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Sinuous rivers in peat

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ABSTRACT: Single-thread rivers flowing through peat are as sinuous as classical alluvial meandering rivers, but have notably different planforms. Rivers in peat have straight segments alternating with sharp bends, as opposed to their more gently curving counterparts. Building on work in Indonesia and the Kushiro Peatlands of Japan, we characterize the statistics of bend shape in 5 nearly pristine peatland rivers in Siberia, Brazil and Indonesia, in terms of the probability density function of dimensionless curvature. Results are compared with 5 nearly pristine alluvial meandering rivers. We show that peatland rivers have significantly larger lengths of reaches with very low curvature (nearly straight) than alluvial rivers. We hypothesize that the formation of local "hard points" in peat may be responsible for the angular shape of river bends.

1 INTRODUCTION

The most commonly known sinuous rivers are meandering rivers in alluvium (e.g. Guo et al., 2019). Meandering, however, can occur in a variety of fluvial settings, including bedrock rivers and channels in ice. Building on the work of Appels et al. (2007), Tanaka (2012) and Tanaka et al. (2012), we study meandering in peat, which is a relatively less investigated case of fluvial meandering.

Peatland has a worldwide distribution as indicated by Figure 1, which shows peatlands that already been discovered. It is readily seen that some river reaches in these peatland areas distinguish themselves with alluvial meandering reaches.

In this article, we introduce the concept of 'hard points', which allow the planform shape of peat meandering to be generated by a numerical model. Firstly, we qualitatively compare an alluvial meandering reach with a meandering reach in peat in section 2. And in section 3, we compare the dimensionless planform curvature probability density distribution of 5 reaches of alluvial meandering rivers with that of 5 reaches of meandering in peat. Then, the concept of 'hard points' is introduced in section 4, and analyzed with a numerical model. Samples of meandering evolution with and without hard points are compared, also in terms of the probability density distribution of planform dimensionless curvature. Section 5 shortly concludes this study and suggests future studies.

2 PLANFORM OF ALLUVIAL RIVERS VERSUS PEAT-CONTROLLED RIVERS

Figure 2a Shows the Tobol River, Russia. This is a typical alluvial meandering river with gently-curving bends, point bars, scroll bars, evidence of active migration, cutoffs, and

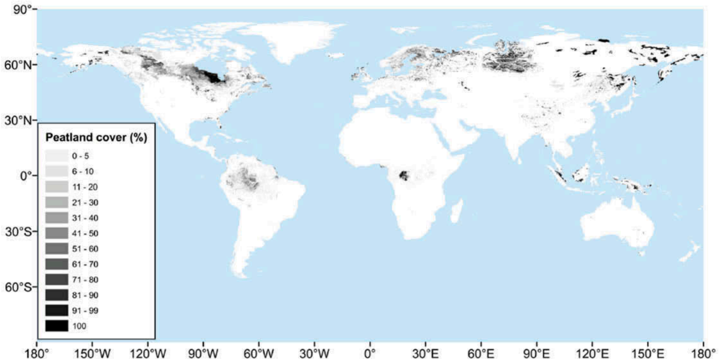


Figure 1. Worldwide map of peatland cover. From Xu et al. (2018).

relatively few nearly straight reaches. Figures 2b and 2c show Cedar Creek, USA. This is a typical peatland river showing many straight bends sandwiched between sharp curves, no clear point bars or scroll bars, no evidence of migration and no cutoffs. These indicators are enough for an informal discrimination between alluvial and peat meanders, but here we seek more quantitative discriminators.

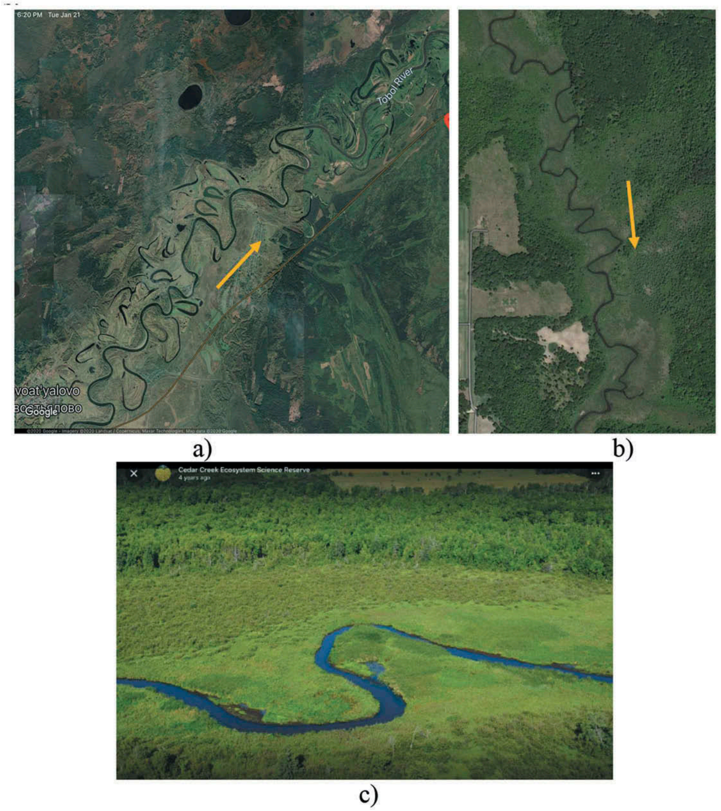


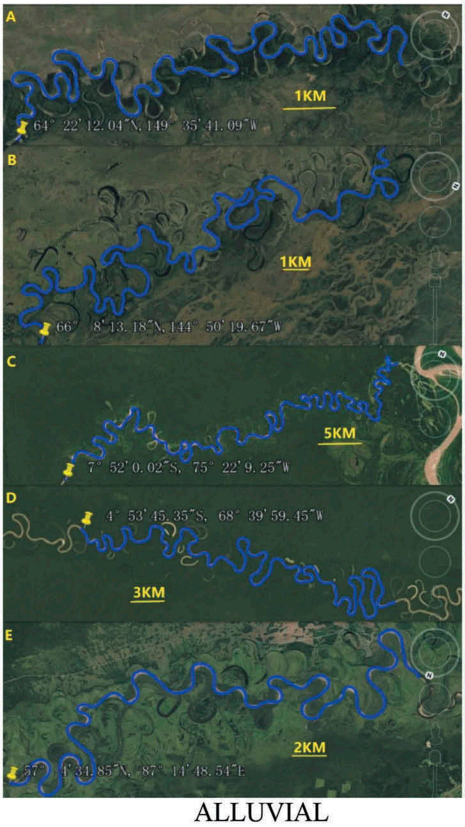
Figure 2. A) Planform of meandering alluvial Tobol River, Russia: width ~ 70 m, 57°5′37.55”N 66° 48′28.87”E. b) Planform of sinuous river in peat, Cedar Creek, USA: width ~ 5 m, 45°24′44.52″N 93° 12′37.58″W. c) Air photo of Cedar Creek, cour. Cedar Creek Ecosystem Science Reserve.

3 PLANFORM OF ALLUVIAL RIVERS VERSUS PEAT-CONTROLLED RIVERS: PROBABILITY DENSITY OF CURVATURE

In Figure 3a we show the planforms of five reaches of alluvial meandering rivers. Correspondingly, five reaches of rivers in peat-controlled settings are shown in Figure 3b. The pin on the left-hand side denotes the upstream end of the reach. GPS coordinates are also provided for each reach. Channel widths range from 50 to 300 m; as determined using the measuring tool of Google Earth.

The five meandering reaches of Figure 3a are characterized by the classical features quoted above; continuously varying curvature, point bars and scroll bars, cutoffs and evidence of migration. The five peat reaches, which were confirmed with the peat map of Figure 1, show a paucity of cutoffs and scroll bars, little evidence of migration, and angular bends.

We use a metric to discriminate between the two types of rivers that builds on the work of Appels (2007), Tanaka (2012), Tanaka et al. (2012) and Watanabe et al. (2015). In particular, we consider the probability density of dimensionless centerline curvature B/r_c, where B denotes channel width as read from Google Earth and r_c is centerline radius of curvature. The peat reaches of Figures 2b,c and Figure 3b are characterized by many very straight segments, ending in abrupt turns. Curvature smoothing techniques in data analysis tend to smear out the sharp curvature, but the straight reaches are resolved in terms of low dimensionless curvature.



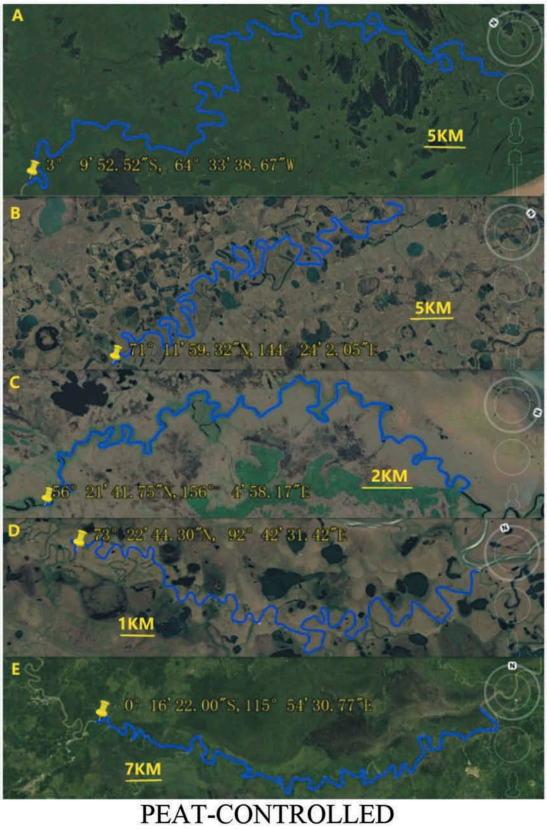


Figure 3a. (left). Alluvial meanders: (A) River Teklanika, USA; (B) Birch Creek; USA; (C) River Pisqui, Peru; (D) River Jutai, Brazil; (E) River Chulym, Russia. Figure 3b (right). Meanders in peat: (A) Parana Copea, Brazil; (B) A small river flowing near Ozero Yuryakh-Terde, Russia; (C) A small river in Taymyrky Dolgano-Nenetsky District; Russia (D) Tributary of Reka Moroshechnaya; Russia; (E) Mahakam River, Indonesia.

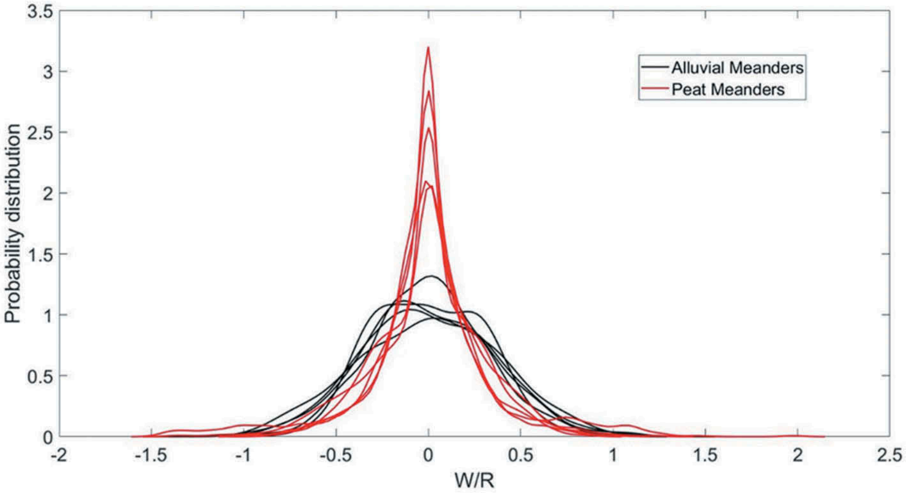


Figure 4. Probability density of dimensionless centerline curvature for the five alluvial reaches (black) and five peat reaches (red) of Figure 3.

Figure 4 shows the probability density distributions for the five alluvial and five peat reaches. The two groups discriminate very clearly. The peat reaches have a peak of zero curvature that is substantially higher than the alluvial reaches. In order to model these straight and angular planform shapes of meandering reaches in peat, we propose that peat can make "hard points" (including peat domes) that block channel migration and cause abrupt changes in channel direction.

4 MODELING OF RIVER MEANDER MIGRATION WITH AND WITHOUT "HARD POINTS" SIMULATING THE EFFECT OF PEAT

To simulate the effect of peat, numerical studies including "hard points" are presented here. Hard points are non-erodible zones added to a meander migration model to stop channel migration toward them. To prevent singularity problems along the discretized nodes of the river centerline, a hard point must have a radius of influence, which is subject to calibration by trial and error. When one or several discretized river centerline nodes of a migrating channel hit hard points, the erosion rates of these nodes drop to zero, while the erosion rates of other nodes remain at their calculated values due to their non-zero curvatures. See Figure 1 for a sample of meander evolution with and without a hard point.

In this section, we present the modeling results of the meander migration of the Trinity River, Texas with and without the effect of hard points. The meander migration model applied in this study is a Python-based tool, pyRiverBed (Li and Garcia, 2018, 2020). The model pyRiverBed provides an interface to perform the curvature-driven type of meander migration modeling, based on Ikeda et al. (1981), Johannesson and Parker (1985) and Garcia et al. (1994).

The river centerline of the Trinity River to initialize the meander evolution modeling is captured from Czapiga et al. (2015), in which the map location and surveying details can be found. The key modeling parameters are: constant width = 150m, constant depth = 6m, friction coefficient $C_f = 0.01$, Froude number = 0.1, bank erosion coefficient = 1e-8, upstream velocity perturbation = 0, upstream curvature perturbation = 0. Note that these parameters are not intended to capture the real-world migration rate of the Trinity River.

In Figure 6(a), the initial and final state of alluvial river migration without hard points are shown. The iconic bend expansion, translation and rotation of alluvial meandering rivers as characterized by earlier studies (e.g. Schwenk et al. 2015) can be easily identified. In Figure 6(b), 32

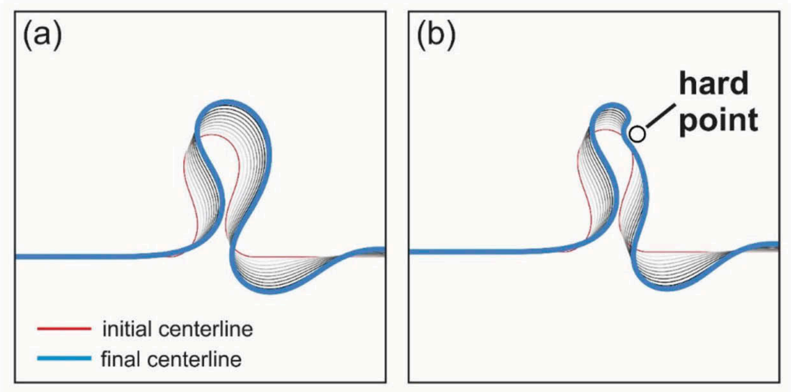


Figure 5. Sample meander evolution (a) without and (b) with a hard point.

hard points are added to distribute along the river reach at the initial state. Run 2, Run 3 and Run 4 are three cases with decreasing meander valley width. The planform of the final states of these three runs show limited discrepancies, except for the size of the oxbow lake after the neck cutoff. In general, the results of Run 2-4 show an essential difference compared to the results of Run 1: their bends are more angular and less sinuous compared to Run 1, which agrees with the peat meandering pattern reported in Appels et al. (2007), and also with the analysis given above.

Figure 7 Shows the PDF nondimensional curvature W/r_c of the final state of numerical Runs 1 ("alluvial") and 4 ("peat"). The patterns discriminate in the same general way as Figure 4: the peat cases show a strong peak around zero curvature that is not shown by the alluvial cases.

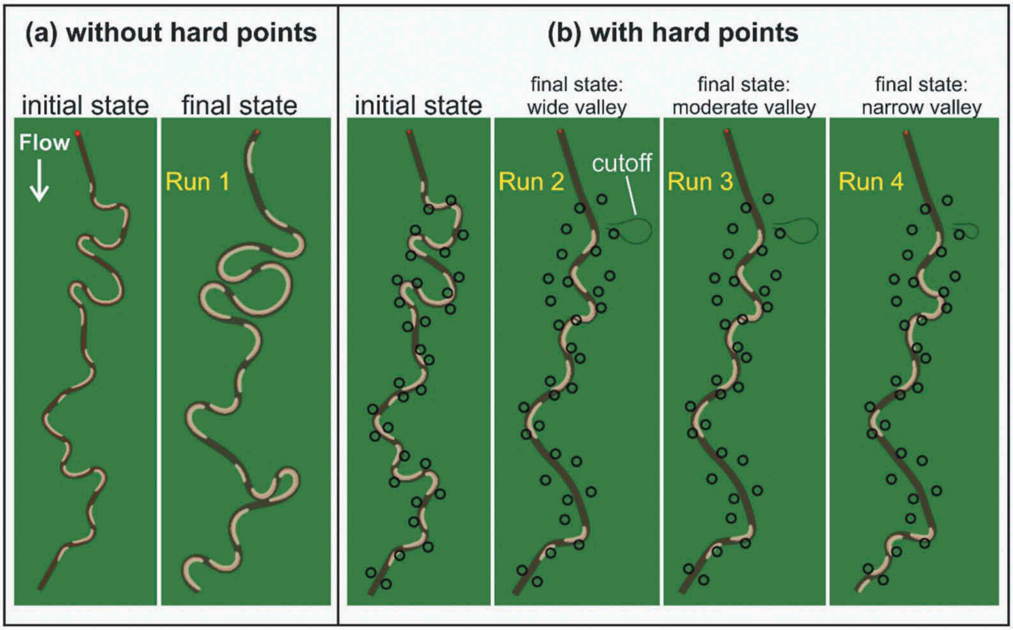


Figure 6. Meander evolution of the Trinity River (a) without and (b) with hard points. Flow is from top to bottom.

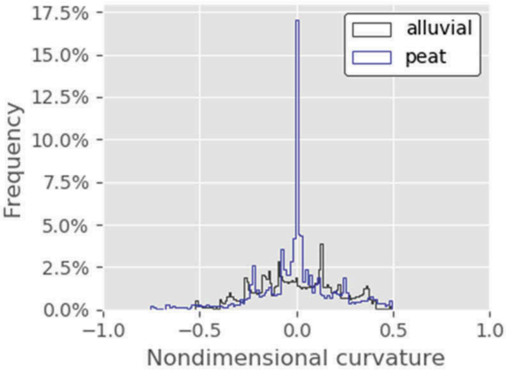


Figure 7. Probability distribution of curvature as model for a stream reach with no hard points (simulated alluvial) and dense hard points (simulated peat).

5 DISCUSSION AND CONCLUSION

Alluvial meanders tend to show continuously curving bends, active channel migration, point bars, scroll bars and oxbow lakes. Meanders in peat, on the other hand, are likely to have long nearly straight reaches bounded by sharp turns, and show little evidence of migration, scroll bars, point bars and oxbow lakes. Here we show that alluvial meanders can be distinguished from some meanders in peat in terms of the probability density distribution of dimensionless planform curvature. The curvature probability density distribution of peat rivers show a sharp peak near zero curvature that is not seen in alluvial rivers. This sharp peak can be represented in part by a numerical model of bend migration that explicitly includes hard points on the floodplain. It should be pointed out that the research presented here is only preliminary in nature. While straight and angular planforms of meandering can be found in some peat areas, not all meandering reaches in peat areas necessarily manifest straight and angular characteristics. Our suggestion is that the depth of peat could partly explain this. Futher study is needed to shed light upon this problem.

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REFERENCES

Appels, W. M., Hoitink, A. J. F., & Hoekman, D. H. (2007). Planform geometry of peat meanders. In River, Coastal and Estuarine Morphodynamics: RCEM 2007, Vol. 1, 271–277.

Czapiga, M. J., Smith, V. B., Nittrouer, J. A., Mohrig, D., & Parker, G. (2015). Internal connectivity of meandering rivers: Statistical generalization of channel hydraulic geometry. Water Resources Research, 51(9), 7485–7500.

Garcia, M. H., Bittner, L., Nino, Y. (1994). Mathematical modeling for meandering streams in Illinois: a tool for stream management and engineering. Civil Engineering Studies Report of the Department of Civil Engineering. Hydraulic Engineering Series, No. 43. University of Illinois at Urbana-Champaign, Urbana, Illinois.

Guo, X-Y, Chen, D. and Parker, G. (2019). Flow directionality of pristine meandering rivers is embedded in the skewing of high-amplitude bends and neck cutoffs.

Ikeda, S., Parker, G., & Sawai, K. (1981). Bend theory of river meanders. Part 1. Linear development. Journal of Fluid Mechanics, 112, 363–377.

Johannesson, H., and Parker, G. (1985). Computer Simulated Migration of Meandering Rivers in Minnesota. Project Report No. 242, St. Anthony Falls Hydraulic Laboratory, University of Minnesota.

Li, Z. and Garcia, M. H. (2018). An improved analytical method to generate synthetic bed topography of single-thread constant-width meandering rivers. AGU Fall Meeting Abstracts.

Li, Z. and Garcia, M. H. (2020). pyRiverBed: A Python toolbox to generate synthetic riverbed topography of constant-width meandering rivers. (Unpublished report available at request.).

Schwenk, J., Lanzoni, S., & Foufoula-Georgiou, E. (2015). The life of a meander bend: Connecting shape and dynamics via analysis of a numerical model. Journal of Geophysical Research: Earth Surface, 120(4), 690–710.

Tanaka, K. (2012). Geomorphologic and hydraulic characteristics of meandering river in lowland area and wetland. Master's Thesis, Hokkaido University.

Tanaka, K., Tanaka, G. and Hasegawa, K. (2012). Formation mechanisms on meandering river in lowland and wetland –Hydraulic characteristics of Chiruwatsunai River in Kushiro Wetland National Park. Journal of Japan Society of Civil Engineering, Ser. B1 (Hydraulic. Engineering), 68 (4), I_1177-I_1182, DOI: 10.2208/jscejhe.68.I_1177, in Japanese with English abstract.

Watanabe, N., Tanaka, G., Parker, G., Shimizu, Y. and Hasegawa, K. (2015): Geometric and hydraulic features of meandering rivers in wetlands, Proc. of 9th Symposium on River, Coastal and Estuarine Morphodynamics RCEM, CD-ROM, V. 9.

Xu, J-R, Morris, P. J, Liu, J-G and Holden, J. (2018). PEATMAP: Refining estimates of global peatland distribution based on a meta-analysis. Catena, 160, 134–140.