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Wind Shear May Produce Long-Lived Storms and Squall Lines on Titan

S. Rafkin and E. Barth
Department of Space Studies, Southwest Research Institute, Colorado, USA (rafkin.swri@gmail.com)

Abstract

The impact of CAPE and wind shear on storms in a Titan-like environment are explored through numerical simulation. Model results indicate that Titan storms should respond to changes in the Richardson Number. Very long-lived storms (>24 hours) propagating for 1000 km or more might be possible. Varying amounts of shear in the Titan environment might explain the variety of convective cloud expressions identified in Cassini orbiter and ground-based observations. The resulting distribution and magnitude of precipitation as well as surface winds associated with storms have implications on the formation of fluvial and aeolian features and on the exchange of methane with the surface and lakes.

1. Introduction

The presence of convective clouds on Titan is now well established, e.g. [1][2][3][4]. Cloud resolving simulations are able to reproduce the observed cloud top heights, the rate of cloud top rise, and the overall timescale of typical convective cells [5]. An increasing number of observations of Titan's convective clouds suggest, however, that not all the deep convective clouds behave the same. There are indications that convective clouds may be able to organize into mesoscale systems [6] or long-lived linear systems [7][8].

Besides convective available potential energy (CAPE), which is a measure of the total energy available to convection, vertical shear of the horizontal wind is known to strongly control the morphology and dynamics of convection on Earth. Given a fixed amount of CAPE, terrestrial storms transition from short-lived single cellular convection to long-lived multi-cellular convection as shear increases. Under some conditions, individual convective cells can organize into long-lived squall lines. This study focuses on the combined impact of CAPE and shear on Titan's storms, as determined from numerical modeling.

2. Numerical Experiment Design

A series of idealized two-dimensional numerical simulations were conducted that closely mirror the experiments done by [9] for terrestrial convection. The numerical model is the Titan Regional Atmospheric Modeling System (TRAMS), as described in [10]. The thermal environment for all simulations is identical and is taken from the retrieved Huygens HASI temperature profile [11]. Nonzero CAPE scenarios were generated by increasing the methane mixing ratio in the lowest 4 km of atmosphere of the profile from [12]. When these CAPE scenarios are combined with four different low level shear profiles a total of eight storm scenarios are generated (Table 1).

3. Results

Numerical modeling indicates that both large-scale shear and CAPE environment control the dynamics of the clouds. This response to the large-scale environment is analogous to the behavior of deep convective clouds on Earth. The balance between shear and CAPE, as expressed through the bulk Richardson Number (N_R) is a good indicator of the response of a storm to its environment. Large N_R results in short-lived single cell storms (Figure 1). As shear increases for a given CAPE, and N_R decreases, the storms transition to a multicellular regime (Figure 2). Multicellular storms are longer-lived and are characterized by a downdraft generated cold pool that interacts with the background shear vorticity to initiate cells along the leading edge of the storm gust front. The most intense multicellular systems simulated in this study behave similar to terrestrial squall lines. Cloud outbursts and linear cloud features observed from ground and Cassini may be the result of these organized storm systems.

Surface winds beneath storms can exceed 10 m/s and total precipitation may be measured in meters; the erosion potential by wind and precipitation is extremely large. Multicell storms can translate over 1000s of kilometers during their lifetime of 12 or more hours. Winds from storms should be more than sufficient to produce waves on any nearby lakes, and the wind stress should also be sufficient to initiate aeolian activity, including over the widespread sand and dune seas. Wind and precipitation from intense but episodic storms may be the primary mechanism shaping the surface of Titan.

3. Figures

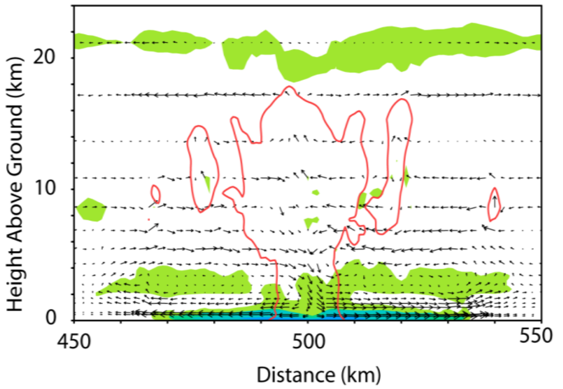

Figure 1: The mature phase of a single cell storm. Red lines indicate cloud boundaries. Vectors show storm-relative motion. Shading indicates sub-cloud cold air mass. The shallow cold air spreads away from the storm and cuts off the supply of convectively unstable air.

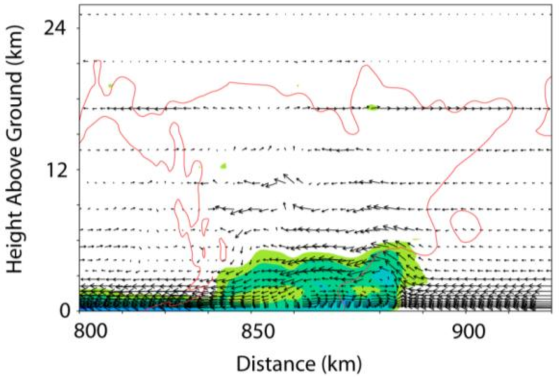

Figure 2: The mature phase of a multicell storm. The cold air lifts convectively unstable air into the storm and produces a continuous train of new cells that maintain the storm for hours.

4. Tables

Table 1: CAPE and SHEAR Scenarios

		CAPE (J/Kg), Mixing Ratio Perturbation (g/kg)	
		250, 5.0	500, 10.0
Shear m(s^{-1} per 5 km)	0	U0R5; Ri=∞	U0R10; Ri=∞
	1	U1R5; Ri=1250	U1R10; Ri=2500
	5	U5R5; Ri=250	U5R10; Ri=500
	10	U10R5; Ri=125	U10R10; Ri=250

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