

The Spatial and Seasonal Distribution of Martian Clouds and Some Meteorological Implications

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The spatial and seasonal distributions of Martian atmospheric clouds, organized according to simple morphologic criteria, exhibit distinct patterns. When interpreted self-consistently using analogies to terrestrial cloud forms and Martian temperature, wind direction, and water vapor measurements, patterns of cloud occurrence provide some loose constraints on global-scale near-surface wind speed, static stability, and humidity. We have examined all Mariner 9 and Viking Orbiter images for this study; we concentrate primarily on the larger Viking data set. Whenever observations are possible, relatively high near-surface winds appear to follow the seasonal cap edges during early fall, late winter, and spring. Moderate to high winds are also inferred in mid-latitudes for mid southern winter and in low latitudes, mainly in the steeply sloping areas of Tharsis, near the solstices. At other times, lower winds are suspected. Hemispheric asymmetries are traced to differences in atmospheric hydration state and to global dust storms related effects on the atmospheric temperature structure and the north polar cap recession schedule. Cloud occurrence data suggest that the near-surface daytime static stability is low in the northern hemisphere during summer and at low latitudes during mid northern spring. Relatively high static stability is deduced near the winter poles and globally during the dust storm seasons. In spite of low atmospheric temperatures, the correspondingly low absolute humidity apparently precludes the formation of thick water ice clouds at high latitudes in mid to late autumn and winter in both hemispheres and in southern mid-latitudes during early winter. During northern spring and summer, saturation conditions seem to be easily achieved at mid-latitudes, and condensate clouds are abundant; the situation is complicated by atmospheric dust in southern spring and summer. Low latitudes generally appear to be farther from saturation than mid-latitudes, and clouds generally form more easily in the northern hemisphere than in the south during corresponding seasons.

1. INTRODUCTION

Much of our knowledge of the global-scale meteorology of Mars comes from deductions based upon remote observations of clouds in the Martian atmosphere. Cloud color and seasonal behavior provided ground-based astronomers with the first clues to the nature of global dust storms and the polar hoods [Süßner, 1963]. Spacecraft reconnaissance by the Mariner 9 and Viking orbiters produced a wealth of more detailed information about cloud morphology and distribution [Mamersky *et al.*, 1972; Leovy *et al.*, 1972, 1973a; Briggs and Leovy, 1974; Briggs *et al.*, 1977, 1979; French *et al.*, 1981]. From this body of work it became evident that clouds in the Martian atmosphere could be classified by morphology. Cloud "types" defined according to easily observable morphologic criteria were found to exhibit distinct spatial distributions and seasonal variations, suggesting that cloud occurrence data may be useful for probing regional meteorological conditions. French *et al.* [1981] began the systematic study of global patterns in cloud occurrence, using a keying scheme that distinguishes six morphologic types, and a data set containing all Mariner 9 and part of the Viking Orbiter images.

This paper is an expansion of the earlier work, with a substantially different emphasis; in addition to presenting new cloud distribution observations, we have focused specifically upon drawing meteorological inferences from the cloud occurrence data. To this end, the coupled spatial and temporal behavior of each cloud type is examined in much greater detail than was done in previous studies. We have generalized the classification scheme used by French *et al.* and have searched all Mariner 9 and all Viking Orbiter pictures (approximately 7,400 and over 50,000 images, respectively) for the

new catalog. In the next section we review the cloud keying scheme and present plots of cloud type occurrence and related statistics. We then interpret these data in light of the combined constraints of meteorological conditions likely to favor formation of each cloud type, according to terrestrial analogy, and the observed water vapor abundance, temperatures, and wind fields on Mars. These results are used to formulate some generalizations about the seasonal and spatial variation of Martian near-surface wind strength, atmospheric static stability, and humidity and to identify areas where more detailed observations and theoretical work could be most valuable.

2. THE SPATIAL AND SEASONAL DISTRIBUTION OF MARTIAN CLOUDS

We separate surface obscuration observed in Viking and Mariner 9 images into seven categories, according to cloud morphology, using the scheme displayed in Figure 1. The resulting "cloud types" are listed in Table 1, together with brief descriptions of each and some conjectures about probable meteorological conditions which would favor formation, based primarily on analogy to terrestrial clouds [e.g., Ludlum, 1980]. These will be discussed in more detail later. Sample images of the Martian cloud types are presented in Figure 2.

The entire Viking and Mariner 9 data sets were examined at least twice for this study, by two independent observers. There are about 16,900 haze events in the catalog and over 1,400 occurrences of the other cloud types. In 5-7% of the cases the cloud morphology was sufficiently unclear for the observers to disagree on the cloud type. In these instances a third observer helped decide upon the designation. The clouds in each image were counted independent of possible occurrence of parts of clouds in adjacent images. However, statistics are compiled by orbit, in part to avoid biases due to this possibility (see discussion of Table 3).

Figures 3-11 show the distributions of each of the cloud types as a function of latitude and season. (L_s , the seasonal

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