

—Data Paper—

A database of global seismic travel timesJunko Yoshimitsu^{1*} and Masayuki Obayashi¹

We have constructed a seismic travel time database as an aid to research on the interior structure of the Earth. We measured various types of travel times from seismic waveform data collected by stations around the world, including broadband ocean bottom seismometers (BBOBSs). We measured absolute arrival times of various seismic phases by manual picking of the phase onset, differential travel times of P waves between two stations, and differential travel times between PP and P waves. The differential travel times were measured using waveform cross-correlation method. So far, we have measured more than 80,000 travel times. These data have been used to improve the spatial resolution of our tomography model, particularly in regions of poor seismic ray path coverage such as the Pacific Ocean. The database is continuing to develop and is publically available at our own web site; we welcome anyone to use the data for further research.

Complete data set is available via site :

http://www.godac.jamstec.go.jp/catalog/jamstec-r_repository/metadataDisp/JAMSTEC-R_24DP01?lang=en

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1. Introduction

Travel time data of various seismic phases are useful in studies of the Earth's interior. Seismic travel time tomography using such data is a key technique to obtain the seismic velocity structure. However, the resolution of seismic tomography models depends on the coverage of seismic ray paths. Efforts toward the improvement of data coverage are thus necessary in order to increase the spatial resolution of seismic tomography. One way is to increase seismic observations in the areas of poor station coverage, e.g., by deploying a temporal land seismic network or/and BBOBSs on deep seafloors. In addition, extracting additional travel time information from seismic records improves the resolution of travel time tomography. Travel time data for both first arrival and later phases are important because different phases interact differently with the Earth's interior.

We collected both broadband and short period seismic waveform data worldwide, including from BBOBSs deployed in the Pacific region, and measured absolute arrival times of various seismic phases by manual picking of the phase onset, differential travel times of P waves between two stations, and differential travel times between PP and P waves. These data have been used in our tomography studies (e.g., Obayashi et al., 2006, 2009, 2013, 2016; Fukao et al., 2009, 2013; Suetsugu et al., 2010). Our database is made available to the public at our web page. Here we introduce our database.

2. Method

2.1 Sources of Seismic Waveform Data

Various seismic observation networks have been deployed globally; at present, it is possible to obtain seismic waveform data from stations around the world. Data from several seismic networks are publically available online; we used data from the following land seismic networks: SKIPPY, LDG, SPANET, JISNET, OHP, Hi-net, F-net, J-array, GEOFON, GSN and other networks served by IRIS DMC.

We also collected waveform data from broadband ocean bottom seismometers (BBOBSs) such as the Stagnant Slab Project network, Polynesia BBOBS array, TIARES network, and Petit Spot network. These BBOBS waveform data are publically available at <<http://p21.jamstec.go.jp/top/>>. Details of these observation networks are summarized in Table 1.

Fig. 1 shows a distribution map of the seismic stations used for travel time measurements.

2.2 Measurement Methods

We measured waveform travel times in suitable ways depending on the seismic phase and the measurement method as described below.

Table 1. List of seismic networks we used travel time measurement.

	Observational Network	Reference etc.	Region
Land Seismic Networks	SKIPPY network	van der Hilst et al., 1994	Australia
	LDG network	Laboratoire de Geophysique in France	French Polynesia
	SPANET network	South Pacific broadband seismic network, Ishida et al., 1999	South Pacific
	JISNET network	Japan-Indonesia Seismic Network, Ishida et al., 1999, Ohtaki et al., 2000	Indonesia
	OHP network	Ocean Hemisphere network Project, < http://p21.jamstec.go.jp/top/ >	Western Pacific
	Hi-net	High sensitivity seismograph network Japan, Okada et al., 2004, < http://www.hinet.bosai.go.jp/ >	Japan Island
	F-net	Broadband seismograph network Japan, Okada et al., 2004, < http://www.fnet.bosai.go.jp/ >	Japan Island
	J-array network	< http://jarray.eri.u-tokyo.ac.jp/ >	Japan Island
	GEOFON network	< http://geofon.gfz-potsdam.de/ >	French Polynesia
Broadband Ocean Bottom Seismometers (BBOBSs)	GSN and other networks served by IRIS DMC	< http://iris.edu/ >	Global
	Stagnant Slab Project network	Fukao et al., 2009	Western Pacific
	Polynesia BBOBS array	Suetsugu et al., 2005	French Polynesia
	TIARES network	Suetsugu et al., 2012	French Polynesia
	Petit Spot network	Shito et al., 2013	Northwest Pacific

2.2.1 Measurement of absolute arrival time by manual picking

We picked the onset times of various seismic phases such as P- and S-waves on raw seismograms by referring to the theoretical travel times and the filtered seismogram record. We also changed the filter types, such as low-pass, high-pass, and band-pass, and adjusted the filter parameters to make the target phase stand out. Fig. 2(a) shows an example of manual picking where we determined the P-wave onset time at the red line. We selected the arrival times of P, pP, and sP waves on the vertical component of the

seismogram, and S waves on the transverse component. We recorded the absolute arrival time with the quality (a, b, or c) determined by visual inspection of the onset clarity and polarity (+ or –) for each phase (see Fig. 3 for examples).

In previous tomography studies using the database (e.g., Obayashi et al., 2006, 2009, 2013, 2016; Fukao et al., 2009, 2013; Suetsugu et al., 2010), the standard deviations of the observational errors are assumed to be 0.1, 0.3 and 1.0 sec for quality notations a, b and c, respectively.

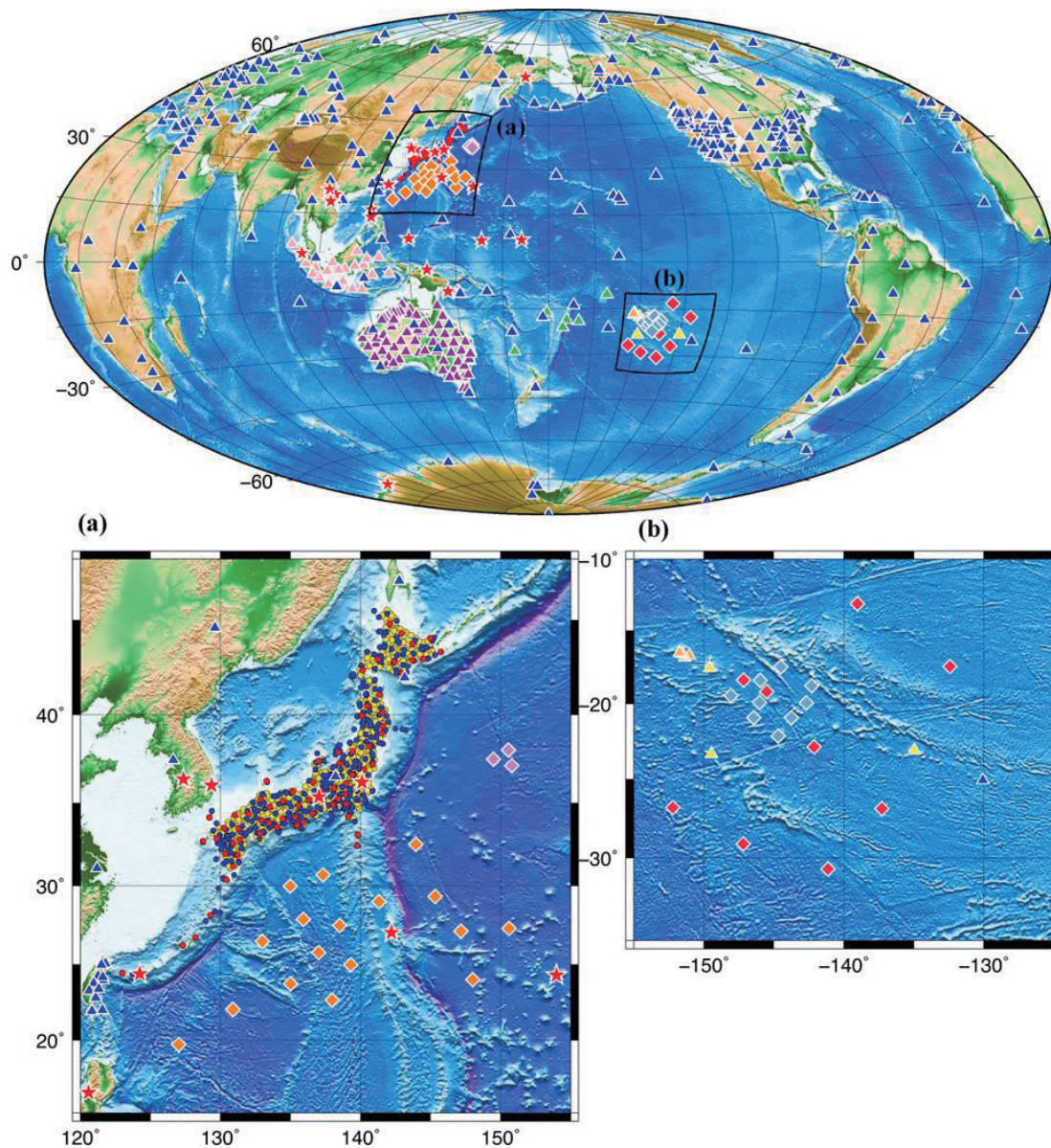


Fig. 1. Distribution of the seismic stations. Triangles, diamonds, dots, and stars are seismic stations used in this work. Colors and shapes represent different network as follows,

▲: SKIPPY; ▲: LDG; ▲: SPANET; ▲: JISNET; ★: OHP; ●: Hi-net; ●: F-net; ●: J-array; ▲: GEOFON; ▲: IRIS; ◆: Stagnant Slab Project; ◆: Polynesia BBOBS array; ◆: TIARES; ◆: Petit Spot network.

2.2.2 Measurement of differential P wave travel time between two stations

Differential travel time information can be extracted even when the onset of the phase is too ambiguous to pick manually due to high background noise. We measured P wave travel times between two different observational stations using a waveform cross-correlation method by selecting a station where the P wave is recorded most clearly as a reference station for each seismic event. We band-pass filtered the seismograms and defined a window in the reference station's record that enclosed the first swing of the P wave. Then we cross-correlated the record in the window with the records of other stations. Fig. 2(b) shows examples of differential travel time measurements between two stations. The reference waveform (shown in red) is

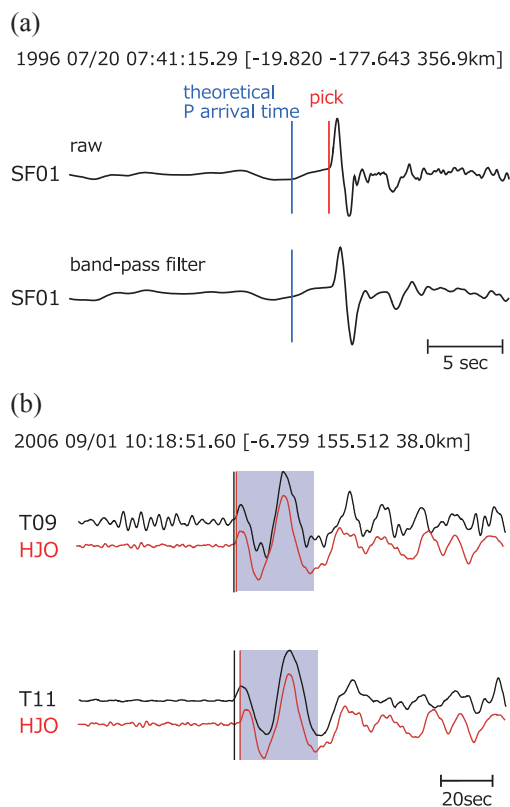


Fig. 2. (a) An example of seismic record used for the arrival time measurement by the manual picking method. The upper trace is the raw seismic record. The second trace is its filtered record. Blue lines are theoretical arrival times expected from the AK135. Red line is the picked arrival time of P-wave by referring to the filtered trace as well as the original raw record.

(b) Example of the seismic records used for the differential travel time measurement of P-wave between two stations. Black traces are seismogram of BBOBSs and red trace are reference waveform recorded on the land. The reference waveform is shifted in time to give the best correlation.

shifted in time to give the best correlation with BBOBS waveforms (shown in black) within the time windows indicated by the shaded area. We applied this method to the BBOBS networks because the background noise level at periods less than 5 sec is generally high on the deep seafloor. As a reference, we also used data from land stations in the vicinity of BBOBS networks for the measurement.

2.2.3 Determining differential travel times between P and PP phases

A P wave that has traveled through the mantle, undergone one reflection from the underside of Earth's surface, and traveled again through the mantle to the station is designated a PP wave. We measured the difference between PP and P wave travel times by cross-correlating the observed PP waveform with a synthetic PP waveform calculated from the observed P waveform. We obtained the synthetic PP waveform by:

- (i) lowpass filtering an observed seismogram with a corner frequency of 0.1 Hz
- (ii) defining a window for the P waveform
- (iii) applying the Hilbert transform
- (iv) convolving with the crustal response at the PP bounce point
- (v) applying a t^* operator to account for different attenuation along the P and PP raypaths
- (vi) correcting for the polarities of P and PP resulting from focal mechanism.

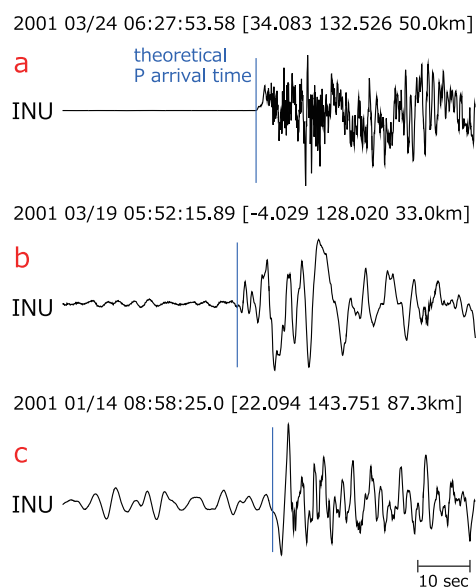


Fig. 3. Examples of seismic record with the quality a, b, and c determined by visual inspection of the onset clarity of P-wave.

At step (iv), the crustal response was calculated for a layered crustal (and sea water, if necessary) structure of the CRUST2.0 (Bassin et al., 2000) using the Haskell matrix method (Haskell, 1962). See also Obayashi et al., (2004) and Fukao et al., (2003) for the detail of the measurement.

3. Data format and contents

The travel time dataset is provided in ASCII text format with all necessary supplementary information described below (as summarized in Table 2).

Table 2. List of contents in our database.

	Absolute Arrival time (a)	Differential Travel time of P-wave between two stations (b)	Differential Travel time between PP and P (PP-P) (c)
1	Epicenter data & time	Epicenter data & time	Epicenter data & time
2	Epicenter latitude	Epicenter latitude	Epicenter latitude
3	Epicenter longitude	Epicenter longitude	Epicenter longitude
4	Epicenter depth (km)	Epicenter depth (km)	Epicenter depth (km)
5	Network code	Filter information	Magnitude
6	Station code	Station code	Station code
7	Location code	Network code	Network code
8	Station latitude	Station latitude	Station latitude
9	Station longitude	Station longitude	Station longitude
10	Station elevation (m)	Station elevation (m)	Station elevation (m)
11	Channel code	Station-to-event distance (degrees)	Difference time of PP-P travel time between theory and measurement
12	Phase name	Event-to-station azimuth (degrees)	PP-P differential travel time (measurement)
13	Arrival time	Theoretical P travel time	Quality
14	Differential time	Station code	Phase name
15	t^*	Network code	
16	Quality	Station latitude	
17	Polarity	Station longitude	
18	Filter information	Station elevation (m)	
19	Note	Station-to-event distance (degrees)	
20		Event-to-station azimuth (degrees)	
21		Theoretical P travel time	
22		Differential P travel time between two stations	
23		Difference of theoretical P travel time between two stations	
24		Correlation coefficient	

(a) Example of absolute arrival times in our database.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
19930416.140838 93	-17.778	-178.864	565.1	PS	OGS		27.057	142.203	20	bhz	P	14 17 41.893	-9999.999	-9.99	B	-	-9.99 - 9.99	
19930416.140838 93	-17.778	-178.864	565.1	PS	PSI		2.694	98.924	987	bhz	P	14 20 7.256	-9999.999	-9.99	A	-	-9.99 - 9.99	
19930416.140838 93	-17.778	-178.864	565.1	PS	TSK		36.21	140.11	350	bhz	P	14 18 32.625	-9999.999	-9.99	B	-	-9.99 - 9.99	
19930603.093825 68	-14.841	167.299	151.8	SK	SA02		-17.364	144.485	465	bhz	P	9 43 10.248	-9999.999	-9.99	A	-	-9.99 - 9.99	
19930603.093825 68	-14.841	167.299	151.8	SK	SA03		-17.364	144.485	465	bhz	pP	9 43 38.432	-9999.999	-9.99	A	+	-9.99 - 9.99	

(b) Example of differential travel time of P-wave between two stations.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
2009 5 28 8 24 46.56	16.731	273.783	19.0	(BP 0.030-0.080)	SOC7	SOC	-19.941	-142.688	-4467.0	66.364	238.876	647.506	SOC6	SOC	-18.805	-142.294	-4484.0	65.488	239.757	641.862	5.650	5.644	0.9242
2009 5 28 8 24 46.56	16.731	273.783	19.0	(BP 0.030-0.080)	SOC5	SOC	-17.500	-144.506	-4031.0	66.726	242.097	649.819	SOC6	SOC	-18.805	-142.294	-4484.0	65.488	239.757	641.862	8.050	7.957	0.9785
2009 5 28 8 24 46.56	16.731	273.783	19.0	(BP 0.030-0.080)	SOC4	SOC	-18.425	-144.987	-4457.0	67.557	241.441	655.100	SOC6	SOC	-18.805	-142.294	-4484.0	65.488	239.757	641.862	13.550	13.238	0.9651
2009 5 28 8 24 46.56	16.731	273.783	19.0	(BP 0.030-0.080)	SOC8	SOC	-20.955	-143.756	-4779.0	67.730	238.452	656.193	SOC6	SOC	-18.805	-142.294	-4484.0	65.488	239.757	641.862	14.150	14.331	0.9373
2009 5 28 8 24 46.56	16.731	273.783	19.0	(BP 0.030-0.080)	SOC9	SOC	-22.169	-144.697	-4513.0	69.083	237.772	664.669	SOC6	SCO	-18.805	-142.294	-4484.0	65.488	239.757	641.862	23.000	22.807	0.9803

(c) Example of differential travel time between PP and P (PP-P).

1	2	3	4	5	6	7	8	9	10	11	12	13	14
19920102 164040.80	48.731	129.221	10.0	5.6MB	AAK	II	42.639	74.494	1645.0	-0.940	204.5	B	PP-P
19920102 194146.40	5.670	-73.836	0.0	5.7MB	ALE	II	82.503	-62.350	60.0	0.040	176.45	B	PP-P
19920120 133704.80	27.929	139.471	521.3	5.8MB	KONO	IU	59.649	9.598	216.0	-0.570	200.25	B	PP-P
19920120 133704.80	27.929	139.471	521.3	5.8MB	PFO	AZ	33.612	-116.459	1259.0	-2.630	205.80	B	PP-P
19920120 133704.80	27.929	139.471	521.3	5.8MB	GRA1	GR	49.692	11.222	499.0	-0.530	224.90	C	PP-P

3.1 Absolute arrival time

The data contain absolute arrival time measured by manual picking, event and station information, channel code, phase name, filter information, polarity of picked phase, and quality of picking precision. Table 2(a) shows some examples of absolute arrival times in our database.

3.2 Differential P-wave travel time between two stations

The data contain measured differential travel times between two stations, correlation coefficient, corner frequencies of the applied filter, seismic event information, and station information. Table 2(b) shows some examples of differential P-wave travel times between two stations in our database.

3.3 Differential travel time between P and PP phases

The data contain measured differential travel times between P and PP phases, seismic event information, station information and quality of measurement precision. Table 2(c) shows some examples of differential travel times between P and PP phases in our database.

4. Expected use of the data

The database is expected to be used for research on the seismic structure of the Earth, seismic source and so on.

5. Accessibility

Our database is made available to the public at our web page <<http://d-earth.jamstec.go.jp/Traveltime/index.html>>.

6. Usage Notes

Refer to this article for using our travel time data. Note that the database is continuing to develop.

7. Ownership

These data belong to the Department of Deep Earth Structure and Dynamics Research, Japan Agency for

Marine-Earth Science and Technology.

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