Japan Geoscience Union Meeting 2015
(May 24th - 28th at Makuhari, Chiba, Japan)

PPS21-23 Room:A02 Time:May 24 16:45-17:00

Climate modeling of an exoplanet possibly holding life GJ667Cc

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In accord with the numerous discoveries of exoplanets in recent years, some studies on the habitability of exoplanets have been conducted by using global circulation models (GCMs) [e.g. Wordsworth et al., 2011; Leconte et al., 2013]. Among the exoplanets possibly holding liquid water on their surface like Earth, terrestrial planets that orbit around red dwarf stars are important as a target of such study because of their relatively high observational feasibility.

In consideration of these backgrounds, we carried out a climate simulation of the exoplanet GJ667Cc, whose ESI [earth similarity index] was the largest as of November 20, 2014, with dcpam5 [Takahashi et al., 2013], one of the GCMs. Considering its orbit and age, this planet orbiting a M-type star is likely to be under significant tidal locking action and accordingly rotates synchronously facing the same hemisphere to its central star. We also performed a simulation of Earth as a control experiment. Based on their results, we compare the simulated climate of GJ667Cc to that of Earth concerning the global average values of surface temperature and precipitation, their distribution related to the atmospheric circulation, and chemical weathering rate. We also estimate the timescale for H2O localization on the night side. Then, possible climate state of GJ667Cc is speculated by combining these analyses.

Incident stellar radiation on the orbit of GJ667Cc is about 90% of the solar radiation on the Earth's orbit. Therefore the equilibrium temperature of this planet is about 7 K lower than that of Earth, if they have the same albedo. GJ667Cc has a radius 1.54 times the Earth's radius and a mass 3.8 times the Earth's mass. We conducted simulations assuming the surface gravity and the mass of atmosphere scaled from those of Earth in proportion to planetary mass and the atmospheric composition identical with that of the present Earth.

The average surface temperature of GJ667Cc experiment is about 40 K lower than that of Earth one and the average annual precipitation of the former one is about 320 mm less than that of the latter one, respectively. Distribution of precipitation, wind speed, and temperature shows that the day side of GJ667Cc is characterized by high temperature and intense precipitation around the substellar point, whereas the night side has cold poles at high latitudes surrounded by subtle precipitation. The circulation pattern is dominated by Hadley circulation reaching high latitudes on the day side with convection over the terminator, weak super rotation, and vortices around the cold poles on the night side. These characteristic structure of GJ667Cc experiment well explains the distribution of surface temperature and precipitation.

Chemical weathering rate of GJ667Cc experiment is estimated at about 5.8 times larger than that of Earth experiment, despite its lower average temperature and less precipitation. This was due to notably high temperature and intense rainfall at the substellar point and its surroundings. Chemical weathering is a process which consumes atmospheric CO2. Given igneous CO2 supply rate on GJ667Cc 3.8 times larger than that on Earth by mass scaling, consumption would exceed supply and thus the average surface temperature is expected to become lower than calculated value according to Walker feedback [Walker et al., 1981]. From the terminator to the entire night side, the surface temperature of GJ667Cc is continuously below the freezing point of H2O. H2O transported there could be fixed as ice, and therefore H2O might be localized on the cold region. Given the total amount of H2O on the surface of GJ667Cc by mass scaling, the timescale of H2O localization is estimated to be about 18.7 million years based on the snowfall and frost flux in the cold region. Here we neglect the possible interaction between weathering and H2O localization, which would prolong the localization timescale.

Keywords: exoplanets possibly holding life, GJ667Cc