Structure from Motion (SfM) orthoimage generation for characterizing methane ebullition features in thermokarst lake ice

Kerstin Schlobies[1,2], Guido Grosse[2], & Katey Walter Anthony[3]

[1] *Department of Physical Geography, Catholic University of Eichstätt-Ingolstadt, Germany*
[2] *Alfred Wegener Institute Helmholtz Center for Polar and Marine Research, Potsdam, Germany*
[3] *Water and Environmental Research Center, University of Alaska Fairbanks, USA*

Thermokarst lakes are characteristic landscape features in Arctic permafrost regions and are relevant emitters of the greenhouse gas methane (Walter et al., 2006). A major pathway for methane emissions from these lakes is through bubbling (ebullition) from discrete seeps. An accurate assessment of the actual emission rates of CH_4 from thawed organic-rich talik sediments under thermokarst lakes is challenging due to poor accessibility and monitoring complexities concerning the spatially and temporally variable behavior of ebullition. In early winter, when lake surfaces start to freeze, or alternatively in late winter, the days before thawing sets in, a snow free ice cover reveals trapped gas-pockets and open hotspots of methane seeps. The detection and characterization of distinct ice-trapped CH_4 bubbles and bubble clusters, which depend on differing methane emission rates, is possible by field and remote sensing surveys of the lake ice cover during a short time window for image acquisition with ideal ice and snow conditions (Lindgren et al., 2015). In this work we aim to generate spatially very high resolution orthophoto mosaics using low altitude aerial imagery from multiple years to provide a set of high quality baseline imagery for characterization of ebullition features in thermokarst lake ice cover in the Fairbanks region, Interior Alaska.

For our image processing, we relied on photogrammetric Structure-from-Motion (SfM) technology, which builds on image-based three-dimensional surface reconstruction algorithms. We applied this technique to large sets of overlapping aerial images using the workflow presented in Fig 1 and the software Agisoft PhotoScan Professional™. In a first step, the software analyzes input photos and detects features that are stable under variable viewpoint and lighting conditions. As a result, a descriptor for each point based on its local neighborhood is obtained and serves for detecting identical tie points across photos. Automated feature detection and matching are then performed using software-internal algorithms comparable to the Scale-Invariant Feature Transform (SIFT) approach. Internal and external camera positions are estimated on basis of bundle- adjustment algorithms. For dense point cloud and mesh construction the software provides several processing methods depending on the final product (orthophoto, pointcloud, digital surface model – DSM), data size (number of photos and resolution), and image acquisition mode (terrestrial vs. airborne, horizontal vs. oblique). For texturing, the reconstructed surface is divided into fragments and blending is applied to generate a texture atlas.

We applied this full processing chain to a large set of 2601 images acquired during airborne flight campaigns with unmanned air vehicles (UAVs) and small aircrafts over several thermokarst lakes in the Fairbanks region in April 2012 and October of 2008, 2013 and 2014. In addition, aerial imagery of lakes in an abandoned gravel pit were gathered for comparison to thermokarst lakes and processed the same way. The 2601 aerial images were acquired at mean flight altitudes of 42 m.a.s.l. (UAV) and 327-606 m.a.s.l. (airplane). The images were grouped into seven regions covering sets of target lakes and provided the basis for 23 orthophoto mosaics. The number of images per mosaic ranged between 9 and 585. About 15 ground control points (GCPs) were equally distributed over the covered area for georeferencing. We achieved a ground resolution of 0.02 m/pixel to 0.12 m/pixel, a DSM resolution of 0.03 m/pixel to 0.24 m/pixel, and a point density of about 19 to 1849 points per m^2, depending strongly on actual flight height and photo resolution. Furthermore, the accuracy for surface reproduction is augmented by increasing image overlap with best results achieved when at least nine photos overlap. In one specific case, when image acquisition was conducted within a low flight altitude of 42 m.a.s.l. the SfM-method failed to align five overlapping images in the center of a thermokarst lake (Goldstream Lake) due to the absence of detectable ice surface features (such as bubbles or cracks) underneath the ice cover. The placement of temporary markers in the misaligned images still did not result in a sufficient matching quality; hence these unaligned photos were not taken into account for further processing. Future field campaigns with UAVs at low flight altitudes over lake ice should therefore include installation of ground control points across very homogeneous surfaces. Inhomogeneous or changing illumination conditions during a flight campaign could also lead to poorer photo alignment due to false corner and edge detection. Orthomosaics consisting of images taken under changing illumination situations (e.g. sunrise, sunset) may result in irregular color parametrization.

The final orthomosaics are of high quality and can be used in further studies aiming at the identification, mapping, and quantification of methane ebullition features in the lake ice. In particular, the detection and characterization of different methane bubble cluster types is enhanced by the very high resolution of the orthophotos. In a further step, the estimation of whole-lake ebullition seep fluxes and the year-to-year development of ebullition seep features seem feasible. Additionally, it would be of major interest to test the practicability and accuracy of SfM generated high resolution repeat DSMs for detecting and quantifying thermoerosion at lake margins. For this, filtering vegetation, assigning an overlapping value to the point cloud, and evaluating the error of photogrammetric data is essential. Direct cloud-to-cloud or cloud-to-mesh distance measurements and horizontal displacement fields from tracking features could be applied for broader analysis.

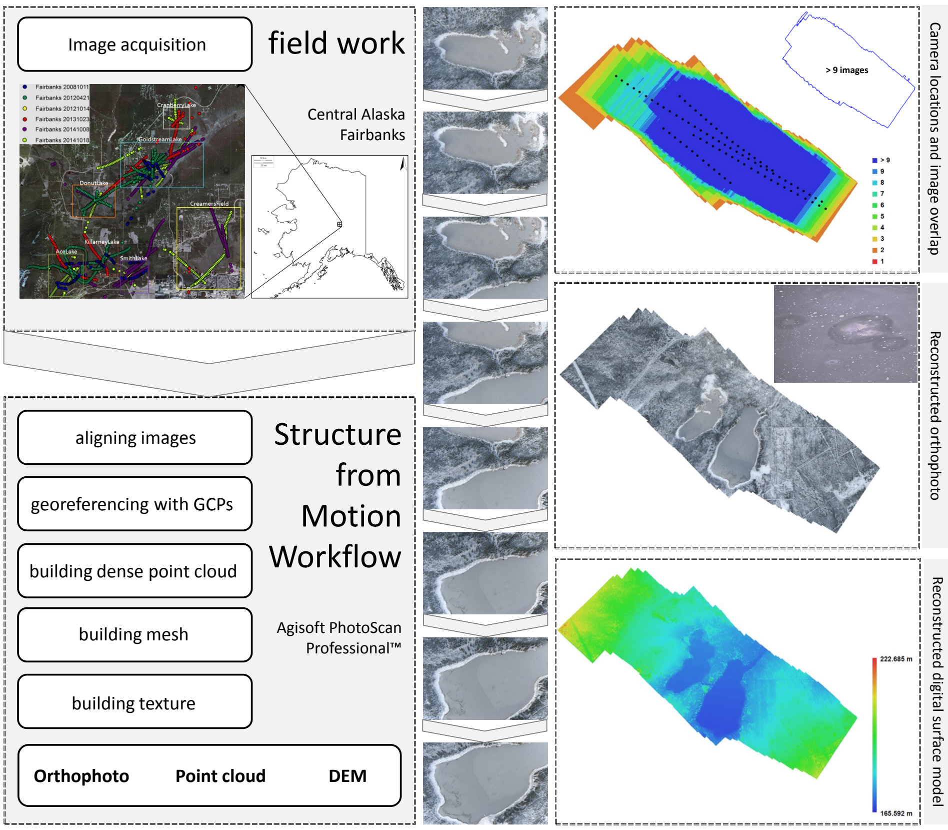

Figure 1: Applied workflow and final products

The presented investigations show, that using SfM within Agisoft PhotoScan Professional™ for processing aerial imagery is a suitable method to generate high resolution orthophoto mosaics that subsequently can be used to characterize ice-trapped ebullition bubbles and bubble clusters on thermokarst lake ice cover. The new dimension of information gain due to the very high resolution within centimeter range in orthophotos, point clouds, and DSMs using SfM offers new insights for better understanding biogeochemical and geomorphological processes in periglacial environments, in particular processes related to thermokarst dynamics such as lake methane ebullition or shore erosion.

Lindgren PR, Grosse G, Walter Anthony KM, Meyer FJ. 2015. Detecting methane ebullition on thermokarst lake ice using high resolution optical aerial imagery. Biogeosciences Discussions 12: 7449–7490. DOI: 10.5194/bgd-12-7449-2015

Walter KM, Zimov SA, Chanton JP, Verbyla D, Chapin III FS. 2006. Methane bubbling from Siberian thaw lakes as a positive feedback to climate warming. Nature 443: 71-75. DOI: 10.1038/nature05040