Geomorphometry – 10 years after the book – challenges ahead ?

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Abstract—**In 2008 the Geomorphometry book was published after several years of work on it. 10 years have passed since the book has been published, many more years since the early work of the grandfathers of this domain. One of the key definition in the book was the following: Geomorphometry is the science of digital terrain modeling, analysis and quantitative land surface analysis. The author argues that this definition still holds true. The paper discusses past developments and future questions and argues that we need to move to a predicted space-time geomorphomerty parameters based approach.**

I. Introduction

In 2008 the Geomorphometry book has been published after several years of work. One of the key definition in there was the following: Geomorphometry is the science of digital terrain modeling, analysis and quantitative land surface analysis (Hengl & Reuter, 2008). This definition still holds true. Several conferences related to the field of research were held across the globe on this definition. 2009 in Zurich, Switzerland, 2011 in Redlands, California, 2013 in Nanjing, China, and 2015 in Pozna□ , Poland with the current in Boulder (USA). The objective of this abstract is to outline past and future developments.

II. Past Developments

One could start with Davis (1899) or Penck (1924) if someone would like discuss the past. More modern work would mention Ian Evans(1972), Moore (e.g. Moore et al. 1991) and many others. We could go at length to outline their many achievements - they all developed the science of Geomorphometry. Still the quote by Jo Wood (2009) holds true: "The visual presentation of geomorphometric analysis has evolved from monochrome low resolution over plotting of line printer output to multi-megapixel full colour output. Yet if we think of graphical output as solely a mechanism for presentation, Geomorphometry will fail to exploit the true power of recent development in visualization.". The same is valid not only for visualizations, but as well as for DEM data creation, processing, storage and decision making. The information content has increased manifold.

Digital Surface Models, Digital Terrain Models, Digital Elevation Models – the author will always recall the vivid discussion we had with the authors and among ourself what will be the correct wording. We as a community have come quite far from single theodolite observations forming a surface over current state of the art global surface based on optical (e.g. ASTER / ALOS) or radar (e.g. SRTM/ TanDEM-X) space borne sensors (e.g. Purinton and Bookhagen, 2017) over LIDAR (e.g. Wan et al, 2018, Montealegre et al., 2015) into 3D real time surface models for guidance of drones (e.g. senseFly.com, Barry et al, 2018). LIDAR has many advantages, still it has to be shown how to create continent wide LIDAR based models with sufficient accuracy.

The same is valid for algorithm developments – starting from derivatives of elevation we have come quite a way over some topographic position indexes (e.g. de Reu et al., 2013) up to geomorphons (Jasiewicz & J. Stepinski, 2013). Again, many more applications and derivatives could be mentioned – each country has its own school centered around a dedicated team. Some examples are e.g. in Germany (e.g. Dikau (1989) in Bonn, Boehner and SAGA team (e.g. Gerlitz et al, 2015) in Hamburg, China (e.g. Yue (2000) at CAS), the USA/Australia (e.g. Wilson & Gallant, 2000), Netherlands (e.g. Kamps et al. 2017 at UWA) or Russia (Florinski, 2016 at Russian Academy of Science).

Quite some development has also taken place with respect to our user community. Geomorphometry is applied from single users (e.g. biking maps using SRTM for estimating height profiles) over local planning up to global operations, being it from civil, engineering or military use (Veenstra et al., 2018) on the earth surface, below the sea level (e.g. Eakins & Grothe 2014) or at other planets in our solar system (e.g. Hynek, 2010).

III. Future

The author argues that the future will bring new technologies into our field of science. Different fields of our community are in various states between research, pre-production and production ready. The author argues that DEM generation is already in a production state as well as many of our hydrological functions. However many other derivatives still need to make the journey from a mainly research based work into production based work. A similar pattern happened with the general development of GIS over the past 100 years. The author predicts that the same will happen with Geomorphometry, while he is not entirely sure if the term will hold for the future.

Some of the following questions will appear and might need to be answered:

Currently, Geomorphometry is mainly placed in the specialist field. Scientific papers like the ones by de Reu et al., 2013 or Jasiewicz & J. Stepinski, 2013 are cited 60 or 75 times respectively according to their journal[1]. However the author argues that we as a community are not yet in the middle of the society (Farr et al. 2007 is cited over 3000 times), so the everyday engineer or grandma knows about the 'science of digital terrain modeling, analysis and quantitative land surface analysis'. This will be quite some work to bring this so far, make it so simple that everybody understands it and everybody can apply it. The author argues for a better communication strategy at each school, university. Let's introduce a Geomorphometry Day.

While we see several really good global elevation sources being provided (e.g. TandemX, MERIT, ALOS, SRTM), the effective question is still not answered: How do we provide a strategy to update the DSM and DTM at the global extent in near real time to provide 3D landscape features. The author argues that especially the daily/weekly DEMs have quite severe importance as satellite data producers would need to have these for orthorectification of their scenes.

The author extrapolates that at least in 10 years from now we will have landscape models which are feed by the e.g. daily mosaics from planet.com (3-5m resolution, commercial product) or the free and open Sentinel Copernicus data (10m resolution, 3-4 days revisit time). Geomorphometry needs to provide an answer to this challenge how to inform these landscape models than about the underlying surface and their changes on a daily basis (e.g. trees clear cut (e.g. Solberg et al., 2013), harvesting crops (e.g. Park et al., 2018) to bring them into 3D status. We predict that a variety of research questions will need to be answered until the domain has gained some specific state of the art/best practice guidelines. These will start from necessary time- space resolution for specific applications (e.g. Leempoel, 2015) up to technological solutions how to generate a DEM every day up to how to merge several DEMs in a consistent manner (e.g. Yue et al,2015; Fuss et al, 2016).

Related to that is the question how in the future we will address uncertainty in our input surfaces as well as in output products. What is the standard we would like to communicate to our users, to our scientific community. A single geomorphometry (e.g. elevation) value as in our current products can be easily communicated to our grand parents and is probably sufficient. We should aim to specify the uncertainty with 95%CI for every pixel for space and time. The widely used SRTM data records are from a 9 day time span while the ALOS, Aster GDEM and TandemX span several years. The author is aware that the provisioning of space-time uncertainty per pixel is challenging and may be not even reachable in in his lifetime but believes that this need to be addressed to be accountable. A similar issue existed in weather forecast 40 years ago where only the precipitation amount was reported. Nowadays even our grand parents understand if the weather app they are using reports to them a 5mm rainfall with 40% probability in the next 3hours and dress accordingly.

Other questions which need to be addressed are a) the free and open access similar to statistics and satellite data, b) how to map not only the surface but the whole planet with sufficient resolution, c) bare and or surface models, and d) how to maintain and versioning these DEMs and derived products.

The last aspect is certainly one of the least communicated yet at the global level. No product exists which will address the DEM time series aspect and related products. We currently only have snapshots at specific dates or time frames but a re-occurring data collection is not yet available to the authors knowledge at the global extent. For small scale applications like glacier mapping (e.g. Melkonian et al.,2016) this is an established method. The author argues that we need to move away from an snap shot based approach (e.g. a single surface of elevation) into a state-space-model based approach (e.g. predicted space-time elevation field).

In general the whole range of questions related to Big Data Processing, Artificial Intelligence, Machine Learning as well as Multi Data Fusion (MDF) need to be addressed.The author resists to discuss on these as these fields are currently evolving so fast except on MDF. In the autonomous car industry MDF is standard – it already started in the 1980 with work by Dickmans (2007) on the than much less powerful computer than todays systems (e.g. Bertozzi et al., 2000; Elfring et al., 2016).

1 https://www.journals.elsevier.com/geomorphology/most-cited-articles

The author forecast that in less than 15 years from now we will have AI-ML models which will generate geomorphometric parameters at various scales autonomously. These solutions are probably already existing in the military sector. The authors argues that our civilian community should catch up.

IV. Conclusion

Ten years have past by in the life of the authors of the Geomorphometry book. Quite significant developments have happened over the last couple of years and will do so in the years to come. The author argues that we need to move away from an snap shot based approach (e.g. a single surface of elevation) into a state-space/system based approach (e.g. predicted space-time elevation field).

References

[1] Barry,A.J. Florence,P.R., Tedrake.R. 2018, High-speed autonomous obstacle avoidance with pushbroom stereo. *Journal of Field Robotics*, 35(1):52-68

[2] Bertozzi,M.,Broggi,A., Fascioli,A. 2000, Vision-based intelligent vehicles: State of the art and perspectives, Robotics and Autonomous Systems, 32(1), p. 1-16, https://doi.org/10.1016/S0921-8890(99)00125-6

[3] Davis, W.M. 1899, The geographical cycle,Geography Journal, 14, 481-504

[4] De Reu, J., Bourgeois, J., Bats, M., Zwertvaegher, A., Gelorini, V., De Smedt, P., Chu, W., Antrop, M., De Maeyer, P., Finke, P., Van Meirvenne, M., Verniers, J., Crombé, P. 2013, Application of the topographic position index to heterogeneous landscapes, 186, p 39-49

[5] Dikau, R**,** 1989, The application of a digital relief model to landform analysis in geomorphology. In: Raper, J. (Ed.): Three Dimensional Application in Geographic Information Systems: 51-77, London.

[6] Dickmans, E.D. 2007, Dynamic Vision for Perception and Control of Motion, Springer, 442p, ISBN 978-1-84628-638-4

[7] Eakins, B.W., Grothe, P.R. 2014, Challenges in Building Coastal Digital Elevation Models, Journal of Coastal Research 297, 942-953

[8] Evans, I. 1972. General geomorphometry. Derivatives of altitude and descriptive statistic. Spatial Analysis in Geomorphology. p.17-90.

[9] Elfring, J., Appeldoorn, R., van den Dries, S., Kwakkernaat, M., 2016, Effective World Modeling: Multisensor Data Fusion Methodology for Automated Driving. *Sensors*, *16*, 1668

[10] Farr T. G.,Rosen P.A.,Caro,E., Crippen,R., Duren,R., Hensley,S., Kobrick M., Paller,M., Rodriguez,E., Roth,L., Seal,D., Shaffer,S., Shimada,J., Umland,J., Werner,M., Oskin,M., Burbank,D., Alsdorf,D., 2007, The Shuttle Radar Topography Mission, Reviews of Geophysics, 45(2), doi 10.1029/2005RG000183

[11] Florinsky, I. 2016, Digital Terrain Analysis in Soil Science and Geology, Elsevier, 506 p., ISBN 9780128046333

[12] Fuss,C.E. Berg,A.A. & Lindsay, J.B. 2016, DEM Fusion using a modified *k*-means clustering algorithm, International Journal of Digital Earth, 9:12, 1242-1255, DOI: 10.1080/17538947.2016.1208685

[13] Gerlitz, L., Conrad, O., and Böhner, J. 2015, Large-scale atmospheric forcing and topographic modification of precipitation rates over High Asia – a neural-network-based approach, Earth Syst. Dynam., 6, 61-81, https://doi.org/10.5194/esd-6-61-2015, 2015

[14] Hengl, T, Reuter H I, 2008, Geomorphometry: Concepts, Software, Applications. Amsterdam: Elsevier, 772p

[15] Hynek, B.M. 2010, Extraterrestrial digital elevation models: constraints on planetary evolution, with focus on Mars, International Journal of Remote Sensing, 31:23, 6259-6274, DOI: 10.1080/01431160903403078

[16] Jasiewicz, J. Stepinski, T. F., 2013, Geomorphons-a pattern recognition approach to classification and mapping of landforms,182, p147-156

[17] Kamps, M. T., Bouten, W., & Seijmonsbergen, A. C. 2017, LiDAR and Orthophoto Synergy to optimize Object-Based Landscape Change: Analysis of an Active Landslide. *Remote Sensing*, *9*(8), p805. DOI: 10.3390/rs9080805

[18] Leempoel, K. , Parisod, C. , Geiser, C. , Daprà, L. , Vittoz, P. , Joost, S. and Kriticos, D. 2015, Very high- resolution digital elevation models: are multi- scale derived variables ecologically relevant?. Methods Ecol Evol, 6: 1373-1383. doi:10.1111/2041-210X.12427

[19] Melkonian,A.K., Willis,M.J., Pritchard,M.E., Stewart,A.J., 2016, Recent changes in glacier velocities and thinning at Novaya Zemlya, Remote Sensing of Environment, 174, p. 244-257, https://doi.org/10.1016/j.rse.2015.11.001.

[20] Montealegre, A.L., Lamelas, M.T., de la Riva,J. 2015, A Comparison of Open-Source LiDAR Filtering Algorithms in a Mediterranean Forest Environment, in *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 8, pp. 4072-4085, doi: 10.1109/JSTARS.2015.2436974

[21] Moore, I. D., Grayson, R. B. and Ladson, A. R. 1991, Digital terrain modelling: A review of hydrological, geomorphological, and biological applications. Hydrol. Process., 5: 3–30. doi:10.1002/hyp.3360050103

[22] Park, S.; Im, J.; Park, S.; Yoo, C.; Han, H.; Rhee, J. 2018, Classification and Mapping of Paddy Rice by Combining Landsat and SAR Time Series Data. *Remote Sens.*, *10*, 447.

[23] Penck, W. 1924, Die Morphologische Analyse. Ver J. Engelshorn Nachf, Stuttgart, 283p

[24] Wan,P. Zhang,W. Skidmore,A.K. Qi,J., Jin,X., Yan,G., Wang,T. 2018, A simple terrain relief index for tuning slope-related parameters of LiDAR ground filtering algorithms, ISPRS Journal of Photogrammetry and Remote Sensing, https://doi.org/10.1016/j.isprsjprs.2018.03.020

[25] Purinton, B., Bookhagen, B. 2017, Validation of digital elevation models (DEMs) and comparison of geomorphic metrics on the southern Central Andean Plateau, Earth Surface Dynamics 5(2), p. 211—237, DOI: 10.5194/esurf-5-211-2017

[26] Solberg, S.; Astrup, R.; Weydahl, D.J. 2013 Detection of Forest Clear-Cuts with Shuttle Radar Topography Mission (SRTM) and Tandem-X InSAR Data. *Remote Sens. 5*, 5449-5462.

[27] Veenstra,B.J., Wyss,T., Roos,L. Delves,S.K., Buller,M., Beeler,N. 2018, An evaluation of measurement systems estimating gait speed during a loaded military march over graded terrain, Gait & Posture, 61,p. 204-209, https://doi.org/10.1016/j.gaitpost.2018.01.011.

[28] Wilson, J.P., Gallant J.C. 2000, Terrain Analysis: Principles and Applications, Wiley, p. 479, ISBN 9780471321880,

[29] Wood, J. 2009, Visualizing Geomorphometry: Lessons from Information Visualization, In: *Geomorphometry 2009*, Edited by R. Purves, S. Gruber, R. Straumann and T. Hengl. University of Zurich, Zurich, 2009

[30] Yue, T.X., 2011, Surface Modeling: High Accuracy and High Speed Methods, CRC press, ISBN 9781439817599

[31] Yue, L., Shen H., Yuan, Q., Zhang,L. 2015, Fusion of multi-scale DEMs using a regularized super-resolution method, International Journal of Geographical Information Science, 29:12, 2095-2120