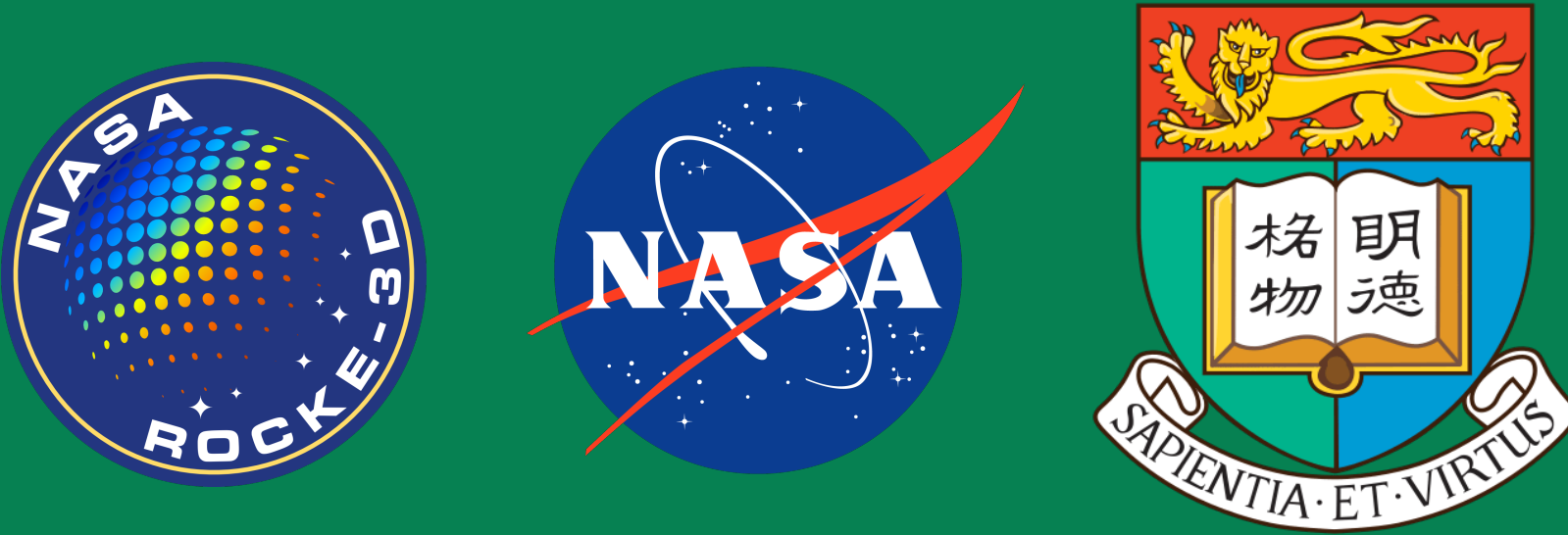


Modeling Titan’s Dune Formation with ROCKE-3D

How does dune-interdune composition in conjunction with topographic variability affect equatorial equinoctial prevailing winds?

Maxwell Collins



ABSTRACT

The Resolving Orbital and Climate Keys of Earth and Extraterrestrial Environments with Dynamics¹ (ROCKE-3D) is a General Circulation Model adapted from the Goddard Institute for Space Studies ModelE2, which expands upon the base model to include the possibility of modelling extraterrestrial bodies such as Saturn’s moon Titan. Previous models of Titan have focused on 1D or 2D radiative-convection models and have neglected large scale spatial distributions. Titan’s dunes contain many organic compounds conducive to early life and may be used to understand Titan’s complex methane-based hydrological system. Equatorial dune formation on Titan is currently poorly understood and few models have successfully explained the conditions required to match observations. The ROCKE-3D Titan GCM may be used to advise future missions in locations of interest and as an analogue to early Earth and origins of life studies.

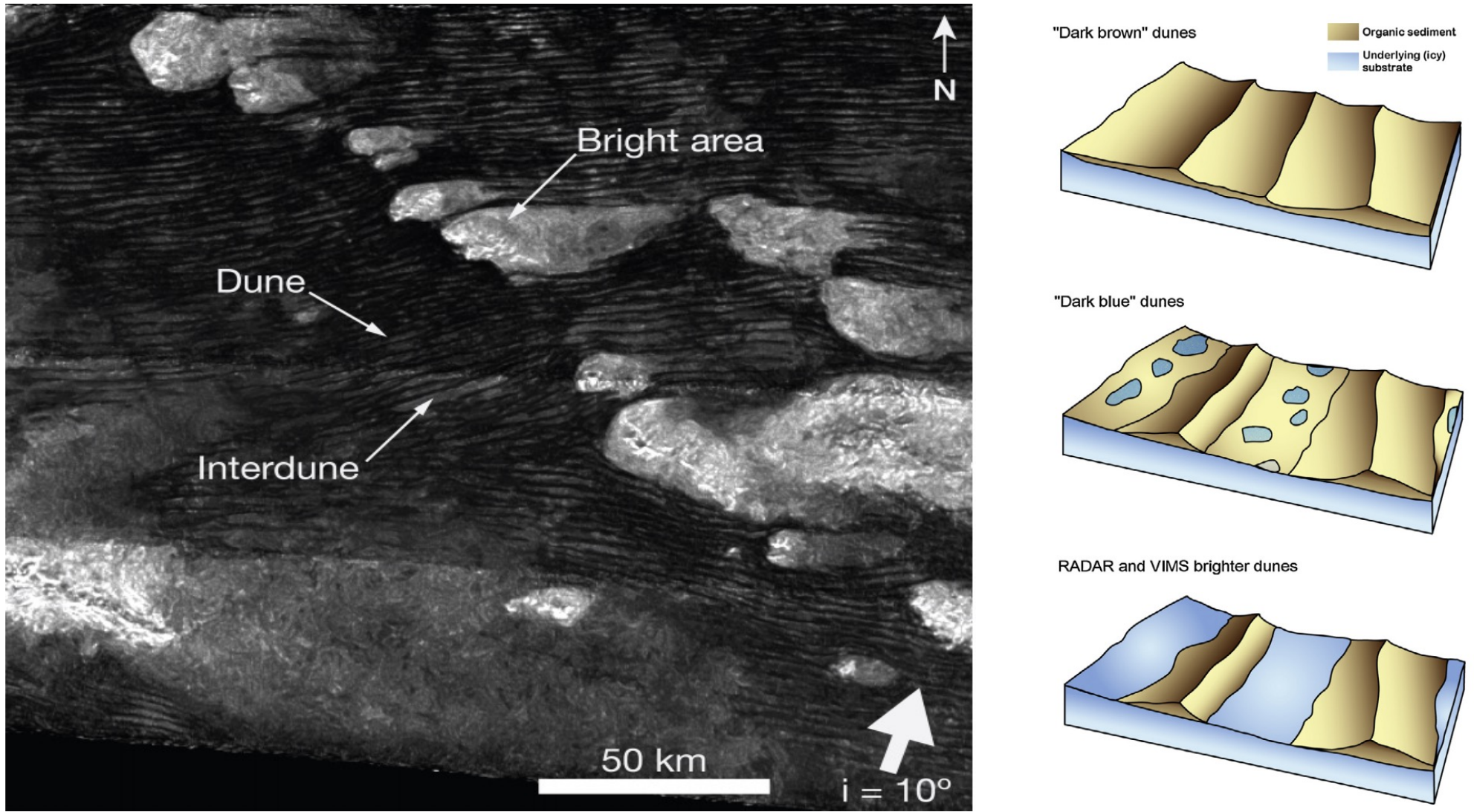


Fig 1. (left)² Titan’s Belet sand sea observed by SAR RADAR after denoising. Individual dunes are distinguishable from interdunes. The look direction is normal to dune crest orientation. Inselbergs are radar bright terrains found in Titan’s dune fields as obstacles. ; Fig 2. (right)³ Sketch of Titan’s dune sediment coverage related to infrared color.

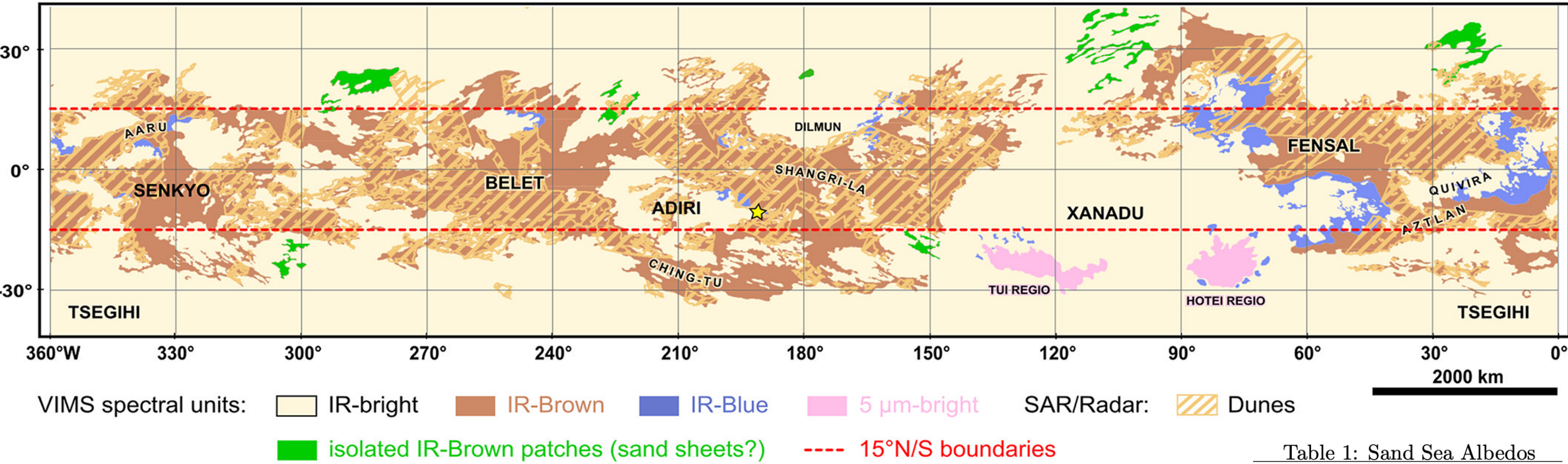


Fig. 3⁴ Map of Titan’s major equatorial sand seas in which terrain types are labelled using observational data from Synthetic Aperture Radar (SAR) and Visual-Infrared Mass Spectrometry (VIMS).

Table 1: Sand Sea Albedos		
Region	Interdune	Dune
Belet	0.8	0.28
Fensel	0.8	0.2
Shangri-La	0.65	0.16

CURRENT UNDERSTANDING

Observational data using infrared, visual and microwave wavelengths have allowed mapping and morphological cataloging of the dune types of Titan’s major sand sea regions (Fig 3.). Dune and interdune regions have vastly different properties, such as albedo and surface roughness, which can affect surface drag and low-level winds crucial to dune formation. However, models do not portray the westerly equatorial winds required to form these longitudinal dunes. As a result, three main hypothesis have developed in an effort to conserve fundamental laws of energetics while explaining model shortcomings.

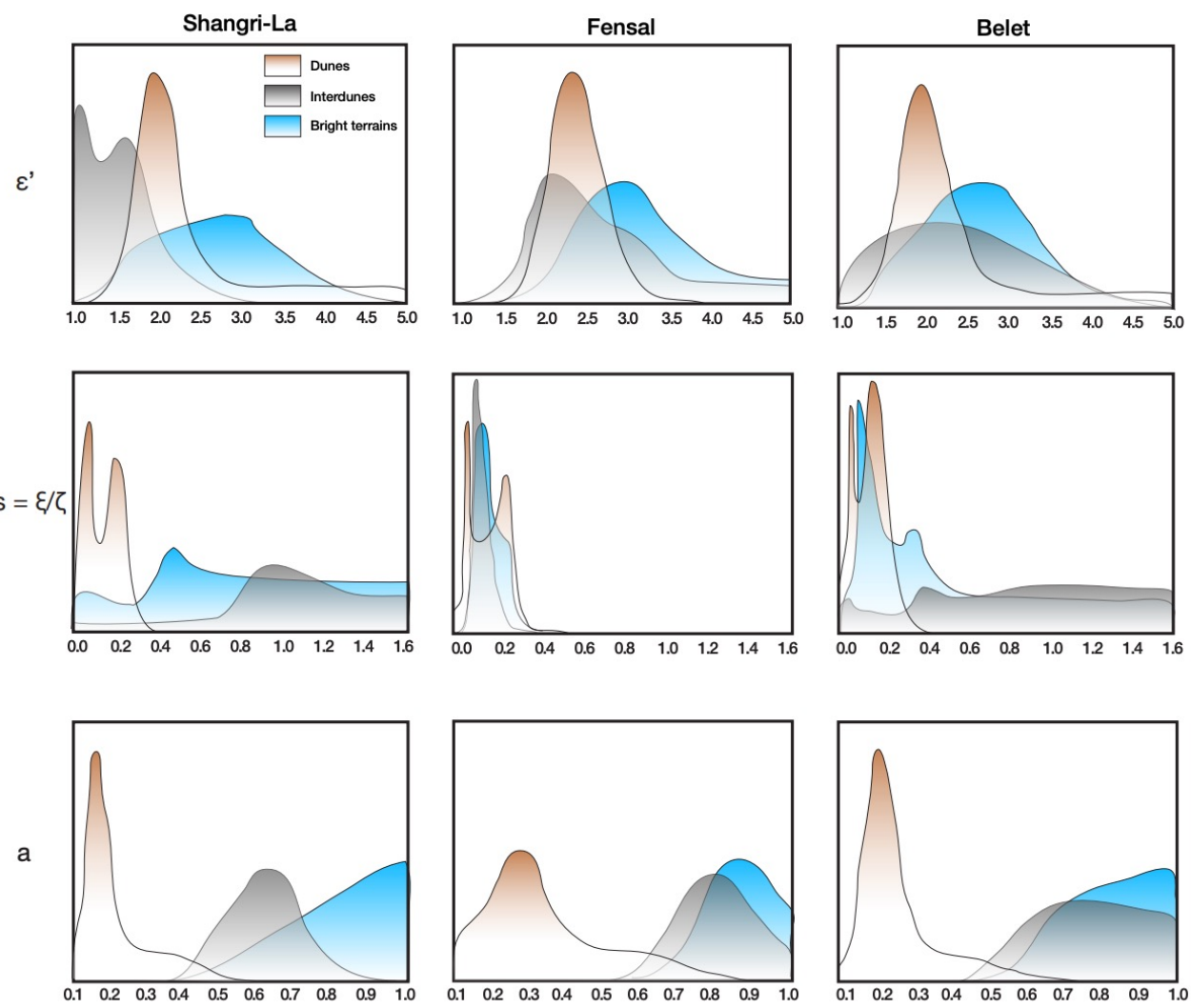


Fig. 4⁸ Marginal posterior probabilities of relative permittivity ϵ' , the surface roughness s , and the albedo α .

DUNE PROPERTIES

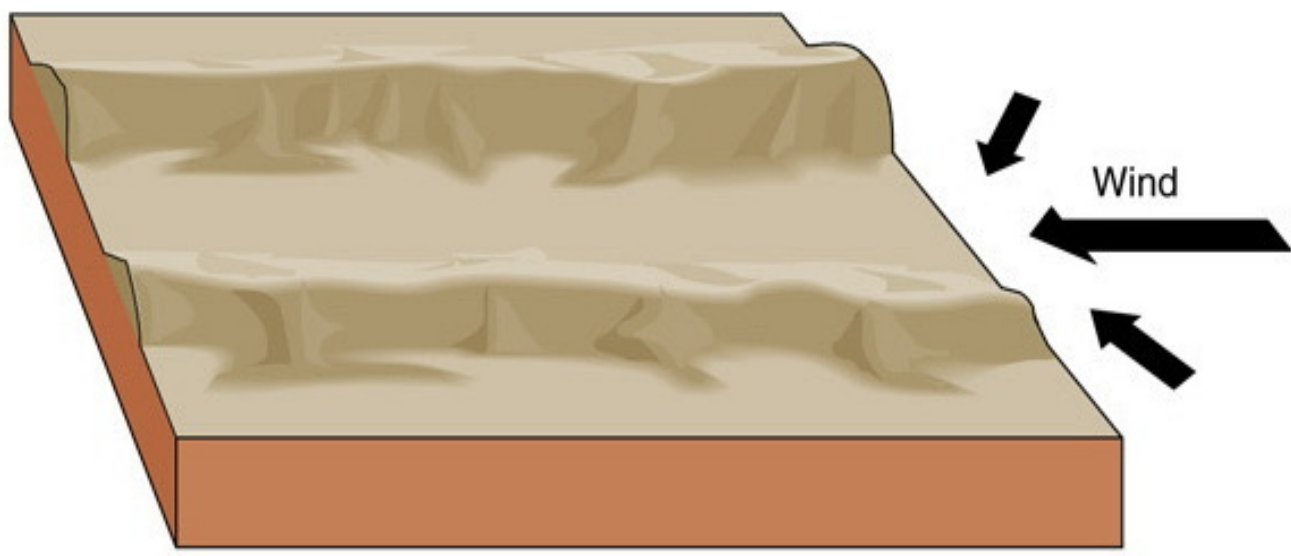
Models currently do not take into account the spatial variability of dune composition.

- > Sand sea regions consistent of multiple components, including dune and interdune features (Fig. 3, 4).
- > These features contain different physical properties, such as surface roughness and albedo as a function of sand availability and adjacent terrain⁵.

TITAN’S DUNE MORPHOLOGY

The dominant dune form in Titan’s equatorial sand seas are longitudinal or seif dunes.

- > Dune type and location depends primarily on sand availability, dune dynamics and wind direction
- > Longitudinal dunes (Fig. 5) are large, parallel features which are a result of high sand availability and a singular dominant wind direction which may be the result of a large angle (>90) between bimodal winds
- > The relation between dune height and spacing is a topic of debate which reflects availability of sand and wind regime which determine the ability to accrete vertically, migrate or extend



D Longitudinal dunes (seifs)
Fig. 5⁹ Schematic of longitudinal (seif) dune formation

HYPOTHESIS

- > During Titan’s equinox, the point at which both hemispheres receive the same amount of radiation, there is a shift in the intertropical convergence zone from pole to pole. During this shift, sufficiently strong westerly winds may occur at the equator to allow for dune formation. Though early, preliminary results using ROCKE-3D model show data consistent with Tokano 2008⁵.
- > Equinoctial methane storms driven by humidity may be generate episodic gusts which could dominate equatorial winds leading to the observed dune morphology⁶.
- > The equatorial dune morphology implies variability in wind direction and sand supply. At long timescales, 3,000 Saturn years or 88,200 Earth years, dune reorientation may be the dominant process controlling landscape evolution⁷.

Experiments	Topography	Albedo	Roughness
1 – Flat			
2 – Only Topography	X		
3 – Topography and Albedo	X	X	
4 – Topography and Roughness	X		X
5 – Topography, Roughness and Albedo	X	X	X

Fig. 6 Table of runs in process for ROCKE-3D in modelling equatorial dune formation through surface winds.

METHODOLOGY AND MODEL RUNS

- > Each run for 1 Saturn year (29.4 Earth years)
- > Interdune fraction computed as a function of latitude¹⁰
- > Albedo taken as weighted average from Fig. 4 as a function of latitude for each sand sea region
- > Interdune roughness derived from glacial roughness length measurements analogous to interdune surface type
- > If interdune roughness is assumed, dune roughness length can be calculated using a proportion of the ratio of dune and interdune root-mean-square slopes from the marginal posterior probabilities (Fig. 4) followed by the weighted average at each latitude

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