Report on the content of the dissertation

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Numerical Simulation of the Hydrological Cycle of Mars
(Title of the dissertation, degree, speciality)

candidate of physical and mathematical sciences

01.03.04 – Planetary Research

Date of the defense: 18.12.2019

The evaluation of the dissertation in accordance with the Regulations on the award of scientific degrees of candidates and doctors of sciences at MIPT (hereinafter – Regulations):

1. Relevance of the topic of the dissertation:
   The dissertation of Dmitry Shaposhnikov is devoted to numerical simulation of the atmospheric water cycle of Mars. Even though atmospheric water is but a negligible fraction of the tiny martian atmosphere, the water cycle is an essential climatic cycle. Firstly, the atmosphere fully controls the transport of water over the planet, including modern and past glaciations, which carved the geological features on the planet's surface. Secondly, the atmospheric water is a pathway through which Mars has supposedly lost its bulk of water, which was once abundant on its surface, following multiple lines of evidence. The topic of the dissertation, modelling of the hydrological cycle, is, therefore entirely relevant to the specialty 01.03.04 – Planetary Research. With new observational data arriving, the question of water escape to space is becoming particularly hot during recent years. Layman-alpha observations suggest that the hydrogen corona of Mars is highly variable with the season, in contradiction with the previously accepted explanation of the escape process. By analogy with the contemporary terrestrial atmosphere and seemingly confirmed by observations, atmospheric water on Mars was, for a long time, considered to be locked in the troposphere below a cold trap (hygropause). To be able to escape, hydrogen was supposed to follow a complicated and long pathway via H2 in order to overcome the cold trap, the pathway excluding any seasonal signal. Fast reaction of the hydrogen corona suggested, though, that water could directly reach higher altitudes, where it dissociates and escapes to space. Further observations of water vapor profiles confirmed that water vapour could indeed reach high altitudes under particular conditions of a dust storm. Modelling the process of water lifting is therefore a question of high scientific of high science importance and high current interest.

2. Scientific novelty of the results:
   The results of the dissertation are novel on multiple occurrences, not limited to some listed below:
   a. The modelling effort, simulating the high propagation of atmospheric water, is completed for the first time. The lifting of water vapor is explained by an intensification of the pole-to-pole meridional circulation cell, caused, in turn, by an intensification of dust activity;

b. The first attribution of the water lifting to the perihelion season and the southern hemisphere, not necessarily requiring a dust storm.
c. The first implementation of a new microphysical scheme in a 3-D circulation model of Mars's atmosphere;
d. The first implementation of a bimodal distribution of dust in a microphysical description.

3. Theoretical and practical importance of the dissertation:
The theoretical importance of the dissertation by D. Shaposhnikov is related to the advancement of 3-D modelling of the general circulation of Mars. German model MAOAM, which is known to provide a more accurate representation of the upper atmospheric levels with respect to other martian general circulation models (MGCMs) was updated regarding the water cycle, including both the vapour and ice cloud components. To accurately describe the processes of cloud formation and disappearance, he has implemented an original microphysical scheme. The model also achieves a reasonable representation of water at higher altitudes (above 100 km), where photodissociation of water vapor occurs. The new updated version of MAOAM model can be further used to study the hydrological cycle on Mars, in particular, addressing the discussed question of the cold trap, where water is captured to form ice-crystal clouds in interaction with dust. The reduced efficiency of the cold trap on Mars, compared to that on the Earth, might be a key to the understanding of how Mars has lost its previously abundant hydrosphere.
The practical importance of the Thesis is related to the interpretation and understanding of the results of multiple new space experiments, which are carried out now to detail the water cycle on Mars. In the Thesis, the modelling results were already compared to the previous (TES/Mars Global Surveyor) and ongoing (SPICAM/Mars Express) space experiment datasets. At this moment, more experiments, including ACS and NOMAD on the ExoMars Trace Gas Orbiter, and MAVEN spacecraft instrument are collecting the corpus of data of much increased accuracy and completeness, extending from the surface to the thermosphere. Modelling of these data with the new model would give a key to understanding the details of the atmospheric hydrological cycle.

4. Completeness of publication of the main results of the dissertation in peer-reviewed scientific journals in accordance with the requirements of the Regulations:
The results of the dissertation by D. Shaposhnikov are published in three peer-reviewed papers in journals, included in the approved list of the Supreme Attestation Committee, Scopus, and Web of Science databases. He is the first author in all of these papers. The concluding paper, describing the water lifting simulation, is published in the highly-ranked journal Geophysical Research Letters (impact factor 4.58). The publication record satisfies the requirements of the Regulations. Together with several conference proceedings, the publications amply describe the contents of the dissertation, and their number and quality are entirely sufficient for the Candidate of Science degree in the field of planetary research.

5. Questions and remarks (according to part 4.13 of the Regulations, the candidate addresses the questions and remarks formulated below during the defence):
a. The general circulation modelling of the martian atmosphere is a highly-competitive field. It would be therefore convincing to compare the results of water simulations of

the modified MAOAM with another widely-used model, the most evident being the Mars Climate Database (LMD MCD; Navarro et al., 2014).

b. The model fails to reproduce some quantitative features of the Mars atmospheric water cycle, in particular the summer water maximum in the southern hemisphere (Figs. 3.1, 3.3). Is there an explanation?
c. The Mars atmospheric state is mainly governed by dust loading and distribution in the atmosphere. The described simulations are based on two scenarios, "basic" and MY28. The dust distribution is not presented, but referenced for the basic scenario, as one from average PFS/Mars Express measurements with the dusty year MY28 removed [Medvedev et al., 2011]. This is very confusing, as the paper by Medvedev et al., 2011 does not mention PFS at all and assumes dust with optical depth of 0.2 everywhere. The reference to the dusty scenario is also not a direct one [Medvedev et al., 2013]. Given the importance of dust loading, it would be instructive to see the dust assumptions used.
d. Minor remark: The reference list, likely software-generated, is weird; the first author name often (but not always) goes after the title. This does not help to trace the references.

6. General evaluation of the dissertation (excluding the introductory part):

The Thesis is generally well-written, well organised, well referenced. It is clear and concise, the quality of the English language is very good. The formulation of statements is clear, and they are well substantiated in the Thesis. The topic of the dissertation corresponds to the specialization 01.03.04 - Planetary Research. The dissertation is in accordance with the Regulations on the award of scientific degrees of candidates and doctors of sciences at MIPT.

Date 25 November 2019

Signature _____ / __ Korablev Oleg Igorevich _____
full name

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