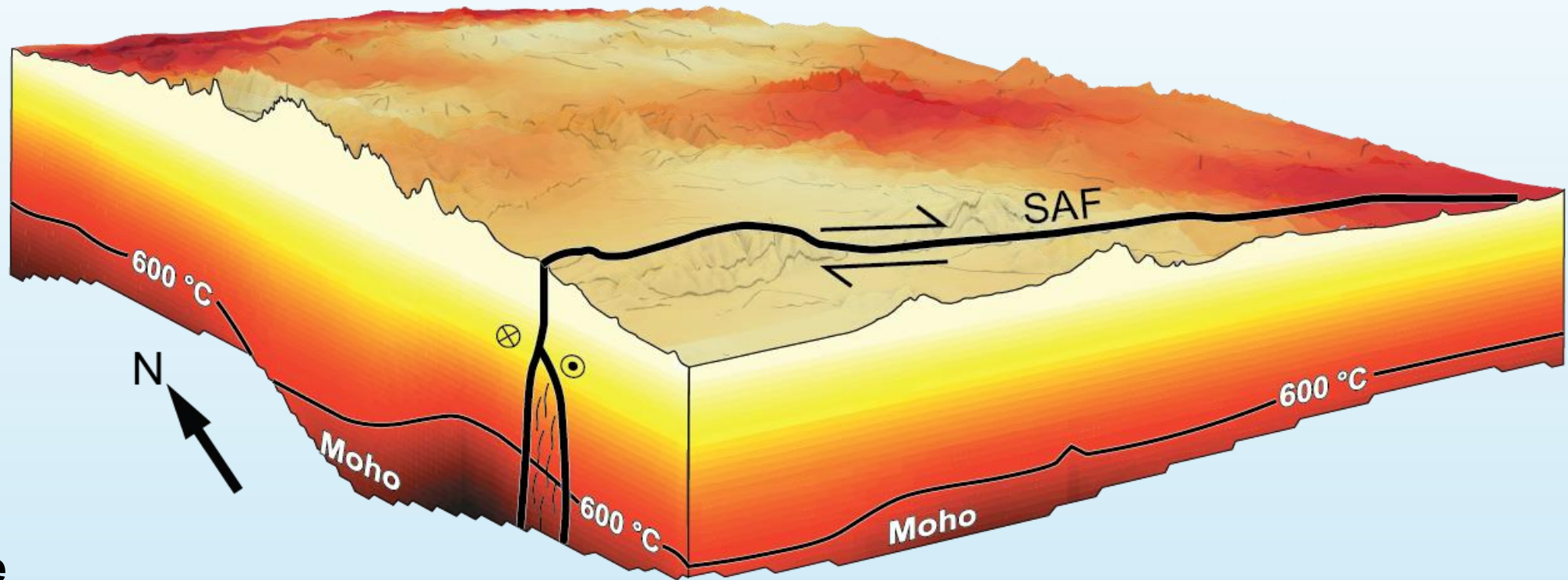


Updates on the Community Thermal Model (CTM)



Terry Lee

(terrywaihol@unr.edu)

Andrew Zuza, Daniel Trugman

Dominik Vlaha, Wenrong Cao

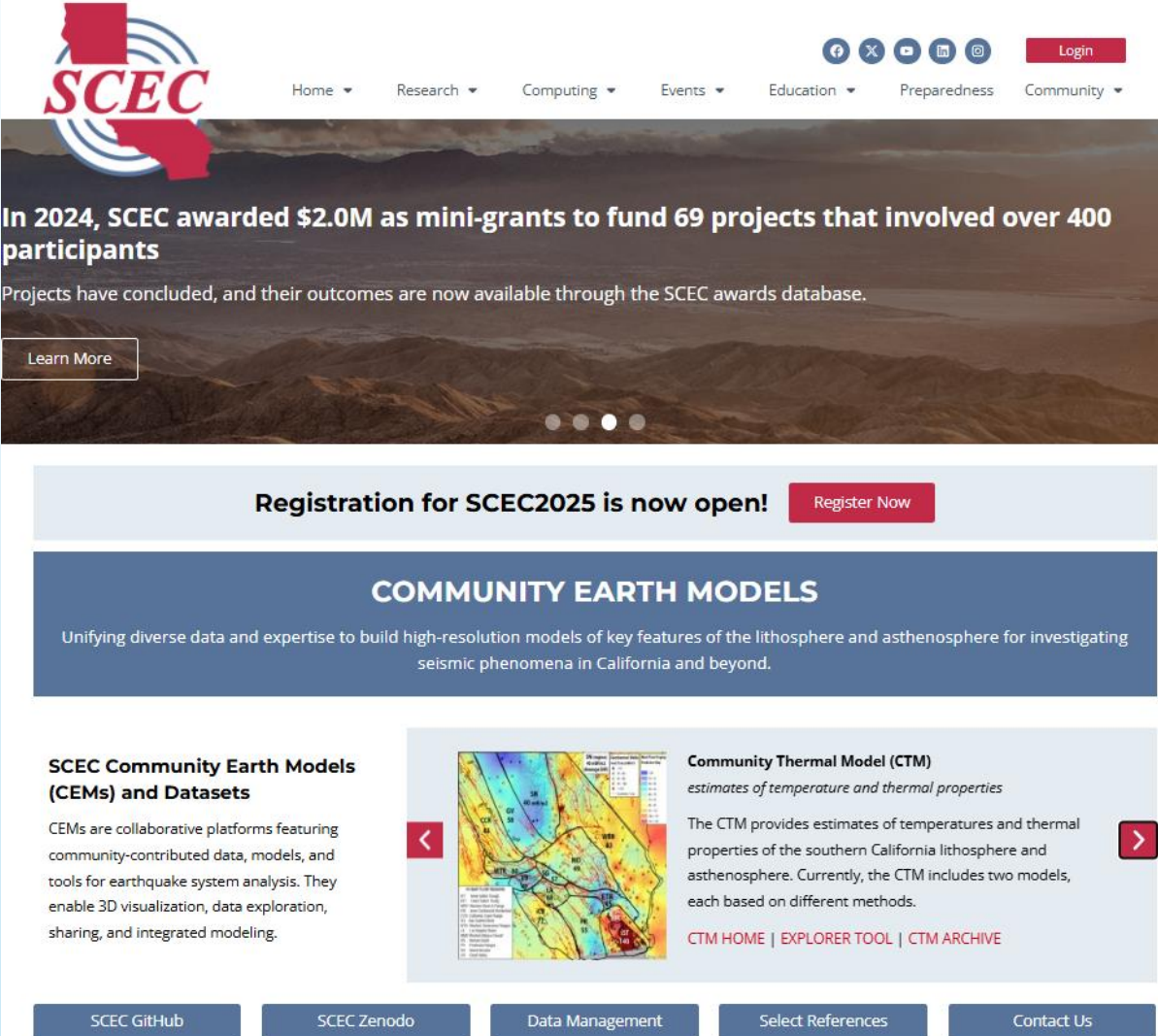


NEVADA
SEISMOLOGICAL
LABORATORY



Community Earth Model (CEM)

- Community Fault Model (CFM)
- Community Geodetic Model (CGM)
- Community Rheology Model (CRM)
- Community Stress Model (CSM)
- **Community Thermal Model (CTM)**
- **Geological Framework Model (GFM)**
- Community Velocity Model (CVM)



The screenshot shows the SCEC (Southern California Earthquake Center) website. At the top is the SCEC logo and a navigation bar with links: Home, Research, Computing, Events, Education, Preparedness, and Community. A 'Login' button is also present. Below the navigation bar is a large banner image of a desert landscape with mountains. The banner text reads: 'In 2024, SCEC awarded \$2.0M as mini-grants to fund 69 projects that involved over 400 participants'. Below this, it says 'Projects have concluded, and their outcomes are now available through the SCEC awards database.' and a 'Learn More' button. Below the banner is a section titled 'Registration for SCEC2025 is now open!' with a 'Register Now' button. Below that is a section titled 'COMMUNITY EARTH MODELS' with the text 'Unifying diverse data and expertise to build high-resolution models of key features of the lithosphere and asthenosphere for investigating seismic phenomena in California and beyond.' Below this is a section titled 'SCEC Community Earth Models (CEMs) and Datasets' with a description of CEMs as collaborative platforms. To the right of this text is a map of Southern California showing various geological features and data points. Below the map is a section titled 'Community Thermal Model (CTM)' with the text 'estimates of temperature and thermal properties'. Below this, it says 'The CTM provides estimates of temperatures and thermal properties of the southern California lithosphere and asthenosphere. Currently, the CTM includes two models, each based on different methods.' and links to 'CTM HOME', 'EXPLORER TOOL', and 'CTM ARCHIVE'. At the bottom of the page are five buttons: 'SCEC GitHub', 'SCEC Zenodo', 'Data Management', 'Select References', and 'Contact Us'.

SCEC

Home Research Computing Events Education Preparedness Community

Login

In 2024, SCEC awarded \$2.0M as mini-grants to fund 69 projects that involved over 400 participants

Projects have concluded, and their outcomes are now available through the SCEC awards database.

Learn More

Registration for SCEC2025 is now open! Register Now

COMMUNITY EARTH MODELS

Unifying diverse data and expertise to build high-resolution models of key features of the lithosphere and asthenosphere for investigating seismic phenomena in California and beyond.

SCEC Community Earth Models (CEMs) and Datasets

CEMs are collaborative platforms featuring community-contributed data, models, and tools for earthquake system analysis. They enable 3D visualization, data exploration, sharing, and integrated modeling.

Community Thermal Model (CTM)
estimates of temperature and thermal properties

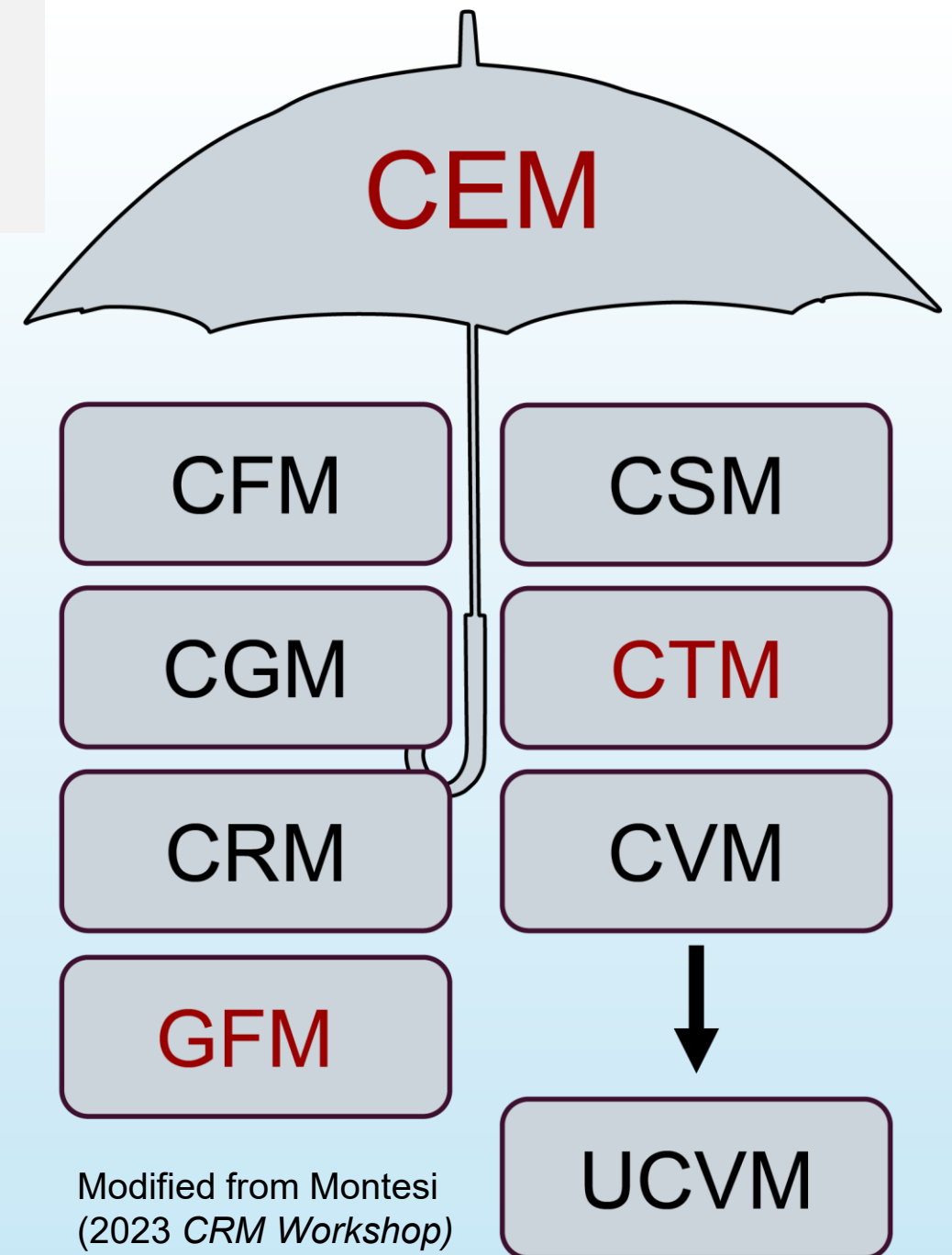
The CTM provides estimates of temperatures and thermal properties of the southern California lithosphere and asthenosphere. Currently, the CTM includes two models, each based on different methods.

CTM HOME | EXPLORER TOOL | CTM ARCHIVE

SCEC GitHub SCEC Zenodo Data Management Select References Contact Us

Community Earth Model (CEM)

- Community Fault Model (CFM)
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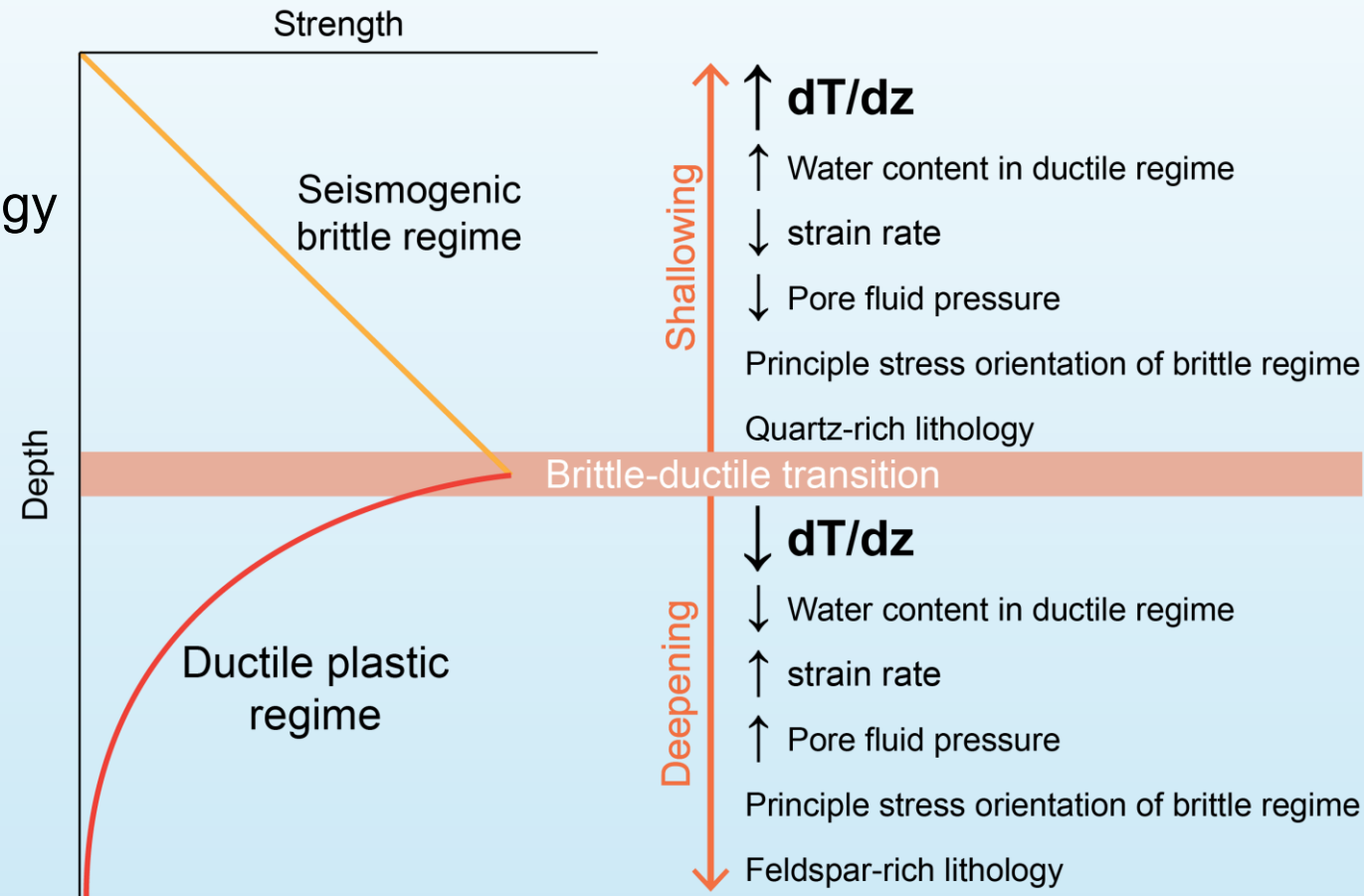
Thermal structure modulates rheology

Exerts a first-order control on lithospheric rheology

- Seismogenic thickness → **seismicity**
- Ductile strength → **crustal flow**
- Temperature-dependent rheology

$$\text{Viscosity} = f(T)$$

$$\text{Temperature} \propto \text{Viscosity}^{-1}$$



Modified from Sibson (1984 *JGR SE*)

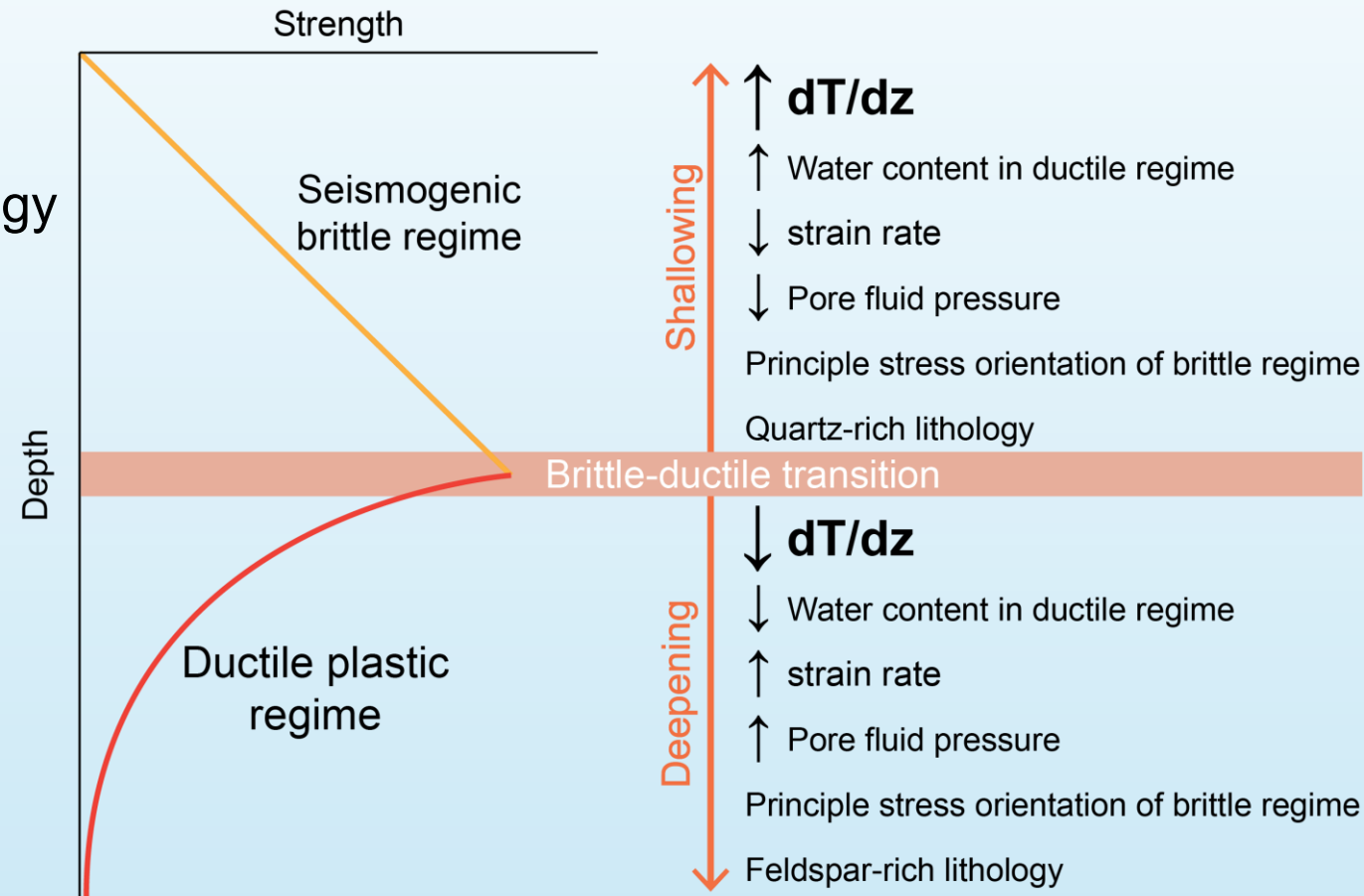
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$$\text{Viscosity} = f(T)$$

↑ Temperature \propto Viscosity⁻¹ ↓



Modified from Sibson (1984 *JGR SE*)

Thermal modeling for the continental lithosphere

1D heat equation:

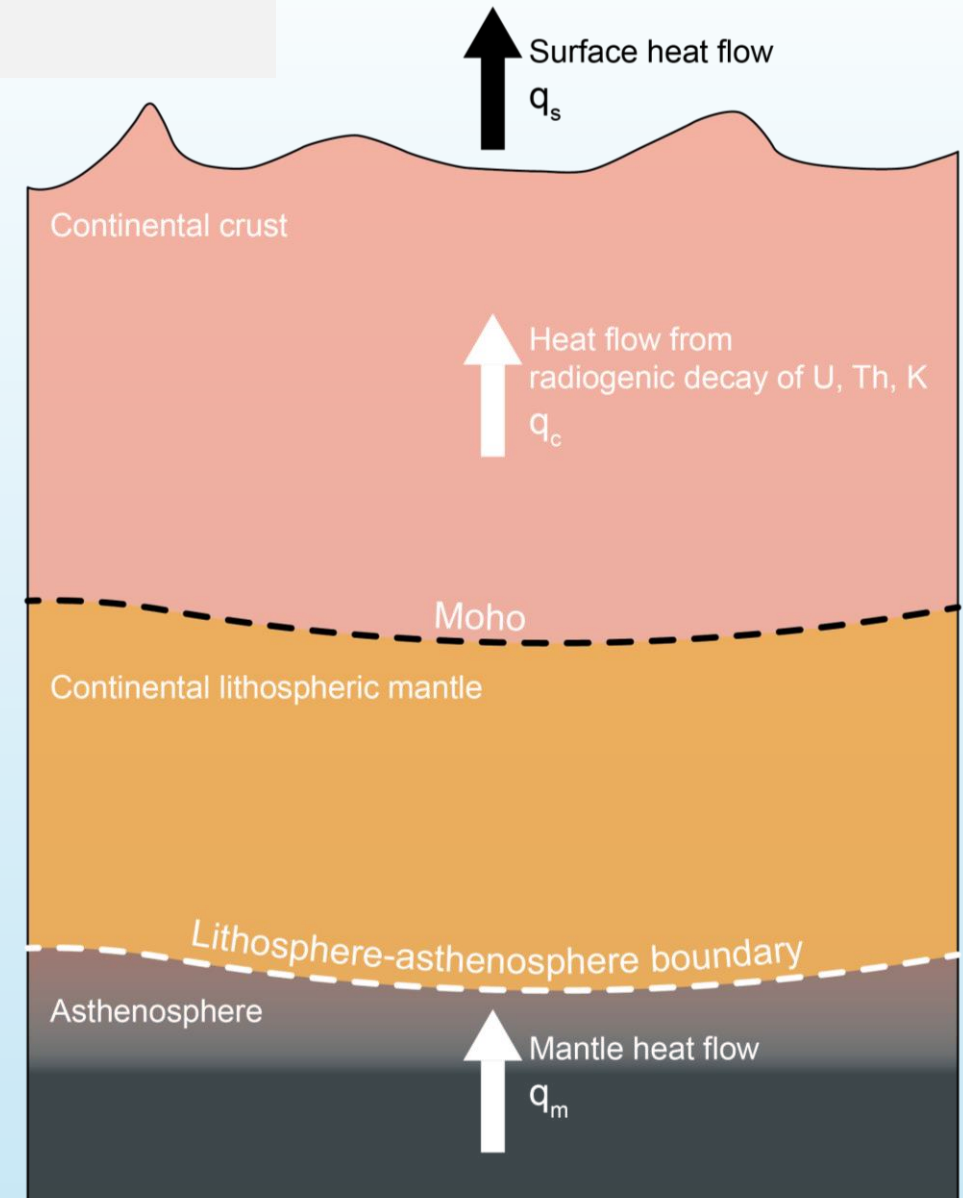
$$\frac{\partial T}{\partial t} = \frac{\partial^2 T}{\partial z^2} \frac{k}{\rho c_p} + \text{Heat source}$$

Heat flow (q):

$$q = -\frac{dT}{dz} k$$

Surface heat flow (q_s):

$$q_s = q_c + q_m$$



Thermal modeling for the continental lithosphere

1D heat equation (steady state):

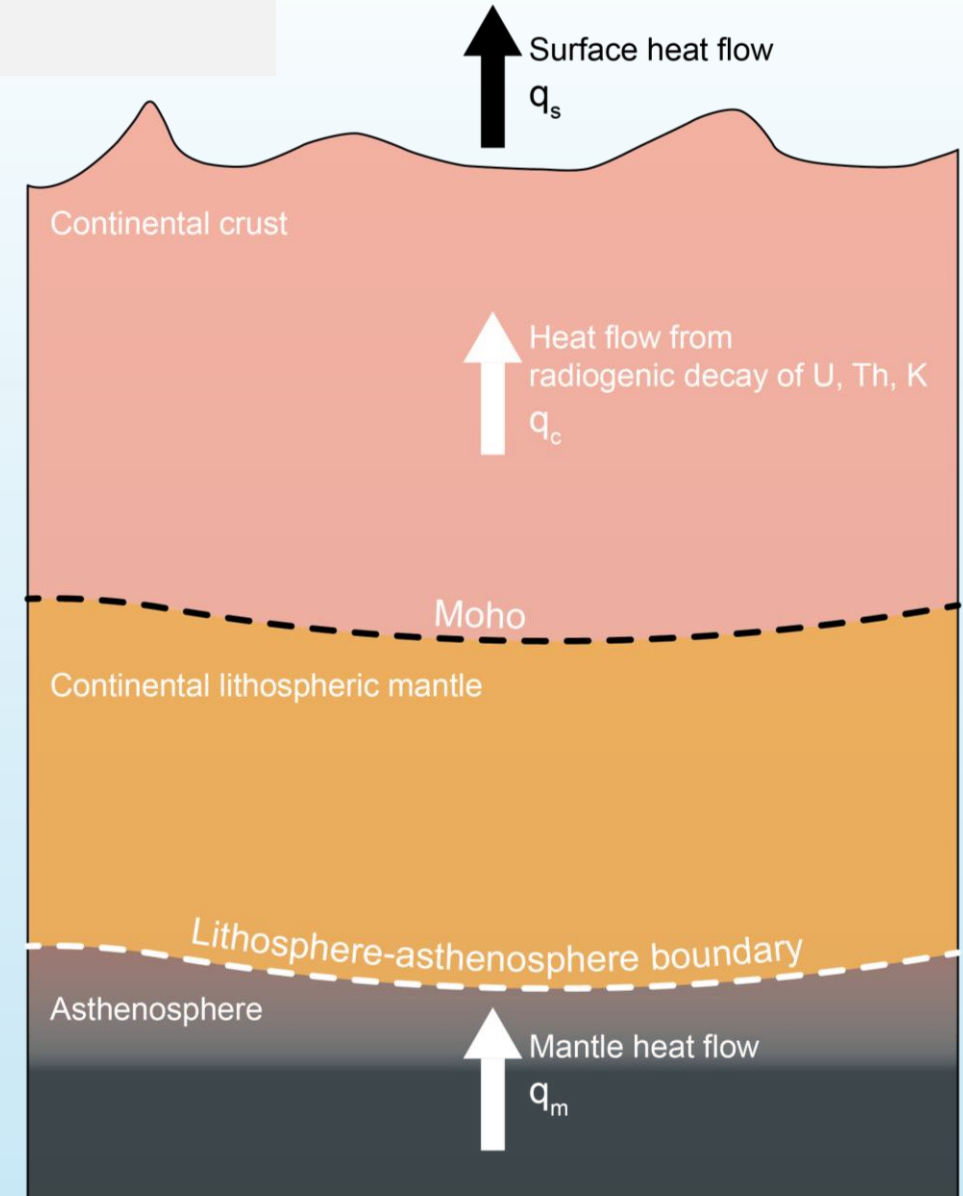
$$0 = \frac{d^2T}{dz^2} \frac{k}{\rho c_p} + \text{Heat source}$$

Heat flow (q):

$$q = -\frac{dT}{dz} k$$

Surface heat flow (q_s):

$$q_s = q_c + q_m$$



Thermal modeling for the continental lithosphere

Surface heat flow (q_s):

$$q_s = q_c + q_m$$

Empirical heat flow relationship (a.k.a geotherm families)

$$q_c \approx 0.26\text{--}0.4 q_s$$

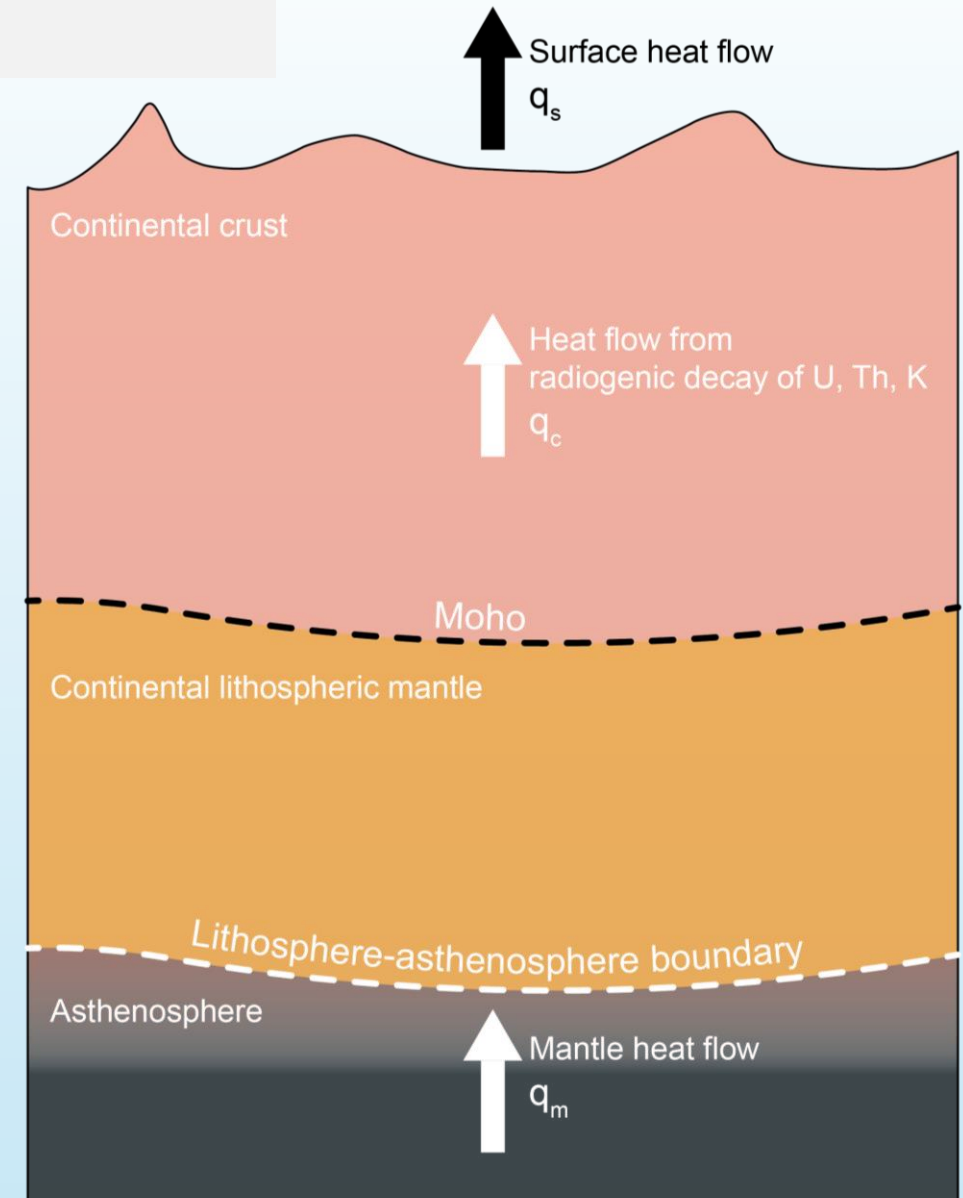
Pollack and Chapman (1977 *Tectonophysics*)

Vitarello and Pollack (1980 *JGR SE*)

Artemieva and Mooney (2001 *JGR SE*)

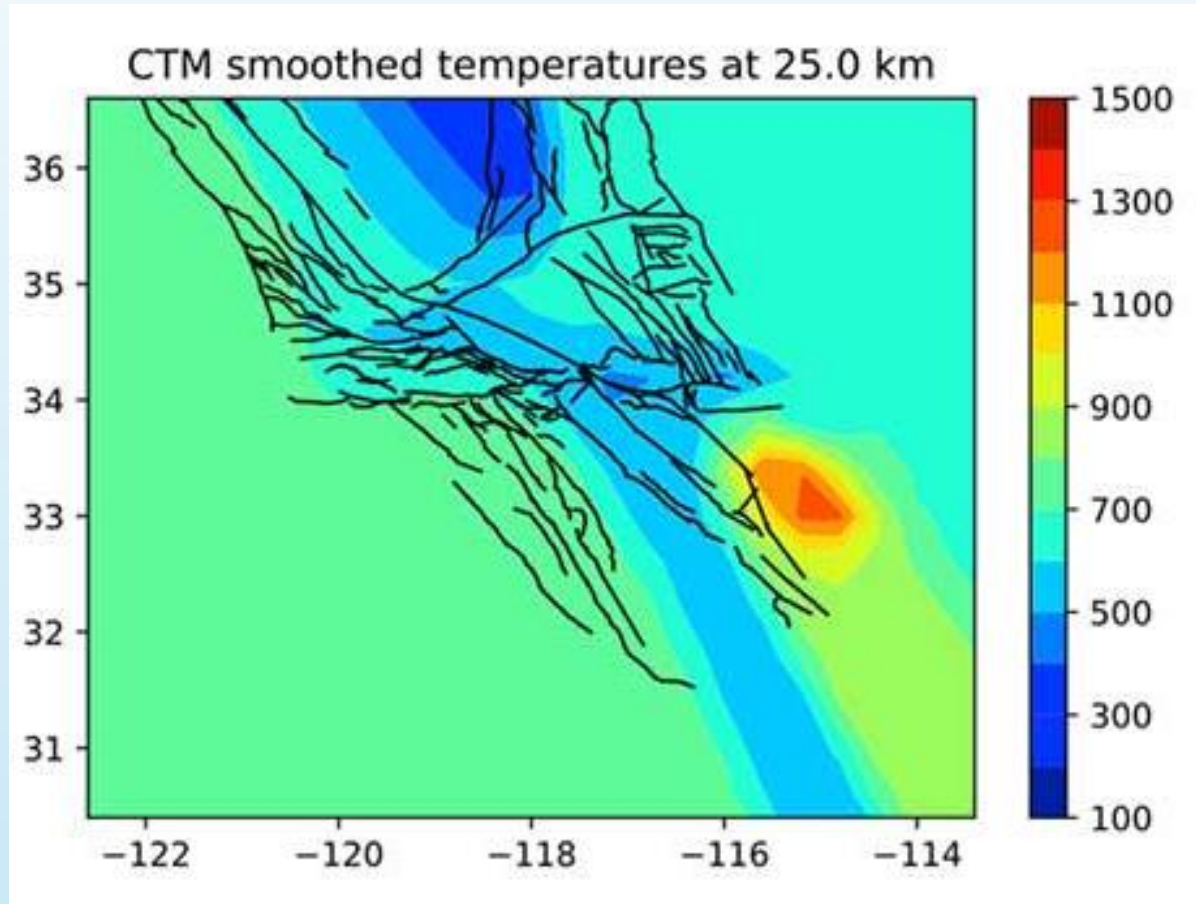
Hasterok and Chapman (2011 *EPSL*)

$$q_m \approx 0.6\text{--}0.74 q_s$$

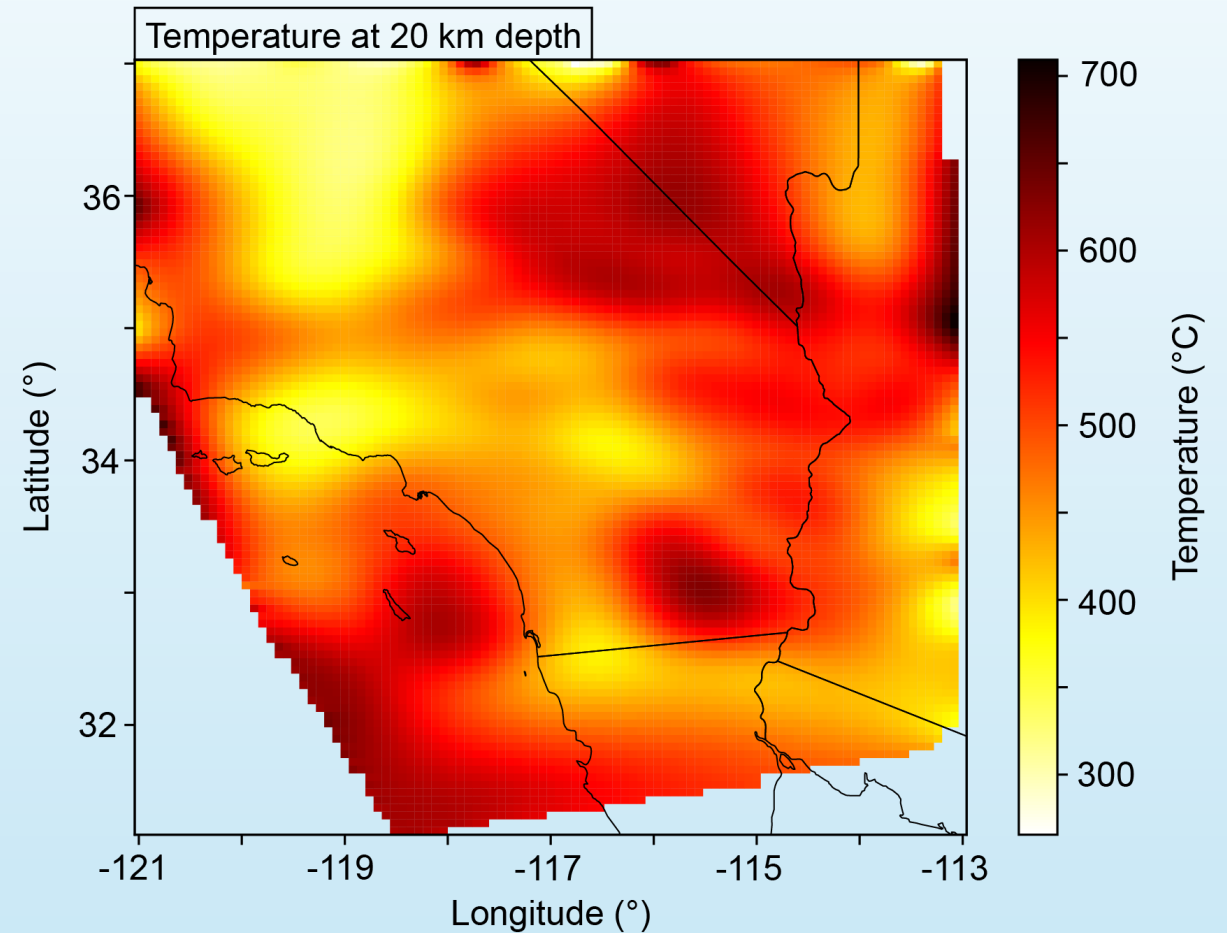


Southern California CTMs

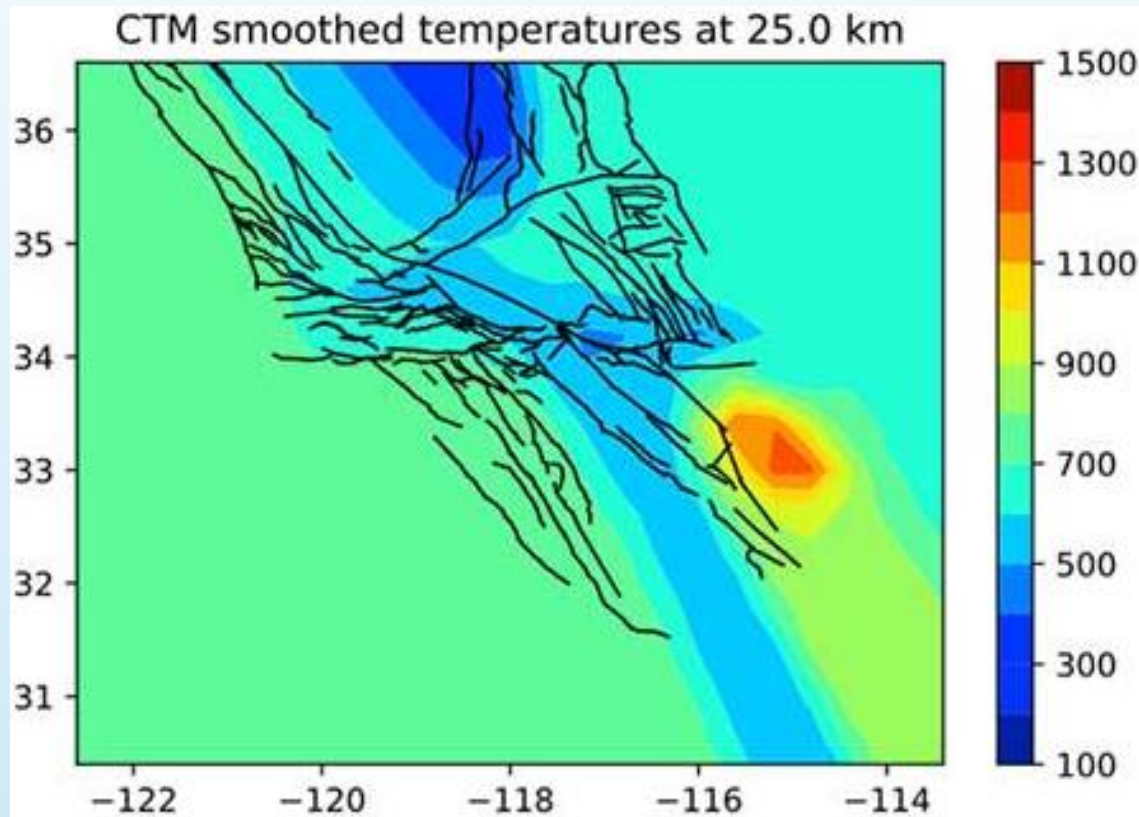
Thatcher and Chapman (2020)



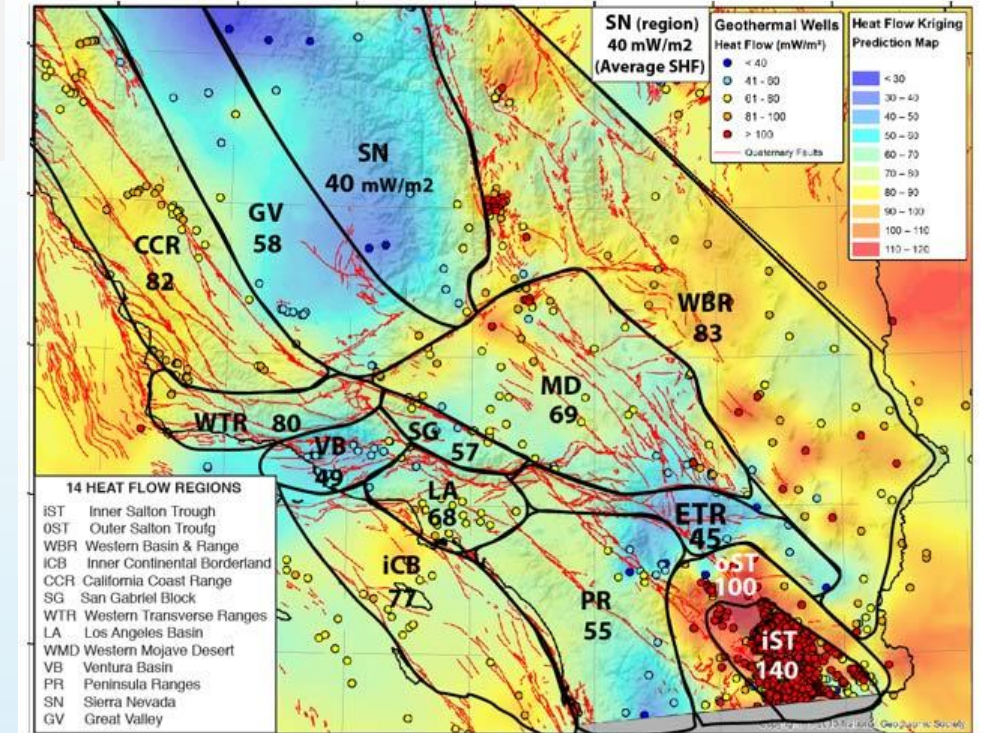
Shinevar et al. (2018)



Thatcher and Chapman (2020) model



14 surface heat flow (q_s) regions

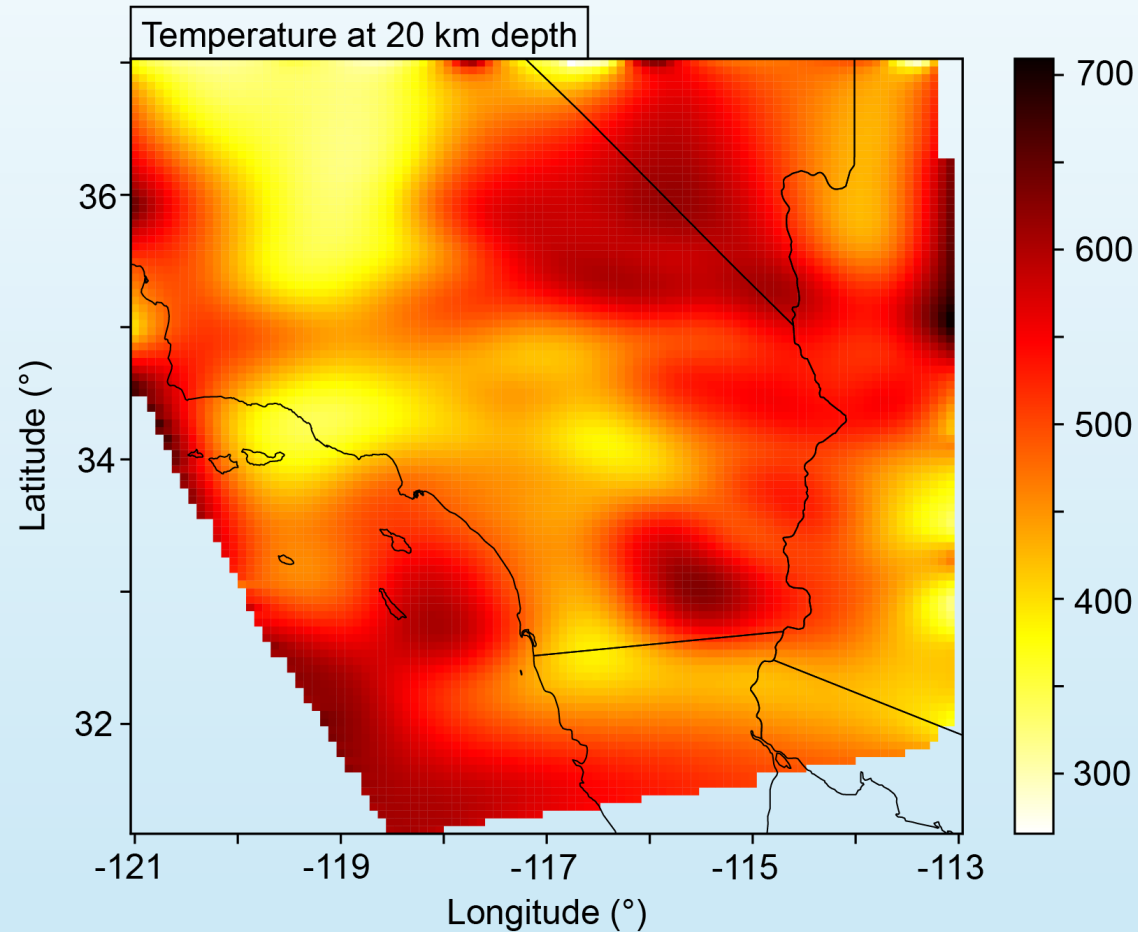


Williams and DeAngelo (2011 *GRC Transactions*)

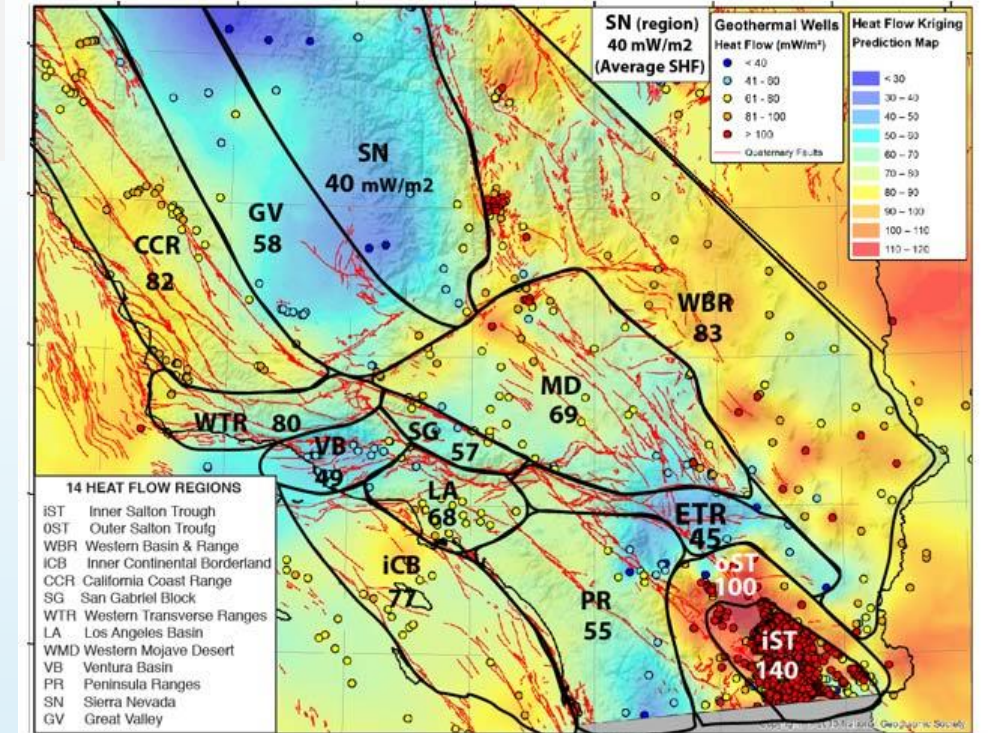
- 1D conductive geotherm at each heat-flow province
 - Assume heat flow relationship
 - $q_c = 0.4 q_s$
 - $q_m = 0.6 q_s$
- Constrain non-steady state heat transport condition with seismic lithospheric thickness
 - Basal heating by the asthenosphere

Pollack and Chapman (1977 *Tectonophysics*)

Shinevar et al. (2018) model



Interpolated heat flow model



Williams and DeAngelo (2011 *GRC Transactions*)

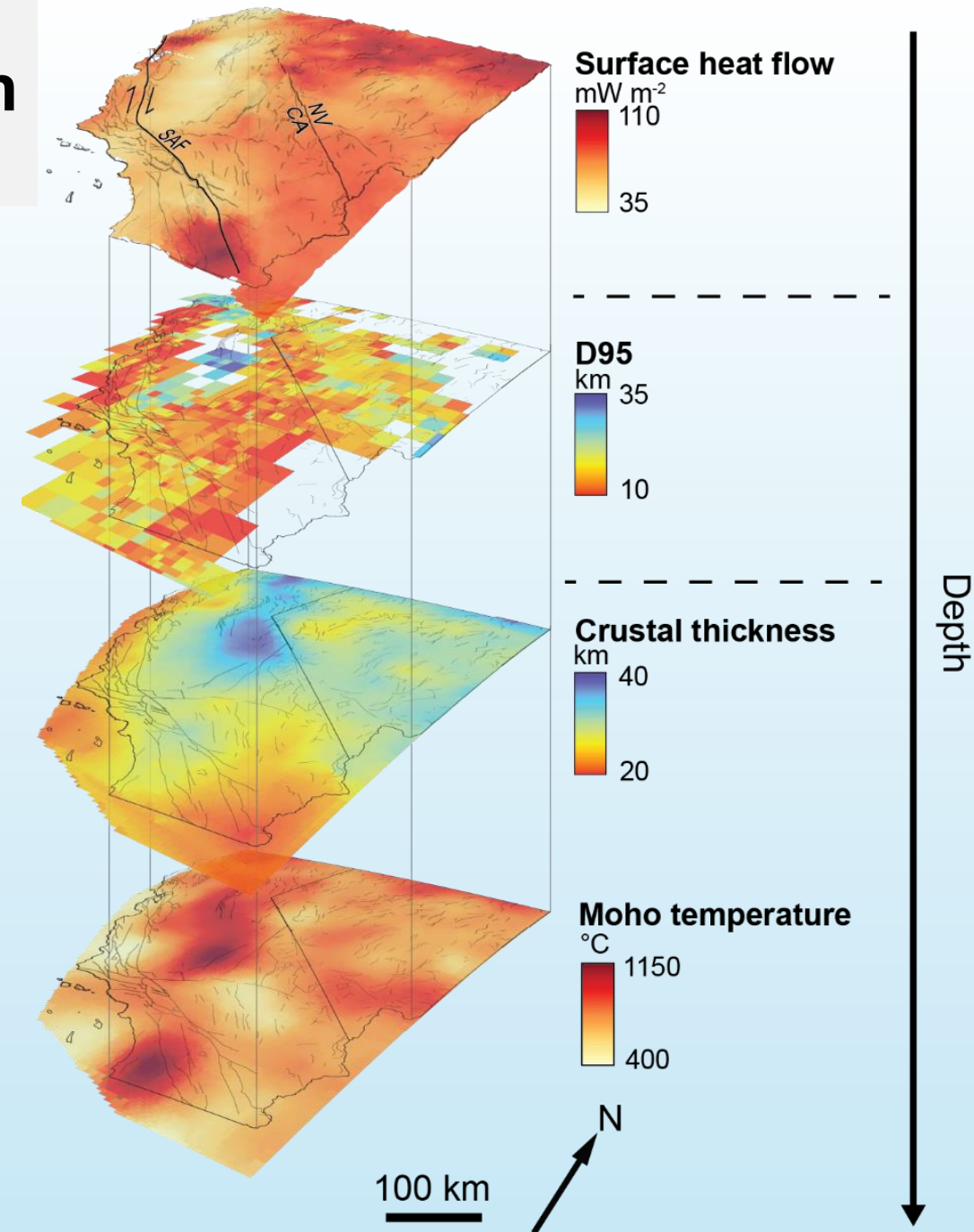
- Leverage smoothed heat flow model to calculate 1D vertical conductive geotherms
- Assume heat flow relationship
 - $q_c = 0.4 q_s$
 - $q_m = 0.6 q_s$

Pollack and Chapman (1977 *Tectonophysics*)

New statewide CTM—different approach

Temperature proxies through the crustal column

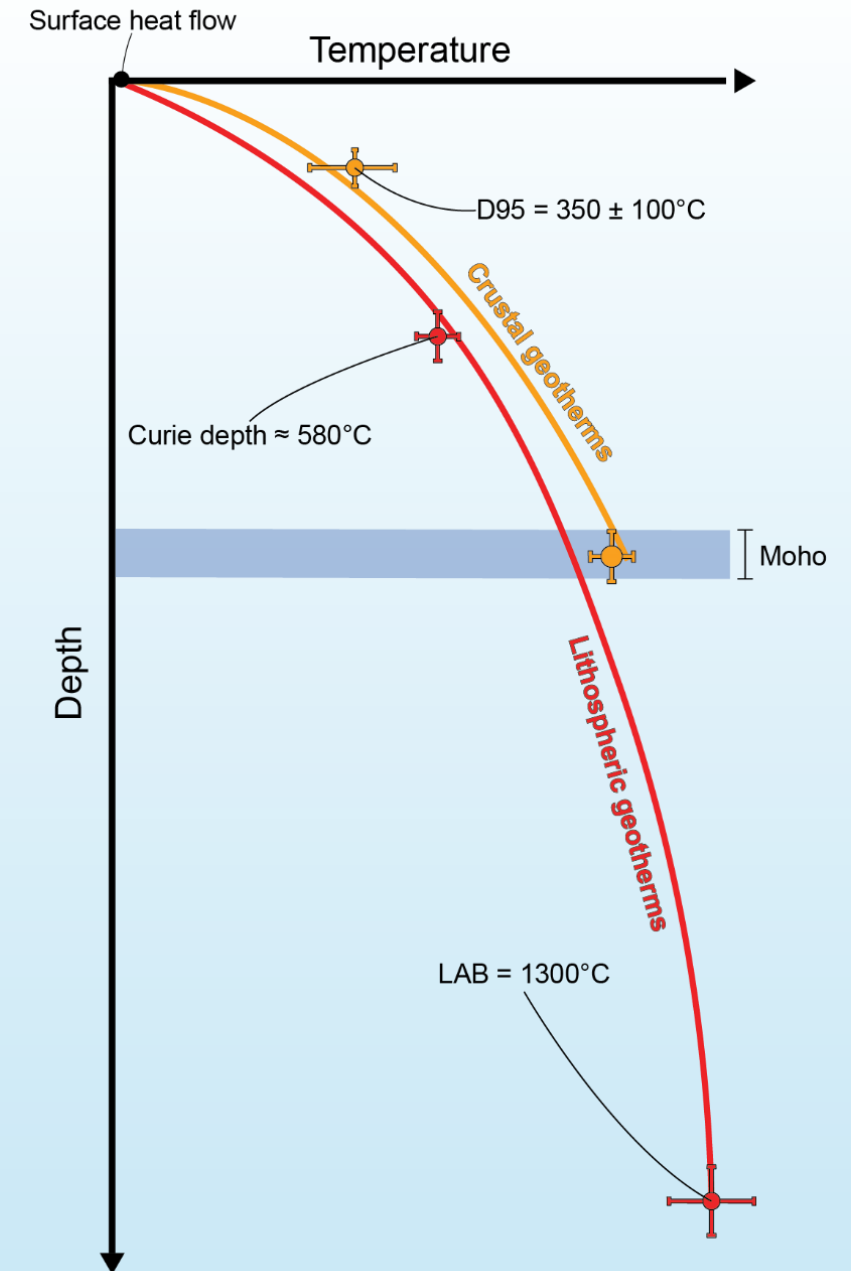
- Surface heat flow (Mordensky et al., 2023 *Geothermics*)
- New seismogenic thickness (D95) model
- Crustal thickness (Buehler and Shearer, 2017 *JGR SE*)
- Moho temperature (Schutt et al., 2018 *Geology*)



New statewide CTM—different approach

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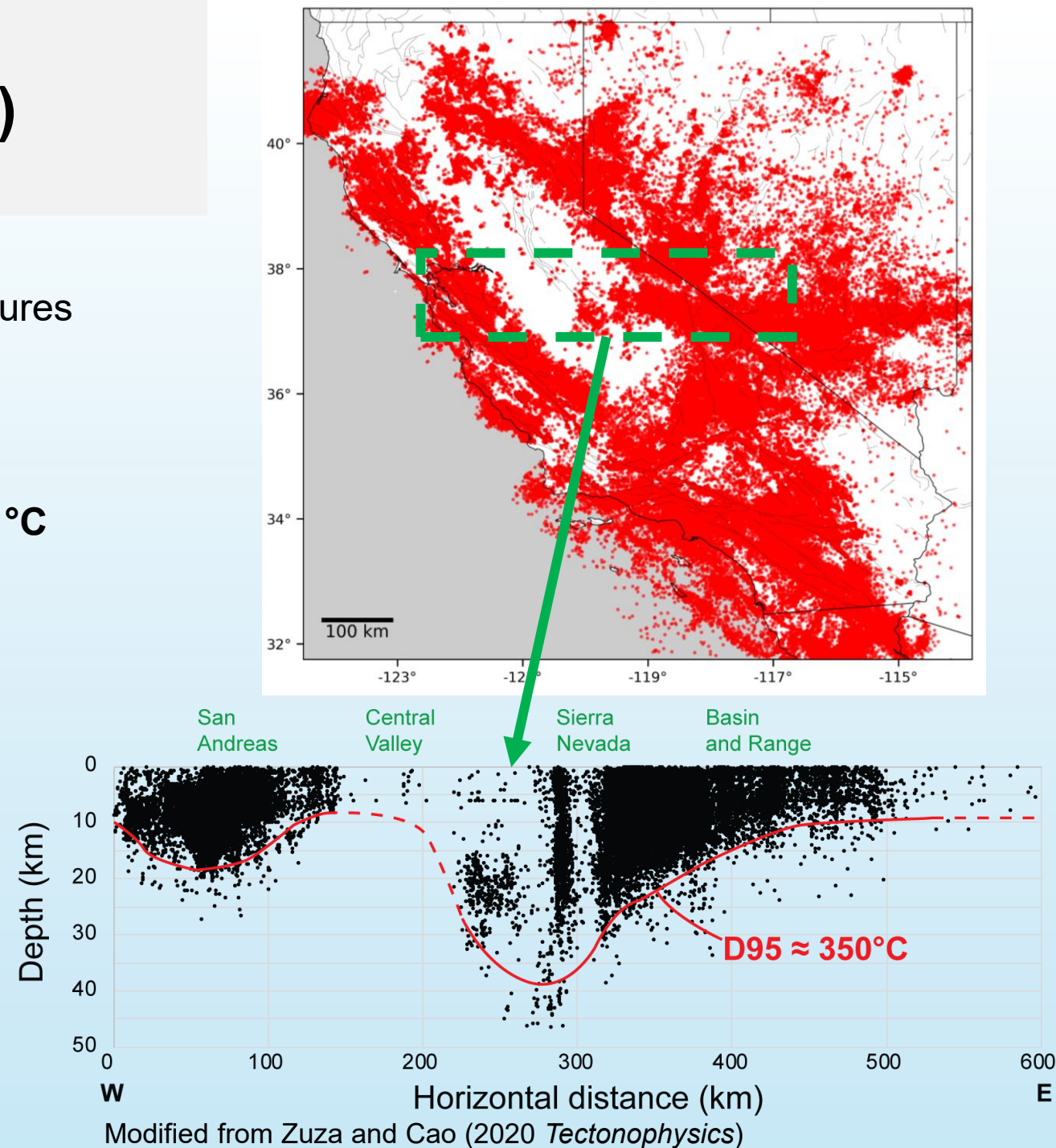
New seismogenic thickness (D95)

95th percentile of the hypocenter distribution (**D95**) captures the seismogenic thickness

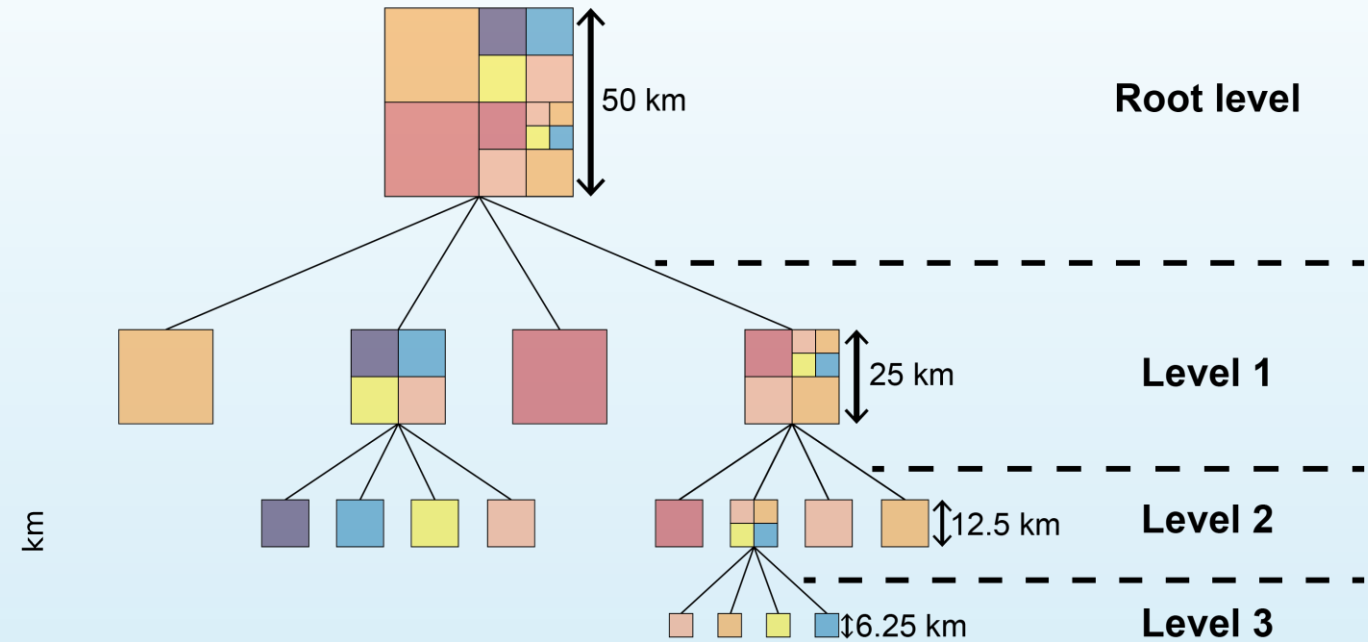
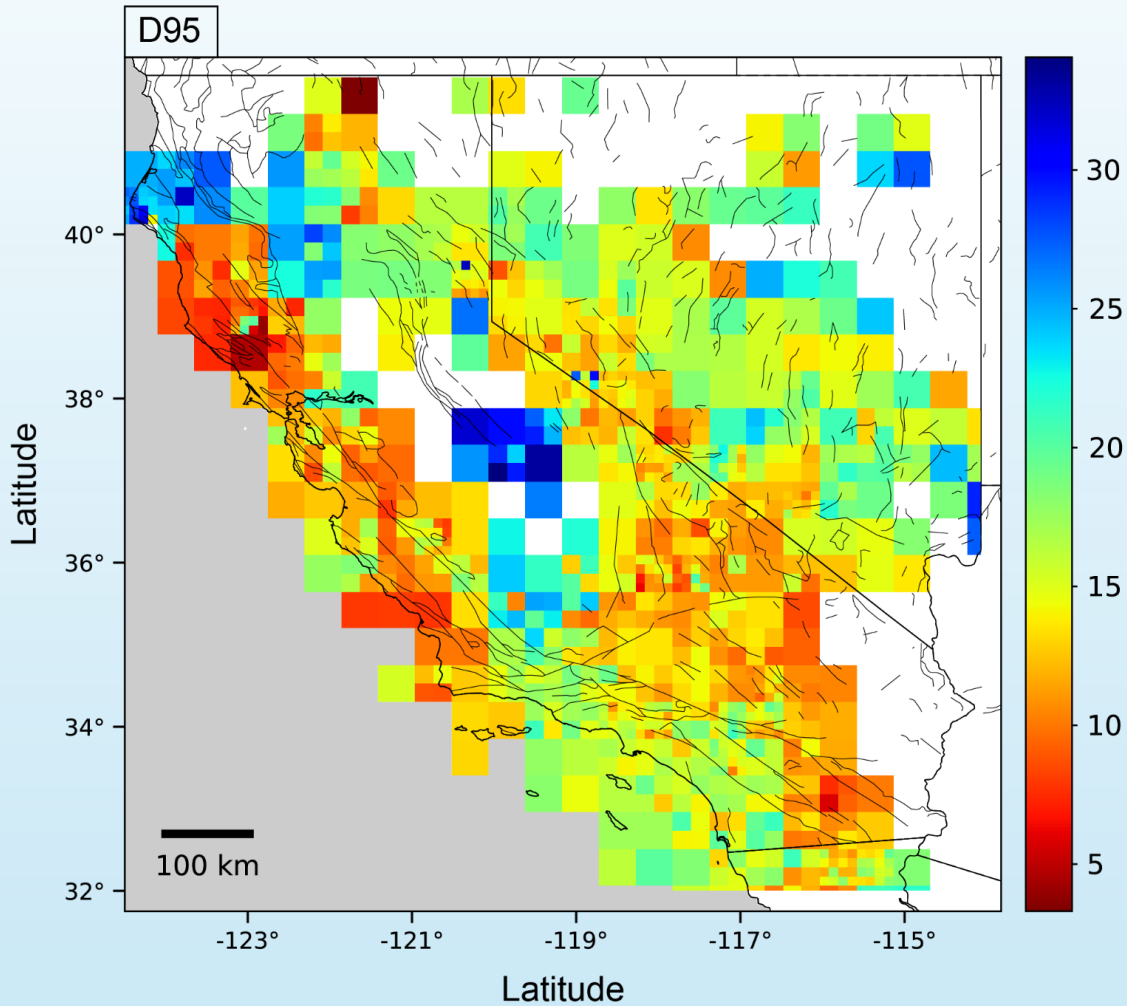
- **D95 \approx BDT $\approx 350 \pm 100$ °C**
- **Quartz and feldspar become ductile at ~ 350 °C**

Merged >40 years of earthquake records from:

- 1984-2024 Northern California
(Waldhauser and Schaff, 2008 *JGR SE*; Waldhauser, 2009 *BSSA*)
- 1981-2023 Southern California
(Hauksson et al., 2012 *BSSA*)
- 1980-2024 Nevada
(Trugman, 2023 *Zenodo*; 2024 *SRL*)



Adaptive binning for D95 model



Adaptively sized bin — **quad tree structure**
(Finkle and Bentley, 1974 *Acta Informatica*)

- Bin width = **50 to 6.25 km**

Monte-Carlo sampling for the thermophysical parameters

Generate 100,000 samples of T_0 , q_m , k , h , H_0
(100,000 **unique heat flow scenarios**)


Calculate 1D steady-state conductive geotherm for each scenarios

Accept geotherms based on these criteria:

1. q_s^{model} is $\pm 10 \text{ mW m}^{-2}$ of heat flow observations
2. Normalized root mean square error (NRMSE) when compared to D95 and Moho condition

Don't follow a specific 'geotherm family'

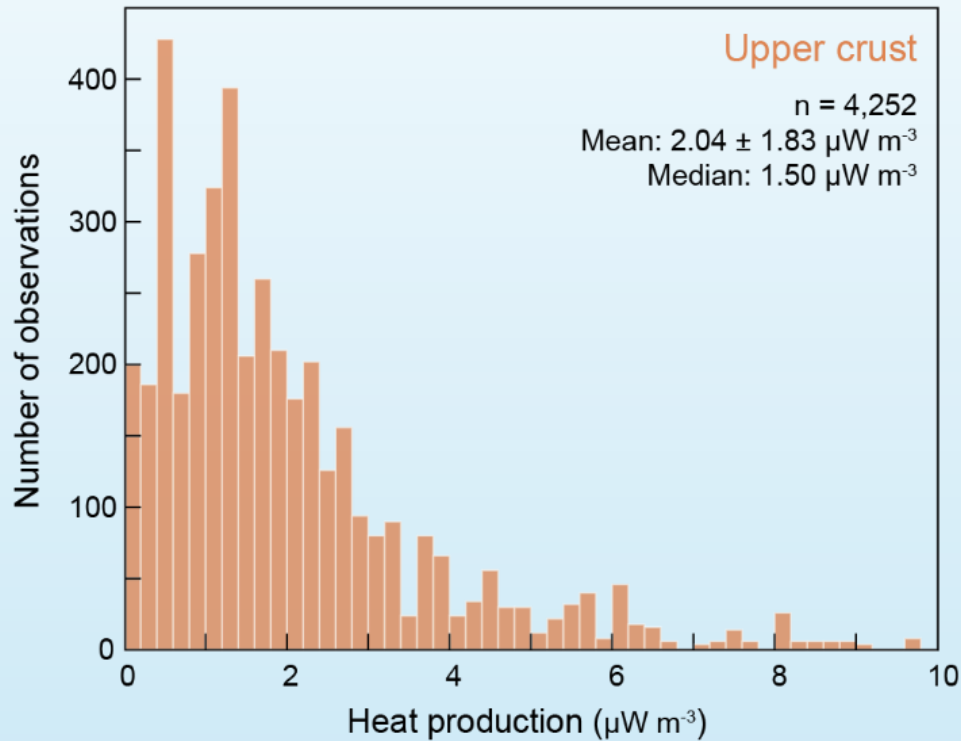
T_0 (Surface temperature)	0 to 20 [°C]
k (Thermal conductivity)	2 to 5 [$\text{W m}^{-1} \text{ } ^\circ\text{C}^{-1}$]
h (Radiogenic heating decay length)	0 to $z_{\text{Moho}} / 2$ [m]
H_0 (Surface radiogenic heat production)	1 to 10 [$\mu\text{W m}^{-3}$]
q_m (Mantle heat flow)	1 to 50 [mW m^{-2}]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

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


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

Monte-Carlo sampling for the thermophysical parameters

H_0 is typically $<5 \mu\text{W m}^{-3}$



Modified from Furlong and Chapman (2013 *Annual review of Earth and Planetary Sciences*)

T_0 (Surface temperature)	0 to 20 [°C]
k (Thermal conductivity)	2 to 5 [$\text{W m}^{-1} \text{°C}^{-1}$]
h (Radiogenic heating decay length)	0 to $z_{\text{Moho}} / 2$ [m]
H_0 (Surface radiogenic heat production)	1 to 10 [$\mu\text{W m}^{-3}$]
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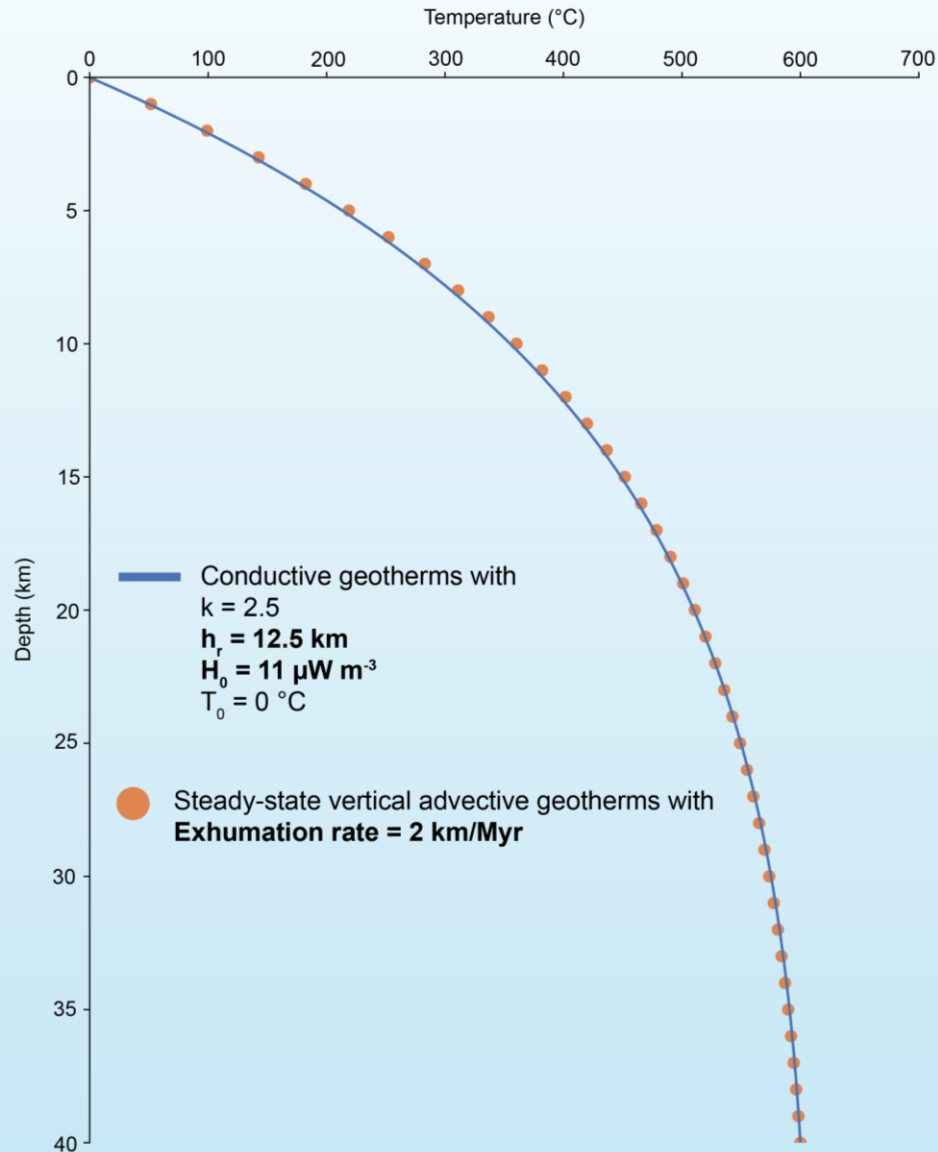
$$q_s^{\text{model}} = q_m + \int_0^{z_m} H_0 e^{-z/h} dz$$

If q_s^{model} is $\pm 10 \text{ mW m}^{-2}$ of heat flow observations

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

Turcotte and Schubert (2014)

Monte-Carlo sampling for the thermophysical parameters



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Turcotte and Schubert (2014)

Monte-Carlo sampling for the thermophysical parameters

Accepted profiles (Red)

- NRMSE coefficient < 0.35

Rejected profiles (Black)

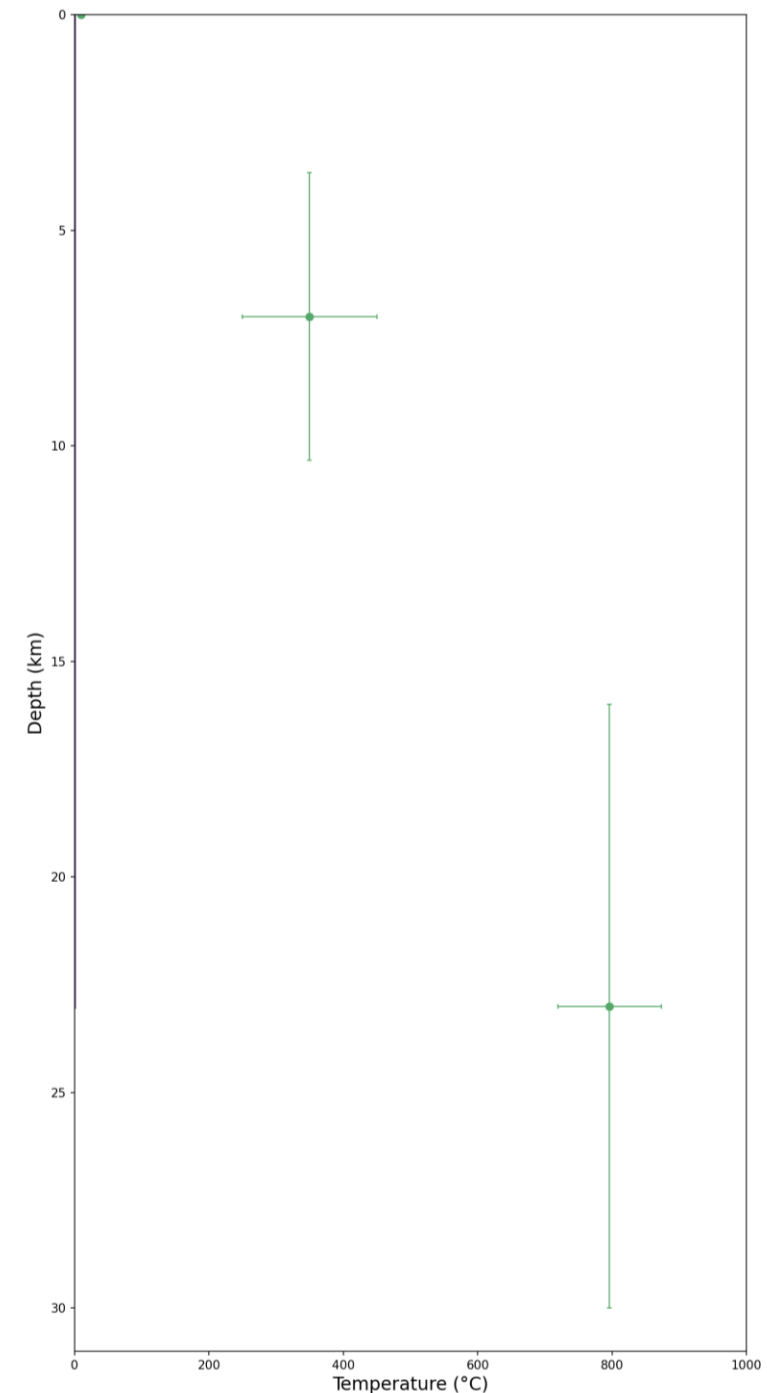
- NRMSE coefficient < 0.55

Output profile (Orange)

- Mean of accepted profiles

Uncertainty (Blue envelope)

- Standard deviation of accepted profiles



Monte-Carlo sampling for the thermophysical parameters

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- NRMSE coefficient < 0.35

Rejected profiles (Black)

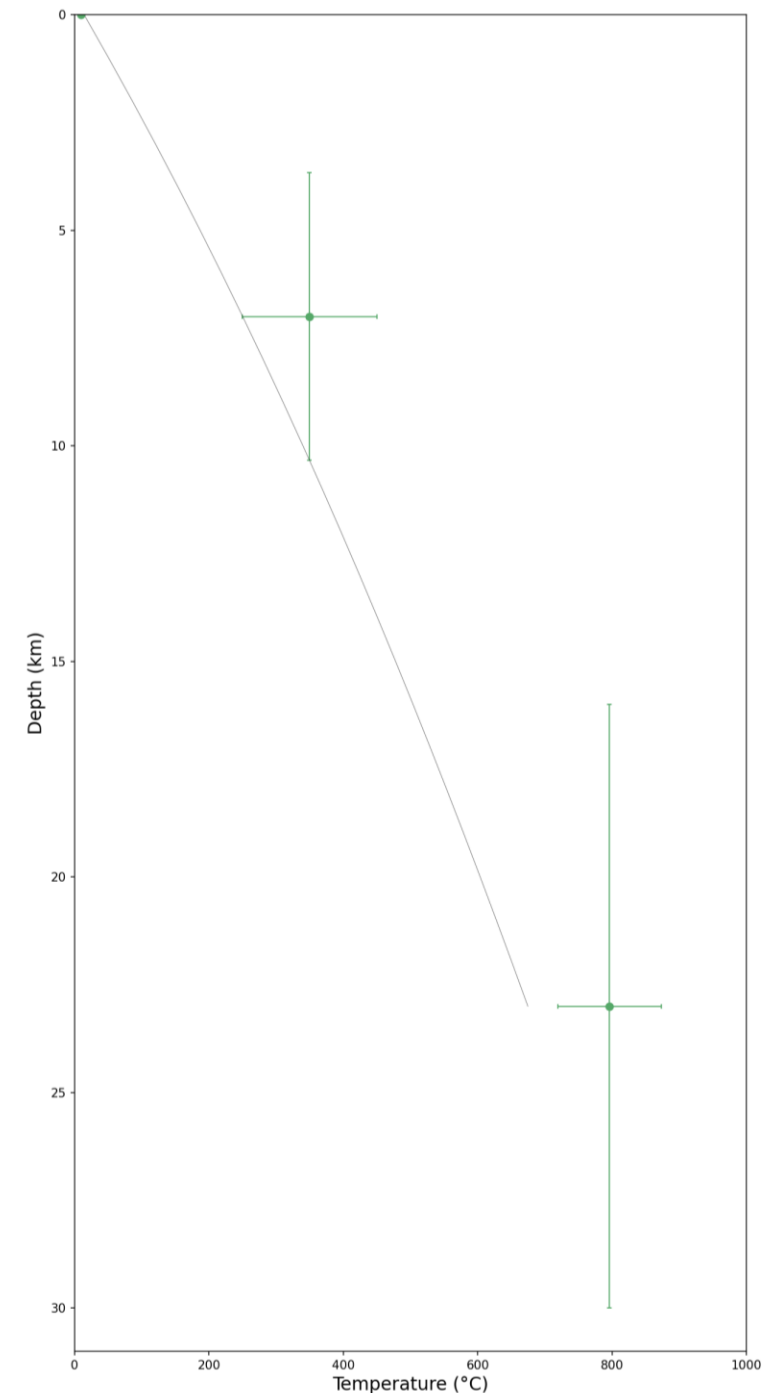
- NRMSE coefficient < 0.55

Output profile (Orange)

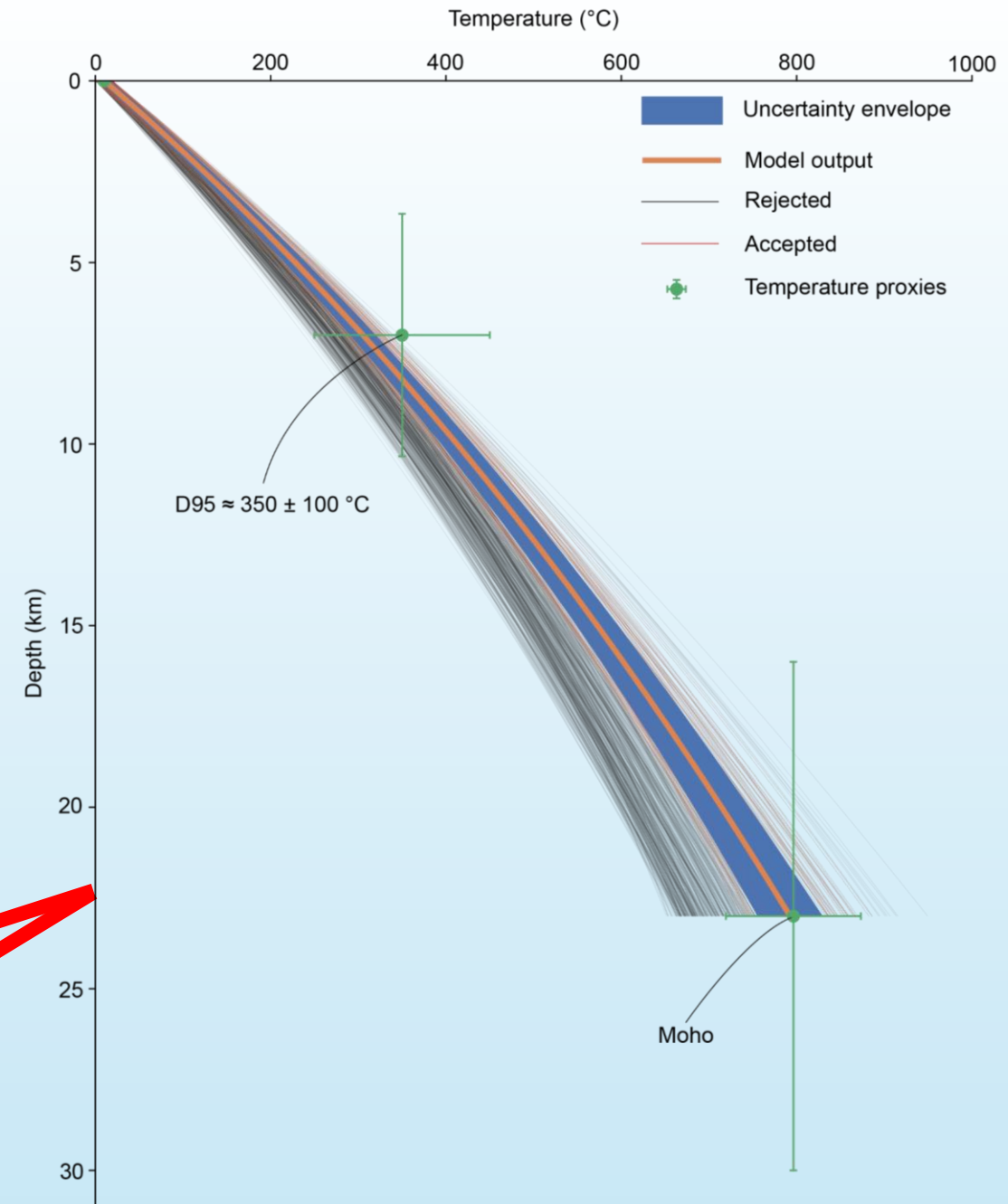
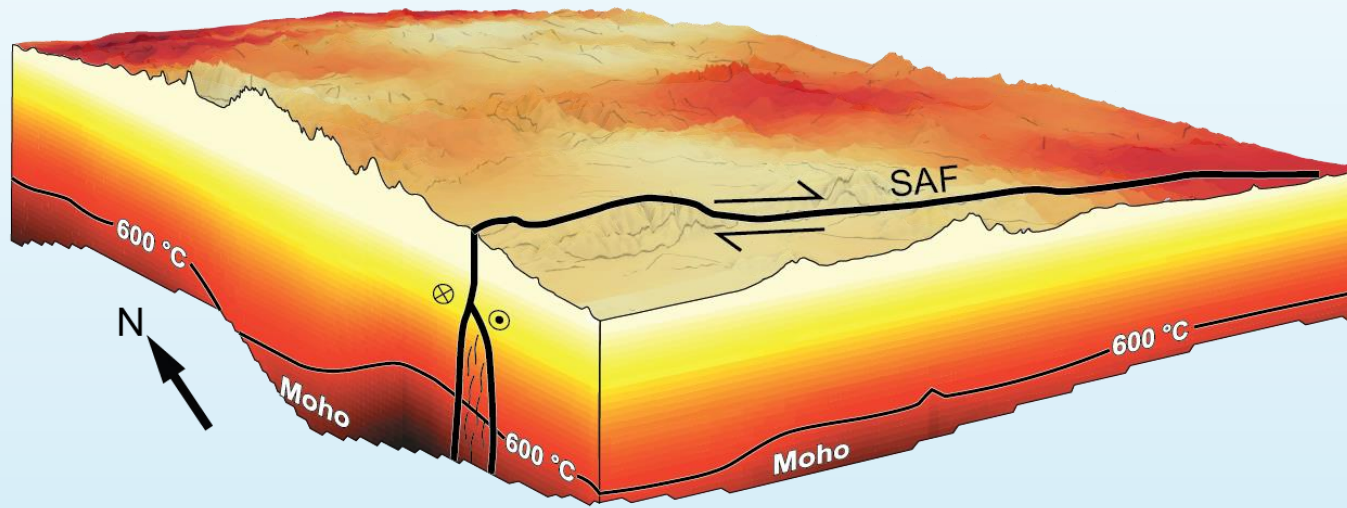
- Mean of accepted profiles

Uncertainty (Blue envelope)

- Standard deviation of accepted profiles



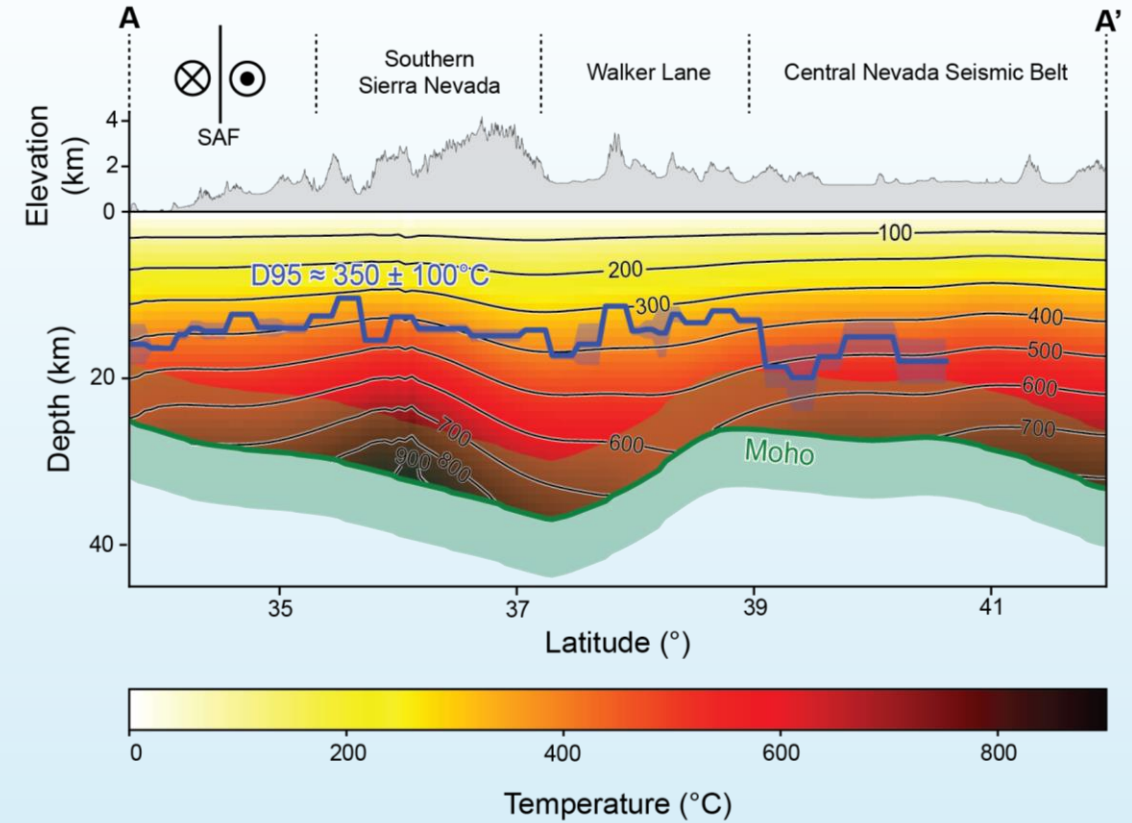
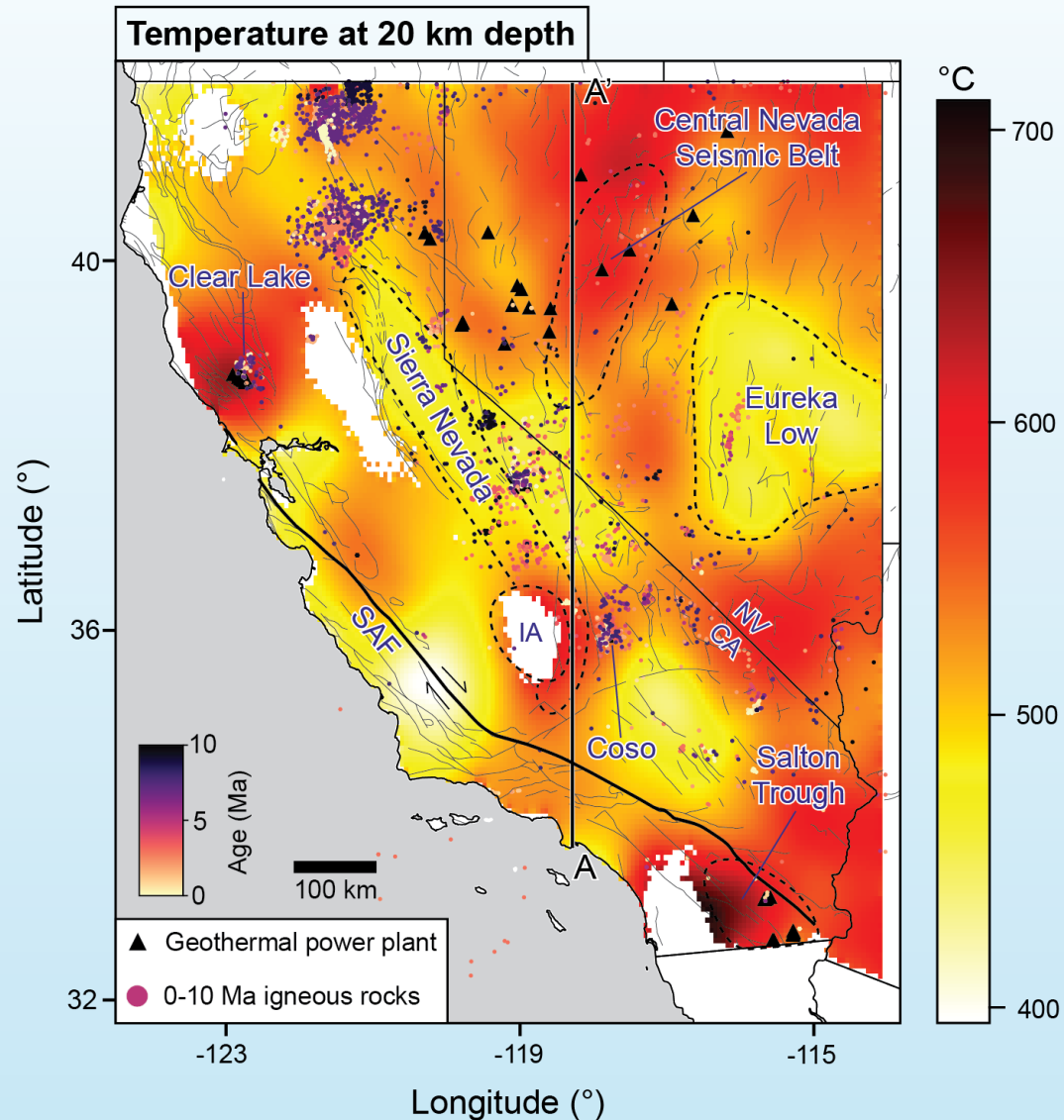
Monte-Carlo sampling for the thermophysical parameters



100,000 iterations at each pixel

Output of 1 pixel out of 25976 pixels

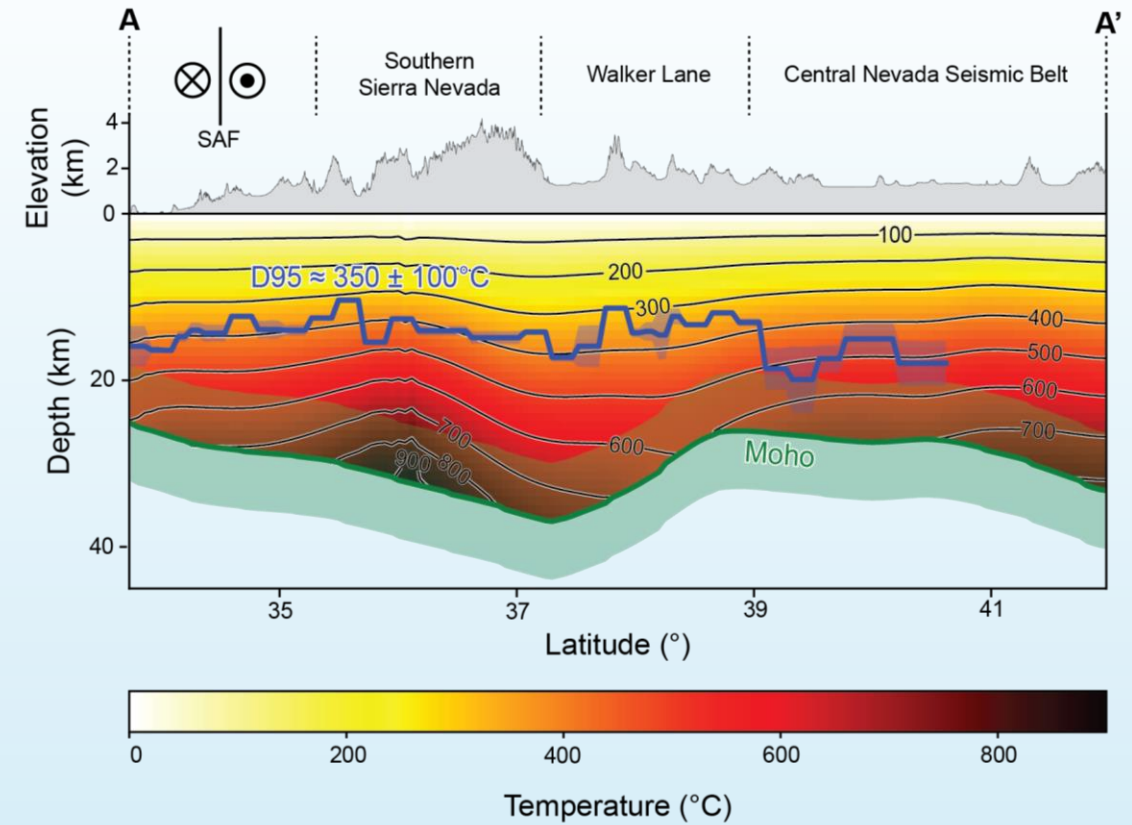
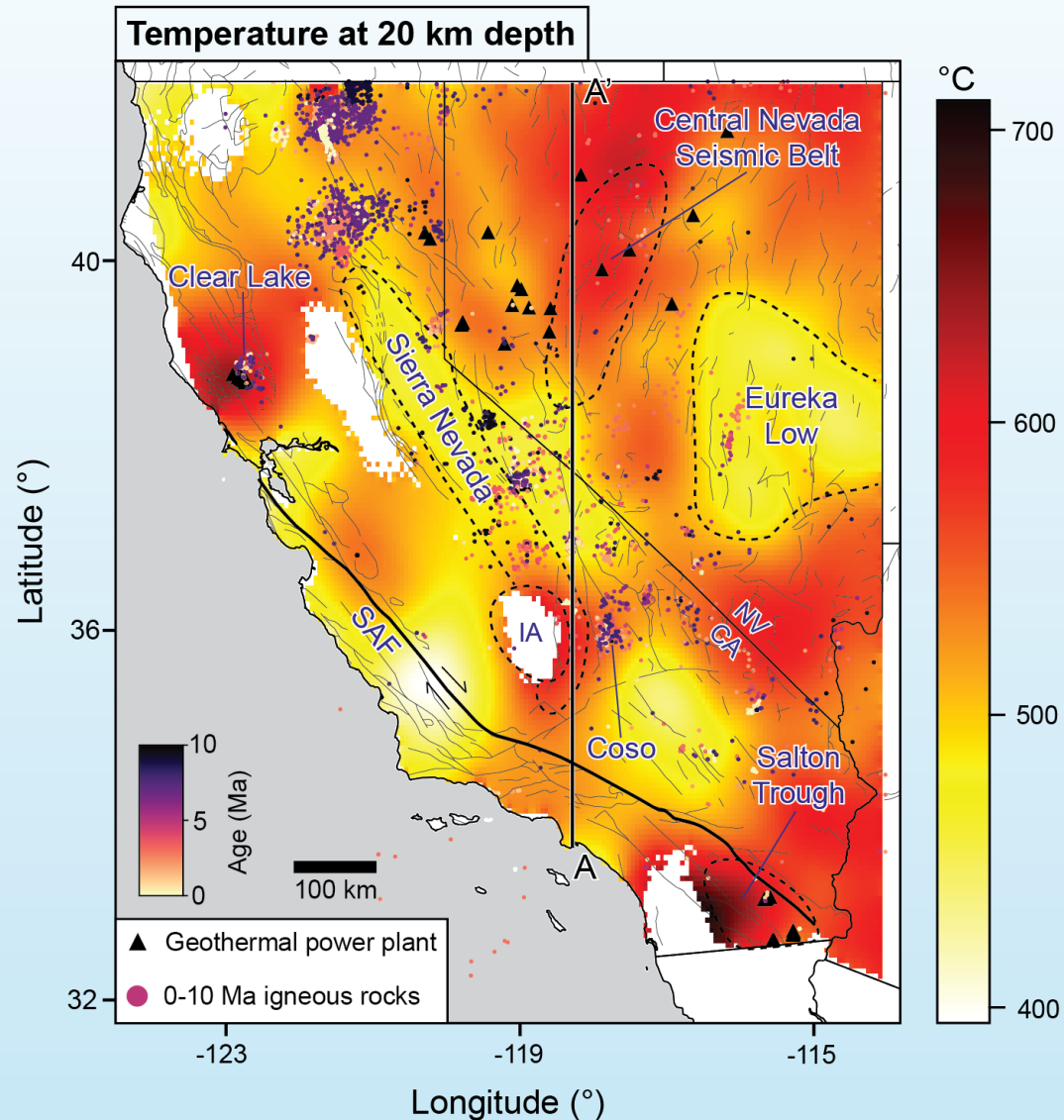
California-Nevada Statewide CTM



Elevated thermal gradient ($>600^\circ\text{C}$ at 20 km):

- Salton Trough, Coso, Clear Lake, Central Nevada Seismic Belt

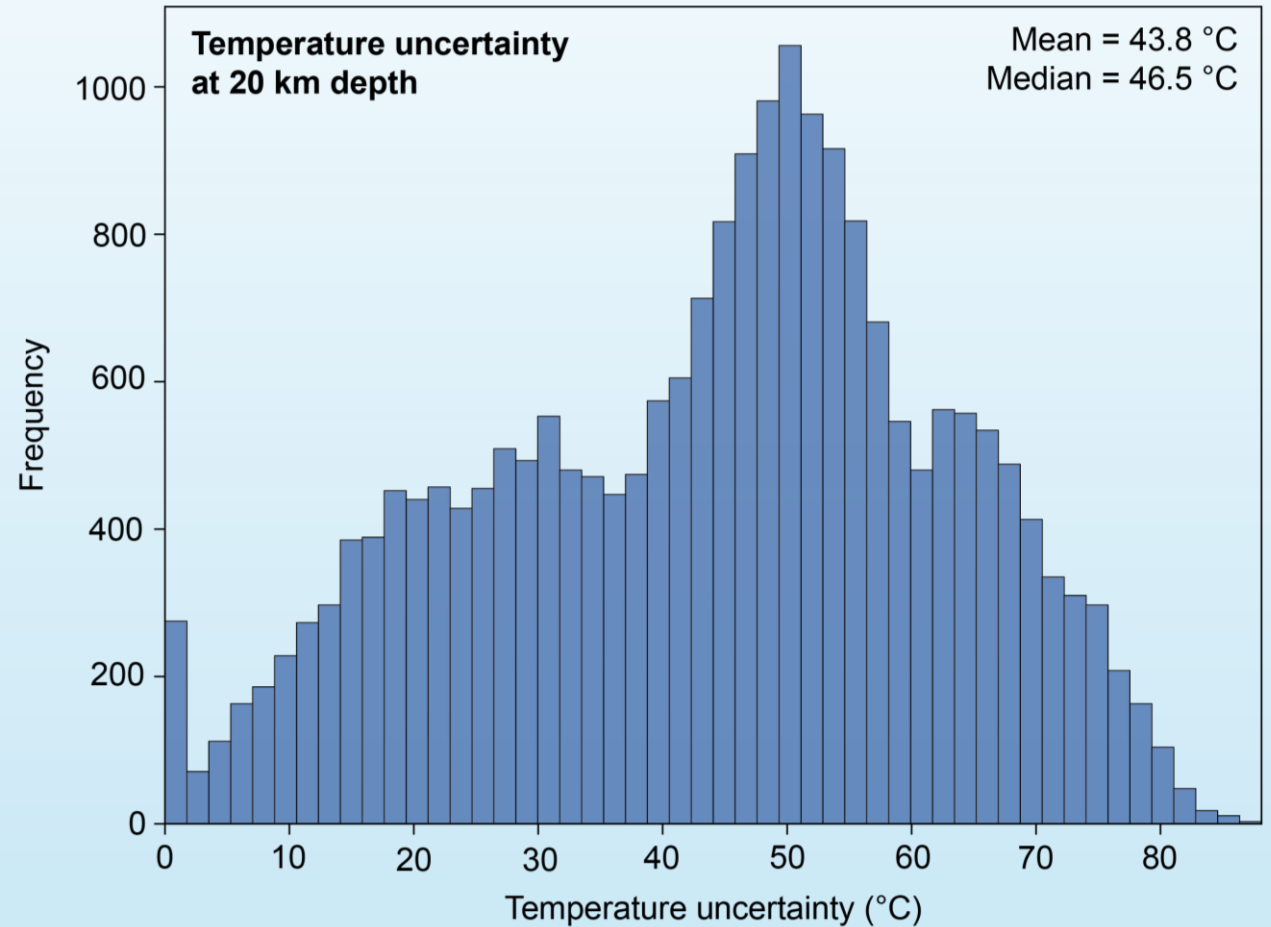
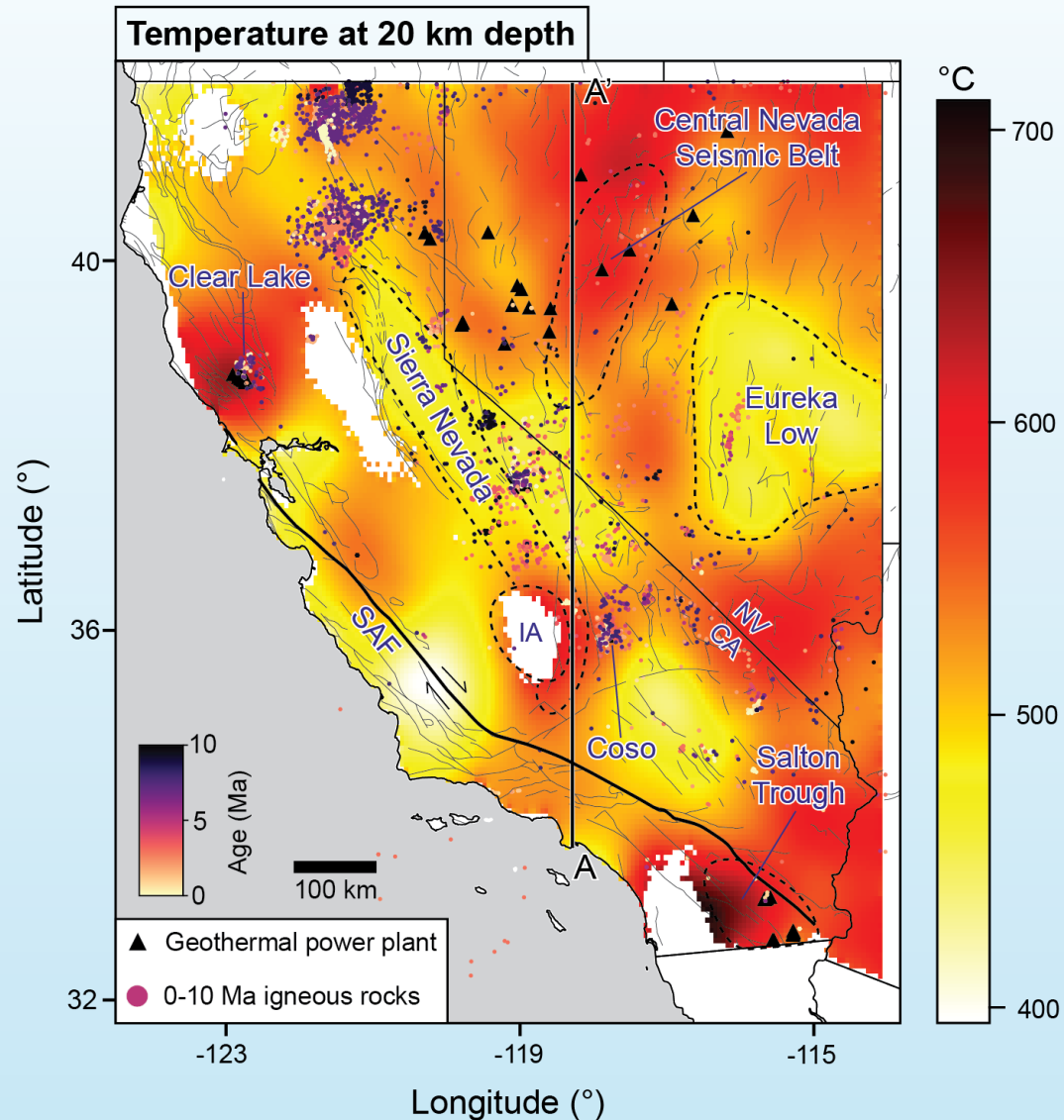
California-Nevada Statewide CTM



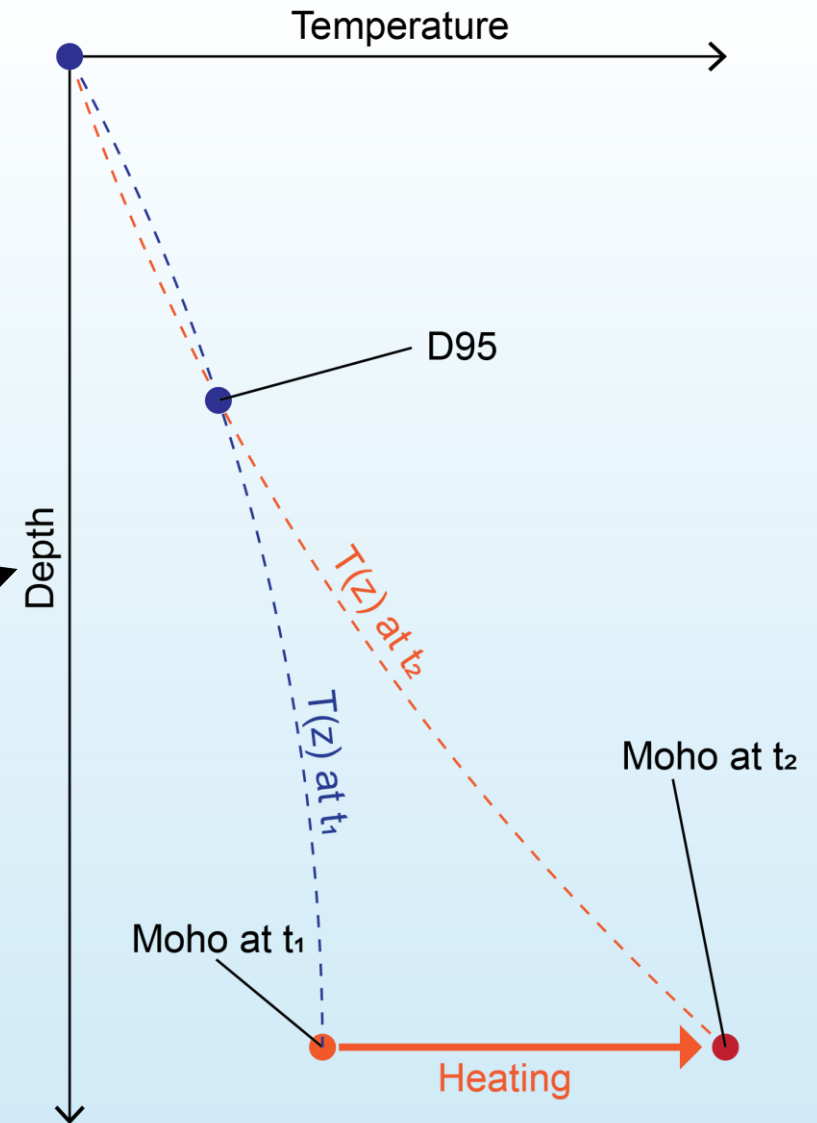
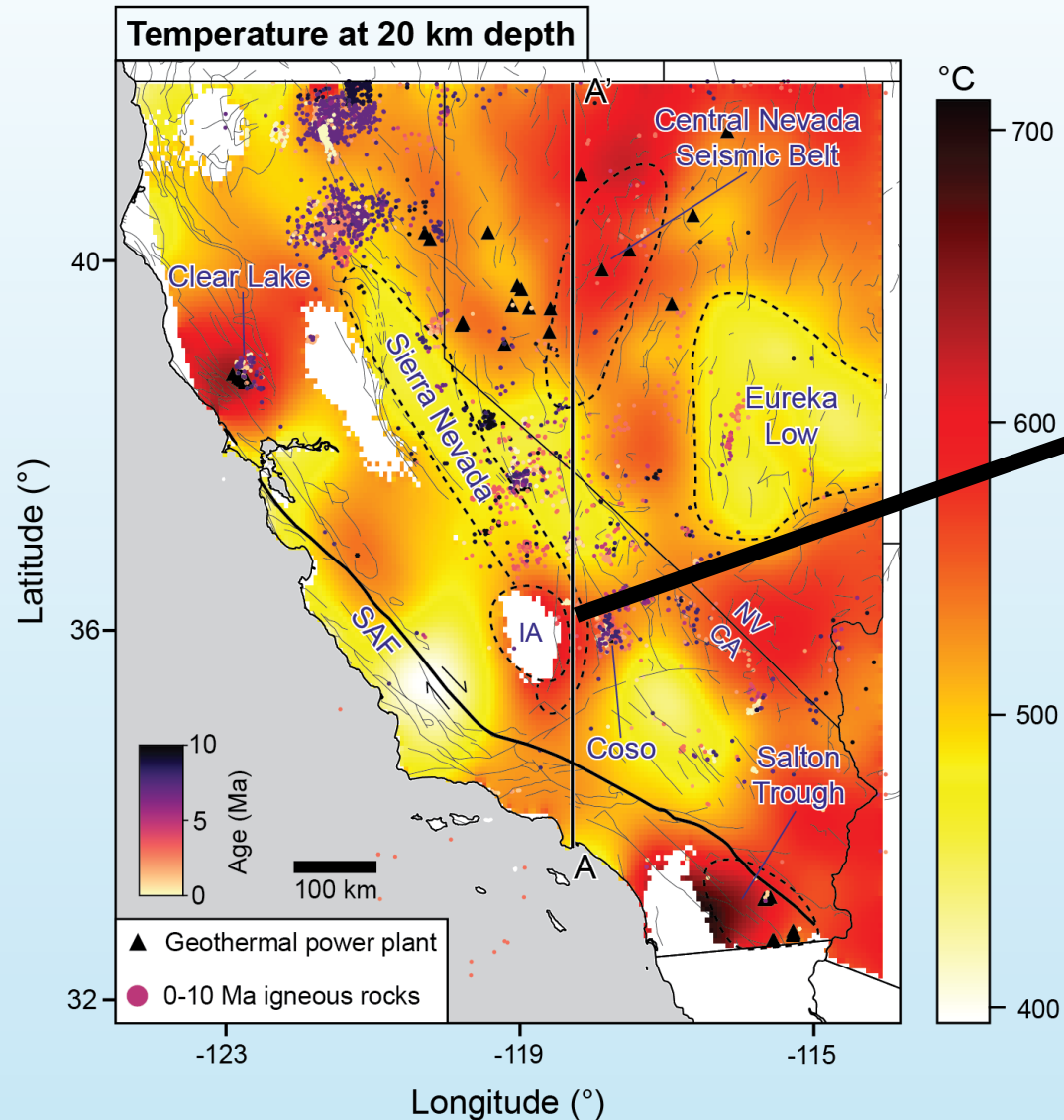
Low thermal gradient ($<500^\circ\text{C}$ at 20 km):

- Sierra Nevada, Mojave, Great Valley, Eureka Low

California-Nevada Statewide CTM



Null output: mapping non-steady-state



Basal heating due to lithospheric delamination (?)

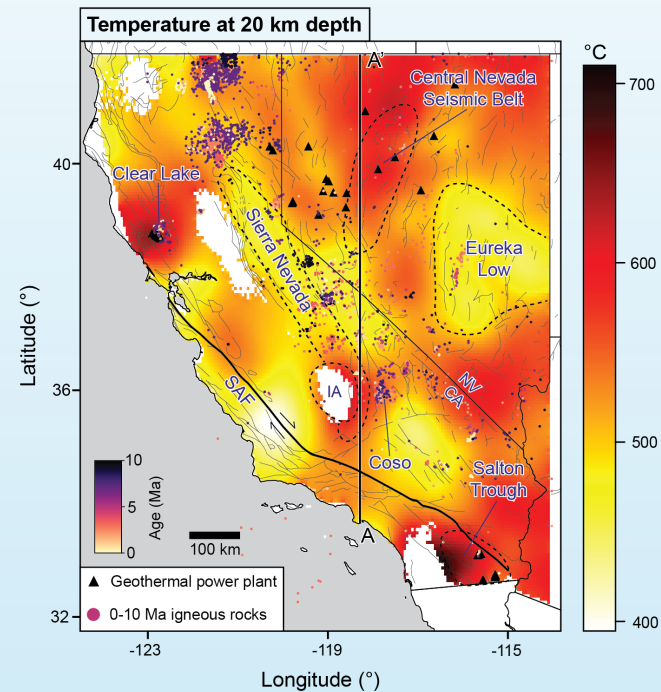
Zandt et al. (2004 *Nature*)

Boyd et al. (2004 *Science*)

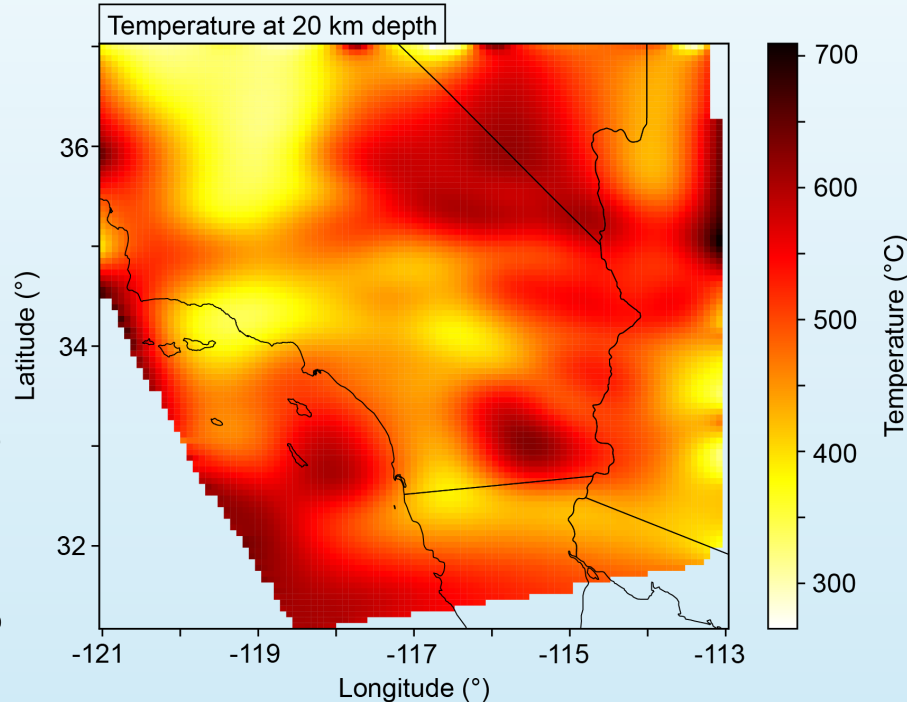
Thatcher and Chapman (2020 *SCEC*)

CTM comparison

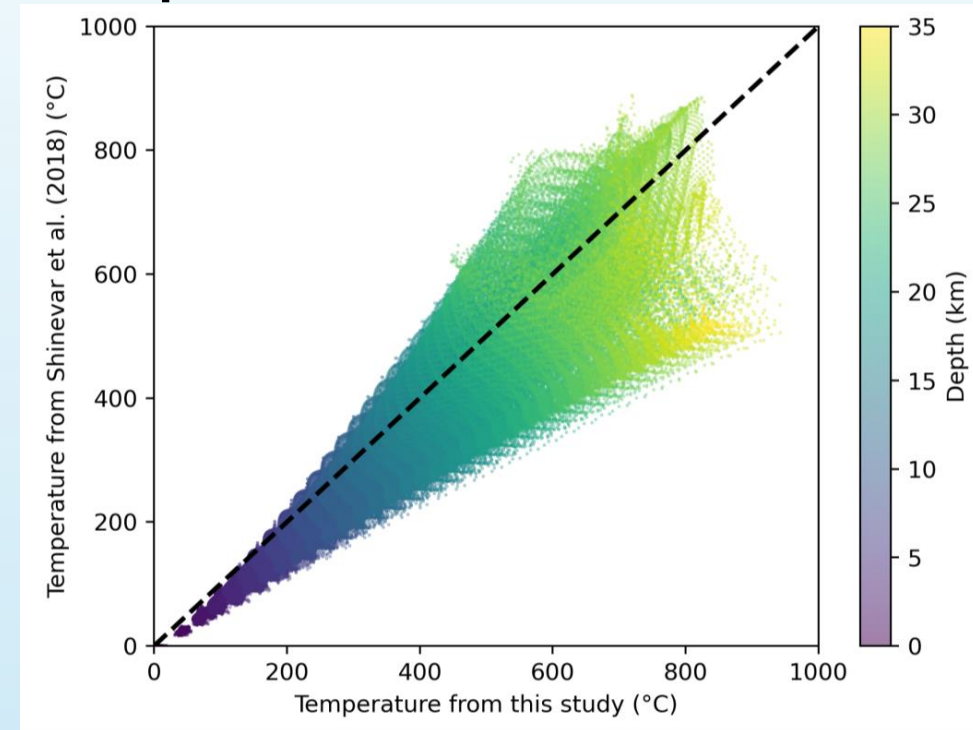
New statewide CTM:



Shinevar et al. (2018) CTM



Comparison



Near one-to-one relationship
Our model yields temperatures that are ~50–100 °C higher

Pearson correlation = 0.95
Mean absolute error = 44.8 °C

Open-sourced Python software

zenodo

Search records...

Communities My dashboard

Published August 8, 2025 | Version v3

Dataset Open

3D thermal and rheological model for the western US and East Asia and the associated thermal model function

Lee, Terry¹; Zuza, Andrew¹; Trugman, Daniel¹; Vlaha, Dominik R.¹; Xu, Xi²; Cao, Wenrong¹

Show affiliations



ContinentalLithosphereThermalModel-CCTM- Public

Pin Unwatch 1 Fork Star 0

main 1 Branch 0 Tags

Go to file Add file Code

TerryLeeTectonics Update README.md 171ecd1 · 1 minute ago 3 Commits

README.md Update README.md 1 minute ago

ContinentalLithosphereThermalModel

This repository contains a Python-based Continental Lithosphere Thermal Model. This model simulates the best-fit 1D steady-state conductive thermal profiles locally and integrates into a 3D model. This model also includes components of deriving the seismogenic thickness, and numerically solved 2D heat diffusion model.

Readme Activity 0 stars 1 watching 0 forks

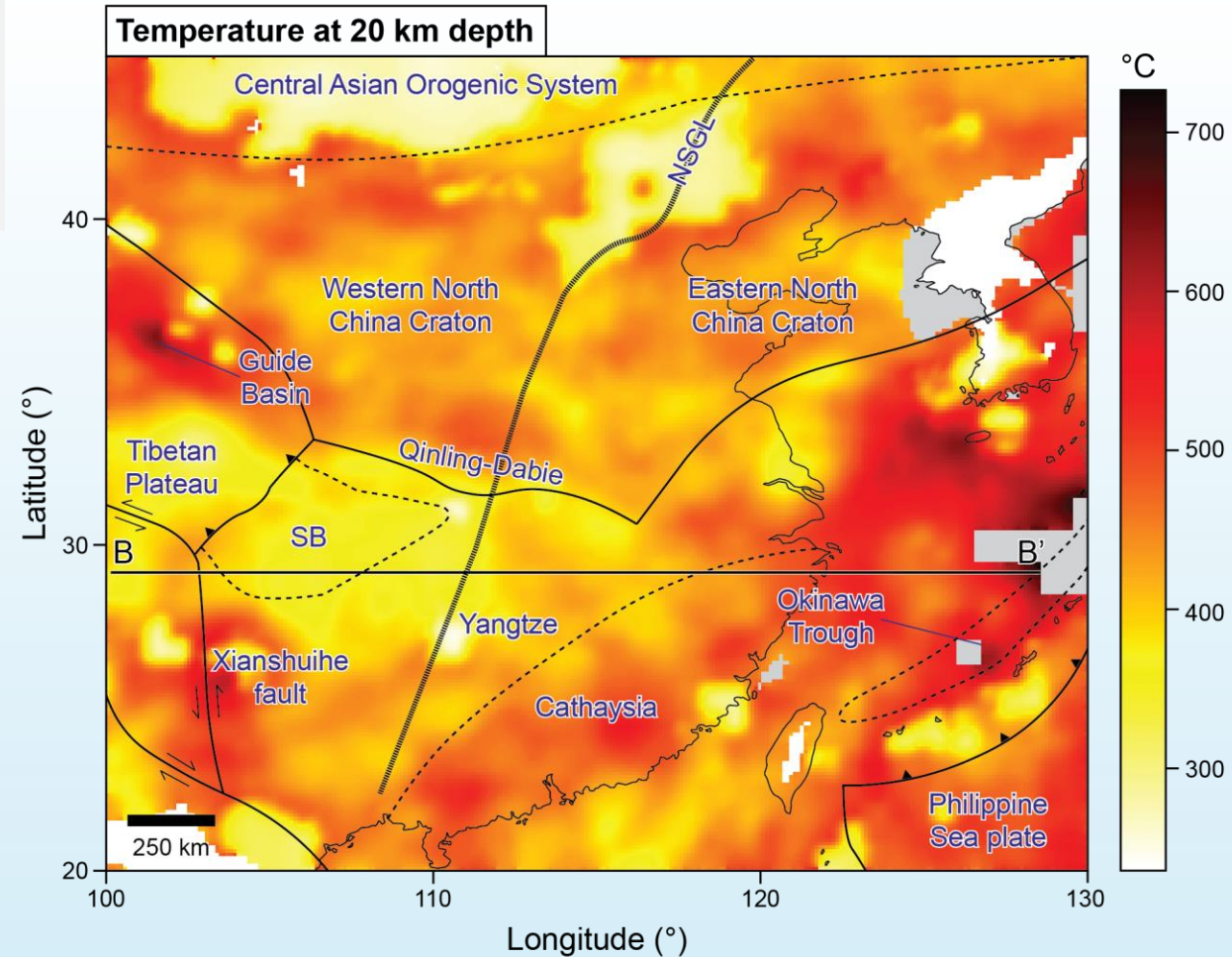
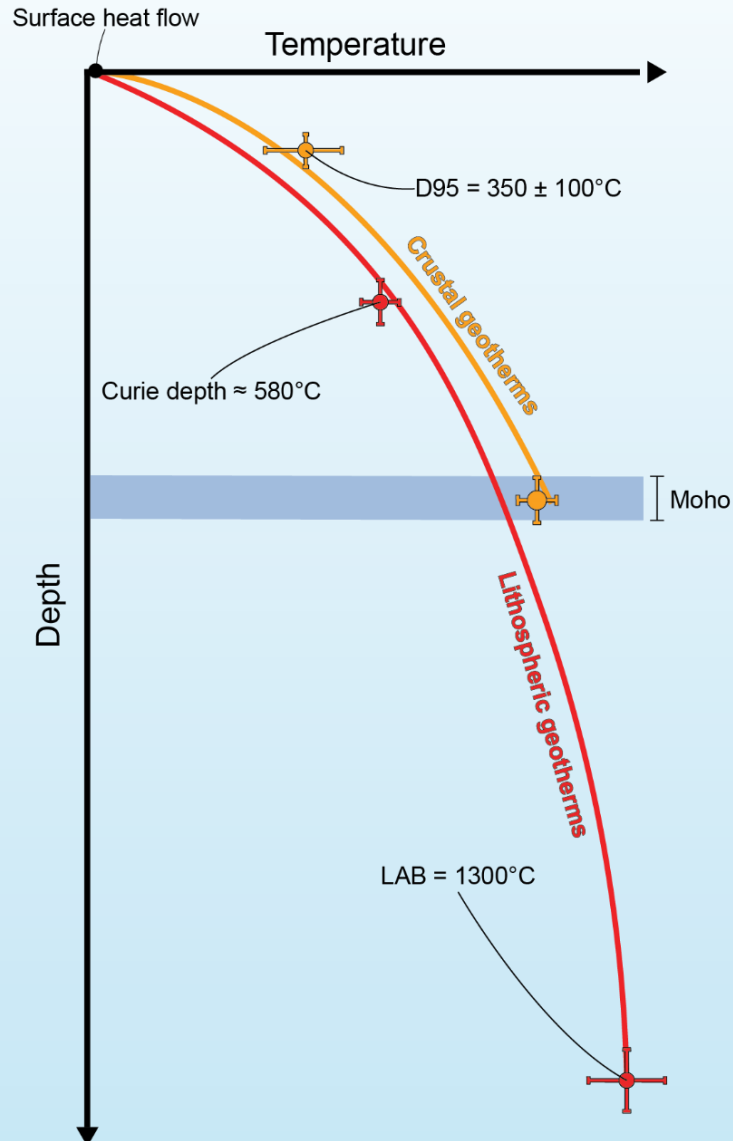


```
[ModelParameters]
Curie_depth_T = 550
Iteration = 100000
T0_range = 0, 20
k_range = 2, 5
H0_range = 1e-6, 1e-5
qm_range = 0.001, 0.05
goodfit = 0.35
moderatefit = 0.55
D95_T_config = 350
Max_goodfit_profile = 200
LAB_T_config = 1300
Uncertainty_box_fitting = False
Diffusion_2D = True
Diffusion_time = 5

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

- Customize model area, resolution, and parameters
- Apply different temperature proxies

Model application in East Asia



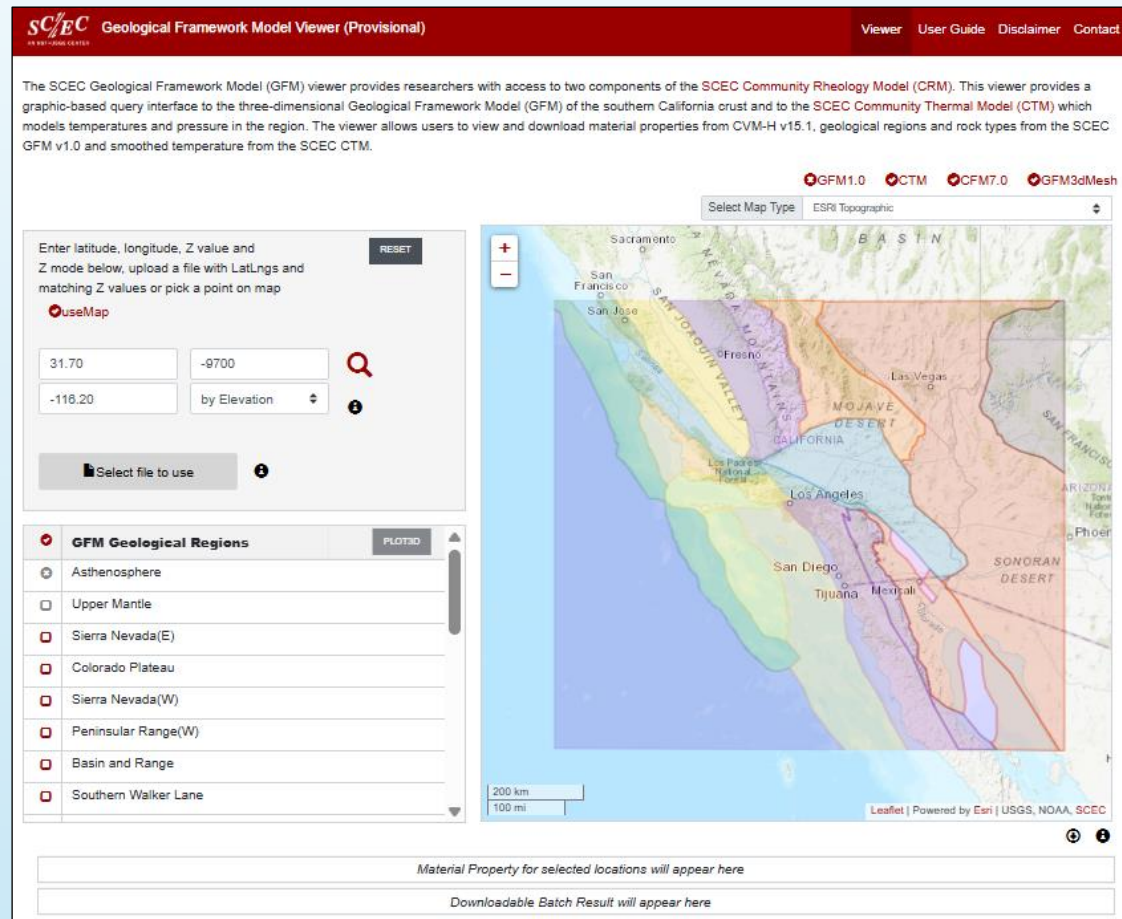
Temperature proxies:

- Surface heat flow
(Jiang et al., 2019 *Tectonophysics*; Sun et al., 2022 *JGR SE*)
- Curie depth
(Li et al., 2017 *Scientific Reports*)
- Lithospheric thickness
(An and Shi, 2006 *Physics of the Earth and Planetary Interiors*)

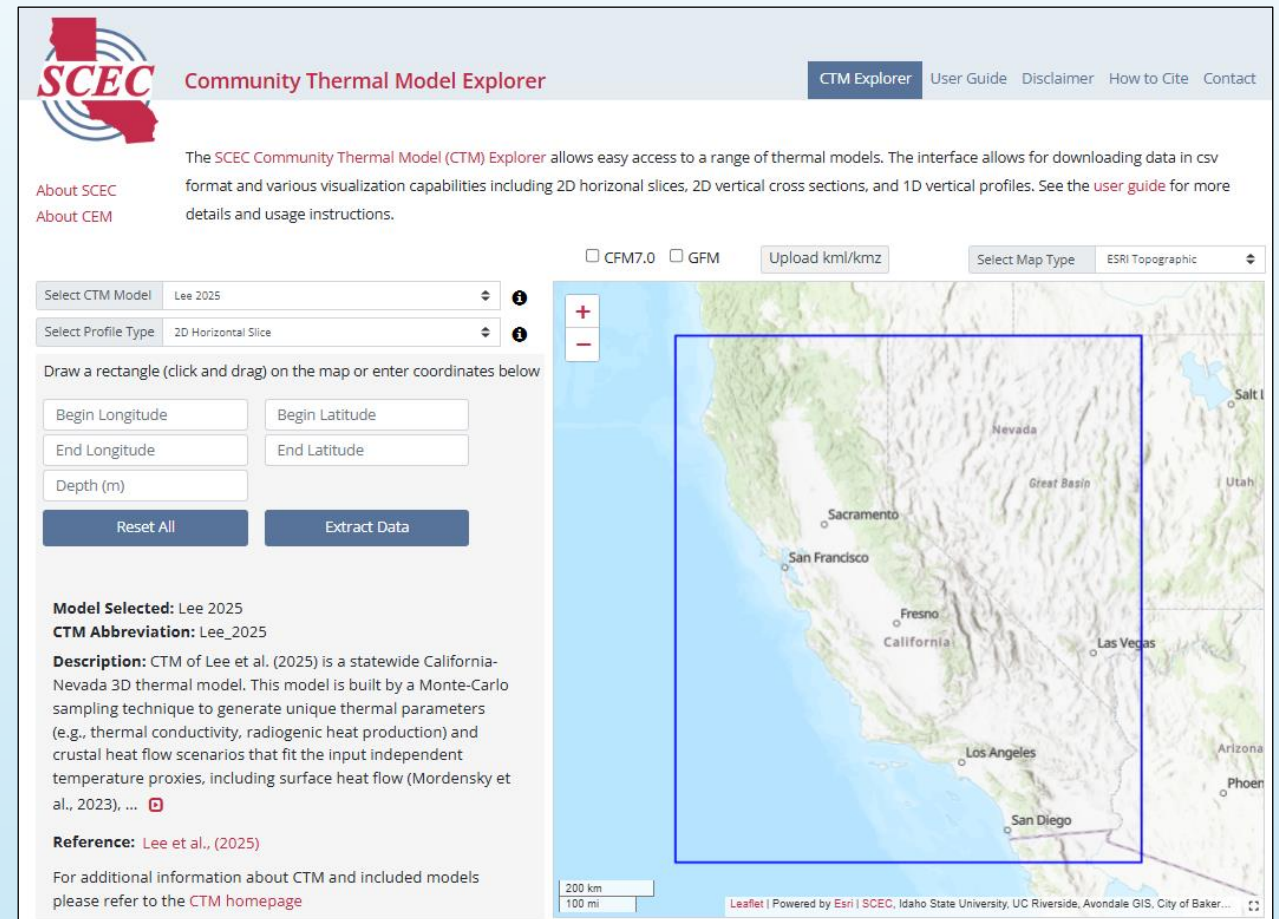
New CTM explorer!

In collaboration with:
Mei-Hui Su
Phil Maechling


Current explorer



New explorer



New CTM explorer!



Community Thermal Model Explorer

[CTM Explorer](#) [User Guide](#) [Disclaimer](#) [How to Cite](#) [Contact](#)

The SCEC Community Thermal Model (CTM) Explorer allows easy access to a range of thermal models. The interface allows for downloading data in csv format and various visualization capabilities including 2D horizontal slices, 2D vertical cross sections, and 1D vertical profiles. See the [user guide](#) for more details and usage instructions.

About SCEC
About CEM

Select CTM ModelLee 2025

Select Profile Type1D Vertical Profile

Pick a profile point on the map or enter latitude and longitude below

-121.7405

38.5449

0

30000

1000

Reset All

Extract Data

Model Selected: Lee 2025

CTM Abbreviation: Lee_2025

Description: CTM of Lee et al. (2025) is a statewide California-Nevada 3D thermal model. This model is built by a Monte-Carlo sampling technique to generate unique thermal parameters (e.g., thermal conductivity, radiogenic heat production) and crustal heat flow scenarios that fit the input independent temperature proxies, including surface heat flow (Mordensky et al., 2023), ...

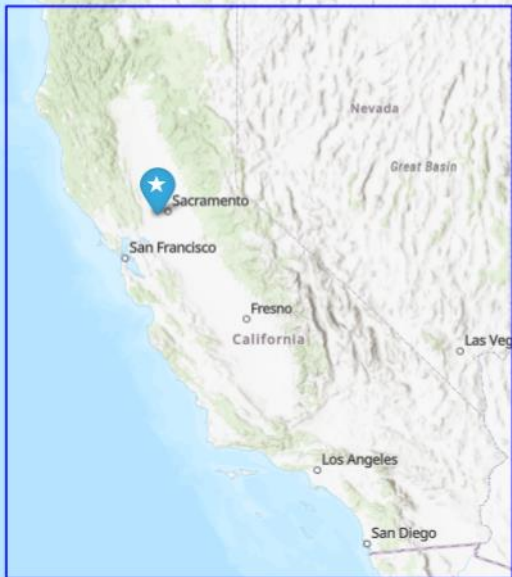
Reference: Lee et al., (2025)

For additional information about CTM and included models please refer to the [CTM homepage](#)

☐ CFM7.0☐ GFM

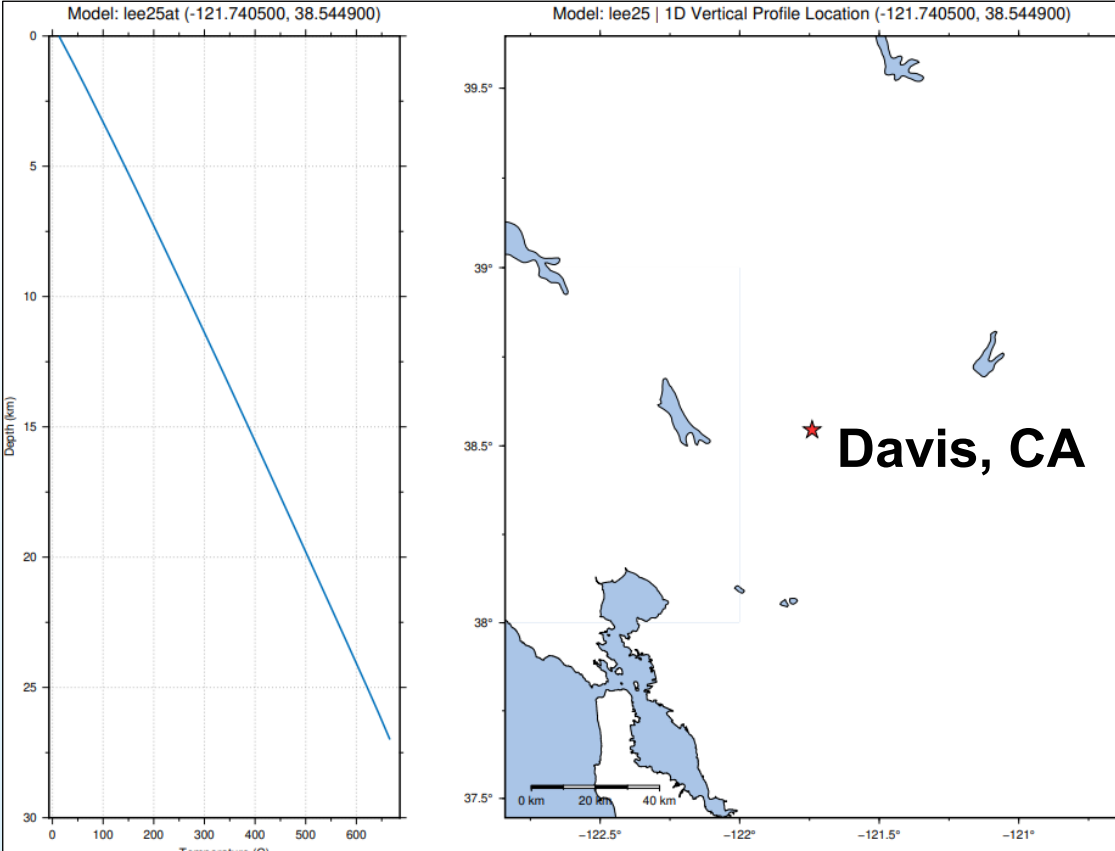
Upload kml/kmz

Select Map TypeESRI Topographic



200 km
100 mi

Leaflet | Powered by Esri | SCEC, Idaho State University, UC Riverside, Avondale GIS, City of Baker...



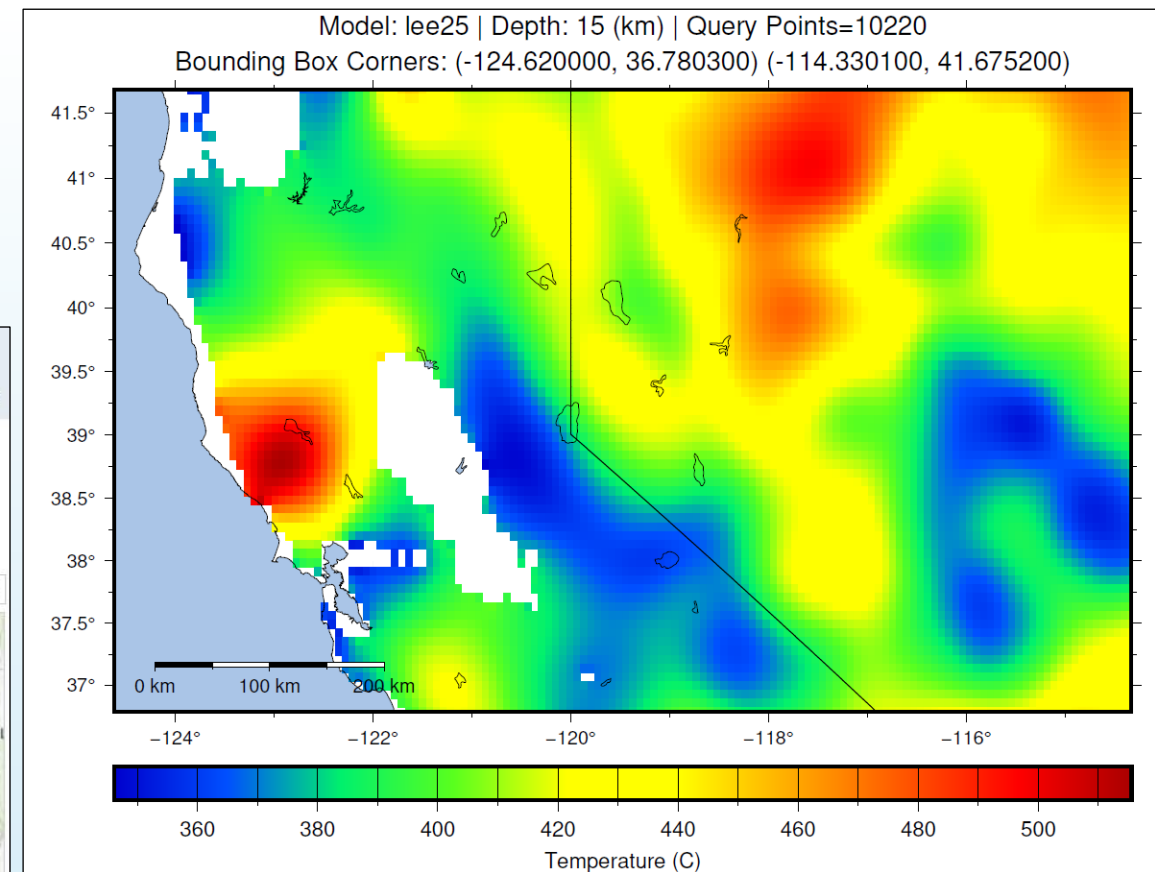
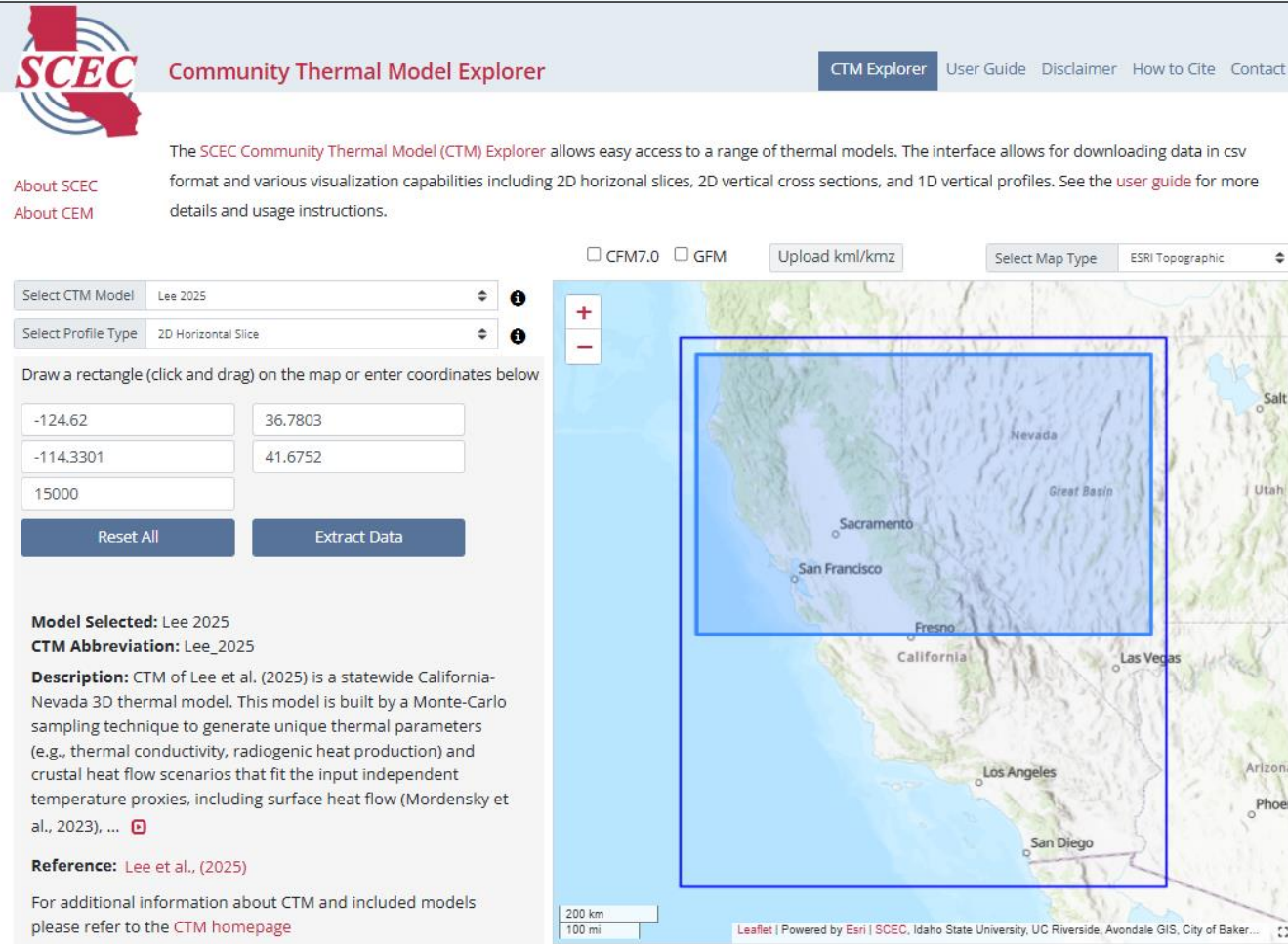
Model: lee25at (-121.740500, 38.544900)

Model: lee25 | 1D Vertical Profile Location (-121.740500, 38.544900)

Davis, CA


- Single point temperature
- 1D vertical thermal profile**
- 2D horizontal slice map
- 2D cross-section profile

New CTM explorer!



- Single point temperature
- 1D vertical thermal profile
- **2D horizontal slice map**
- 2D cross-section profile

New CTM explorer!



Community Thermal Model Explorer

[CTM Explorer](#) [User Guide](#) [Disclaimer](#) [How to Cite](#) [Contact](#)

The SCEC Community Thermal Model (CTM) Explorer allows easy access to a range of thermal models. The interface allows for downloading data in csv format and various visualization capabilities including 2D horizontal slices, 2D vertical cross sections, and 1D vertical profiles. See the [user guide](#) for more details and usage instructions.

[About SCEC](#)
[About CEM](#)

☐ CFM7.0 ☐ GFM

Select CTM Model: Lee 2025

Select Profile Type: 2D Vertical Cross Section

Draw a line on the map or enter latitudes and longitudes below

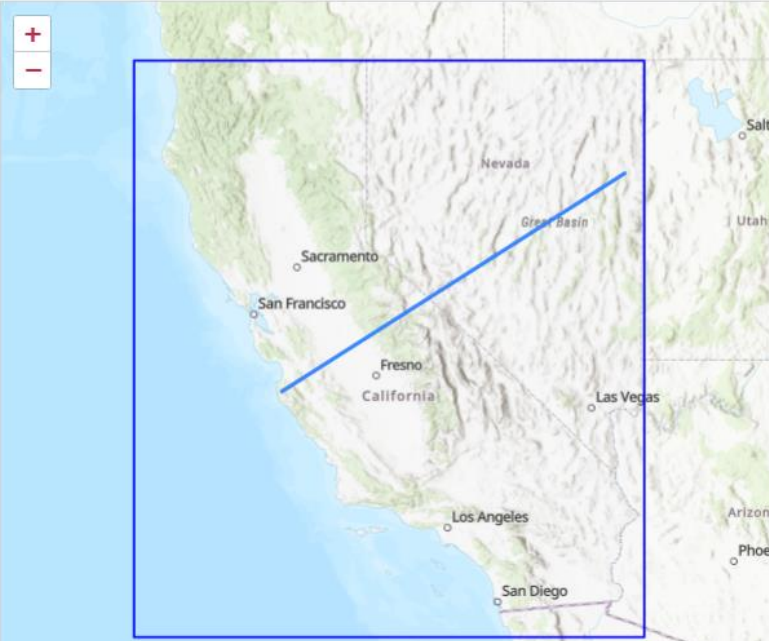
<input type="text" value="-121.7994"/>	<input type="text" value="36.4447"/>
<input type="text" value="-114.4084"/>	<input type="text" value="40.1349"/>
<input type="text" value="0"/>	<input type="text" value="40000"/>

Model Selected: Lee 2025
CTM Abbreviation: Lee_2025

Description: CTM of Lee et al. (2025) is a statewide California-Nevada 3D thermal model. This model is built by a Monte-Carlo sampling technique to generate unique thermal parameters (e.g., thermal conductivity, radiogenic heat production) and crustal heat flow scenarios that fit the input independent temperature proxies, including surface heat flow (Mordensky et al., 2023), ... [📄](#)

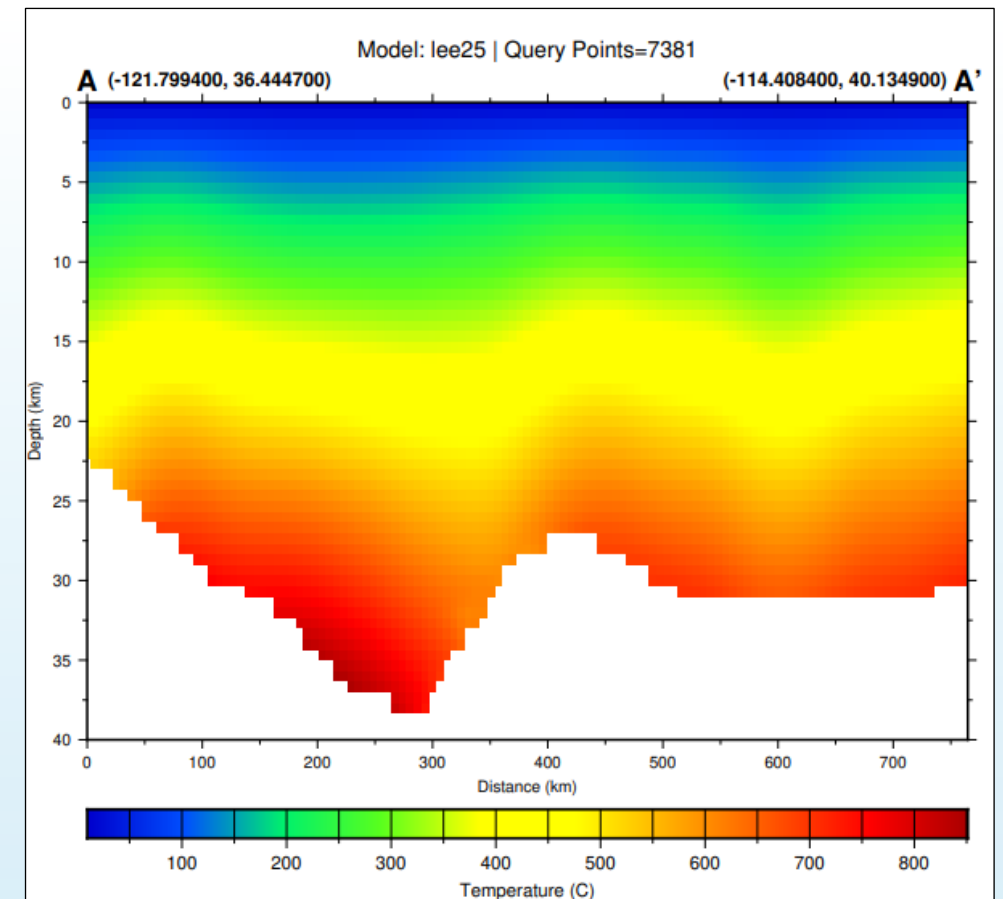
Reference: [Lee et al., \(2025\)](#)

For additional information about CTM and included models please refer to the [CTM homepage](#)



200 km
100 mi

Leaflet | Powered by Esri | SCEC, Idaho State University, UC Riverside, Avondale GIS, City of Baker...



- Single point temperature
- 1D vertical thermal profile
- 2D horizontal slice map
- **2D cross-section profile**

Work in progress

Current homepage

Figure 1: Southern California heat flow map, showing CTM heat flow regions (outlined in black), mean surface heat flow in each heat flow region (HFR), and point measurements from wells (Williams and DeAngelo, 2011).

Zenodo repository

zenodo

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SCEC Statewide California Earthquake Center (SCEC)

Published August 15, 2020 | Version 20.8

[Download] [Open]

SCEC Community Thermal Model (CTM)

Thatcher, Wayne¹; Shinevar, William²; Chapman, David³; Hearn, Elizabeth H.⁴

Show affiliations

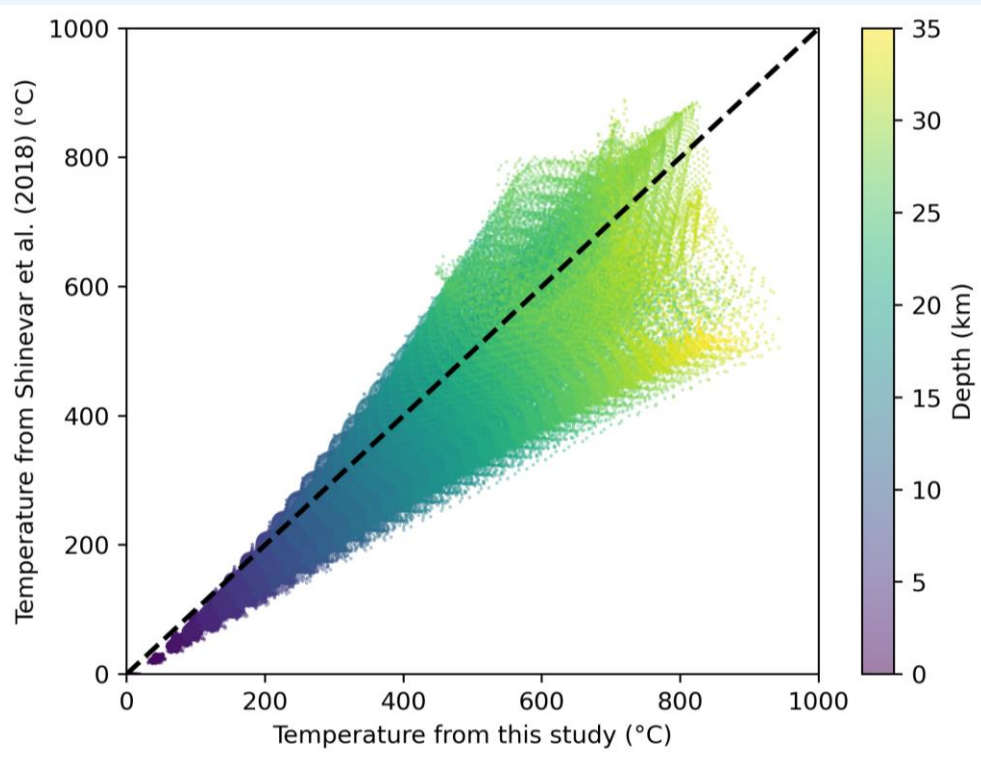
The CTM provides estimates of temperatures and thermal properties of the southern California lithosphere. It is shared as a download archive with data and tools organized into three folders: components and metadata, a Google Colab notebook query tool with associated files, and an alternative (Shinevar et al., 2018) thermal model. README files in each directory describe the contents in detail.

Please see <https://www.scec.org/research/ctm> for more information.

Files

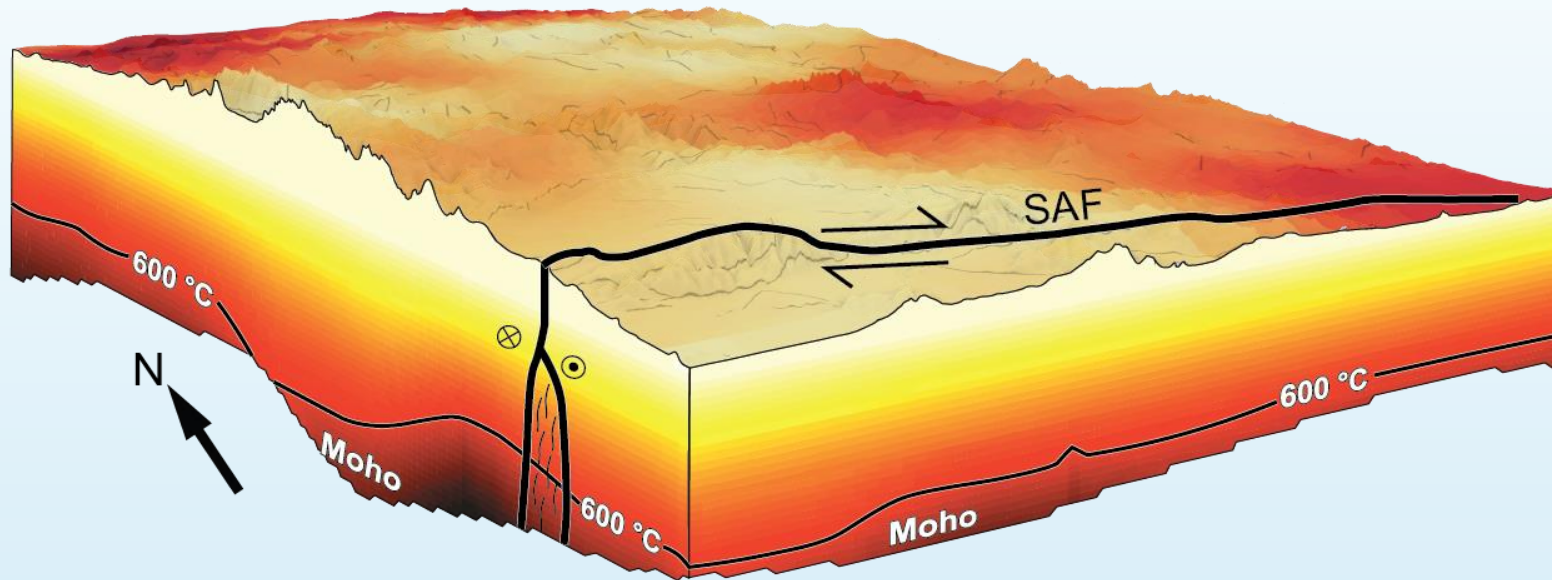
File Name	Size
CTM_August_8_2020.zip	12.3 kB
CTM_August_8_2020	-
_DS_Store	8.2 kB
CTM_Jup_Notebook	-
_DS_Store	8.2 kB
CTM_tools.py	123.9 kB
For_CTM_Notebook	-
CTMfig_smooth_25.eps	197.8 kB
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CTMfig_smooth_25_jet_alparameters.eps	205.7 kB
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CTMfig_unsmoothed_25_jet.eps	808.1 kB
CTMfig_unsmoothed_25km.eps	808.2 kB
CTMpolygonstorPythonrev.txt	1.0 MB
M_CTM_1p10.txt	18.5 kB
QueryPoints.txt	180 Bytes
QueryPoints_Shinevar.txt	37.3 MB

Discussion/questions



- How to evaluate model accuracy? (Compare to observables?)
- Estimate uncertainty? (Standard deviation for statewide CTM)
- How to compare and contrast between models?
- Steady state vs non-steady state
(Shear heating, basal heating, advection)
- GFM constrain D95 temperature?
- Extend the statewide CTM to lithospheric scale?
(include Curie depth and LAB proxies?)

Statewide California-Nevada CTM



New explorer



<http://moho.scec.org/ctm-explorer/explorer.php>

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