Multi-temporal UAV-survey of a calving glacier in Northwest Greenland

Yvo Weidmann, Guillaume Jouvet, Martin Funk

Laboratory of Hydraulics, Hydrology and Glaciology (VAW)

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12.1.2017
Villach

Agenda

- ETH Zurich / VAW
- Location and motivation Bowdoin Glacier (NW Greenland)
- Expeditions and Instrumentation
- Requirements, choice, type and assembly of used UAV
- Ground Control Points
- Selection of flight plans
- Challenges Photogrammetry
- Some results
- Summary
- Outlook

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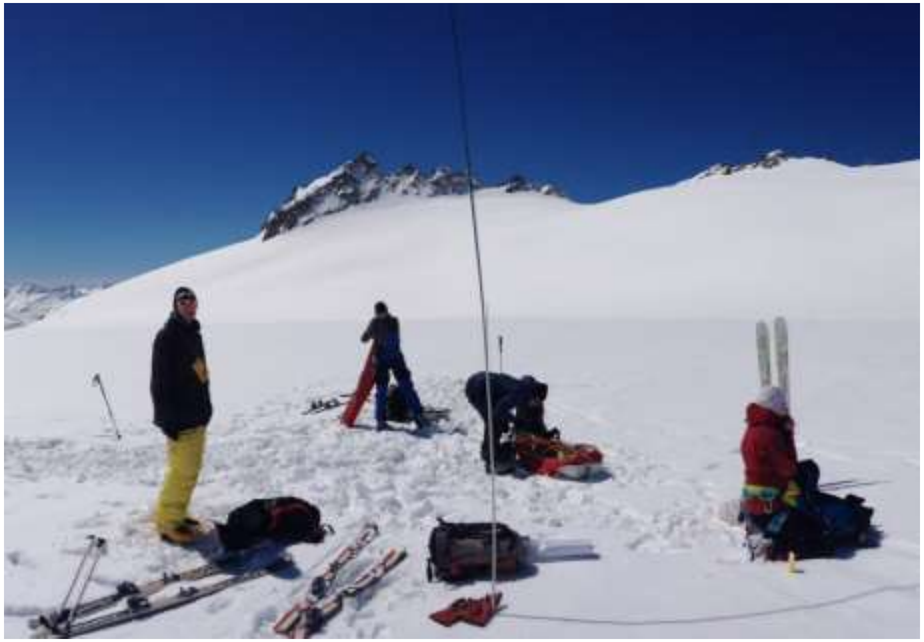
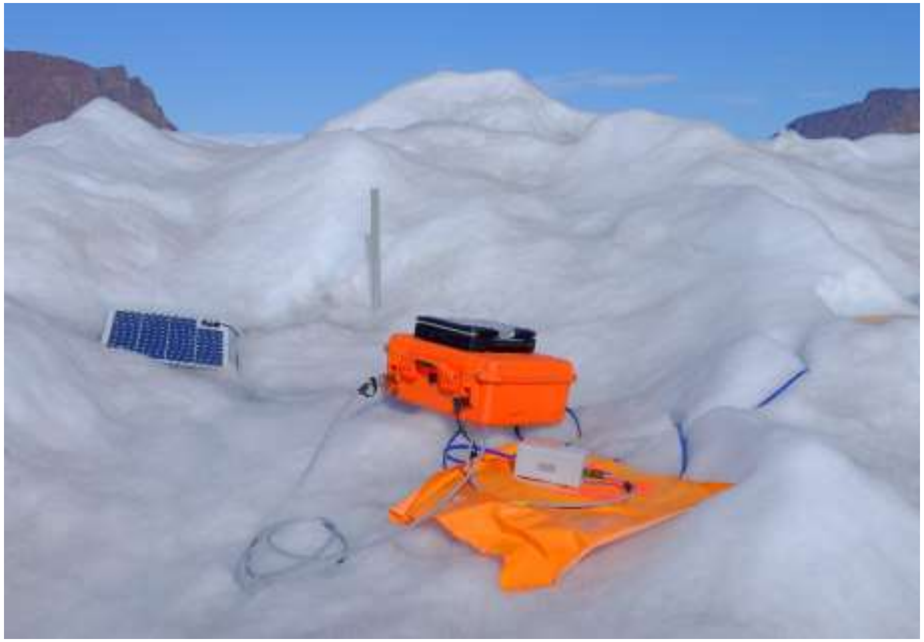
- **Laboratory of Hydraulics, Hydrology and Glaciology**

ETH Zurich / VAW: > 30 years of Glaciology

- **Fundamental Research**
- **Applied Studies (Consulting)**
- **Fluctuations of Glaciers (Glacier Monitoring)**



e.g. Mass Balance, Length Change, …



e.g. Ice Seismic, …

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e.g. Tilt, Water Pressure, …

e.g. Ice Dynamics, Surveillance, …

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e.g. Surface Velocity, Surveillance, …

e.g. Length Change, Mass Balance, Surveillance, …

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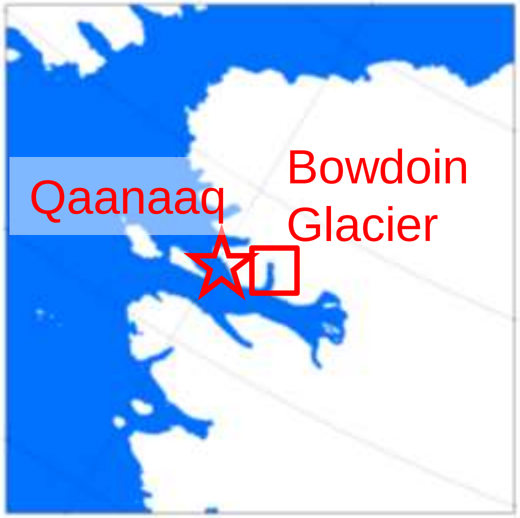
Bowdoin Glacier (Location 77° 42' N; 68° 35' W)



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Motivation Bowdoin Glacier

Science:

- Processes of sea glaciers
- Modell of the calving front

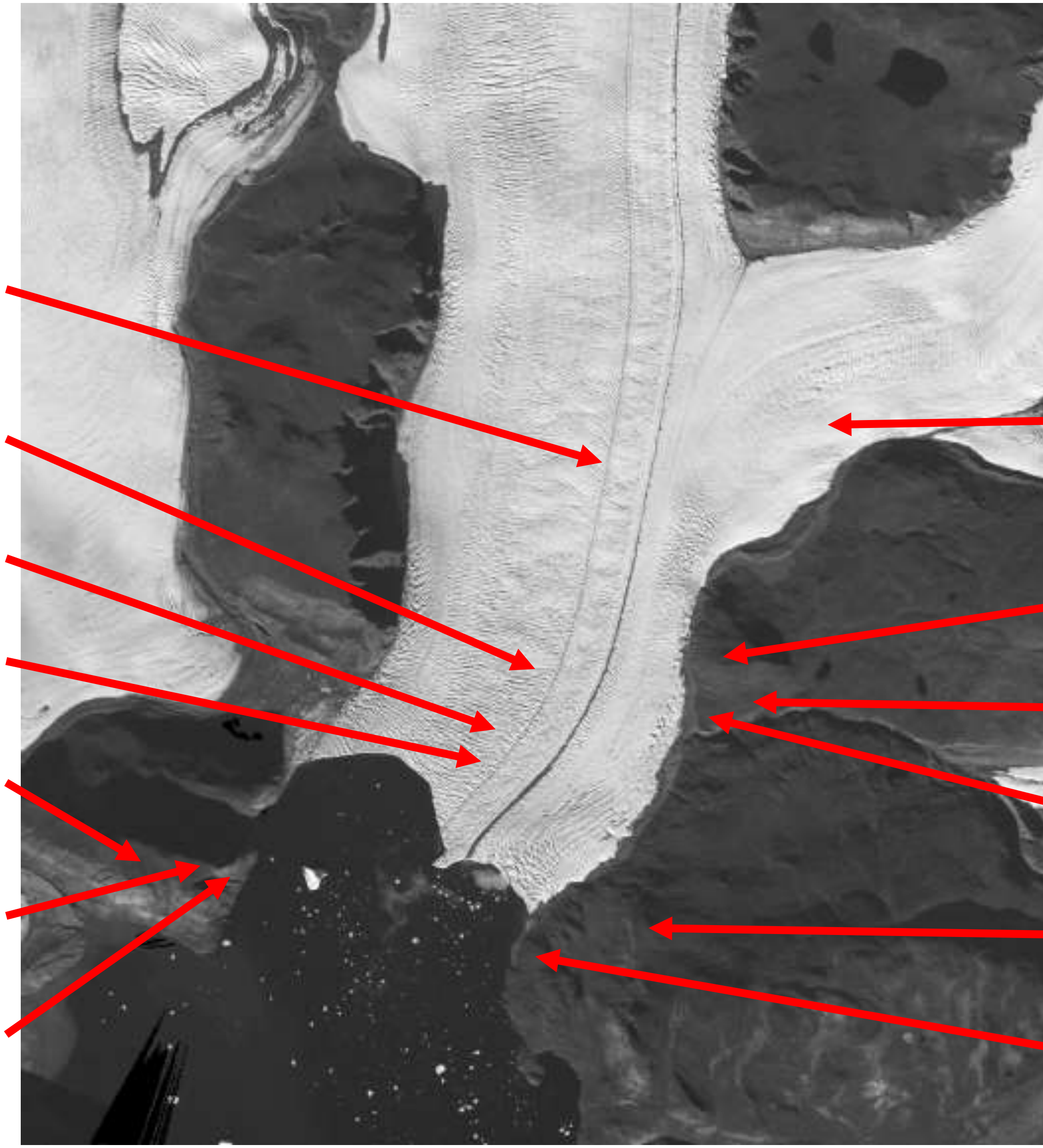
Facts:

- Retreat after 2008
- Installations at the calving front
- Easy access
- 24h daylight

Expeditions 2014, 2015, 2016

- **Participating Universities:**
  - Institute of Low Temperature Science Hokkaido University (Japan)
  - Laboratory of Hydraulics, Hydrology and Glaciology ETH Zurich
- **Various experiments and measurements:**
  - Drilling of 3 boreholes of appr. 300m depth and instrumentation
  - Collection and maintenance of drill sites (water pressure, deformation, temperature)
  - Collection und maintenance of several timelaps cameras
  - Permanent GPS stations (with local reference station)
  - Seismic and Infrasound arrays (on and off glacier)
  - Interferometric terrestrial radar during expedition (2016)
  - **UAV-based surface models and orthophoto mosaics of the calving front (2015 experimental, 2016 productive)**

Instrumentation Bowdoin Glacier



Requirements for a UAV at Bowdoin

Requirements for a UAV at Bowdoin

Requirements:

- Flights > 50 kilometres autonomously and out of sight
- Flight height up to 500 meters above ground
- Payload > 0.5 kg to 1.0 kg
- Arctic conditions (wind, camp, no workshop, …)
- Easy to repair, open configuration and documentation

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No suitable commercial UAV -> Homemade!

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Used framework:

- *Skywalker X8* fix wing (2.1 m wingspan)
- *Pixhawk* Autopilot
- *APM:Plane* und *MissionPlanner* as software base

Choice, type and assembly of used UAV

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The Cryosphere
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UAV photogrammetry and structure from motion to assess calving dynamics at Store Glacier, a large outlet draining the Greenland ice sheet

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[2]Department of Geology, University of Tromsø, 9037 Tromsø, Norway
[3]Geological Survey of Denmark and Greenland, Copenhagen, Denmark
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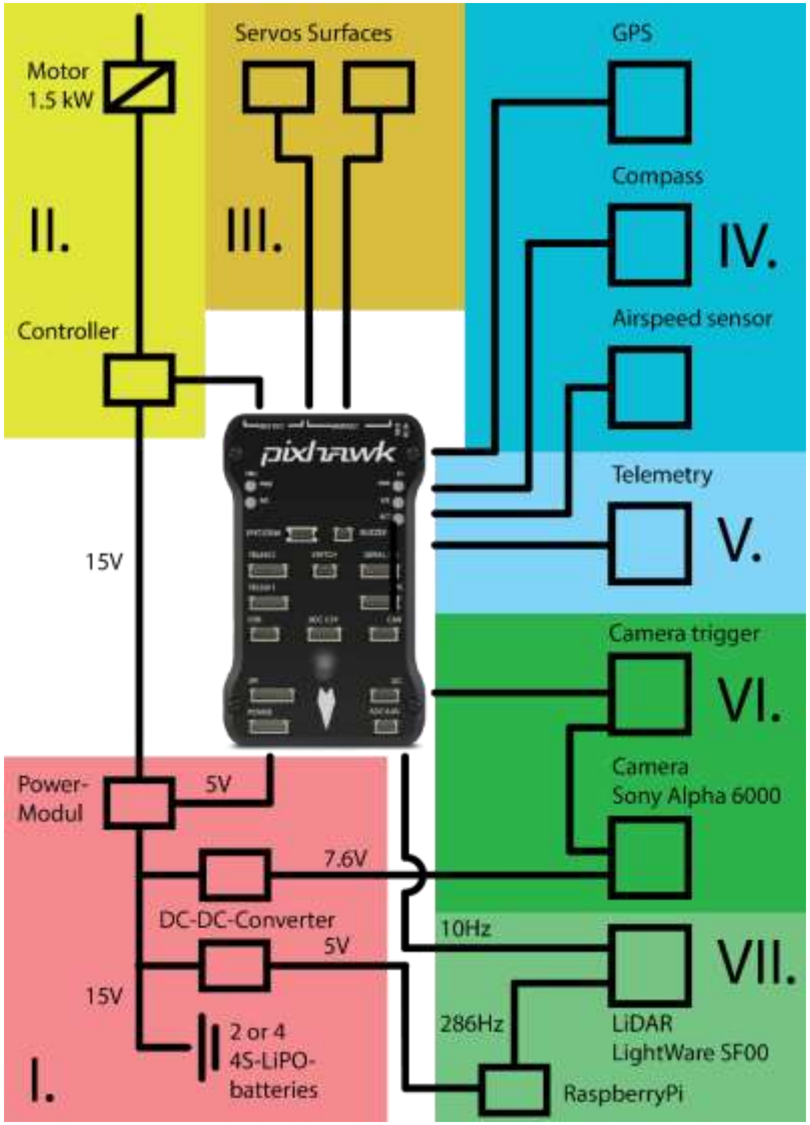
Assembly of the homemade UAV



Fully configurable, inter-exchangeable and open system based on standard components!

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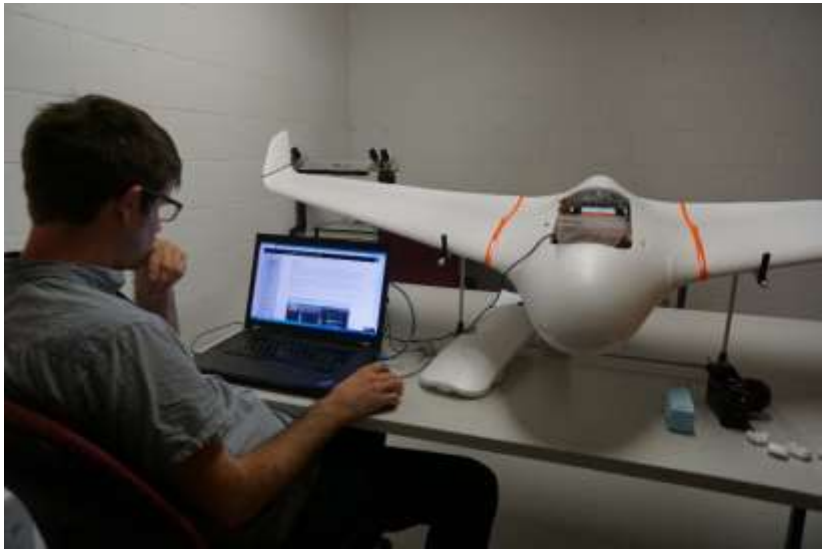
Assembly … not without obstacles … :-)



"Always Look On The Bright Side Of Life"

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Camera releaser, flexibility, Pixhawk

- **StratoSnapper2, Pixhawk, APM:Plane**
  - Universal camera releaser for most camera models and types
  - Simple and robust, IR- or cable-based
  - Calibration and triggering with servo signal of Pixhawk
  - Individual log entry with X, Y, Z, Roll, Pitch und Yaw
  - `CAM,420509800,1853,77.69099,-68.45031,230.54,31.97,5.64,16.35,244.12`

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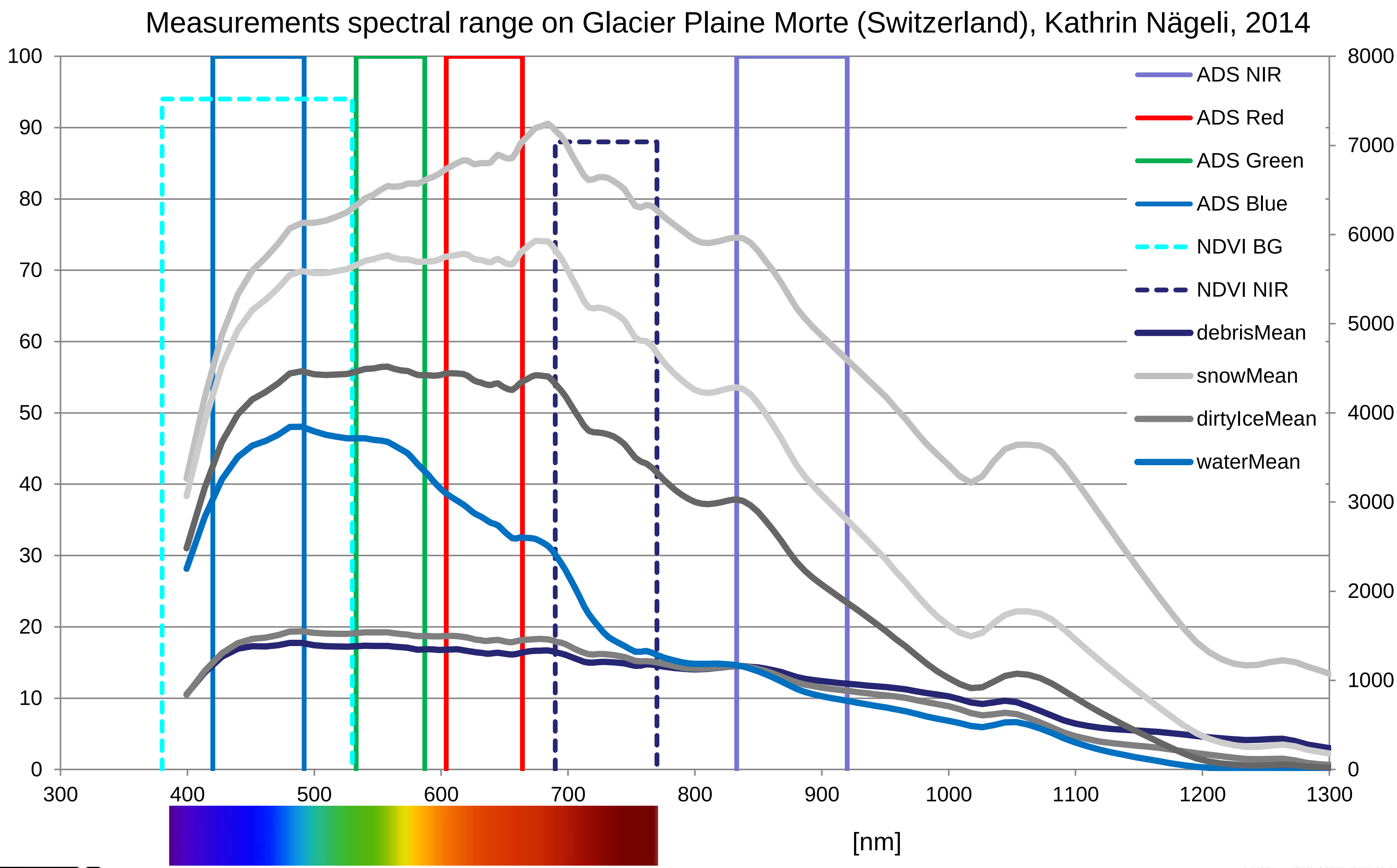
Spectral range



Choice of camera

- **Sony α6000 E-Mount camera mit APS-C-Sensor**

  Sensor resolution: 24 Megapixel, Raw

  Lens: 16mm, f2.8

  Weight: 344g + 67g (Total ca. 450g)

  IR- and cable-based trigger

- **Sony α7 E-Mount Full-Frame Mirrorless Camera**

  Sensor resolution : 36 Megapixel, Raw

  Lens: 35mm, f2.8

  Weight: 625g + 120g (Total ca. 750g)

  IR- and cable-based trigger

Requirements UAV flight plans and processing

- **Processing**

  Horizontal resolution <= 10cm ground sampling distance (GSP)

  Vertical resolution <= 50cm (about 3 to 4 times GSP)

- **Image block**

  Overlap along image strip > 85%

  Overlap cross image strip > 70%

➢ **Main flight plan**

  Footprint ca. 270 x 390m -> Flight height 250m above ground

  Horizontal resolution appr. 7cm (GSD)

  Average cruising speed appr. 15m/s

  Distance between images along strip appr. 20m (>= 1sec flight time)

  Distance between image strips appr. 100m

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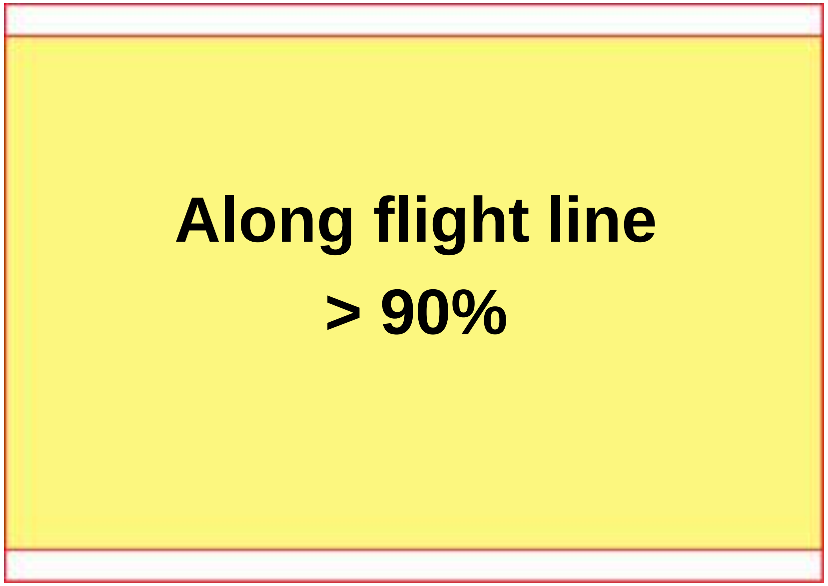
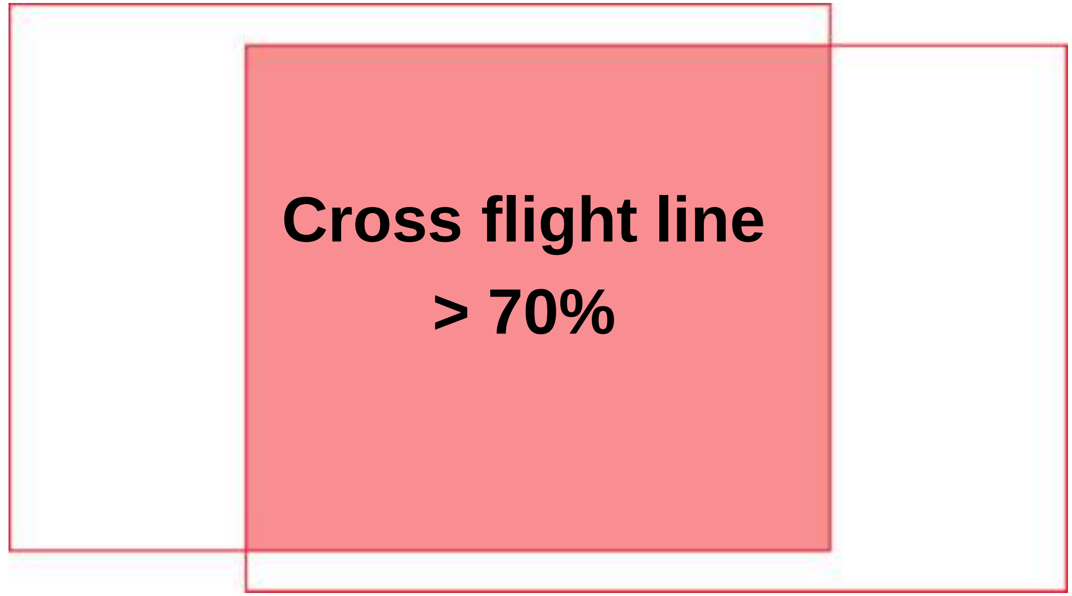
Overlaps along flight line and cross flight line





Conservative approach, high redundancy and new opportunities

Ground control points – Types and challenges

- Stable Ground Control Points (GCP) at both sides of the glacier:
  - No stable GCP at the right side of the glacier (2015)
  - Many stable GCP at both sides of the glacier (2016)
- Moving GCP on glacier

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Ground control points – Types and challenges

Temporary

Plastic foil
40 x 40 cm
Approx. 5 GSD

Permanent

Paint
50 x 50 cm
Approx. 7 GSD

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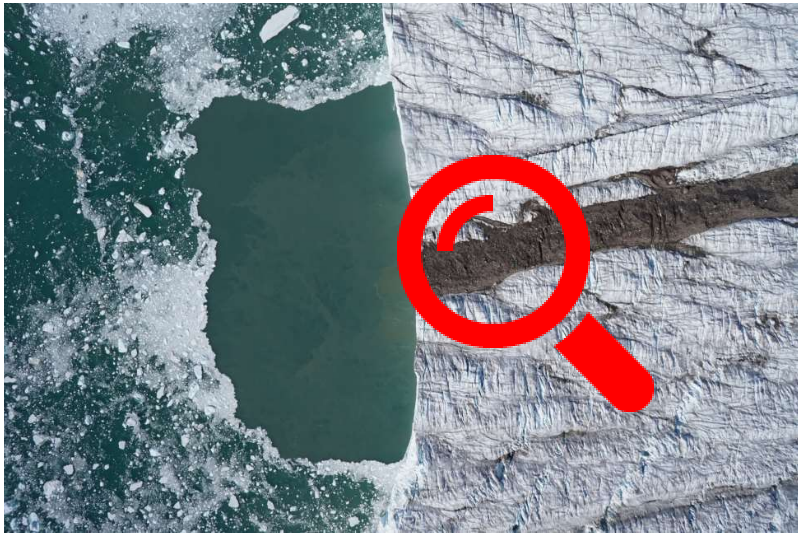
Ground control points – Types and challenges

Moving



Plastic foil
40 x 40 cm
Approx. 5 GSD

Auxiliary

Ground control points – Moving points

- Moving GCP on the middle moraine ~ 1 – 2m / day
- Permanent GPS stations on the glacier + 1 fix station
- 6 - 8 GPS readings of all GCP on the glacier
- Linear interpolation X,Y, Z of GCP for each UAV flight

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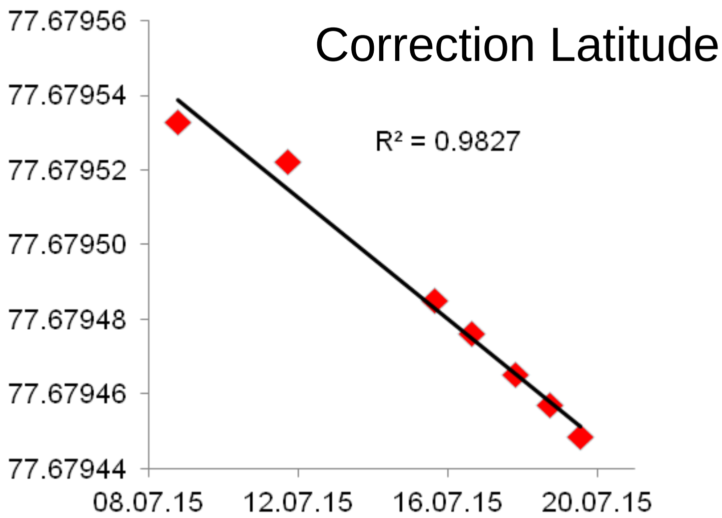
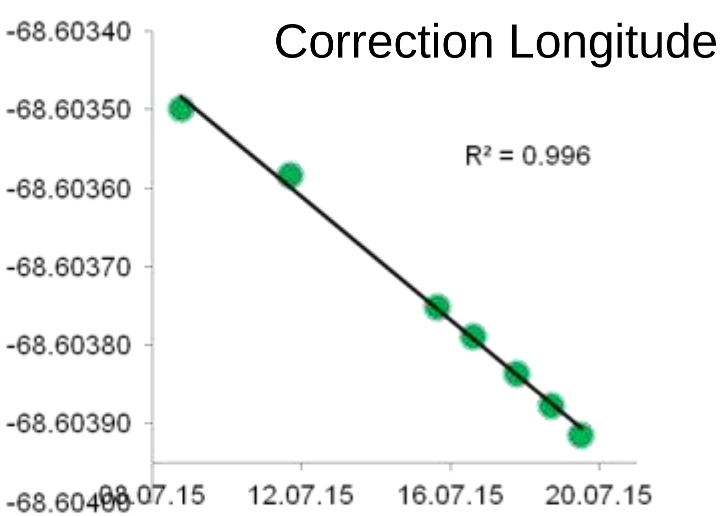
Ground control points – Moving points





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Expedition 2015 vs. 2016 – UAV improvements

- Flights with high temporal resolution (<= 12h) of calving front
- Using of a VTOL for the temporal high resolution flights
- Different flight plans (detailed front, long tracks)
- Longitudinal profiles with nadir-looking LiDAR

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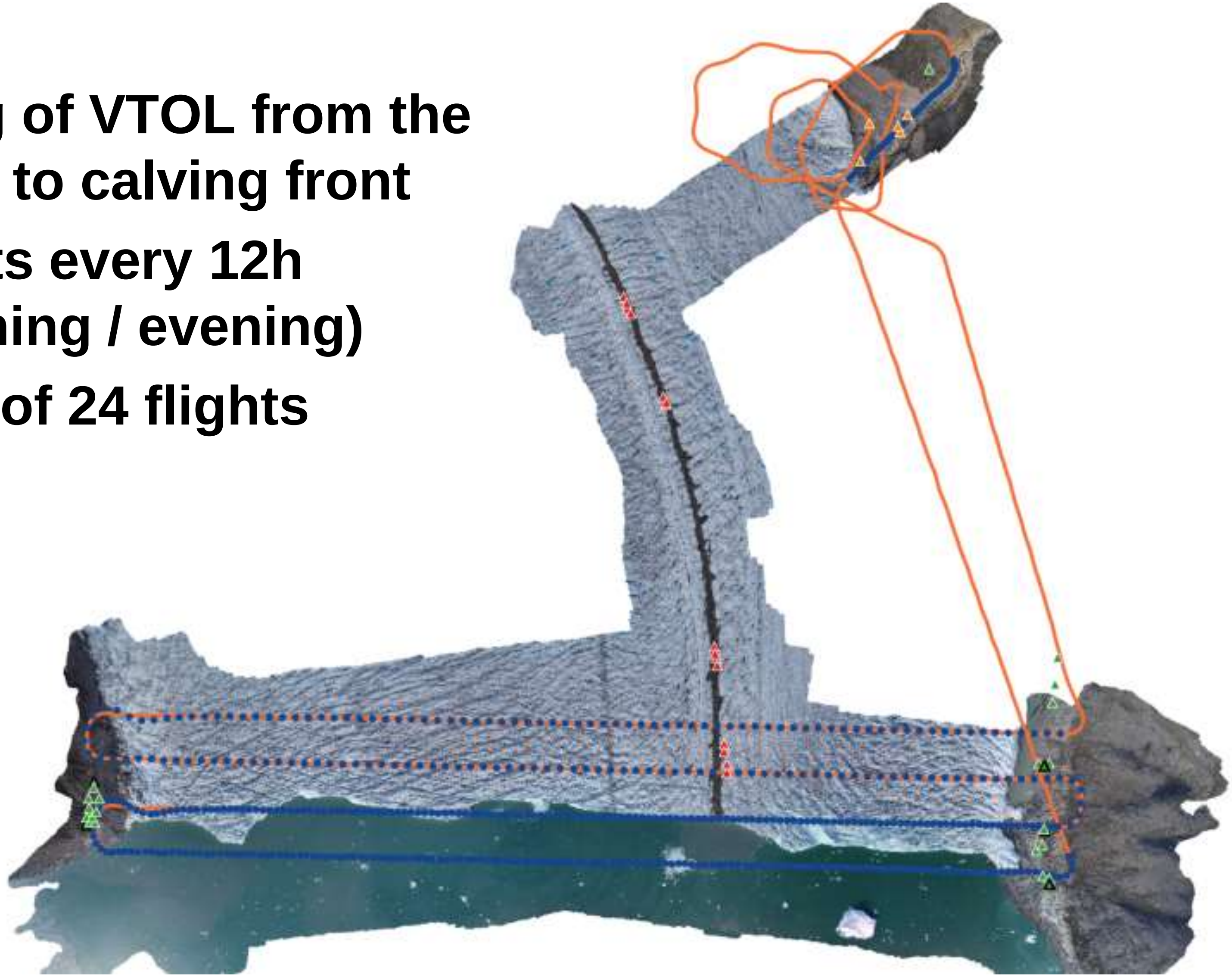
Flight plans – High temporal resolution (<= 12h)

- **Using of VTOL from the camp to calving front**
- **Flights every 12h (morning / evening)**
- **Total of 24 flights**



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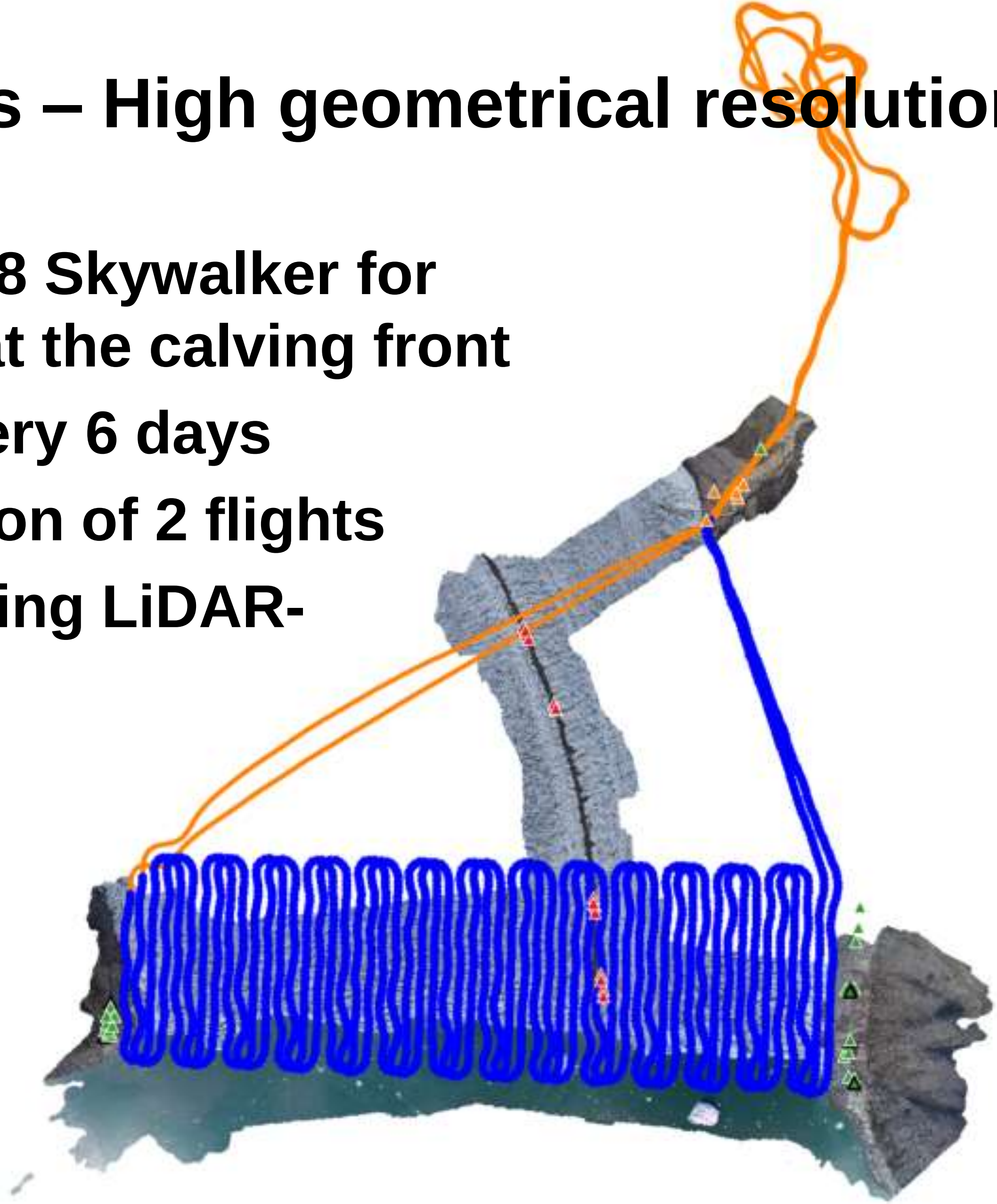
Flight plans – High geometrical resolution

- **Using of X8 Skywalker for overview at the calving front**
- **Flights every 6 days**
- **Combination of 2 flights**
- **Nadir-looking LiDAR-profiles**



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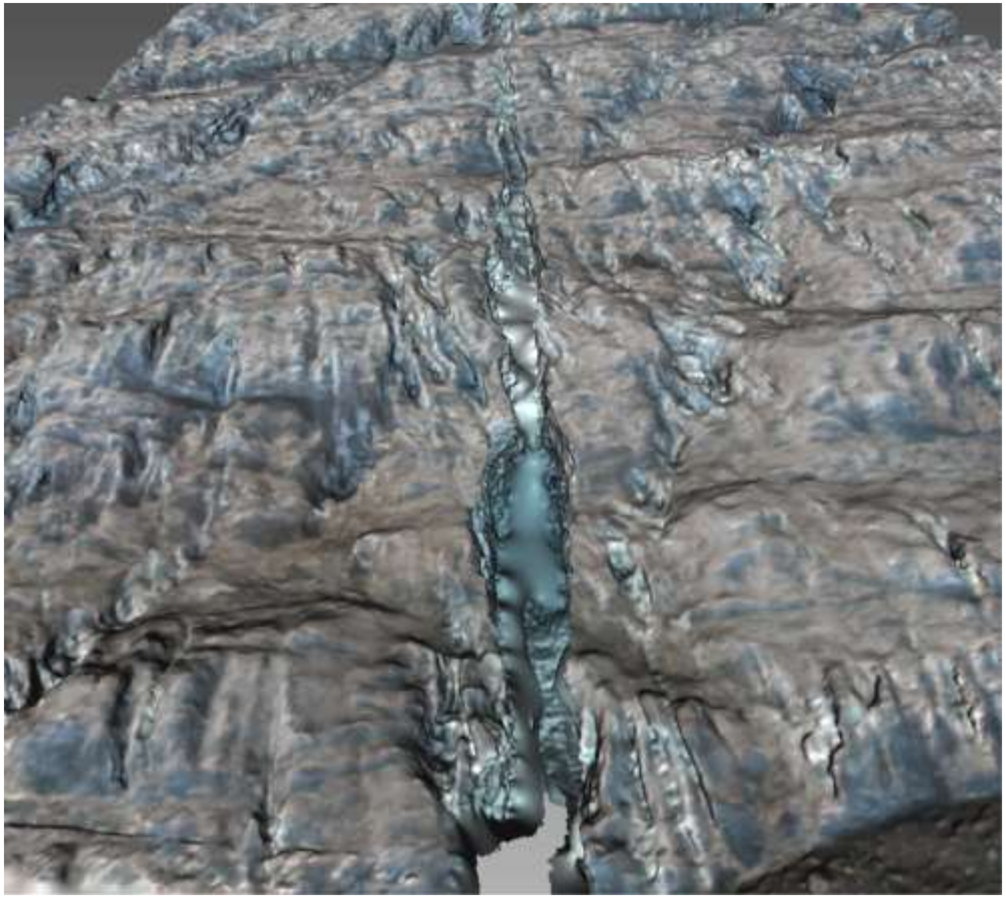
Flight plans – High geometrical resolution

- **Quantification and recording of crevasses**



SF00-LiDAR
286 Hz
250 m

Sony
Alpha6000
f = 16 mm

Skywalker X8
Version 2

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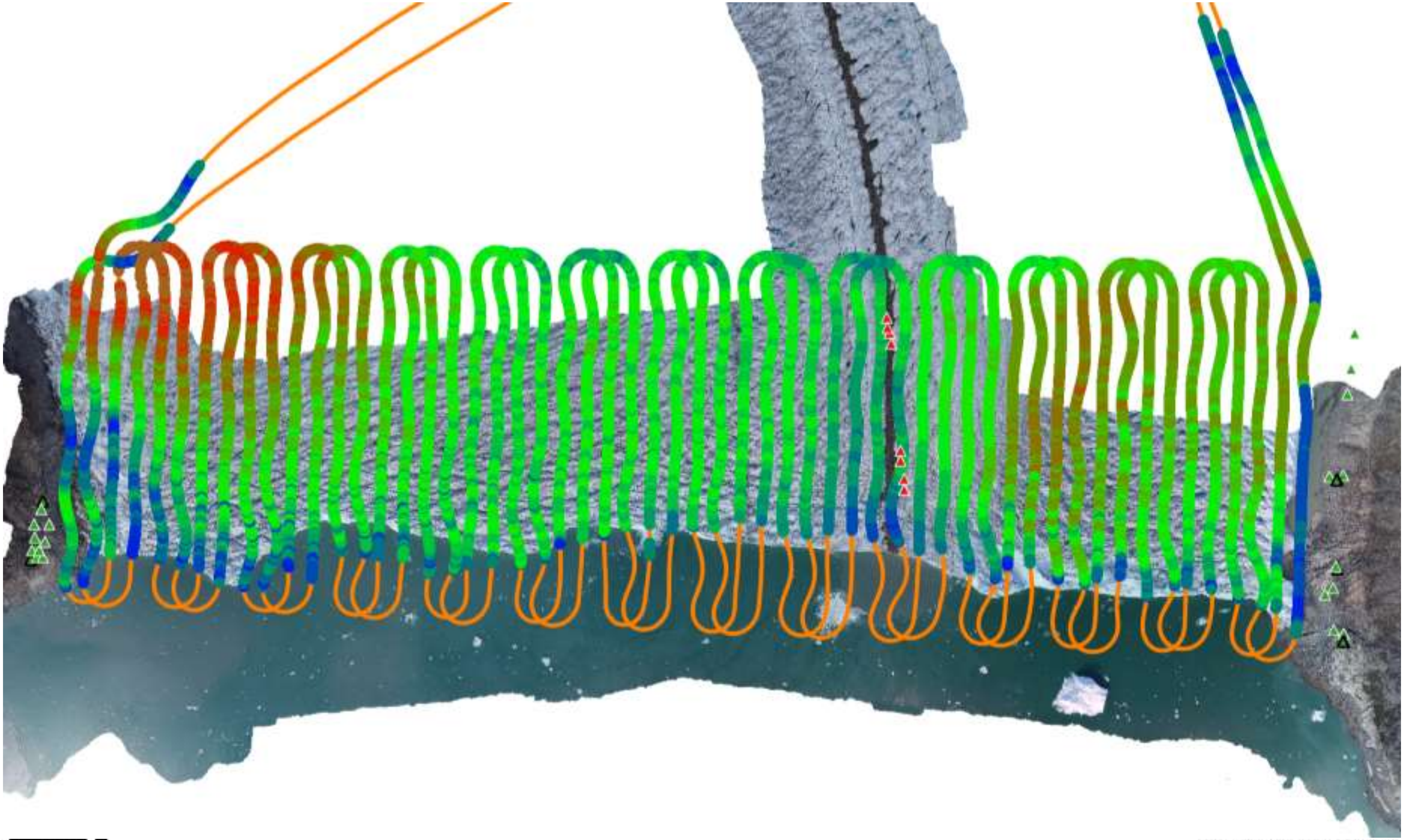
Flight plans – High geometrical resolution



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Unexpected challenges - Photogrammetry

- **Noisy parts of the point clouds**

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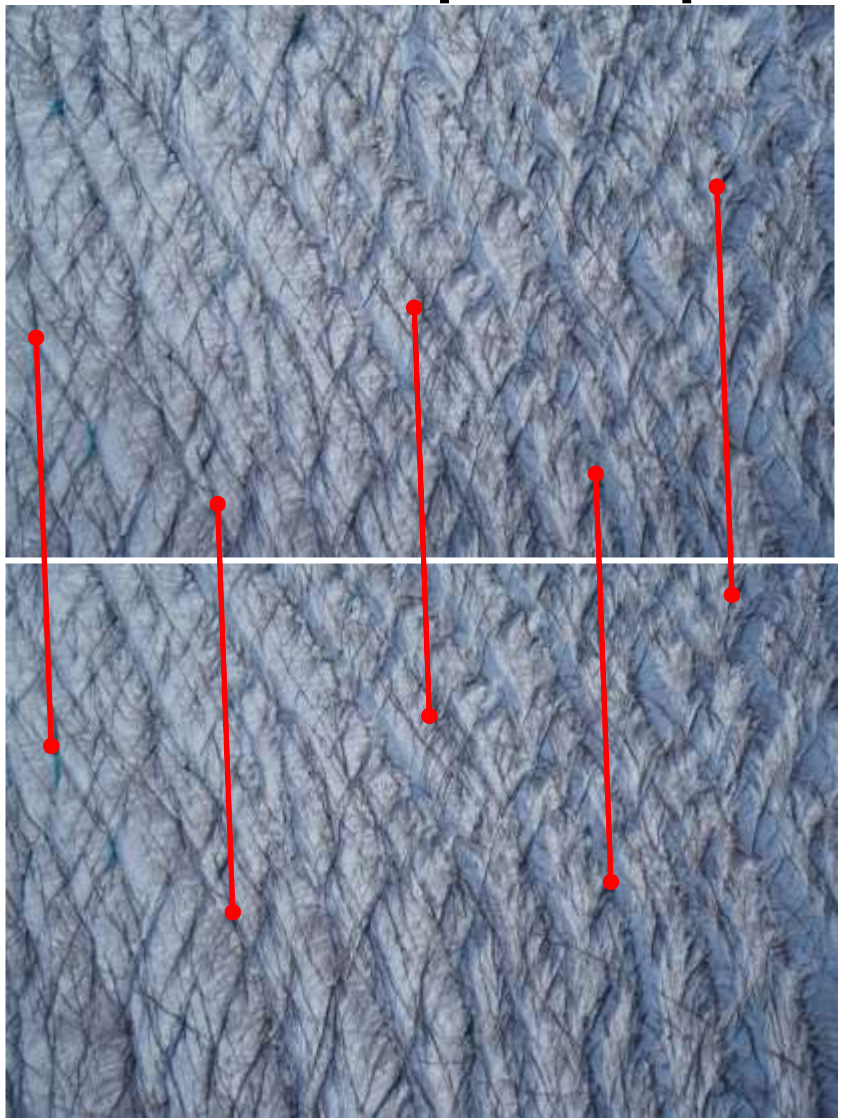
Unexpected challenges - Photogrammetry

- **Demanding tie point generation due to repetitive patterns**



Results – Orthophoto mosaics

July 7th 2015 | July 11th 2015 | July 16th 2015

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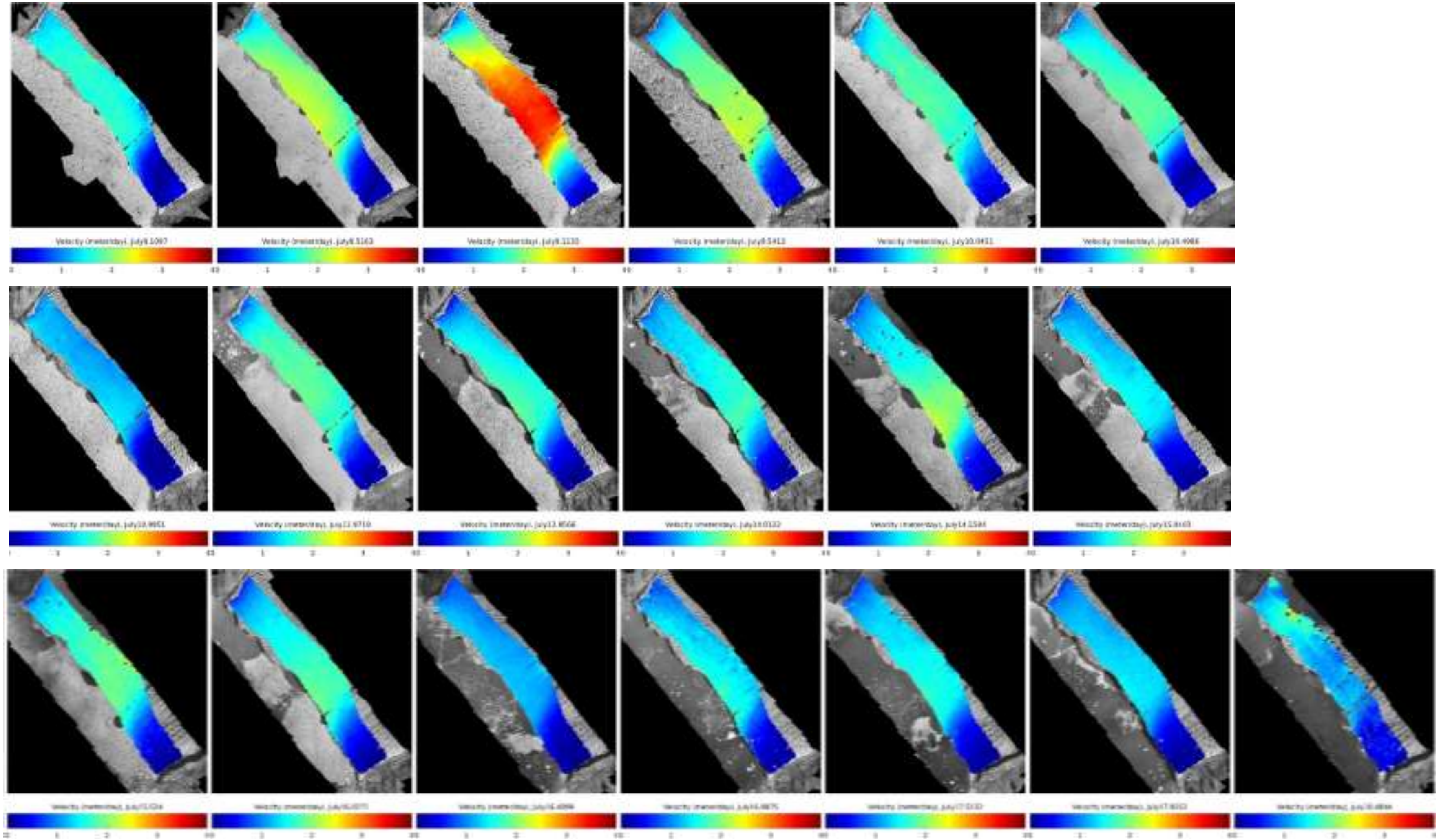
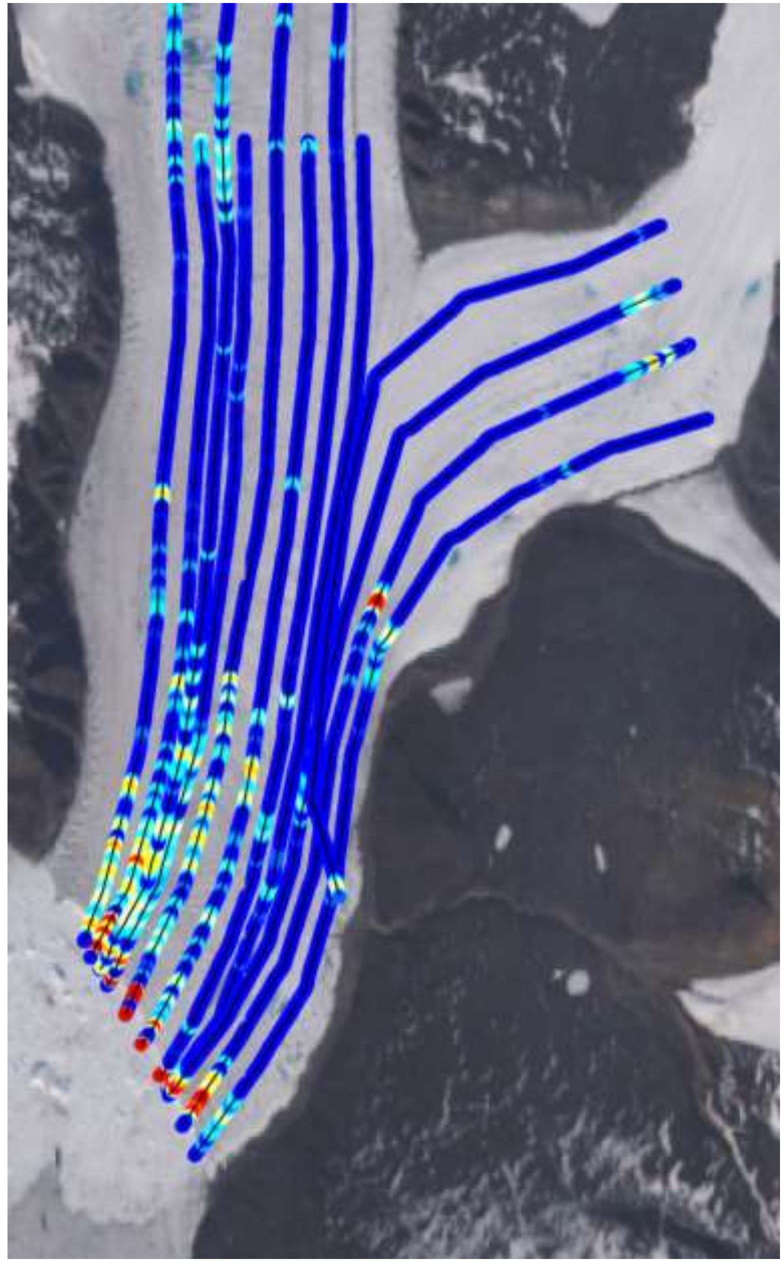
Results – Derived surface velocity



Results – Derived surface velocity

Movie

Results – Nadir-looking LiDAR profiles



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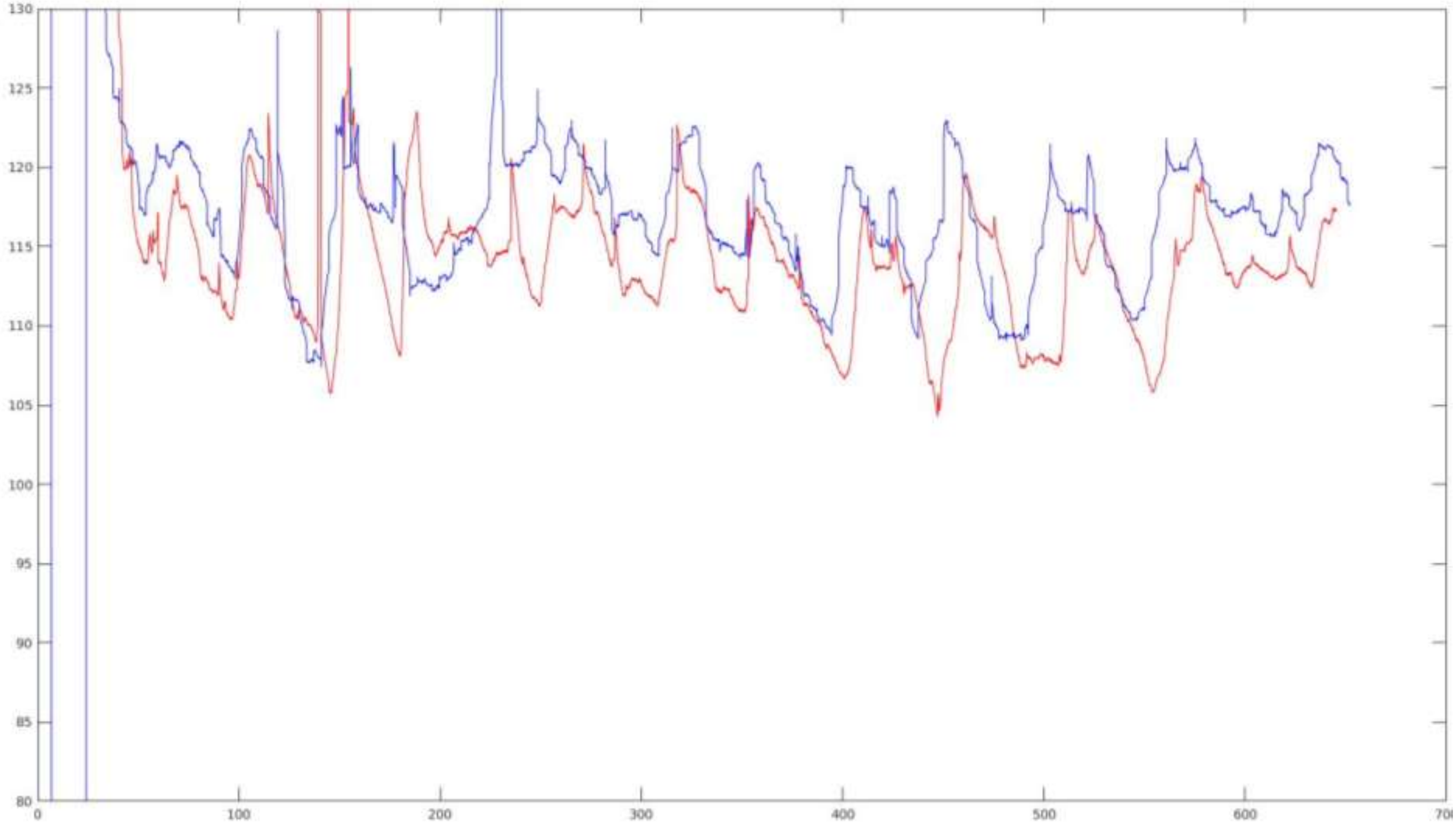
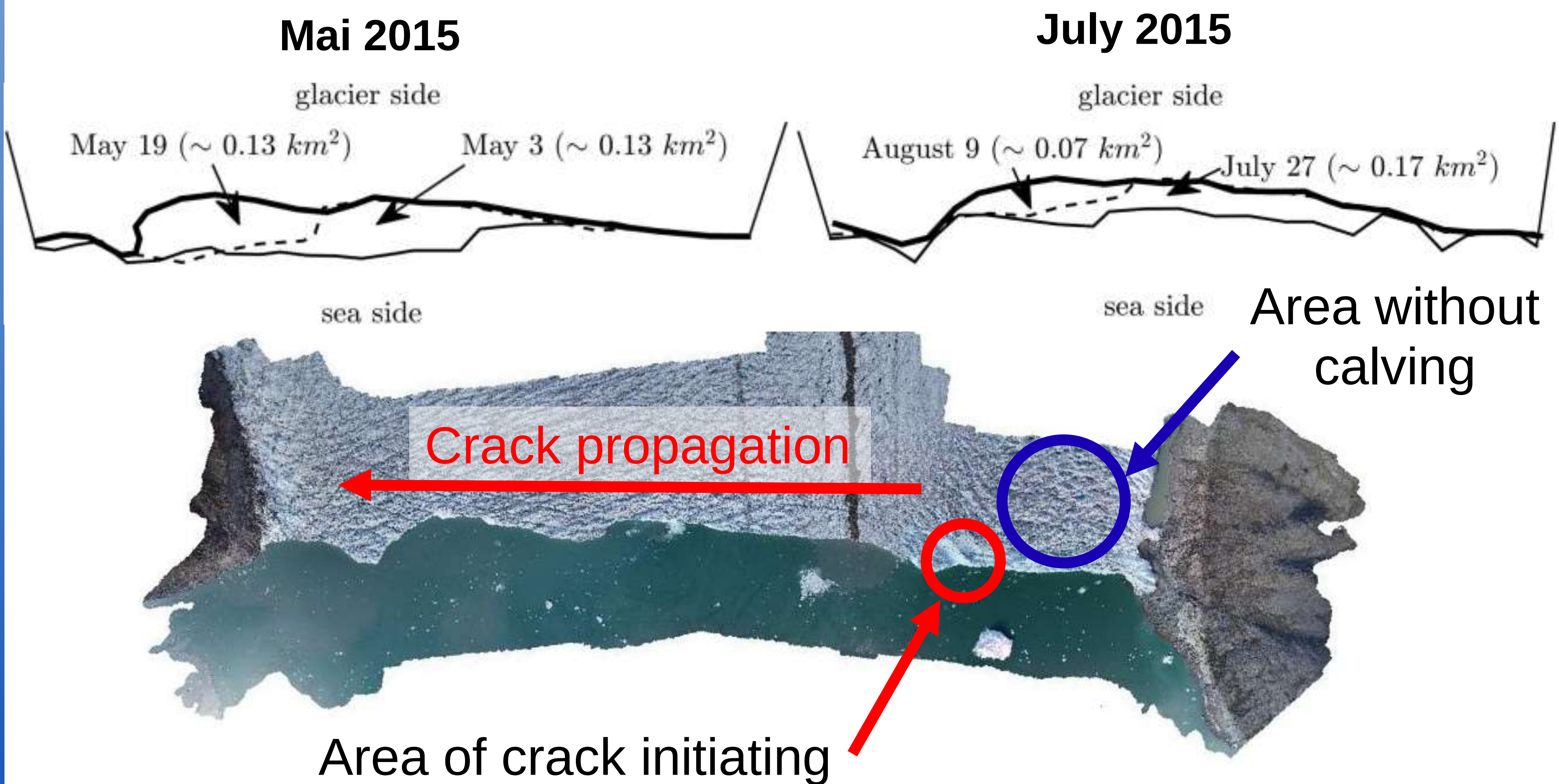
Results – Nadir-looking LiDAR profiles



Results – Initiating calving events



3 - 4 events in < 1 month ~ 20% of the yearly amount of calving

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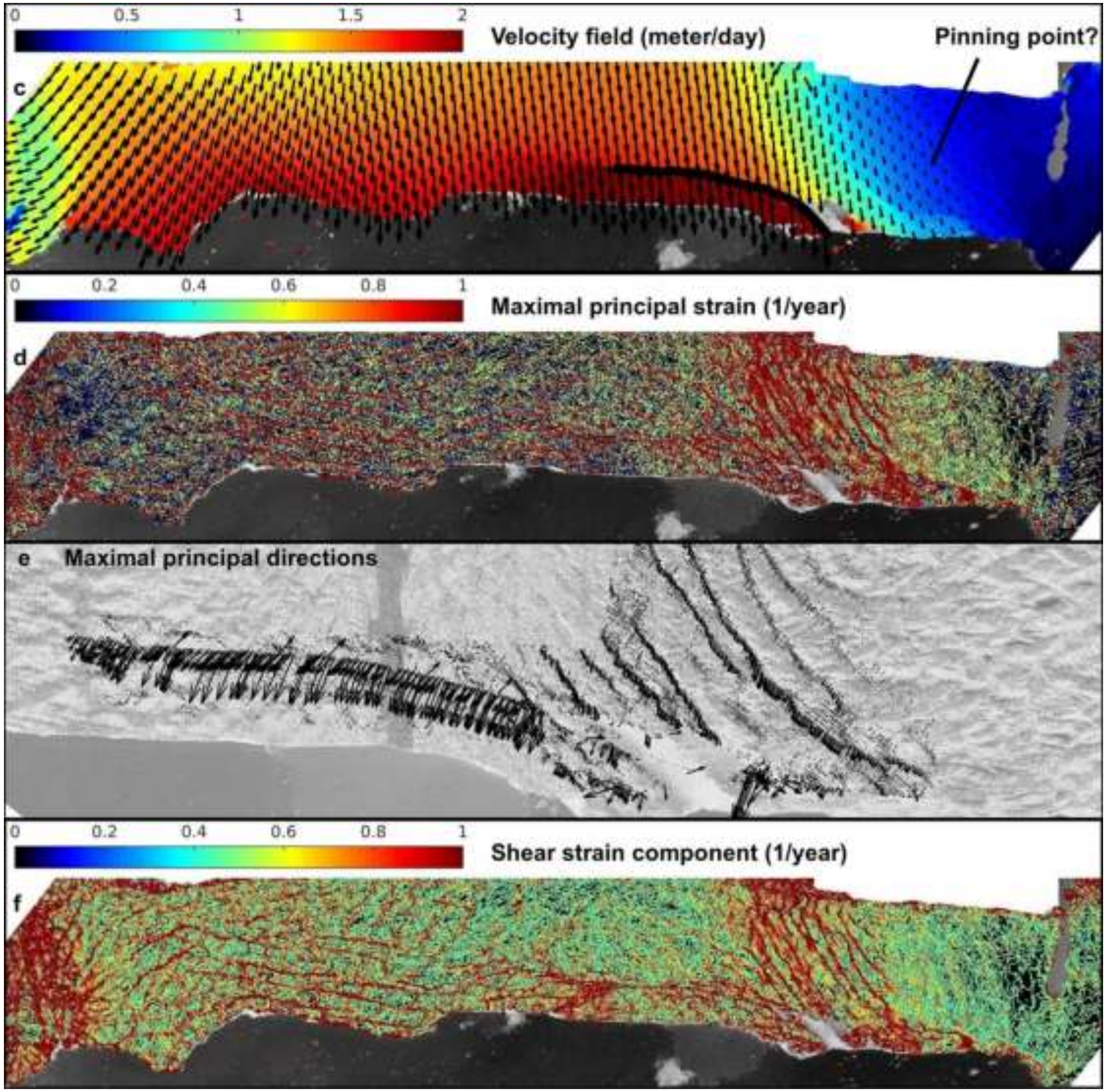
Results – Derived analysis



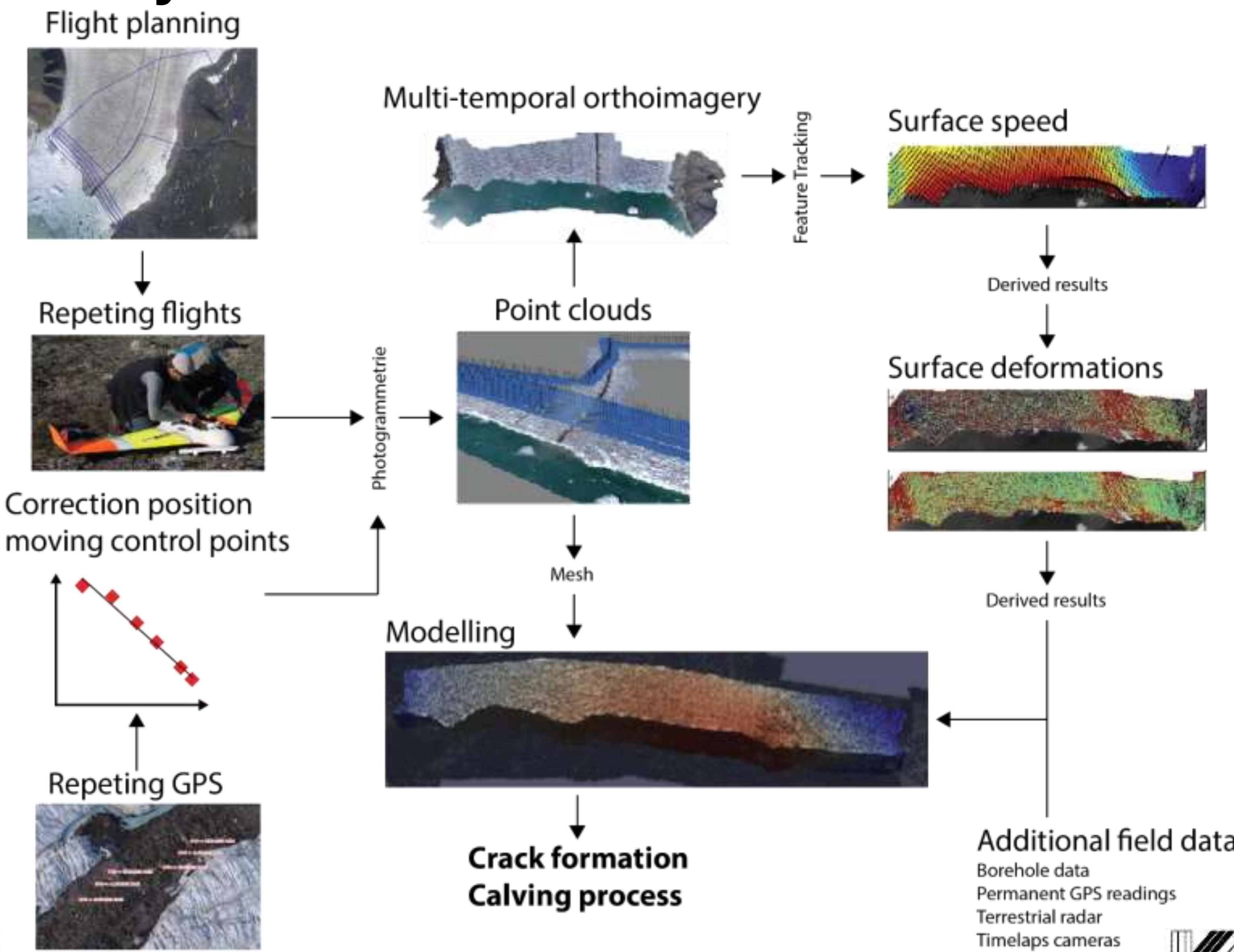
Velocity field

Maximal principal strain

Maximal principal directions

Shear strain component

Summary – Workflow and Results



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Summary – Homemade UAV

- **Conception and assembling:**
  - \+ Very economic but durable standard RC components
  - \+ Free configuration and extension
  - \+ Full access to flight parameters
  - \+ Access to all log parameters and -analysis
  - \- Massive underestimation of the complexity and needed effort
- **Application:**
  - \+ Very efficient behaviour during the flight
  - \+ Well and efficient to fix
  - \+ Complex missions and large distances
  - \- Demanding pre-flight-procedure and launching
  - \- Large landing space

Outlook

- **Analysis, data and processing:**
  - Improving LiDAR analysis
  - Refinement of mathematical model inputs
  - Comparison with Ground-based Radar interferometry
  - Extending the Python-based processing chain

- **Extending the area of interest (2017):**
  - Application of long-range flights with Skywalker X8
  - Reducing the need of GCP
  - Combination with solar-based long-range UAV Atlantik-Solar
  - Parallel monitoring of several calving glacier fronts

Thank you for your attention

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