Use of UAVs to assess satellite measurements of snow albedo in mountainous regions

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Start & end date: February 1, 2019 to August 31, 2019

Budget Requested: $7,000

Budget Summary:

Deliverables	Amount
Purchase two Kipp & Zonen PR1 sensors & data logger	$3,500
Mount and test sensor on UAV	$1,000
Quantify scale dependent controls on snow albedo	$2,000
Present results at ESIP Summer meeting	$1,000

Project description

Earth's albedo (relative reflectance) is a critical component for the planet's energy balance calculations. Because albedo varies spatially and temporally, accurate measurements across a landscape are important and challenging. This project focuses on quantifying the albedo of mountain snowpack. Mountain snowpack is an essential water resource for people, economies, and ecosystems in Montana, the western United States, and across the Earth. This resource functions as a natural water tower that collects, stores, and releases water to fill streams and recharge aquifers for socio-environmental systems downstream.

Despite its importance, measurements of mountain snowpacks are sparse, and even when available they rely monitoring sites that are location-specific. These point-based networks are not representative of rugged mountain landscapes, and are stationary locations in an unstationary climate. Satellite measurements offer a unique perspective from space, providing global-scale products (e.g. MODIS and Landsat) that capture variability across mountain topography and bridge sparse monitoring networks, providing near-real time data (including albedo) with global coverage. These Earth Observations (EO) provide novel insights that improve our understanding of complex land-atmosphere interactions from pole to pole, fundamentally changing the way that the Earth is measured, mapped, and modeled.

These initial raw Earth Observations (EO) from space require *in situ* data to calibrate the satellite signal. However scaling issues exist between *in situ* and satellite data, creating calibration and validation challenges for raw EO. Unmanned Aerial Vehicles (UAVs) provide the flexibility to measure albedo at multiple scales and locations, bridging the challenges associated with resolving fixed-position *in situ* data and EO. Recent technological advances in albedo sensors provide smaller, lighter units capable of being mounted to a single UAV.

Project objectives, significance and impact

The overarching goal of this project is to assess the spatial and temporal variability mountain snowpack's albedo. Levy et al. [1] demonstrated the utility of UAVs to measure physical albedo across level, forested stands in the northeastern United States. Reflected irradiance was measured from the UAV, and incoming irradiance was measured from a fixed position (pole). Irradiance is used to calculate albedo. This experiment represents considerable progress in the application of UAVs, but it did not resolve the issue of a single fixed-position *in situ* measurement, nor did it measure albedo during the snow season and across mountainous terrain.

Recent technological advances in sensors provide smaller, lighter instrumentation that allow two pyranometers to be mounted to a single UAV. A pyranometer is a sensor that measures solar irradiance over an area (Wm^{-2}). Measuring incoming and outgoing irradiance from a single UAV provides the ability to capture albedo variability across landscapes and at a range of altitudes. This enhanced range extends the ability to measure the variability across landscapes that is not represented by fixed-location measurements. UAV's spatial flexibility in the x,y,z plane begins to address the scaling issues (from 10s of meters to several square kilometers) that have commonly hampered the calibration and validation of EO (e.g. MODIS and Landsat albedo products). They also provide the ability to assess the albedo of the terrain under a range of conditions, and after dramatic alteration of the Earth's surface (e.g. changes in seasonal snowpack).

Specifically this project will:

1) Develop and test paired pyranometers mounted to a UAV.
2) Quantify scale-dependent controls on snow albedo using a UAV.

Looking forward, these methods and protocols are a logical step forward in utilizing UAV measurements as *in situ* data for validating EO. These advances will positively impact the EO community by helping address the scaling challenges associated with calibrating satellite data (specifically MODIS and Landsat), and the snow science community by developing novel techniques that measure snow processes across landscapes at relatively low costs.

Additionally the PI, Sproles, will recruit undergraduate students at Montana State University to participate in the field collection, post-processing, and analysis of data.

Description of key project steps and timeline

Component 1 - Develop and test a UAV mount for pyranometers

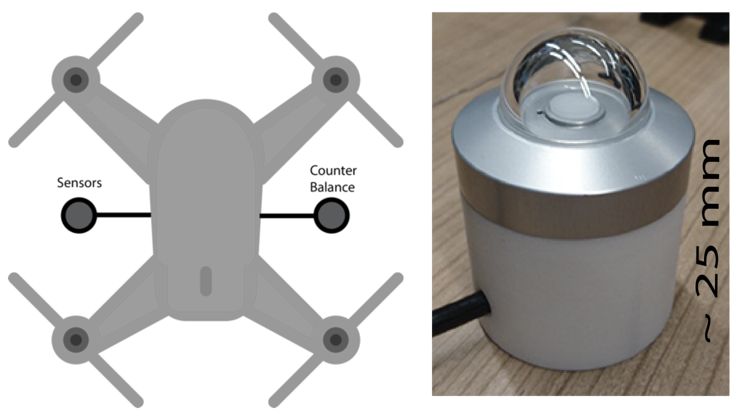

Figure 1: A schematic of how the prototype mount will be designed and implemented (left). The image on the right is the PR1 pyranometer (Kipp and Zonen).

Incoming and outgoing irradiance will be measured using Kipp & Zonen PR1 pyranometers mounted on the UAV, with one sensor upward facing and the other downward facing. The PR1 pyranometers are digital sensors that have a 180º field of view, a spectral range of 285 to 2000 nm, a mass of 145 g, and connect to a digital data logger. To balance the UAV payload two design approaches will be tested prior to field measurements. The first approach will use an extension on either side of the UAV, with one pyranometer attached to each extension. The second approach will mount both pyranometers to a single arm, and a second counterbalancing arm with mass equal to the sensors will extend from the opposite side (Figure 1). The digital data logger will be mounted on the bottom of the UAV.

The Department of Earth Sciences at Montana State University funding available for the purchase of a state-of-the-science UAV with Real Time Kinematics (RTK). RTK data allows the calibration of data resulting from varying measurement angles from the UAV. The selection of the UAV will be based upon consultation with industry experts to ensure that a robust platform is purchased for the project.

Prototyping will first be conducted using a "dummy payload", a simple mass equivalent mounted on the UAV. Initial design and creation of the arm extensions will be developed using a 3D-printer readily available in the Office of Technology and Outreach at Montana State University. If required, the final versions of the arm extensions will be made using carbon fiber printing off campus.

Once mounts have been designed and developed, the sensors will be deployed and tested over flat, unobstructed areas. These tests will provide practice flying the UAV with operational sensors, the ability to verify that the sensors are functioning properly, and experience post-processing the data. Practice flights will also provide realistic guidelines for the UAV's battery and energy needs when in the field, and identify the temporal resolution that irradiance measurements should be averaged and recorded (balancing the need for robust data and flight energy limitations).

Component 2- Deploy the UAV to quantify the scale-dependent controls on albedo in mountain snowpack

The broadband albedo will be measured from the upward- and downward-facing pyranometers that measure solar irradiance. The upward-facing sensor captures the incoming irradiance ($K\downarrow$), and the downward-facing sensor measures the reflected irradiance from the surface ($K\uparrow$). The ratio between incoming and reflected irradiance represents the physical albedo ($\propto$) of the snow surface [2] as measured by the pyranometer.

$$\propto = \frac{K\uparrow}{K\downarrow} \qquad \text{(eq. 1)}$$

The path of the UAV will be flown in a spiral-shaped pattern (Figure 2) designed to: 1) provide integrated measurements of albedo across the landscape; 2) provide representative coverage of an entire MODIS grid cell; 3) encompass a majority of the Landsat8 grid cells within the larger MODIS grid cell.

Flights will be conducted at a series of relative altitudes (e.g. 1m, 5m, 10m, and 25m) or as conditions allow. The combination of the spiral-shaped pattern at multiple altitudes provides up to four paths also support subsets of data by relative location (i.e. aspect or slope). For example, different slopes or regions with or without shade would provide a sub-set of the primary flight data set.

The scheduling date and time of flights will best correspond to geographically coincident flight paths of the MODIS and Landsat8 satellites, providing robust data for inter-instrument comparison [3]. Flight planning will also place a priority on days with clear skies in order to mitigate the influence of clouds and water vapor.

Flights will be conducted at least once during the accumulation and melt cycles. Every attempt will be made to conduct additional flights as logistics and weather allow. The priority for these additional flights will focus on ablation (melt).

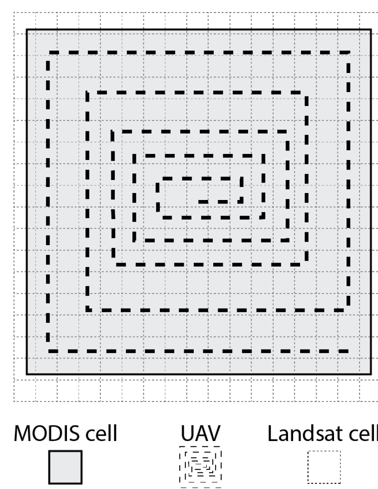

Figure 2: Conceptual drawing of the UAV flight plan with regards to a MODIS and Landsat cell.

Outreach

This project will provide undergraduate students at Montana State University the opportunity to gain hands-on experience in the developing the sensor mount, field-based science, and post-processing of remotely-sensed data. Undergraduates participating in STEM research have a higher comprehension of scientific concepts and higher levels of success in graduate school [5].

Sproles will also work with the Office of Technology and Outreach at Montana State University to promote the field-based activities including photos and a video highlighting the field work and results. Photos and the video will be published on Sproles' professional website, (soon to be) Instagram account, and will also be available for ESIP's use as they deem appropriate. Additionally, undergraduate students will be encouraged to write a blog post on Sproles' website that describes their experiences.

This results of this project will be disseminated at the ESIP summer meeting (2019), specifically the Drone Cluster. The project and its results will also be presented at domain specific meetings like the Western Snow Conference and the American Geophysical Union as funding allows. Additionally the results and suggestions from this project will be published on Sproles' website.

Assessment of this project's impact will include the considerable emphasis on the outreach and dissemination of this project, and a post-project evaluation by all participating undergraduate students.

The most important metric of this incubator project will be reflected in the success of subsequent proposals. This project will serve as a testbed for a proposal to NASA's Terrestrial Hydrology Program that will continue collaborative efforts between Montana State University and NASA Goddard (Co-I). The subsequent proposal will expand upon the objectives of this study to quantify the scale-dependent controls on snow albedo in montane regions in comparison to MODIS and Landsat albedo products. Additionally subsequent efforts with the Office of Technology and Outreach will co-develop curriculum for class lessons focused on albedo research.

Project Partners

Dr. Eric Sproles (PI), is an Assistant Professor of Earth Sciences at Montana State University and a faculty member of the university's Snow and Avalanche Lab. Sproles will maintain project oversight, mentor students, track progress, coordinate field work and data management, manage the budget, write reports, make professional and public presentations, and generally keep the project moving forward.

Timeline

Task	**Month**					
	1	2	3	4	5	6
Purchase the sensors	■					
Develop the mounts for the sensors	■					
Test the UAV with sensors		■	■			
UAV flights and field work			■	■		
Post-processing of data			■	■		
Analysis and reporting of results				■	■	■
Final reporting of results and assessment					■	■

Charles Gatebe (Co-I) serves as the Principal Investigator of the Cloud Absorption Radiometer at NASA Goddard. Gatebe also serves as one of the Organizing Leads on SnowEx, a multi-year airborne campaign with the goal of better quantifying the amount of water stored in the Earth's snowpack. Gatebe will provide scientific assistance regarding scaling issues of UAV measurements, the analysis of the albedo data, and disseminating the research.

Suzi Taylor's (Co-I) area of expertise is Outreach and Communications, and serves as the Assistant Director of Academic Technology and Outreach at Montana State University. Taylor will provide her expertise in the conceptualization, promotion, and dissemination of outreach materials.

This project will work directly with members of the ESIP community at the 2019 summer meeting, specifically the Drone cluster. Additionally, Sproles is a member of the NSIDC DAAC's User Working Group and has introduced the idea that UAV data will become an increasingly relevant data resource for the snow and ice research communities. The NSDIC DAAC leadership has stated their interest in providing guidance on data standards and management of UAV data.

Citations

1. Levy, C.; Burakowski, E.; Richardson, A. Novel Measurements of Fine-Scale Albedo: Using a Commercial Quadcopter to Measure Radiation Fluxes. *Remote Sens.* **2018**, *10*, 1303.
2. DeWalle, D. R.; Rango, A. *Principles of snow hydrology*; Cambridge University Press: Cambridge, UK, 2008; ISBN 0521823625.
3. Kharbouche, S.; Muller, J.-P.; Gatebe, C. K.; Scanlon, T.; Banks, A. C. Assessment of Satellite-Derived Surface Reflectances by NASA's CAR Airborne Radiometer over Railroad Valley Playa. *Remote Sens.* **2017**, *9*, doi:10.3390/rs9060562.
4. Gleason, K. E.; Nolin, A. W.; Roth, T. R. Charred forests increase snowmelt: Effects of burned woody debris and incoming solar radiation on snow ablation. *Geophys. Res. Lett.* **2013**, n/a-n/a, doi:10.1002/grl.50896.
5. Gilmore, J.; Vieyra, M.; Timmerman, B.; Feldon, D.; Maher, M. The relationship between undergraduate research participation and subsequent research performance of early career STEM graduate students. *J. Higher Educ.* **2015**, *86*, 834–863.