Drones in the Arctic

Geomorphic change detection using unmanned aerial vehicles (UAVs)

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Who we are?

- We are geomorphologists interested in landscape dynamics in mountain and polar areas in multiple temporal and spatial scales. Drones have been used by us for different projects since 2013.
- Our experience from using drones:
  - **Several projects related among other to:** quantification of debris flows activities, landslides dynamics, alluvial and colluvial fans morphology and dynamics, mapping of proglacial areas, glacier mass balance, ice velocity, cliffs morphodynamics, soil erosion, vegetation mapping, creation of 3D models of buildings
  - **Countries where we flown**: Norway (Svalbard), Iceland, Greenland, UK, Poland, New Zealand, Peru, Colombia
  - **Drones which we have (and use most often)** - DJI quadcopters: Phantom 2 Vision+, Phantom 3 Advanced, Phantom 4 Pro; Mavic Pro Platinum
  - We also used sporadically other models: quadcopters - Inspire, S1000, S800, F550; fixed-wing - SmartPlane SmartOne
  - Both of us have valid UAV operator license for VLOS as well as BVLOS operations

How did we decide what type of drone will be good for us?

- Our general aim is to monitor short-term landscape dynamics, i.e. we create time-series of digital elevation models and orthomosaics to see landscape changes
- Conditions:
  - We would like to monitor short-term dynamics (daily, monthly, annually)
  - Our study sites are relatively small (up to 2 km sq.)
  - Most of our sites involved some (or more than some) hiking
  - Sky is usually clouded – the light is not good for taking pictures
  - It can be cold, windy and rainy
- Therefore, we were looking for something (perfect solution):
  - Small and light (to put it into the backpack together with some other stuff)
  - Able to take pictures in low-light conditions
  - Characterised by relatively long flying time
  - Able to operate in close to 0°C condition
  - Easy to use and reliable
  - Able to withstand winds

Why did we choose small 'ready-to-fly' quadcopters?

- We tried different solutions:
  - Large quadcopters (DJI S1000, S800) – they were simply too large to transport them.
  - fixed-wing plane SmartOne SmartPlane (used during 2014 Iceland campaign – surveys of proglacial areas):

PROS	CONS
Efficiency – large area can be covered in one flight	The metal case was extremely inconvenient to carry in the field
Working (and easy) GCS – operator needs only to select the areas of interest and software will calculate photo positions	Very hard to find proper landing spot (at least on Iceland)
Images' coordinates can be retrieved by aerial mapper software and use for further processing	Photos were blurred or noised, especially in weak light condition
No issues with taking photos	Price
No problem with GPS signal	

Why did we choose small ‘ready-to-fly’ quadcopters?

- Finally we decided to use DJI quadcopters: Phantom 2 (2014, 2015); Phantom 3 Advanced (2016, 2017); Phantom 4 Pro (2017); Mavic Pro Platinum (2018) mainly due to:
  - stabilization: ability to hoover over one spot + 3-axis gimbal = sharp pictures even in low light conditions (clouded sky and 1/20 or less shutter speed)
  - Light and compact – they fit into large photographic backpack = easy transport within study area
  - Small footprint (less than 50cm) – it is possibly to take-off from almost any kind of terrain (including boulder surface of the moraine)
  - Easy to pilot and relatively cheap
- Some cons:
  - Relatively short flying times (however, newer models are much better, increase from 18-20 min (P2) to 25-27 mins (P4 and Mavic)
  - Sometimes issues with application
- **Mobility was a key for us**

Our approach (step-by-step): Stage I – preparation

- Check national and local regulation – in some countries (e.g. Morocco, Thailand) drones are not allowed
- Register (if necessary) with Civil Aviation Authorities – (1) we passed exams for UAV operators in Poland (both VLOS and BVLOS), (2) registered as RO1 operator in Norway (VLOS); registered and marked our drones to operate them in the USA
- Ask for permission (if needed) from National Park managers and/or local authorities and owners – we asked for permission from Vatnajokull National Park authorities, The Governor of Svalbard, Ministry of Transport and Communications in Peru, Station managers etc.
- Prepare all necessary paperwork: operation manuals, flight procedures - in some countries it is obligatory (e.g. Poland) in other voluntary, but it is good to prepare such documents for our own sake.
- Purchase insurance
- Upgrade all kit (drone, controller, batteries, application) – it is much easier to do it in a warm place with good internet connection than in the field!
- Double check if everything works, perform test flights etc.
- Check transit countries regulations (e.g. in Thailand drone had to stay at the airport).
- Check airlines regulations:
  - In general drone can be taken on board if it fits into hand luggage
  - LIPO batteries are not allowed in checked-in luggage, so they must be taken on-board: < 100 Wh – unlimited; 100-160 Wh - two per passenger; >160 Wh (large drones like S1000 use them) – not allowed at all; must be shipped separately using special courier service. However, some airlines have their own regulations, e.g. Avianca limits <u>ALL</u> LIPO batteries <160 Wh to two per passenger

Stage II – travel, airport security, etc.

- One option is to check-in drone as additional luggage (or put it into luggage if it fits) – we did it several times in the past using hard (metal or plastic) cases and our drones survived air travel without incident.
- Recently, we usually have taken drone on-board, just in case our checked-in lugged get lost somewhere (and it happened to us several times). We use dedicated backpack for Phantom (which can fit drone, spare batteries, normal DSLR camera and laptop) or large photographic backpack for Mavic and other stuff.
- We usually travel with 1 or 2 drones, 8 to 16 batteries, and dGPS distributed in hand-luggage of two or three people (with the exception to South America fieldtrips with Avianca, where we only can take 5 batteries – 4 spares (2 per person) and one in the drone).
- So far, we have never encountered any problems during Airport security or border control check (Poland, UK, Norway, Iceland, Greenland, China, USA, New Zealand, Colombia, Peru). We have travelled with drone(s) with the following airlines:
  - Air China; Airberlin (before it bankrupt); American Airlines; Avianca (allows only 2 batteries per passenger); British Airways; China Eastern; Copa Airlines; Icelandair; LOT; Lufthansa; Norwegian; SAS; Thai Airways; Wizzair

Stage III: Take-off preparation

- Contact airport towers/local authorities/owners etc – e.g. for operations near Longyearbyen we called LYR airport tower before each survey session; in Zackenberg, Greenland we asked station manager if any other flying activities are planned
- Take a proper look of the area we are going to survey:
  - Any obstacles which potentially can block line of sight or radio signal
  - Andy obstacles like trees or electric wires (not a common problem in the arctic but often a nightmare in Colombia)
  - Avoid concrete surfaces and object (they can contain metal parts which will interfere with drone magnetometer
- Choose place for take-off from which offers us as much visibility as possible
- Prepare all equipment: remove gimbal protection, mount propellers, connect phone/tablet with remote controller (RC), check if the drone has not been damaged during transport
- Turn-on RC and THAN drone
- Check the sensors (accelerometer, magnetometer, gyroscope etc.), if they behave in a normal way - sometimes it was necessary to calibrate compass; especially when we flew in a new place (in case of Phantom 2 we did it everyday).
- Check the app settings – Return-to-home (RTH) altitude should be set-up higher than the highest obstacles

Stage IV: Take-off, surveys, landing (1)

- Take-off and hoover for a while at about 5 m above the ground, pull the drone forward/backward left/right, rotate it rapidly - if the drone responds in a normal way we are ready to go; if not it is necessary to land and check what is wrong
- We usually fly in GPS mode, but without mission planning – we fly in straight lines (using 'course lock' function), taking vertical photos manually with high overlap (80-90%). It might seem unnecessary, but in case of damaged/blurred photos it helps a lot during processing.
- If the studied site is characterised by steep/near vertical fragments (e.g. cliff, landslide, building) we are also take slant, sometimes even horizontal photos to ensure that all surfaces will be covered by images.
- When the battery level reaches 30% we return and land. Then, change the battery and repeat the previous steps.
- We usually operate as a team – one of us is a pilot (responsible for flying and taking pictures), the other one is observer (trying to keep visual contact with drone for all time). We switch roles every one or two batteries. Sometimes, we are using two drones at the same time adding an extra person (2 pilots + 1 observer).

Stage IV: Take-off, surveys, landing (2)

- We survey ground control points (GCP) with dGPS. Points can be natural (like boulders) or artificial (printed and laminated black and white targets). Usually about 2/3 of the surveyed points are used as (GCP), i.e. they are used for georeferencing of the point cloud, whereas the remaining 1/3 serve as independent check points, i.e. they are not used for georeferencing, but to assess the overall error of DEMs and orthomosaics.
- 8 batteries for Phantom 3/4 is more than three hours of flight – it is quite a lot in Arctic conditions (especially, when we fly from the glacier surface), so warm cloth is crucial. Gloves which allow touch screen operations are also very helpful (as some functions are accessible only via phone application).
- If we are lucky enough to have a car and power generator close to our sites (e.g. Iceland) we return to car park, charge four batteries (~1-1.5h) and return to do some more flying.
- In most cases we are using folded landing pad – it helps to protect drone from dust and is easily visible from the air, which facilitate landing. If the terrain is too rugged, we simply catch the drone during landing (see the title slide)
- Hi-vis Vests are obligatory in some countries (e.g. Poland), in some other places we were asked to wear them (e.g. Vatnajokull National Park) so we usually use them. Again, they help us to find take-off/landing place from the air.

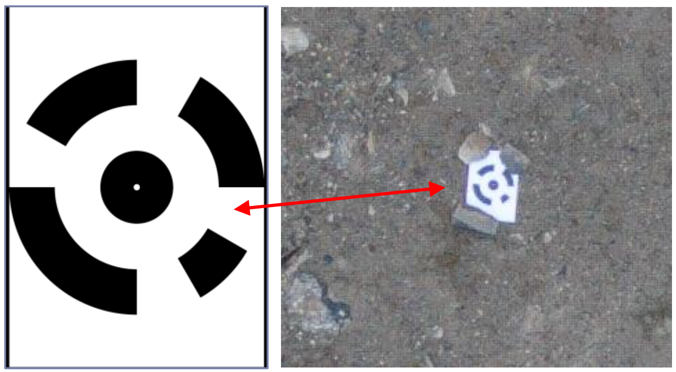
Stage V: Data management and processing

- Back in the station/hostel, we copy data to at least two separate drives. After the fieldwork we are creating one more copy of raw data in separate physical location (so, in total, we have three copies of raw data)
- During the fieldtrip, we usually process photographs using lowest settings (overnight) to ensure that we have proper coverage. If not, we return next day and repeat missing fragments.
- Full processing is done at home using proper workstations – that is the most tedious part of the process…
- We use Structure-from-motion in Agisoft Photoscan to process data, generate point clouds, DEMs and orthomosaics. The approach which we proposed has been published in Evans at al., 2016 http://dx.doi.org/10.1080/17445647.2015.1073185 (see the next slide)

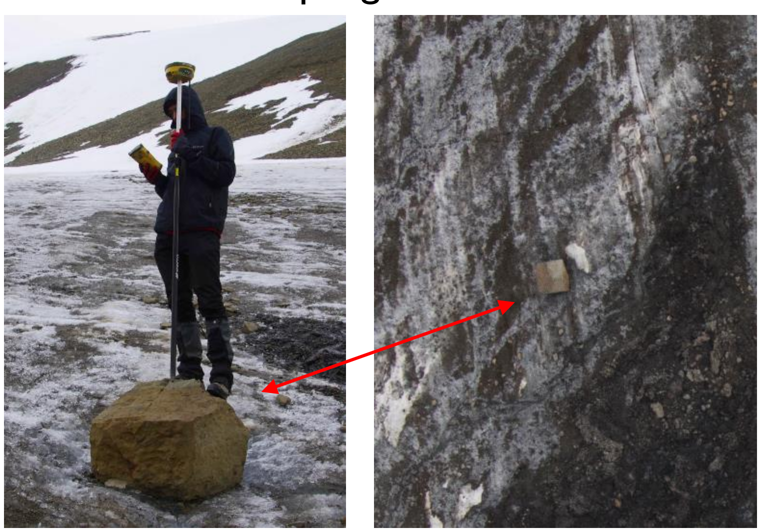
Methods: Processing

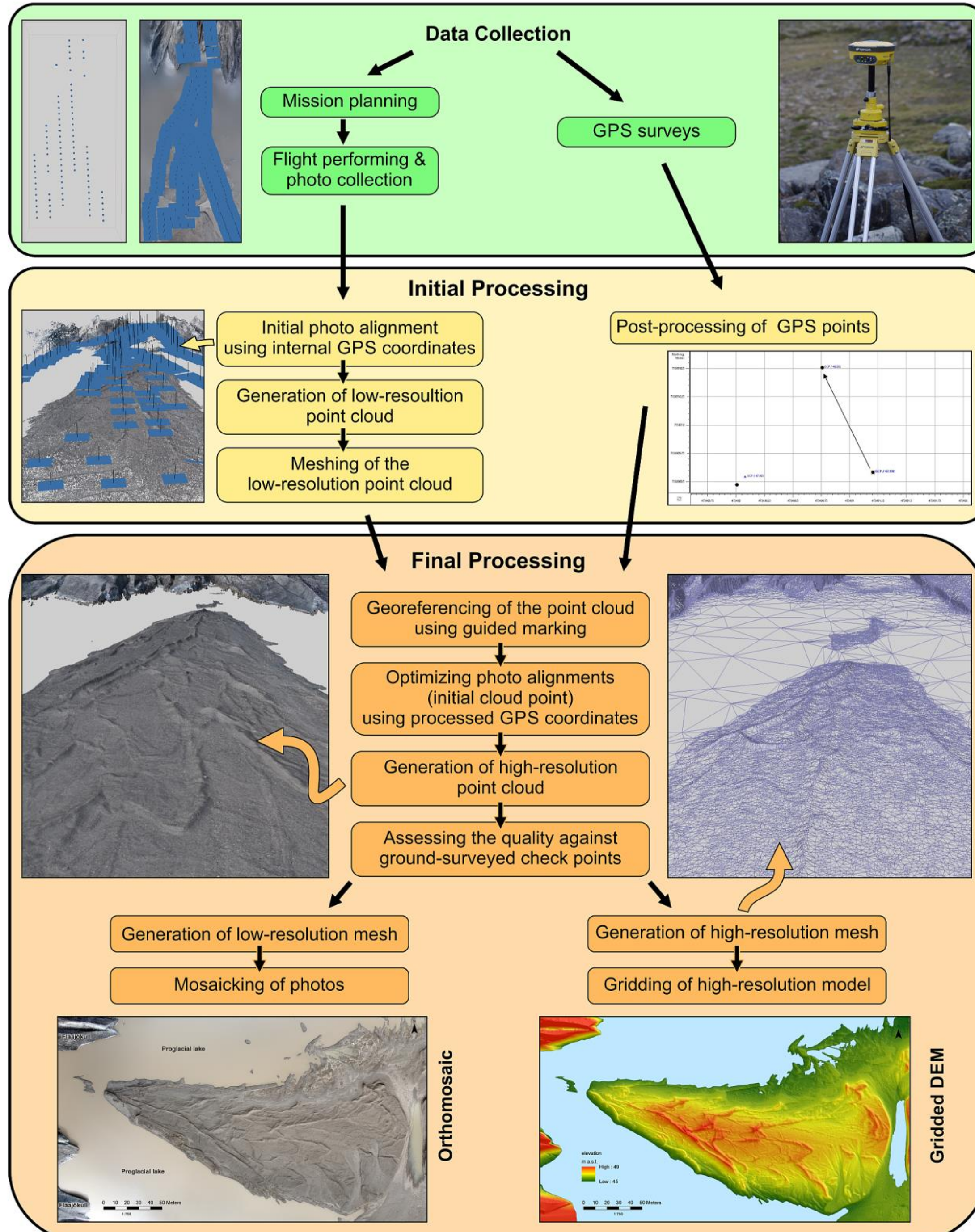
GCP collection:

Scenario I – laminated targets



Scenario II – unique ground features





(Evans, Ewertowski & Orton, 2016, Journal of Maps)

Challenges/considerations regarding using drones in our study areas (1)

- **Environmental conditions:**
  - Iceland, Svalbard and New Zealand were always demanding for us, it was often windy and rainy. We always planned some extra days in case of bad weather, usually 3-4 spare days for each 7 days of planned work. Sometimes it was not enough (e.g. Iceland 2017 was characterised by pretty bad weather with very strong winds which forced us to drop off some of the planned work).
  - We had almost perfect conditions (sunny and calm, only one day of fog) on Greenland (July/August 2017) during INTER-ACT-funded project. But the mosquitos were really nasty, often causing serious problem.
  - High altitude above sea level had a significant impact on drone flying time (thin air), e.g. we flew in Peruvian Andes at 5000 m a.s.l. and drone started RTH procedure when the battery status indicator showed still almost 50% of the battery
- **Flight restrictions:**
  - Svalbard - We always contacted tower in LYR before surveying session – only two times we were asked to wait with our flights until proper helicopter performed some of planned activities
  - Iceland – We got permission from Vatnajokull National Park staff: we were asked to try to avoid tourist, and in one case we were also asked to postpone days of flying due to local farmers gathering their sheep.

Challenges/considerations regarding using drones in our study areas (2)

- **Technical challenges:**

Phantom Series and Mavic should not be used in Polar areas! – that is from DJI manual guides (because magnetometer can sometimes not work properly in such high latitude).

BUT:

We used them with quite a lot of success, however, some troubles must be acknowledged:

- Phantom 2 – it was generally stable (Iceland and Svalbard), however only after everyday compass calibration. As it used only GPS (no GLONASS) number of satellites were sometimes too low for GPS-mode (especially in steep valleys on Iceland). It was also the main cause that we crashed it on Svalbard (however, we managed to repair it and continue our research).
- Phantom 3 Advanced – gave us some problems on Svalbard: used to lost magnetometer reading very often (almost every flight), which caused that drone could not make use of GPS mode (P-mode) and switched automatically to ATTI-mode (aircraft stabilised altitude, but not horizontal position) for some time (usually less than 1 minute). Continuing mission in ATTI-mode in windy conditions was doable but challenging. We did not have similar issues in other places.
- Phantom 4 pro – it was much more stable than P2 and P3. But once, on Greenland, it lost GPS signal. As a result, we had to fly it back manually. That is one of the reason that we usually perform surveys in pilot-observer team. The problem on Svalbard is that a bear-watcher is also needed…
- Many people complain about DJI GO app. We had some problems, but in general our phones worked very stable (we used: Sony Xperia Z3, Xiaomi Mi5, iPhone 5, Huawei P9). However, App installed on Motorola had so large lag, that it was not possible to perform surveys.
- During Greenland fieldtrip, we accidentally reset DJI GO app on our main phone… As there were no internet connection we were not able to log in and use the app. Our second phone showed very large lags. Fortunately, it was our last day and one of station managers had a phone with DJI GO app installed and working, so we could finish our work. Since that time, we always have at least two devices compatible with the app (as well as spare cables, etc)

Costs and budget

- When we started drone-related research, we bought drones using our private money: Phantom 2 Vision+, Phantom 3 Advanced. Each of them costed about 2500 EUR (drone with accessories: 8 batteries, memory cards, spare propellers, case, backpack, spare parts, battery hub, additional chargers etc). From the perspective of Polish academics, costs were rather high (equivalent of our bi-monthly salary), but in our opinion, it was definitively good decision.
- More recently Aleksandra got project funded by National Sciences Centre in Poland, which allowed us to buy Phantom 4 Pro with accessories (~4000 EUR) and Mavic Pro Platinum (~2500 EUR)
- Drones really boosted our ability to collect detailed topographic data leading to much better understanding of the dynamics of geomorphological process. However, as the processing times are long, most of our results have not yet been published (but we have several papers which are going to appear soon).
- Some additional costs to consider:
  - Both of us did course (obligatory) and pass the national exam to become UAV operator. We also took additional course and exam to operate drones heavier than 5 kg. In total: courses, exams, medical examinations etc. costed us ~750 EUR per person.
  - Annual insurance of the operator (obligatory in Poland and in most countries) varies from 30 to 200 EUR depending on quotas and conditions.
  - Norway: there are fees for RPAS operators flying beyond visual line of flight.
  - USA: registering as a pilot (recreational) 5 USD.

Limitations or experiences after as well as before the use of drones within the project (1)

- For us, small "ready-to-fly" drones, combined with Structure-from-motion photogrammetry are extremally useful – they became our everyday research tool.
- Our approach is good for relatively small areas (1-2 km^2). To survey larger areas, you should consider using some mapping applications to perform automatic missions (however, they might sometimes not work properly in the Arctic), like Pix4D mission planner, Maps Made Easy, Drone Deploy, Altizure.
- Fixed-wing planes might also be solution, but to fly beyond visual line of flight it is much more complicated from legal point of view.
- Some other limitations are related to weather conditions – we are using small drones (the maximum wind which they can handle is about 10-12 m/s) which are not waterproof.

Limitations or experiences after as well as before the use of drones within the project (2)

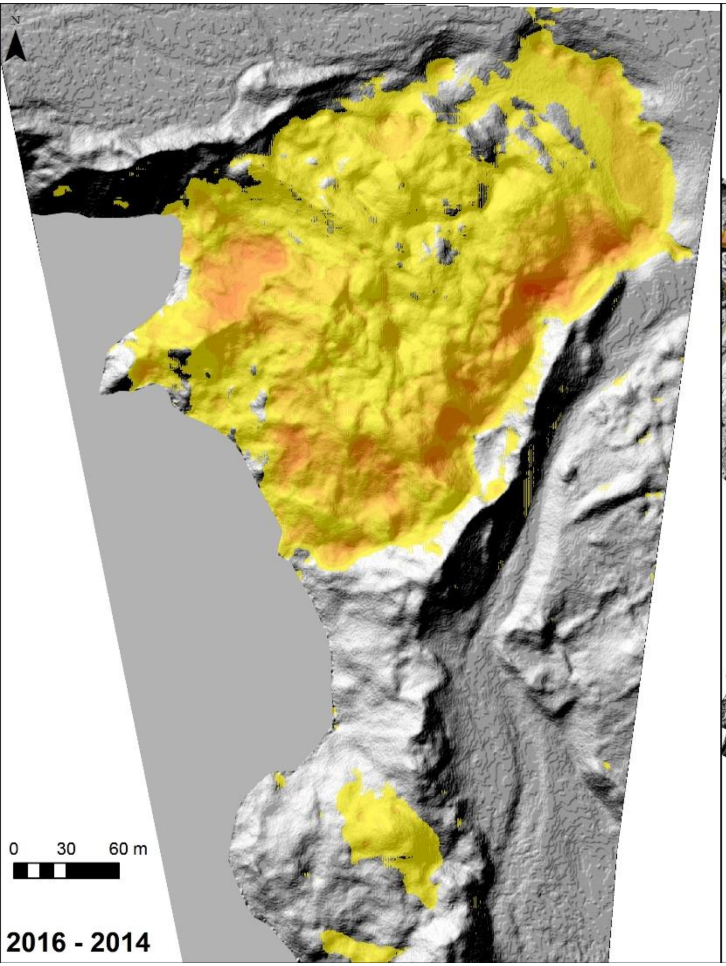
- There are some locations which cannot be surveyed with drone due to environmental conditions (trees, wires, animals, etc.) or legal/ethical regulations (no fly zones, privately-owned grounds etc.).

Flying with mosquitos (Greenland)

- Data management and processing is painful. Drones can deliver HUGE amount of data. The problem is where to store them safely, and how to find enough time to process them.

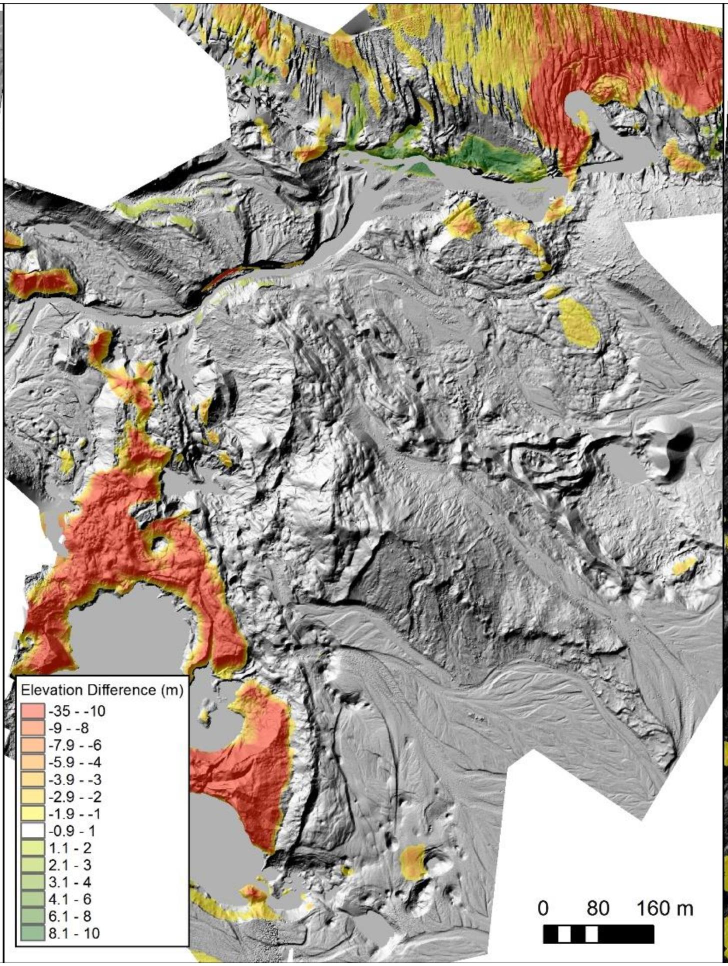
No-fly area (New Zealand)

Some examples of our results: Quantification of landscape changes in proglacial areas (2014 – 2016)



- 7344 m³

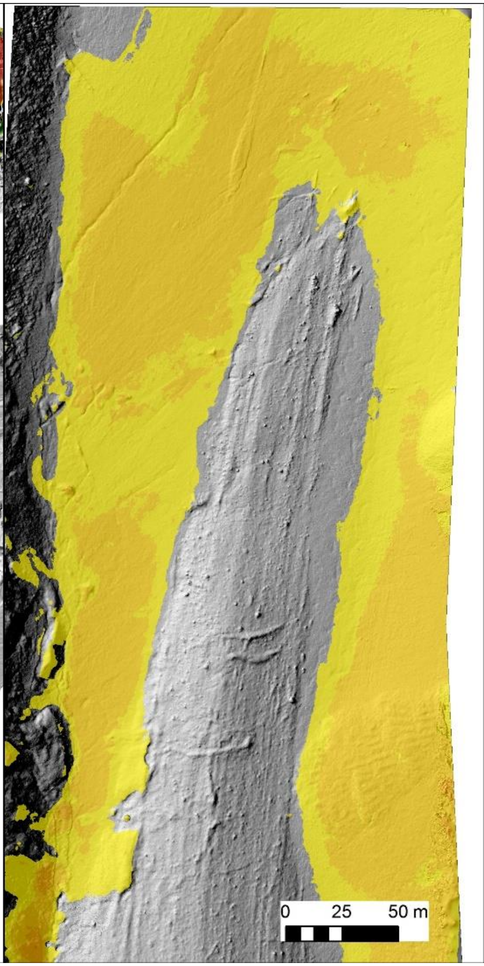
Kviárjökull, Iceland



- 57 310 m³

+ 4528 m³

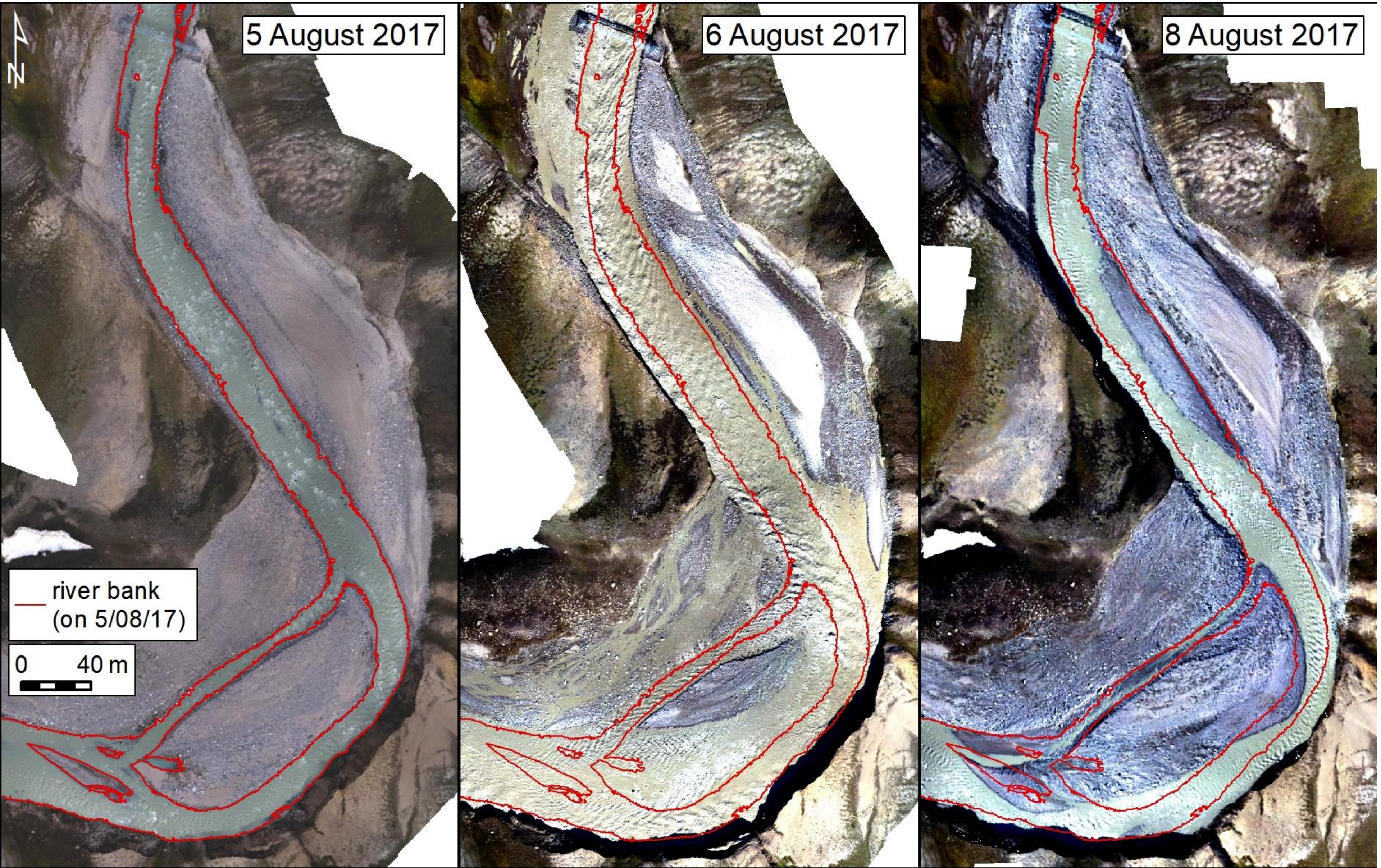
Fjallsjökull, Iceland



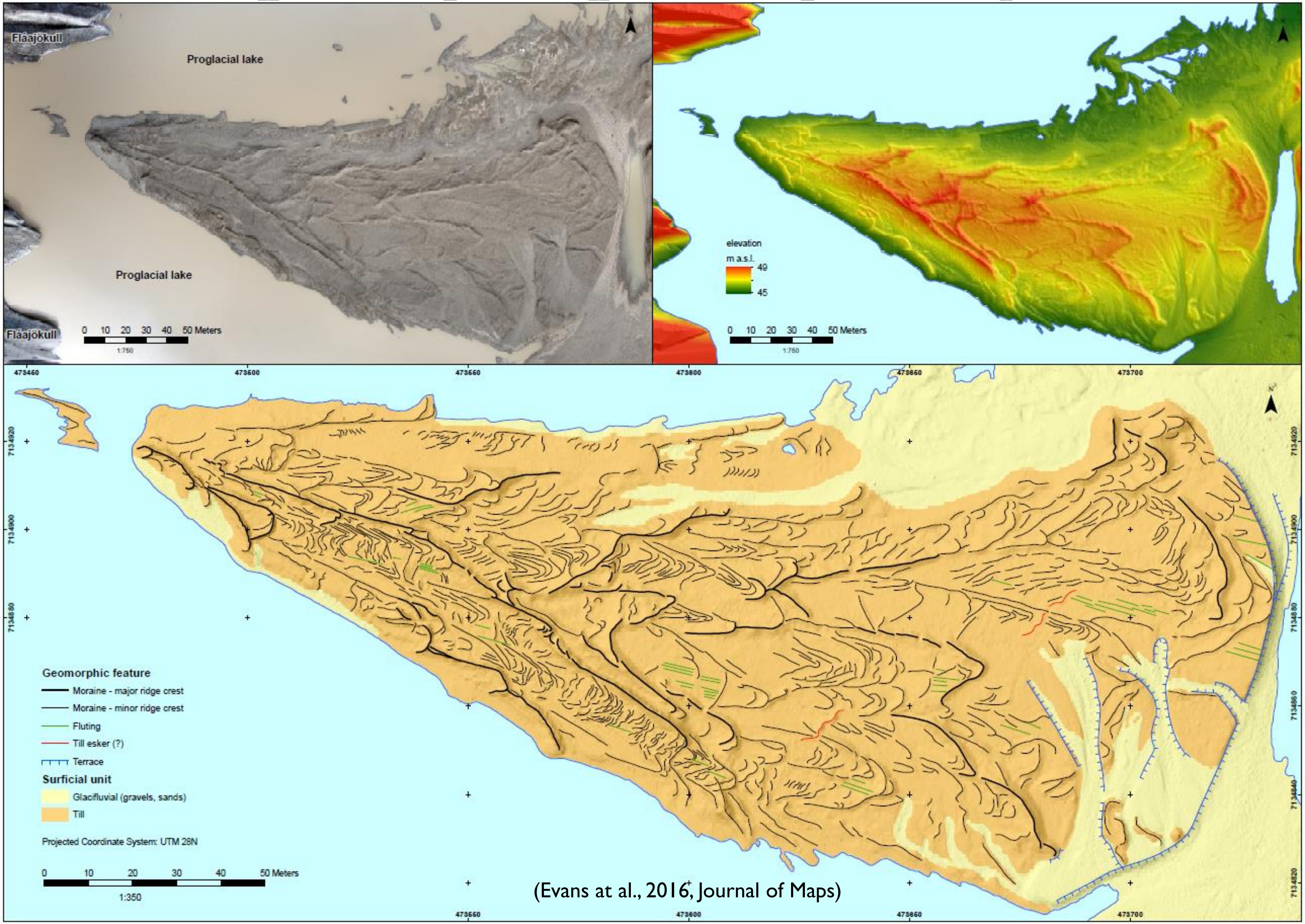
- 10 475 m³

Rieperbreen, Svalbard

Geomorphic effects of single flood event: Zackenberg river, Greenland

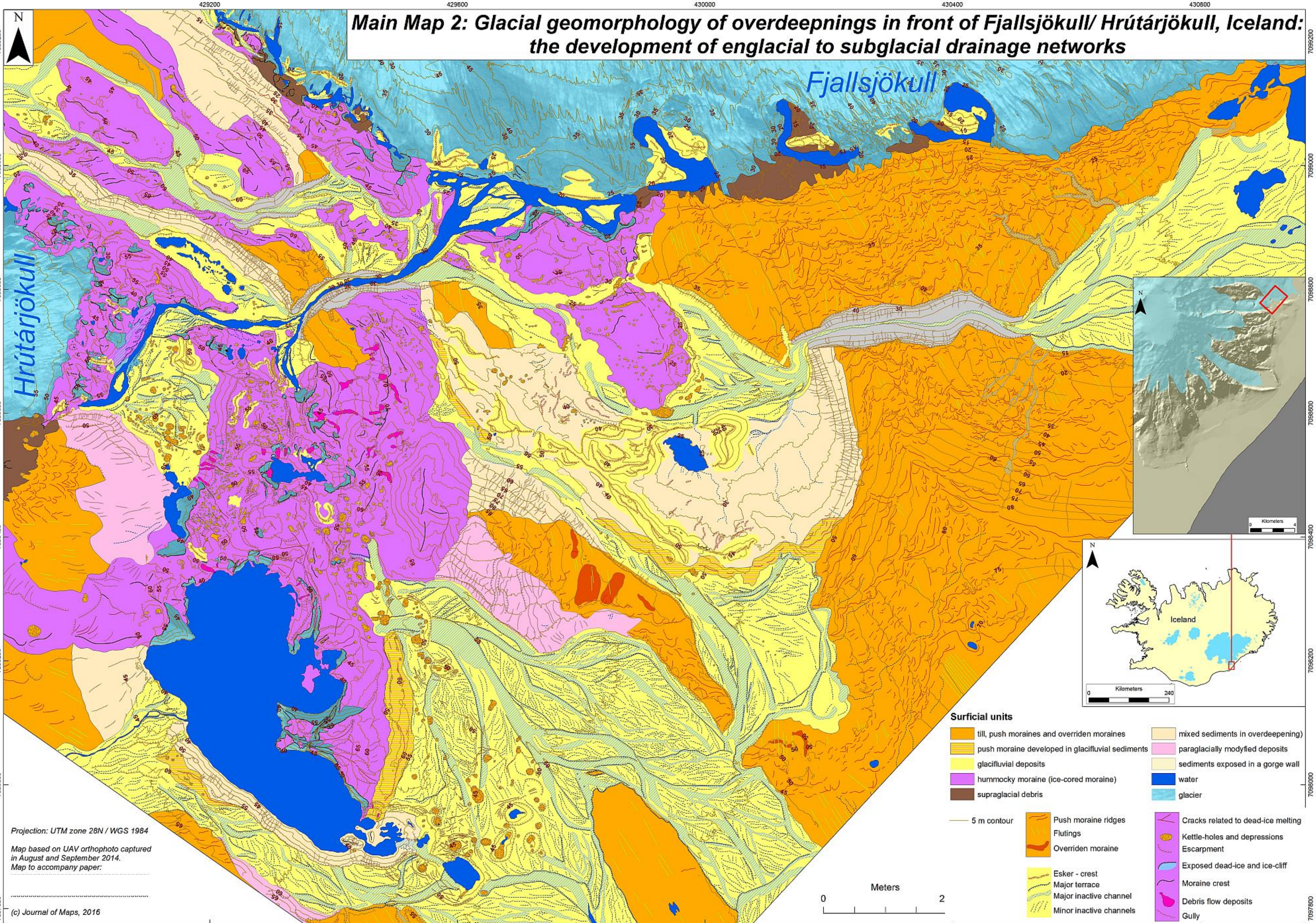


Detailed geomorphological maps: Fláajökull



(Evans at al., 2016, Journal of Maps)

Detailed geomorphological maps: Fjallsjökull



Detailed geomorphological maps: Nordenskiöldbreen

Main Map 2: An example of fluted till surface at Northern side of the Nordenskiöldbreen foreland, Adolfbukta, Svalbard

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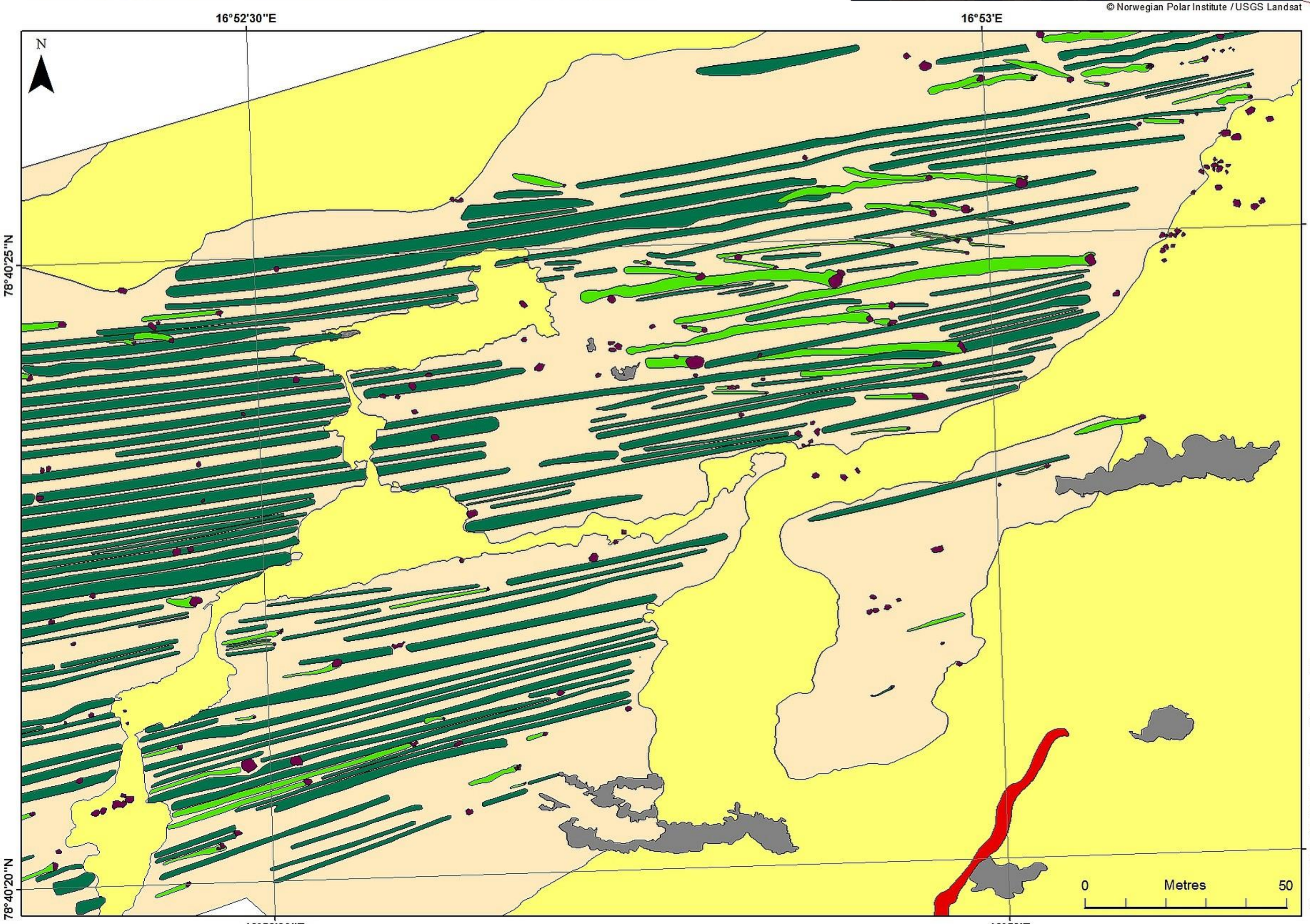

- till
- bedrock
- glacifluvial deposits
- flute not associated with boulder
- flute associated with boulder
- boulder
- esker

Projection: UTM zone 33N / WGS 1984

Map based on UAV imagery captured at 29th July 2014.

Field verification in 2005, 2007, 2013 and 2014.

Map to accompany paper:
Ewertowski M.W., Evans D.J.A., Roberts D.H., and Tomczyk A.M. 2016. Glacial geomorphology of terrestrial parts of tidewater glacier: Nordenskiöldbreen, Svalbard

Thank you for your attention☺

- If you have any questions or if you are interested in cooperation, please contact us:

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Greetings from Colombia!