Computing Velocities

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Aim

This tutorial is designed to introduce the user to the various aspects of computing velocities in GPlates.

Included files

Click here to download the data bundle for this tutorial.

The tutorial dataset (9.6-Computing_Velocities.zip) includes the following files:

Rotation file: Caltech_Global_20100713.rot

Topologies: Caltech_Global_20100713.gpml

Coastline file: Seton_etal_ESR2012_Coastlines_2012.1.gpmlz

For Exercise 3, you will use:
Coastline file: Matthews_eral_GPC_inrev_Coastlines_Polyline

Rotation file: Global_EarthByte+230-0Ma_GK07_AREPS.rot

Deforming Network files:

Deforming Network Features: NATL_Deforming_EarthByte.gpml

Continent Ocean Boundaries:
NATL_BreakUP-COBs_Deforming_EarthByte.gpml

Age Segments:
NATL_Age_Segments_extinctDef_EarthByte.gpml

Deforming Mesh:
NATL_PhaseI_DeformationMesh_EarthByte.gpml

Background

What is a mesh? What is it used for?

A mesh is an equally spaced grid of coordinate points. The distance between the points is equal on a spherical surface such as the Earth[1]. The use of a mesh is critical in linking plate kinematics and geodynamic models. For example, CitcomS uses a static mesh that measures the velocity of the tectonic plates through time at each node.
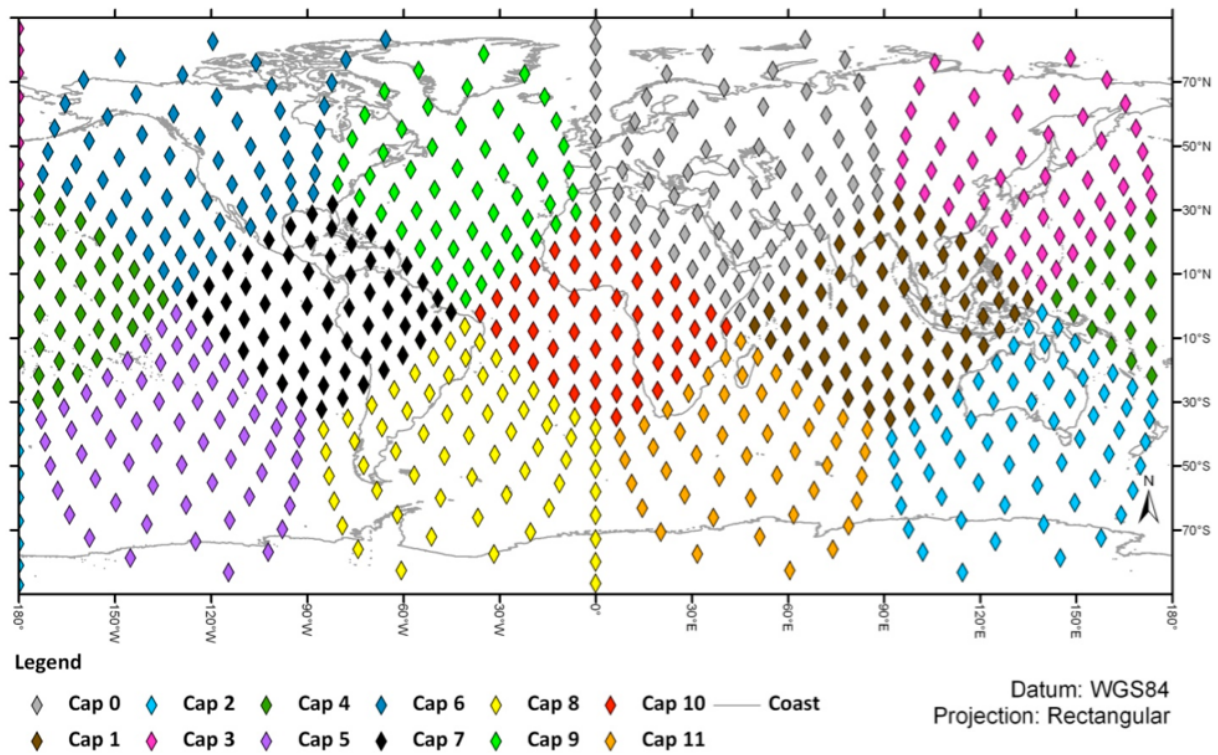
Figure 1: CitcomS 9-mesh global cap and node distribution
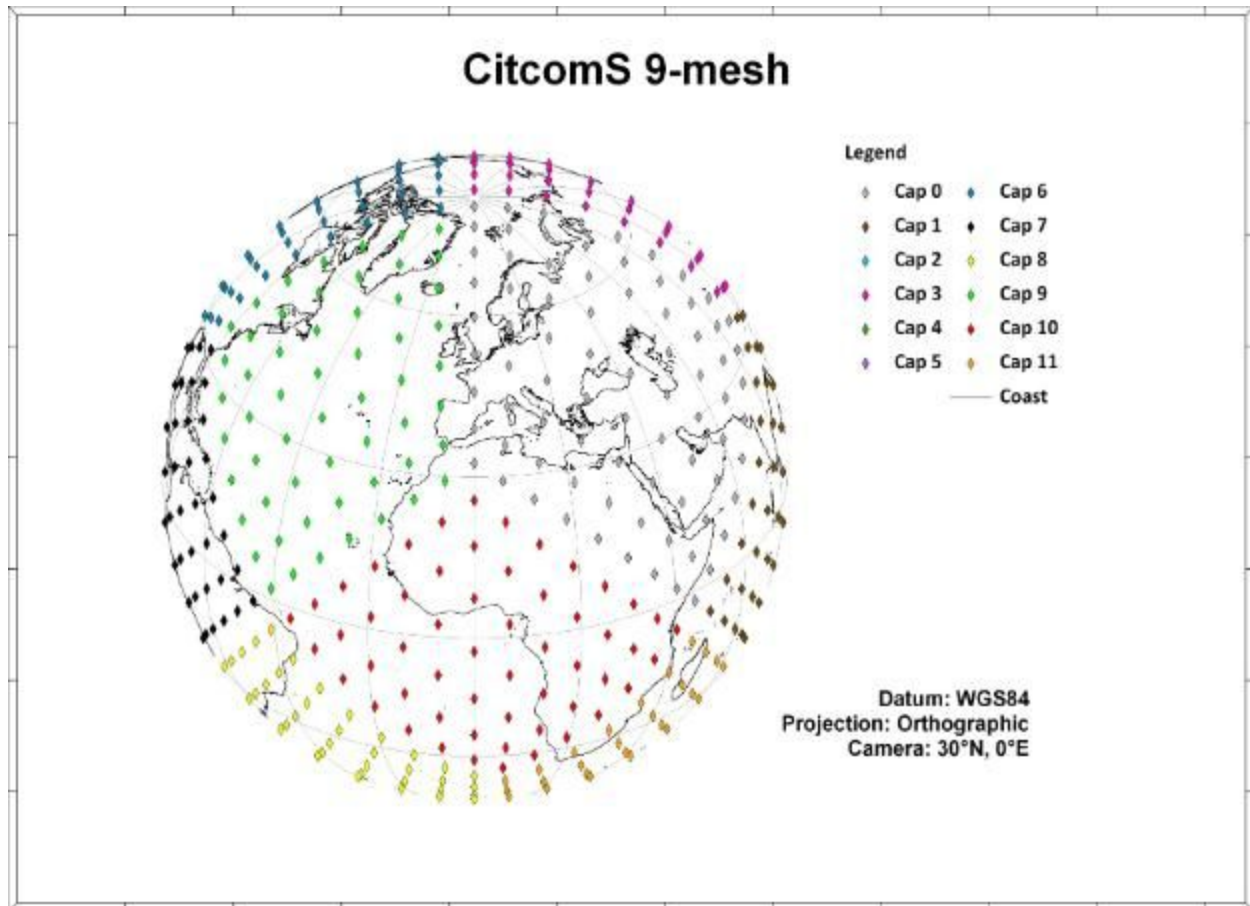
Figure 2: CitcomS 9-mesh node distribution

CitcomS Mesh Specifications[2]

CitcomS meshes can be either regional or global. A global mesh is composed of 12 diamond-shaped 'caps' – numbered from 0 to 11. The density of the mesh nodes can be adjusted. The global distribution of 'caps' can be seen in Figure 1. The rectangular projection does not preserve the uniform distance between the nodes, whereas an orthographic projection is a better representation of the inter-nodal distance (Figure 2).
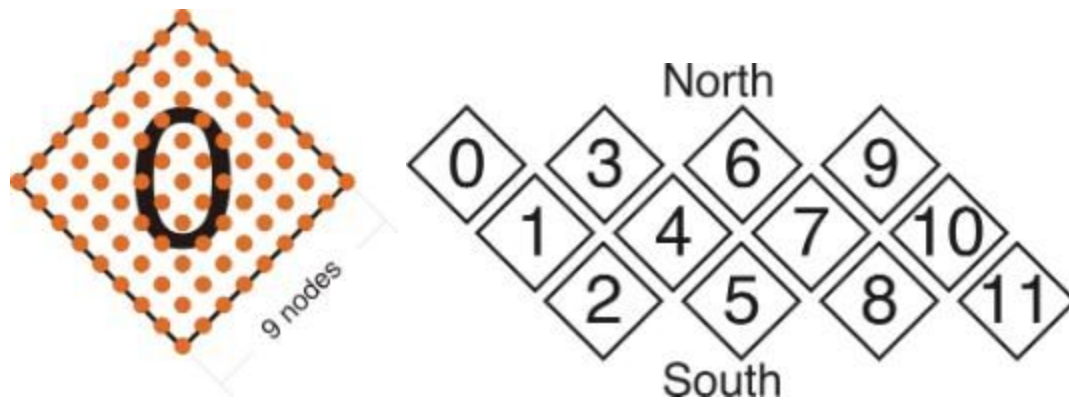
Figure 3: CitcomS Mesh – Cap 0 with 9 X 9 nodes (Left), and Caps 0 to 11 global distribution (Right)

In Exercise 2 we will make each cap comprise 9 X 9 nodes (Figure 3). This is a reasonably coarse mesh, especially for mantle convection modelling purposes. Mesh caps are composed of n^2 nodes (n being the number of points along each side of the cap), and so processing the velocity of denser grids increases proportionally to the square of the node numbers along each cap side (See Figure 4).
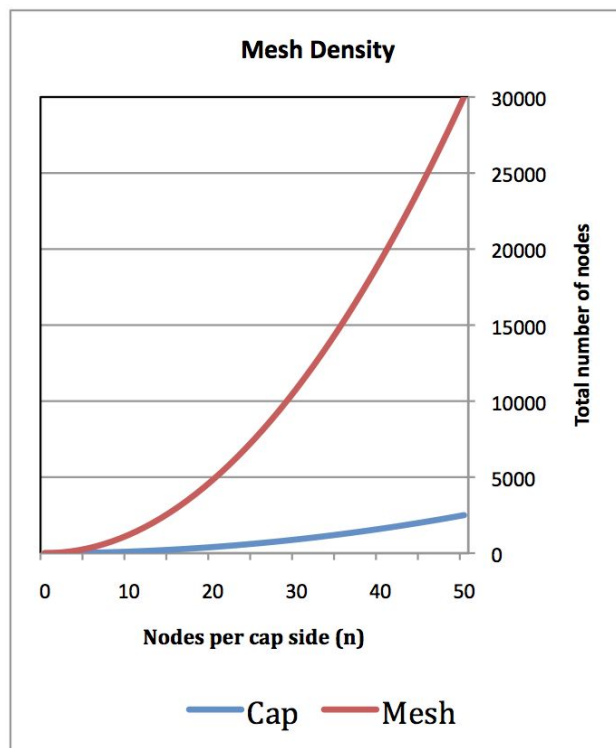
Nodes per cap side	Nodes in One Cap	Total number of Mesh nodes	Increase in global density from 9 X 9 cap
9	81	972	0 %
10	100	1,200	23 %
11	121	1,452	50 %
12	144	1,728	77 %
…	…	…	…
50	2,500	30,000	2990 %

Figure 4: The increase in mesh density follows the square law, meaning that computation time of velocities increases significantly with increasing mesh density

GPlates uses a rotation file to reconstruct geometries through time. The geometry features are a set of intersecting lines, each assigned a Plate ID and thus move according to the information in the rotation file. These geometries can be used to create a set of dynamically-closed plate polygons. The result of this is that the surface of the Earth is split into a discrete number of tectonic plates to cover the temporal span of the plate kinematic model. The velocity of each plate through time will be tracked in GPlates by the mesh files we will create in the next exercise.

At each time interval in GPlates the mesh nodes are assigned Plate IDs according to the plate polygon on which they are located. These velocities can be used as boundary conditions for mantle convection models, including CitcomS and TERRA. In this way GPlates provides a link between plate kinematics and mantle dynamic processes.

In order to generate and export plate velocities through time, GPlates expects a rotation file and a file of dynamically-closing plate polygons, along with our mesh files. The sample data contains all the necessary input files.

GPlates automatically displays the velocity vectors based on the dynamically closing polygon and rotation files. That means your data MUST contain topological polygons created in GPlates with assigned Plate IDs, as it reads the rotation file and calculates velocity vectors on the fly for each mesh node.

Exercise 1 - Generating a Mesh File

GPlates currently supports the generation of global mesh files. These mesh files consist of 12 caps that cover the globe (see CitcomS Mesh Specifications above). Each point in the mesh is a "sampling" location of velocity, for the tectonic plate in which it is located. This is a CitcomS standard.

Ultimately the following steps will allow you to create velocity fields as input for mantle convection modelling in CitcomS. Information can be extracted for other purposes, CitcomS modelling is merely the example used here.

The density of the mesh points can vary, and is dependent on your application. For the purpose of this tutorial, we will use a coarse mesh of 9 X 9 nodes.

1. Open GPlates and load in the following files
   - Caltech_Global_20100713.gpml
   - Caltech_Global_20100713.rot
   - Seton_etal_ESR2012_Coastlines_2012.1.gpmlz

The coastline file has been included so that you can orient yourself on the globe (you may wish to make it invisible later).

2. In GPlates, go to Features > Generate Velocity Domain Points > CitcomS…

3. Our mesh file will have a 9 X 9 nodes resolution, so enter 9 into the 'nodeX' box (9 will automatically be entered in the nodeY box) (Figure 5).
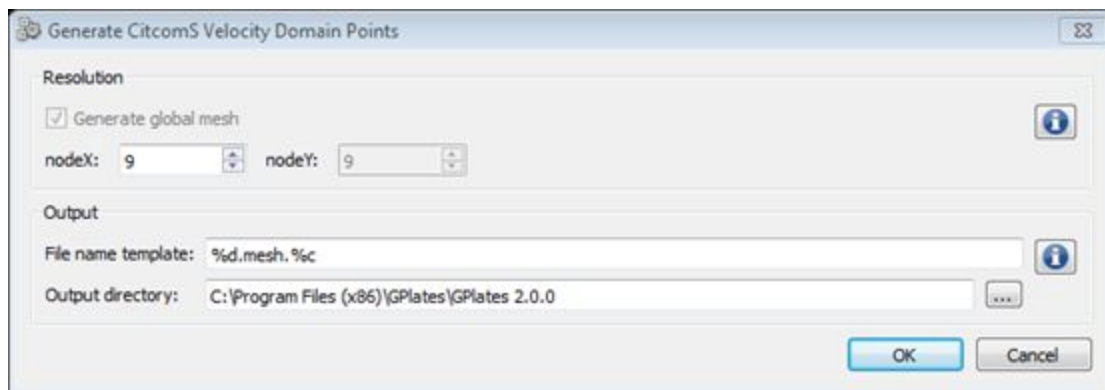

Figure 5: The Generate Mesh Caps window enables you to define the resolution and saving destination of your mesh file.

4. Enter the destination where you would like the save the mesh files (it is suggested that you make a directory called 'Velocity_Tutorial') > Select the Folder and then click OK.

You will now notice that there are arrows all over the globe (Figure 6). 12 mesh files with 9 X 9 nodes have been saved into the directory you specified. These files have also been loaded into GPlates. The files are named 9.mesh.X.gpml, where X is the cap number, ranging from 0-11. You can see that they are loaded by opening the Manage Feature Collections window (File > Manage Feature Collections).

In Figure 6, the pink arrows correspond to the velocity vectors of the Indo-Australian Plate. The velocity vectors indicate both the *magnitude* and *direction* of motion. The plate velocity display is quite useful to assess shortcomings or bugs in plate tectonic models.
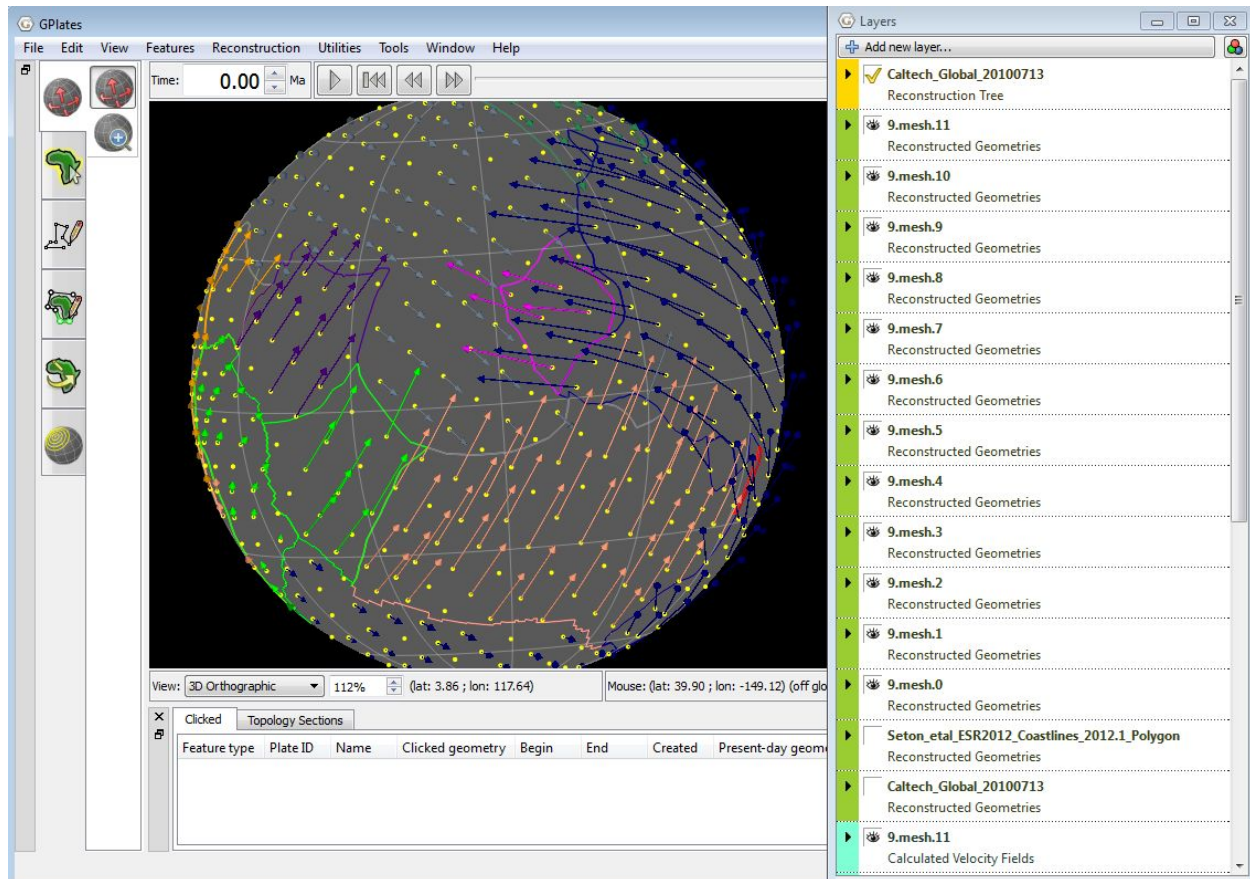
Figure 6: The GPlates globe displaying polygon outlines and velocity vectors.

4. Reconstruct and animate the globe through time and inspect visually how absolute plate velocities change through time.

Exercise 2 - Computing Velocities of Topologies

1. If coming directly from Exercise 1, go File > Manage Feature Collections > eject all the mesh files that were generated. Ensure that you still have the rotation file, coastlines and topologies loaded in.

2. Open the Layers window (Window > Show Layers)

3. At the top of the Layers window, click +Add new layer… > Select the light blue layer (Calculated Velocity Fields)
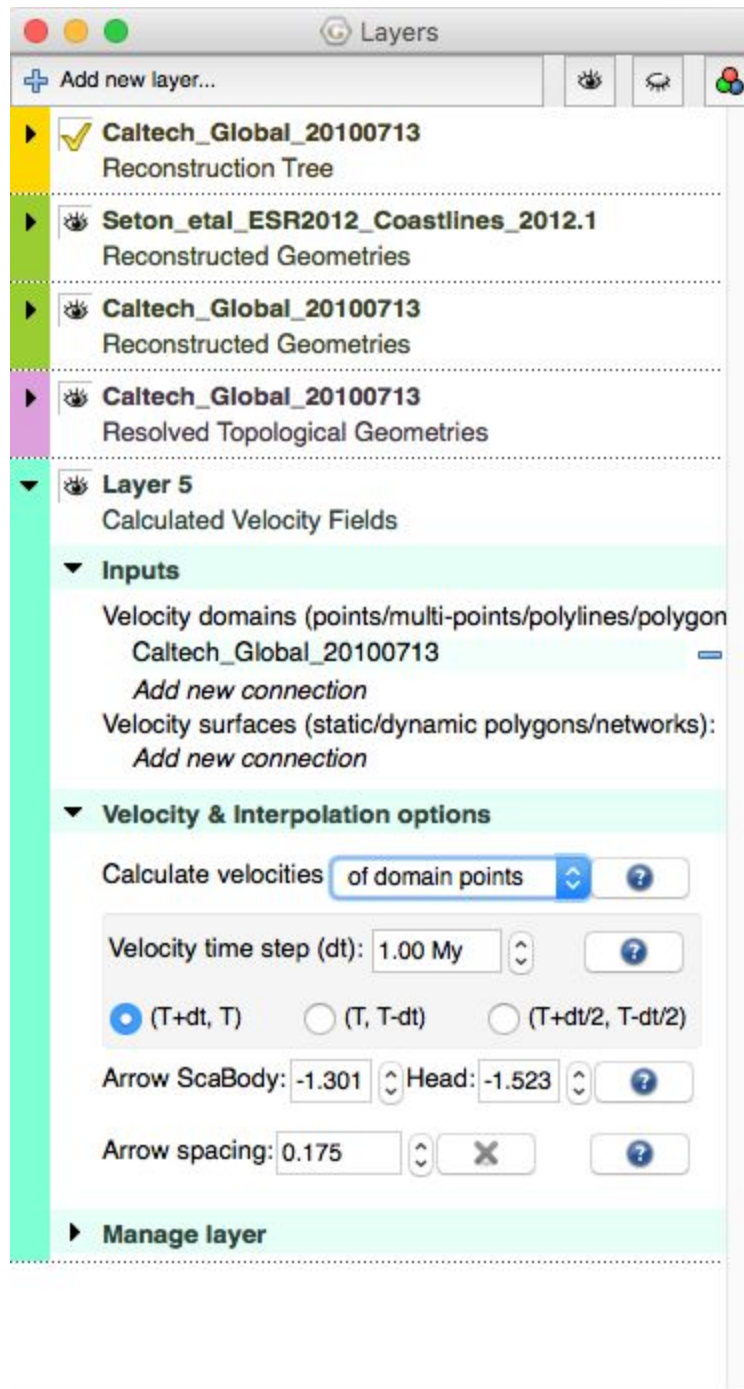
4. Expand the options for the layer (Figure 7)
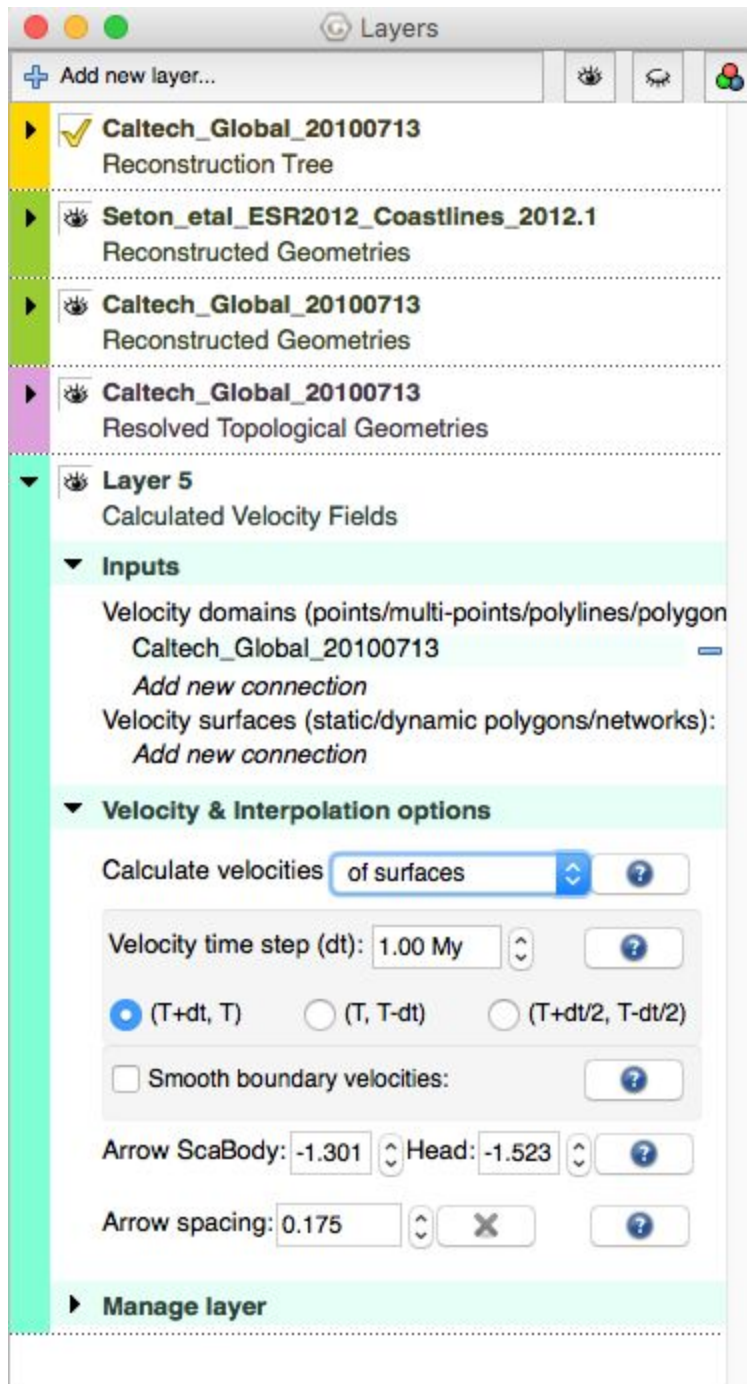
**Figure 7:** Layer options for the new Calculated Velocity Fields layer.

5. Under Inputs > Velocity domains > Add new connection > Caltech_Global_20100713 (Figure 8)

6. Under Velocity & Interpolation options > Calculate velocities > 'of domain points' (Figure 8)

Figure 8: Layer options for the new Calculated Velocity Fields layer.

You should now notice that there are arrows along the topologies that represent the direction and magnitude of their motion (Figure 9).
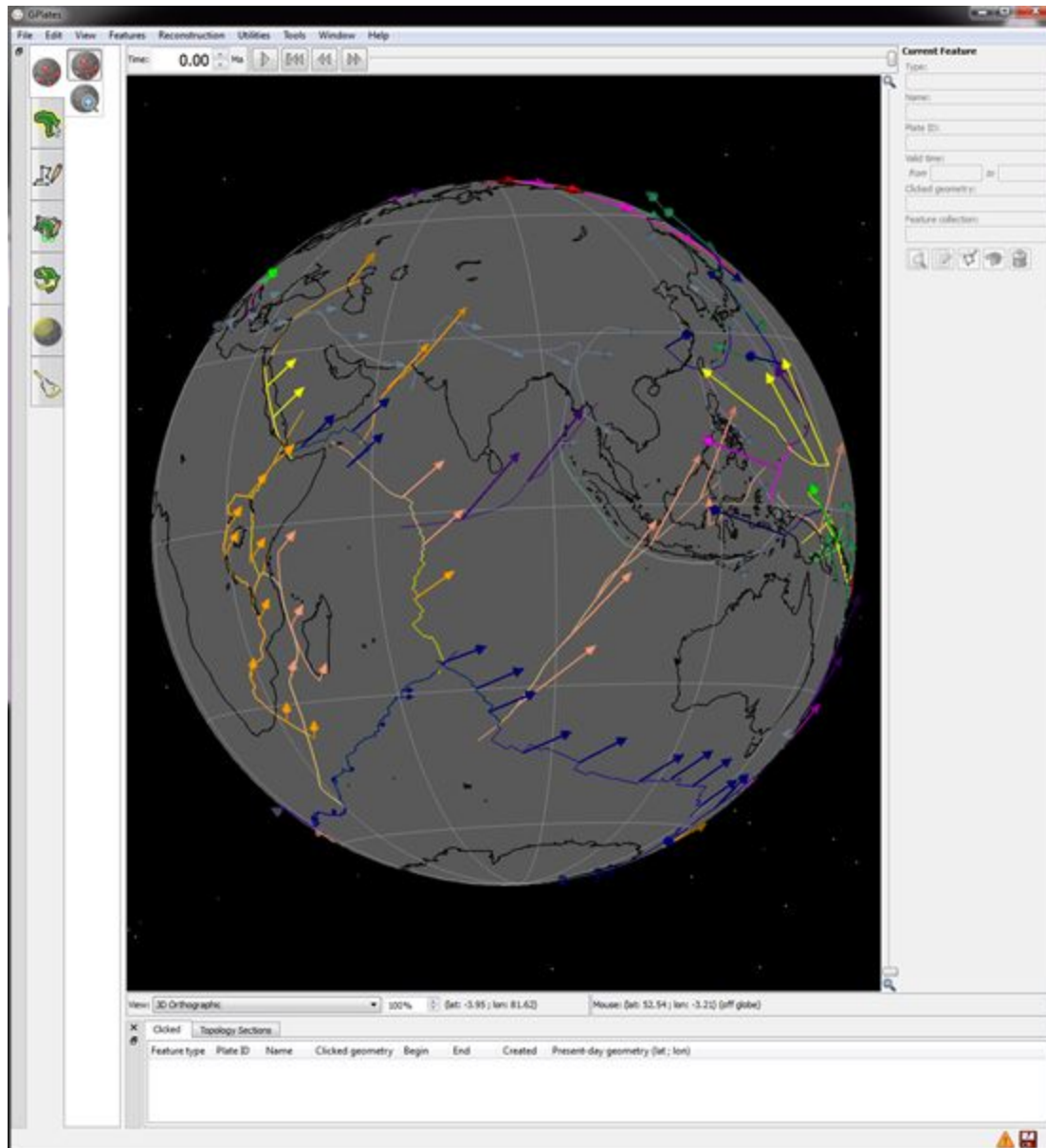
Figure 9: Calculated velocities of topologies.

7. Reconstruct back to 50 Ma and play the animation forward. Look at how the velocities of the topologies change in direction and magnitude through time.

Exercise 3 - Computing Velocities of Deforming Regions

We looked at deforming networks in Tutorial 9.4 and now we will look at how to compute velocities for points within the network.

1. File > Clear Session (if coming from Exercise 2)

2. File > Open Project > Load in the file Velocity_Deforming.gproj

3. Change the reconstruction time to 120 Ma and rotate the globe to the North Atlantic area (Figure 10).
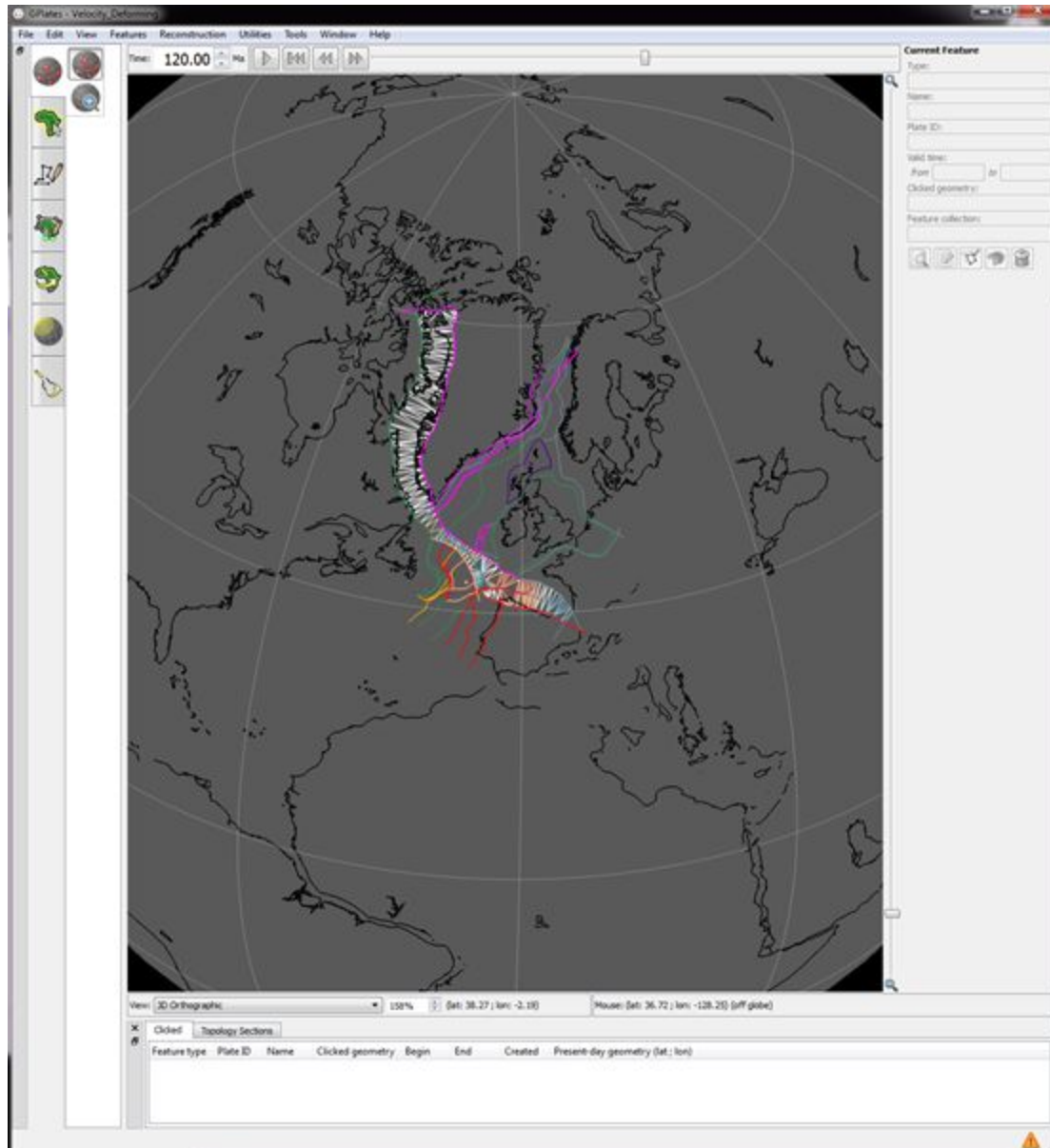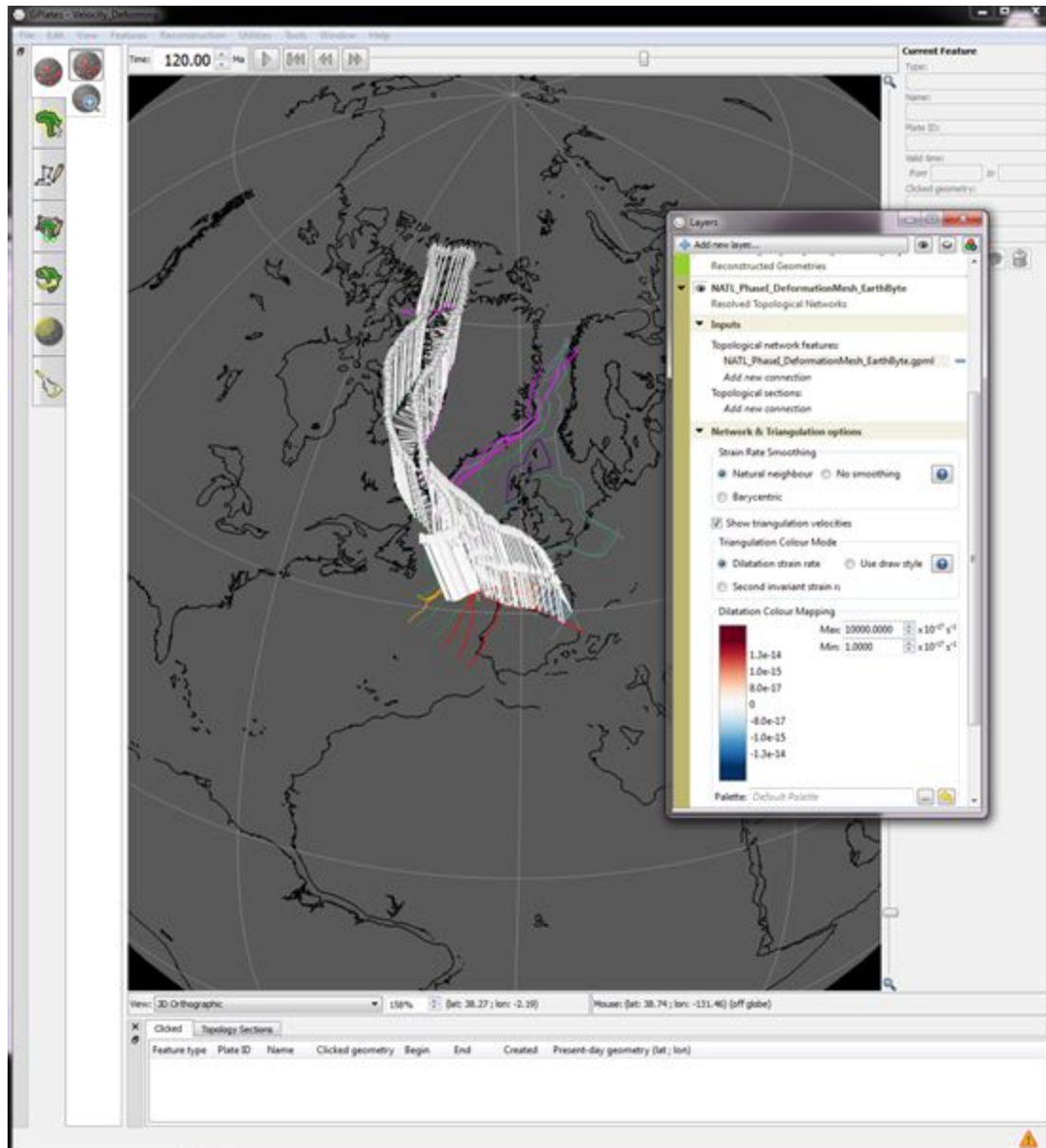

Figure 10: North Atlantic Deforming Region

You will notice that the area is filled in with a triangulation, and is coloured white (no strain), red (extension) and blue (compression).

4. Open the Layers window (Window > Show Layers if not already open) and expand the options for the gold layer (Resolved Topological Networks).

5. Under Network & Triangulation options > Tick Show triangulation velocities (Figure 11)

You should now have white arrows appearing along the boundary of the deforming region, which are proportional to the magnitude of motion, and show the direction of motion of the boundary of the deforming region (Figure 11).

Figure 11: White arrows show velocity (both magnitude and direction) of boundary of deforming region in North Atlantic

6. Play the animation from 120-62 Ma to see how the velocity of the deforming region changes.

7. Untick the 'Show triangulation velocities' box

We will now compute the velocities for the inside of the deforming region. To do this, we must generate points within the deforming region - we will do this the same way that we generated crustal thickness points in Tutorial 9.4.

8. Ensure the reconstruction time is 120 Ma.

9. Select the deforming network using the Feature Inspection Tool

10. Features > Generate Crustal Thickness Points

11. Specify (Figure 12):

- Density level = 8
- Begin time = 120 Ma
- End time = 62 Ma
- Name = whatever you choose (eg. NATL_points)

Figure 12: Generating crustal thickness points

12. Click Next > Create a new feature collection > Create

13. Expand the options of the new green (Reconstructed Geometries Layer) and under Inputs > Topology Surfaces > Add new connection > Select the gold layer (NATL_PhaseI_DeformationMesh_EarthByte)

14. Under Reconstruction options > Reconstruct using topologies > select Yes (Figure 13)
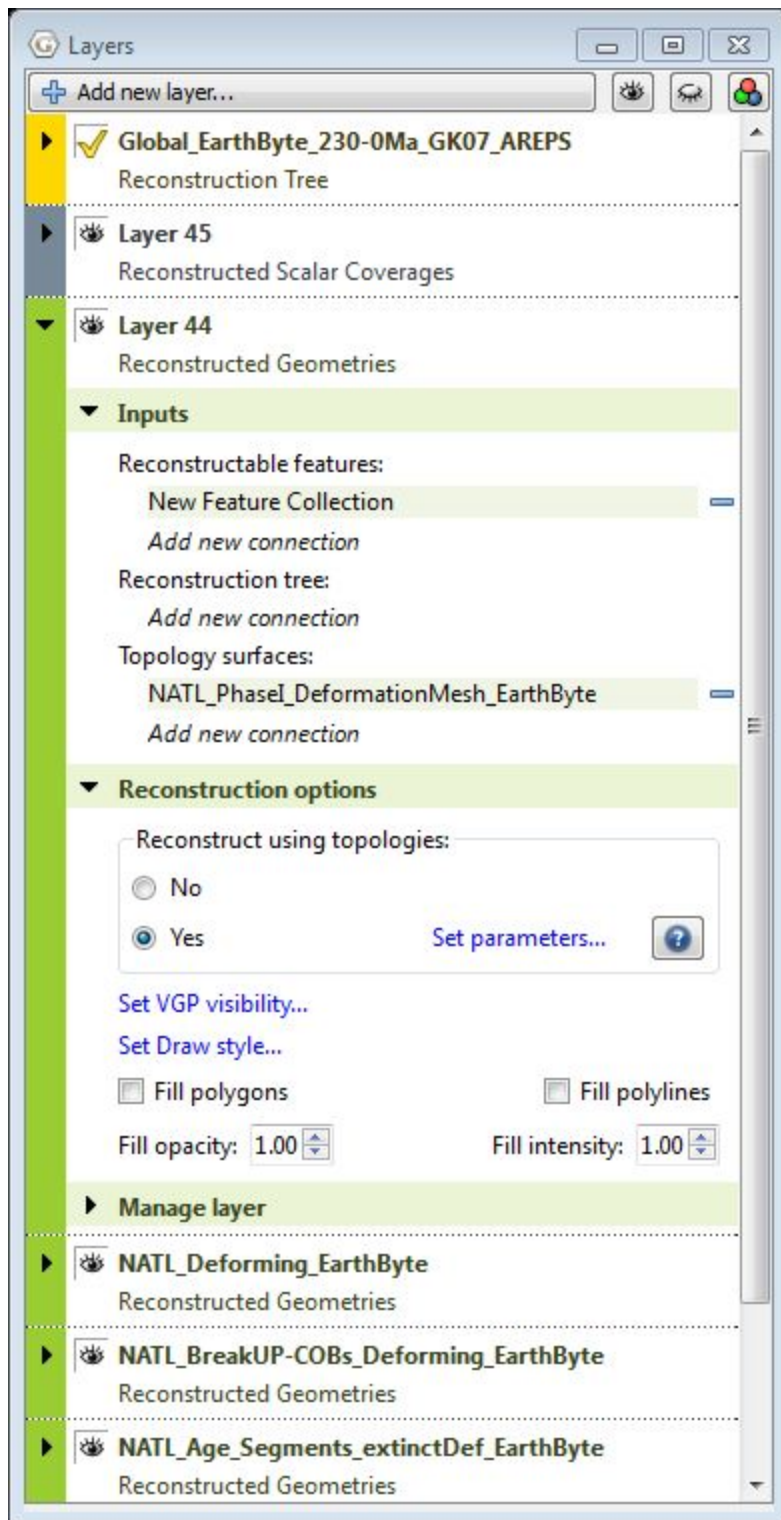

Figure 13: Layer window showing options for newly generated crustal thickness points

15. In the new window, specify the youngest and oldest age (120 & 62 Ma respectively) > OK

16. File > Manage Feature Collections > Save your new feature collection (possibly as 'NATL_deform_points')

17. At the top of the Layers window, select +Add new layer… and select the light blue layer (Calculated Velocity Fields)

18. Expand the options and under Inputs > Velocity domains > Add new connection > select your new layer (whatever you called it in Step 15).

19. Under Inputs > Velocity surfaces > Add new connection > select the gold topological network layer (NATL_PhaseI_DeformationMesh_EarthByte) (Figure 14)
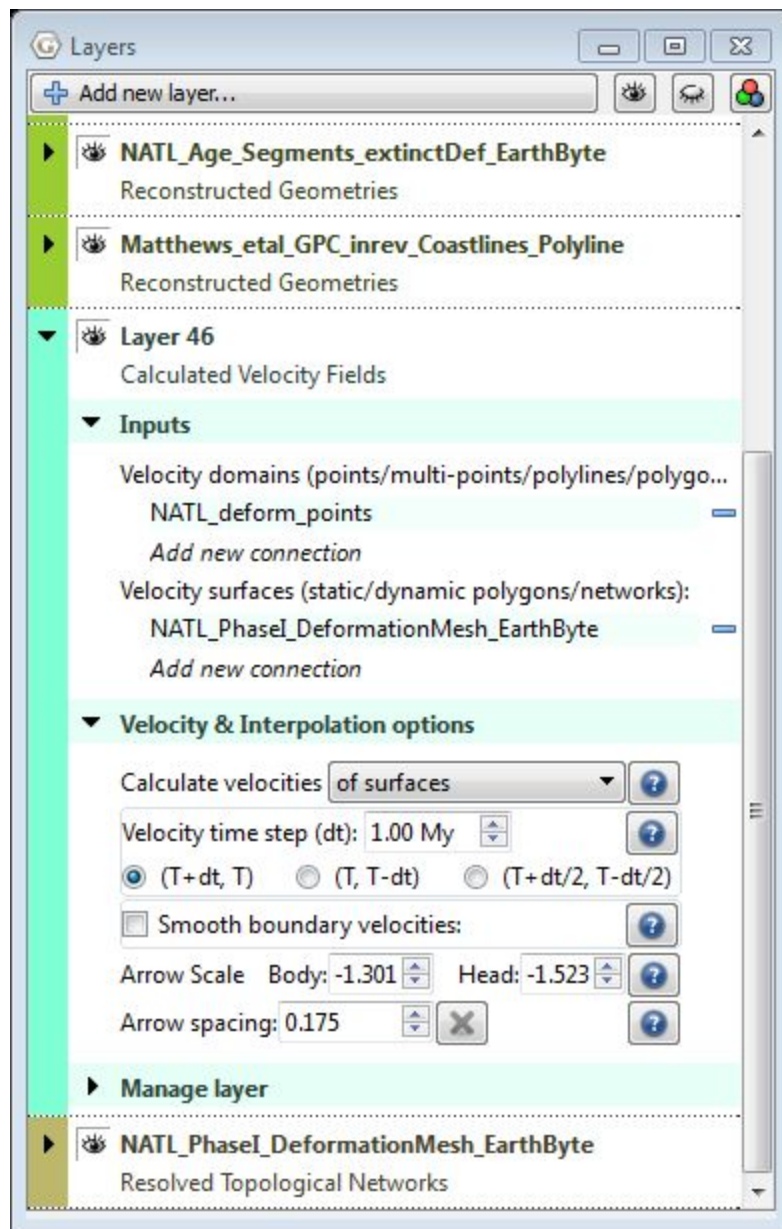
Figure 14: Options for generating velocity domain points

You should now have some black arrows appear within your deforming network (Figure 15).
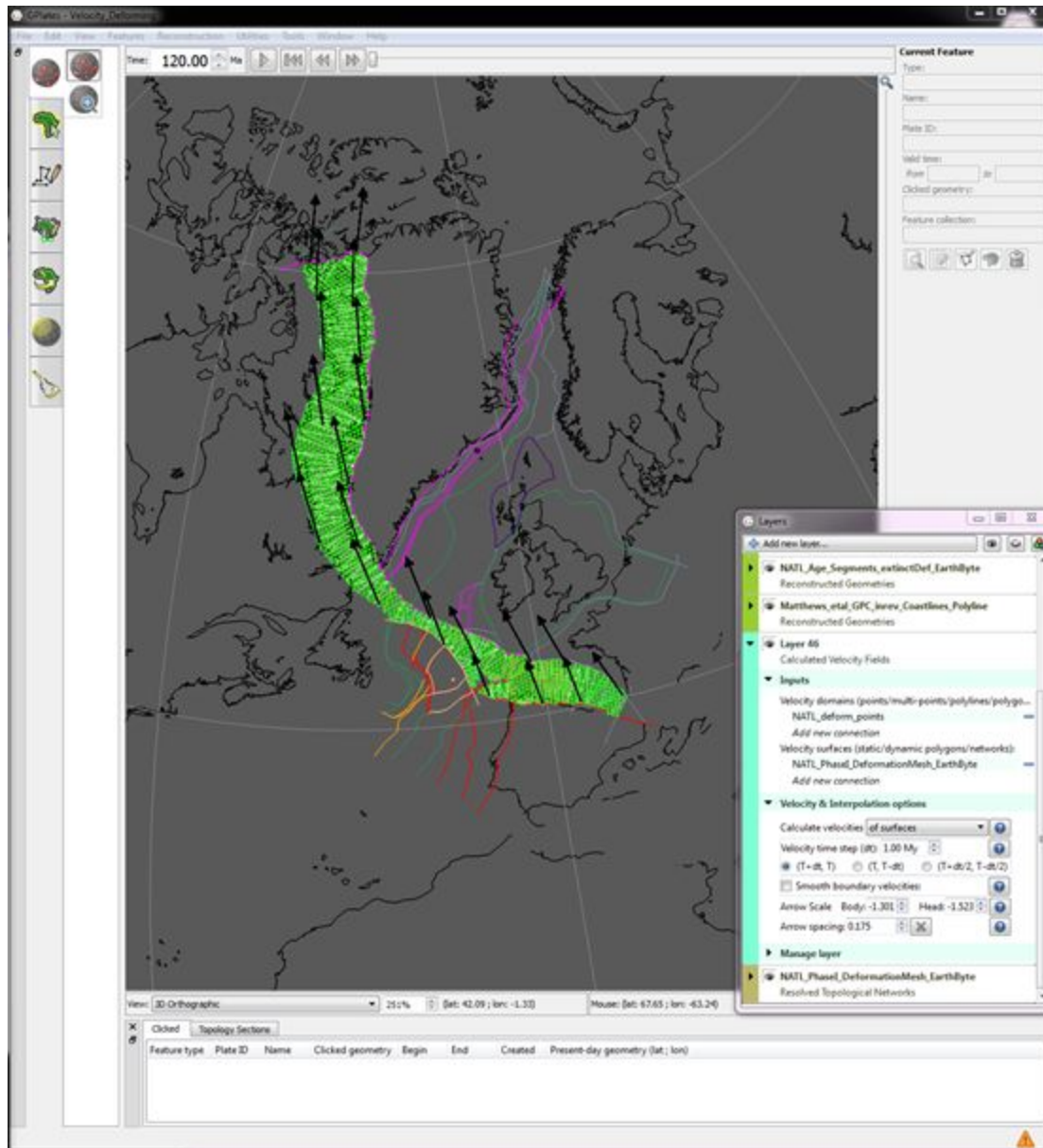
Figure 15: Velocity arrows within the deforming network

Notice that the coverage of the arrows is rather sparse.

20. Zoom in to the network and notice that more arrows begin to appear. This is because the arrow spacing is at 0.175 (default) (under Velocity & Interpolation options - Figure 14).

21. Click the X next to the arrow spacing box so that the spacing is 'Not limited' and notice that all our points now have arrows on them showing their velocity (Figure 16)
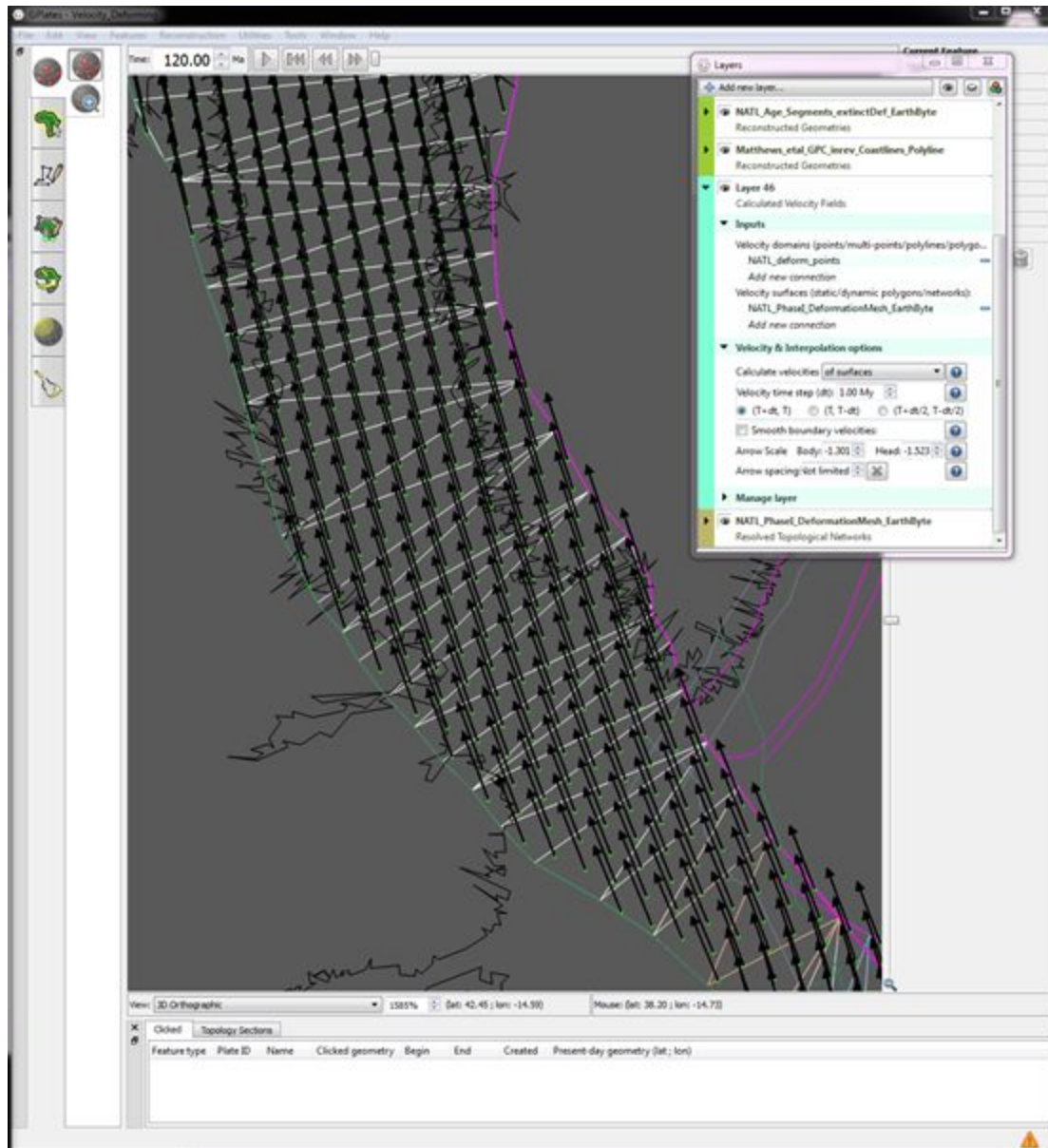
Figure 16: Velocity of each crustal thickness point

22. Zoom out and see that this dense coverage of arrows is not ideal.

23. Have a play around with the spacing of the arrows to find something that is more appropriate (starting at 0.175 is a good starting point).

Exercise 4 - Exporting Velocities

GPlates can export animations in a number of formats. For the purposes of creating velocity fields, only one is of interest to us. The output files generated will be in plain ASCII (GMT xy) format)

We will export the velocities we generated in the deforming region (from Exercise 3) however this can be applied to any velocities that have been calculated.

1. Reconstruction > Export…

2. We will export velocities from 120 -100 Ma to present-day, with an increment of 1 Myr per frame - change the animate from and to times at the top of the window (Figure 17)
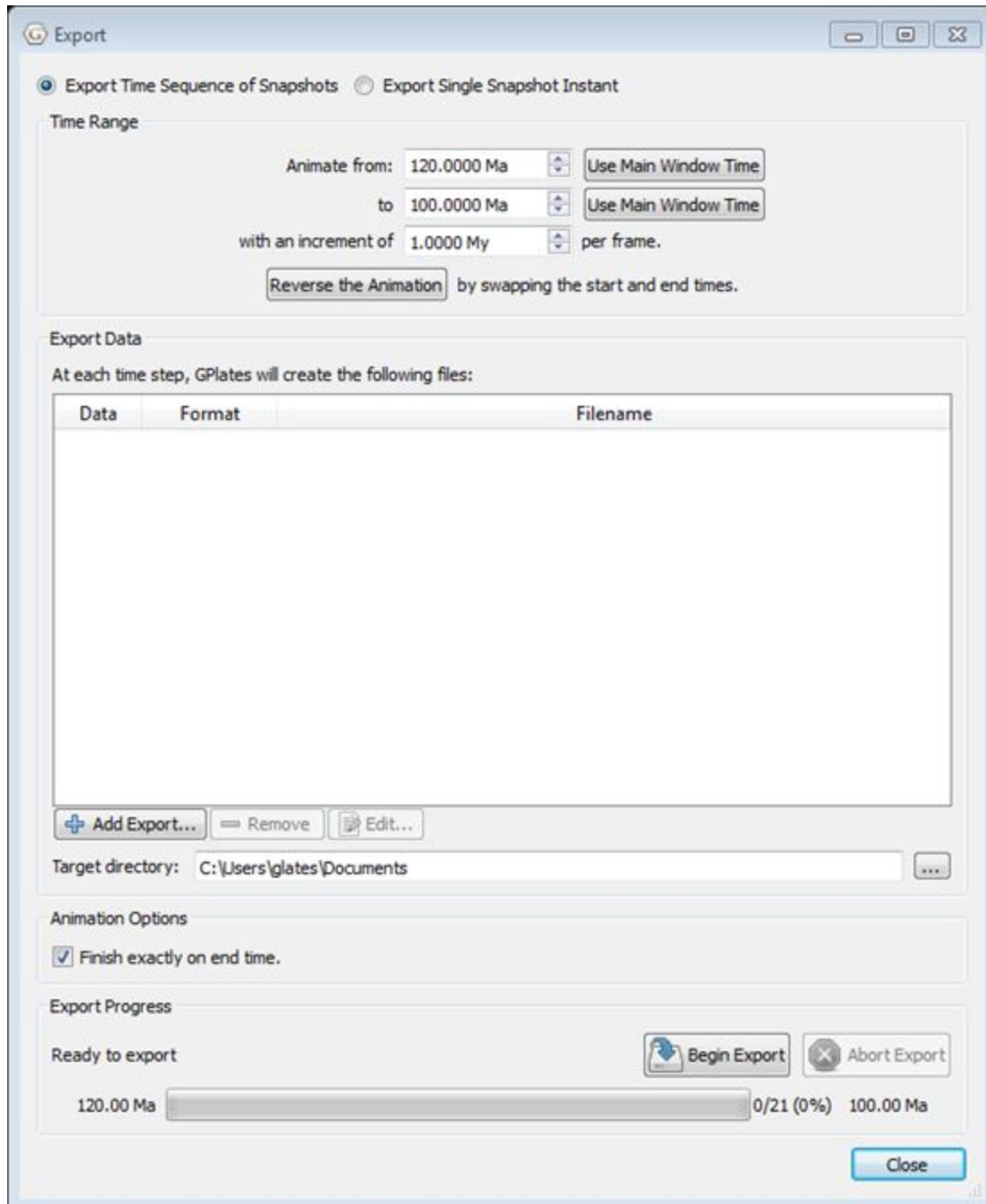
Figure 17: Export window showing correct export times

3. We must now specify what files we wish GPlates to generate > click Add Export....

4. In the 'Add Data to Export' window select Velocities and then the GMT (*.xy) format (Figure 18). Select the following: Export to a single file (deselect the Export to multiple files) and choose Magnitude / Azimuth (0 to

360 degrees clockwise from North). Click OK (the Add Data to Export window should close automatically).
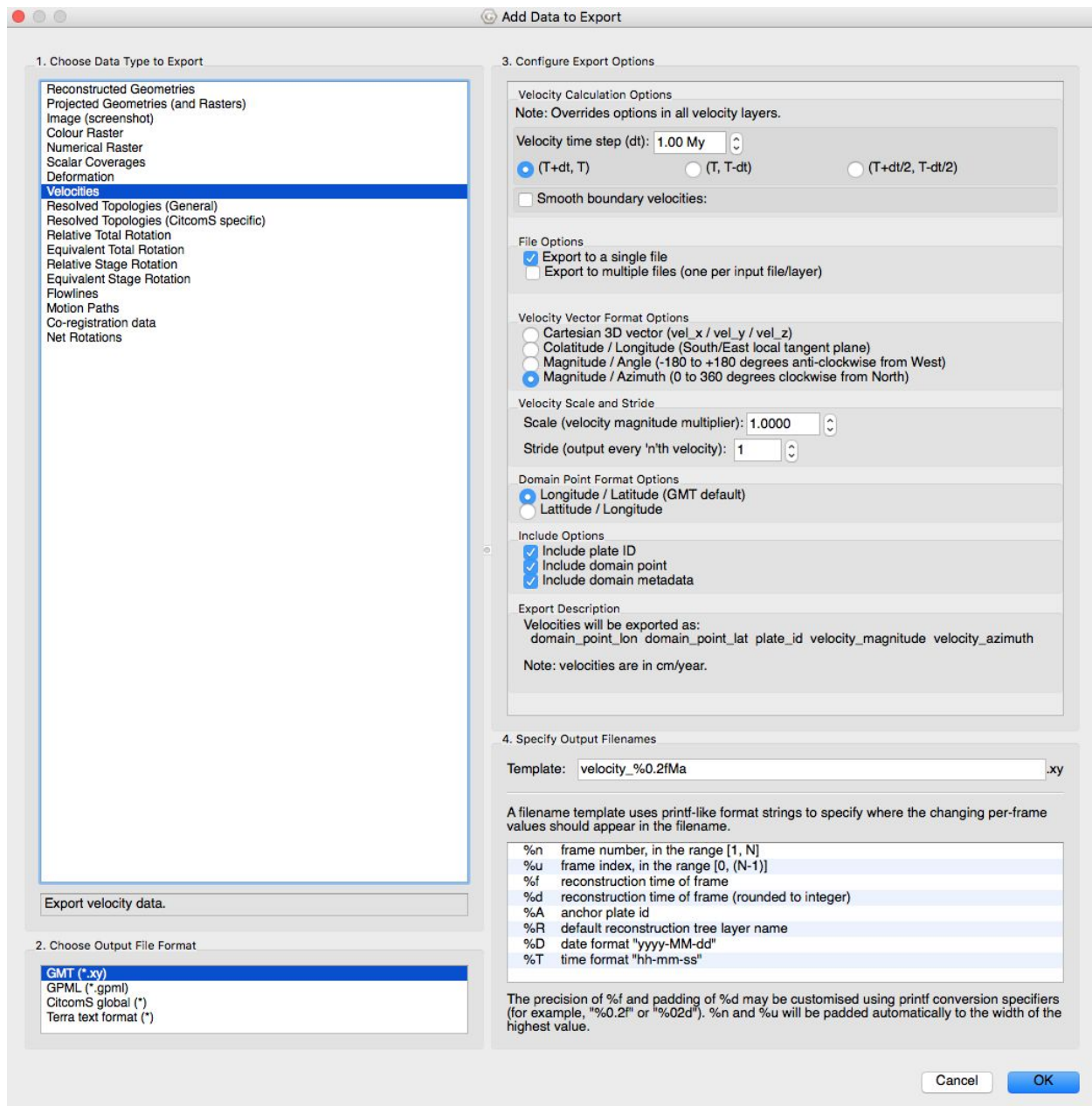
Figure 18: The Add Export window enables you to choose which files GPlates will generate for your time interval.

5. Choose the target directory where the output will be created and then click Begin Animation. The files will now be generated. To save time we have only selected 20 Myr of velocities to export.

The velocity files are now saved in your selected target directory. A velocity file is generated for every point, every 1 Myr (as this was the interval

chosen). The file will contain multiple columns, including Longitude, Latitude, Plate ID, Azimuth (clockwise from North) and the Speed (cm/yr) for these export options.

For more detailed information about calculating velocities, see Tutorial 5.3 or the GPlates User Manual

References

Barnett-Moore, N., Müller, R., Williams, S., Skogseid, J., and Seton, M., 2016, A reconstruction of the North Atlantic since the earliest Jurassic: Basin Research.

Müller, R.D., Royer, J.-Y. and Lawver, L.A., 1993. Revised plate motions relative to the hotspots from combined Atlantic and Indian Ocean hotspot tracks. Geology, 16: 275-278.

O'Neill, C., Müller, R.D. and Steinberger, B., 2005. On the uncertainties in hotspot reconstructions, and the significance of moving hotspot reference frames. Geochemistry, Geophysics, Geosystems, 6, Q04003, doi:10.1029/2004GC000784, 1-35.

Gurnis, M., Turner, M., Zahirovic, S., DiCaprio, L., Spasojevic, S., Müller, R., Boyden, J., Seton, M., Manea, V., and Bower, D., 2012, Plate Tectonic Reconstructions with Continuously Closing Plates, Computers & Geosciences, 38(1): 35-42, doi:10.1016/j.cageo.2011.04.014.