RecReadMe.pdf

The following document discusses fundamental concepts of earthquake seismology as they pertain to recorded signals and their contents in relation to the user-selected parameters in this code.

Generally, seismic waves travel between a source and receiver along many paths. Reflections and diffractions can generate additional arrivals. These arrivals at the receiving station, or **seismic phases**, correspond to different travel paths.

The amplitude, frequency content, and dominant recording component of recorded seismic phases depend on the three major contributions to a seismogram: (1) the earthquake source, (2) path geometry and medium material properties, and (3) instrument recording effects.

This tool accounts for instrument corrections, and thus the contents of the output seismograms depend, to the first order, on earthquake type (source geometry and magnitude) and epicentral distance for recordings spanning the globe.

The **epicentral distance** (Δ) of a seismogram refers to the surface distance between earthquake epicenter (approximate source location) and the receiver, often reported in degrees. For a given event, recordings are categorized as **local**, **regional**, or **teleseismic** depending on the epicentral distance. The exact boundaries between these categories varies between agencies, but can be generally defined in the following way:

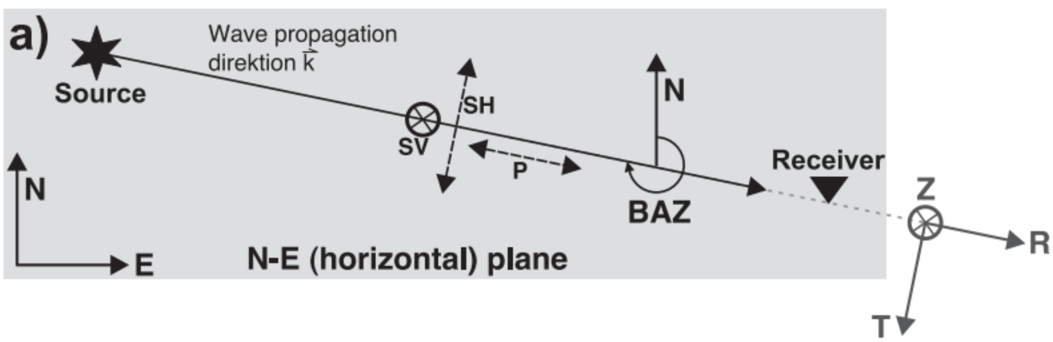
- Local: $0° < \Delta < 10°$
- Regional: $10° < \Delta < 20°$
- Teleseismic: $\Delta > 30°$

Path geometry between source and receiver varies dramatically with epicentral distance. Local and regional events best sample shallow nearby structure with some energy sampling the uppermost mantle. Over increasingly teleseismic distances, body-wave energy travels deeper before bottoming out and arcing back towards the surface, arriving at the receiver at increasingly more vertical incidence angles. Thus, epicentral distance impacts the strength of phase polarization on individual recording components.

Seismogram frequency content also varies by epicentral distance. Earth materials are not perfectly elastic. Attenuation is the process by which seismic energy is converted into heat and thus lost from the seismic waves. This process is frequency- and material-dependent and tends to attenuate energy at higher frequencies more quickly. Thus, at local and regional distances, seismograms will still contain high-frequency content, while at teleseismic distances records will contain less high-frequency content as seismic waves experience more attenuation along these longer distances.

Seismometers typically record motion along three orthogonal components, or components perpendicular to one another. If oriented correctly, land-based stations are deployed such that these components align with north-south (N), east-west (E), and up-down (Z). Ocean-bottom seismometers are rarely deployed in such a way as to control their horizontal components, but methods exist to rotate these components using recorded earthquakes (e.g., Stachnik et al., 2012; Zha et al., 2013).

This code re-orients measurements along these components into a reference frame aligned with the source-receiver geometry in order to better separate seismic phases. These new components are vertical (Z), radial (R), and transverse (T). This reorientation requires the backazimuth and incidence angle of the incoming seismic wave, with the former calculated from the station and epicentral coordinates and the latter calculated from the focal depth and epicentral distance. A visualization of these components can be found below (Diehl and Kissling, 2007, https://www.researchgate.net/publication/237348802_Users_Guide_for_Consistent_Phase_Picking_at_Local_to_Regional_Scales/link/004635255a58611631000000/download).

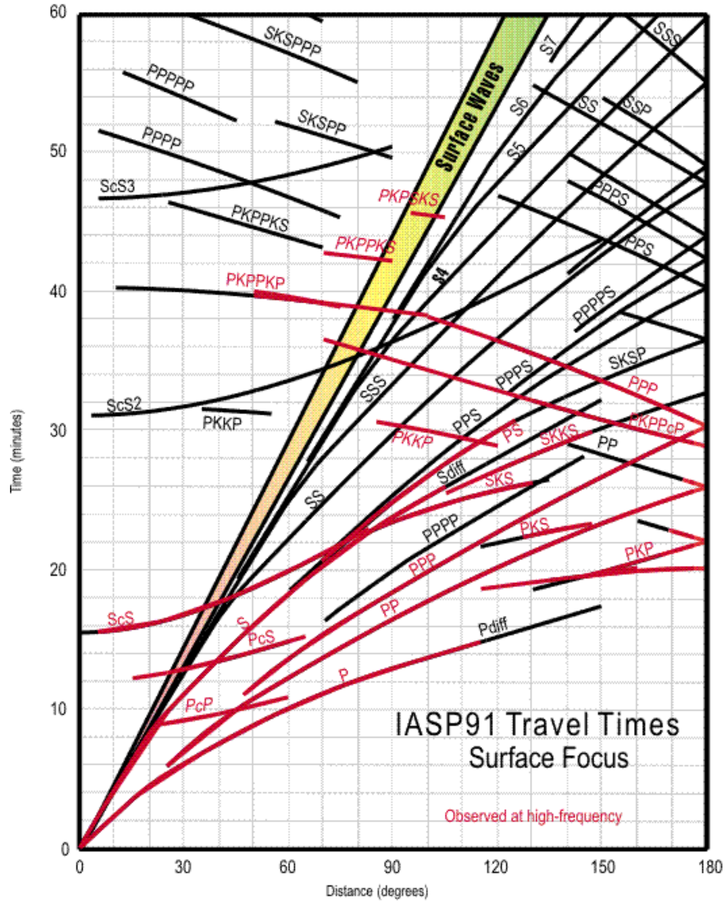


The particle motion of the compressive P wave is parallel to the direction of wave propagation, so for teleseismic events at epicentral distances exceeding 60-70°, P waves arrive most clearly on the vertical component. Displacements from the S-wave are transverse to the direction of wave propagation and can be subdivided into a vertical component (SV) and a horizontal component (SH). For a purely isotropic material, SH should be recorded entirely along the transverse direction, with SV mixed between the vertical and radial directions. The ratio of energy partitioned between SV and SH depends strongly on source geometry and observation azimuth.

Table A: Summary of seismogram characteristics at various epicentral distances

	Local	Regional	Teleseismic
Epicentral Distance	$0° < \Delta < 10°$	$10° < \Delta < 20°$	$30° < \Delta$
Peak Band for Period	0.3 – 2 s	2 – 5 s	5 – 25 s
Key Characteristics	(a) little attenuation, high-frequency content (b) localized structure (c) crustal and moho reflections/refractions (d) smaller event magnitude required compared to teleseismic (e) recordings from large events may contain complicated source	(a) some attenuation, still some high-frequency content (b) regional structure (c) crustal and uppermost mantle sampling (d) smaller event magnitude required compared to teleseismic (e) recordings from large events may contain complicated source	(a) low-frequency content due to attenuation (b) clear separation of body and surface waves (especially for shallower events with strong surface waves) (c) core effects (P diffraction from 140 onwards, shadow zone starting at 105, etc) (d) recordings require larger event magnitude (e) complicated source effects from large events less impactful to record section

For teleseismic earthquakes, you can use a travel-time plot such as this or the code's CheatSheet function to help identify arrivals at particular times and epicentral distances.



Travel-time curves of earthquakes (USGS, https://www.usgs.gov/media/images/travel-time-curves).

Seismic waves arrivals, or phases, are identified using a nomenclature describing the path followed from wave source to receiver. Each letter describes a part of the wave path. Generally, upper-case letters denote travel through a part of the earth (e.g., P or S), while lower-case letters denote reflections from boundaries. However, a preceding lower-case letter can refer to a "depth phase" or a path involving a reflection from the Earth's surface (p or s) or the ocean surface (w) before traveling along teleseismic paths.

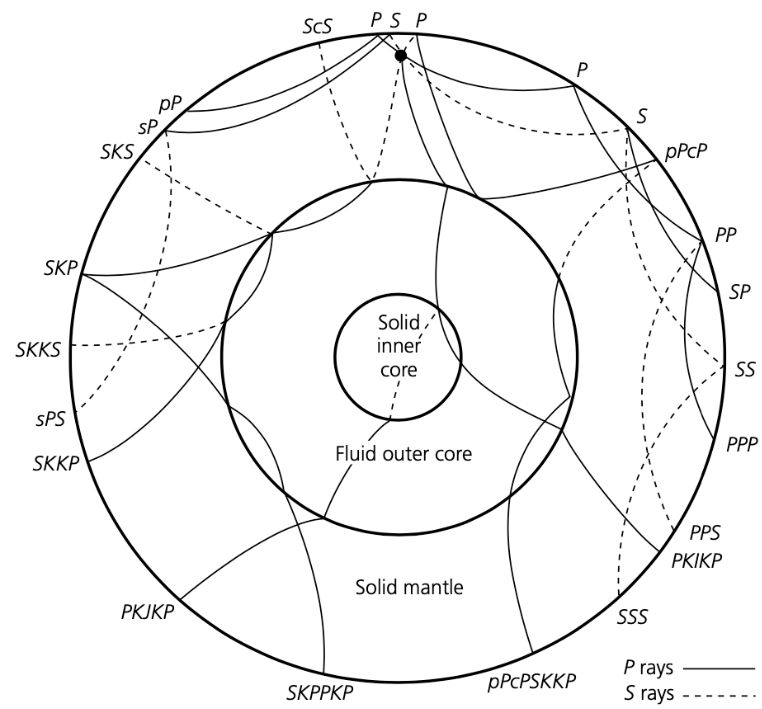
Table B: Nomenclature Guide

Teleseismic Waves	
P	Primary (compressional) wave in the mantle
S	Secondary (shear) wave in the mantle
K	P wave in the outer core
--	S waves cannot travel in liquids, so there is no name for S waves in the outer core
I	P wave in the inner core
J	S wave in the inner core
c	Reflection from the outer core boundary
I	Reflection from the inner core boundary
$R(G)_1$*	Rayleigh (Love) surface wave traveling along shortest path from station to receiver
$R(G)_2$*	Rayleigh (Love) surface wave traveling along longest path from station to receiver
Regional Waves	
Pg (Sg)	Upgoing P(S) wave traveling entirely within the upper crust
Pn (Sn)	P(S) wave bottoming in the uppermost mantle
Lg	SH- or Love-type wave group reverberating within the crust

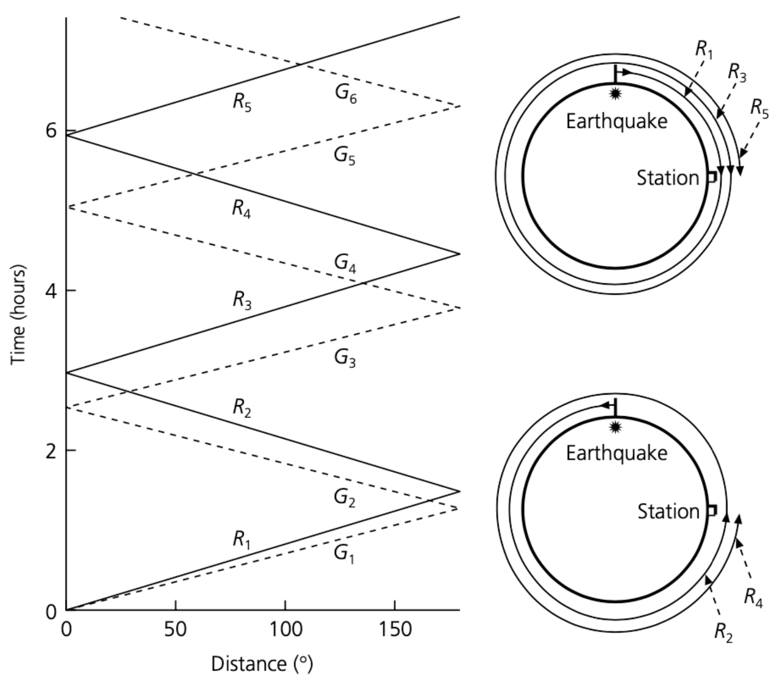
* Successive surface-wave paths around the earth increase the subscripted index by 2.

Table C: Phase Nomenclature Examples

PcP	P wave that reflects off the outer core boundary as a mantle P wave
Pdiff	P wave bent around (diffracted along) the outer core boundary
SScS	S wave that reflects off the surface, then the outer core boundary
PKP	P wave that travels through the outer core and then back into the mantle as P
PKiKP	P wave that travels through the outer core, reflects off the inner core boundary
SKIKS	S wave converting to P in the outer core, travels through inner and outer core, before converting to S across the outer core boundary
R_3	Rayleigh wave traveling along the shortest source-receiver path after traveling around the world once
G_6	Love wave traveling along the longest source-receiver path after traveling around the world twice



Examples of body wave phases illustrating phase nomenclature. (Fig. 3.5-5, from Stein and Wysession, 2003. From *An Introduction to Seismology, Earthquakes, and Earth Structure*, ©2003 by Blackwell Publishing)



Travel times for multiple Rayleigh (R_n) and Love (G_n) waves, and visualization of corresponding phase paths. (Fig. 2.7-3, from Stein and Wysession, 2003. From *An Introduction to Seismology, Earthquakes, and Earth Structure*, ©2003 by Blackwell Publishing)

Further Notes:

- Surface waves can travel around the globe for 2.75-3 hrs before decaying! Expand record duration for teleseismic perspective on large-magnitude events.
- Be aware that earthquake location and depth as imported from the repository of choice may not be exact. Some agencies have a prescribed default depth for reported solutions on shallow events.