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Future Climate Changes on Mars: Science Fiction or Possible Reality?

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Mars at the present time is the second most studied planet of the Solar System after our own Earth. Its atmosphere, surface, and sub-surface have been the subjects of several successful spacecraft and robotic missions as well as theoretical studies carried out with numerical models of increasing degree of sophistication and complexity. The interest in investigating its remote past, both from the observational and the modeling point of view, has also grown.

At present, Mars is cold, dry, bombarded by radiation and covered by oxidants; a very hostile environment for life. According to recent observations from Mars Odyssey, Mars Express and the Mars Exploration Rovers, though, between 4.5 and 3.5 billion years ago it might have been a very different planet: stable liquid water on its surface might have created a warm and moist environment, prompting the emergence of life [2].

What then is the future of Mars? Is the concept of "climate change" relevant for its future?

We are learning from the case of the Earth that there are two causes of climate change on a planet: a naturally induced climate change, which is usually a slow process due to changes in orbital parameters, internal instabilities of the climate system or the occurrence of life, and an artificially induced climate change, due to the action of intelligent beings (the human race in the case of the Earth).

The future of Mars can certainly include the former: the planet is likely to undergo dramatic changes in the tilting of its rotational axis, although on a time scale of million of years, as it already happened in the past [8]. On a much shorter time scale (years), the observed shrinking of the deposits of frozen carbon dioxide near Mars' south pole and the expansion of the pits formed in the planet's perennial southern polar ice cap suggest a climate change in progress [10], although this conclusion is still controversial, as such phenomena might just be evidences of inter-annual variability. What about the second possible cause? Could an artificially induced climate change be foreseen on Mars?

NASA, ESA and other Space Agencies worldwide advocate the human exploration of the Red Planet on a time scale of about 30 years from now, with a remote possibility of future human settlements in the long term. NASA, for instance, strengthened the concept of human exploration of Mars in its "Vision for the Space Exploration" programme after President Bush's speech on January 14th, 2004, and ESA replied with a specific programme of exploration of the Solar System (the "Aurora Programme") which also includes the future human involvement on the planet. If this scenario is realized, the future of Mars might hold the certain presence of life on its surface, in the form of human beings, for short or not-so-short periods. What could happen next?

If the human exploration of Mars will only be a one-off event, there is little if any reason to think about any possible artificial change of the Martian climate. Still, natural climate changes on the planet would be of the highest scientific interest, not to mention the possible ramifications for the study of climate changes on the Earth. Nevertheless, the human race might realize in the future that Mars could be or should be a possible second home planet, for whatever reason. In this case, the demand of improving its habitability will become an extremely important issue.

This issue started to be scientifically addressed in the early 70's [1, 3, 12], then had a further boost in the 90's (see [5], which includes an exhaustive bibliography). Currently, it is a concept for which several "Mars societies" worldwide (http://www.marssociety.org) are trying to lobby, after the publication of the popular book by Robert Zubrin, "The Case for Mars", in 1996 [14]. Laboratory experiments to study the feasibility of increasing the habitability on Mars are currently being carried out, mostly from the engineering and biological points of view. See [4], for instance, as an example of review article on nanotechnologies applied to the idea of "terraforming".

Terraforming a planet is therefore a concept which is no longer exclusive to science fiction. Terraforming ultimately means artificially inducing changes on an extraterrestrial planetary environment in order to make it similar to our Earth, for the sake of improving the habitability to the advantage of life. I write "life" and not specifically "the human race" because in my view human beings are not the only beings worth of having a chance on another planet.

In a certain sense, we (as human beings) have been transforming our own planet for centuries, and this transformation process has assumed the dramatic connotations of "climate change" and "global warming" in the most recent years, with an exponential increase in the scale of the impact on the Earth's atmosphere and climate. Therefore, the concept of terraforming an extraterrestrial planet on a local, regional or global scale can be considered as a challenging and cutting-edge engineering task ("planetary engineering") which finds its pragmatic bases and motivations in our direct experience on the Earth.

I will not enter any discussion here about the advantages or disadvantages of artificially inducing changes in the Martian environment, nor any ethical consideration about the responsibility of the terraforming concept. The interest of my commentary is merely scientific, and is aimed at suggesting a possible direction to find answers to three specific questions which could arise after having assumed that humans will decide one day that improving the habitability of Mars is a useful, if not necessary, task.

- How will the climate on Mars be affected by any artificially induced change?
- What should the magnitude of such a forcing be in order to obtain different degrees of habitability?
- What is the time scale of such climate changes and how stable can they be?

In other words, the interest is to study if, how, how much, when and for how long the habitability of Mars can be improved by introducing changes in the Martian climate system and environment provided by possible planetary engineering ideas. It is my view that the only way to find exhaustive answers to these questions is through numerical simulations of the future Martian climate.

Currently, the state-of-the-art of the numerical models of the atmosphere of Mars is extremely advanced. There are few global circulation models (GCMs) and mesoscale (or regional scale) models available worldwide, all having a completeness, accuracy and reliability comparable to those of Earth's climate models (see [6, 7, 11, 13, 15] and reference therein). The results on the present-day Martian climate which are provided by such models are continuously compared and validated against observations, and improvements in physical parameterizations are endlessly carried out, along with the increase of our knowledge of the Martian environment by means of ground-based, robotic and remote-sensed exploration.

Recently, some world-leading numerical models of the global Martian atmosphere have been re-formulated to simulate the remote past of Mars, stimulated by the new observations which seem to point towards an early epoch on Mars when aqueous processes occurred (see [9] for a review on the topic). The challenge of adapting these GCMs to the conditions which might have been present on Mars billions of years ago is remarkable, because of the important role played by water in all its states on a planet which might have been much warmer, with a much denser atmosphere than the one it is left with at the present time. The experience of the numerical modelers with the atmosphere of the Earth helped in successfully achieving this task.

Given the degree of sophistication and reliability that the numerical models of the Martian atmosphere have achieved in studying the present Martian climate and simulating its remote past, what should prevent their use to investigate the future of the climate of the Red Planet? This investigation then can be aimed either toward the natural evolution of the Martian climate or the artificially induced evolution suggested by the planetary engineering. Conversely, it might also stimulate the planetary engineering itself.

Using these numerical models to simulate the future will be an absolutely non-trivial task: many physical processes have to be taken into account, parameterized and analyzed. Some of these processes are obviously neglected for present climate studies, and only partially resolved for the past climate simulations performed to date. Examples of new processes that will have to be introduced in the models are the activation of the complete water cycle in all its complexity (hydrology) and the increased interaction between water vapour and dust (cloud formation and scavenging). Examples of physical processes that will have to be analyzed in detail are the positive (or negative) feedbacks produced by an increased carbon dioxide greenhouse effect (the possible "runaway greenhouse effect"). The parameterization of all these processes in the models will probably have to be adapted step-by-step to the evolving future climate scenario.

Nevertheless, the experience gathered for the Earth will be invaluable to adapt the present-day Martian GCMs and mesoscale models to the requirements for simulating the future, and very valuable feedbacks to the scientific community of Earth's modelers can be foreseen.

It seems beyond doubt to me that, at the present time, all research into issues such as artificially induced climate changes, terraforming, improving habitability of an extraterrestrial planet on a short or long time scale, whether applied to Mars or anywhere else, has an intrinsic motivation in defining the boundaries of the possible. Numerical simulations will obviously not eliminate the need for further, detailed, step-by-step exploration of Mars, but at the advanced stage of the current models of the Martian atmosphere and climate, they can:

- scientifically establish the feasibility of the tasks of planetary engineering;
- define pragmatically the boundaries of the possible on a long time scale, in the same way as they are helping to define the boundaries of the global warming on the Earth;
- help to foresee valuable routes into the future.

Last but not least, we will learn an even greater amount of things about our own planet, its climate change and the way climate systems respond to external forcing.

Numerical simulations of future climate changes on Mars (both natural and artificially induced) could be an invaluable way to use Mars right now as a planetary laboratory for the sake of the Earth, the future of the human race and of life in general, without having an immediate need to deal with any ethical, political, economical or technological issues.

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