NUMERICAL SIMULATION OF IMPACT-INDUCED SEISMIC WAVE GENERATION AND PROPAGATION USING A COUPLED APPROACH. Y. Gao[1,2], M.-H. Zhu[1,2], R. Luther[3], K. Wünnemann[3,4], [1]State Key Laboratory of Lunar and Planetary Sciences, Macau University of Science and Technology, Macau, China (yijgao@must.edu.mo), [2]CNSA Macau Center for Space Exploration and Science, Macau, China, [3]Museum für Naturkunde, Leibniz Institute for Evolution and Biodiversity Science, Berlin, Germany, [4]Institute für Geologische Wissenschaften, Freie Universität Berlin, Berlin, Germany.

Introduction: Impacts of cosmic bodies on planetary surfaces are an important source for the generation of seismic waves. In turn, the analysis of seismic waves allows for determining impact parameters and provides insights into the internal structure of planets [1-3].

Impact-induced seismic waves were subject of several modeling studies [e.g. 4-9]. However, most of them either focus on modeling wave propagation in the far-field assuming a simplified initial wave signal or they study the impact seismicity in the near-field by modeling the impact process itself.

Classical seismic wave simulation (SWS) is based on solving the elastic wave equations [10-12]. The difficulty in the impact-induced seismic wave simulation lies in the choice of the source time function. Most studies assume the Gaussian function or its (first-order and second-order) partial derivative functions as the theoretical source time function [1, 5]; however, it is questionable whether it describes the initial characteristics of the impact-induced seismic signal accurately. Furthermore, the seismic wave equations are based on the assumption of elastic deformation, but this assumption only holds true at sufficient distance from the point of impact. In a certain zone surrounding the impact, shock waves and plastic deformations dominate the wave characteristics, which cannot be treated by an elastic approach.

The iSALE shock physics code [13] has been used previously to simulate the seismic signatures from impact events as a function of material properties such as porosity and strength [7-9, 14]. Instead of solving the elastic wave equations, iSALE-2D is based on the conservation equations of mass, momentum, and energy. Therefore, it allows for simulating plastic deformation of an impact, and is also capable of accounting for the generating and propagation of the elastic wavefield. However, the high computational demands of such simulations limit the spatial domain to be investigated to the near field.

Here we simulate the impact-induced seismic wave by combining iSALE-2D and SWS. In the near-field area, we use iSALE-2D to determine the initial impact-induced seismic wave signal. Then we use the data from iSALE-2D at a certain distance, when the shock wave is attenuated and the elastic part of the wave dominates, as input for the SWS. Our simulation results show that the coupled approach accounts for both a realistic description of the source signal and accurate treatment of the propagation of the seismic waves in the far field.

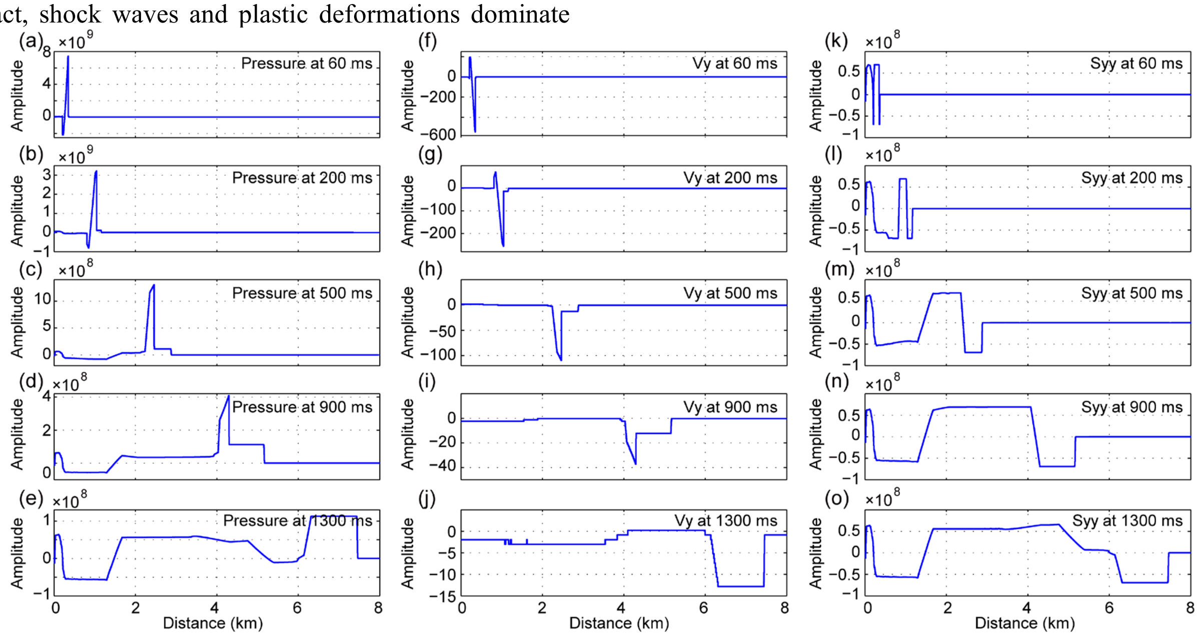

Fig. 1. Pressure, Vy, and Syy component at different times. The plate-shaped impactor is 1 meter in thick with an impact velocity of 18 km·s^{-1}, and the cell per projectile radius is 5.

Method: We use a plate-shaped impactor to generate a planar shock wave in our one-dimensional iSALE (Dellen version, [10]) impact simulation with a impact velocity of 18 km·s^{-1}. Both thermodynamic and mechanical material behavior of projectile and target are modeled with the Tillotson equation of state for basalt and a Von Mises strength model.

The seismic wavefield components of the iSALE output data are the velocity and stress components. For consistency, we use the first-order stress-velocity elastic wave equations for the seismic wave numerical simulation [12].

For the coupling of the two modeling approaches (iSALE and SWS) the choice of the specific location for the data hand off is key. It is given when the shock wave has decayed to an elastic wave. Fig. 1 shows the impact-induced pressure, the vertical component of the particle velocity Vy, and the Syy component of the stress tensor at different times, from which we can see the transition from a shock wave to an elastic wave. The spike of the shock wave decays within ~1,300 ms, while the elastic precursor occurs after ~200 ms (see Fig. 1). For the Syy-component, the elastic wave shows a constant plateau in Fig. 2f, which propagates with time. We therefore conclude that, for this impact scenario, the elastic wave has been generated at 1,300 ms, and we select 6 km as the data hand-off location (see Fig.2).

Result of Seismic Benchmark: Fig. 2 shows the results of SWS simulation, iSALE, and iSALE-SWS coupled simulation. The pure SWS simulation uses Gaussian function as the seismic source, and the elastic parameters in the seismic wave equations are obtained based on the iSALE model parameters. The travel time of the wave in SWS is consistent with that of the iSALE simulation, but the waveform is inconsistent owing to the different source descriptions. The result of the iSALE-SWS coupled simulation matches with that of the iSALE simulation, which indicates that the coupled approach works for the impact-induced seismic wave propagation model.

Conclusions and Discussions: To obtain a credible impact-induced seismic wavefield, we use iSALE-SWS coupled approach. Our numerical simulation results demonstrate that using a SWS with a Gaussian source oversimplifies the impact induced wave pattern, while the coupled approach provides a much more realistic description of the source signal and much more accurate far-field modeling. The results we show here only address a simplified 1D scenario, Simulations of the seismic wave field generated by a vertical impact in a cylindrically geometric space will be presented. In the future, we intend to study heterogenous target conditions and oblique impacts.

Acknowledgement: We gratefully acknowledge the developers of iSALE. This research is supported by the Science and Technology Development Fund, Macau SAR (0002/2019/APD, 0064/2022/A2), and is also supported by the National Natural Science Foundation of China (41704063, 11773087). RL and KW are funded by the NEO-MAPP project (870377) by the EC's Horizon 2020 program.

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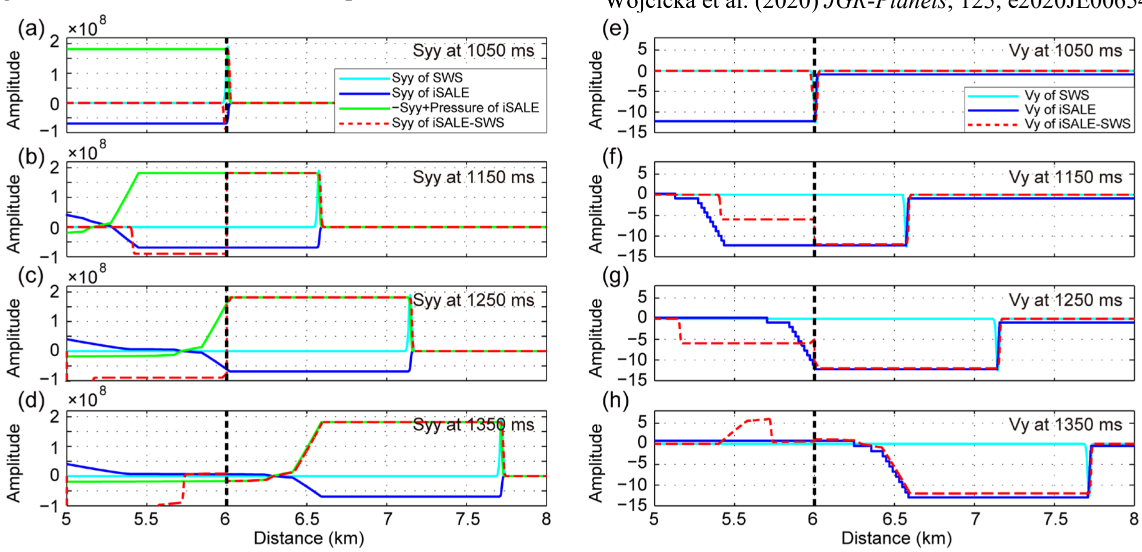

Fig. 2. Results of SWS, iSALE, and iSALE-SWS simulation. The data hand-off location of iSALE data is 6 km (the black dashed lines).