

¹ FEniCS-SZ: two-dimensional modeling of the thermal structure of subduction zones

³ Cian R. Wilson  ^{1*}, Cameron Seebeck^{1*}, Kidus Teshome^{1*}, Nathan Sime  ^{1*}, and Peter E. van Keken  ^{1*}

⁵ 1 Earth and Planets Laboratory, Carnegie Institution for Science, Washington D.C., United States  ¶
⁶ Corresponding author * These authors contributed equally.

DOI: [10.xxxxxx/draft](https://doi.org/10.xxxxxx/draft)

Software

- [Review](#) ↗
- [Repository](#) ↗
- [Archive](#) ↗

⁷ Summary

⁸ Plate tectonics ... subduction zones ... volcanoes, earthquakes,... metamorphism temperature control ([van Keken & Wilson, 2023](#))

¹⁰ Figure of SZ thermal structure with oceanic and continental Moho.

Editor: [Open Journals](#) ↗

Reviewers:

- [@openjournals](#)

Submitted: 01 January 1970

Published: unpublished

License

Authors of papers retain copyright and release the work under a Creative Commons Attribution 4.0 International License ([CC BY 4.0](#)).
¹⁴ ¹⁵ ¹⁶ ¹⁷ ¹⁸

¹¹ Statement of need

¹² FEniCS-SZ is cool and is based on Wilson & van Keken ([2023](#)).

¹³ FEniCS-SZ is intended also for classroom use and interactive work via a Jupyter notebooks ([Wilson et al., 2025](#)) that explore the FEM examples in Wilson & van Keken ([2023](#)). The didactic nature of these tutorials (progressing from the stand-alone Poisson and Stokes equations, reproduction of mantle convection benchmarks, to the fully coupled set of time-dependent equations used in the subduction models) augments the FEniCSX Tutorial ([Dokken, 2023](#)), which is itself built on the FEniCS Tutorial ([Langtangen & Logg, 2016](#)).

¹⁹ Comparison with other approaches

²⁰ Thermal models of subduction zones that are most useful in the prediction of metamorphic dehydration reactions and their role in seismogenesis and seismic structure, slab dehydration, arc volcanism, and the long term chemical evolution of the Earth require high numerical resolution, faithful gridding of material boundaries (such as the slab surface and oceanic Moho), and ability to handle velocity discontinuities along the seismogenic zone and its extension to about 80 km depth. Semi-analytical techniques can be used successfully along the shallow plate interface to limited depth (see discussion and references in van Keken et al. ([2019](#))), but the effects of the cornerflow with realistic mantle rheology requires numerical solution of the Stokes and heat equations. A number of dynamical approaches exist that can be used to trace subduction zone thermal evolution ([Holt & Condit \(2021\)](#), [Gerya \(2011\)](#)) but these provide slab evolution models that are difficult to use when predicting the thermal structure of present-day subduction zones since geometry and convergence parameters such as convergence speed cannot be controlled. Other workers have provided finite element and finite difference approaches to study the thermal structure (e.g. [Wada & Wang \(2009\)](#); [Lee & King \(2009\)](#); [Lin et al. \(2010\)](#); [Rees Jones et al. \(2018\)](#); [van Zelst et al. \(2023\)](#)). These approaches have shown good comparisons with other codes in a code intercomparison ([van Keken et al., 2008](#)), by reproduction of benchmark cases therein, or in direct intercomparisons ([van Keken & Wilson, 2023](#)). Many of these subduction implementations, however, are not readily available as open source software even if they are based on general open source finite element software.

³⁹ **Software design**

⁴⁰ **Research impact statement**

⁴¹ **AI usage disclosure**

⁴² No information or code was harmed by AI.

⁴³ **Acknowledgements**

⁴⁴ We acknowledge support from the National Science Foundation (NSF) grants (EAR-1850634
⁴⁵ and EAR-202102) and the Carnegie Institution for Science through its summer intern programs
⁴⁶ (SURI, 2023 and EPIIC, 2024) sponsored principally by NSF (EAR-2244322) DUE XXXX.

⁴⁷ **References**

- ⁴⁸ Dokken, J. S. (2023). *The FEniCSx Tutorial*. <https://jsdokken.com/dolfinx-tutorial/>
- ⁴⁹ Gerya, T. (2011). Future directions in subduction modeling. *Journal of Geodynamics*, 52,
⁵⁰ 344–378. <https://doi.org/10.1016/j.jog.2011.06.005>
- ⁵¹ Holt, A. F., & Condit, C. B. (2021). Slab temperature evolution over the lifetime of a
⁵² subduction zone. *Geochemistry, Geophysics, Geosystems*, 22.
- ⁵³ Langtangen, H. P., & Logg, A. (2016). *Solving PDEs in Python* (p. 146). Springer Open.
⁵⁴ <https://doi.org/10.1007/978-3-319-52462-7>
- ⁵⁵ Lee, C., & King, S. D. (2009). Effect of mantle compressibility on the thermal and flow
⁵⁶ structures of the subduction zones. *Geochemistry, Geophysics, Geosystems*, 10. <https://doi.org/10.1029/2008GC002151>
- ⁵⁸ Lin, S.-C., Kuo, B.-Y., & S-L, C. (2010). Thermomechanical models for the dynamics and
⁵⁹ melting processes in the Marianas subduction zone. *Journal of Geophysical Research: Solid
⁶⁰ Earth*, 115.
- ⁶¹ Rees Jones, D. W., Katz, R. J., Tian, M., & Rudge, J. F. (2018). Thermal impact of
⁶² magmatism in subduction zones. *Earth and Planetary Science Letters*, 481, 73–79. <https://doi.org/10.1016/j.epsl.2017.10.015>
- ⁶⁴ van Keken, P. E., Currie, C., King, S. D., Behn, M. D., Cagnioncle, A., He, J., Katz, R.
⁶⁵ F., Lin, S.-C., Parmentier, E. M., Spiegelman, M., & Wang, K. (2008). A community
⁶⁶ benchmark for subduction zone modeling. *Phys Earth Planet Int*, 171, 187–197. <https://doi.org/10.1016/j.pepi.2008.04.015>
- ⁶⁸ van Keken, P. E., Wada, I., Sime, N., & Abers, G. A. (2019). Thermal structure of the
⁶⁹ forearc in subduction zones: A comparison of methodologies. *Geochemistry, Geophysics,
⁷⁰ Geosystems*, 20, 3268–3288. <https://doi.org/10.1029/2019GC008334>
- ⁷¹ van Keken, P. E., & Wilson, C. R. (2023). An introductory review of the thermal structure of
⁷² subduction zones: III—Comparison between models and observations. *Progress in Earth
⁷³ and Planetary Science*, 10(1), 1–18.
- ⁷⁴ van Zelst, I., Thieulot, C., & Craig, T. J. (2023). The effect of temperature-dependent
⁷⁵ material properties on simple thermal models of subduction zones. *Solid Earth*, 14,
⁷⁶ 683–707. <https://doi.org/10.5194/se-14-683-2023>
- ⁷⁷ Wada, I., & Wang, K. (2009). Common depth of slab-mantle decoupling: Reconciling diversity
⁷⁸ and uniformity of subduction zones. *Geochem Geophys Geosys*, 10.

79 Wilson, C. R., Seebeck, C., Teshome, K., Sime, N., & van Keken, P. E. (2025). *The FEniCS*
80 *Subduction Zone Jupyter Book*. <https://github.com/cianwilson/fenics-sz/blob/main/readme.md>

82 Wilson, C. R., & van Keken, P. E. (2023). An introductory review of the thermal structure of
83 subduction zones: II—numerical approach and validation. *Progress in Earth and Planetary
84 Science*, 10(1), 1–29.

DRAFT