MONITORING OF RIVERS AND CATCHMENTS USING REMOTE SENSING TECHNIQUES

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No extended abstract available.

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Monitoring of Rivers and Catchments using Remote Sensing Techniques

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Contents

- Some Remote Sensing Systems
- Automated Analysis of…

  … Hyperspectral images: Land cover classification
  … 3D data: Roughness classification and derivation of catchments
  … Interferometric SAR Data: Water flow and water level

- Final remarks

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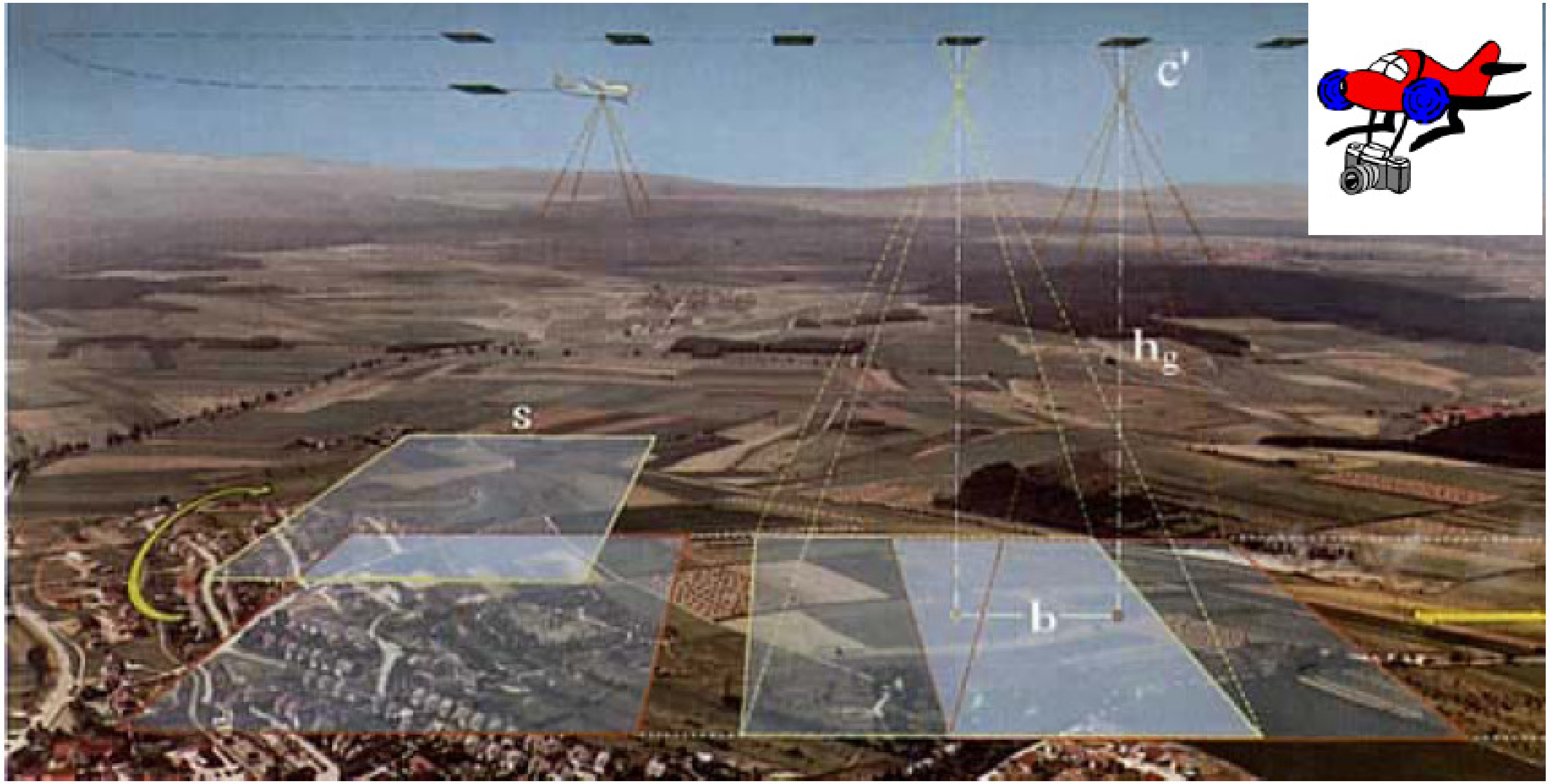
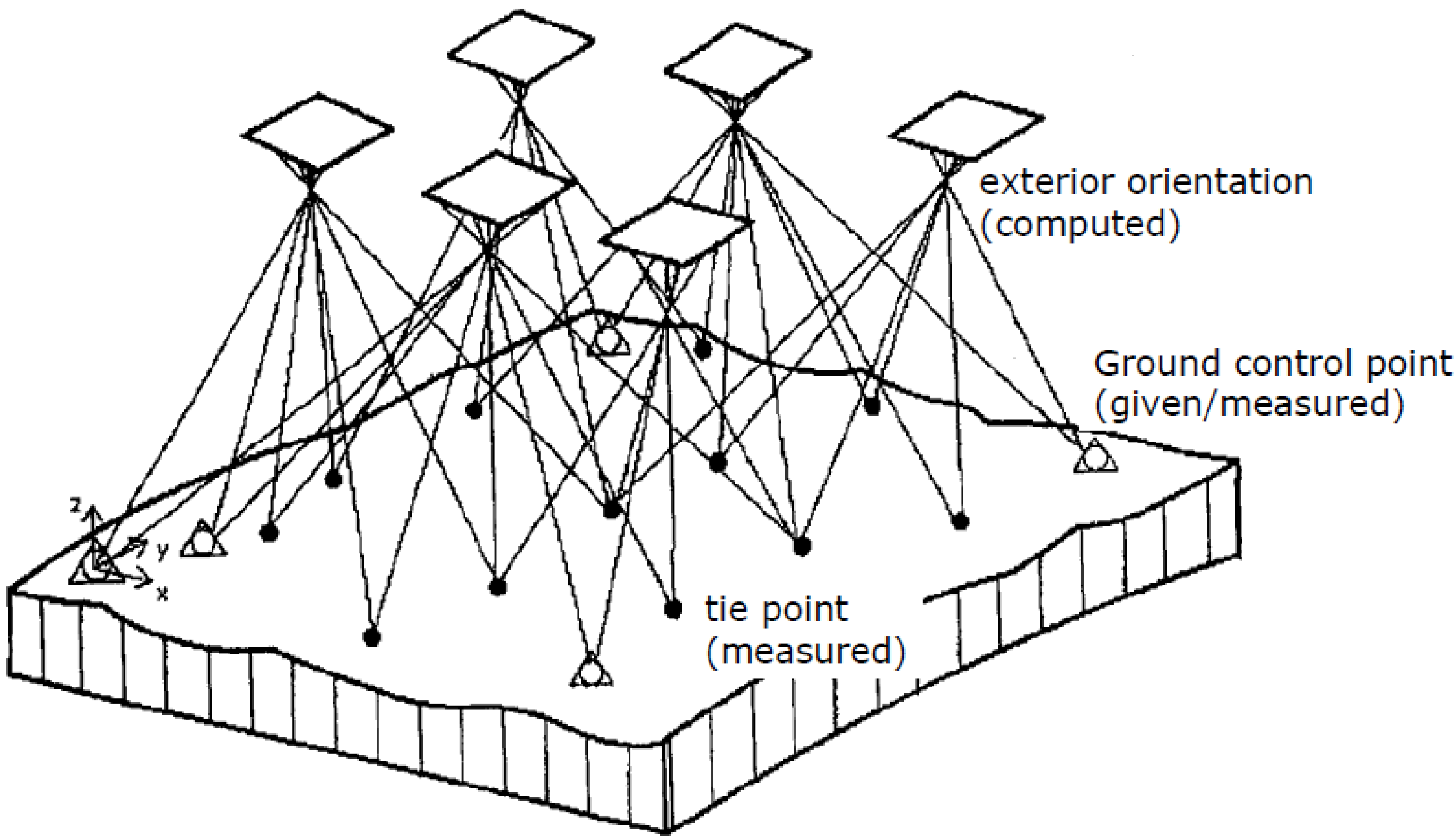
Examples of Remote Sensing and Photogrammetry

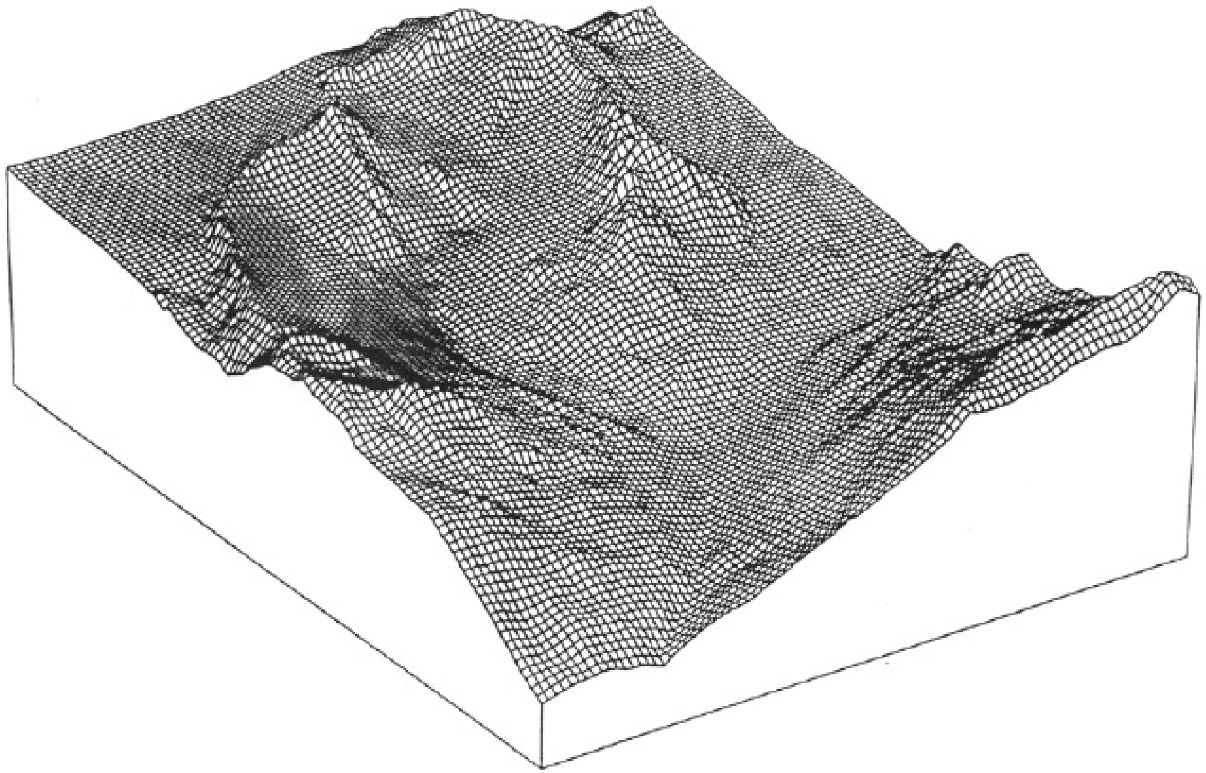


Photogrammetry – Image block adjustment



Position, orientation and (some) intrinsic parameters can be determined afterwards

DEM – Products of Remote Sensing and Photogrammetry



Another Remote Sensing Platform: Quadcopter

Quadkopter

3D Reconstruction from UAV

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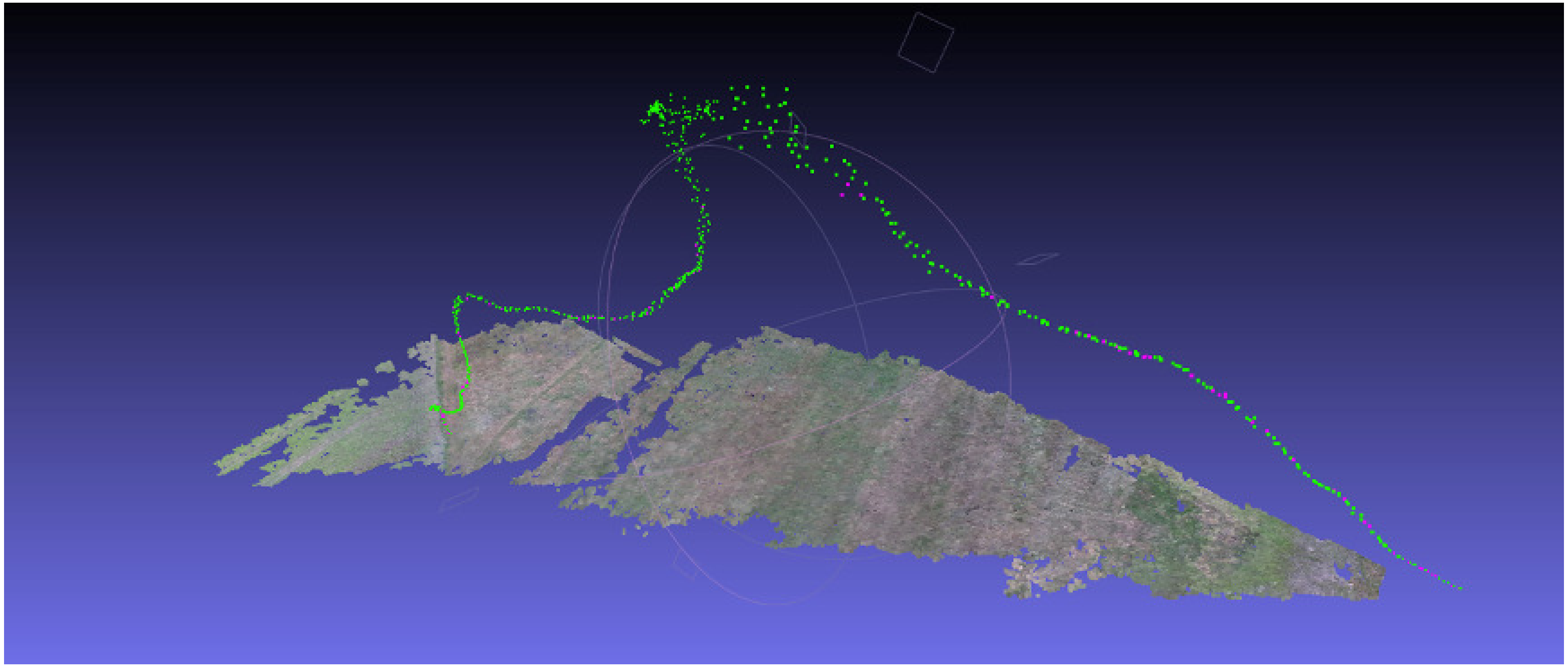
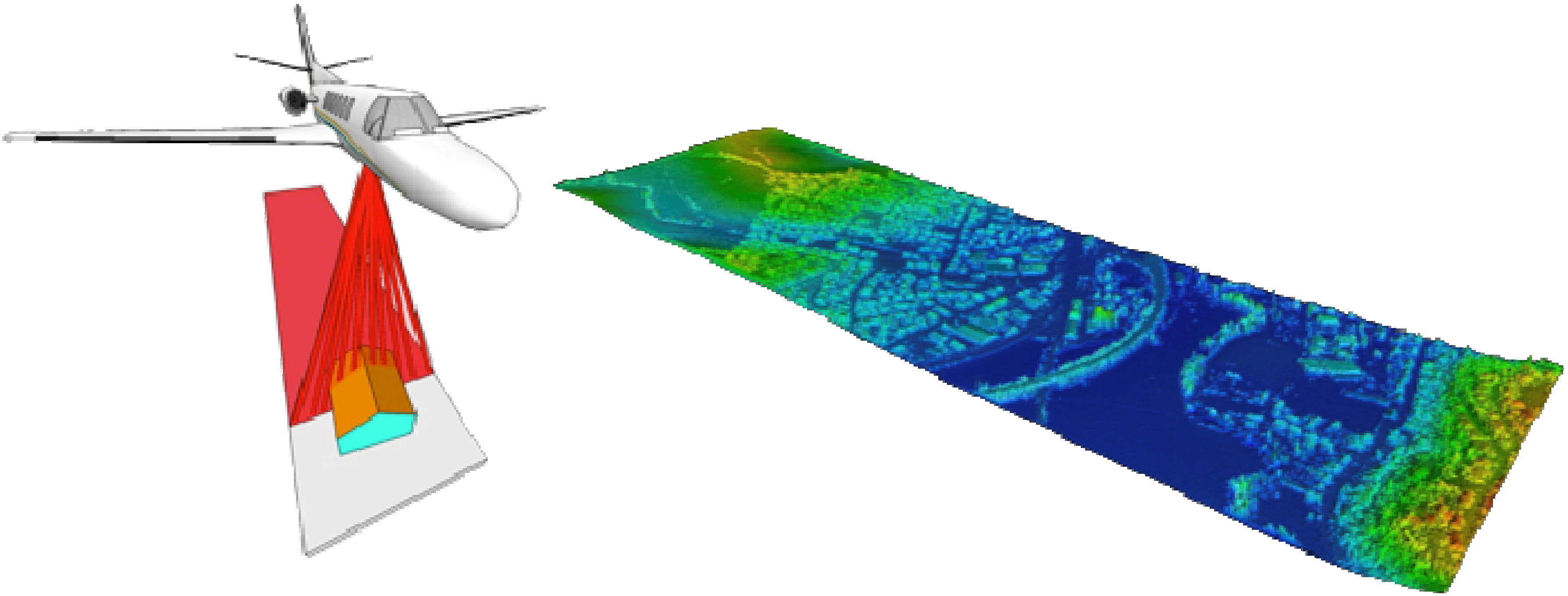
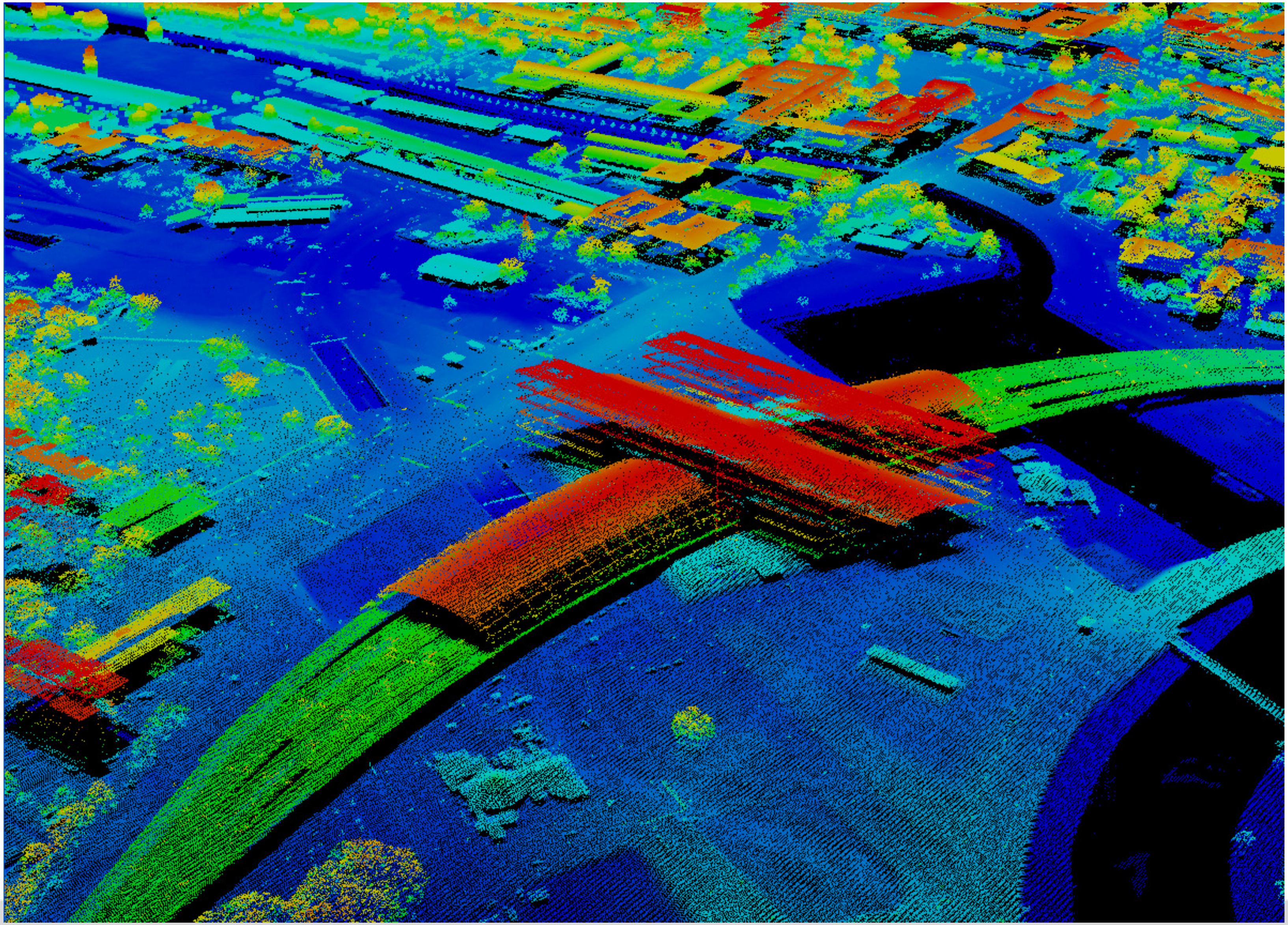


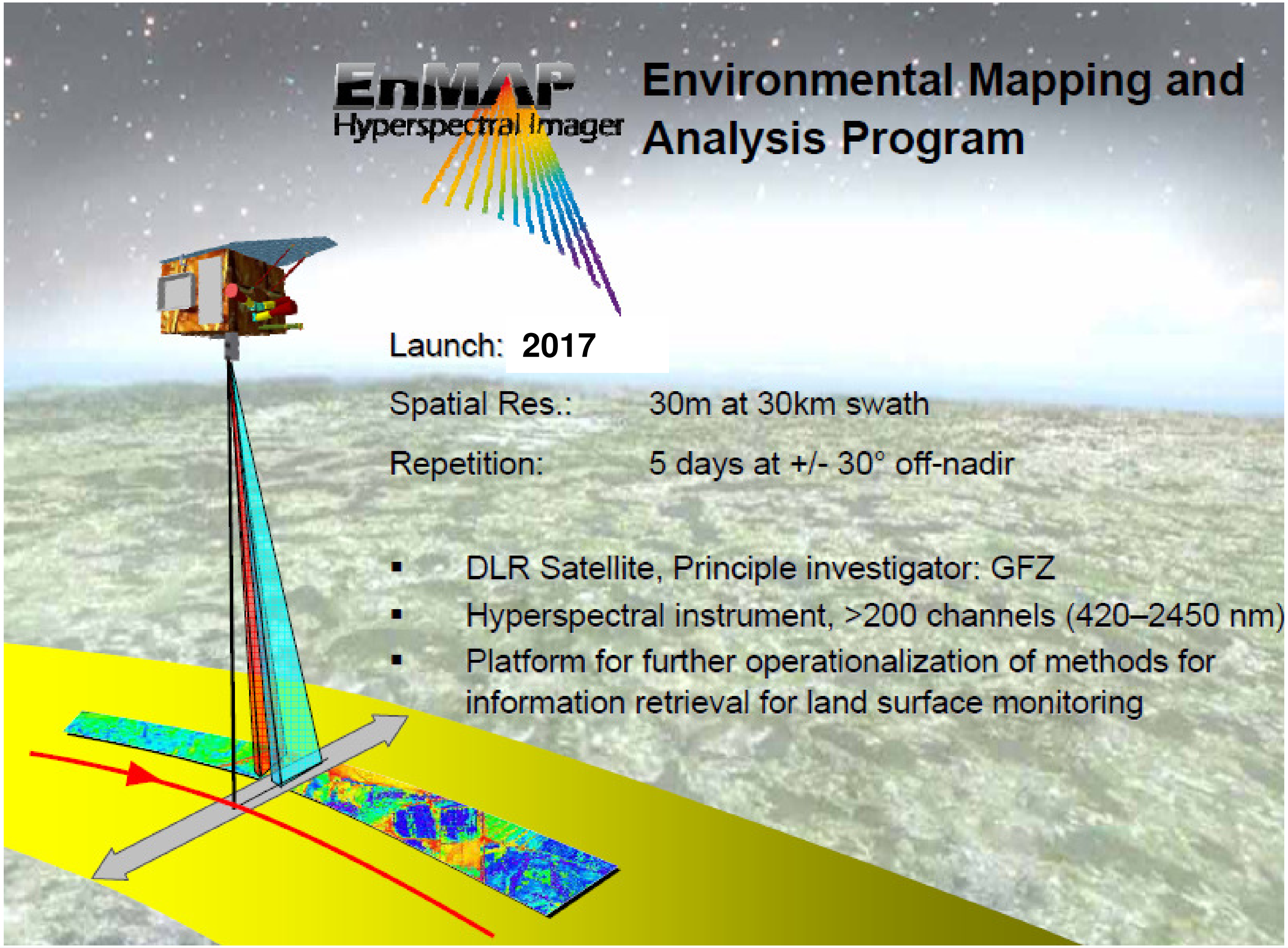
Airborne Laserscanning



Point Cloud from Airborne Laserscanning



Hyperspectral Sensing



Environmental Mapping and Analysis Program

Launch: **2017**

Spatial Res.: 30m at 30km swath

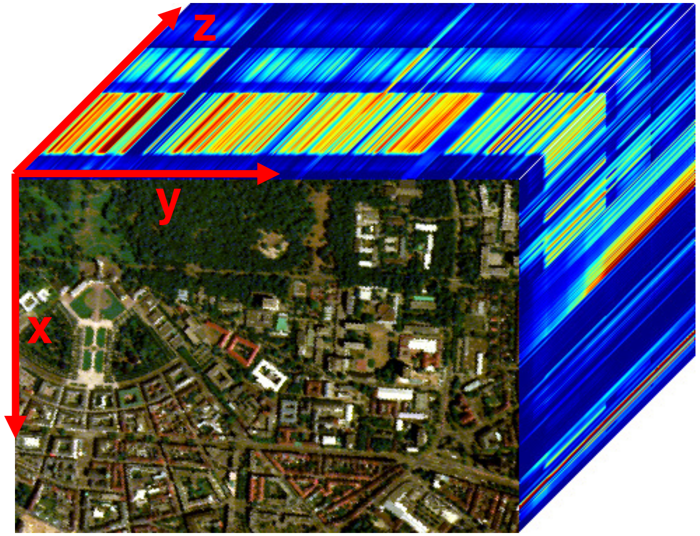
Repetition: 5 days at +/- 30° off-nadir

- DLR Satellite, Principle investigator: GFZ
- Hyperspectral instrument, >200 channels (420–2450 nm)
- Platform for further operationalization of methods for information retrieval for land surface monitoring

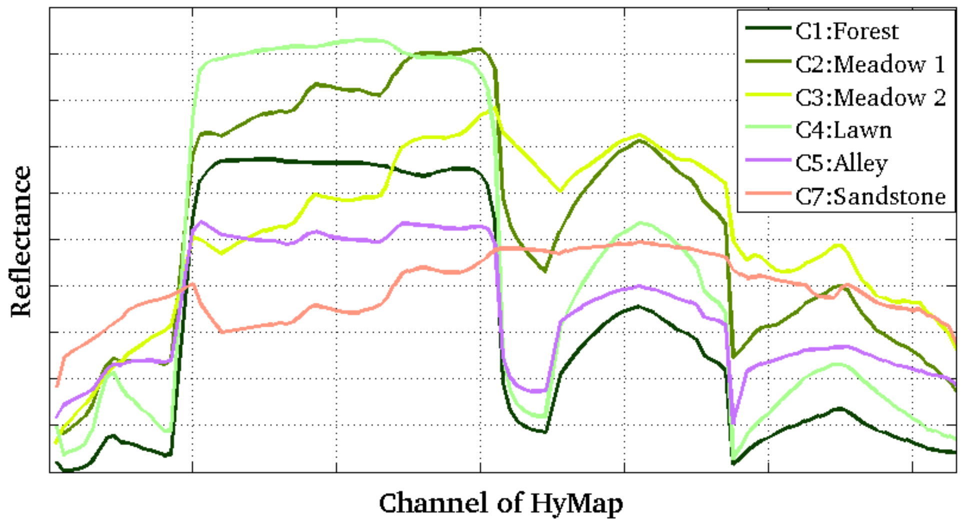
Hyperspectral Remote Sensing Datasets

- Hyperspectral Data produce a „data cube“ due to the high number of channels. Data can be viewed in various spaces

- **Image Space**
  - X: image height
  - Y: image width
  - Z: spectral channels

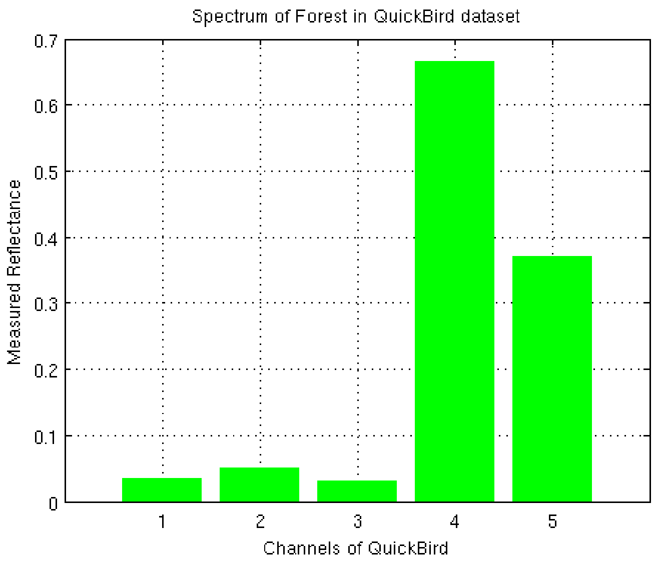


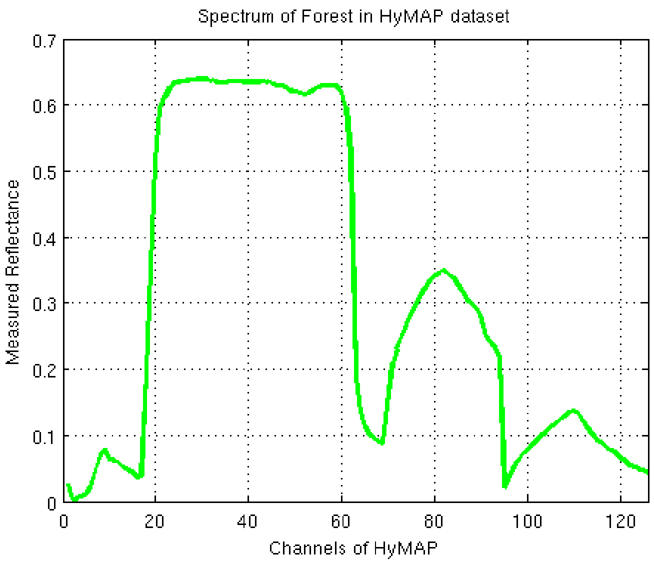
- **Spectral Space**
  - R = f (λ,....)



Hyperspectral Remote Sensing Datasets

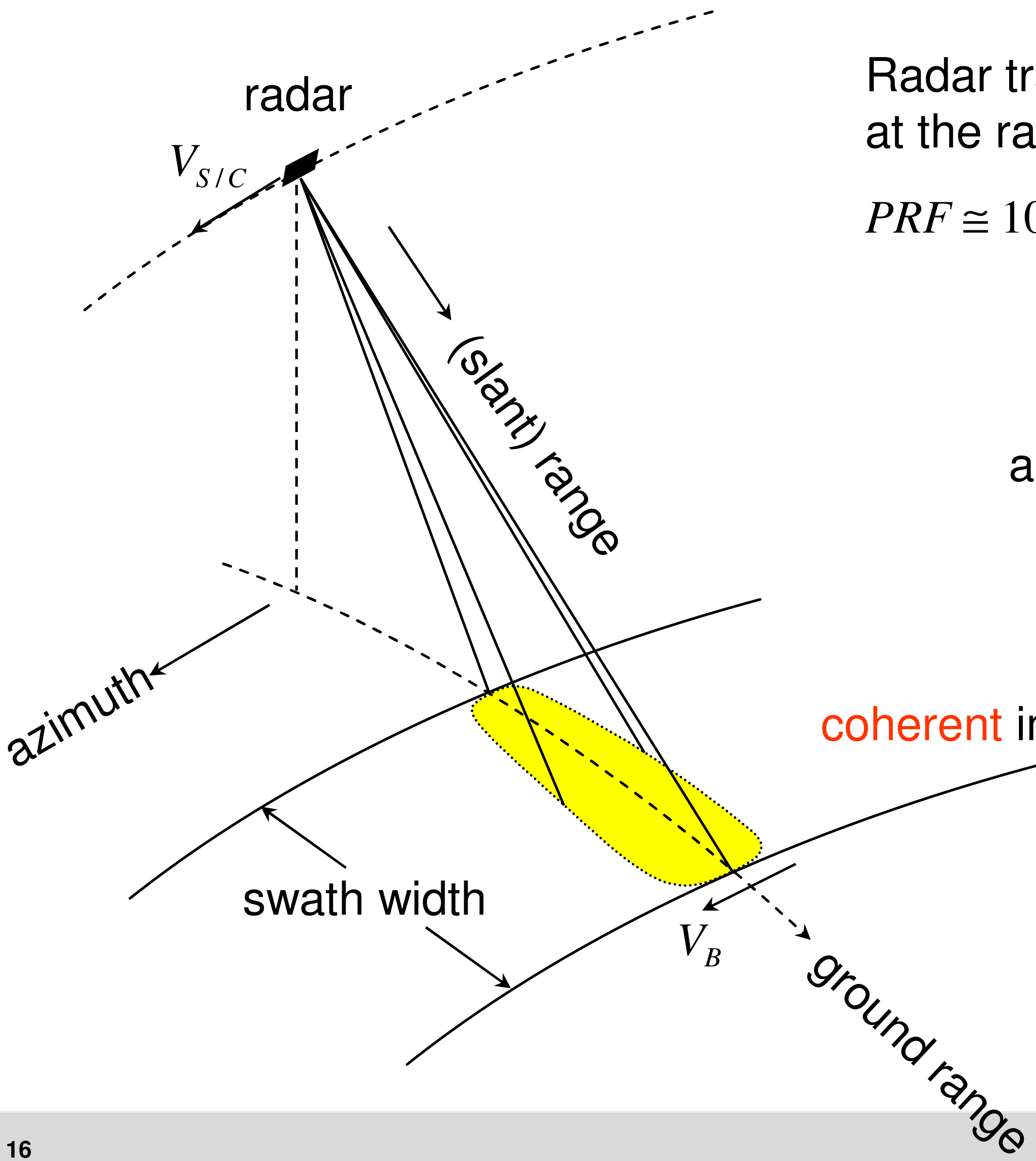
- Hyperspectral Data
  - High number of spectral channels (per def. > 60, Hyperion/EnMAP ~ 250)
  - Narrow bandwidth channels (bandwidth ~10-15nm)
  - Broad spectral range (typically 450 – 2500nm)
  - Continuous channels (i.e. no „gaps“ within the sampled spectrum)
  - Platforms: Spaceborne, Airborne, mounted to Eddy-Covariance Towers, mounted to agricultural machinery, handheld, mounted on UAV





Synthetic Aperture Radar (SAR)

SAR Imaging Geometry



Radar transmits pulses and receives echoes at the rate of the pulse repetition frequency:

$$PRF \cong 1000 - 6000 \text{ Hz}$$

range: radar principle = scanning at speed of light

azimuth: scanning in flight direction at V_B plus aperture synthesis (holography)

coherent imaging: complex-valued pixels contain amplitude (brightness) and **phase** information

Synthetic Aperture Radar - SAR

active ⇒ independent of sun illumination

microwave ⇒ penetrates clouds and (partially) canopy, soil, snow

wavelengths:	X-band:	3 cm
	C-band:	6 cm
	L-band:	24 cm

coherent ⇒ interferometry, speckle

polarization can be exploited

spatial resolution:	space-borne:	1 m - 100 m
	air-borne:	> 0.1 m

Pixel brightness depends on **physical** properties (roughness, electrical properties), while optical (multi-/hyperspectral) images reflect **chemical** properties.

Nördlingen

Remote Sensing Systems – Summary

- **Panchromatic and Multispectral Remote Sensing**
  - High geometric accuracy, high spatial resolution
  - ⇒ Good for 3D reconstruction and navigation purposes
  (but lower spectral resolution)

- **Laserscanning**
  - Direct 3D data acquisition, good reflection required

- **Hyperspectral Remote Sensing**
  - High spectral resolution
  => Good for thematic classification, identification of materials
  (but low spatial resolution)

- **SAR Remote Sensing**
  - Independent of weather and daylight (active system)
  - Interferometry and Polarimetry
  - ⇒ Good for analysis and monitoring of rough materials
  (but monochromatic)

All systems can be operated from ground, air and space

All systems can be influenced by atmosphere

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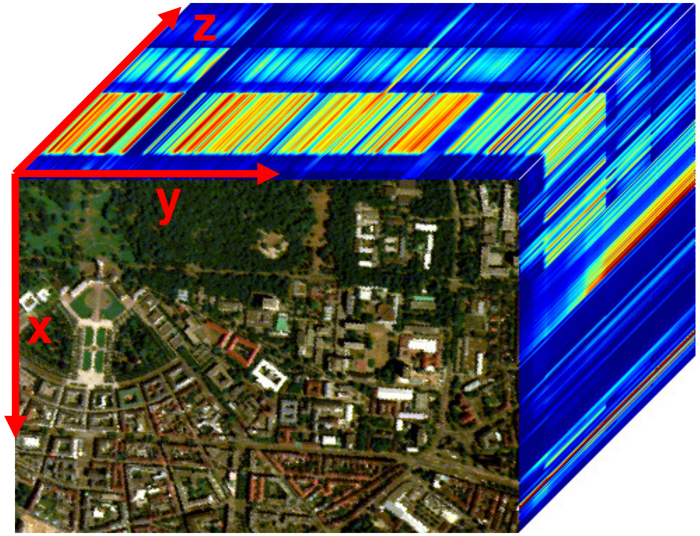

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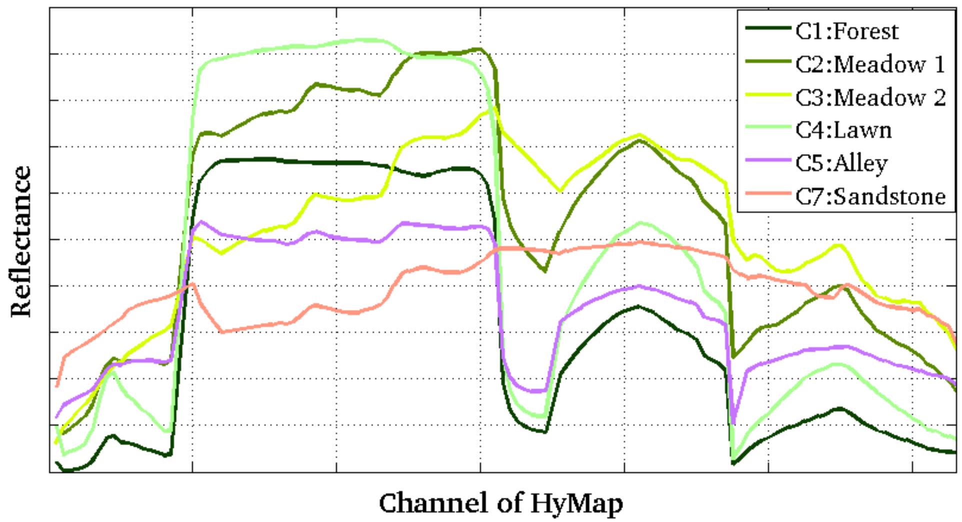
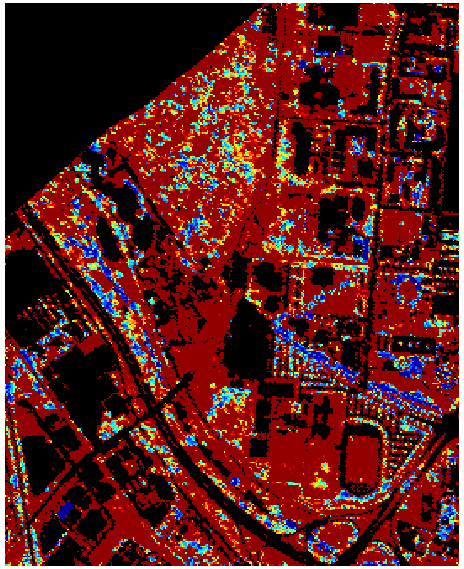


Environ. Modification: quantification of N, H_2O

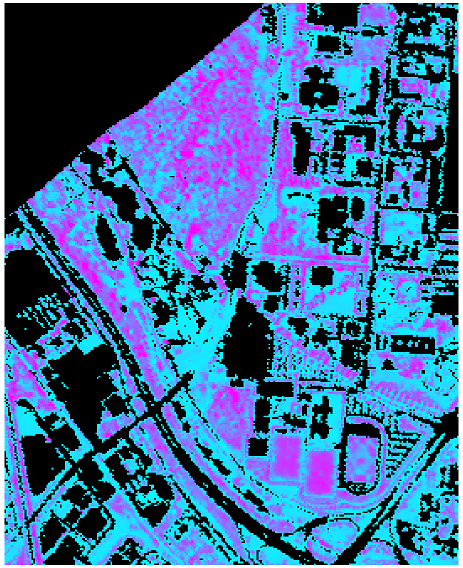
- <u>Continuous representation:</u>
- Left: NDWI: Normalized Difference WATER Index: H_2O Content of Veg.
- Right: NDNI: Normalized Difference NITROGEN Index: N Content

- Example: European „Heat Summer“ of 2003: water-stressed vegetation



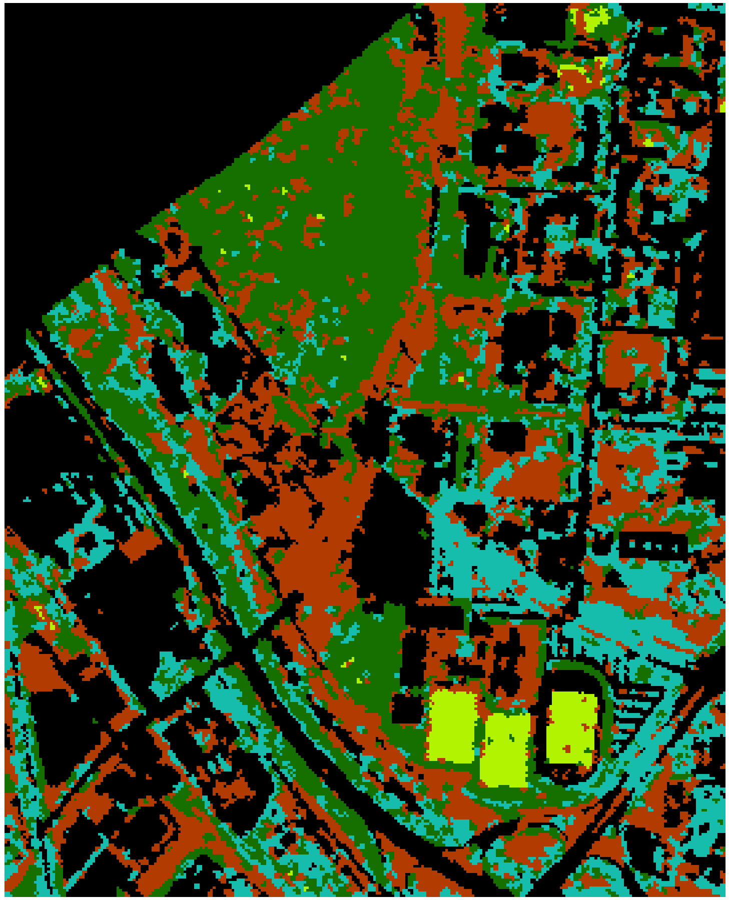
NDWI:
blue, high H_2O content

NDNI:
purple: high N content



Land cover classification

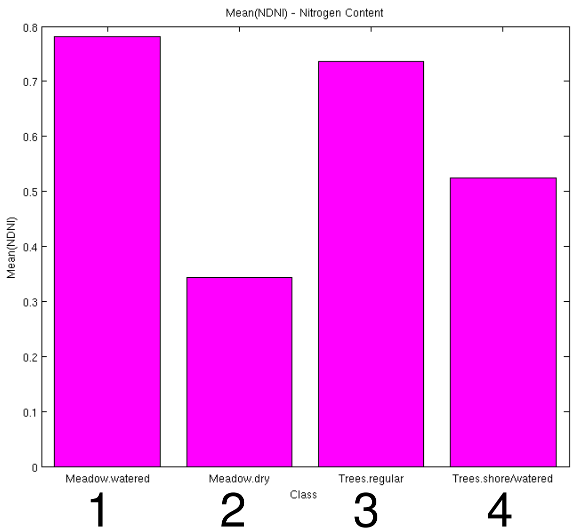
- Classification in order to detect vegetation classes



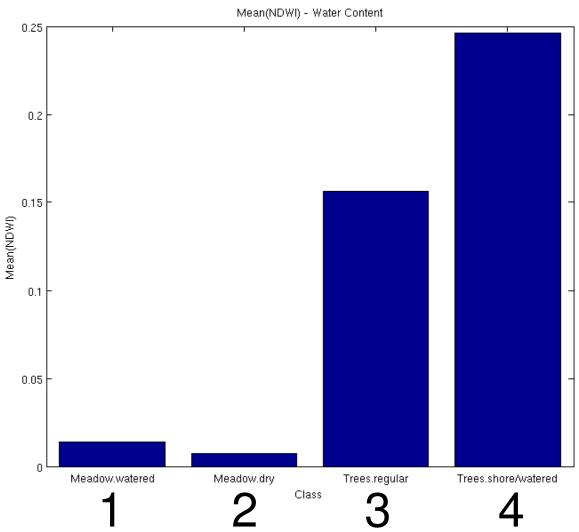
- Legend
  - Meadow watered
  - Meadow dry
  - Trees deciduous
  - Trees riparian/alley (i.e. watered)
  - No vegetation

Fusion of results: Estimation of N, H_2O contents for each vegetation class

Nitrogen



Water



1: Meadow watered
2: Meadow dry
3: Trees (deciduous forest)
4: Trees riparian/alley (i.e. watered)

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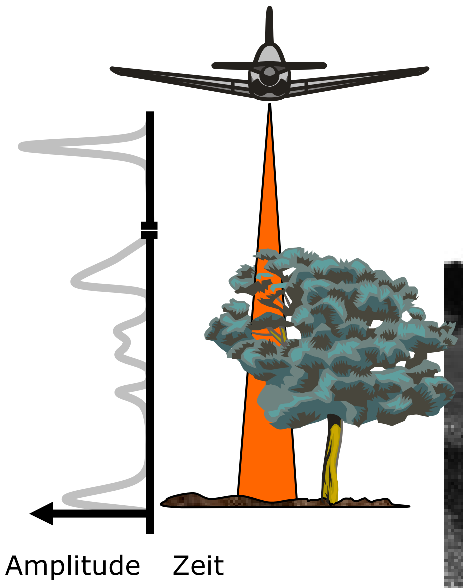
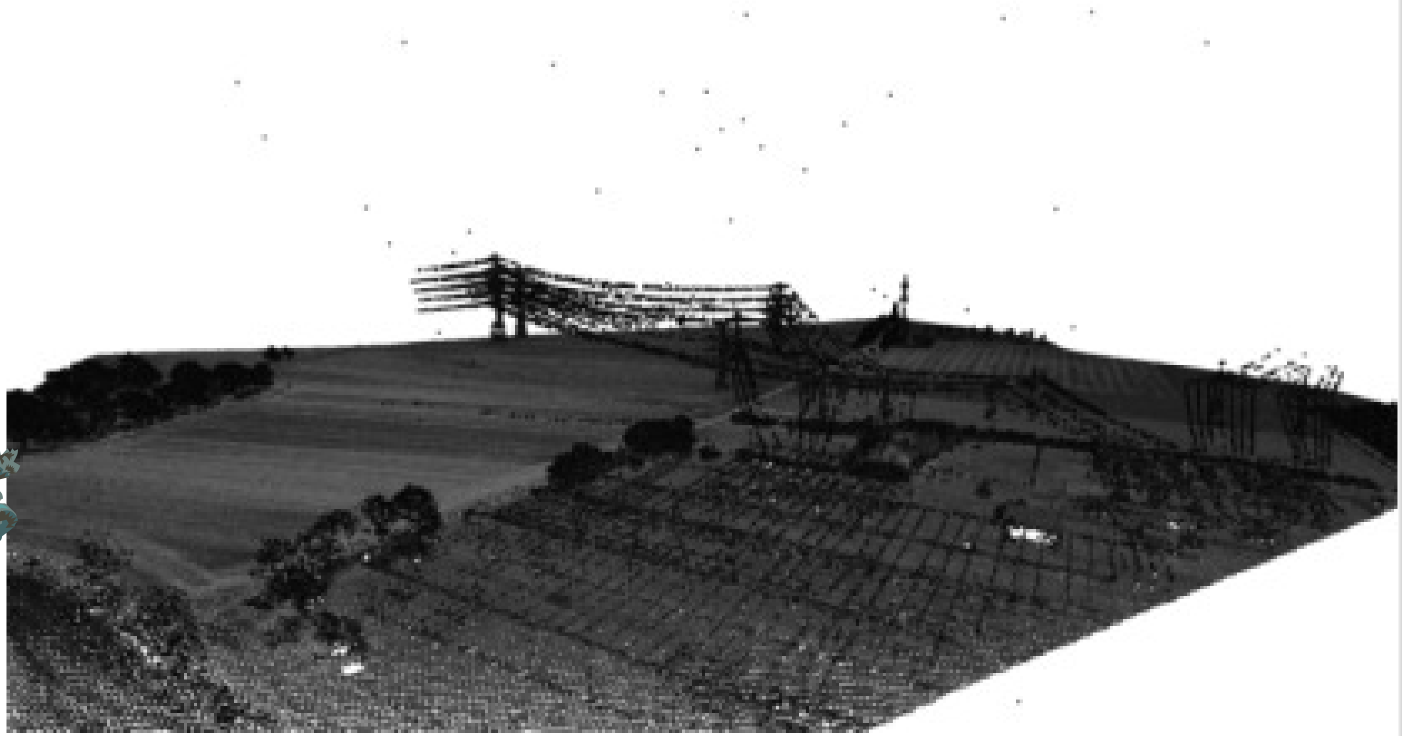
Full waveform sensing



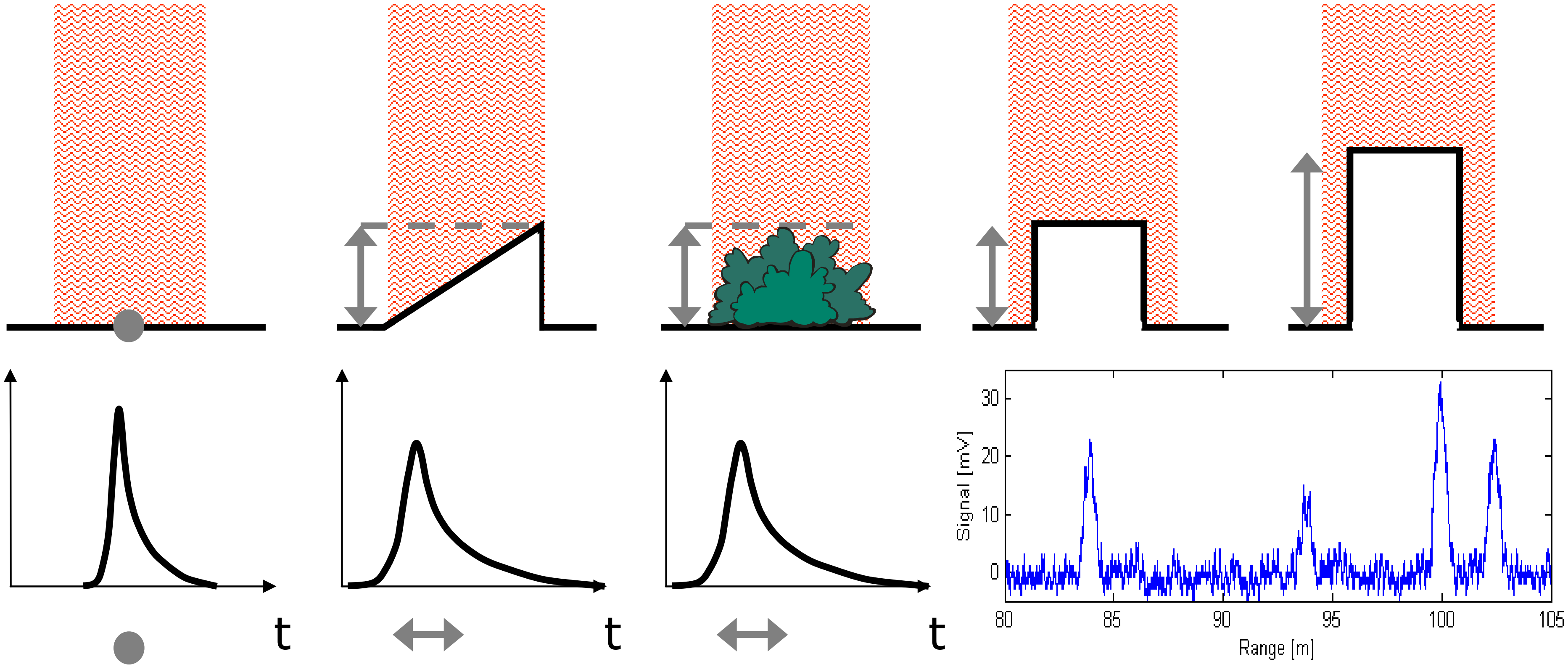


Sensororientierung:

- GPS
- INS
- Kalibrierung des Lasers
- Passflächen

Pulse modelling ("Waveform")

Surface characteristics and time-dependent waveform



Plane surface	Slope surface	Fine structured object	Low object	High object

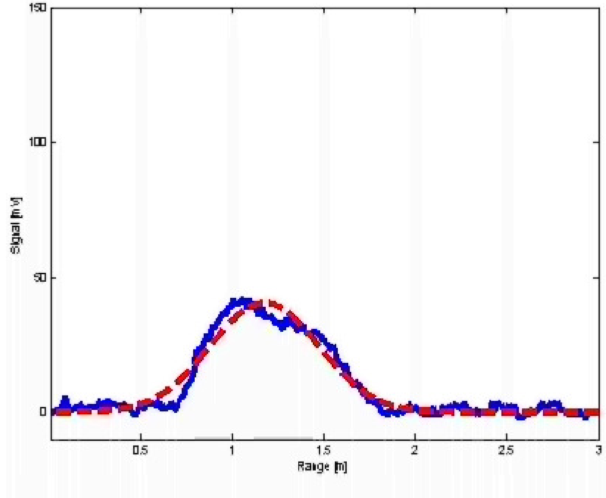
Feature extraction (I)

Simultaneous filtering and parameter estimation

⇨ "Multiple Gaussians"

Here: iterative parameter estimation by Levenberg-Marquardt method

$$g(t) = a\exp(-4 \cdot \ln(2) \cdot \frac{(t-\tau)^2}{w^2})$$



Measured and estimated waveform

Feature extraction (I)

Simultaneous filtering and parameter estimation

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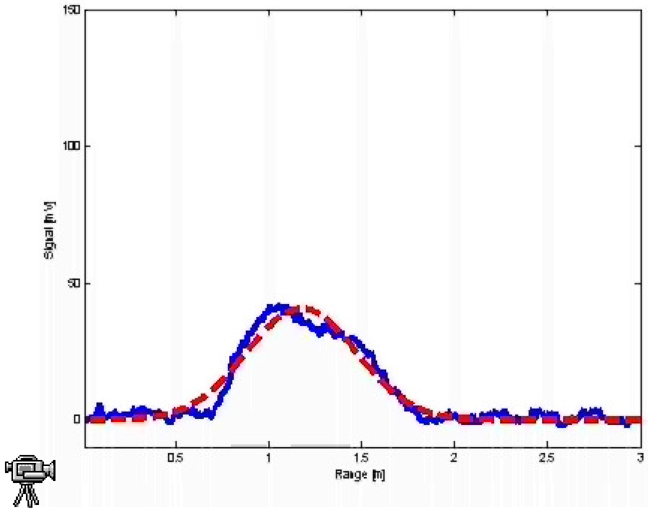
Pulse properties	Feature
Time τ	Range
Width w	Range variation
Amplitude a	Reflectivity



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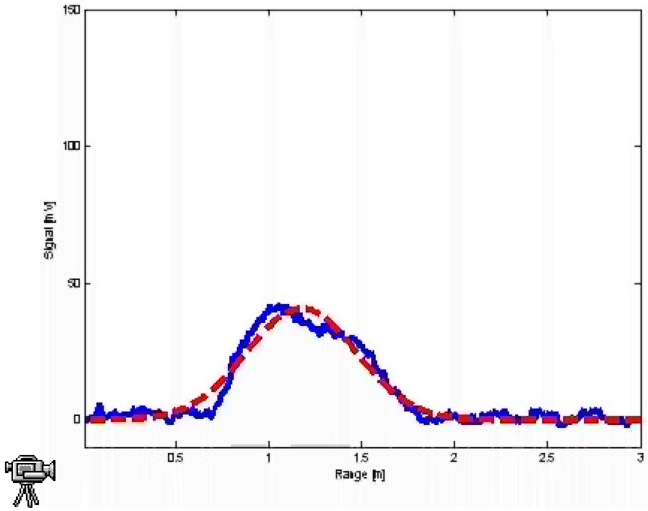
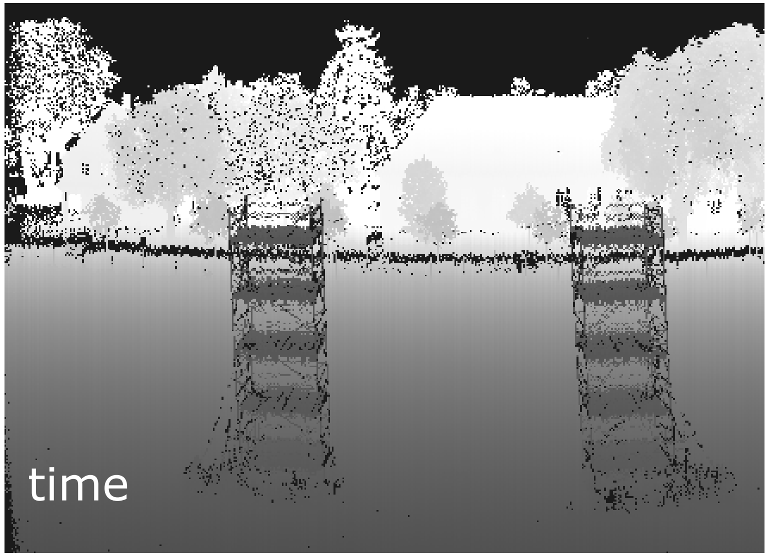
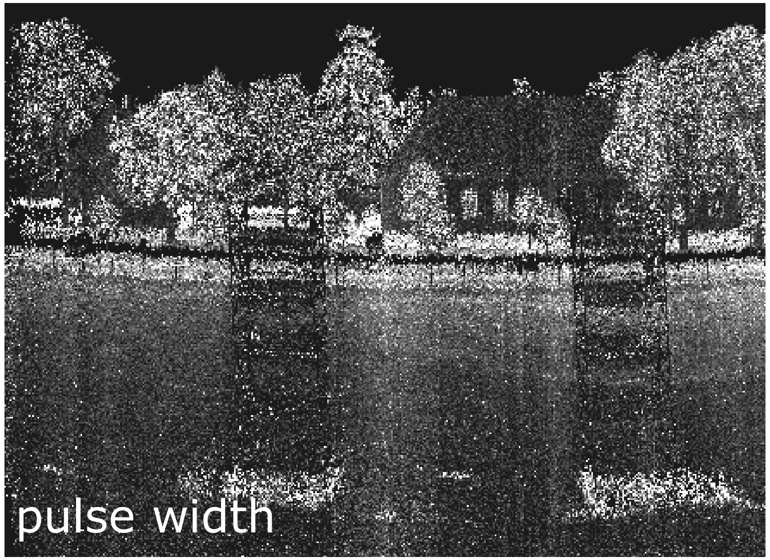


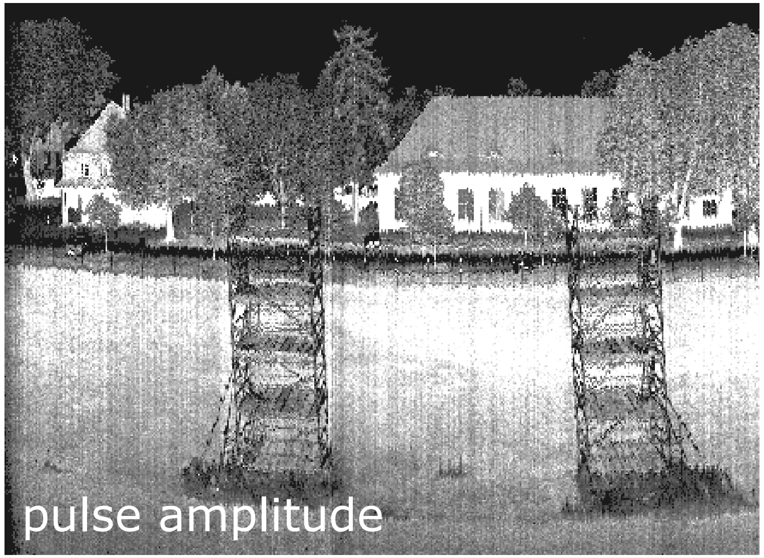
Measured and estimated waveform

- Advantage
  - No limitation for number of measured pulses (echoes) per emitted pulse
  - Various feature extraction possibilities
  - Adaptive threshold for pulse detection

Feature extraction (II)







Test data

- **2TB raw data**
- 3 test areas of full waveform Laser data
- **5 billion points in total**
  with following attributes:
  - 3 full waveform features (xyz Position, Amplitude, Pulse width)
  - 3 derived features (normalized intensity, number of echos, (ordered) echo number)

Test data

Land cover classes

Bundesamt für Kartographie DLM-DE 2009		Rauheitsklasifizierung (BAW) Erstellung von Rauheitsflächen Version 1.0 02/2009		Rauheitsklasifizierung (BfG) Leistungsbeschreibung V1.0 24.11.2011	
CLC_UPD_ Code		Klasse RKG	Bezeichnung	Klasse	Bezeichnung
112	Nicht durchgängig städtische Prägung	500	Vorland - Ortschaft	k.A.	Bebauung (Wohn-, Industrie-, Gewerbe)
121	Industrie- und Gewerbeflächen	510	Vorland - Industrie	k.A.	Bebauung (Wohn-, Industrie-, Gewerbe)
		520	Vorland - Sonderfläche	k.A.	Bebauung (Wohn-, Industrie-, Gewerbe)
		530	Vorland - Sonderfläche nicht erodierbar	k.A.	Verkehrsflächen
		60	Technik - Pflaster	k.A.	Bauwerke am Gewässer "glatt"
		80	Technik - Steinschüttung	k.A.	Bauwerke am Gewässer "rauh"
		81	Technik - Steinschüttung Buhne		
122	Straßen, Eisenbahn				
123	Hafengebiete	900	Hafen	k.A.	Bebauung
141	Städtische Grünflächen				
142	Sport- und Freizeitanlagen				
211	Nicht bewässertes Ackerland	220	Ackerland		
231	Wiesen und Weiden	210	Vorland - Grünland	k.A.	Grün-, Grasland
311	Laubwälder	420	Vorland - Laubwald	k.A.	Wald* **
312	Nadelwälder			k.A.	Wald* **
313	Mischwälder	400	Vorland - Wald	k.A.	Wald* **
322	Heiden und Moorheiden	230	Vorland - Heide	k.A.	Hecken, Buschwerk, Gestrüpp**
324	Wald-Strauch-Übergangsstadien	260	Vorland - Wildwuchs	k.A.	Hecken, Buschwerk, Gestrüpp**
		310	Vorland - geschlossenes Buschwerk	k.A.	Hecken, Buschwerk, Gestrüpp**
331	Strände, Dünen und Sandflächen	101	Gewässerbett - schlammig-sandig		
		102	Gewässerbett - sandig-kiesig		
411	Sümpfe	270	Nasser Boden	k.A.	Moor, Sumpf, Ried
511	Gewässerläufe	0	Fluss	k.A.	Offene Wasserflächen
		910	Nebengewässer - seitlicher Zufluss / Kanal	k.A.	Offene Wasserflächen
512	Wasserflächen	930	Nebengewässer - Sonstiges Gewässer	k.A.	Offene Wasserflächen

* Wald (Hartholz, Weichholz, mit/ohne Unterholz)
** mit Spezifizierung Höhe und Dichte des Bewuchses

Test data

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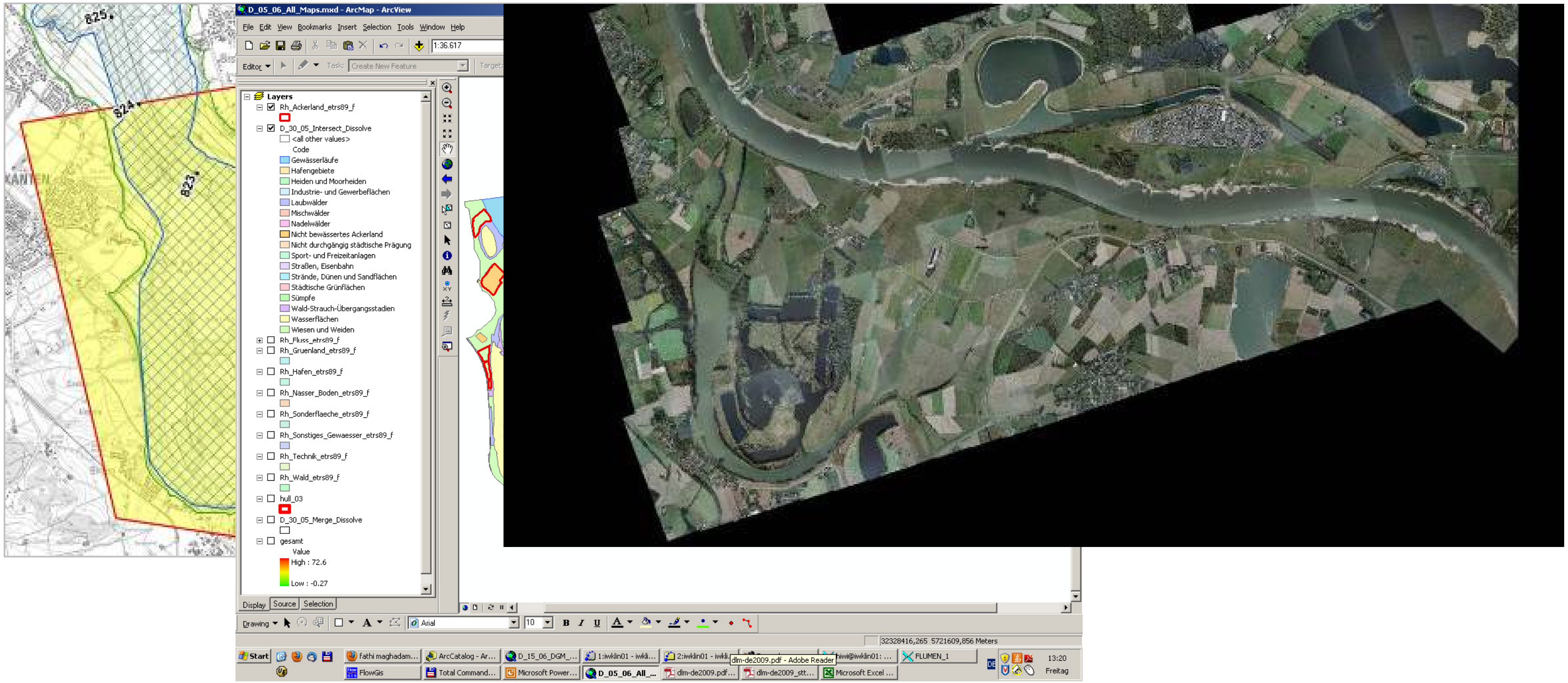
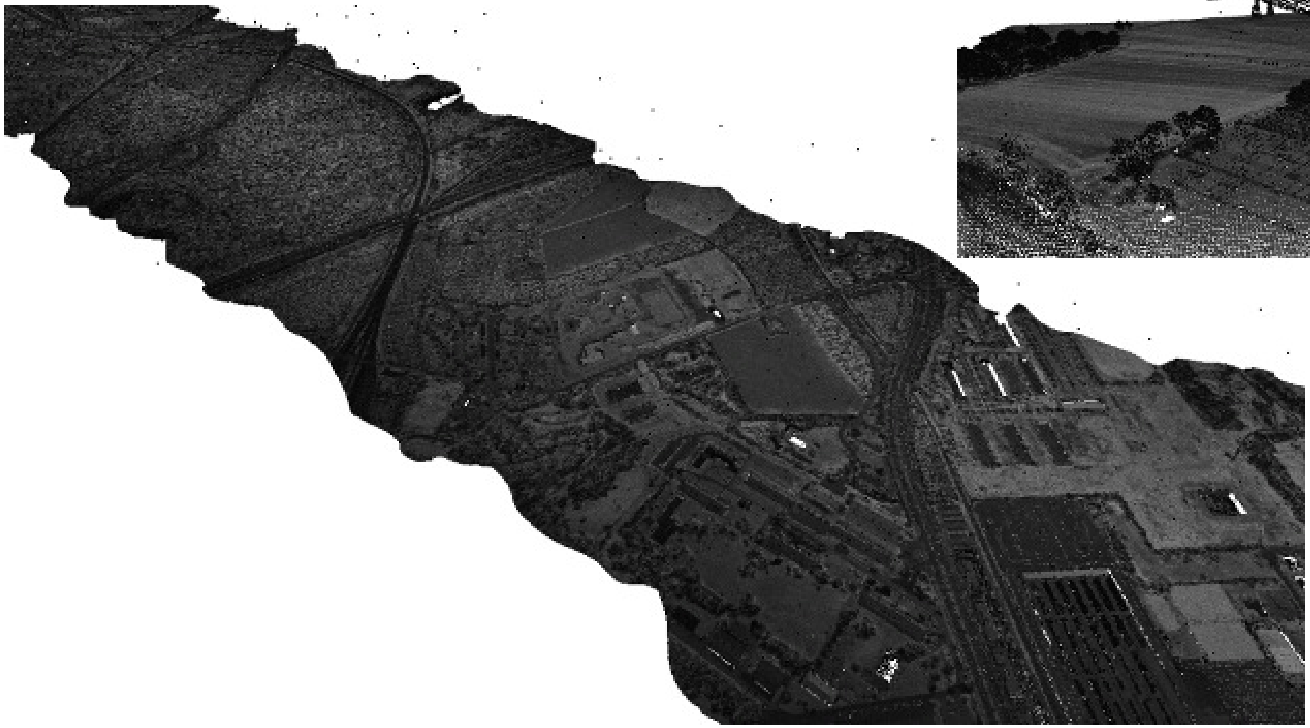
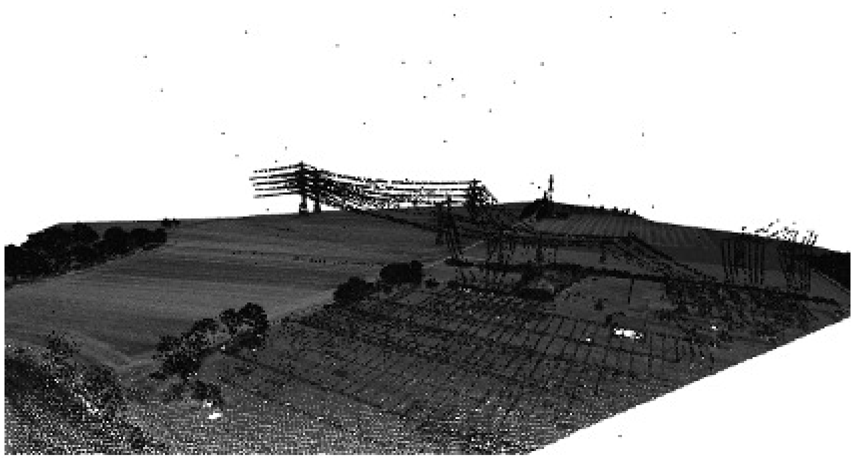
- **Area 2: Perrich, Rhein-km 815,0 – 824,0, ca. 39 km²**



- **Generalized Map data**
- **Roughness classes (hydraulic classes)**
- **RGB-NIR Images**

Test data

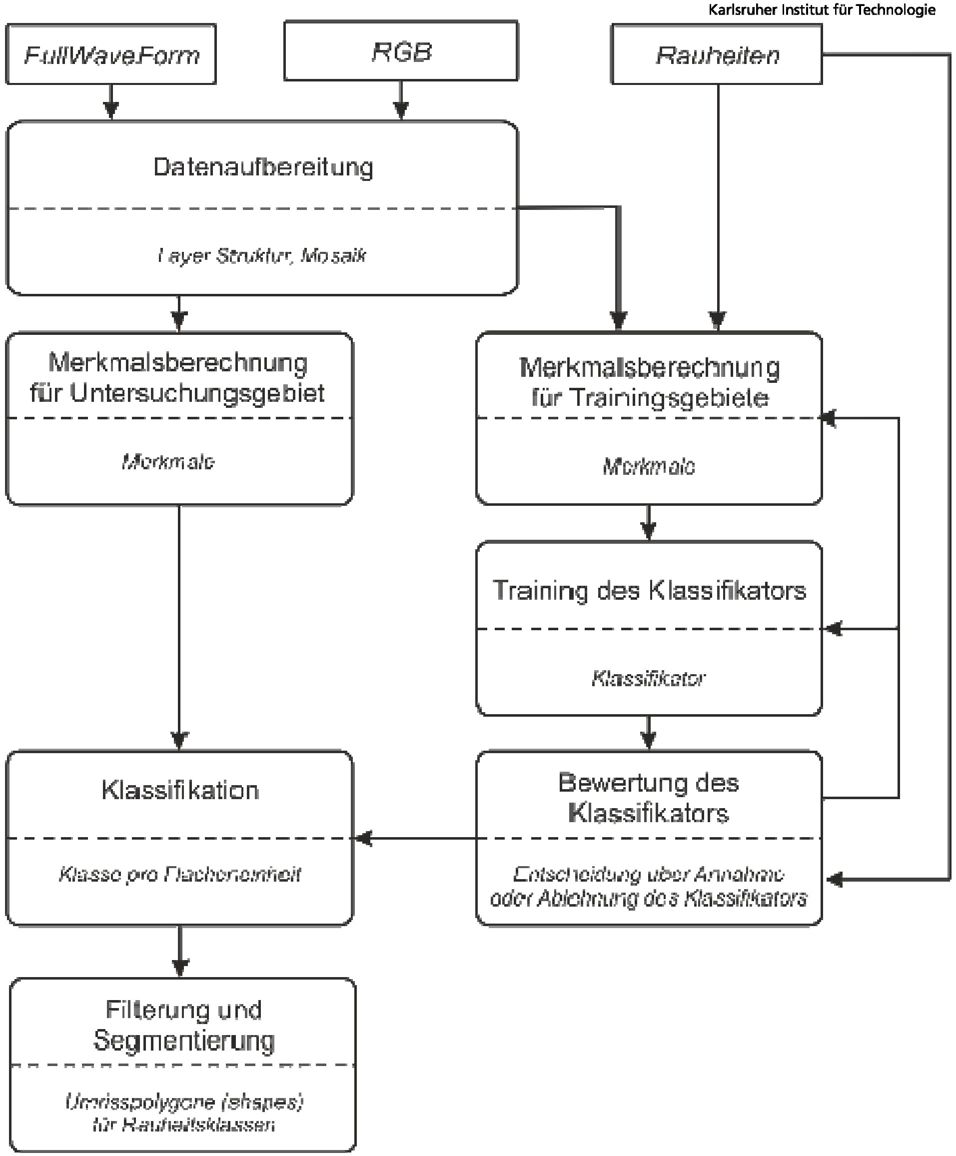




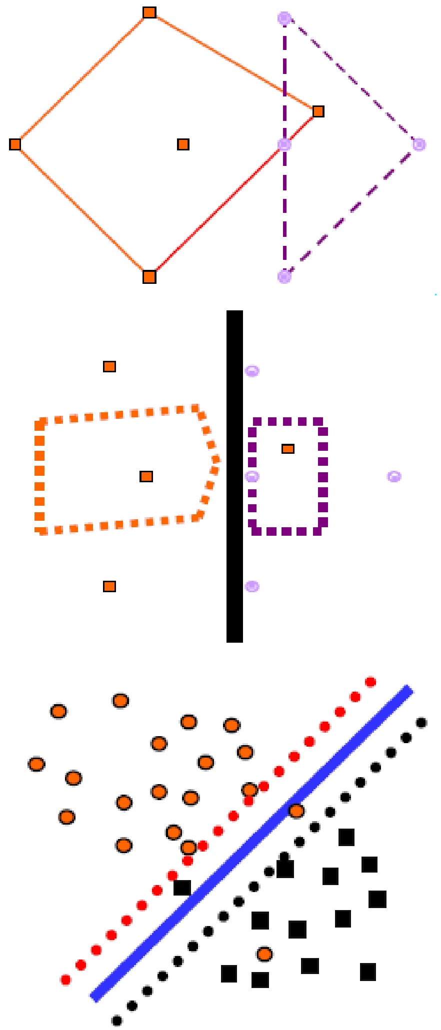
point_cloud_2012-06-18_reg_data_small_01ss3.ply
point_cloud_2012-06-18_reg_data_small_01sss5.ply

Klassifikationskonzept

Überwachte Klassifikation



Supervised classsification by Support Vector Machines



- For inseparable classes the convex hulls intersect

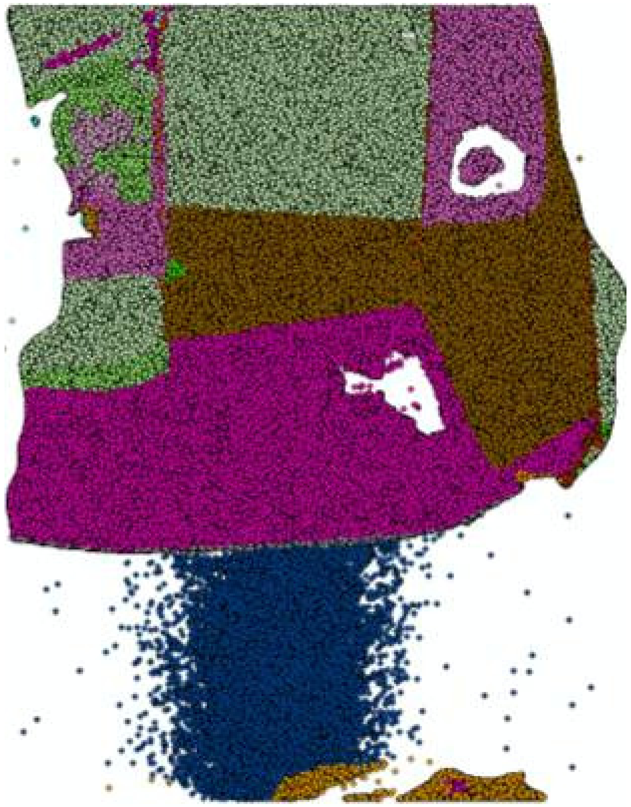
- Solutions:
  - „Kernel trick“ (higher dimensionality)
  - „Generalization“ by slack-variable(s)

=> Kernel trick and slack-variable can be combined

Classification results

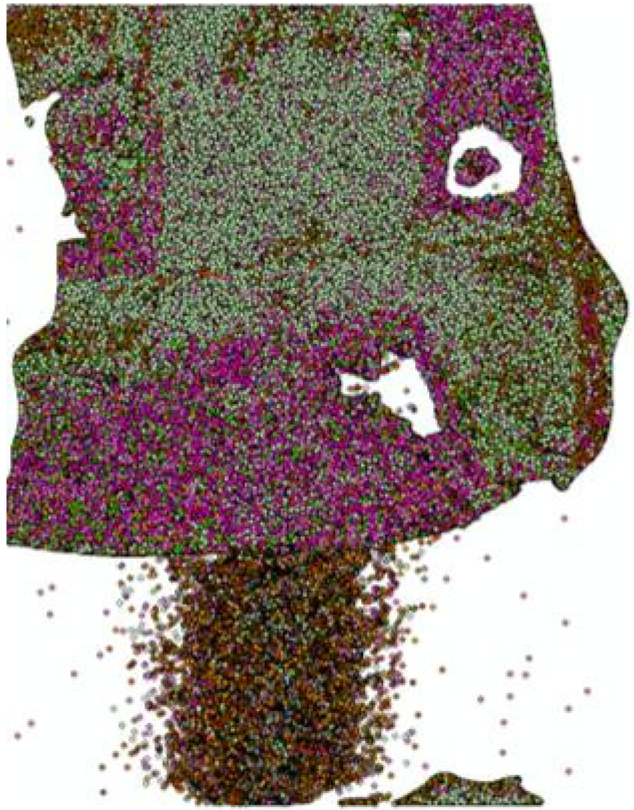
- 210 - Vorland- Grünland
- 220 - Ackerland
- 230 - Vorland - Heide
- 260 - Vorland - Wildwuchs
- 310 - Vorland - geschlossenes Buschwerk
- 400 - Vorland - Wald
- 420 - Vorland - Laubwald
- 500 - Vorland - Ortschaft
- 520 - Vorland - Sonderfläche
- 530 - Vorland - Sonderfläche nicht erodierbar

- **Comparision of classification with reference data (derived from ortho photos)**



reference

DOP-NW 09/2009



classification result (without neighborhood)

Confusion matrix (results for 5x5 neighborhood)

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	vorgegebene Klassen																	
klassifizierte Klassen	0	60	80	81	101	102	210	220	230	260	270	310	400	420	500	510	520	530
	60	0,6881	0,0191	0,0777	0,0000	0,0650	0,0825	0,0615	0,1080	0,0275	0,0162	0,0072	0,0014	0,0055	0,0074	0,0000	0,0292	0,0164
	80	0,0207	0,6237	0,1268	0,0455	0,0702	0,0041	0,0019	0,0379	0,0548	0,0240	0,0388	0,0283	0,0527	0,0074	0,0001	0,0059	0,0008
	81	0,0757	0,1331	0,5762	0,1263	0,1922	0,0032	0,0004	0,0387	0,0134	0,0215	0,0018	0,0012	0,0079	0,0002	0,0000	0,0013	0,0009
	101	0,0000	0,0115	0,0102	0,6818	0,0086	0,0002	0,0001	0,0016	0,0001	0,0086	0,0003	0,0001	0,0008	0,0000	0,0000	0,0000	0,0000
	102	0,0535	0,0640	0,1648	0,0404	0,5404	0,0290	0,0073	0,0421	0,0348	0,0141	0,0111	0,0105	0,0223	0,0013	0,0000	0,0098	0,0079
	210	0,0443	0,0025	0,0012	0,0000	0,0154	0,3565	0,1394	0,0800	0,0384	0,0017	0,0275	0,0067	0,0155	0,0286	0,0029	0,0693	0,0704
	220	0,0493	0,0020	0,0002	0,0000	0,0028	0,2308	0,5867	0,0554	0,0177	0,0000	0,0384	0,0037	0,0060	0,0556	0,0037	0,1359	0,0859
	230	0,0200	0,0217	0,0088	0,0253	0,0389	0,1296	0,0714	0,4988	0,0741	0,0048	0,0368	0,0073	0,0283	0,0330	0,0003	0,0661	0,0156
	260	0,0064	0,0315	0,0071	0,0000	0,0159	0,0189	0,0098	0,0415	0,4011	0,0069	0,1195	0,0756	0,1483	0,0297	0,0112	0,0433	0,0228
	270	0,0278	0,0161	0,0216	0,0808	0,0257	0,0017	0,0002	0,0184	0,0064	0,8847	0,0011	0,0012	0,0241	0,0002	0,0002	0,0001	0,0000
	310	0,0007	0,0250	0,0014	0,0000	0,0056	0,0167	0,0106	0,0227	0,0889	0,0012	0,4445	0,0922	0,1654	0,0488	0,0037	0,0367	0,0171
	400	0,0000	0,0135	0,0004	0,0000	0,0042	0,0052	0,0044	0,0042	0,0577	0,0008	0,0669	0,5349	0,1772	0,0229	0,0300	0,0199	0,0308
	420	0,0014	0,0302	0,0034	0,0000	0,0121	0,0061	0,0032	0,0135	0,1038	0,0151	0,1290	0,1647	0,2961	0,0203	0,0134	0,0173	0,0137
	500	0,0014	0,0034	0,0001	0,0000	0,0004	0,0119	0,0125	0,0163	0,0186	0,0004	0,0367	0,0138	0,0150	0,5441	0,0497	0,0801	0,0612
	510	0,0000	0,0003	0,0000	0,0000	0,0000	0,0047	0,0047	0,0004	0,0069	0,0000	0,0009	0,0219	0,0128	0,0404	0,7846	0,0129	0,0866
	520	0,0071	0,0025	0,0001	0,0000	0,0023	0,0350	0,0426	0,0149	0,0326	0,0001	0,0297	0,0095	0,0108	0,0718	0,0069	0,3765	0,0825
	530	0,0036	0,0001	0,0001	0,0000	0,0003	0,0639	0,0434	0,0057	0,0232	0,0000	0,0099	0,0270	0,0112	0,0884	0,0934	0,0957	0,4873

Overall accuracies for different neighborhoods

	patch	Without neighborhood	3x3 neighborhood	5x5 neighborhood
60	0,0000	0,4276	0,6504	0,6881
80	0,0954	0,4557	0,4673	0,6237
81	-	0,4590	0,5353	0,5762
101	-	0,0606	0,5244	0,6818
102	0,0430	0,4452	0,4158	0,5404
210	0,6772	0,2171	0,2689	0,3565
220	0,1065	0,5699	0,6153	0,5867
230	0,0495	0,3822	0,4686	0,4988
260	0,0182	0,3279	0,3860	0,4011
270	-	0,6415	0,6735	0,8847
310	0,0148	0,2741	0,4210	0,4445
400	0,3306	0,4346	0,5320	0,5349
420	0,2118	0,2181	0,2956	0,2961
500	0,3077	0,2907	0,5100	0,5441
510	-	0,7403	0,7755	0,7846
520	0,0065	0,2785	0,3522	0,3765
530	0,3529	0,3373	0,4664	0,4873

Assessment

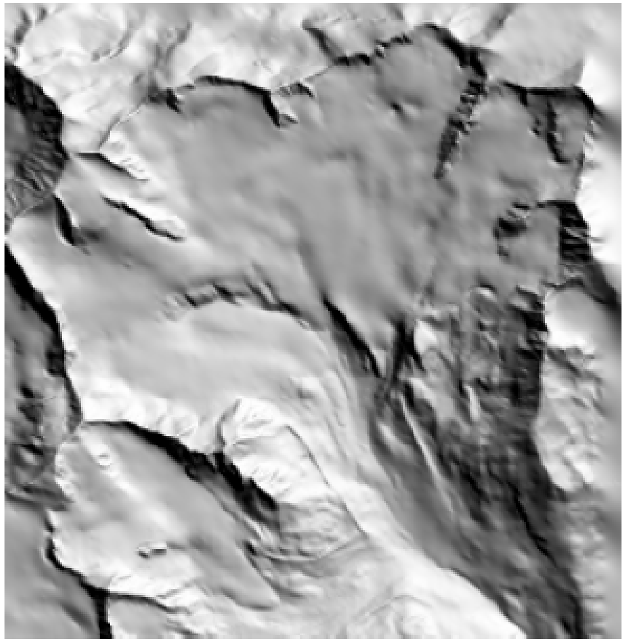
- Data load of Laserscanning data requires automated processing
- Significantly faster processing
- Mainly geometric features considered (up to now)
- Moderate completeness:
  - Some classes are not seperable
  - Yet, definition of some classes can be modified for hydrodynamic modelling
- Outlook:
  - Integration of context (relation between objects)

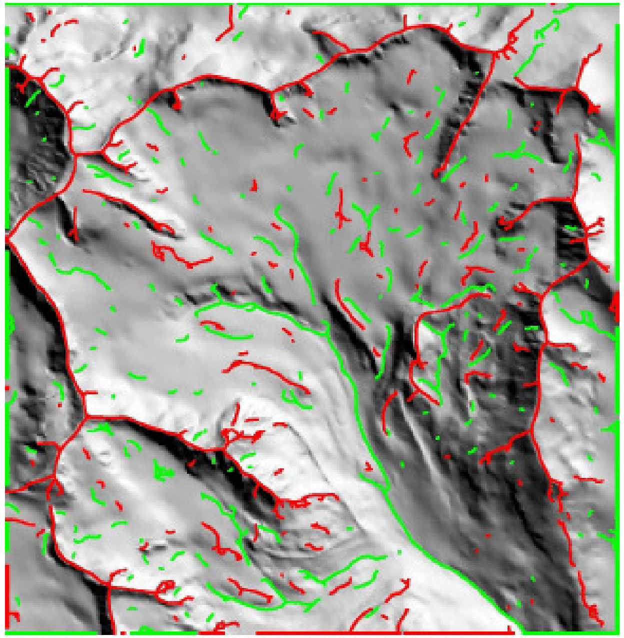
    => „Conditional Random Fields“

Extraction of Watersheds and Catchments

- Watersheds and watercourses
  - are important features in hydrological GIS applications
  - play an important role for the segmentation of images

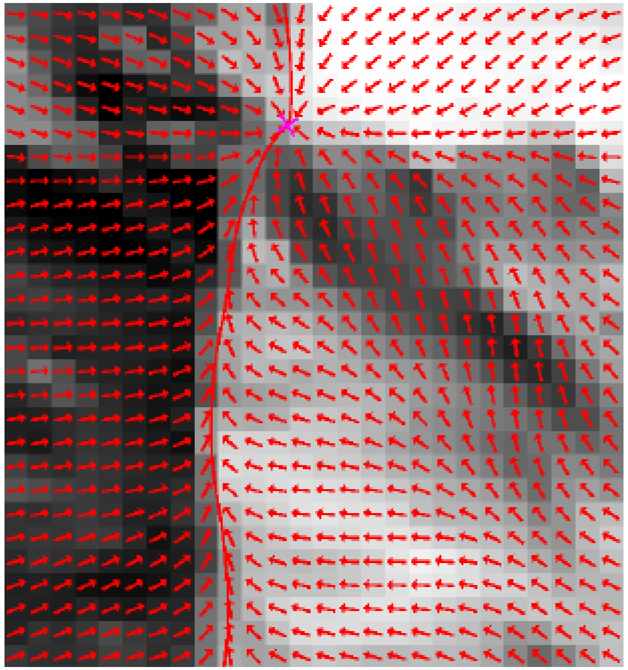
- Extracted watersheds often are incomplete and inaccurate (especially when ridge detectors are used)





Theory (I)

- Regard the surface (terrain) as a function $f(x)\ (x \in \mathbb{R}^2)$
- Critical points of the surface: $\nabla f = 0$ (minima, maxima, saddle points)
- Every non-critical point p lies on exactly one slope line
- The point p divides the corresponding slope line into an ascending and a descending part
- The two parts of the slope line are the solutions of the ODE $\dot{x}(t) = \pm \nabla f(x(t))$ with the initial condition $x(0) = p$



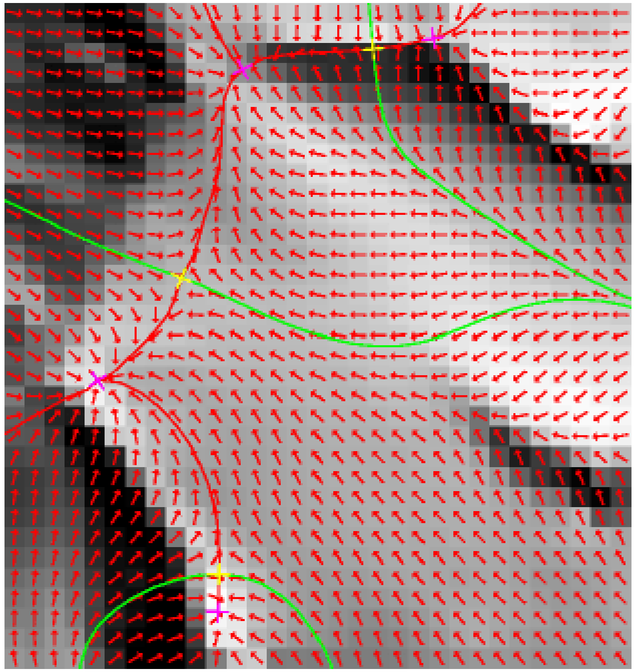
© C.Steger

Theory (II)

- From every saddle point, exactly two ascending and two descending slope lines “emanate” in the principal directions
- The two ascending slope lines are the ridge lines; they reach a maximum or saddle point
- The two descending slope lines are the valley lines; they reach a minimum or saddle point

Every maximum is surrounded by a ring of valley lines,
on which only minima and saddle points occur as critical points

Every minimum is surrounded by a ring of ridge lines,
on which only maxima and saddle points occur as critical points

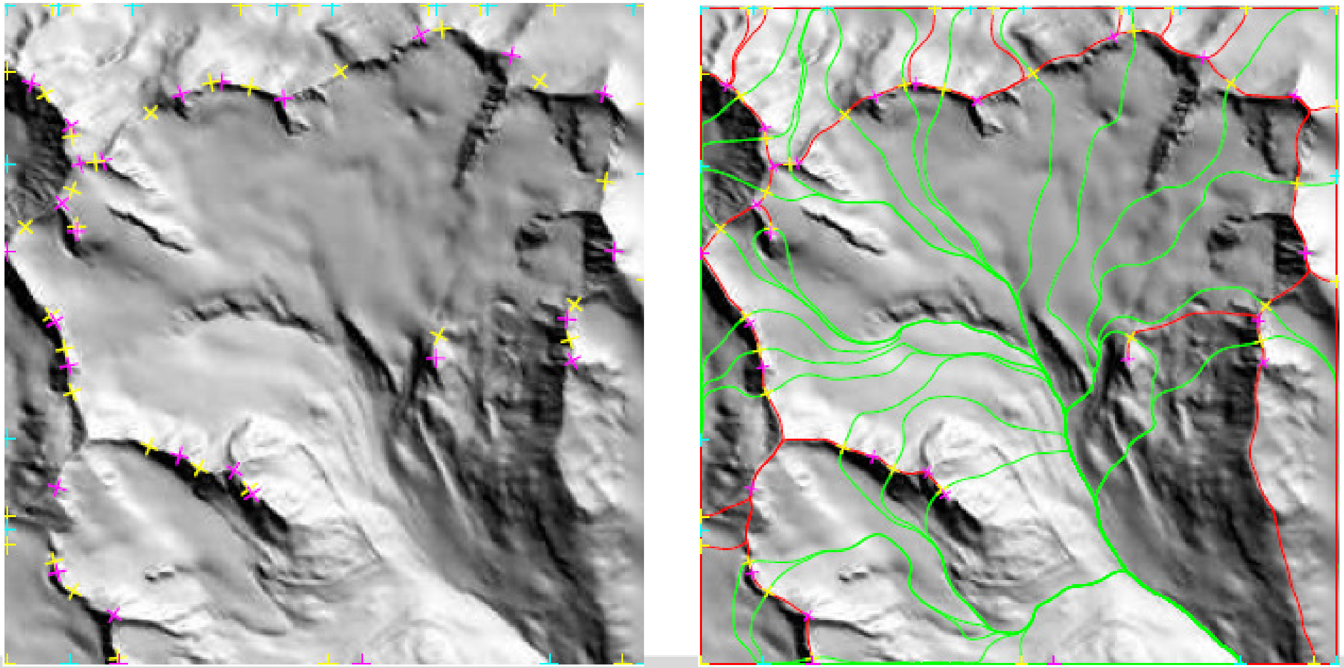


Extraction of Critical Points

- Critical points, especially saddle points, are essential for the construction of the ridge and valley lines
- Smoothing of the DTM or image with the derivatives of Gaussian masks leads to a second-order Taylor polynomial in each pixel
- Subpixel-precise extrapolation of the critical points from the Taylor polynomial ($\mathbf{H}f \cdot x = -\nabla f$)
- Eigenvalues λ_1, λ_2 of the Hessian matrix give the classification into maxima ($\lambda_1, \lambda_2 < 0$), minima ($\lambda_1, \lambda_2 > 0$), and saddle points ($\lambda_1 < 0, \lambda_2 > 0$)
- Eigenvectors e_1, e_2 of the Hessian matrix give the starting directions of the four special slope lines in each saddle point

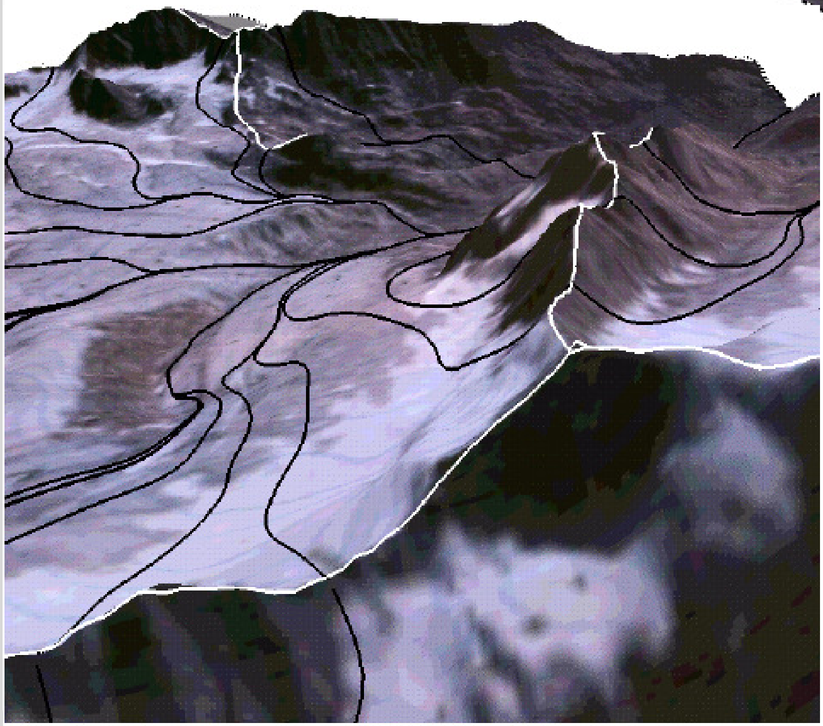
Extraction of ridge lines and valley lines

- Construction of the separatrices starting from the saddle points
- Solve the defining ODE $\dot{x}(t) = \nabla f(x(t))$ for ridge lines and $\dot{x}(t) = -\nabla f(x(t))$ for valley lines
- Initial condition $x(0) = p$ given by a small step in the direction $\pm e_1$ $(\lambda_1 < 0)$ for valley lines and $\pm e_2$ $(\lambda_2 > 0)$ for ridge lines



Examples

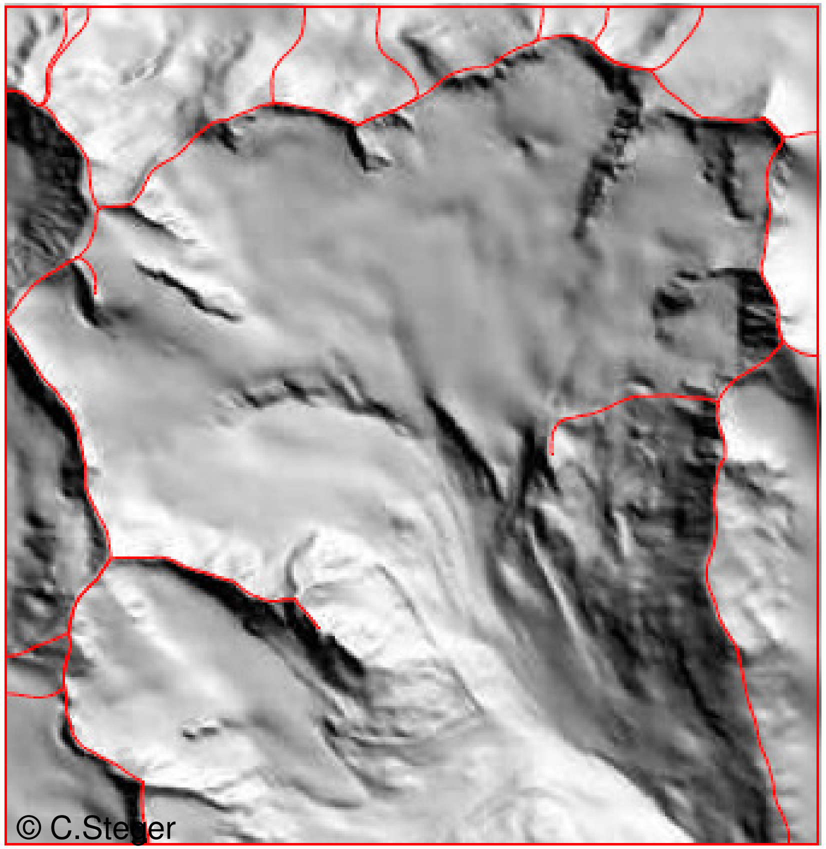
3D view on Vernagt glacier (Austria)

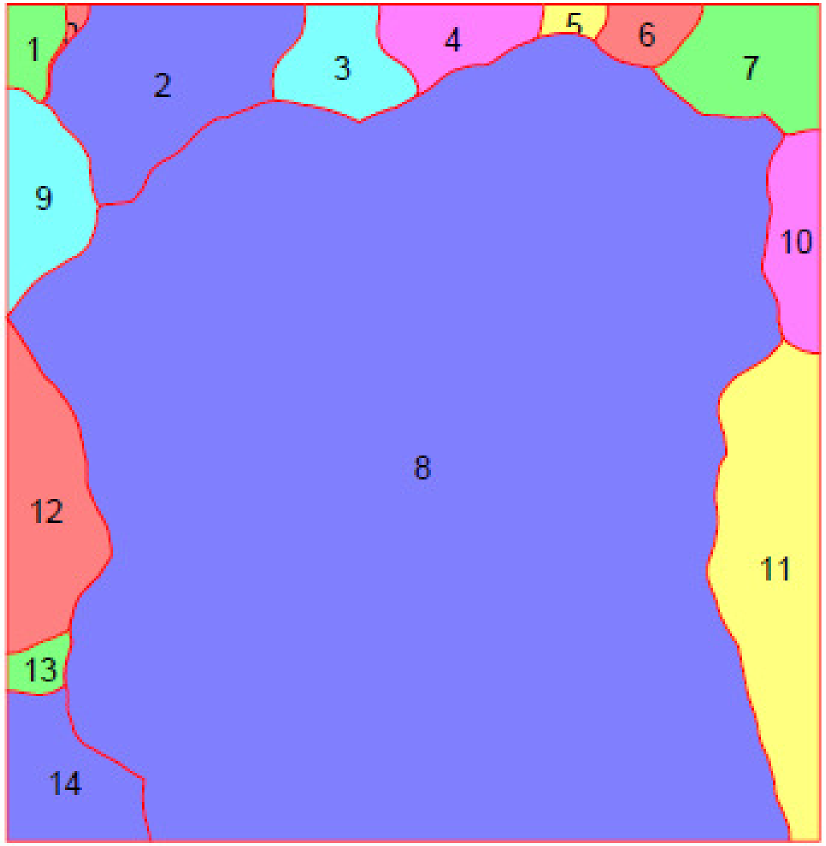


© C.Steger

Examples

Extracted Catchments/Basins: complete solution





Contents

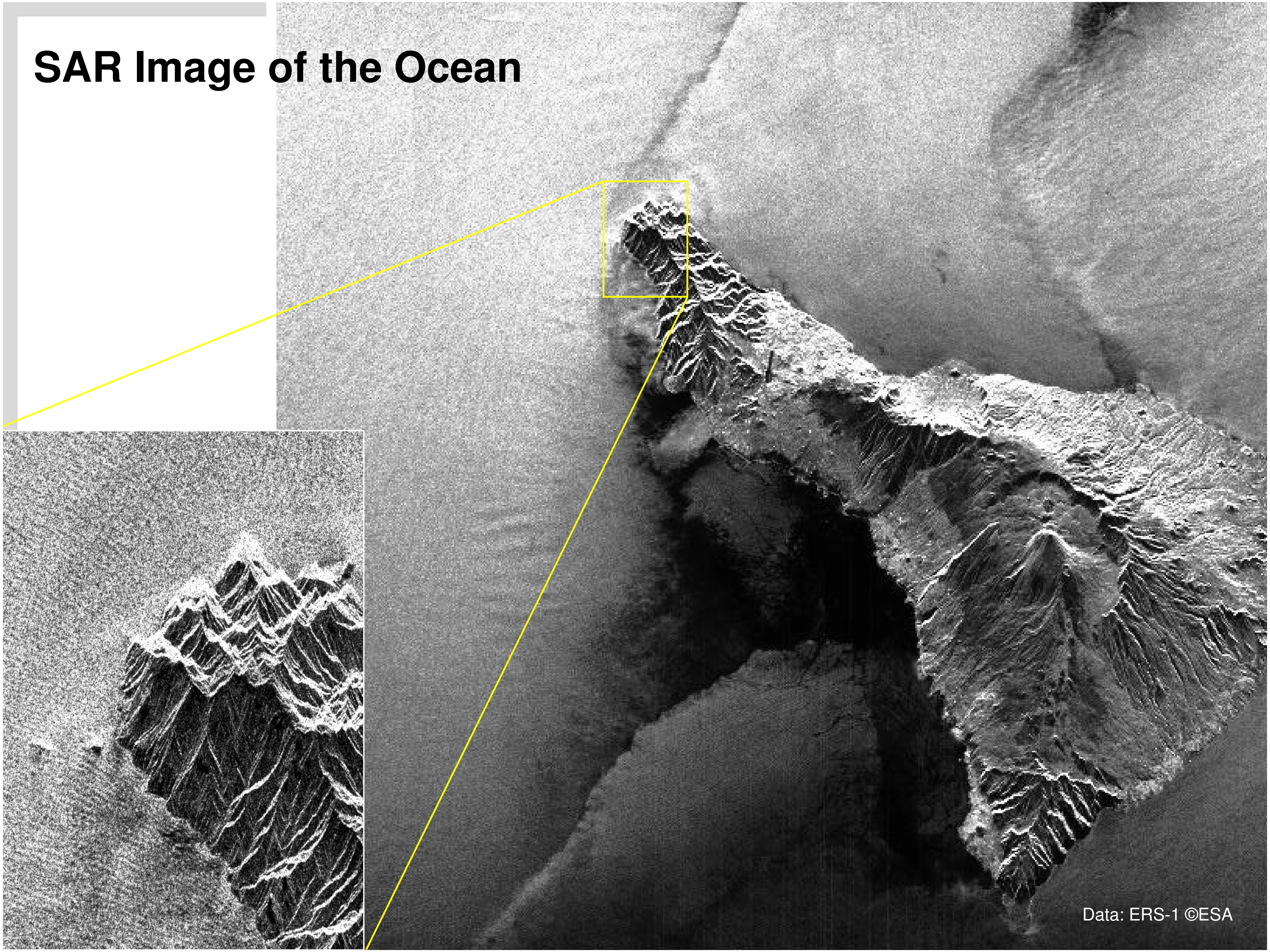
- Some Remote Sensing Systems

- Automated Analysis of…

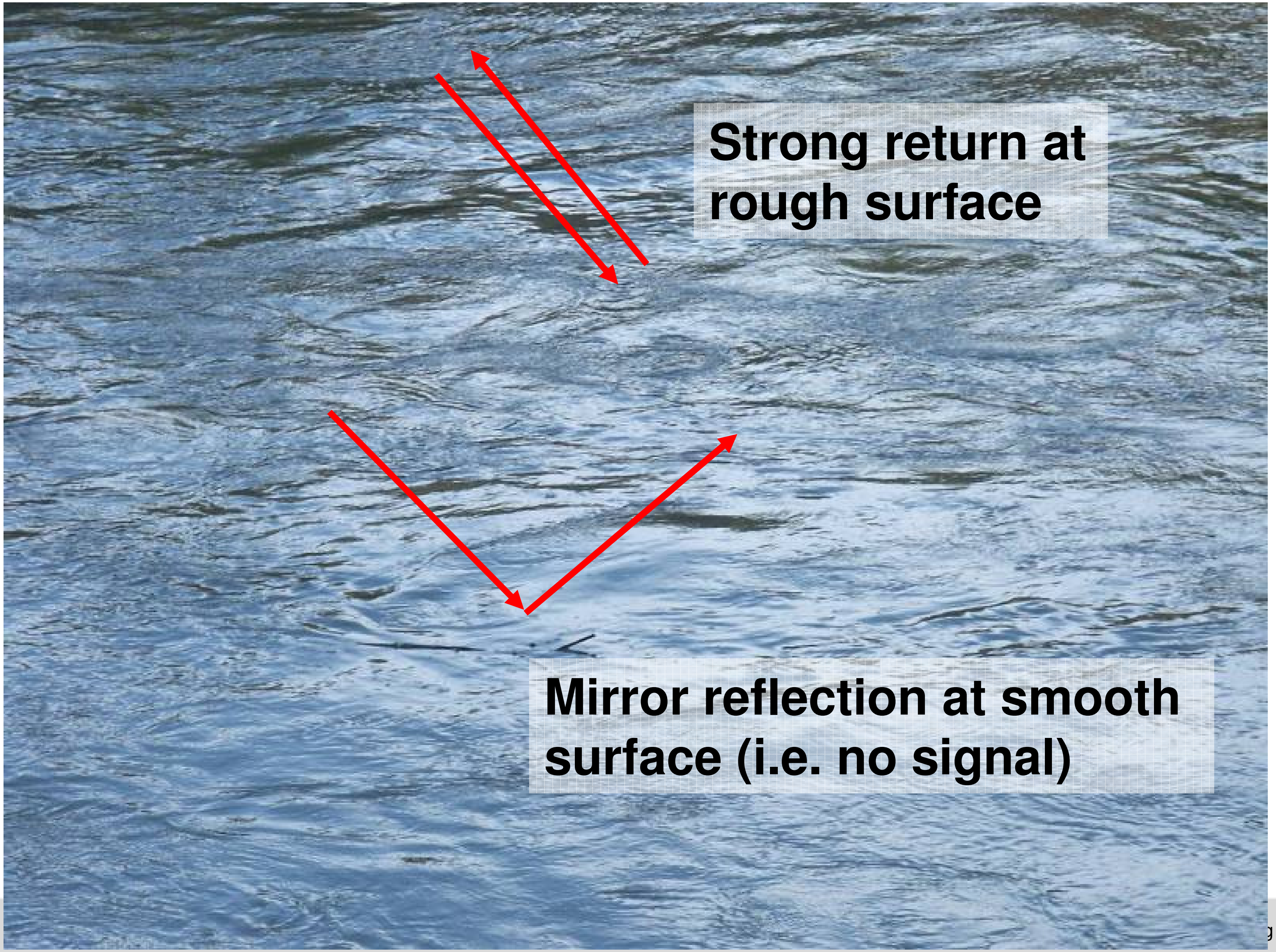
  … Hyperspectral images: Land cover classification
  … 3D data: Roughness classification and derivation of catchments
  … Interferometric SAR Data: Water flow and water level

- Final remarks

SAR Image of the Ocean

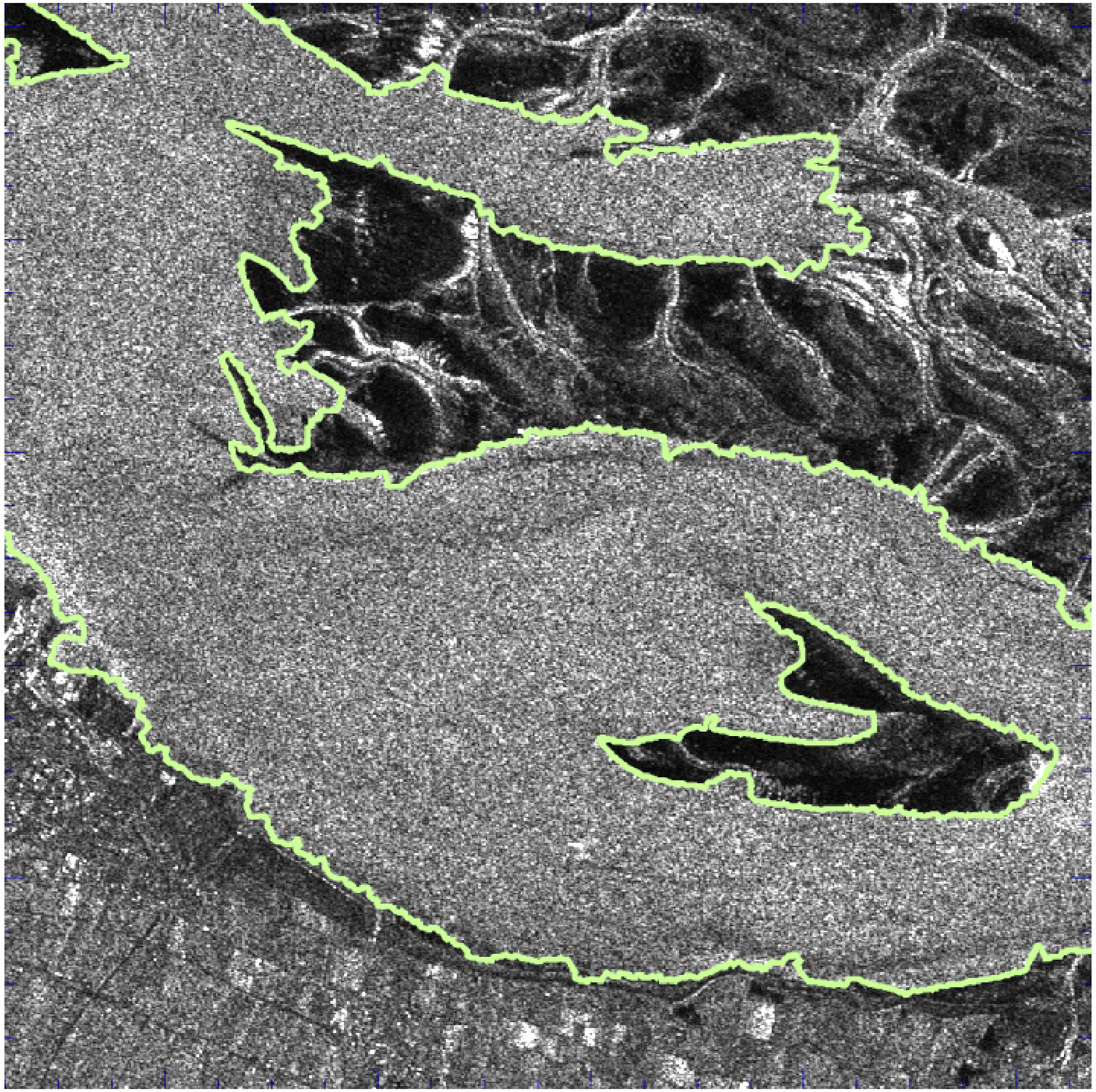


Reflection properties

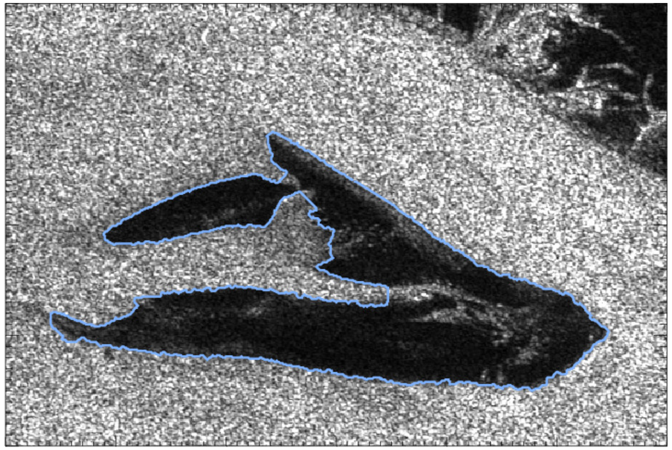


Coastline Detection from SAR Images

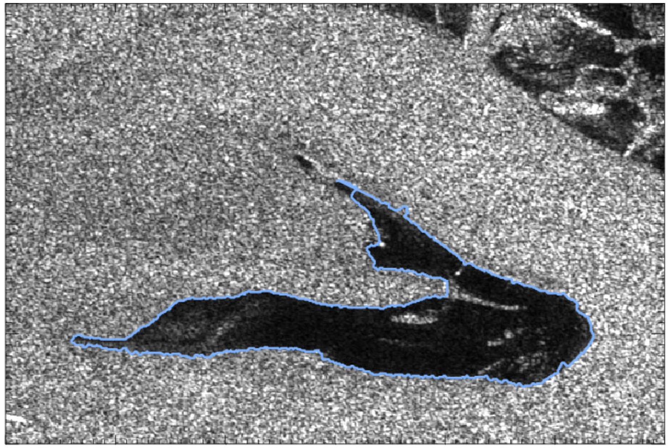
Karlsruher Institut für Technologie



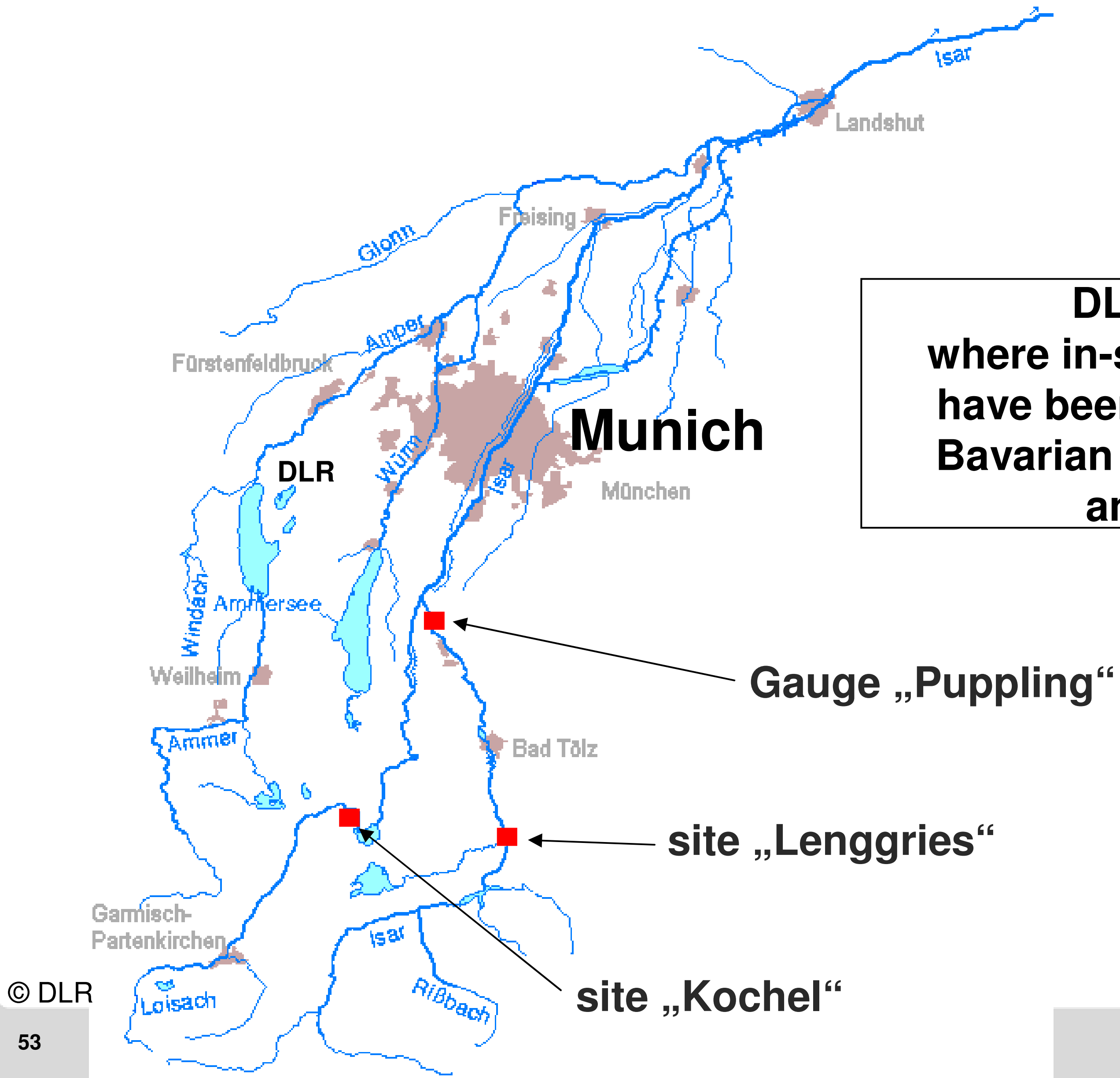
© DLR



different tidal situations



Drainage Basin of the River Isar



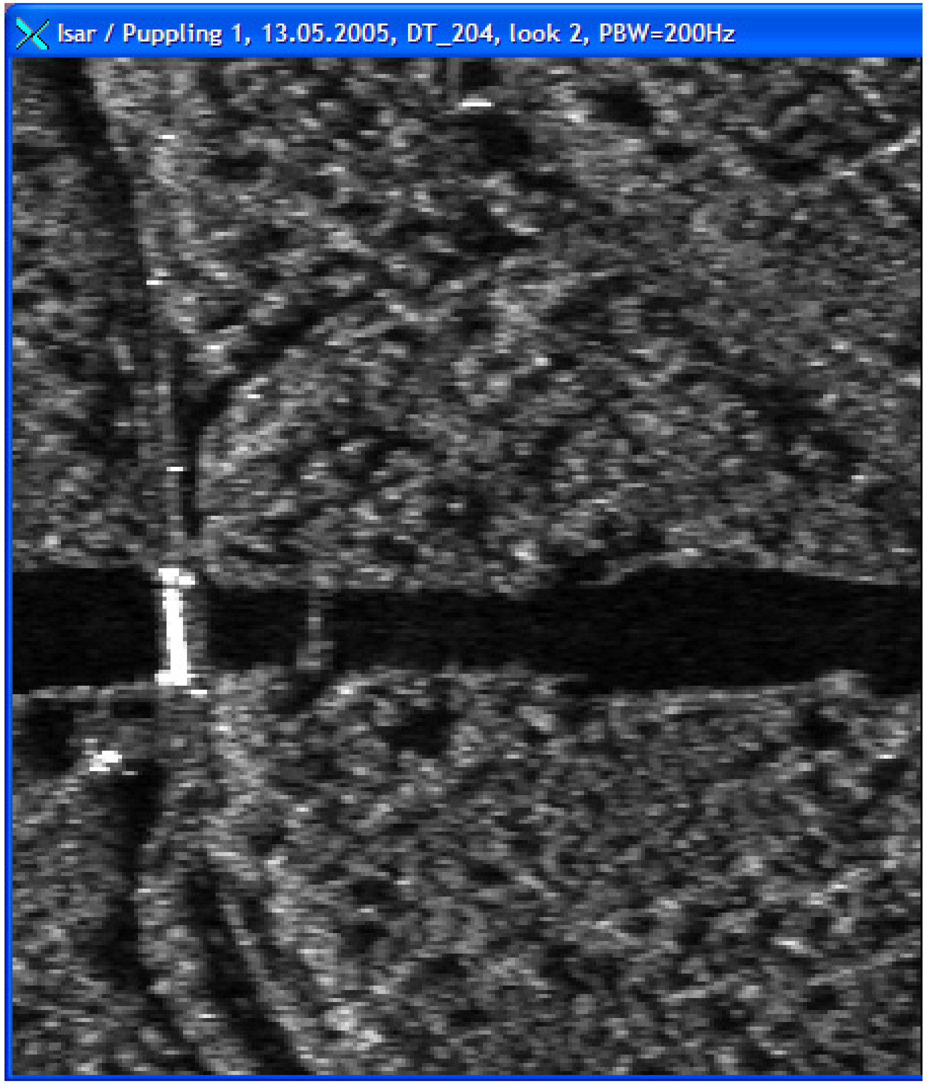
DLR test sites where in-situ measurements have been performed by the Bavarian Hydrological Office and our team

ESAR Aircraft

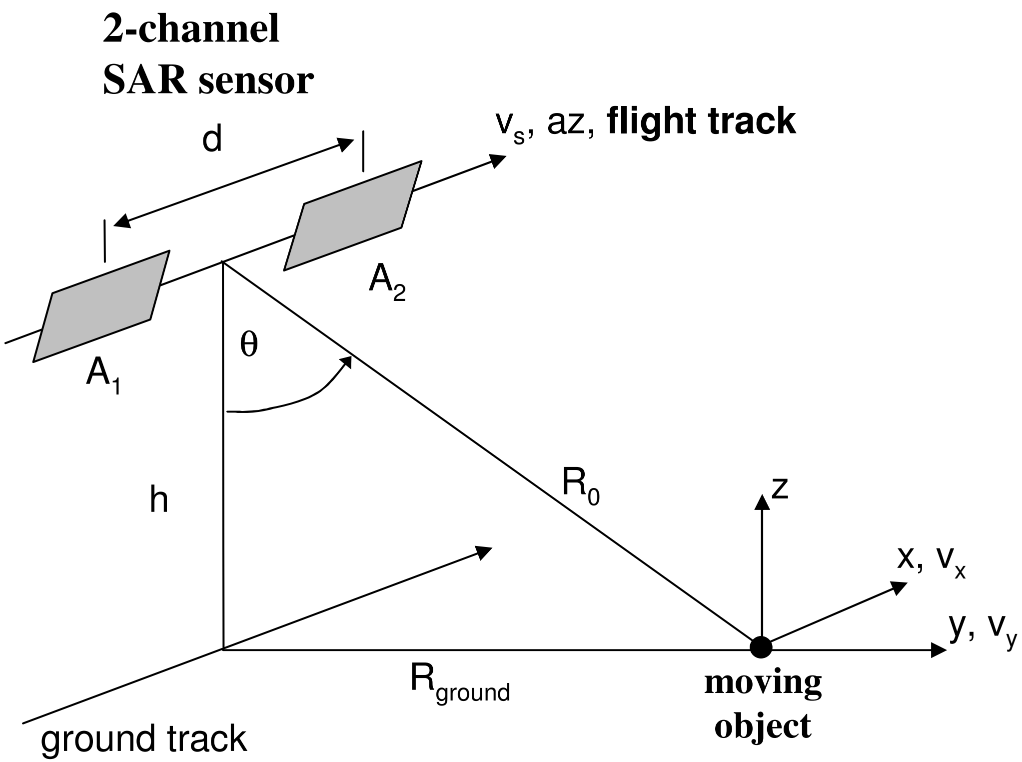
E-SAR ATI system	
frequency band:	**X (9.6 GHz)**
range bandwidth:	**100 MHz**
pulse repetition frequency:	**1000 Hz / channel**
antenna separation:	**0.87119 m**
sensor velocity:	**88 m/s**
incidence angle:	**20 – 60 deg**
SLC resolution:	**1.50 x 0.09 m**

Puppling Test Site I

SAR Amplitude Image of the Puppling Site



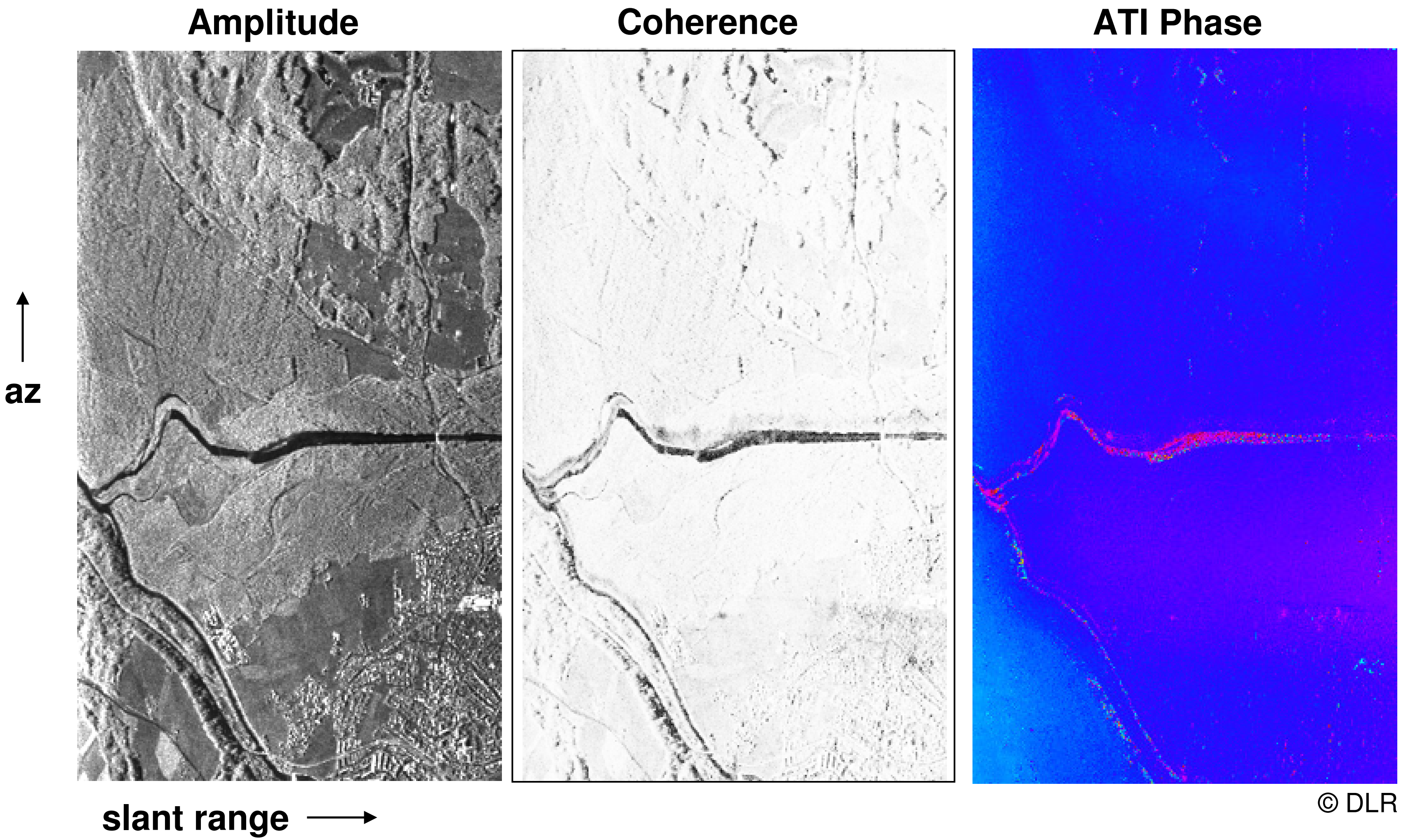
SAR Along-Track Interferometry



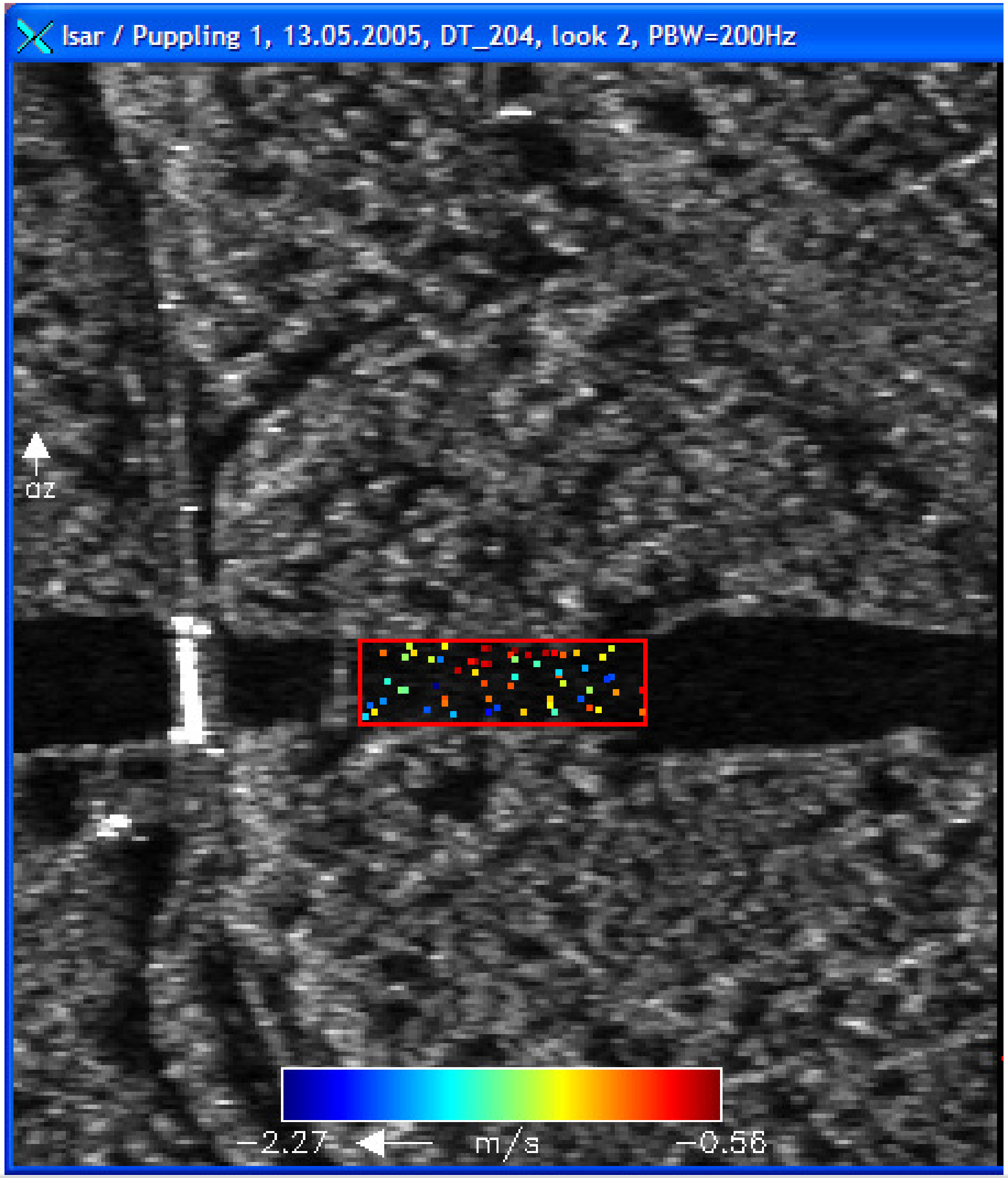
Interferometric phase:

$$\phi_{ATI} = \frac{2\pi \cdot d \cdot v_y \cdot \sin\theta}{\lambda \cdot v_s}$$

ESAR Data of Puppling Test Site



Result from ATI Analysis



© DLR

Result for ATI current velocity:

Pixel analyzed: 61

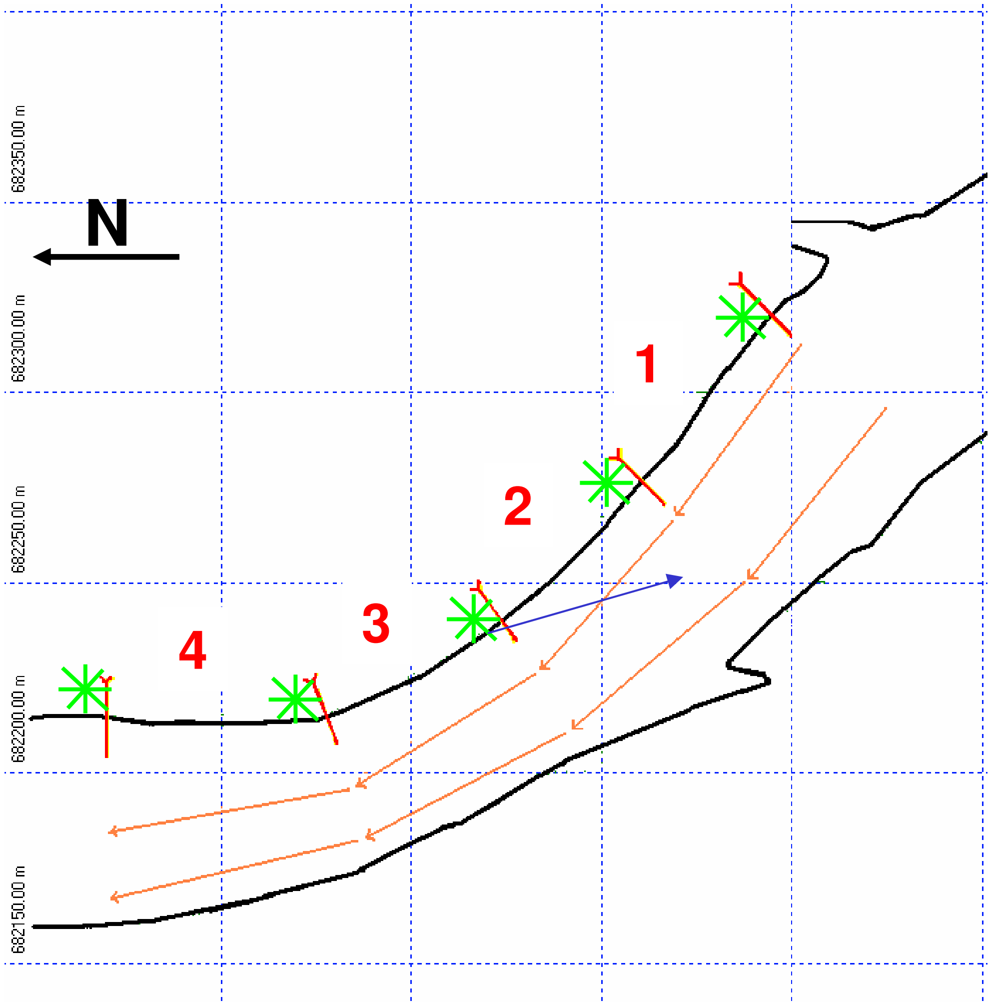
Min/Max: 2.27 / 0.56 m/s

Mean: 1.22 m/s

Result from in-situ measurement:

Mean: 1,70 m/s

Isar 12/05/06 - Ground Truth Measurements



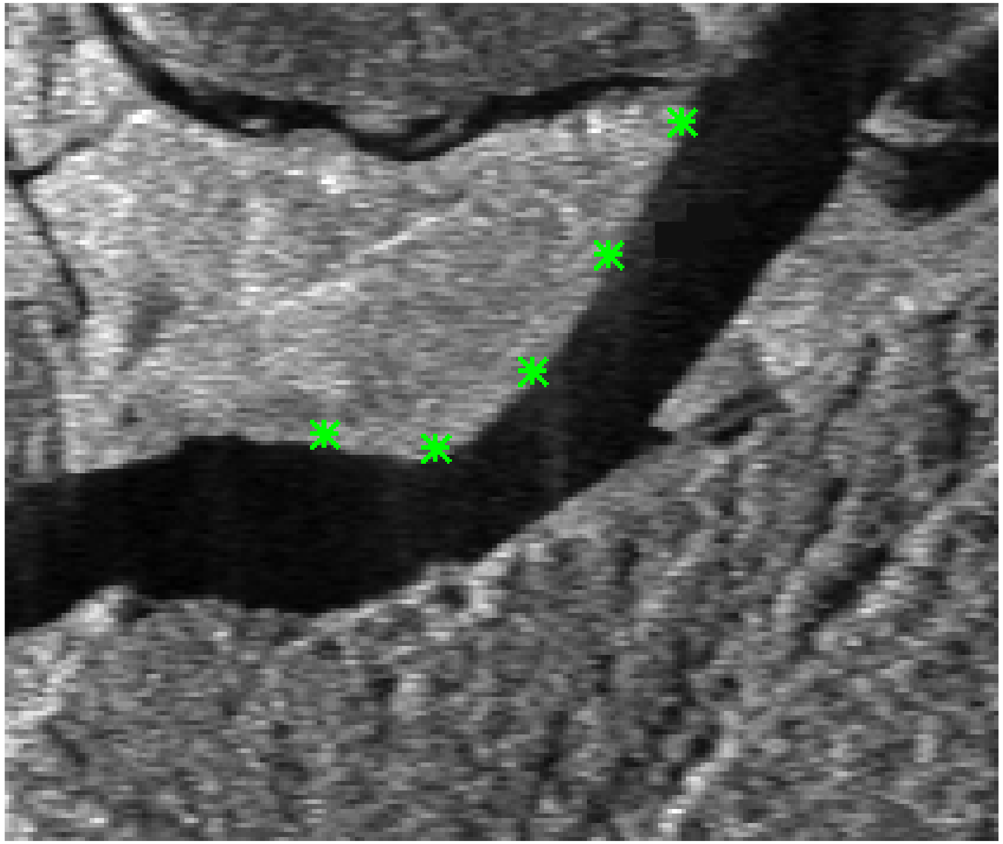
© DLR

1-4:
Sections where ground truth data were acquired with floaters.

Main river stream with greatest surface roughness

Section	Reference Measurement [m/s]
1	2.43
2	2.37
3	1.90
4	2.04

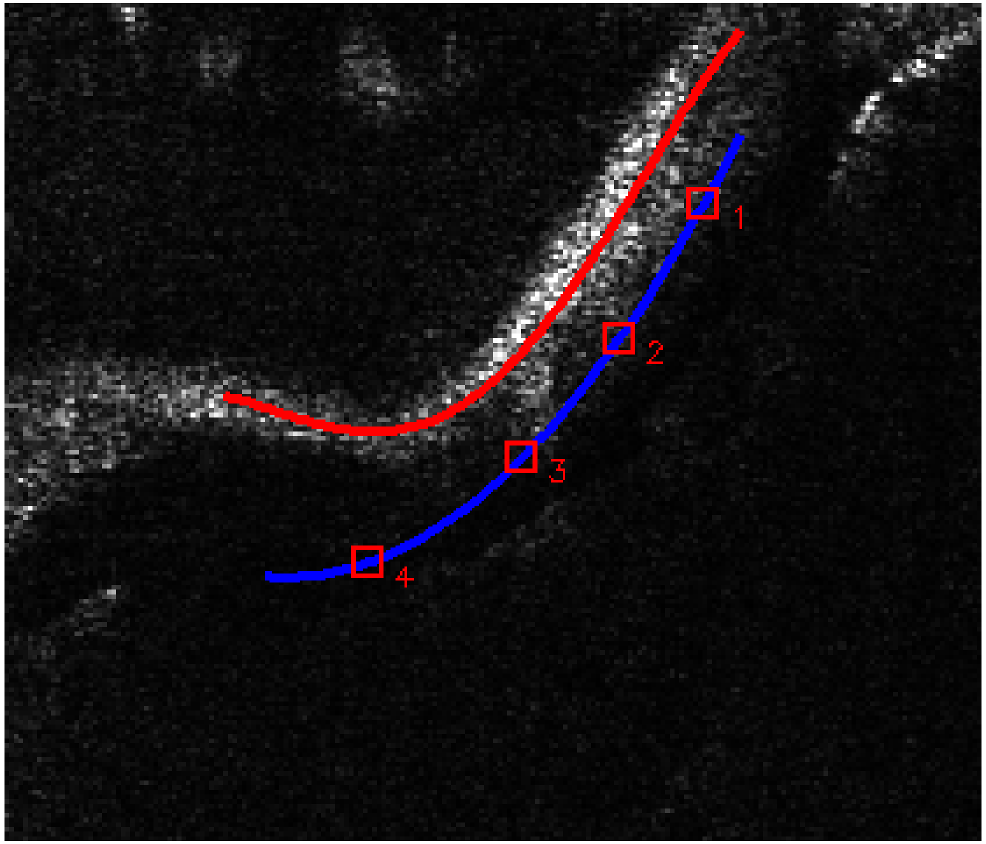
Amplitude image of DT0210x1



flight direction

Illumination

1st fly over: Surface velocity from displacement



flight direction

Illumination

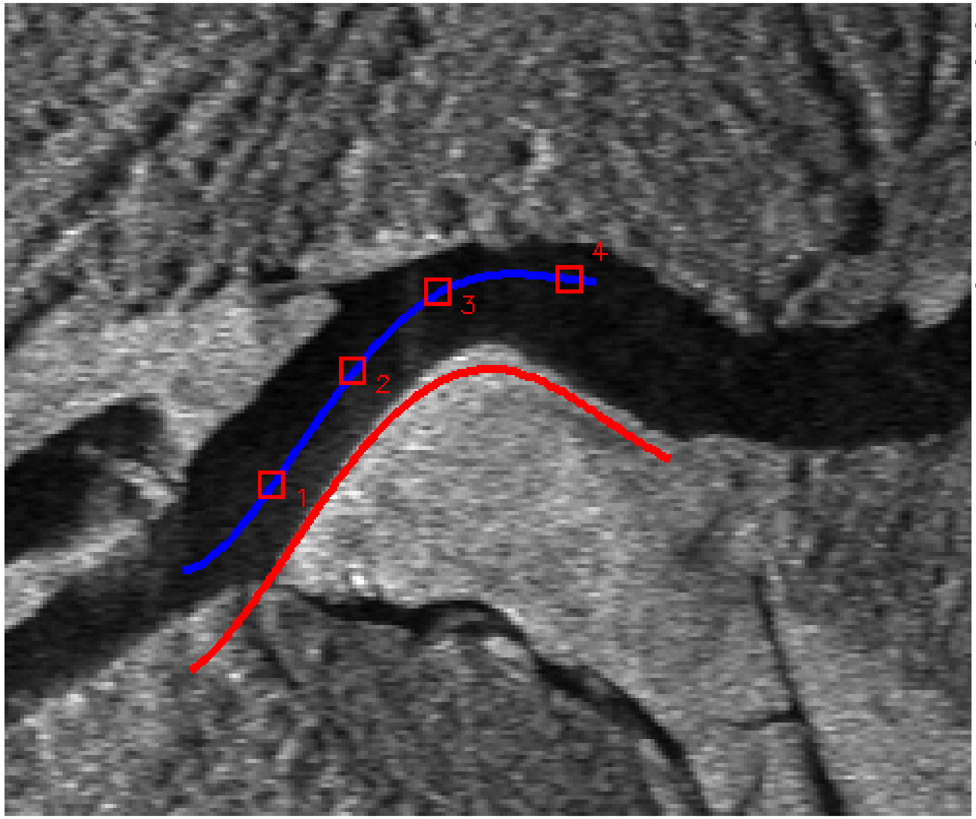
VEL. FROM DPCA DISPLACEMENT

P. no.	daz [m]	R0 [m]	Theta [deg]	v [m/s]
1	36	3130	43.5	−2.9
2	36	3103	43.0	−2.5
3	31	3071	42.4	−1.8
4	38	3022	41.3	−1.7

Section	Reference Measurement [m/s]
1	**2.43**
2	**2.37**
3	**1.90**
4	**2.04**

In average the SAR measuremts are 12% off the reference value.

2nd fly over: Surface velocity from displacement



VEL. FROM DPCA DISPLACEMENT

P. no.	daz [m]	R0 [m]	Theta [deg]	v [m/s]
1	−29	2798	35.9	2.6
2	−29	2829	36.8	2.3
3	−29	2862	37.6	1.7
4	−39	2913	38.9	1.8

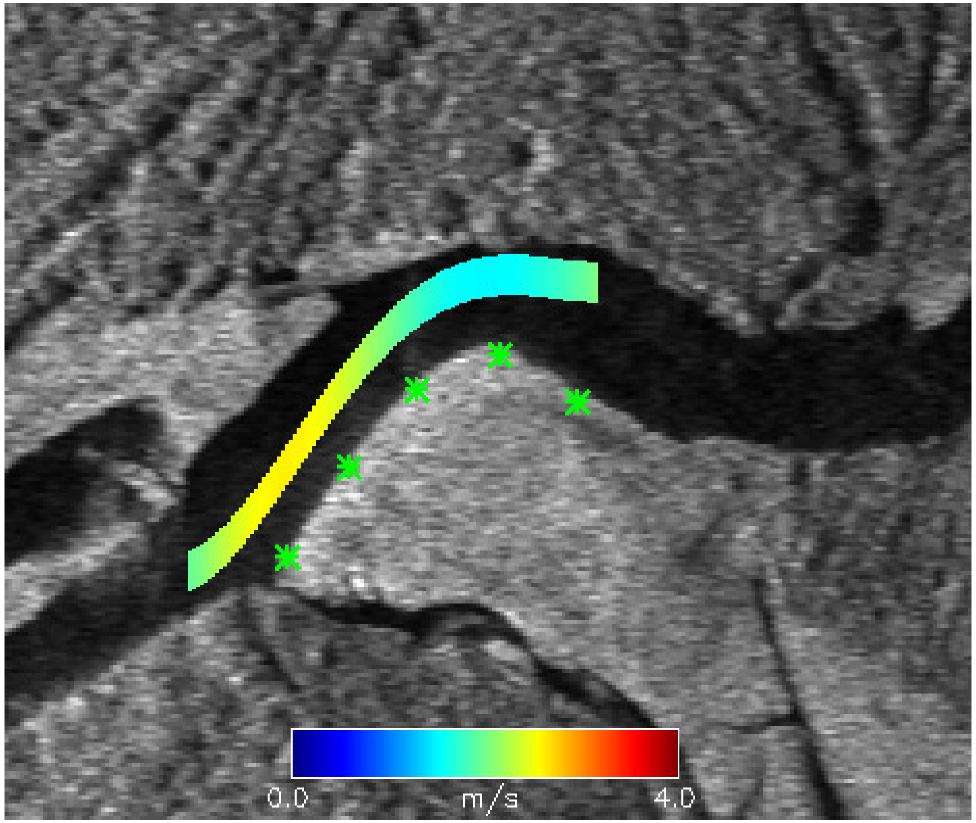
Section	Reference Measurement [m/s]
1	**2.43**
2	**2.37**
3	**1.90**
4	**2.04**

In average the SAR measuremts are 8% off the reference value.

flight direction ↑

Illumination →

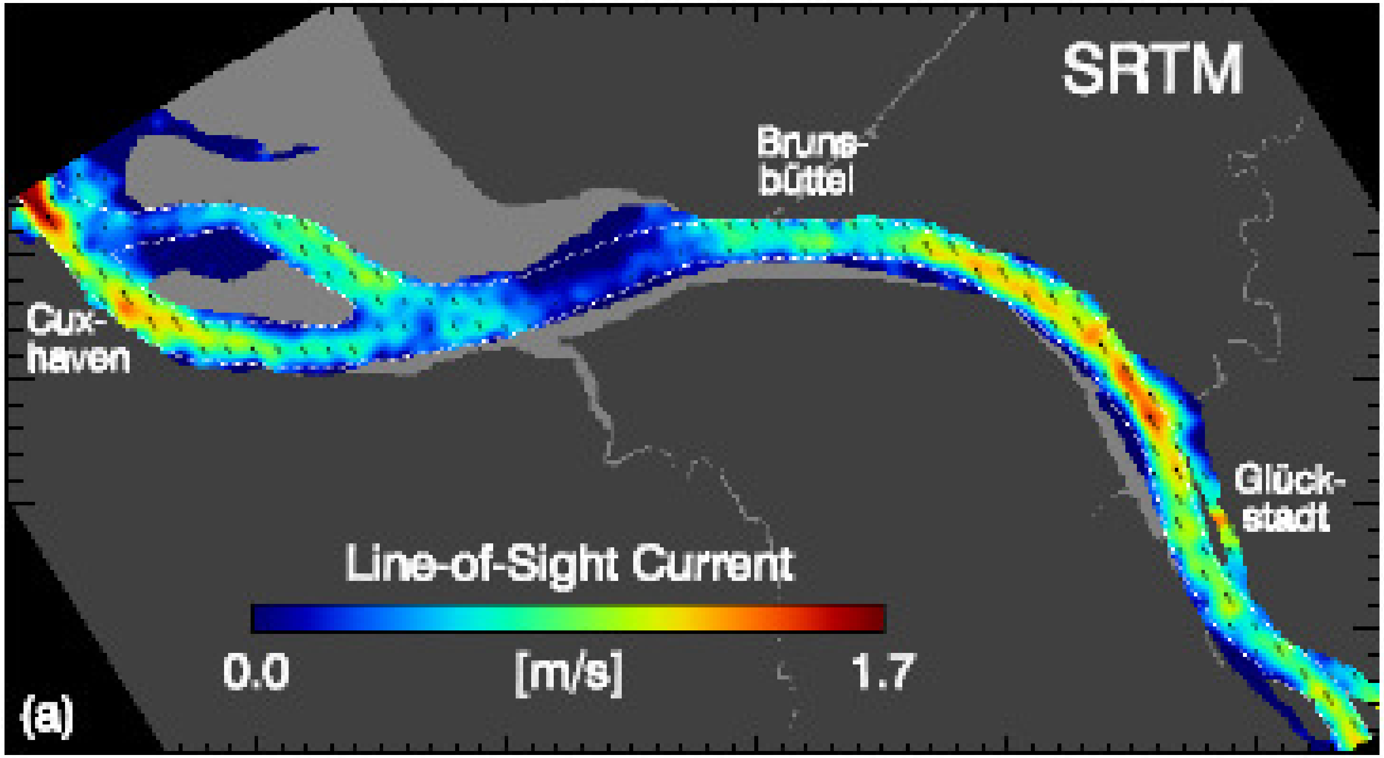
2nd fly over: Surface velocity from displacement



flight direction

Illumination

SRTM river Elbe Results (R. Romeiser, H. Runge, S.Suchandt)



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Final remarks:

3 Examples:

- Water analysis based on hyperspectral data:
  - Expensive sensors, currently only one satellite available (Hyperion)
  - Complex methods: balance of data-driven and model-based methods
  - Much room for research, only first steps towards operational systems
- Automatic roughness classification and derivation of catchments from 3D data:
  - High geometric accuracy
  - Operational methods, yet more context knowledge necessary
  - Data-driven method: results depend heavily on quality of input data
- Interferometric SAR for assessing water dynamics
  - Expensive technology, complex data acquisition and processing
  - Much room for research, esp. model-based approaches
  - Large-scale research, joint projects necessary (DLR, GFZ, industry, etc.)

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Thank you very much for your attention!