GPlates and Mantle Convection

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Outline

• Overview of plate reconstructions & paleogeography in geodynamics
• Why are new reconstructions and methods needed? Isn’t this a solved problem?
• GPlates
• Continuously closing plates
• Use of GPlates in our recent work
Examples of plate tectonic reconstructions in geodynamics

- Plate motion models (driving & resisting forces)
- Drift of hot-spots and TPW
- Prediction of present day seismic structure
- Sea-level and stratigraphy
- Geochemical transport and mantle domains
Models of global plate motions

Key points:
- Prior plate motions used for evolving mantle structure
- Plate geometry used for mechanical specification of plates

Lithgow-Bertelloni & Richards [1998]
Key Points:

- High & low seismic velocities develop from history of subduction
- Alternative reconstructions to assess uncertainty
Models of Stratigraphy and Mantle Domains

Key Points:

- Mapping of topography, stress, temperature, etc. from mantle to plate frames.
- Sampling at mid-ocean ridges and assignment to plates
- Assignment of paleogeographic data to the rotating plates.

Gurnis, Müller & Moresi [1998]
Global plate tectonic reconstructions & associated software have become inadequate for geodynamics (especially time-dependent models with variable viscosity), either as information to be assimilated into a model or as the basis to map a geodynamic prediction back for comparison with the geological record.

Published reconstructions are often:
• Reconstructions with polygons are too widely spaced in time
• Large swaths of the surface ambiguously defined
• Plate margin evolution inconsistent with plate motions
• Difficult to incorporate alternative reconstructions (or modifications to existing reconstructions) into the geodynamics workflow
Most reconstructions have gaps and do not have closed polygons

Robert Hall [2000]
GPlates

- *GPlates* is an international effort aimed at developing software that goes beyond existing paleogeographic systems with enhanced tools for reconstructions and geodynamic modeling. Development is shared between Sydney University (main hub), Caltech, and Geological Survey of Norway.
- Working under Dietmar Müller, James Boyden at Sydney developed the first prototype of the code.
- Mark Turner at Caltech expanded the system and introduced the tools needed for geodynamic modeling (version 0.8).
- The code has been redesigned by Boyden *et al.* (version 0.9) and Robin Watson (NGU) and Turner are adding enhanced capabilities.
GPlates 0.9.2 is available and can be downloaded from http://www.gplates.org
Current development status
GPLates 0.9.2

- Geometry classes and functions
- Finite rotations, resolve and display rotation hierarchy
- OpenGL rendering
- Accommodates time-dependent grids and extended GPML information model
- Display of global time-dependent raster images (oceanic age, spreading rates, dynamic topography)
- The Query Feature Properties dialog enables editing of GPGIM feature properties
- Runs on Windows XP/Vista and Linux
- Backward compatible (reads PLATES 4 data and rotation files)
Current development status
GPlates 0.9.2 (cont.)

- Total Reconstruction Poles dialog provides:
  - tables of relative and equivalent finite rotations
  - a tree-like representation of the hierarchy
  - circuit between any two plates
  - export options
- Shapefile import with mapping of attributes to GPGIM feature/property model
- GPlates-compatible global coastline file and a rotation file available from EarthByte (Muller et al., G-cubed, 2008) or http://www.earthbyte.org/resources.html
- The native file format will be XML-based, reflecting the underlying data structures of the code
XML/GML/GPML

• GML: Geography Markup Language
  • an XML-based file format defined by the Open Geospatial Consortium (OGC) on its way to becoming an ISO standard
  • defines building blocks for common use
    • geometric primitives
    • temporal primitives
    • time scales, coordinate reference systems, etc.

• GPML: GPlates Markup Language
  • an XML-based native file format for geological/geophysical data attached to tectonic plates
  • is an application schema of GML that combines and extends the GML building blocks.
GPlates 0.9.2 provides the basics for traditional reconstructions.

We have also developed a new concept to allow a closer linkage to geodynamic models: Continuously closing plates.
Continuously Closing Plate
Continuously Closing Plate
Plate margins + closed plates
Plate polygons
Plate polygons + CitComS FEM mesh
Plate
Polygons
+
velocity
Plate Polygons + 2 frames of reference
Plate Polygons + 2 frames of reference
Plate Polygons + 2 frames of reference
Plate Polygons + 2 frames of reference
Plate
Polygons
+ 2 frames of reference
Plate Polygons + 2 frames of reference
Some additional features & statistics

- Asymmetry of trenches tracked
- Subduction boundaries linked to database [C. Tape et al., 2008]
- Consistent with the paleo age grids of [Müller, et al., 2008]
- Using moving hotspot reference frame [O'Neill et al., 2005].
- For the Global Reconstruction (“0.8.6”), we have
  - 31 ‘Plates’ that are identifiable units connected to the rotation tree
  - 423 ‘Logical plate polygons’. These are manual closures that embody the rules allowing continuous closure (life span is between 1 Myr and ~40 Myr).
  - The Pacific Plate is the most complex with 49 closures with polygons lasting on average ~3 Myr; global average >5Myr.
Our own applications of the GPlates plate tectonic work flow:

• Global flow models of the lower mantle (including thermo-chemical plumes & PV-PPV)
• Models of global plate motions with plate and slab strength
• Regional forward models (regional-global coupling)
• Adjoint models of convection incorporating tomography & vertical motion constraints*
GPlates development plan

• August 2008 (Oslo IGC meeting)
  • Feature digitizing and graphical manipulation of geometries
  • Ability to color features by plate ID, feature-type and time of appearance
  • Interactive fitting of plates to derive new rotations
  • GPlates on Mac OS X

• December 2008 (Fall AGU meeting)
  • More map-projections
  • Interactive plate-boundary closure
  • Velocity grid output
  • Import point and vector data not yet broken up into plates
  • GPlates tutorial, user manual, & GPlates-geodynamics cookbook
Conclusions

• A new open source plate tectonic package, GPlates, is available; expect several new releases in the coming calendar year.

• Continuously closed plate polygons can be created and used in geodynamic models.

• Such continuous polygons can be used in adjoint models of mantle convection with seismic tomography. After finding the best fit to stratigraphic data, the Farallon flat slab can be inferred.