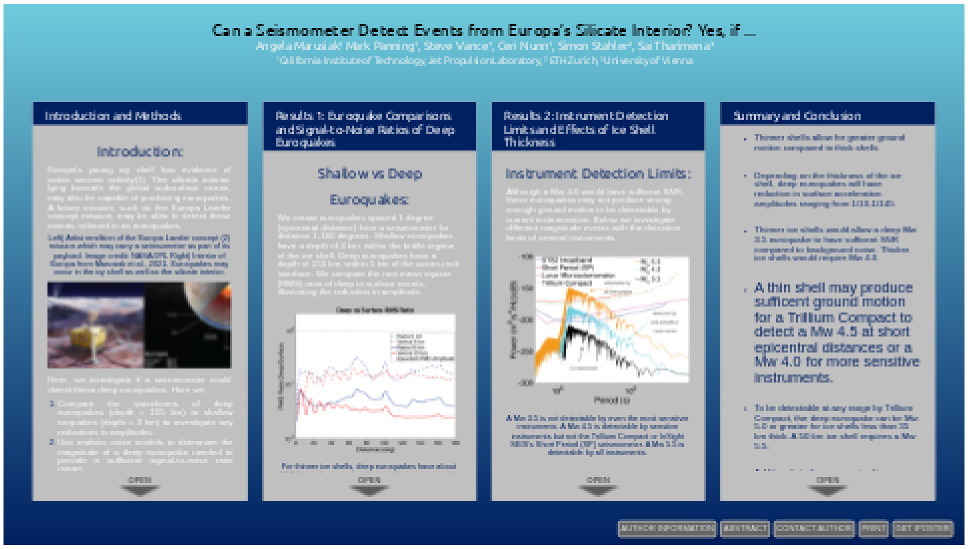
Can a Seismometer Detect Events from Europa’s Silicate Interior? Yes, if ...



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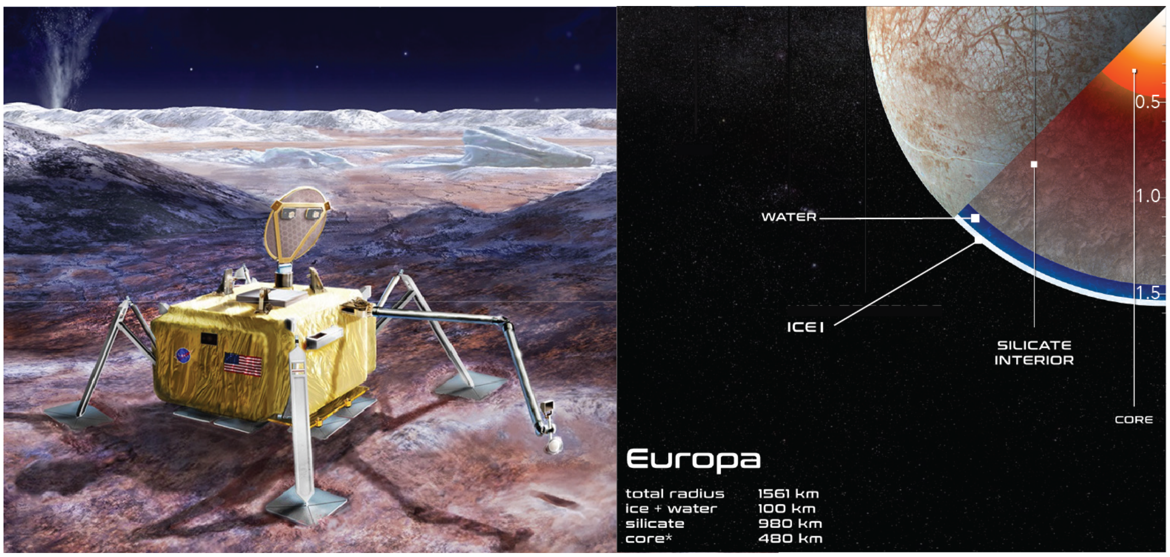
PRESENTED AT:

INTRODUCTION AND METHODS

Introduction:

Europa's young icy shell has evidence of active seismic activity (*1*). The silicate interior, lying beneath the global subsurface ocean, may also be capable of producing euroquakes. A future mission, such as the Europa Lander concept mission *(2)*, may be able to detect these events, referred to as euroquakes.

Left) Artist rendition of the Europa Lander concept *(2)* mission which may carry a seimsometer as part of its payload. Image credit: NASA/JPL Right) Interior of Europa from Marusiak et al., 2021. Euroquakes may occur in the icy shell as well as the silicate interior.



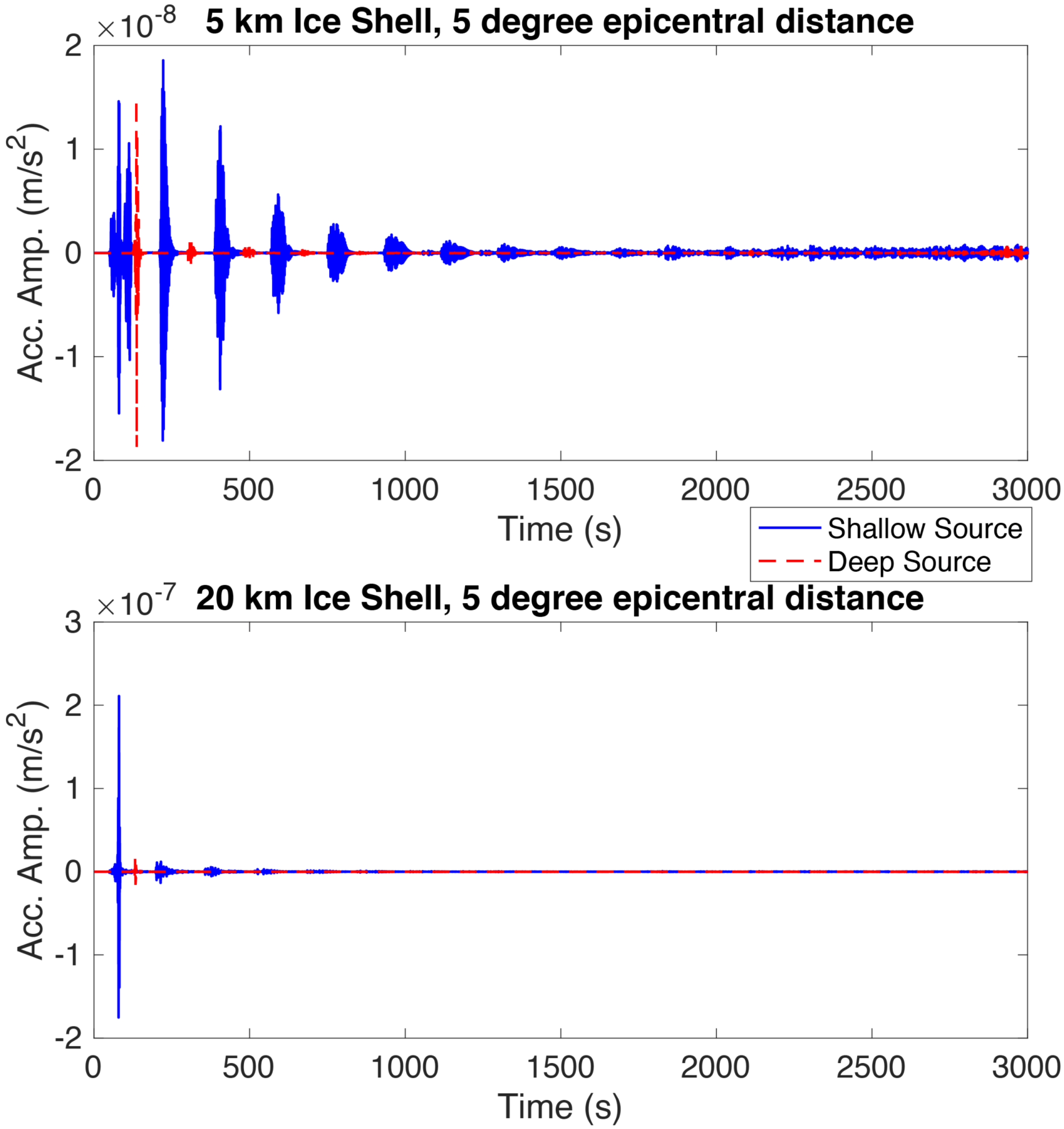
Here, we investigate if data from a seismometer could be used to detect these deep euroquakes. Here we:

1. Compare the waveforms of deep euroquakes (depth = 155 km) to shallow icequakes (depth = 3 km) to investigate any reductions in amplitudes
2. Use realistic noise models to determine the magnitude of a deep euroquake needed to provide a sufficient signal-to-noise ratio (SNR)
3. Compare the signal strength of deep events to current instrument capabilities
4. Investigate if ice thickness plays a role in detection limits.

Methods:

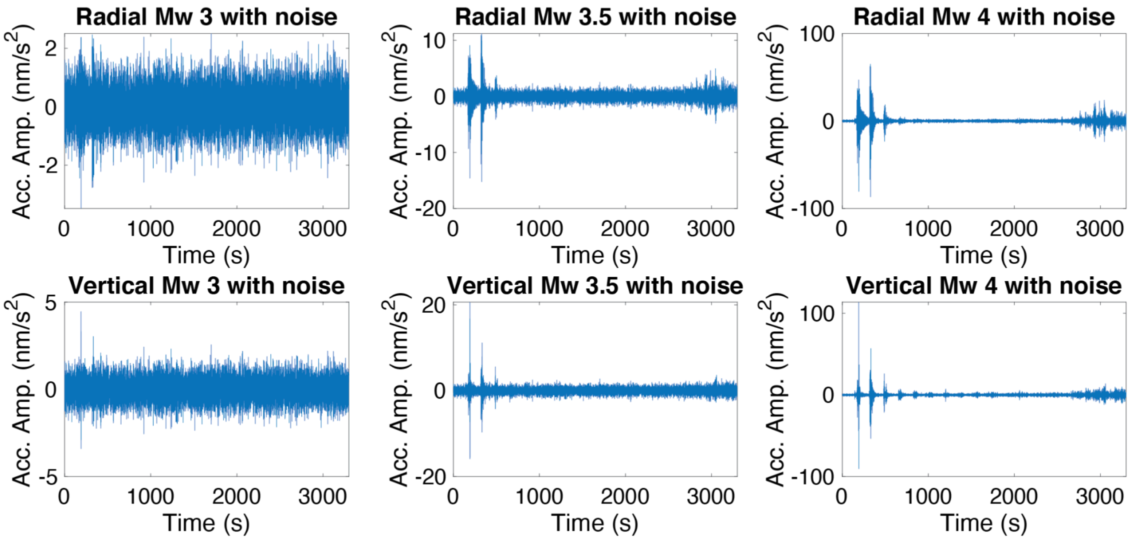
We use PlanetProfile (3) to generate several internal structure models with ice shells ranging from 5-50 km. PlanetProfile models are then used as inputs for AxiSEM (4) and Instaseis (5) to generate seismic waveforms.

Example of deep vs shallow euroquakes using the 5km (top) and 20 km (bottom) ice shell models. Waveforms are generated using AxiSEM and Intaseis codes.



To generate realistic background nouse, we use the approach of Panning et al., 2018 *(6)*. Signal-to-Noise Ratios (SNRS) are calculated using the root mean square(RMS) of the background noise:

$$SNR = RecordAmplitude/RMS(BackgroundNoise)$$

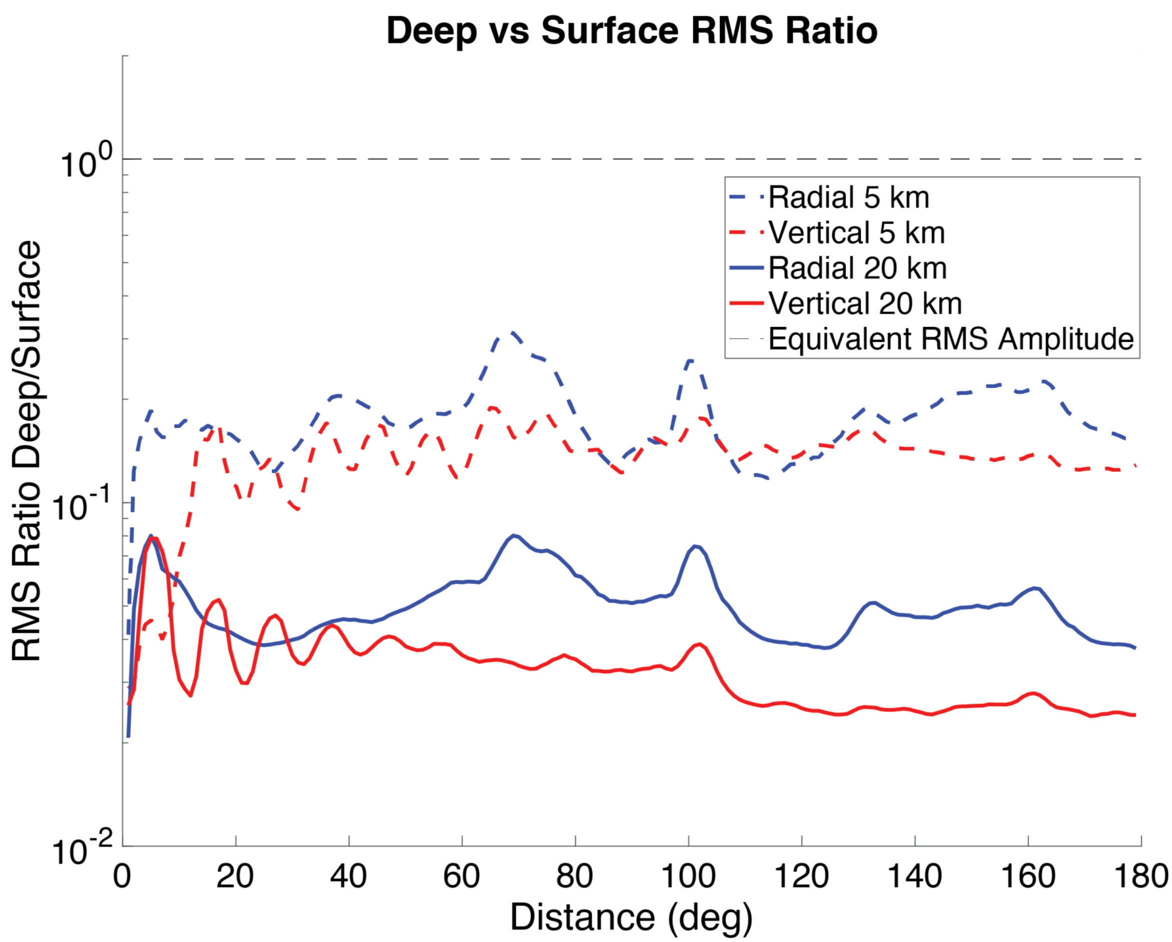


Waveforms with realistic noise added for a 10 km thick ice shell. The M_w 3.0 is hard to see above the background noise, but a M_w 3.5 surface waves can be seen, and a M_w 4.0 can be easily seen.

RESULTS 1: EUROQUAKE COMPARISONS AND SIGNAL-TO-NOISE RATIOS OF DEEP EUROQUAKES

Shallow vs Deep Euroquakes:

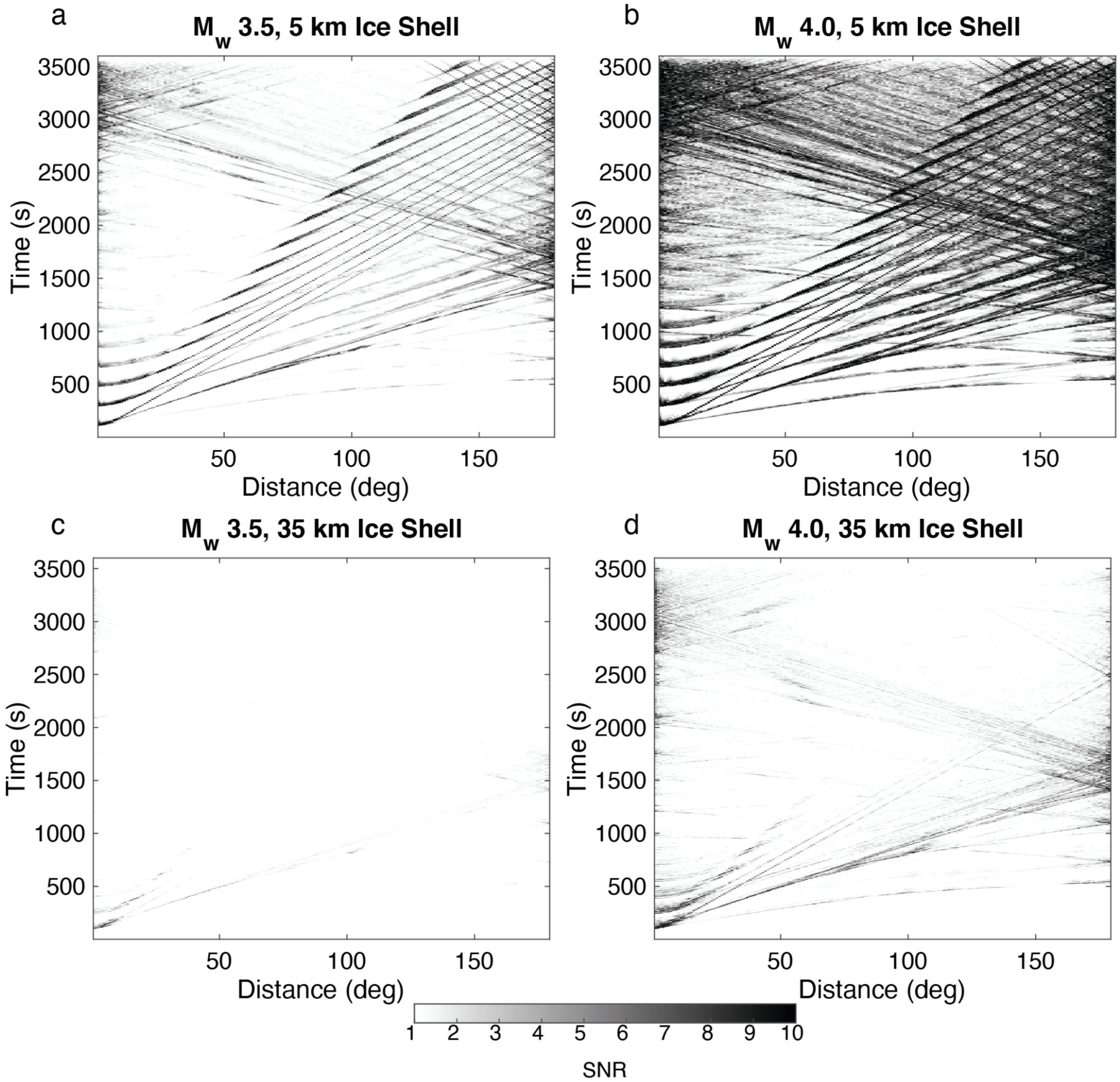
We create euroquakes spaced 1 degree (epicentral distance) from a seismometer for distance 1-180 degrees. Shallow euroquakes have a depth of 3 km, within the brittle regime of the ice shell. Deep euroquakes have a depth of 155 km, within 5 km of the ocean-rock interface. We compare the root mean square (RMS) ratio of deep to surface events, illustrating the reduction in amplitude.



For thinner ice shells, deep euroquakes have about 1/10 the surface acceleration ampltiude compared to shallow euroquakes. Thicker ice shells have greater differences in ampltiudes. Deep euroquakes have 1/12-1/100 the acceleration amplitude compared to shallow euroquakes.

SNRs of Deep Euroquakes:

We investigate the minimum event magntitude required to overcome background noise.

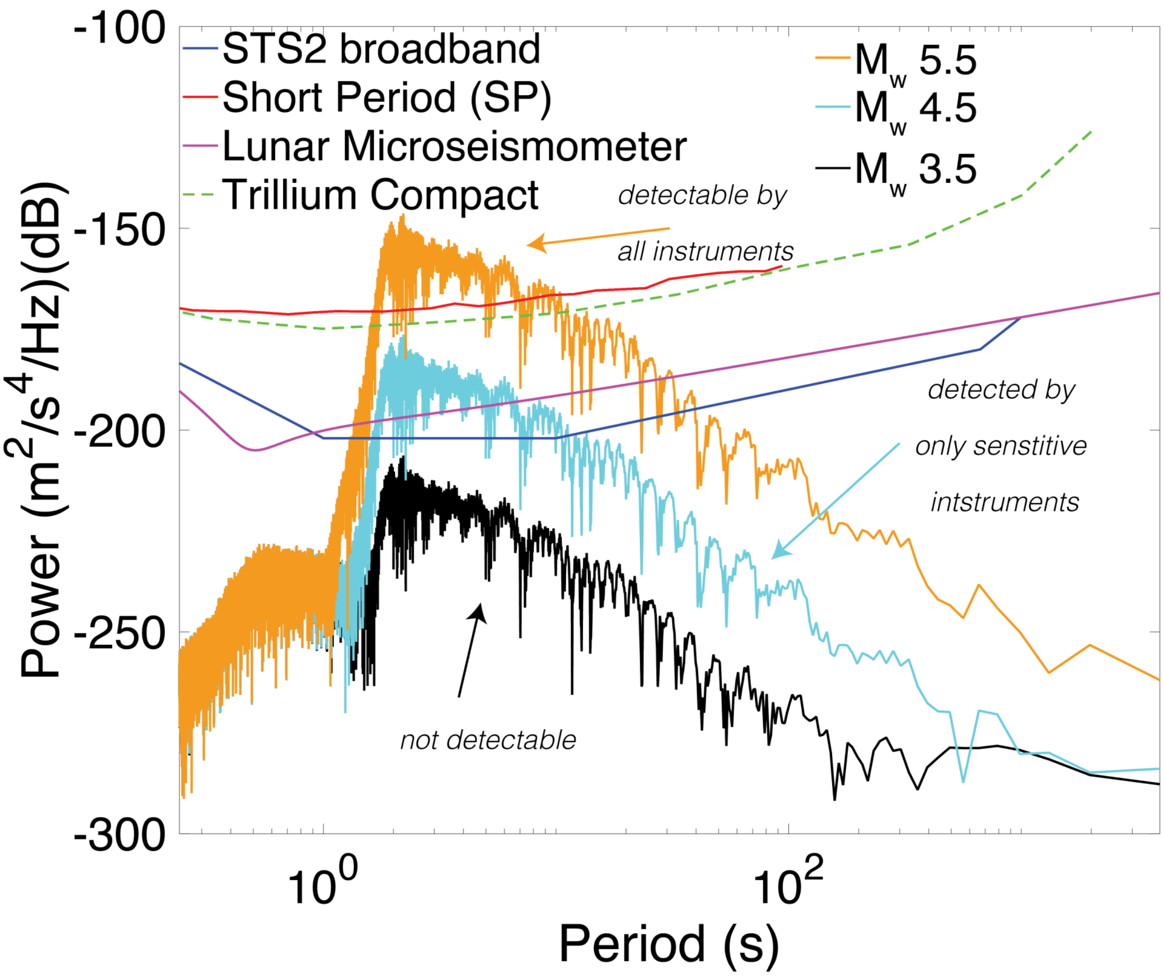


Thinner ice shells have higher SNRs for the same magnitude euroquake compared to thicker ice shells. While a Mw 3.5 can be seen well when the ice shell is 5 km thick, a Mw 4.0 is needed for ice shells of 35 km or greater.

RESULTS 2: INSTRUMENT DETECTION LIMITS AND EFFECTS OF ICE SHELL THICKNESS

Instrument Detection Limits:

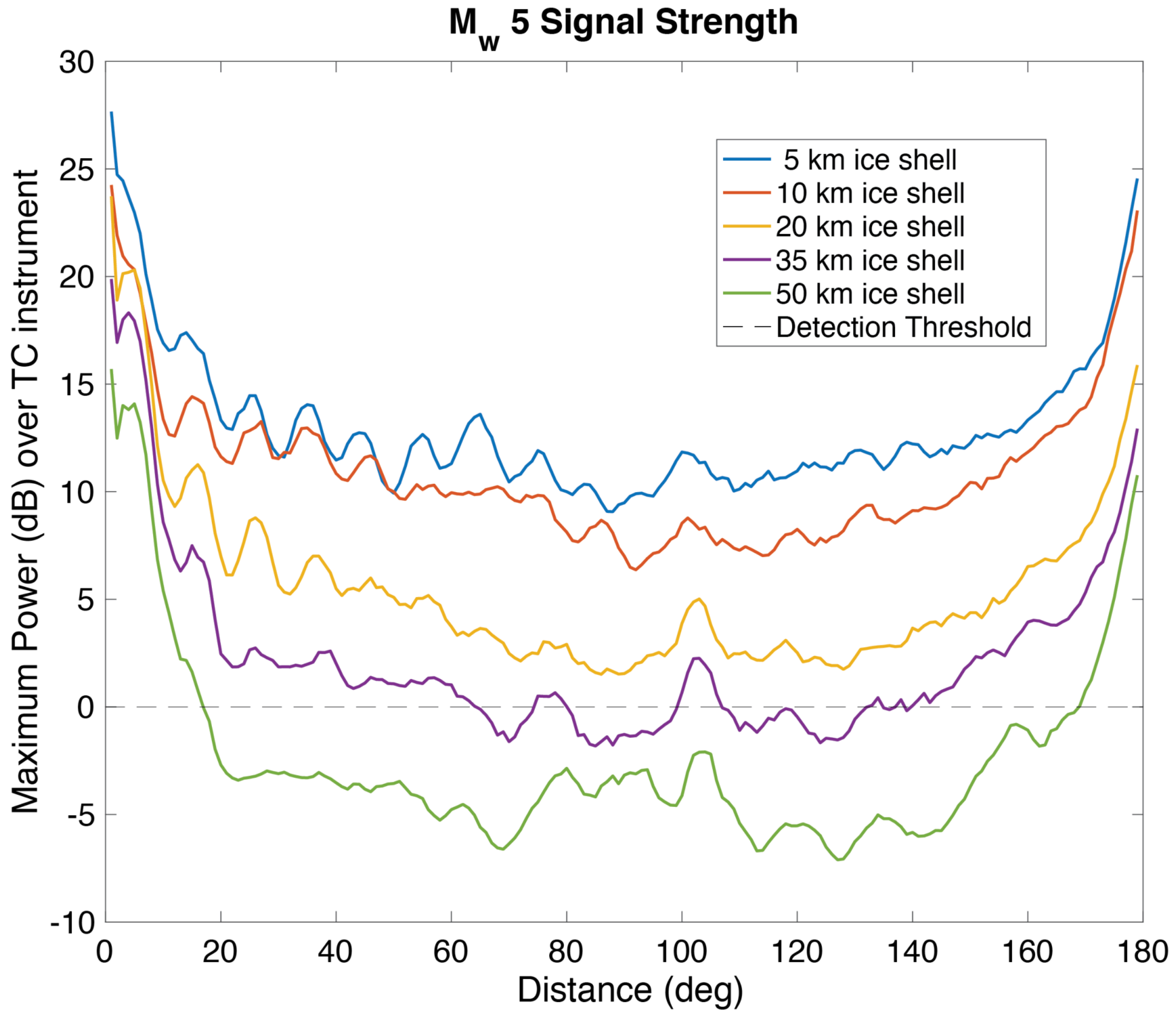
Although a Mw 4.0 would have sufficent SNR, these euroquakes may not produce strong enough ground motion to be detectable by current instrumention. Below we investigate different magntiude events with the detection limits of several instruments.



A Mw 3.5 is not detectable by even the most sensitive instruments *(7)*. A Mw 4.5 is detectable by senstive instruments but not the Trillium Compact or InSight SEIS's Short Period (SP) seismometer (*8)*. A Mw 5.5 is detectable by all instruments.

Effects of Ice Shell Thickness:

For a range of distances, we measure the maximum value of an euroquake's periodgram (above figure) compared to the detection limits of the Trillium Compact seismometer. This value shows the detection limits based on distance and ice shell thickness.



A Mw 5.0 produces sufficent ground motion when the ice shell is less than 35 km thick. When the ice shell is 35 km thick, the euroquake could be detected at distances less than 60 degrees or greater than 130 degrees. For a 50 km thick ice shell, the Mw 5.0 euroquake is only detectable at distances less than 20 km or greater than 170 degrees.

A Mw 5.0 is globably detectable when Europa's ice shell is less than 35 km thick. For thicker ice shells, a larger euroquake is required.

SUMMARY AND CONCLUSION

- Thinner shells allow for greater ground motion compared to thick shells
- Depending on the thickness of the ice shell, deep euroquakes will have reduction in surface acceleration amplitudes ranging from 1/10-1/145.
- Thinner ice shells would allow a deep Mw 3.5 euroquake to have sufficent SNR compared to background noise. Thicker ice shells would require Mw 4.0.
- A thin shell may produce sufficent ground motion for a Trillium Compact to detect a Mw 4.5 at short epicentral distances or a Mw 4.0 for more sensitive instruments.
- To be detectable at any range by Trillium Compact, the deep euroquake can be Mw 5.0 or greater for ice shells less than 35 km thick. A 50 km ice shell requires a Mw 5.5.
- Additional studies are required to determine whether Europa could produce a Mw 5.0 or greater.

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ABSTRACT

Europa likely has an active surface ice shell producing numerous low-magnitude (<Mw 4.0) events over its tidal cycle. Several studies have investigated Europa's potential seismicity due to tidal forces[1], and have estimated background noise levels[2]. However, these studies assumed events originated in Europa's ice shell. Here, we investigated if an event from Europa's silicate interior could be detected by a surface seismometer. Such an event could be caused by tidal interactions analogous to deep moonquakes[3] or by large scale eruptions[4] and/or faulting at the ocean-rock interface. In order to be detected, the seismic event needed to have sufficient signal-to-noise ratios and created ground displacements large enough to be measured by seismic equipment. We used PlanetProfile[5] to generate interior structures models for a thin (5 km) and thick (20 km) ice shell. We then used those models as inputs for AxiSEM[6] and Instaseis[7] to generate synthetic waveforms with events originating in the shallow (3 km source depth) ice shell and in the silicate interior (155 km source depth). We measured the reduction in amplitudes of deep events compared to the shallow events. To determine the minimum event magnitude that could be detected we added probable background noise[2] to calculate the signal-to-noise ratios. Lastly, we compared periodograms of deep events to instrument noise levels to determine the smallest event that could be detected. We found that although a Mw 4.0 event created sufficient signal-to-noise ratios, an event needed to be at least a Mw 5.0 to be detected by a surface seismometer. A thinner ice shell was more conducive to the detection of the deep events.

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