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Lab experiment for simultaneous reconstruction of water surface and bottom with a synchronized camera rig

Hydro 2024

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Context

- PhotoBathyWave project, collaboration between TU Dresden and TU Wien
- Goal:
  - Developing a generic approach for multimedia photogrammetry through a dynamic water surface
- Issue: Optical rays are refracted at the air-water interface, according to Snell’s law
  - Need to know the shape of the water surface at time T to obtain an accurate model of the topography

Objectives

Data acquisition set-up for simultaneous capture of water surface and water bottom

<u>Objectives:</u>

- is it possible to capture and reconstruct the water surface ?
- initial set-up of a more ambitious experiment: the survey of inland waters using cameras embedded on a squad of UAVs

- A water tank in a lab with a printed topography to obtain a non-flat bottom

- The set-up is static, with at least:
  - 2 nadir looking cameras for bottom mapping
  - 2 oblique looking cameras for water surface reconstruction

- A dynamic sea state will be generated using a pump

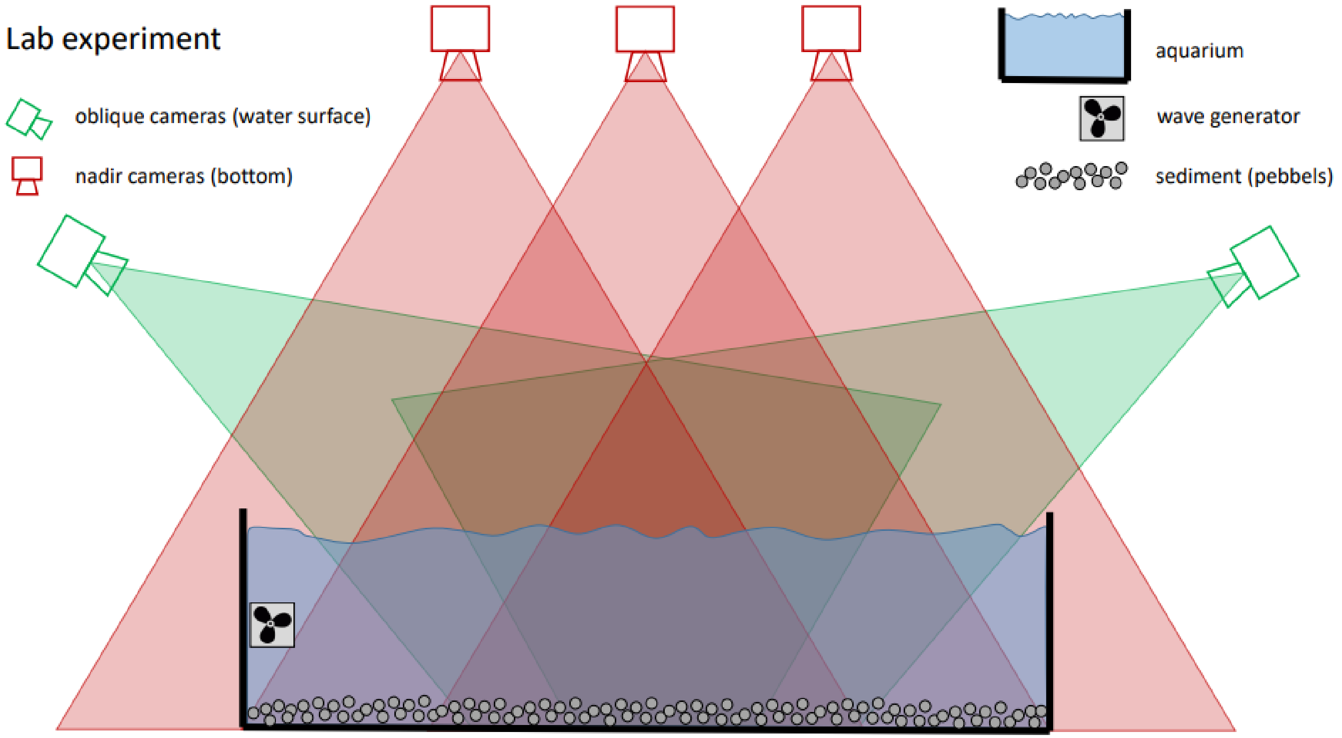
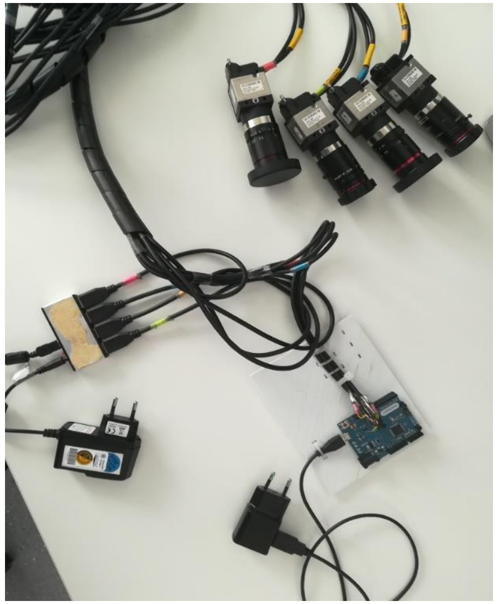


Figure: Data acquisition set-up with multiple static cameras over a water tank. The nadir cameras deliver the bottom via multimedia photogrammetry whereas the nadir cameras are only used for water surface reconstruction.

Description

- Borrowed a full multi-camera setup and lenses from IfP Stuttgart
- One Arduino triggers the cameras simultaneously every 1sec
- A concrete plate with stones to create topography
- Oblique-looking cameras on the same side to capture more common features



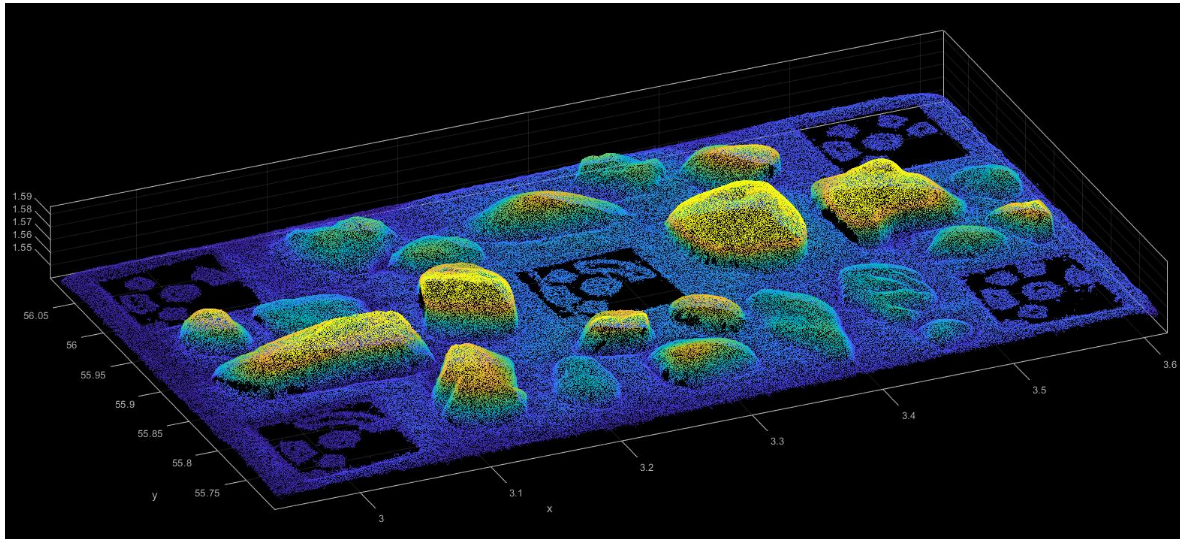
Preliminary steps

Calibration

- Distortion, interior and exterior orientations are estimated during processing by Metashape
- Georeferencing of the model in the lab coordinate system

Ground truth

- Reference model for the topography (without water) to serve as validation

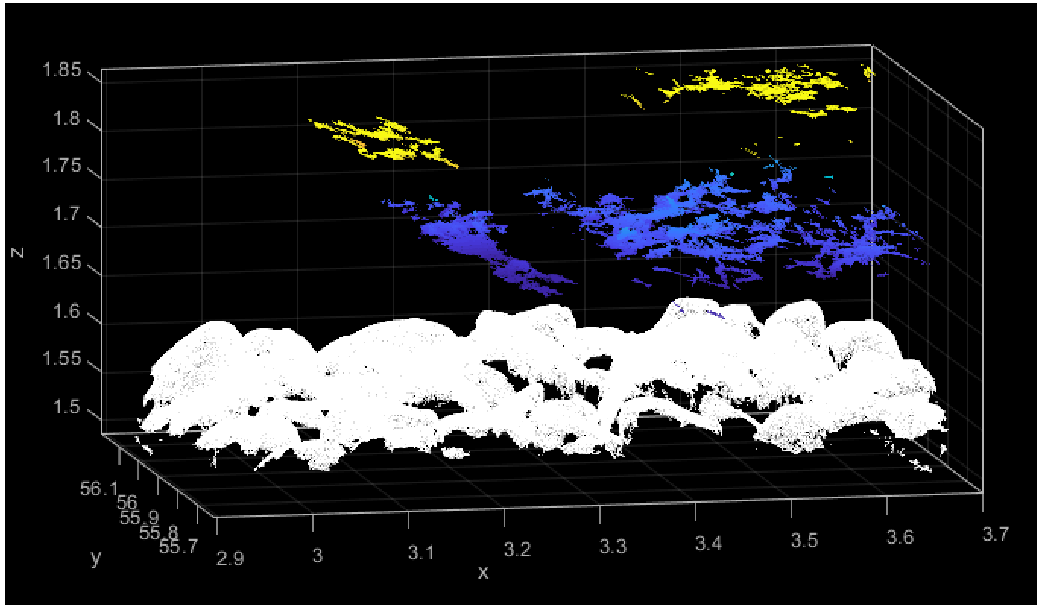


Acquisition plan

- Gather comprehensive datasets and try to identify an optimal configuration
- Variation of acquisition parameters:
  - Exposure time
  - Aperture
  - Gamma correction (contrast enhancement)
  - Gain
  - Lighting conditions

- What can we achieve using a standard Structure-from-Motion approach (Metashape) ?

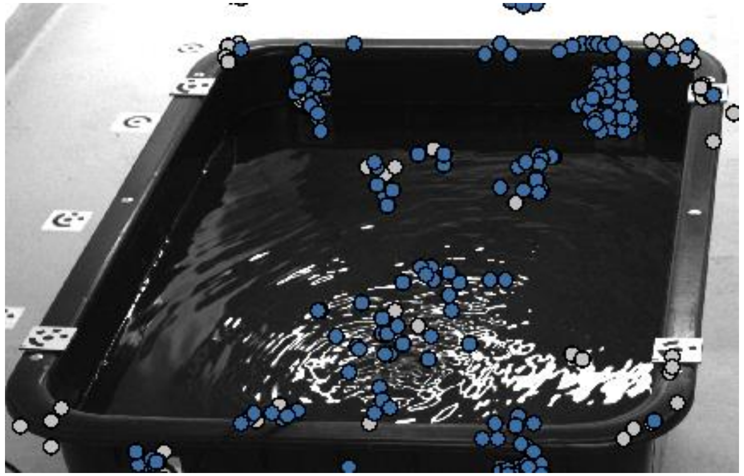
- First results → transparency of water is an issue



Acquisition plan

- From insights gained from first rounds of data acquisition:
  - Addition of turbidity
  - Maximisation of specular reflection on the water surface

- From ~3 to ~40 surface points, maximum is 77 points



Feature detection and matching using deep learning

- Reached a limit with Metashape
- Deep learning for feature detection and matching

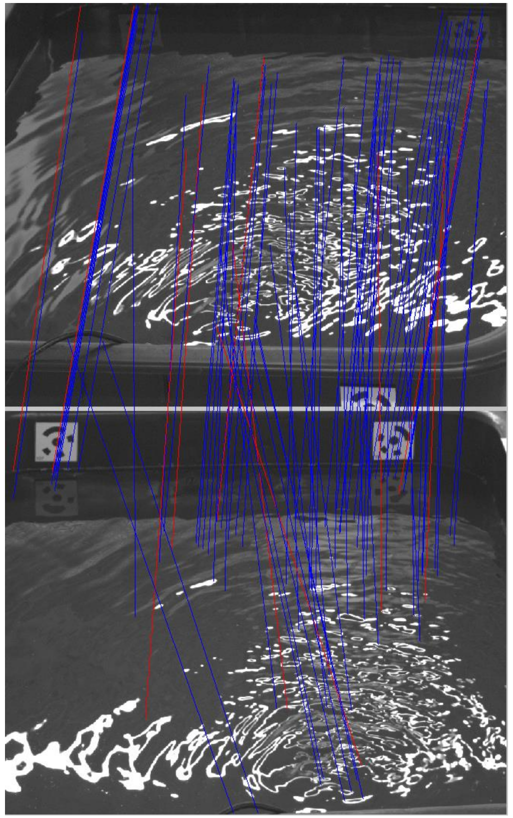
→ Hloc toolbox (Hierarchical Localization – available on Github)

Extractors: Superpoint, disk, sift

Matchers: Superglue, Lightglue, NN (nearest neighbour)

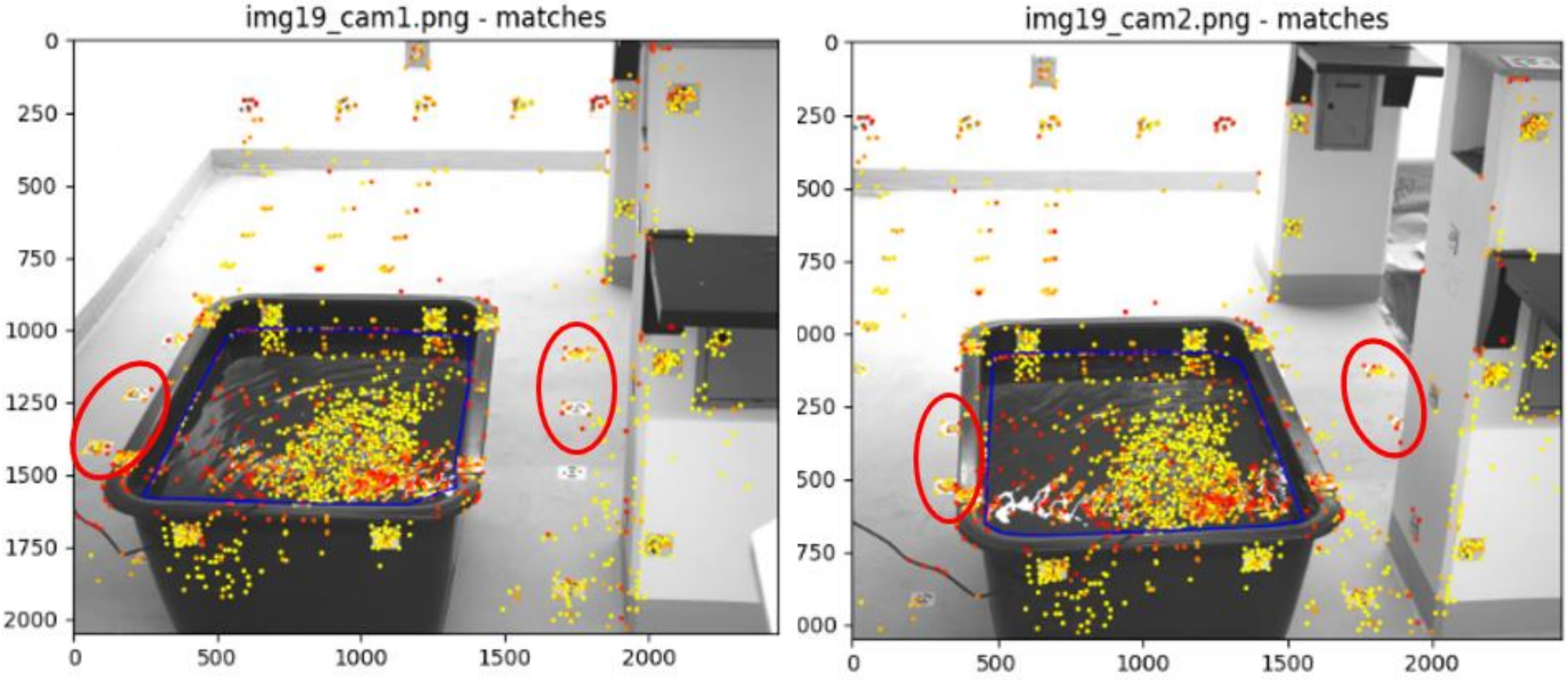
Feature extractors (columns) / *Feature matchers* (rows)

	Superpoint_aachen	Superpoint_inloc	Superpoint_max
Superglue	331 tie points	643 tie points	694 tie points
Superglue_fast	330 tie points	649 tie points	692 tie points
Lightglue	323 tie points	666 tie points	708 tie points



Pair of images: 54 tie points with Metashape

Feature detection and matching using deep learning

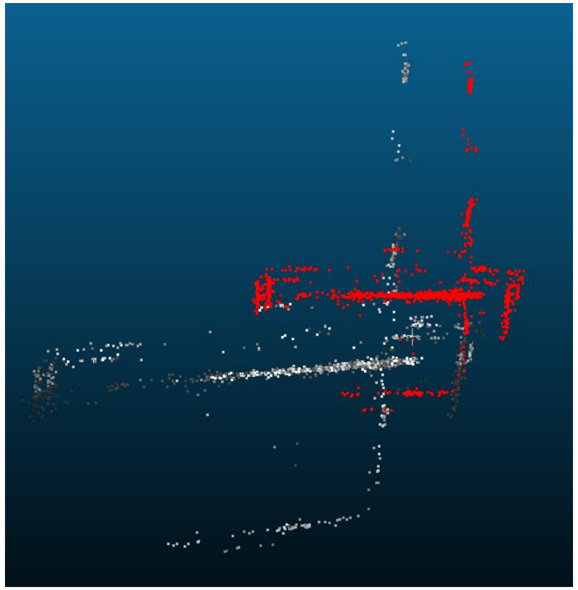


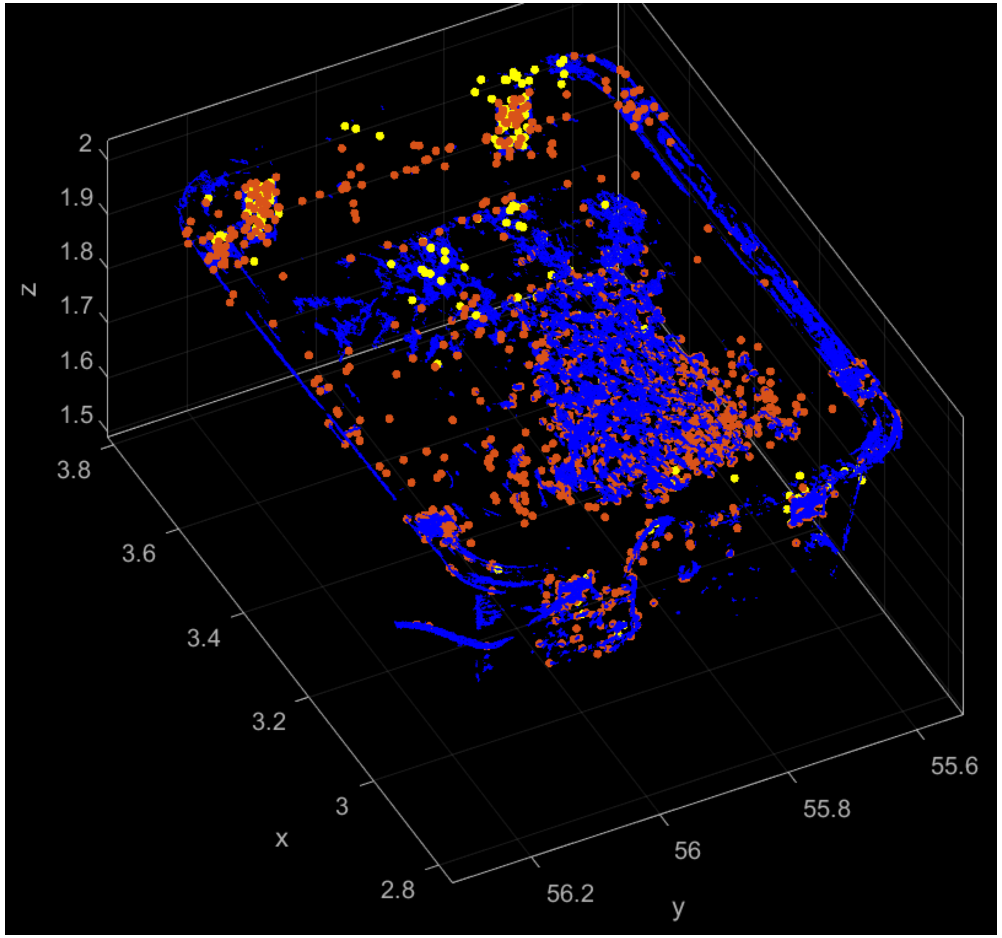
Feature detection and matching using deep learning

- Import into Metashape via Colmap

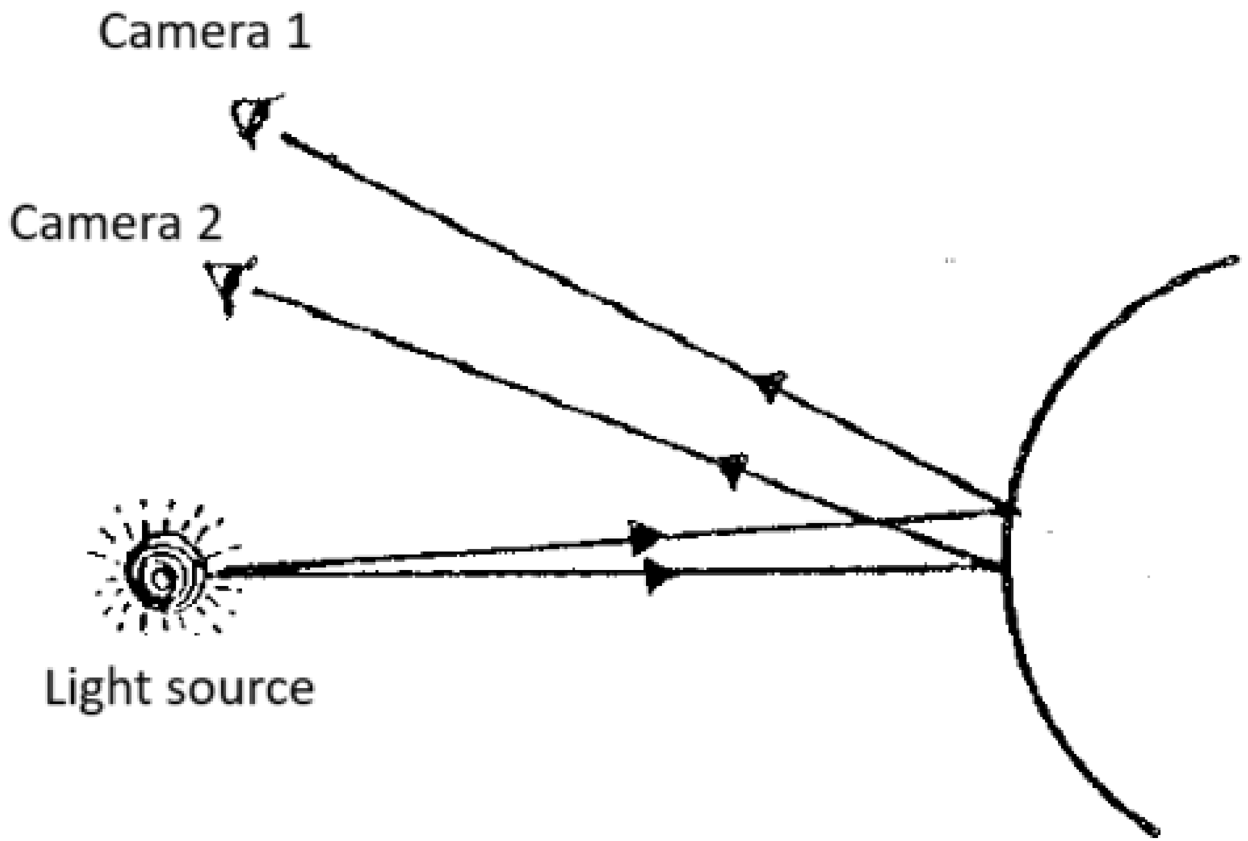
- In Metashape:
  - Apply exterior and orientation + distortion

    (previously estimated)





Error due to specular reflection



Source: Blake and Brelstaff, 1988

Error due to specular reflection

- Need to assess the accuracy of the matches

→ Reprojection error of the surface tie points

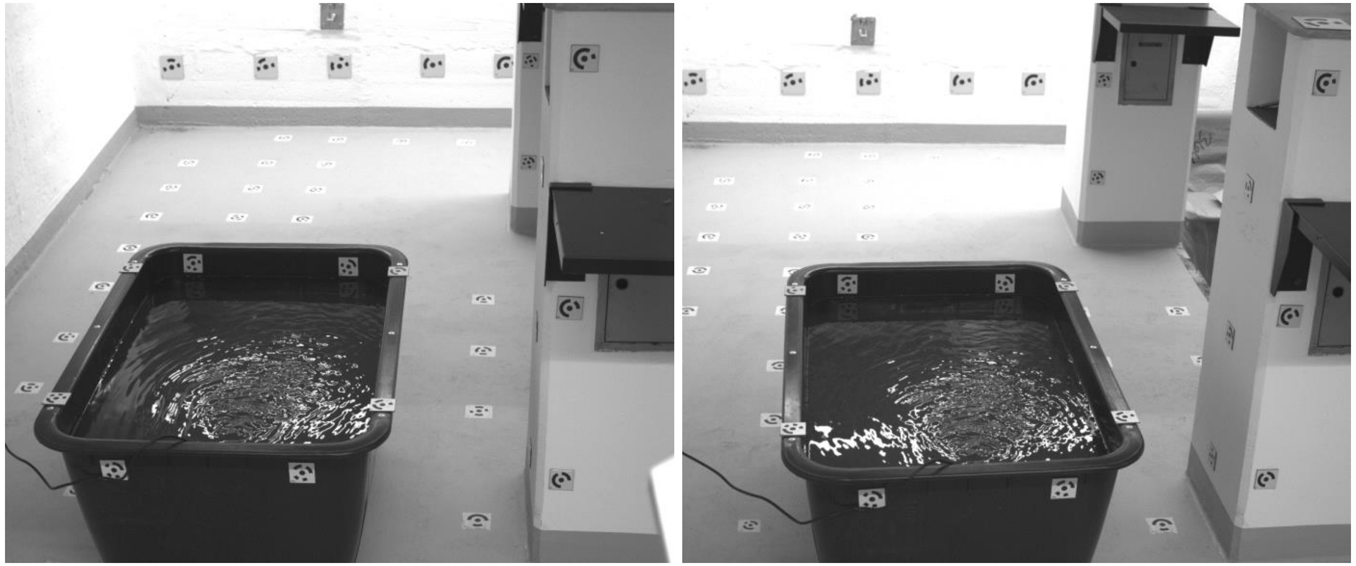
Metashape tie points:

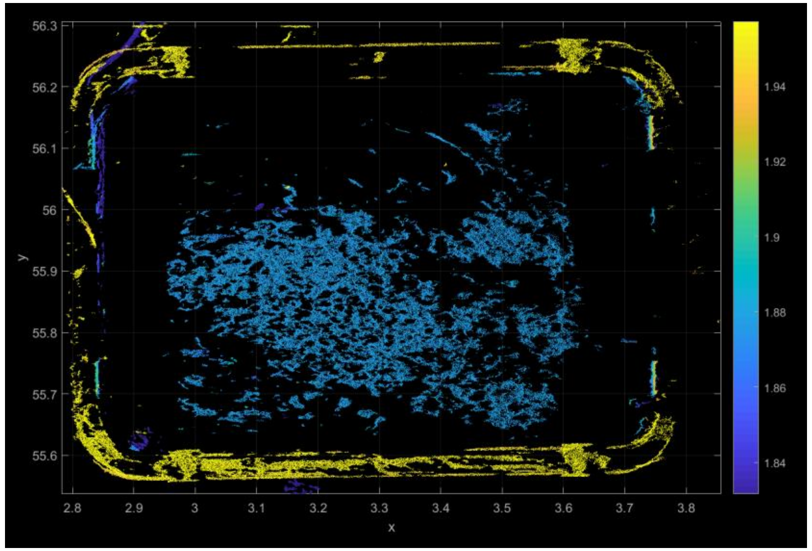
Mean error	0.29 pixels
Median error	0.19 pixels
Std	0.37 pixels
Threshold highest 10%	0.63 pixels

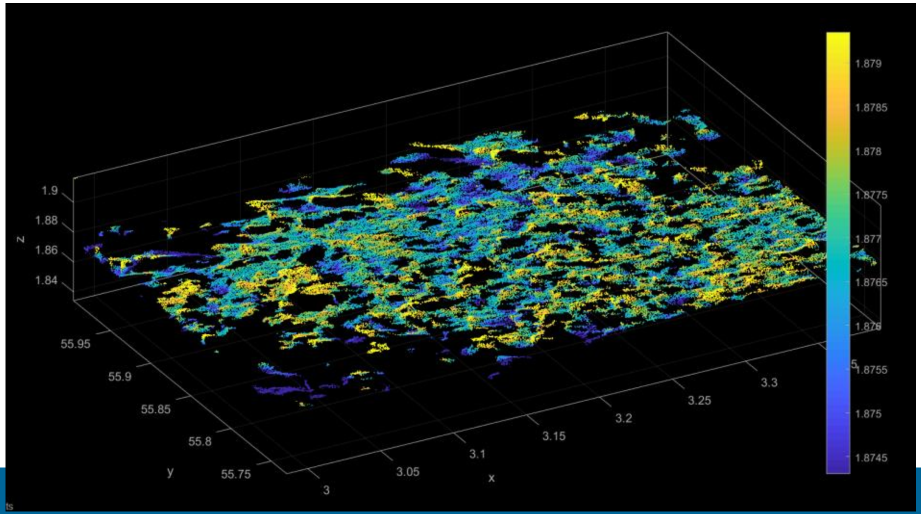
Superpoint + lightglue (after manual filtering of outliers):

Mean error	0.83 pixels
Median error	0.66 pixels
Std	0.64 pixels
Threshold highest 10%	1.76 pixels

Processing – Oblique images







WORKFLOW

Feature detection
Feature matching
Alignment

→ Sparse point cloud

Georeferencing

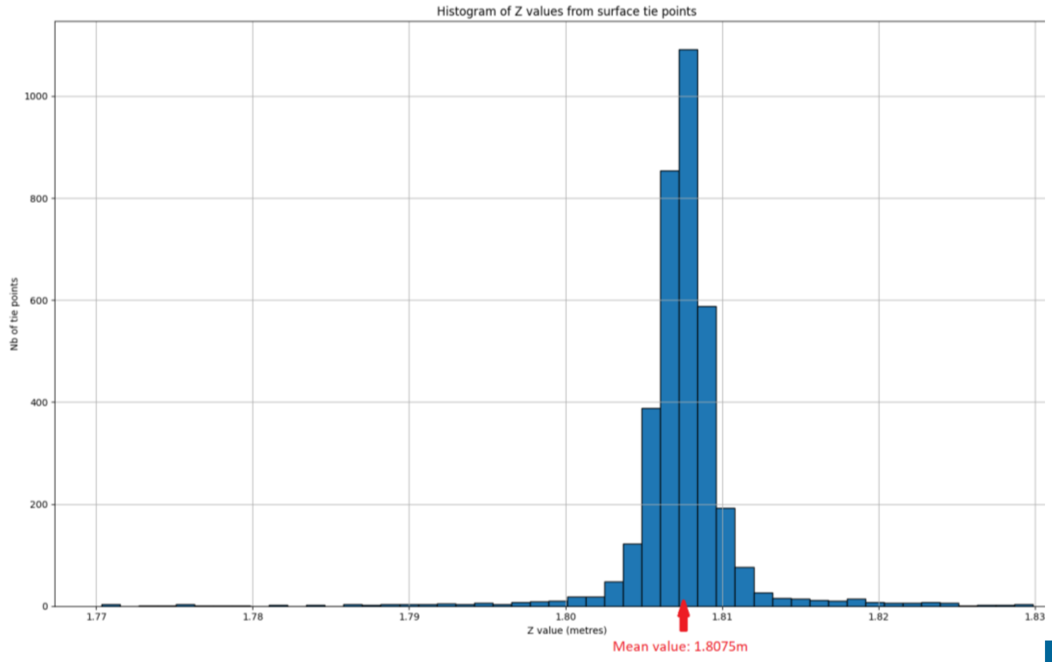
Dense matching → Dense point cloud

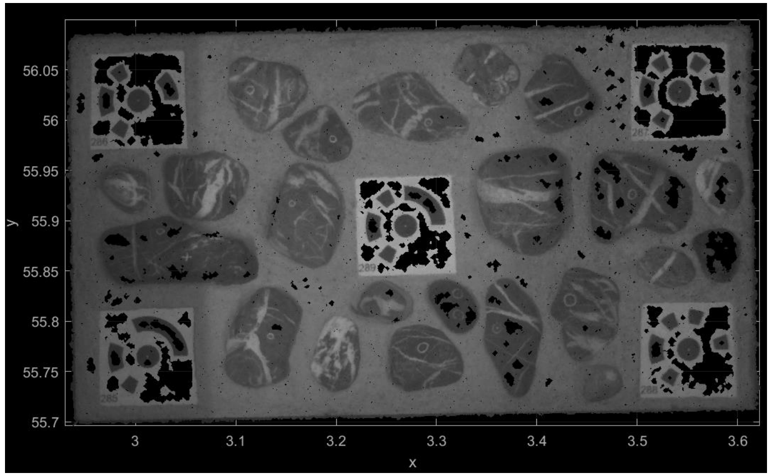
Processing – Oblique images

- From sparse point cloud :

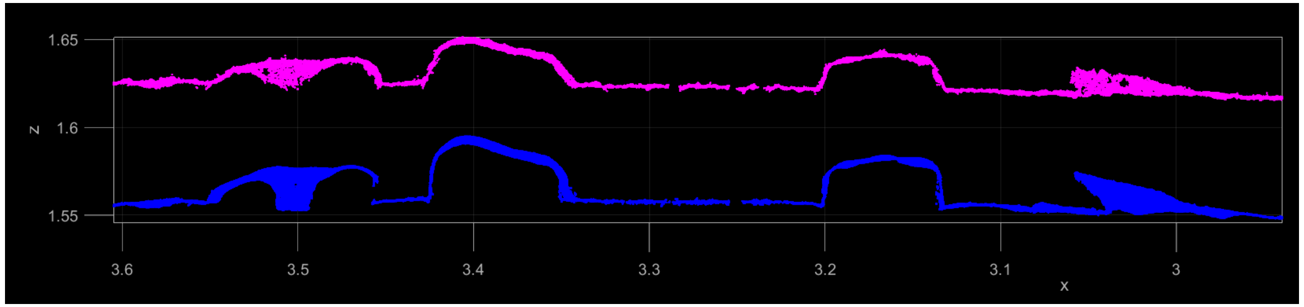
  average of Z coordinates -> mean water height

Mean water height = 1.8075m





Evaluation dataset: 4 images from grid of nadir cameras, with flat water surface



Difference with ground truth:

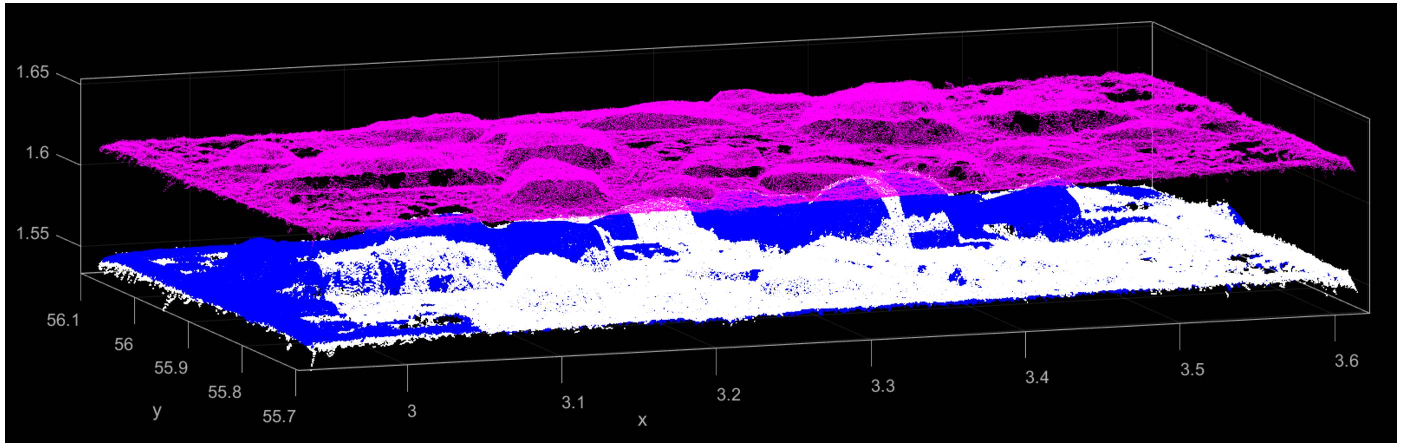
Mean: 66 mm - Median: 66 mm - Std: 3 mm

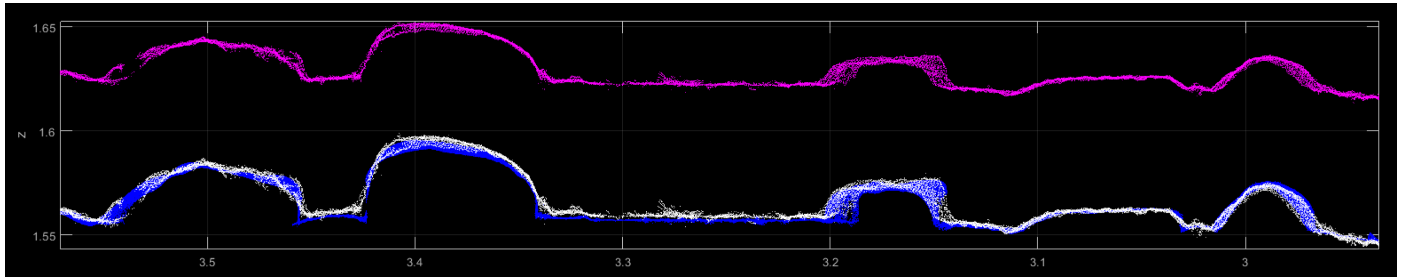
Verification – Mean water height

- Application of refraction correction to the models:
  - Refractive index used for water : 1.33
  - Single value for mean water height
    → the water surface is approximated as a planar surface at the height previously estimated

https://opals.geo.tuwien.ac.at/html/stable/index.html

After refraction correction





Blue: ground truth – Magenta: reconstructed topography – White: topography corrected by refraction

Refractive index of water

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Diff each column: -1 mm

Diff each row: -0.3 mm

	Refractive idx = 1.33	Refractive idx = 1.335	Refractive idx = 1.34
Water height = 1.806m	Mean = 2.3mm Median = 2.5mm	Mean = 1.4mm Median = 1.5mm	Mean = 0.4mm Median = 0.6mm
Water height = 1.807m	Mean = 2.0mm Median = 2.1mm	Mean = 1.0mm Median = 1.2mm	Mean = 0mm Median = 0.2mm
Water height = 1.8075m	**Mean = 1.8mm** **Median = 2.0mm**	**Mean = 0.8mm** **Median = 1.0mm**	**Mean = -0.1mm** **Median = 0.0mm**
Water height = 1.808m	Mean = 1.6mm Median = 1.8mm	Mean = 0.6mm Median = 0.8mm	Mean = -0.3mm Median = -0.1mm
Water height = 1.809m	Mean = 1.3mm Median = 1.4mm	Mean = 0.3mm Median = 0.5mm	Mean = -0.7mm Median = -0.5mm

High impact of the refractive index on the results
→ need a proper estimation

$$n_w = 1.338 + 4\times10^{-5}(486 - \lambda + 0.003d + 50S - T)$$

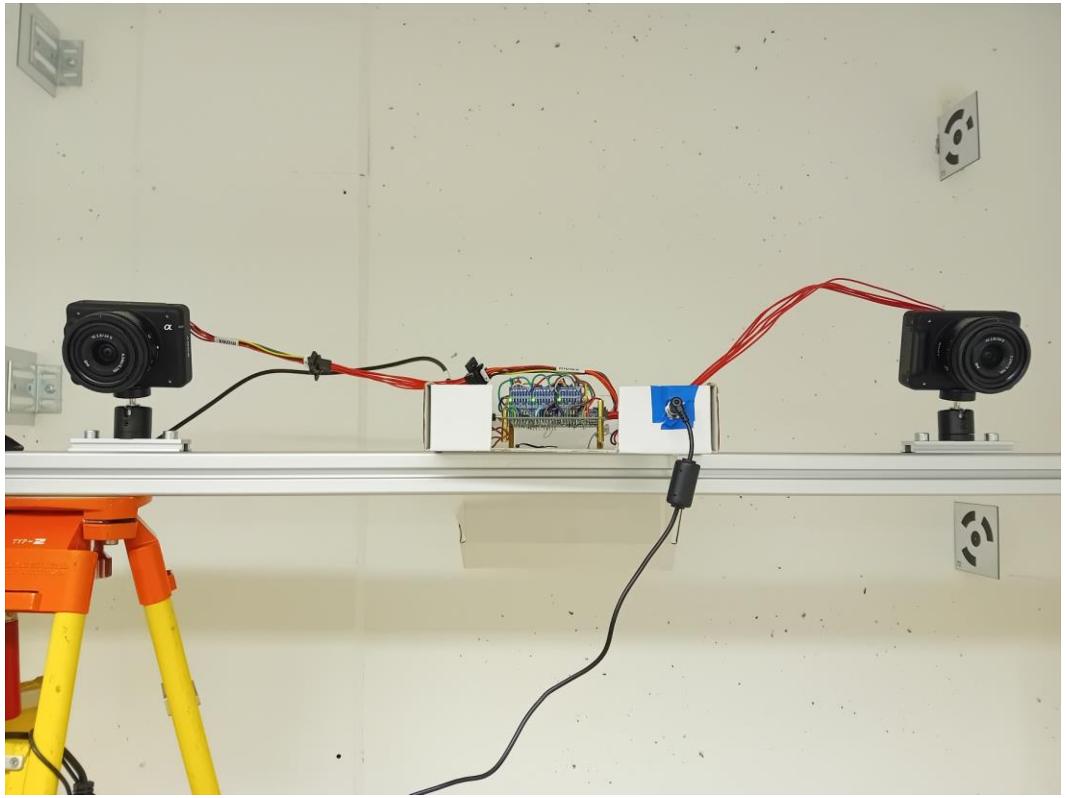
- Wavelength: 520nm (estimated)
- Depth: 0.15m (estimated)
- Temperature: 22.2°C (measured)
- Salinity: 0% (measured)

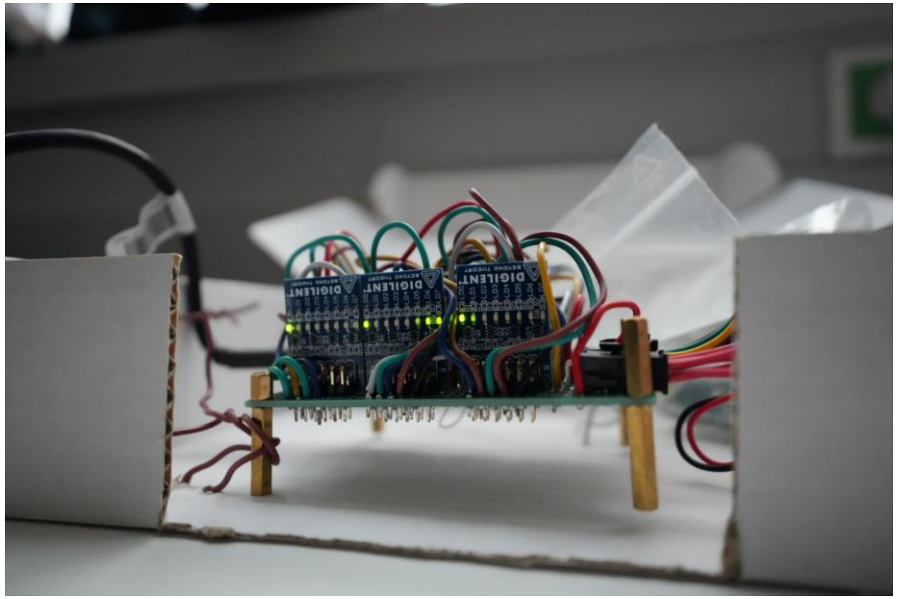
Estimation : $n_{water} = 1{,}33575$

→ Difference with ground truth: mean = 0.7mm, median = 0.9mm

Future activities

Time synchronisation → aiming for 2-3 ms exposure time





Conclusion

- Various processing workflows to obtain tie points on the surface
- Estimation of the mean water height
- Limitation of Structure-from-Motion

Future activities & Outlook:

- Focus on time synchronisation of cameras
- Deepening assessment of tie points
- Using specular reflection to retrieve surface normal vectors

Save the date

- ISPRS WG II/7 Workshop on Underwater Photogrammetry
- Jointly organised by **ISPRS** and **DGPF**
- **Venue: TU Wien**
- **Date: July, 08-11, 2025**
- **Program**
  - Invited lectures
  - Call for papers (in preparation)
  - Tutorials
  - Demonstrations (Water lab TU Wien)
  - Excursion (pre Alpine Pielach River)
  - Social events (Ice breaker, conference dinner)