WEATHER FORECAST ON MARS: SIGNIFICANCES AND WHAT WE NEED

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Background: The developers of rockets and artificial satellites for the utilization of space contributing to the development of society and industry have been shifted from governments/public institutions such as NASA to private companies, and venture companies are also starting to enter the market. In this trend, the Ministry of Internal Affairs and Communications (MIC) of Japan has reported the discussions in an advisory board including the business use of Mars for the resource exploration, immigration and entertainment as an imaged attainment in 2030, and the Japanese government has announced to support the cultivation of ventures related to space technology. Moreover, NASA is planning the manned Mars missions in 2030s, and ensuring the safe activities on Mars is important. Therefore, the realization of weather forecast including temperature, wind, dust storm and snowfall, as well as the distributions of water and minor species as the hints of resource and life explorations, would be important in the next decade for the efficient manned explorations and business use of Mars.

About the CO_2 snowfall in winter polar regions, there is a study to indicate the possible forecasting much longer in advance than the terrestrial snowfalls, along with the regular and large-amplitude baroclinic waves (Figure 1) [1]. But there are still a lot of unknowns about the weather system on Mars. What are the necessary steps to realize the weather forecast there?

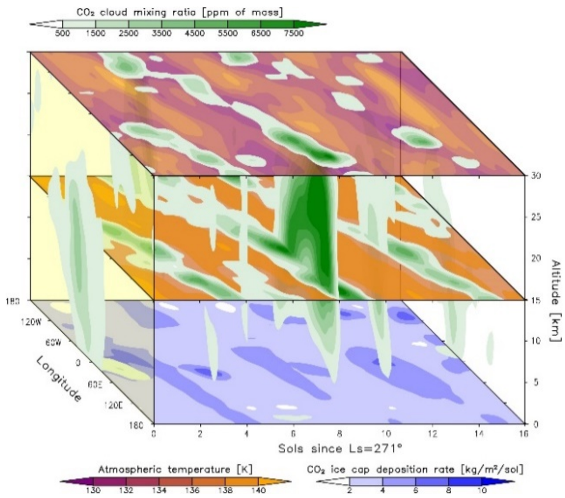

Figure 1: Composited features at 80° N simulated by a Mars Global Climate Model (GCM) [1]: Mass mixing ratio of CO_2 ice clouds (Hovmöller diagrams at 0, 15 and 30 km altitudes and longitude-altitude cross-sections for every 4 sols since $L_s = 271°$), atmospheric temperature at 15 and 30 km altitudes, and CO_2 ice cap deposition rate on the surface. All values represent as daily-averaged.

Towards the predictions of dust storms: The prediction of dust storms, which strongly affect the temperature fields with the radiative effects of dust, must be the key challenge for the weather forecast on Mars. At present it is very difficult as the dust lifting mechanisms have not been well studied. Theoretically the small-scale wind stress distributions and convective activities (dust devils) are thought to be key parameters to define the dust lifting, but numerous computational resources are needed for the numerical investigations of them [2]. Some Mars GCMs have implemented the parameterizations of those processes [3-6], but the realistic predictions of dust storms have never been achieved. Also, the observational system of Martian dust storms up to now is poor with only ground-based telescopes with limited horizontal resolutions, several polar-orbit satellites and 7 succeeded landers, which the small-scale and short-lived storms are almost impossible to be observed.

As for the Earth, geostationary satellites play important roles in the weather forecasts including the dust/aerosol distributions. For example, Himawari 8 observes the distributions of aerosol opacity and angstrom parameter covering the East Asia with high resolutions for both time (10 minutes) and space (~5 km), which are useful for the productions of reanalysis data and possible predictions with data assimilation [7,8] (Figure 2). We hope the similar observation and data assimilation systems will be established on Mars. Moreover, the wide-range and high-time-frequency observations of dust storms for a long period will accumulate the patterns/conditions of the occurrences of storms, and provide the basement of better predictions of dust storms with the machine learning technique.

Future observations with micro-satellites: For the weather forecast on Mars, the formation of observational network is also indispensable. Especially, on the background of that only 7 landers have succeeded to observe the weather of Martian surface up to now, sending more and more landers for atmospheric observations would be very important to sophisticate the reanalysis data and possible predictions. The developments of inexpensive micro-satellites to send Mars would strongly contribute that.

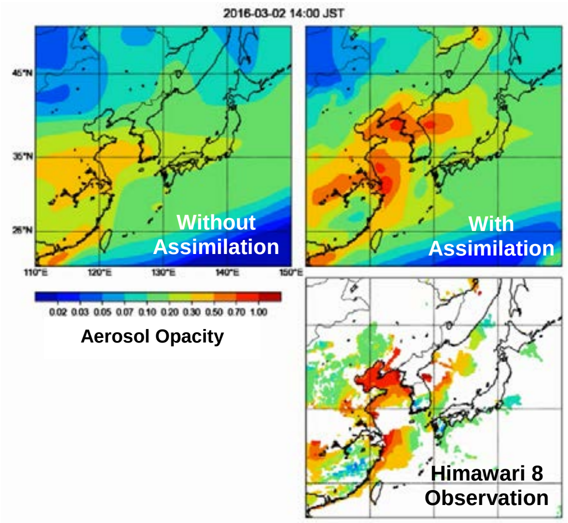

Figure 2: Comparison of the simulated distributions of aerosol opacity between without (left-top) and with (right-top) assimilation, as well as the assimilated Himawari 8 observation (right bottom) at the same time [8]. The model used is global NICAM-SPRINTARS [9] with horizontal resolution of ~56 km.

The National Institute of Information and Communication Technology (NICT), The University of Tokyo and Osaka Prefecture University are developing the TERahertz EXplorer (TEREX) mission series to Mars which can be launched as piggyback payloads with terahertz spectrometers (Figure 3). The first TEREX Mars lander (TEREX-1) is planned to be launched in early 2020s to observe the mixing ratios of O_2, H_2O, etc. for the search of surface water environment and hints of life on Mars. Also we are developing TEREX-2 as an Mars orbiter. One TEREX payload will cost 10-20M US$, less than 1/10 of previous Mars missions. Through TEREX we aim to realize frequent opportunities to send spacecrafts to Mars to get the information for future resource exploration and habitation.

Summary: In the next decade or two we expect to make Mars to be the place of human activity for business. Weather forecast on Mars is definitely needed to realize that, but there are still problems for the realization mainly due to the lack of 1) understanding and information of dust storms, and 2) opportunities to launch the spacecrafts to observe Martian weather.

About 1), the observational missions with brand-new concepts are welcomed. For example, the Emirates Mars Mission (EMM), which is launching in 2020 and arriving at Mars in 2021, will have the orbit with 20,000 km periapsis altitude to keep the global-scale-view observations with daily coverage of all longitudes and local times [10]. Also JAXA, which originally had the concept to observe Mars with nearly-geostationary attitude [11], intends to observe Martian atmosphere in their Martian Moons eXploration (MMX) mission, launching in 2024 and arriving at Mars in 2025, from the quasi-satellite orbit of Phobos [12]. These observations are expected to provide different views about Martian weather from the previous orbital observations, which may result in obtaining the brand-new information and better understanding.

About 2), the frequent use of micro-satellites to explore Mars would be expected. In addition to the pursuance of TEREX series, we hope the developments of small-size Mars explorers and establishment of inexpensive launch technology for them as the enterprise of private/venture companies.

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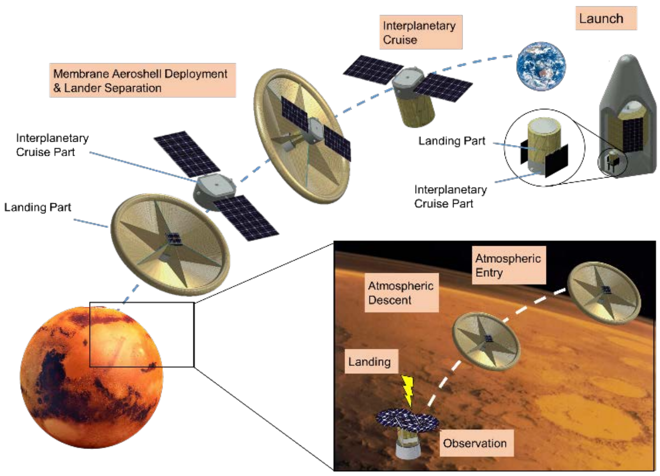

Figure 3: Overview of the TEREX-1 mission.