Icarus 317 (2019) 337–353

Contents lists available at ScienceDirect

Icarus

journal homepage: www.elsevier.com/locate/icarus

Orbitally and geographically caused seasonal asymmetry in Titan's tropospheric climate and its implication for the lake distribution

Tetsuya Tokano

Institut für Geophysik und Meteorologie, Universität zu Köln, Albertus-Magnus-Platz, 50923 Köln, Germany

A R T I C L E I N F O

Keywords:
Titan
Atmospheres
Surface
Meteorology

A B S T R A C T

Previously, seasonal asymmetry in Titan's climate caused by Saturn's orbital eccentricity was proposed as a possible external cause of the asymmetric polar lake distribution on Titan. However, climate studies of other planets indicate that seasonal asymmetry can also be caused by a hemispheric asymmetry in geography such as the ocean-continent distribution or topography. A global climate model is used to investigate whether orbital forcing or hemispheric asymmetry in geography is more important for the seasonal asymmetry in Titan's climate and the distribution of polar methane deposits. Titan's large-scale topography generally decreases from equator to pole and thereby induces meridional circulation with upwelling at low latitudes and downwelling at high latitudes due to near-surface horizontal temperature gradients. This circulation is stronger in the southern hemisphere, which contains steep slopes at mid latitudes, and acts to transport dry air downward near the south pole and to reduce the precipitation in southern summer. Consequently, the annual precipitation minus evaporation is substantially smaller in the south polar region than in the north polar region. Orbital parameter variations quantitatively affect the polar precipitation, yet are unable to reverse the vast hemispheric asymmetry in the polar precipitation. The accumulation of Titan's lakes near the north pole could therefore be a semi-permanent feature related to Titan's topography and may resist the Croll–Milankovitch cycle.

1. Introduction

Titan's lightcurves continuously observed at the Lowell Observatory since 1972 clearly exhibit a seasonal asymmetry (Lockwood and Thompson, 2009). Seasonal asymmetry on Titan recently attracted attention in the context of the observed strongly asymmetric global distribution, i.e. concentration near the north pole, of hydrocarbon seas/lakes (Aharonson et al., 2009). Aharonson et al. (2009) suggested that a hemispheric asymmetry in insolation-driven evaporation, precipitation, or both, may explain the present lake distribution and that the lake distribution may reverse with period of ∼ 45 kyr as with the seasonal asymmetry in insolation due to Saturn's apsidal precession as part of the Croll-Milankovitch cycle.

Schneider et al. (2012) showed with their Titan general circulation models (GCMs) that the present orbital configuration with a perihelion passage in southern summer gives rise to a preferential accumulation of methane in the north polar region at the expense of the south polar region. Also the GCMs of Lora et al. (2014) and Newman et al. (2016) predicted similar methane accumulation at the north pole in the present epoch, whereas this trend reverses in epochs with a perihelion passage in the opposite season. These model predictions support the mechanism proposed by Aharonson et al. (2009). However, this mechanism is also a subject of controversial discussion among climate modelers and geologists: Schneider et al. (2012) argued that precession would cause a hemispheric asymmetry only in annual precipitation but not in annual evaporation. Moore et al. (2014) suggested that the observed lacustrine features should have evolved over timescales greater than a few hundred kyr and thus questioned the Croll–Milankovitch cycle as being the cause of the observed lake distribution. MacKenzie et al. (2014) pointed out that evaporites - mineral sediments that are found in areas where evaporation of standing bodies of liquids took place - are much scarcer near the south pole compared to the north pole. According to them this can be explained if there have always been few lakes in the south or last former lakes have since been covered by sediments, which could also have occurred within the last Croll–Milankovitch cycle.

Despite the widely recognized importance of orbitally forced climate variations on Earth (Berger, 1988) or Mars (Montmessin, 2006), it is also important to investigate whether orbital eccentricity is the sole possible cause of seasonal asymmetry in the climate. Seasonal asymmetry can also be caused by a hemispheric asymmetry in the geography patterns. For instance, Mars GCMs have shown that the hemispheric dichotomy of topography would cause a seasonal asymmetry in the meridional circulation even if Mars' orbit were circular and thus the insolation pattern were seasonally symmetric (Richardson and Wilson,

E-mail address: tokano@geo.uni-koeln.de.

https://doi.org/10.1016/j.icarus.2018.07.025
Received 27 September 2017; Received in revised form 4 June 2018; Accepted 31 July 2018
Available online 17 August 2018
0019-1035/

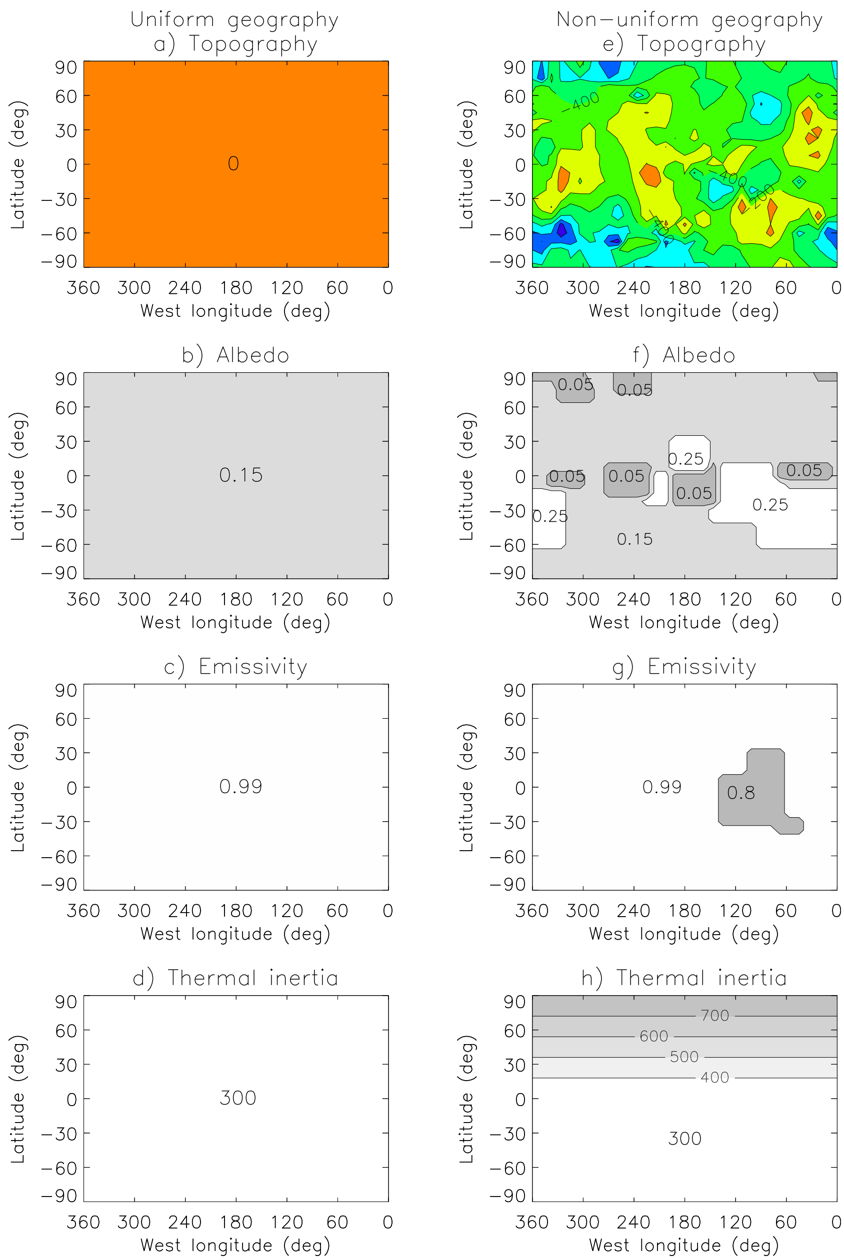

Fig. 1. Global map of topography (in meters), surface visible albedo (dimensionless), surface emissivity (dimensionless) and surface thermal inertia (in J m^{-2} $s^{-1/2}$ K^{-1}) implemented in simulations with uniform and non-uniform geography. Topography is the elevation relative to the geoid with a mean radius of 2575 km and increases from blue to red areas. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

2002; Takahashi et al., 2003).

Identifying the orbital or geographic cause of possible seasonal asymmetry in the climate is crucial in interpreting Titan's geomorphology that may contain climate records: If the seasonal asymmetry is predominantly caused by orbital parameter changes, it is natural to expect a periodical reversal of the asymmetry with the period of Saturn's precession cycle. If instead the seasonal asymmetry is predominantly a result of inhomogeneities (or hemispheric dichotomy) in geography, the asymmetry may be less sensitive to orbital parameter changes. In the case of Titan, the influence of geography on seasonal asymmetry has not been investigated so far.

The present study aims at filling this gap and investigates the following objectives:

1. How does seasonal asymmetry in Titan's climate in the present epoch manifest itself?
2. What is the relative importance of orbital parameters and geography for the seasonal asymmetry?
3. How does seasonal asymmetry in Titan's climate evolve due to orbital parameter variations?
4. Can Titan's geography cause a permanent hemispheric asymmetry in the climate and lake distribution regardless of apsidal precession?

These objectives are addressed by a couple of GCM simulations described in Section 2. Section 3 presents and discusses the results of the simulations and show the relative importance of orbital forcing and geography for the seasonal asymmetry in Titan's tropospheric climate. Section 4 discusses how the model results may alter previous interpretations of the observed lake distribution.