EGU2020-3515: 3D printing the world: developing geophysical teaching materials and outreach packages

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3D printing allows us to visualise concepts that are difficult to grasp in 2D, such as geophysical fields and structures within the Earth. However, printing times remain the limiting factor for large-scale production. Paper globe equivalents are a cheap alternative for classrooms. Together, these materials form a complete and inclusive teaching package.

3D printing methodology

1) Take scalar geophysical field with data in lat,lon,z
2) Combine with continental outlines and small-scale topography into composite greyscale image
3) Apply this "bump map" to the surface of a sphere using UV mapping in Blender and export as .stl
4) Halve and hollow out globes to speed up printing times
5) Slice for printing using Ultimaker Cura / Prucaslicer (or similar)

The process is illustrated here for dynamic surface topography.

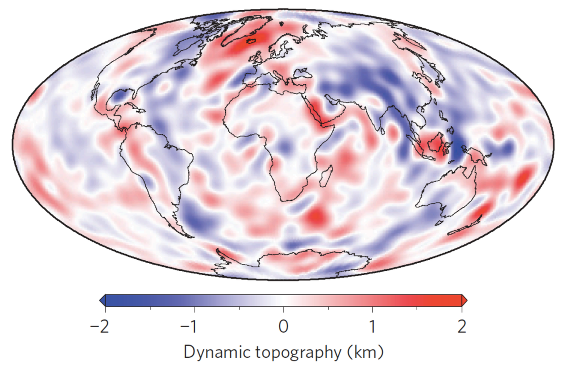
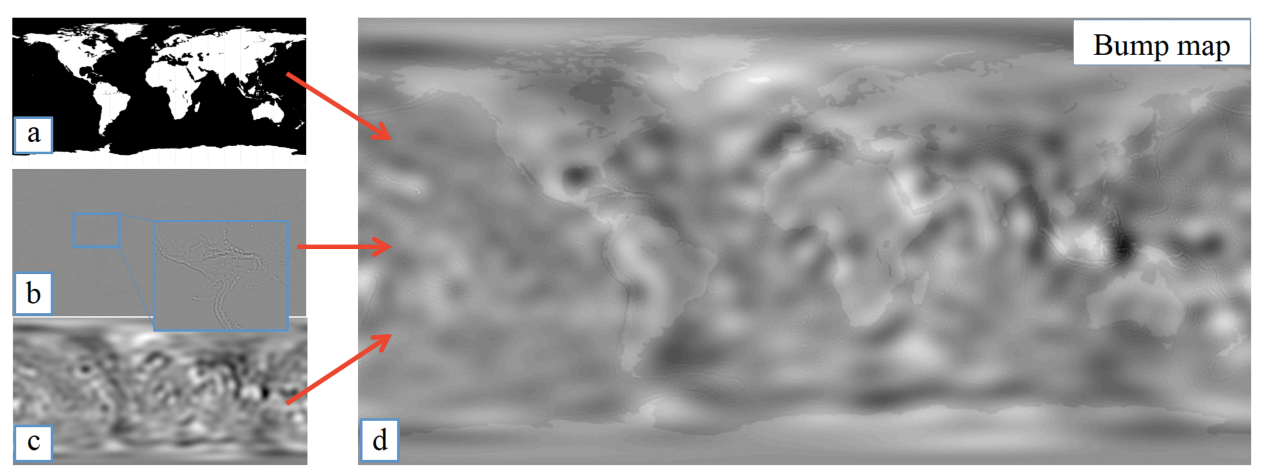


Fig 1. Global dynamic topography (data from Hoggard et. al, 2016).



White = up (bump), black = down (dent)

Fig 2. (a-c) Greyscale layers are composited to form a (d) bump map. Continent outlines (a) provide spatial reference, while high pass filtered surface topography (b) provides geological features. Dynamic topography (c) provides the long wavelength component here. Input images were generated using the Generic Mapping Tools (Wessel et al., 2013) and composited using Python.

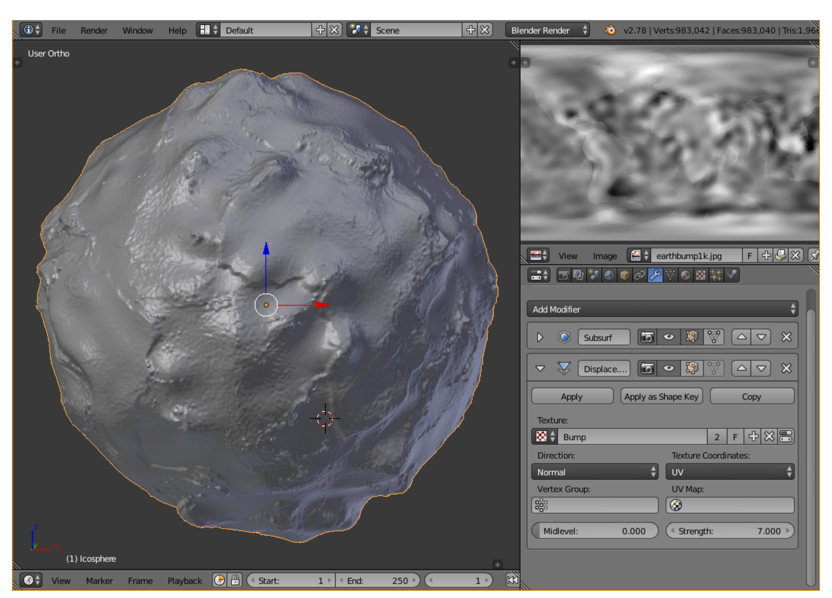
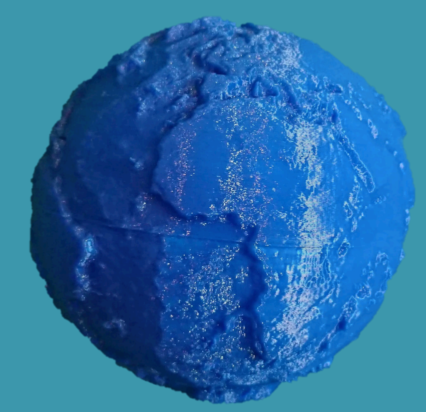


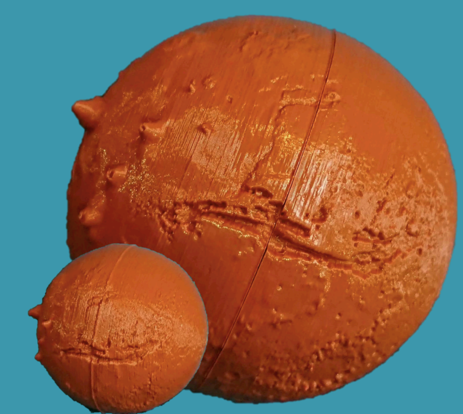
Fig. 3. Screenshot showing the application of the bump map in the Blender software.

3D printing the world

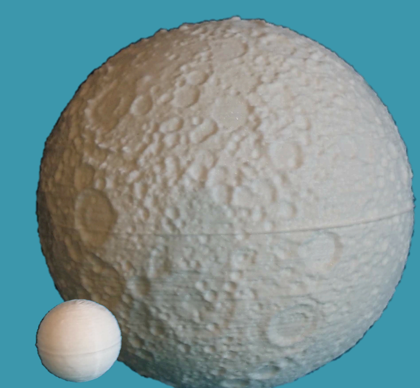
PLANETARY TOPOGRAPHY



EARTH	
Data:	ETOPO1
True diameter:	12,742 km
Vertical exagg.:	50 : 1
Relative size:	1 : 1

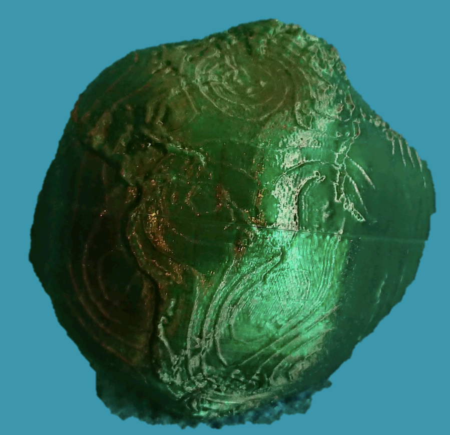


MARS	
Data:	MOLA
True diameter:	6,779 km
Vertical exagg.:	20 : 1
Relative size:	1 : 1.9

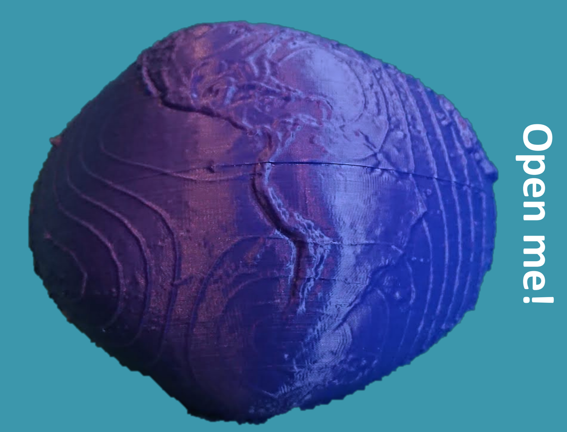


MOON	
Data:	LOLA
True diameter:	3,747 km
Vertical exagg.:	14 : 1
Relative size:	1 : 3.4

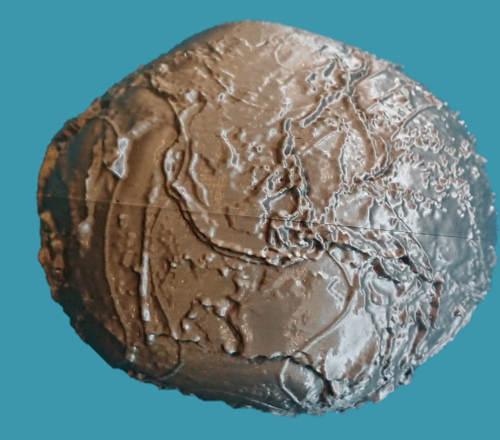
STANDING WAVE FREQUENCY VARIATIONS



MODE $_0S_{26}$	
Data:	KDR13
Centre frequency:	3.45 mHz
Max freq variation:	27.6 µHz
Sensitive to:	Upper mantle



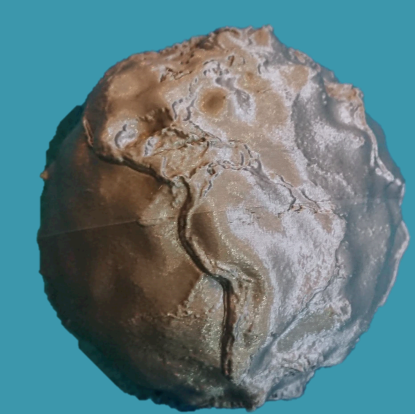
MODE $_2S_{16}$	
Data:	KDR13
Centre frequency:	3.44 mHz
Max freq variation:	27.3 µHz
Sensitive to:	Lower mantle



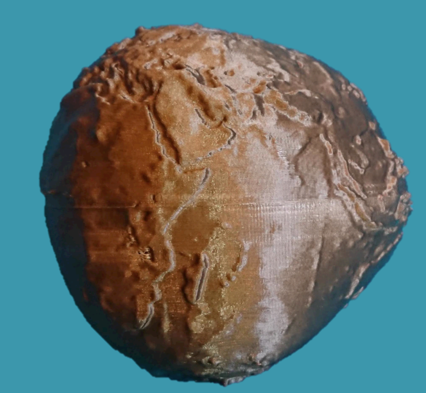
MODE $_{13}S_6$	
Data:	DRH13
Centre frequency:	6.16 mHz
Max freq variation:	16.1 µHz
Sensitive to:	Inner core

CRUSTAL THICKNESS, DYNAMIC TOPOGRAPHY & GEOID

CRUSTAL THICKNESS	
Data:	ETOPO1 / CRUST1.0
True diameter:	6,371 km
Vertical exagg.:	50 : 1
Information on:	Isostasy



DYNAMIC TOPOGRAPHY	
Data:	Hetal16
True diameter:	6,371 km
Vertical exagg.:	300 : 1
Information on:	Mantle flow

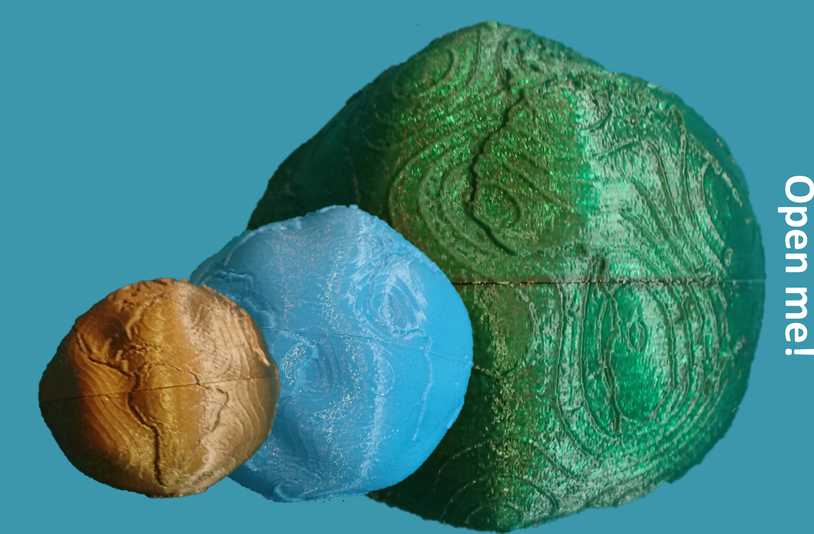


GEOID	
Data:	GGM05C
True diameter:	6,371 km
Vertical exagg.:	10,000: 1
Information on:	Density

EARTH INTERIOR

SURFACE, OUTER CORE & INNER CORE	
Data:	ETOPO1 / PREM
True radii:	6,371 km
	3,481 km
	1,221 km
Vertical exagg.:	50 : 1
Relative size:	1 : 1

SEISMIC TOMOGRAPHY



50, 660 & 2850 KM DEPTH	
Data:	SP12RTS
True radii:	6,321 km
	5,711 km
	3,521 km
Max velocity variation / contour level:	3.3 / 0.50 %
	1.3 / 0.25 %
	1.4 / 0.25 %

Take a picture for a link to 3D-printing designs

Acknowledgements: PK is funded by a Royal Society University Research Fellowship (URF\R1\180377) and gratefully acknowledges their support. Outreach funding is provided by an Enhancement Award (RGF\EA\181029).
Models: Script to make dodecahedrons can be downloaded from https://github.com/renaud71/dodecahedron (Toussaint, 2018, doi:10.5281/zenodo.2531114). 3D-printed designs are available at https://www.thingiverse.com/jeffwinterbourne/designs.
Data used in 3D printing: Earth topography: ETOPO1 (https://www.ngdc.noaa.gov/mgg/global/). Mars topography: MOLA (https://attic.gsfc.nasa.gov/mola/). Moon topography: LOLA (https://lola.gsfc.nasa.gov/). Seismic tomography: SP12RTS (Koelemeijer et al., GJI, 2016). Splitting functions: KDR13 & DRH13 (Koelemeijer et al., GRL, 2013; Deuss et al., GJI, 2013). Crustal thickness: CRUST1 (Laske & Masters, Geophys. Res. Abs, 2013). Geoid: GGM05C (Ries et al., CSR-16-02, 2016). Dynamic topography: Hetal16 (Hoggard et al., Nature Geosc, 2016).
Software: GMT (Wessel & Smith, EOS Trans, 2013), Blender (https://www.blender.org/), Autodesk MeshMixer (www.meshmixer.com/), Ultimaker Cura (https://ultimaker.com/en/products/ultimaker-cura-software), PrucaSlicer (https://www.prusa3d.com/prusaslicer/).

DEEPSCAPE

ROYAL HOLLOWAY UNIVERSITY OF LONDON

Ecole et Observatoire des Sciences de la Terre

Paper globe equivalents

Printing full-size globes takes roughly 6-8 hours on a cheap desktop 3D printer, prohibiting large-scale production, even though material costs are low ($3 each). To ensure availability of sufficient material in a teaching session, we have developed complementary paper equivalents, which have the added advantage of being full-color.

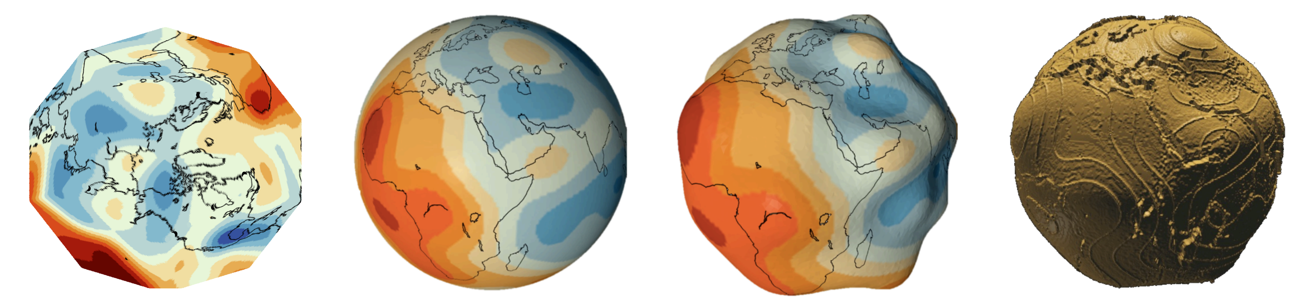
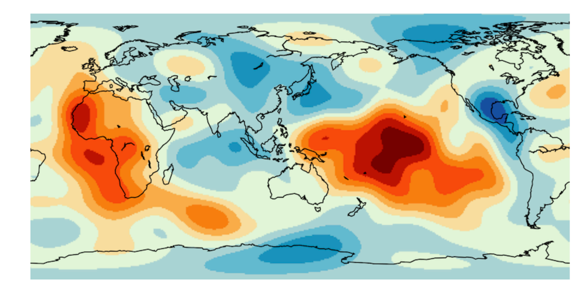


Fig 4. Different representations of the same scalar geophysical field (here seismic tomography at 2850 km depth), showing the relationship between a paper dodecahedron (left) and 3D-printed globe (right).

Paper globe methodology

1) Plot scalar geophysical field in Cartesian projection
2) Project the image onto faces of dodecahedron
3) Flatten the dodecahedron faces onto sheet of paper



This process is illustrated here for seismic tomography at 2850 km depth.

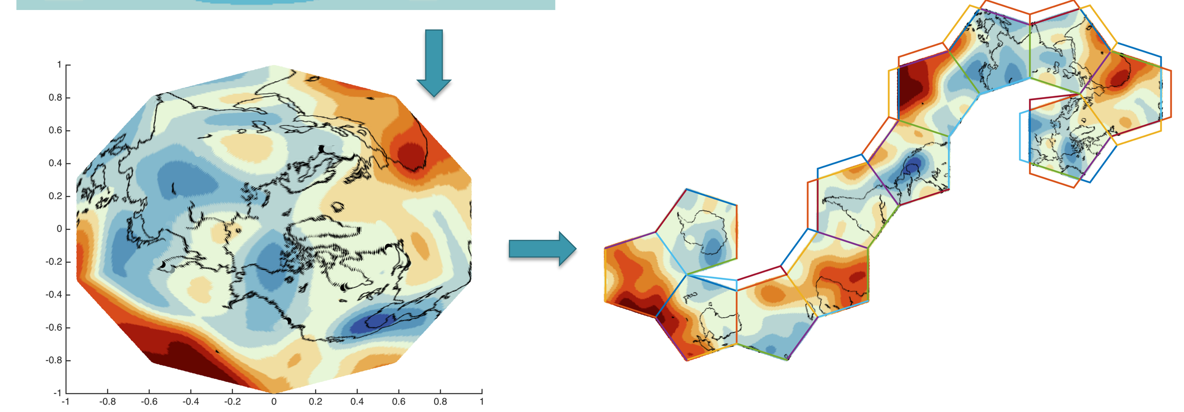


Fig 5. Illustration of the process to create a dodecahedron globe. A Cartesian image is created of the data (1 deg = 1 map unit), which is projected onto the faces of the dodecahedron.

Use in outreach and teaching settings

The 3D-printed globes and paper equivalents, together with animations, suggested questions and instructor cheat-sheets form a complete package that is both interactive and inclusive.

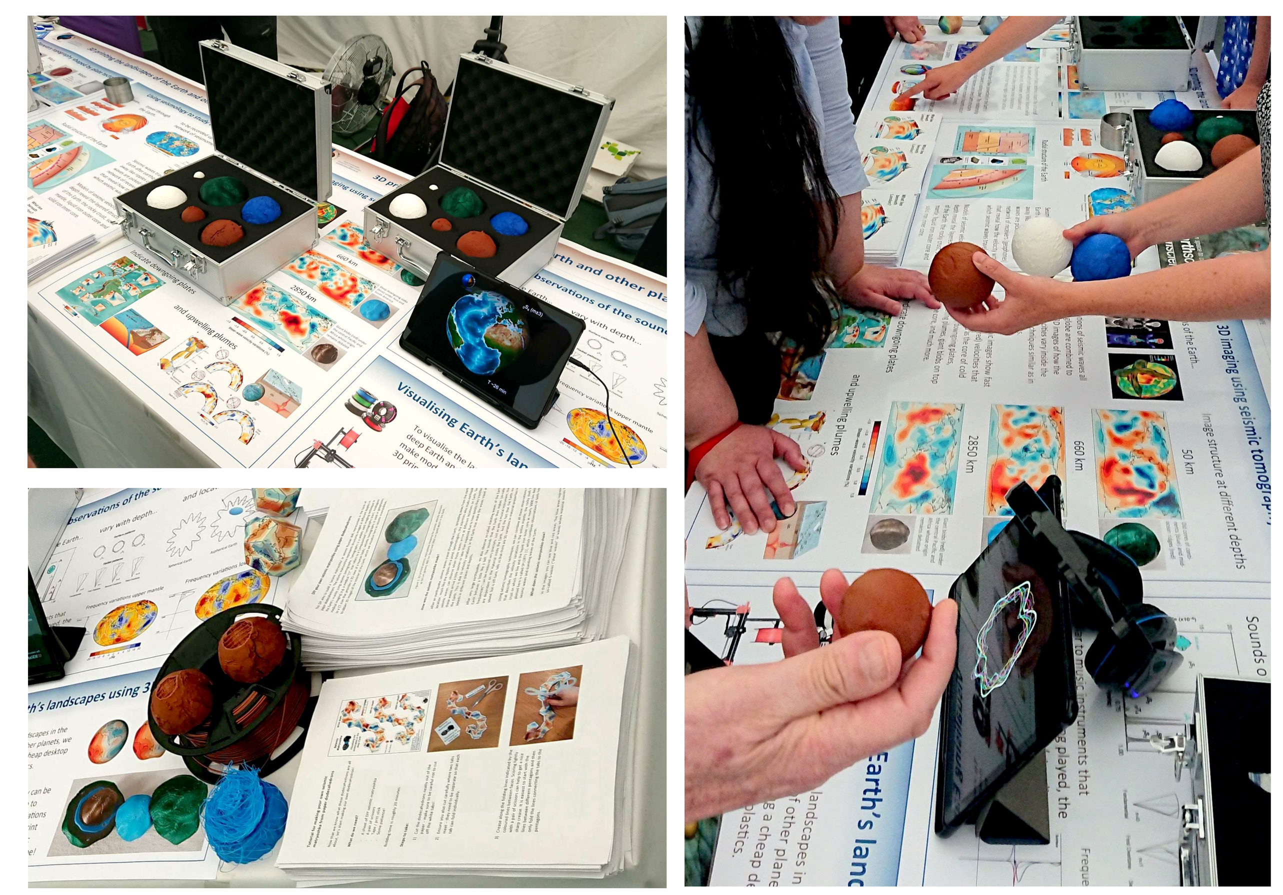
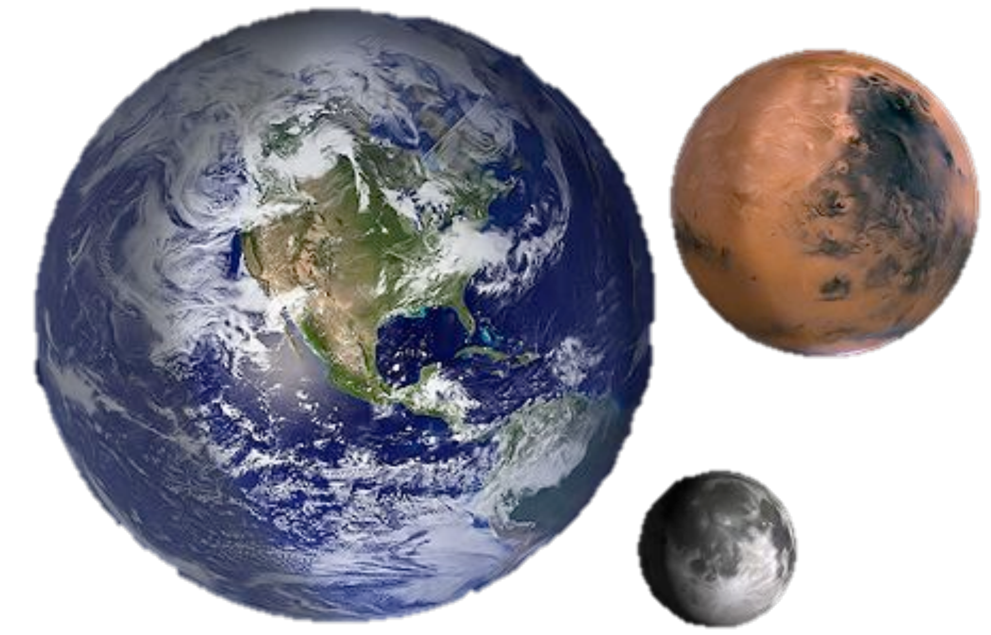


Fig 6. Pictures of an outreach session, where 3D-printed globes are used together with paper equivalents and animations to discuss various concepts in the Earth Sciences.

Possible topics that can be discussed with the globes

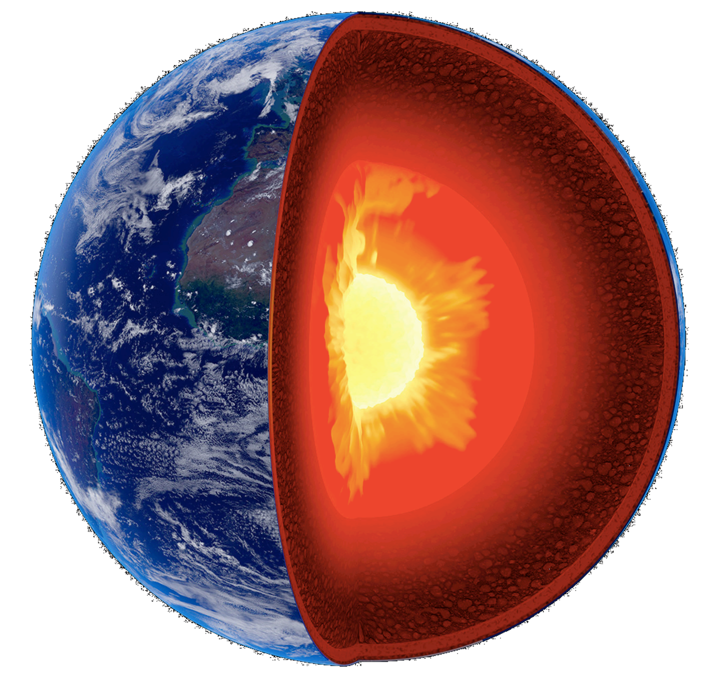
- Planetary topography (Earth / Mars / Moon):

  What determines the landscape of a planet? What is the influence of plate tectonics and how does this relate to internal dynamic processes within a planet



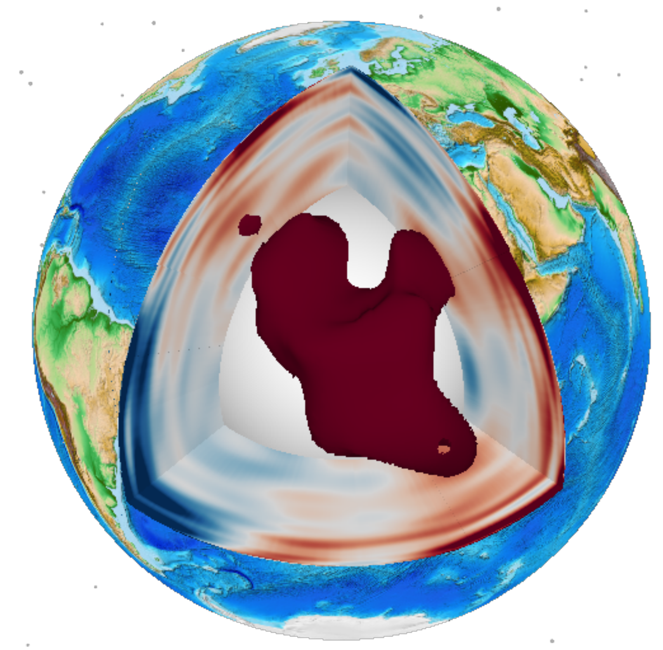
- Earth interior (opens up):

  Structure of the Earth, how do we learn this from seismology, with a side note that the outer and inner core are similar in size to Mars and Moon resp.



- Seismic tomography (opens up):

  Seismology reveals the 3D structures due to dynamic processes, how do we interpret these in terms of hot / cold material and how this moves around, cooling the planet down



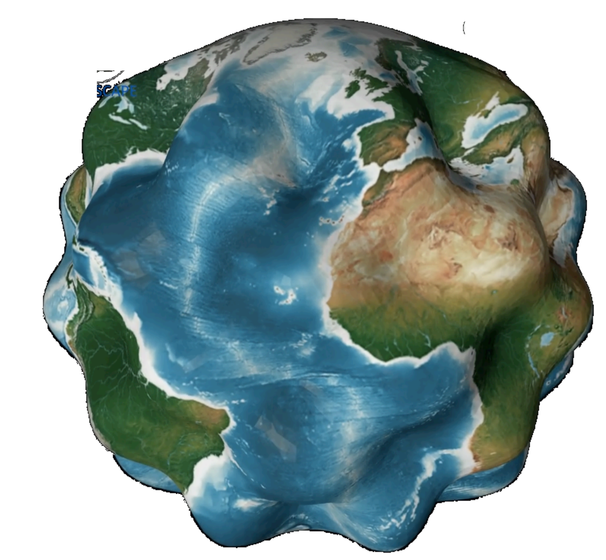
BY NC SA

Sources for images (from top to bottom): Bluedharma on Flickr; Shutterstock.com; Own image

Possible topics that can be discussed with the globes

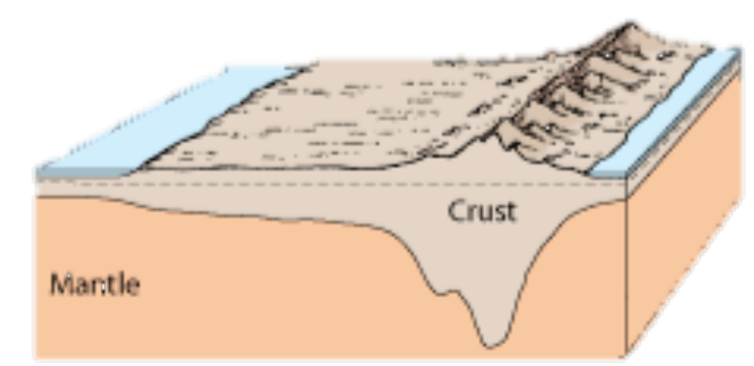
- Standing wave frequency variations:

  How resonance frequencies of whole-Earth vibrations depend on 3D structures inside the Earth, similarly to musical instruments, how these observations are used in seismic tomography



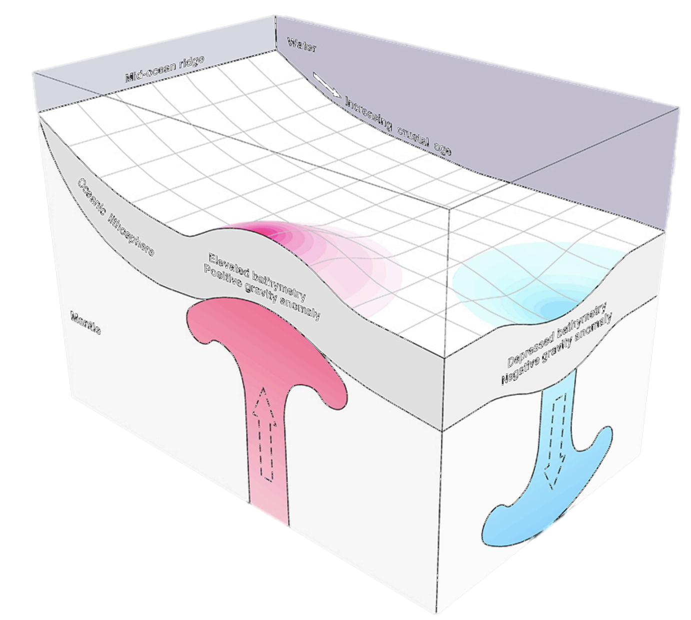
- Crustal thickness (opens up):

  What is the difference between oceans and continents, what is isostasy



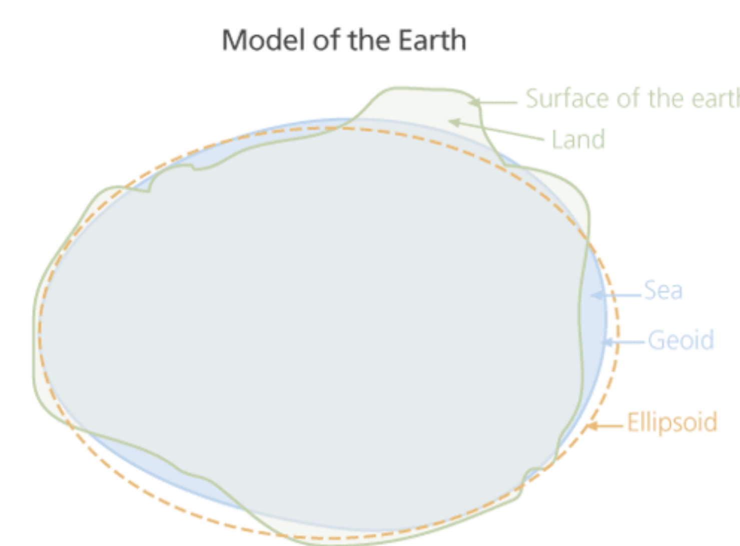
- Dynamic topography

  What is the response of the surface to flow in the mantle



- Geoid

  What can we measure using gravity, what does this tell us about density structures within the Earth



BY NC SA

Sources for images (from top to bottom): Own image; explanet.info; Karol Czarnota; esri.com