MORPHOLOGIC AND COMPUTATIONAL FLUID DYNAMIC ANALYSIS OF SAND DUNE-TOPOGRAPHIC OBSTACLE INTERACTIONS ON EARTH AND TITAN.

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Introduction: Linear dunes are predominant along the equatorial region of Titan and their morphology and interaction with topographic obstacles are used as indicators of wind direction [1]. The morphology of this interaction implies a westerly wind flow on Titan because of the streamlined appearance of the dunes around the obstacles. Westerly flow at the equator is opposite the predicted easterly flow expected to balance the angular momentum of Titan's atmosphere and predicted from global climate models (GCMs) [2–4]. We analyze the topographic obstacles and surrounding dunes on Titan and Earth through morphometric characterization. Additionally, we model wind flow around obstacles through computational fluid dynamic analysis and use this data to predict dune orientations around obstacles.

Purpose: The purpose of this study is to understand how winds interact with topography within a dune field. With this information, we can determine what morphologic signatures exist from the sand dune-topographic obstacle interaction. We perform geomorphic mapping analysis of the study areas on Earth and Titan to understand the geomorphic environment that arises due to the obstacle interaction with wind. We then use a mass consistent computational fluid dynamic model, WindNinja, to predict dune orientations in the study area. With the predicted dune orientations, we can compare the predicted dune orientations with the mapped dunes. The overall objective is to determine if the morphologic signatures can help determine winds on Titan.

Study areas: Examples of sand dune-topographic obstacle interactions can be seen throughout the Sahara Desert and the Namib Desert. The study area for Earth is a topographic obstacle, about 500 m high, located in southern Mauritania. This obstacle is one of three obstacles in the area and is the most isolated obstacle; therefore, it is less affected by the surrounding geomorphology. The complex local geomorphic environment surrounding this obstacle includes superimposed linear dunes, complex crescent dunes, alluvial fans, drainage, a closed basin in the lee of the obstacle, and two types of nebkha dune fields differentiated by degree of vegetation (Fig. 1).

The study area on Titan is a topographic obstacle located in the Shangri-La Dune Field. This obstacle was chosen because it is also isolated and it is unique because topographic SAR data swaths cover the obstacle. The geomorphic environment surrounding this obstacle includes linear dunes, deflected dunes, a radar mottled dark and bright texture, and interdune areas (Fig. 2).

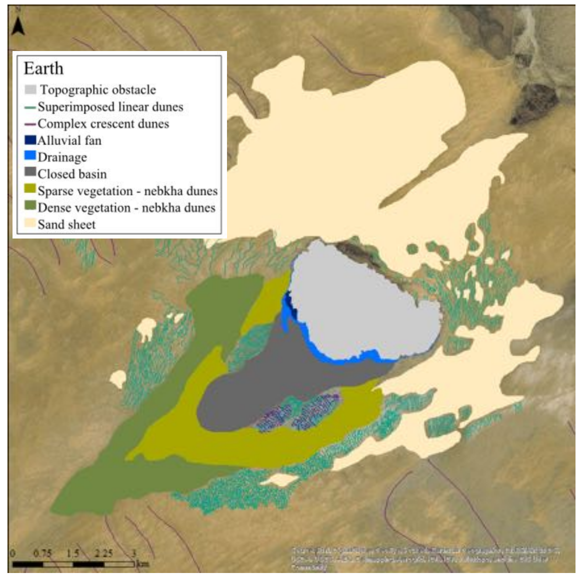

Figure 1: A geomorphic map of the study area on Earth located in Mauritania (17.398764°, -11.380843°).

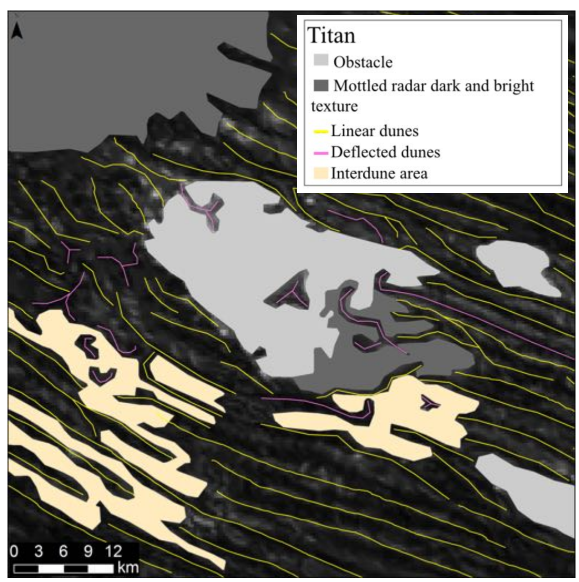

Figure 2: A geomorphic map of the study area on Titan located in the Shangri-La Dune Field (1.836048°, -150.816048°). Cassini SAR data processed by Antoine Lucas [5].

Methods: In order to perform the computational fluid dynamic analysis using WindNinja, we need two inputs: wind data and digital elevation data. We acquire wind data from Earth weather stations for Mauritania and the Titan Tokano 2010 GCM [2] for the Shangri-La Dune Field. We filter Earth's winds by inferred saltation threshold and chose one per day, and we similarly filter Titan's winds by threshold. The digital elevation data is acquired from ASTER data sets on Earth and interpolated topographic SAR data sets from Titan. With this data, we run WindNinja for each filtered wind on a loop. After getting the modified wind data for each wind, we use a gross bedform normal transport function to predict a dune orientation at each spatial point from the compiled modified winds [6]. The final output of this function is a spatial data matrix that can be overlain on the study area and visualized in ArcMap as a shape file.

Results: When comparing the predicted dunes and the modified dunes, differences occur between the upwind and downwind areas. On Earth, the predicted dunes do not match the mapped dunes in the downwind area. This likely arises because WindNinja does not capture the secondary flow (turbulence) that affects the dune orientation in the obstacle lee. We also think that the dune orientation here depends on sediment availability. Conversely, the mapped dunes diverge radially outward from the obstacle on the upwind side, but the dunes align with each other and the predicted dunes about 500 m away from the obstacle. We infer that the alignment of dunes on the upwind side of the obstacle reflects the regional winds and recent dune orientation. On Titan, the predicted dunes do not match the mapped dunes on either side of the obstacle. This likely occurs because WindNinja does not capture the secondary flow and the generalization of the Tokano 2010 GCM for our study area. Additionally, further processing on the SAR topo is needed to most effectively use these data in Wind Ninja.

Additional work: In order to analyze WindNinja's accuracy, we performed an additional computational fluid dynamic analysis with OpenFOAM, which is a mass and momentum consistent model. By comparing the wind interactions for the same wind, we see considerable differences between the models on the downwind side of the obstacle. We also see that the interaction on the upwind side of the obstacle is less pronounced with the addition of the conservation of momentum. OpenFOAM captured the secondary flow and the low velocity wake on the lee side of the obstacle. Interestingly, the low velocity wake of the obstacle is offset from the actual tail of the obstacle where the full wind distribution is considered (Fig. 3).

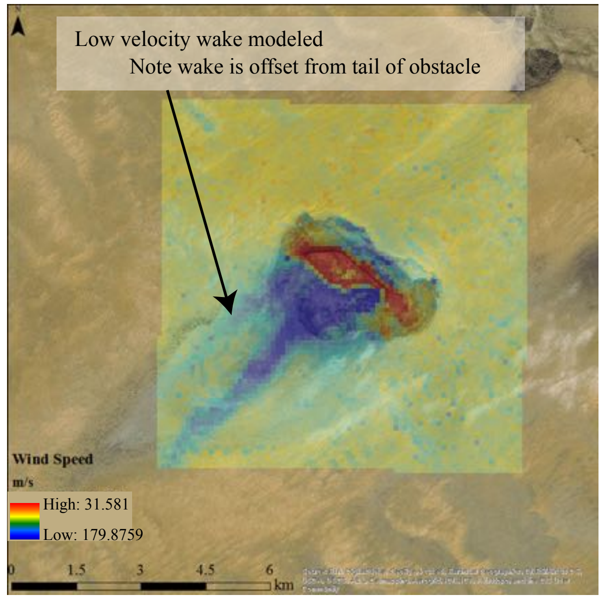

Figure 3: Modeled wind speed from the OpenFOAM analysis over Earth study area.

Final thoughts: The interaction between the obstacle and wind creates a complex geomorphic environment. This complexity includes dunes only being affected about 500 m out from the obstacle, smaller dune fields forming in the lee of the obstacle, and the lee acting as a closed basin which captures runoff from the obstacle. In response to these findings, we investigate what parameters of the obstacle, wind, and dunes influence the dune morphology around the obstacle. Additionally, it is apparent that the complex secondary flow around the obstacle affects the complex geomorphic environment. We also acknowledge that OpenFOAM captures the secondary flow that WindNinja does not and it better matches the structure of the dune-obstacle interaction.

References: [1] Lorenz, R.D. et al., 2006. The sand seas of Titan: Cassini RADAR observations of longitudinal dunes. *Science 312*, 724–7. [2] Tokano, T., 2010. Relevance of fast westerlies at equinox for the eastward elongation of Titan's dunes. *Aeolian Res. 2*, 113–127.. [3] Radebaugh, J. et al., 2008. Dunes on Titan observed by Cassini Radar. *Icarus 194*, 690–703. [4] Rubin, D.M., Hesp, P.A., 2009. Multiple origins of linear dunes on Earth and Titan. *Nat. Geosci. 2*, 653–658. [5] Lucas, A. et al., 2014. Insights into Titan ' s geology and hydrology based on enhanced image processing of Cassini RADAR data *2149–2166.* [6] Rubin D.M. and Hunter R.E., 1987. *Science 237*, 276-278.