再解析データEMARSを用いた火星大気大循環力学の研究

A study of the dynamics of the Martian general circulation using the reanalysis data

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Lagrangian mean meridional circulation is an important factor in determining the distribution of mass and minor constituents, as well as the structure of temperature of the planetary atmospheres. The general circulation of Mars has been studied by using the Mars general circulation model or a variety of observational data. Besides, several Martian reanalysis datasets based on data assimilation techniques, which are commonly used in the terrestrial weather and climate study, are now available. However, studies using the Martian reanalysis datasets are still limited.
In our study, the Ensemble Mars Atmosphere Reanalysis System (EMARS; Greybush et al., 2019), is used to examine the climatology of the residual mean circulation, which is approximated to Lagrangian mean circulation. With over 10 Mars years of global data, EMARS allows us to understand the climatological features of the Martian atmosphere. The transformed Eulerian mean (TEM) equation is used for the present analysis of the Martian atmosphere. First, we verify that residual mean meridional velocity closely resembles zonal mean meridional velocity, suggesting that Stokes drift is small compared to Eulerian mean velocity. In the solstitial season, the residual mean meridional circulation is dominated by a single Hadley cell with a width of at least 90 degrees of latitude, consistent with previous studies (e.g., Haberle et al., 2017). In the boreal winter at 60-80 km altitudes and 50-80 degrees north, poleward fast residual mean meridional wind up to 28 m/s is observed. To investigate the mechanism of maintaining the strong residual mean meridional winds, we focus on the zonal mean absolute angular momentum distribution. At low latitudes, the latitudinal gradient of absolute angular momentum is small, in the altitude range where the strong southerly wind is observed. It is shown that, on both the northern and southern edges of the strong meridional wind, the residual mean flow crosses isopleths of angular momentum, indicating that wave forcing plays a significant role in driving the residual mean meridional circulation.
The distribution of EP flux divergence is roughly consistent with the residual mean meridional wind. However, for quantitative analysis, it is necessary to consider not only resolved waves in the reanalysis data but also the forcing associated with sub-grid scale waves. Using the method proposed by Sato and Hirano (2019) for the stratospheric circulation on Earth, we attempt to indirectly estimate the contribution of sub-grid scale waves. This method utilizes the fact that the residual mean stream function, calculated from the vertical integration of the residual mean meridional wind, is linearly decomposed into the contributions of resolved waves, zonal wind acceleration, and unresolved waves in reanalysis data. The contribution of unresolved waves can be indirectly estimated as the residual obtained by subtracting the contribution of resolved waves and the zonal wind acceleration from the residual mean stream function. The results show that the contribution of resolved waves is large below an altitude of about 70 km, and it is positive in NH and mainly negative in SH with a width of at least 50 degrees of latitude. The contribution of unresolved waves is large below 80 km and is positive over the entire latitude range. In the

winter hemisphere in the middle and high latitude, the contribution of unresolved waves is several times larger than that of resolved waves, and the structure of the circulation is largely determined by the forcing due to unresolved waves. Even in the summer hemisphere, the absolute values of the stream function associated with unresolved waves are large compared to resolved waves. We will discuss the different contributions between resolved and unresolved waves to the residual mean meridional circulation in the extratropics.

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