ENHANCED SCIENCE RETURN FOR PROCESS INVESTIGATIONS FROM ENVIRONMENT-RESPONSIVE CONOPS.

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Motivation and Summary: Our aim is to initiate conversations about development of a data-efficient, strategic ConOps plan for in situ investigations of planetary surface/atmosphere interactions and environments [1], and to understand how development of such ConOps plans enhances science return for process or environment-focused planetary investigations. When studying processes, it is important to gather integrated/concurrent measurements of both the activity and environmental drivers. Additionally, accurate measurement of both the meteorological environment and activities requires measurement of background values/cycles as well as during transient phenomena (such as wind gusts or convective vortices). Typical "pre-scheduling" of data acquisition thus requires either continuous high-frequency measurements or serendipitous capture of transient conditions; the first is not data-efficient and the second is not strategic and limits science value of returned data. Recent advances in onboard processing capabilities present agile science options [2]—e.g., data acquisition timing that responds to current environmental conditions, thus addressing both issues.

Some Environmental & Process Investigations:

(1) Dust devils (Figure 1) have been imaged on Mars from orbit and rovers. These regular phenomena contribute to dust lofting on Mars. Characterizing them yields insight to general dust lifting mechanisms and rates – which is vital for Mars climate studies [3], and provides a novel analog to dust devils seen on Earth and hypothesized for e.g., Titan [4].

(2) Models of wind speed distribution and wind-induced sediment transport are, at present, strongly based on terrestrial experiments and observations [5]. It is generally assumed that similar physics applies in other planetary environments, with appropriate scaling. But extraterrestrial in situ "field" measurements of atmospheric boundary layer dynamics would provide critical model validation/calibration data.

(3) On Earth, turbulent fluxes in the near-surface atmosphere can be directly calculated from correlated, high frequency measurements of the 3D wind components and the quantity of interest; such fluxes are also related to large-scale (and more easily measured) quantities such as the vertical temperature gradient and wind shear, based on models that have been carefully calibrated by terrestrial field studies [e.g., 6]. These same relationships are often assumed in planetary studies, but have not yet been proven to extend to those environments—which may be far outside of terrestrial conditions.

(4) Sublimation of subsurface ice is thought to form many planetary landforms [5], such as pits (e.g., Pluto) and scalloped terrain (e.g., Mars), as well as exospheres (e.g., Ceres [7]). Within the martian mid-latitudes, large reservoirs of near-surface ice are thought to be stabilized under a coating of dust/regolith [5]. In addition to ice, regolith can harbor adsorbed water, brine, pre-melted liquids at mineral-ice and ice-grain interfaces, or hydrous minerals—all of which may exchange H_2O with the atmosphere. Understanding these processes, as well as how they may depend on local relative humidity and temperature conditions, requires careful environmental monitoring.

Figure 1. A martian dust devil imaged by MER [8], with a mock instrumented mast. As dust devils sporadically may pass a lander, science return would be enhanced if onboard data analysis was able to detect when a dust devil is present, so as to prioritize downlinking data from that observation period or to prompt a "dust devil observation" mode.

Strategies for Data-driven Discovery & Analytics: Environmental and process focused investigations have different observation frequency/timing needs than many geological studies. In particular, the science value of relevant measurements is significantly enhanced when we have:

- Correlated measurements of drivers and activity,
- Large range of measurable scales, as drivers and activity occur over many scales,
- Ability to focus measurements (e.g., fidelity, frequency) around transient conditions/changes – e.g., high-frequency during short events, low-frequency during cycles, and the
- Ability to capture both cycles/background and transient, random "events."

Typical "pre-scheduling" of data acquisition consists of either continuous high-frequency measurements or lower-frequency measurements and a hope for serendipitous capture of transient conditions (Figure 2). Even when guided by predictive models for when increased observations are needed, it is generally impossible to ensure capture of the full range of natural dynamics. Additionally, the first method is not data-efficient, and the second is not strategic and limits science value of returned data. Finally, this assumed framework means that when we encounter data volume or power issues, the response is to descope an instrument, decrease observation time, or decrease correlation of measurements.

Recent advances in onboard processing capabilities present options for data acquisition timing that responds (in real time) to environmental conditions. For example, we can use detection of a change or anomalous condition to either change downlink priority of previously collected data, or change the data acquisition parameters. The first could decrease the required downlink data volume (to achieve the same science goals), and the second would decrease both power and data volume. This change in ConOps also changes strategies for resource management, as now there are options for changing the strategy for observation collection and data downlink, while maintaining a focus on the most important events/surface activities (rather than e.g., descoping an instrument). For example:

- For studies of dust devils, pressure sensor observations might be used to "trigger" collection of other data types, such as those collected by: cameras, sediment sensors, temperature/energy sensors, wind sensors, or electrostatic sensors.
- Wind sensors could detect when anomalous/higher wind conditions are occurring (e.g., wind gusts), so as to collect more and more detailed sediment transport data, beyond averaged/non-optimized wind and sediment transport rates.
- Volatile surface-atmosphere exchange rates could be tracked specifically during periods of the day when such exchange is enhanced (i.e., replacing the scheme in Figure 2).

References: [1] Diniega et al., 2020 PS&A Decadal Survey white paper, "A Critical Gap." [2] https://cs.jpl.nasa.gov/public/projects/agile-science/. [3] Newman et al., 2020 PS&A DS white paper. [4] Jackson et al. 2020, *JGR Planets* **125**(3), e2019JE006238. [5] Diniega et al. 2020, *Geomorphology* **380**, 107627. [6] Li et al. 2010, *GRL* **37**, L15404. [7] Tu et al. 2014, *P&SS* **104** B, 157-162. [8] NASA photo, pia20012-1041.jpg.

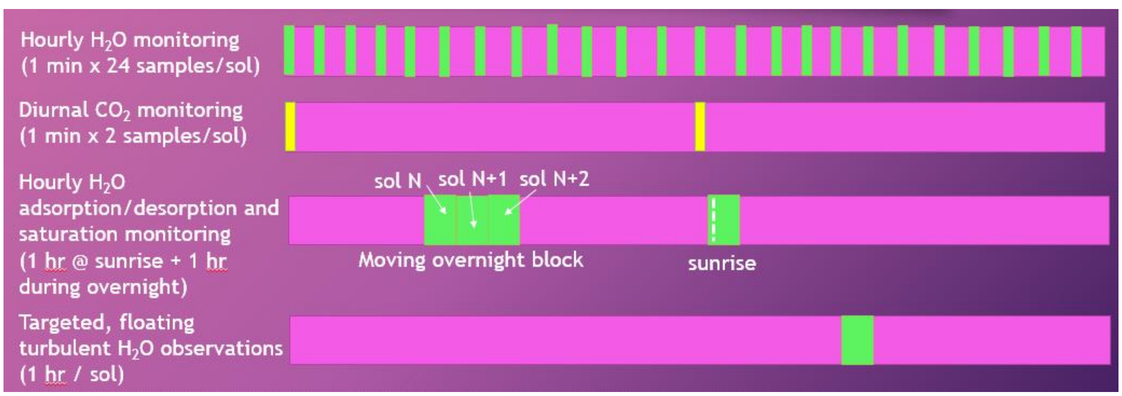

Figure 2. Example of common strategies within a "prescheduled" observation acquisition strategy. Volatile exchange (in this case, of martian H_2O) is expected to peak around sunrise, but may have significant, varying rates through other parts of the diurnal cycle. Exchange rates are likely based on local environmental conditions such as temperature and pressure. To capture the general trends as well as brief peaks, but without overwhelming the data budget, short samples (1 min) are collected at regular intervals, and larger samples (1 hr) are collected at sunrise and during "floating" blocks (some cycling through the day, and some may be targeted, if a time beyond sunrise is identified, in advance, to be important).