Development and Initial Testing of a Venus-Analog Seismic Events Catalog

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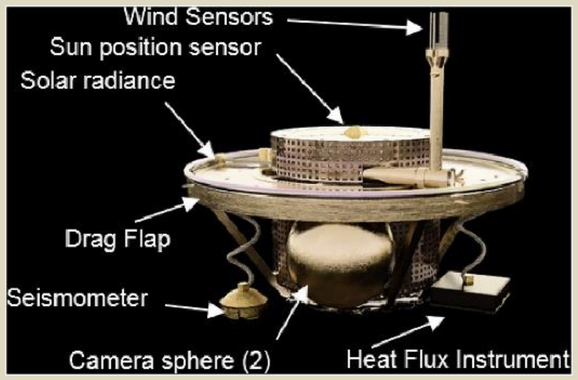
Introduction: A network of seismometers on Venus would be highly valuable, but the desired observation period of at least weeks far exceeds the ~1-hour lifetimes of previous landers in the harsh Venusian surface conditions. NASA Glenn Research Center (GRC) has been working through various aspects of instrument design and testing for a seismometer that can survive for an extended period in ambient Venus conditions. The instrument will likely have a variety of limitations and restrictions. In particular, the instrument will be battery powered and have little or no memory capability, and both data transmission and continuous operation will rapidly expend the battery. Part of the design process is testing approaches to solve these problems against anticipated Venus seismicity.

Project Overview: With funding from NASA EPSCoR's Rapid Response Research and Research Infrastructure Development grant programs, we have developed a partnership with GRC and the Alaska Earthquake Center (AEC) to conduct a one-year research project to do the following; highlighted points are some initial results shown here:

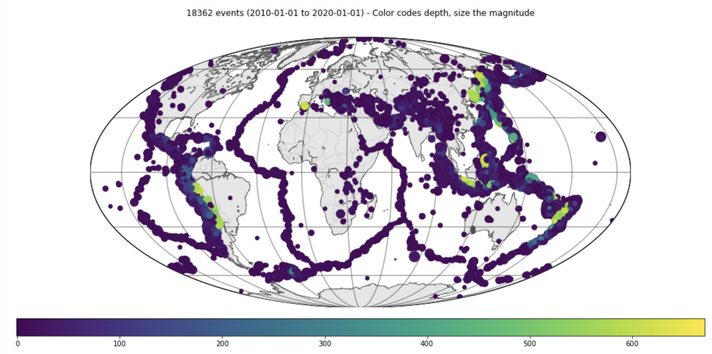
1. Evaluate the expected level and nature of seismic activity on Venus.
   a. Examine favored analog regions, e.g.:
      i. African plate – rifts, surrounded by spreading;
      ii. Rollback subduction areas, like Caribbean plate.
   b. Evaluate differences in surface and subsurface properties, e.g.:
      i. No asthenosphere on Venus;
      ii. Better surface-atmosphere coupling;
      iii. Dry rocks and brittle-ductile transition.
2. Construct a catalog of terrestrial analog events.
   a. Earthquake types – e.g., standard thrust, transform, eruptions, landslides, explosions for bolides.
   b. Sensor types – noise levels, frequency response, ocean-bottom and different coupling on land, etc.
3. Assess how potential design restrictions of a Venus seismometer affect interpretability.
   a. Simple amplitude trigger. Misses p-wave; triggered by surface waves? Triggers other stations in network in time to see p-wave?
   b. Are there better implementable analog triggers; e.g, filtering for minimum-phase pulse?
   c. Convolve catalog events with expected Venus seismometer response.
   d. Approaches to interpreting data beyond "standard" seismology; e.g., normal mode analysis, ambient noise analysis.



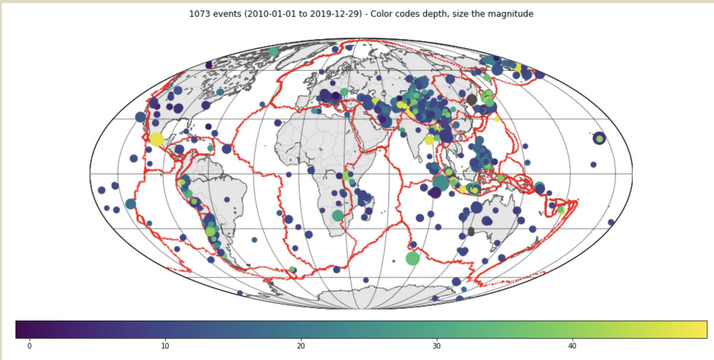
Schematic of NASA Glenn's concept of the SAEVe (Seismic and Atmospheric Exploration of Venus) lander showing the deployed seismometer.

Seismicity of Different Earth Regions

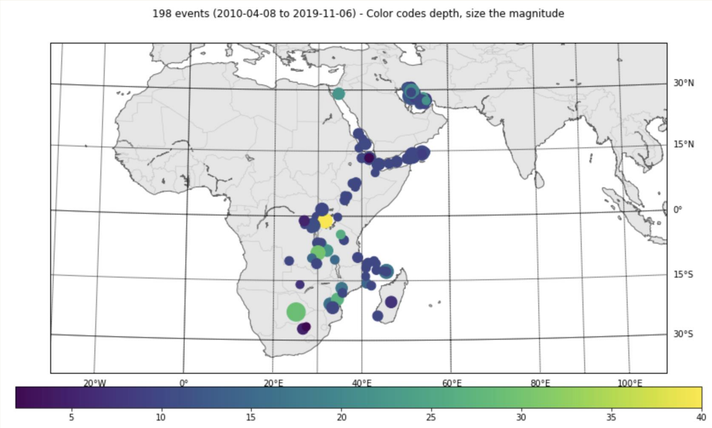
Plots below show Earthquakes with magnitudes > 5 over 10-year period. Color codes show depth and size of dot depicts magnitude.



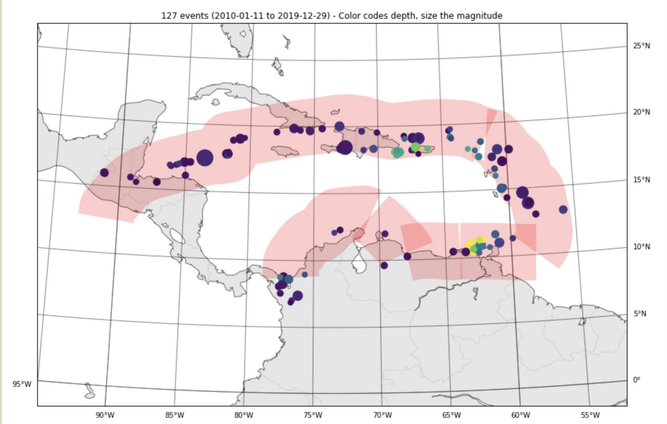
Earth average: 18K events over 10-year period (2010-2019) results in 3.6 events with M > 5 per year per million square kilometers.



Intraplate seismicity: All events not within ~200 km of plate boundary and with depth < 50 km to exclude events in deep subduction zone. Events are still dominated by those associated with major collision boundaries, esp. continent-continent collision in Tibetan plateau.



African Plate: Over same time period the events in rectangle from 30 S – 31 N, 20 E – 55 E. We consider this area to be a good Venus analog because it is bordered on all sides by spreading centers, moves minimally relative to the hot-spot reference frame, and has rifting with limited extension that morphologically bears resemblance to the Venusian chasmata zones.

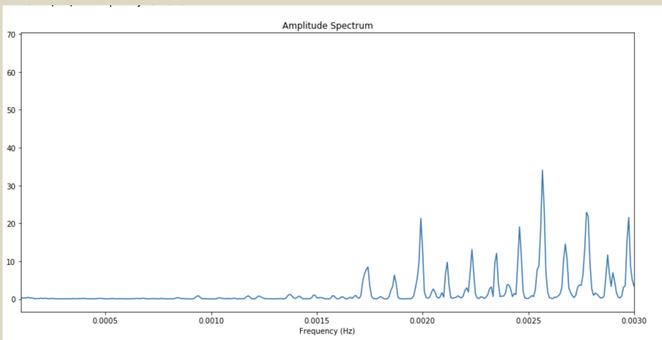


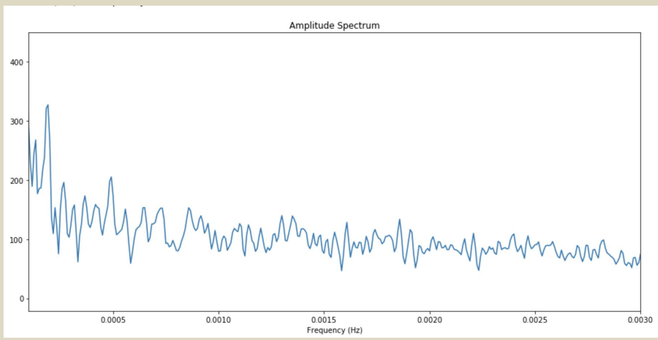
Caribbean Plate: There are areas on Venus where "rollback subduction" is thought to develop as an outgrowth of large coronae. With no "ridge push", rollback subduction can be thought of as a plate "falling" into the mantle, dragging the subduction trench outward. The Caribbean Plate is thought to be an example of this. There is still seismicity associated with the plate boundary, but less than at a boundary under compressional stress.

Region	Earth average	East Africa	Caribbean plate	Central Alaska	All Intra-plate
Number of events per year with M > 5 per year per million square kilometers. Range reflects different ways to define the encompassing area.	3.6	0.8 - 1.6	2.0 - 4.0	0.27	0.27

Bottom line: While there are many uncertainties regarding the exact nature of Venus geodynamics and its current level and nature of tectonic activity, the quietest areas on Earth, and those that seem most analogous to Venus, are within an order of magnitude or so of the overall level of Earth's mean seismicity.

Normal mode analysis





Normal mode analysis is probably not feasible for Venus: Exceptionally large terrestrial events set up globe-encircling standing waves whose frequencies are reflective of Earth's internal structure and its major internal layers. These standing waves show up as spikes in the amplitude spectrum of a long-term seismic record, such as a 2000-minute record from the 2012 Sumatra quake (M = 8.6) shown in the left plot. Unfortunately, stacking numerous records from smaller events does not yield a similar result; on the left we show stacking from 31 events with M 5-6.5 that occurred and were recorded in Central Alaska. In short, for realistic deployment scenarios of seismometers on Venus the odds are exceedingly low that a large enough event to enable normal mode analysis will occur.