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Comparison of sedimentary processes in rivers of Titan and the Earth

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Abstract

Titan is a very special body in the Solar System. As the only one moon, it has a dense atmosphere and liquid on its surface. Through the work of the probe Cassini-Huygens, we know that there are similar geological structures and processes (e.g. meandering, sediment transport, bank erosion) on the Titan as well as on the Earth. In the present paper we compare these processes on the Earth and on Titan.

1. Introduction

Titan is the only celestial body, beside the Earth, where liquid is present on the surface. The liquid is composed of methane and ethane. It forms a number of lakes and rivers. However sedimentary processes depend on many parameter, e.g. gravity, fluid viscosity and density, density of solid material etc. Therefore processes on Titan could evolve in different way and rate than similar processes on the Earth. In our research we use numerical model to investigate effects of some chosen parameters on considered processes. We use data about terrestrial rives as well as about the rivers observed by Cassini in the vicinity of the Huygens landing site and some other regions of Titan.

2. Results

The results of our calculation of sediment transport are seen on Figure 1, 2 and 3. The first conclusion is that on Titan the transport of sediment is more efficient than on Earth (at least during the first hour of simulation). Another statements is that different combination of initial conditions of suspended and bedload for Earth and Titan is able to reconstruct sedimentation of meandering rivers. Also simulations of flow show many interesting conclusions as relationship between initial total discharge and gravity acceleration. This simulation was performed for water (for Earth) and for liquid corresponding to rain for Titan.

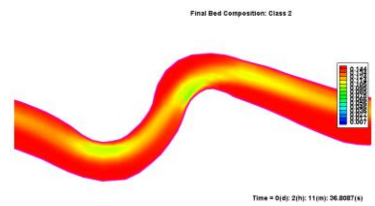

Figure 1: Results of sediment transport for terrestrial river for $\mathbf{3 \times 10^{-5}}$ m diameter.

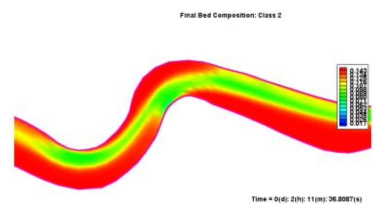

Figure 2: Results of sediment transport for Titan's river for $\mathbf{3 \times 10^{-5}}$ m diameter. Note that in Figure 1 there are only small regions where sediment was eroded (small green spots), when in Figure 2 sediment was eroded on larger region (it is well seen green line).

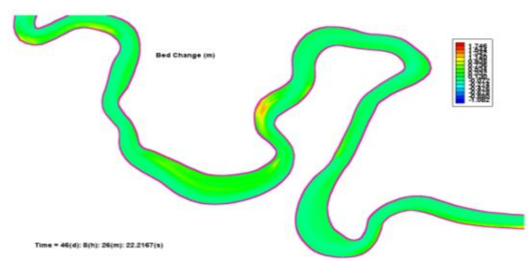

Figure 3: Results of final bed change for Titan's river after 46 days of simulations, with constant total discharge 20m³/s.

3. Parameters of the model

A few kinds of liquid are found on Titan. The liquid that fall as a rain has different properties than the fluid forming lakes. To our calculation we use only the liquids mentioned in Table 1 and 2 (e.g. [3]).

Table 1: Composition of two considered liquid existing on Titan's surface.

	Rain	Lake liquid
Methane	75%	10%
Ethane		74%
Propane		7%
Butane		8,5%
Nitrogen	25%	0,5%

Table 2: Material properties of liquids.

	Viscosity [Pa s]	Density [kg m^{-3}]	Heat capacity [J kg^{-1} K^{-1}]	Thermal expansivity [K^{-1}]
Water	$1,52\times10^{-3}$	999,8	4187	$2,07\times10^{-4}$
Rain	$1,51\times10^{-4}$	518	3250	$1,14\times10^{-3}$
Methane	$2,08\times10^{-4}$	454	3290	$3,54\times10^{-3}$
Lake liquid	$1,42\times10^{-3}$	658	2400	$1,61\times10^{-3}$

4. Basic equations of our model

The dynamical analysis of the considered rivers is performed using the package CCHE modified for the specific conditions on Titan. The package is based on the Navier-Stokes equations for depth-integrated two dimensional, turbulent flow (e.g. [1] , [2]).

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=-g\frac{\partial Z}{\partial x}+\frac{1}{h}\left(\frac{\partial(h\tau_{xx})}{\partial x}+\frac{\partial(h\tau_{xy})}{\partial y}\right)-\frac{\tau_{bx}}{h\rho} \quad (1)$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}=-g\frac{\partial Z}{\partial y}+\frac{1}{h}\left(\frac{\partial(h\tau_{yx})}{\partial x}+\frac{\partial(h\tau_{yy})}{\partial y}\right)-\frac{\tau_{by}}{h\rho} \quad (2)$$

where u and v are the depth-integrated velocity components in the x and y directions respectively; g is the gravitational acceleration; Z is the water surface elevation; ρ is water density; h is the local water depth; τ_{xx}, τ_{xy}, τ_{yx} and τ_{yy} are the depth integrated Reynolds stresses; and τ_{bx} and τ_{by} are shear stresses on the bed surface.

Essential equation for sediment transport is three-dimensional convection-diffusion equation for nonuniform sediment transport (sediment mixture is divided into several size classes):

$$\frac{\partial c_k}{\partial t}+\frac{\partial(uc_k)}{\partial x}+\frac{\partial(vc_k)}{\partial y}+\frac{\partial(wc_k)}{\partial z}-\frac{\partial(\omega_{sk}c_k)}{\partial z}=\frac{\partial}{\partial x}\left(\varepsilon_s\frac{\partial c_k}{\partial x}\right)+\frac{\partial}{\partial y}\left(\varepsilon_s\frac{\partial c_k}{\partial y}\right)+\frac{\partial}{\partial z}\left(\varepsilon_s\frac{\partial c_k}{\partial z}\right)$$

where c_k is concentration, ω_{sk} is terminal settling velocity of k-size sediment and ε_s is turbulent diffusivity.

5. Conclusions

The results of our simulation show the differences in behaviour of the flow and of sedimentation on Titan and on Earth. Our preliminary results indicate that transport of material by Titan's rivers is more efficient than by terrestrial rivers of the same geometry parameters.

Acknowledgements

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