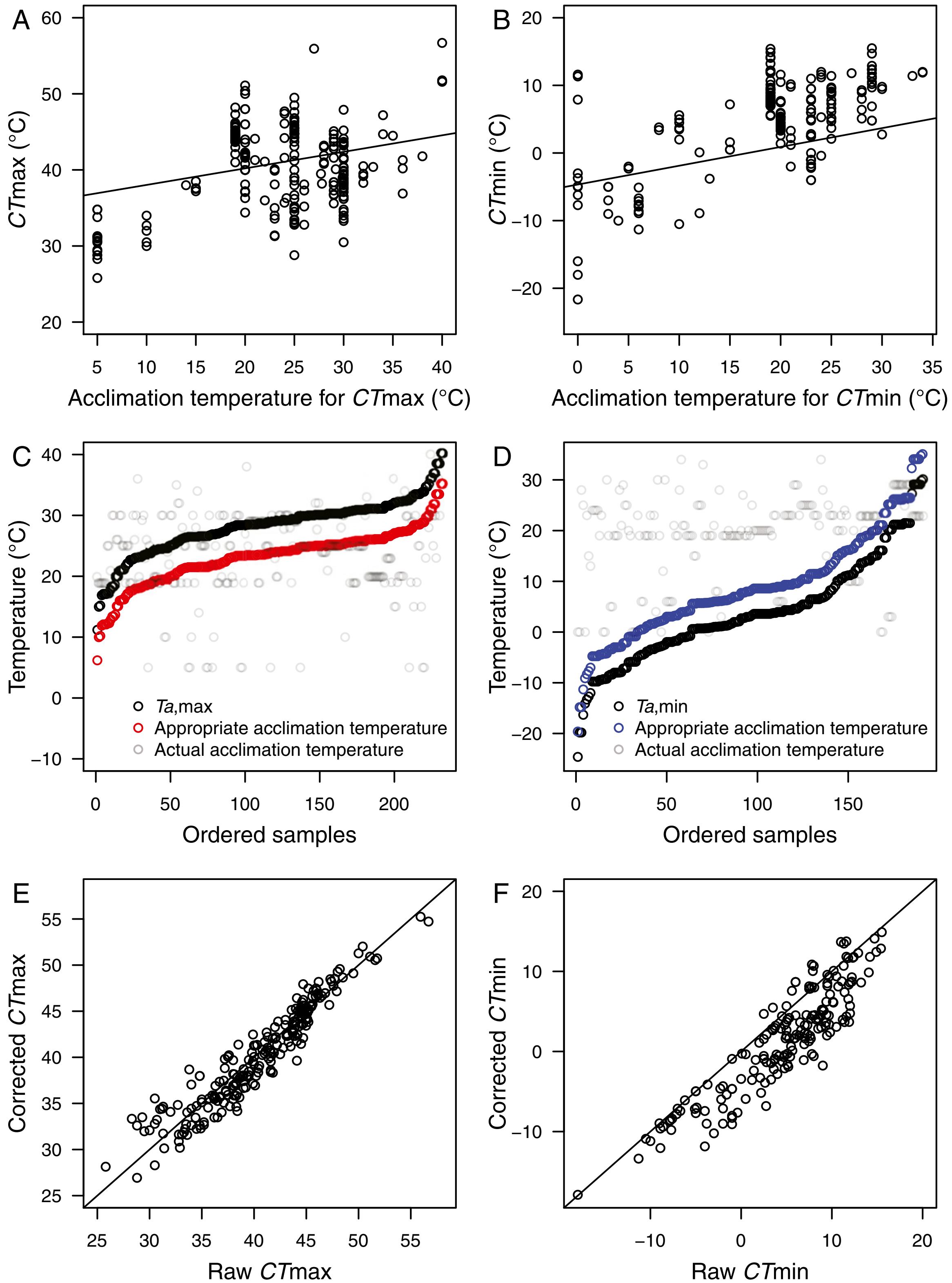


**Fig. S6.** Correction for different acclimation temperatures used in laboratory experiments. (*A* and *B*) $CT_{max}$ and $CT_{min}$ as a function of acclimation temperature used in laboratory experiments. Lines represent the best-fit linear model slope and intercept used in correction for acclimation temperature. (*C* and *D*) Extreme environmental air temperatures ($T_{a,max}$, $T_{a,min}$), acclimation temperatures, and ideal acclimation temperatures for each $CT_{max}$ and $CT_{min}$ experiment. Points show maximum and minimum air temperatures at each collection site ordered from smallest to largest (black), maximum air temperatures minus 5 °C, considered the ideal warm acclimation temperature (red), minimum air temperatures plus 5 °C, considered the ideal cold acclimation temperature (blue), and actual acclimation or field temperatures used in each experiment (gray). (*E* and *F*) Thermal-tolerance limits corrected for acclimation temperature shown as a function of raw (uncorrected) thermal-tolerance limits. Lines indicate 1:1 relationships.

**Table S1. Linear model results for maximum and minimum air temperatures and estimated equilibrated body temperatures as a function of latitude and elevation**

| Fixed effects | Estimate | SE | $t$ | $P$ value | Sig. |
|---|---|---|---|---|---|
| | Maximum temperatures | | | | |
| Air temperature ($T_{a,max}$) / Equilibrated temperature in the shade ($T_{e,max}$ dry shade) | | | | | |
| Intercept | 26.26 | 0.96 | 27.3 | < 2e-16 | *** |
| Absolute latitude | 0.461 | 0.063 | 7.30 | <0.001 | *** |
| Elevation, km | −1.99 | 0.80 | −2.50 | 0.0131 | * |
| Latitude^2 | −0.010 | 0.001 | −8.88 | < 2e-16 | *** |
| Elevation^2 | −0.528 | 0.150 | −3.51 | 0.0005 | *** |
| Latitude:elevation | 0.0089 | 0.0199 | 0.447 | 0.655 | |
| Equilibrated temperature in open habitats ($T_{e,max}$ open) | | | | | |
| Intercept | 56.47 | 1.335 | 42.3 | < 2e-16 | *** |
| Absolute latitude | −0.0006 | 0.0878 | −0.007 | 0.995 | |
| Elevation, km | 1.72 | 1.11 | 1.55 | 0.122 | |
| Latitude^2 | −0.0060 | 0.0016 | −3.81 | <0.001 | *** |
| Elevation^2 | −0.549 | 0.209 | −2.63 | 0.009 | ** |
| Latitude:elevation | −0.0622 | 0.0276 | −2.25 | 0.025 | * |
| Equilibrated temperature in 20-cm burrows ($T_{e,max}$ burrow) | | | | | |
| Intercept | 27.80 | 0.80 | 34.9 | < 2e-16 | *** |
| Absolute latitude | 0.223 | 0.052 | 4.26 | 2.74E-05 | *** |
| Elevation, km | −5.32 | 0.66 | −8.062 | 1.93E-14 | *** |
| Latitude^2 | −0.0084 | 0.0009 | −9.061 | < 2e-16 | *** |
| Elevation^2 | −0.082 | 0.125 | −0.661 | 0.509 | |
| Latitude:elevation | 0.056 | 0.017 | 3.331 | 0.00098 | *** |
| Equilibrated temperature in open habitats, wet skin ($T_{e,max}$ wet open) | | | | | |
| Intercept | 33.53 | 0.742 | 45.2 | < 2e-16 | *** |
| Absolute latitude | 0.110 | 0.0487 | 2.26 | 0.0246 | * |
| Elevation, km | −2.81 | 0.615 | −4.57 | 7.11E-06 | *** |
| Latitude^2 | −0.00639 | 0.00087 | −7.38 | 1.67E-12 | *** |
| Elevation^2 | 0.0354 | 0.116 | 0.305 | 0.761 | |
| Latitude:elevation | 0.0240 | 0.0153 | 1.57 | 0.118 | |
| Equilibrated temperature in the shade, wet skin ($T_{e,max}$ wet shade) | | | | | |
| Intercept | 23.431636 | 1.086112 | 21.574 | < 2e-16 | *** |
| Absolute latitude | 0.06587 | 0.071368 | 0.923 | 0.35679 | |
| Elevation, km | −6.757516 | 0.901283 | −7.498 | 7.95E-13 | *** |
| Latitude^2 | −0.005083 | 0.001268 | −4.009 | 7.76E-05 | *** |
| Elevation^2 | 0.471766 | 0.170012 | 2.775 | 0.00588 | ** |
| Latitude:elevation | 0.052128 | 0.022438 | 2.323 | 0.02086 | * |
| | Minimum temperatures | | | | |
| Air temperature ($T_{a,min}$) / Equilibrated temperature in the shade ($T_{e,min}$ dry shade) | | | | | |
| Intercept | 31.60 | 1.06 | 29.9 | < 2e-16 | *** |
| Absolute latitude | −0.78 | 0.07 | −11.3 | < 2e-16 | *** |
| Elevation, km | −9.91 | 0.88 | −11.3 | < 2e-16 | *** |
| Latitude^2 | 0.0006 | 0.0012 | 0.51 | 0.610 | |
| Elevation^2 | 0.46 | 0.17 | 2.77 | 0.006 | ** |
| Latitude:elevation | 0.11 | 0.02 | 4.84 | 2.16E-06 | *** |
| Equilibrated temperature in open habitats ($T_{e,min}$ open) | | | | | |
| Intercept | 27.13 | 0.93 | 29.2 | < 2e-16 | *** |
| Absolute latitude | −0.625 | 0.0611 | −10.2 | < 2e-16 | *** |
| Elevation, km | −7.64 | 0.771 | −9.91 | < 2e-16 | *** |
| Latitude^2 | −0.001 | 0.00109 | −0.93 | 0.35 | |
| Elevation^2 | 0.240 | 0.145 | 1.652 | 0.10 | . |
| Latitude:elevation | 0.0695 | 0.0192 | 3.62 | 0.0003 | *** |
| Equilibrated temperature in 20-cm burrows ($T_{e,min}$ burrow) | | | | | |
| Intercept | 33.66 | 0.89 | 37.7 | <2e-16 | *** |
| Absolute latitude | −0.63 | 0.06 | −10.8 | <2e-16 | *** |
| Elevation, km | −7.41 | 0.74 | −10.0 | <2e-16 | *** |
| Latitude^2 | −0.002 | 0.001 | −2.26 | 0.024 | * |
| Elevation^2 | 0.30 | 0.14 | 2.18 | 0.030 | * |
| Latitude:elevation | 0.056 | 0.018 | 3.06 | 0.002 | ** |

**Table S1. Cont.**

| Fixed effects | Estimate | SE | $t$ | $P$ value | Sig. |
|---|---|---|---|---|---|
| | Minimum temperatures | | | | |
| Equilibrated temperature in open habitats, wet skin ($T_{e,min}$ wet open) | | | | | |
| Intercept | 20.47 | 0.89 | 23.07 | < 2e-16 | *** |
| Absolute latitude | −0.49 | 0.06 | −8.36 | 2.73E-15 | *** |
| Elevation, km | −6.07 | 0.74 | −8.24 | 6.06E-15 | *** |
| Latitude^2 | −0.001 | 0.001 | −1.11 | 0.2697 | |
| Elevation^2 | 0.12 | 0.14 | 0.87 | 0.3876 | |
| Latitude:elevation | 0.06 | 0.02 | 3.15 | 0.0018 | ** |
| Equilibrated temperature in the shade, wet skin ($T_{e,min}$ wet shade) | | | | | |
| Intercept | 22.46 | 1.04 | 21.7 | < 2e-16 | *** |
| Absolute latitude | −0.4 | 0.07 | −5.93 | 8.73E-09 | *** |
| Elevation, km | −7.16 | 0.86 | −8.33 | 3.29E-15 | *** |
| Latitude^2 | −0.003 | 0.001 | −2.61 | 0.009 | ** |
| Elevation^2 | 0.19 | 0.16 | 1.17 | 0.24 | |
| Latitude:elevation | 0.06 | 0.02 | 2.81 | 0.005 | ** |

Maximum and minimum temperatures were the average warmest hour of the warmest month and the average coldest hour of the coldest month, based on historical climatologies (*Methods*). SE, standard error. Latitude is in units of degrees latitude. Sig., significance, denoted with asterisks: ***$P$ > 0.001; **$P$ > 0.01; *$P$ > 0.05.

**Table S2. Table of AIC scores for models of $CT_{max}$ and $CT_{min}$, with and without inclusion of 2nd-order polynomial for latitude and elevation. DF = degrees of freedom, AIC = Akaike Information Criterion. Best-fit model (with lowest AIC score) highlighted in grey**

| Model no. | Terms included | | | | | | DF | AIC |
|---|---|---|---|---|---|---|---|---|
| $CT_{max}$ | | | | | | | | |
| | absolute latitude | elevation | latitude^2 | elevation^2 | latitude* elevation | | | |
| 1 | + | + | + | + | + | | 11 | 1205.3 |
| 2 | + | + | + | | + | | 10 | 1173.7 |
| 3 | + | + | | + | + | | 10 | 1215.2 |
| 4 | + | + | | | + | | 9 | 1183.6 |
| $CT_{min}$ | | | | | | | | |
| | absolute latitude | elevation | latitude^2 | elevation^2 | latitude* elevation | cold limit metric | | |
| 1 | + | + | + | + | + | + | 12 | 1113.2 |
| 2 | + | + | + | | + | + | 11 | 1101.3 |
| 3 | + | + | | + | + | + | 11 | 1084.9 |
| 4 | + | + | | | + | + | 10 | 1073.6 |

Plus (+) symbol denotes inclusion of term within the model; AIC, Akaike Information Criterion; DF, degrees of freedom. Shading, best-fit models (with lowest AIC score).

**Table S3. Heat and cold thermal safety margin modeled as a function of latitude and elevation for reptiles, insects, and amphibians. Latitude is in units of degrees latitude**

| Heat thermal safety margin ($CT_{max}$ - $T_{e,max}$) | | | | | Cold thermal safety margin ($CT_{max}$ - $T_{e,min}$) | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Fixed effects | Value | Std.Error | t-value | p-value | Fixed effects | Value | Std.Error | t-value | p-value |
| reptiles | | | | | reptiles | | | | |
| intercept | −31.69 | 2.64 | −12.0 | <0.0001 | intercept | 11.05 | 1.53 | 7.22 | <0.0001 |
| absolute latitude | 0.74 | 0.07 | 10.5 | <0.0001 | absolute latitude | −0.31 | 0.04 | −7.25 | <0.0001 |
| elevation (km) | 0.0035 | 0.0014 | 2.51 | 0.014 | elevation (km) | −0.0029 | 0.0008 | −3.55 | 0.0007 |
| latitude x elevation | −0.00003 | 0.00005 | −0.48 | 0.63 | latitude: x elevation | 0.000016 | 0.00003 | 0.53 | 0.598 |
| insects | | | | | insects | | | | |
| intercept | −4.20 | 2.67 | −1.57 | 0.13 | intercept | 19.34 | 5.82 | 3.32 | 0.005 |
| absolute latitude | 0.010 | 0.068 | −0.15 | 0.88 | absolute latitude | −0.48 | 0.16 | −3.06 | 0.055 |
| elevation (km) | 0.0010 | 0.0104 | −0.10 | 0.92 | elevation (km) | −0.0042 | 0.0016 | −2.54 | 0.085 |
| latitude x elevation | −0.0001 | 0.0002 | −0.35 | 0.73 | latitude x elevation | 0.00011 | 0.00006 | 1.89 | 0.155 |
| amphibians | | | | | amphibians | | | | |
| intercept | 0.43 | 2.15 | 0.20 | 0.841 | intercept | 5.84 | 3.24 | 1.80 | 0.085 |
| absolute latitude | 0.24 | 0.05 | 4.84 | <0.0001 | absolute latitude | −0.16 | 0.09 | −1.79 | 0.087 |
| elevation (km) | 0.00064 | 0.00122 | 0.52 | 0.602 | elevation (km) | 0.0042 | 0.0024 | 1.76 | 0.091 |
| hemisphere (S) | −5.47 | 1.30 | −4.20 | 0.0001 | latitude x elevation | −0.00015 | 0.00008 | −1.98 | 0.060 |
| latitude x elevation | −0.00001 | 0.00003 | −0.27 | 0.724 | | | | | |

Latitude is in units of degrees latitude.
*Included to account for difference between elevation in the simulation and that reported in the study.

**Table S4. $CT_{max}$ and $CT_{min}$ modeled as a function of latitude and elevation, using values of $CT_{max}$ and $CT_{min}$ uncorrected for acclimation temperature**

| Fixed effect | Coefficient | SE | *t* value | *P* value |
|---|---|---|---|---|
| $CT_{max}$ | | | | |
| Intercept | 34.21 | 3.08 | 11.11 | <0.0001 |
| Absolute latitude | 0.18 | 0.07 | 2.41 | 0.017 |
| Elevation, km | 0.23 | 0.43 | 0.54 | 0.590 |
| Latitude^2 | −0.004 | 0.001 | −2.75 | 0.007 |
| Latitude:elevation | −0.03 | 0.01 | −1.75 | 0.082 |
| Acclimation temperature | 0.23 | 0.03 | 8.89 | <0.0001 |
| $CT_{min}$ | | | | |
| Intercept | 6.65 | 2.15 | 3.09 | 0.0025 |
| Absolute latitude | −0.20 | 0.03 | −5.68 | <0.0001 |
| Elevation, km | −2.20 | 0.5 | −4.02 | 0.0001 |
| Latitude:elevation | 0.03 | 0.02 | 1.39 | 0.1671 |
| Cold limit metric (lethal) | −3.81 | 1.00 | −3.82 | 0.0002 |
| Acclimation temperature | 0.14 | 0.04 | 3.37 | 0.0011 |

Models include the same terms as in corrected $CT_{max}$ and $CT_{min}$ models (see *Methods*), with the additional inclusion of acclimation temperature as a fixed effect. Results are qualitatively similar to model results using corrected $CT_{max}$ and $CT_{min}$ values.

**Dataset S1. Thermal limits, collection points, and operative temperatures by species**

Dataset S1

Tmax, upper thermal limit; tmin, lower thermal limit; tmax_metric, metric used for upper thermal limit (leth, lethal temperature; crit, critical temperature); tmin_metric, metric used for lower thermal limit; tmax_acc, acclimation temperature used for upper thermal limit; tmin_acc, acclimation temperature used for lower thermal limit; lat, latitude of collection in decimal degrees, negative values denote southern hemisphere; altitude, elevation of collection in meters (m); Te_min_dry, minimum operative body temperature of exposed dry-skinned ectotherm; Te_min_wet, minimum operative body temperature of exposed wet-skinned ectotherm; Ta2m_min_dry, air temperature and minimum operative body temperature of dry-skinned ectotherm in the shade at 2 m height; Ta2m_min_wet, minimum operative body temperature of wet-skinned ectotherm in the shade at 2 m height; D20cm_min_dry, minimum operative body temperature of an ectotherm at 20 cm depth; D200cm_min_dry, minimum operative body temperature of an ectotherm at 200 cm depth; Te_max_dry, Te_min_wet, Ta2m_min_dry, Ta2m_min_wet, D20cm_max_dry, D200 cm_max_dry, same as above but for maximum temperatures; sim_altitude, altitude used for simulations of operative temperatures; ref., reference of original study.