THE SEASONAL CYCLE OF WATER ON MARS

BRUCE M. JAKOSKY

Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO 80309, U.S.A.

(Received 8 January, 1985)

Abstract. A review of the behavior of water in the Mars atmosphere and subsurface is appropriate now that data from the Mariner and Viking spacecraft have been analyzed and discussed for several years following completion of those missions. Observations and analyses pertinent to the seasonal cycle of water vapor in the atmosphere of Mars are reviewed, with attention toward transport of water and the seasonal exchange of water between the atmosphere and various non-atmospheric reservoirs. Possible seasonally-accessible sources and sinks for water include water ice on or within the seasonal and residual polar caps; surface or subsurface ice in the high-latitude regions of the planet; adsorbed or chemically-bound water within the near-surface regolith; or surface or subsurface liquid water. The stability of water within each of these reservoirs is discussed, as are the mechanisms for driving exchange of the water with the atmosphere and the timescales for exchange. Specific conclusions are reached about the distribution of water and the viability of each mechanism as a seasonal reservoir. Discussion is also included of the behavior of water on longer timescales, driven by the variations in solar forcing due to the quasi-periodic variations of the orbital obliquity. Finally, specific suggestions are made for future observations from spacecraft which would further define or constrain the seasonal cycle of water.

Table of Contents

1. Introduction
2. The Physics of Water
   2.1. Phase Equilibrium and Non-Equilibrium States for Pure Water
   2.2. Adsorption
   2.3. The Presence of Salts
3. Observations of the Seasonal Water Cycle on Mars
   3.1. The Seasonal Cycle of Water
   3.2. The Vertical Distribution of Water in the Atmosphere
   3.3. Clouds
4. Observations of the Polar Caps
   4.1. The Residual Caps
   4.2. The Seasonal Caps
   4.3. Why are the Two Polar Caps Different?
5. Exchange of Water with Seasonal Reservoirs
   5.1. Subsurface Ice
   5.2. Adsorption within the Regolith
   5.3. Atmospheric Transport of Water Vapor
6. Possible Localized Reservoirs of Water
   6.1. Surface Ice or Water
   6.2. Possible 'Oasis' Regions
7. The Seasonal Cycle of Water
   7.1. Control of the Seasonal Cycle
   7.2. The Behavior of Water at other Epochs
8. Major Questions and the Potential for the Future
1. Introduction

The seasonal behavior of water on Mars is an important indicator of many aspects of the nature of the Mars surface and atmosphere. Perhaps the most interesting area is that of the Mars climate at the current epoch and how it may have varied over geologic time. By examining the variability of atmospheric water, we are able to place constraints on the processes controlling the behavior of the polar caps and their seasonal cycles, the exchange of volatiles between the atmosphere and the subsurface regolith and possible resultant chemical processes, the dynamics and general circulation of the atmosphere, and mechanisms which may result in the occurrence of net sources or sink for volatiles over the course of a year. By understanding the physical processes which occur during a single year, one is able to examine their response to long-term forcing due to changes in the sun or in the Mars orbit, and to begin to unravel the history of the Mars climate.

There is abundant evidence for dramatic climate change or variability on Mars. Perhaps the most intriguing involves the presence of channels on the surface which may have been carved by liquid water at some time when water was more stable on the surface than it is today. The layered terrain in the polar regions also suggests dramatic changes, apparently consisting of layers of water ice and dust mixed together in varying amounts and indicating the variable and episodic nature of the transport of both species to the poles. Nitrogen isotope measurements indicate that there has been a large change in the atmospheric abundance of nitrogen, yet oxygen isotope measurements require a significant long-term exchange of atmospheric oxygen with a non-atmospheric source (McElroy et al., 1976; Nier et al., 1976; Fanale and Cannon, 1978). Variations in the orbital obliquity of Mars occur periodically (e.g., Ward, 1979), suggesting a causal relationship between climate change driven by the obliquity changes and the formation of the polar terrain and perhaps even the channels, and the evolution of the composition of the atmosphere.

In this paper we will review the observations of water vapor in the atmosphere and its variability over the seasonal cycle and discuss the physical processes which may contribute to the variations. The results will be integrated as much as possible with other data in order to provide an overview of the current climate and a self-consistent picture of the seasonal water cycle.

To briefly summarize, the column abundance of atmospheric water vapor varies from nearly zero to about 100 precipitable micrometers (100 pr μm, equal to $10^{-2}$ g H$_2$O cm$^{-2}$), depending on location and season; the globally-integrated atmospheric abundance varies between about 1 and $2 \times 10^{15}$ g (Jakosky and Farmer, 1982). A number of processes contribute to this variability. Motions of the atmosphere tend to redistribute the water with the seasons, and exchange with non-vapor reservoirs contributes to both the local and the global variations. Possible seasonal reservoirs for water include: surface ice, either as part of the seasonal or residual polar caps or on the ground at non-polar locations at some seasons or times of day; subsurface ice, either in equilibrium with the atmospheric vapor or in diffusive contact with the atmosphere.