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

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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
ETH Zurich / VAW

- 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, …
ETH Zurich / VAW: > 30 years of Glaciology

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- Applied Studies (Consulting)
- Fluctuations of Glaciers (Glacier Monitoring)

e.g. Surface Velocity, Surveillance, …

e.g. Length Change, Mass Balance, Surveillance, …
Bowdoin Glacier (Location 77° 42’ N; 68° 35’ W)
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

- **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 and maintenance of several timelapse 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

- Ice speed GPS
- Boreholes
- Borehole seismic
- Seismic arrays
- Infrasound array
- Ground-based Radar
- Camera
- Radar profiles
- Permanent Camera
- Weather station
- GPS fix station
- Permanent Camera
- Gauging station
Requirements for a UAV at Bowdoin
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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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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

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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Assembly of the homemade UAV

Fully configurable, inter-exchangeable and open system based on standard components!
Assembly … not without obstacles … :-)

"Always Look On The Bright Side Of Life"
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
Spectral range

Measurements spectral range on Glacier Plaine Morte (Switzerland), Kathrin Nägeli, 2014

- ADS NIR
- ADS Red
- ADS Green
- ADS Blue
- NDVI BG
- NDVI NIR
debrisMean
snowMean
dirtyIceMean
waterMean
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
Overlaps along flight line and cross flight line

- **Along flight line**: > 90%
- **Cross flight line**: > 70%

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
Ground control points – Types and challenges

Temporary

Permanent

Plastic foil
40 x 40 cm
Approx. 5 GSD

Paint
50 x 50 cm
Approx. 7 GSD
Ground control points – Types and challenges

Moving

Auxiliary

Plastic foil
40 x 40 cm
Approx. 5 GSD
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
Ground control points – Moving points

Correction Latitude

\[ R^2 = 0.9827 \]

Correction Longitude

\[ R^2 = 0.996 \]
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
Flight plans – High temporal resolution (<= 12h)

- Using of VTOL from the camp to calving front
- Flights every 12h (morning / evening)
- Total of 24 flights
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
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
Flight plans – High geometrical resolution
Unexpected challenges - Photogrammetry

- Noisy parts of the point clouds
Unexpected challenges - Photogrammetry

- Demanding tie point generation due to repetitive patterns
Results – Orthophoto mosaics

July 7th 2015  July 11th 2015  July 16th 2015
Results – Derived surface velocity
Results – Derived surface velocity

Movie
Results – Nadir-looking LiDAR profiles
Results – Nadir-looking LiDAR profiles
Results – Initiating calving events

Mai 2015
- glacier side
  - May 19 (≈ 0.13 km²)
  - May 3 (≈ 0.13 km²)

July 2015
- glacier side
  - August 9 (≈ 0.07 km²)
  - July 27 (≈ 0.17 km²)

- sea side

Crack propagation

Area without calving

Area of crack initiating

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

Velocity field

Maximal principal strain

Maximal principal directions

Shear strain component
Summary – Workflow and Results

Flight planning

Repeating flights

Correction position moving control points

Multi-temporal orthoimagery

Point clouds

Surface speed

Derived results

Surface deformations

Derived results

Modelling

Crack formation

Calving process

Additional field data

Borehole data
Permanent GPS readings
Terrestrial radar
Timelapse cameras

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich
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