NEW EVENTS DISCOVERED IN THE APOLLO LUNAR SEISMIC DATA. R. C. Bulow[1], C. L. Johnson[1], and P. M. Shearer.[1] [1]Cecil H. and Ida M. Green Institute of Geophysics and Planetary Physics, Scripps Institution of Oceanography, University of California, San Diego.

Introduction: The Apollo Passive Seismic Experiment (APSE) consisted of four seismic stations deployed on the lunar surface between 1969 and 1972. Data were recorded continuously from deployment until 1977. Lunar seismic events detected in the continuous time series have been previously classified into three types: deep moonquakes, shallow moonquakes, and impacts. Deep events are thought to be tidally triggered, and originate from distinct source regions that produce repeatable waveforms. Original classification was performed on a visual basis and took advantage of this repeatability.

Our goal is to better constrain the properties of these deep event clusters. Modern processing of the event data refines the manner in which events are assigned to clusters. Application of these techniques to the continuous data may pick out previously unidentified events belonging to these clusters. This will permit improved source region location estimates.

Overview: We have read and processed all of the lunar seismic event tapes available from the IRIS Data Management Center. Our studies have focussed on the long-period data, and have included filtering and despiking noisy data, event classification, cluster identification, and robust methods for amplitude estimation. We have completed cross-correlation analyses for known groups [1] of deep events. In these analyses, every event in a previously-classified group was cross-correlated with every other event in that group. We find good correlation between events, confirming earlier visual classifications. By combining the cross-correlation approach with a running median despiking algorithm, we have obtained improved estimates of differential times and amplitudes, enabling us to construct high-quality stacks for the deep clusters.

Both a manual "grading" technique and our new amplitude estimates indicate that stations 12 and 16 have the greatest number of "visible" events with the most consistent amplitudes. We have begun our search for previously undetected events using the continuous data from these stations.

Each deep event group can be represented by a stack of its constituent members, appropriately despiked and time-shifted. This permits new waveform cross-correlations. Instead of using the time-consuming event-by-event method employed earlier, each event group, represented by a single waveform stack, can be correlated with the continuous time series. Using this approach, we have been examining the continuous data from station 16. Our technique successfully isolates known events in the continuous data. Additionally, we have discovered new, previously unidentified events.

Event Data: *Data Processing:* Scattering of seismic energy due to the moon's regolith, temperature fluctuations between lunar day and night, and telemetry errors all contributed to the poor quality of the seismic traces. We attempt to remove as many of these errors as possible by checking for known error flags and by filtering and despiking the data.

Filtering: Band-pass filtering from 0.25 - 3.3127 Hz removes most long-period fluctuations from the data. However, the short-period signature of probable thermal transients are not completely removed by filtering. These remaining spikes can bias amplitude estimates for an event, and must be removed.

Despiking: To remove spikes, we use a robust median despiking algorithm [2]. In this method, we apply a running median filter to obtain the median and deviation from the median for each point in the time series. Points that lie outside a user-specified multiple of the median deviation are replaced with the median of the nearest *m* points of the original time series. We found the best results for a window length *m* of 701 samples (about 2 minutes) and a median multiplier of 5.

Cross-Correlation: Despiking the data allows us to produce improved differential times and amplitudes when performing event cross-correlation. Using a list of known deep events [1], we select a source region and cross-correlate every event with every other event within that group.

Because original event classifications were performed visually, our method of cross-correlation may not pick out all of the catalogued events. We search for "good" correlations using a minimum correlation coefficient cutoff and by checking for agreement in time shifts with the results for each pair. For a correlation cutoff of ~0.2 the average standard deviation in time shifts is less than 0.1 seconds, which is less than the data sampling interval.

Application of the despiking algorithm reveals smaller events which may have previously been dwarfed by large spikes. By performing cross-correlation of a target trace with the continuous time series, it is possible to pick out events that were overlooked in the original investigations.

Stacking: To create a stack, we use all of the catalogued events for a given deep event group with individual traces receiving a grade of ‘C’ of better (each event is manually assigned a grade of A, B, or C based on such factors as signal-to-noise and initial impulse coherence). These graded traces are despiked and appropriately time-shifted before being added to the stack. Each component is stacked separately. Despiking the traces before they are stacked leads to greatly improved signal-to-noise.

Continuous Data: To search for new events in the continuous time series, we apply the correlation techniques used on the event data, with a stack of a certain group's constituent members as our target trace for cross-correlation. To best determine where to begin our search for new events in the continuous time series, we chose the stations with the highest event visibility and most consistent amplitudes.

Event visibility: Significant variability in the detection of visible events is seen among different stations and for a given station among the x, y, and z channels. Because the deep events tend not to appear in the short-period seismograms, we are considering only the long-period traces for the preliminary continuous cross-correlations.

Although the y-component of station 14 has the highest number of visible events, the z-component of the instrument was inoperative for most of the deployment, and did not record any seismograms. Stations 12 and 16 show the highest number of visible traces, with nearly equal numbers of visible x-component events.

Amplitudes: Because of the poor signal-to-noise ratio exhibited by a majority of the traces, we have investigated several methods of calculating the amplitude of an event. These include relative amplitudes calculated through cross-correlation and several different estimates of absolute amplitude. Our preferred amplitude estimate is the 75th percentile of the absolute deviation of the data about the median, or

$$d_{75} = | a - a_{median} | (0.75 * n)$$

where n is the number of points in the time series. Typically for a 20-minute time window n ~ 8000. This measure produces the best x-component vs. y-component correlation when plotting events from a single deep event group. Using this amplitude estimate, stations 12 and 16 show the most consistent amplitudes on the horizontal channels.

Previously Undetected Events: The results of our preliminary continuous cross-correlations for station 16’s x- and y-component are shown in Figure 1. We use a 30-minute time window of the stack, which reduces the number of false returns at the expense of an overall reduction in correlation coefficient value.

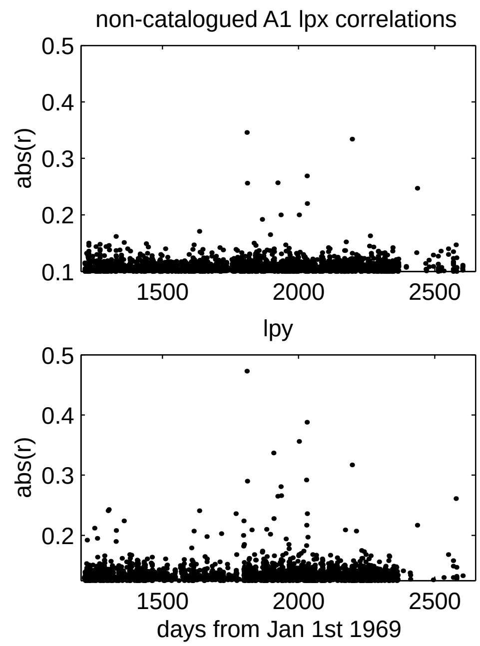

Figure 1: Cross-correlation of A1 stack with continuous data from station 16. The x-axis runs from April 21, 1972 to February 29, 1976. The y-axis shows the absolute value of the correlation coefficient.

The figure shows the time of occurrence of each peak in the cross-correlation function falling above a correlation cutoff of 0.1. Previously catalogued events are not shown in the plots.

Most of the correlations falling below r = 0.15 are due to “ghost” images returned close to the local maxima of the cross-correlation function. Points falling above that level can be considered new events.

Results: We have analyzed all of the long-period data from station 16 and will soon begin on station 12. To date we have discovered 40 new events, 7 of which appear on two or more channels. Most of these new events cannot be visually distinguished from background noise, so we produced stacks of the new events to increase SNR. These stacks reflect the presence of new events discovered in the continuous data.

References: [1] Nakamura et al. (1981) *Galveston Geophysics Laboratory Contribution No. 491*, Tech. Rept. No. 18. [2] J. R. Evans (1982) *BSSA* Vol. 72 No. 1, p. 331-338.