**NUMERICAL SIMULATION OF LUNAR SEISMIC WAVE SCATTERING.** Xianghua Jiang[1] , Takashi Furumura[2], Yanbin Wang[1], [1]Peking University (No. 5 Yiheyuan Road, Haidian District, Beijing 100871, China. E-mail: jxh22255@sina.com), [2]The University of Tokyo (1-1-1 Yayoi, Bunkyo-ku, Tokyo, 113-0032, Japan).

**Introduction:** The lunar seismic signals was always characterized by a long duration coda. The codas show an intense scattering character and are strong enough to mask the phases after P- and S-wave. Recent numerical simulation of 2-D global seismic wave propagation in a whole-Moon model provided an understanding of wave propagation inside the Moon [1]. However, the simulation could not provide sufficient explanation of the coda character in the lunar seismic wave.

In this study, we focus on scattering effects caused by small-scale structure in the Moon on waveform. We apply a parallel FDM on a 2-D half-Moon model to simulate seismic wave propagation in the Moon with random heterogeneity. Our basic lunar layer model is based on recent proposed velocity and attenuation models [2, 3]. We will simulate the influence of subsurface low velocity sedimentary layer, scattering in the lunar crust and mantle, respectively.

**Method and Models:** We calculate the P- and SV-wavefield in a half-Moon model. We solve the wave equation in velocity-stress form in Cartesian coordinate system. The spatial derivatives are calculated by a fourth-order staggered grid FDM scheme. The time domain differentiation is represented by a finite difference scheme. The whole model is discretized into 150 million grids. The grid size is 0.2 km that enables us to calculate for frequencies up to 2 Hz.

Our simulation were carried out for four models (Table 1). First, we consider the influence of the sedimentary layer. To do this, we simulate Model0 without sedimentary layer and Model1 with a sedimentary layer. Then, we include effects of scattering in our simulation. Model2 considers scattering only in the lunar crust and Model3 includes scattering in the lunar mantle also. The random fluctuation of media is described by a von Karmann function.

**Table1:** Models used in our simulation. The word 'sediment' represents the subsurface 1 km layer which has a very low seismic wave velocity. $a$ is heterogeneous scale length, and $\varepsilon$ is standard deviation of fluctuation.

| Models | Description | $a$ (km) | $\varepsilon$ (%) |
|---|---|---|---|
| Model0 | No sediment, no scattering | | |
| Model1 | Sediment, no scattering | | |
| Model2 | Scattering in crust only | 1.0 | 3 |
| Model3 | Scattering in mantle also | 20.0 | 1 |

**Wavefield Snapshots:** Figure 1 shows wavefield snapshots at 300 second for the four models. We can see clear wave fronts for both P- and S-waves for Model0. In Modle1 the low velocity sedimentary layer caused strong reverberations following the direct and reflected waves. In Model2 the scattering in lunar crust caused perturbation of direct and reflected waves and energy diffusion in the wavefield after P- and S-wave. In Model3 extension of scattering into whole mantle enhanced energy diffusion.

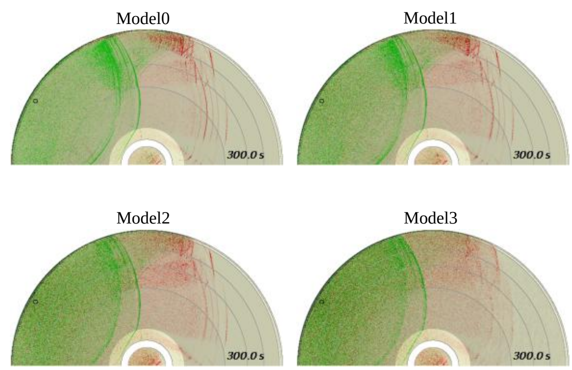


**Figure 1**. Comparison of wavefield snapshots at 300 second for the four models. P- and S-wave energy are shown in red and green colors.

**Synthetic Seismograms:** We compare synthetic waveforms with Apollo seismic records at station 12 for a shallow event occurred at March 13, 1973. The focal depth is 71.3 km and epicentral distance is 89.1 °. Figure 2 and 3 show seismograms and their envelope comparison for the radial component. Comparing Model0 and Model1, we find that low velocity sedimentary layer significantly enlarged amplitude of seismogram. As the P- and S-waves entered this layer propagate as trapped waves, energy are built up due to the superposition of multiple reflections and conversions. Including scattering in the crust reduced the peak amplitude and slowed the decay of coda amplitude. This can be seen clearly as smoothly reduction of envelope in Figure 3. Such characteristics are more consistent with the observation than those for models without scattering. From both seismogram and envelope representing Model3, we find that extension of scattering into the whole mantle further shape the waveform. In Figure 2, both P- and S-wave coda shape are more similar to the observed seismograms than other three models. In Figure 3, the trend of P- and S-wave coda envelope show a more similar pattern to the observation also. The above mentioned features can be observed more apparently on both seismograms and envelopes for the vertical component shown in Figure 4 and 5.

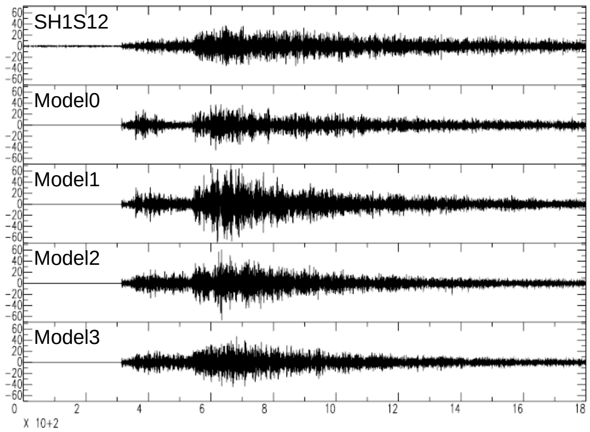


**Figure 2**. Comparison of synthetic radial component seismograms with Apollo recording for a shallow event. The horizontal axis shows time in second.

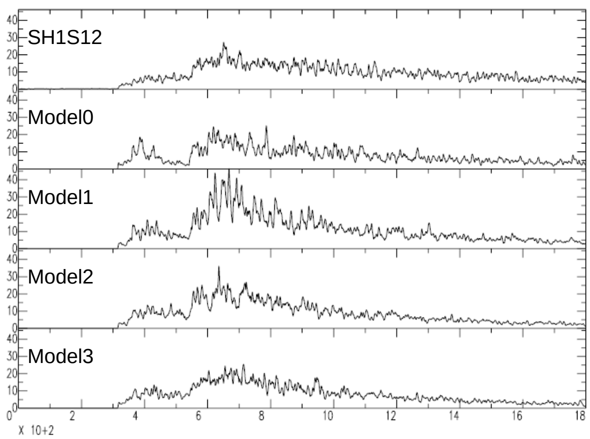


**Figure 3**. Comparison of envelope of the synthetic radial component seismograms with Apollo recording for a shallow event. The horizontal axis shows time in second.

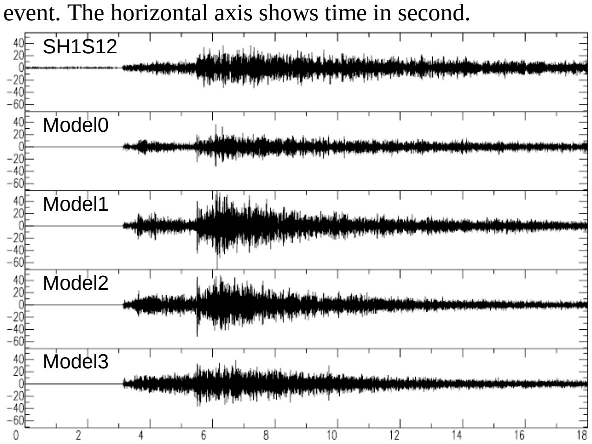


**Figure 4**. Comparison of synthetic vertical component seismograms with Apollo recording for a shallow event. The horizontal axis shows time in second.

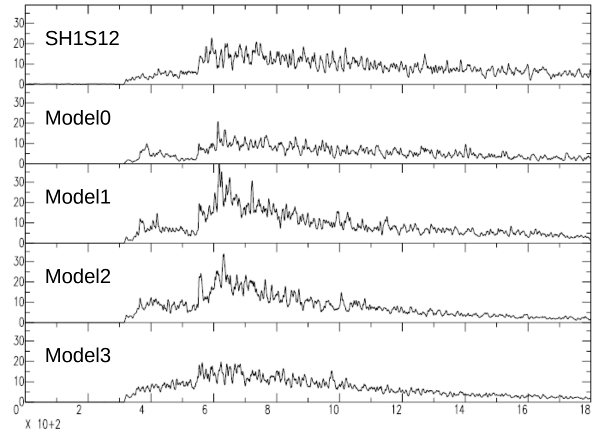


**Figure 5**. Comparison of envelope of the synthetic vertical component seismograms with Apollo recording for a shallow event. The horizontal axis shows time in second.

**Discussion and Conclusion:**

1. We successfully implemented a parallel simulation of seismic wave propagation in the Moon model. The modeling enables us to calculate wavefield up to a frequency of 2 Hz and hence suitable for lunar scattering modeling.
2. The low velocity sedimentary layer plays an important role in the seismic wave propagation in the Moon. Reverberations in this layer significantly enlarges amplitude of seismograms.
3. Scattering in lunar crust causes energy diffusion in the wavefield, reduction of peak amplitude and slow decay of coda amplitude.
4. Extension of scattering into the whole mantle further enhances energy diffusion in the wavefield, and causes change in waveform shape, which make both seismogram and envelope be more similar to the observations than other three models.
5. Our simulation results suggest that scattering may exist not only in the crust but also in the whole mantle of the Moon.

**References:** [1] Wang Y. et al. (2013) *Geophy. J. Int., 192*,1271-1287. [2] Weber R. C. et al. (2011) *Science*, *331*, 309-312. [3] Garcia R. F. et al. (2011) *Phys. Earth planet. Inter.*, *188*, 96-113.