Comparison of frontal and lateral erosion of periglacial fluvial islands

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Abstract

Frozen islands on the Lena floodplain present head retreats greater than on-side ones. The aim of this study is to quantify the difference of erosion between the island head and sides using the Erosion Ratio (ER). A GIS study of 19 islands of the Lena River from 1967 to 2010 provides an average Erosion Ratio (ER) equal to 4.7. We propose a model of thermal erosion for a frozen cylinder in a turbulent water flow. Thermal erosion of 19 frozen cylinders is measured for different water flows in a cold chamber. As in the field, the frontal erosion is always higher than the lateral one, with an averaged ER equal to 1.6, which decreases when temperature increases from 5 to 15°C. The higher value of ER in the field may be explained by the interaction with the neighboring islands and banks. We propose an empirical law including phase change and erosion.

Keywords: Thermal erosion ; island ; permafrost ; Lena ; physical modelling

Introduction

Periglacial rivers are affected by ice break-up, inducing a sudden rise of water level, discharge and temperature which induces thermal erosion and generates bank retreats up to 40 m. The aim of this study is to quantify the difference of erosion between the island head and sides, and to investigate the effects of the water temperature. Satellite images of fluvial islands in the Lena river have been analyzed in order to compare frontal and lateral erosion. A 2D cylindrical model of local thermal erosion of a frozen cylinder in a water flow has been developed. We have performed 6 series of repetitive measurements of local thermal erosion of a frozen cylinder in a hydraulic flume. Differences of local erosion of frozen islands were interpreted in the light of our model and experiments.

Analysis of satellite images of the Lena river

Aerial pictures (1967 (Corona): 20 m/px ; 1980 (Corona) : 15 m/px) and satellite images (1992 (Landsat 4) : 30 m/px ; 2002 (Landsat 7) : 30 m/px ; 2008 and 2010 (Spot5) : 2,5 m/px) were used to perform a follow-up of the temporal evolution of 33 islands of the Lena River (Costard & Gautier; 2007). We selected 19 islands upstream of the Yakutsk city, located in the middle of the channel in order to reduce boundary effects. We estimated the thermal erosion affecting the front and the lateral sides of these 19 islands during each period of time : The frontal erosion is always greater than lateral erosion (Fig. 1).

Figure 1. Estimation of the front, left and right erosion rate for the island 12 between 1967 and 1980. The Back point (B_{1967}) of the island is the point farthest from the center C_{1967} in the streamflow direction. The intersection of ($B_{1967}C_{1967}$) with the upstream outline of the island in 1967 (1980) defines the 1967 (1980) Front point F_{1967} (F_{1980}). The front erosion rate is calculated as (F_{1967}-F_{1980})/(1980-1967)=166/13=12.9 m/year. In the same way, the right (left) erosion rates is equal to -1.5 (5.7 m/year).

Thermal erosion of frozen cylinders
Problem statement and experiments

We have developed a model of local thermal erosion of a frozen cylinder crossing turbulent water flow. The melted sediments are instantaneously removed by the water flow and the ablation velocity is supposed to be constant (Dupeyrat *et al.*, 2011). The energy balance at the cylinder's surface between the heat brought by convection, the heat transferred by conduction in the solid and the latent heat of melting provides an estimation of the local ablation velocity $Va(\theta)$ and the Nusselt number $Nu(\theta)$ at every point a the surface of the cylinder defined by its θ angle.

We prepared 19 frozen cylinders (radius= 57 mm, height=70 mm, ice+sand, -15°C). Each cylinder was fixed in a water flow (temperature T_w=, 5 or 10 or 15°C ; velocity U_w=0.1 or 0.2 m/s). After 2 min of erosion, the cylinder was scanned with a 3D laser scanner. From the measurement of the local radius $r(\theta)$ of an horizontal section, we deduced the thermal erosion. The most eroded point (minimum $r(\theta)$) was at the front point F (θ=0°) of the cylinder. The erosion decreased from the front (θ=0°) to the separation point (θ around 90°) and then increased again (Fig. 2).

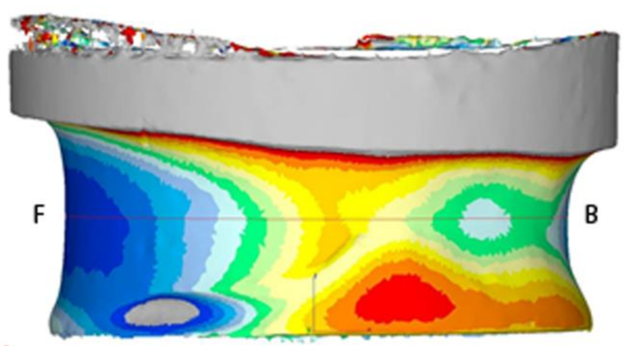

Figure 2. A frozen cylinder after erosion. During erosion, the water flow (T_w=5.6°C, U_w=0.2 m/s) came from the left. The eroded thickness is represented by colours from red (-2 mm) to dark blue (-10.5 mm) and grey (-12 mm). The upper part above water (>35 mm) is not eroded (grey). The studied horizontal section (line in red) is chosen at the location of the most eroded point (F (θ=0°)). The erosion decreases from F (-11 mm) to θ around 90° (-4 mm).

Comparison between experiments and field

The Erosion Ratio was estimated from a linear regression between the front and lateral erosion rates. Frontal erosion is always greater than lateral erosion (Fig. 3). Nevertheless, the ER gives a higher value in the field (=4.7) than in the laboratory (=1.6). In the field, the proximity of river banks or other islands prevents the lateral erosion and should increase the ER.

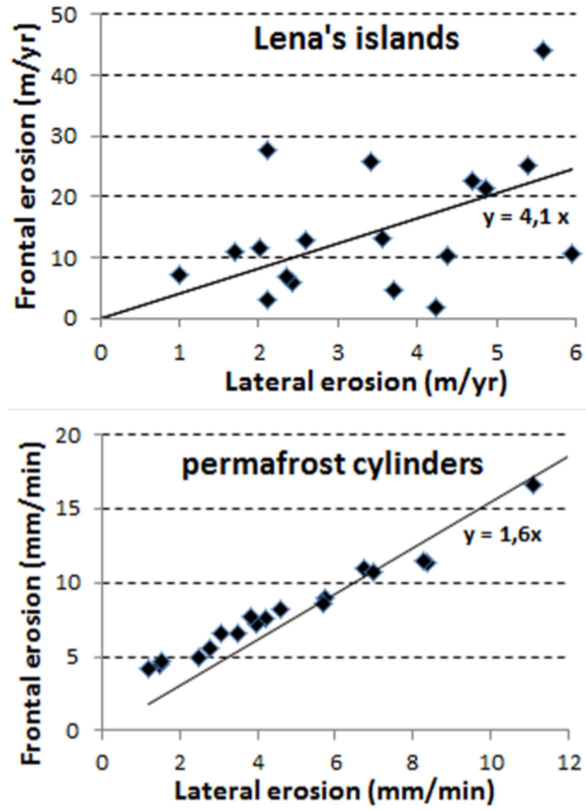

Figure 3. Comparison of the ER of the 19 Lena islands (1967 to 2010) (ER=4.7) and the 19 permafrost cylinders (ER=1.6).

Conclusions

We propose a quantification (Erosion Ratio) and a physical understanding of the greater thermal erosion at the front of islands compared to the sides in periglacial fluvial systems. The ER from the satellite image analysis of 19 islands on the Lena River from 1967 to 2010 (4.7) was higher than that derived in the laboratory experiments of 19 frozen cylinders in turbulent water flow (1.6). Boundary effects account for this discrepancy. Future work could extend this methodology to other periglacial islands.

References

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