DUNES AS STREAMLINES : MODELING TOPOGRAPHIC DIVERSION AND BLOCKING OF LINEAR DUNES WITH POTENTIAL FLOW THEORY R. Lorenz, JHU Applied Physics Laboratory, Laurel, MD 20723 (Ralph.lorenz@jhuapl.edu).

Abstract: Potential flow theory is used to generate 2-dimensional streamlines which compare favorably with the observed patterns of linear dunes on Earth and Titan. The blocking of dunes by topographic obstacles, and their diversion around topography, is modeled by the superposition of source (and possibly sink) terms onto a uniform flow. This formalism provides a means of quantifying the effect of obstacles on the dune field and opens the way to correlating this effect with the scale and height of the obstacles.

1. Introduction

One of the most striking aspects of the appearance of dunes on Titan[1,2,3] in Cassini Radar images was how they resembled streamlines, parting around bright topographic obstacles (e.g. figure 1). Such diversion of linear dunes around obstacles is also evident on Earth (e.g. figure 2). Yet how can we quantitatively describe this diversion? Topography on Titan is not well known, although an initial assessment with some of the sparse data available[3] suggests a steepness threshold of about 1/100 determines whether dunes are blocked or diverted. Perhaps dune arrangements can be used to estimate the topography.

Figure 1. Example of dark organic sand dunes on Titan parting around a bright, presumably elevated, obstacle.

2. Potential Flow Theory

The morphological resemblance of the dune arrangement with streamlines suggests that perhaps a fluid dynamical description may be effective. One of the simplest of these is the 2-dimensional description of an incompressible and inviscid flow by potential flow theory. Here one defines a velocity potential (whose derivative yields the velocity). A corresponding potential, termed the stream function, can also be defined, and streamlines are contours of constant stream function (the flow never crosses the streamlines). Analytic expressions exist for uniform flow, and for sources and sinks. An example is shown in figure 3, wherein a set of sources, arranged like the ridge in the Australian desert, diverts a uniform flow.

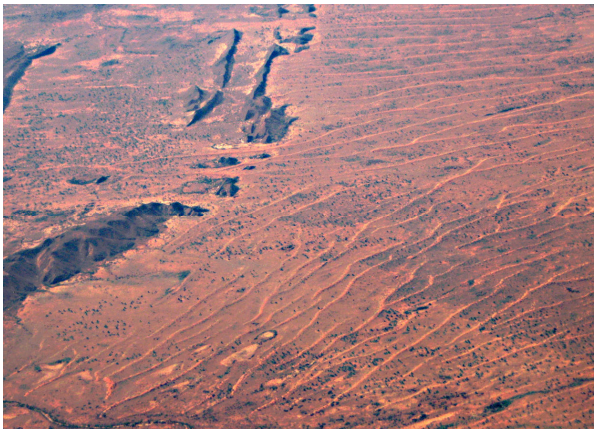

Figure 2. An photograph (from a commercial airliner Melbourne-Alice Springs) of linear dunes in the northwestern Simpson Desert in Australia. The dunes are diverted by a broken ridge of hills.

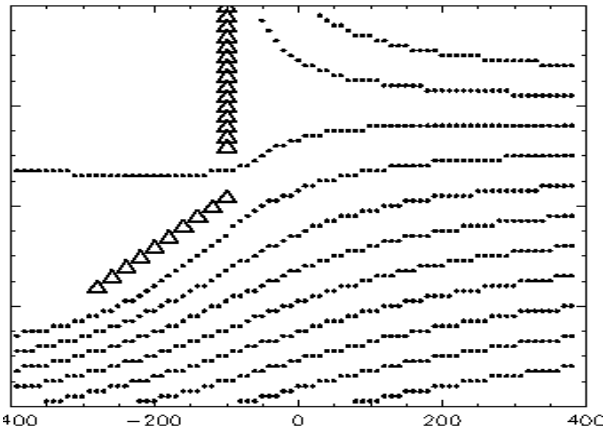

Figure 3. Dunes (dots) plotted to follow constant values of the streamfunction. Streamfunction is modeled for a uniform flow right to left, wth a set of sources indicated by triangles.The morphology compares favorably with figure 2.

3. Discussion

Figure 3 shows that at least part of a dunefield can be described to a degree by a uniform flow plus source terms. However, there are some deficiencies in the description. Around the edge of the obstacle, the streamlines are compressed, which does not happen for dunes (where the spacing[4] is likely controlled by the height of the atmospheric boundary layer).

Potential flow theory requires that the equation of continuity be satisfied, so streamlines cannot simply terminate, yet of course that is observed in dunefields. In future work we will examine whether sink terms may be used to force such effects.

The quantitative meaning of the size of the source terms defining the obstacle, as compared with the value of stream function defining the background flow (i.e. the assumed uniform velocity) remains to be determined. Presumably it can be related to the streamline curvature (i.e. degrees of deviation per kilometer, or a radius of curvature).

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4. Conclusions

Potential flow theory shows some promise as an analytic means of describing linear dune arrangements on Earth and Titan. The source terms used to cause the deviation of model dunes can be used as quantitative metrics of the effect of topographic obstacles, and can be correlated with the height of such obstacles.

References: [1] R. Lorenz et al., Science, 312, 724-727, 2006 [2] J. Radebaugh, et al., Geomorphology, 2010 [3] R. Lorenz and J. Radebaugh, Geophysical Research Letters, 36, L03202, 2009. [4] Lorenz et al., Icarus, in press, 2010.

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