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

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DOI: 10.xxxxxx/draft

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Submitted: 01 January 1970
Published: unpublished

Summary

Plate tectonics on Earth is the surface expression of the slow convective release of heat from its interior. Subduction zones form the location of the return flow of mantle convection and are sites of mountain building and significant natural hazards in the form of earthquakes and explosive volcanism. The depth extent of large and sometimes tsunamogenic earthquakes, intermediate-depth earthquakes, and melt formation are linked to thermal transitions and corresponding thermally activated processes such as metamorphic reactions (including those causing dehydration and release of volatile phases such as water and carbon). To understand the short- and long-term evolution of the tectonic and geological processes it is critically important to understand the thermal structure of subduction zones (van Keken & Wilson, 2023a).

Figure of SZ thermal structure with oceanic and continental Moho.

Statement of need

`FEniCS-SZ` is cool and is based on Wilson & van Keken (2023).

`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 coupledset 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).

Comparison with other approaches

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, 2023b). 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.

Software design

Research impact statement

AI usage disclosure

No information or code was harmed by AI.

Acknowledgements

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

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