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Use of remote sensing data in environmental hydraulics

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Outline

- General comments
- Applications
- Conclusions

Remote sensing

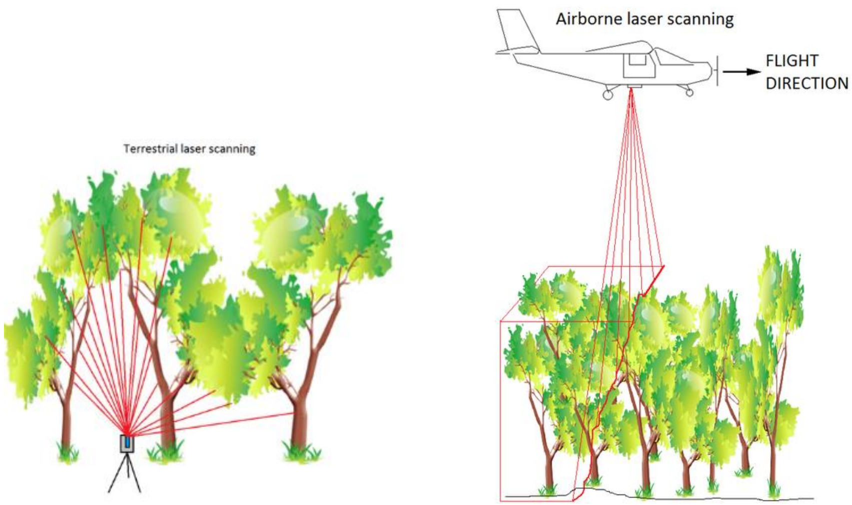
Rivers are continuous systems that vary across multiple space and time scales. To truly document the range of river structures and functions therefore requires continuous data (Lane et al., 1994) across a wide range of spatial and temporal scales (Fonstad and Marcus, 2010). Methods classically used to map rivers, such as cross-sections or detailed reach scale surveys, capture only a small portion of a river and often do not portray the range of variations throughout the system. ***Remote sensing can provide continuous coverage at varying resolutions on a repeat basis, thus creating the potential to document a remarkable range of variations in river parameters.*** *In this case, necessity (for the river scientists) has been the mother of invention.*

Marcus, W. A., and Fonstad, M. A. (2010). "Remote sensing of rivers: the emergence of a subdiscipline in the river sciences." *Earth Surf. Process. Landforms, DOI: 10.1002/esp.2094.*

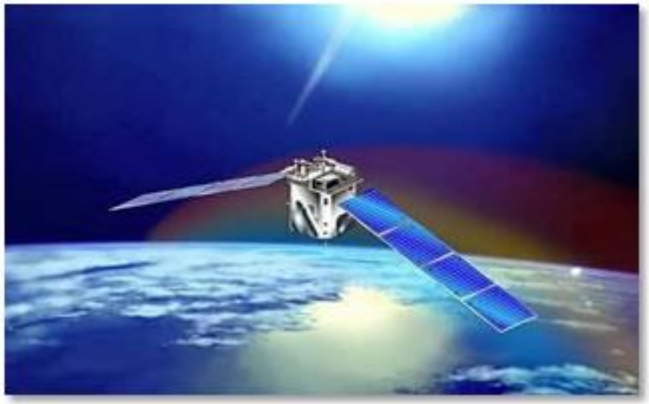
Remote sensing

- Acquisition of information without physical contact
  - For example: ultrasonic, radar, optical, laser, photogrammetry, etc.

- Terrestrial, airborne, and from space



Source: AWF-Wiki (Universität Göttingen)



Source: http://ccar.colorado.edu/rses/

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Remote sensing

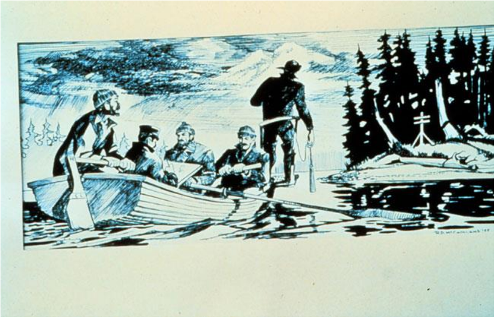
- Provides data covering small to large spatial scales with high resolution

Source: Juha Järvelä

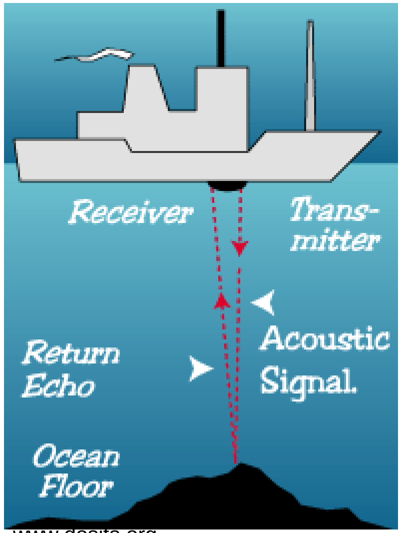
- Repeated remote sensing allows for monitoring over time

Remote sensing data – some examples

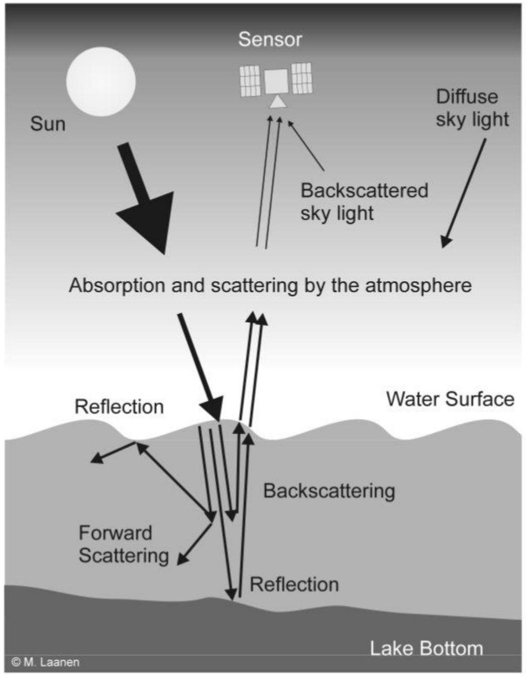
- Determination of water levels, bed levels and water depth



Picture from
http://celebrating200years.noaa.gov



www.dosits.org
(Source: Naval Meteorology and Oceanography Command)



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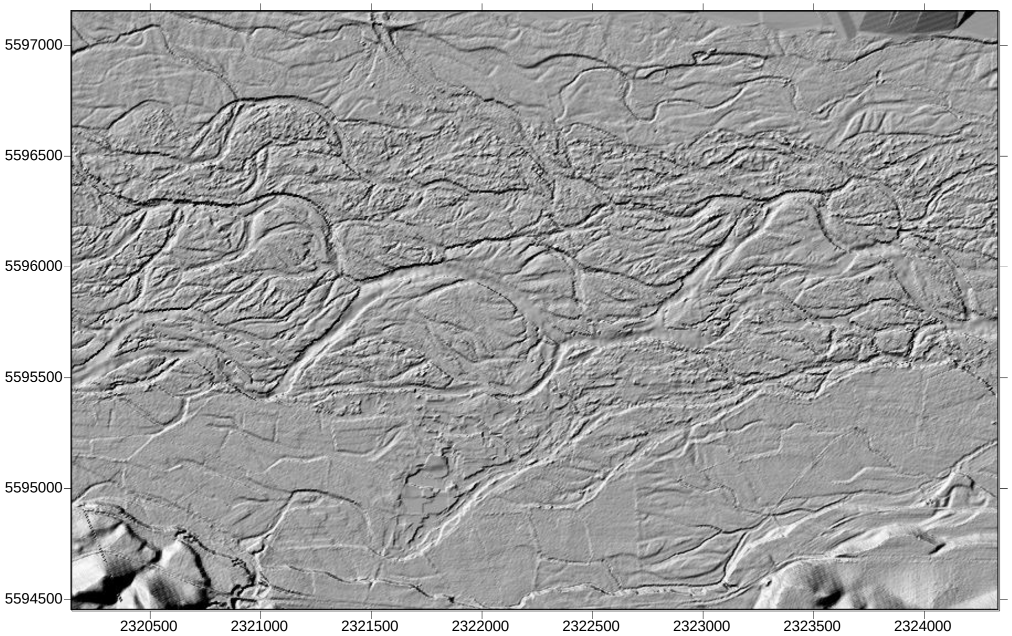
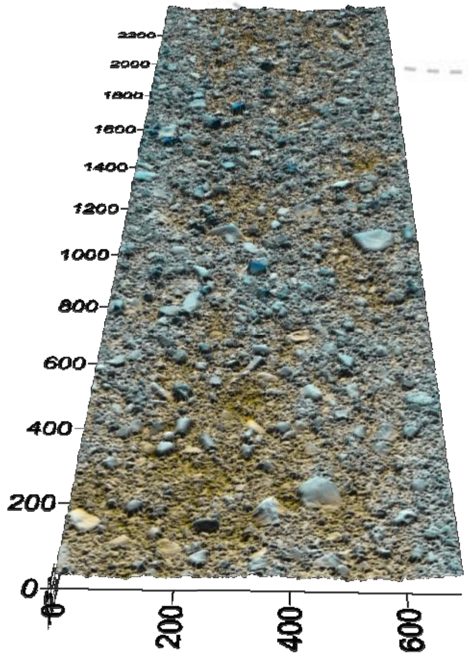
Remote sensing data – some examples

- Bathymetry and digital elevation models



Waitaki River, New Zealand



DEM of a gravel bed
in a laboratory study

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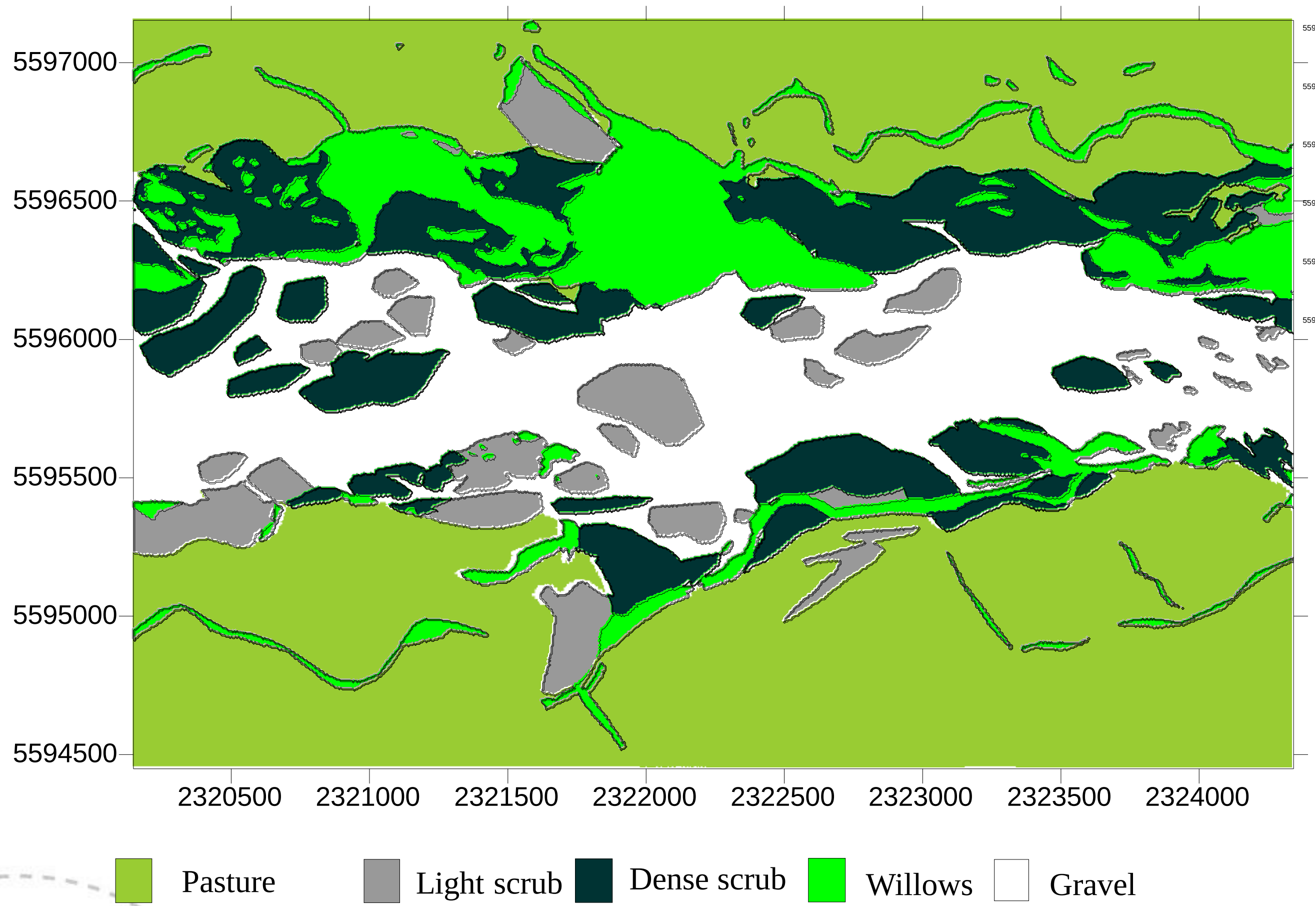
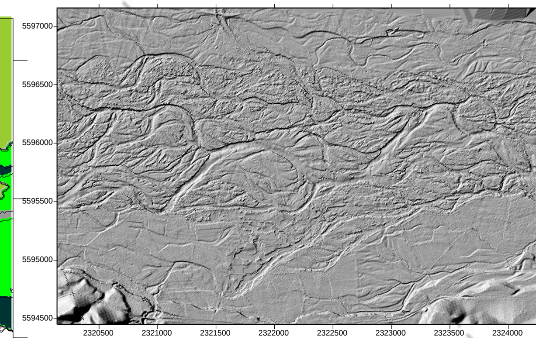
Remote sensing data – some examples

- Vegetation mapping





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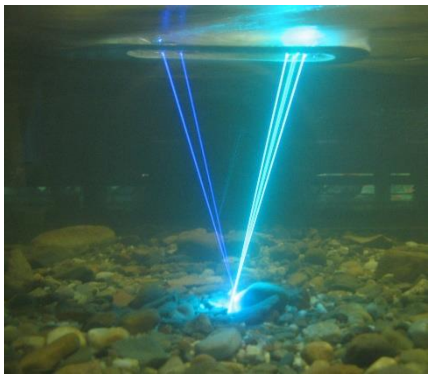
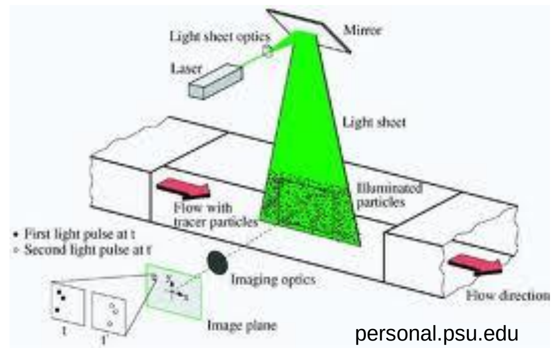
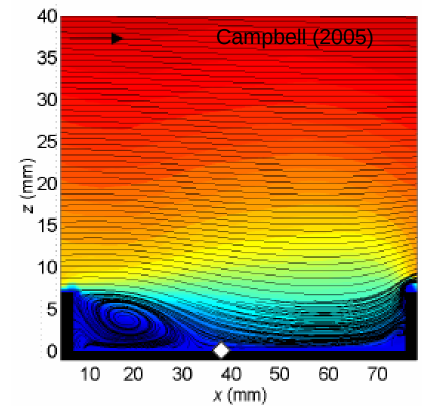
Remote sensing data – some examples

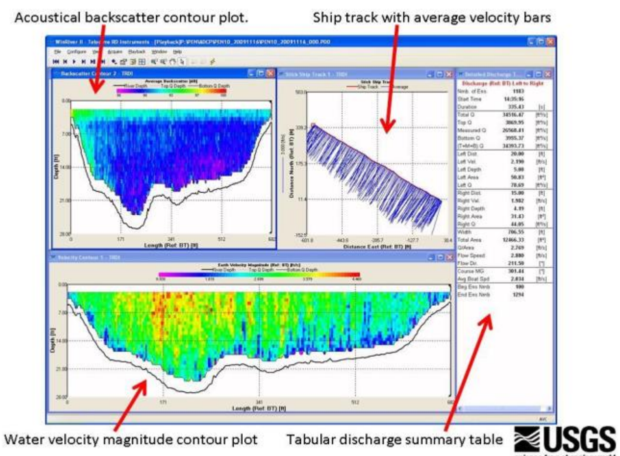
- Velocity measurements





personal.psu.edu






Nortek

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Remote sensing data – applications…

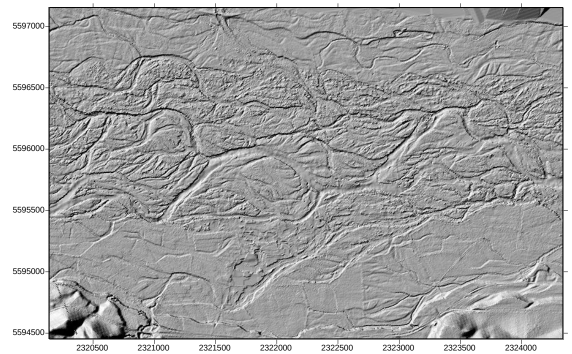
- Google search for *remote sensing data*: 567 000 hits
  - Including *environment*: 451 000
  - Including *hydrology*: 305 000
  - Including *hydraulics*: 145 000

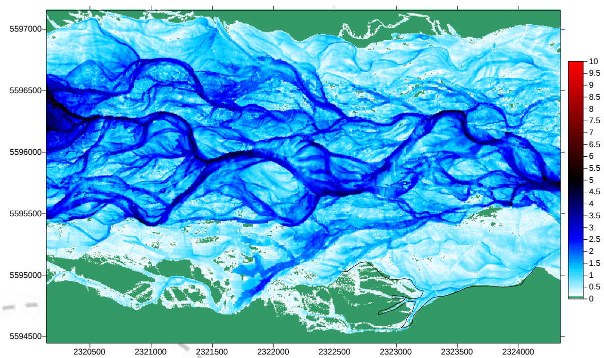
- Many applications for environmental hydraulics
  - Many recent publications in specialized as well as hydraulic journals…

- The use of remote sensing data in *environmental hydraulics* can best be shown by some recent examples…

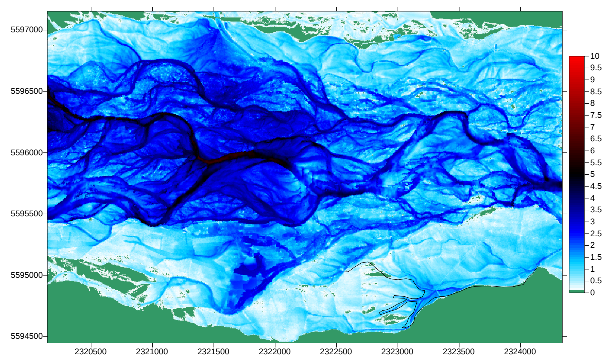
Flood inundation modelling

- Hicks, D.M., Shankar, U., Duncan, M.J., Rebuffe, M., Aberle, J. (2006). **"Use of remote-sensing technology to assess impacts of hydro-operations on a large, braided, gravel-bed river: Waitaki River, New Zealand."** In Sambrook- Smith, G.H., Best, J.L., Bristow, C.S., and Petts, C.S. (eds,), raided rivers - process, deposits, ecology and management, Special Publication 36 of the IAS, Blackwell, 311-326.

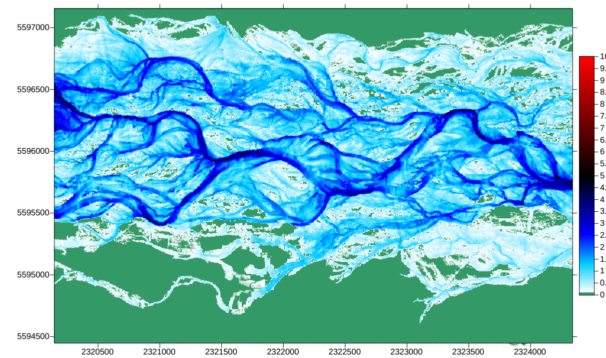




Water depth: existing vegetation (Q = 2700 m³/s)



Water depth: extreme vegetation



Water depth: cleared fairway

Flood inundation modelling

- New possibilities for model setup and model calibration
  - Large scale DEM's with high resolution
  - Assessment of accuracy
  - Measurement of water surface elevations and velocities for model calibration

– Alessio,D., Attilio, C., Brath, A.(2015). "**Hydraulic model calibration using remote-sensing data: The usefulness of ERS-2 and ENVISAT water surface levels.**" In: G. Lollino et al. (eds.), Engineering Geology for Society and Territory – Volume 3, DOI: 10.1007/978-3-319-09054-2_120.

– McKean, J., Tonina, D., Bohn, C., Wright, C.W. (2014). "**Effects of bathymetric lidar errors on flow properties predicted with a multi-dimensional hydraulic model.**" *Journal of Geophysical Research: Earth Surface*, 2013JF002897.

– Pan, F., Nichols, J. (2013). **"Remote sensing of river stage using the cross-sectional inundation area-river stage relationship (IARSR) constructed from digital elevation model data."** *Hydrolog. Process.,* 27(25), 3596-3606.

– Williams, R. D., Brasington, J., Hicks, M., Measures, R., Rennie, C. D., and Vericat, D. (2013). "**Hydraulic validation of two-dimensional simulations of braided river flow with spatially continuous aDcp data.**" *Water Resour. Res.*, 49(9), 5183-5205.

– Hopkinson, C., Crasto, N., Marsh, P., Forbes, D., Lesack, L. (2011). **"Investigating the spatial distribution of water levels in the Mackenzie Delta using airborne LiDAR."** Hydrolog. Process., 25(19), 2995-3011.

– Schumann, G., Bates, P. D., Horrit, M. S., Matgen, P., and Pappenberger, F. (2009). "**Progress in integration of remote sensing–derived flood extent and stage data and hydraulic models.**" *Reviews of Geophysics, 47(RG4001), doi:10.1029/2008RG000274.*

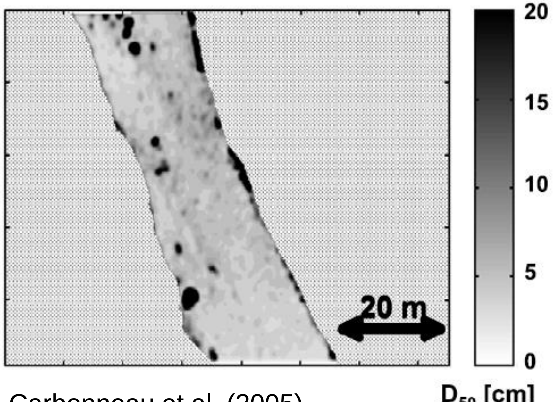
– …

Characterisation of roughness

- Classical approach:
  Grain size distribution
  - Black, M., Carbonneau, P., Church, M., Warburton, J. (in press). **"Mapping sub-pixel fluvial grain sizes with hyperspatial imagery."** *Sedimentology*.

Hyperspatial imagery of a bar (A) and D50 grain-size map (B). (Black et al., in press)

  - Dugdale, S.J., Carbonneau, P.E., Campbell, D. (2010). **"Aerial photosieving of exposed gravel bars for the rapid calibration of airborne grain size maps."** Earth Surf. Process. Landforms, 35, 627-639.
  - Carbonneau, P.E., Bergeron, N., and Lane, S.N. (2005). **"Automated grain size measurements from airborne remote sensing for long profile measurements of fluvial grain sizes."** Water Resour. Res., 41, W11426, doi:11410.11029/12005WR003994.
  - …



Carbonneau et al. (2005)

Characterisation of roughness

- Enables development of novel approaches:
  Random field approach – information on roughness structure
  - Huang, G.-H., Wang, C.-K. (2012). "**Multiscale geostatistical estimation of gravel-bed roughness from terrestrial and airborne laser scanning.**" *Geoscience and Remote Sensing Letters,* IEEE, 9(6), 1084-1088.
  - Coleman, S.E., Nikora, V.I., Aberle, J. (2011). **"Interpretation of alluvial beds through bed-elevation distribution moments."** *Water Resour. Res.*, 47(W11505), doi:10.1029/2011WR010672.
  - Aberle, J., Nikora, V., Henning, M., Ettmer, B., Hentschel, B. (2010). **"Statistical characterization of bed roughness due to bed forms: A field study in the Elbe River at Aken, Germany."** *Water Resour. Res.,* 46(W03521), doi:10.1029/2008WR007406.
  - Aberle, J., Nikora, V. (2006). **"Statistical properties of armored gravel bed surfaces."** *Water Resour. Res., 42,* W11414, doi:11410.11029/12005WR004674.
  - Aberle, J., Smart, G.M. (2003). **"The influence of roughness structure on flow resistance on steep slopes."** *J. Hydraul. Res., 41(3), 259–269.*
  - …

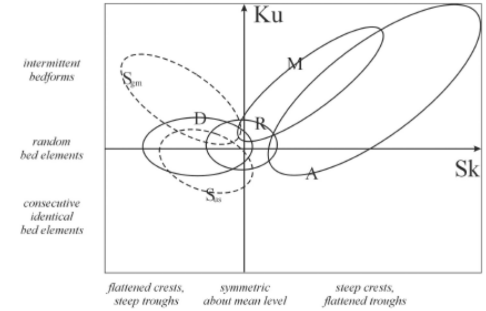


Figure 9. Bed-structure classification based on bed-elevation distribution moments, where "R" = ripples, "D" = dunes (with fully 3D dunes tending toward "R"), "S_{us}" = artificially screeded uniform sands, "S_{gm}" = artificially screeded gravel mixtures, "M" = planar beds of mobile uniform sands, "A" = armoured gravel beds, and $Sk = Ku = 0$ at the intersection of the axes.

Coleman et al. (2011)

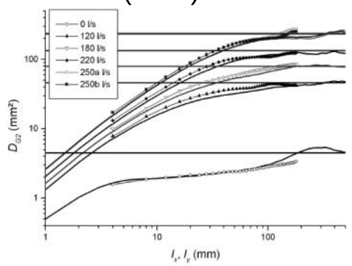
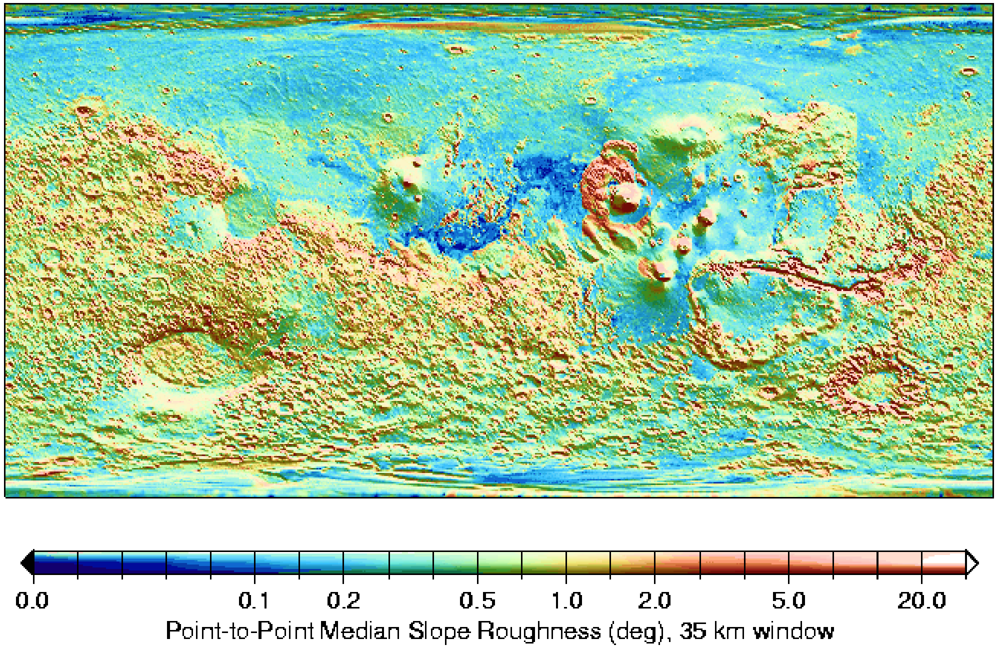


Figure 5. Second-order structure functions for $l_y = 0$ (straight lines) and $l_x = 0$ (line and symbol) for the surfaces shown in Figure 2 and for the initial bed ($Q_a = 0$ L s^{-1}). The horizontal lines indicate the corresponding values of $2\sigma_z^2$.

Aberle and Nikora (2006)

We are no longer restricted to earth…

- A look into space…
  - Pommerol, A., Chakraborty, S., Thomas, N. (2012). **"Comparative study of the surface roughness of the Moon, Mars and Mercury."** Planetary and Space Science, 73(1), 287-293.
  - Bourke, M. C., Balme, M., Beyer, R. A., Williams, K. K., Zimbelman, J. (2006). **"A comparison of methods used to estimate the height of sand dunes on Mars."** Geomorphology, 81, 440–452.
  - …



http://tharsis.gsfc.nasa.gov/slopes.html

mars-pic-nasa-511014976.jpg

Morphology

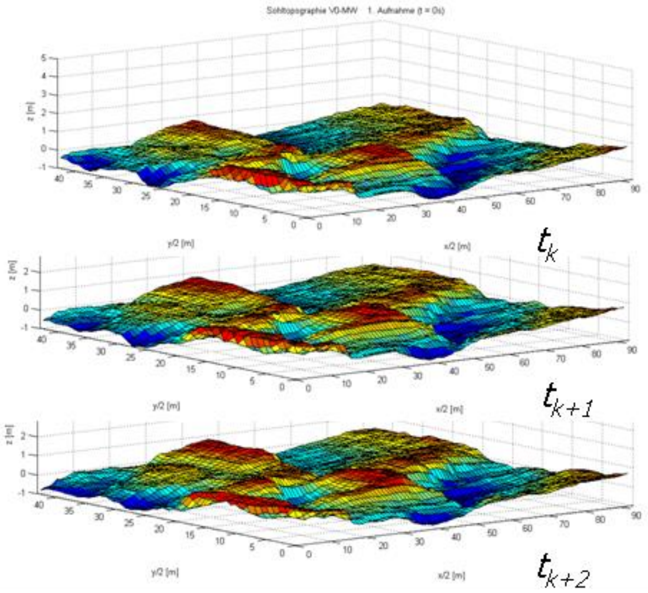
- A look from space on earth…
  - Legleiter, C. J., Overstreet, B. T. (2012). **"Mapping gravel bed river bathymetry from space."** *J. Geophys. Res.*, 117(F4), F04024.

We can also stay on earth…

- Javernick, L., Brasington, J., and Caruso, B. (in press) "**Modelling the topography of shallow braided rivers using Structure-from-Motion photogrammetry.**" *Geomorphology.*
- Lague, D., Brodu, N., and Leroux, J. (2013). **"Accurate 3D comparison of complex topography with terrestrial laser scanner: Application to the Rangitikei canyon (N-Z)."** *ISPRS Journal of Photogrammetry and Remote Sensing*, 82(0), 10-26.
- Brasington, J., Vericat, D., Rychkov, I. (2012). **"Modeling river bed morphology, roughness, and surface sedimentology using high resolution terrestrial laser scanning."** *Water Resour. Res., 48(11), W11519.*
- Legleiter, C. J. (2012). **"Remote measurement of river morphology via fusion of LiDAR topography and spectrally based bathymetry."** *Earth Surf. Process. Landforms,* 37(5), 499-518.
- Hodge, R., Brasington, J., Richards, K. (2009). **"In situ characterization of grain-scale fluvial morphology using Terrestrial Laser Scanning."** *Earth Surf. Process. Landforms, 34, 954-968*
- …

… and look into

- Sediment transport and flow processes



  - Anderson, S., Pitlick, J. (2014). **"Using repeat lidar to estimate sediment transport in a steep stream."** *Journal of Geophysical Research: Earth Surface,* 119(3), 621-643.
  - Aberle, J., Coleman, S.E., and Nikora, V.I. (2012). **"Bed load transport by bed form migration."** *Acta Geophys., 60(6), 1720-1743.*
  - Sarmiento, C. J. S., Gonzalez, R. M., and Castro, P. P. M. (2012). **"Reservoir inflow estimation using remote sensing, GIS and geosimulation."** *Journal of Earth Science and Engineering,* 2012(2), 472-487.
  - Smith, M.W., Cox, N.J., Bracken, L.J. (2011). **"Terrestrial laser scanning soil surfaces: a field methodology to examine soil surface roughness and overland flow hydraulics.**" *Hydrolog. Process., 25, 842-860.*
  - Hodge, R., Brasington, J., and Richards, K. (2009). **"Analysing laser-scanned digital terrain models of gravel bed surfaces: linking morphology to sediment transport processes and hydraulics."** *Sedimentology,* 56, 2024-2043.
  - Thoma, D. P., Gupta, S. C., Bauer, M. E., and Kirchoff, C. E. (2005). **"Airborne laser scanning for riverbank erosion assessment.**" *Remote Sensing of Environment,* 95, 493-501.
  - Brasington, J., Langham, J., Rumsby, B. (2003). **"Methodological sensitivity of morphometric estimates of coarse fluvial sediment transport."** *Geomorphology,* 53, 299-316.
  - …

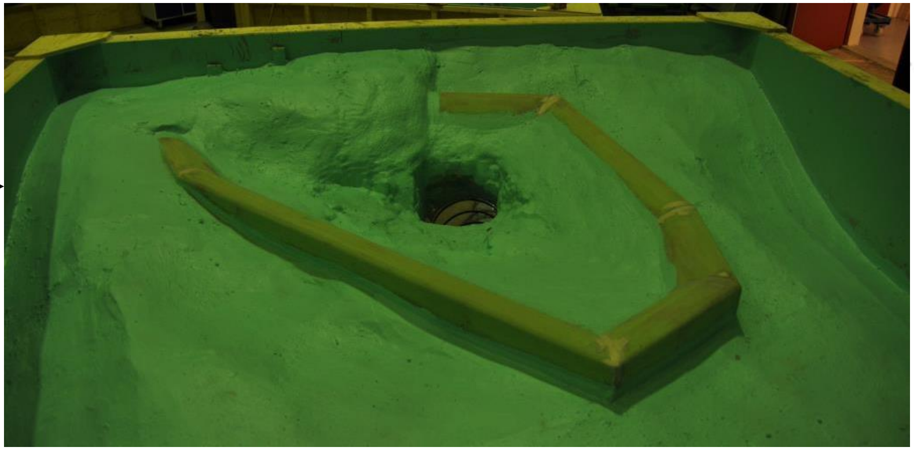
… and look into

- Determination of floodplain vegetation characteristics
  - Jalonen, J., Järvelä, J., Koivusalo, H., Hyyppä, H. (2014). **"Deriving Floodplain Topography and Vegetation Characteristics for Hydraulic Engineering Applications by Means of Terrestrial Laser Scanning.**" *J. Hydraul. Eng., 140(11), 04014056.*
  - Forzieri, G., Castelli, F., Preti, F. (2011). **"Advances in remote sensing of hydraulic roughness."** *International Journal of Remote Sensing, 33(2), 630-654.*
  - Antonarakis, A. S., Richards, K. S., Brasington, J., Muller, E. (2010). **"Determining leaf area index and leafy tree roughness using terrestrial laser scanning."** *Water Resour. Res.,* 46(W06510), doi:10.1029/2009WR008318.
  - Antonarakis, A.S. (2010). **"Evaluating forest biometrics obtained from ground lidar in complex riparian forests."** *Remote Sensing Letters,* 2(1), 61-70.
  - Antonarakis, A.S., Richards, K.S., Brasington, J., Bithell, M. (2009). **"Leafless roughness of complex tree morphology using terrestrial lidar."** *Water Resour. Res.,* 45(W10401), doi:10.1029/2008WR007666.
  - …

- Improve approaches for flow-vegetation interaction
  - Aberle, J., Järvelä, J. (2013). **"Flow resistance of emergent rigid and flexible floodplain vegetation."** *J. Hydraul. Res., 51(1), 33-45.*
  - Jalonen, J., Järvelä, J., and Aberle, J. (2013). **"Leaf area index as vegetation density measure for hydraulic analyses."** *J. Hydraul. Eng.,* 139(5), 461-469.
  - …

Last but not least…

- Novel possibilities for physical modelling…
  - Bertin, S., Friedrich, H., Delmas, P., Chan, E., Gimel'farb, G. (2014). "**DEM quality assessment with a 3d printed gravel bed applied to stereo photogrammetry**." *The Photogrammetric Record, 29(146), 241-264.*
  - Guttormsen, O., Roe, M., Belete, K., Aberle, J. (2014). "**Modellforsøk flomløp Dam Vasslivatn.** " Rapport B1-2014-1, ISBN 82-7598-087-9, NTNU, Trondheim, Norway.



Summary

- This talk provided only a glimpse of the use of remote sensing data in environmental hydraulics
- Remote sensing data will trigger further important advances in environmental hydraulics