Using High-Frequency *P* Wave Radiation to Investigate the Directivity Effects of the 2020 M_W7.8 Alaska Earthquake

Abstract

The earthquake directivity refers to the variation of source duration as a function of azimuth due to the rupture front propagation on a finite-length fault. In the Haskell fault model, the directivity varies with a cosine pattern that the duration will be shorter in the direction of rupture propagation and longer in the opposite direction. Using high-frequency (2-4 Hz) *P*-wave radiation to suppress interference of later phases (PP, PPP) and given horizontal phase velocity from ray parameter, the duration of the great 26 Dec. 2004 Sumatra-Andaman earthquake was determined to be ~500 second with a ~1200 km rupture length (Ni et al., 2005). In this study, we aim at determining the source duration and rupture length for the recent M_W7.8 Alaska earthquake on 22 July 2020, using the same approach of high-frequency *P*-wave radiation. Applying STADIUM-Py Python package, teleseismic data of the earthquake from the Global Seismographic Network were downloaded with instrument response removed to obtain vertical component displacements of *P*-wave radiation. We sorted out data of stations with high signal-to-noise ratio filtering with 2-4 Hz band, normalized and then derived *P*-wave envelopes by conjugating with those of Hilbert transformed. The envelopes were smoothed with 10 sec window length and integrated to derive the cumulative energy of *P*-wave radiation, where the end of duration is determined by the slope of the cumulative curve approaching zero. In the future, we will examine the source duration as a function of azimuth to estimate the average duration and rupture length of the Alaska earthquake.

Introduction

For rupture front propagates on a finite fault, the rupture time will variate from the station azimuth with relative to the rupture direction. Figure 1. shows how the azimuth influences the duration of rupture and the duration of rupture (τ_c) in Haskell fault model, for observed at the station at (r,θ), is:

$$\begin{aligned}\tau_c &= \left[\frac{L}{v_r} + \frac{r - Lcos\theta}{c}\right] - \frac{r}{c} \\ &= \frac{L}{v_r} - \frac{Lcos\theta}{c}\end{aligned}$$

L: the length of fault; c: phase velocity of *P*-wave; v_r: rupture velocity; θ: station azimuth with respect to the rupture direction. According to the formula above, if a station is located in the direction of rupture propagation, θ = 0° and τ_c is short, since the area under the seismogram is constant, the amplitude will be high. In the contrast, if a station is located in the opposite direction of rupture propagation, θ = 180°, and τ_c is long and amplitude will be small (Fig. 2). Following the concept above, given the horizontal phase velocity to each station, the duration of the great 26 Dec. 2004 Sumatra-Andaman earthquake was estimated about 500 second with a ~1200 km rupture length and ~2.5 km s^{-1} average rupture speed by investigating the high-frequency *P*-wave. (Ni et al., 2005). In this study, we will follow the same concept to determine the strike of fault plane and rupture direction for 22 July 2020 Mw7.8 Alaska earthquake.

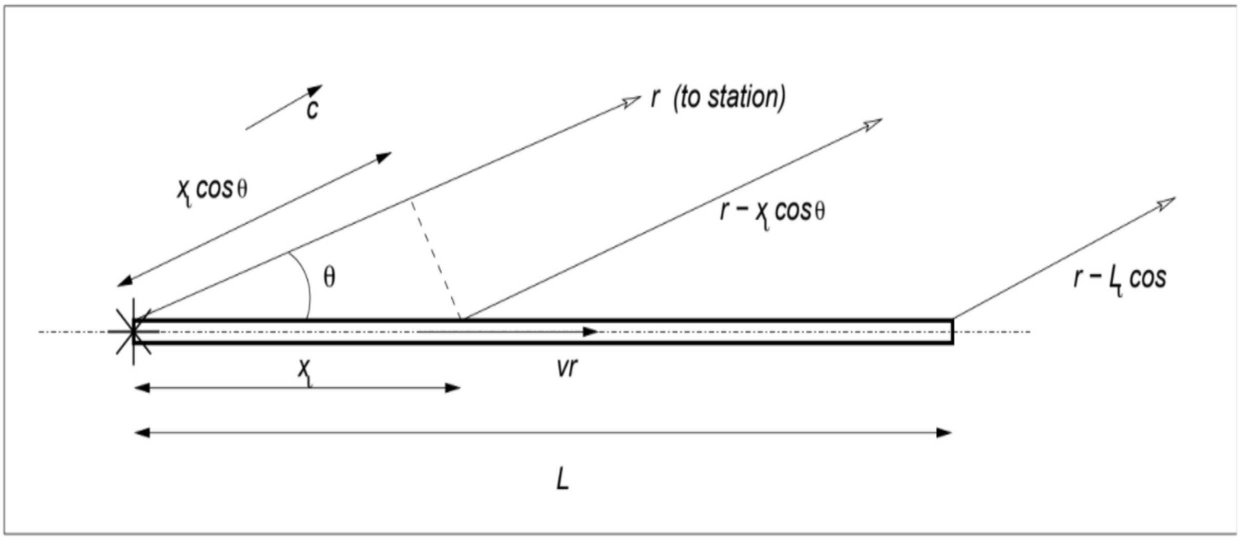

Figure 1. Azimuthal dependency of source duration, for fault plane rupturing from left to right.

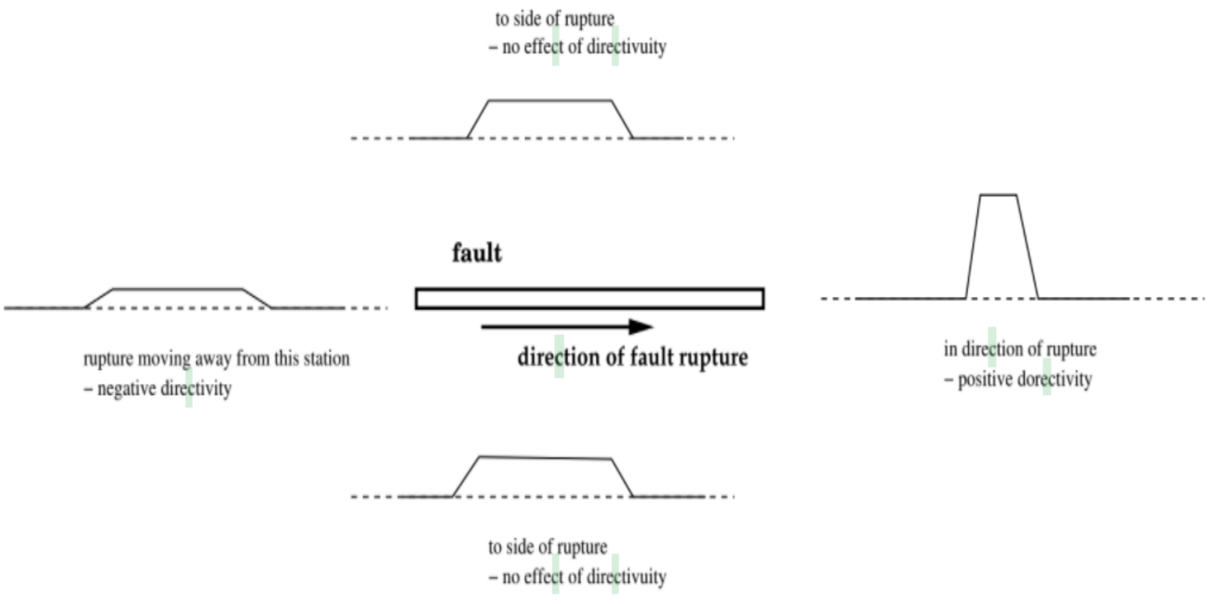

Figure 2. Simplified azimuthal variations for source time functions in a unilaterally fault rupture.

Data and Methods

We download vertical component data of 89 telesismic stations from GSN (Global Seismographic Network) (Fig. 3) with instrument response removed and filtered with 2-4 Hz bandpass to reduce the interference of later-arriving *P*-waves (PP,PPP) (Fig. 4). 77 out of 89 were sort out with high SNR with 100 s after theoretical *P*-wave arrival as signal window and 30s before theoretical P-wave arrival as noise window then calculating root mean square for each point in signal and noise window. If SNR is above 10, we define that data have relative high quality. In order to investigate the energy of high frequency P-wave radiation, we derive *P*-wave envelope by conjugating amplitudes of the data and its Hilbert-Transform with normalized and 10s window smoothed and also integrate the envelope to get cumulative energy. To obtain the trend of cumulative energy, we fit cumulative energy with quintic polynomial. However, when calculating cumulative energy, the energy of background noise will be included, so we shift the envelope according to averaging the envelope time window which 50s before theoretical P-wave arrival. Finally, If the moment which cumulative energy of *P*-wave is slower growth, we assume that there is the end of rupture. So the criteria for the end of rupture we determine is when slope of fitting curve approach to 0.2 (Fig.5).

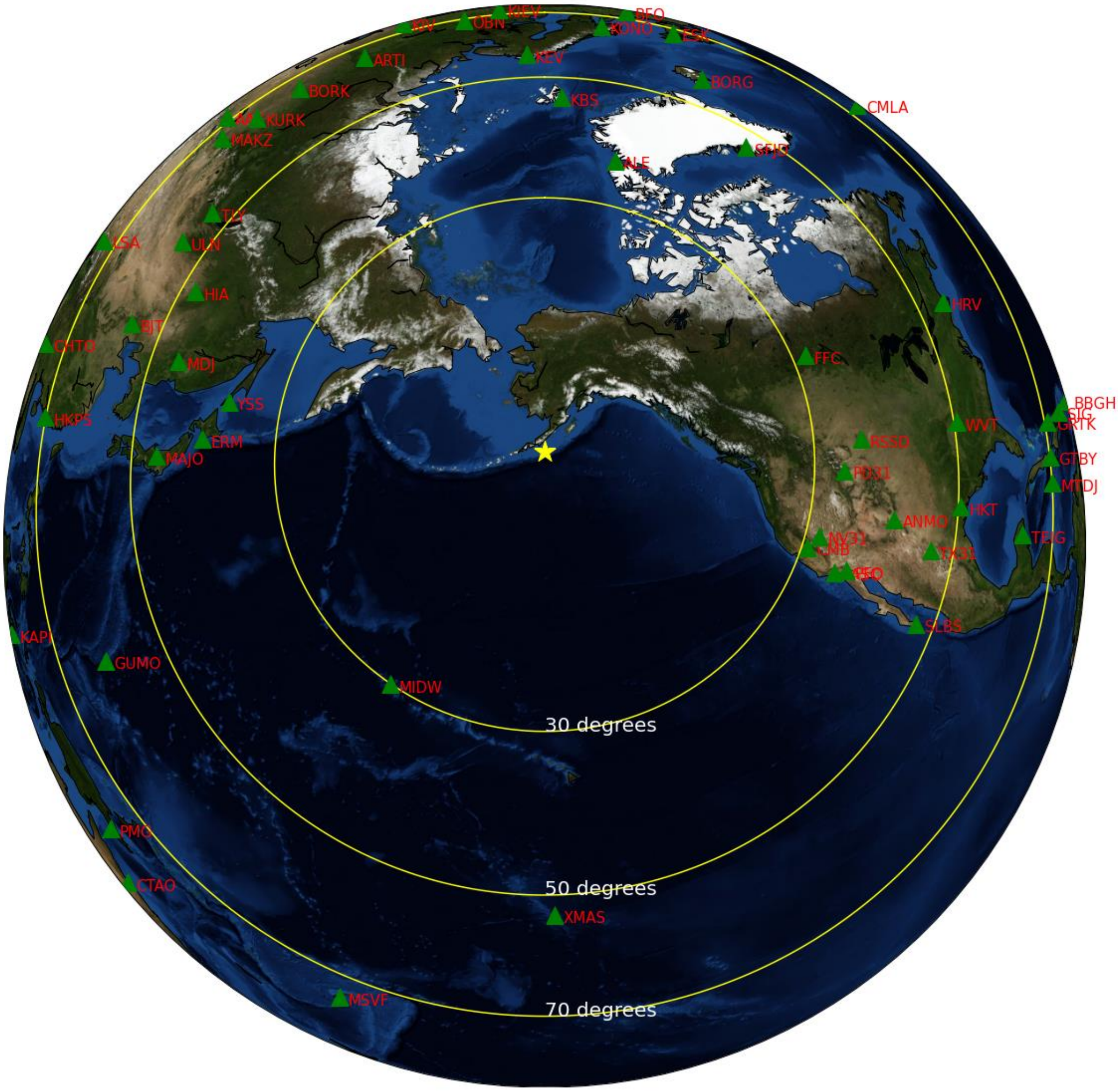

Figure 3. The distribution of GSN stations with epicenter distance between 30 to 90 degrees and arrange by azimuth. Green triangle represent stations and yellow star is Alaska earthquake.

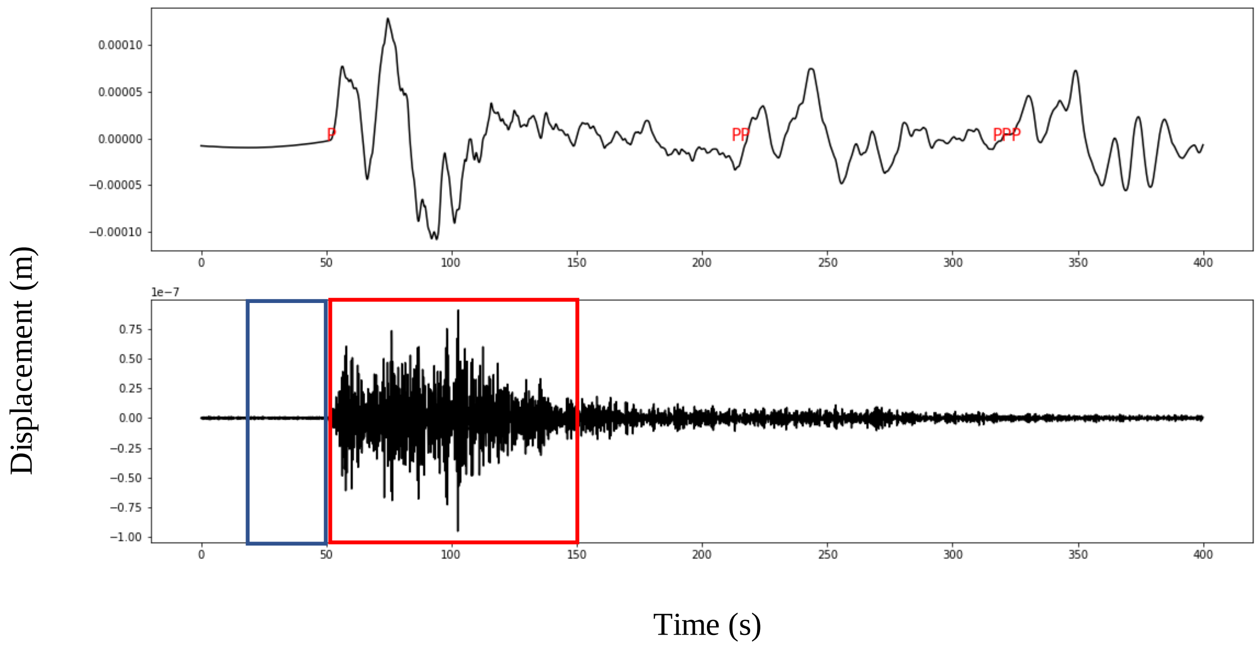

Figure 4. *P*-wave seismograms before (top) and after (bottom) 2-4 Hz bandpass filter; later-arriving *P*-waves (PP and PPP phases) are suppress significantly after high-bandpass. Blue box in bottom is noise window and red box is signal window.

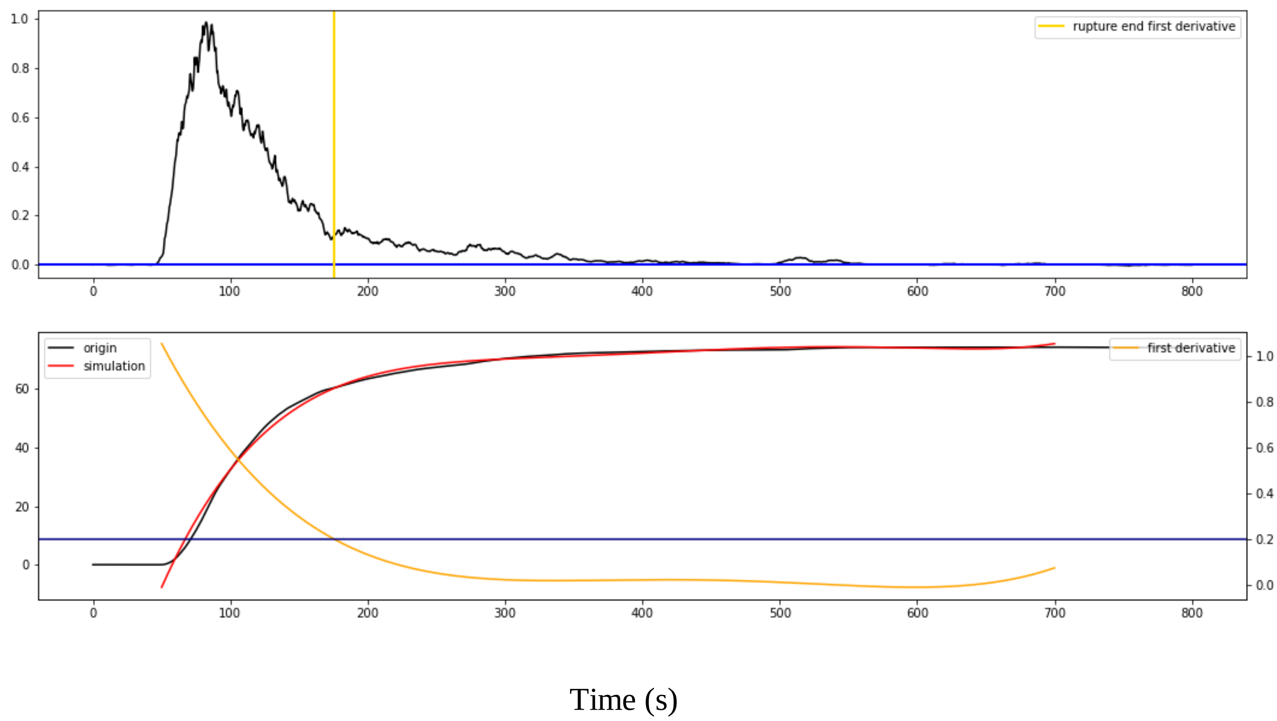

Figure 5. The upper picture shows normalized and shifted envelope with end of rupture (vertical yellow line) and envelope equal to zero (horizontal blue line); The lower picture shows the cumulative energy of *P*-wave (black curve) and its fitting curve (red line); yellow curve is the slope of red line and blue line is the threshold to determine the end of rupture.

Results

According to our observation, the end of rupture time we determine follows cosine pattern clearly (Fig 7.). The station TEIG (azimuth about 94 º) was observed the latest end of rupture time and in 180 º azimuth difference, the station MAJO (azimuth about 274º) was observed the earliest end of rupture time. In conclusion, in light of the result, we infer that the strike of fault plane of Alaska earthquake on 22 July 2020 is E-W orientation and rupture starting from eastern and end in western.

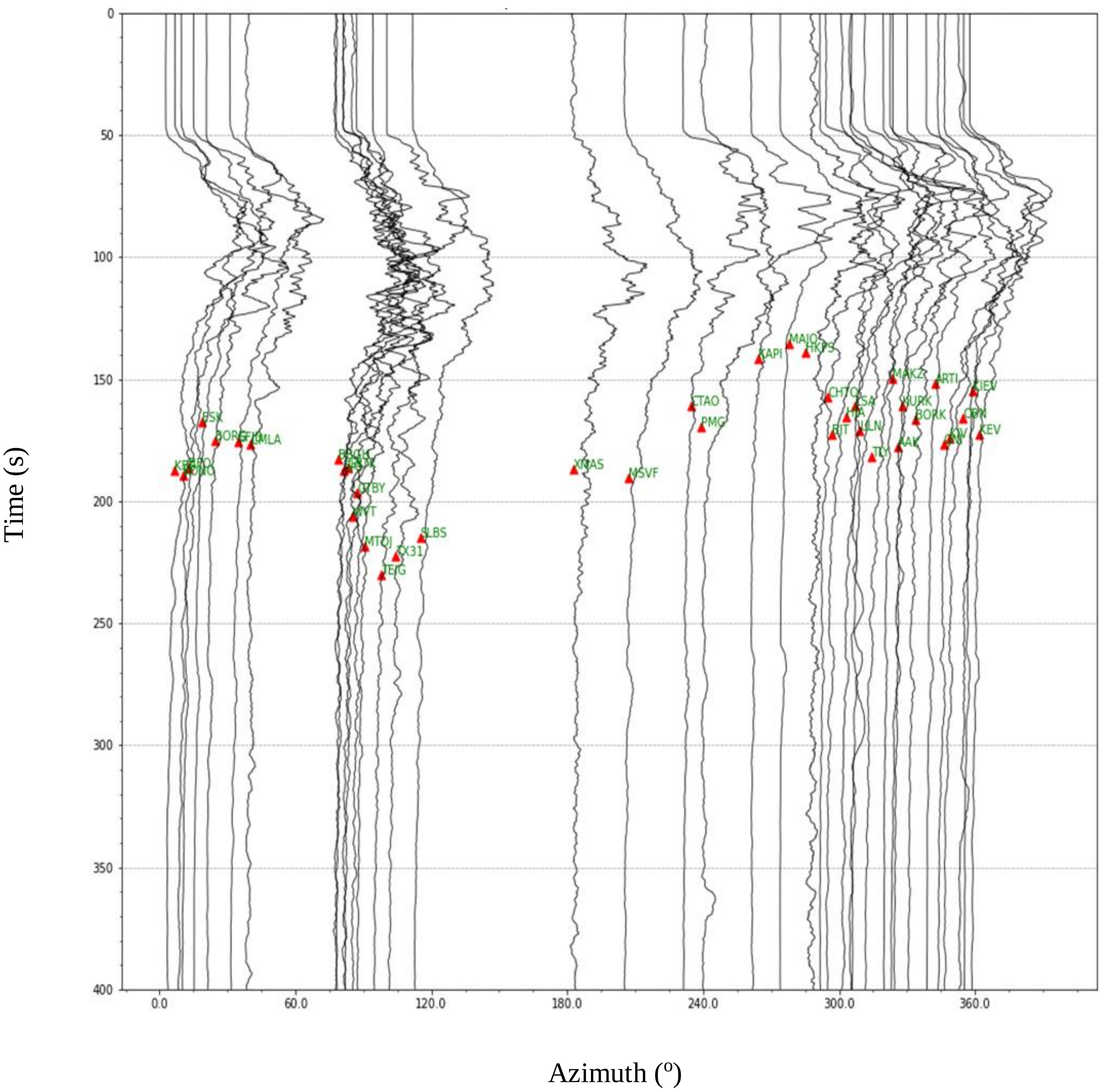

Figure 7. plotting the 39 the normalized and smoothed envelope seismograms of high frequency *P*-wave as function of azimuth with epicenter distance from 45 to 90 degrees and azimuth partition is 1 º.