The Effect of Tectonic Plate Motion on OpenStreetMap Data

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Abstract

The tectonic plates of the Earth shift relative to each other, which creates the need to adapt coordinate values on a regular basis. However, such systematic adaptions are not carried out in case of the OpenStreetMap dataset, which should render possible to trace this effect within the dataset. We empirically demonstrate that the effect cannot be traced yet but will most likely become traceable in some years. Despite the potential traceability, the effect of plate motion will first become relevant in some decades.

Keywords: OpenStreetMap (OSM); Volunteered Geographic Information (VGI); World Geodetic System 1984 (WGS84); plate tectonics; global datasets; data quality

1 Introduction

The lithosphere, i. e., the outermost shell of the Earth, is broken into a number of tectonic plates. These plates shift and rotate relative to each other with a velocity of up to some centimetres per year. Distances between locations and angles on the Earth's surface change accordingly over time, which results in a constant change of the coordinates that describe a certain location on Earth (Kreemer et al., 2014). If the coordinates used in a global dataset are not updated despite referring to a *global* coordinate reference system, the accuracy of the data decreases over time. Long-existing global datasets such as the OpenStreetMap (OSM) dataset thus have to take plate motion into account.

Tectonic plates are relatively rigid, and their interiors are often regarded as not being subject to deformation. The coordinates of two locations in the same vicinity in the interior of a plate change thus in the same way, and the distance between the two locations remains stable. If two pairs of coordinates remain unchanged, also the distance between the corresponding locations on Earth remain unchanged, despite the locations being subject to change. The precision of a global dataset thus remains constant over time, which is in contrast to the decrease of the spatial accuracy.

Datasets that are updated on a regular basis, e. g., Volunteered Geographic Information (VGI) data, will eventually be implicitly corrected for plate motions and correspondingly changing coordinates. As the Global Position System (GPS) is independent of any plate motion, any coordinates that are measured anew by using GPS are, e. g., automatically corrected for the effect of plate motion. Even renewed aerial imagery, which is often used to determine the position of geographical features, counteracts the effect of plate motion by being correctly georeferenced. Under the hypothesis that all effects that lead to shifts of coordinates within the data have no systematic bias, i. e., that the shifts of the coordinates sums up to zero in average, the effect of plate motion should become visible in the data: the coordinates on each tectonic plate shift, in average, in the opposite direction of the plate motion.

This article aims at discussing the effect of plate motion on coordinates within the OSM dataset. Thereby, it tackles the following two research questions:

RQ1: Can the effect of plate motion practically be traced within OSM data?

RQ2: When might the effect become relevant in case of OSM data?

In the next section, we demonstrate that the effect of plate motion can currently not be traced within OSM data, most likely because the dataset is too new. We however reason, based on empirical investigations, that this effect will become traceable in the next decades, which answers RQ1 (Section 2). We set our considerations into context by discussing when the effect might even become relevant, which answers RQ2, and we identify limitations of our approach (Section 3).

2 Tracing the Effect

The coordinates of some location on Earth potentially changes over time due to the motion of the tectonic plates. A Geodetic Reference Systems (GRS) needs to be established before a coordinate system can be deployed. The GRS consists of a reference ellipsoid and a corresponding reference frame, which provides information about how the reference ellipsoid and the surface of the Earth relate in terms of translations and rotations. The World Geodetic System 1984 (WGS84; National Imagery and Mapping Agency 2000) is one of the most used GRSs. It is aligned to the International Terrestrial Reference Frame (ITRF) on a regular basis (Boucher and Altamimi, 2001; National Imagery and Mapping Agency, 2000), which assumes the reference ellipsoid and the Earth, including its atmospheric mass, to share a common centre of gravity, and which assumes a no-net-rotation condition (NNRC; Altamimi et al. 2003; Kreemer and Holt 2001; Argus and Gordon 1991) – the total angular momentum of the tectonic plates vanishes in respect to the ITRF. When the Coordinate Reference System (CRS), consisting of a GRS and a coordinate system, e. g., WGS84 in combination

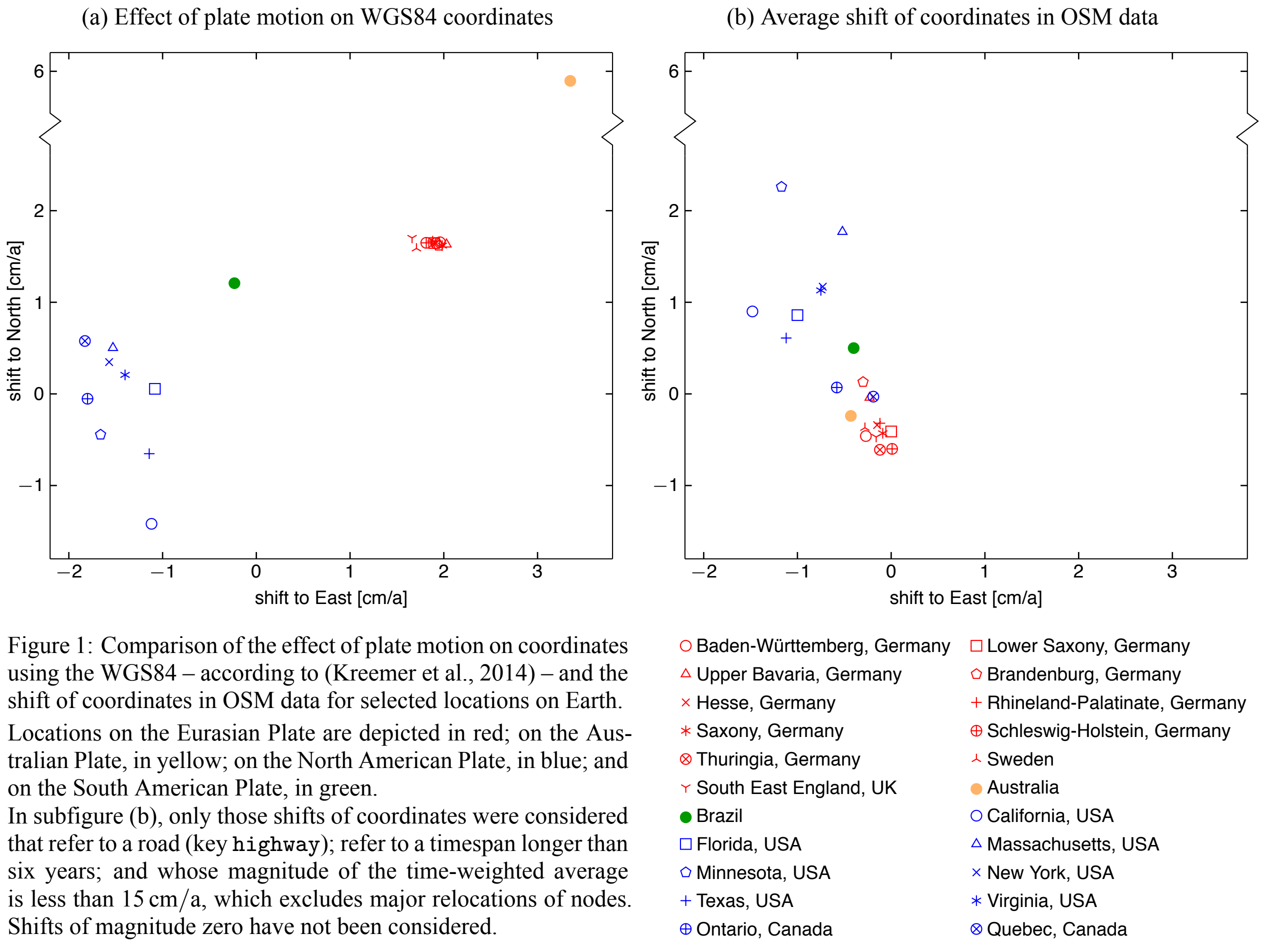

Figure 1: Comparison of the effect of plate motion on coordinates using the WGS84 – according to (Kreemer et al., 2014) – and the shift of coordinates in OSM data for selected locations on Earth. Locations on the Eurasian Plate are depicted in red; on the Australian Plate, in yellow; on the North American Plate, in blue; and on the South American Plate, in green.
In subfigure (b), only those shifts of coordinates were considered that refer to a road (key `highway`); refer to a timespan longer than six years; and whose magnitude of the time-weighted average is less than 15 cm/a, which excludes major relocations of nodes. Shifts of magnitude zero have not been considered.

with the geographic coordinate system consisting of latitude and longitude, meets a NNRC, the coordinate shifts due to tectonic plate motion are minimized.

The effect of plate motion on the coordinates of a location can be traced within OSM data, if coordinates within the dataset are frequently updated. Such updates happen, however, only in parts in case of OSM data. Despite being maintained and undergoing regular updates, the coordinates and geometries stay often untouched within the OSM dataset. To avoid the problem of regular updates, datasets of more local character often refer to CRSs that are aligned with the corresponding plate of the represented area, which renders systematic updates of coordinates unnecessary. Such a strategy does, however, not work for OSM data because the OSM dataset is of global nature. When the geometries are, at least in parts, updated to current coordinates, the shift of coordinates is accordingly implicitly contained in the dataset. This shift can only be measured if we assume all other effects that lead to a shift of individual coordinates to add up to zero, i. e., to have no bias. In this case, the shift due to plate motion becomes statistically apparent when examining the average shift of all coordinates.

The data provided by the OSM project is subject to the effect of plate motion. Due to the global nature of OSM data, WGS84 has been chosen as a GRS (OSM, accessed on February 11, 2018), which both minimizes the effects of plate motion and stays compatible with many potential data sources. The data is updated by volunteers, who steadily improve the representation of the environment within the OSM dataset. Geometric information is thereby often updated, because initial mapping activities often focus on introducing new elements to the dataset while subsequent activities often improve existing information, among them geometries (Neis et al., 2013, 2012). Whenever a geometry is improved, the coordinates potentially incorporate the coordinate shift due to plate motion if the data source allows for the determination of current coordinates. This is, e. g., the case for up-to-date georeferenced aerial imagery and GPS measurements.

A comparison of the expected shift of coordinates due to plate motion and the actual shift of coordinates in OSM data reveals only little commonalities (Figure 1). There are several reasons that most likely contribute to the poor conspicuity of this effect within the data. First, there are different data sources being used by the volunteers who contribute to OSM, and many of these data sources do not show up-to-date information. Aerial imagery and the corresponding georeferencing is, e. g., often some months or even years old when being used for mapping purposes. Secondly, data is sometimes imported from other datasets that refer to a different GRS. As an example, Tiger/Line data has been imported in large parts in the USA, and this dataset refers to the North American Datum of 1983 (NAD83; U. S. Department of Commerce and U. S. Census Bureau 2006). The conversion between different GRS can lead to a systematic shift, which may, in parts, be retracted during the subsequent maintenance of the data by volunteers. The same problem might also apply to datasets about Australia, because they tend to refer to the Geocentric Datum of Australia 1994 (GDA94) due to the large plate motion of the Australian Plate (Donnelly et al., 2014; Intergovernmental Committee on Surveying and Mapping and Permanent Committee on Geodesy, 2018). Other factors that strongly influence the shift in OSM data are the short timespan of existence of the OSM dataset (compared to the slow motion of the tectonic plates) and the differing quality of OSM data about different places of the world (Barron et al., 2014).

The current shift of coordinates in OSM data provides much information about when the effect of plate motion on OSM data might become traceable. Despite the fact that neither relative nor absolute values of the expected and the actual shifts coincide (Figure 1), there is only very little variation of the shifts measured for different places of one plate (Figure 1b). In particular, the considered places of the Eurasian Plate are very similar in respect to their shifts. Due to the large size of the North American Plate, different places on this plate are expected to expose very different motions. This variation of the expected motions is reflected by the variation of the measured motions in the OSM data. These similarities suggest that the effects that superimpose the effect of plate motion do not alter the resulting shifts in an arbitrary way. Instead, certain characteristics of plate motion seem to be visible already now. There are three reasons that suggest the effect of plate tectonics to become traceable and measurable in the next years, and very likely in the next decades: the variation of the shifts is small, the measured and the expected values are of the same order of magnitude, and the quality of the data is steadily improving.

3 Discussion and Limitations

The effect of plate motion can, at least without more detailed knowledge about OSM, not be traced nor measured in current OSM data. We have, however, argued that the effect will most likely become traceable in the next years or decades. Whether the effect will become relevant as well depends on the quality of the contributed data – the accuracy of GPS measurements is in the range of meters in case of mobile phones and consumer GPS devices, and so is the accuracy of aerial imagery used in OSM. In addition, the relevance of the effect strongly depends on the purpose for which the data are used for.

Despite being presumably able to trace the effect of plate motion in OSM in some years, the data cannot serve as a source for determining the shift of single plates. The information about the shifts in the OSM dataset originates from different sources. The coordinates are, e. g., often extracted from aerial imagery or old maps. In order to make aerial imagery accessible for the purpose of being used in mapping activities, it needs to be georeferenced. This georeferencing, in turn, relies on the exact determination of coordinates for some points in the map, and often knowledge about plate tectonics needs to be incorporated. It makes thus only sense to measure plate motion by referring to long-existing global datasets if the coordinates in the dataset are independently measured in a global GRS, which is the case for GPS measurements.

The considerations about OSM data are strongly limited by the fact that there is no clear specification of how locations shall be represented within the data. The original reference frame of WGS84 has been established in 1987. Due to improved models of the Earth, refined computational models, and changes in the reference stations, new realizations of the reference frame have been published. For instance, the realizations WGS84 (G730) and WGS84 (G1150) are aligned to ITRF92 and ITRF2000 respectively, where the latter for the first time combines unconstrained space geodesy solutions without the need to explicitly refer to models of plate tectonics (Altamimi et al., 2002, 2003). The current realization is WGS84 (G1762), where 1762 refers to the week number of the GPS system. In addition to the realization of WGS84, there is the need to name the epoch that coordinates refer to, because the realizations can include temporal changes. It is though very common to not specify the revision and the epoch of the reference frame. In case of OSM, this is no substantial limitation because the common error is much larger. Omitting such information may rather facilitate the incorporation of geometries from many different sources, because the widely-used sources refer to different realizations in case of OSM. Despite being no substantial limitation, this circumstance sets limits to the traceability of the effect of plate motion in the data.

4 Conclusion

The traceability and the relevance of the effect of plate motion in the OSM dataset are two different issues. While it is evident that the former will become possible in some years – technology as well as the accuracy and precision of OSM are usually improving – the latter might be avoidable if it is addressed by systematic updates of the coordinates. If the data are not systematically updated – this is currently the case – the effect of plate motion becomes relevant in some decades.

There are many factors that superimpose the effect of plate motion on the OSM dataset. While some of the factors might be of systematic nature, e. g., extensive imports from another dataset and the corresponding transformation of the coordinates, other factors are more unsystematic. Among these unsystematic factors are the influence of poor data quality, which increases the variation in very different ways and can lead to a bias (Barron et al., 2014), and the use and import of a multitude of data sources with very differing characteristics. The effects that superimpose the effect of plate motion need to be studied in more detail to allow for a better traceability of the effect of plate motion.

Author contributions

F.-B. Mocnik developed the main ideas, wrote the text, and produced the figure. F.-B. Mocnik and M. Raifer jointly prepared the data. M. Raifer provided helpful comments.

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