

Geoid Tutorial: Integrating observations: mantle density heterogeneity, viscosity structure and geoid anomalies

On your laptops you will need a terminal that runs X11 so we can display graphics properly. Ideally if you are on Windows you will have installed Mobatek Xterm. If you are on a Mac, you can use terminal (/Applications/Utilities) and the X11 app (Xquartz on Mountain Lion).

Start **Mobaxterm** or the **Mac terminal app**, on the mac, also start **X11**. You will get a terminal window.

You will login to my server at UCL.

Type **ssh spqr@supercronopio.es.ucl.ac.uk**

(Mac: type **ssh -X spqr@supercronopio.es.ucl.ac.uk**)

Password- Same as HeFESTo Practical, but ending number 13 not 77

As soon as you are logged in type **tcsh**

Type **cd people**

Type **cd your_emperor**

Type **cp -r .././rome13 .** [You only need to do this the first time you log in, after that, if you need to log in again, you just need to go to directory rome13 and start working)

Type **cd rome13**

Vi as an editor. To view and edit files we will use an old-fashioned but very powerful text editor. Lars has written instructions for vi use in his practical, which you can download.

Okay now we are ready to go (I HOPE)!!!

In this tutorial we will try to predict a very important geophysical observable: geoid anomalies. The geoid is the equipotential surface of the Earth's gravity field which best fits global mean sea level. Deviations from the hydrostatic figure of the Earth are due to both the distribution of mass anomalies in the interior and their effect on the gravitational field, and the deflection of physical interfaces (dynamic topography) caused by the viscous flow induced by the mass anomalies. Hence, geoid anomalies are affected by the viscosity structure of the mantle. Our present understanding of the Earth's geoid is nicely laid out by *Richards and Hager* (1984) and *Ricard et al.* (1984).

To compute geoid anomalies in a spherical Earth we will use the formulation of *Hager and O'Connell* (1979, 1981) and first applied to predicting the geoid with seismic tomography by *Hager et al.* (1985). With this formulation we may use any inferred density heterogeneity field and compute the geoid anomalies for a given viscosity structure.

We will explore the effects of two models of density heterogeneity and the effects of viscosity structure. The code you will be using has been written and modified by many people, and it is not hard to reproduce. For this exercise the executable permits 4 viscosity layers: lithosphere (**vis_li**), upper mantle (**vis_um**), transition zone (**vis_tr**), lower mantle (**vis_lm**).

What do you need to know about running the code? I have set things up so that you may run two simple scripts to run the code for a tomographic density field (**rungeoidtomo**) or a slab density field (**rungeoidslab**). These will compute the geoid, the correlation coefficient and variance reduction with respect to the observed geoid and give you the option of changing viscosity field (1=no 0=yes). There is also a script to plot geoid and dynamic topography maps **makemaps**. These gmt scripts are designed for gmt 3.4.5 not 4.1.3.

You have two choices of density heterogeneity, a tomographic model (S20RTS by *Ritsema and Van Heijst*) and a geodynamic model, based on subduction history (*Ricard et al.*, 1993; *Lithgow-Bertelloni and Richards*, 1998).

To run type either: **rungeoidtomo** or **rungeoidslab**

When running the script the code will ask you for some interactive input. It will ask you to specify what type of density model you are using (1 for the slab model, 2 for tomography). Type **1** if you are running the **rungeoidslab** script and **2** if you are running the **rungeoidtomo** script. After it runs it will ask you if you would like to change the viscosity structure and rerun (in French, 0 for yes, 1 for no). You may also do this in the file called data. If you have typed yes for changing the viscosity structure it will give you four options for changing the viscosity of each layer (vis_li, vis_um, vis_tr, vis_lm). Here you enter an integer value, which will be the viscosity contrast with respect to the upper mantle. So for convenience always keep 1 for the vis_um value.

There are many output files, two of them we will use to plot the results and get some other information.

geosynt – predicted geoid anomalies

dyntopo – predicted surface topography

There will be some output on the screen, ignore everything but the last line. The first number is the correlation coefficient between predicted and observed geoid, the second is the variance reduction. Let's worry only about the first.

1. Baseline case: compute the geoid for both the slab model and the tomographic model for an isoviscous mantle. Run the code using the script rungeoid.
 - a) What is the correlation coefficient?
 - b) What can you say about the locations of geoid lows and highs with respect to observations?
 - c) Any differences between the density heterogeneity models?
 - d) How do the C20 values of the predicted geoid vary between the models (this issue came up in discussion). Look at the file called geosynt with **vi**, which has a series of columns. Degree (l), order (m), cosine term, sin term. C20 is for l=2, m=0 of the cosine term.
2. Find the best fitting lower mantle viscosity structure for both models
 - a) Change the value of the viscosity contrast between upper and lower mantle. Rerun the code. Record the correlation coefficient. Try a series of viscosity contrasts and plot the results.

- b) What did you find? What gives you a better fit, an isoviscous mantle, or a lower mantle with greater viscosity?
 - c) Compare the C20, C21, and S21 terms for the best fitting geoid for each model to observations (file grime).
3. More changes to viscosity structure. Now fix the viscosity contrast for the lower mantle to that you found in question 2. Vary the viscosity contrast of the transition zone.
- a) When do you get anti-correlation between observed and predicted geoids?
 - b) Why? Does looking at a map of dynamic topography help explain the result?
4. What did I have to do to compute the geoid from the tomographic model? Seismic tomography gives velocity anomalies. What assumptions might I have made about how velocity is related to the mass anomalies?
5. Let's meet at 5 and go over the results!