
**Introduction:** Based upon discoveries in the previous Mars Reconnaissance Orbiter (MRO) extended mission period (2014-2016) and ongoing analyses of the data by both MRO and the science community, we will pursue four goals with 16 investigations in the 4th Extended Mission (EM4; 2016-1028). Although much progress has been made, key outstanding questions from the Vision and Voyages Planetary Decadal Survey [1] remain and new questions have arisen. The MRO goals, ordered by Martian era, and key questions to address are:

- **Goal 1: Ancient Mars: Environmental Transitions and Habitability**—MRO, other orbiters, and rovers revealed there were multiple types of water-related environments on ancient Mars. Key questions are how long did liquid-water activity persist and how did the environments evolve in their physical and chemical conditions?

- **Goal 2: Amazonian Ices, Volcanism, and Climate**—MRO data are revealing the global distribution of water and CO₂ ices, including ground ice and buried polar CO₂ ice exceeding in mass the present atmosphere. Key questions are what are the extents of the deposits and can their stratigraphy be matched to astronomical forcing functions (e.g., obliquity)?

- **Goal 3: Modern Dynamic Mars: Surface Changes and Implications**—MRO discoveries point to possible brines or deliquescent salts at Mars' surface today. Key questions are what are the mechanisms driving recharge and modern surface change, and can the prevalence of water be determined? The answers have implications for, science, in situ resource utilization, and Planetary Protection.

- **Goal 4: Modern Dynamic Mars: Atmospheric and Polar Processes**—Systematic coverage and new observing campaigns by MRO are providing new insights into atmospheric and polar-ice variability. Key questions are what determines the frequency of regional and global dust storms and what are the storms’ effects on the current climate?

Water, albeit in ever-more-exotic locales and forms, continues to be a primary cross-cutting theme of the MRO investigations. Study of the suite of aqueous minerals detected across the planet will characterize climatologically transitional and episodic regimes, some occurring later in Mars history than previously thought. Identifying and mapping the global and local distribution of ice-related features—e.g., periglacial landforms, ice-exposing impacts, sublimation depressions—is central to determining the modern distribution and time variability of ice deposits. The importance of dust layers and even thin volatile-ice clouds to the radiative forcing of the general circulation is now recognized, but not fully characterized. Likewise, discovery of surface change and possible extant liquid water has emphasized the dynamic nature of the present climate.

The investigations needed to address these four EM4 goals are discussed below. Several involve coordinated observations with other Mars missions.

**Goal 1. Ancient Mars: Environmental Transitions and Habitability**: MRO has discovered evidence that environmental change on ancient Mars may have been spatially heterogeneous or temporally cyclic, with conditions apparently shifting back and forth between wet/neutral pH and dry/acidic before fully transitioning to today’s climate. Five EM4 investigations will focus on the formation history of younger aqueous deposits, weathered glass deposits, and older layered clays and sulfate deposits. These investigations will have important implications for the Decadal Survey goals related to life (i.e., habitability and preservation potential) and climate for early Mars. The five investigations are:

- **Determine Extent and Nature of Young Aqueous Deposits on the Valles Marineris (VM) plateau:** Understand extent & source of Hesperian to Amazonian aged Si-rich, radar-reflective deposits.
- **Characterize Effects of Persistent Impact Heating:** Determine distribution & age range of impact glass, its potential for chemical and thermal energy for biology, & effects of impact on aqueous alteration.
- **Characterize Transitional Environments:** Determine if late Noachian environment change was monotonic or fluctuating, and globally uniform or regionally variable.
- **Search for Carbonates:** Continue the ongoing campaign to reveal deeply buried Fe/Ca carbonates that record an older pre-Noachian environment.
• Rovers and MRO—Characterize Crust in Meridiani and near Gale Crater: Understand the terrains and their history near Endeavour and Gale Craters by combining orbital and in situ data.

Goal 2. Amazonian Volatiles, Volcanism, and Climate: MRO has been instrumental in revealing buried H₂O and CO₂ ices; evidence of geologically recent climate change. Three investigations will refine our understanding of these Amazonian climate signals by addressing near-surface ice deposits, polar cap layering and composition, and the potential for volcanic flows to have contributed substantial greenhouse gases to the climate. The three investigations are:
  • Constrain Near-surface Ice Inventory: Improve knowledge of location & extent of polar/non-polar volatiles.
  • Constrain Volatile Transfer on Obliquity Timescales: Improve knowledge of the quantity and frequency of volatile (H₂O & CO₂) transfers between the poles & lower latitudes during recent geologic times.
  • Characterize Amazonian Volcanics: Estimate volumes and compositions of volcanic deposits, to assess the associated outgassing and to assist evaluation of climatic implications.

Goal 3. Modern Dynamic Mars - Surface: MRO has dramatically advanced our understanding of active surface processes on Mars. These results accelerate with each mission extension, as more repeat imaging over a longer baseline increases the ability to detect change. MRO will expand observation types to enhance understanding of possible liquid water on Mars today, will evaluate surface change resulting from large dust events, and will continue to monitor known sites while searching for new dynamic surface events indicative of ongoing activity. The three investigations are:
  • Understand RSL and Water Today: Test brine hypothesis by refining association with hydrated salts and by quantifying color & albedo change; compare 3 p.m. data with TGO variable time-of-day imaging.
  • Observe Active Phenomena over an Extended Temporal Baseline: Observe sediment flux (dune migration), new impacts, gullies, & mass wasting to quantify slower deposition and erosion rates.
  • Investigate changes in Gale Crater: Investigate active dunes, potential RSL and other surface change phenomena in Gale crater.

Goal 4. Modern Dynamic Mars - Atmosphere and Polar Processes: MRO observed new atmospheric features in EM3, some confirming model predictions. During EM4, interannual variability in a greater number of local times will be observed, via standardization of augmented local time measurements begun in EM3. Higher altitude observations will measure the top of the dust, if a global dust storm occurs. The influence of CO₂ snowfall on the caps and on surface changes will be measured. Collaborations with other missions will enable an understanding of atmospheric energy transport and chemistry, enhancing the scientific return of each mission. The five investigations are:
  • Define the Martian Climate and Evaluate Weather in a New Mars Year: Detect change, including diurnal and interannual variability, cyclic patterns and trends in the meteorological fields and synoptic weather by adding a 6th Mars year of atmospheric observations.
  • Understand Dust Storm Origin/Evolution and Polar Responses: Understand onset and evolution of global and/or large regional dust storms; characterize effects on atmosphere and surface, including polar caps.
  • Understand CO₂ Ice, Frost, and Snow Trends: Understand accumulation/ablation of CO₂ ice, including mid-latitude frost and high-latitude snowfall to characterize mass and energy balance and surface erosion/deposition effects.
  • Understand Energy and Momentum Transport: MRO-MAVEN-MSL: Trace vertical transport through linked observations covering the upper, middle and lower atmosphere, by measuring temperature, water & CO₂ ice clouds, dust hazes and ionospheric properties, together with corresponding links to Curiosity-based data.
  • MRO Atmospheric Observations for the Interpretation of TGO Chemistry Measurements: Evaluate role of aerosols & temperature in controlling atmospheric chemistry by comparing to TGO observations that are complementary in time.

Summary: MRO will conduct an exciting and important extended mission during 2017-2018. The nature of extended missions means a focus on obtaining the measurements necessary to conduct the investigations cited here and archiving the data to the PDS for the community to use. As such, the MRO team invites researchers to pursue these objectives and thereby enhance the scientific return of the MRO mission. Please contact us for a copy of the science plan.

References: