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 work is highly relevant as the Martian atmospheric circulation, hydrological cycle and climate in general are heavily understudied compared to the Earth's atmosphere. Under limited amount of measurement data, numerical modelling becomes a critical tool to get new knowledge on these topics.

2. Scientific novelty of the results:

   There is a number of new results achieved by a candidate, including disclosure of effects caused by bimodality of dust size distribution on a hydrological cycle of Mars, and a new pumping mechanism for vertical transport of water vapor and ice particles.

3. Theoretical and practical importance of the dissertation:

   The work brings attention to importance of accurately taking into account the dust size distribution effects on microphysical processes and hydrological cycle of Mars in general. The discussion of pumping mechanism rises a question of influence of tidal dynamics on mass transport in Martian atmosphere. An improved GCM of Mars would serve as a tool for better planning the future Mars survey missions.

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 main results of dissertation are published in leading peer-review journals including those from Q1 list.

5. Questions and remarks (according to part 4.13 of the Regulations, the candidate addresses the questions and remarks formulated below during the defense):

   I have no major concerns on the dissertation. There are some minor issues which could be elaborated in this work. They are as follows:

1) The numerical scheme for water vapor transport could be presented in more detail. I could not find which boundary conditions are used for poles. What is numerical scheme for temperature? Should the schemes for temperature and humidity be the same, at least in order to ensure the conservation of thermodynamic invariant $c_pT + Lq$ during phase transitions? The author states the tests of Largangian scheme for water vapor demonstrated good conservation properties; it would be better to show numbers.
2) The work is lacking details on vertical diffusion and subgrid convection parameterizations used in the GCM of Mars. What is their contribution for water vapor and ice vertical transport compared to advection?
3) In formulas 2.24-2.25 the subsidence speed of particles is given; subgrid-scale turbulence characteristics should be included in these formulations, as the traditional Stokes formula is valid for laminar flows only. For instance, under unstable stratification in the planetary boundary layer (BL) of summer hemisphere, the mean subsidence should be different from that in stable BL in the winter hemisphere.
4) In aerodynamic formula (2.46) for evaporation rate from the surface ice layer, it is surface temperature which should be used to define saturated water vapor pressure q_{va} at the surface, not atmospheric temperature.
5) On Figures 3.3 and 3.8, there are sharp maxima of water ice in the model at Northern and Southern edges of the domain, which are not seen in observations. I could not find comments on the reasons for emergence of those maxima. Could you speculate on that?
6) One of the main outcomes of the work is the conclusion that taking into account bimodality of dust size distribution allows to notably improve simulation of Martian hydrological cycle. The main physical mechanism responsible for this improvement assumes that bimodality leads to larger total number of particles acting as condensation nuclei at the same ice mass concentration. However, this increase may be achieved in the model not only by bimodal size distribution but by other distributions with increased contribution of small radii. So, there is no specific physical mechanism which improves hydrological cycle in the model *requiring* two maxima in particle size distribution. Is that right?
7) The "pumping mechanism" declared in the dissertation is an interesting finding, however, I could not see a succinct formulation of this mechanism. Tides lead to alternating upward and downward motions in the atmosphere, which move water vapor and ice up and down, but is there a net vertical flux, when this transport is averaged over a tidal cycle (or a number of cycles)?

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

This is a high-level dissertation which presents new scientific knowledge in the area of Martian climate formation mechanisms. 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 25.11.2019

Signature _____ / Victor Mikhailovich Stepanenko
full name

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