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Global continental and ocean basin reconstructions since 200 Ma

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ABSTRACT

Global plate motion models provide a spatial and temporal framework for geological data and have been effective tools for exploring processes occurring at the earth's surface. However, published models either have insufficient temporal coverage or fail to treat tectonic plates in a self-consistent manner. They usually consider the motions of selected features attached to tectonic plates, such as continents, but generally do not explicitly account for the continuous evolution of plate boundaries through time. In order to explore the coupling between the surface and mantle, plate models are required that extend over at least a few hundred million years and treat plates as dynamic features with dynamically evolving plate boundaries. We have constructed a new type of global plate motion model consisting of a set of continuously-closing topological plate polygons with associated plate boundaries and plate velocities since the break-up of the supercontinent Pangea. Our model is underpinned by plate motions derived from reconstructing the seafloor-spreading history of the ocean basins and motions of the continents and utilizes a hybrid absolute reference frame, based on a moving hotspot model for the last 100 Ma, and a true-polar wander corrected paleomagnetic model for 200 to 100 Ma. Detailed regional geological and geophysical observations constrain plate boundary inception or cessation, and time-dependent geometry. Although our plate model is primarily designed as a reference model for a new generation of geodynamic studies by providing the surface boundary conditions for the deep earth, it is also useful for studies in disparate fields when a framework is needed for analyzing and interpreting spatio-temporal data.

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1. Introduction

Plate tectonic reconstructions are essential for providing a spatio-temporal context to geological and geophysical data and help uncover the driving forces of supercontinent break-up, separation and accretion, linkages between surface processes and the deep earth, modes of intraplate deformation and the mechanisms behind geological processes. Currently, plate reconstructions fall into three main categories: (1) "Geologically current" models based on present day plate motions from GPS measurements (Argus and Heflin, 1995), space geodesy e.g. GEODVEL (Argus et al., 2010) or a combination of spreading rates, fault azimuths and GPS measurements e.g. NUVEL-1 (DeMets et al., 1990, 2010) and MORVEL (DeMets et al., 2010); (2) Traditional plate tectonic models based on the interpretation of the seafloor spreading record and/or paleomagnetic data to reconstruct the ocean basins, continents and terranes within an absolute reference framework (Scotese et al., 1988; Scotese, 1991; Golonka and Ford, 2000; Schettino and Scotese, 2005; Golonka, 2007; Müller et al., 2008b); (3) Coupled geodynamic–plate models, which model plate boundary locations and mantle density heterogeneity to predict past and/or present plate motions (Hager and O'Connell, 1981; Lithgow-Bertelloni and Richards, 1998; Conrad and Lithgow-Bertelloni, 2002; Stadler et al., 2010).

"Geologically current" plate models provide the most accurate representation of global plate motions, are available in several global reference frameworks and can be independently verified with present day observations. However, they are limited from the Pliocene to present. Traditional plate tectonic reconstructions have good temporal coverage, which may extend as far back as the Paleozoic, but are often instantaneous snapshots rather than dynamically evolving models. For example, rather than representing plates in terms of their evolving shape, these models are generally built on rotating selected objects that form part of plates, such as continents, back through time, without addressing the implied evolution of the surrounding mid-ocean ridges, transform faults and subduction zones in a self-consistent manner. This limits the adaptability of traditional plate motion models, as they cannot easily be used as boundary conditions for geodynamic models. This is particularly acute for tracking the evolution of subduction since static plate reconstructions cannot simultaneously trace the continuous rollback of subduction zones while having slabs coupled to the subducting plate. Coupled geodynamic-plate models, which use numerical calculations to predict past and present plate motions, are sensitive to initial boundary conditions, as well as physical mantle properties, all subject to uncertainties and often work only for selected or interpolated timesteps. In addition, these published plate models are usually available in a form that does not easily lend itself to an exploration of the plate kinematic parameter space, in terms of testing alternative models in a geodynamic sense.

The rapid improvement in computational capability and efficiency (in terms of algorithms and hardware) with the simultaneous advancement in geodynamic modeling tools capable of addressing a range of applications, has created a need within the earth sciences community for a "deep-time" (i.e. time scales of a few hundred million years) reference plate motion model provided in digital form in such a way that it can be easily used, modified, and updated to address a variety of geological problems on a global scale. To ensure self-consistency, tectonic plates and plate boundaries should be explicitly modeled as dynamically evolving features rather than the previous paradigm, which modeled the motion of discrete tectonic blocks, without much thought to the shape, size and boundaries between tectonic plates.

We have developed a "deep-time" reference plate motion model consisting of a set of dynamic topological plate polygons using the approach described in Gurnis et al. (2012) with associated plate boundaries and plate velocities since the break-up of Pangea (~200 Ma). Our model is underpinned by plate motions derived from reconstructing