INSIGHTS ABOUT CORRELATIONS BETWEEN SOLAR ACTIVITY AND SHALLOW AND THERMAL MOONQUAKES.

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Introduction: Our Sun ejects out high-speed particles, the solar wind. This wind may pull the Earth's magnetic tail, exposing the Moon's surface to charged particles. During a high solar activity, the Sun may release extra eruptions of material into the wind [1]. The solar wind ions generate low-frequency plasma waves around the Moon [2], joining analysis of ions and magnetic field data, since this interaction is due to the absorption of the solar wind plasma on the lunar surface [3].

Unlike the Earth, the surface of the Moon absorbs most of the particles sent from the Sun. The Moon's interaction with the Sun characterizes many physical properties in the surface, including magnetic properties, ion densities, temperatures, and flow, during the solar wind [4]. By producing and comparing time series involving these physical properties, it may possible to relate some influences by flows of ions, solar wind, and storms, at the dynamics of the lunar surface. Some of these dynamic variations may influence the trigger of thermal and shallow moonquakes.

Previous studies suggested that these quakes may be triggered by tidal forces and/or thermal interaction. Solar radiation has been associated with thermal moonquakes occurrence, due to movement on the lunar regolith. The contraction/expansion of the crust, related to shallow moonquakes, where their distribution was correlated with sites of weakened zones. These sites also suggested localized variations of temperature regimes [5]. Future studies of planetary winds may reveal more about the trigger of shallowest quakes in other planetary bodies and the effects of solar activity on the solar system.

Methods: A database with ten time series was produced, consisting of values per month from January 1970 to September 1977. These limits were chosen because it is the period that Apollo has a continuous record. The shallow and thermal moonquakes time series consists of counting events per month. The quakes time series were made using [6]. Heliographic inertial latitude, Heliographic inertial longitude, Field magnitude average, Bulk flow speed, Proton density, and Temperature time series were also made during the same period, using the OMNI2 dataset. Sunspots and storms, using the IAG-USP dataset.

The database was discretized, normalized, and analyzed using unsupervised Machine Learning methods, in order to detect the relations between the series. The database was analyzed in the attribute evaluator mode, to explain the percentage in which the parameters are related. This mode returns a two-dimensional array of ranked attributes and their associated merit scores as doubles.

Results: The results are summarized in the table below, in the percentage of correlation.

Time series	Thermal moonquakes	Shallow moonquakes
Helio Inertial Latitude	10	100
Helio Inertial Longitude	100	0
Field Magnitude Average	90	70
Bulk Flow speed	80	0
Proton Density	70	100
Temperature	100	30
Shallow moonquakes	0	-
Thermal moonquakes	-	50
Sunspots	100	100
Storms	100	40

It is possible to observe that the time series of Sunspots correlates with both thermal and shallow moonquakes. On the other hand, storms correlate in a higher percentage with the series of thermal moonquakes. Same for Bulk flow speed and Temperature time series. This result shows that, although all the parameters used, related to solar activity, correlate with both types of moonquakes, the variability in temperature and in the particle flow velocity have more influence in the dynamics of the shallower layers, where the thermal moonquakes occur. On these insights, future studies of solar wind and planetary seismology can reveal more about the potential effects of solar activity on planetary bodies, including the Earth. Expanding this knowledge will require new ground-based geophysical equipment with sensors on the body surface.

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