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Original paper

Differences in Epicentral Location of Mexican Earthquakes between Local and Global Catalogs: An update

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Resumen

Las diferencias en las localizaciones epicentrales entre catálogos locales y globales para sismos ocurridos en la zona de subducción mexicana fueron, primeramente, observados en 1980, con base en unos cuantos eventos bien estudiados. En este escrito se comparan las localizaciones de dos catágolos locales; (1) un catálogo reciente de alta precisión para la zona de Guerrero y (2) el catálogo del Servicio Sismológico Nacional (SSN), contra el catálogo global del United States Geological Service (USGS). Encontramos que en promedio las localizaciones epicentrales reportadas en los catálogos globales, para sismos de magnitudes mayores a 5, generados en la zona de subducción mexicana, se encuentran 26 km en dirección N54ºE comparados con los reportados en catálogos locales. Investigamos cómo el error varía para diferentes tipos de sismos en Guerrero y cómo éstos mismos varían a lo largo de la trinchera, desde el estado de Jalisco hasta Chiapas. En promedio, las diferencias son mayores para sismos inversos ocurridos cerca de la trinchera y para eventos ocurridos en Michoacán. Las diferencias son mayores en promedio para eventos de magnitud mayor. Existe una compensación entre la distancia a la trinchera y el tiempo, lo cual indica una baja resolución para estos parámetros, debido a la falta de estaciones ubicadas en el Océano Pacífico. Las diferencias entre las localizaciones pueden ser atribuidas a un modelo sistemático en la estructura de velocidad para el manto, consistente con trayectorias rápidas al noreste y trayectorias lentas relativas al suroeste.

Palabras clave: Sismicidad, zona de subducción mexicana, localización epicentral.

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Abstract

Differences in epicentral locations between local and global catalogs for earthquakes in the Mexican subduction zone were first observed to be biased in the 1980s, based on a few well studied events. In this study we compare locations between two local catalogs; (1) a recent high precision catalog of events in the state of Guerrero and (2) the catalog of the Servicio Sismológico Nacional (SSN), to the global catalog of the United States Geological Service (USGS). We find that on average epicentral locations in the global catalog of earthquakes larger than M 5 in the Mexican subduction zone are 26 km towards N54°E of those in the local catalogs. We investigate how the errors vary for different types of earthquakes in Guerrero, and how they vary along the trench, from the state of Jalisco to the state of Chiapas. The average differences are largest for thrust events occurring close to the trench, and for events in Michoacán. The differences are greater on average for large earthquakes than for small. There is a trade-off between the distance from the trench and timing, suggesting a poor resolution of these parameters, due to the lack of stations the Pacific Ocean. We attribute the differences in locations to systematic patterns in the velocity structure of the mantle, with consistently fast paths to the northeast and relatively slow paths towards the southwest.

Key words: seismicity, mexican subduction zone, earthquake location.

Introduction

In the immediate aftermath of an earthquake, the location of the hypocenter helps identifying regions most affected by the event and its tsunamigenic potential, until fault slip distributions (obtained from analysis of seismic waveforms), as well as aftershock locations, become available. However, locating large earthquakes quickly from local data is often difficult as the duration of the P wave can be similar to or larger than the separation between the P and S waves, which can lead to large errors in S-wave picks. For this reason, hypocenters obtained from teleseismic data, if accurate, can be helpful for quick identification of regions severely affected by an earthquake.

In the early 1980s it was observed that earthquakes in the Mexican subduction zone were systematically mislocated in global catalogs, such as the PDE and ISC catalogs (Singh *et al*. 1980, Havskov *et al*. 1983). A comparison of hypocenter locations obtained by carefully analyzing locally recorded data, to those obtained from teleseismic data, showed that the mislocation was typically about 35 km towards N 35° - 45E° (Singh & Lermo, 1985). Due to the short distance from trench to shore in this area, about 80 km, this error is sufficient that earthquakes occurring offshore, with significant tsunamigenic potential, will appear as occurring inland, with capability of generating only a very small tsunami. This systematic difference in location also may affect seismotectonic studies based on global catalogs.

A possible explanation for the difference in location, put forward in the initial studies, is that waves traveling towards the northeast are speeded up on the ray segment going through the relatively fast downgoing plate. However, recent studies have shown that the subducting plate is nearly flat for a large distance from the trench (e.g. Suárez *et al*., 1990, Singh & Pardo 1993, Pérez-Campos *et al*., 2008, Husker & Davis 2009) along a large segment of the subduction zone, and therefore the near-vertical rays travel only a very short distance inside the plate.

Earthquakes breaking the Middle America Subduction Zone occur on the edge of the Pacific Ocean, a vast expanse in which there are relatively few seismic stations. This causes an uneven distribution in azimuths of stations recording earthquakes in this zone, with almost all seismometers situated on land areas towards the east and the north, and relatively few in the ocean to the west and to the south.

In this paper we repeat the studies from the 1980s, comparing the locations of earthquakes in modern global catalogs to those obtained from detailed studies of regional seismicity, and update the results and the interpretation.

Data

We use hypocenter locations from three catalogs; (1) From Pacheco & Singh, 2010 (which we will refer to as PS2010), (2) From the National Earthquake Information Center of the United States Geological Survey (NEIC of USGS), (3) From the Mexican National Seismological Service (spanish: Servicio Sismológico Nacional, referred to as SSN).

The PS2010 catalog was obtained by detailed analysis of earthquakes in the state of Guerrero. The earthquakes were relocated using data from permanent and portable broadband stations and accelerometers in the region, and only the best located events entered the catalog. Earthquakes were kept for which the hypocenter locations had an RMS error below 1 second and (except for a few moderate sized earthquakes at the edge of the state of Guerrero) where at least one digital station was at a distance less than the focal depth. The formal errors in location for these events are ~5 km or less. The 1D velocity model used for the locations is modified from Iglesias *et al*. (2001).

The second catalog is the global earthquake catalog of the National Earthquake Information Center (NEIC) of the United States Geological Survey (USGS). The earthquake hypocenters reported in this catalog are based on arrival times of phases observed at local to teleseismic distances, together with a 1D velocity model AK135 (Kenneth *et al*., 1995).

The third catalog is that of the SSN. This catalog includes earthquakes in Mexico and surrounding areas and uses phase arrival times recorded by the SSN network. The seismic network has a station density that varies significantly between different regions of the country and as a result the quality of the locations can vary significantly between them. In the densest part (in the state of Guerrero) the inter-station distance is on the order of 50 km, but it increases to several hundreds of kilometers in the northern part of the country. The velocity model used by the SSN for the locations is based on the Jeffreys & Bullen (1940) model, but has been modified in order to obtain smaller residuals in the locations.

Method

In this study we compare the locations of the global USGS catalog to two local catalogs; 1) PS2010 that contains only earthquakes in Guerrero and 2) SSN that contains earthquakes along the Mexican subduction zone from Jalisco to Chiapas. We are interested in the bias or systematic error in the locations, i.e. the average mislocation between the catalogs. This value can potentially be subtracted from the teleseismic location to get a very quick, "corrected estimate" of the hypocenter.

We calculate the difference in location between the two estimates as the vector **x** pointing from the location in the local catalog (PS2010 or SSN), towards the location in the global USGS catalog, $\mathbf{x_i}=(x_i,y_i)$ where x_i and y_i are the distance in kilometers along longitude and latitude respectively, for event *i* in the catalogs. To estimate the average error in location we calculate the vector sum of all the vectors, and dividing by the number of elements: $(x_{ave},y_{ave})=1/N\ \mathrm{Sum}(\ (x_i,y_i))$. As the average is sometimes dominated by outliers, we also calculate the median difference as the vector $(x_{median},y_{median})= (\mathrm{median}(x_i),\mathrm{median}(y_i))$.

Results

Earthquakes in Guerrero

First we associate events in the PS2010 and USGS catalogs, by looking for the events in the USGS catalog that occur within 10 seconds of those in the PS2010 catalog. This did not lead to any erroneously associated events to earthquakes outside the study area. There are 8 earthquakes in the PS2010 catalog that are not in the USGS catalog (number 2, 5, 17, 18, 32, 45, 47, 127), that could not be associated. The unassociated events all have magnitudes M <= 4.2, and are not expected to necessarily be observed on a global scale. A total of 121 events are common to both catalogs. The earthquakes in the PS2010 catalog were divided into five groups by its authors, depending on their location and focal mechanisms; 1) shallow thrust events, 2) normal faulting and 3) steeply dipping thrust events in the down-going plate, 4) upper plate events and 5) unusual events, mostly strike slip in the upper plate. We compare the locations of the events in the different groups to those of the USGS. The differences in location between the two catalogs are shown as a vectors on a map (Figure 1) and on a polar plot (Figure 2) for the five types of events (Figures 1 and 2, a-e) and for all events together (Figures 1 and 2, f).

The hypocenter locations of the thrust events obtained by USGS are mostly towards the NE of the PS2010 locations, although there are also a few event locations in the opposite direction. The average difference in location is 12.5 km towards N72°E, and the median is 17.3 km towards N66°E. Events occurring under the coast have smaller differences in locations than those closer to the trench, but both in the same direction. This leads to a closer clustering in space of the USGS locations.

The normal faulting events have over all smaller errors than the thrust events, but they are all in the same direction, leading to an average that is larger than that of the thrust events, or: 25 km towards N57°E, and a median of 22 km towards N51°E.

The steeply dipping thrust events have a large scatter in location differences (some towards NE and others towards SW), leading to a small average error of 13 km towards N92°E and median of 7 km towards N85°E. There are errors of close to 40 km both in directions NE and SW. The events in the upper plate, all close to Acapulco, have errors smaller than 30 km. The unusual events also have a large scatter, with four events having differences in locations on the order of 10 km, whereas the other three all have errors of 32-55 km. All the average and median differences in locations are listed in Table 1.

Table 1. Average and median length and angle of vector pointing from USGS epicenter location toward PS2010 epicenter, for the different types of events defined in the PS2010 catalog.

Event Type	Average Length [km]	Average Angle [NºE]	Median Length [km]	Median Angle [NºE]
Thrust	12.5	72.2	17.2	66.2
Normal	24.5	56.5	21.7	50.5
Steep Thrust	13.2	91.8	6.7	85.2
Upper Plate	6.7	143.3	5.8	149.0
Unusual	13.9	61.5	10.2	64.8
Total	12.8	75.0	11.2	67.4

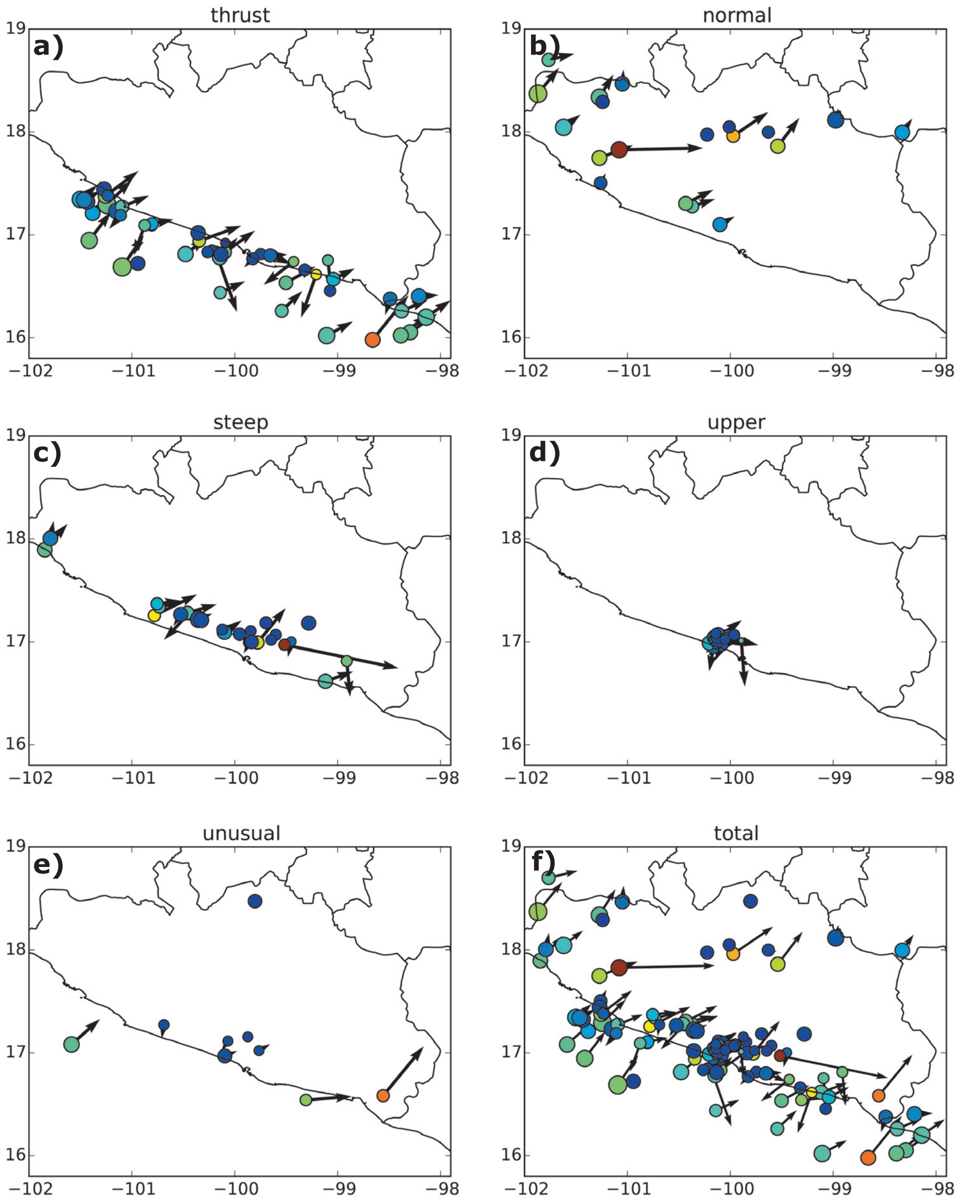

Figure 1. Location difference between events in the PS2010 catalog and the USGS catalog, for 5 different types of earthquakes; a) shallow thrust events, b) normal faulting and c) steeply dipping thrust events in the downgoing plate, d) upper plate events and e) unusual events, mostly strike slip in the upper plate, as well as f) all events together. The arrow points from the PS2010 location to the USGS location. The color of the circle is proportional to the distance between the two locations (the length of the arrow) and the size of the circle is a function of the size of the event. (See Figure 2 for a definition of colores).

Table 2. Average and Median length and angle of vector pointing from USGS epicenter location toward SSN epicenter, for the different segments along the Mexican subduction zone.

Event Type	Average Length [km]	Average Angle [NºE]	Median Length [km]	Median Angle [NºE]
Jalisco-Colima	21.4	62.1	20.6	64.1
Michoacán	33.4	41.6	33.9	42.8
Guerrero	19.6	45.1	16.7	41.5
Oaxaca	27.3	44.4	27.4	55.6
Chiapas	30.8	66.4	31.2	69.3
Total	25.8	53.6	26.1	57.6

The total difference in locations is dominated by the shallowly dipping thrusts and the normal faulting events, as they are relatively more numerous, and shows a striking pattern principally towards the NE and to a lesser extent towards SW, with an average and median differences in location of 13 km towards N75°E and 11 km towards N67°E, respectively. We find that the scatter in location errors is much larger in the trench perpendicular direction, than the trench parallel direction, indicating that the locations are better determined in the latter than the previous.

Effect of magnitude

It is notable that for the thrust events in Figure 2, the error in location appears to be larger for the larger events. This is somewhat counter intuitive, as one would expect smaller events to be more to locate due to their lower signal to noise ratio, and therefore that the errors would be larger. Viewing the distance between the PS2010 and USGS epicenter locations as a function of magnitude (Figure 3), it is evident that the smaller events have a large scatter, ranging from 0-60 km, whereas for events larger than M~5.5 the distance is between 15 and 40 km, and for the three largest events, with 6.5 < M < 7.0, the distance is between 35 and 40 km.

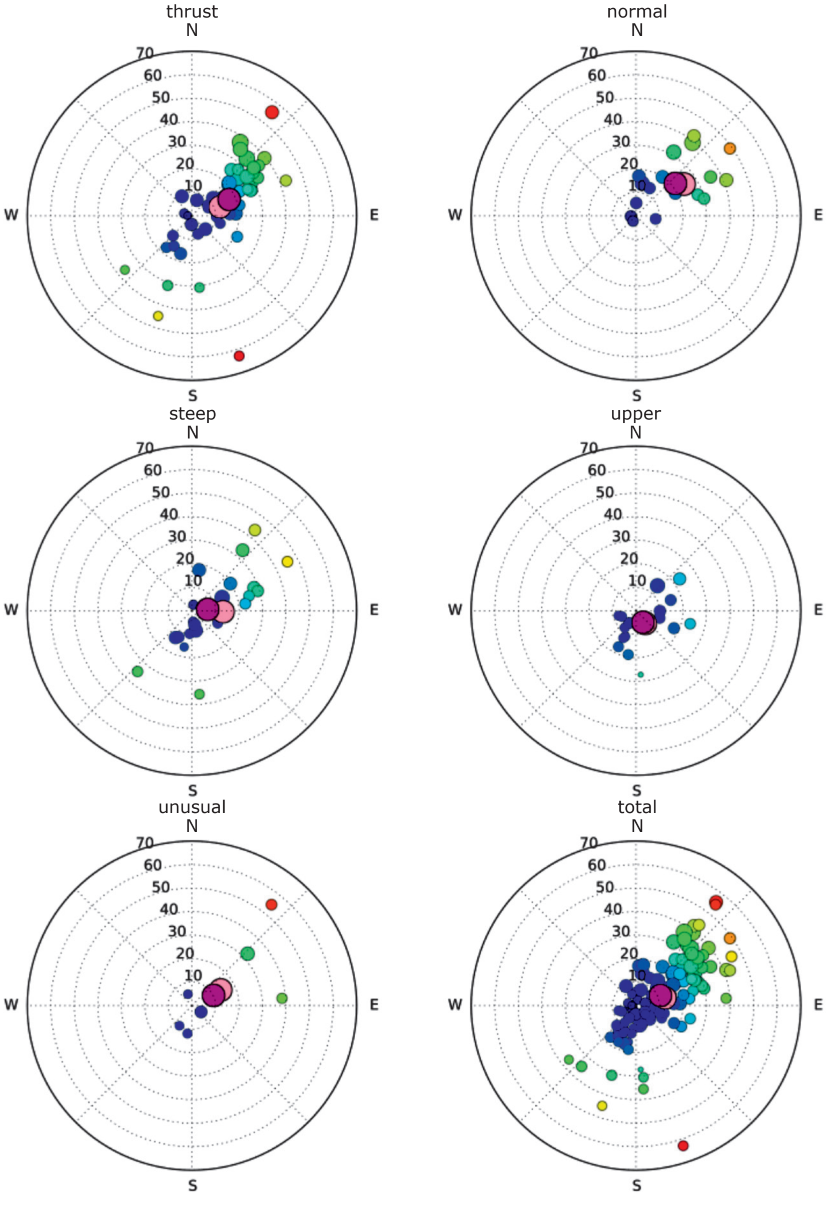

Figure 2. Distance and azimuth from the epicenter in the PS2010 catalog to the one in the USGS catalog, for earthquakes occurring in five different tectonic settings. The subplots, colors and sizes of circles are the same as in the previous figure, except the light pink large circle indicates the mean difference in location, and the large, dark pink circle shows the median difference in location.

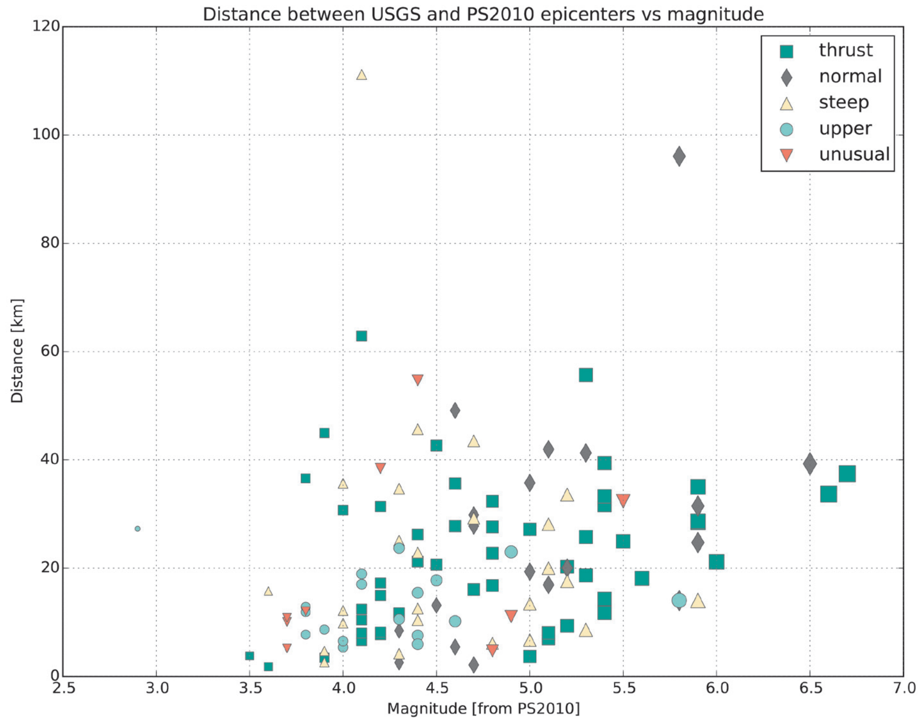

Figure 3. Distance between event location in the PS2010 catalog and the USGS catalog, for earthquakes occurring in five different tectonic settings, as a function of the magnitude of the event. Sizes of symbols represent the size of the event and colors refer to type of event.

Variations with time

It is plausible that the difference in epicenter locations between the PS2010 and USGS catalogs depend on the quantity and distribution of stations available at the time of the event, and as a consequence, could vary over time. We analyzed the difference in locations as a function of time. Although both the local SSN network in Mexico, as well as the global network have changed during this time, this does not seem to have affected the errors in locations, with the possible exception of the steeply dipping thrust events, of which several were detected during the MASE experiment carried out in the period 2005-2007 (Pérez-Campos *et al*., 2008), and all have small differences in locations.

Trade off between location and origin time differences

Due to the asymmetry in distribution of stations, there is a possibility for tradeoff between event location and origin time. We find that most events have differences in origin time between the USGS and PS2010 catalogs of -3 to 2 seconds (Figure 4), with a few exceptions, and for this group of events, there is no strong correlation with difference in epicenter location. Of the 121 events, a total of 11 have timing errors of 2 seconds or more, and all of these have errors in location of 30 km or more. The events with relatively large origin time differences are mostly larger thrust events located closer to the trench, although there are three normal faulting events, and one of each of steeply dipping thrusts and unusual earthquakes in this group as well.

Earthquakes along the Mexican subduction zone

In the previous section we have seen how earthquake locations, as determined by a global network, are systematically offset from those determined by careful analysis of well-recorded earthquakes in Guerrero. The geometry of the subducting slab in Guerrero is unusual in the sense that once the slab gets to a depth of about 40 km, at a distance of 150 km from the trench, it flattens out, and remains so until reaching a distance of about 290 km from the trench (Pardo & Suarez, 1995; Pérez Campos *et al*., 2008; Husker & Davis, 2009). If we suppose that the difference in epicenter locations observed in this study is due to the downgoing rays interacting with the subducting

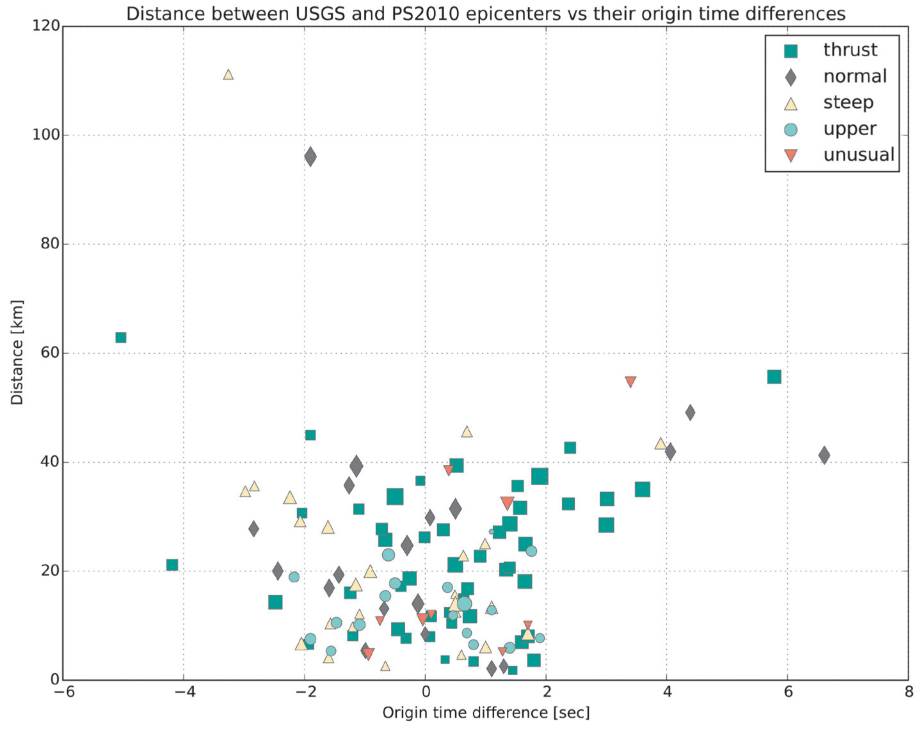

Figure 4. Distance between event location in the PS2010 catalog and the USGS catalog, for earthquakes occurring in five different tectonic settings, as a function of differences in hypocentral time. Sizes of symbols represent the size of the event and colors refer to type of event.

slab, we would expect that the difference in epicenter location would vary along the trench, reflecting the dip of the slab. A larger dip would lead to longer segments of the raypaths within the fast slab, and therefore larger travel time anomalies and consequently larger differences in epicenter locations between local and global data. In this section we look for such a variation.

We compare epicenter locations from the NEIC/USGS catalog used in the previous sections, to locations obtained using data from the local SSN network. Again we associate events in the two catalogs. In this case there are many events that are only in one catalog, and those are discarded. The associated catalog contains 6266 events, registered in the period between 2000 and 2014, of magnitudes ranging from 3.2 to 7.6. As we are mainly interested in the location differences for larger events in the subduction zone, we limit ourselves to the 272 events with $M \geq 5.0$ and depths ≤ 40 km. It is to be kept in mind that for these two catalogs the interpretation of the difference in epicenter location is not as straight forward as for the previous two, given that in this case there may be significant errors in both locations. We divide the subduction zone, from the west to east, in sections as determined by the states (joining the first two); Jalisco-Colima, Michoacán, Guerrero, Oaxaca and Chiapas.

As in the previous section, the differences in epicentral location between the two catalogs are shown as vectors on a map (Figure 5) and on a polar plot (Figure 6), now for the five different regions (Figures 5 and 6, a-e) and for the whole subduction zone (Figures 5 and 6, f). The differences in epicenter location between the two catalogs in Jalisco-Colima (Figure 5) show a very consistent pattern, with differences reaching values of up to 80 km, with a very consistent direction, slightly more eastward than seen for Guerrero in the previous section. The average difference is 21 km, at an angle of N62°E.

Offshore Michoacán the differences are larger, but have a smaller variability and are consistently towards the north-east, with an average difference of 33 km at an angle of N42°E. The USGS location is towards the shore of the SSN location for all events. Events closer to the trench have a larger difference in locations than events near the coast.

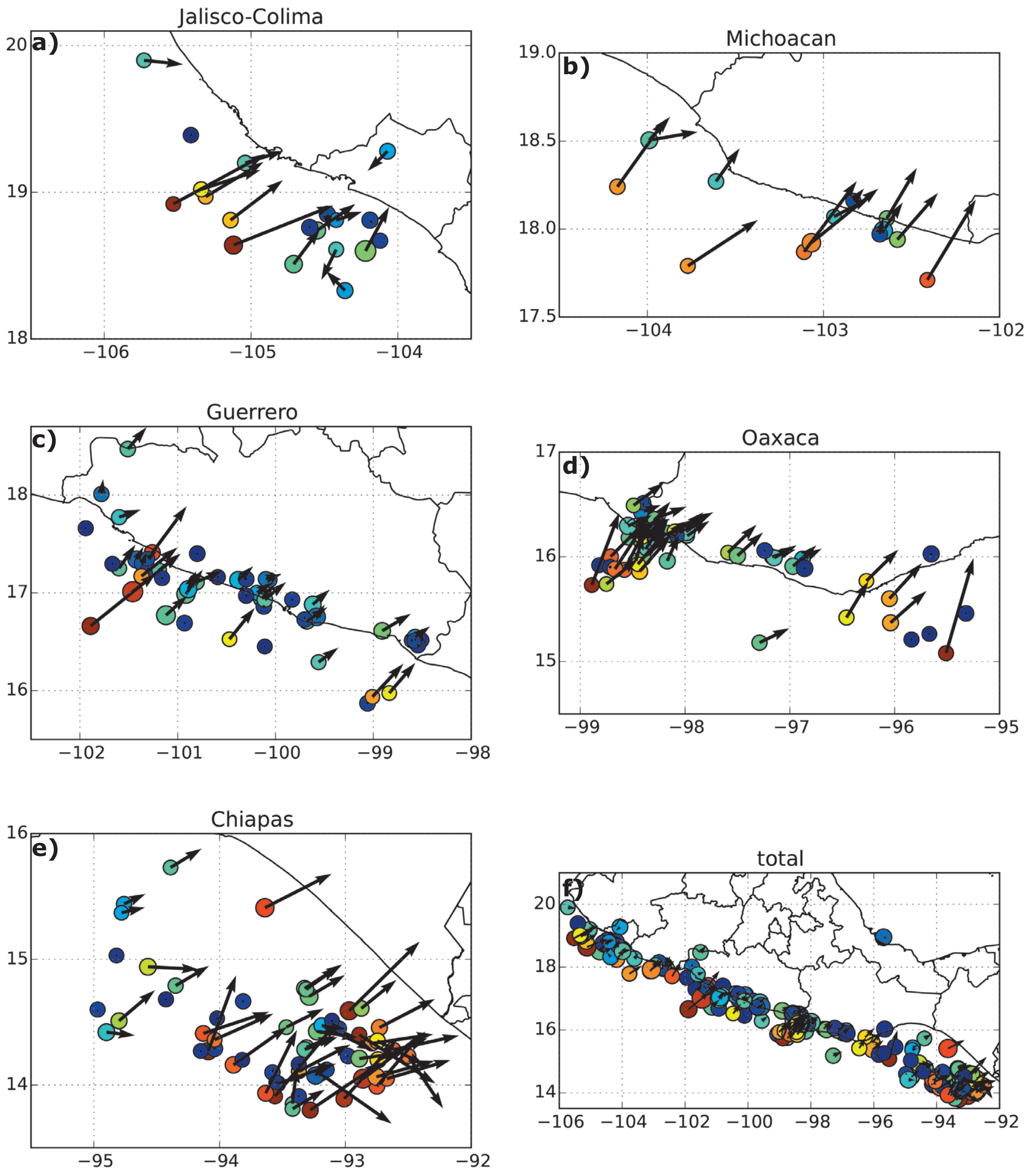

Figure 5. Location difference between events in the SSN catalog and the USGS catalog, for 5 different regions; a) Jalisco-Colima, b) Michoacán c) Guerrero, d) Oaxaca and e) Chiapas, as well as f) all events together. The arrow points from the SSN location to the USGS location. The color of the circle indicates the distance between the two locations and the size of the circle is proportional to the size of the event.

The pattern in Guerrero is similar to that of Michoacán, with a smaller average error, or 20 km towards N45°E. The largest error, of close to 80 km, is observed for an event very close to the trench, also studied in the previous section. The average error is substantially larger than obtained for the same region in the previous section.

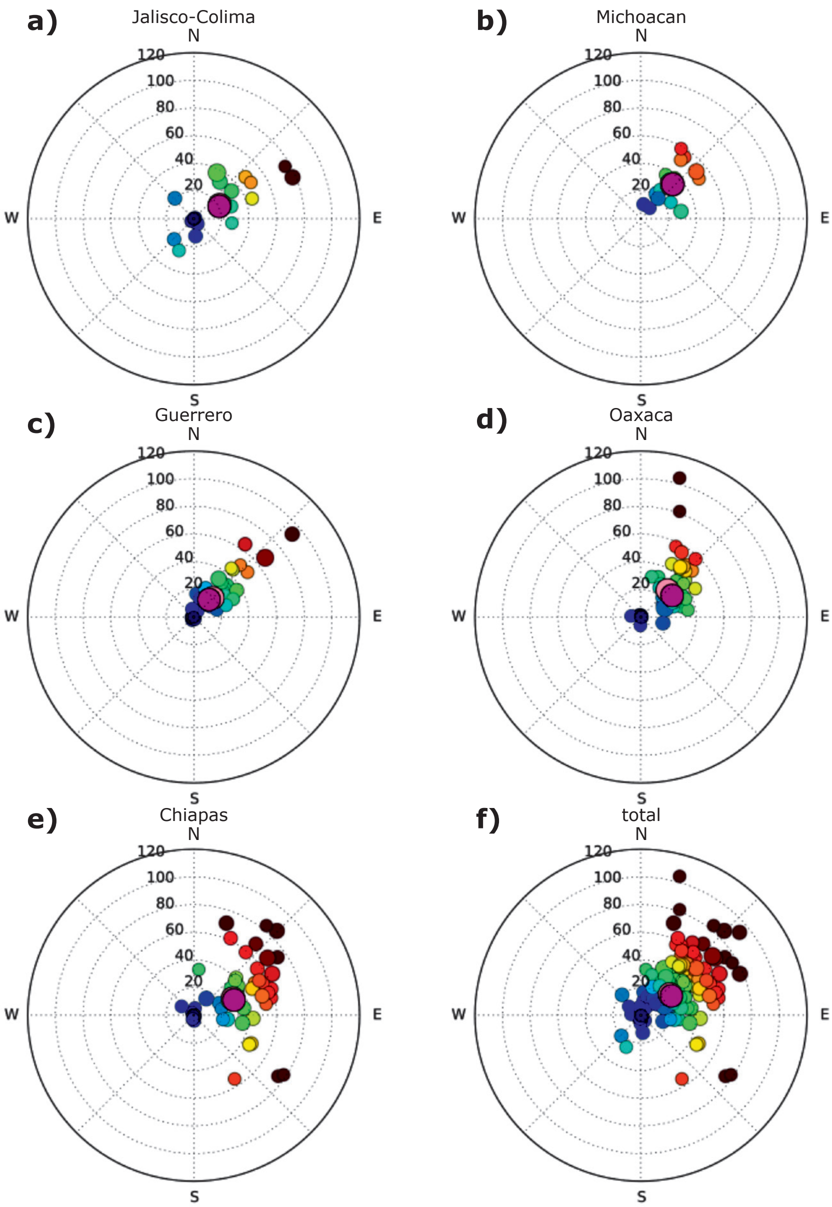

Figure 6. Distance and azimuth from the epicenter in the SSN catalog to the one in the USGS catalog, for earthquakes occurring in five different regions. The subplots, colors and sizes of circles are the same as in the previous figure, except the light pink large circle indicates the mean difference in location, and the large, dark pink circle shows the median difference in location.

The earthquakes in Oaxaca split into three groups. The first group clusters around the rupture zone of the 2012 Ometepec-Pinotepa Nacional earthquake. There are a large number of events in this cluster, with similar differences in locations. As seen in other regions, the differences in locations for events closer to the trench are larger than those for events closer to the coast. In central Oaxaca there is a group of earthquakes, located just onshore, with smaller differences in locations. In eastern Oaxaca there are more events far offshore with a relatively indecisive pattern, with one earthquake with a difference in location of more than 100 km right next to earthquakes with differences smaller than 10 km. We reanalyzed the very anomalous event, and confirmed that S-P time differences observed on the SSN network stations were consistent with the SSN location.

The events in Chiapas occur mostly in the aftershock zone of the 2012 Guatemala earthquake. These events have relatively large errors, with two dominant directions, towards NE and SE, overlapping. Here it is useful to keep in mind that these events are further from the core of the SSN network than other events in this study, and it is therefore probable that a substantial part of the differences in SSN locations and USGS locations for these events may be due to errors in the SSN location.

In summary, we find that there are differences in average mislocations for the various regions. The average errors are larger in Michocán, and smallest in Guerrero. However, we also notice that in Michoacán (Figure 5b), there are relatively more earthquakes closer to the trench, where we do see larger errors in the whole subduction zone, compared to the area closer to the coast where there is an abundance of earthquakes in Guerrero (Figure 5c). We therefore conclude that the bulk of the variation of the difference in location along the coast is not from interaction with the fast slab, but rather an effect of varying location perpendicular to the trench.

Effect of Magnitude

When comparing the USGS and PS2010 catalogs, we found that for events in Guerrero, the difference in epicenter location was larger for larger earthquakes. Analyzing the difference in location as a function of magnitude (Figure 7) between the USGS and SSN catalogs, we find that the trend is not as clear as was seen in the previous section. However, for events with M > 6.0, it is uncommon that the difference is smaller than ~20 km, and for about half those events, the difference is larger than ~40 km, again suggesting an increase in error with magnitude. It should also be mentioned, that when including the whole associated catalog, with events of magnitudes 3.2 to 7.6, the errors were not so systematic and average errors were on the order of 5 km. On the contrary, while analyzing the differences in locations from different agencies for events in the 70s and 80s Singh & Lermo, (1985), found that the difference does not increase with magnitude, rather the opposite. We attribute this change, from then to now, to the very different station coverage and data quality.

Differences in event time

For the events in Guerrero studied in the previous section, we found that there was a trade-off between the difference in epicenter location and the origin time difference between the two catalogs. For the events studied in this section, we find an even stronger pattern (Figure 8). In general, the difference in location is smallest for events with an USGS determined event time of 0-5 seconds later than the SSN event time. This is true for events in all regions, except for Chiapas, where there is a relatively larger scatter. A difference in time of 10 seconds is observed for the event in Oaxaca that has a difference in location of more than 100 km. Similarly to the previous section, we find that the events that have the largest positive differences in time are on average closer to the trench.

Discussion

In the previous sections we observed that there is a systematic bias in hypocenter locations for events on the subduction interface in Mexico, with hypocenters obtained from teleseismic seismograms located 10-40 km towards the north-east from hypocenters from obtained from local seismograms. As this is true for both very well located earthquakes in Guerrero, as well as for events in the local SSN catalog located along the whole subduction zone from Jalisco to Chiapas, we deduce that the bulk of the difference comes from bias in the teleseismic locations, rather than the locations based on local data.

The SSN, PS2010 and USGS all use different 1D velocity models for locating the events. We suppose that the main source of error in location is that the 1D models used are not representative of the velocity along the trajectories between the events and the stations, and that the velocity may be different for the same event but different stations, due to lateral heterogeneities. Lateral heterogeneities that are of opposite sign in opposite directions have the largest effect on the locations.

There are two possible locations of the velocity anomalies that translate into travel time anomalies and therefore location errors; 1) near the source and 2) in the deep mantle along the trajectories of the rays. To discriminate between these two sources of error several observations are to be kept in mind. First, the errors are larger for shallow thrust events close to the trench. Second, the error is larger for larger events. Third, the station distribution is very uneven in azimuth, with most of the global network towards the north and east (in North-America, North-Asia and Europe), with few and noisy island stations towards the south and west. Fourth, the errors are consistent all along the trench, with large errors both where the slab is relatively steep (Jalisco, Chiapas) and where it is flat (Guerrero).

In order to investigate further the ray coverage for events of different sizes within the Mexican subduction zone used by the USGS for the event location determination, we show the ray coverage for four earthquakes of M 7.2, 6.4, 4.8 and 3.9 occurring in the western Guerrero region in April/May of 2014 (Figure 9). The color of the ray is determined by the residual ($t_{observed} - t_{predicted}$) for each path, where $t_{predicted}$ is the travel time calculated between

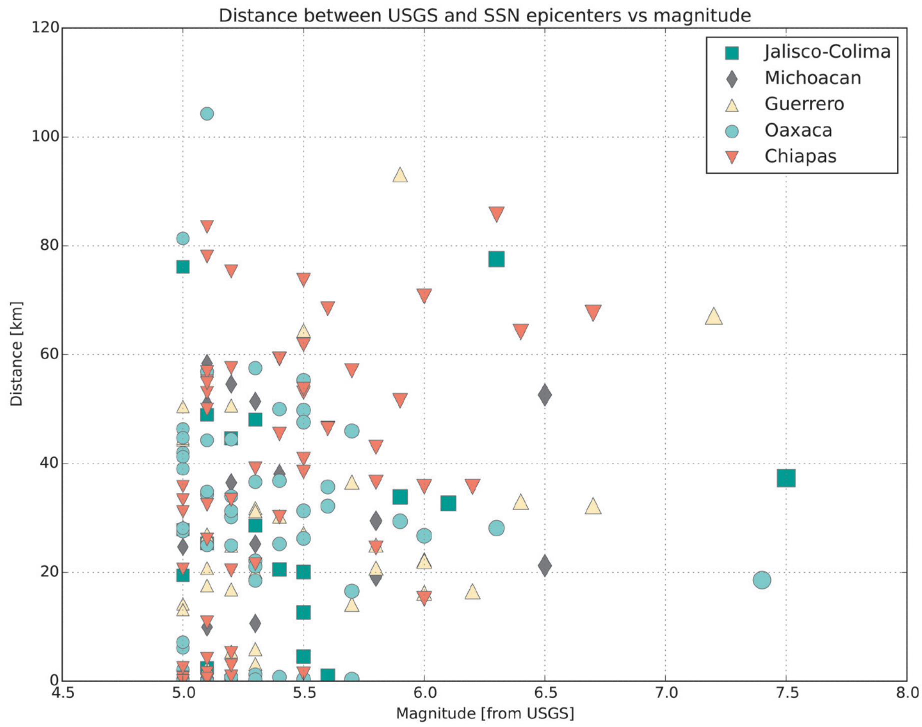

Figure 7 Distance between event location in the SSN catalog and the USGS catalog, for earthquakes occurring in five different regions, as a function of time of occurrence. Sizes of symbols represent the size of the event and colors refer to type of event.

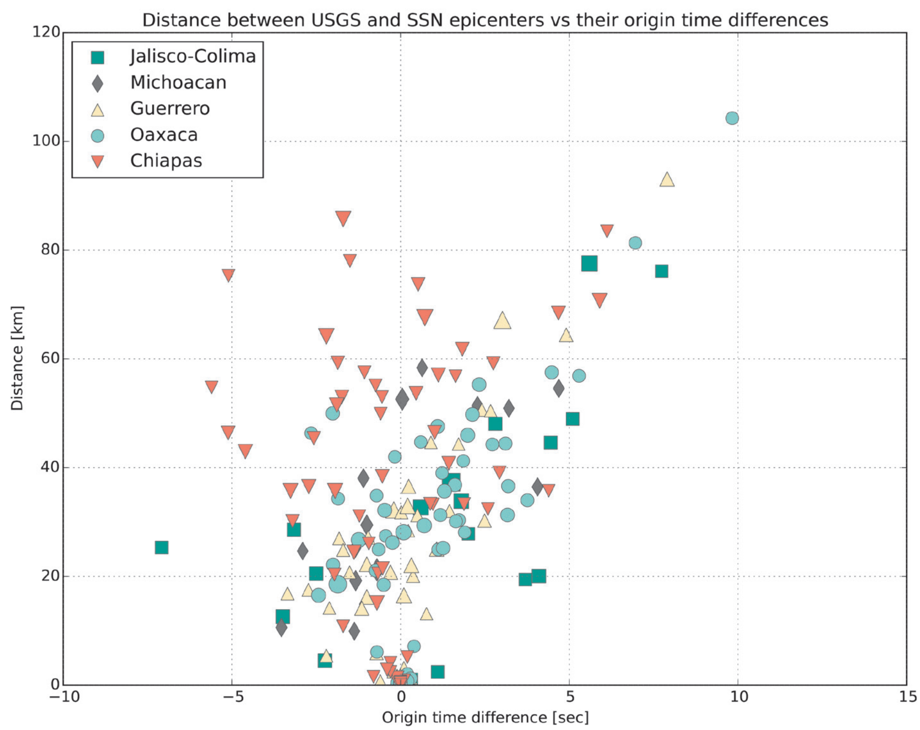

Figure 8. Distance between event location in the SSN catalog and the USGS catalog, for earthquakes occurring in five different regions, as a function of differences in hypocentral time. Sizes of symbols represent the size of the event and colors refer to type of event.

the USGS location and each station for a 1D Earth model.

The azimuthal coverage for the largest event is relatively even, and P-waves are reported on several stations in the Pacific Ocean, including Wake Island (WAKE), Fiji (MSVF) and two stations in Hawaii (KIP and POHA). Furthermore, PKP_{df} waves are reported on stations in Australia (COEN, WRAB, FORT and NWAO). The second largest event is observed at much more stations, or a total of 724 phases. Of these, several (MLOD, HSSD, AIND, POHA, MLOA, HUAD, OPA, HON, KIP, KEKH and MSVF) are located in the Pacific Ocean. Core phases from 45 stations are used for the location. The two smallest events are not observed on any stations in the Pacific and have azimuth gaps of almost 200°. For all events we see slower than predicted (red) paths to the NW and SE, whereas paths to the NE and SW are faster (blue) or similar to predicted. However, the delays observed in opposite directions are generally similar.

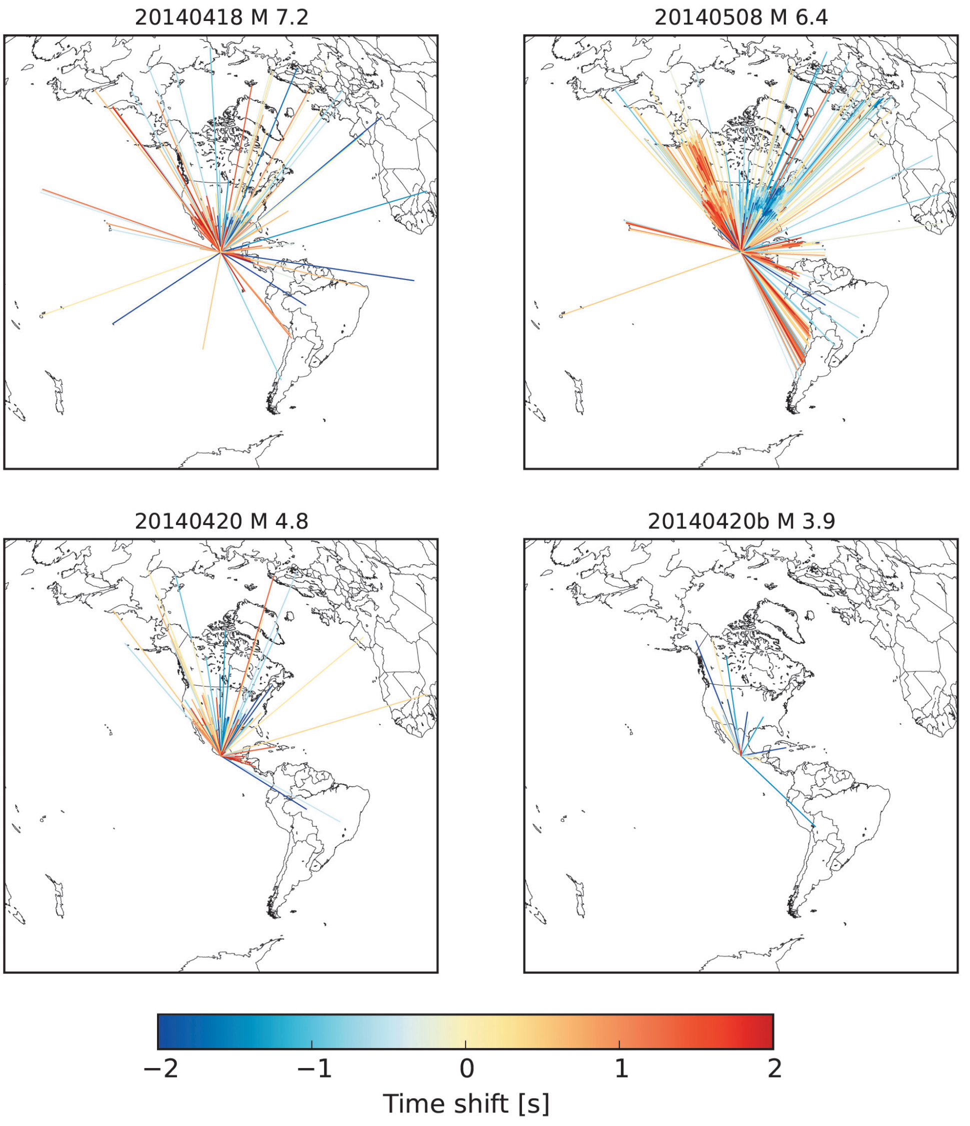

Figure 9. Delay times as reported by USGS/NEIC, for their best fit location. The four different events is the April 18th, 2014, 14:27:25, Papanoa earthquake, and three of its aftershocks; M 6.4, 2014-05-08, 17:00:15, M 4.8, 2014-04-20, 12:40:36, M 3.9 2014-04-20b, 07:42:49.

Residuals calculated for the SSN location (Figure 10) are very different. All the paths between NW and SE (going clockwise) are too fast, whereas paths going in the opposite directions are relatively slower. For the M 4.8 event, all the paths are too fast, but almost equally fast in all directions.

The length and angle (east of north) of the vector pointing from the SSN location towards the USGS locations of the four events, listed in order of magnitude, from largest to smallest, are; (67 km, N40°E), (33 km, N57°E), (15 km, N45°E) and (4 km, N180°E) respectively. The location reported by the SSN for the April 18th event is significantly different to that obtained from careful analysis of particle motion at several close stations, 17.375N, 101.055W (UNAM Seismolog Group , 2015). The USGS hypocenter is 9 km N74°E of this location. This event was particularly emergent, which may have caused different parts of the emergent P-wave to be picked at different stations, depending on their noise level, causing the mislocation.

In summary we find that as the duration of the event increases and as more distant stations, as well as stations in the Pacific are added, the difference in the location increases. For the 2014 Papanoa mainshock, the increased difference is a combination of; (1) an error in the SSN location, which is more difficult to estimate due to a lack of S-waves uncontaminated by late arriving P-waves, and (2) a bias due to the 3D structure along the rays.

Global tomography models (e.g. Kustowski *et al*., 2008) show that in the deep mantle there is a relatively fast zone towards the northeast of the study area, whereas there is a relatively slower zone (the Pacific superplume) towards the southwest. The interaction of rays with these zones would speed rays towards the northeast and slow rays towards the southwest. Consequently they would appear originating from a source further towards the northeast than the true location.

Conclusions

We have analyzed the differences in hypocenter locations of earthquakes in Mexico, between the USGS catalog which is principally based on globally observed travel times and two catalogs obtained from locally observed travel times; the PS2010 and SSN catalogs. The former contains 132 very well located earthquakes in the Guerrero segment of the subduction zone, and the latter is comprised of almost 40000 earthquakes in all of the Mexican territory, that do not adhere to as strict criteria in quality of locations as the PS2010 catalog.

We find that the average distance from hypocenter locations of earthquakes larger than M 5 in the Mexican subduction zone in the global catalogs is 26 km towards N54°E of those in the local catalogs. We find that the magnitude and angle of the mislocation varies, by a small amount, along the coast. This value can be used for a very approximate correction of the USGS hypocenter, for early response purposes. The largest average errors of 33 km, are observed in Michoacán, and the smallest in Guerrero, where they are only 20 km on average. The average angle ranges from N42°E in Michoacán to N66°E in Chiapas.

The errors are found to be larger for shallowly dipping thrust events close to the trench, and smaller for steeply dipping thrust events, occurring inland. The errors are due to lateral variations in mantle structure that is asymmetric with respect to the Mexican subduction zone coastline. The errors seem to be exaggerated by using stations at large distances, and hence they may be larger for earthquakes of larger magnitudes.

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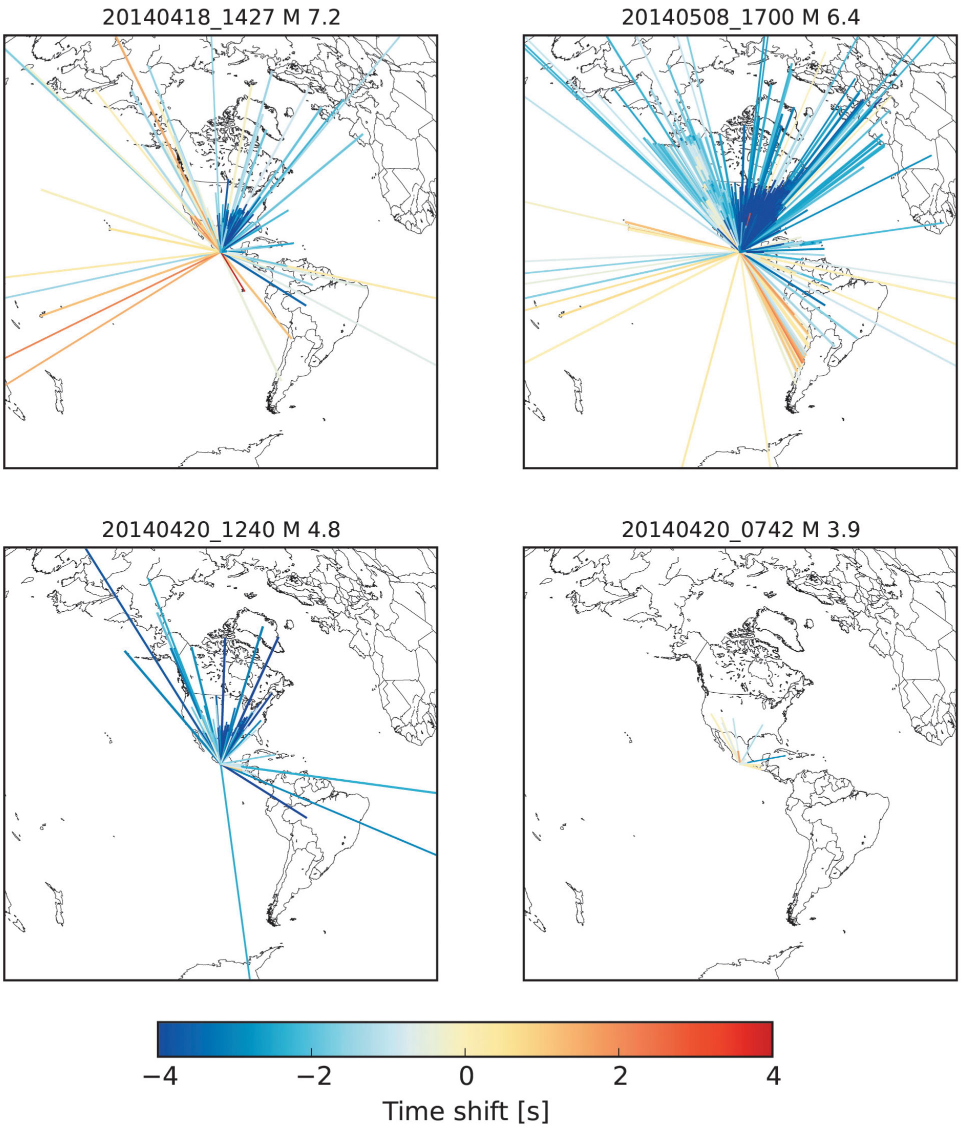

Figure 10. Same as Figure 9, except with delay times as would have been calculated by the USGS for the hypocenter reported by the SSN. Note that, the colorbar has a larger range.

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