The University of Oxford Department of Earth Sciences

EARTHSCIENCES

UNIVERSITY OF OXFORD

Large-scale assessment of seismic ground motion in New Zealand with physics-based simulation and machine learning

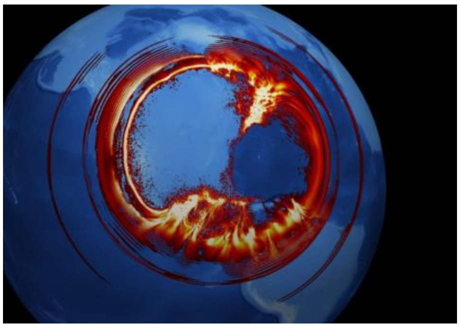
Supervisory Team	• **Supervisor 1 Tarje Nissen-Meyer** https://www.earth.ox.ac.uk/people/tarje-nissen-meyer/ • **Supervisor 2 Richard Walker** https://www.earth.ox.ac.uk/people/richard-walker/ • **External supervisor: Bill Fry** https://www.gns.cri.nz/who/staff/2310.html
Key Words	Seismic hazard, earthquake models, wave propagation, machine learning

Overview

The full seismic cycle (thousands to millions of years) in any region of earthquake hazard extends over time scales that are orders of magnitude longer than available observations: Modern seismology provides us with models of earthquakes over the last few decades. This limited time-window is insufficient to capture the stochastic range of possible natural earthquakes, in particular the largest and rarest events. As part of a New Zealand National Science Challenge (NSC), scientists at GNS New Zealand have used earthquake cycle simulators to create a large catalogue of synthetic earthquake events. In NZ, much like other regions around the Pacific rim, seismic observatories have not yet recorded any large subduction zone earthquakes, yet geology suggests that they often occur and likely trigger crustal earthquakes. By using earthquake simulators, we attempt to overcome some of this observational bias by simulating earthquakes over millions of years.

We are searching for a PhD candidate to conduct research on the synthetic NZ earthquake catalogue by using numerical techniques and machine learning to generate realistic ground motions resulting from the synthetic events. This encompasses simulations with our in-house wave propagation algorithms on supercomputers, combining in a most efficient manner the best of both worlds from numerical simulation and machine learning to be able to scale this up to millions of simulations. This will be the basis for a novel probabilistic interrogation of the resultant waveforms. The project thereby aims to strike a balance between realistic ground motion and probabilistic assessment, aided by recent advances in efficient wave propagation and machine learning. Methods to be used include AxiEM3D, instaseis, and deep neural networks. Beyond enabling such computations for hazard in the first place, the key question is: How do realistic shaking scenarios influence earthquake and tsunami risk analysis? This research serves to 1) better understand earthquake and tsunami hazard, and 2) develop novel ways to improve societal resilience to natural disaster. The project comes with a genuine opportunity to use science to improve the human condition and provides a clear science-to-society implementation pathway. Fully funded by GNS and Wolfson College's Marriott scholarship for candidates from anywhere, the project will be based in the seismology group at Oxford (under supervision of Tarje Nissen-Meyer) and embedded with the NZ-based group led by Bill Fry. We especially encourage candidates from underrepresented minorities to apply.

GNS New Zealand project:
https://resiliencechallenge.nz/scienceprogrammes/earthquake-and-tsunami/
https://www.mbie.govt.nz/dmsdocument/11852-2020-endeavour-round-successful-projects (p. 2)



Snapshot of a seismic wavefield modelled with our in-house methods. Simulations for 1 Million New-Zealand earthquake models.

Further Information

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Methodology

AxiSEM: geodynamics.org/cig/software/axisem/ (Fortran90)
Instaseis: instaseis.net (python)
AxiSEM3D: github.com/kuangdai/AxiSEM-3D (C++)
Deep neural nets: github.com/benmoseley/ (python)

Application:earth.ox.ac.uk/teaching/graduates/graduate-admissions ("Direct Application")

Training & Skills

Experience in machine learning methods, numerical methods, seismic hazard assessment, collaborating with governmental agency.

Timeline

Year 1: Familiarising with earthquake model from GNS, numerical methods, and machine learning, developing ML-integrated modelling

Years 2 and 3: Full-scale modelling of the earthquake catalogue

Year 4: ground shaking assessment: probabilistic sampling, comparison to approximate methods, integration with NZ earthquake programme

References & Further Reading

[1] Moseley, Markham, Nissen-Meyer, 2021. *FBPINNs: a scalable domain decomposition approach for solving differential equations*, arXiv, arXiv:2107.07871.

[2] Haindl, Leng, Nissen-Meyer, 2021. *A 3D Complexity-Adaptive Approach to Explore Sparsity in Visco-Elastic Wave Propagation*, Geophysics, doi.org/10.1190/geo2020-0490.1.

[3] Moseley, Markham, Nissen-Meyer, 2020. *Deep learning for fast simulation of seismic waves in complex media*, Solid Earth, doi: 10.5194/se-2019-159.

[4] van Driel, Krischer, Stähler, Hosseini, Nissen-Meyer, 2015. *Instaseis: instant global seismograms based on a broadband waveform database.* Solid Earth, 6, 701-717.