THE HISTORY OF WATER ON EARLY MARS: THE SUN, THE WIND, AND THE RAIN.  R. A. Craddock1, R. P. Irwin, II1, A. D. Howard2 and D. W. Latham3, 1Smithsonian Institution, Center for Earth and Planetary Studies, National Air and Space Museum, MRC-315, Washington, DC 20560, craddockb@si.edu, irwinr@si.edu, 2University of Virginia, Department of Environmental Sciences, 205 Clark Hall, 291 McCormick Road, Charlottesville, VA 22904, ah6p@virginia.edu, 3Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, MS-09, Cambridge, MA 02138, dlatham@cfa.harvard.edu

Introduction: After decades of exploration the history of water on Mars remains a highly contentious issue, and for a variety of reasons suggestions that early Mars was cold and dry continue to persist [e.g., 1]. Understanding the processes that occurred during the Noachian and through the Hesperian is predicated on investigations that are taking place in three disparate scientific disciplines: astronomy, meteorology, and geology. Unfortunately, researchers in these disciplines rarely talk to one another let alone interact. Compounding the problem is that the investigations conducted by the researchers in these fields tend to take place at different temporal scales. That is to say, astronomers tend to focus on the evolution of a star (billions of years), geologists tend to look at discrete geologic episodes (~1 billion year), and meteorologists design models that are typically limited to certain conditions that may only be representative of short periods (~millions to hundreds of millions of years). Here we review what we know, what we think we know, and the future research directions that we need to pursue as a community to better understand the history of early Mars.

The Sun: Standard solar evolution models state that the Sun was 30% fainter early in its history [2]. This “faint young sun” paradigm suggests that both Earth and Mars should have been much too cold for liquid water to be present on the surface of either planet creating a paradox [3]. On Earth, the geologic record from the Precambrian contains fluvial sediment [4], indicating warmer surface conditions. It is also unlikely that life would have started on Earth [3].

A controversial solution to the “faint young sun” problem supposes that the Sun was more massive in the past, and thus more luminous [5]. Although this is supported by inconsistencies in solar elemental abundances [6], observations of young stars do not indicate that they lose much mass [7]. However, new data from the Kepler mission suggests that mass loss from the young Sun may be dependent on the history of its spin [8], which slows down due to “magnetic braking” [9]. We are currently exploring new ways of characterizing how Sun-like stars spin down through advanced modeling and Kepler observations of star clusters of different ages, including NGC6811 (1 billion years old) and NGC6819 (2.5 billion years old).

The Rain: The “faint young sun” also presents a paradox to early Mars. There is a variety of geologic evidence indicating that early Mars supported rainfall as well as an advanced hydrologic cycle. Although valley networks are “most commonly cited as evidence” that liquid water was once stable on the Martian surface [10], it is now apparent that their formation was restricted towards the end of the Noachian when climatic conditions become optimum [e.g., 11]. This is suggested by the fact that valley networks are not well-integrated with the surrounding cratered landscape [11, 12]. Nevertheless, the scale of erosion represented by many valley network systems is immense and can often rival the Grand Canyon (Figure 1). Quantitative evaluation of their paleohydrology also indicates that their formation took place over a prolonged period (i.e., hundreds of thousands of years at least) [13].

If valley networks do not represent the climatic conditions that occurred through the Noachian [13], modified impact craters do [14]. Modified impact craters occurred at all crater diameters; however, the degree of modification is independent of size [14]. This indicates that modification processes were continuously (if not episodically) operating as new craters were forming on early Mars. Unlike valley networks, which are restricted to a band near the equatorial region of Mars, modified impact craters also occur at higher latitudes (Figure 2) indicating that the erosional processes—and thus the associated climatic conditions—were global. This suggests that early conditions may have been controlled by a primordial steam atmosphere that slowly collapsed and precipitated into the Martian regolith, eventually resulting in lakes and even an ocean. These standing bodies of waters subsequently drove a more regional hydrologic cycle represented by valley networks [14].

The Wind: There have been a variety of global climate models simulating the early martian climate assuming a faint young sun and a CO2 atmosphere with surface pressure between ~0.1 and a few tens of bars [e.g., 15]. A short summary of such models is that a CO2 atmosphere is incapable of sustaining surface conditions above freezing, and early Mars is doomed to be cold and dry. A number of ad hoc models have been suggested to explain the formation of valley net-
works under such conditions, most recently heat generated by volcanism or impact cratering [1]. However, such models ignore the empirical data and the geology. For the Earth, the most obvious evidence that ancient surface conditions supported liquid water is the fact that all of us are here to worry about such problems. On Mars, valley networks and modified impact craters attest to the fact that Mars experienced periodic if not sustained rainfall during the Noachian and through the Hesperian. In addition, there are the outflow channels that also required catastrophic release of liquid water [16] as well as compelling evidence for an ocean in the northern hemisphere [17, 18]. Unlike the Earth, however, the spatial and temporal variations of the ancient climate as represented by the geology are preserved on Mars. We are currently looking at the record of modified impact craters to understand the history of water at least through the Noachian. Ultimately, reconciliation of the astronomy, geology and meteorology rests with at least through the Noachian. Ultimately, reconciliation of the astronomy, geology and meteorology rests with climate models. If a pure CO2 atmosphere does not work regardless of the surface pressure, then some other combination of atmospheric conditions and constituents is needed. Climate modelers need to explore these possibilities. The implications are not only for understanding the history of water on Mars, but the origin of life on Earth as well as habitable zones and extrasolar planets.

Figure 1. Valley networks located in the Iapygia region of Mars (5.97° S, 56.22° E). The modified impact crater located in the center of the image is ~58-km in diameter. The colored insert at the bottom shows the Grand Canyon at the same scale.

Figure 2. Examples of modified impact craters located at higher latitudes (56.93° S, 24.75° E). The crater at the bottom is ~30-km in diameter. Note the absence of valley networks. Craters such as these suggest that modification processes were ubiquitous in the early Noachian and that the climate conditions supporting erosion was global. (Google Mars image.)