Response to the Reviewer’s comments

On the manuscript **esurf-2016-30** submitted to ESurf

Manuscript: Frontiers in Geomorphometry and Earth Surface Dynamics: Possibilities, Limitations and Perspectives

Authors: Giulia Sofia, John K. Hillier, Susan K. Conway

First of all, we wish to thank two reviewers for their careful evaluation of our manuscript. We have tried our best to address all the issues raised during the review process, and believe that the manuscript benefited from the suggested changes and from further minor editing.

Here we provide our detailed answers (regular font) to the reviewers’ specific annotations (in italics). Attached is also a version of the manuscript with changes tracked in order to highlight all the changes made.

Reviewer #1

The manuscript by Sofia et al. presents an introduction to the special issue entitled “Frontiers in Geomorphometry and Earth Surface Dynamics: Possibilities, Limitations and Perspectives” that collects thirteen contributions in the field of geomorphometry. To this end, the authors provide a convincing overview on the strengths, mainly related to interdisciplinarity and to the wide range of potential fields of application, and major challenges of the science of quantitative land-surface analysis. The contributions are then grouped into Perspective and Research categories and main findings of each article summarized. The manuscript is well presented and suitable for publication.

We thank the reviewer for this comment.

Minor comments:

Page 1, L. 26: references: I believe that the geomorphometry book by Hengl and C1 Reuter is dated 2009 and not 2008. Please check the reference.

Thank you, We have double-checked the date, making sure to use the publisher’s website (http://store.elsevier.com/Geomorphometry/isbn-9780123743459/). This indicates a publication date of late 2008 (i.e. 17th Oct), so we use the reference: Hengl, T., Reuter, H.I. (eds) 2008. Geomorphometry: Concepts, Software, Applications. Developments in Soil Science, vol. 33, Elsevier, 796 pp.

The work by Pike (1995) could be added to the list since it’s one of the first introducing the term “geomorphometry”.

Done; we have added this reference and also a reference to Pike (2000).

Page 1, L. 21: “Research and innovation technique”->”Research and innovative technique”

Done; we changed the word.

Page 1, L. 25: “. . .Model”->”. . .Models”

Done.

Page 1, L. 29: Please consider revising the sentence "These datasets have broad applications to all kinds of processes, both natural and anthropogenic. . ."-> "These datasets have been widely used as a topographic base to analyze both natural and anthropogenic processes. . ."

Done.

Page 1, L.33: you could stress that assessing accuracy of DTM is a very important step in geomorphometry since errors are propagated in DTM derivatives.

Done, we added a sentence about this ''Errors are propagated and amplified in surface derivatives (Burrough and McDonnell, 1998; Heuvelink, 1998), thus the usefulness and validity of the results obtained in geomorphometry are intimately associated with the quality of the original data (Felicísimo, 1994)."

Page 1, l. 34: not only modelling but also DTM are widely used to derive more simplified indices or indicators. I think geomorphometric indices could be mentioned here. Few references could be added here.

We thank the reviewer for the suggestion. We added few sentences in this part of the manuscript. We believe that for the purpose of the editorial, adding references to specific indices or parameters (or models) without detailed explanations, would add complexity. We'd rather keep the text more clean and general, thus we opted for a simple approach, as follows 'Second, these data are used to derive simplified indices, or are integrated into modelling, to portray and understand the specific process of interest. Initially, geomorphometry was used mainly for drainage basin analysis from topographic maps (Miliaresis, 2008), but with time, quantitative techniques, and various geomorphometric parameters have been developed and applied in an attempt to characterize the landscape and identify processes (e.g. Evans, 2012).''

Page 2, L. 1-2: the sentence seems truncated.

We think the sentence is correct, but to emphasise its link to the previous sentence we now use a semi-colon to link the two.

Page 2, L. 29: maybe "landform features" could be used in place of "shape"

Done; we have changed the term.

Page 3, L. 20: "sediment"->"sediment dynamic"

Done; we have changed the term.

Page 3, L. 30: "roughness"->"surface roughness"

Done; we have changed the term.

Page 4, L. 19: "indexes"->"indices"

Done; we have changed the term.

Reviewer #2

This is a well-written preface of a Special Issue (SI). The paper introduces the SI on "Frontiers in Geomorphometry and Earth Surface Dynamics: Possibilities, Limitations and Perspectives". I'm pretty sure it will reach a high impact in our Earth science community. I haven't major issues to highlight. Just a suggestion related to the chapt.1 and 3, in addition to other minor comments.

We thank the reviewer for his/her comments.

Introduction (chapt.1): Why not providing at the end of the introduction a table or a flow diagram summarizing the papers (and their main findings) collected in this SI? This will be very useful for the readers. Prefaces of SI are always written without any illustrations. Maybe this time should be a good opportunity to provide something more attractive. Note that this is my personal view. In the hands of the authors the decision if following such advice.

We thank the reviewer for his/her comments. In the revised text we added a new table (table 1) showing an overview of the main themes covered by the research presented in the Special Issue. Furthermore, in the revised text, we took inspiration from the figure below by (Anderson and Burt, 1990), and we adapted the same concept to a new figure (now Figure 1 in the revised manuscript) where we illustrate a) the dominant geomorphic feature(s) and spatial extent of the techniques presented in the SI papers, and b) the dominant temporal scale and spatial extent of the applications in the SI papers.

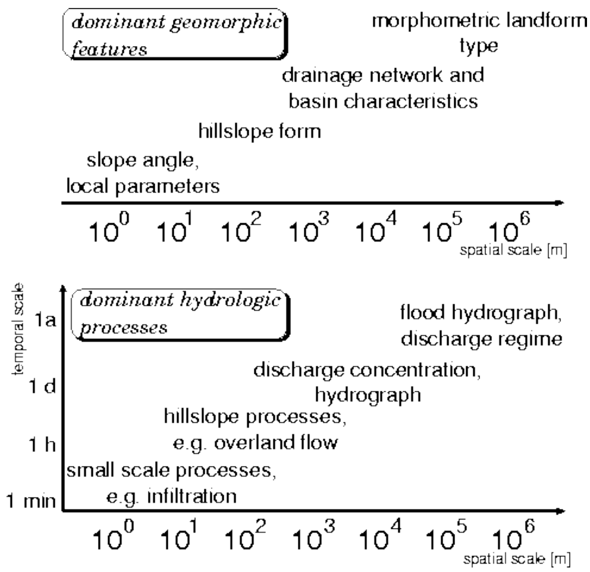

Figure 1: Scales in hydrology and geomorphology. The figure shows in a simple way some dominant features of each discipline in a spatial and spatio-temporal context (Anderson and Burt, 1990).

Future challenges (chapt.3): this chapter can be enlarged. I have some difficulties to see specific future challenges here. It seems just a general discussion. I'm sure that the authors have enough background to extract from their articles collection, and from the literature the future challenges of Geomorphometry. Are these only "synthetic DEMs, or neural networks"? Surely not.

We thank the reviewer for this comment. We changed the title of the chapter to 'closing remarks', and we highlighted few more points about the future and challenges of Geomorphometry

Minor comments

Pag. 1, line 27-28: and "hydrology"? also there a DEM can help in supporting analysis, isn't it?

We have added the term.

Pag. 1, line 30: switch the order of citation as (Tarolli, 2014; Tarolli and Sofia, 2016), so it is consistent with the previous sequence of words ("natural" first, "anthropogenic" then).

Done.

References

Anderson, M.G., Burt, T.P., 1990. Process studies in hillslope hydrology: an overview, in: Anderson, M.G., Burt, T.P. (Eds.), Process Studies in Hillslope Hydrology. Wiley, pp. 1–8.

Burrough, P.A., McDonnell, R.A., 1998. Principles of Geographical Information Systems, Economic Geography, Spatial Information Systems. Oxford University Press.

Evans, I.S., 2012. Geomorphometry and landform mapping: What is a landform? Geomorphology 137, 94–106. doi:10.1016/j.geomorph.2010.09.029

Felicísimo, A.M., 1994. Parametric statistical method for error detection in digital elevation models. ISPRS J. Photogramm. Remote Sens. 49, 29–33. doi:10.1016/0924-2716(94)90044-2

Heuvelink, G.B.M., 1998. Error propagation in environmental modelling with GIS. Taylor & Francis, London, UK.

Miliaresis, G.C., 2008. Quantification of Terrain Processes, in: Advances in Digital Terrain Analysis. Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 13–28. doi:10.1007/978-3-540-77800-4_2

Pike, R.J., 2000. Geomorphometry -diversity in quantitative surface analysis. Prog. Phys. Geogr. 24, 1–20. doi:10.1177/030913330002400101

Frontiers in Geomorphometry and Earth Surface Dynamics: Possibilities, Limitations and Perspectives

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Abstract. Geomorphometry, the science of quantitative land-surface analysis, has become a flourishing interdisciplinary subject, with applications in numerous fields. The interdisciplinarity of geomorphometry is its greatest strength and also one of its major challenges. Gaps are still present between the process focussed fields (e.g. soil science, glaciology, volcanology) and the technical domain (such as computer science, statistics…) where approaches and theories are developed. Thus, interesting geomorphometric applications struggle to jump between process-specific disciplines, but also struggle to take advantage of advances in computer science and technology. This special issue is therefore focused on facilitating cross-fertilization between disciplines, and highlighting novel technical developments and innovative applications of geomorphometry to various Earth-surface processes. The issue collects a variety of contributions which fall into two main categories: *Perspectives* and *Research,* further divided into 'Research and innovative techniques' and 'Research and innovative applications'. It showcases potentially exciting developments and tools which are the building blocks for the next step-change in the field.

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1 Introduction

Elucidating the dynamics of Earth surface processes through analysis of Digital Elevation Models (DEMs), or 'geomorphometry' (Evans et al., 2003; Hengl and Reuter, 2008; Pike, 1995, 2000), has become a flourishing interdisciplinary subject, with applications in numerous fields (e.g., geomorphology, hydrology, planetary science, archaeology, geo-biology, natural hazards, and computer science). The Earth's morphology can be measured at all scales, from macro (e.g. globally via space missions), to micro (e.g. using laser scanners and most recently structure-from-motion techniques). These datasets have been widely used to analyse both natural (Tarolli, 2014) and anthropogenic (Tarolli and Sofia, 2016) landscapes, and they underpin much modern geomorphological research.

Conceptually any analysis in geomorphometry is a two-step process. Firstly, data must be obtained and their accuracy assessed. Errors are propagated and amplified in surface derivatives (Burrough and McDonnell, 1998; Heuvelink, 1998), thus the usefulness and validity of the results obtained in geomorphometry are intimately associated with the quality of the original

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data (Felicísimo, 1994). Secondly, these data are used to derive simplified indices, or are integrated into modelling to portray and understand the specific process of interest. Initially, geomorphometry was used mainly for drainage basin analysis from topographic maps (Miliaresis, 2008), but with time, quantitative techniques and a range of geomorphometric parameters have been developed and applied in an attempt to characterize the landscape and identify processes (Evans, 2012). There are advantages and disadvantages of each method, technique, parameter and topographic datatype, which vary depending on the objectives of the analysis; often significant weaknesses or methodological limitations exist, which prevent us from gaining the insights into processes that we otherwise might. The interdisciplinarity of geomorphometry is its greatest strength and also one of its major challenges. Specifically, process-focussed fields (e.g. soil science, glaciology, volcanology, hydrology) use their own set of established geomorphometric approaches, and geomorphological specialists often play a key role in developing these. However, these specialists in turn struggle to incorporate the most innovative approaches and theory being developed in the associated technical domains (such as, computer vision, machine learning, and statistics), or even approaches being used in neighbouring disciplines. So, interesting geomorphometric applications struggle to jump between process-specific disciplines, but also struggle to take advantage of advances in computer science and technology.

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If we are to best exploit the wealth of information held within DEMs it is important to i) gather knowledge about the current technical state-of-the-art in order to consolidate and disseminate established advances; ii) evaluate stubbornly unproductive areas to identify key future challenges and opportunities; iii) provide specific and innovative case studies to assist in cross-disciplinary communication; iv) provide clear and understandable translations from the technical domains where algorithms and techniques find their basis.

In light of the challenges set out above, this special issue in Earth Surface Dynamics highlights current frontiers in geomorphometry. In order to collect recent research advancements and motivate further research in this direction, we organized a 'Frontiers in geomorphometry' session at the European Geosciences Union General Assembly in 2015, and it has continued successfully since then. The session was focused on facilitating cross-fertilization of best practice across disciplines, highlighting novel technical developments, and showcasing innovative applications of geomorphometry to various Earth-surface processes. The issue collects a variety of contributions, which fall into two main categories: *Perspectives* and *Research*, where *Research* is further divided into 'Research and innovative techniques' and 'Research and innovative applications' (Table 1).

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Table 1: Main themes covered by the research in the Special Issue

Perspectives	Research and innovative techniques	Research and innovative applications
Synthetic DEMs:	*Sediment dynamics/Fluvial incision*:	*Past tectonic history*:
Hillier et al., 2015	Hergarten et al., 2016	Andreani and Gloaguen, 2016
Structure-From-Motion (SfM) Photogrammetry:	*Stage dependent patterns in rivers*:	*Past interaction between ice sheets and glacial systems*:
	Brown et al., 2016	
Eltner et al., 2016	*Erosion and connectivity at the hillslope or catchment scale*:	Wickert, 2016
Learning Algorithms:		*Multitemporal dataset to evaluate erosion patterns*:
Valentine and Kalnins, 2016	Sklar et al., 2016;	
	Trevisani and Cavalli, 2016;	Loye et al., 2016;
	Bigelow et al., 2016;	Bechet et al., 2016;
	Grieve et al., 2016	*SfM for glacial processes*:
		Westoby et al., 2016;
		Piermattei et al., 2016.

The collected *Perspective* works are reviews of state-of-the-art developments as applied to geomorphometry, with a forward-looking component seeking to identify opportunities and challenges. They are intended to stimulate discussion and new experimental approaches, and they offer a general framework for scientists in different disciplines, dealing with geomorphometry. The papers in the *Research* section present developments of novel techniques, or showcase innovative application(s) of existing methods; the novel techniques are applicable to a variety of dominant geomorphic features, whilst the applications cover different spatial and temporal scales (Figure 1). The works display how geomorphometry can provide sets of useful techniques and tools for research in different geomorphic and spatio-temporal contexts, given that sufficient data, in sufficient quality, are available.

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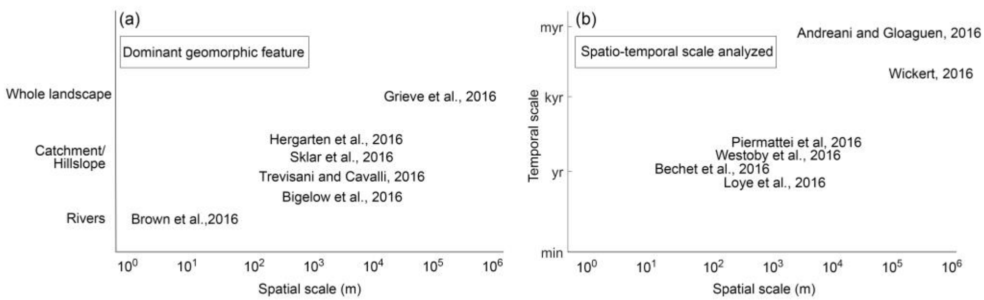

Figure 1: Dominant geomorphic feature(s) and spatial and temporal scales investigated by the research papers in this special issue: (a) dominant geomorphic feature(s) and spatial extent of the suggested applicability of the innovative techniques (Section 2.2); (b) dominant temporal scale and spatial extent covered in upon which the innovative applications are demonstrated (Section 2.3)

2 Frontiers

2.1 Perspectives

The collected perspectives investigate three major questions. i) Physical processes, including anthropogenic feedbacks sculpt planetary surfaces (e.g., Earth's). A fundamental tenet of geomorphology is that mapping and, increasingly, quantifying landform features produced can yield insights into the processes. However, the precision and accuracy of mapped data are not well understood. So, how good are these geomorphological data that underpin analyses, and how can we more objectively investigate this? ii) The human brain has a remarkable capability for identifying patterns in complex, noisy datasets, and then applying this knowledge to problem solving. Can we transfer and replicate this ability via computational means, to advance geosciences? iii) One of the most recent revolution in geomorphology is the multiview photogrammetry, or Structure-from-Motion (SfM) technique (Fonstad et al., 2013; Micheletti et al., 2015; Smith et al., 2015; Westoby et al., 2012). What are the key developments and potential future avenues for research in this field, and how do they relate to geomorphometry?

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To respond to the first point, Hillier et al. (2015) introduce synthetic DEMs. This perspective reviews the possible approaches to the generation of artificial DEMs. highlighting their limitations, potential, and the opportunities for application. Realistic synthetic DEMs offer a way to assess and understand geomorphological data, allowing users to proceed with uncertainty-aware landscape analysis to examine physical processes.

Valentine and Kalnins (2016) offer an overview about machine learning and its potential in geosciences. Learning algorithms come from the computer science world, and they are designed to replicate the human approach of inferring information from a dataset, and then apply that information predictively. In this work, the authors provide a review of the existing applications in geosciences, and discuss some of the factors that determine whether a learning algorithm approach is suited to geomorphological problems.

Eltner et al. (2016) provide a summary for researchers wanting to apply the SfM method. They summarize the state of the art of published research on SfM photogrammetry applications in geomorphometry. In addition, they give an overview of terms and fields of application, and they identify key future challenges, with a specific focus also on the errors associated with such a technique.

2.2 Research and innovative techniques

A fundamental operation in geomorphometry is the extraction of parameters from DEMs to understand the underlying process. How these parameters or objects are evaluated and identified still presents a challenge, and there is still room for improvement. Papers included here extend our knowledge about sediment dynamics and fluvial incision, or stage-dependent patterns in rivers. A further collection of work focuses on sediment, erosion and connectivity at the hillslope or watershed scale.

Hergarten et al. (2016) develop and explore an extension of the chi-transformation (χ) to small catchment sizes. They solve the limitation of the χ technique for different watershed sizes, extending the stream power equation to headwater areas dominated by debris flows. In addition, the authors introduce an alternative optimization scheme to linearize the chi-elevation relation.

Brown and Pasternack (2016) demonstrate a relatively new method of analysis for stage-dependent patterns in rivers named geomorphic covariance structures (GCSs). Using meter-scale resolution DEMs, their approach aims to understand if and how the covariance of bed elevation and flow-dependent channel top width are organized in a partially confined, incising gravel-cobble bed river with multiple spatial scales of anthropogenic and natural landform heterogeneity across a range of discharges.

Trevisani and Cavalli (2016) propose a flow-oriented directional measure of surface roughness based on geostatistics that takes into account surface gravity-driven flow directions. Their approach shows the potential impact of considering directionality in the calculation of roughness indices. In addition, they demonstrate how the use of flow-directional roughness can improve the geomorphometric modelling of sediment connectivity, and the interpretation of landscape morphology.

Sklar et al. (2016) propose a novel way to quantify the three-dimensional geometry of catchments. The authors develop an empirical algorithm for generating synthetic source-area power distributions, parameterized with data from natural catchments. Their model can be used to explore the effects of topography on the distribution on fluxes of water, sediment, isotopes and other landscape products passing through catchment outlets.

Bigelow et al (2016) focus on erosion and sedimentation, and the identification of sediment sources and sinks across landscapes from a practitioners' point of view. Their approach demonstrates a modern analysis of important geomorphic processes affected by land use that can be easily applied by agencies to solve common problems in watersheds, improving the integration between science and environmental management.

Grieve et al. (2016) present software for the automatic extraction and processing of relevant topographic parameters to rapidly generate non-dimensional erosion rate and relief data. This application allows identification of whether landscapes are in

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topographic steady state, and to identify clear signals of an erosional gradient, or evidence for a landscape decaying following uplift.

2.3 Research and innovative applications

In this section, the collected papers expand the applications of geomorphometry to a larger spatial and temporal domain, investigating past tectonic history, or past interactions between ice sheets and climate in glacial systems. Other researchers show the effectiveness of multitemporal datasets at the hillslope or catchment scale to give new insights into sediment dynamics and the seasonal pattern of erosion processes. Finally, two more papers push the frontier of which processes can be examined using SfM for quantitative analysis in the glaciological field.

Andreani and Gloaguen (2016) present a study that uses geomorphic indices to classify the landscape into different regions in order to unravel its tectonic history. These observations/interpretations allow for a better understanding of the recent evolution of the diffuse triple junction between the North American, Caribbean, and Cocos plates in northern Central America.

Wickert (2016) offers a general method to compute past river flow paths, drainage basin geometries, and river discharges at the continental-scale. By integrating numerical modelling (i.e. ice sheet, isostatic adjustment and climate) with field data including geomorphology, his work builds new insights into past glacial systems and climate–ice-sheet interactions.

In Loye et al. (2016), terrestrial Laser Scanning (TLS) is used as a monitoring tool at the catchment scale to analyse the coupling between sediment dynamics and torrent responses in terms of debris flow events. Similarly, Bechet et al. (2015) provide a novel example of how high-resolution time-lapse DEM collection can give insights into processes, in particular for understanding the seasonal pattern of erosion processes for black marls badland-type slopes.

The work by Piermattei et al. (2016) demonstrates the advantages and potential of SfM to calculate the geodetic mass balance of glacier in the Ortles-Cevedale Group, Eastern Italian Alps. In addition, they investigated the feasibility of using the image-based approach for the detection of the surface displacement rate of an active rock glacier. Westoby et al. (2016) analyse the surface evolution of an Antarctic blue-ice moraine using multi-temporal DEMs from TLS and SfM. The authors' results provide an additional understanding of inter-annual development of moraine systems.

3 Closing remarks

The availability of DEMs at multiple scales in terms of resolution and spatial and temporal coverage offers great opportunities for the investigation of Earth-surface processes. Geomorphometry has become inter-disciplinary, with focus on new techniques in digital terrain production but also analyses, independent of the subject, and/or field. This special issue showcases exciting developments and tools (e.g. synthetic DEMs, neural networks, Structure-From-Motion) that are the building blocks for the next step-change in the field. Research continues to evolve as computing power increases, and new instrumentation is developed to observe and analyse the Earth and its interacting processes. Geomorphometry is becoming essential to the understanding of global issues, such as water supply, natural hazards, sediment production and anthropogenic changes to the

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Earth system, among others. Such multidisciplinary analytical tools will only become more effective in improving our knowledge of the Earth at a variety of spatio-temporal scales. In reading and compiling the contributions in this Special Issue, we hope that you, the scientific community, will be inspired to seek out collaborations and share your ideas across subject-boundaries, between technique-developers and users, enabling us as a community to fully exploit the wealth of knowledge inherent in our increasingly digital landscape.

References

Andreani, L. and Gloaguen, R.: Geomorphic analysis of transient landscapes in the Sierra Madre de Chiapas and Maya Mountains (northern Central America): implications for the North American–Caribbean–Cocos plate boundary, Earth Surf. Dyn., 4(1), 71–102, doi:10.5194/esurf-4-71-2016, 2016.

Bechet, J., Duc, J., Loye, A., Jaboyedoff, M., Mathys, N., Malet, J.-P., Klotz, S., Le Bouteiller, C., Rudaz, B. and Travelletti, J.: Detection of seasonal erosion processes at the scale of an elementary black marl gully from time series of Hi-Resolution DEMs, Earth Surf. Dyn. Discuss., 3(4), 1555–1586, doi:10.5194/esurfd-3-1555-2015, 2015.

Bigelow, P., Benda, L. and Pearce, S.: Delineating incised stream sediment sources within a San Francisco Bay tributary basin, Earth Surf. Dyn., 4, 531–547, doi:10.5194/esurf-4-531-2016, 2016.

Brown, R. A. and Pasternack, G. B.: Analyzing bed and width oscillations in a self-maintained gravel-cobble bedded river using geomorphic covariance structures, Earth Surf. Dyn. Discuss., 1–48, doi:10.5194/esurf-2015-49, 2016.

Burrough, P. A. and McDonnell, R. A.: Principles of Geographical Information Systems, edited by R. A. De By, Oxford University Press. [online] Available from: http://www.jstor.org/stable/144481?origin=crossref, 1998.

Eltner, A., Kaiser, A., Castillo, C., Rock, G., Neugirg, F. and Abellán, A.: Image-based surface reconstruction in geomorphometry – merits, limits and developments, Earth Surf. Dyn., 4(2), 359–389, doi:10.5194/esurf-4-359-2016, 2016.

Evans, I. S.: Geomorphometry and landform mapping: What is a landform?, Geomorphology, 137(1), 94–106, doi:10.1016/j.geomorph.2010.09.029, 2012.

Evans, I. S., Dikau, R., Tokunaga, E., Ohmori, H. and Hirano, M., Eds.: Concepts and Modelling in Geomorphology: International perspectives, TERRAPUB, Tokyo., 2003.

Felicísimo, A. M.: Parametric statistical method for error detection in digital elevation models, ISPRS J. Photogramm. Remote Sens., 49(4), 29–33, doi:10.1016/0924-2716(94)90044-2, 1994.

Fonstad, M. A., Dietrich, J. T., Courville, B. C., Jensen, J. L. and Carbonneau, P. E.: Topographic structure from motion: a new development in photogrammetric measurement, Earth Surf. Process. Landforms, 38(4), 421–430, doi:10.1002/esp.3366, 2013.

Grieve, S. W. D., Mudd, S. M., Hurst, M. D. and Milodowski, D. T.: A nondimensional framework for exploring the relief structure of landscapes, Earth Surf. Dyn., 4(2), 309–325, doi:10.5194/esurf-4-309-2016, 2016.

Hengl, T. and Reuter, H. I., Eds.: Geomorphometry: Concepts, Software, Applications, Elsevier, Amsterdam., 2008.

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Hergarten, S., Robl, J. and Stüwe, K.: Tectonic geomorphology at small catchment sizes – extensions of the stream-power approach and the χ method, Earth Surf. Dyn., 4(1), 1–9, doi:10.5194/esurf-4-1-2016, 2016.

Heuvelink, G. B. M.: Error propagation in environmental modelling with GIS, Taylor & Francis, London, UK., 1998.

Hillier, J. K., Sofia, G. and Conway, S. J.: Perspective – synthetic DEMs: A vital underpinning for the quantitative future of landform analysis?, Earth Surf. Dynam, 3, 587–598, doi:10.5194/esurf-3-587-2015, 2015.

Loye, A., Jaboyedoff, M., Theule, J. I. and Liébault, F.: Headwater sediment dynamics in a debris flow catchment constrained by high-resolution topographic surveys, Earth Surf. Dyn., 4(2), 489–513, doi:10.5194/esurf-4-489-2016, 2016.

Micheletti, N., Chandler, J. H. and Lane, S. N.: Investigating the geomorphological potential of freely available and accessible structure-from-motion photogrammetry using a smartphone, Earth Surf. Process. Landforms, 40(4), 473–486, doi:10.1002/esp.3648, 2015.

Miliaresis, G. C.: Quantification of Terrain Processes, in Advances in Digital Terrain Analysis, pp. 13–28, Springer Berlin Heidelberg, Berlin, Heidelberg., 2008.

Piermattei, L., Carturan, L., de Blasi, F., Tarolli, P., Dalla Fontana, G., Vettore, A. and Pfeifer, N.: Suitability of ground-based SfM–MVS for monitoring glacial and periglacial processes, Earth Surf. Dyn., 4(2), 425–443, doi:10.5194/esurf-4-425-2016, 2016.

Pike, R. J.: Geomorphometry - progress, practice, and prospect, Zeitschrift fur Geomorphol. Suppl., 101, 221–238, 1995.

Pike, R. J.: Geomorphometry -diversity in quantitative surface analysis, Prog. Phys. Geogr., 24(1), 1–20, doi:10.1177/030913330002400101, 2000.

Sklar, L. S., Riebe, C. S. ., Lukens, C. E. and Bellugi, D.: Catchment power and the joint distribution of elevation and travel distance to the outlet, Earth Surf. Dyn. Discuss., 1–39, doi:10.5194/esurf-2016-9, 2016.

Smith, M. W., Carrivick, J. L. and Quincey, D. J.: Structure from motion photogrammetry in physical geography, Prog. Phys. Geogr., 1–29, doi:10.1177/0309133315615805, 2015.

Tarolli, P.: High-resolution topography for understanding Earth surface processes: Opportunities and challenges, Geomorphology, 216, 295–312, 2014.

Tarolli, P. and Sofia, G.: Human topographic signatures and derived geomorphic processes across landscapes, Geomorphology, 255, 140–161, doi:10.1016/j.geomorph.2015.12.007, 2016.

Trevisani, S. and Cavalli, M.: Topography-based flow-directional roughness: potential and challenges, Earth Surf. Dyn., 4(2), 343–358, doi:10.5194/esurf-4-343-2016, 2016.

Valentine, A. and Kalnins, L.: An introduction to learning algorithms and potential applications in geomorphometry and Earth surface dynamics, Earth Surf. Dyn., 4(2), 445–460, doi:10.5194/esurf-4-445-2016, 2016.

Westoby, M. J., Brasington, J., Glasser, N. F., Hambrey, M. J. and Reynolds, J. M.: "Structure-from-Motion" photogrammetry: A low-cost, effective tool for geoscience applications, Geomorphology, 179, 300–314, doi:10.1016/j.geomorph.2012.08.021, 2012.

Westoby, M. J., Dunning, S. A., Woodward, J., Hein, A. S., Marrero, S. M., Winter, K. and Sugden, D. E.: Interannual surface

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Deleted: 2015-48

Deleted: Analysis

Deleted: using structure from motion

Deleted: . Discuss., 3(

Deleted:), 1345–1398

Deleted: esurfd-3-1345-2015, 2015

Deleted: doi:10.1016/j.geomorph.2014.03.008, 2014.

Deleted: . Discuss., 1–23

Deleted: -6

Deleted: Inter-annual

evolution of an Antarctic blue-ice moraine using multi-temporal DEMs, Earth Surf. Dyn., 4(2), 515–529, doi:10.5194/esurf-4-515-2016, 2016.

Wickert, A. D.: Reconstruction of North American drainage basins and river discharge since the Last Glacial Maximum, Earth Surf. Dyn. Discuss., 1–50, doi:10.5194/esurf-2016-8, 2016.

Deleted: . Discuss., 3(

Deleted:), 1317–1344

Deleted: esurfd-3-1317-2015, 2015