Introduction

Surface conditions on Mars are currently cold and dry, with water ice unstable on the surface except near the poles and surface liquid water thought to be never present. However, geologically recent glacier-like landforms have been identified in the tropics and mid-latitudes of Mars, an ice-rich mantling seems to cover both hemisphere above 60° latitude. The corresponding climate changes seem to have been recorded in the multi-layered polar deposits.

Modelling the water cycle in the past. To better understand the climate conditions and processes that have formed such features, we have conducted a set of studies by adapting models used to simulate present-day Mars to other orbital and obliquity parameters.

First, we have performed high resolution climate simulations with a numerical model designed to simulate Mars current climate [1] and the details of the present-day Mars water cycle [2], but using different obliquities, like on Mars a few millions of years ago.

At high obliquity (e.g. 45°), the model predicts the accumulation of ice and the formation of glaciers on the western flanks of the great Tharsis volcanoes if the current northern polar cap remains a source of water, and in eastern Hellas if a water ice polar cap is assumed to be present at the southern pole [3]. This is precisely where some of the most characteristic Glacier-like features have been discovered. The agreement between observed glacier landform locations and model predictions points to an atmospheric origin for the ice and permits a better understanding of the details of the formation of Martian glaciers.

Using the same model, we show that when Mars returns to lower obliquity conditions, the low and mid-latitude glaciers becomes unstable, partially sublimes and tend to accumulate in both hemisphere above 60°. Once water is no longer available from the low and mid-latitude glaciers, water tends to return to the poles (where it is now), but probably leave some ice under a dry layer. We suggest that such a processes probably explain the presence of the ice-rich mantling observed by geomorphology and detected by the GRS instrument aboard Mars Odyssey, as in [4], but at higher obliquity, which is more realistic.

Moreover, we have discovered a new climate regime that could explain the formation of glacier in the midlatitude of Mars, in particular in the Deuteronilus-Protonilus Mensae region (0-80°E, 30-50°N), where large concentrations of lobate debris aprons and incised valley fills (that resemble flow lines in glacial ice on Earth) are found. This is something we could not understand until recently [9]. We can now propose a new climatic process able to induce these accumulations. We examined the meteorological conditions after this period of high obliquity, when the tropical mountain glaciers were a new possible source of atmospheric water, and the obliquity was leaning towards lower values (35°). We show that, assuming a relatively dusty atmosphere, the resulting climate favors the formation of a thick cloud belt in the northern mid-latitudes of Mars, with precipitation and accumulation of ice in regions in good agreement with geological observations. Not only is the modeled accumulation maximum in the regions where glacier-like landform has been observed, but it is found that everywhere poleward of ~50° latitude, some ice could have accumulated. This could explain the origin of the ice-rich mantling detected by the GRS instrument aboard Mars Odyssey, as in [10], but at higher obliquity, which is more realistic.

Fig. 1 A map of the annual accumulation of ice predicted by the GCM with obliquity 45° in the Tharsis area (right) compared to a geologic map of the Tharsis region showing the location of fan-shaped deposits of Amazonian age (yellow) that are thought to be the remnant of large glacier.
climate system as that of today, except that the enhanced water cycle allows the precipitation and accumulation of ice in specific locations controlled by the atmospheric circulation. In reality, the complex variations of orbital parameters probably led to all sorts of regimes in the past, with water ice alternatively mobilized from the poles to the tropical and mid-latitude glaciers and to the high latitudes. After several obliquity cycle, all these processes should have created layers that could be detected by Phoenix in 2008. Moreover, on the basis of the ice accumulation or loss rate that are modeled at the pole, we can try to reconstruct the history of the ice accumulation at the North pole in the past 10 Million years and compare the modeled layers with the actual structures that are observed in the polar deposits throughs [5].

It is also likely that some of the past Mars Climate regimes led to the accumulation of ice on slopes that could have had reached the melting point of water and initiate debris flows and Gullies, in some specific conditions that we can investigate with the climate models [6].

Overall, we can thus propose a simple, consistent scenario to explain the formation many of the amazonian icy landforms by the climate system that we know today, without the involvement of subsurface reservoir.

Subsurface Ice stability. With our water cycle model, we can also investigate the evolution of ice stability in the subsurface, which is controlled by mechanisms than ice at the surface (e.g. annual mean temperature, annual mean water vapor pressure). At the Mars Conference, we will report some results of a study that could help understand the evolution of subsurface ice in the past 10 million years.

Some Issues

Large uncertainties that remains in the current past climate simulations. For instance, the radiative feedback of water ice clouds and water vapor may play a role, but we do not yet take them into account. Another uncertainty is atmospheric dust, which has a strong impact on our results. In particular, the amount of dust present in the atmosphere at high obliquity is unknown. GCM simulations show that the near-surface circulation amplifies considerably with increasing obliquity [7,8] such that potential dust lifting could be much higher than today. However, the atmospheric dust load may have been limited by the finite amount of surface dust available in the windy locations so that the opacity may not have been higher than today. In any case; in the ice accumulation region, precipitations should have contributed to the cleaning of the atmosphere by scavenging dust particles, as on Earth today. Such a process should be investigated in future studies. Similarly, the formation of lag deposits on sublimaing water ice reservoir remains to be well understood, as well as the local stability of water ice and liquid water.

Another issue may be the relative edge of the observed ice deposits and glacier landforms. The major equatorial deposits appear to be much older (several tens of million of years) than the mid latitude ice mantling. This could be related to the present stability of subsurface ice in these regions, or to the fact that in the past 10 millions years ice was only moved to the tropics for a time too short to form very large glaciers (i.e. only when the obliquity was near its maximum in
its 20 degree oscillation) before being transported to the mid-latitudes. In this scenario, the major glaciers would have formed in the Tharsis region only when the mean obliquity was above 40 degree for several million years, several tens of millions of years ago.

Reference


