16. Modern Atmospheric Conditions at the Crater ❖ ❖ ❖

The crater continues to be modified in the current arid environment, so it is important to understand the meteorological conditions operating today. Those conditions are also important because they govern the distribution of biologically attractive niches in the crater and, thus, are critical parameters for any assessment of astrobiological conditions that might be applicable to other planetary (*e.g.*, Martian) systems.

In 2009, an extensive set of meteorological measurements were made in an NSF-sponsored campaign called the Meteor Crater Experiment (METCRAX). The consortium team chose Meteor Crater for their experiment, because it was a near-perfect topographical basin and, thus, suitable for a study of the structure and evolution of temperature inversions and cold-air pools that form on a daily basis in larger topographic basins and valleys, such as Phoenix. The physical processes leading to the buildup and breakdown of temperature inversions and the formation of atmospheric seiches (atmospheric oscillations caused by wind disturbances at the basin crest) were studied in the crater without the complications introduced by more complex topography. The experiment produced a large number of papers relevant to atmospheric sciences (Whiteman *et al*., 2008, 2010; Fu *et al*., 2010; Hoch and Whiteman, 2010; Mayer *et al*., 2010; Doringer *et al*., 2011; Haiden *et al*., 2011; Hoch *et al*., 2011; Lehner *et al*., 2011; Adler *et al*., 2012; Lehner and Whiteman, 2012) and, importantly for the planetary science community, an immense amount of data that can be used for astrobiological purposes.

The implications of those results for microniches on Mars immediately followed (Whiteman *et al*., 2008). Two sets of observations are relevant. First, measurements of wind found that horizontal-axis eddies were produced by the crater rim and vertical-axis eddies formed over the crater floor during the daytime. In contrast, at night, a large drainage flow from the higher terrain of the Mogollon Rim southwest of the crater would sometimes pour over the rim of the crater. Second, measurements of temperature over a year (Fig. 16.1 and 16.2) showed how it varied between the crater rim and crater floor, between opposing crater walls, and between seasons.

Temperature inversions formed in the crater late in the day. During those periods, temperatures were similar from one side of the crater to the other at the same altitude. A 30-m thick stable cold-air pool formed on the crater floor with a temperature increase of ~5 °C over that distance, covered by a nearly isothermal layer that extended to the altitude of the crater rim. The thermal inversions were destroyed within 2½ hours of sunrise and replaced by a convective layer of air that grew upward as the crater floor and crater walls grew hotter. The daytime growth of that convective layer created strong winds at the crater by carrying strong winds from aloft downward. Those conditions would have been moderated in the crater when a lake was present, because of differences in the thermal properties of the soil (today) and water (then), except when the lake was frozen.

The experiment suggests that cold air may pond on crater floors, deepening thermal inversions seen in craters on Mars (Smith *et al*., 2004). Those inversions, like the ones in Meteor Crater, may have been less severe on early Mars when lakes were filled with water, if that water was not capped by a frozen shell of ice (Whiteman *et al*., 2008). The variation in temperature each day is greater on the crater floor than on the crater rim and the average temperature is less on the crater floor than on the crater rim at Meteor Crater and similar patterns should apply on Mars. Downslope winds may enhance the ablation of volatiles from bedrock, caves, and talus on crater walls, particularly in gully channels (Chapter 15).

It also seems reasonable that the condensation of volatiles is more likely on shadowed slopes and where large-scale nocturnal drainage flows spill over a crater rim.

Those nocturnal drainage flow winds were an unexpected observation at Meteor Crater and prompted NSF to support a second experiment called METCRAX II in 2013 to study the flow as an analogue for downslope windstorm-type flows. In the case of Meteor Crater, the process begins with katabatic winds draining the Mogollon Rim and flowing towards the crater where they spill over the rim in higher-velocity downslope flows along the southwest crater wall (Fig. 16.3). To study those winds, an array of meteorological equipment was temporarily installed (Fig. 16.4). This experiment, like the first experiment, generated a wealth of meteorological data that will be useful for astrobiological and planetary analogue studies. That data is still being evaluated, but two papers describing the experiment in greater detail (Cherukuru *et al*., 2015; Lehner *et al.*, 2016a) and an initial result relevant to atmospheric sciences (Lehner *et al*., 2016b) have appeared. The data confirm the inferences drawn for Mars from the original METCRAX experiment, but I expect to see a broader application of the data to conditions on early and modern Mars as the METCRAX II data is processed further.

The data produced by both experiments can be accessed through the LPI website that complements this guidebook (http://www.lpi.usra.edu/publications/books/barringer_crater_guidebook/).

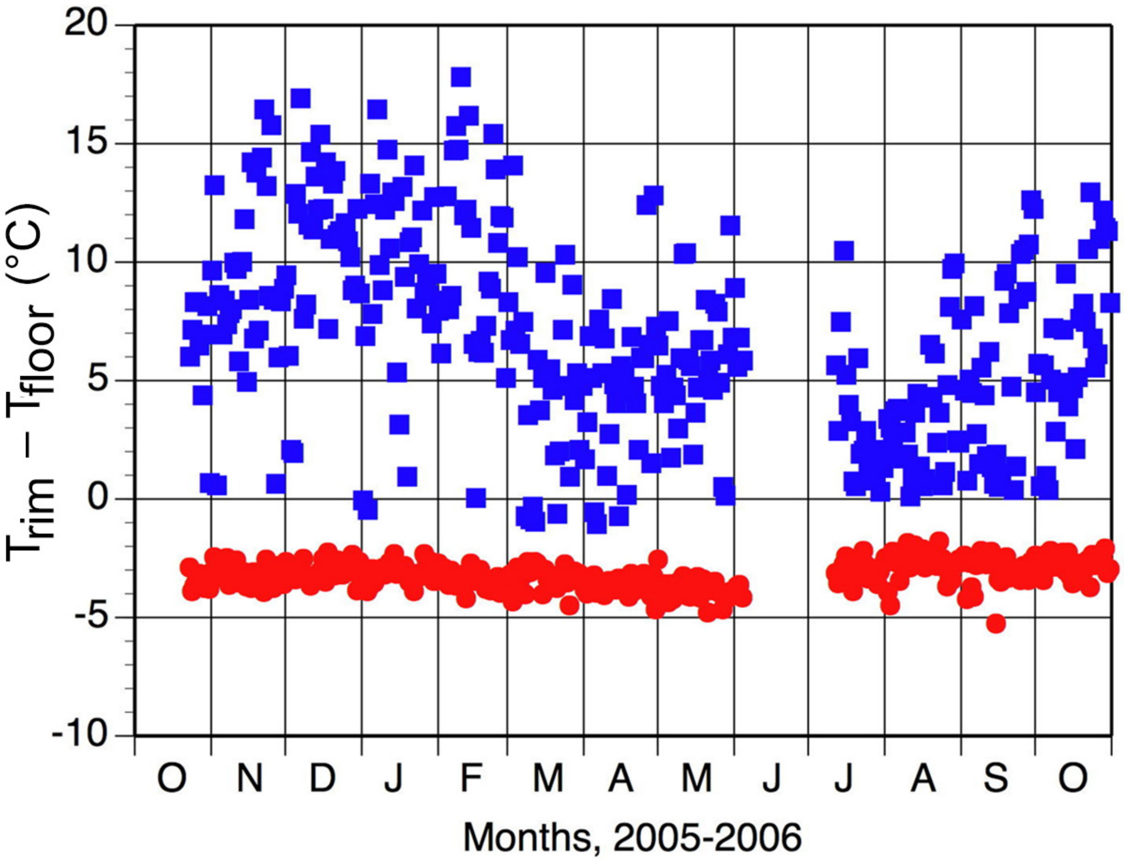
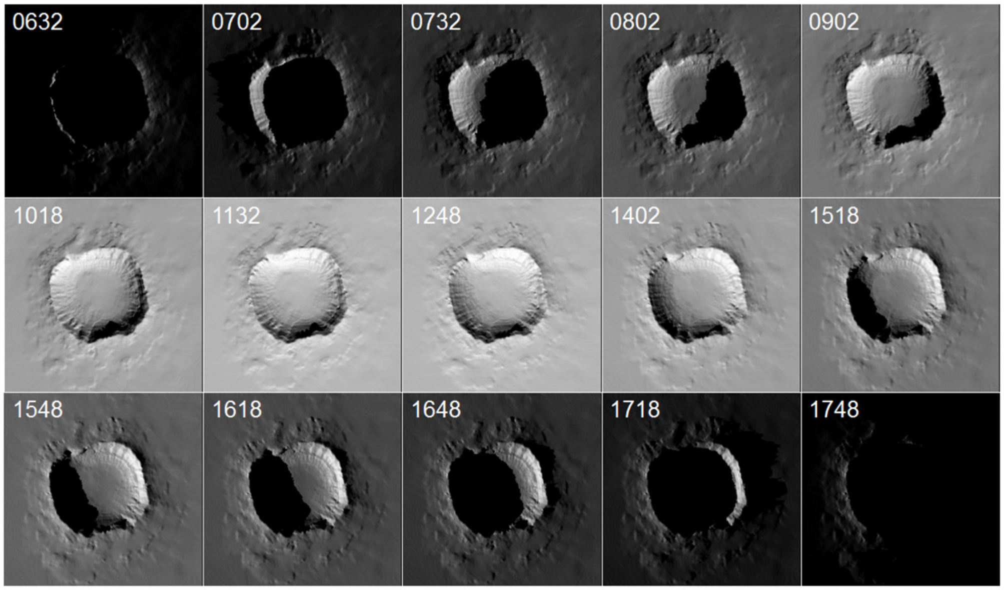


Fig. 16.1. The METCRAX experiment documented the temperature differences between the crater rim and crater floor as a function of time from October 22, 2005 through October 31, 2006, albeit with a data gap between June 4 and July 11, 2006. The data represent daily maximum (blue) and minimum (red) temperature differences between the rim and floor. The data indicate a daily temperature inversion, wherein the rim is hotter than the floor. Those inversions form in the late afternoon and evening. The minimum daily temperature differences (red) are always negative, indicating the nocturnal temperature inversions are broken up daily. The strongest inversions occur in the winter months, when temperatures increase by 15 °C from the floor to the rim. Illustration from Whiteman *et al.* (2008).



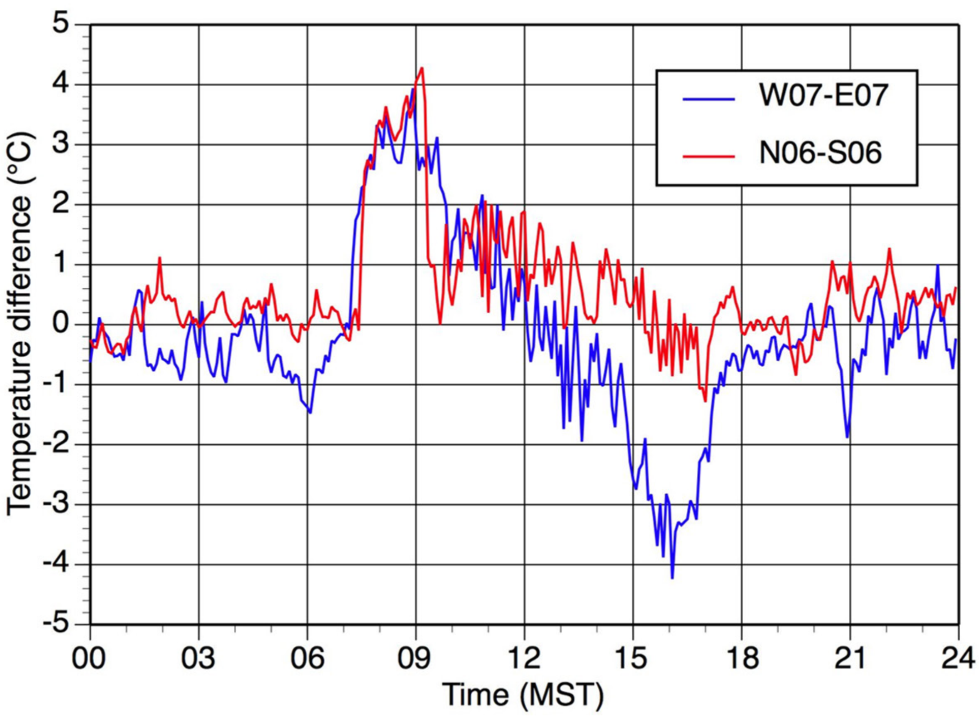


Fig. 16.2. The METCRAX experiment documented the diurnal air temperature differences caused by oblique sunlight and shadows on the crater walls. The upper panel shows the modeled progression of sunlight and shadowing in the crater on October 15, 2006, with time stamps in units of Mountain Standard Time (MST). That differential solar radiation created differential air temperatures that were measured. To illustrate those differences, the bottom panel shows the temperature differences between opposing west-east (blue line) and north-south (red line) crater walls at about 75 m above the crater floor on October 22, 2006, as recorded as a function of MST. At night, temperature differences between the same heights on the crater walls are small. (Although not shown here, that is not the case at the level of the rim, where a large scale cold air drainage flow from the southwest can produce temperatures that are 3 °C colder on the southwest rim than on the northeast rim.) During the day, temperature differences rise to 4 °C when a crater wall is in sunlight and the opposing crater wall is shadowed. In general, the north and west crater walls are relatively warmer in the morning and the east crater wall is relatively warmer in the afternoon. Illustrations from Whiteman *et al.* (2008) and their poster presentation.

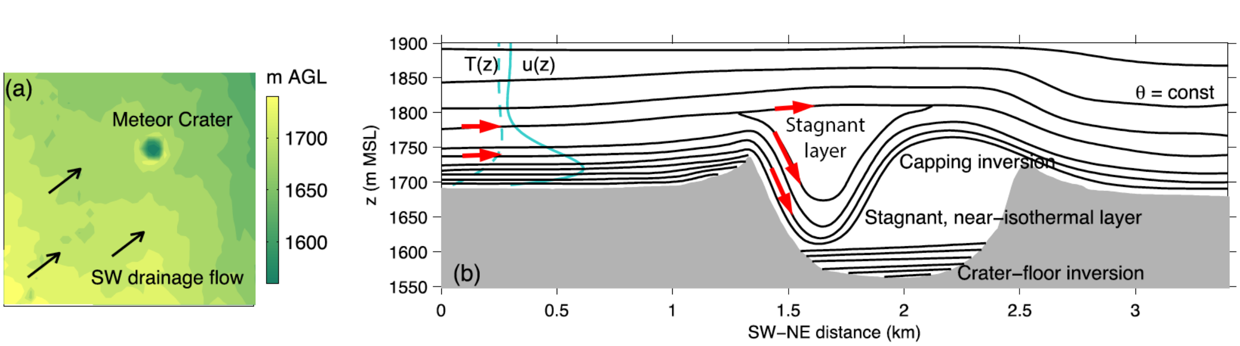


Fig. 16.3. The METCRAX II experiment was designed to study downslope flows to better understand windstorms in mountainous areas; *e.g.*, the chinook winds that sometimes level forests and damage buildings in the Rocky Mountain region. Similar winds, called föhn winds, affect areas within Europe's Alps. Meteor Crater provides an analogue environment, because winds blowing southwest to northeast (left panel) plunge over the crater rim (right panel). On clear, undisturbed nights, cold air pools on the plain southwest of the crater, forming a near-surface inversion (*i.e.*, warm air over colder air). That air flows downhill over the slightly-sloping plain towards the northeast. When the cold air reaches the crater rim, it spills over the rim and drains to the crater floor. When that cold air layer deepens, warmer air aloft also spills over the rim, producing a wavelike flow structure with higher wind speeds. That warm-air intrusion creates a large horizontal temperature gradient from the southwestern crater wall towards the crater center. The METCRAX II experiment, designed to study a modern meteorological problem, provided data relevant to our understanding of environmental conditions within impact craters and possible microniches in localities as distant as Mars. This illustration is used with permission and is modified slightly from its form in Lehner *et al*. (2016), which amplified the work of Adler *et al.* (2012).

Fig. 16.4. The METCRAX II experiment deployed instruments in the crater and on the surrounding plain. Instruments were secured to booms at several different heights on a tower (upper left) to measure differences in atmospheric properties as a function of height above the crater rim. Six arrays of HOBO temperature data-loggers (left side of middle panel) were temporarily installed on the crater floor, crater walls, and rim. Infrared and LiDAR cameras were deployed (right side of middle panel) to measure air flow into and within the crater. Towers were also erected on the surrounding plains to evaluate the atmosphere before air reached the vicinity of the crater. Data are accessible from the guidebook's website http://www.lpi.usra.edu/publications/books/barringer_crater_guidebook/.