NEW PROPOSED STUDY: CRATER VARIABILITY DETECTION. S.J. Robbins[*,1], J. D. Riggs[2]. [*]stuart@boulder.swri.edu. [1]Southwest Research Institute, 1050 Walnut Street, Suite 300, Boulder, CO 80302. [2]Northwestern University.

Introduction: The study of impact craters is one that has persisted for over 400 years, and one that has seen innumerable researchers study millions of craters on dozens of Solar System bodies. Many researchers who study craters do so as their main avenue of research, while many others do so less for crater studies and more as a means to an end, such as deriving a model age of a geologic unit or feature they are investigating.

The most common aspect of an impact crater study is measuring a crater's location and diameter. However, with innumerable researchers using a myriad of datasets and techniques, the seemingly objective measurement of (a) whether a crater exists (b) at a certain location and (c) is of a certain size, must have an inherent uncertainty attached to it based on many factors. What that uncertainty is, is poorly understood.

Background: Many different research groups do run internal calibrations to minimize variability *within that group* in impact crater detection. Similarly, some mission teams will calibrate or at least seek to understand the variability within their own group. However, many researchers do not, and new researchers in the field who may not have had an advisor or colleague who studies impact craters will often not have training to understand standards in the field.

There have been very few published studies that have tried to examine researcher variation. One was published in 1970 [1] and had several researchers in the same lab use the same equipment to identify craters. A study in 2014 [2] had eight researchers participate, and they used almost as many different techniques. What both studies found is that the absolute range in number of craters found for any given diameter range can be factors of several, while the standard deviation of that variability is around ±15–45%, depending on terrain or technique. The 1970 study was limited in techniques and scope, while the 2014 study was limited in participants and variables that could be examined.

Some Critiques of the 2014 Study: Over the past few years, some of us have made efforts to promote the results of the 2014 study to convey the fact that there is variation in how individuals identify craters that should not be ignored. As with any study, it has received some meaningful criticism. The primary critiques have been:

- Relatively little involvement.
- Some of the terrain selected was saturated and may have been a particularly "difficult" region upon which to identify craters.
- Some individual researchers' experience is to only map impact craters they are absolutely sure exist, while others' is to map every feature they think could be an impact crater.

The first item is difficult to improve upon for this work is entirely voluntary and unpaid, and we are not proposing a large grant to a funding agency to fund ~50+ individuals for a few days' work each. Given overhead costs, the cost to write the checks would be more than the amount disbursed to each researcher. In that 2014 study, the primary researcher reached out to two dozen colleagues, so there was a 1/3 positive response rate. For the success of this new proposal, we will need to find ways to increase participation.

The second critique is perhaps true (though perceived difficulty is subjective), but it is also a reality that crater investigators will work on most terrains in the Solar System, so it is not necessarily bad that a harder terrain / image scale than average may have been chosen for one or two of the three terrains. The third critique is certainly true, and it may have contributed to the rather large range in results. However, it is also true that any single individual involved could have published the crater population they measured, derived an age from it, and reviewers would likely not have questioned the results (barring a severe departure from previously established research).

What We Propose: We propose a new study, to be conducted over the course of ~one year to encourage maximum participation, to study several factors related to how we detect impact craters and whether there is an inherent, minimum uncertainty in this type of crater research.

Wish List of Variables: There are many factors that contribute to how well an impact crater may be identified, and while some of them do not lend themselves well to a study such as we propose, many do. In the list below, items with an asterisk are ones we propose to study, ones that are plain text are those we would like to study, and those in parentheses are variables that contribute to the uncertainty but we do not think can be studied through this effort. (List subject to significant revision and discussion at the PCC meeting.)

- *How an individual researcher decides whether a feature is a crater, and how big it is. (This is the fundamental issue, and fundamental aspect studied in [1,2].)
- *How well a calibrated group compares with other researchers.
- *Pixel Scale
- *Incidence Angle
- *Images versus Topography/DTM Map
- *Image Quality (*e.g.*, compression, bit-depth)
- *Local Albedo Variation
- *Surface "Type" (*e.g.*, lunar highlands vs Isidis basin on Mars vs secondary crater chains on Mercury)
- *Software / Method to Identify and Measure Craters
- *Crater Preservation

- Phase Angle
- Emission Angle
- Pre-Existing Terrain "Difficulty"
- Saturation or Near-Saturation and Resurfacing Effects
- (Geologic Context (*e.g.*, is a feature an impact crater or a pit crater?))

Control Craters: One of the barriers to performing an absolute calibration is that any planetary surface could be interpreted in a variety of ways by "experts" in the field, and it is unknown which "expert" may be closest to what must be an underlying objective reality. Fortunately, synthetic terrain modeling has advanced considerably over the years and can now produce realistic terrains, at least so far as simple impact craters are concerned [*e.g.* 3]. We propose in this study to use synthetic terrains as an absolute calibration of the participants so that we do know what objective reality is supposed to be, and we can compare how well individuals identify craters upon the terrain. Similarly, we can use synthetic terrain models to vary several of the parameters we want to study as further control (in addition to using real planetary imagery and elevation models).

Sampling and Analysis: Once the study variables and the parameter space for each variable are chosen, a minimum sample size (number of participants) can be determined to adequately address the root question: How much variation is there based on this variable? This does not preclude the study from having more than the minimum number of participants, but it does let us determine how many variables can be addressed. A second factor of determining the sample size is the expected amount of variability in the measurements. The 2014 study can be used as a baseline, as could an *a priori* expectation for variables it did not investigate.

The sampling protocol can make the participants anonymous. The protocol would randomly assign images to participants with the only requirement of each participant examine at least one synthetic terrain model (the "control"). The image randomization would be made blind, that is, participants won't be informed as to what terrains they are assigned (though more experienced researchers would likely be able to guess at several terrains and identify a synthetic terrain, such that the study would be only semi-blind). The images would include one or more levels of the variables in the study, and individuals could be assigned any number of images they are willing to analyze (such that, *e.g.*, Robbins may analyze 25 images, while another participant may analyze a minimum of 2). The analysis process itself can also be anonymized such that the person conducting the analysis would not be biased towards nor against any particular researcher.

Participants / Participation: We have many variables we wish to investigate. Consequently, we would like to have as much participation as we can, from as many different crater analysts as we can get. We could advertise this study on:

- Relevant Facebook groups (*e.g.*, Young Scientists for Planetary Exploration).
- The PCC mailing list.
- Other community mailing lists, *e.g.* DPS and PEN.
- Word-of-Mouth.

We welcome additional ideas. Ideally, several dozen participants with varying levels of experience will be involved. Additionally, by setting an approximate deadline of a full year to submit results, along with sending reminders to participants, we hope individuals will be able to find a ~week of time to participate.

Desired Outcomes: We hope to:

(1) Better understand the amount of uncertainty imposed on crater identification and measurement due to each of the study variables, including how software and/or measurement technique may affect the results.

(2) Better understand how researchers measure "completeness" of their dataset so that we may produce a statistically meaningful metric of minimum pixel required to accurately identify and measure craters.

(3) We should be a able to create a predictive model such that a participant in this study *could* adjust their future crater measurements to match the collective "average," though we recognize that very few individuals would want to do this.

(4) New researchers could use the images to calibrate their work to be closer to the collective outcome – *i.e.*, produce a "standard" training dataset for the field, which does not formally exist.

Questionnaire: There would be a questionnaire accompanying each image or participant that would be as simple to fill out as possible. The questionnaire per image would include questions about: Perceived difficulty of image, time expended to identify craters, completeness level and method to determine it, sub-optimal external factors during analysis (*e.g.*, screaming child). The questionnaire about participants would include: Software and tool/technique to analyze the images and mark craters, and experience in crater analysis.

Discussion and Feedback: We would like to discuss this at the Planetary Crater Consortium meeting in 2017 and get community feedback. At the meeting, we would also like to develop a path forward, nominal timeline, and list of potential participants to contact. We would also like to better define the variable space to make this project feasible and get the most out of it, including having contingencies for various numbers of participants.

References: [1] Greeley & Gault (1970) doi:10.1007/BF00561875. [2] Robbins *et al*. (2014) doi:10.1016/j.icarus.2014.02.022. [3] Huang, Y.-H. *et al*. (2017) doi:10.1002/2016JE005160.