SOEE2212 Tectonophysics Lab 1: Using GPS to determine plate motions and to test the rigidity of continental plates.

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1. Theory

The motion of "plates" can be described by a pole of rotation (lat λ, lon φ), also called an Euler pole, and an angular velocity (α deg/My). Alternatively, it can be given by a rotation vector $\mathbf{\Omega}$ = (ω_x, ω_y, ω_z), which has its origin at the Earth's centre and passes through the Euler pole. The length of $\mathbf{\Omega}$ gives its scalar angular velocity.

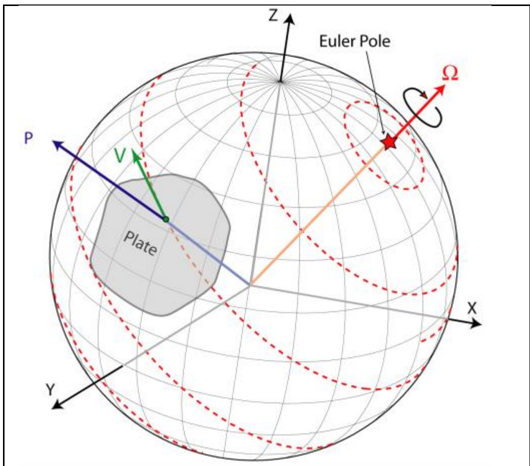

Figure 1: Schematic diagram illustrating the rotation of a plate about an Euler pole.

$\mathbf{\Omega}$ = rotation vector for the plate
P = position vector for a point on the plate
V = velocity vector for the point P
X,Y,Z = axes for a Cartesian, geocentric coordinate system. Z points along the north pole. X-Y is the equatorial plane and X-Z contains the prime (Greenwich) meridian.

The velocity of any point defined by position vector **P** = (X,Y,Z) can be found by

$$\boldsymbol{V} = \left(\frac{\pi}{180}10^{-6}\right)\boldsymbol{\Omega} \times \boldsymbol{P} \qquad \text{[m/yr]} \qquad [1]$$

where **P** is in geocentric coordinates, and the factor in front of the cross product is to convert $\mathbf{\Omega}$ from deg/My into radians/yr.

Multiplying out the cross product, we can say

$$\mathbf{V} = \left(\frac{\pi}{180}10^{-6}\right)\begin{pmatrix} Z\omega_y - Y\omega_z \\ X\omega_z - Z\omega_x \\ Y\omega_x - X\omega_y \end{pmatrix} \qquad \text{[m/yr]} \qquad [2]$$

or

$$\mathbf{V} = \left(\frac{\pi}{180}10^{-6}\right)\begin{pmatrix} 0 & Z & -Y \\ -Z & 0 & X \\ Y & -X & 0 \end{pmatrix}\begin{pmatrix} \omega_x \\ \omega_y \\ \omega_z \end{pmatrix} \qquad \text{[m/yr]} \qquad [3]$$

[3] can be written **V=AΩ.** If we have at the velocities of at least two GPS sites, the problem is over-determined and we can estimate it using a weighted least squares linear inversion,

$$\mathbf{\Omega} = \left(\mathbf{A^T C_V^{-1} A}\right)^{-1}\mathbf{A^T C_V^{-1} V} \qquad [4]$$

where $\mathbf{C_V^{-1}}$ is the inverse of the variance co-variance matrix of velocities **V**.

2. Aims of the lab

1. To show how GPS data can be used to determine plate motions
2. To test how well Africa can be modelled by a single plate
3. To investigate the motion of, and test the concept of, the Anatolian ‘microplate’.

3. Data sets

1. GPS data from Africa from Stamps et al. (2008).

2. GPS data for the Mediterranean from Nocquet (2012).

4. Getting started

Download the zip file: http://see.leeds.ac.uk/~eartjw/data/tectonophysics/lab1.zip and unzip.

Open matlab and move into the lab1_files directory.

Keep all your *matlab* commands in a script and run this, rather than running them on the command line.

Add some required codes to your path:

> addpath mbin/gps_ec mbin/stats

Load a coastline file and make a basemap for Africa:

> load data/coast.mat

> plot(long,lat,'b')

> axis equal

Zoom in on Africa: e.g.

> axis([-30 75 -45 50])

5. Task 1: Determine whether the velocities of Africa are best fit by 1, 2 or more plates.

5.1 First load in the GPS data that have been provided in ITRF 2005 reference frame.

> [lo,la,ve,vn,sve,svn,cne,site]=textread('data/africa_itrf2005.all','%f %f %f %f %f %f %f %s');

The columns of this data file (and the corresponding variables that you have imported) are:

lo = longitude of GPS site; la = latitude

ve = velocity in easterly direction [mm/yr]; vn = velocity in northerly direction [mm/yr]

sve = 1 sigma standard deviation on east velocity; svn = 1 sigma standard deviation on north velocity

cne = Correlation between sve and svn

site = site name (4 letter code)

5.2 Plot the GPS data using the quiver command.

First set a scale that you can use to adjust the length of the arrows, e.g.:

> *s=0.7;*

Then plot on the map using quiver, e.g.:

> quiver(lo,la,ve*s,vn*s,0,'b');

5.3 Calculate the rotation vector between Nubia and ITRF 2005.

We do this by solving equation [4] using the code *psvelo2rot*. This code deals with the transformation from long/lat to geocentric coordinates, as well as solving for the rotation vector. I have selected a subset of the GPS sites that are on the Nubian part of Africa, in file velo.nubia.

Run *psvelo2rot* like this:

> *[OM,COM,E,EL,chi2,chi2r,dof] = psvelo2rot('data/velo.nubia',10,1);*

OM is the rotation vector (deg/Myr). COM is the variance-covariance matrix for OM. E is Euler pole and EL is the associated error ellipse for it. Use *help psvelo2rot* for what the other terms are.

Q. Where is the pole of rotation, and what is the rotation rate.

5.4 Now calculate a predicted velocity for all of the GPS sites assuming that they are all on Nubia and Nubia behaves like a perfect plate.

Step 1: Convert coordinates of all GPS sites into a geocentric, Cartesian reference frame:

> *[x,y,z] = wgs2xyz(lo,la,zeros(length(lo),1));*

Step 2: Use the rotation vector that you calculated earlier to calculate predicted velocities at all the sites:

> *[Vxyz,Venu] = rotate(OM,COM,[x y z]);*

Step 3: Plot the results using quiver, e.g.:

> *quiver(lo,la,Venu(:,1)*s,Venu(:,2)*s,0,'r');*

Q. How well do they fit? Is Africa well modelled as a single plate?

5.5 Calculate and plot the residual velocities to the Nubia plate model at all the sites (i.e. the velocities of all the sites in a Nubia reference frame).

[You'll need to work out the commands to do this]

Q. What are the largest residuals? What geological features might be accommodating this motion?

Note: If you wish to save these Nubian velocities in a file, then these commands will do it:

> *fp = fopen('velo.nubia','w');*

> *fprintf (fp,'%f %f %f %f %f %f %f\n',[lo la Venu]');*

> *fclose(fp);*

5.6 If we divide Africa into two plates, Somalia and Nubia, what is the pole of rotation between them?

I've put the three sites with the largest residual velocities (in Nubian reference) in file *velo.residual.soma*. Using psvelo2rot (as before) you should be able to calculate the rotation vector and Euler pole.

Plot the Euler pole location, noting that the location given might be on the other side of the globe (each rotation axis has two poles that you can plot).

5.7 Repeat steps 5.4 and 5.5 to plot residuals to the 'Somalian plate' model.

You probably want to do this on a second figure.

Q. How well does the two plate model explain the observations?

5.8 Now we are going to compare our estimate for the Nubia-Somalia opening along the East African Rift with that of the REVEL model (Sella et al., 2002), which is a global plate model derived from GPS.

Again, you probably want to do this on another figure.

First load in the data for the REVEL model:

> [lo,la,ve,vn,sve,svn,cne]=textread('data/nubi_soma.revel','%f %f %f %f %f %f %f');

and plot using *quiver* as before.

Then compute predicted displacements for our model at these sites, using *wgs2xyz* and *rotate* as in 5.4 and plot.

Q. How does the opening vary along the East African Rift? Why are the predictions different?

6. Task 2: Assess whether Anatolia can be considered as a rigid plate, or if there is significant internal deformation.

You now have the tools to take GPS data and find poles of rotation, and plot GPS data in different frames of reference. The final part of the lab uses GPS data from the whole Mediterranean region compiled by Nocquet (2012). Specifically you should

1. plot the GPS data (given in a Eurasian reference frame) for Greece and Turkey.

[*nocquet_eurasia.all* contains these data and more]

2. using a subset of sites, determine a relative pole of rotation for Anatolia with respect to Eurasia.

[*nocquet_eurasia.anat* is a subset of data from 'Anatolia', but you may wish to reduce these points even further.]

3. plot the GPS vectors in the Anatolian reference frame.

Q. How well does the microplate assumption works for this region, and what do the results tell us about plate tectonic forces and the rigidity of plates.

References

NOCQUET, J.-M. 2012. Present-day kinematics of the Mediterranean: A comprehensive overview of GPS results. *Tectonophysics*.

SELLA, G. F., DIXON, T. H. & MAO, A. 2002. REVEL: A model for recent plate velocities from space geodesy. *Journal of Geophysical Research,* 107**,** 2081.

STAMPS, D., CALAIS, E., SARIA, E., HARTNADY, C., NOCQUET, J. M., EBINGER, C. & FERNANDES, R. 2008. A kinematic model for the East African Rift. *Geophys. Res. Lett,* 35**,** L05304.