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Air-Sea Interaction on Titan

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Abstract

In general, there will be a turbulent exchange of methane and sensible heat between the atmosphere and the surface of Titan's lakes. Previous studies have estimated the magnitude of the turbulent fluxes, but have also made sweeping simplifying but questionable assumptions. Here, we present results from numerical simulations that explicitly calculate the turbulent fluxes of methane and energy. Comparison of the results to previous estimates and models show that: dynamics must be considered, that changes in atmospheric stability over time are important, and that equilibrium conditions are not achieved in most cases. We further show that evaporative cooling of the lakes results in the production of a low level atmospheric inversion, which diminishes the magnitude of the fluxes by suppressing turbulent winds and lowering the bulk exchange coefficient. In general fluxes are far below previous estimates

1. Introduction

Titan has lakes and seas with volatiles that exchange energy and mass with the atmosphere. This exchange is an important component of the overall global energy and volatile cycle. Lakes are the only known source of methane that can replenish the permanent photochemical loss. The level of some lakes of Titan have been observed to change, both upward and downward, presumably in part to both evaporation and filling from storm runoff. Evaporation and moistening of the atmosphere in conjunction with atmospheric circulations have been invoked to explain the presence of clouds in and near lakes.

Earth's air-sea interaction involving water is a direct analog to Titan's methane and energy exchange. To the extent that the analog is a good one, the air-sea exchange on Titan is likely to be complex, sometimes counterintuitive, and not easily amenable to simple analytic representation. Numerical models that explicitly resolve atmospheric circulations and which use parameterize the turbulent eddy exchange with functionally realistic expressions are one way to explore the complexities of Titan's air-sea exchange.

We employ the Weather Research and Forecasting (WRF) model suitably modified for Titan to test the impact of various independent variables on the air-sea exchange process. Under most scenarios, the cooling and stabilizing effect of evaporatively cooled lake water on the atmosphere is shown to greatly limit the heat and mass exchange.

2. Turbulent Flux Parameterization

Turbulent eddies are responsible for the exchange between the liquid reservoir and the atmosphere. The flux of a quantity χ from the liquid reservoir to the atmosphere may be represented by Eq. (1), where C_D is a bulk aerodynamic exchange coefficient, U is the wind friction velocity, and subscripts l and a refer to the liquid and atmosphere, respectively.

$$Flux = C_D U(\chi_l - \chi_a) \quad (1)$$

The exchange coefficient is not constant, but depends on the Richardson number, which itself is the ratio of the square of the atmospheric wind shear to the Brünt-Väisälä frequency.

3. Model Design and Configuration

Three scenarios are explored, all alike except for the initial background wind speed. The 2-D model domain is 200 km with 1 km grid spacing in the horizontal and 20 km in the vertical with grid spacing starting at a few meters, gradually stretched with height. In the center of the domain is a lake 40 in width. The temperature profile is initialized following that observed by the Huygens probe [1]. The lake temperature is set to the lowest atmospheric temperature. The methane profile is generated by assuming a mixing ration of 25 g/kg, well mixed until saturation and then saturated above. There is no radiation. Any sensible heat exchanges with the lake that result in a temperature change are instantly mixed through and assumed thermocline depth of 10 m. The three initial wind conditions are 0.0 m/s, 0.1 m/s, and 1.0 m/s.

4. Results and Discussion

Figure 1 is representative of the circulation results for the 0.0 and 0.1 m/s cases. Early on, a land breeze is forced through mass continuity due to the rising, buoyant vapor over the lake. However, cooling of the lake through evaporation and of the atmosphere through sensible heat flux starts to drive a superimposed sea breeze. By 48 hours, the sea breeze dominates, with gravity waves above. Note that the magnitude of the circulation is on the order of a few 0.1 /s. Similar results are seen for the 0.1 mean wind case, but the circulation is slightly offset in the downstream direction (not shown). At 1.0 m/s the mean wind overwhelms the sea breeze and results in a completely different dynamical regime characterized by domain-wide alternating layers of east-west winds (not shown). In all cases, there is strong cooling and atmospheric stabilization over the lake.

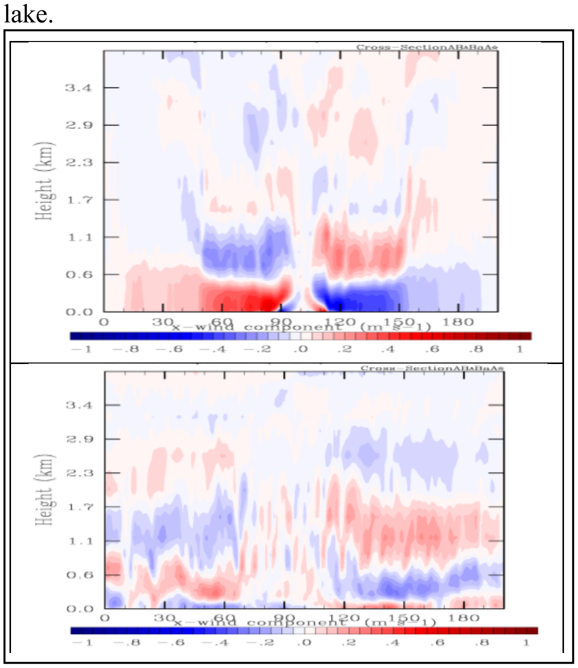

Figure 1: Wind field for the 0.0 m/s case at 3 hours (top) and 48 hours (bottom) after initialization.

Figure 2 shows the average sensible and latent heat fluxes and the average Bowen ratio over the lake. With the exception of the 1.0 m/s case, all fluxes decrease with time. The Bowen ratio asymptotes to a value between -0.8 and -0.9. The decrease in the flux magnitudes are due to the stabilization of the atmosphere, which reduces the exchange coefficient and also reduces the winds speed. Values of only a few hundredths of a W/m^2 are one to two orders of magnitude below those previously calculated by simply analytical models [2]. This suggests that methane is far more stable in the lakes than previously thought. Furthermore, because undiluted methane was assumed, the fluxes of an organic cocktail are likely to be even smaller.

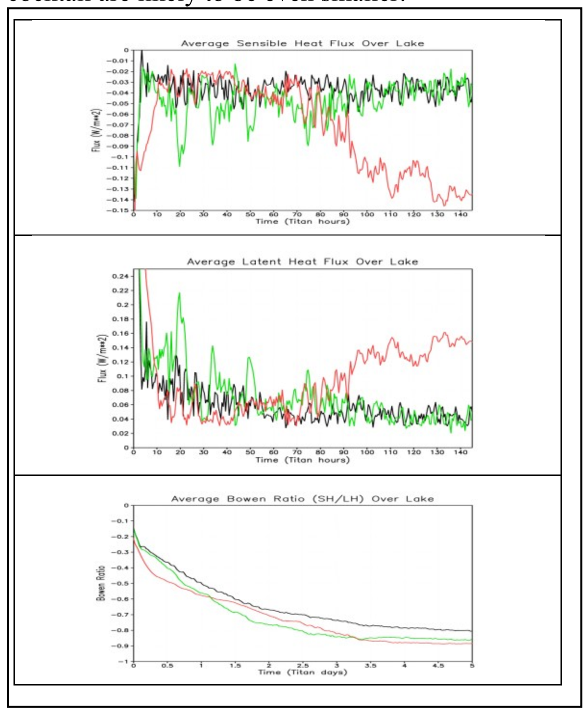

Figure 2: Average fluxes and Bowen ratio over the lake. Black=0.0 m/s; Green=0.1 m/s; Red=1.0 m/s.

Acknowledgements

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References

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[2] Mitri, D., et al: Hyrocarbon lakes on Titan, Icarus, 186, 385-394, 2007.