MARS CLIMATE AND OUTFLOW EVENTS.

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Abstract: Large flooding events, evidenced by outflow channels, hypothetically triggered a new robust water cycle on Mars. Here we use the Ames Mars General Circulation Model (MGCM) to examine what happens to the climate of Mars after outflow events, both in a present day spin/ orbital scenario and a Recent past spin/ orbital scenario. Preliminary results suggest:

- Atmospheric water abundance increases by an order of magnitude post-outflow, with even more in a Recent Mars scenario.
- A Recent Mars scenario has more surface ice distributed to lower latitudes than a Present Mars scenario.
- Outflow events lead to some cooling of the atmosphere, with less cooling in the Recent Mars scenario. The albedo feedbacks (resulting from changes in reflected visible light) exceed radiative warming from water vapor.
- In the long term, the atmospheric water cycle and temperatures seem to reach new equilibriums post-outflow, but the rate of water accumulation still varies a lot post-outflow.

Introduction: Long ago on Mars, sudden gigantic floods carved out large areas of the Martian surface, forming what today we call 'outflow channels'. Over three billion years ago, several outflow channels formed at Chryse Planitia, east of Tharsis. Ares Valles was formed by a particularly large flood with an upper estimate of 8×10^4 km^3 water carving out the channel [*1-3*]. Recently, newer outflow events have been discovered. Athabasca Valles is an outflow channel formed perhaps within the last tens to millions of years, with an estimated 3×10^2 km^3 of water released at the same [*3-5*]. See review in [*6*].

While the present Martian climate is characterized as cold and dry, the climate changes induced by an outflow event could have led to a different scenario in Mars' past, possibly explaining some younger water or ice-related features we see on Mars today.

Previous work by the authors suggested that albedo feedbacks alone result in a 4 K cooling post-outflow for the globally averaged ground temperature. The radiative effects of water vapor alone result in 1 K of warming, leading to a net cooling of 3 K post-outflow. These results are for a present-day spin/ orbital scenario.

With the possibility of outflows occurring in the more recent past, such as within the last few million years, we combine the examination of an outflow's effect on Mars climate with the question of what happened in the recent history of Mars. Questions examined in this work include:

- Where does the water go?
- How does temperature change?
- What are the impacts on the greenhouse effect?
- What are potential long-term changes?
- How do all of these variables differ with different spin/ orbital scenarios?

Methodology: We explore the climatic effects of an outflow event under both present-day spin/ orbital conditions and for the recent past of Mars. For the past orbital conditions, we use an eccentricity of 0.085 (versus 0.093 today) and an obliquity of 34.75° (versus 25.19° today). The present-day value of perihelion was used in both scenarios. The run with the current day orbital configuration is referred to as "Present", and the run with the past configuration is referred to as "Recent". The Present day configuration has been chosen as a baseline for these outflow climate studies in order to see how an outflow event would affect the best-known Martian climate system. The Recent configuration is for Mars ~630 Ka [*7*], which is when other Recent Mars studies are considering. This time is of interest due to possible increased in CO_2 to the atmosphere.

The outflow is added to the simulations after spinning up the model for five Martian years, during which the atmospheric water cycle approaches equilibrium. The outflow is over Ares Valles and covers 1% of the planet. It is represented as a single layer frozen lake and behaves as an infinite water vapor source. These conditions are an upper limit of the water that would have been available from an outflow event.

The MGCM includes the radiative effects of water vapor, latent heat effects of water sublimation and condensation in the atmosphere and at the surface boundary layer, and an advanced cloud microphysics scheme, described in [*8-9*]. The atmosphere is set to the current pressure of 6 mbar, and the resolution is 5° latitude x 6° longitude. Current solar luminosity is used. The radiative effects of water ice clouds are not included. Simulations with radiatively active clouds will be conducted for future studies. Simulations are allowed to run 10 years post-outflow.

Preliminary Results: The results presented here are preliminary and still under analysis.

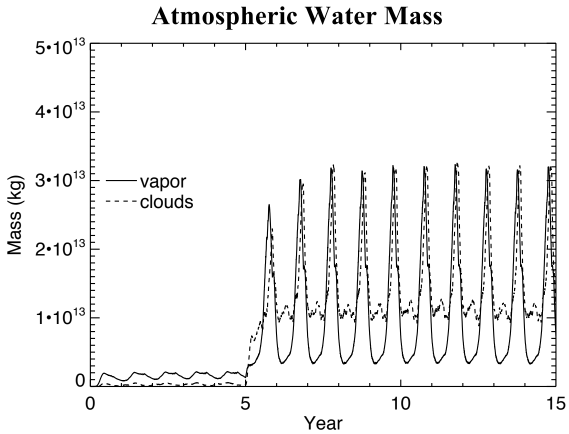

Figure 1: Annually, globally averaged atmosphere water vapor and water ice clouds for the Present Mars scenario, with the outflow at year 5.

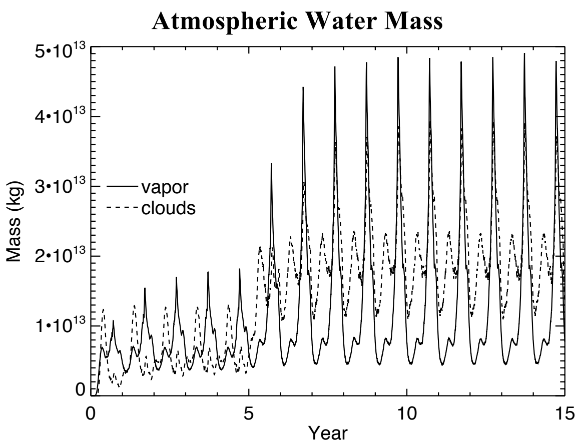

Figure 2: Annually, globally averaged atmosphere water vapor and water ice clouds for the Recent Mars scenario, with the outflow at year 5.

Water distribution: Prior to the outflow event, the Recent Mars scenario starts off with more water in the atmosphere compared to Present day Mars, because the North polar cap receives more insolation at ~35° obliquity than at ~25° obliquity. For a Present Mars (Figure 1), the global atmospheric water mass increases by over an order of magnitude post-outflow, and cloud water mass often exceeds the water vapor mass. For the Recent Mars case (Figure 2), global water mass increases over 50 times post-outflow, with the relative amount of water ice clouds increasing here, too. Ten years after the outflow occurs, these high amounts of global water mass are maintained, with the same seasonal pattern.

During the first year of the outflow, surface water clearly accumulates globally, over the course of the year, to varying degrees. A substantial amount of water goes to the poles, as well as the Arabia Terra region, south of the outflow, Hellas, and west of Hellas. Comparing the runs three years after the outflow vs. each run the year before the outflow, the difference in surface water distribution is similar for both runs, with some parts at the equator gaining centimeters more surface water. The Recent Mars scenario shows distinctly more water going to the North Pole than the South pole.

Temperatures and the energy budget: For the zonally, annually averaged temperature profiles, the Recent Mars simulation shows less temperature differences post-outflow, compared to before the outflow, than the Present case. This could be reflective of more radiative warming from water in the atmosphere, and could also lead to the atmosphere holding more water in the atmosphere and thus transporting water more globally.

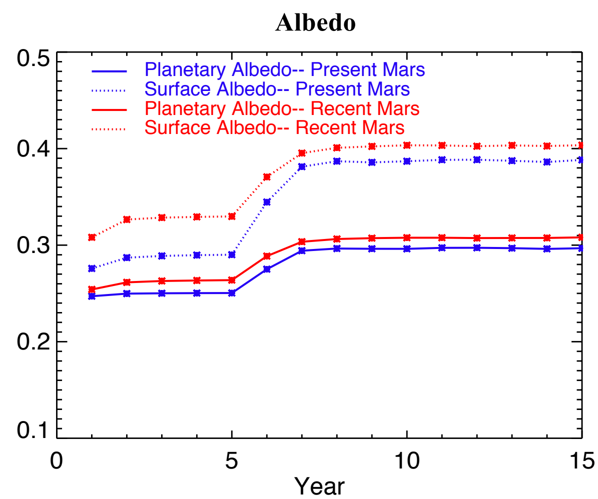

Figure 3: Annually, globally averaged planetary and surface albedos for Recent and Present scenarios, with the outflow at year 5.

Both runs have increased planetary and surface albedo after the outflow (Figure 3), likely due to the greater amount of water ice on the surface. Cloud albedo is not incorporated into these runs. The Recent Mars scenario has overall higher albedos than the Present Mars run, likely because of the more extended seasonal surface ice coverage due to the higher obliquity. The difference between surface albedo for a Recent and Present Mars is more pronounced than for the planetary albedo as a whole, probably because the radiative effects of water (which are incorporated into the planetary albedo calculations) seem to not have as strong a forcing as the albedo effects.

So overall, higher obliquity, smaller eccentricity results in more warming from the increased water vapor in the air (increased greenhouse effect), but also more cooling due to albedo feedbacks, with albedo feedbacks exceeding the effects of radiatively active water vapor.

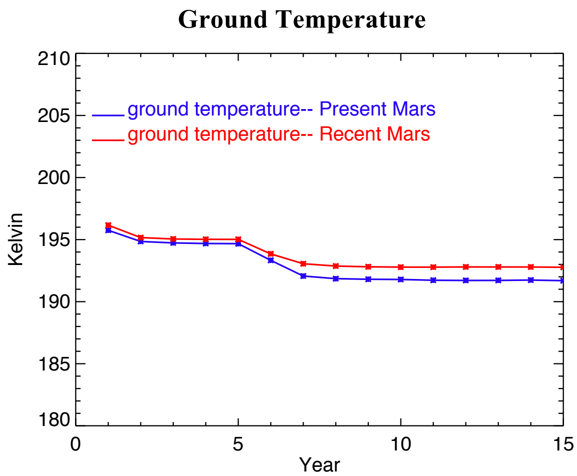

Figure 3: Annually, globally averaged ground temperatures for Recent and Present scenarios, with the outflow at year 5.

Ground temperature patterns are consistent with the zonal temperature and albedo patterns (Figure 3). Before the outflow, the globally, annually averaged ground temperature is less than a half-a-Kelvin different between the two simulations, with the Recent Mars run being a little warmer. Post-outflow, for the Present day scenario the ground temperature cools by ~3 K, while the Recent Mars scenario cools down by ~2 K. Both scenarios cool due to albedo feedback from the increased surface ice, with the Present scenario cooling more, possibly because it was already cooler than the Recent scenario due to albedo differences and it has less radiative warming from water vapor.

Long-term effects: For both Present and Recent Mars, the accumulation of water in the long-term is difficult to assess. In the next few years after the outflow, the geographic areas of accumulation and removal of surface ice move around a lot, so much that from year to year, most areas seem to switch between accumulation and removal of ice. This does not seem to equilibrate for the length of the simulation, so determining the long-term accumulation pattern of surface ice may prove difficult.. Considering the high-mass atmospheric water cycle, water could have been transported globally for years past the outflow.

The planetary albedo for the Recent Mars scenario appears to be leveling off to 0.4, which is how the model defines an ice surface. This would suggest that global surface ice could lead to a 'Snowball Mars' scenario. This would drastically change the climate of Mars in a significant, long-term way.

Summary: Addressing the questions laid out at the beginning of this abstract:

Where does the water go? Post-outflow, most of the water goes to the poles. The Recent Mars scenario has more surface ice distributed to lower latitudes than the Present Mars scenario. There are some areas where centimeters of ice accumulate, other than the poles themselves. These could be areas where, at longer timescales, glacial deposits could form, though more information on ice accumulation over time is needed.

There is also a lot more water in the atmosphere, so the radiative effects of water vapor and the effects of latent heat at the surface are important. The radiative effects of clouds will be very important to study in the future.

How does temperature change? What are the impacts on the greenhouse effect? Outflow events lead to some cooling of the atmosphere, with less cooling in the Recent Mars scenario. This pattern holds for the ground temperatures, as well.

The effects of albedo exceed the radiative effects of water vapor. This is due to the increase in surface albedo, for both scenarios, which cools the planet more than the increased atmosphere water vapor warms the planet. While the planetary albedo increases for both scenarios, indicating less energy is remaining in the planet's system, the Present day run shows more of a relative increase than the Recent Mars run. Present day Mars may be more sensitive to the outflow in terms of the global energy budget. Clouds will enhance this story, along with the incorporation of the albedo feedback of clouds.

What are potential long-term changes? For both Present and Recent scenarios, a new equilibrated water cycle seems to be reached within a few years after the outflow event. Long term surface ice accumulation patterns is not clear yet, aside from accumulation at the poles, for both scenarios. The planetary albedo remains high for both spin/ orbital scenarios post-outflow, possibly leading to a snowball Mars scenario for the Recent Mars past, post-outflow. Temperatures appear to stay cooler years past the outflow.

Future Work: The incorporation of radiative effects of water ice clouds may change the results of this work. The large mass of clouds visible in both Present and Recent scenarios emphasizes this. One prediction is that the clouds will warm the atmosphere, perhaps reducing the effect of albedo feedback. However, the cloud albedo, part of the cloud radiation scheme, could also have a cooling effect.

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