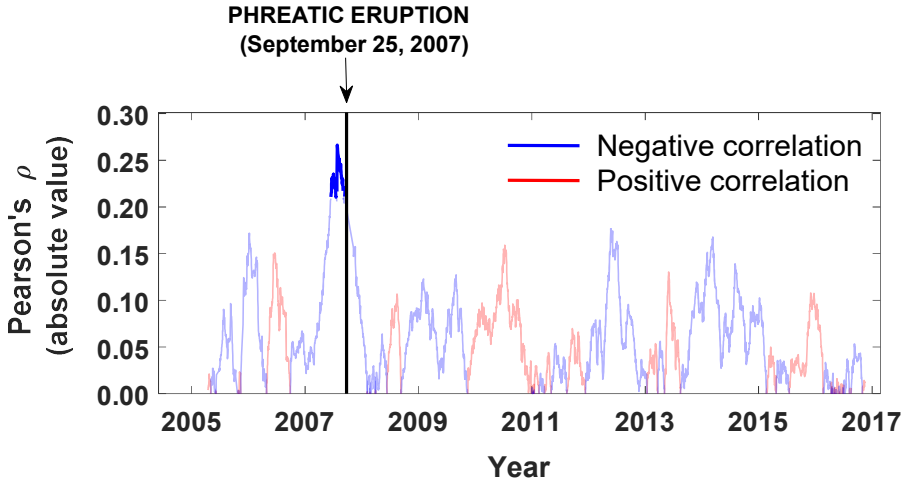
National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

Towards using lunar cycles to forecast volcanic eruptions

Társilo Girona



Correlation coefficient between seismic amplitude and lunar cycles for Ruapehu volcano (ρ). Note the increase of correlation before the 2007 phreatic eruption (deep blue).

Girona, T., Huber, C., and Caudron, C. (2018), Sensitivity to lunar cycles prior to the 2007 eruption of Ruapehu volcano, *Sci. Rep. Accepted*, doi: 10.1038/s41598-018-19307-z.

This work was supported by National Science Foundation CAREER Grant (1454821). T. Girona is currently supported by an appointment to the NASA Postdoctoral Program. C. Caudron is supported by an FNRS postdoctoral grant.

Science Question: The Moon-Sun gravitational force induces tidal stresses on the Earth. How do volcanoes respond to tidal stresses? Hypothesis: the response of volcanic systems to tidal stresses depend on the state of criticality of the volcano, a concept which could be potentially used to forecast eruptions.

Data & Results: We use seismic data from a permanent short-period station (Geonet-GNS) installed on top of Ruapehu volcano (New Zealand). We find that the shallow seismicity of Ruapehu was sensitive to lunar cycles (fortnightly tides) during ~9-15 months before the 2007 phreatic eruption.

Significance: Monitoring the sensitivity of volcanoes to lunar cycles can help to forecast imminent eruptions.

National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

Contact:
Társilo Girona, MS 183-501, Jet Propulsion Laboratory, Pasadena, CA 91109
tarsilo.girona@jpl.nasa.gov

Citation:
Girona, T., Huber, C., and Caudron, C. (2018), Sensitivity to lunar cycles prior to the 2007 eruption of Ruapehu volcano, *Sci. Rep. Accepted*, doi: 10.1038/s41598-018-19307-z.

Data Sources:
Data are obtained from a permanent short-period seismic station installed on top of Ruapehu volcano (~700 m from the crater lake). In particular, we use the vertical component waveform over a period spanning from February 22, 2004, to November 15, 2016 (downloaded from the open access Geonet-GNS archive: http://magma.geonet.org.nz/ resources/network/netmap.html, DRZ station). This time period was selected because the same type of seismometer was consistently used; we note that the seismometer was destroyed during the 2007 eruption, although it was replaced a few days later by the same type of sensor.

Technical Description of Figure:
Pearson product-moment correlation coefficient (ρ) between lunar cycles and seismic amplitude recorded close to the crater of Ruapehu volcano (New Zealand). Note the increase of correlation before the 2007 phreatic eruption. The correlation is calculated with 1-year backward windows; positive and negative correlations are in red and blue, respectively; and deep blue means that the probability of obtaining that correlation by chance is $< 0.006\%$. This plot depicts the case of $N = 81$ days of significant correlation, but we find $N = 59 - 86$ days (after repeating the method 500 times) depending on the random values used to replace gaps and spikes in the data. The probability of obtaining by chance $2 - 3$ months of significant 1-year rolling correlation (at a 4-sigma confidence level) with a dataset of 12 years is extremely low ($< 10^{-36}$).

Scientific significance, societal relevance, and relationships to future missions:
One of the most intriguing open questions since ancient times is whether lunar cycles may influence seismic and volcanic activity. Here, we have discovered through a novel statistical analysis that the persistent seismicity recorded over the last 13 years at Ruapehu volcano (New Zealand) was not modulated by lunar cycles, except for the 9 to 15 months preceding the unpredicted 2007 eruption. We demonstrate that volcanoes like Ruapehu can be sensitive to lunar cycles when the gas accumulated beneath volcanic craters is overpressurized; monitoring the sensitivity of volcanoes to lunar cycles can therefore help to detect when an eruption is approaching. Coordinating seismic data, our robust statistical algorithms, and satellite measurements (gas emissions, thermal anomalies, deformation) is required to understand how tidal stresses affect volcanoes and to better forecast volcanic activity remotely.