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Impact of microtopography and land cover captured by UAS on distribution of water flow

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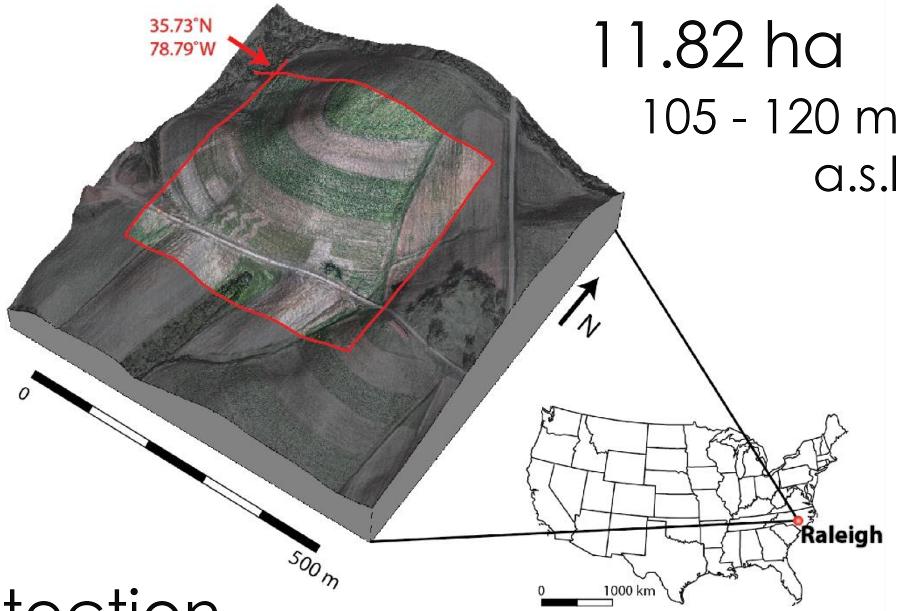
Research problem

- Are of digital surface models (DSMs) produced by sUAS photogrammetry **suitable for overland flow simulation**?
- What is the **workflow** for **overland flow pattern simulation** using high spatial and temporal resolution DSMs derived from sUAS data?
- Are there any **differences** between **flow patterns** based on **sUAS** derived DSMs and **LiDAR** based DEMs?

Study area

- City of Raleigh
  - central region of North Carolina, USA
- part of delimited Special Area identified by the local authorities as protection area for maintaining water quality



11.82 ha

105 - 120 m a.s.l.

- selected based on the terrain features, changing land cover and presence of stable features such as roads.

Data acquision - sUAS

- **UX5 by Trimble**
- software for flight planning and control – Trimble Access Aerial Imaging → automated workflow and semi-autonomous flight

Source: Trimble promotional materials acquired from:
http://www.ee.co.za/wp-content/uploads/2015/02/optron-134-02-2015.jpg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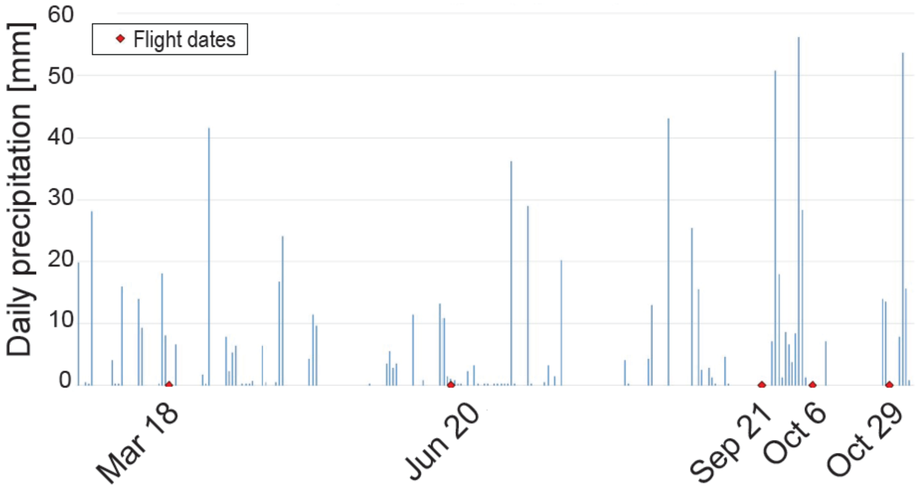
Data acquision - sUAS

- 5 flight missions:
- 225 days timespan between the first and last flight
- overlap 80 %
- 6 to 11 GCPs
- after several days of significant rainfall (except Sep 21)

date	resolution [cm/px]	GCPs	error [px]	density [pts/m^2]	altitude [m]
Mar 18	3.11	6	0.047	64.73	88
Jun 20	3.31	11	0.080	63.75	100
Sep 21	3.12	6	0.091	63.88	100
Oct 06	3.12	9	0.125	63.80	100
Oct 29	3.18	9	0.135	61.63	100

Properties of sUAS surveys performed in the year 2015



Flight dates and daily precipitation between Mar 1, 2015 and Oct 31, 2015 for Lake Wheeler Rd. Field Lab Station

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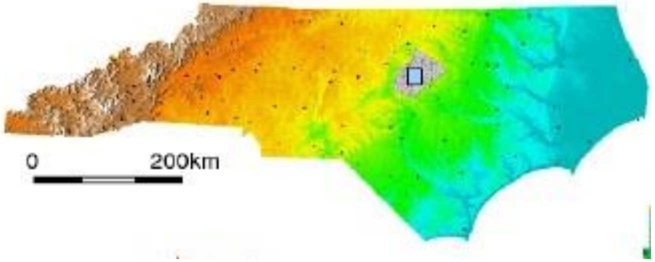
Data acquision - LiDAR



- Airborne LiDAR survey
  - project of Wake County,
    City of Raleigh and Town of Cary
  - detailed multiple return and ground elevation data covering approximately 2500 km^2;
  - completed **February 2013** using ALS70 HP at 2750 m a.g.l., 40 field of view, 11 % minimum sidelap, 0:82 m average point spacing.
- All deliverables met or exceeded standards for both vertical and horizontal accuracy of 95 % confidence*

*according to NDEP Guidelines for Digital Elevation Data

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Methods

Photogrammetric data processing

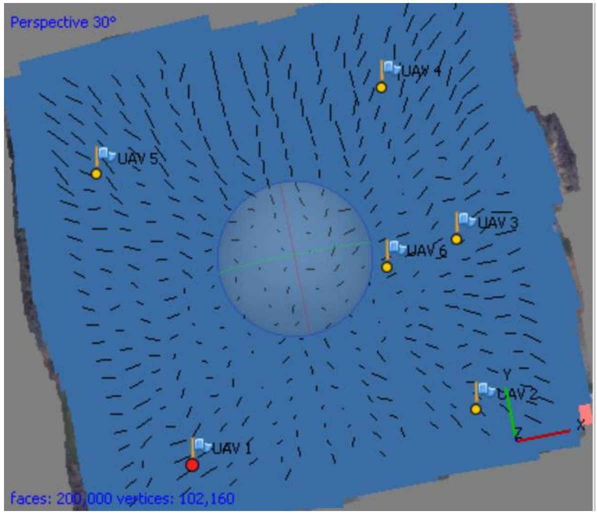
Agisoft PhotoScan Professional

PhotoScan

3D Modeling and Mapping

Agisoft

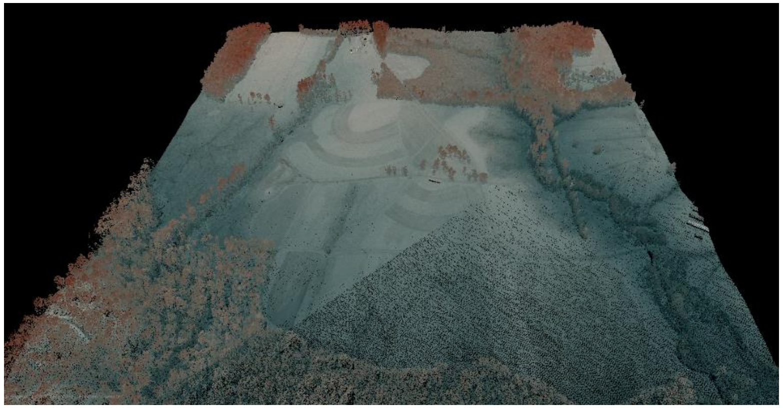
- **aerial triangulation**
  - **doming error** (inaccuracy of camera self-calibration estimates + algorithms used by the software) → resolved optimization based on ground control data.
- **dense point cloud generation** based on depth maps calculated for every image
- **Orthophoto** (for validation), produced with default values



Methods

Classification and interpolation of point clouds

- Both: sUAS and LiDAR based DSMs generated **from raw points** clouds using the same technique
  - control over the desired resolution and level of detail
  - compare modelled water flow on raster DSMs from two completely different sources



- The process consists of:
  - **removing tree crowns** from the point clouds → classified high vegetation and removed it using a modified multiscale curvature classification method.
  - **interpolating the DSMs** using regularized spline with tension

Methods

Overland flow simulation

- The **path sampling technique** (Green's function Monte Carlo) → a robust, mesh-free alternative for solving the **shallow water flow continuity equation** on complex surfaces

depth of overland flow [m]

rainfall excess [m/s]

(rainfall – infiltration –
– vegetation intercept)

spatially variable diffusion coefficient

$$-\frac{\varepsilon}{2}\nabla^2 h^{5/3} + \nabla \cdot (h\ \mathbf{v}) = i_e$$

flow velocity vector [m/s]

- spatially variable diffusion term $\mathcal{E}$ supports approximate simulation of water depth evolution in locations with flat topography and depressions

Methods

Overland flow simulation

- **diffusion** - function of water depth and the velocity of flow as a function of an **approximate water flow momentum**, → water fills the depressions and flows out in the prevailing flow direction.
- implemented in **GRASS GIS** in the module **r.sim.water**
- simulation for each DSM in the time series
    - at 0.3 m resolution
    - using **design storm** with:
        - uniform rainfall excess rate of **30 mm/hr**
        - uniform surface roughness coefficient 0.15
        - 40 minutes duration (until steady state was reached in most of the modeled area)

GRASS GIS

Results

DSM accuracy and spatial pattern of distortions

- **2013 LiDAR DEM** – high accuracy confirmed based on 12 available GCPs (installed in 2015)
  - mean difference of 5 cm
  - RMSE of 8.7 cm
- **sUAS derived DSMs** - generated using **the same parameters** but the **accuracy** of the results **varied** based on the flight conditions and availability of GCPs.

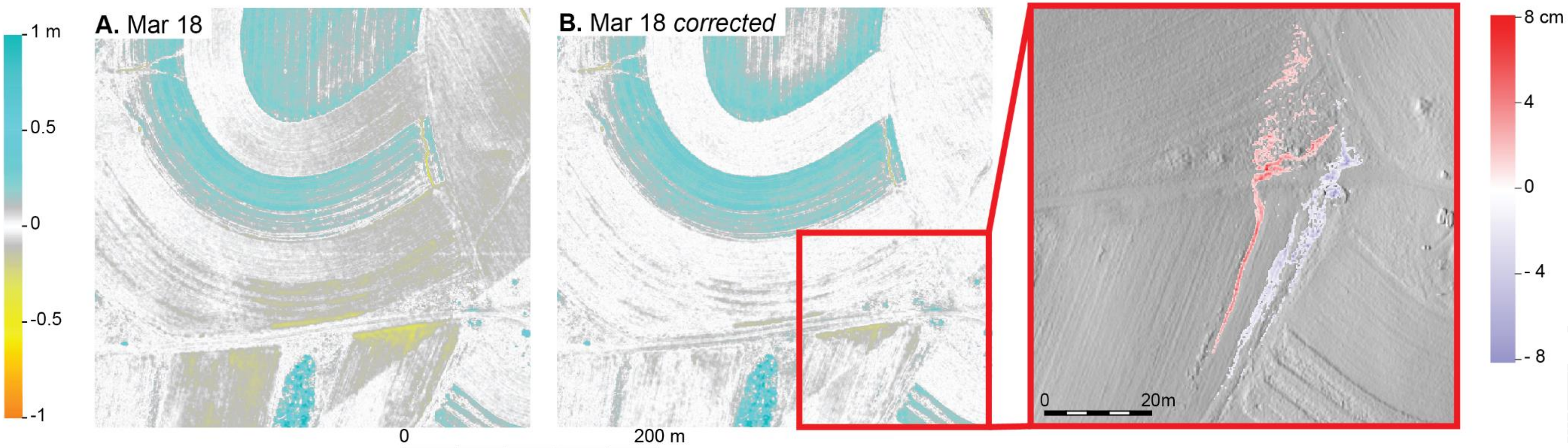
date	RMSE	mean
Mar 18	11.5	-0.1
Jun 20	62.6	-36.7
Sep 21	20.0	8.3
Oct 06	15.7	1.6
Oct 29	19.3	13.9

Comparison of LiDAR based DSM and sUAS derived DSMs,
RMSE – root-mean-square error [cm],
mean – meandifference between LiDAR DSM and sUAS DSM [cm]

LiDAR vs. sUAS DSMs

- spatially variable pattern of geometric distortions
- artificial surface at the height of dense vegetation (sUAS is unable to capture bare ground)

Differences in elevation between the LiDAR and sUAS based terrain models from the March flight.

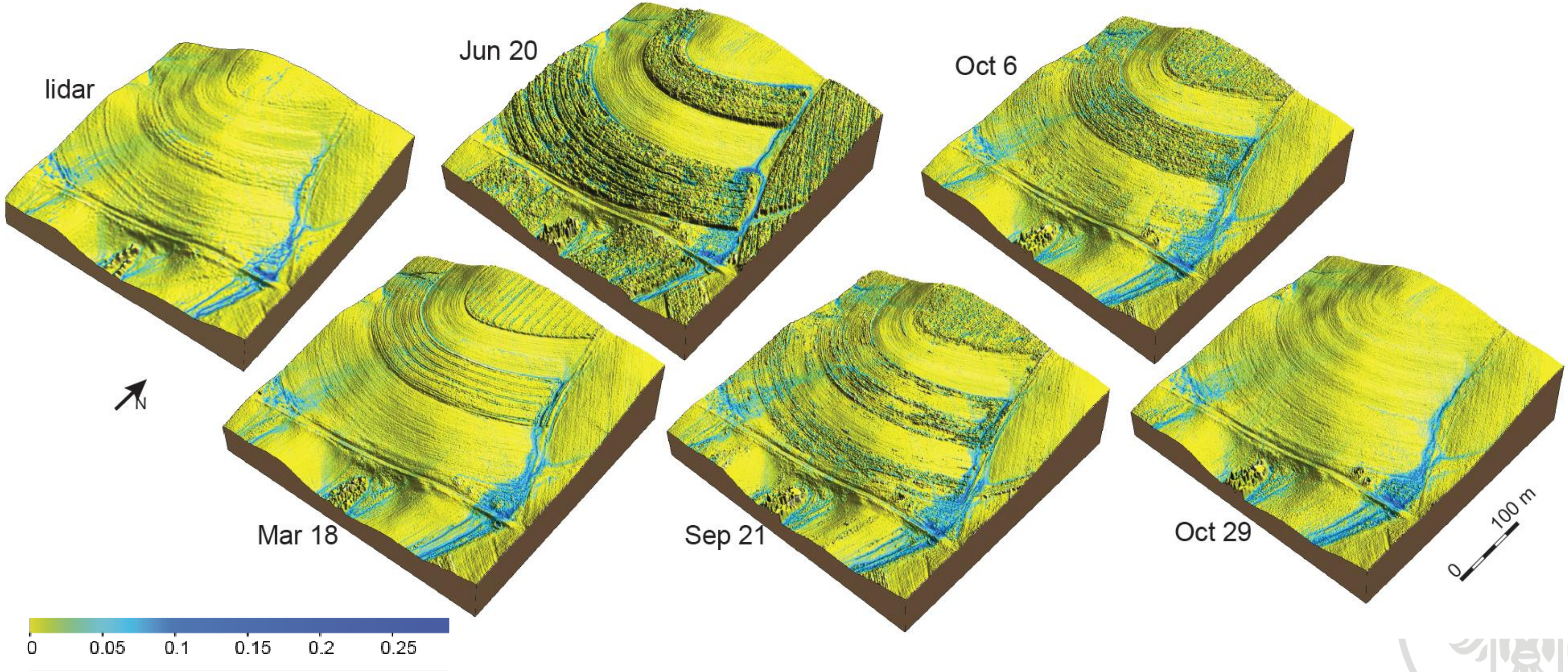


differences higher than 1 cm of overland flow depth simulated on these two DSMs.

Results

Evolution of the overland flow pattern

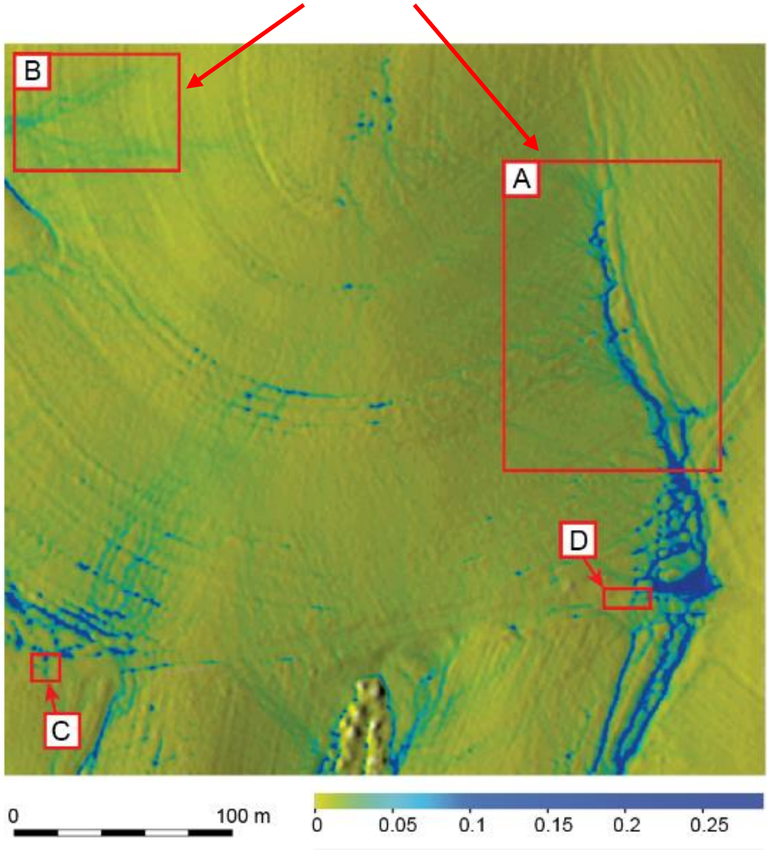
- **persistent, relatively stable flow pattern** of overland flow in spite of changes in the field due to tillage, crop growth and harvest



Results

Evolution of the overland flow pattern

Small gullies were observed in the fields



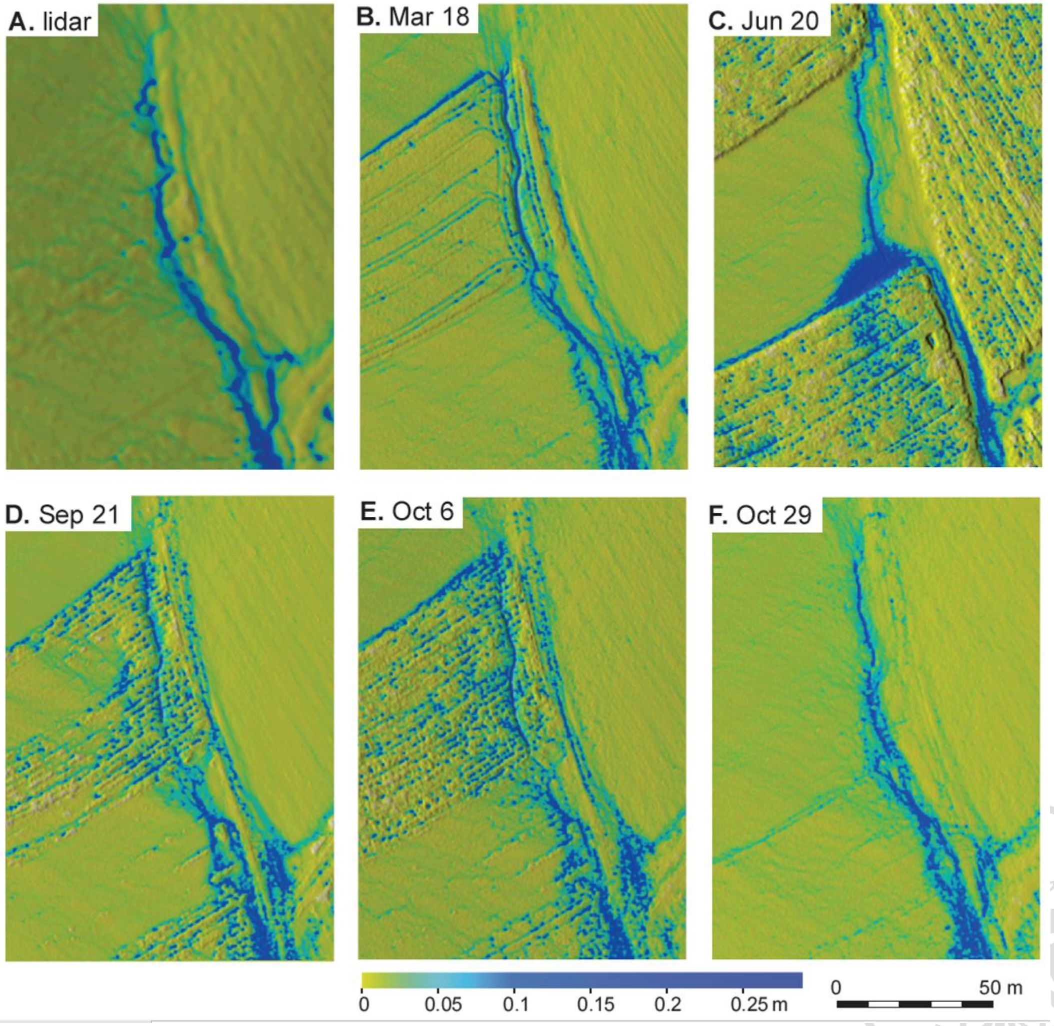
gully A - June 20, 2015

Results

Evolution of the overland flow pattern

GULLY A

- consistent pattern through the seasons, with the exception of the June DSM, where the dense vegetation being part of the terrain creates an **artificial ponding pattern**
- smaller plants are not occluding the ground Surface and their influence on the flow pattern is negligible



Results

Evolution of the overland flow pattern

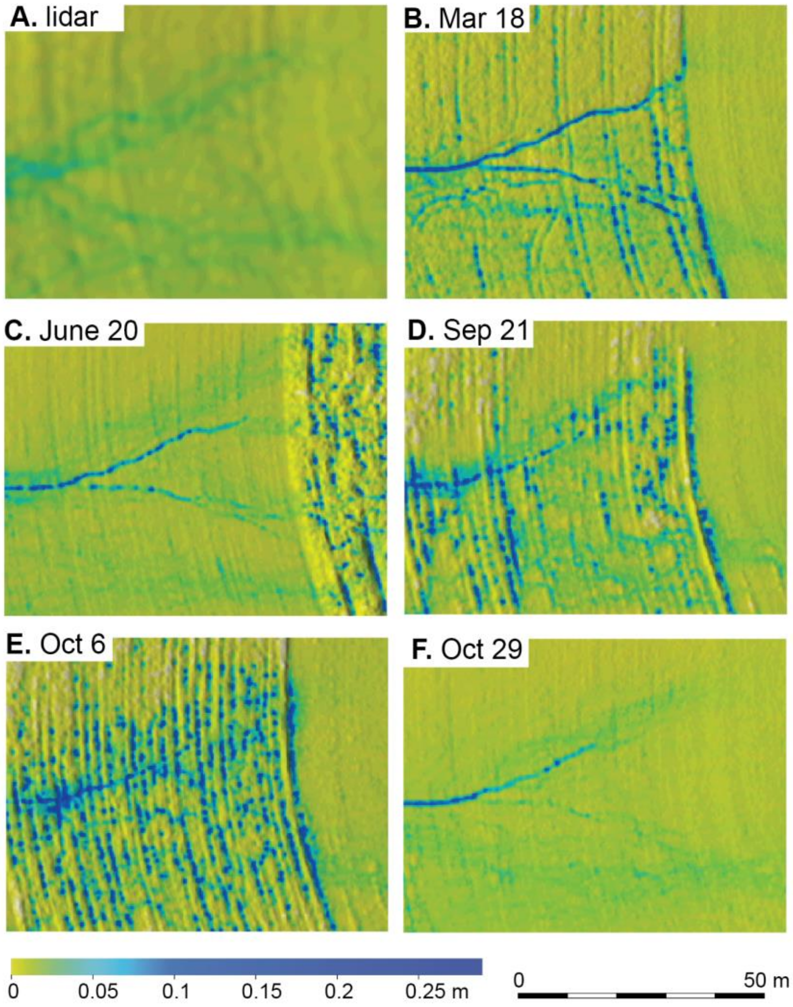
GULLY B

captured on all the sUAS DSMs

not clearly visible on the LiDAR data

Possible explanations:

- gully could have developed after the LiDAR data collection (LiDAR survey - 2013, sUAS data - 2015)
- micro changes in the terrain (similar to the tillage pattern) are not well represented due to **lower detail** of LiDAR data and the simulation **reflects this simplified micro relief**



Results

Prediction and validation of water ponding

- **No direct monitoring of runoff during storms** → validation by **comparing ponding** on service roads predicted in the simulation **with the actual situation** in the field known from the **orthophotos***
- Despite the fact that puddles of turbid water **are interpreted as ground surface** by the SfM algorithm and thus we **cannot accurately represent the local depressions**, we hypothesized that the sUAS derived data still **provide more accurate representation** of the overland flow pattern than LiDAR data.

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* There was no orthophoto available for the time of LiDAR data survey

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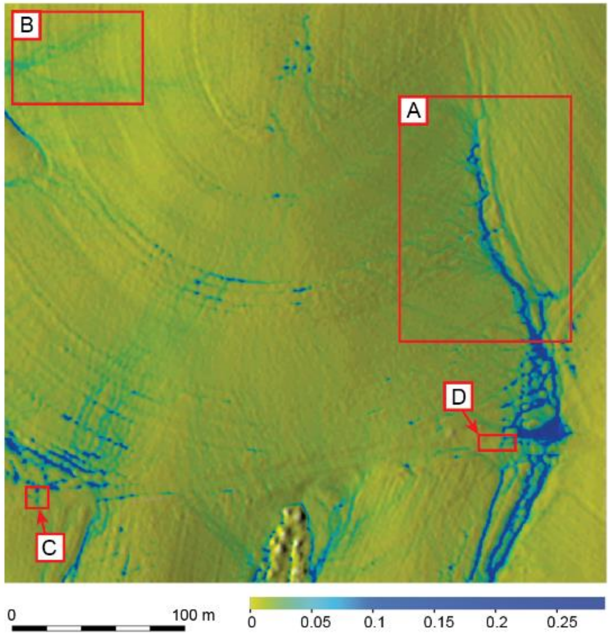
Results

Prediction and validation of water ponding

- June and both October missions **several puddles** appear **along the unpaved road** in the southern part of the targeted area (C, D)
- Comparison of the shape of a puddle visible on ortophoto with the result of simulation
  - for all sUAS missions
  - for simulation based on LiDAR data and orthophoto generated based on sUAS mission*



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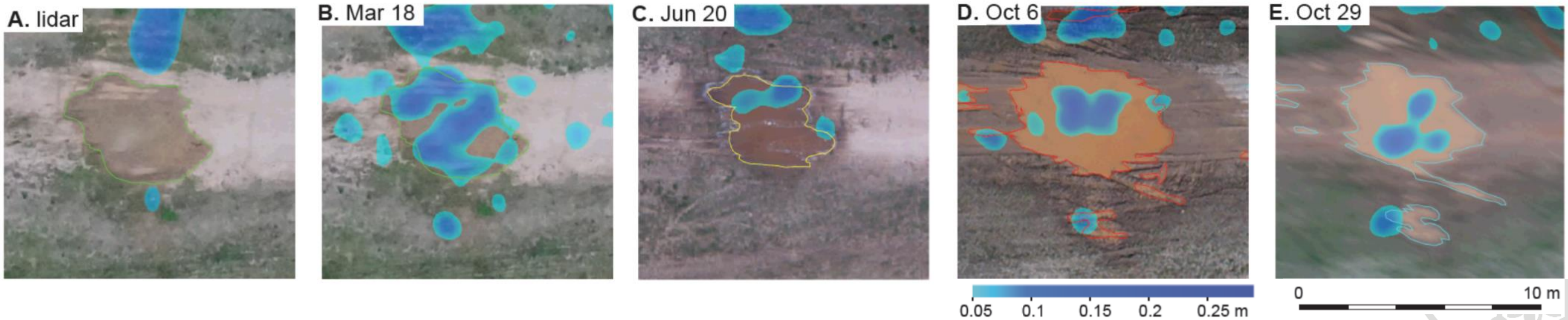


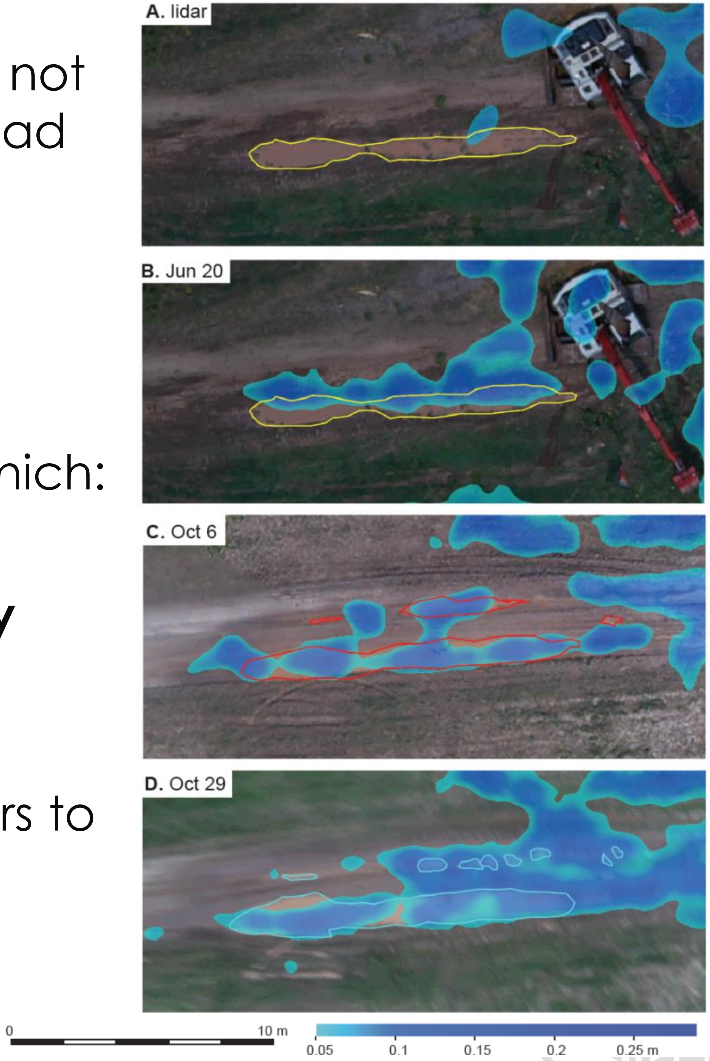
Results

Prediction and validation of water ponding

- Simulation based on the LiDAR DEM (A) does not predict the water accumulation along the road (Figure 5 D)
- the shape of the puddle aligns with the sUAS based simulations in all cases (B, C, D)

sUAS derived data allow for accurate spatial prediction of surface water on service roads, which:

- provides valuable information for road maintenance and assessment of **accessibility after storms**
- can improve **delineation of the potentially inundated areas** and thus enables landowners to adjust water management practices and prevention procedures.



Conclusions

- sUAS derived data can **improve the quality** of the flow pattern modeling due to the **increased spatial and temporal resolution**. It can **capture preferential flow along tillage** that is represented by capturing the changing microtopography.
- Overland water flow modeling based on data from airborne **lidar** surveys is suitable for **identifying potentially vulnerable areas. sUAS** based data, however, is needed to actually **identify and monitor gully formation**.
- Due to the high resolution of obtained data, **vegetation significantly disrupts the flow pattern**. Therefore densely vegetated areas are not suitable for water flow modeling.

Thank you

for your attention