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Modeling alpine geomorphology using laser altimetry data

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Citation for published version (APA):

Anders, N. S. (2013). Modeling alpine geomorphology using laser altimetry data

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Bibliography

- Adams, J. C., Chandler, J. H., 2002. Evaluation of LiDAR and medium scale photogrammetry for detecting soft-cliff coastal change. *Photogrammetric Record* 17 (99), 405–418.
- Adediran, A., Parcharidis, I., Poscolieri, M., Pavlopoulos, K., 2004. Computer-assisted discrimination of morphological units on north-central Crete (Greece) by applying multivariate statistics to local relief gradients. *Geomorphology* 58 (1-4), 357–370.
- Ahnert, F., 1976. Brief description of a comprehensive three-dimensional process-response model for landform development. *Zeitschrift für Geomorphologie*, N.F. Supplement 25, 29–49.
- Aksoy, B., Ercanoglu, M., 2012. Landslide identification and classification by object-based image analysis and fuzzy logic: An example from the Azdavay region (Kastamonu, Turkey). *Computers & Geosciences* 38 (1), 87–98.
- Alleman, F., 1985. *Geologische Karte Fürstentum Liechtenstein*, 1:25.000. Liechtenstein, Schulb Verlag, Vaduz.
- Ampferer, O., Benzinger, T., Reithofer, O., 1932. *Geologische Karte der Lechtaler Alpen*: 1:25,000. Herausgegeben und verlegt von der Geologischen Bundesanstalt, Wien.
- Anders, N. S., Seijmonsbergen, A. C., Bouten, W., 2009. Modelling channel incision and alpine hillslope development using laser altimetry data. *Geomorphology* 113, 35–46.
- Anders, N. S., Seijmonsbergen, A. C., Bouten, W., 2011a. Segmentation optimization and stratified object-based analysis for semi-automated geomorphological mapping. *Remote Sensing of Environment* 115, 2976–2985.
- Anders, N. S., Seijmonsbergen, A. C., Bouten, W., 2013a. Geomorphological change detection using object-based feature extraction from multi-temporal lidar data. *IEEE Geoscience and Remote Sensing Letters* In press.
- Anders, N. S., Seijmonsbergen, A. C., De Jong, M. G. G., Bouten, W., 2013b. A protocol for digital geomorphological mapping in mountainous areas. *Geomorphology* In review.
- Anders, N. S., Smith, M. J., Seijmonsbergen, A. C., Bouten, W., 2011b. Optimizing object-based image analysis for semi-automated geomorphological mapping. In: Hengl, T., Evans, I. S., Wilson, J. P., Gould, M. (Eds.), *Geomorphometry 2011*. Redlands, CA, pp. 117–120.
- Anthony, D. M., Granger, D. E., 2007. An empirical stream power formulation for knickpoint retreat in Appalachian Plateau fluvio-karst. *Journal of Hydrology* 343, 117–126.
- Antonarakis, A. S., Richards, K. S., Brasington, J., 2008. Object-based land cover classification using airborne LiDAR. *Remote Sensing of Environment* 112 (6), 2988–2998.
- Arrell, K. E., Fisher, P. F., Tate, N. J., Bastin, L., 2007. A fuzzy c-means classification of elevation derivatives to extract the morphometric classification of landforms in Snowdonia, Wales. *Computers & Geosciences* 33 (10), 1366–1381.
- Arrowsmith, J. R., Zielke, O., 2009. Tectonic geomorphology of the San Andreas Fault zone from high resolution topography: An example from the Cholame segment. *Geomorphology* 113 (1-2), 70–81.
- Baatz, M., Schäpe, A., 2000. Multiresolution segmentation—an optimization approach for high quality multi-scale image segmentation. In: *Angewandte Geographische Informationsverarbeitung XII. Beiträge zum AGIT-Symposium Salzburg*. Vol. 200. pp. 12–23.
- Barsch, D., Liedtke, H., 1980. Principles, scientific value and practical applicability of the geomorphological map of the Federal Republic of Germany at the scale of 1:25 000 (GMK25) and 1:100 000 (GMK100). *Zeitschrift für Geomorphologie N.F. Supplement Band*, 36, 296–313.
- Benz, U. C., Hoffmann, P., Willhauck, G., Lingenfelder, I., Heynen, M., 2004. Multi-resolution, object-oriented fuzzy analysis of remote sensing data for GIS-ready information. *Journal of Photogrammetry and Remote Sensing* 58, 239–258.
- Berlin, M., Anderson, R. S., 2007. Modeling of knickpoint retreat on the Roan Plateau, western Colorado. *Journal of Geophysical Research* 112, F03S06.
- Bishop, P., Hoey, J. D., Jansen, J. D., Artza, I. L., 2005. Knickpoint recession rate and catchment area: The case of uplifted rivers in Eastern Scotland. *Earth Surface Processes and Landforms* 30, 767–778.
- Bishop, P., Young, R. W., McDougall, I., 1985. Stream profile change and long term landscape evolution: Early Miocene and modern rivers of the east Australian highland crest, central New South Wales, Australia. *Journal of Geology* 93, 455–474.

- Blaschke, T., 2010. Object based image analysis for remote sensing. *ISPRS Journal of Photogrammetry and Remote Sensing* 65 (1), 2–16.
- Blaschke, T., Burnett, C., Pekkarinen, A., 2004. Image segmentation methods for object-based analysis and classification. In: De Jong, S. M., Van der Meer, F. D. (Eds.), *Remote Sensing Image Analysis: Including The Spatial Domain. Remote Sensing and Digital Image Processing*. Springer Netherlands, pp. 211–236.
- Blaschke, T., Strobl, J., 2001. What's wrong with pixels? Some recent developments interfacing remote sensing and GIS. *GIS—Zeitschrift für Geoinformationssysteme* 6, 12–17.
- Bocco, G., Mendoza, M., Velázquez, A., 2001. Remote sensing and GIS-based regional geomorphological mapping—a tool for land use planning in developing countries. *Geomorphology* 39, 211–219.
- Bolongaro-Crevenna, A., Torres-Rodríguez, V., Sorani, V., Frame, D., Ortiz, M. A., 2005. Geomorphometric analysis for characterizing landforms in Morelos State, Mexico. *Geomorphology* 67 (34), 407–422.
- Braun, J., Sambridge, M., 1997. Modelling landscape evolution on geological time scales: a new method based on irregular spatial discretization. *Basin Research* 9, 27–52.
- Burrough, P. A., McDonnell, R. A., 1998. *Principles of Geographical Information Systems*. Oxford University Press.
- Burrough, P. A., Van Gaans, P. F. M., MacMillan, R. A., 2000. High-resolution landform classification using fuzzy k-means. *Fuzzy Sets and Systems* 113 (1), 37–52.
- Cammeraat, L. H., 1986. A geomorphological investigation of the Northern Lechquellengebirge, Vorarlberg, Austria. Unpublished MSc. Thesis, Laboratory for Physical Geography and Soil Science, University of Amsterdam, Amsterdam, 174pp.
- Cammeraat, L. H., De Graaff, L. W. S., Kwadijk, J. K., Rupke, J., 1987. On the origin of debris pillars in the Alps of Vorarlberg, western Austria. *Z-Geomorphologie N.F.* 31 (1), 85–100.
- Cavalli, M., Tarolli, P., Marchi, L., Fontana, G. D., 2008. The effectiveness of airborne LiDAR data in the recognition of channel-bed morphology. *Catena* 73 (3), 249–260.
- Chaplot, V., Darboux, F., Bourennane, H., Leguédois, S., Silvera, N., Phachomphon, K., 2006. Accuracy of interpolation techniques for the derivation of digital elevation models in relation to landform types and data density. *Geomorphology* 77, 126–141.
- Charlton, M. E., Large, A. R. G., Fuller, I. C., 2003. Application of airborne LiDAR in river environments: The River Coquet, Northumberland, UK. *Earth Surface Processes and Landforms* 28, 299–306.
- Chiari, M., Mair, E., Rickenmann, D., 2008. Modelling sediment stream and comparison of the morphologic change with LiDAR data. *Interpraevent Conference Proceedings band I*, 295–306.
- Chu-Agor, M. L., Fox, G. A., Cancienne, R. M., Wilson, G. V., 2008. Seepage caused tension failures and erosion undercutting of hillslopes. *Journal of Hydrology* 359, 247–259.
- Cobby, D. M., Mason, D. C., Davenport, I. J., 2001. Image processing of airborne scanning laser altimetry data for improved river flood modelling. *Journal of Photogrammetry and Remote Sensing* 56, 121–138.
- Congalton, R. G., 1991. A review of assessing the accuracy of classifications of remotely sensed data. *Remote Sensing of Environment* 37 (1), 35–46.
- Congalton, R. G., Green, K., 1999. *Assessing the accuracy of remotely sensed data: principles and practices*. Lewis Publishers, Boca Raton.
- Coratza, P., Giusti, C., 2005. Methodological proposal for the assessment of the scientific quality of geomorphosites. *Italian Journal of Quaternary Sciences* 18, 307–313.
- Coulthard, T. J., 2001. Landscape evolution models: a software review. *Hydrological Processes* 15, 165–173.
- Coulthard, T. J., Kirkby, M. J., Macklin, M. G., 2000. Modelling geomorphic response to environmental change in an upland catchment. *Hydrological Processes* 14, 2031–2045.
- Coulthard, T. J., Macklin, M. G., Kirkby, M. J., 2002. A cellular model of Holocene upland river basin and alluvial fan evolution. *Earth Surface Processes and Landforms* 27, 269–288.
- Crosby, B. T., Whipple, K. X., 2006. Knickpoint initiation and distribution within fluvial networks: 236 waterfalls in the Waipaoa River, North Island, New Zealand. *Geomorphology* 82, 16–38.
- De Graaff, L. W. S., 1996. The fluvial factor in the evolution of alpine valleys and of ice-margin topography in Vorarlberg (W-Austria) during the Upper Pleistocene and Holocene. *Zeitschrift für Geomorphologie N.F.* 104, 129–159.
- De Graaff, L. W. S., De Jong, M. G. G., Busnach, T., Seijmonsbergen, A. C., 2003. Geomorphologische Studie Bregenzerwald. Bericht an das Amt der Vorarlberger Landesregierung, Abt. Raumplanung und Baurecht, Landhaus Bregenz, 113p.
- De Graaff, L. W. S., De Jong, M. G. G., Rupke, J., Verhofstad, J., 1987. A geomorphological mapping system at scale 1:10,000 for mountainous areas. *Zeitschrift für Geomorphologie N.F.* 13 (2), 229–242.
- De Jong, M. G. G., De Graaff, L. W. S., Rupke, J., 1995. Der Eisabbau im Vorderen Bregenzerwald und in den Bachargebieten (Vorarlberg, Österreich; Bayern, Deutschland) nach dem letzteiszeitlichen Eishochstand. *Jahrbuch der Geologischen Bundesanstalt*, 138/1, Wien, Austria, 27–54.
- Definiens AG, 2009. *Definiens eCognition Developer 8 User Guide*.
- Desclée, B., Bogaert, P., Defourny, P., 2006. Forest change detection by statistical object-based method. *Remote Sensing of Environment* 102 (1–2), 1–11.
- Dewitte, O., Jaselette, J. C., Cornet, Y., Van den Eeckhout, M., Collignon, A., Poesen, J., Demoulin, A., 2008.

- Tracking landslide displacements by multi-temporal DTMs: A combined aerial stereophotogrammetric and LiDAR approach in western Belgium. *Engineering Geology* 99, 11–22.
- Dielman, T. E., 2005. Least absolute value regression: recent contributions. *Journal of statistical computation and simulation* 75 (4), 263–286.
- Dietrich, W. E., Reiss, R., Hsu, M. L., Montgomery, D. R., 1995. A process-based model for colluvial soil depth and shallow landsliding using digital elevation data. *Hydrological Processes* 9, 383–400.
- Dikau, R., Brabb, E. E., Mark, R. K., Pike, R. J., 1995. Morphometric landform analysis of New Mexico. *Z. Geomorphologie Suppl. Bd.*, 101, 109–126.
- Dodge, Y., 1987. An introduction to L1-norm based statistical data analysis. *Computational Statistics & Data Analysis* 5 (4), 239–253.
- Doornkamp, J. C., Griffiths, J. S., Lee, E. M., Tragheim, D., Charman, J. H., 1980. *Geology, Geomorphology and Pedology of Bahrain*. GeoBooks, Norwich.
- Dorren, L. K. A., 2003. A review of rockfall mechanics and modelling approaches. *Progress in Physical Geography* 27, 69–87.
- Dorren, L. K. A., Maier, B., Putters, U. S., Seijmonsbergen, A. C., 2004. Combining field and modelling techniques to assess rockfall dynamics on a protection forest hillslope in the European Alps. *Geomorphology* 57, 151–167.
- Drăguț, L., Eisank, C., 2012. Automated object-based classification of topography from SRTM data. *Geomorphology* 141–142, 21–33.
- Drăguț, L., Blaschke, T., 2006. Automated classification of landform elements using object-based image analysis. *Geomorphology* 81 (3–4), 330–344.
- Drăguț, L., Tiede, D., Levick, S., 2010. ESP: a tool to estimate scale parameter for multiresolution image segmentation of remotely sensed data. *International Journal of Geographical Information Science* 24 (4), 859–871.
- Duvall, A., Kirkby, E., Burbank, D., 2004. Tectonic and lithologic controls on bedrock channel profiles and processes in coastal California. *Journal of Geophysical Research* 109, F03002.
- Ehsani, A. H., Quiel, F., 2008. Geomorphometric feature analysis using morphometric parameterization and artificial neural networks. *Geomorphology* 99 (1–4), 1–12.
- Etzelmüller, B., Romstad, B., Fjellanger, J., 2007. Automatic regional classification of topography in Norway. *Norwegian Journal of Geology* 87, 167–180.
- Evans, I. S., 2012. Geomorphometry and landform mapping: What is a landform? *Geomorphology* 137, 94–106.
- Evans, I. S., Hengl, T., Gorsevski, P., 2009. Applications in geomorphology. In: Hengl, T., Reuter, H. (Eds.), *Geomorphometry — Concepts, software, applications*. Vol. 33 of *Developments in Soil Science*. Elsevier, Amsterdam, pp. 497–525.
- Fagherazzi, S., Howard, A. D., Wiberg, P. L., 2004. Modeling fluvial erosion and deposition on continental shelves during sea level cycles. *Journal of Geophysical Research* 109, F03010.
- Friebe, J. G., 2007. *Geologie der Österreichischen Bundesländer Vorarlberg*. Geologischen Bundesanstalt, Wien.
- Gallant, J. C., Wilson, J. P., 2000. Primary topographic attributes. In: Wilson, J. P., Gallant, J. C. (Eds.), *Terrain Analysis, Principles and Applications*. John Wiley & Sons, pp. 51–85.
- Gasparini, N. M., Whipple, K. X., Bras, R. L., 2007. Predictions of steady state and transient landscape morphology using sediment-flux-dependent river incision models. *Journal of Geophysical Research* 112, F03S09.
- Giles, P. T., 1998. Geomorphological signatures: classification of aggregated slope unit objects from digital elevation and remote sensing data. *Earth Surface Processes and Landforms* 23, 581–594.
- Glenn, N. F., Streutker, D. R., Chadwick, D. J., Thackray, G. D., Dorsch, S. J., 2006. Analysis of LiDAR-derived topographic information for characterizing and differentiating landslide morphology and activity. *Geomorphology* 73, 131–148.
- Grass, V., 2009. Aktualisierung des Biotopinventars Vorarlberg - Gemeinde Lech, Vorarlberger Landesregierung. <http://www.vorarlberg.at/archiv/umweltschutz/biotopinventar/Lech.pdf>.
- Gray, M., 2004. *Geodiversity: Valuing and Conserving Abiotic Nature*. John Wiley, Chichester, UK.
- Grebby, S., Naden, J., Cunningham, D., Tansey, K., 2011. Integrating airborne multispectral imagery and airborne LiDAR data for enhanced lithological mapping in vegetated terrain. *Remote Sensing of Environment* 115, 214–226.
- Griffiths, J. S., Smith, M. J., Paron, P., 2011. Introduction to applied geomorphological mapping. In: Smith, M., Paron, P., Griffiths, J. S. (Eds.), *Geomorphological mapping: methods and applications*. Vol. 15 of *Developments in Earth Surface Processes*. Elsevier, Elsevier, pp. 3–11.
- Gustavsson, M., Seijmonsbergen, A. C., Kolstrup, E., 2006. A new symbol-and-GIS based detailed geomorphological mapping system: renewal of a scientific discipline for understanding landscape development. *Geomorphology* 77 (3–4), 90–111.
- Gustavsson, M., Seijmonsbergen, A. C., Kolstrup, E., 2008. Structure and contents of a new geomorphological GIS database linked to a geomorphological map - With an example from Liden, central Sweden. *Geomorphology* 95 (3–4), 335–349.
- Hakala, T., Suomalainen, J., Kaasalainen, S., Chen, Y., 2012. Full waveform hyperspectral LiDAR for terrestrial laser scanning. *Optics Express* 20 (7), 7119–7127.
- Hantke, R., 1980. *Letzte Warmzeiten, Wurm-Eiszeit, Eisabbau und Nacheiszeit der Alpen-Nordseite vom Rhein-zum Rhone-System*. Ott, Thun, Switzerland.

- Heimsath, A. M., Furbish, D. J., Dietrich, W. E., 2005. The illusion of diffusion: Field evidence for depth-dependent sediment transport. *Geology* 33, 949–952.
- Heissel, W., Oberhauser, R., Reithofer, O., Schmidegg, O., 1965. Geologische Karte des Rätikon 1:25,000. Geologische Bundesanstalt, Wien.
- Hengl, T., Najat, B., Blagojević, D., Reuter, H., 2008. Geostatistical modeling of topography using auxiliary maps. *Computers & Geosciences* 34, 1886–1899.
- Hengl, T., Reuter, H., 2008. *Geomorphometry: Concepts, Software, Applications*. Vol. 33. Elsevier, Amsterdam.
- Hengl, T., Rossiter, D. G., 2003. Supervised landform classification to enhance and replace photo-interpretation in semi-detailed soil survey. *Soil Science Society of America* 67, 1810–1822.
- Hervás, J., Barredo, J. I., Rosin, P. L., Pasuto, A., Montovani, F., Silvano, S., 2003. Monitoring landslides from optical remotely sensed imagery: the case history of Tessina landslide, Italy. *Geomorphology* 54, 63–75.
- Hilldale, R. C., Raff, D., 2008. Assessing the ability of airborne LiDAR to map river bathymetry. *Earth Surface Processes and Landforms* 33, 773–783.
- Howard, A. D., 1994. A detachment limited model of drainage basin evolution. *Water Resources Research* 30, 2261–2285.
- Howard, A. D., 1998. Long profile development of bedrock channels: interaction of weathering, mass wasting, bed erosion, and sediment transport. In: Tinkler, K. J., Wohl, E. E. (Eds.), *Rivers Over Rocks: Fluvial Processes in Bedrock Channels*. American Geophysical Union, Washington DC, pp. 297–319.
- Howard, A. D., Kerby, G., 1983. Channel changes in badlands. *Geological Society of America Bulletin* 94, 739–752.
- Iwahashi, J., Pike, R. J., 2007. Automated classifications of topography from DEMs by an unsupervised nested-means algorithm and a three-part geometric signature. *Geomorphology* 86, 409–440.
- James, L. A., Watson, D. G., Hansen, W. F., 2007. Using LiDAR data to map gullies and headwater streams under forest canopy: South Carolina, USA. *Catena* 71 (1), 132–144.
- Jenson, S. K., Domingue, J. O., 1988. Extracting topographic structure from digital elevation data for Geographic Information System analysis. *Photogrammetric Engineering and Remote Sensing* 54, 1593–1600.
- Jones, A. F., Brewer, P. A., Johnstone, E., Macklin, M. G., 2007. High-resolution interpretative geomorphological mapping of river valley environments using airborne LiDAR data. *Earth Surface Processes and Landforms* 32, 1574–1592.
- Keller, O., 1988. Ältere Spätwürmzeitliche Gletschervorstöße und Zerfall des Eisstromnetzes in den nördlichen Rhein-Alpen (Weissbad-Stadium/Bühl-Stadium). *Schriftenreihe Physische Geographie* 27, Geogr. Inst. Zrich, 2 Bde + Profilkarten (1988).
- Kienzle, S., 2004. The effect of DEM raster resolution on first order, second order and compound terrain derivatives. *Transactions on GIS* 8, 83–111.
- Kim, M., Madden, M., Warner, T., 2008. Estimation of optimal image object size for the segmentation of forest stands with multispectral IKONOS imagery. In: Blaschke, T., Lang, S., Hay, G. (Eds.), *Object-Based Image Analysis—Spatial Concepts for Knowledge-Driven Remote Sensing Applications*. Springer, pp. 291–307.
- Kirkby, M. J., 1971. Hillslope process-response models based on the continuity equation. In: Brunsden, D. (Ed.), *Slopes: Form and Process*. Vol. 3 of Special Publication. Institute of British Geographers, pp. 15–30.
- Klimaszewski, M., 1982. Detailed geomorphological maps. *ITC Journal* 3, 265–271.
- Knight, J., Mitchell, W. A., Rose, J., 2011. Geomorphological field mapping. In: Smith, M., Paron, P., Griffiths, J. S. (Eds.), *Geomorphological mapping: methods and applications*. Vol. 15 of *Developments in Earth Surface Processes*. Elsevier, pp. 151–188.
- Kraus, K., Mikhail, E., 1972. Linear least squares interpolation. *Photogrammetric Engineering* 38 (10), 1016–1029.
- Kraus, K., Otepka, J., 2005. DTM modelling and Visualization—the SCOP approach. *Photogrammetric Week* (Heidelberg, 2005), Wichmann Verlag, 241–252.
- Kraus, K., Pfeifer, N., 1998. Determination of terrain models in wooded areas with airborne laser scanner data. *ISPRS Journal of Photogrammetry and Remote Sensing* 53 (4), 193–203.
- Lahoni, B., Mason, D. C., 2001. Application of airborne scanning laser altimetry to the study of tidal channel geomorphology. *Journal of Photogrammetry and Remote Sensing* 56, 100–120.
- Lillesand, T. M., Kiefer, R. W., Chipman, J. W., 2007. *Remote Sensing and Image Interpretation*, 6th edition. John Wiley & Sons.
- Ling, H., Okada, K., 2007. An efficient earth movers distance algorithm for robust histogram comparison. *Pattern Analysis and Machine Intelligence* 29(5), 840–853.
- Listner, C., Niemeyer, L., 2011. Recent advances in object-based change detection. *Geoscience and Remote Sensing Symposium (IGARSS) 2011 IEEE International*, 110–113.
- Liu, X., 2008. Airborne LiDAR for DEM generation: some critical issues. *Progress in Physical Geography* 32, 31–49.
- Lu, P., Stumpf, A., Kerle, N., Casagli, N., 2011. Object-oriented change detection for landslide rapid mapping. *IEEE Geoscience and Remote Sensing Letters* 8, 701–705.
- MacMillan, R. A., Pettapiece, W. W., Nolan, S. C., Goddard, T. W., 2000. A generic procedure for automatically segmenting landforms into landform elements using DEMs, heuristic rules and fuzzy logic. *Fuzzy Sets and Systems* 113 (1), 81–109.
- Mantovani, F., Gracia, F., De Cosmo, P., Suma, A., 2010. A new approach to landslide geomorphological mapping

- using the Open Source software in the Olvera area (Cadiz, Spain). *Landslides* 7, 69–74, 10.1007/s10346-009-0181-4.
- Marcus, W. A., Fonstad, M. A., 2008. Optical remote mapping of river at sub-meter resolutions and watersheds extent. *Earth Surface Processes and Landforms* 33, 4–24.
- Martin, Y., 2000. Modelling hillslope evolution: linear and nonlinear transport relations. *Geomorphology* 34, 1–21.
- Mason, D. C., Scott, T. R., Wang, H. J., 2006. Extraction of tidal channel networks from airborne scanning laser altimetry. *Journal of Photogrammetry and Remote Sensing* 61, 67–83.
- McCormack, D. C., Irving, D. H. B., Brocklehurst, S. H., Rarity, F., 2008. Glacial geomorphological mapping of Coire Mhic Fhearchair, NW Scotland: The contribution of a high-resolution ground-based LiDAR survey. *Journal of Maps* 2008, 315–331.
- Milan, D. J., Heritage, G. L., Hetherington, D., 2007. Application of a 3D laser scanner in the assessment of erosion and deposition volumes and channel change in a proglacial river. *Earth Surface Processes and Landforms* 32 (11), 1657–1674.
- Minasny, B., McBratney, A. B., 2001. A rudimentary mechanistic model for soil formation and landscape development:: II. A two-dimensional model incorporating chemical weathering. *Geoderma* 103, 161–179.
- Minasny, B., McBratney, A. B., 2006. Mechanistic soil-landscape modelling as an approach to developing pedogenetic classifications. *Geoderma* 133, 138–149.
- Mitasova, H., Overtun, M. F., Recalde, J. J., Bernstein, D. J., Freeman, C. W., 2009. Raster-based analysis of coastal terrain dynamics from multi-temporal LiDAR data. *Journal of Coastal Research* 25, 507–514.
- Möller, M., Lymburner, L., Volk, M., 2007. The comparison index: A tool for assessing the accuracy of image segmentation. *International Journal of Applied Earth Observation and Geoinformation* 9 (3), 311–321.
- Montgomery, D. R., 2001. Slope distributions, threshold hillslopes, and steady-state topography. *American Journal of Science* 301, 432–454.
- Oberhauser, R., 1998. Erläuterungen zur geologisch-tektonischen Übersichtskarte von Vorarlberg 1:200.000, Geologische Bundesanstalt, Wien.
- Oberhauser, R., Bertle, H., Bertle, R., 2007. Zur Geologie der Ost-Westalpen-Grenze anhand der geologischen Karte von Vorarlberg 1:100.000 mit dem zugehörigen Profilschnitt vom Bodensee ins Unterengadin. In: *Vorarlberg Geologie der Österreichischen Bundesländer: 174 S. Wien, Geologische Bundesanstalt, p. Beilage 2.*
- O’Callaghan, J. F., Mark, D. M., 1984. The extraction of drainage networks from digital elevation data. *Computer Vision, Graphics, and Image Processing* 28 (3), 323–344.
- Oreskes, N., Shrader-Frechette, K., Belitz, K., 1994. Verification, validation, and confirmation of numerical models in the Earth sciences. *Science* 263, 641–646.
- Ostermann, M., Sanders, D., Kramers, J., 2006. $^{230}\text{Th}/^{234}\text{U}$ ages of calcite cements of the proglacial valley fills of Gamperdona and Bürs (Riss Ice Age, Vorarlberg, Austria): geological implications. *Austrian Journal of Earth Sciences* 99, 31–41.
- Pal, N. R., Pal, S. K., 1993. A review on image segmentation techniques. *Pattern Recognition* 26, 1277–1294.
- Paron, P., Smith, M. J., Van der Meulen, F., Reyns, J., Anders, N. S., Roelvink, D., Luijendijk, A., 2012. Kite aerial photogrammetry system for monitoring coastal change in the Netherlands. In: *Remote Sensing & Photogrammetry Society annual meeting, Greenwich University UK, 12-14 September.*
- Pelletier, J. D., 2007. Fractal behavior in space and time in a simplified model of fluvial landform evolution. *Geomorphology* 91, 291–301.
- Penck, A., Brückner, E., 1909. *Die Alpen im Eiszeitalter.* Tauchnitz, Leipzig.
- Pfeiffer, T. J., Bowen, T. D., 1989. Computer simulation of rockfalls. *Bulletin of the Association of Engineering Geologists* XXVI, 135–146.
- Pike, R. J., 1988. The geometric signature: Quantifying landslide-terrain types from digital elevation models. *Mathematical Geology* 20, 491–511.
- Pike, R. J., 1995. Geomorphometry—progress, practice and prospect. *Zeitschrift für Geomorphologie Supplementband* 101, 221–238.
- Pirotti, F., Tarolli, P., 2010. Suitability of LiDAR point density and derived landform curvature maps for channel network extraction. *Hydrological Processes* 24 (9), 1187–1197.
- Pralong, J.-P., 2005. A method for assessing tourist potential and use of geomorphological sites. *Géomorphologie: relief, processus, environnement* 3, 189–169.
- Prima, O. D. A., Echigo, A., Yokoyama, R., Yoshida, T., 2006. Supervised landform classification of Northeast Honshu from DEM-derived thematic maps. *Geomorphology* 78 (3-4), 373–386.
- Reusser, L., Bierman, P., 2007. Accuracy assessment of LiDAR-derived DEMs of bedrock river channels: Holtwood Gorge, Susquehanna River. *Geophysical Research Letters* 34, L23S06.
- Reynard, E., 2004. Geosites. In: Goudie, A. S. (Ed.), *Encyclopedia of Geomorphology.* London, Routledge, p. 440.
- Ring, U., Ratschbacher, L., Frisch, W., Dürr, S., Borchert, S., 1990. The internal structure of the Arosa Zone (Swiss-Austrian Alps). *Geologische Rundschau* 79, 725–739.
- Roering, J. J., Stimely, L. L., Mackey, B. H., Schmidt, D. A., 2009. Using DInSAR, airborne LiDAR, and archival air photos to quantify landsliding and sediment transport. *Geophysical Research Letters* 36.
- Ruff, M., 2005. GIS-gestützte Risikoanalyse für Rutschungen und Felsstürze in den Ostalpen (Vorarlberg,

- Österreich). Ph.D. thesis, University of Karlsruhe.
- Saadat, H., Bonnell, R., Sharifi, F., Mehuys, G., Namdar, M., Ale-Ebrahim, S., 2008. Landform classification from a digital elevation model and satellite imagery. *Geomorphology* 100, 453–464.
- Saha, K., Wells, N. A., Munro-Stasiuk, M., 2011. An object-oriented approach to automated landform mapping: A case study of drumlins. *Computers & Geosciences* 37 (9), 1324–1336.
- Schiewe, J., 2002. Segmentation of high-resolution remotely sensed data — concepts, applications and problems. *International Archives of Photogrammetry and Remote Sensing* 34, 380–385.
- Schlunegger, F., 2002. Impact of hillslope-derived sediment supply on drainage basin development in small watersheds at the northern border of the central Alps of Switzerland. *Geomorphology* 46, 285–305.
- Schmid, S. M., Fügenschuh, B., Kissling, E., Schuster, R., 2004. Tectonic map and overall architecture of the alpine orogen. *Eclogae Geologicae Helvetiae* 97, 93–117.
- Schmidt, J., Hewitt, A., 2004. Fuzzy land element classification from DTMs based on geometry and terrain position. *Geoderma* 121 (3-4), 243–256.
- Schmidt, K. M., Montgomery, D. R., 1995. Limits to relief. *Science* 270, 617–620.
- Schoorl, J. M., Sonneveld, M. P. W., Veldkamp, A., 2000. Three-dimensional landscape process modelling: the effect of DEM resolution. *Earth Surface Processes and Landforms* 25, 1025–1034.
- Seidl, M. A., Dietrich, M. E., 1992. The problem of channel erosion into bedrock. *Catena Supplement* 23, 101–124.
- Seijmonsbergen, A. C., 1992. Geomorphological evolution of an alpine area and its application to geotechnical and natural hazard appraisal. Ph.D. thesis, University of Amsterdam, 109 pp.
- Seijmonsbergen, A. C., Anders, N. S., Bouten, W., 2012. Geomorphological change detection using object-based feature extraction from multi-temporal LiDAR data. In: *Proceedings of GEOBIA 2012*. Rio de Janeiro, Brazil, May 2012., pp. 484–489.
- Seijmonsbergen, A. C., De Jong, M. G. G., De Graaff, L. W. S., 2009. A method for the identification and assessment of significance of geomorphosites in Vorarlberg (Austria), supported by Geographical Information Systems. *Memorie Descrittive della Carta Geologica d'Italia LXXXVI*, 163–172.
- Seijmonsbergen, A. C., De Jong, M. G. G., De Graaff, L. W. S., Anders, N. S., in prep. Geomorphological mapping and Geoconservation in Vorarlberg and Liechtenstein. Ruth und Herbert Uhl-Forschungsstelle für Natur- und Umweltschutz, Bristol-Stiftung, Zürich.
- Seijmonsbergen, A. C., Hengl, T., Anders, N. S., 2011. Semi-automated identification and extraction of geomorphological features using digital elevation data. In: Smith, M., Paron, P., Griffiths, J. (Eds.), *Geomorphological Mapping: Methods and Applications*. Vol. 15 of *Developments in Earth Surface Processes*. Elsevier, Elsevier, Amsterdam, pp. 297–335.
- Seijmonsbergen, A. C., Sevink, J., Cammeraat, L. H., Recharte, J., 2010. A potential geoconservation map of the Las Lagunas area, northern Peru. *Environmental Conservation* 37 (02), 107–115.
- Selby, M. J., 1980. A rock mass strength classification for geomorphic purposes: with tests from Antarctica and New-Zealand. *Zeitschrift für Geomorphologie* 24, 31–51.
- Selby, M. J., 1982. Controls on the stability and inclinations of hillslopes formed on hard rock. *Earth Surface Processes and Landforms* 7, 449–467.
- Selby, M. J., 1987. Rock slopes. In: Anderson, M. G., Richards, K. S. (Eds.), *Slope Stability*. Wiley, Chichester, pp. 475–504.
- Seong, Y. B., Owen, L. A., Bishop, M. P., Bush, A., Clendon, P., Copland, L., Finkel, R. C., Kamp, U., Shroder Jr, J. F., 2008. Rates of fluvial bedrock incision within an actively uplifting orogen: Central Karakoram Mountains, northern Pakistan. *Geomorphology* 97, 274–286.
- Serrano, E., González-Trueba, J. J., 2005. Assessment of geomorphosites in natural protected areas: the Picos de Europa Natural Park (Spain). *Géomorphologie: relief, processus, environnement* 3, 197–208.
- Sharples, C., 2002. Concepts and principles of geoconservation. Electronic document, <http://goo.gl/SC1RH>.
- Shepard, D., 1968. A two-dimensional interpolation for irregularly-spaced data. In: *Proceedings of the 23rd ACM National Conference*.
- Siart, C., Bubenzer, O., Eitel, B., 2009. Combining digital elevation data (SRTM/ASTER), high resolution satellite imagery (Quickbird) and GIS for geomorphological mapping: A multi-component case study on Mediterranean karst in Central Crete. *Geomorphology* 112 (1-2), 106–121.
- Simpson, G., Schlunegger, F., 2003. Topographic evolution and morphology of surfaces evolving in response to coupled fluvial and hillslope sediment transport. *Journal of Geophysical Research* 108, B6, 2300.
- Sklar, L. S., Dietrich, W. E., 2001. Sediment and rock strength controls on river incision into bedrock. *Geology* 29, 1087–1090.
- Smith, M. J., Chandler, J., Rose, J., 2008. High spatial resolution data acquisition for the geosciences: kite aerial photography. *Earth Surface Processes and Landforms* 34, 115–161.
- Stürm, B., 1994. The geotope concept: geological nature conservation by town and country planning. In: O'Halloran, D., Green, C., Harley, M., Stanley, M., Knill, J. (Eds.), *Geological and Landscape Conservation*. Geological Society, London, pp. 27–31.
- Tarboton, D. G., 1997. A new method for the determination of flow directions and upslope areas in grid digital elevation models. *Water Resources Research* 33, 309–319.

- Tarboton, D. G., Bras, R. L., Rodriguez-Iturbe, I., 1991. On the extraction of channel networks from digital elevation data. *Hydrological Processes* 5 (1), 81–100.
- Tarolli, P., Borga, M., Fontana, G. D., 2008. Analysing the influence of upslope bedrock outcrops on shallow landsliding. *Geomorphology* 93 (3-4), 186–200.
- Tarolli, P., Fontana, G. D., 2009. Hillslope-to-valley transition morphology: New opportunities from high resolution DTMs. *Geomorphology* 113 (1-2), 47–56.
- Thoma, D. P., Gupta, S. C., Bauer, M. E., Kirchoff, C. E., 2005. Airborne laser scanning for riverbank erosion assessment. *Remote Sensing of Environment* 95 (4), 493–501.
- Thompson, J. A., Bell, J. C., Butler, C. A., 2001. Digital elevation model resolution: effects on terrain attribute calculation and quantitative soil-landscape modeling. *Geoderma* 100, 67–89.
- Trimble, 2010. Trimble eCognition Developer reference book. Document Version 8.7, Trimble Germany GmbH, 420pp.
- Tucker, G. E., Bras, R. L., 1998. Hillslope processes, drainage density, and landscape morphology. *Water Resources Research* 34, 2751–2764.
- Tucker, G. E., Hancock, G. R., 2010. Modelling landscape evolution. *Earth Surface Processes and Landforms* 35, 28–50.
- Tucker, G. E., Lancaster, S. T., Gasparini, N. M., Bras, R. L., Rybarczyk, S. M., 2001. An object-oriented framework for distributed hydrologic and geomorphic modeling using triangulated irregular networks. *Computers & Geosciences* 27, 959–973.
- Tucker, G. E., Slingerland, R. L., 1994. Erosional dynamics, flexural isostasy, and long-lived escarpments; A numerical modeling study. *Journal of Geophysical Research* 99, 12229–12243.
- Tucker, G. E., Slingerland, R. L., 1996. Predicting sediment flux from fold and thrust belts. *Basin Research* 8, 329–349.
- Van Asselen, S., Seijmonsbergen, A. C., 2006. Expert-driven semi-automated geomorphological mapping for a mountainous area using a laser DTM. *Geomorphology* 78 (3-4), 309–320.
- Van Den Eeckhaut, M., Poesen, J., Verstraeten, G., Vanacker, V., Nyssen, J., Moeyersons, Van Beek, L. P. H., Vandekerckhove, L., 2007. Use of LiDAR-derived images for mapping old landslides under forest. *Earth Surface Processes and Landforms* 32(5), 754–769.
- Van Noord, H., Rupke, J., Seijmonsbergen, A. C., De Graaff, L. W. S., 1996. Integralpilotstudie Montafon: geomorphological, geotechnical and natural hazard maps at scale 1:10.000 in the eastern Rätikon Mountains and the Montafon region, Vorarlberg. Report to the Bundesministerium für Land- und Forstwirtschaft.
- Ventura, G., Vilardo, G., Terranova, C., Belluci Sessa, E., 2011. Tracking and evolution of complex active landslides by multi-temporal airborne LiDAR data: The Montaguto landslide (Southern Italy). *Remote Sensing of Environment* 115, 3237–3248.
- Verstappen, H. T., 2011. Old and new trends in geomorphological and landform mapping. In: Smith, M. J., Paron, P., Griffiths, J. S. (Eds.), *Geomorphological Mapping: Methods and Applications*. Vol. 15 of *Developments in Earth Surface Processes*. Elsevier, Amsterdam, pp. 13–38.
- Walter, V., 2004. Object-based classification of remote sensing data for change detection. *ISPRS Journal of Photogrammetry and Remote Sensing* 58, 225–238.
- Wang, F., 1990a. Fuzzy supervised classification of remote sensing images. *IEEE Transactions on Geoscience and Remote Sensing* 28, 194–201.
- Wang, F., 1990b. Improving remote sensing image analysis through fuzzy information representation. *Photogrammetric Engineering and Remote Sensing* 56, 1163–1169.
- Whipple, K. X., Tucker, G. E., 2000. Rates and processes of bedrock incision by the Upper Ukak River since the 1912 Novarupta ash flow in the Valley of Ten Thousand Smokes, Alaska. *Geology* 28, 835–838.
- Willgoose, G., Bras, R. L., Rodriguez-Iturbe, I., 1991a. A coupled channel network growth and hillslope evolution model 1: Nondimensionalization and applications. *Water Resources Research* 27, 1685–1696.
- Willgoose, G., Bras, R. L., Rodriguez-Iturbe, I., 1991b. A coupled channel network growth and hillslope evolution model 1: theory. *Water Resources Research* 27, 1671–1684.
- Wilson, 2012. Digital terrain modeling. *Geomorphology* 137, 107–121.
- Yokoyama, R., Shirasawa, M., Pike, R. J., 2002. Visualizing topography by openness: a new application of image processing to digital elevation models. *Photogrammetric Engineering and Remote Sensing* 68 (3), 257–265.
- Zhou, Q., Liu, X., Sun, Y., 2006. Terrain complexity and uncertainties in grid-based digital terrain analysis. *International Journal of Geographical Information Science* 20, 1137–1147.