BAROCLINIC WAVES AND CO₂ SNOWFALLS IN MARTIAN WINTER POLAR ATMOSPHERE SIMULATED BY A GENERAL CIRCULATION MODEL. T. Kuroda¹,², A. S. Medvedev¹, Y. Kasaba¹ and P. Hartogh¹, ¹National Institute of Information and Communications Technology (4-2-1 Nukui-Kitamachi, Koganei, Tokyo 184-8795 Japan, tkuroda@nict.go.jp), ²Department of Geophysics, Tohoku University (6-3 Aramaki-aza-Aoba, Aoba, Sendai 980-8578 Japan), ³Max Planck Institute for Solar System Research (Justus-von-Liebig-Weg 3, 37077 Göttingen, Germany).

Introduction: The seasonal CO₂ polar cap is formed from ice particles that have fallen from the atmosphere as well as those condensed directly on the surface. The possible occurrence of CO₂ snowfall in the winter polar regions have been observed [1,2]. In addition, especially in the northern polar region, transient planetary waves are the prominent dynamical feature during winter, as have been detected from the data analyses [3] and general circulation modeling [4]. This study focuses on revealing the mechanism of how the dynamical influence, such as transient planetary waves and gravity waves, affects the occurrences of CO₂ ice clouds, snowfalls and formations of seasonal CO₂ polar cap in high latitudes during northern winters using a Martian general circulation model (MGCM).

Model description: The DRAMATIC (Dynamics, RAdition, MAterial Transport and their mutual Interaction) MGCM used in this study has been developed on the dynamical core of CCSR/NIES/ FRCGC MIROC with a spectral solver for the three-dimensional primitive equations [5]. For the application to Mars, radiative effects of gaseous CO₂ and airborne dust has been implemented as well as realistic surface parameters (topography, albedo, thermal inertia and roughness) [6]. A simple scheme representing the formation and sedimentation of CO₂ ice clouds has been implemented into the MGCM [7], in which we assume the particle size of CO₂ ice clouds to be ~50 μm near the surface. The formed clouds can be transported also by advection.

We set two kinds of horizontal resolutions for the simulation. One is the spectral resolution of T21 or 5.6° × 5.6° grid interval, and the other is T106 or 1.1° × 1.1° grid interval. The vertical grid consists of 49 or 69 σ-levels with the top of the model at 100-100 km. The non-LTE effect is not considered in the radiative effects of CO₂ molecules.

Results: In the T21 simulation, the CO₂ snowfalls are seen in the north of 70° N below ~40 km height around the northern winter solstice (Ls=270°), which is consistent with the observed signals by Mars Orbiter Laser Altimeter (MOLA) onboard Mars Global Surveyor [2] and Mars Climate Sounder (MCS) onboard Mars Reconnaissance Orbiter [8,9].

Figure 1 shows the composite features of the simulated mixing ratio of CO₂ ice clouds, atmospheric temperature at 15 and 30 km altitudes, and CO₂ ice deposition rate on the surface at 80° N. It is apparent that the occurrence of CO₂ ice clouds is very much aligned with cold phases of the baroclinic waves with zonal wavenumber of 1 and 5–6 sols period which have been indicated in past studies [3,4]. Although the amplitudes of wave-induced variations in temperature are of the order of a few degrees Kelvin, they are sufficient enough to modulate the CO₂ cloud formation by dropping the local air temperature below the condensation threshold.

It takes ~0.2 sols for particles to descend from 25 km to the surface, which is much shorter than the periods of the transient waves. Thus, the fate of ice particles during sedimentation depends on the thermal structure below. Regions where the warmer and colder anomalies alternate vertically, which results in the sublimations of CO₂ clouds formed in upper atmosphere, except in the longitude of 30° W–60° E where the deposition rate is at its largest. At 30° W–60° E, CO₂ ice particles formed below ~20 km can reach the surface. Calculations show that about 42% of the ice cap is created due to the snowfalls, while the rest is by direct condensation.

In the T106 simulation, the small-scale features of the snowfalls are also simulated, in addition to the synoptic features due to planetary waves which can be simulated with T21. Figure 2 shows a snapshot of the conditions of snowfall in the atmosphere and accumulation of the CO₂ ice cap on the surface. Small-scale dynamical disturbances such as gravity waves can be simulated with this resolution, and the winter polar jet seems to be an important source of gravity waves [10]. Thus, such waves generated in the winter polar region would affect to make small cold pockets which contribute to condense the CO₂ atmosphere.

Conclusions: Our simulations using a MGCM showed that the CO₂ ice clouds are formed at altitudes of up to ~40 km in the northern polar region during winter, and their occurrence correlates to the cold phases of transient planetary waves as well as the small-scale disturbances due to gravity waves. Ice particles formed up to ~20 km can reach the surface in the form of snowfall in certain longitude regions, while in others these particles likely sublime in the lower warmer atmospheric layers. In a synoptic view, given the regular nature of planetary waves, our results suggest that statistics of the occurrence of such snow
events in high latitudes may be reliably predicted.


Figure 1: Composited features at 80° N simulated by our MGCM with T21 resolution: Mass mixing ratio of CO₂ ice clouds (Hovmöller diagrams at 0, 15 and 30 km altitudes and longitude-altitude cross-sections for every 4 sols since $L_s = 271^\circ$), atmospheric temperature at 15 and 30 km altitudes, and CO₂ ice cap deposition rate on the surface. All values represent as daily-averaged.

Figure 2: Upper: A snapshot of CO₂ ice cloud mixing ratio (white contour, interval of 2000 ppm of mass) and temperature (K, shades) at 80° N around the northern winter solstice simulated by our MGCM with T106 resolution. Lower: The corresponding snapshot of the accumulation rate of CO₂ ice cap in which both the effects of snowfall and direct condensation on surface are reflected (cm sol⁻¹, green), and the total accumulation for 20 sols (cm, red).