



Retracted: Lizards could be warming faster than climate

Francisco Ferri-Yáñez and Miguel B. Araújo

F. Ferri-Yáñez (francisco_ferri@mncn.csic.es) and M. B. Araújo, Depto de Biogeografía y Cambio Global, Museo Nacional de Ciencias Naturales, CSIC and Laboratorio Internacional en Cambio Global CSIC-PUC (LINCGlobal), Calle José Gutiérrez Abascal, 2, ES-28006, Madrid, Spain, and InBIO-CIBIO, Univ. of Évora, Largo dos Colegiais, PT-7000 Évora, Portugal, and Imperial College London, Silwood Park Campus, Buckhurst Road, SL5 7PY Ascot, Berkshire, UK.

Global annual mean temperatures increased 0.74°C in the second half of the 20th century and projections are for even greater increases in the 21st century (Solomon et al. 2007). But how do such increases in air temperature affect species on the ground? Studies examining climate change effects on species distributions investigate the relationship between the distributions of species and atmospheric variables, such as air temperature. The projections of altered species distributions are then made assuming that the effects of climate change on species are proportional to changes in the variables used for modelling (Araújo et al. 2006). But even with ectotherms – that regulate their body temperature from external heat sources – changes in body temperature are not expected to equal changes in air temperature. We measure differences in air temperature and expected body temperature (operative temperature) of a non-thermoregulating ectotherm with the convective and radiative properties of a lizard across the Iberian Peninsula, Supplementary material Appendix 1. Mean operative temperatures were calculated for every 5-yr interval between 1956–2010, using well-known biophysical equations (Bakken and Gates 1975) and outputs from a new Regional Climate Model (RCM). The RCM was dynamically downscaled at 5 × 5 km resolution with hourly climate estimates across the entire period of time considered (Prasad Dasari et al. 2014). Expected operative temperatures were then compared with air temperatures. The latest climatic numerical downscalings for Europe have a maximum horizontal resolution of 25 km (Haylock et al. 2008, Kendon et al. 2010) or 12 km (Jacob et al. 2014). The RCM downscaling used in this study has a horizontal resolution of 5 km (Prasad Dasari et al. 2014) making it, to our knowledge, the highest resolution available for the Iberian Peninsula and Europe. This spatial resolution is similar to that of previous studies modelling the relationship between reptiles and climate and operative temperatures (Kearney and Porter 2004, Buckley 2010).

We found that mean operative temperatures increased twice as much as mean air temperatures over the past 50 yr (Fig. 1). The trend of increasing temperatures was also less

variable for operative temperatures. The disproportionate rate of increase in operative temperatures, with regard to air temperatures, means that the degree of exposure of species to climate warming in this region is greater than usually inferred from models that correlate species distributions with aspects of climate (Araújo and Peterson 2012). A complex relationship between the thermal environment and body temperature is what ultimately influences the organismal physiology. In animals for which the contribution of evaporative cooling is negligible, the difference between the body temperature of a non-thermoregulating ectotherm and air temperature is due to the effect of absorbed and emitted radiation in combination with convection and conduction processes with the air and the surface (Porter et al. 1973).

Many ectotherms use solar radiation to increase their body temperature above the surrounding air, and this process is also influenced by wind speed and surface heat. In addition, operative temperatures are influenced by microhabitat variables such as shadowing by vegetation and orography (Sears et al. 2011). In addition to temperature warming, climate change also implies changes in other variables that affect the thermal balance of an organism. Some, like wind patterns at ground level, are difficult to predict and it is unclear if and how they are going to change in the coming decades. Total cloud cover shows a general decreasing trend in Iberian Peninsula (Sanchez-Lorenzo et al. 2009) allowing more sunlight to reach the ground. Likewise, surface radiation has been globally increasing since the 1980s (Wild et al. 2005). These factors might explain why operative temperatures were predicted to increase more than air temperature in our study.

Obviously, lizards can thermoregulate by adjusting their behavior to microclimate (Huey 1974). That is, a two-fold increase in operative temperatures does not translate immediately into similar increases of body temperature in the field. However, for a dry skinned ectotherm, the range of available temperatures lies between full sun conditions, when the contribution of radiation is greatest, and full shadow conditions, when in the absence of evaporative cooling operative temperatures approximate air temperatures. The distribution of intermediate operative

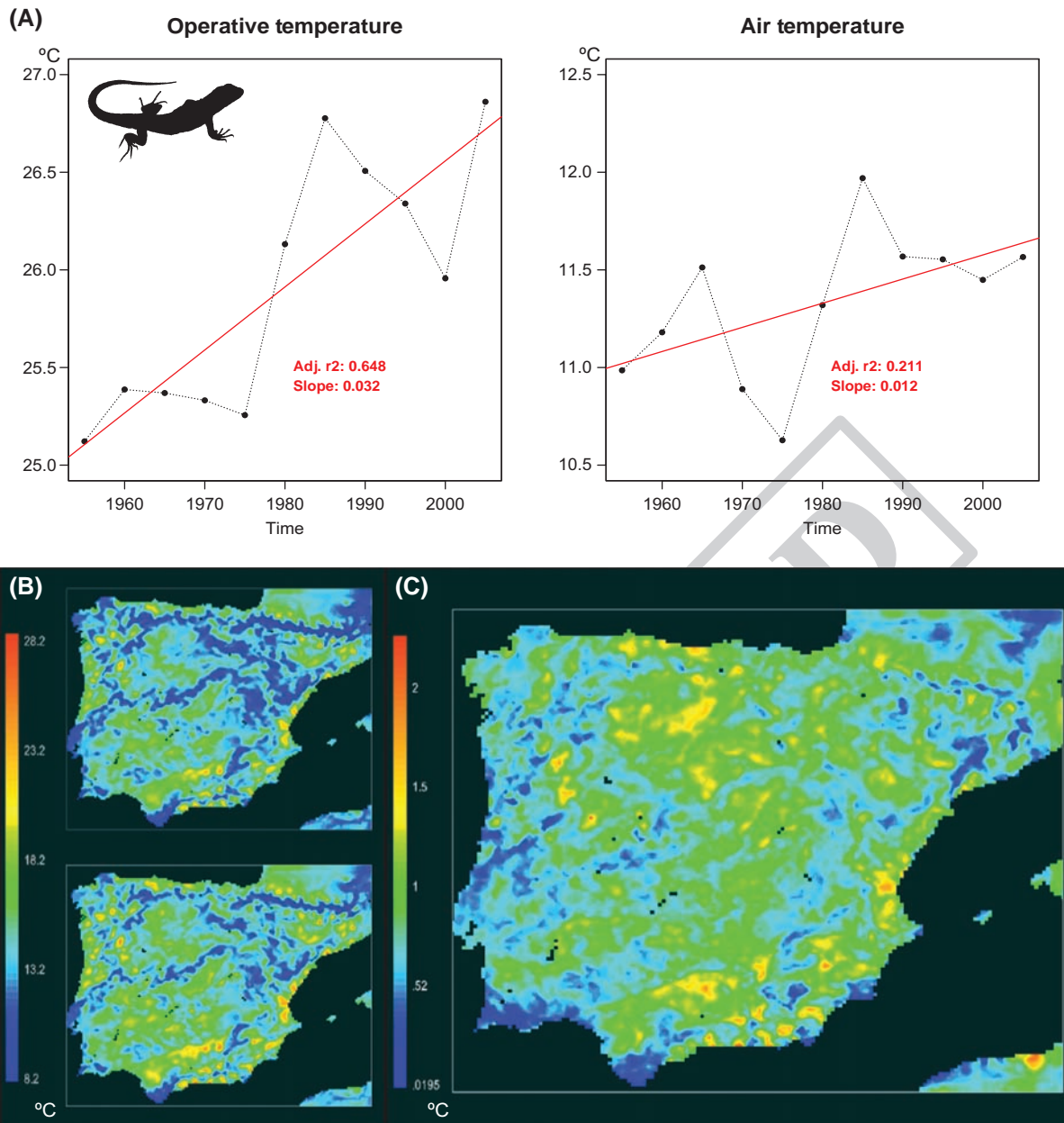


Figure 1. (A) Changes in average operative temperature (left) and air temperature (right) in 5 yr intervals from 1955 to 2010. Red lines show regression lines with slope of 0.03 for operative temperature and 0.01 for air temperature. Notice that operative temperature and air temperature change at different paces, operative temperature increasing more than two fold (almost three folds) faster than air temperature. (B) Difference between operative temperature and air temperature for the period between 1955–1960 (top) and the period 2005–2010 (bottom). (C) Shows how the differential has increased between the two periods depicted in (B).

temperatures depends on the structure of the microhabitat and the land cover and should have an intermediate rate of change, which would be higher than air temperature. Our results show that the exposure of lizard species, probably of any animal species, is greater than anticipated on the basis of projected changes in air temperature. Making progress in the field of forecasting climate change effects on biodiversity not only requires that clearer mechanistic links are made between changes in the environment and the thermal eco-physiologies of the focal organisms (Sinervo et al. 2010, Araújo et al. 2013), but also that higher resolution climate estimates are provided with which to calculate relevant bioclimatic variables.

Acknowledgements – This study is partly funded through the NICHE project (CGL2011-26852) of the Spanish Ministry of Economy and Competitiveness and the Integrated Program of IC&DT Call No 1/SAECTN/ALENT-07-0224-FEDER-001755. FF-Y was also funded through a CSIC-JAE PhD studentship (2010 00735). MBA also thanks Imperial College's Grand Challenges for Ecosystems and Environment for support of his research.

References

Araújo, M. B. and Peterson, A. T. 2012. Uses and misuses of bioclimatic envelope modeling. – *Ecology* 93: 1527–1539.

- Araújo, M. B. et al. 2006. Climate warming and the decline of amphibians and reptiles in Europe. – *J. Biogeogr.* 33: 1712–1728.
- Araújo, M. B. et al. 2013. Heat freezes niche evolution. – *Ecol. Lett.* 16: 1206–1219.
- Bakken, G. S. and Gates, D. M. 1975. Heat transfer analysis of animals: some implications for field ecology, physiology, and evolution. – In: Gates, D. M. and Schmerl, R. B. (eds), *Perspectives of biophysical ecology*. Springer, pp. 255–290.
- Buckley, L. B. 2010. The range implications of lizard traits in changing environments. – *Global Ecol. Biogeogr.* 19: 452–464.
- Haylock, M. R. et al. 2008. A European daily high-resolution gridded data set of surface temperature and precipitation for 1950–2006. – *J. Geophys. Res. Atmos.* 113: D20119.
- Huey, R. B. 1974. Behavioral thermoregulation in lizards: importance of associated costs. – *Science* 184: 1001–1003.
- Jacob, D. et al. 2014. EURO-CORDEX: new high-resolution climate change projections for European impact research. – *Reg. Environ. Change* 14: 563–578.
- Kearney, M. and Porter, W. P. 2004. Mapping the fundamental niche: physiology, climate, and the distribution of a nocturnal lizard. – *Ecology* 85: 3119–3131.
- Kendon, E. J. et al. 2010. Using and designing GCM–RCM ensemble regional climate projections. – *J. Clim.* 23: 6485–6503.
- Porter, W. P. et al. 1973. Behavioral implications of mechanistic ecology. Thermal and behavioral modelling of desert ectotherms. – *Oecologia* 13: 1–54.
- Prasad Dasari, H. et al. 2014. A regional climate study of heat waves over the Iberian Peninsula. – *Atmos. Clim. Sci.* 4: 841–853.
- Sanchez-Lorenzo, A. et al. 2009. Dimming/brightening over the Iberian Peninsula: trends in sunshine duration and cloud cover and their relations with atmospheric circulation. – *J. Geophys. Res. Atmos.* 114: D00D09.
- Sears, M. W. et al. 2011. The World is not flat: defining relevant thermal landscapes in the context of climate change. – *Integr. Comp. Biol.* 51: 666–675.
- Sinervo, B. et al. 2010. Erosion of lizard diversity by climate change and altered thermal niches. – *Science* 328: 894–899.
- Solomon, S. et al. 2007. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. – Cambridge Univ. Press.
- Wild, M. et al. 2005. From dimming to brightening: decadal changes in solar radiation at Earth's surface. – *Science* 308: 847–850.

Supplementary material (Appendix ECOG-01481 at <www.ecography.org/readers/appendix>). Appendix 1.

RETRACTED