BAYESIAN INVERSION OF IMPACTOR PARAMETERS FROM PROPERTIES OF CRATER CLUSTERS ON MARS

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Introduction: More than $\sim$1000 newly formed impact features have been detected in images taken by orbiting spacecraft around Mars [1]. In recent months, several of these impacts were also detected seismically by the InSight seismometer [2]. Detailed characterization of the observed impact features [3, 4] has been used to calibrate a model of atmospheric disruption of meteoroids on Mars [5]. This paves the way for relating observed impact features to the properties of the impacting meteoroids. Here we use a Markov-Chain Monte Carlo (MCMC) approach to determine the statistical distribution of impactor parameters that are most likely to have formed recent impact craters and crater clusters observed on Mars that were also detected seismically. Our results inform interpretation of seismic wave signals generated by these impacts [2].

Methods: We simulate the formation of specific craters and clusters on Mars using an implementation of the Separate Fragments Model [SFM; 6, 7], calibrated by comparison with observed craters and clusters on Mars [5]. Crater sizes are predicted from fragment properties at the ground using π-group crater scaling relationships [8]. A MCMC approach is used to generate a statistical distribution of impact scenarios consistent with the observed feature. Given an observed crater or cluster of craters, we determine its characteristics B (e.g., size and number of craters). Using the SFM, together with knowledge about the variability of cluster characteristics, we compute the likelihood $p(B|A)$ that an impact with parameters A (mass, velocity, etc.), produces a crater or cluster with the same characteristics B as the observed one. $p(A)$ expresses our prior knowledge of impactor parameter probability. Then, with Bayes' theorem $p(A|B) \propto p(A)p(B|A)$, we can infer the likelihood of impact parameters A given the observations B.

We employed the Metropolis-Hastings MCMC algorithm with Metropolis sampling, which assumes that there is no correlation between impactor parameters. Prior distributions of impactor mass [9], angle [10], velocity [11] and strength [5] were based on previous work. Impactor density and ablation parameter were held constant at representative values for stoney meteorites. We defined the likelihood $p(B|A)$ to be the product of likelihoods for four cluster characteristics: effective diameter, number of craters, median separation distance between craters and the aspect ratio of the best-fit ellipse encompassing the craters. We assumed that all characteristics are log-normally distributed with the standard deviations based on observed cluster characteristics [4]. Because MCMC algorithms reach the desired distribution asymptotically, the first n samples were discarded. The distribution of remaining accepted samples defines the impactor parameters of maximum likelihood.

Results: Impactor parameter likelihood distributions were determined for four impacts (two single craters and two clusters). One cluster-forming impact provides a particularly useful test of the approach as its highly elongated distribution of craters implies a shallow trajectory angle. The inferred trajectory is consistent with the interpreted ray paths of acoustic phases in the seismogram of the associated seismic event that were generated by the meteoroid's flight through the atmosphere [2]. The most likely pre-entry impactor mass informs comparison of the impact flux rate at the top of the atmosphere on Earth and Mars [5, 9]. The most likely impactor momentum at the ground provides a test of empirical relationships between seismic moment and impactor momentum [e.g., 12].

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