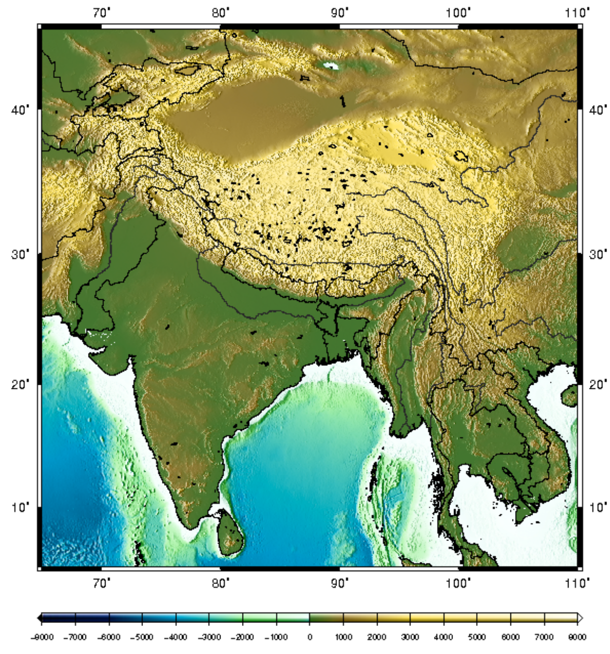
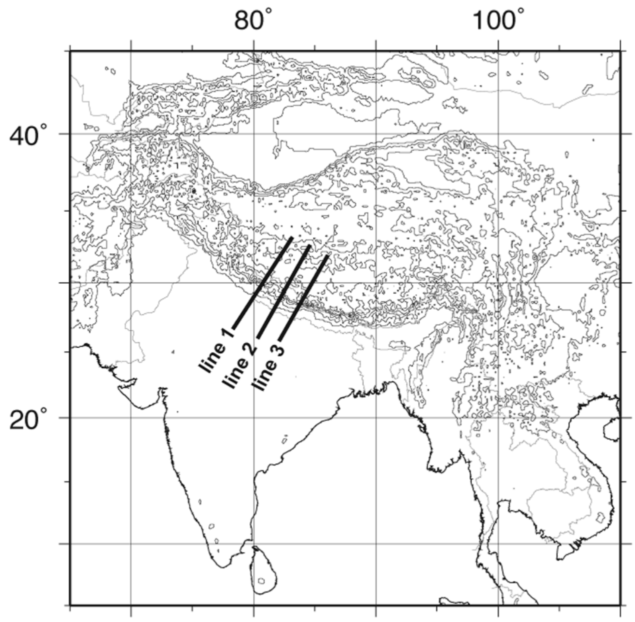
Gravity Modelling–Testing Hypotheses Using Gravity Data

How is the high topography of the Himalaya and Tibetan Plateau supported at depth?

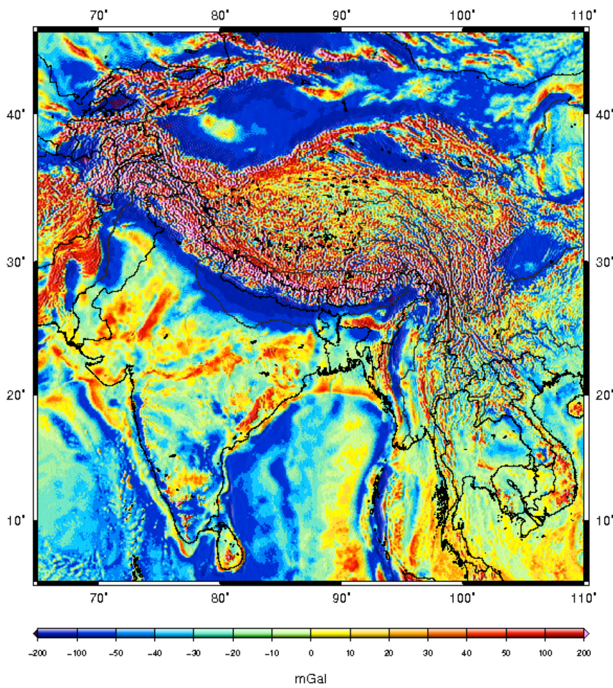
The aim of this practical is to use a forward modelling approach (using the semi-infinite slab approximation) to assist in the interpretation of the gravity anomalies observed along three transects (lines 1, 2 and 3) for the Himalaya-Tibetan Plateau region (see maps below).

ETOPO1 topography

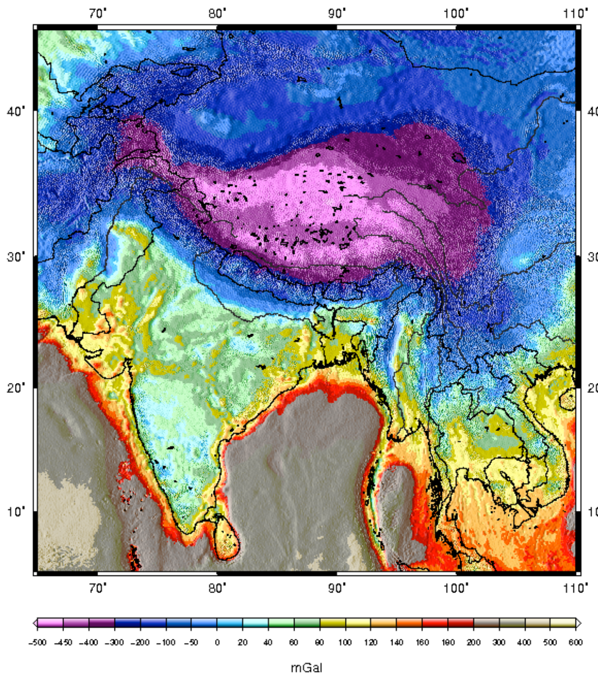




WGM2012 - Surface Free Air Anomaly (mGal)



WGM2012 - Complete Spherical Bouguer Anomaly (mGal)



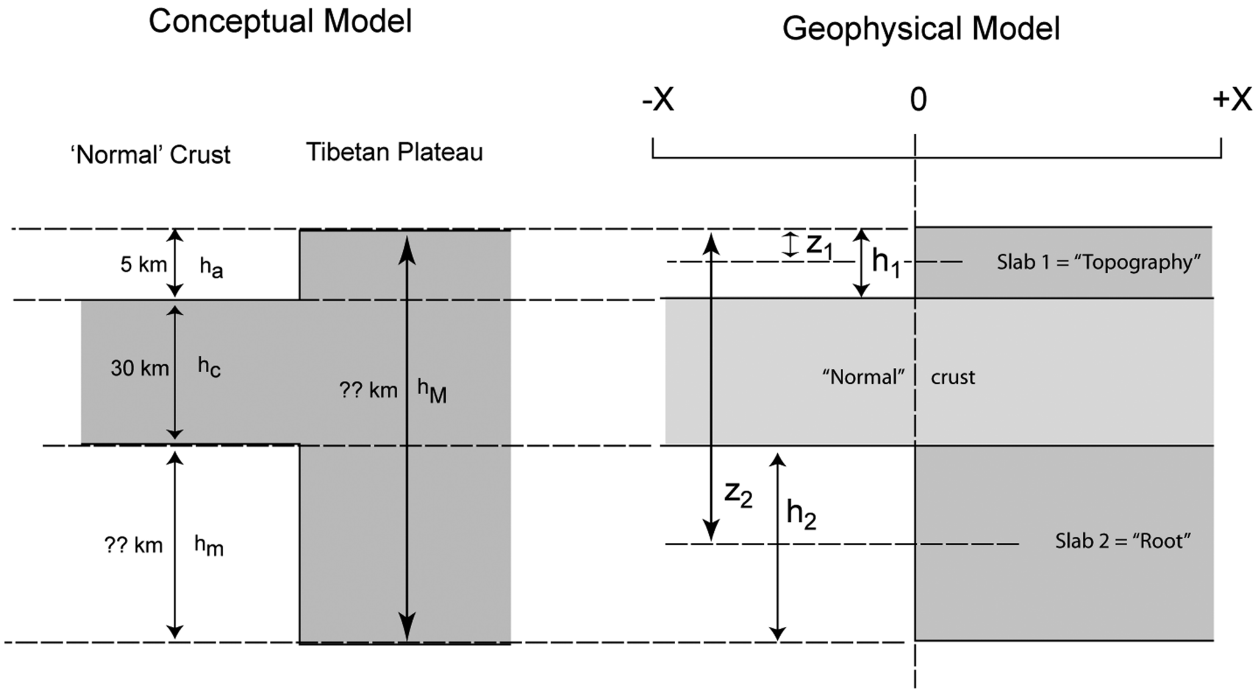
Task 1.
Down load the observed gravity data for the three transects (lines 1, 2 and 3) from the Moodle site. These are provided individually (one line per file) and also as a combined file (one file, each line on a separate workbook page). These data were extracted from the WGM2012 data set which a high resolution global dataset of Earth's gravity anomalies (Bouguer, isostatic and surface free-air), computed at global scale in spherical geometry. See the BGI website for further details; http://bgi.omp.obs-mip.fr/data-products/Grids-and-models/wgm2012

The raw gravity data have been processed following the standard procedures you used in previous labs to calculate the Free Air and Bouguer anomalies. For each transect the mean gravity anomalies (and the calculated standard deviation) were extracted from 20km wide (measured at right angles to the transect line) and 5km long (measured along line of transect) windows along the line of the transect. This yields estimates of the gravity anomalies and the standard deviation at 5km intervals along each profile.

Inspect the gravity anomaly profiles for each line by plotting graphs of the anomaly values and the topography (adjust the scale of the topography as required so you can plot the curves on one graph) on the y-axis versus centre distance on the x-axis. Compare the shape and magnitude of the anomalies with respect to the topography (i.e. elevation) for each transect.

Compare the observed anomalies for the Himalaya-Tibet mountain range to those analysed in the previous lab session for a mountain in Airy isostatic equilibrium.

Task 2.



Use an Airy isostatic model and a simplified crustal structure such as illustrated in the sketch above to calculate the thickness of the crustal root (h_m) and the total crustal thickness (h_M) under the Tibetan Plateau assuming the surface topography is completely supported by the crustal root, i.e. it is in Airy isostatic equilibrium (ρ_c = 2.67, ρ_m =3.1, ρ_a = 0 all in $g.cm^{-3}$).

Task 3.
Use the **semi-infinite slab approximation** (see pages 250, 257 and 258, Chapter 8, Lillie) to model the Free Air gravity anomaly and the Bouguer gravity anomaly across the Himalaya-Tibet mountain front assuming a simple Airy isostatic model. It will be useful and convenient to set up your model so that the x-distance intervals match those in the observed datasets (i.e. -300 t0 400 km with intervals of 5km).

Test your model predictions of the BA and FAA by comparing the model anomalies with the observed anomalies along each of the three transects, lines 1, 2 and 3. You could do this by testing your model against each transect separately.

Given that our model design/geometry is very simple, you might consider whether an "average model", i.e. a model that attempts to fit the mean of the observations calculated across all three lines is appropriate. That is calculate the mean Free Air anomaly and the mean Bouguer anomaly (based on the three transect values available) and fit a single model to these mean values. Averaging the observations made along the three transects will "smooth" some of the variation arising from spatial differences in density, topography etc.

Ensure that you calculate the **Root Mean Square Deviation (RMSD)**, i.e. the average misfit between your model predictions and the observations, and any other suitable estimate of "goodness of fit", for each model you test and compare this with the measurement uncertainties on the observations for the transect.

Also, make sure you plot a set of suitable graphs to illustrate and visualise the observed anomaly data, topography and your model results for each transect/line, ensuring that a plot of the residuals is also included to aid the evaluation and assessment of the model.

Task 4.

• Compile all the outputs from the tasks 1 to 3 (include a simple sketch for your model design (from Task 1), and you <u>must</u> show your workings for the calculation of h_m and h_M in Task 1) into a report. Explicitly discuss, and quantify using the appropriate statistics, how well your model fitted the observed gravity data. [40% of CA grade]

• Read the papers discussing the gravity and structure of the Himalaya-Tibetan Plateau and those on lithospheric strength and effective elastic thickness listed on Moodle and at LEAST two other relevant papers (use Google Scholar and the web, or even the library, to find other relevant papers).

Discuss your model results and your interpretation of these in terms of George Box's famous statement that "All models are wrong, but some are useful." Focus on what your model can and can't tell us about the likely mode of isostatic compensation of the Tibet Plateau-Himalaya. Make sure you include commentary on the problem of defining and measuring the strength of the continental lithosphere, and its role in regional isostasy [60% of CA grade]

Your overall report must be less than 2500 words (excludes references and figure captions etc).

You must submit this report using the Moodle submission link as a single pdf format file for assessment by the appropriate deadline.

You must also submit, along with your report, a single Excel spread sheet file with all your data analysis, plots and modelling results. This file will be uploaded using the Moodle assignment link.

Deadline: 1000 Monday 27th Nov 2017.

Additional Notes for Geophysics CA assignment

This assignment is based on processing, analysing and interpreting real data. There will therefore be all sorts of uncertainties that arise naturally from uncertain measurements through to the natural heterogeneity of the geology itself…all of which are simply par for the course, so to speak, for geophysicists and geologists. And, of course, there is not, and can never be, a "correct" answer, just the scientific process of data analysis, organisation, and interpretation.

The key question posed, and that we wish to answer, is "How is the topography of the Himalaya-Tibet mountain range supported at depth?" This question begs the additional one of "Is a purely Airy-type local compensation mechanism appropriate, or is part of the topographic load supported in other ways, e.g. by the strength of the lithosphere, and if so how/what indicates this?"

One of the key skills geoscientists' possess, and the one highlighted as the skill most valued by employers from my experience, is the ability to make sensible decisions about complex situations based on woefully little and often ambiguous data. So, to some extent, this assignment will test all sorts of skills…mostly geophysical ones (I hope) but also skills at identifying the key points/arguments of a paper/s relevant to the question/task at hand, being able to synthesise a lot of information into a small (or better still, very small) number of key diagrams/graphs and with minimal but effective and sufficient explanation.

So, what I'm getting at, I guess, is that I have deliberately not been, and do not want to be, prescriptive about what you MUST hand in for this exercise. So there is no list of items I want to see…you could easily write 20 pages of text on this topic/material with dozens of really interesting plots I'm sure. But you don't want to do this, I suspect, and I certainly do not want you to do this. And rest assured, I will be happy and delighted to receive a wide and varied array of examples of cutting this particular cake…so do not worry about what your peers are doing or whether somebody has included different graphs etc to you…do what <u>you</u> think works best.

So, please try not to get lost in the forest of data columns, variable names and plots, but step back a bit so you can see the wood from the trees, so to speak. Be ruthless about what figures/graphs you really must include to support/illustrate your interpretation of the gravity data in the context of the question we posed.

So, without being prescriptive, and as a very rough guide to what to include in your report, I would consider;

1. A terse summary and description of the relevant observations we have to work with (i.e. the pattern/variation of the gravity anomalies (Bouguer and Free Air) and the topography along the three transects).
2. A brief description of the model and of the rationale for the forward modelling approach you used to help interpret the observed data.
3. A terse **description** of the model results (including description/comment on any relevant statistics concerning "goodness of fit". Did it "fit" the observed data well, poorly, in places very well an in others poorly etc).
4. A **discussion** of your model results. This is the most important part of the report and should include your interpretation/discussion of what your model has enabled you conclude regarding how the mass of the Tibetan plateau is supported by the crust/lithosphere? And, importantly how your conclusions/results compare/contrast with relevant work published by other scientists (i.e. the published papers identified and any others that you discovered). Note it is not sufficient, or sensible, to conclude that the model worked or didn't work or that it was 'right' or 'wrong'. As George Box said, "All models are wrong, but some are

useful”. So was your model useful? If it was, why, and what did it indicate about the state of isostatic support of the plateau.

So, in a nutshell, we’re after a 2500 word (or less) report that explains as clearly and succinctly as possible what you did, with what, why, and what you found out.

School of Geographical and Earth Sciences

Earth Science Geophysics CA Feedback Sheet

Student No:	**Assignment: L4 Geophysics CA**

The following criteria give an indication of your performance in key areas. The criteria are not all equally weighted.

Additional feedback is provided in the comments box below.

Key descriptors	*Excellent*	*Good*	*Competent*	*Limited/Basic*	*Unacceptable*
Data Analysis [40%]					
Prepare, analyse & present data					
Data processed correctly & completely					
Data presented clearly and usefully including reporting and plotting of errors and uncertainties					
Effective use of graphs & tables (i.e. clear, neat, labled, legible, captioned)					
Modelling					
Model implemented correctly					
Model parameters & results clearly reported and summarised using graphs and tables effectively					
Model evaluation					
Appropriate statistics used and reported clearly					
Appropriate graphs & tables used effectively					
Report [60%]					
Well structured, coherently written, beautifully illustrated using graphs and tables, and carefully edited					
Evidence that wider use of literature was effectively used, and critically assessed/evaluated					
References are properly and consistently cited in text AND reference list					
Interpretation of the model results and discussion in the context of other published work, demonstrating a nuanced and sophisticated understanding of isostasy, and particulalrly the role of the strength of the lithosphere.					

Additional comments and suggestions for improved performance:

Marker: Roderick Brown

Overall grade: