UNIVERSITY OF OXFORD

- The Ocean Matters -

High-frequency seismic modelling with realistic ocean layers

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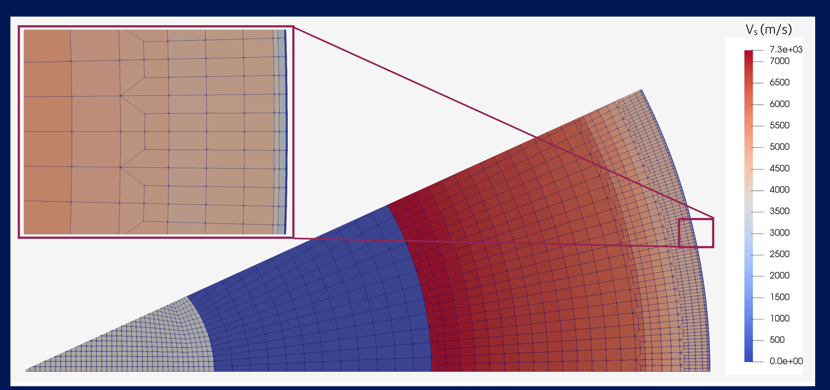
1. Motivation

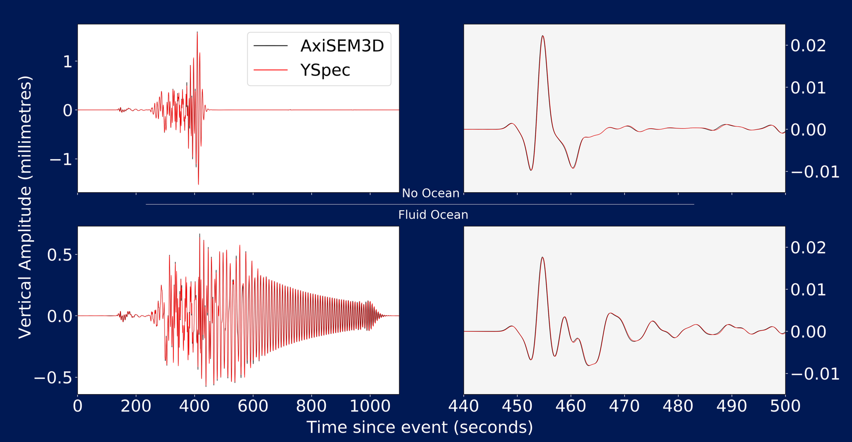
- Oceans cover most of our planet, but are challenging to model seismically.
- Nonetheless they are interesting and significant (e.g. in microseism generation).
- Previous approximations include 'ocean loading'[1] or localised formulations[2,3].
- These are of limited applicability - new methods must be developed.

This method enables computation of global, high-frequency synthetics in a 3D model with realistic oceans.

2. Implementation & Validation

- AxiSEM3D[4] is an efficient spectral element method for generation of synthetics which exploits wavefield smoothness by using an azimuthal Fourier expansion.
- Hence, we require only a 2D axisymmetric mesh (Fig. 1), even for fully 3D calculations. 1D Model: PREM. Where used, fluid ocean is 3km deep.





LEFT: Fig. 1 - Mesh section (10s resolution, with explicitly meshed ocean layer).

RIGHT: Fig. 2 - A 1D benchmark[5], at 2s. Left column: 20° distance, right column: P wave detail at 50°. Top row: without ocean, bottom row: with ocean.

We implement and benchmark a global fluid ocean in AxiSEM3D, and enable inclusion of seafloor topography.

3. Results

3.1 Effects of a fluid ocean (1D Models)

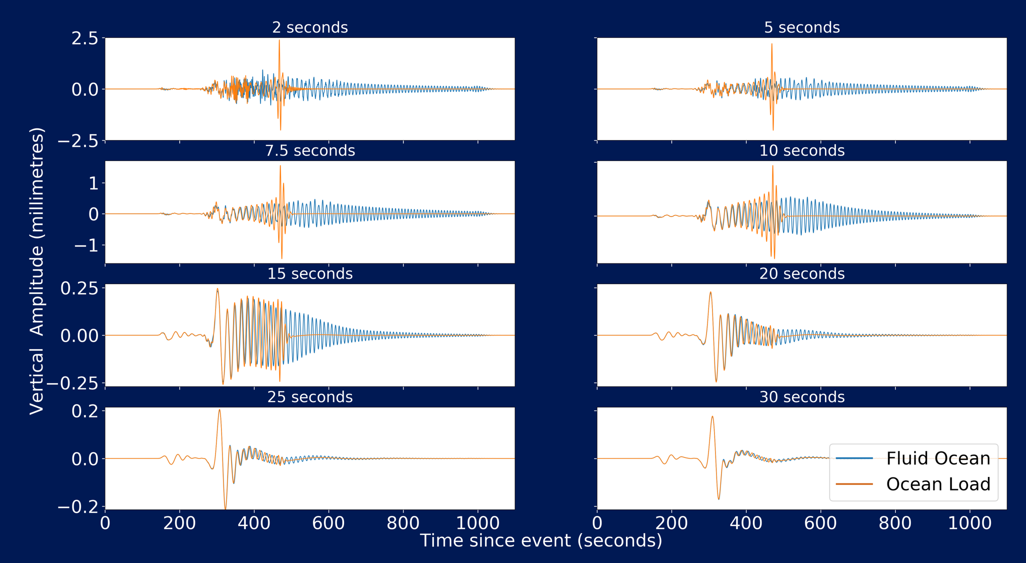


Fig. 3 - 1D Realistic ocean/ocean load approximation comparison at 20° distance. Decrease in misfit is non-linear (steepest between ~8s and ~15s).

<u>Body waves</u> (Fig. 2):

P waves become trapped in the water column

<u>Surface waves</u> (Fig. 2):

Lengthened by ocean, dispersion modified

<u>Ocean Loading</u> (Fig. 3):

Discrepancies small at ~20s, significant at ~15s. Agrees with Zhou (2016)[6], but not Komatitsch (2002)[1]

3.2 Effects of bathymetry (3D Models)

ANIMATION

Test source: *2015 April 30 New Guinea Earthquake (Mw = 6.6, 38km depth).*

3D Models: *Crust 1.0[7], SEMUCB-WM1[8]. Fourier order: 1500 in upper mantle.*

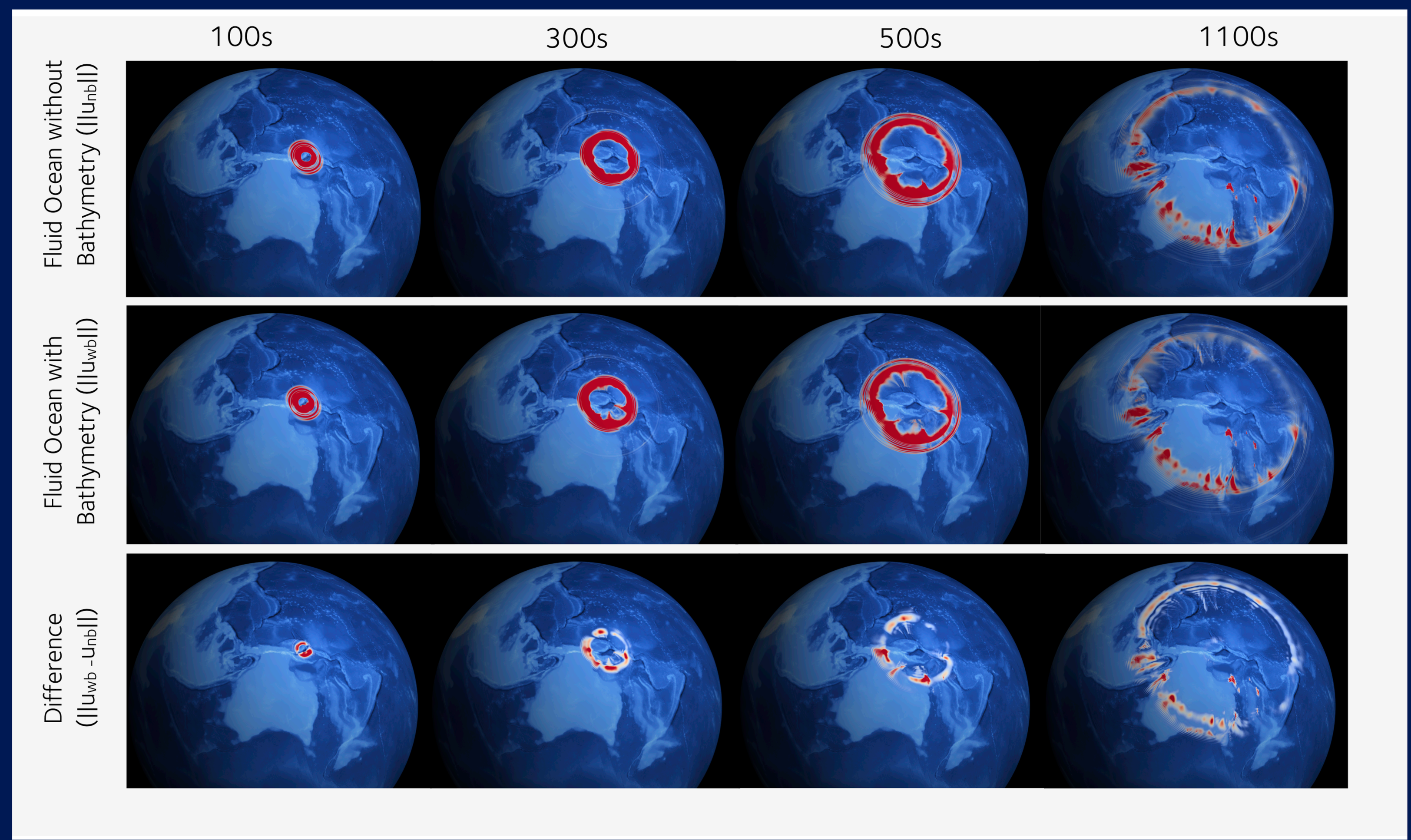
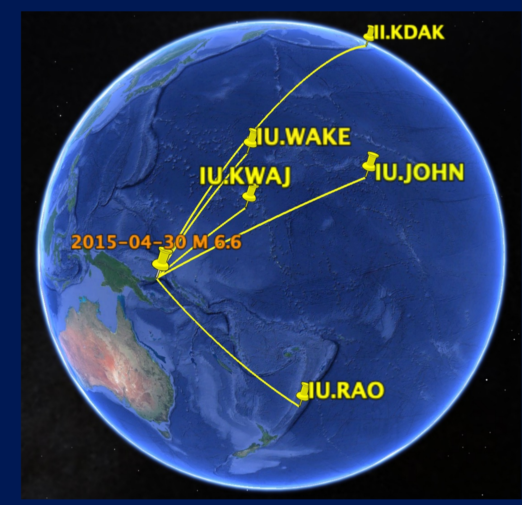
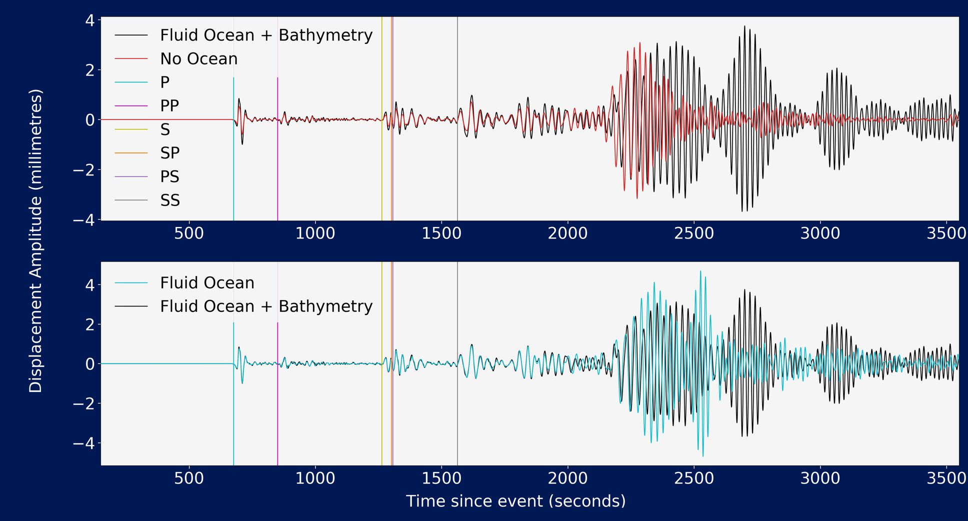


Fig. 4 - 3D synthetic wavefields. Top/Middle: without/with bathymetry; bottom: difference.





LEFT: Fig. 5 - Station Locations. Google Earth Pro[9]

RIGHT: Fig. 6 - Synthetics for station II.KDAK, log-gabor filtered (25s)

Bathymetry has less of an effect on synthetics than a fluid ocean. Differences greatest for surface waves.

3.3 Comparison to Data

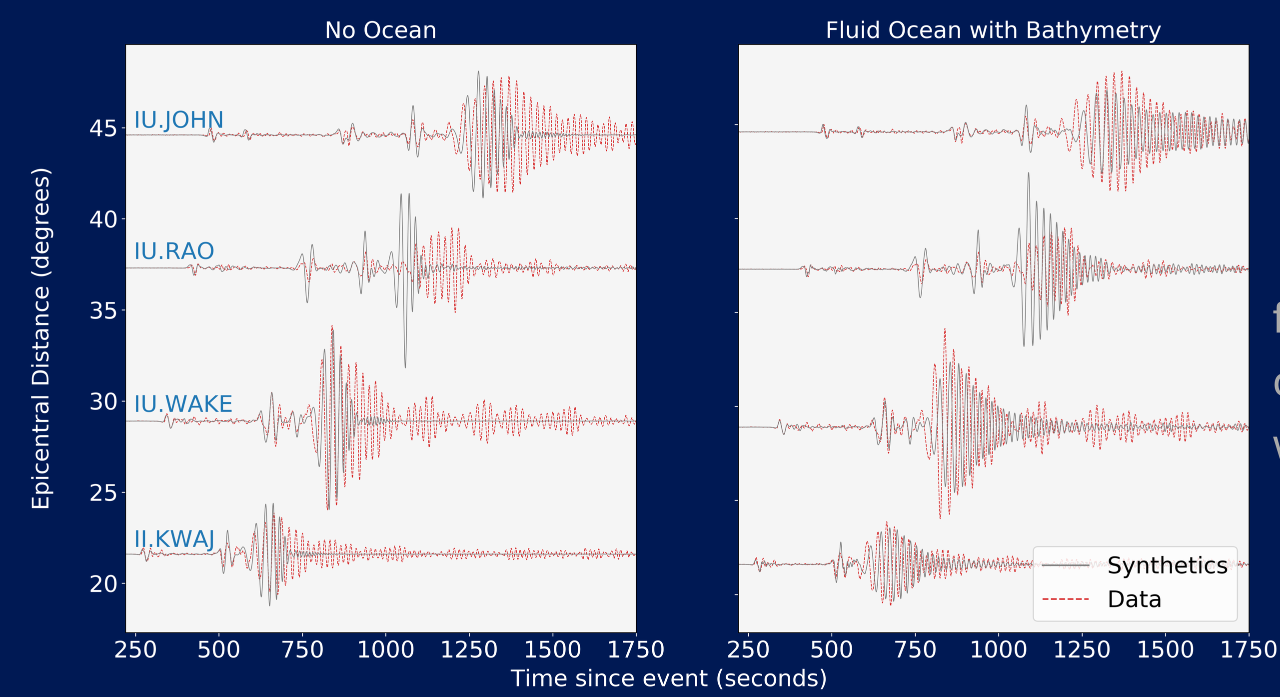


Fig. 7 - Comparison to data. 10s resolution, log-gabor filtered at 25s, vertical component convolved with the SCARDEC[10] STF.

Inclusion of a bathymetry gives a better fit to observed island data.

4. Discussion & Outlook

- 30 min global simulation at 10s (e.g Fig 6):
  - PREM + 3D model: 6000 processor-hours (p-h).
  - Add ocean: 90% increase. Add bathymetry: further 120% increase.
- Cut cost by shrinking mesh and optimising Fourier order:
  - 15 min at 5s with bathymetry: 33,500p-h; optimise for P-waves and save 80%.
- Possible developments: localised oceans, microseism generation.

- The seismic effects of the oceans and their bathymetry are significant -

Natural Environment Research Council

1. Komatitsch & Tromp, GJI 150(1), 2002 || **2. Cristini & Komatitsch**, J. Acoust. Soc. Am. 131(1), 2012 || **3. Bottero et al.**, J. Acoust. Soc. Am. 140, 2016 || **4. Leng et al.**, GJI 217(3), 2019 **5. Al-Attar & Woodhouse**, GJI 205(1), 2008 || **6. Zhou et al.**, GJI 206, 2016 || **7. Laske et al.**, EGU Abstract, 2013 || **8. French & Romanowicz**, GJI 199(3), 2014 || **9.** Landsat/Copernicus/IBCAO images &. SIO/NOAA/ US Navy/NGA/GEBCO data ||**10. Vallée & Douet**, Phys. Earth Planet. In. 257, 2016

CO_2 emissions

Per 10s, 30 minute global run with full bathymetry: ~170kWh = 70kg CO_2

Or 1/40th a return flight to AGU (from London)