Statewide Community Thermal Model of California and Nevada: Model comparisons, implications, and a new explorer platform

Terry Lee (terrywaihol@unr.edu), **Andrew V. Zuza**, **Daniel T. Trugman**, **Dominik R. Vlaha**, **Wenrong Cao**

Nevada Geosciences, University of Nevada, Reno

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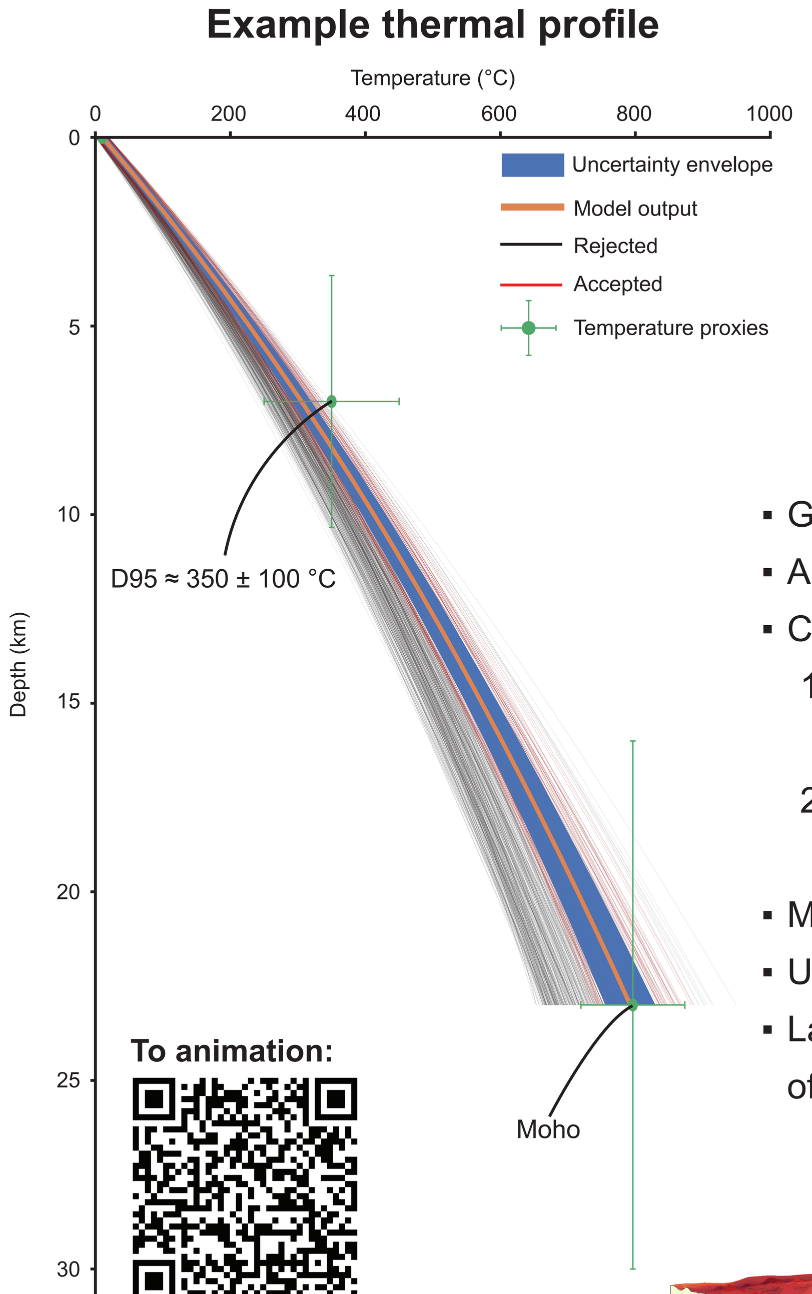
Summary

- The thermal architecture of the continental crust impacts its rheology and deformation
- Extrapolating surface heat flow to depths can be problematic due to the significant spatial variation of heat production and thermal properties
- A new **statewide California-Nevada community thermal model (CTM)** integrates surface heat flow, seismogenic thickness (D95), crustal thickness, and Moho temperature
- Adopting a **Monte Carlo sampling method**, generating unique thermal parameters and thermal profiles and seeking profiles that best-fit the independent crustal temperature proxies
- An **open-source Python software package**, allowing users to generate thermal structure and customization of modeling parameters and temperature proxies
- A strong agreement between our statewide CTM and southern California CTM
- A new CTM explorer allows rapid visualization and access of all CTMs

Modeling method and assumption

Example thermal profile



Governing equations

$$q_s^{model} = q_m + \int_0^{z_m} H_0 e^{\frac{-z}{h}} dz$$

$$T(z) = T_0 + \frac{q_m z}{k} + \frac{(q_s^{model} - q_m)\, h}{k}\left(1 - e^{-z/h}\right)$$

Turcotte and Schubert (2014 *Geodynamics*)

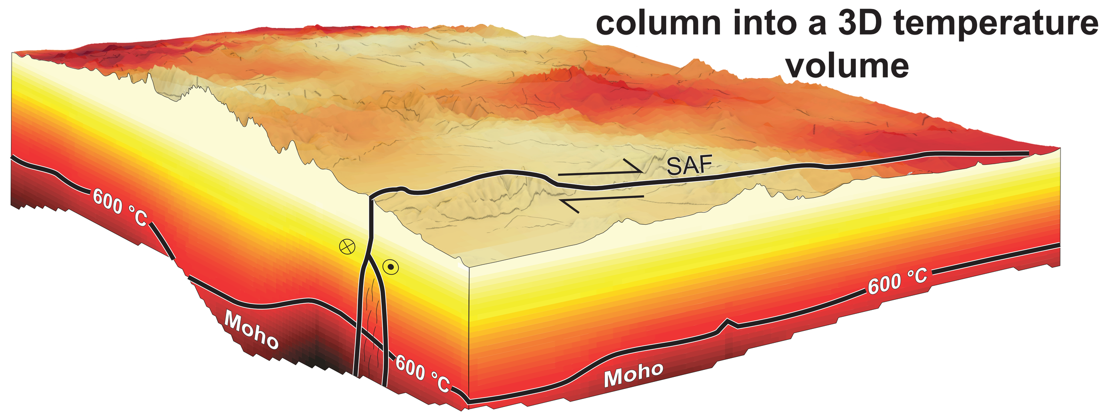
$$\frac{\partial T}{\partial t} = \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}\right) K$$

- Generate 100,000 unique thermal profiles at each column
- Assume steady-state heat conduction
- Criteria to accept thermal profiles:
  1. Modeled heat flow is ± 10 mW m^{-2} of heat flow observation
  2. Normalized root mean square error between modeled profile and temperature proxies is less than 0.35
- Model output as the mean of accepted profiles
- Uncertainty as the standard deviation of accepted profiles
- Lateral heat diffusion for 5 mya with a thermal diffusivity (K) of 10^{-6} m^2 s^{-1}

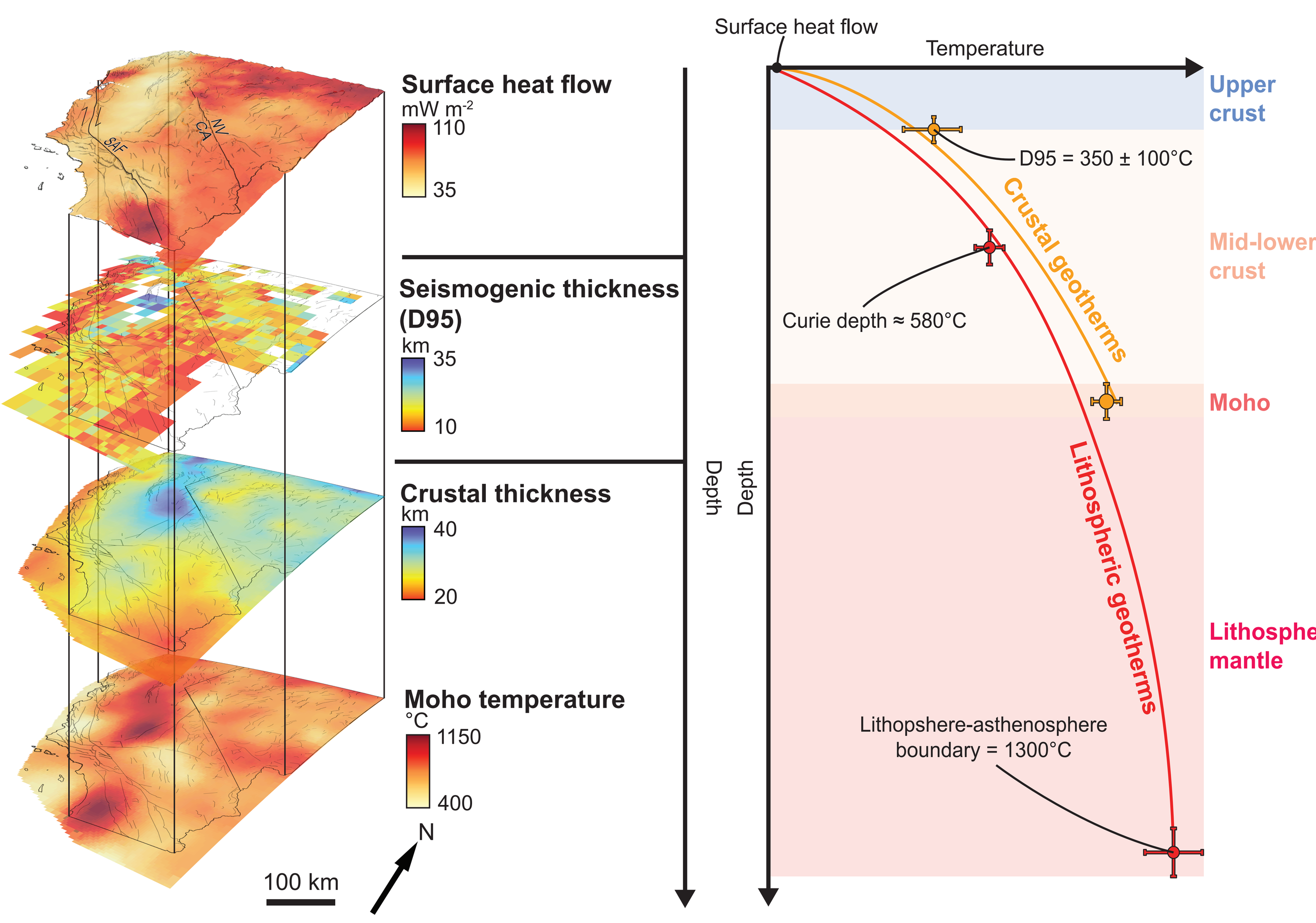
Thermal modeling parameters

T_0 (Surface temperature)	0 to 20 [°C]
k (Thermal conductivity)	2 to 5 [W m^{-1} °C^{-1}]
h (Radiogenic heating decay length *scale*)	0 to z_{Moho} / 2 [m]
H_0 (Surface radiogenic heat production)	1 to 10 [μW m^{-3}]
q_m (Mantle heat flow)	1 to 50 [mW m^{-2}]
$n_{simulation}$	100,000

Integrates each crustal column into a 3D temperature volume

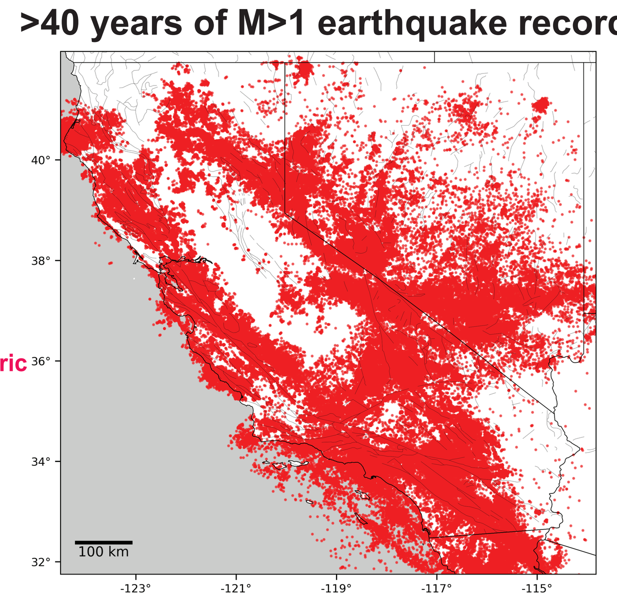


Lithospheric temperature proxies

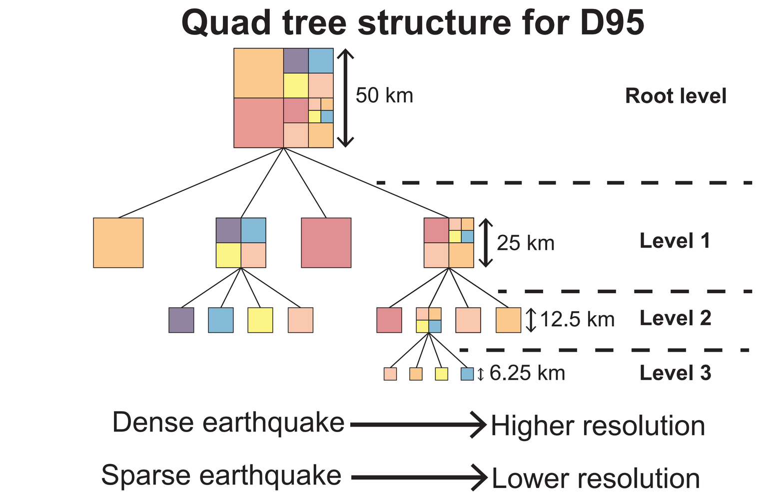


Constrained by temperature proxies:
- Surface heat flow (Mordensky et al., 2023)
- Seismogenic thickness (D95)
- Crustal thickness (Buehler and Shearer, 2017)
- Moho temperature (Schutt et al., 2018)

>40 years of M>1 earthquake records

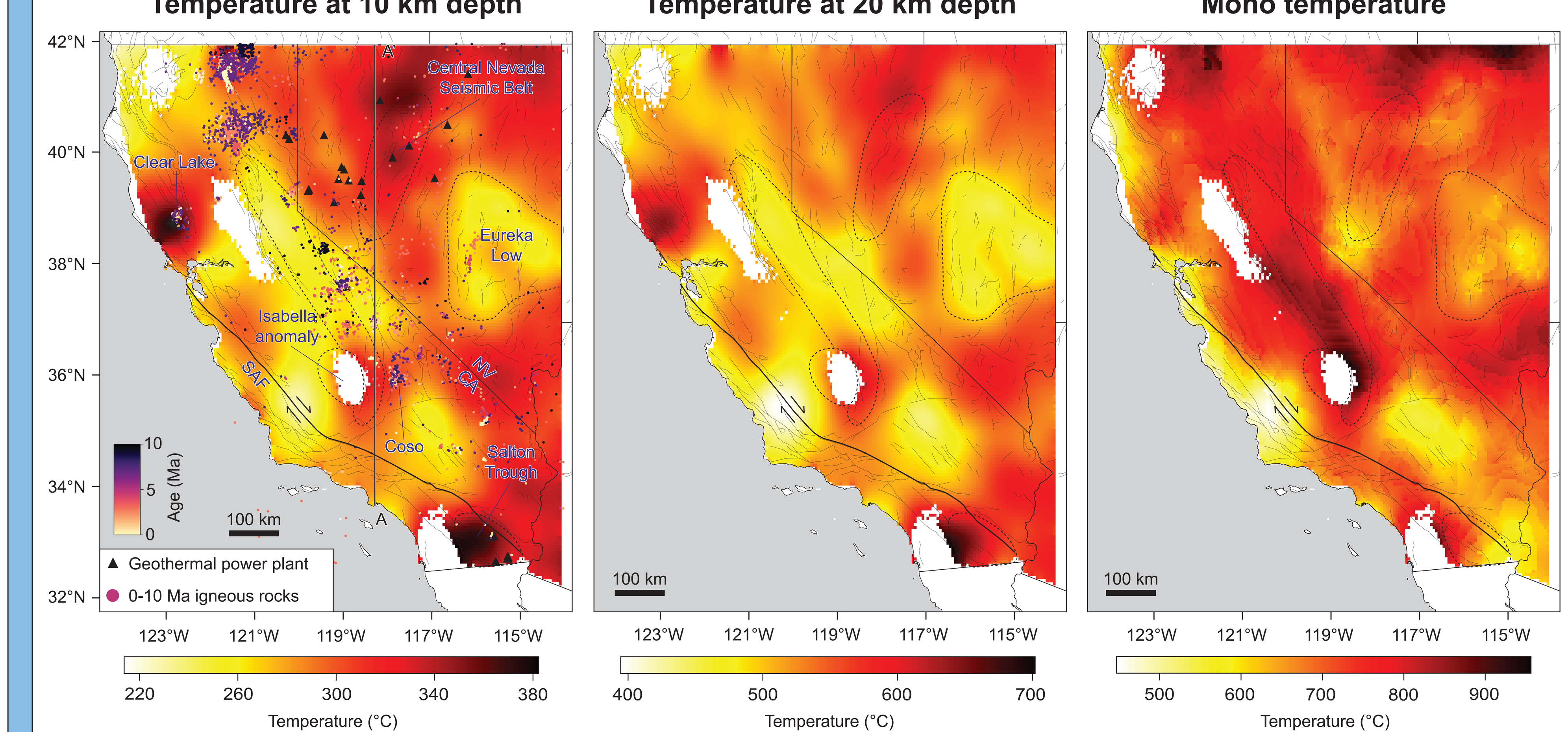


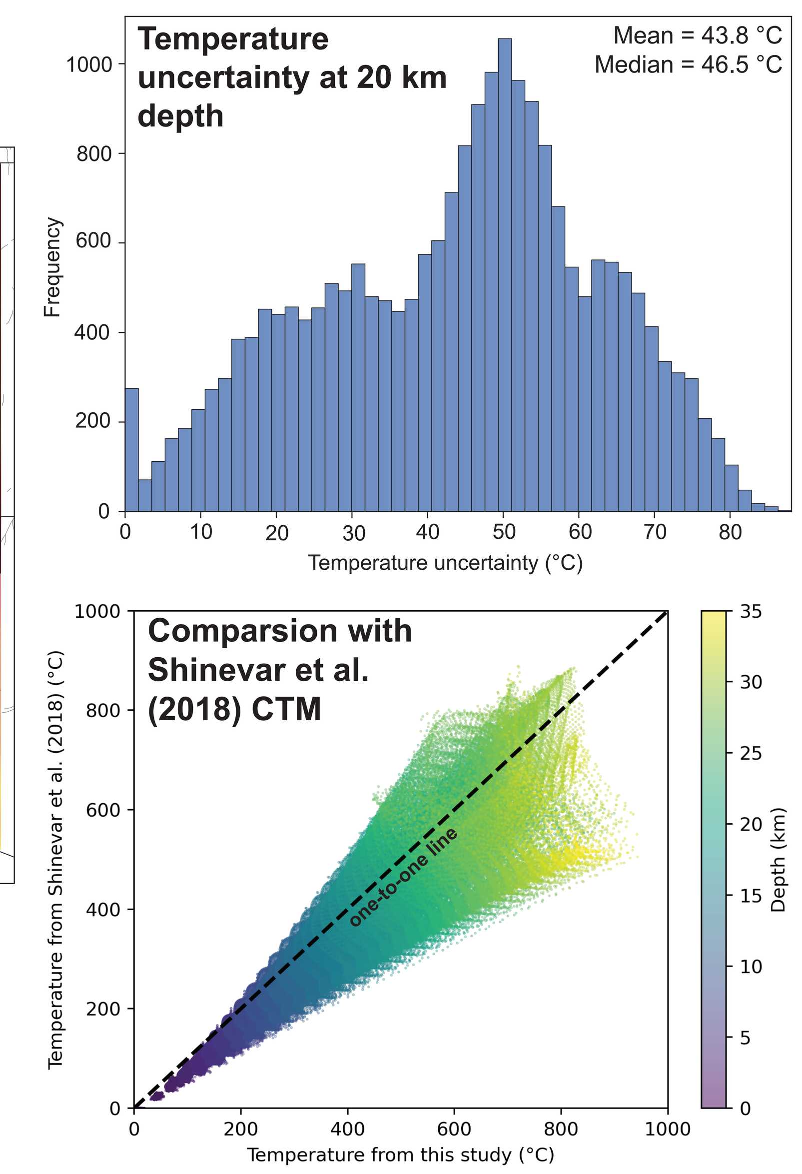
Quad tree structure for D95

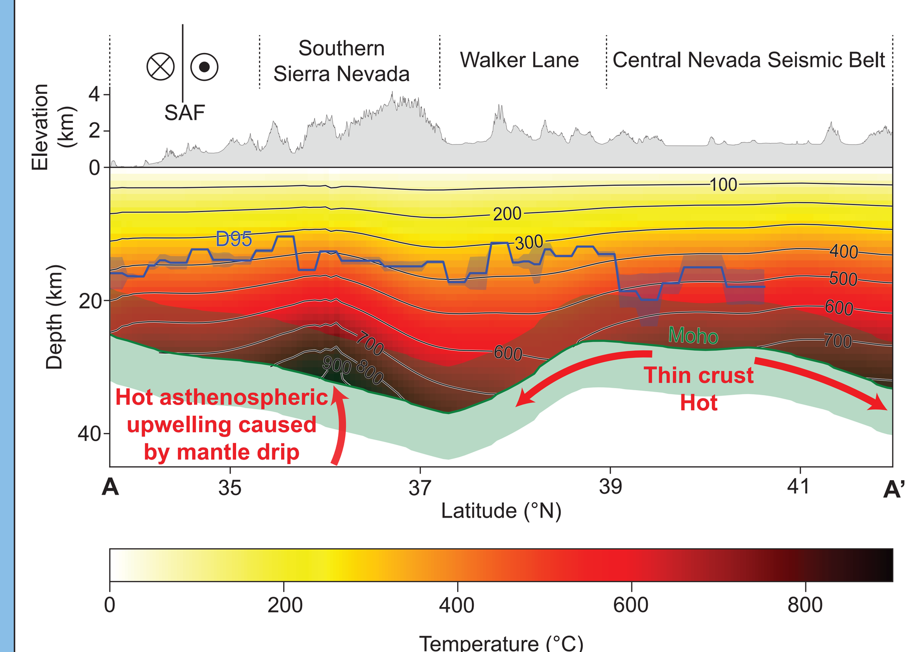


- D95 is the 95th percentile of the hypocenter distribution
- **D95 ≈ brittle-ductile transition ≈ 350 ± 100 °C**
- Assuming quartz and feldspar are the rock-forming minerals, the onset of ductile flow occurs at 250–450 °C (Hirth et al., 2001 *International Journal of Earth Sciences*; Rybacki and Dresen, 2004 *Tectonophysics*)
- Northern California (Waldhauser and Schaff, 2008 JGR SE; Waldhauser, 2009 *BSSA*)
- Southern California (Hauksson et al., 2012 *BSSA*)
- Nevada (Trugman, 2023 *Zenodo*, 2024 *SRL*)
- Uncertainty: (1) earthquake catalog quality and completeness, (2) transcient D95 during early aftershock (Cheng and Ben-Zion, 2019, 2019 *GRL*), and (3) mid-crustal lithological variation

New statewide CTM



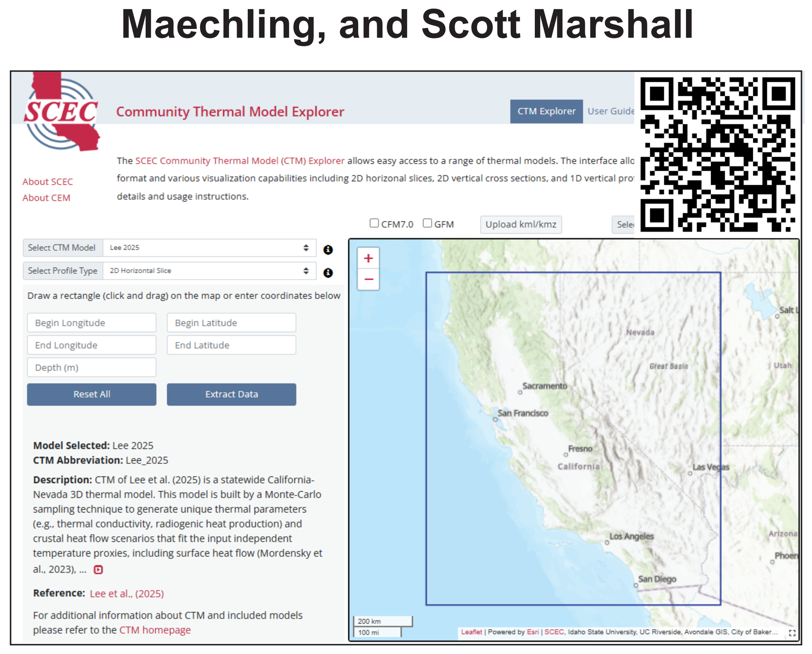




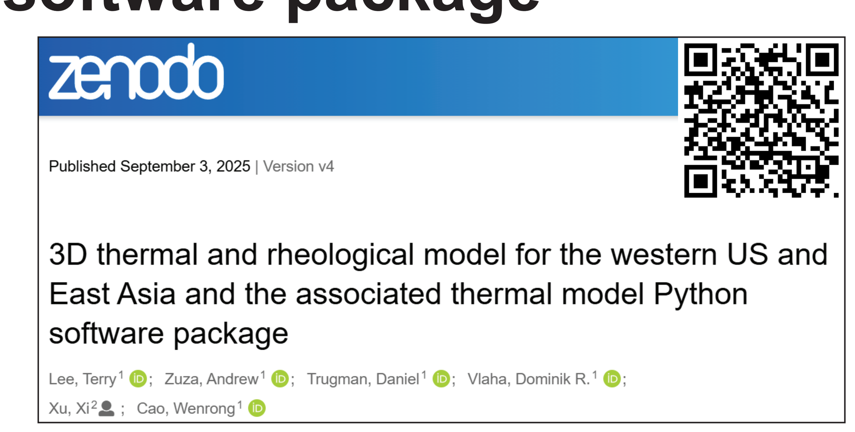
- **Hot** Salton Trough, Coso, Clear Lake volcanic field, and Central Nevada Seismic Belt with **>600 °C at 20 km depth**
- **Cold** Mojave, Seirra Nevada, Eureka Low with **<500 °C at 20 km depth**
- Southern Cascade, Isabella anomaly, and western Salton Trough lacks temperature fits, potentially due to transicent, non-conductive condition
- Localized hot spot at the southern Sierra Nevada related to mantle drip and asthenospheric counter flow
- Mean mid-crustal uncertainty of ~50 °C
- Similar estimations between our statewide CTM and the southern California CTM of Shinevar et al. (2018 EPSL)

Web explorer and modeling software package

In collabration with Mei-Hui Su, Phil Maechling, and Scott Marshall



- Rapid access and visualization of our statewide CTM and southern California CTM of Shinevar et al. (2018)
- 1D vertical profile
- 2D horizontal-slice map
- 2D cross-section


zenodo

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3D thermal and rheological model for the western US and East Asia and the associated thermal model Python software package

Lee, Terry; Zuza, Andrew; Trugman, Daniel; Vlaha, Dominik R.; Xu, Xi; Cao, Wenrong

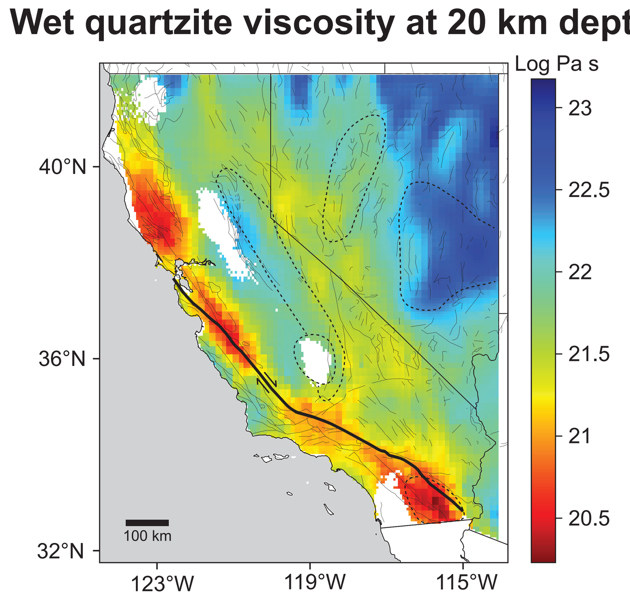
- Python-based software package allows customization of temperature proxies, model boundary, resolution, and thermal-statistical parameters
- **Generate 3D lithospheric thermal structure at any geographic locations of interest**
- Embedded a function to calculate D95 based on input earthquake catalog

```
[GeographicBoundary]
lat_max = 42
lat_min = 32
lon_max = -114
lon_min = -125
maximum_pixel_size = 50000
```

```
[ModelParameters]
Curie_depth_T = 550
Iteration = 100000
T0_range = 0, 20
k_range = 2, 5
H0_range = 1e-6, 1e-5
qm_range = 0.001, 0.05
goodfit = 0.35
moderatefit = 0.55
D95_T_config = 350
Max_goodfit_profile = 200
LAB_T_config = 1300
```

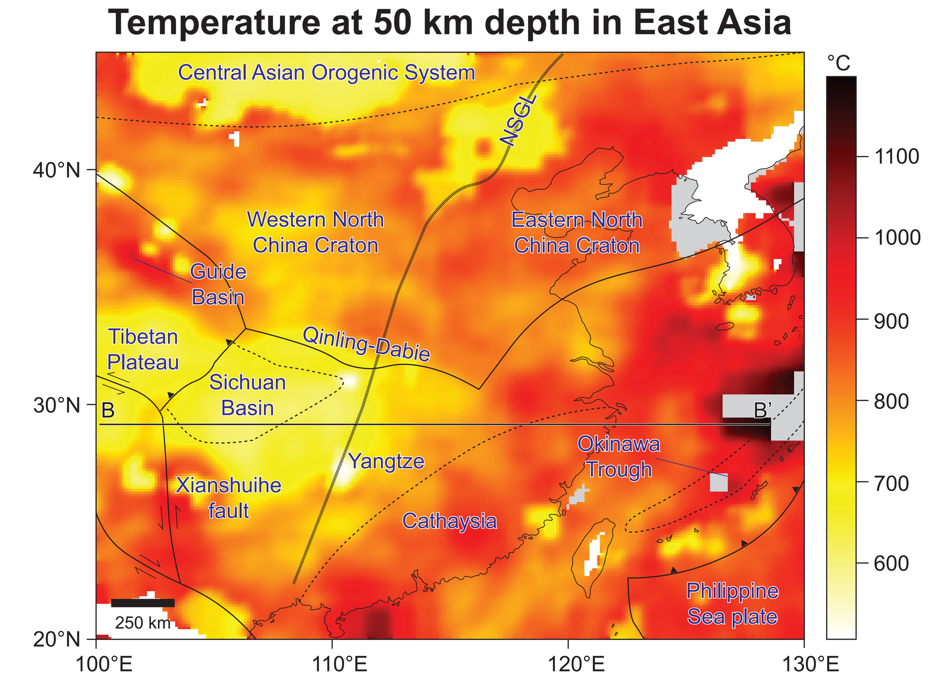
Implications

Wet quartzite viscosity at 20 km depth

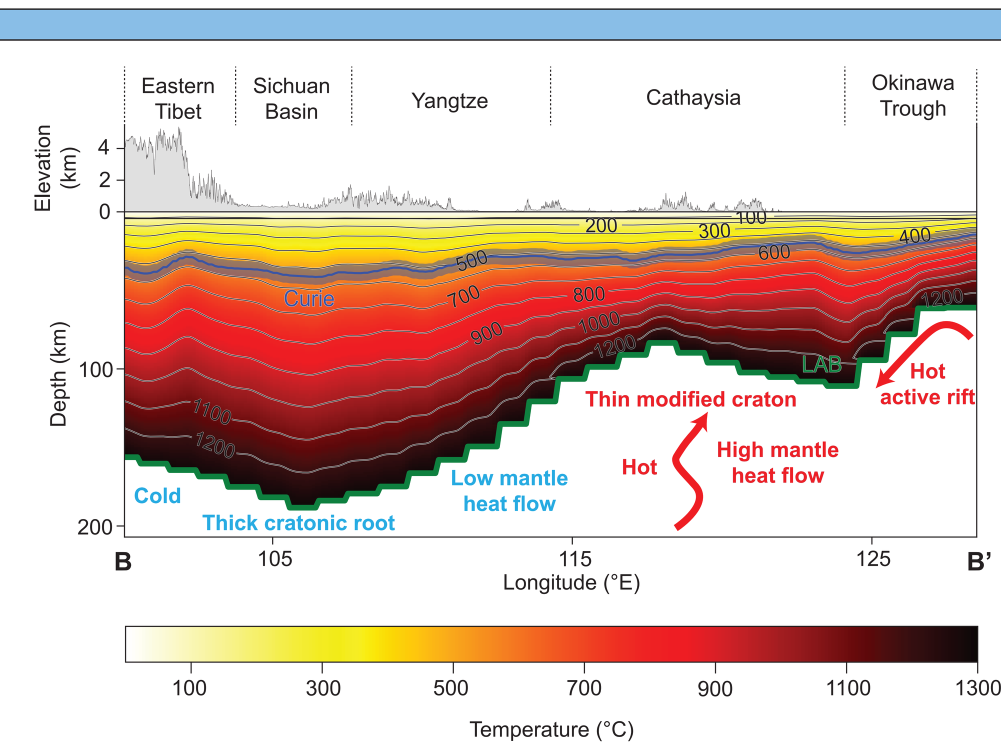


- Wet quartzite dislocation creep (Hirth et al., 2001)
- Geodetic strain rate (Kreemer and Young, 2022 *SRL*)
- Coupling our modeling framework to yield insights in lithospheric rheology

Temperature at 50 km depth in East Asia



- Surface heat flow (Sun et al., 2022 JGR SE; Wu et al., 2013 *Terr. Atmos.*)
- Curie depth (Li et al., 2017 *Scientific Reports*)
- Lithospheric thickness (An and Shi, 2006 *Physics of the Earth and Planetary Interiors*)



- Imaging the margin of modified cratons
- Warm Cathaysia vs cold Yangtze
- Higher mantle heat flow under modified cratons
- Hot, active back-arc of the Okinawa Trough