Absolute Tectonic Plate Motion Optimization

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Plate Tectonics and Continental Drift

- Continental drift theory first developed in 1915, now widely accepted
- Earth's crust is partitioned into tectonic plates
- Supercontinents such as Pangea and Gondwana
  - Occur every 300-500 million years (Myr)
  - Separated by 90 degrees of latitude
Plate Reconstructions

- Plate motion models reconstruct the movement of plates millions of years ago

  - APM Contribution
  - RPM

**Relative Plate Motion Models (RPMs)**
- Tree structure
- Plates represented by nodes, with edges relating two plates

**Absolute Plate Motion Models (APMs)**
- Determine the relative motion between a “root” plate and the mantle
optAPM

- Code written in 2018 to optimize an absolute plate motion model (APM)
- Models are not continuous: absolute motion optimized **only at 5-million-year (5Myr) intervals**
  - Optimizing from 0-80Myr ago, the code adds 16 lines to the relative plate motion model (RPM)
  - Each line contains an Euler rotation at some reconstruction time

<table>
<thead>
<tr>
<th>Plate</th>
<th>Time</th>
<th>Lat</th>
<th>Long</th>
<th>Angle</th>
<th>Ref. Plate</th>
</tr>
</thead>
<tbody>
<tr>
<td>African</td>
<td>5.0</td>
<td>−26.805</td>
<td>−93.7412</td>
<td>8.8682</td>
<td>Mantle</td>
</tr>
<tr>
<td>African</td>
<td>10.0</td>
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<td>−141.4427</td>
<td>−8.0848</td>
<td>Mantle</td>
</tr>
<tr>
<td>African</td>
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<td>−102.3182</td>
<td>21.3154</td>
<td>Mantle</td>
</tr>
<tr>
<td>African</td>
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<td>−54.4163</td>
<td>−144.6204</td>
<td>−8.4758</td>
<td>Mantle</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
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<td>...</td>
</tr>
</tbody>
</table>

**Table**: A simplified version of what would be appended to a rotation file in the optimized APM.
Data Constraints and Cost Functions

- 3 different constraints
- **Net Lithospheric Rotation** (crust’s rotation relative to mantle)
  \[
  \omega_{net} = \frac{3}{(8\pi r^4)} \sum_i \int (\omega_i \times R) \times R \, dS_i
  \]
- **Trench Migration** (absolute plate boundary motion)
  \[
  TM_k = \frac{\sum |VT|}{T_n} + TM_{gT}\sigma
  \]
- **Hotspot Trail Misfit** (focal point of research)
  \[
  HS_m = \sum_{i=0}^{n} (d_{1i} - d_{2i})^{-1} + HS_{gm}\sigma
  \]
- Objective function to minimize:
  \[
  J = \frac{HS_m}{\sigma_1} + \frac{TM_k}{\sigma_2} + \frac{\omega_{net}}{\sigma_3}
  \]
**Hotspot Motion**

**Definition**

**Hotspots:** Area of Earth over a mantle plume.

- **Hotspot trails** form when a plate slides over a hotspot
- Hotspots are essentially stationary relative to the mantle
  - Reconstructing present-day hotspot locations according to model should reflect hotspot trail data
- Hotspot trail data is discrete
  - Data is considered robust for past 80Myr
Hotspot Motion

- optAPM uses 9 well-studied hotspot trails
Isolating Constraints

What happens when we run the code with only one of the three constraints?
Hotspot Cost Function

Code "guesses" absolute motion at reconstruction time (e.g. 20Myr ago)

Original Cost Function:
1. Interpolates model output at hotspot data times (e.g. 17.5 Myr ago)
2. Minimize distances between
   - Model output (interpolated)
   - Hotspot data

New Cost Function:
1. Interpolates hotspot data at reconstruction times (e.g. 20Myr ago)
2. Minimize distances between
   - Model output
   - Hotspot data

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Africa Motion Paths to 80Myr Ago

- Original Hotspot
- New Hotspot

Present-Day Location
Results

Africa Motion Paths to 80Myr Ago

- Trench Migration
- Net Lithospheric Rotation
- RMS Plate Velocities
- Original Hotspot
- New Hotspot

Present-Day Location

Longitude
-25 -20 -15 -10 -5 0 5

Latitude
12.5 15.0 17.5 19.0 20.0 22.5 25.0 27.5
Plate motion models are helpful for understanding Earth’s long-term tectonic development.

Modeling has improved a lot, but many aspects still have significant room for growth.

- Weightings for 3 different constraints in the objective function:

\[ J = \frac{HS_m}{\sigma_1} + \frac{TM_k}{\sigma_2} + \frac{\omega_{net}}{\sigma_3} \]

- Chi-square weighting using standard errors?
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