**The current mass balance of the North Polar Layered Deposits, Mars**

**Introduction**

The climatic history of Mars has been a topic of interest since the earliest Mars observations (Lowell, 1908), and the polar deposits play a major role in Mars’ climate history. The polar deposits represent major reservoirs of carbon dioxide (Leighton and Murray, 1966) and water ice (Kieffer et al., 1976).

The North Polar Layered Deposits (NPLD) are made up of layers of water ice (Phillips et al., 2008) with varying dust content and have a bulk content less than ~5% (Grima et al., 2009). These stacks of layers are also visible in scarps eroded into the NPLD, and remain the basis of a long-term unanswered question in Mars polar science. The NPLD is covered largely by the northern residual ice cap (NRIC), mostly composed of water ice (Kieffer et al., 1976). This layer is generally considered to be the current layer being added to the NPLD.

Layering in the NPLD has been postulated to be linked to geologically recent martian climate change (e.g Murray et al., 1973; Laskar et al., 2002; Milkovich and Head, 2005; Fishbaugh and Hvidberg, 2006; Perron and Huybers, 2009). Modeling suggests that the NPLD ice has only been accumulating for about ~5 Mya (Laskar et al., 2003) and crater counts of the surrounding basal unit (Planum Boreum) suggest that the underlying surface has an Amazonian age (1-3 Gya).

Previous work has estimated NPLD accumulation rates to be on average 0.5 mm a^-1 over the last ~5Myr (Hvidberg et al., 2012) but examining the current mass balance of the NRIC has produced contradictory results. Modeling of the current NRIC surface suggests that, in the current climate, the NRIC should be accumulating ice liberated from reservoirs at the mid-latitudes (Chamberlin and Boynton, 2007). However, grain size measurements from the NRIC in late summer suggest that old ice is currently being exposed, and therefore net ablation is occurring (Langevin et al., 2005). Being able to constrain the current mass balance of the NRIC in the current climate will be the link between the current climate and surface to the past surfaces and climates recorded in the stratigraphy of the NPLD.

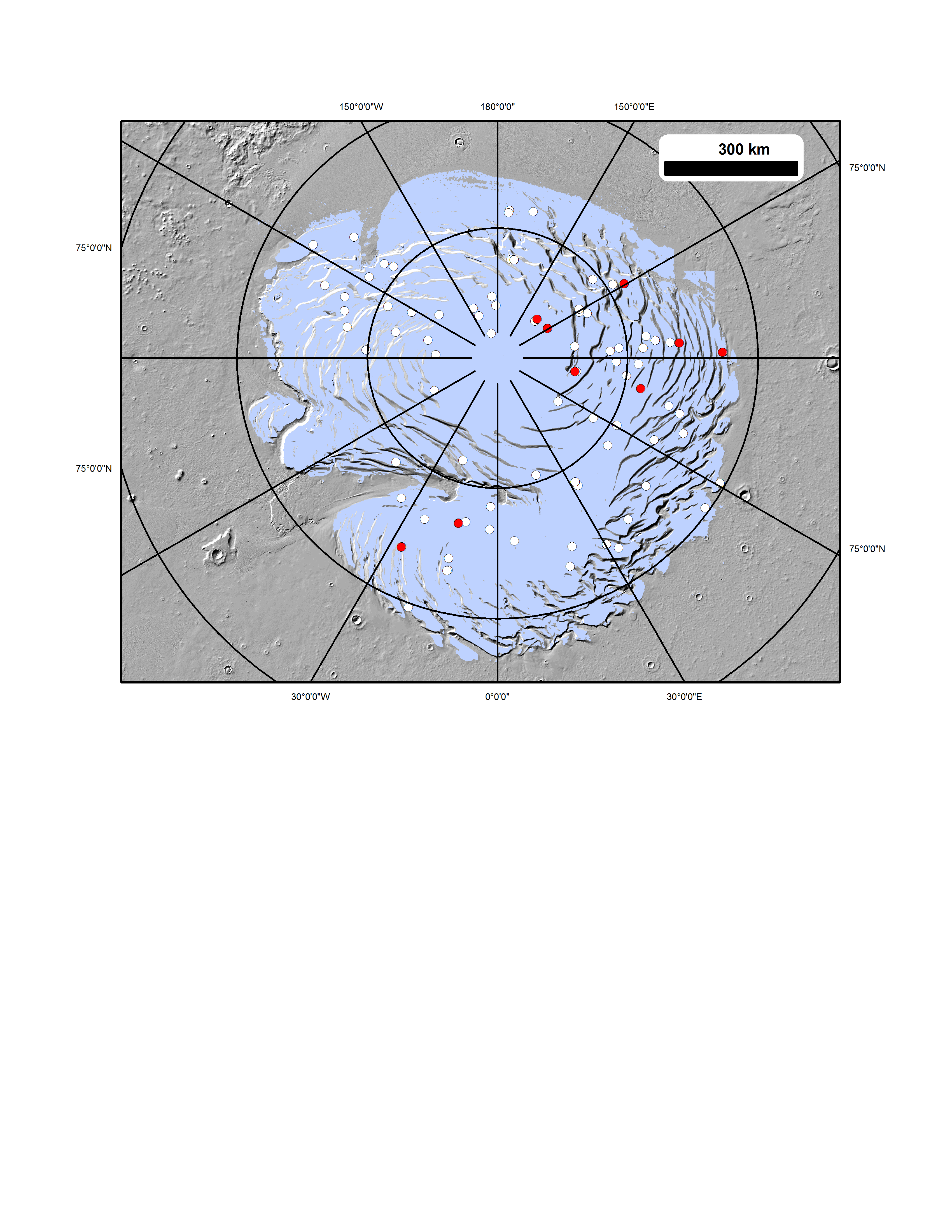
Previous work using crater age statistics utilized the Hartmann et al., (2005) production function, based on crater counts from the Moon being scaled for Mars. These previous studies found that the surface age of the NPLD was in the range of 10’s of Kyr (Herkenhoff and Plaut, 2000; Tanaka 2005). A more recent study using HiRISE images and the Hartmann et al. (2005) production function found that the crater population was in an equilibrium state, and therefore only a maximum age of 10Kyr could be determined. Since then, a new production function for small craters (tens of meters in diameter) on Mars has been developed (Daubar et al., 2013).

This research proposal has two questions based on determining the surface age of the NPLD/NRIC and determining the current mass balance and accumulation rate:

1. What is the surface age of the NPLD/NRIC? What do the crater population statistics indicate has been the recent history of the NPLD surface?
2. How does in the infill rate of the craters relate to the surface NPLD/NRIC accumulation rate?

**Work to date and motivation for proposed work**

Crater age dating is the current method to determine the exposure age of a solid surface for places in the solar system. The NPLD represents a challenge, however, due in part the small size of the craters (maximum crater diameter: ~360m) and small number of craters (~90 confirmed crater sites were included in this study, see Landis et al., in prep). However, current advances in crater age dating techniques have for the utilization of smaller and smaller craters (D<500m).



**Figure 1:** Map showing the NPLD region of interest (light blue), locations of crater sites in this catalog (white and red points), and sites with digitial terrain models (DTMs). Each line marks 30o longitude and each concentric circle 5oof latitude.

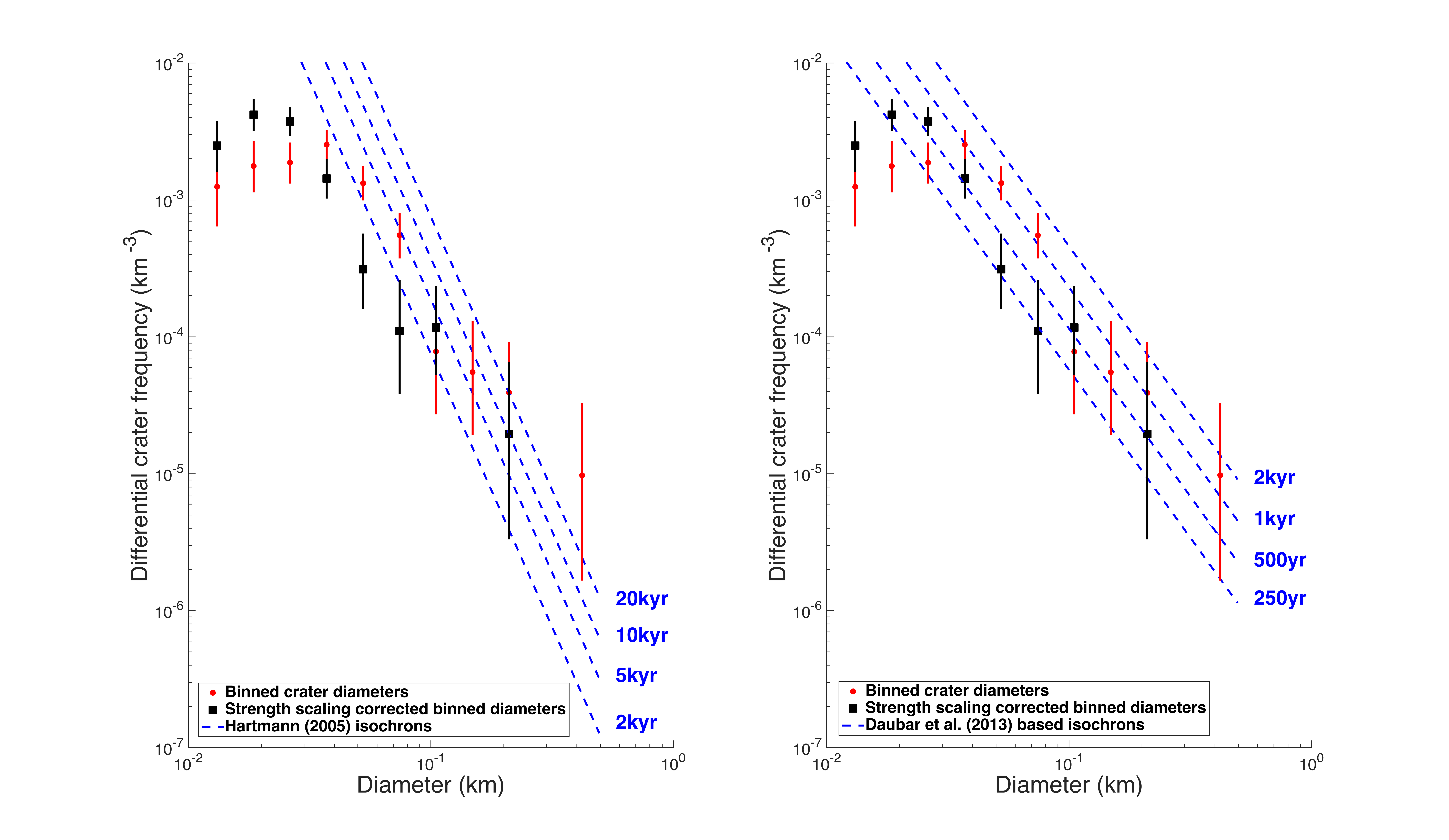
This proposal utilizes a production function based on the work of Daubar et al., (2013), where new, small martian craters were observed forming between sets of Context Camera (CTX) observations. This production function reflects more closely the current impact size frequency distribution and impactor flux to the NPLD timescale due to the shorter baseline when compared with the Gyr long baselines used in the Hartmann (2005) production function. This adjustment to the Hartmann (2005) production function directly the small craters (<300m-diameter) of the NPLD.

The crater statistical technique will follow what is described in Crater Working Group (1979) including the construction of differential size-frequency distribution (SFD) plots for comparison with isochron lines derived from both the Hartmann and Daubar production functions. One variation of the method described in Crater Working Group (1979) being utilized in the crater statistics phase of the project is using error calculations based specifically on calculations from small number statistics (Gehrels, 1986). While there is an implicit uncertainty with all crater counting, using these error bars rather that the typical sqrt(N) allows for a better reflection of the small number of diameter data points being utilized.

High Resolution Imaging Science Experiment (HiRISE) images were collected for all the potential cratering sites larger than ~30m identified in Banks et al. (2010) (Figure 1).

The differential SFD showing the isochrons based on Daubar et al. (2013) and Hartmann (2005) is shown in Figure 2. The Hartmann (2005) production function leads to the conclusion that the NPLD surface is an equilibrium population of craters (craters are removed at the same rate that they are produced) with a maximum age of ~10Kry as the data (in red) cuts across multiple isochrons, also the conclusion of Banks et al. (2010). The Daubar et al. (2013) based isochrons, however, have almost the same slope as the data, indicating that the NPLD is actually a production surface, reflecting the same population of craters as would be expected on a surface that records all the impacts during its period of geologic exposure. The data also matches the ~1Kyr isochron, revising down the age of the surface by an order of magnitude.

We are comparing the same values when applying isochrones based on production functions that both rely on craters that formed in predominantly rocky rather than icy targets to craters in mostly icy targets, and scaling argument need to be used to determine what effect this has on the results. This work has been completed to the current state of the Pi-group scaling (dimensionless numbers for crater parameters like volume and diameter) and crater strength evaluation field by using the values and diameter scaling parameters described in Holsapple (1993).The resultant values, while dependent on the yield strength of the material, are all positive and greater than one for realistic yield strengths of ice, indicating that transferring a rocky crater production function to an icy target will consistently produce an overestimate of the absolute age, especially at small diameters

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**Figure 2:** Differential size-frequency distribution of the NPLD craters plotted with the two isochrones systems, one based on the production function given in Hartmann (2005), and the other based on the one given in Daubar et al. (2013). Red points are NPLD crater data, while black squares are the strength-scaled (assuming 1MPa yield strength of ice) crater diameters.

**Proposed Research**

The two production functions discussed above have dramatically different implications for the lifetime of individual craters and by extension the recent history of the polar deposits. Thus, one can distinguish between them by modeling ice accumulation rates within these craters.

I propose to develop a thermal model that uses a semi-implicit method to solve the thermal conduction equation through a stack of numeric layers that can have varied thermo-physical properties. My preliminary work has developed a thermal model that is fully explicit method of solving the thermal diffusion equation for a stack of layers on a Mars, including the ability to calculate this for a stack of layers that is on an incline and currently, my version of the model is being adapted to include seasonal carbon dioxide frost. I will utilize these surface temperatures with ice accumulation/ablation models similar to that of Dundas and Byrne (2010) to deduce ice accumulation rates within these craters.

The thermal model will be solved in two cases, one for the bottom of a crater (where the features of the model taking into account slope as well as the ability to mask out solar radiation at times of day when the interior of the crater will be in shadow) and one for the flat surrounding surface on the NPLD. Digital terrain models (DTMs) of the NPLD craters are both currently released in the Planetary Data System (PDS) or have been generated by me using the resources available from HiRISE and the Regional Planetary Image Center (RPIF) at the University of Arizona. Our models will allow us to extrapolate accumulation rates within craters to those on the surface surrounding the crater. None of the age estimates above are long enough to be affected by long term changes in obliquity so changing orbital parameters will not play a large role in this modeling (Montmessin et al., 2007).

This modeling will comprise the remainder of the time to the PhD thesis, and constitute a second paper on the topic of polar accumulation rates (the first being already in preparation on the crater population ststistics). The tasks for this section of the proposal are therefore the following:

1. Develop the fully explicit version of the thermal model into a semi-implicit one for speed.
2. Add in the carbon dioxide frost affect on the temperature and develop a “mask” method for blocking out the solar insolation for the bottom of the crater.
3. Model temperatures for the interior of the crater and also for the flat surrounding terrain.
4. Take the temperature arrays and run them through a model based on Dundas and Byrne (2010) to produce accumulation rates that then can be checked against the amount of observed accumulation of ice within craters from DTMs.
5. Extrapolate the intra-crater accumulation rates to those at the surface of the NPLD and publish these results in a relevant journal.

Tasks 1 and 2 are currently in progress, but developing the water/carbon dioxide ice modeling portion of the project is yet to be completed. Task 5, the paper, will combine a description of the thermal model with the ice accumulation result for the surface of the NPLD.

**North Polar Summary**

There are still many unknowns with respect to the recent history of the NPLD on Mars, including the age of the surface and the current mass balance. Crater age dating techniques can now incorporate a production for small, currently observable craters on Mars (based on Daubar et al., 2013) and therefore re-examining the crater population of the NPLD is a timely way of gaining new insight into the age of the surface. The surface age of the NPLD, however, is only part of the puzzle and does not directly inform us of recent accumulation rates. Thermal models, constrained by observations from DTMs, can be used to model the accumulation of ices inside craters and therefore constrain the NPLD surface ice accumulation on surrounding flat surfaces. In total, this proposed work will produce at least two papers and new insight into a long-standing problem of linking climate to polar geology.

**Concurrent Research**

An additional facet of the project that can be done concurrently with the model development is extending this project to the South PLD. Mars has two polar deposits, and a current published SPLD crater catalog does not exist. This is the first step towards looking at the history of the SPLD in addition to the same type of work that has already been described in this proposal for the NPLD. A HiRISE campaign to cover small craters can be run concurrently with this work by doing a search of Context Camera (CTX) images for potential impact sites that can be followed up with HiRISE images during the next south polar summer. About ~50 craters have already been documented on the SPLD with HiRISE from the previous south polar summer.