MaRGEE: Move and Rotate Google Earth Elements

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Abstract

Google Earth is recognized as a highly effective visualization tool for geospatial information. However, there remain serious limitations that have hindered its acceptance as a tool for research and education in the geosciences. One significant limitation is the inability to translate or rotate geometrical elements on the Google Earth virtual globe. Here we present a new JavaScript web application to “Move and Rotate Google Earth Elements” (MaRGEE). MaRGEE includes tools to simplify, translate, and rotate elements, add intermediate steps to a transposition, and batch process multiple transpositions. The transposition algorithm uses spherical geometry calculations, such as the haversine formula, to accurately reposition groups of points, paths, and polygons on the Google Earth globe without distortion. Due to the imminent deprecation of the Google Earth API and browser plugin, MaRGEE uses a Google Maps interface to facilitate and illustrate the transpositions. However, the inherent spatial distortions that result from the Google Maps Web Mercator projection are not apparent once the transposed elements are saved as a KML file and opened in Google Earth. Potential applications of the MaRGEE toolkit include tectonic reconstructions, the movements of glaciers or thrust sheets, and time-based animations of other large- and small-scale geologic processes.

Introduction

In the years since its debut in 2005, the Google Earth virtual globe has become a highly effective visualization tool for geospatial information (Butler, 2006; Bailey and Chen, 2011). The initial wonder and awe of members of the general public at the ease with which they could fly to any place on the globe and view detailed imagery of the ground surface has been supplanted by its ubiquitous use as a geobrowser of Earth imagery and data. By integrating Keyhole Markup Language (KML), now an OpenGIS scripting language, within the Google Earth platform the utility of Google Earth was greatly expanded beyond just passive viewing of the modern-day Earth surface (Ballagh et al., 2011). Geoscientists and others have the means to display original data and models within a user-friendly, 3D virtual globe interface. Introduction of the TimeSpan feature further expanded the features of Google Earth to allow geoscientists to incorporate the 4th dimension of time within Google

Earthvisualizations. In many aspects, Google Earth has become the preeminent way to display 4D geoscientific and environmental information.

Unfortunately, there remain several limitations in Google Earth that have restricted its full potential as a research and educational tool. Many of these limitations have been previously documented in publications that describe workaround solutions (De Paor and Whitmeyer, 2011; Blenkinsop, 2012, Zhu et al., 2014b). Examples include Screen Overlays that must be coded outside of the Google Earth application (e.g. Whitmeyer, 2010; Dordevic, 2012), 3D COLLADA models that can be positioned on the Google Earth terrain, but must be created by an external application such as SketchUp (De Paor and Pinan-Llamas, 2006; De Paor and Williams, 2006; Dordevic et al., 2010; De Paor and Whitmeyer, 2011; Mochales and Blenkinsop, 2014), and an opaque ground surface that makes displaying and visualizing subsurface data and models challenging (De Paor et al., 2008; Whitmeyer and De Paor, 2008).

Perhaps the most significant limitation of Google Earth from a process-focused science perspective is the inability to transpose (translate, rotate) Google Earth elements, such as lines (paths), polygons, or groups of placemarks. This limitation makes it extremely difficult to show dynamic natural processes, as the creator of a visualization has to draft each incremental position of an element individually. Our initial solution to this problem used a command-line PERL script to load a KML file with geometrical components that the visualization creator wanted to translate or rotate (Whitmeyer and Patterson, 2013). Initially our application focused on local or regional transformations, and therefore didn't address aerial distortions of polygons or line elements that would occur when translating across multiple degrees of latitude (e.g. the methodology of Zhu et al., 2014a). However, as the focus of our Google Earth visualizations expanded to include movements and processes through geologic timescales (thousands to millions of years) it became apparent that our transposition algorithm needed to be based on spherical geometry to preserve the shapes and spatial relationships of Google Earth geometry elements across multiple degrees of latitude and longitude (e.g. De Paor, 1996).

Details of how geometry elements are represented in KML and processed in Google Earth have been documented elsewhere (Wernecke, 2009; Zhu et al., 2014a) and don't warrant reiteration here. In the sections that follow we focus on relevant KML file structures, the importance of using spherical geometry to transpose Google Earth geometry elements, and the algorithms we use to accomplish spherical transpositions. This is followed by a description of the JavaScript web application: "Move and Rotate Google Earth Elements" (MaRGEE): <http://geode.net/margee/>. A github link to code for the files used in the MaRGEE web application and an example KML file that was produced using MaRGEE and the methods described below are included in Appendix A.

KML Structure

MaRGEE functions by loading a KML or standard KMZ (zipped KML package) file that contains the Google Earth geometry elements (points, paths, polygons) to be transposed or edited (Fig. 1). The primitive KML geometry types (Google, 2013a; Fig. 2) that MaRGEE can handle are KmlPoint, KmlLineString (path) and

KmlPolygon(polygon), as these proved to be most relevant in global-scale transpositions of Google Earth elements.

Paths are rendered in Google Earth as segments of a great circle. However, polygons are rendered in Google Earth by connecting individual coordinates, such that lines of constant bearing result in visually 'deformed' polygons near the poles (Fig. 3). By changing the KmlAltitudeMode in the polygon style element to something other than "Clamped..." polygons are rendered in the same manner as Paths. The same effect can be achieved by changing the polygon fill mode to "outline": KmlPolyStyle.setFill(0).

Other geometry types (KmlModel, KmlGroundOverlay, KmlMultiGeometry) were excluded from our implementation. KmlModel is used to display COLLADA models in Google Earth. It is anchored with a single coordinate (KmlLocation), scale (KmlScale) and model orientation (KmlOrientation). KmlGroundOverlay is positioned using KmlLatLonBox and is not particularly useful for rotation as it is bounded by lines of constant bearing. KmlMultiGeometry could be useful, as it represents all of the above as a collection of primitive geometries. However, it cannot be created directly in the Google Earth application, which significantly diminishes its usability in creating polygons and other KML elements.

MaRGEE can read and write to KML and KMZ filetypes (Google, 2013b). A KMZ file is a Zip archive that contains a KML document (doc.kml) and all of the affiliated resources (imagery, COLLADA models, sound files, etc.) in an associated files folder. Users can browse local file structures and choose a file to manipulate, or load files located on publicly accessible servers. The third party library used for file manipulation [FileSaver.js](#) caps the file size for uploads to 300MB. This KML file size would be equivalent to a single polygon containing about 8 million points.

Once a KML file is loaded and read by the browser as a text string (Mozilla, 2014), it is parsed using `ge.parseKml` (KMLString). This returns a KMLObject, which is used in subsequent operations. To allow users to choose which Google Earth elements will be subjected to manipulation, MaRGEE creates a list of KML elements similar to the "Places" menu in the stand-alone Google Earth application (upper left of Fig. 1).

Calculations

Operations that are possible in MaRGEE are: rotation, translation, inverse rotation, simplification, and editing of elements. In addition it is possible to create intermediary steps in a specified rotation or translation (Fig. 4), as well as assign a TimeSpan (KmlTimeSpan) to each step to facilitate time-based animation.

Our approach to transposing Google Earth elements uses spherical geometry, specifically the haversine (half-versed-sine) formula, as commonly used by navigators and astronomers (Sinnott, 1984). Rotation is calculated using the following sequence of formulas, where θ represents a clockwise rotation (in radians), G is a geometry containing n points (P_i), and E (λ_E, φ_E) is the pole of rotation (Euler

pole)with coordinates λ_i, φ_i (longitude and latitude in radians). The firststep is to calculate angular distance $c_i = |P_i E|$:

$$c_i = 2 \operatorname{atan2}(\sqrt{a_i}, \sqrt{1 - a_i})$$

$$\text{where } \operatorname{atan2}(x, y) = \frac{-x + \sqrt{x^2 + y^2}}{y}$$

$$\text{and } a_i = \sin^2\left(\frac{\Delta\varphi}{2}\right) + \cos\varphi_E \cos\varphi_i \sin^2\left(\frac{\Delta\lambda}{2}\right)$$

The next step is to find constant bearing ρ_i between points E and P_i :

$$\rho_i = \operatorname{atan2}(\sin(\Delta\lambda)\cos\varphi_i, \cos\varphi_E \sin\varphi_i - \sin\varphi_E \cos\varphi_i \cos(\Delta\lambda))$$

Finally, we find the coordinates of the destination point P_i' given a starting point E , a distance c_i and a bearing $\theta + \rho_i$:

$$\varphi_i' = \arcsin(\sin\varphi_E \cos c_i + \cos\varphi_E \sin c_i \cos(\theta + \rho_i))$$

$$\lambda_i' = \lambda_i + \operatorname{atan2}(\sin(\theta + \rho_i)\sin c_i \cos\varphi_E, \cos(\theta + \rho_i) - \sin\varphi_E \sin\varphi_i')$$

This procedure, when iterated over all n points, will produce a rotated geometry G' .

Translation performed on a sphere can be represented by a rotation around a particular Euler pole. To translate geometry G an angular distance d along a bearing θ we first determine the destination point E that is π radians away from P_i along a bearing of $\theta + \pi/2$. Then, we perform a rotation, as described above, of point P_i around E for d radians. The JavaScript implementation used for the transposition of coordinates in both the rotation and translation functions is from the thirdparty library: [geo.js](#) (Veness, 2014).

Determining the Euler Pole and Angle of Rotation for a Transposition

The `Interpolate Rotation Parameters` function gives the location of the Euler pole E and the angle of rotation θ if two geometries G and G' are provided, where the geometries contain at least two analogous points. In other words, given two locations of the same polygon, the interpolation function finds the Euler pole and angle of rotation that would enable the transposition between the starting and ending locations. The first step is to find midpoint pairs M_i along $P_i P_i'$ and M_j along $P_j P_j'$. Next, we find the bearings θ_i for $P_i M_i$ and θ_j for $P_j M_j$, and then calculate the intersection point E between the two great circles defined with starting point M_i, M_j and bearings $\theta_i + \pi/2, \theta_j + \pi/2$. The angular distance $P_i P_i'$ is the angle of rotation θ . As there are two possible solutions for the pole, E and antipodal E'' there are also

174 two possible angles of rotation. Our convention is that the first geometry *G* is the
175 geometry prior to transformation, and the second geometry selected (*G'*) is post
176 rotation. Thus, the first solution presented is the counter-clockwise rotation,
177 followed by the clockwise rotation solution. Our JavaScript routine for the
178 Interpolate Rotation Parameters function is as follows:

```
179  
180     function findEuler ( selectedGeometriesArray ) {  
181     if ( selectedGeometriesArray.length !== 2 ) {  
182         return alert("You have to select two and only two geometries.");  
183     }  
184     var e1 = selectedGeometriesArray[ 0 ];  
185     var e2 = selectedGeometriesArray[ 1 ];  
186     if ( e1.type !== e2.type ) {  
187         return alert("You have to select two geometries of the same type.");  
188     }  
189     var e1Cor = getLatLngArray( e1 );  
190     var e2Cor = getLatLngArray( e2 );  
191     var ln = e1Cor.length;  
192     if ( ln !== e2Cor.length ) {  
193         return alert("Selected features do not match in number of points");  
194     }  
195     if ( ln < 3 ) {  
196         return alert("A polygon/path with at least 3 points needs to be  
197         selected");  
198     }  
199     var v1Start = LatLonV.set( e1Cor[0] );  
200     var v1End = LatLonV.set( e2Cor[0] );  
201     var v2Start = LatLonV.set( e1Cor[3] );  
202     var v2End = LatLonV.set( e2Cor[3] );  
203     var v2Midpoint = v2Start.midpointTo( v2End );  
204     var v2Bearing = v2Midpoint.bearingTo( v2End );  
205     var v1Midpoint = v1Start.midpointTo( v1End );  
206     var v1Bearing = v1Midpoint.bearingTo( v1End );  
207     var solution1 = LatLonV.intersection( v1Midpoint, v1Bearing + 90,  
208     v2Midpoint, v2Bearing + 90 );  
209     var solution2 = LatLonV( -solution1.lat, ( solution1.lon + 360 + 180 ) % 360 );  
210     if ( solution2.lon > 180 ) {  
211         solution2.lon = solution2.lon - 360;  
212     }  
213     var angleOfRotation = solution1.bearingTo( v1Start ) - solution1.bearingTo(  
214     v1End );  
215     solution1.az = angleOfRotation;  
216     solution2.az = -angleOfRotation;  
217     return {  
218         sol1 : solution1,  
219         sol2 : solution2
```

```
220     };
221     }
```

222

223 Note that we check to see that the user has selected two elements (geometries) and
224 that the elements have the same number of vertices (points). This is to verify that
225 the two elements are, in fact, a single element in its original and transposed
226 positions.

227

228 *Simplification of Paths and Polygon Outlines*

229 The simplification routine is included within MaRGEE in order to reduce calculation
230 times for transposing elements and improve the smoothness of time-based
231 visualizations of elements in Google Earth. Early versions of MaRGEE showed that
232 detailed polygons with thousands of points took several seconds to transpose. If the
233 Google Earth viewpoint is at a distance where the full globe is visible, most polygons
234 don't need to be more detailed than a few hundred points, and this routine
235 automates the process of simplifying the polygons without significantly changing
236 the apparent resolution of the element. The simplification routine reduces the
237 number of points in a geometry based upon the parameter ϵ used in the Stack-based
238 line simplification routine of Douglas and Peucker (1973). It recursively splits a
239 geometry starting from the ends, finding the furthest point from a line connecting
240 start and end points. If this distance is smaller than ϵ , the point is discarded.
241 Otherwise, the whole process repeats until sub geometries become lines. The
242 JavaScript routine for simplification is derived from the third party library:
243 [douglas_peucker_line_simplification.js](#) (Robinson, 2010).

244

245 **Web Interface and Workflow**

246 The MaRGEE web interface is divided into three sections: the main window that
247 shows the Google Earth virtual globe, a panel of tools on the left, and several drop
248 down menus at the top (Fig. 1). The tools panel is subdivided into nine collapsible
249 subsections, where clicking on the minus icon will expand or collapse the subsection
250 content. The subsections include: KML list, Simplify, Translate, Rotate, Intermediate
251 Steps, and Batch Processing (see Figs. 1, 4, 6). The top panel includes the dropdown
252 menus: File (upload and download KML and KMZ files), Edit (Undo and Redo
253 options), Map Options (toggle visibility of a latitude / longitude grid), Tools
254 (includes a tool to Interpolate Rotation Parameters – i.e. find the pole of rotation for
255 a transposed polygon), and View Panels (make hidden tools panels reappear); see
256 Table 1.

257

258 The first step in operating MaRGEE is to load a KML file that contains Google Earth
259 elements (points, lines, polygons) to be transposed. This can be done by simply
260 dragging and dropping a KML file at any place in the MaRGEE window, or by clicking
261 the File dropdown menu and browsing for the desired KML or KMZ file. The File
262 menu is also where you select the option to save your transposed elements as KML
263 or KMZ files.

264

Once a KML or KMZ file is loaded, its content is listed in the KML List section in the tools panel along the right side of the MaRGEE window. Each KML element within the file will be listed by name, as derived from the <name> associated with each <Placemark> header. Here you can select individual KML elements or groups of KML elements to manipulate by lassoing a sequential group or clicking on individual elements while holding Ctrl/Command. Selected elements and their intermediate steps can also be deleted by clicking the trashcan icon, or hidden from view by clicking the “eye”

As described above, the Simplify tool smooths the path or polygon outline and reduces the number of vertices in selected KML elements. This is useful when a given polygon has thousands of vertices, but will typically be viewed from a global viewpoint. An example of this is India, as shown in Fig. 1.

The Translate tool moves selected KML elements by allowing users to set the initial heading of translation in decimal degrees measured in a clockwise direction from north (0 degrees), and the distance of the translation in km. Alternatively, the user can drag the red and white bullseye marker to a new location on the map, and the initial heading and distance will be shown in their respective fields. Clicking the Translate button will then move the element(s).

Rotation is performed in similar manner to translation. Once KML elements are selected, the user enters an Euler pole latitude and longitude in decimal degrees, followed by the angle of rotation in degrees (clockwise is positive). Location of the Euler pole can be manually positioned by dragging the rotation marker (red circle with arrows) on the map. Note that a user can calculate the position of an Euler pole and the angle of rotation if two elements are selected that are the result of one consecutive rotation. This is accomplished by clicking Interpolate Rotation Parameters in the Tools dropdown menu. Two antipodal solutions will appear at the top of the Rotate subsection.

When building animations of KML elements that move through time (e.g. tectonic reconstructions) we found it useful to have the option to interpolate intermediate steps between a starting and ending locations. This is accomplished with the Intermediate Steps tool, which breaks up a given rotation or translation, as defined above, and adds a specified number of intermediate steps (Fig. 4). Note that the number of steps defaults to 0, which results in no intermediate steps. Users can also create a Google Earth Time Span animation (Google, 2013c) by selecting the Create Time Span box. The Start and Stop fields assign the beginning and ending dates for the Time Span animation. We typically use integer numbers to represent millions of years ago (mya), since Google Earth can't handle Time Span dates greater than a few thousand years.

If many transpositions are desired the user can process all of the transpositions as a single batch, using the Batch processing tool. This tool will accept a string of commands with one or more lines processed in sequence, where each line is a single

transposition. Each command line starts by specifying the transposition type: a “t” for translate, and an “r” for rotate. The syntax for the command line for a rotation continues with values for Euler pole latitude and Euler pole longitude in decimal degrees, followed by the rotation angle: “r -37.0 20.0 -90”. The syntax for a translation command line accepts heading in decimal degrees (0-359), distance of translation in meters, and looks like: “t 1208000”. By adding three extra arguments to the command lines for either of the operations the user can set the number of intermediary steps and the start and stop time for a Time Span. For example: “r -37.0 20.0 -90 5 0 6” will rotate the selected elements around an Euler pole located at -37.0 degrees latitude and 20.0 degrees longitude for 90 degrees in a counterclockwise direction and create five intermediate steps (seven figures in total) with a time span from 0 to 6 mya (see the India example in Fig. 4).

Batch processing is especially helpful for tectonic reconstructions where stage pole rotational information is known for a set of time slices. For example, the following sequence of command lines when entered in the batch processing field will produce a Google Earth Time Span animation of the movement of the India subcontinent relative to Eurasia over the past 80 million years (data from Copley et al., 2010).

r	26.61	23.39	2.60	5	-1	4
r	25.41	20.11	2.10	5	4	9
r	23.81	21.06	2.56	5	9	14
r	24.29	20.88	2.85	5	14	19
r	21.36	27.95	3.65	5	19	24
r	23.39	27.74	3.21	5	24	29
r	24.43	27.68	3.25	5	29	34
r	22.92	29.37	4.15	5	34	39
r	21.74	28.84	4.08	5	39	44
r	20.35	25.68	3.94	5	44	49
r	21.67	19.67	6.34	5	49	54
r	-19.89	-161.39	-7.36	5	54	59
r	-18.79	-163.25	-7.30	5	59	64
r	-20.47	-168.60	-4.54	5	64	69
r	-21.06	-169.94	-4.14	5	69	74
r	20.79	9.56	4.39	5	74	79

See the online supplement for the KML file (GreaterIndiaMovement.kml) of the animation produced by this batch.

Challenges for Implementation

Polygon Fill

During trouble-shooting phases in the development of the MaRGEE tool we encountered several issues that largely derived from quirks in the Google Earth

application. One of the challenges we encountered was polygons that filled incorrectly (*e.g.* the fill occurred outside the polygon's outline; Fig. 5a) when the polygon straddled the meridian or antimeridian. When a polygon's longitudinal coordinates are within the range of -180 to 180, Google Earth's polygon filling routine renders incorrectly when successive vertices fall on opposite sides of the antimeridian (orange polygon in Fig. 5a). However, in Fig. 5b the yellow polygon is rendered correctly across the antimeridian because the longitudes have been normalized to a range of 0 to 360 by adding 180 to the real longitude value. A similar rendering error can happen when a polygon intersects the meridian, but in this situation polygons are correctly rendered when longitudes are between the normal range of -180 to 180.

To remedy this problem, we presume that no polygon would span more than 180 degrees in longitude. Next, after every transformation and normalization to -180 to 180 longitude we check to see if the difference between the maximal longitude and the minimal longitude is smaller than 180. If so, we continue with this normalization, otherwise we normalize the longitudes to a range of 0 – 360.

As mentioned above, polygon fill is determined by lines of constant bearing connecting vertices. When a polygon is transposed close to poles or around poles, rendering can significantly distort the shape of a polygon (Fig. 3) or render the polygon fill outside of the polygon outline (Fig. 5a). Though not an ideal solution, our approach is to look for three problematic situations after each transposition: 1. is the maximum latitude in a polygon greater than 85 degrees, 2. is the minimum latitude smaller than -85 degrees, or 3. do the maximum and minimum longitudes span more than 180 degrees. If any of these conditions are met, we set the outline color of the polygon to the same value as the fill color and change the style of the polygon to "outline" only. When these conditions no longer apply the original style of the polygon ("filled") is restored. This way, the user sees either a filled or an outlined polygon at any given position.

Calculation Speed

When we tested the transposition algorithm with the Google Earth plugin we noticed significant increases in processing time when transposing geometries with many vertices. For example, a KML file with a single polygon containing ~40,000 vertices was rotated 45 degrees around an Euler pole located at longitude 45° and latitude 45°. The test machine was an Intel i7 3rd generation cpu at 2.66GHz, running Windows 7 Professional and Google Chrome browser (Version 38.0.2125.101). After performing the first run, which took a relatively lengthy 14s, we started a timing procedure to find the bottleneck. The procedure we used was as follows:

1. loop through all polygon coordinates and extract them to JavaScript arrays "lat" and "lon"
2. split arrays amongst four webworkers
3. workers perform operations necessary for rotation
4. each worker sends data to main script

5. transformed coordinates are merged to a single array “latNew,
lonNew”
6. latNew and lonNew are pushed to new polygon coordinates
The timing for each step showed that about 95% of the time was spent getting and
putting coordinates from KmlPolygon. It turns out that it is much faster to do
getKml() on KmlPlacemark with KmlPolygon geometry to export the KML string and
from this string to parse the coordinates. The inverted procedure is done to
calculate new coordinates for the Google Earth polygon. With this new procedure,
the total time necessary for the benchmark operation was reduced to 1.1s, using the
same hardware.

Deprecation of the Google Earth API and the Google Maps interface

The MaRGEE tool was originally implemented using the Google Earth Application
Program Interface (API) – e.g. the web browser plugin (cf Zhu et al., 2014a).
However, due to increasing incompatibility of the Google Earth API with modern
web browsers, Google has deprecated the Google Earth API and it will cease to be
available after 12/15/2015 (Google, 2013d). Our Google Earth API implementation
will remain functional until that date and can be accessed here:

<http://dev.geode.net/poly/>

However, given the limited future of the Google Earth API, we have rewritten
MaRGEE using the Google Maps web interface: <http://dev.geode.net/poly-maps/>

In many ways the Google Maps implementation is superior to the previous
Google Earth plugin platform. Google Maps does not require installation and use of a
browser plugin, which makes it more user friendly and available across various
platforms. In addition, the MaRGEE tools work significantly faster with Google Maps
than the Google Earth plugin implementation. One complication with Google Maps is
that it uses the WGS 84 /Pseudo-Mercator projection to display maps (EPSG, 2014),
as opposed to a virtual globe. Google Maps uses this projection to preserve angles
for street-level viewing, which is how the majority of users use Google Maps.
However, when viewing Google Maps at the global scale, significant distortion
occurs at high latitudes (Fig. 6a). In addition, the Google Maps interface does not
wrap around at the poles, so polygons that straddle polar regions look quite
peculiar. However, this is just an artifact of the Google Maps projection, as the
polygons render correctly and are not distorted when imported into Google Earth
(Fig. 6b).

Conclusions

The limitations of Google Earth that restrict its use as a serious research tool have
been known for several years, and many of these limitations still remain. Developers
within the geoscience and cyber communities have had to create work-around
solutions to ameliorate many of these deficiencies. This paper documents one
approach to address the issue of moving KML elements across the Google Earth
globe. The MaRGEE web application presented here (<http://geode.net/margee/>)
provides a user-friendly GUI for accurate spherical transpositions at global scales.
By adding TimeSpan information to transpositions, the fourth dimension of time can
be included to create animations of movements and processes for Google Earth. We

envision geoscientists and others using this tool for plate tectonic reconstructions, animations of continent and micro-continent movements through time (see Appendix A), and illustrations of other large-scale geologic processes. However, the MaRGEE toolkit is equally adept at regional and local transpositions, and should therefore aid in a wide variety of applications that require moving things around the Google Earth virtual globe, such as landslides or the movements of glaciers or thrust sheets. Planned future developments for this toolkit include the ability to alter or deform polygons, though the algorithms and inherent assumptions for these transformations are more complex.

The deprecation of the Google Earth API and browser plugin resulted in our use of Google Maps as the primary interface for the MaRGEE toolkit, which has both advantages (speed of processing) and disadvantages (visual distortion that is most apparent near the poles). Apparent distortion in the Google Maps Web Mercator projection has little effect for small polygons (meters to kilometers in scale) transposed short distances. For transpositions of larger polygons across greater distances an extra verification step may be required to make sure elements are in the desired locations and/or orientations in Google Earth after transposition. However, as Google Earth is a virtual globe and does not incorporate the distortion of the Web Mercator projection, all transposed KML elements appear correctly in the stand-alone application. We plan to update the browser platform for MaRGEE to whatever Google releases as an update to the Google Earth browser plugin, but at present we are not aware of the timeframe from Google for the release of a new web-based version of Google Earth.

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Appendix A. Supporting files

Code for all of the files used in the MaRGEE web application is available at the github URL: <https://github.com/mladen-dordevic/margee>

The online supplement includes the file [GreaterIndiaMovement.kml](#), which is a TimeSpan animation of the relative movement of the India subcontinent relative to Eurasia over the past 80 million years.

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Figure and Table Captions

Figure 1. View of the initial MaRGEE screen after a KML file has been loaded. The file consists of three elements: a filled polygon named India, an outlined polygon named India Outline, and a filled polygon named Sri Lanka. The India polygon is selected, and the India Outline and Sri Lanka polygons have been hidden from view.

Figure 2. Schematic of geometry types in KML file structure.

Figure 3. Rendering of paths versus polygons. Each square has green outlines drawn as paths and red outlines around blue polygons; note the deviation from a uniform square in the polygon rendering as the objects are positioned closer to the pole. Translation of geometry with 10 intermediary steps along 18 degrees bearing along a distance of 18000 km.

Figure 4. MaRGEE screen illustrating the Rotate and Intermediate Steps tools. India is rotated -90 degrees (counterclockwise) around a pole of latitude -37.0° and longitude 20.0°. The number of intermediate steps is 5, resulting in 7 incremental polygons of India, including the starting and ending polygons. The Time Span box is also selected, which will produce a KML file that activates the Google Earth TimeSpan animation box to incrementally show the movement of India from 6 (mya) to 0 (mya).

Figure 5. Antimeridian rendering problem where a polygon straddles the antimeridian; A. orange polygon fill is incorrectly drawn outside the polygon outline, B. yellow polygon fill is correctly drawn within the polygon outline.

Figure 6. A. MaRGEE screen showing an incremental translation of the India polygon to the north, where the distortion from Google Maps's Mercator projection becomes increasingly manifest. B. Google Earth screen showing the same polygons rendered correctly on the virtual globe.

Table 1. Dropdown menus available at the top of the MaRGEE screen (first column), with the available options for each menu (second column).

Figure 1

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6