The Rupture Characteristics of the 1999 Izmit Earthquake Sequence Using Geodetic and Seismic Data

A. Ozgun Konca[1], Don Helmberger[1], Sebastien Leprince[1], Jean-Philippe Avouac[1]

[1]Tectonic Observatory, California Institute of Technology e-mail: ozgun@gps.caltech.edu

Introduction

[The 1999 M_W7.5 Izmit and M_W7.1 Duzce earthquakes provide unique opportunities to study source caharacteristics using multiple datasets including teleseismic and strong-motion, SPOT GPS and field measurements. This study focuses on using various combinations of datasets to understand the kinematics of these earthquakes. The proximity of these events are also very useful since they can be used for path calibrations of teleseismic body waves.

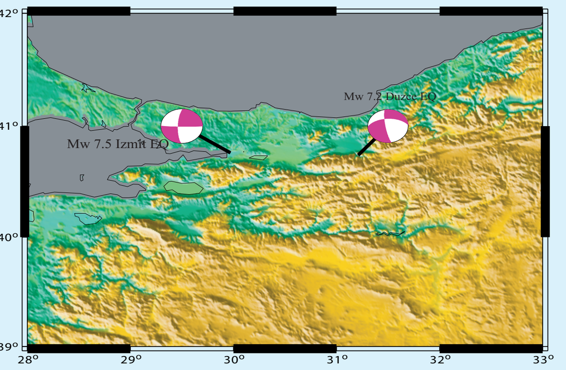


Figure 1: Local network (Kandilli) locations and Harvard CMT solutions of the events used in this study

1. Path Calibration for teleseismic inversions

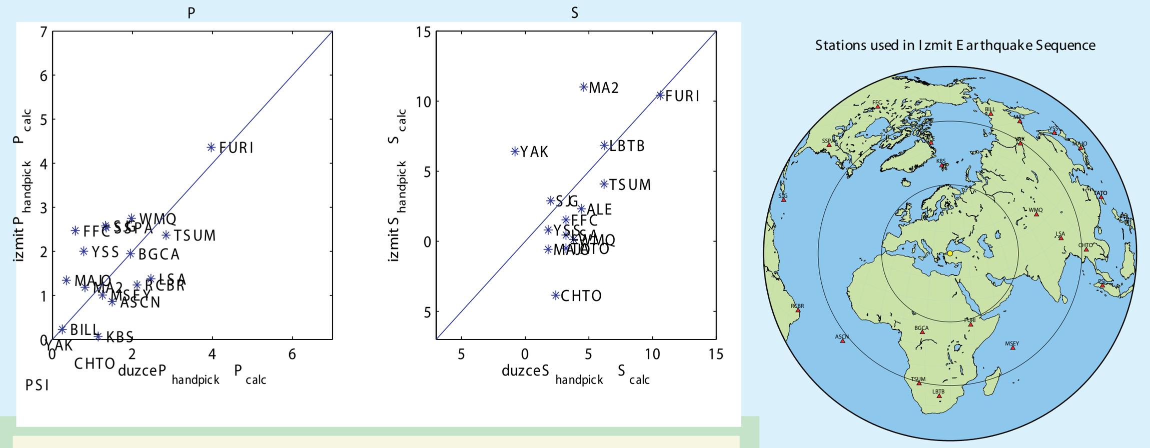


Figure 2: Comparison of variations in handpicked arrival times from the arrival times calculated with IASP 90 model.

The conventional method of doing source inversion involves "handpicking" of the arrival times of P and SH waves. The variations of handpicked arrival times from a reference one dimensional model are interpreted as a consequence of velocity variations. If that is the case, then two close events are predicted to have the same path corrections.

The Duzce and Izmit earthquakes are close enough, that their teleseismic arrival times would be similar relative to a 1-D reference model. However, as can be seen in Figure 2, the variations of handpicked arrival times from IASP 90 model, differ significantly despite the proximity of the two events. Especially, the incompatibility of the SH wave arrival picks is significant. In most stations, Izmit SH handpicks are earlier compared to Duzce picks.

Especially for S waves, the process of picking arrival times turns out to be harder for large events because of the presence of PS-coda arriving on top of the initial S onset. Since S waves have a slower apparent velocity, they are more sensitive to the rupture details. Hence picking their right arrival times is of critical importance.

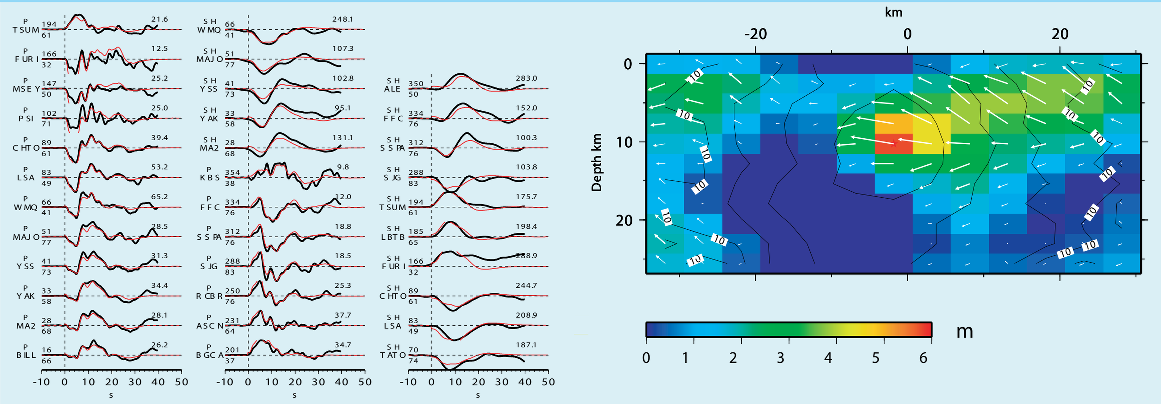


Figure 3, 4: Waveform fits and spatial distribution of slip for Nov 12, 1999, Mw7.2 Duzce Event using the inversion method by Ji, *et al*, 2002. Note that the slip is concentrated around the hypocenter.

We used the KOERI (Turkey) location for inversion. A single plane dipping 54^o, from InSAR and GPS studies of Burgmann, et al, 2002 was used for the source inversion.

Inversion was done in two steps. First we perform an inversion with only handpicked P waves to get a preliminary distributed slip. We use this preliminary model to forward calculate synthetic seismograms and cross-correlate them with all the records that will be used in inversion. The time shifts obtained in this process are used to perform a second inversion with both P and SH waveforms.

Our inversion fits the teleseismic body waves very well. This inversion is also consistent with the result of joint InSAR and GPS inversion of Burgmann, et al, 2002.

Results for 17 Aug, 1999, Izmit Earthquake

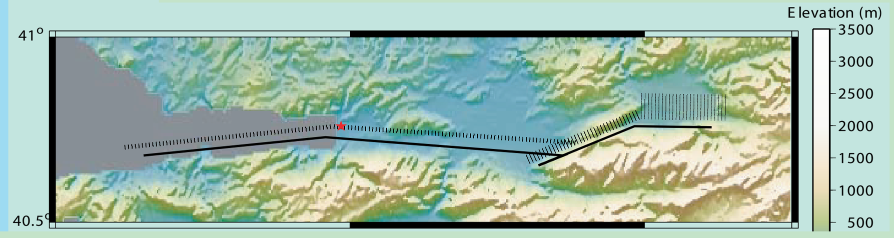


Figure 6: Izmit Earthquake is modelled with four segments based on the surface rupture observations (Delouis *et al*, 2002).

The dip of each segment is modified from a model by Wright *et al*;,2001, based on inversion of InSAR data for six segments.

A one dimensional velocity model for Western Turkey is used from Sekiguchi *et al*, 2002.

Figure 7: Waveform fits, Rupture Pattern , Static Field and GPS predictions for the inversion with the Calibrated Arrival Times

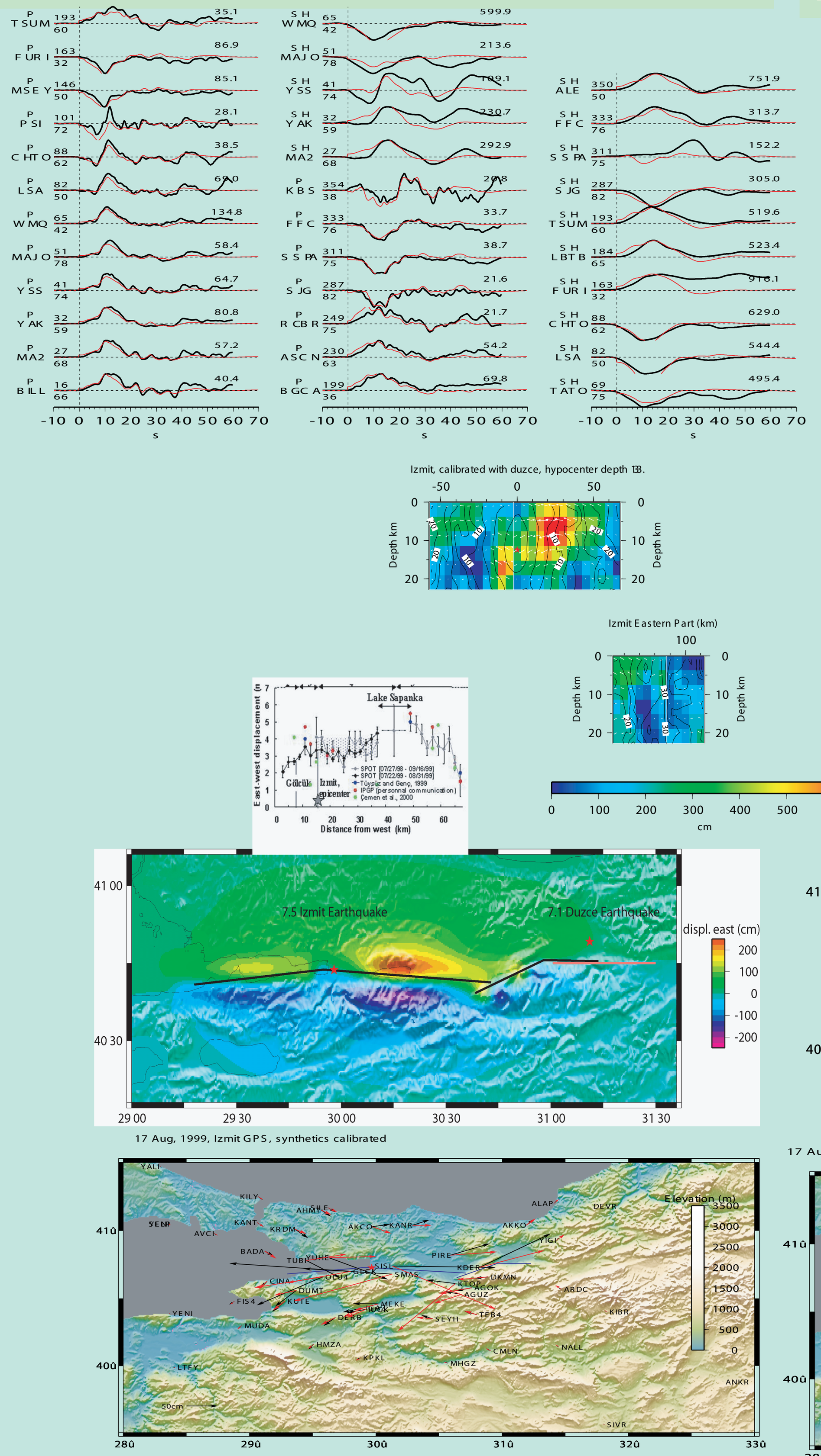
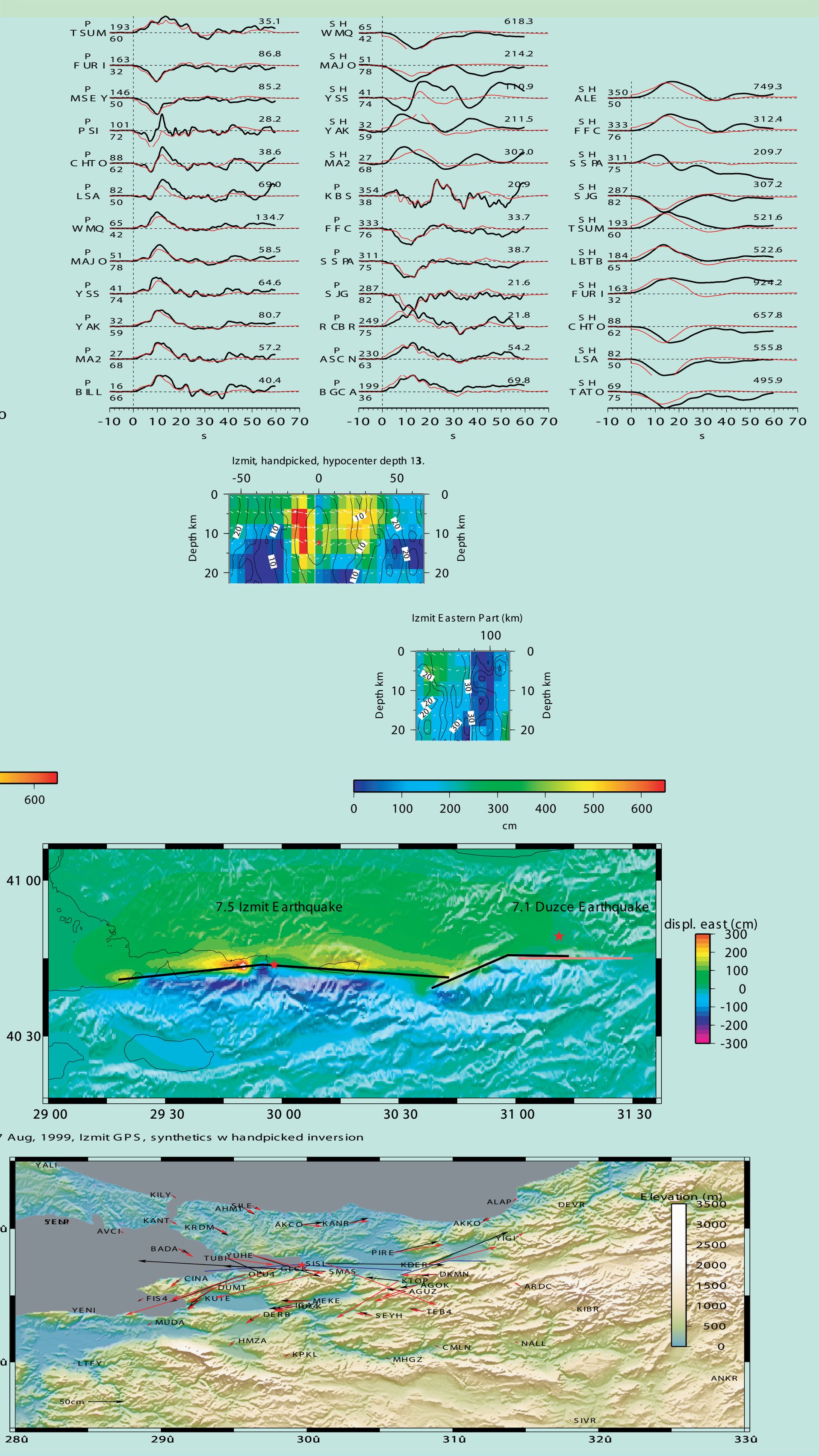


Figure 8: Waveform fits, Rupture Pattern, Static Field and GPS predictions for the inversion with the Handpicked Arrival Times.



Results

Using calibrated arrival times reduces the overall waveform mismatch of the teleseismic data (~0.20 vs. 0.25).

The slip distribution for the two inversions differ considerably. For the calibrated inversion, the maximum displacement is to the east of the hypocenter, while it is west in the handpicked inversion. The asperity to the west is deeper in calibrated inversion. This effect is clearly revcealed in the estimated static field plots.

The SPOT data is more consistent with the calibrated arrival time inversion. The maximum slip in east-west direction is on the eastern end of Lake Sapanca as it is revealed in spot data.

The GPS predicted from handpicked inversion fits the data better than calibrated inversion. Relatively poor fit of the calibrated inversion is due to north south component of the slip. The reason for this could be the complexities of the fault geometry as well as the slip distribution. However, understanding the actual reason for this inconsistency (fitting SPOT data better, but fitting GPS poorer) remains as a future work for us.

2. Joint Inversion of Duzce Earthquake

Similar to Izmit Earthquake, supershear rupture velocity (~4.5 km/s) to the east is estimated from strong-motion data for Duzce earthquake while rupture to the west is about 3 km/s. Here we test two scenarios **(a)** fast rupture speed (3.8-4.8 km/s) to the east and slow (2.5-3.5km/s) to the west (b) slow rupture speed (2.5-3.5km/s) to the east to the east and slow (3.8-4.8 km/s) to the west. The goal of this comparison is to test whether teleseismic data together with near-field geodesy has any significant sensitivity to rupture velocity or not.

(a) fast to the east **(b) fast to the west**

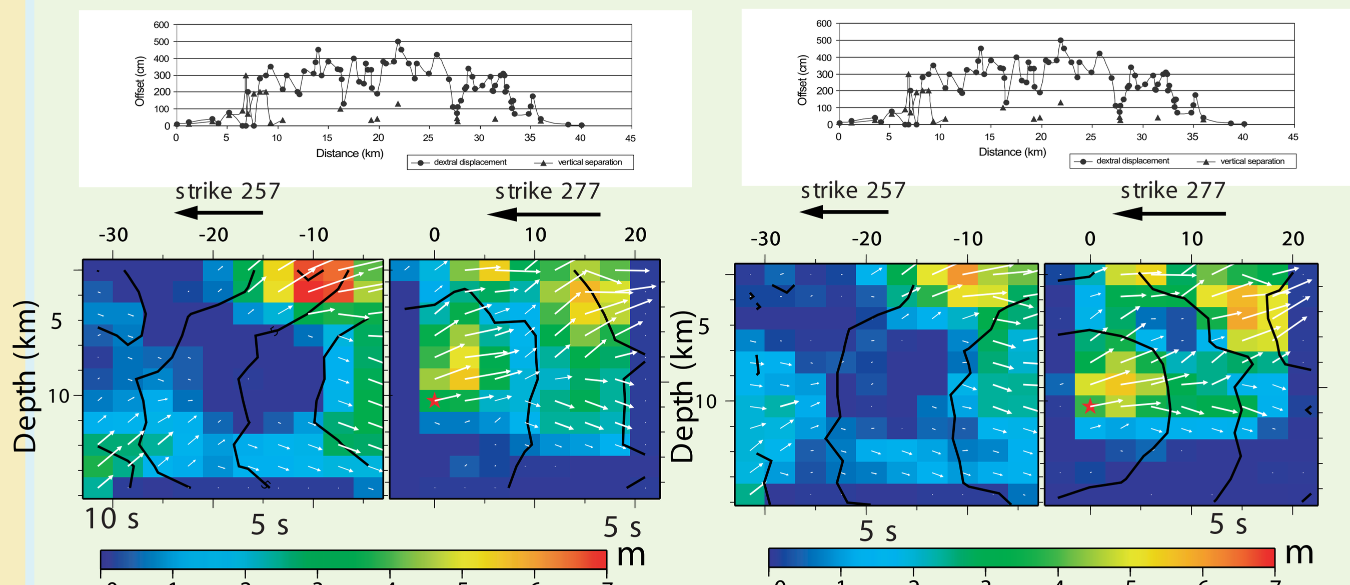
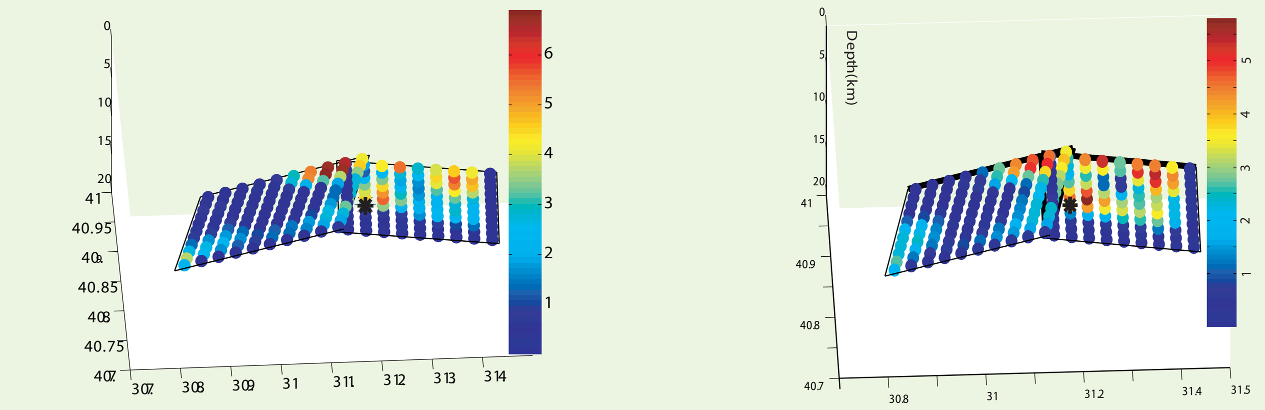


Figure 9: Slip model for joint (teleseismic, GPS and InSAR inversion of Duzce earthquake. Rise time is between 1-5 s.



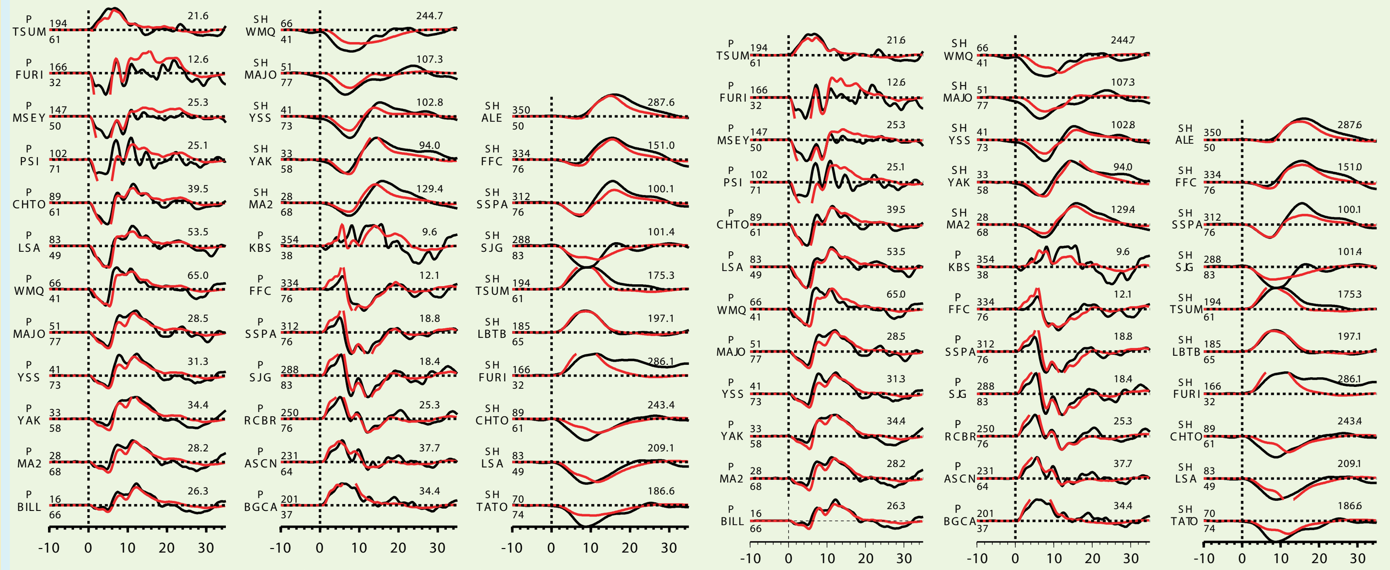


Figure 9: Fits to the teleseismic P and S waves

M_W7.1 Duzce earthquake is a significant earthquake to study.

There is a wealth of teleseismic, strong-motion, geodetic and geological data available. There has not been a study yet that used all available data. The goal here is to use all data available. The results shown here are shown here do not include the strong-motion data yet. The model shown in Figure 9 is quite consistent with geodetic inversion (Burgmann et al, 2002), and GPS and strong-motion inverson (Bouin et al., 2004).

Another target of this study is to understand whether supershear rupture speed proposed to explain strong-motion data is consistent with other datasets. The geodetic data and surface offset measurements constrain the slip distribution significantly. Therefore, the rise time and rupture velocity are the two parameters to play with, in order to fit both teleseismic and strong-motion data.

(a) fast to the east **(b) fast to the west**

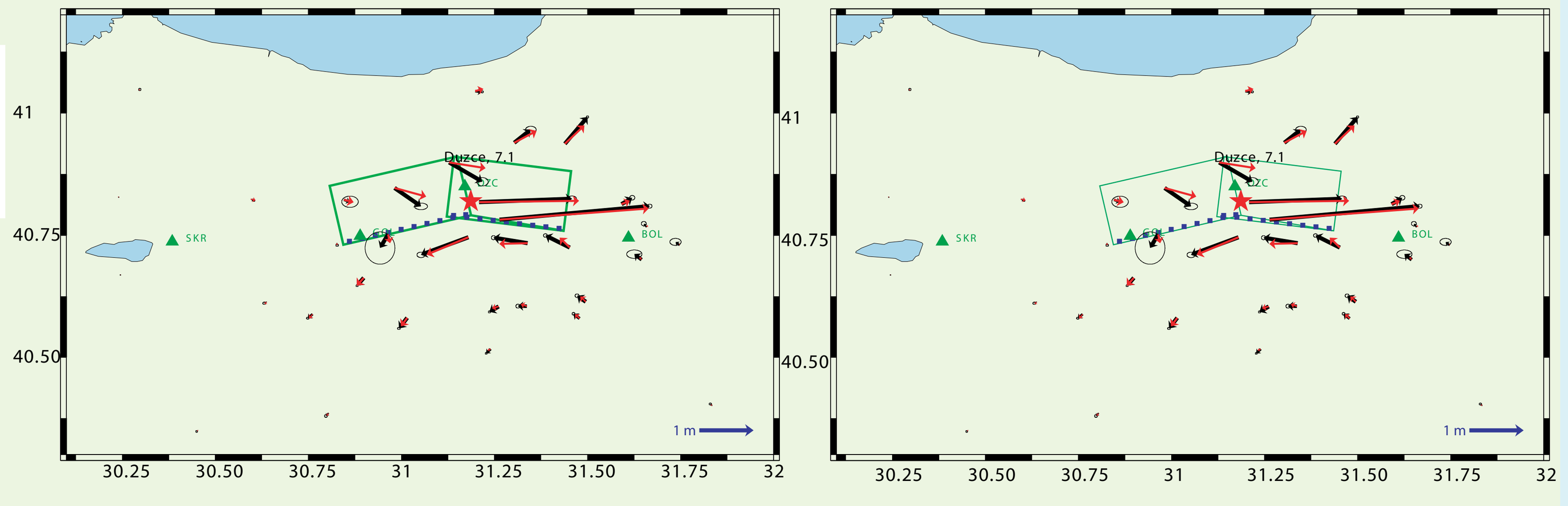


Figure 11:Fits to GPS data. Data is in black and synthetics are in red. Strong-motion stations that are going to be used are shown with green triangles.

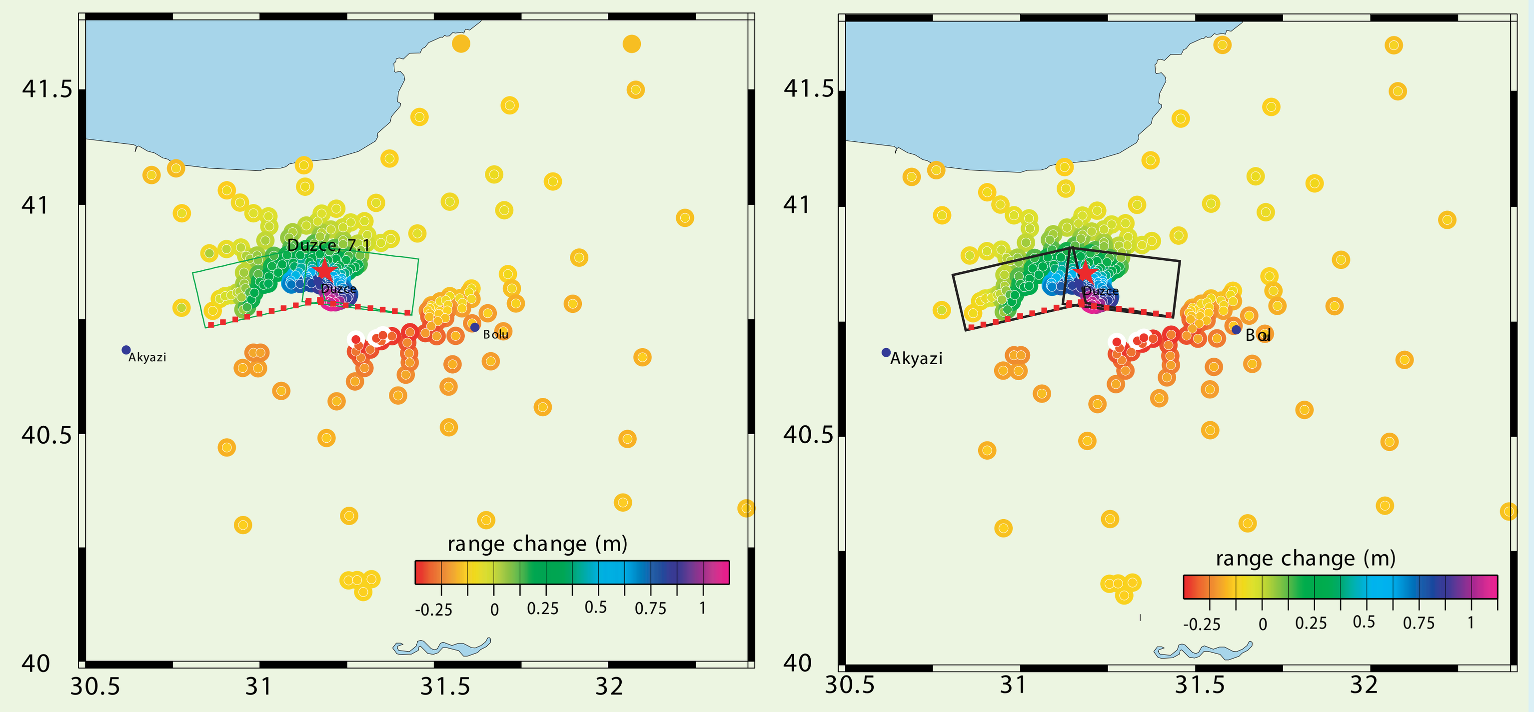


Figure 12:Fits to InSAR data. Each circle is a datapoint, where the smaller circle inside is the synthetic and outer circle is the data. Two fault planes are also shown.

These results show that the combination of far field seismic data and near-field geodetic data is not sufficient to resolve the details of the rupture velocity. The misfits to the datasets for the two scenarios are similar.

Summary and Future Work

This study aims to study Izmit and Duzce earthquakes using consistent travel times for both events and all available datasets to resolve the details of rupture velocity and slip distribution. As a start, we have used the calibration of travel times to see what difference it makes in teleseismic inversions. We have also modeled Duzce earthquake using geodetic ad teleseismic data. We will also implement strong-motion and surface offsets using SPOT images in future. It is of great interest to model strong-motion data together with geodetic data to test whether the observed waveforms are due to a supershear rupture or not.

Once good slip distributions are achieved for these two events, we can learn about the interactions and how stress change of Izmit earthquake has effected the Duzce earthquake.

Moreover, we can use these calibration events to reexamine historical events of the 20th century using existing teleseismic recordings by methods similar to previous studies of the 1906 San Francisco earthquake