Three-dimensional simulations of methane-based hydrological cycles in north-pole regions of Titan

*Takufumi Chida[1,2], Yasuhito Sekine[1], Hidenori Genda[1]

1. Earth-Life Science Institute, Tokyo Institute of Technology, 2. Department of Earth and Planetary Science, University of Tokyo

Observations of lakes, surface modification by fluvial activities, and cloud formation all indicate that Saturn's moon Titan has the only active hydrological cycles known besides Earth [1]. Hydrocarbons such as methane and ethane condense out of a nitrogen-rich thick atmosphere, and precipitate onto the surface [1]. Methane observed in the atmosphere is continuously destroyed and lost by processes such as photolysis and direct escape [1]. Thereby, the persistence of the methane in the atmosphere is dependent on the availability of a hidden methane reservoir, resupplying the lost methane from the surface [1]. Quantifying the volume of the potential sources of methane resupply is one of the key questions of Titan's hydrological cycles [1].

Previous studies on remote-sensing observations of Titan's surface show that the elevations of some lakes and seas located near the north pole are constant from summer to early winter (corresponding to several Earth's years) within the observational errors, implying a connection with a mutual ground-methane table [2]. The preference of clouds at mid-latitudes over high-latitudes suggests that while surface methane is only observed at high latitudes, there may be a significant subsurface methane table at mid-latitudes that is available for exchange with the atmosphere [3]. The influence of subsurface flow on the hydrological cycle has been studied using a two-dimensional (2D) hydrological model, which treats the subsurface as one box at each location [4]. Thus, the 2D models cannot determine the subsurface hydraulic connection among lakes and oceans. They also cannot quantify the total volume of the subsurface methane reservoir, therefore being unable to estimate the extent of the methane-based hydrological cycles.

Here, we calculate the methane-based hydrological cycles using a surface-subsurface coupled three-dimensional hydrological simulator "GETFLOWS". GETFLOWS calculates surface and subsurface flows in a three-dimensional corner-grid blocks using Darcy's law, law of mass conservation, and Manning's equation. The main input parameters are (1) topography, (2) precipitation and evaporation rates, (3) permeability and porosity of the subsurface, and (4) levels of ground-methane table (i.e., the total methane volume in the subsurface). The topographic data was derived by interpolating the data obtained from the Cassini RADAR using the inverse distance weighting method [5]. The precipitation and evaporation data were applied from previous calculation results using general circulation model (GCM), which show good agreements of cloud formation and distribution with the observations [3,6]. The porosity and permeability values were estimated from the observations of the size of the icy grains on Titan's surface [7]. Using this model, we constrain the ground-methane table through reproducing the size and distribution of the lakes and oceans on Titan's surface as well as seasonal changes in their elevation. We discuss (1) whether the lakes and seas in the north-pole regions are hydraulically connected to the groundwater table, (2) what volume of subsurface liquid methane is active in the hydrological cycles, and (3) whether there is a subsurface transport of methane from the high to the low latitudes.

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