BOUNDS ON VENUS'S SEISMICITY FROM THEORETICAL AND ANALOG ESTIMATIONS. I. Ganesh[1], R. R. Herrick[1], and T. Kremic[2]. [1]Geophysical Institute, University of Alaska Fairbanks, AK (iganesh@alaska.edu). [2]NASA Glenn Research Center, Cleveland, OH.

Introduction: Seismic investigations of the Moon and Mars have been instrumental in establishing precise constraints on the interior structure, properties, and seismicity of these bodies [1,2]. Similar seismic studies of Venus would significantly advance our understanding of the internal structure and current tectonic regime of Venus, global and regional seismicity, and the possibility of ongoing volcanism. At least multiple weeks of data collection would be needed to establish a baseline of Venus seismicity, far exceeding the ~1-hour duration of previous Soviet landers. Recent advances in high-temperature electronics have enabled the ongoing development of a landed seismometer projected to be able to operate for a period of 60–120 days [3]. Other researchers have also focused on utilizing the strong surface-atmosphere coupling to perform seismic investigations from an aerial platform [4]. Engineering requirements for both landed and airborne seismic instruments will be driven by the expected spatial and temporal distribution of seismic events on Venus over the course of the mission. In this study, we focus on the temporal distribution of seismicity and present two approaches for estimating the magnitude-frequency distribution of venusquakes:

1. Theoretical estimations based on mechanisms capable of inducing seismic stresses on Venus.
2. Treating Earth as an analog and scaling short-duration terrestrial seismicity.

Moment M_0 (Nm)	Num. of events / year	Num. of events / 120 days
3.981×10^{10}	274944	90331
3.162×10^{11}	68587	22534
2.512×10^{12}	17110	5621
1.995×10^{13}	4268	1402
1.585×10^{14}	1064	350
1.259×10^{15}	265	87
1.000×10^{16}	66	22
7.943×10^{16}	16	5
6.310×10^{17}	4	1
5.012×10^{18}	0.77	0.25
3.981×10^{19}	0	0

Table 1. Number of venusquakes with moment > M_0

Theoretical approach: Amongst the different mechanisms that generate seismic stresses in the Earth's lithosphere [5], ones that are not associated with plate boundaries and asthenosphere (and therefore more likely to be operational on Venus today) include contraction of the lithosphere due to cooling at the global scale, and mantle plumes at regional scales. Currently, we focus only on global scale seismicity caused by lithospheric cooling. We use an approach introduced by [6] to compute the strain rate, cumulative seismic moment, and event recurrence rates associated with planet-wide cooling and contraction of the lithosphere over a 500 Myr timespan. We consider a seismogenic layer that is 40 km thick, has a depth- and time-averaged cooling rate of $5\text{x}10^{-10}$ K yr^{-1}, shear modulus of 50 GPa, and volumetric thermal expansion coefficient of $3\text{x}10^{-5}$ K^{-1} in our calculations.

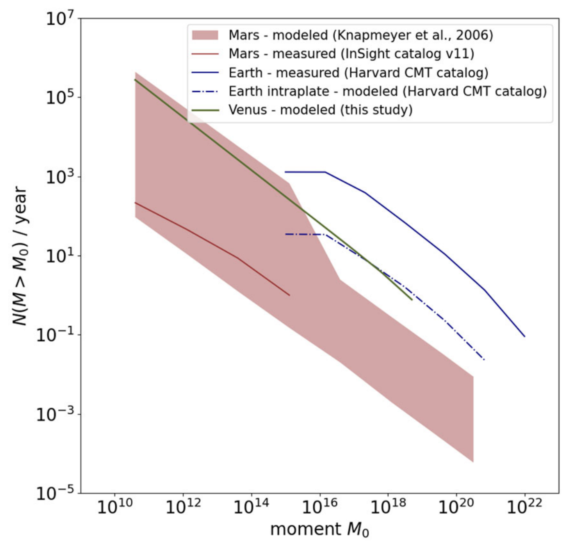

Fig 1. Predicted seismicity on Venus, compared with existing models and data for Earth and Mars.

The estimated seismic strain rate and cumulative moment are 1.85×10^{-20} s^{-1} and 2.07×10^{19} Nm, respectively. We further compute recurrence rate of venusquakes assuming a moment-frequency relationship of the form $N(M_0) = a\, {M_0}^b$, with $b = 0.67$, consistent with intraplate earthquakes. For more details on the computation of a and $N(M > M_0)$, refer to [6]. Table 1 shows the number of expected venusquakes over two different time periods. The annual event distribution allows for comparison with existing seismicity models and observations (Fig. 1), while the 120-day seismic distribution is more relevant to ongoing studies [3,4]. We estimate roughly 5 quakes of magnitude 5 or larger (corresponding to $M_0 = 7.943 \times 10^{16}$ Nm in Table 1) within a 120-day period. Quakes with smaller magnitude are numerous and likely to be easily detected for small epicentral distances.

Fig. 1 shows a comparison of the computed annual seismicity on Venus with moment frequency distributions predicted by pre-InSight seismic models of Mars [7], post-InSight regional seismicity [8], Earth's seismicity computed from the Harvard CMT catalog [9], and Earth intraplate seismicity modeled as ~ 0.5% of Earth's seismicity. The predicted seismicity for Venus (green line in Fig. 1) is similar to the seismicity of intraplate regions on Earth, higher than the regional seismicity measured by InSight, and towards the upper limits of predicted seismicity in Mars.

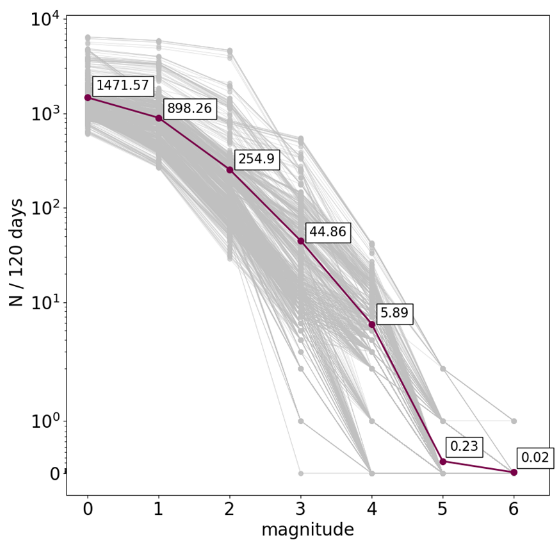

Fig 2. Cumulative magnitude-frequency distribution of global earthquakes for a 120-day period.

Analog approach: Previous estimations of Venus's seismicity computed by scaling Earth's values focused primarily on large magnitude events (>4-5), over annual to decadal timescales [10,11]. To better understand the distribution of events on Venus observable by a 120-day long mission, we implement a statistical approach that covers a larger magnitude range (0 to 7) and shorter period. We compile 1000 seismic catalogs, each containing events occurring during 1000 randomly selected 120-day periods between 2000 and 2021, by querying the USGS earthquake database. Using such a bootstrap approach ensures that we do not overestimate the likelihood of event recurrence at large magnitudes. We search for events occurring after 2000 in order to restrict our search to periods of improved seismic monitoring. We exclude all events with magnitudes > 7 (as suggested by [12]), and all events occurring at depths > 50 km (typically associated with deep subduction). Limiting our search in this way makes the predicted magnitude-frequency distribution in Fig 2. comparable to the expected seismicity on Venus. The cumulative distributions of earthquake magnitudes for all the catalogs (grey lines), and the average distribution (purple line) are shown in Fig 2.

Precise comparisons between the theoretical and analog predictions are precluded by differences between the approaches used. However, to first order, we see that the number of events on Venus over a 120-day period estimated using the analog approach (Fig. 2) is consistently less than predictions from the theoretical approach (Table 1), across the entire range of moments (and magnitudes) considered. The analog approach predicts no events with magnitude >5 except in a handful of cases. These results could be considered a lower bound for the expected seismicity on Venus.

Conclusions and future work: We present two approaches for estimating Venus's seismicity. Estimations from the theoretical approach are consistent with Venus's seismicity being comparable to Earth's intraplate seismicity (Fig. 1). Under the assumptions made, estimations from the analog approach (which emphasize event recurrence within a 120-day period), suggest that the number of large quakes (magnitude > 5) likely to occur within this period is very small, if not zero. One or more events with magnitude > 5, if observed, will provide insights into the deep interior of Venus. In the absence of such large events, smaller quakes will still aid in placing limits on regional seismicity and crustal structure.

Future efforts will involve expanding this work to include seismicity of specific geodynamic settings that are likely on Venus, e.g., hotspots, rifts, fault-bounded basins. This will allow us to explore plausible spatial distributions of seismicity on Venus, in addition to the temporal distribution considered here. We will also investigate the detectability of seismic events as a function of epicentral distance, taking into account the spatial and temporal distribution, and lithospheric conditions (temperature, hydration) expected on Venus.

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