

1. Abstract

Reducing the prediction error of seismic-phase travel times leads directly to improvement in earthquake location accuracy. One-dimensional (1D) velocity models are most commonly used to calculate seismic phase travel times because computer codes are readily available and the computations are inexpensive. Travel time predictions based on 1D models are accurate to within 1 to 2 seconds at teleseismic distance, but complex crust and upper mantle structure can triple prediction errors at regional distance. Increased travel time prediction error at regional distance is particularly prevalent in regions like Central America, where subduction tectonics results in large lateral variations in seismic velocity and crustal thickness. The Regional Seismic Travel Time (RSTT) method (Myers et al., 2010) was specifically developed to improve travel time prediction accuracy by accounting for 3D seismic velocity structure. In this study, we update the RSTT 3D velocity model in northern and central Costa Rica using published studies of velocity structure (DeShon et al., 2006 and Arroyo et al., 2009). Travel times for the updated model are compared to observed travel times for well-constrained earthquakes. We relocate the earthquakes using only regional data to measure the improvement in location that can be achieved with the updated model.

2. Regional Seismic Travel Time (RSTT) Model

- > The RSTT model has 6 crustal layers at each node and the mantle is separated into a mantle velocity below the Moho boundary and a velocity gradient with depth (Figure 1). Interpolation between the nodes creates the 3D velocity model (Myers et al., 2010).
- > Following Zhao and Xie (1993) the traveltimes is calculated as shown below. This constrains the ray path in the mantle, making travel time calculation computationally efficient.
- > Tomographic ray coverage is excellent for North America and Eurasia, but could be improved in other regions, Latin America being our focus.

$$TT = \sum_{i=1}^N d_i s_i + \alpha + \beta + \gamma, \quad \gamma = \frac{c^2 X_m}{24V_0}$$

where

- d, s : distance and slowness
- $!: crustal travel times at receiver/source$
- X_m : horizontal dist. traveled in the mantle
- V_0 : regional av. mantle velocity at Moho
- c : mantle velocity gradient

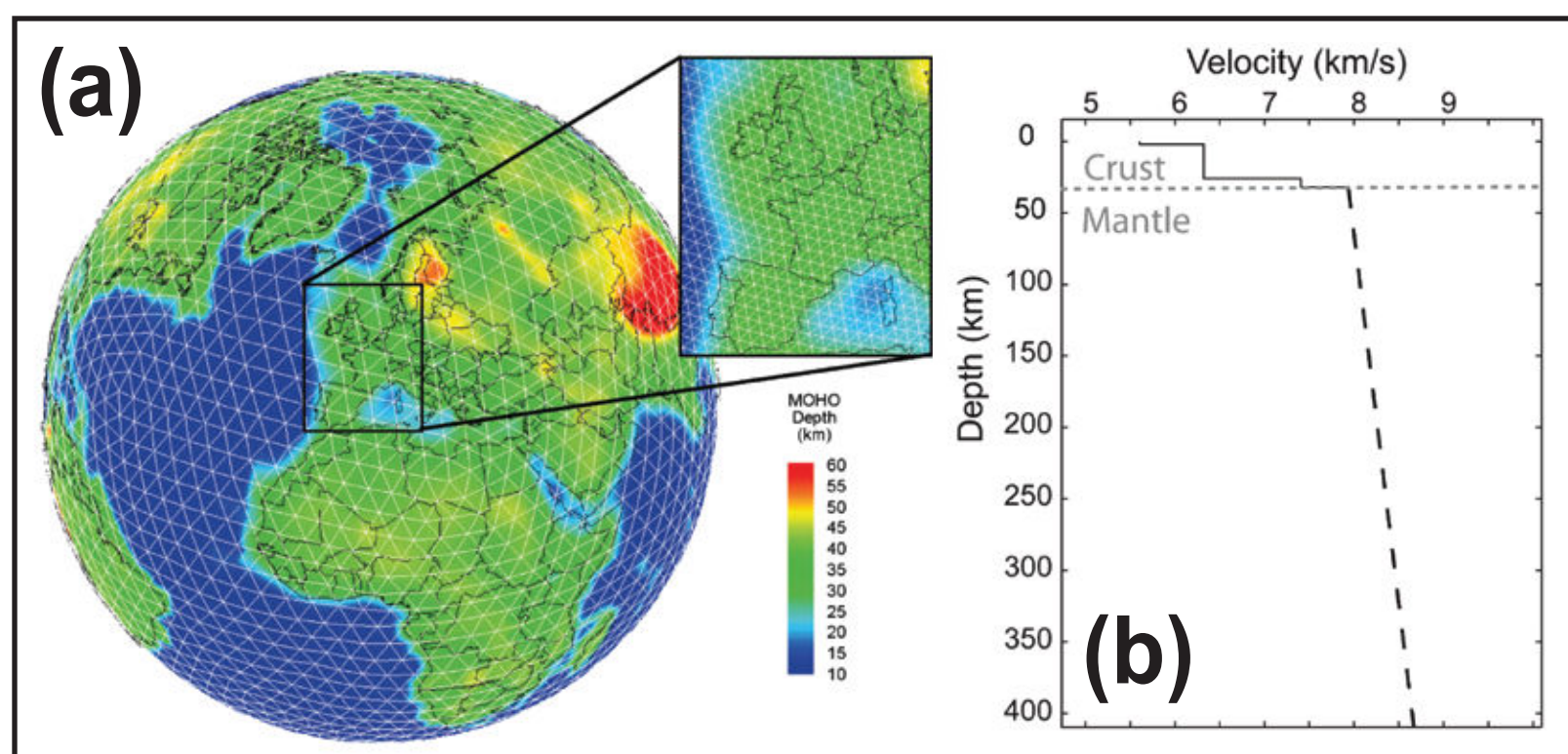


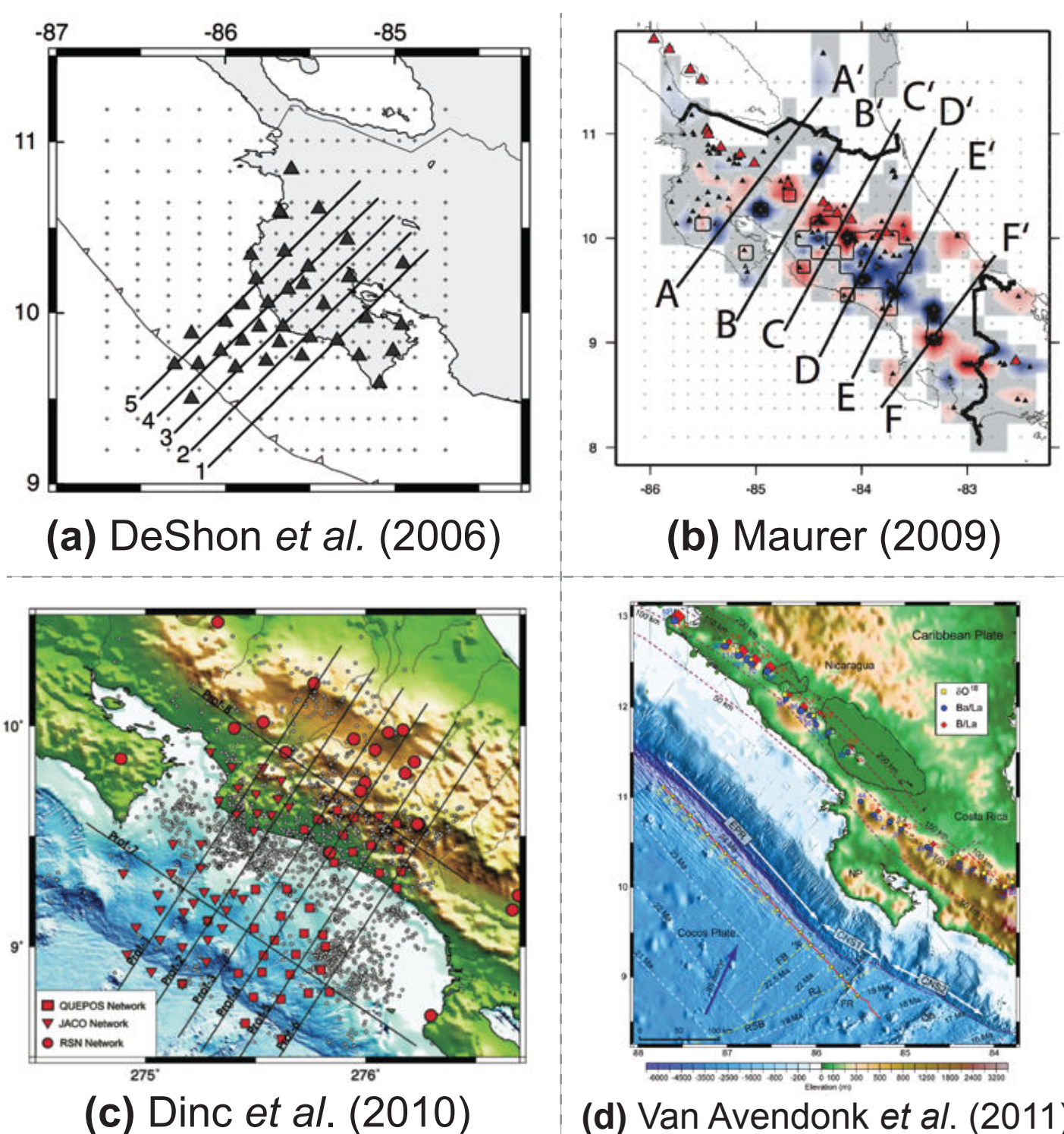
Figure 1. From Myers et al. (2010) showing the global model tessellation with color as the Moho depth (a) as well as an example of the velocity model vs depth in each node of the grid (b).

3. Tomography in Costa Rica

Many tomographic studies have focused on improving velocity models for Costa Rica, partially incorporating the well instrumented Nicoya Peninsula, as well as including many ocean bottom stations. Several of these studies are shown in Figure 2 below.

We used these studies to improve the RSTT velocity model in this area. We replaced a total of 10 nodes in Northern, Central Costa Rica as well as some on the Pacific and Caribbean coasts (Figure 4).

Figure 2. Several imaging studies performed to improve velocity models in Central and Northern Costa Rica. The references for these studies are shown below each map.



4. RSTT Tomography and the Modified Model

The starting model is well developed for North America and Eurasia (Figure 3). For these areas, tomography was performed for all regional phases (Pn, Sn, Pg, Lg). The method performs an LSQR inversion that solves for upper mantle slowness and square of the gradient, and an adjustment to the crustal slowness (Myers et al. 2010).

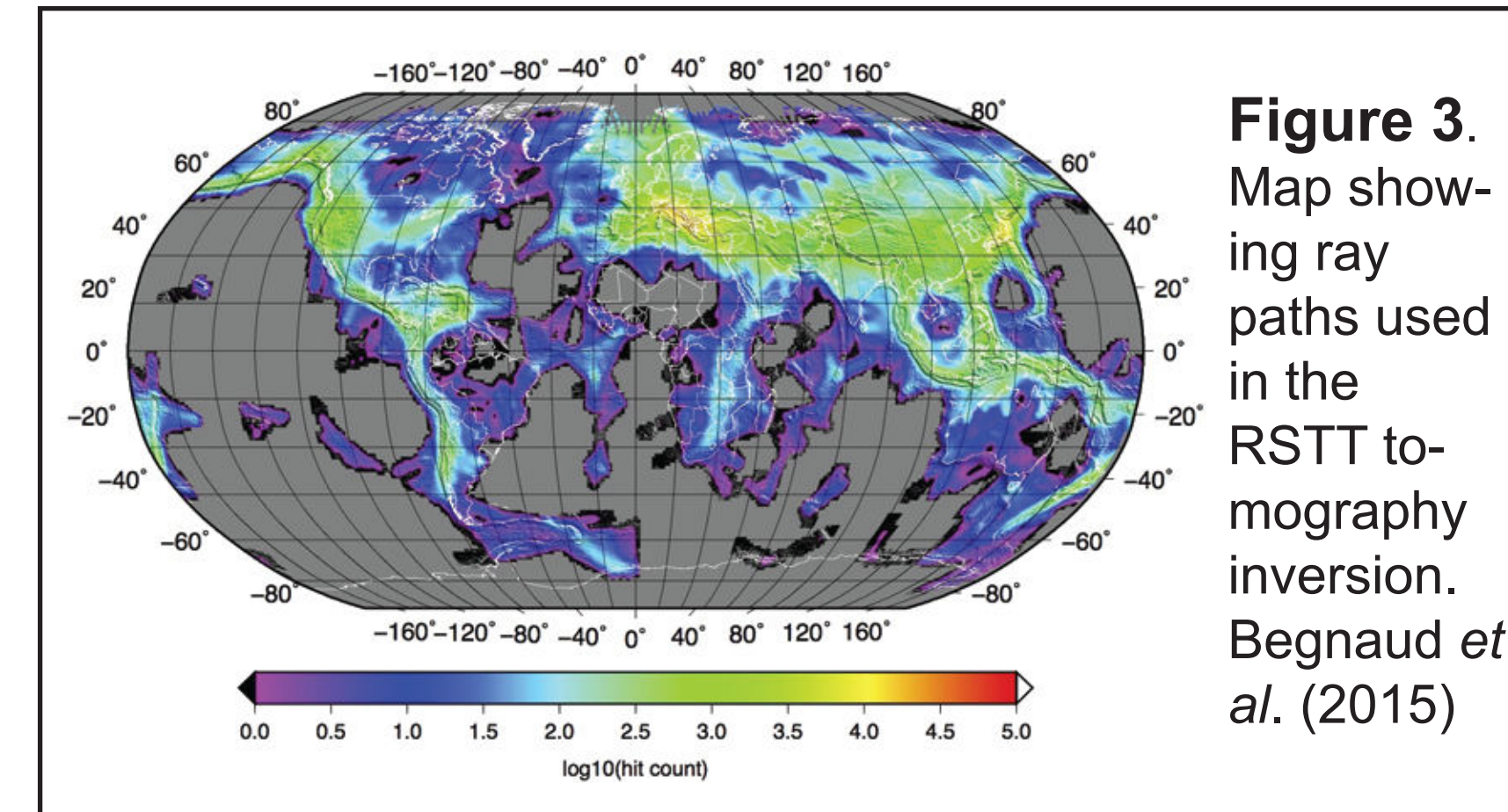


Figure 3. Map showing ray paths used in the RSTT tomography inversion. Begnaud et al. (2015)

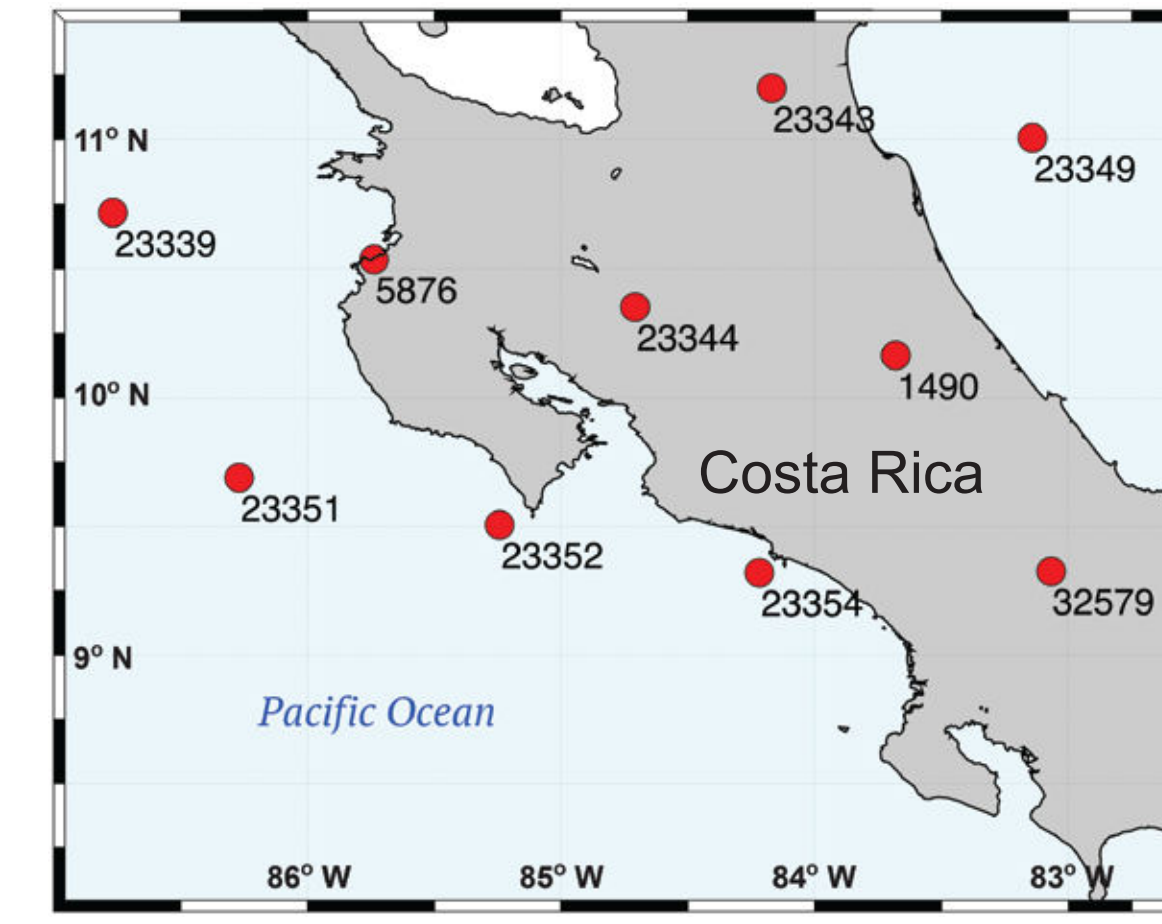


Figure 4. Map of Costa Rica showing the nodes modified in the RSTT model to calibrate tomography for the area in this study.

To fill in the data gaps in the RSTT model it is necessary to incorporate more data in those areas not well covered yet.

As we focus on the central and northern regions of Costa Rica, we use the tomographic models shown in Figure 2 to modify and improve the model nodes shown in Figure 4, where data is available.

We create a modified RSTT model and use it to relocate local well constrained events. We can see the difference between the old and modified models in Figure 5 for P-wave velocity and Moho depth.

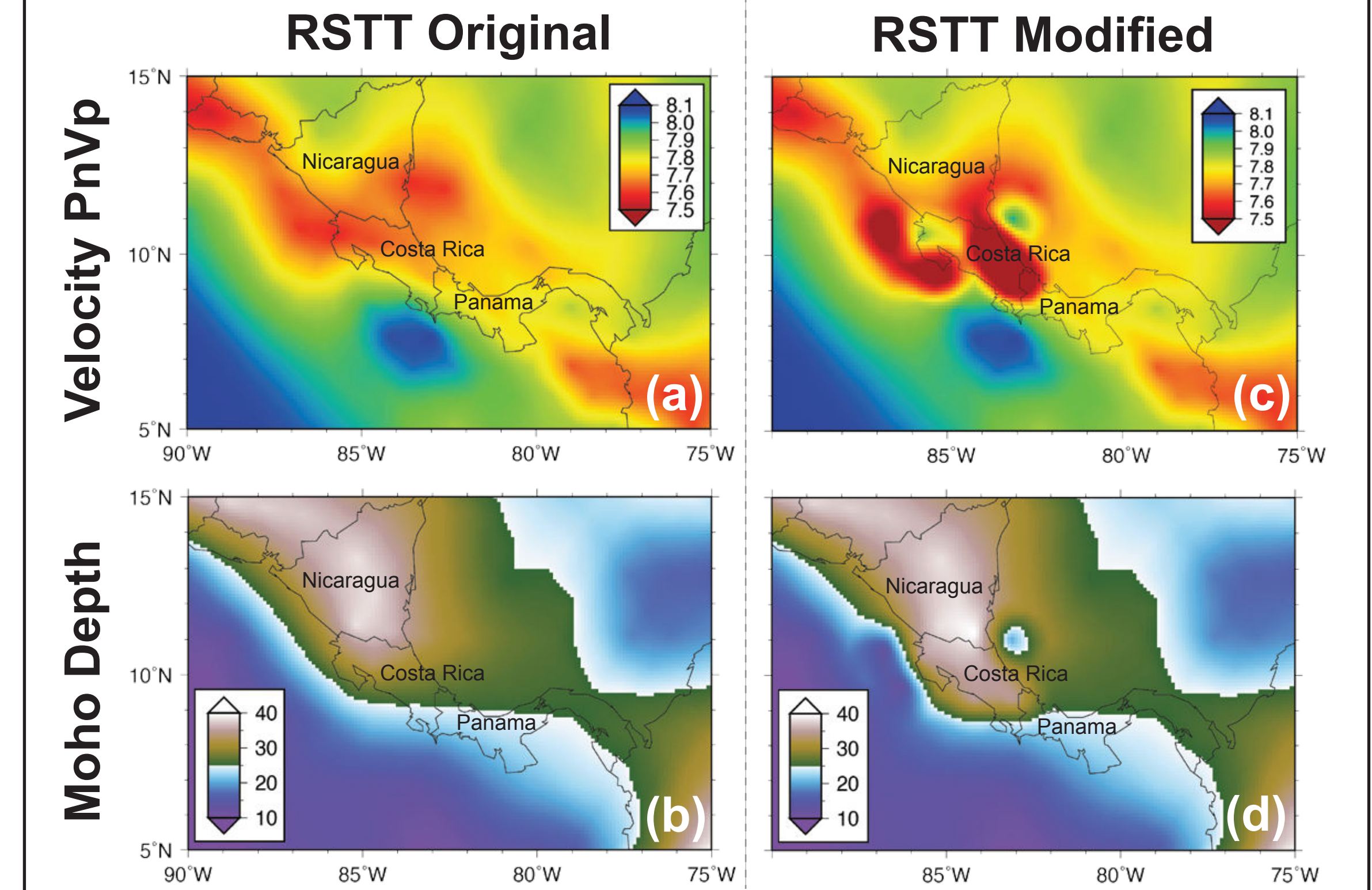
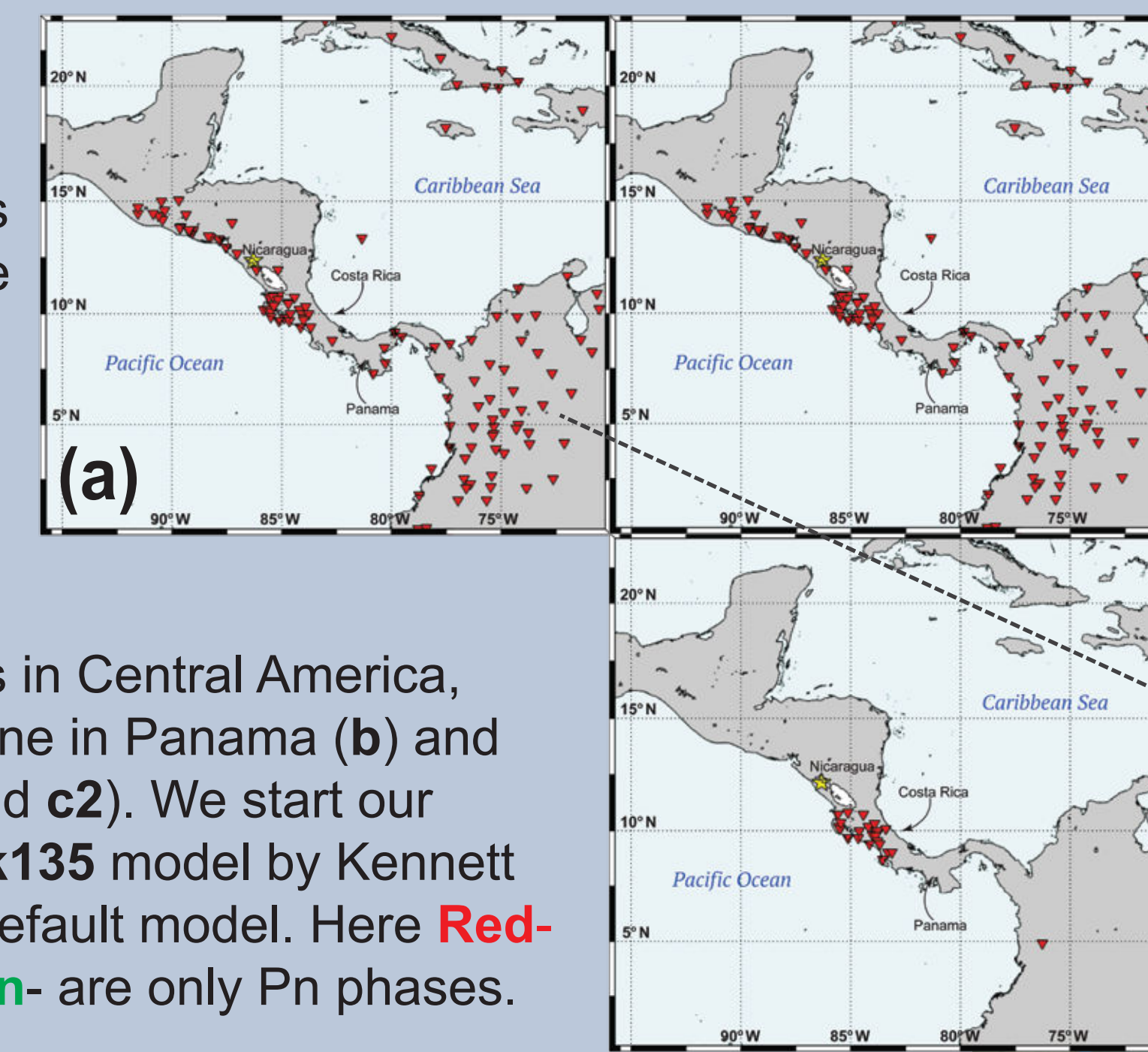


Figure 5. RSTT Tomography using the original model (a and b) and the new RSTT model (c and d) with the modified nodes shown in Figure 4. Top figures show the mantle velocity at the Moho (km/s) for each model and the bottom figures show the Moho depth (km).

5. Improved Locations

To test the improved RSTT model (Figure 5), we focus on events with high confidence locations based on a large number of arrival times (ground truth events, "GT"). We locate these events using iLoc, an iterative reweighted least squares method, which downweights hypocenter outliers as it progresses (Bondár and Storchak, 2011). The locator supports local velocity models.

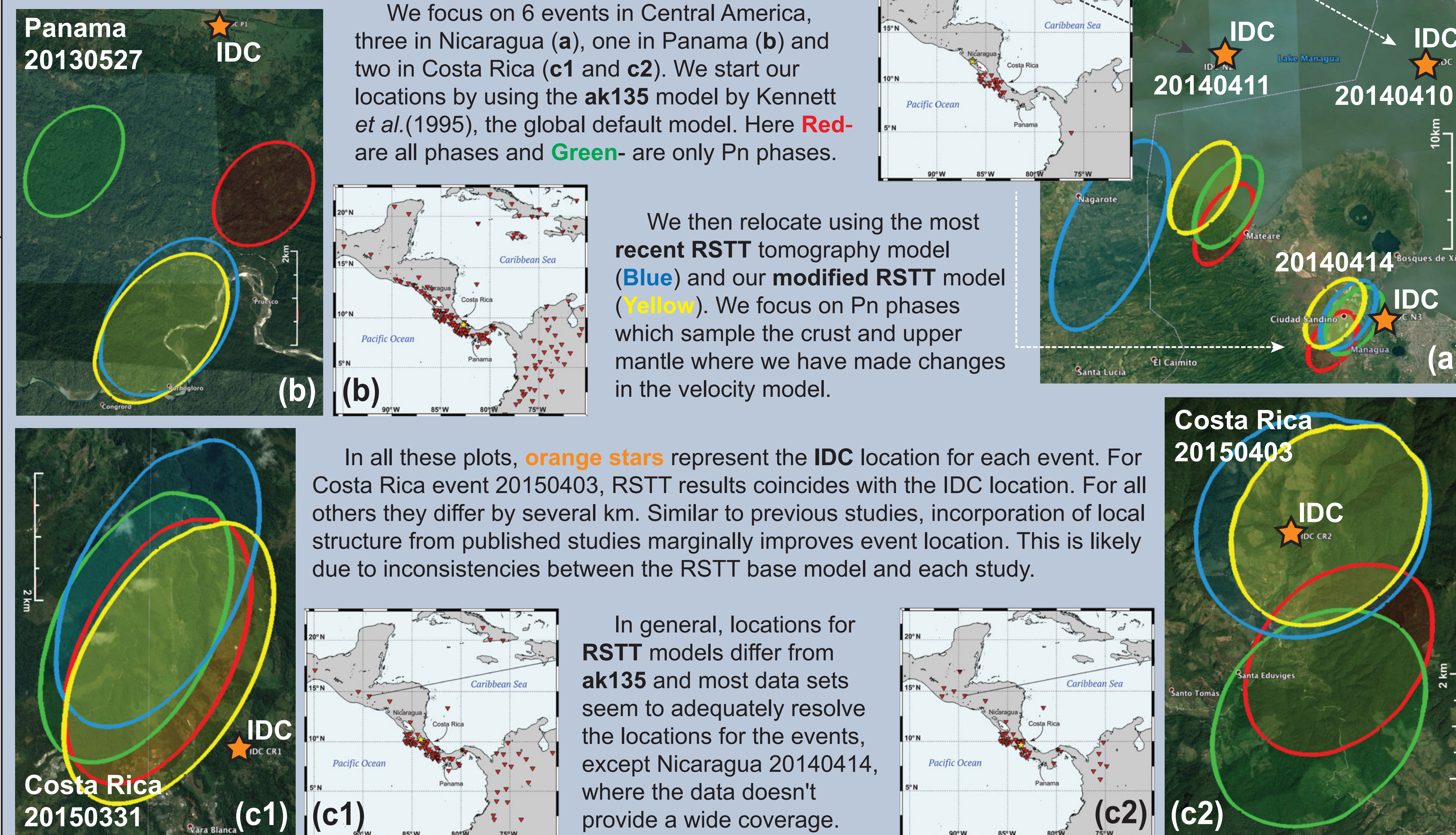


We focus on 6 events in Central America, three in Nicaragua (a), one in Panama (b) and two in Costa Rica (c1 and c2). We start our locations by using the ak135 model by Kennett et al. (1995), the global default model. Here Red- are all phases and Green- are only Pn phases.

We then relocate using the most recent RSTT tomography model (Blue) and our modified RSTT model (Yellow). We focus on Pn phases which sample the crust and upper mantle where we have made changes in the velocity model.

In all these plots, orange stars represent the IDC location for each event. For Costa Rica event 20150403, RSTT results coincides with the IDC location. For all others they differ by several km. Similar to previous studies, incorporation of local structure from published studies marginally improves event location. This is likely due to inconsistencies between the RSTT base model and each study.

In general, locations for RSTT models differ from ak135 and most data sets seem to adequately resolve the locations for the events, except Nicaragua 20140414, where the data doesn't provide a wide coverage.



6. Conclusions

- > RSTT is a powerful method as it allows the incorporation of local structure in the model for improved locations.
- > Adjustments to the RSTT model based on published studies improve estimates of crustal thickness and velocity, which are consistent with the regional tectonics.
- > Similar to previous studies, incorporation of structure from published studies marginally improves event location.
- > The next step is incorporating the new data into an update of the RSTT tomography model.

References

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