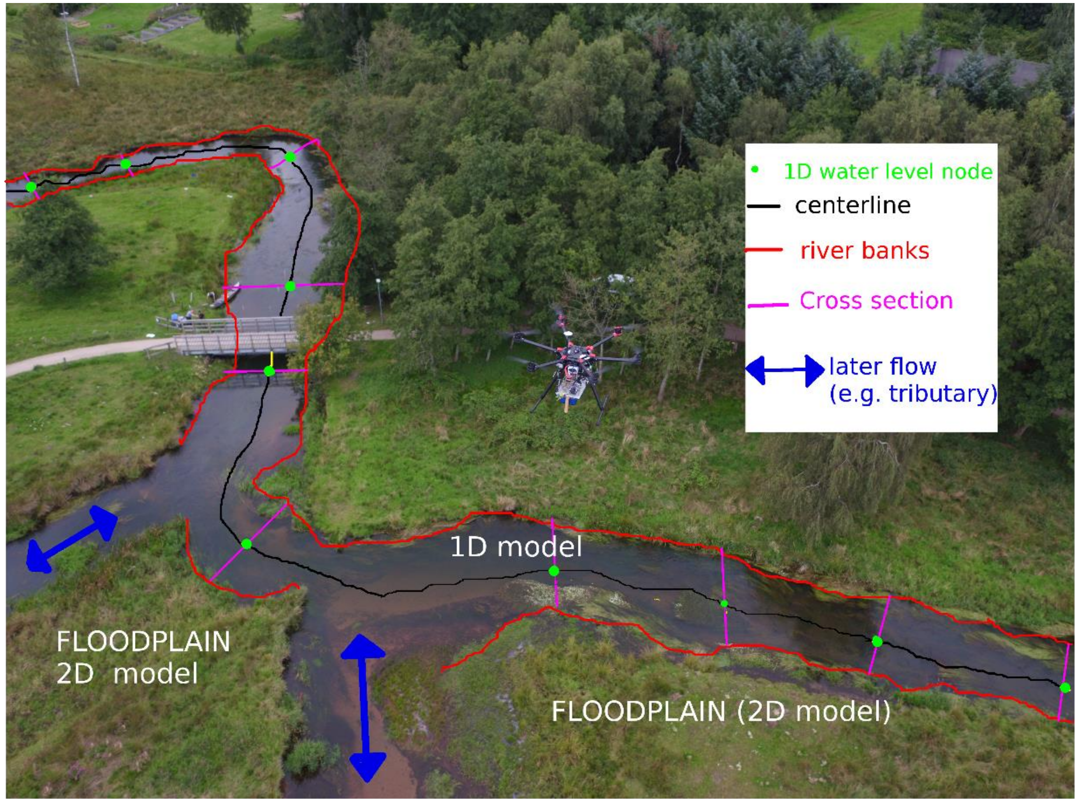
Hydraulics and Drones: Observations of water level, bathymetry and water velocity from UAVs

Filippo Bandini
PostDoctoral researcher
DTU Environment
fban@env.dtu.dk

Hydraulic variables



Hydraulic observations are used to inform open-channel hydrodynamic models

- **Water level [m]**: water surface elevation above mean sea level (m.s.l.)
- **Bathymetry [m]** : riverbed elevation above m.s.l.
- **Water depth [m]**: water surface elevation above the riverbed
- **Velocity [m/s]** : speed varies along, across the river course and throughout water depth
- **Discharge [m^3/s]** : it is generally derived from depth-integrated water speed profiles and water depth.

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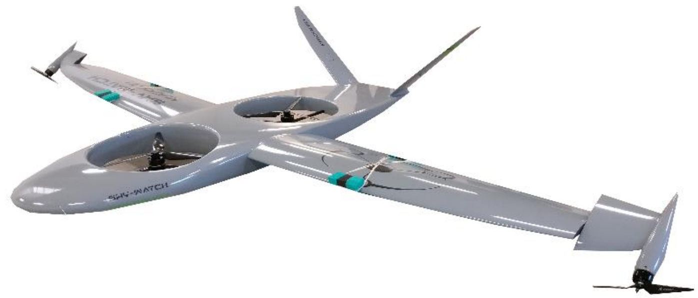
Platforms

(a)

(b)



(c)

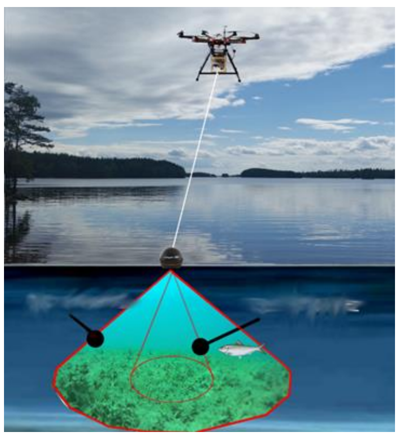
a) multirotor rotary wing (DJI S900): maximum take-off weight 8.2 kg, maximum payload of ca. 2 kg, and a wingspan of ca. 1 m.

b) Hybrid UAV with VTOL capability (SmartUAV): total weight of ca. 15 kg, maximum payload capability of only 1.5 kg, and a wingspan of ca. 5 m.

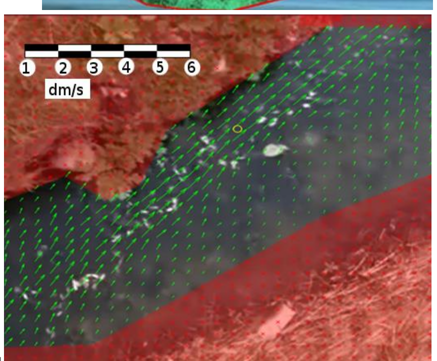
c) fixed wing (Mini Apprentice S.): maximum take-off weight of ca. 735 g, maximum payload capability of ca. 100 g, and a wingspan of ca. 1.2 m.

Research goal

Orthometric water level (W.L.)

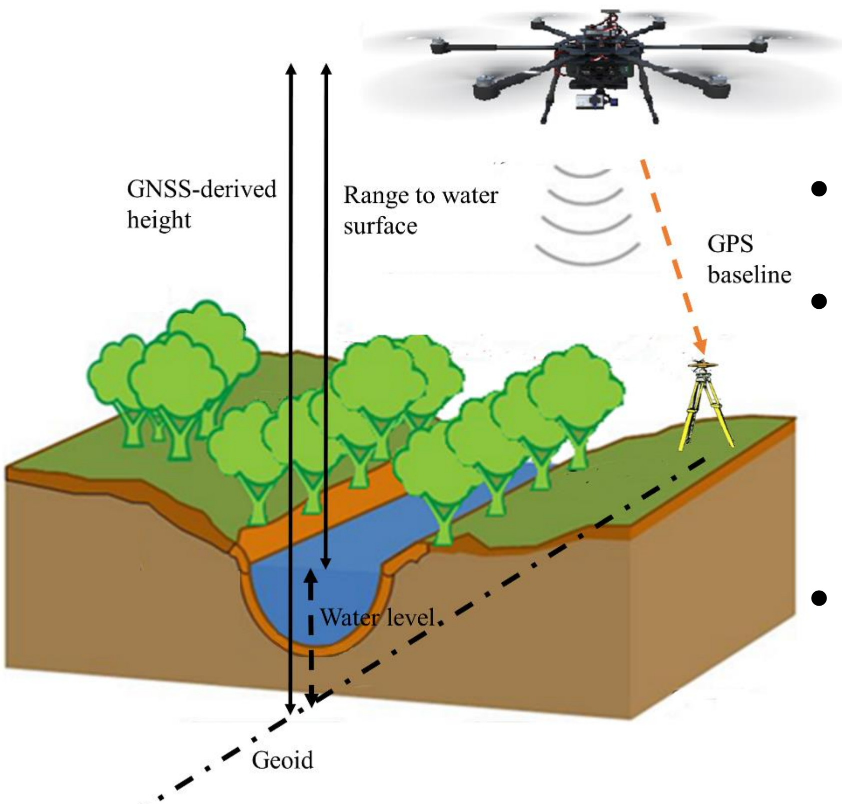


Water depth (and bathymetry)



Surface velocity

Measurements of W.L. (orthometric water height)



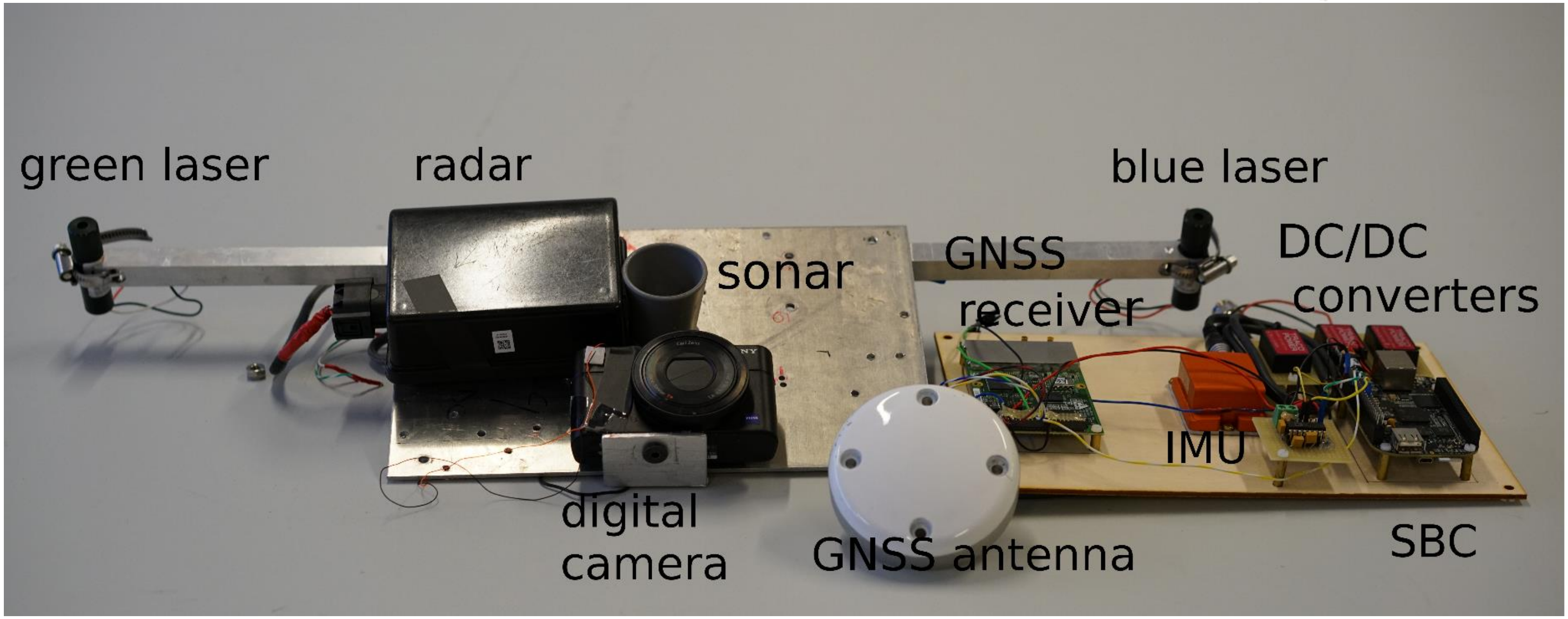
- A ranging sensor measures the range to water surface
- The GNSS (Global Navigation Satellite System) measures the drone height above the reference ellipsoid (convertible into **altitude above geoid**)

- **Water level** (elevation of the water surface) is computed by subtracting the range measured by the radar from the GNSS-derived height.

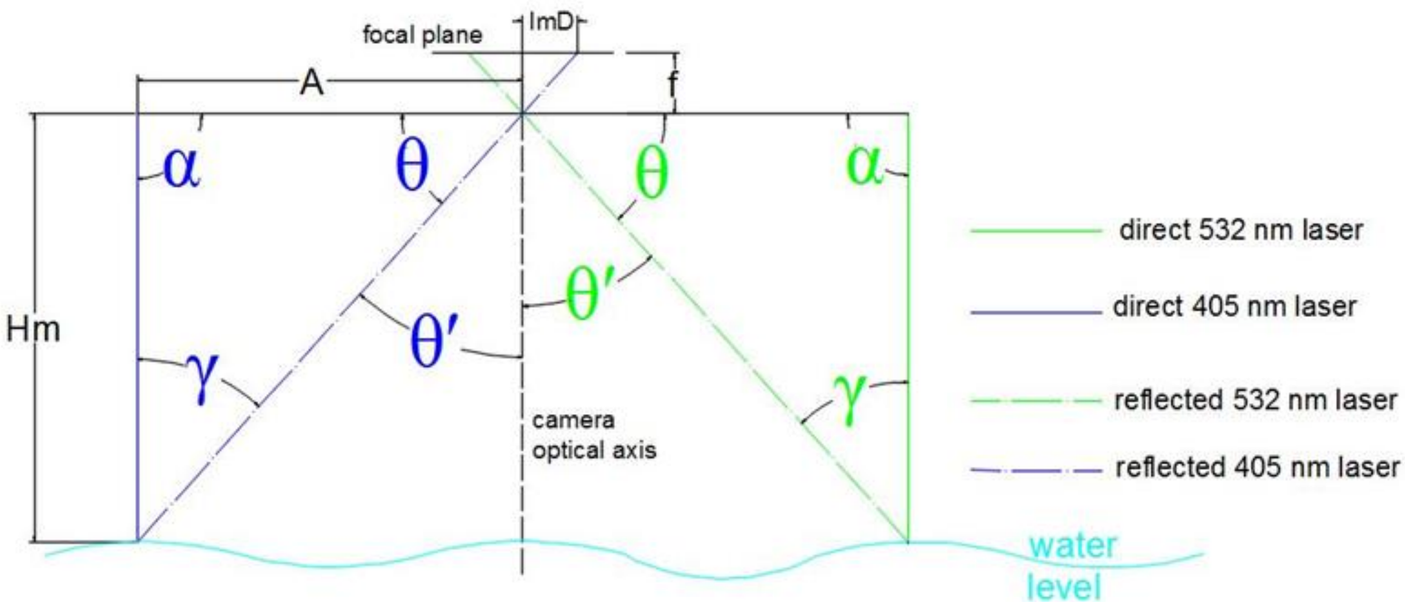
Water surface ranging sensors

We tested different sensors for measuring the range to water surface:

- A radar: Continental-ARS 30X-77 GHz W-band
- A sonar: Maxbotix-MB7386 42 KHz
- The CLDS (**camera**-based laser distance sensor) prototype developed at DTU



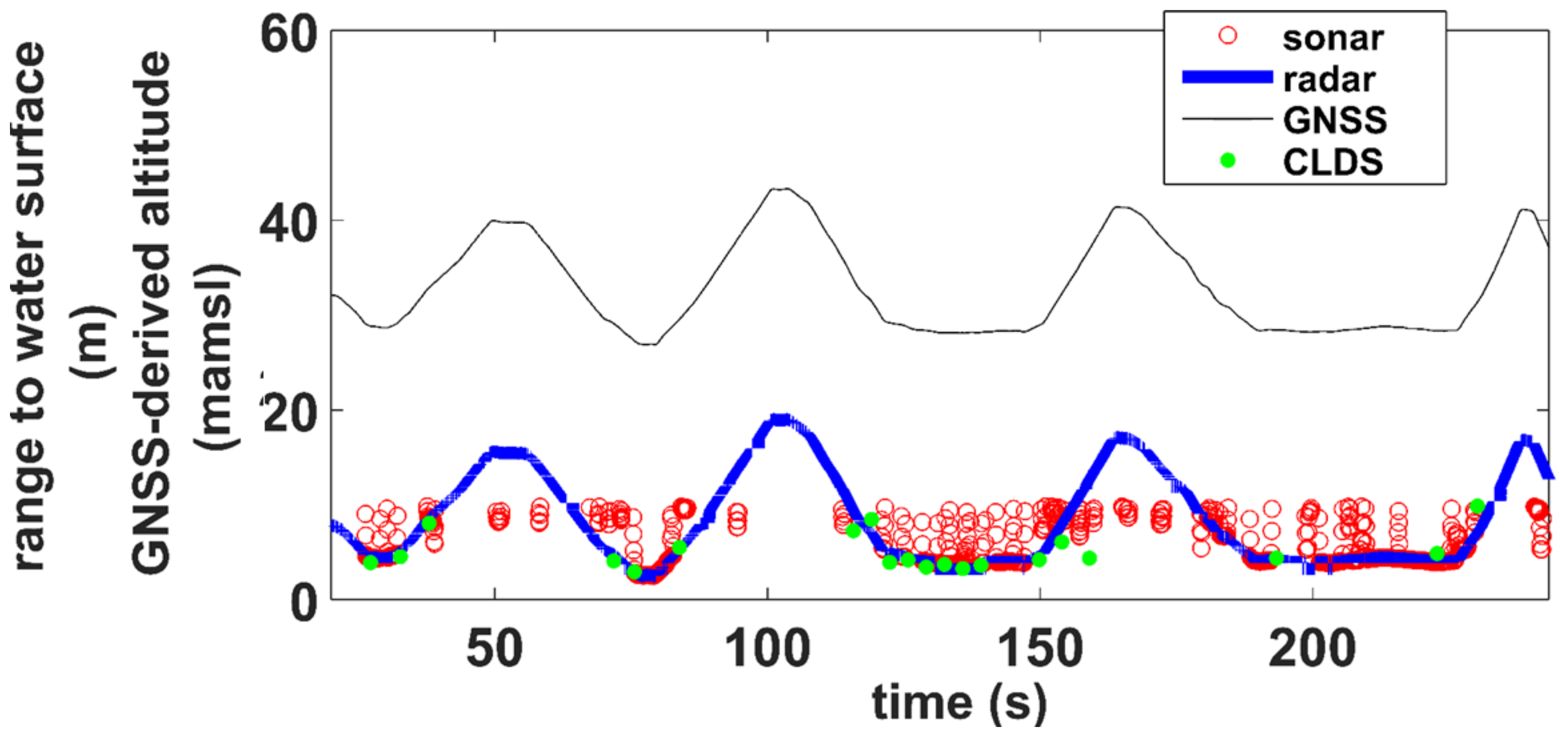
Methodology: **camera-based laser distance sensor**



Two laser dots for redundancy

Image of the water surface showing the two laser dots.

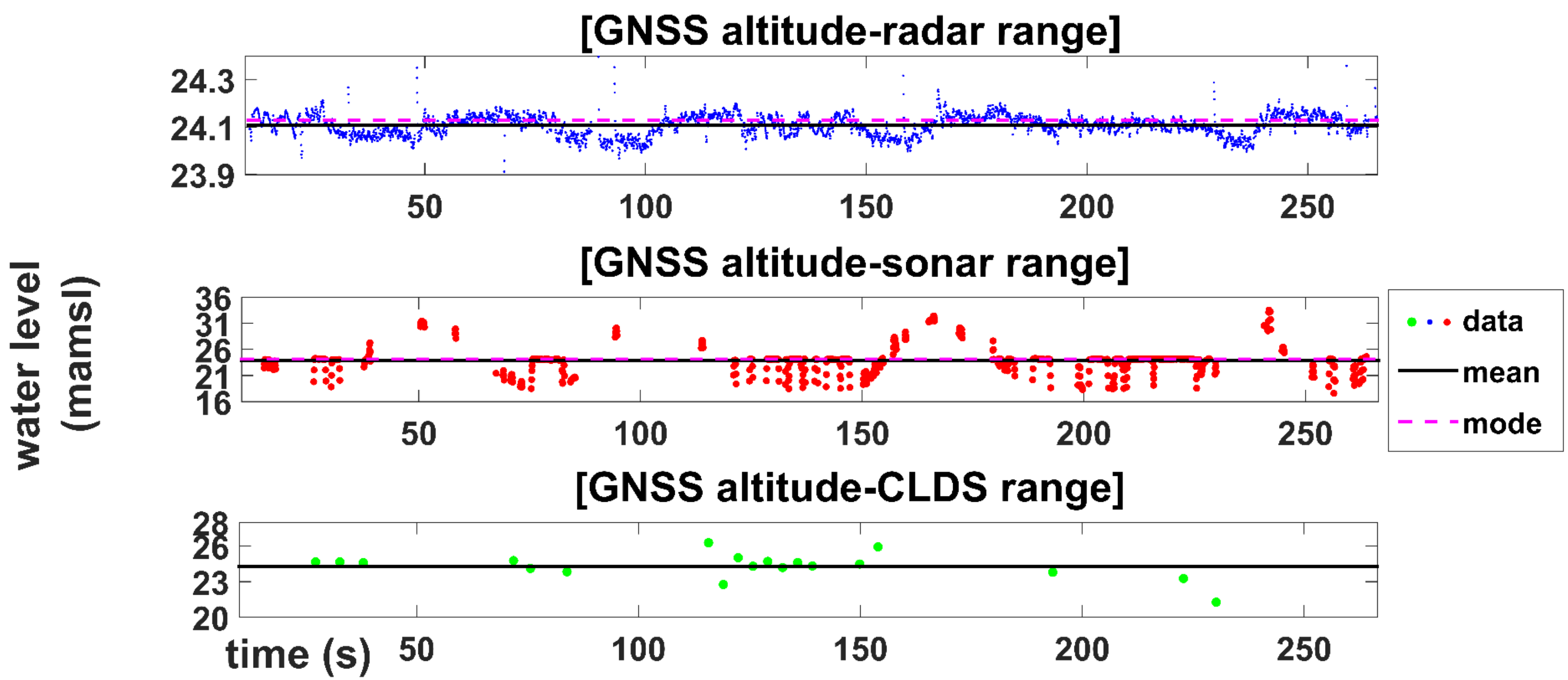
Proof-of-concept:
Flight above Furesø lake



++ high correlation between radar and GNSS curves
-- Sonar observations appear very noisy and with low range capability
-- Few observations with CLDS

Proof-of-concept:

Flight above Furesø lake



++ W.L. measured by GNSS/radar system is almost a constant line, with an estimated accuracy of ≈5-7 cm

-- W.L. measured by GNSS/sonar system shows multiple outliers

-- Few observations with CLDS, but the CLDS has the advantage of a low beam divergence

Water level observations technology comparison

Location	Technique	Ground footprint	Accuracy	Reference
Airborne	LIDARs	20 cm-1 m	4-22 cm	(Hopkinson et al., 2011)
Spaceborne	laser altimetry (ICESat)	50–90 m	10-15 cm	(Phan et al., 2012)
Spaceborne	radar altimetry (e.g. ERS2, Envisat, Topex/Poseidon)	400 m-2 km	30-60 cm	(Frappart et al., 2006)
Ground-based	radar/sonar/pressure transducers	mm-cm	1 mm-10 cm	Widely known metrology
UAV-borne	radar altimetry	dm-m	5-10 cm	Bandini et al., I, II, IV

Source: Bandini, F, PhD thesis (2017)

Reference

Journal of Hydrology 548 (2017) 237–250

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

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Research papers

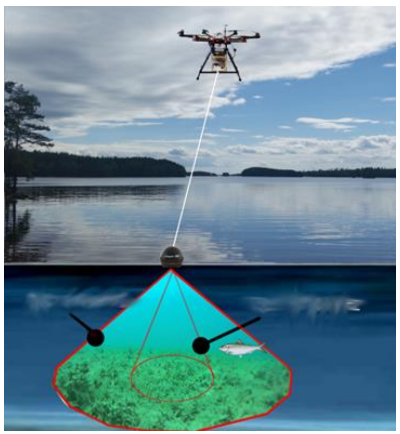
Measuring water level in rivers and lakes from lightweight Unmanned Aerial Vehicles

Filippo Bandini [a,*], Jakob Jakobsen [b], Daniel Olesen [b], Jose Antonio Reyna-Gutierrez [a], Peter Bauer-Gottwein [a]

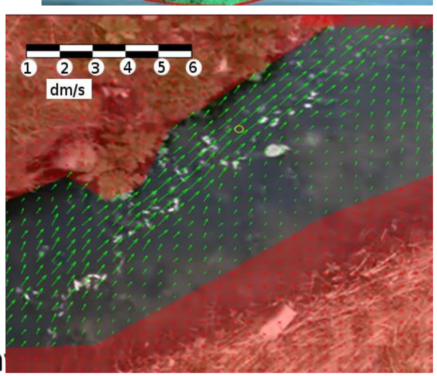
[a] Department of Environmental Engineering, Technical University of Denmark, Lyngby 2800, Denmark
[b] National Space Institute, Technical University of Denmark, Lyngby 2800, Denmark

Research goal

Orthometric water level (W.L.)



Water depth (and bathymetry)



Surface velocity

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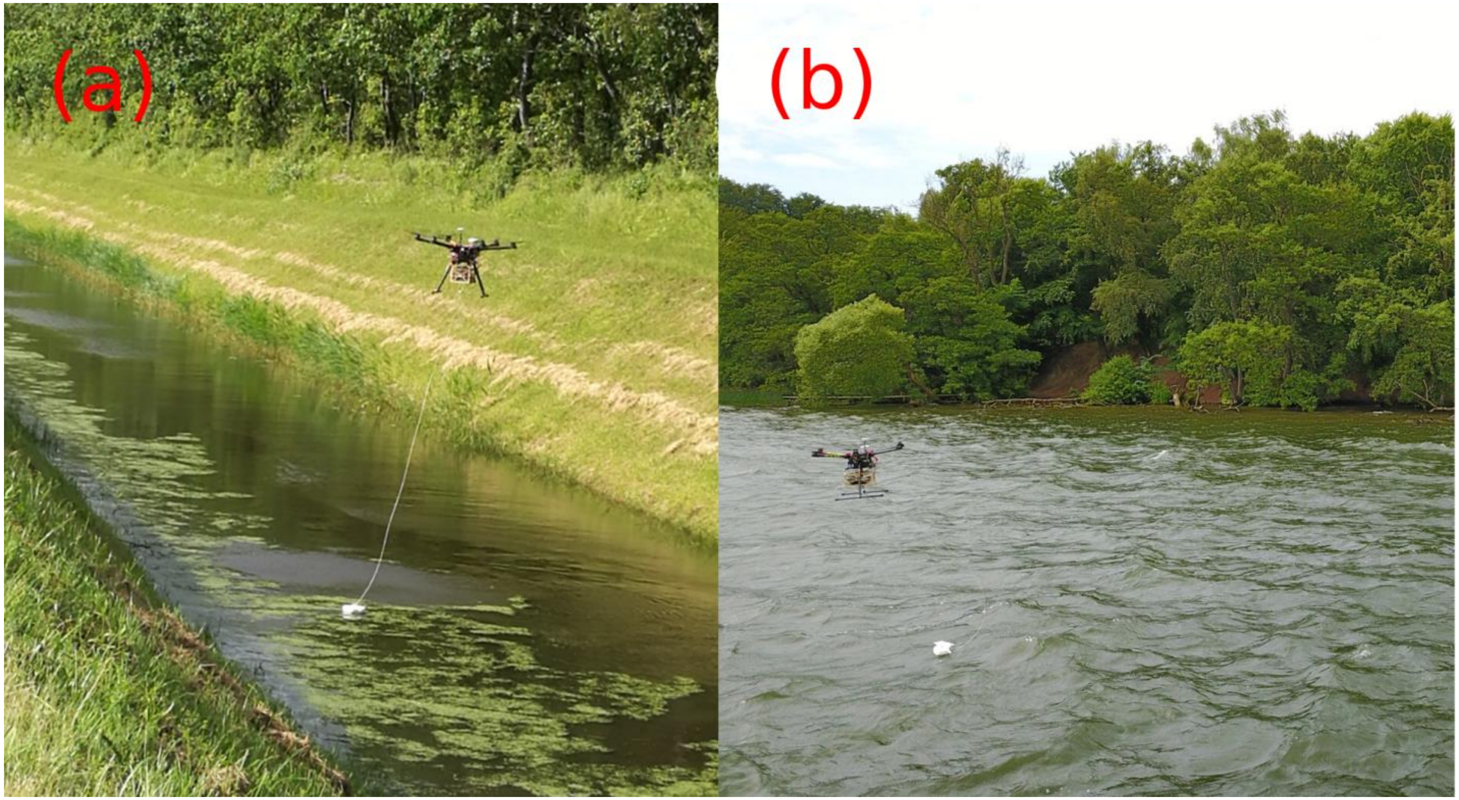
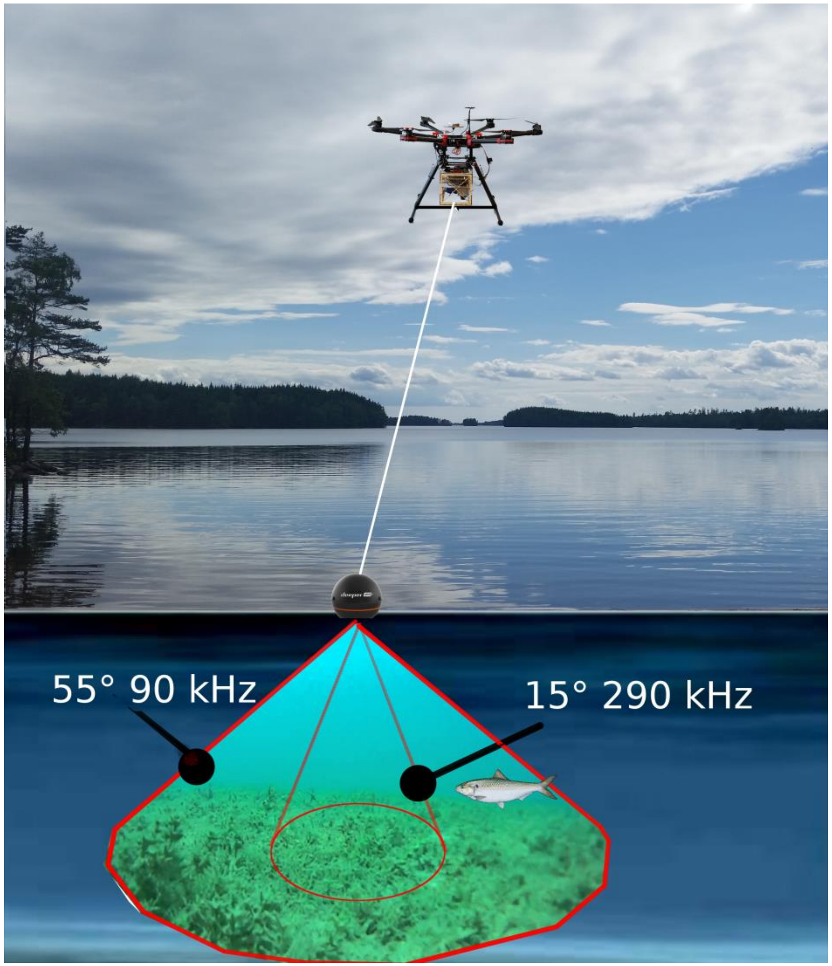
Tethering sonar



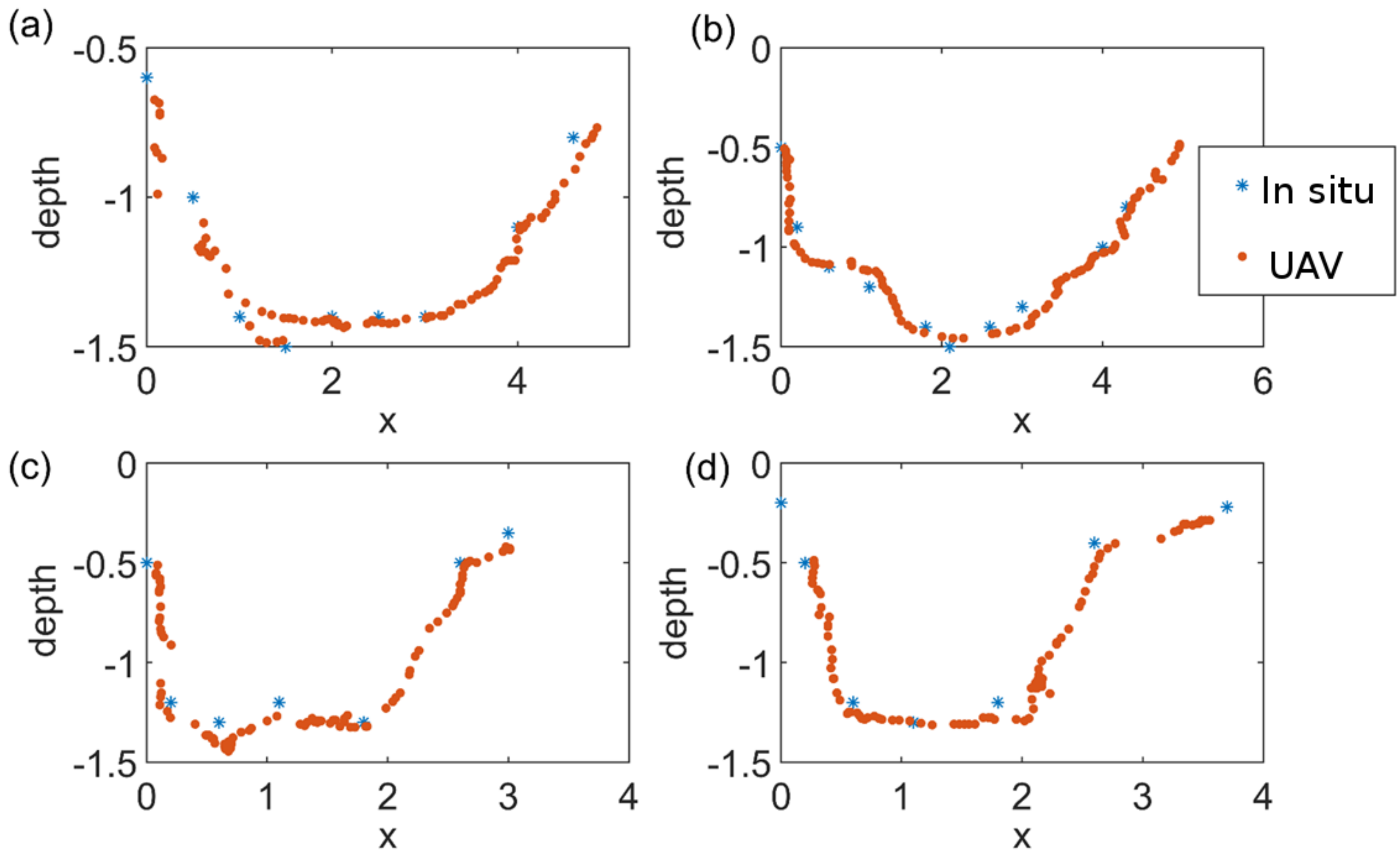
Picture of the drone with the tethered sonar flying above
(a) Danish stream
(b) Furesø

Measurements of water depth and bathymetry



- 290/90 kHz, with
  15 ° / 55° beam angles
- The narrower beam is generally used for measuring **water depth and bottom structure**
- The larger beam can be potentially used for identifying **fish**
- **Water depth** can be obtained with an **accuracy of 2.1%** of the actual depth
- **Bathymetry** (Orthometric height of the riverbed) can be obtained by subtracting water depth observations from water level (meters above mean sea level)

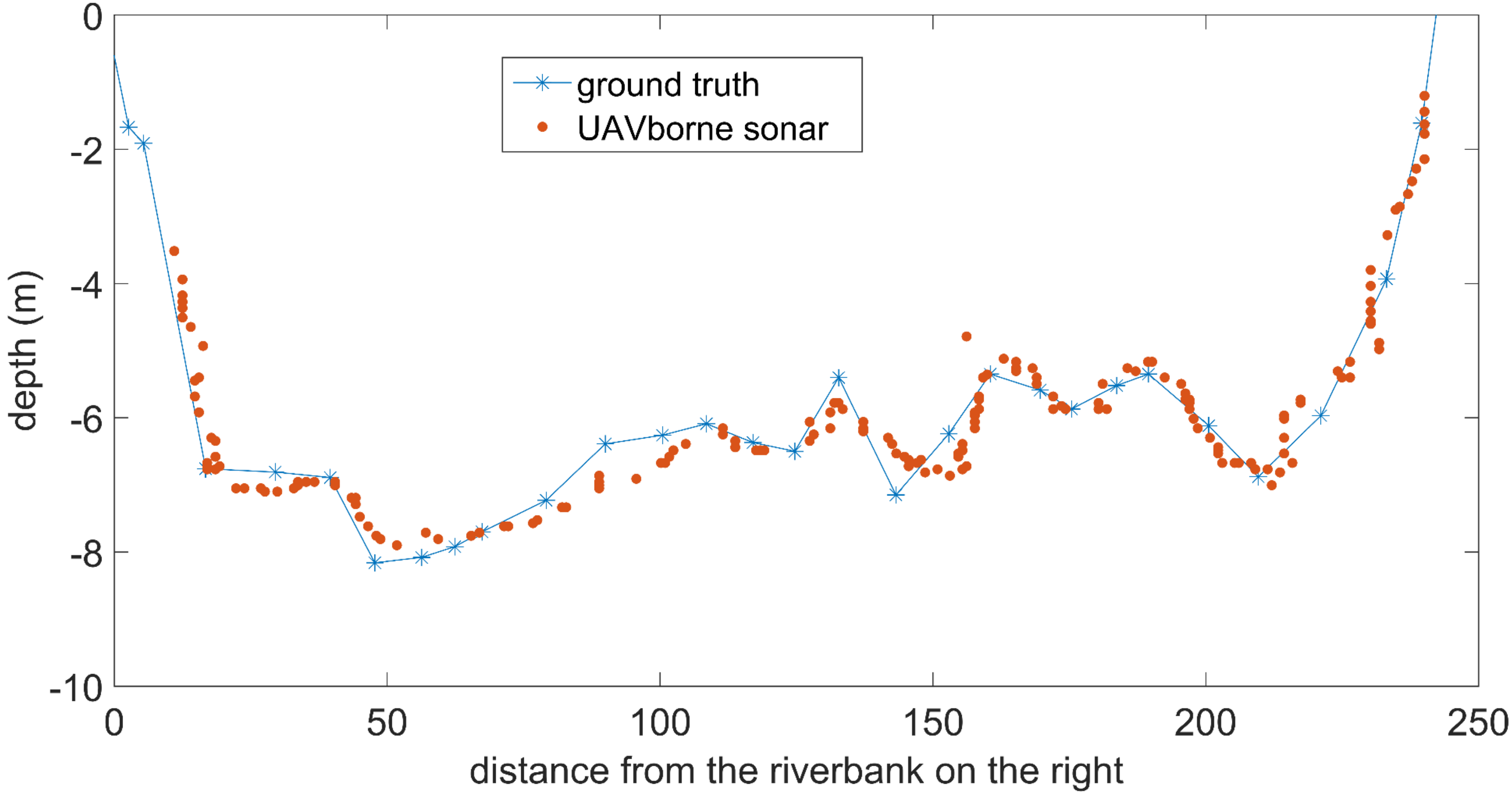
Observations of river cross sections (1)



Sydkanalen, Falster (Denmark)
(a) 54.676300° , 11.913296° (b) 54.675507° , 11.913628° (c) 54.682117° , 11.911957° (d) 54.681779° , 11.910723° (WGS84 Lat, Long coordinates).

Observations of river cross sections (2)

- UAV-borne bathymetry observations in Po river, Italy (2017)
- Ground truth retrieved with a single beam sonar on boat (2012)



Po River cross section at WGS84 coordinates LAT 45.073375° , Long 10.934940° (Italy)

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Water depth technology comparison

Technique	Max. water depth (m)	Typical error (m or %)	Applicability	References
Spectral signature	1-1.5 m	0.10-0.20 m	Clear water	**Satellite**: (Fonstad and Marcus, 2005; Legleiter and Overstreet, 2012) **Aircraft**: (Carbonneau et al., 2006; Legleiter and Roberts, 2005; Winterbottom and Gilvear, 1997) **UAV**: (Flener et al., 2013; Lejot et al., 2007)
Through-water photogrammetry	1-1.5 m	0.08-0.2 m	Gravel-bed water bodies with extremely clear water	**Aircraft**: (Feurer et al., 2008; Lane et al., 2010; Westaway et al., 2001) **UAV**: (Bagheri et al., 2015; Dietrich, 2016; Tamminga et al., 2014; Woodget et al., 2015)
LIDAR	1-1.5 m	≈13 m	Gravel-based water bodies with very clear water: 1-1.5 Secchi Depth	**UAV**: (Mandlburger et al., 2016)
	6 m	0.05-0.3 m	Clear water	**Aircraft**: (Bailly et al., 2012, 2010; Charlton et al., 2003; Hilldale and Raff, 2008; Kinzel et al., 2007)
Sonar tethered to UAV	0.5-80 m	≈2.1% of actual depth	All water conditions	**UAV**: (Bandini et al., III)

Reference

Hydrology and Earth System Sciences
An interactive open-access journal of the European Geosciences Union

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https://doi.org/10.5194/hess-2017-625

Discussion papers

Abstract | Discussion | Metrics

Technical note

01 Nov 2017

Bathymetry observations of inland water bodies using a tethered single-beam sonar controlled by an Unmanned Aerial Vehicle

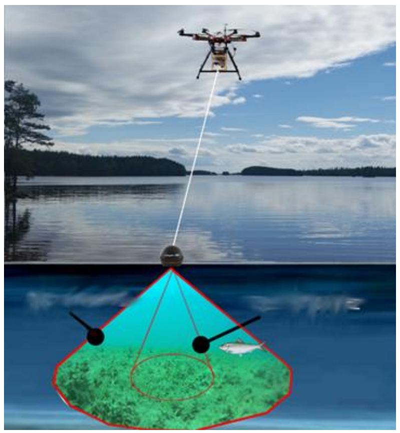
Filippo Bandini[1], Daniel Olesen[2], Jakob Jakobsen[2], Cecile Marie Margaretha Kittel[1], Sheng Wang[1], Monica Garcia[1], and Peter Bauer-Gottwein[1]
[1]Department of Environmental Engineering, Technical University of Denmark, Kgs. Lyngby, Denmark
[2]National Space Institute, Technical University of Denmark, Kgs. Lyngby, 2800, Denmark

Review status
This discussion paper is a preprint. It is a manuscript under review for the journal Hydrology and Earth System Sciences (HESS).

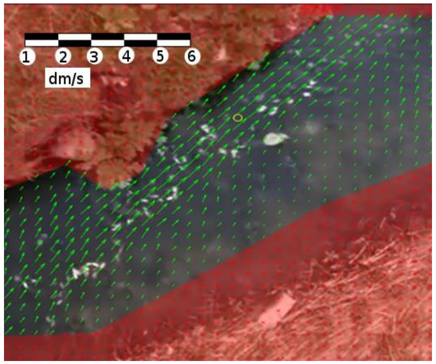
Received: 22 Oct 2017 – Accepted for review: 28 Oct 2017 – Discussion started: 01 Nov 2017

Research goal

Orthometric water level (W.L.)



Water depth (and bathymetry)



Surface velocity

UAV-borne
Water Surface Velocity

- UAV-borne high-resolution video of the water surface

- Video stabilization (high and low frequency vibrations)

LSPIV
(Large Scale Particle Image Velocimetry)

Water surface 2D velocity field

Lille Skensved, Sjælland, Denmark

UAV-borne
Water Surface Velocity

Tracers

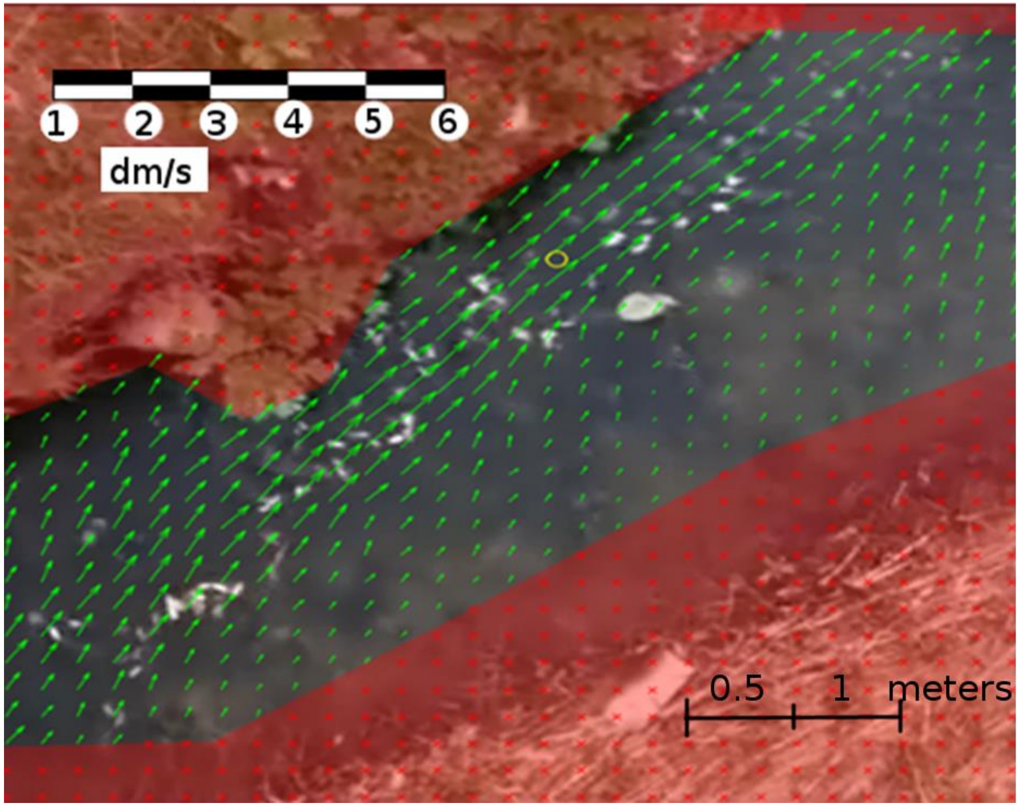
Natural Artificial

Video Stabilization

High frequency Low frequency

Conversion
from pixel units to metric units

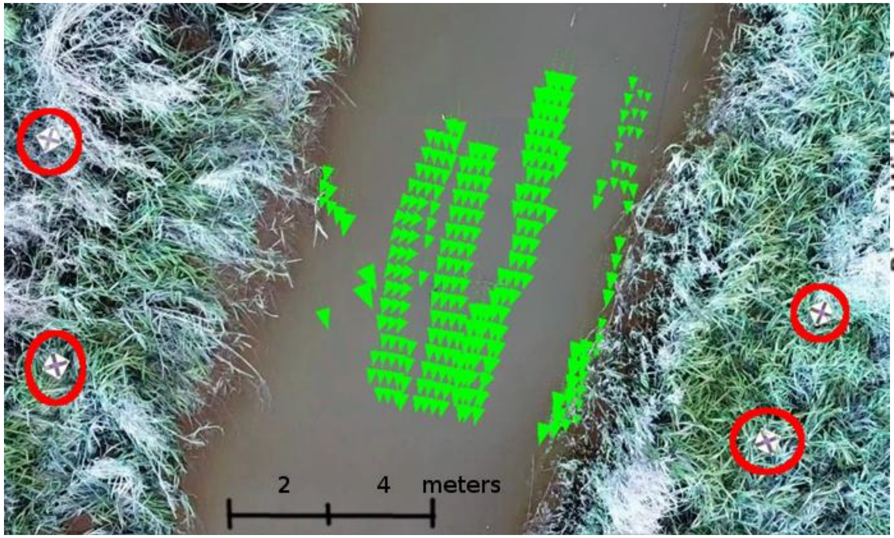
Radar GCPs



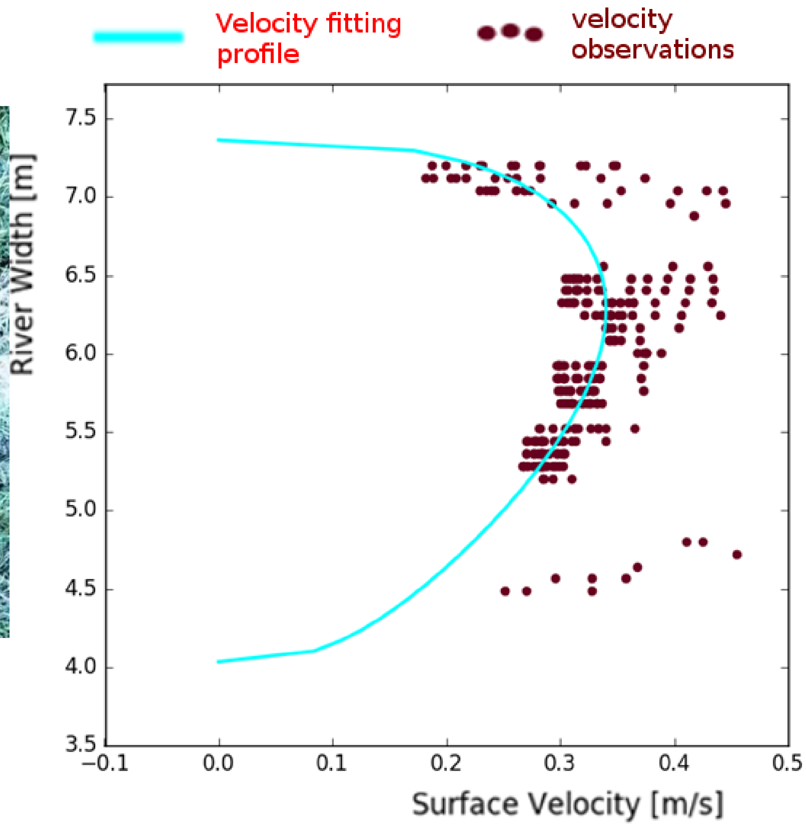
Lille Skensved, Sjælland, Denmark

Water surface velocity

- **4 GCPs** to convert pixel units into metric units
- **No artifical seeding**. Cross-correlation on natural tracers



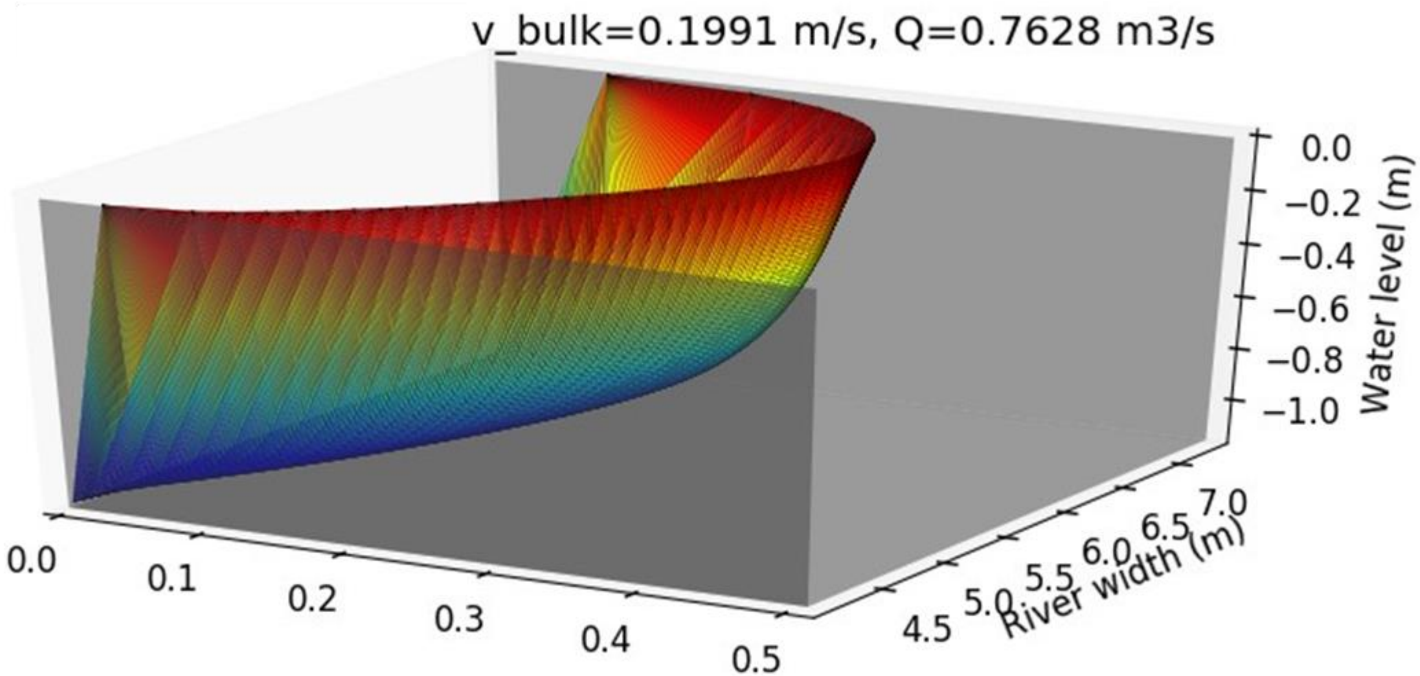
VÆREBRO Å, SNYDEBRO (VEKSØ, DENMARK);
Coordinates: 5544'28.6"N; 1215'00.9"E



≈15% accuracy in surface velocity when compared to in-situ probe

Video processed by **http://www.photrack.ch/**

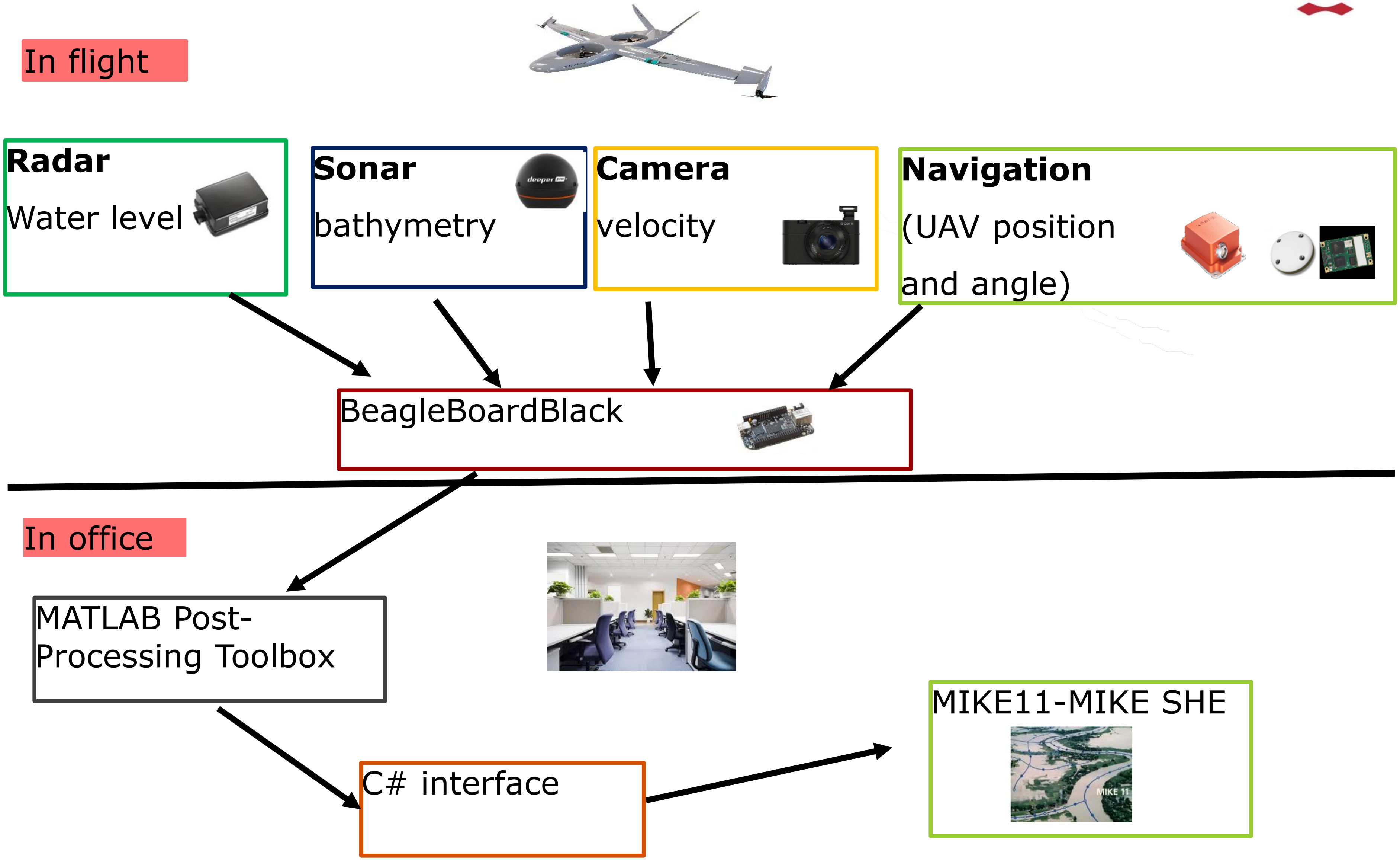
From surface velocity to discharge



- Bulk average velocity can be computed from surface velocity
- A velocity vertical profile can also be estimated from surface velocity
- Velocity vertical profile and bathymetry allow for computation of discharge

Video processed by **http://www.photrack.ch/**

Flowchart


In flight
Radar
Water level
Sonar
bathymetry
Camera
velocity
Navigation
(UAV position
and angle)
BeagleBoardBlack
In office
MATLAB Post-
Processing Toolbox
C# interface
MIKE11-MIKE SHE
MIKE 11

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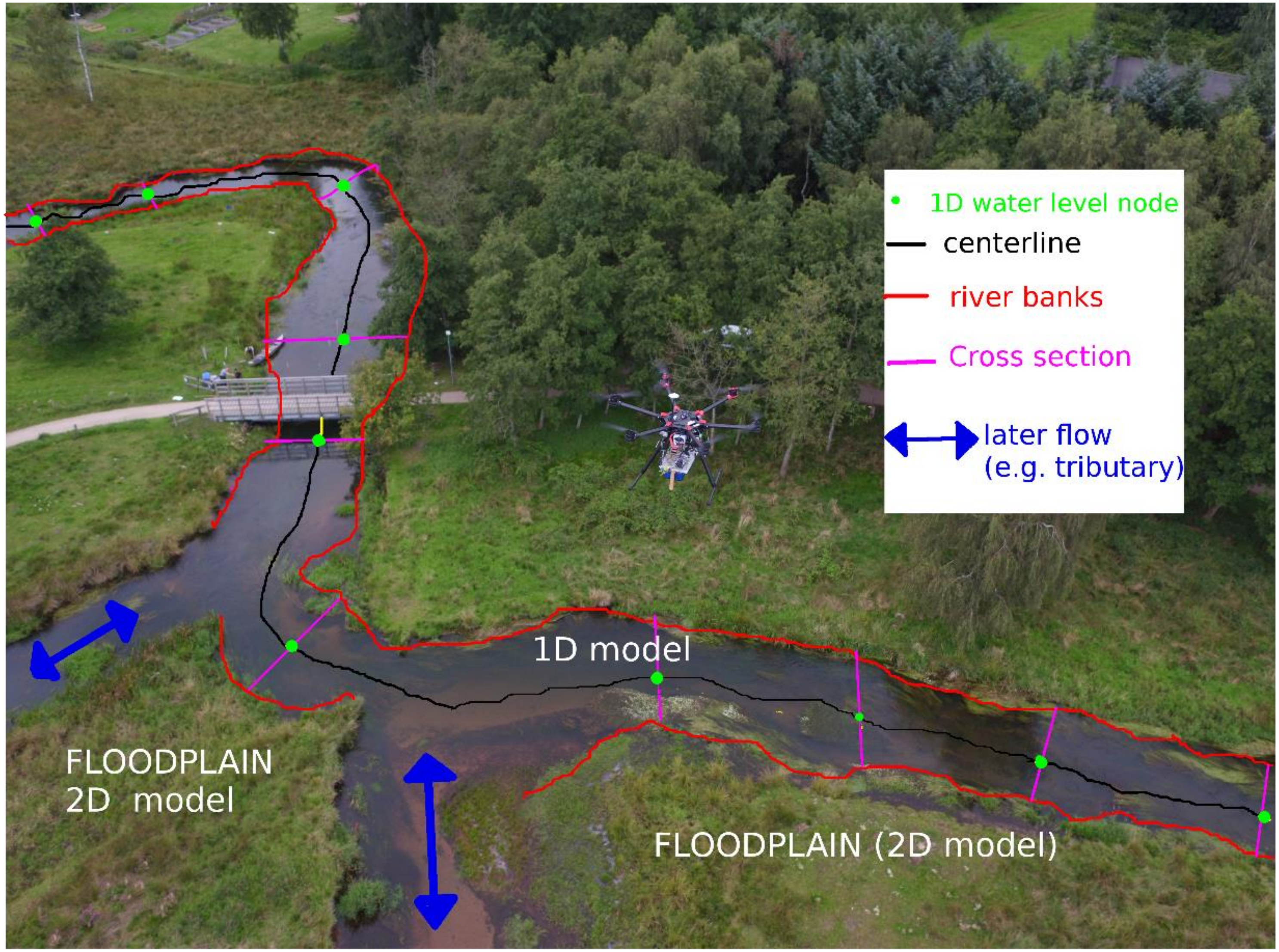
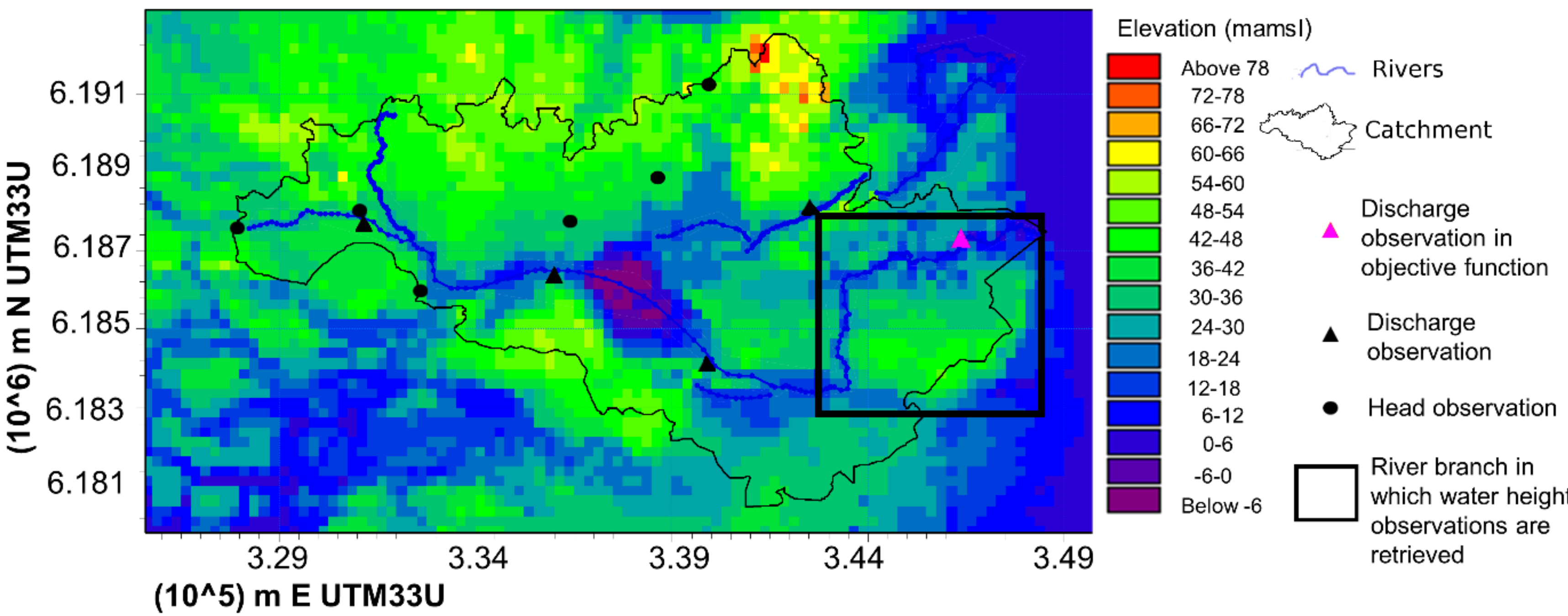
River hydrodynamic model



Calibration of an hydrological model with UAV-borne water level observations

- Mike 11-SHE model of Mølleåen stream and its integrated catchment



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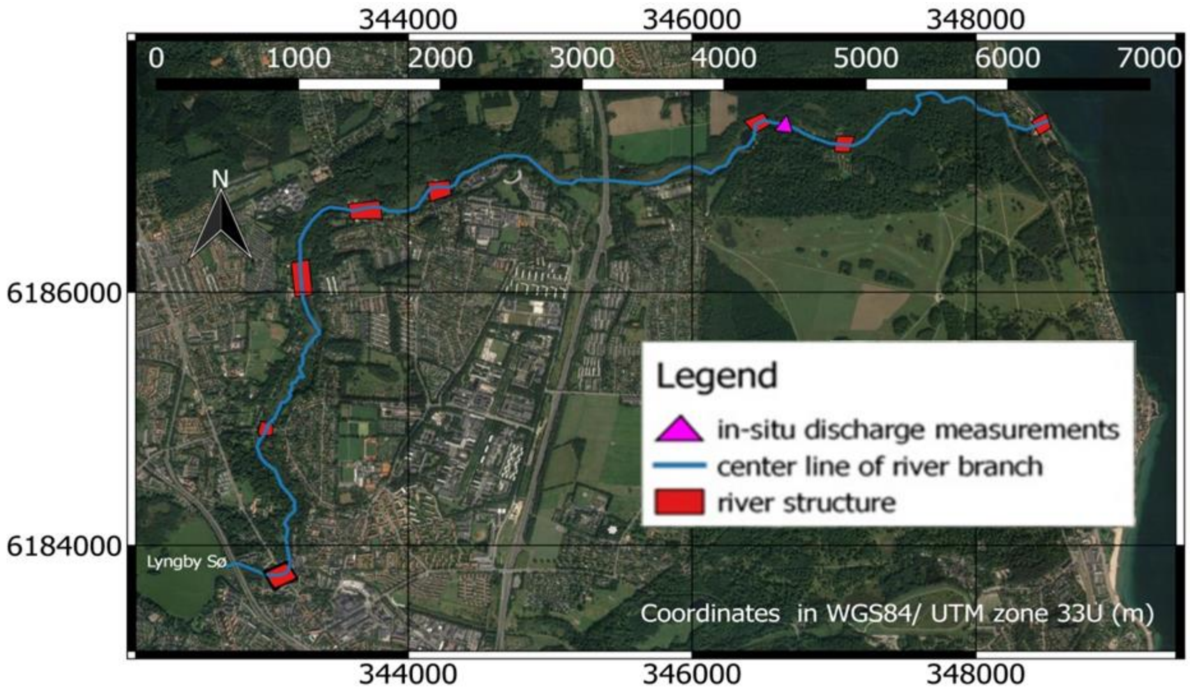
Workflow

- We retrieve **UAV-borne W.L. observations** in some stretches of Mølleåen stream



- We perform a **synthetic** study to evaluate if W.L. observations retrieved with high spatial resolution can improve model estimates
- We calibrated against these W.L. observations with DREAM algorithm
- We evaluated the improvement in sharpness and reliability of the estimates of GroundWater (**GW**)-SurfaceWater (**SW**) interaction

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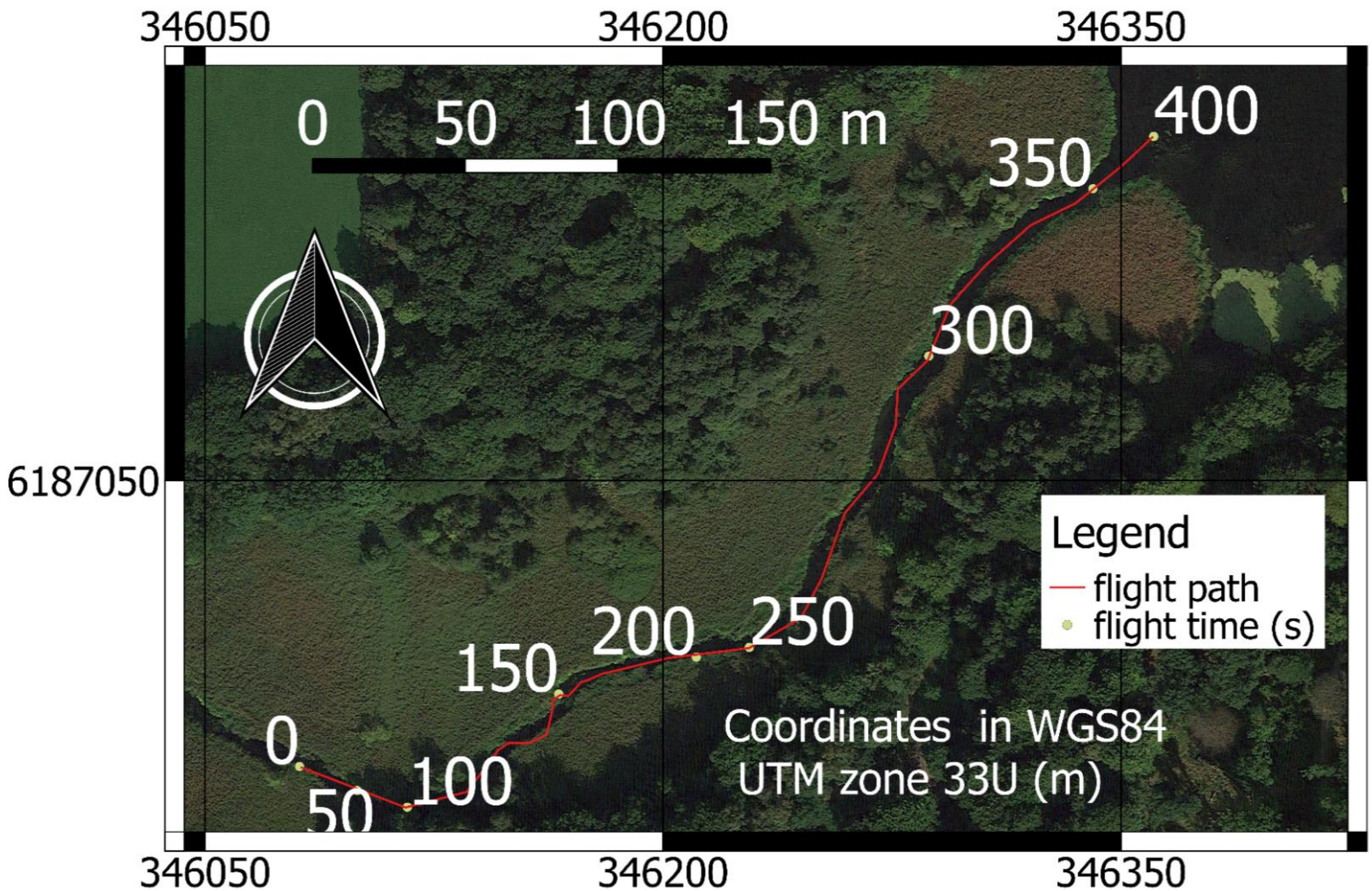
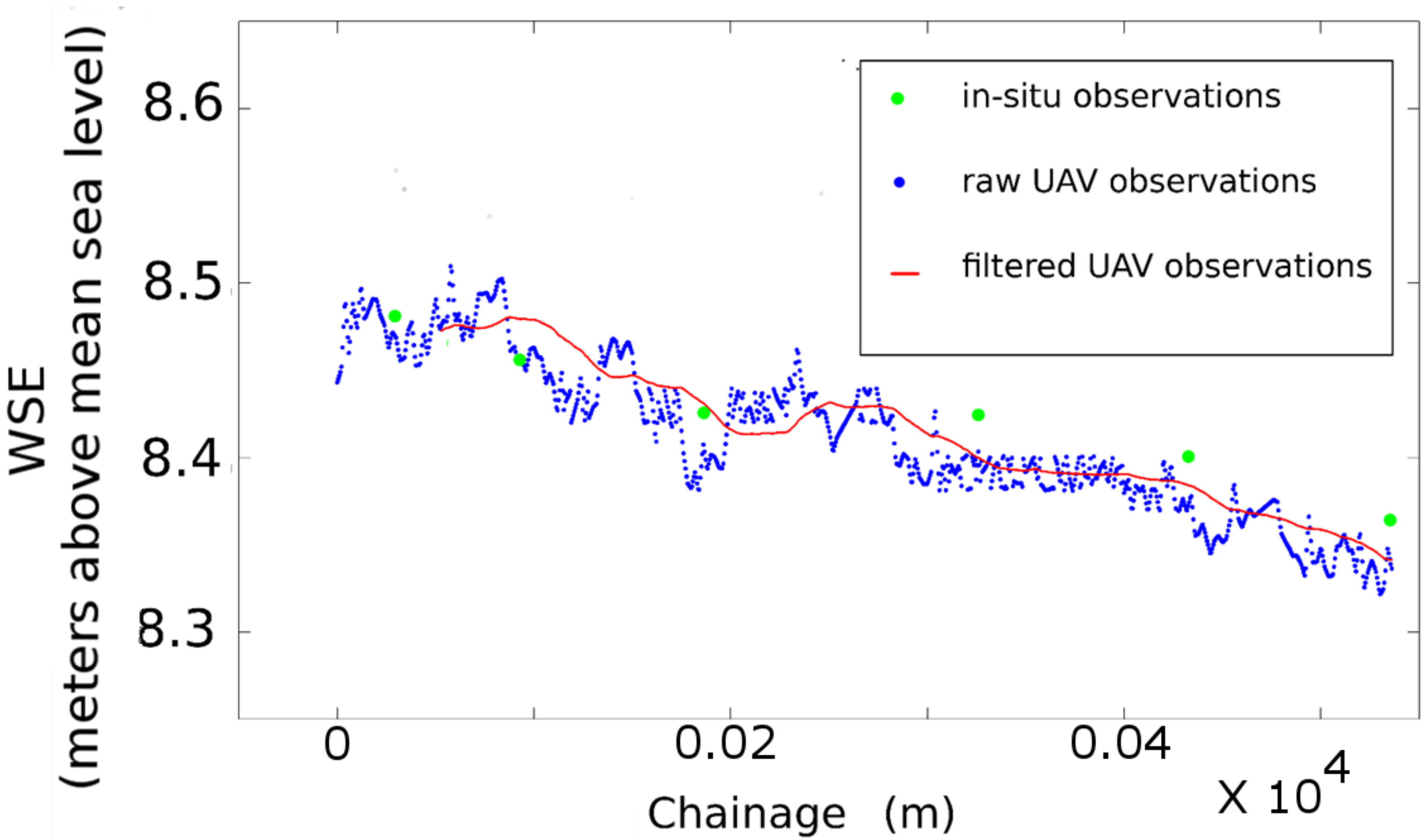
A flight to retrieve WSE of a river



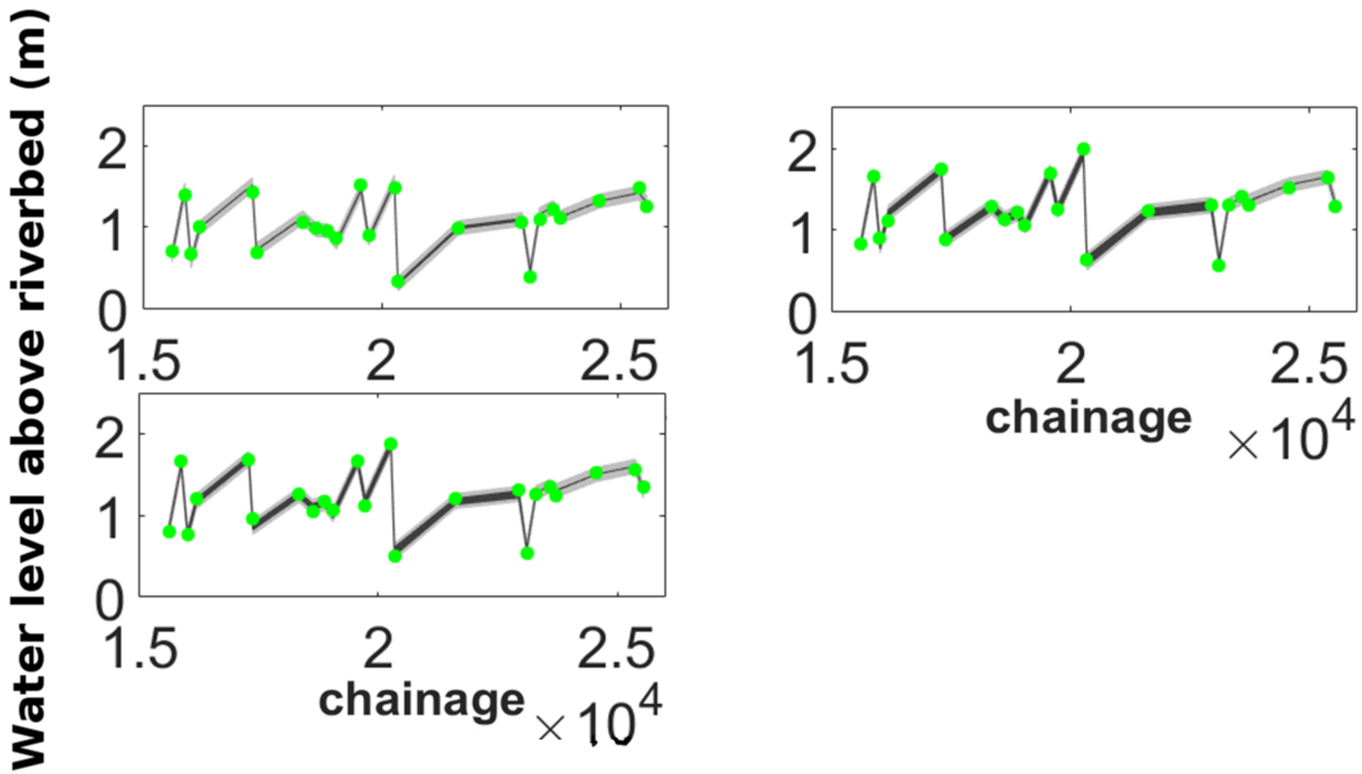
- Flight route over Mølleåen (Sjælland, Denmark)
- Flight time: ≈400 seconds
- Flight height: 30 m above ground level with σ=5 m.

WL and its slope along the surveyed stretch



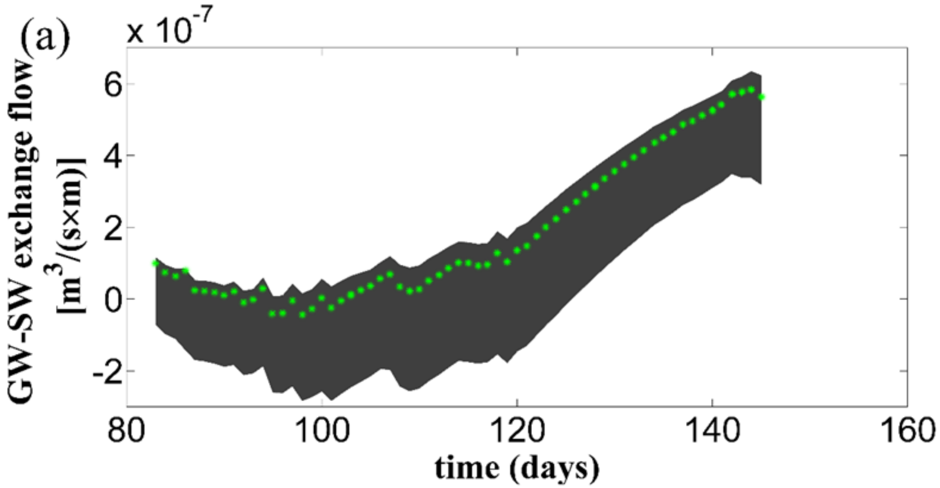
Accuracy:
- In situ RTK-GPS rover station observations: 3-5 cm
- UAV-observations: 5-10 cm

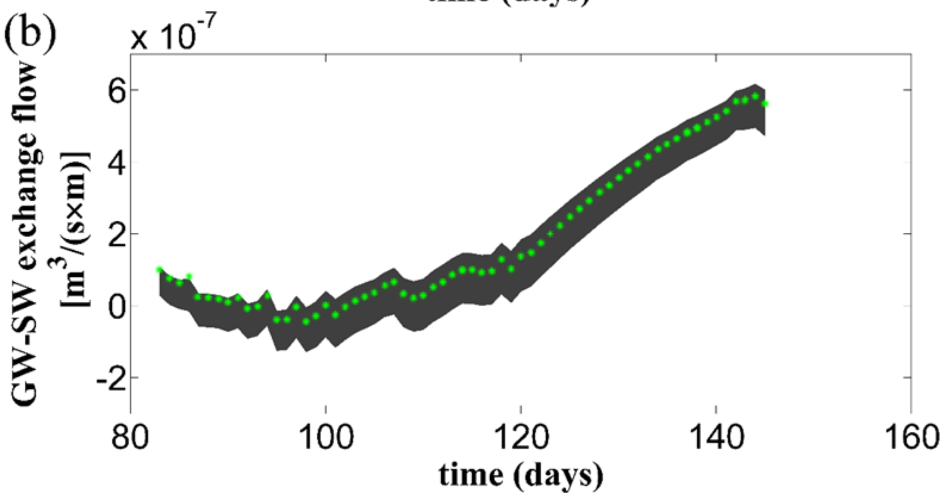
Calibration against synthetic W.L.



- The green dots: perturbed synthetic water level observations
- Dark grey colour: 95% confidence intervals of the output prediction due to parameter uncertainty.
- Light-grey region: remaining 95% prediction uncertainty

SW-GW exchange flux time series





(a) Calibration against discharge observations only
(b) Calibration again discharge and W.L. observations

After W.L. calibration

- **Sharpness**: **improved by ≈55%**
- **RMSE** (Root Means Square Error) **improves by ≈75%**
- **Brier score improves by ≈70%**

: synthetic GW-SW observations
Dark grey colour: 95% confidence interval of the output prediction

Reference

Received: 19 November 2016 | Accepted: 18 September 2017
DOI: 10.1002/hyp.11366

WILEY

RESEARCH ARTICLE

Water level observations from unmanned aerial vehicles for improving estimates of surface water–groundwater interaction

Filippo Bandini[1] | Michael Butts[2] | Torsten Vammen Jacobsen[2] | Peter Bauer-Gottwein[1]

Conclusions

- UAVs equipped with a W-band radar and GNSS system can measure **water level** at high spatial resolution with an accuracy better than 5-10 cm.
- **Water depths** can be monitoring by a tethered sonar system, controlled by the UAV, with an accuracy of ca. 2.1 % of the actual depth for depths potentially up to 80 m. For depths up to 30 m, this relative error is in agreement with the 1st level accuracy of the IHO standards.
- **2D surface velocity** field can be measured with the UAV-borne LSPIV with an accuracy of ≈15% of actual surface velocity.
- UAV can indirectly estimate **discharge**


Thanks for attending