SIO 182: Environmental and Exploration Geophysics

(Spring 2020)

Introductory Material and Course Synopsis

What's in this document:

Who the instructor is and how to contact him, where we teach, and how.

SIO182 lecture material synopsis.

SIO182 field material outline, including notes on writing reports.

An introduction to applied geophysics and short list of references.

SIO 182: When and Where, Who Teaches, Assessment.

Who. Steven Constable's email address is sconstable@ucsd.edu.

Grading. The SIO182A will be assessed by assignment, mid-term, final, participation in the field projects, and field reports. These will count toward the final grade as follows:

Assignments: 15%,

Midterm: 15%

Final: 40%

Field reports: 30%

The assignments will not be intended to be arduous, but to keep you in touch with what is being taught and to make you work through some simple examples. The mid-term will mainly serve to give you some idea of how you are going to fare in the final, before you run out of opportunity to catch up, if indeed you need to.

Course notes will be distributed via the web site. It is important to use the text books as necessary to provide additional examples and material, but if you are familiar with all the material in the notes, you will excel. We have forgone a required textbook in favor of requiring access to MATLAB, through a purchased student license if necessary.

A few notes on doing assignments.

There is no need to regurgitate the notes. Really!

On the other hand, some words describing the mathematical steps are very helpful. For example: "multiplying free-air correction by height:" followed by the math. That way if you make a mistake in the math then I know that you understood the concept.

And please, please, describe every variable, especially those that you are introducing as new. If an "s" suddenly appears I might guess what it represents, or then I might not.

You have to be intelligent about precision. A few things require a LOT of precision, such as using the entire international gravity formula to compute latitude effects. Other things do not - if you are using the differential form of the IGF then you only need to carry as much precision as a gravimeter can measure.

Keep track of units. Meters are not the same as kilometers. I guarantee someone will make that mistake at some point in the quarter. By the same logic, all answers should have units, so I know if your answer is 10 km or 10 m. (The exception is dimensionless quantities, which we tend not to use in SIO182 but are common in SIO103.)

I will help you learn MATLAB, but I can't accept a program as a homework solution. By all means include the program if you want to, but I would like to see the results written up in a way that I can understand (reading my own code is bad enough if I haven't touched it for a couple of months - reading other people's code is a real challenge).

Course Synopsis

Introduction

Overview of the course. Motivation; why do geophysics? Examples of fields in which exploration techniques are used.

Gravity

Force and potential (Newtons's law, acceleration, potential, gradient operators in various coordinate systems, potential due to an extended mass)

Gauss' Law (flux, derivation of Gauss' law using Gauss' theorem, demonstration that spherically symmetric masses are indistinguishable from point masses, use of Gauss' law to find gravity due to symmetric bodies)

Rock densities (relative density of rock types, effect of porosity and saturation, other factors affecting density, methods of estimating rock densities, Nafe-Drake relationship)

Gravity meters (absolute versus relative measurements, sensitivity of linear and non-linear meters, construction of LaCoste-Romberg meter, factors affecting meter measurements of g)

Earth's gravity (equipotential surfaces and the geoid, global gravity field, reference spheroid and the international gravity formula)

Gravity reductions (derivations of latitude correction, free-air correction, and Bouguer correction, Nettleton's method, tides, drift corrections, terrain corrections, regionals and residuals, methods for regional removal)

Interpretation (Excess mass calculation, forward modelling, depth rules)

Magnetic Methods

Introductory theory (current elements, H and B, units)

Magnetization (polarization, susceptibility, diamagnetism, paramagnetism, ferromagnetism, hysteresis and residual magnetism and coercive force, types of remnant magnetism)

Magnetic properties of rocks. Earth's magnetic field (coordinate systems, main field, origin of the field)

Basic theory (potential and field due to a dipole, extended bodies, Laplace and Poisson's equations)

Magnetometers (overview, fluxgate and PPM operation principles, optically pumped mags and SQUIDS)

Field operation (aeromagnetics and the effect of flight altitude, ground surveys)

Interpretation (effect of latitude, depth rules)

Electrical and Electromagnetic Methods

Introductory theory (Coulomb's law, field and potential, Ohm's law and current density, units)

Resistivity of rocks and minerals (metallic conduction, semiconduction, electrolytic conduction, factors affecting resistivity, measuring resistivity in the laboratory, anisotropy)

DC resistivity theory (theory for a point source, 4-electrode arrays, apparent resistivity, common arrays)

Resistivity sounding and profiling (the sounding curve, profiling curves, electrode effects)

Resistivity equipment (current circuit, potential circuit, electrodes, DC offsets, stacking)

Resistivity interpretation (curve matching, forward modeling, equivalence/suppression of layers, anisotropy)

Self-potential method

Induced polarization method (concept, membrane polarization, electrode polarization, time and frequency domain systems, chargeability, PFE, metal factor)

Electromagnetic methods (Earth response as part of source-receiver coupling, primary and secondary fields, skin depth, telluric, MT and AFMAG natural-source methods, VLF, phase and amplitude, and TEM controlled source systems, relation of the time and frequency domain systems through the Fourier transform, simple analysis of square wave)

Reports

Industrial and academic institutions both stress the importance of being able to plan and execute a project, to a timetable, and communciate the results both verbally and by writing. To the extent that it is possible, we will use this course as means of teaching these skills in parallel with the geophysical techniques.

For this class you will be required to produce several reports, describing the field work and the data collected. Report writing is a useful skill not often taught during an undergraduate science degree. The following outline and notes are a guide to putting together the sort of report you need for SIO182.

INTRODUCTION: Brief description of the experiment or survey. Why it is being carried out (i.e. what problems will be solved or questions answered by this work).

METHODOLOGY: Description of the equipment used and how the survey was carried out. Any problems encountered.

DESCRIPTION OF DATA: The extent of the data set, data quality (estimation of errors and reliability). Tabulation of data if appropriate. Map of survey area if appropriate. Plots of complete data set. Qualitative assessment of information contained in the data.

MODELING OF DATA: If quantitative modeling is used, describe the algorithm used. Present the data and model fits, and tabulate or plot the model parameters derived.

INTERPRETATION: Turn the qualitative or quantitative assessment of the data into a geophysical, geological, or structural interpretation.

CONCLUSIONS: Did the problem get solved? Discuss the importance of the result and how conclusive it was. How would you extend the work or repeat it in a better way?

Some notes on scientific writing:

Although not essential, third person past tense is preferable to first person writing. That is, “the data were collected” is better than “I collected the data”.

This brings up the point that technically, “data” is a plural noun (singular “datum”). That is, “the data are” is better than “the data is”. I am so used to doing things correctly that the latter sounds as bad as “the pencils is in the tray”, but "data is” is used so extensively in a colloquial setting that most people don’t notice and most people don’t care. But, if you ever get to the point of publishing a paper, you will be held to the correct standards, so it doesn’t hurt to start now.

Wherever possible quantify what you are talking about. “For the past eight years the SIO 182 class has collected magnetic data” is better than “The SIO 182 class has collected many years of data”. Note here that I have not only quantified the time but also made clear what sort of data are being collected.

Flowery descriptive words like “beautiful”, “impressive”, even “huge” and “tiny” are not generally desirable in scientific writing. Keep things objective. “Mount Soledad is festooned with many desirable houses” is bad on three counts - the use of “festooned” and “desirable”, and the fact that the real estate situation has nothing to do with gravity data.

Define all the variables you introduce. I can’t think of any case where it would be so obvious you don’t need to do this.

All numbers need units unless they are non-dimensional. Try to be consistent - use either mgal or ms^{-2}, g/cc or kg/m^3.

Be careful with “it” and “they”. Even if the subject you are referring to is in the last sentence, it is better to be specific. "The gravimeter was leveled” is better than “It was leveled”.

Many writers use “the” far too much - in many instances it is superfluous and can just be deleted. Using “the” is fine if you have introduced the specific thing already or it is a title: “The Rose Canyon Fault .... . The fault is offset by 300 m” are OK, because in the second sentence we know we are talking about a specific fault introduced in the first senctence. But, “The data were corrected for the altitude” should be “Gravity data were corrected for altitude” because there is no specific altitude involved and it is better to be clear which data you are talking about.

Unless something is common knowledge, or a result of your own work, a reference is required. For example, “The Scripps Formation sandstone is 42 million years old” would normally require a citation.

Normally MATLAB code would be included, if needed, in an appendix, rather than interrupting the flow of the text.

All figures need captions. And all axes need labelling. If you have both points (usually data) and a line (usually a model) then you need to describe what is plotted. Normally figures will be numbered and referred to in the text. Unless you made the figure yourself, it needs attribution.

And speaking of attribution, cutting and pasting material from books or from online (this includes figures), verbatim and without attribution, is plagiarism, one of the most serious forms of scientific misconduct. The German Defense Minister and the German Education Minister both lost their jobs (in 2011 and 2013) when plagiarism was discovered in their doctoral theses. According to the UCSD Policy on Integrity of Scholarship, “Any violation of the Policy by the Student may be considered grounds for failure in the course.” Plagiarism is a violation of the Policy and is relatively easy to spot and document. Even if you paraphrase other’s work, you still need to include attribution.

SIO182 Motivation and Introduction

Why geophysics?

Geophysics covers a great deal of study, from Earth's core to planetary magnetic fields. In this course we are going to focus on the application of geophysical methods to natural resources, also called applied geophysics. We will include engineering geophysics and what has become known as environmental geophysics. Indeed, the applications of the techniques you will learn in this class are extremely diverse, from traditional areas like petroleum and mineral exploration, to finding grave sites, both modern and historical. The one thing that links all these methods is that they are 'shallow', that is they are primarily concerned with features that can be drilled to or dug up. For the petroleum industry, this can still be quite deep, 5 km or more, but for the most part we will be dealing with exploration tools for the top 100 to 1000 m.

For geophysics to work, there must be a contrast in physical properties associated with the features you are trying to study, and it is important to match the method to the subject matter. So, electrical methods map electrical conductivity contrasts, gravity methods map density contrasts, seismic methods measure acoustic velocities, and magnetic methods rely on variations in magnetic susceptibility.

A very oversimplified list of applications and tools would be:

The search for energy resources: oil, gas, coal, geothermal energy (seismics, gravity, resistivity).

The search for mineral resources: base metals mainly but also others (electromagnetic methods).

Hydrogeology (electrical methods).

Engineering geology (seismics, electrical, gravity).

Regional geology (gravity, magnetics).

Environmental (radar, electrical, seismics).

Archaeological (radar, electrical, magnetics).

Suggested References:

Sharma, P.V., 1997 (re-issued 2004): *Environmental and Engineering Geophysics*. Cambridge U. Press. (Used to be the recommended text, but I checked the pricing on Amazon and at over $200 seems a bit expensive. Modern and at an appropriate level. The examples are for engineering/environmental work, but the descriptions of the methods are discussed more generally and the mining/petroleum applications are not lost.)

Reynolds, J.M., 1997 (second edition 2011): *An Introduction to Applied and Environmental Geophysics*. Wiley. (Modern, and pitched at the right level. Notable in that it deals with modern techniques such as radar and marine electrical methods, left out of almost all other texts. It is new, however, so watch for errors and typos, many of which have been fixed in the second printing. Available for Kindle and in paperback for about $50, so a cheaper option to Sharma.)

Telford, W.M., Geldart, L.P., Sheriff, R.E., and Keys, D.A., 1976 (second edition 1990): *Applied Geophysics*. Cambridge University Press. (A comprehensive text with lots of examples, good value for money. Detailed but somewhat dry. Available for Kindle about $75 and in paperback for about $100.)

Kearey, P., and M. Brooks, 1984 (third edition 2002): *An Introduction to Geophysical Exploration*, Blackwell. (A good modern text is pitched at about the right level for our class. Was expensive but now available for Kindle about $75 and in paperback for about $100.).

Everett, M.E., 2013: *Near-surface Applied Geophysics*, Cambridge University Press. (A new offering - comprehensive and up to date. Good for electrical methods, but only one page on gravity! Kindle for about $45 and hardcover $60.)

Appendix to Syllabus

Academic integrity

Academic Integrity is expected of everyone at UC San Diego. This means that you must be honest, fair, responsible, respectful, and trustworthy in all of your actions. Lying, cheating or any other forms of dishonesty will not be tolerated because they undermine learning and the University's ability to certify students' knowledge and abilities. Thus, any attempt to get, or help another get, a grade by cheating, lying or dishonesty will be reported to the Academic Integrity Office and will result sanctions. Sanctions can include an F in this class and suspension or dismissal from the University. So, think carefully before you act by asking yourself: a) is what I'm about to do or submit for credit an honest, fair, respectful, responsible & trustworthy representation of my knowledge and abilities at this time and, b) would my instructor approve of my action? You are ultimately the only person responsible for your behavior. So, if you are unsure, don't ask a friend – ask your instructor, instructional assistant, or the Academic Integrity Office. You can learn more about academic integrity at `academicintegrity.ucsd.edu` .

Students with Disabilities

Students requesting accommodations for this course due to a disability must provide a current Authorization for Accommodation (AFA) letter issued by the Office for Students with Disabilities (OSD) which is located in University Center 202 behind Center Hall. Students are required to present their AFA letters to faculty (please make arrangements to contact your professor privately) and to the OSD Liaison in the department in advance so that accommodations may be arranged. Contact the OSD for further information (858-534-4382, osd@ucsd.edu, or `disabilities.ucsd.edu`).

Student Affairs

Throughout your time at UC San Diego, you may experience a range of issues that can negatively impact your learning. These may include physical illness, housing or food insecurity, strained relationships, loss of motivation, depression, anxiety, high levels of stress, alcohol and drug problems, feeling down, interpersonal or sexual violence, or grief. These concerns or stressful events may lead to diminished academic performance and affect your ability to participate in day-to-day activities. If there are issues related to coursework that are a source of particular stress or challenge, you may speak with your professor, so that they are able to support you. UC San Diego provides a number of resources to all enrolled students, including:

- Counseling and Psychological Services (858-534-3755 – `caps.ucsd.edu`)
- Student Health Services (858-534-3300 – `studenthealth.ucsd.edu`)
- CARE at the Sexual Assault Resource Center (858-534-5793 – `care.ucsd.edu`)
- The Hub Basic Needs Center (858-246-2632 – `basicneeds.ucsd.edu`)

We care about you at UC San Diego, and there is always help available.

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