Applications of GIS-based Laboratory Exercises In Entry-level Geoscience Courses

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As instructional lab manager in the Geosciences Department at Princeton, I develop the lab curricula used in our solid earth entry-level courses, train and supervise the graduate student lab instructors (while teaching some labs myself), provide general support for overall geoscience undergraduate instruction, and provide professional development for K-12 school teachers.

Integrating various visualization strategies is critical to education activities in all of these areas. Our classrooms, as are most geoscience classrooms, are littered with not only with rocks, minerals and fossils but also computers, globes, maps of all sorts, Styrofoam, Silly Putty, clay, string, pegboards and plastic syringes (for the ever popular "Jelloea" lab), slinkies, fault models, etc.

Over the last three years we have added computer labs using GIS to our educational bag of tricks, with great success. One technique has been to use GIS-based SAGUARO modules as launching pads for project-based lab exercises. This approach has allowed students to master significant science content at a level and pace far beyond our previous experience. Additionally, it has allowed students to model the process of doing scientific research; an important goal of our entry-level geoscience courses.

Note that I speak of "entry-level" geoscience courses. I have never been comfortable with the term "introductory" courses, because the vast majority of students taking such courses at Princeton our lower level courses are taking them to fulfill a distribution requirement and will likely not take another geoscience course. This is the case at many colleges and universities. The courses might just as aptly be called "terminal" geoscience courses.

This has greatly influenced the way we approach these courses in general, and the way I develop lab curricula in general. Just as important as teaching about the earth, are our goals of teaching students about the process of doing science and developing their critical thinking skills.

As an example, students in GEO210B: Earthquakes, Volcanoes and Other Natural Hazards have just completed one of these lab exercises titled <u>Testing Plate Tectonics.</u> About three weeks into the course and after lectures and assigned textbook readings on plate tectonics, students complete the lab which is organized in three parts

> <u>In Part A</u> of the lab, students work though exercises from the SAGUARO Dynamic Earth module, in which they deduce plate movements by analyzing age data from the Mid Atlantic Ridge, East Pacific Rise, and Hawaiian/Emperor volcanic trend. We present this as data used to formulate a plate tectonic model, NUVEL1, which predicts plate motions based on certain assumptions and long-term average plate motions such as the ones they just calculated in the SAGUARO exercises.
>
> <u>In Part B</u> of the lab, students are introduced to the technique of Very Long Baseline Interferometry (VLBI) and showed how to access on-line data from various radio telescope pairs that can be interpreted in terms of near-real time plate motions.

In Part C of the lab, student pairs are assigned either a plate boundary or plate interior to research. They use the SAGUARO GIS ArcView views to image their area of interest, and add geophysical data sets such as telescope locations, volcanoes and earthquake epicenters. They choose baselines that span their plate or plate boundary and compare VLBI rates of baseline length changes with NUVEL1 model rates. They conclude the lab by composing an essay which:

> "…(focuses) on your plate or plate boundary -- do not discuss the whole theory of plate tectonics…some points to consider (not an exhaustive list):
>
> - Interpret your baseline length changes in terms of plate movements.
> - How do your VLBI results agree with your NUVEL predictions?
> - How well do your results fit with assumptions of stable plate interiors and active plate boundaries? What could account for discrepancies?
> - Are plate velocities constant with time?
> - Are your data consistent with the presence or absence of earthquakes, volcanoes and/or topographic features that occur along your plate boundaries or within your plate?"

The result of this exercise is that by the third week of their first (last?) geoscience course, students are working with actual data and testing a fundamental theory. We have developed several other exercises that are organized in a similar fashion. The exercises are well-received by students, who feel immediately engaged and empowered as they manipulate large three-dimensional geophysical data sets, and gain a sophisticated understanding of both geoscience content and the process of doing science.

Geo210B Spring 2004
Feb 16-19

Your Name____
Lab Partner____
Computer #('s) ______________________________________

Part C investigation: __________________________________

Lab 2: Testing Plate Tectonics

Objectives:

- To understand how movements of lithospheric plates can be tracked through time.
- To distinguish between long-term average and near real-time rates of tectonic plate movements.
- To test plate tectonic theory.

In Part A, you will work through several GIS exercises which illustrate how age data from the ocean floor can be used to track long-term movements of tectonic plate over tens of millions of years.

This ocean floor age data, combined with information from transform fault orientations and earthquake slip data forms the basis of a plate tectonic model called **NUVEL-1** (DeMets et al., 1990, 1991; Argus et al., 1994). NUVEL-1 assumes that the earth's lithosphere is divided into 12 rigid plates that move relative to one another. Within NUVEL-1, plates are not allowed to deform internally, and all the action is assumed to occur along plate boundaries.

Argus D.F., R.G. Gordon, No-net-rotation model of current plate velocities incorporating plate motion model NUVEL-1. Geophys. Res. Lett., Vol 18, 2039-2042, 1991.
DeMets, C., R. Gordon, D. Argus, and S. Stein, Current plate motions, Geophys. J. Int., 101, 425-478, 1990.
DeMets, C., R. Gordon, D. Argus, and S. Stein, Effect of recent revisions to the geomagnetic reversal time scale on estimates of current plate motions, Geophys. Res. Lett., Vol. 21, No. 20, 2191-2194, 1994.

In Part B, you will be introduced to a way to test the NUVEL-1 plate tectonic model. This method uses Very Long Baseline Interferometry (VLBI) from NASA radio telescopes to precisely measure actual changes in lengths of imaginary baselines over the past 20 years.

In Part C, you and a partner will be assigned a particular plate or plate boundary to investigate. You will compare and discuss actual plate motions measured by VLBI, to the motions predicted by the NUVEL-1 model.

Part A. Tracking Lithospheric Plates by Investigating Seafloor Age

Individual work : complete questions on pages 2-6 *(not included here)*. This should take about one hour.

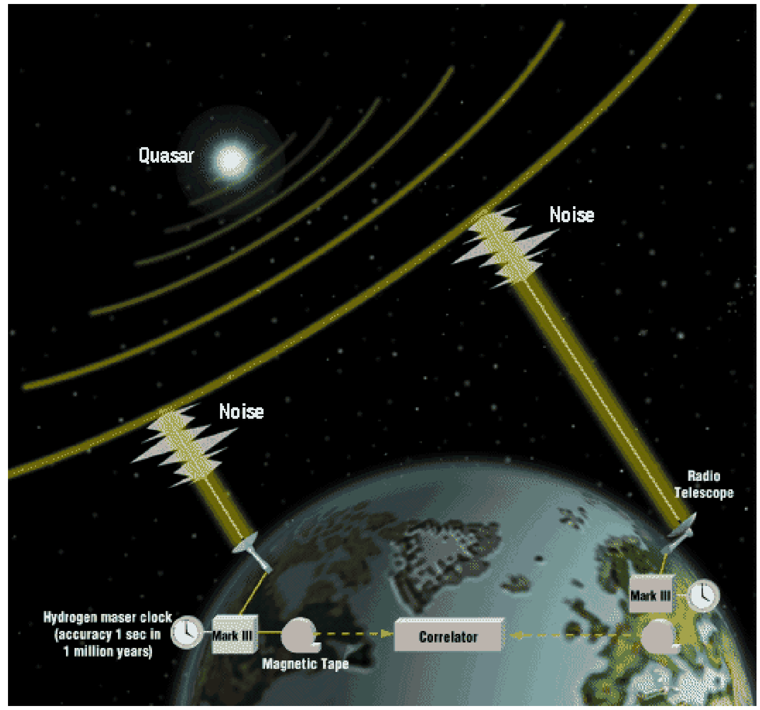
Launch ArcView GIS

Open the existing project dynamic.apr which can be found via d:/saguaro/dynamic/dynamic.apr

Open the Changing Plates view (last week you worked with the Clues view)

Part B. Near real-time actual baseline length changes with VLBI (Very Long Baseline Interferometry)

Radiotelescope ORVO in the Owens Valley, California. See tiny lab manager at base of telescope for scale.



Class discussion:

- Review homework assignment.

- Add a theme with VLBI telescope locations to ArcView:

  Go to View→Add→Theme and then find d:\users\geo210\lab2\location.shp and click ok.
  You will have added the theme "locations" to the top of the legend.
  Click and activate it.
  Use zoom and the identity tool to identify individual telescopes and plates on which they sit.

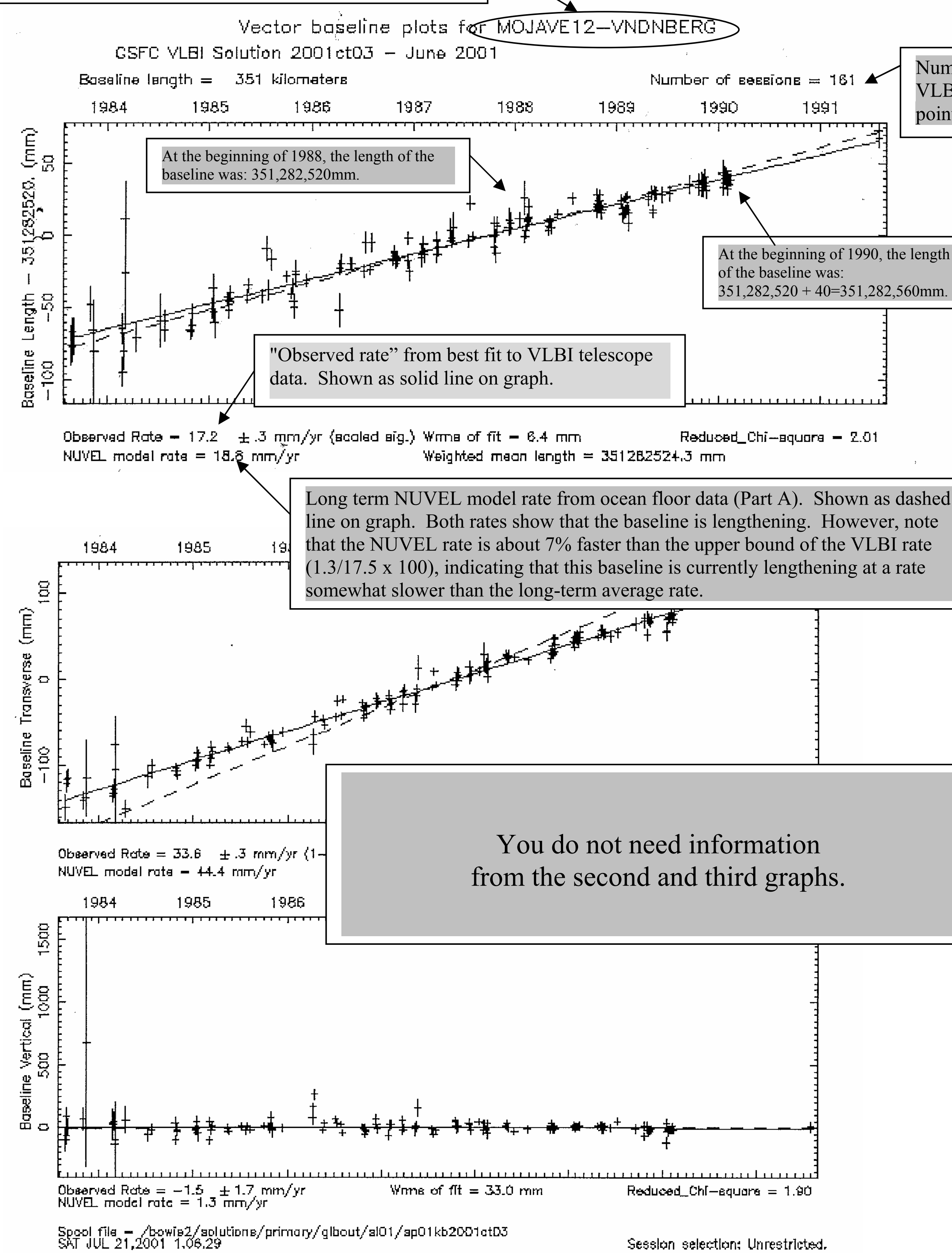
- Using either Netscape or Internet Explorer, your instructor will show you how to access VLBI baseline data from http://lupus.gsfc.nasa.gov/plots/baseline/gif

  Not all baselines have data: see provided list of available baselines.

  See the following page for an example of the data you will collect.

Obtaining VLBI data and NUVEL rates for a baseline

Name of baseline. Both telescopes are in California: one in the Mojave Desert and the other at Vandenberg Air Force Base.



Number of VLBI data points on graph.

At the beginning of 1988, the length of the baseline was: 351,282,520mm.

At the beginning of 1990, the length of the baseline was: 351,282,520 + 40=351,282,560mm.

"Observed rate" from best fit to VLBI telescope data. Shown as solid line on graph.

Long term NUVEL model rate from ocean floor data (Part A). Shown as dashed line on graph. Both rates show that the baseline is lengthening. However, note that the NUVEL rate is about 7% faster than the upper bound of the VLBI rate (1.3/17.5 x 100), indicating that this baseline is currently lengthening at a rate somewhat slower than the long-term average rate.

You do not need information from the second and third graphs.

Part C. Investigating your plate or plate boundary

Your plate or plate boundary: ________________________________

<u>C1 Hypothesis:</u> The NUVEL-1 plate tectonic model proposes that plate interiors do not deform and that all the action happens at plate boundaries. What do you predict should happen to the lengths of baselines within your plate or across your plate boundary?

<u>C2 Analysis and Results</u> *(teamwork)*

⇒ Investigate the motions within your plate or across your plate boundary and fill out the chart provided; teammates can fill out one or two charts together. Find at least three baselines with data (different baselines can have one endpoint in common); the more, the better. Teams with more telescopes available to them should use four or more baselines. Don't choose baselines that cross more than one plate boundary. Do not print out the NASA data plots; just list the results in the chart.

⇒ On the map provided for your area, label your plate or plate boundary. Draw in the baselines that you list in your chart, and key them to your chart so you know which data refers to which baseline. Be sure to confirm the orientation of E/W trending baselines at mid to high latitudes; the baselines are <u>great circle traces</u> and may not be straight lines on a map. (Again, teammates compile their maps together.)

⇒ Answer the following questions about your data (a few sentences each). Print out one copy.

1. Do both VLBI data and NUVEL rates indicate that your baselines are lengthening, shortening or not changing? Or do they contradict one another?
2. Explain how well the magnitudes of the VLBI and NUVEL rates agree. Be sure to consider the +/- limits of the VLBI rates.
3. Does the quality of the data give you more confidence in some VLBI rates than others? You might consider number of data points, time span over which data were collected, lengths of error bars, etc.
4. Any other comments on your results.

C3 Discussion/Conclusions *(individual work)*

Prepare a one-page (maximum) discussion of your results. Be focused on your plate or plate boundary -- do not discuss the whole theory of plate tectonics! Confer with your teammate and your lab instructor as much as you like, but write your own discussion. Some points to consider (not an exhaustive list):

- Interpret your baseline length changes in terms of plate movements.
- How do your VLBI results agree with your NUVEL predictions?
- How well do your results fit with assumptions of stable plate interiors and active plate boundaries? What could account for discrepancies?
- Are plate velocities constant with time?
- Are your data consistent with the presence or absence of earthquakes, volcanos and/or topographic features that occur along your plate boundaries or within your plate? (Use the GIS database to see these features).

To finish up:

Compile a packet for your team (binder clips provided) that includes, in the following order:

- Lab handouts from each team member.
- Homework assignments from each team member.
- One copy of the C2 Analysis and Results for the team.
- C3 Discussion/Conclusions from each team member.

Close all programs

Click “Start” at bottom left and choose “Log Off geo210”