Boreal Wetland Mapping by UAV to Upscale Greenhouse Gas Emissions

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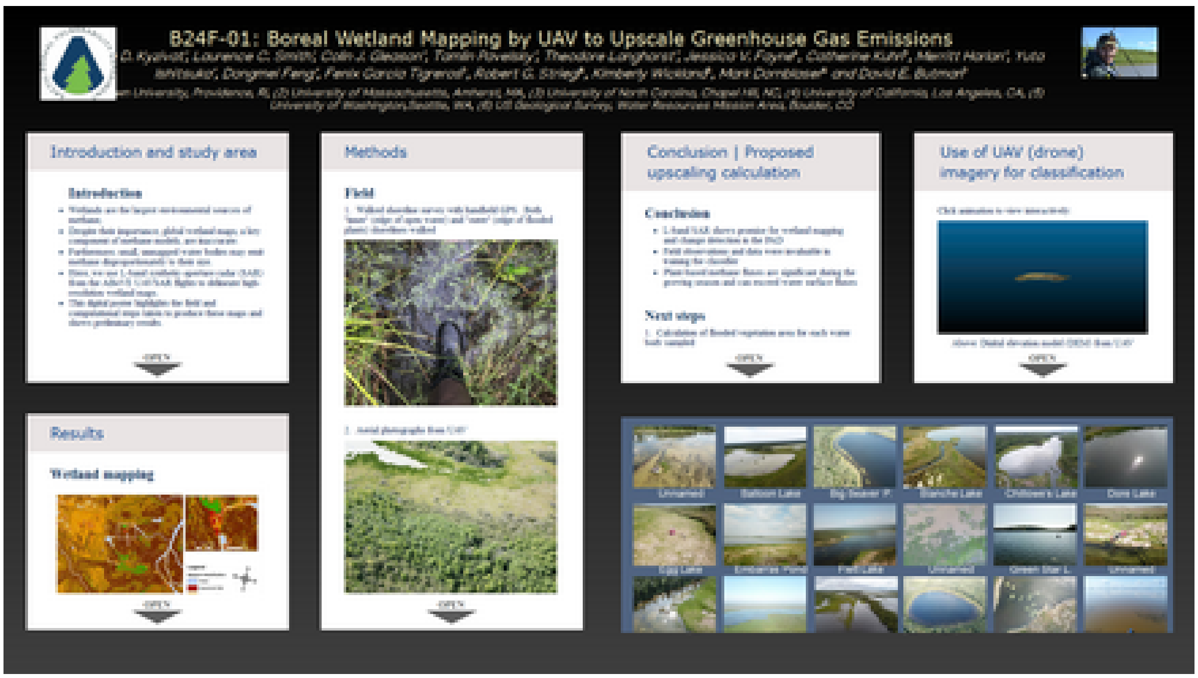
November 24, 2022

Abstract

Wetlands are the largest environmental sources of methane, and interannual changes in wetland methane fluxes explain most of the variability in the global flux. Despite their importance, global wetland maps, a key component of methane models, are inaccurate for at least three reasons: (1) Their temporal variability is poorly suited for static maps; (2) Optical remote sensing cannot penetrate foliage, making water hard to identify; and (3) satellites cannot resolve their fine-scale features. Furthermore, small, unmapped water bodies may emit methane disproportionately to their size due their shallow depths inhibiting bacterial oxidation from the water column and their large perimeter: volume ratios, which introduce the potential for organic matter input and plant-mediated fluxes from shorelines. However, in boreal regions, there is conflicting evidence on the effects of water body size on methane and carbon dioxide fluxes. Here, we measure methane emissions in lakes and wetlands in an Arctic-Boreal delta and compare to open water and vegetated area with the goal of improving methane emission estimates in this region. We expect small, shallow, and vegetated wetlands to produce more methane than those bordering deeper lakes. To test this hypothesis, we map wetlands in the Peace-Athabasca Delta, a 5,000 km2 inland delta in northern Alberta, Canada containing abundant open and vegetated wetlands. We use airborne remote sensing from three sources: (1) High-resolution (<5 cm pixel) unmanned aerial vehicle (UAV) imagery, (2) Coincident L-band synthetic aperture radar (SAR) from NASA's UAVSAR airborne imaging system, and (3) 2017 AirSWOT Ka-band interferometric SAR with color-infrared imagery. With a wavelength of 23.8 cm, UAVSAR L-band returns are ideal for mapping vegetated wetlands due to double-bounce backscatter between vegetation and the water surface. Combining two field campaigns of flux chamber gas sampling from over twenty lakes, walked shoreline surveys, and over 70 thousand UAV photos, we present a collection of wetland maps and a methodology for efficiently mapping them from UAV. We then upscale methane and carbon dioxide emissions to the scale of the delta and compare to existing estimates. These results will help improve greenhouse gas emission estimates for boreal zone wetlands.

B24F-01: Boreal Wetland Mapping by UAV to Upscale Greenhouse Gas Emissions



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Washington,Seattle, WA, (6) US Geological Survey, Water Resources Mission Area, Boulder, CO

PRESENTED AT:

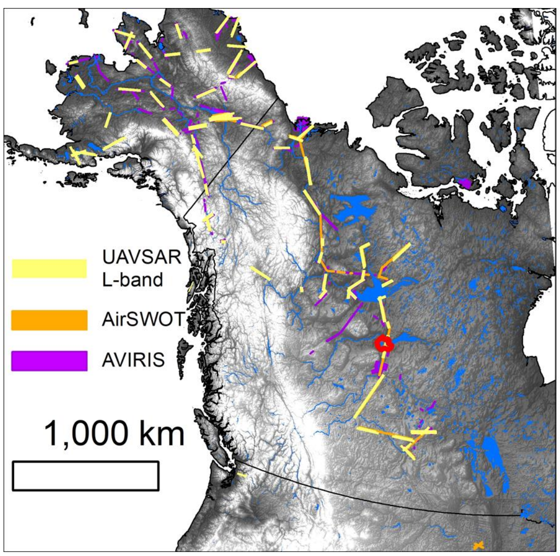
AGU 100 ADVANCING EARTH AND SPACE SCIENCE | FALL MEETING Washington, D.C. | 10–14 Dec 2018

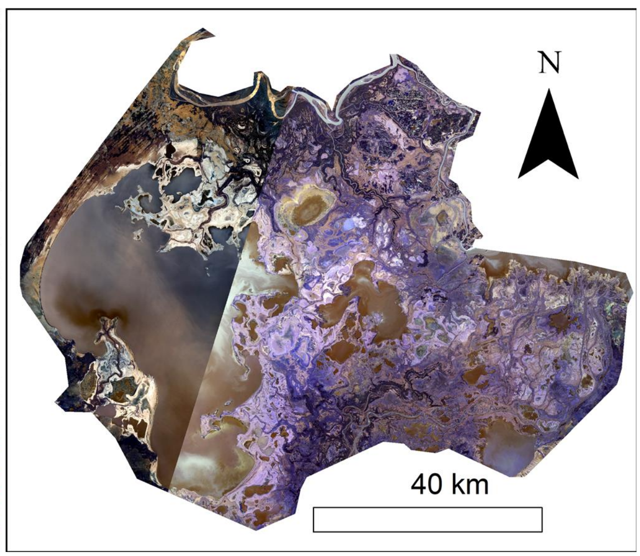
INTRODUCTION AND STUDY AREA

Introduction

- Wetlands are the largest environmental sources of methane,
- Despite their importance, global wetland maps, a key component of methane models, are inaccurate.
- Furthermore, small, unmapped water bodies may emit methane disproportionately to their size.
- Here, we use L-band synthetic-aperture radar (SAR) from the ABoVE UAVSAR flights to delineate high-resolution wetland maps.
- This digital poster highlights the field and computational steps taken to produce these maps and shows preliminary results.

Study Area



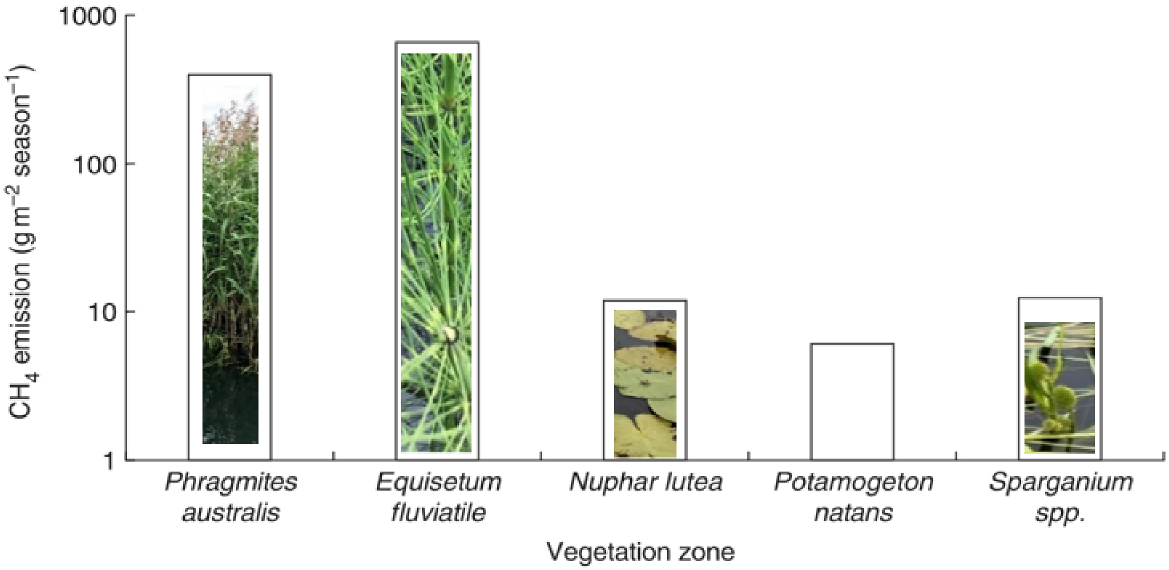


- We visited the Peace-Athabasca Delta (PAD) in ~August 2018 and 2019 to collect samples and ground validation.
- The ~6,000 km^2 delta contains 2,500 km^2 of permanent and 1,500 km^2 of temporary water bodies.
- Comprising Wood Buffalo National Park, it is recognized as a UNESCO World Heritage Site and Ramsar Convention Wetland.

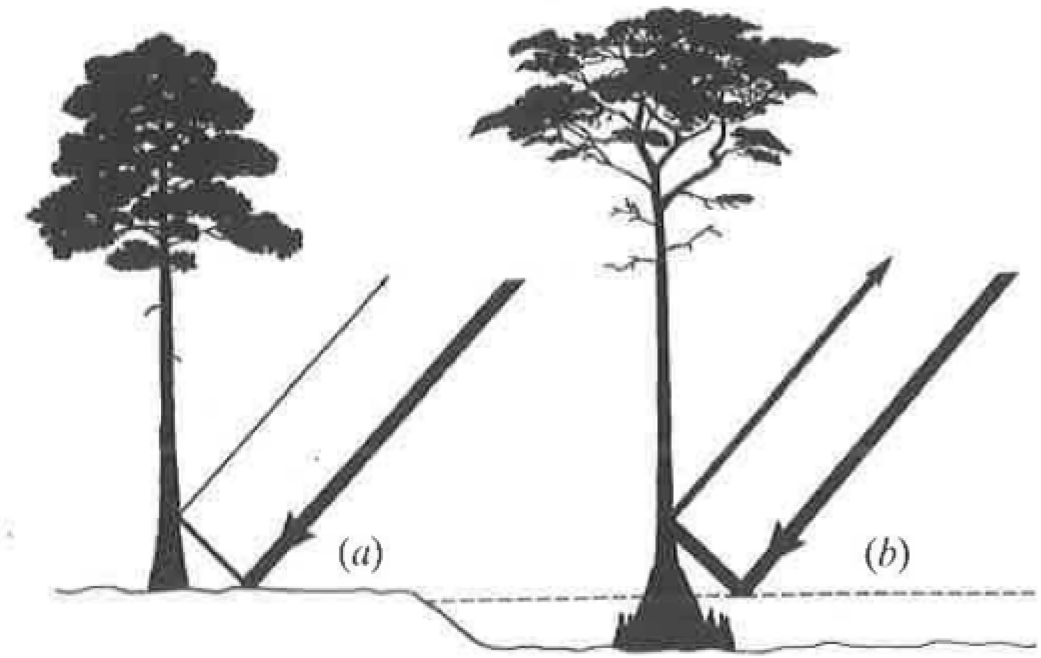
Rationale

- Small (<0.01 ha) lakes and wetlands are poorly-mapped globally, and in the Arctic.
- Gas transfer in wetland plants is a well-developed field of research.
- Airborne remote sensing can be a useful tool for upscaling open water and plant-based greenhouse gas (GHG) fluxes for regional estimates and model comparison.
- Specifically, L-band synthetic-aperture radar (SAR) offers the potential to distinguish between upland and flooded vegetation of various types.

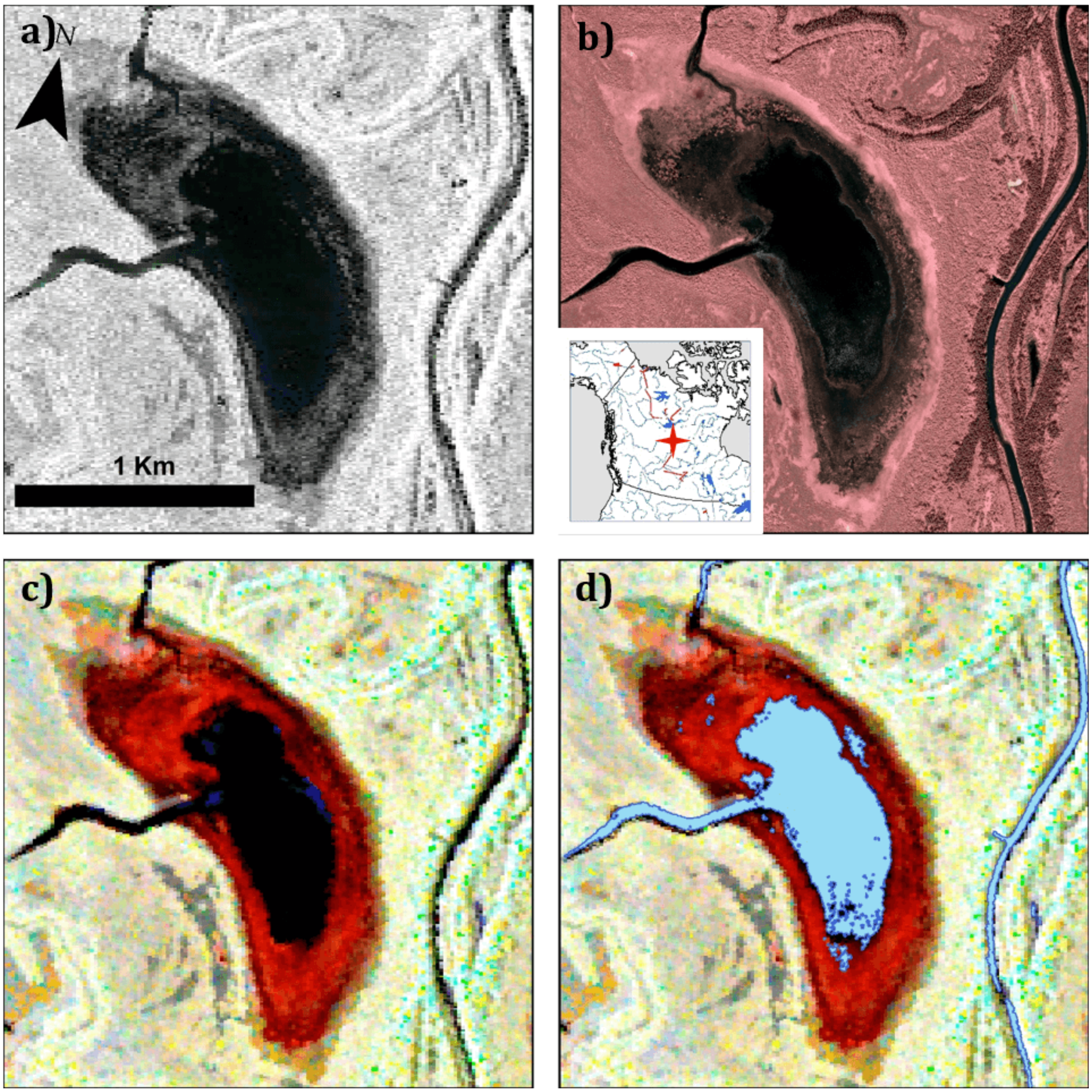
Measured fluxes of typical wetland plants



Double-bounce SAR returns from flooded trees



PAD wetlands as seen by three different sensors



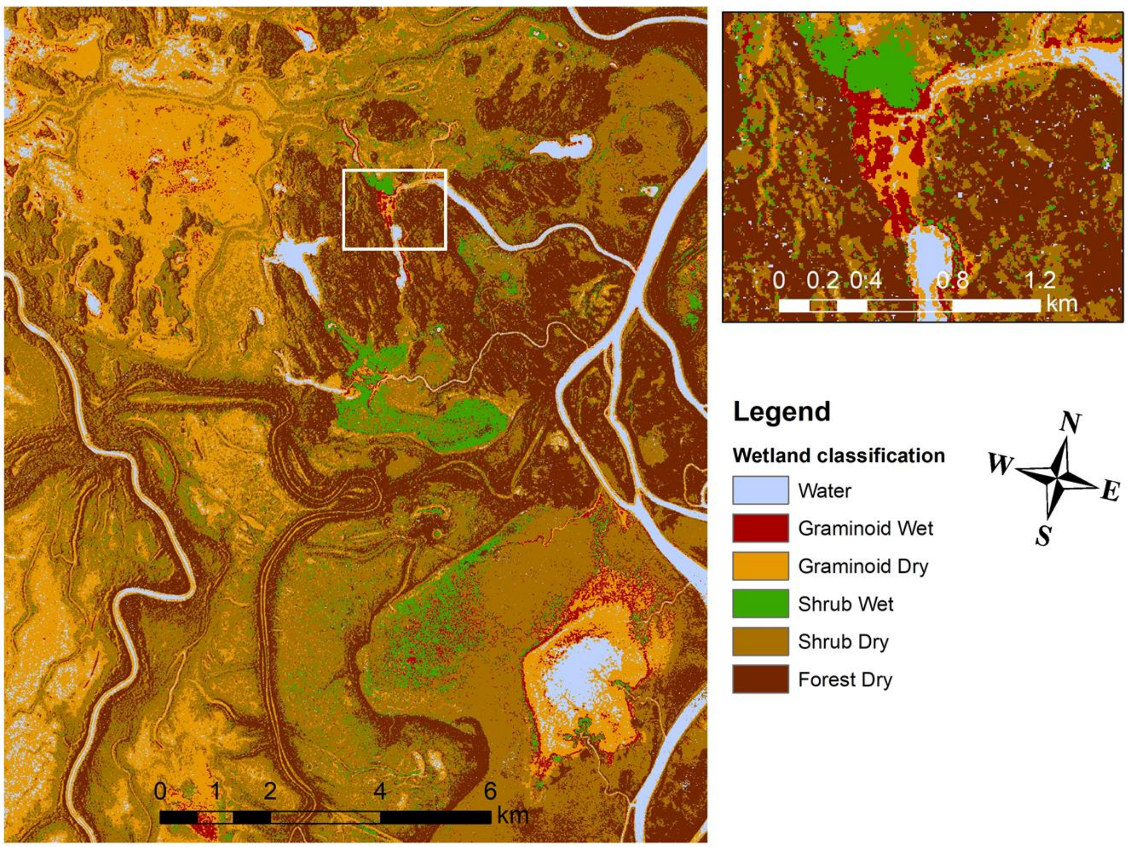
a)
N
1 Km
b)
c)
d)

Above: Wetlands and a river-connected lake in the PAD. (a) UAVSAR L-band backscatter in HH polarization, (b) AirSWOT color-infrared (CIR) imagery in false color, (c) L-band polarimetric returns are shown in a Freeman-Durden decomposition [78], and (d) same, with CIR open water classification superimposed.

Source: Kyzivat et al. 2019, *Remote Sensing*

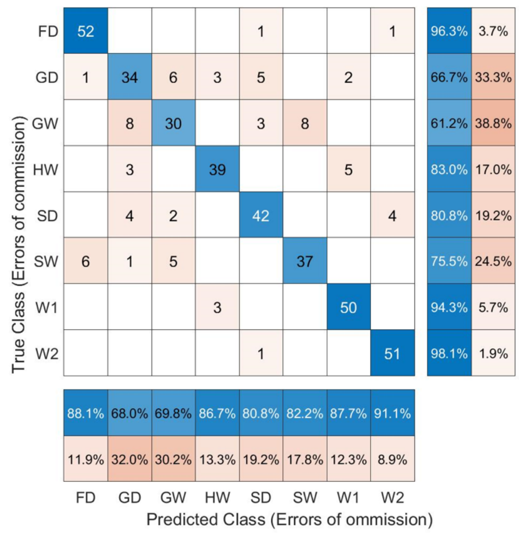
RESULTS

Wetland mapping



Above: Example map output

Code	Class name
W1	Open water I (dark)
W2	Open water II (less dark)
BG	Bare, bedrock, mud (>=60%)
HW	Wet (emergent) herbaceous (water lilies)
GW	Wet (emergent) graminoid (marsh/meadow)
GD	Dry graminoid (marsh/meadow)
SW	Wet (emergent) savannah (thicket/shrub) 1-5m
SD	Dry savannah (thicket/shrub) 1-5m
FW	Wet (emergent) forest >5m
FD	Dry forest >5m

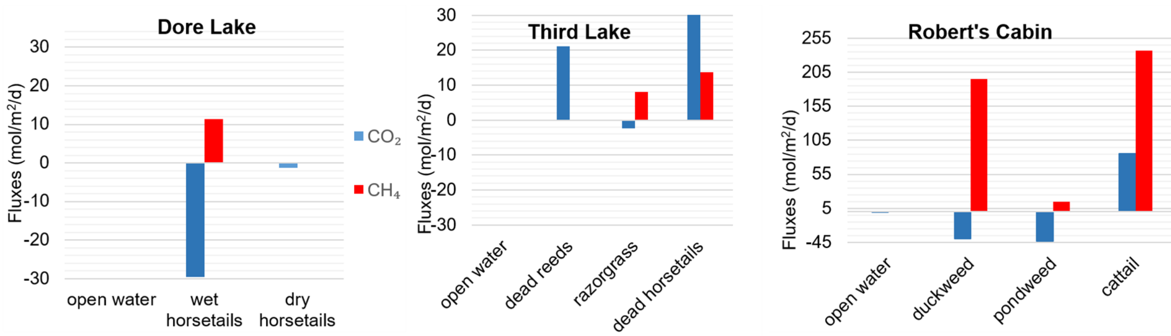


Above: Confusion matrix

- Classification accuracy improves from k=0.69 to k=0.73 when kernal filters are included, as opposed to using scattering products alone

- The most difficult classes to distinguish are dry vs. wet graminoids (grasses, sedges, rushes)
- Water lillies and slightly protruding pondweed are virtually-indistinguishable from open water
- C-band may be better-suited for these classes

Greenhouse gas fluxes from lakes and wetlands



Fluxes from three lakes (open water values are ~0)

- Methane emissions are significantly higher over littoral vegetation than open water.
- Carbon dioxide fluxes to the atmosphere are negative over living vegetation, as expected.
- Open water fluxes are negligible for the lakes shown, but

METHODS

Field

1. Walked shoreline survey with handheld GPS. Both "inner" (edge of open water) and "outer" (edge of flooded plants) shorelines walked

2. Aerial photographs from UAV

3. Geolocated photographs

4. Greenhouse gas sampling from boats, in addition to chemistry suite

Computer

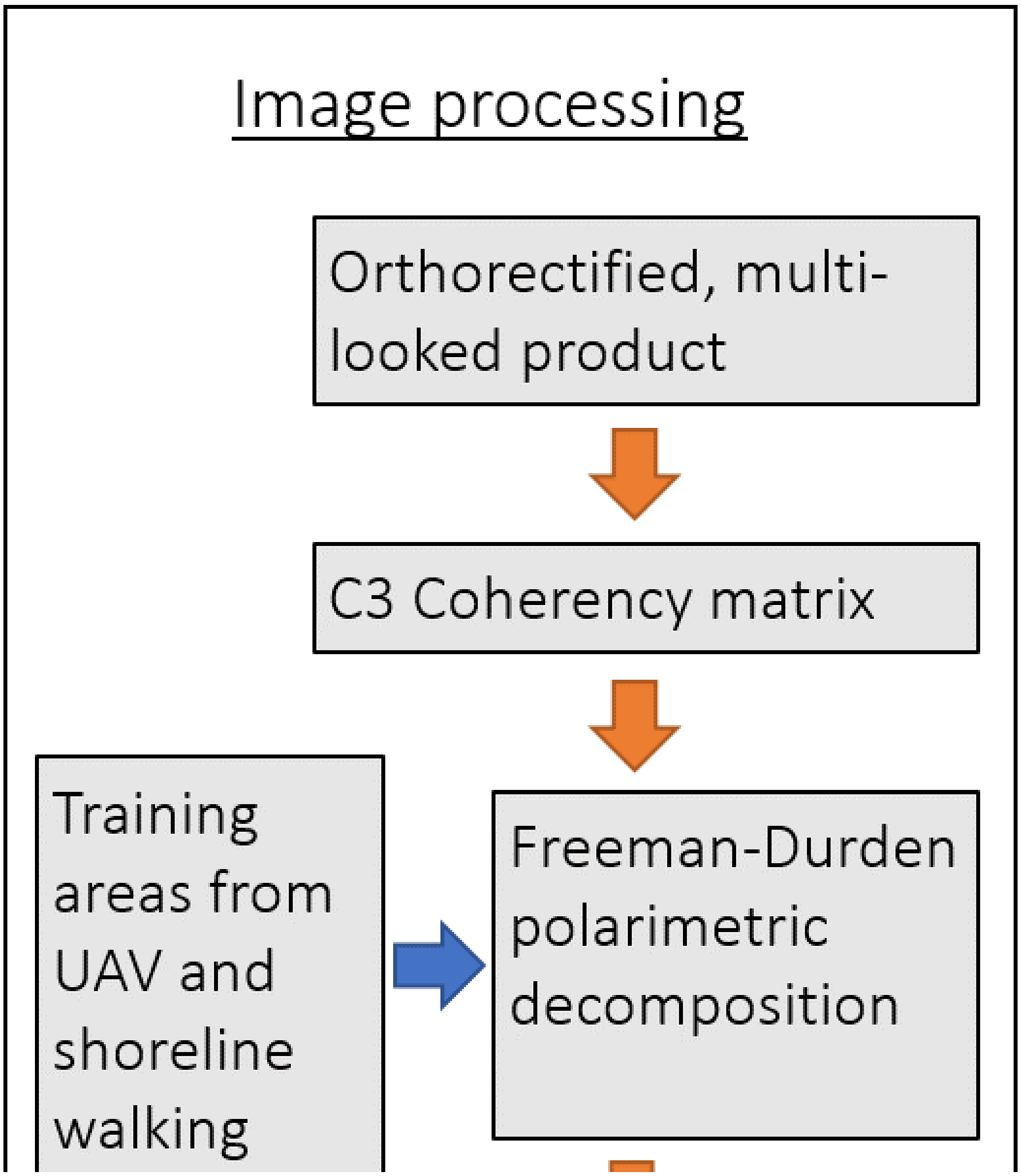
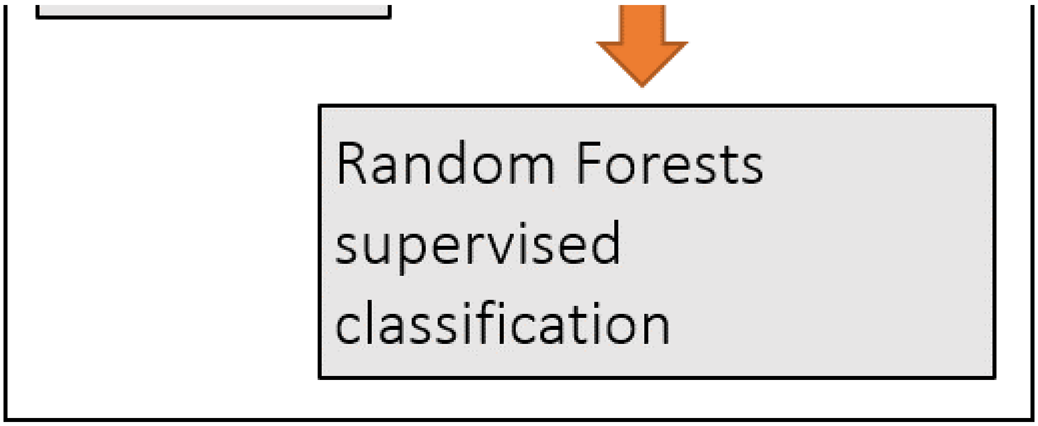
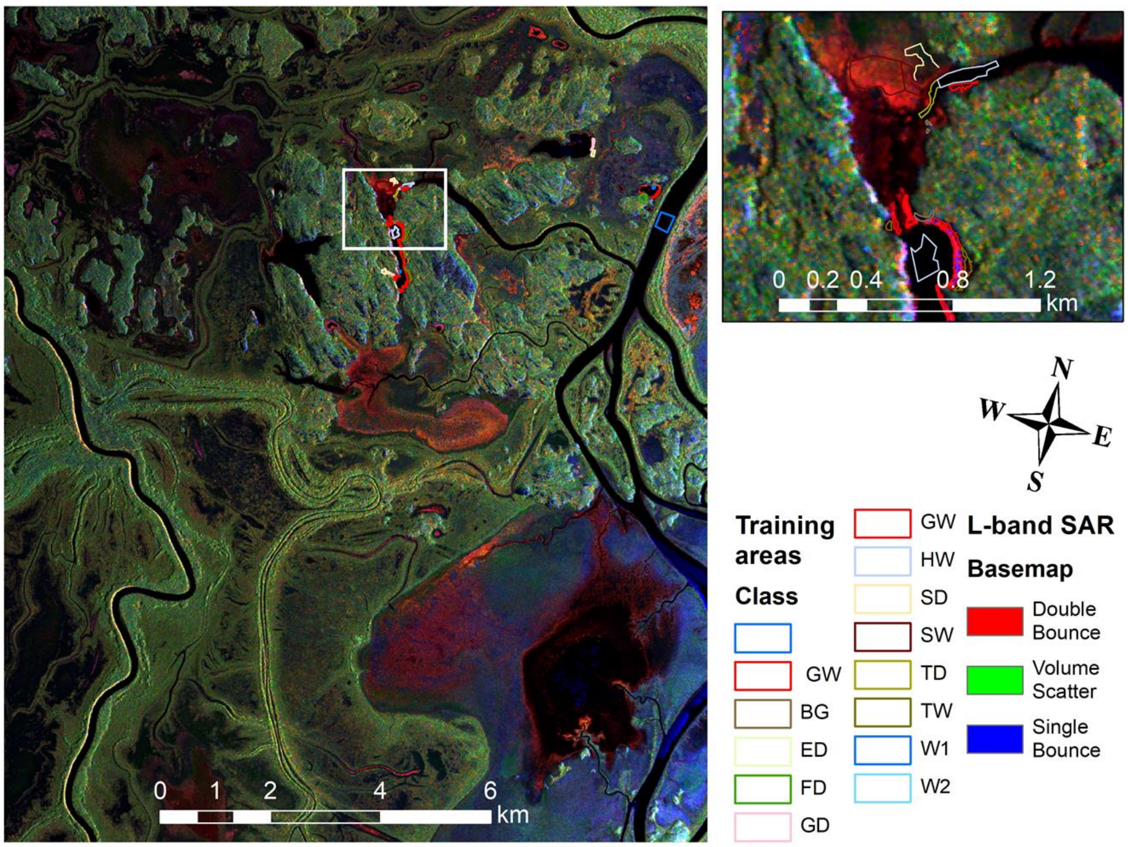


Image processing
Orthorectified, multi-looked product
C3 Coherency matrix
Training areas from UAV and shoreline walking
Freeman-Durden polarimetric decomposition



1. Orthomosaicking of UAV images from dronedeploy.com

2. Digitization of training areas based on ground/UAV photos, walked shorelines, imagery, hydrographs



3. Process UAVSAR L-band imagery in PolSAR Pro v6.0 to obtain Freeman-Durden decomposition to model scattering mechanism

4. Train Random Forests classifier in Matlab 9.6. For each decomposition class, create ~10 derivative images using various kernal filters to use as Random Forest features

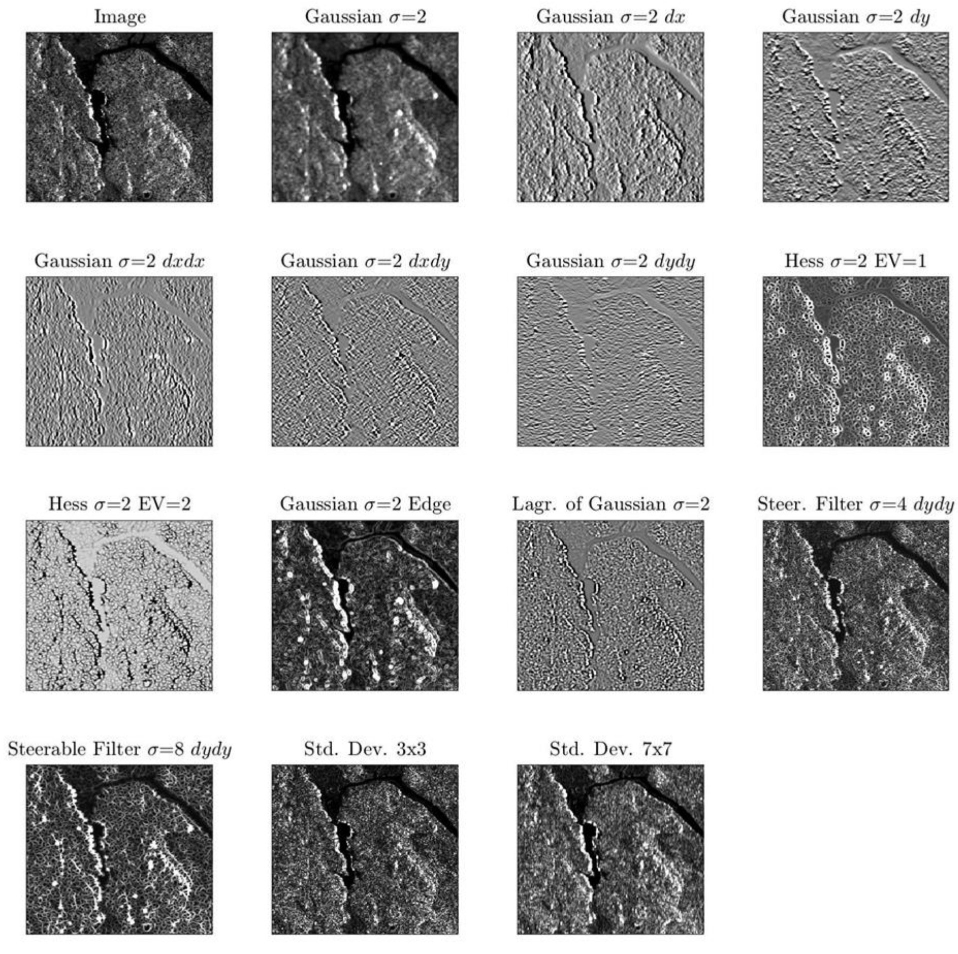
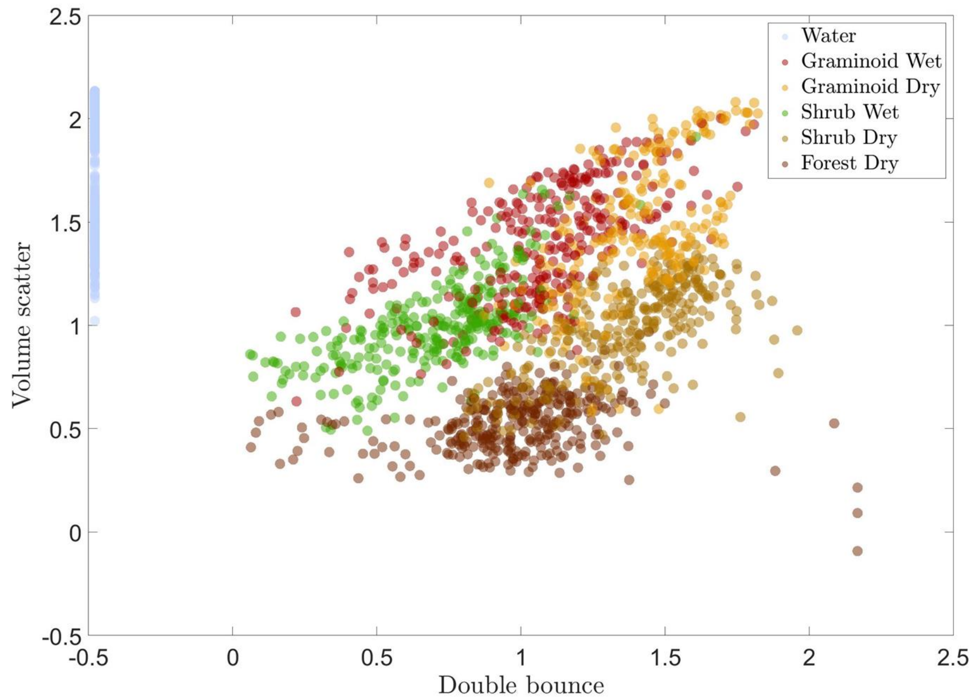


Image
Gaussian σ=2
Gaussian σ=2 dx
Gaussian σ=2 dy
Gaussian σ=2 $dxdx$
Gaussian σ=2 $dxdy$
Gaussian σ=2 $dydy$
Hess σ=2 EV=1
Hess σ=2 EV=2
Gaussian σ=2 Edge
Lagr. of Gaussian σ=2
Steer. Filter σ=4 $dydy$
Steerable Filter σ=8 $dydy$
Std. Dev. 3x3
Std. Dev. 7x7

- Here is an example of how the training classes can be plotted, based on the scattering-based decomposition features



5. Generate wetland map showing open water and dry/flooded graminoid and shrub classes.

6. Next steps: greenhouse gas flux upscaling and comparison to models

CONCLUSION | PROPOSED UPSCALING CALCULATION

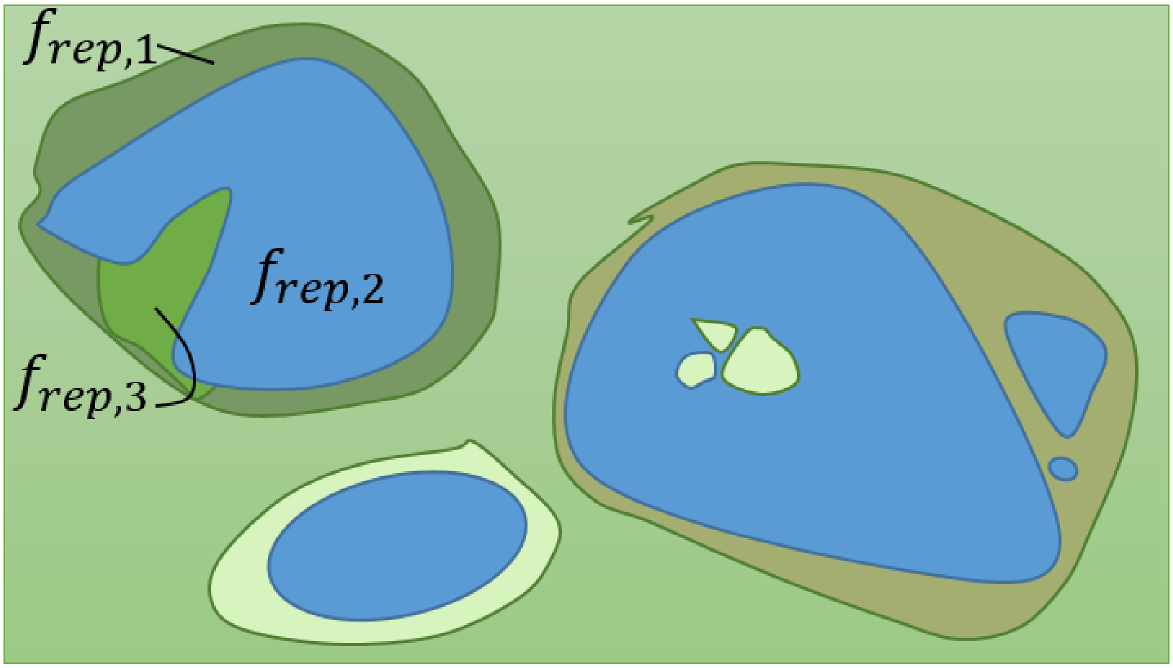
Conclusion

- L-band SAR shows promise for wetland mapping and change detection in the PAD
- Field observations and data were invaluable in training the classifier
- Plant-based methane fluxes are significant during the growing season and can exceed water surface fluxes

Next steps

1. Calculation of flooded vegetation area for each water body sampled

2. Upscaling calculation based on vegetation class



Above: Illustration of proposed upscaling

$$\sum_{i=pixel} f_{rep}(Area_{total}, Type_{plant}, Temp., \ldots) * \frac{Area_i}{Area_{total}}$$

3. Repeat over other ABoVE areas with L-band coverage (Please send me any geolocated field photos you can share!)

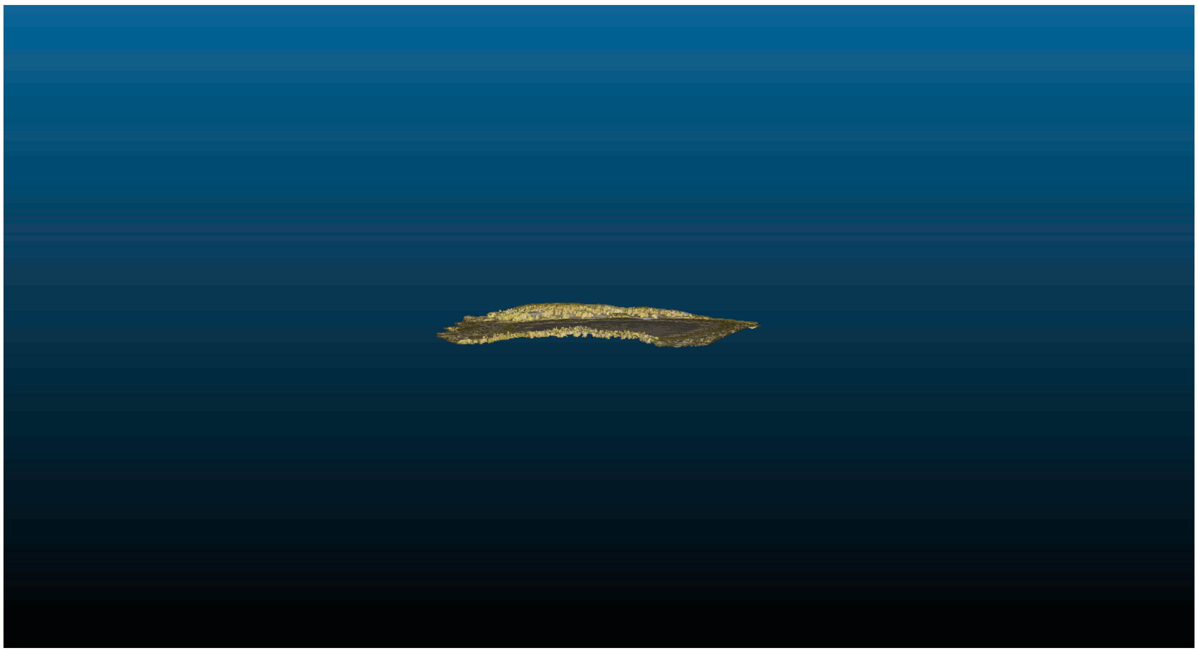
4. Comparison with models, flux towers and airborne GHG observations

Acknowledgements:

We would like to thank Wood Buffalo National Park and Robert Grandjambe in Ft. Chipewyan, AB for providing access to field sites. UAVSAR data courtesy NASA/JPL-Caltech. Resources supporting this work were provided by the NASA High-End Computing (HEC) Program through the NASA Center for Climate Simulation (NCCS) at Goddard Space Flight Center. This work was funded by the NASA Terrestrial Ecology Program Arctic-Boreal Vulnerability Experiment (ABoVE), grant numbers NNX17AC60A and 80NSSC19M0104, managed by Hank Margolis; and the NASA Surface Water and Ocean Topography mission, grant number NNX16AH83G, managed by Eric Lindstrom. E.D.K. also received Graduate Fellowships from the American Meteorological Society, and the Rhode Island Space Grant Consortium.

USE OF UAV (DRONE) IMAGERY FOR CLASSIFICATION

Click animation to view interactively:



(https://sketchfab.com/3d-models/rochers-pond-1101fc4570ef46929ee9c482749800bd)

Above: Digital elevation model (DEM) from UAV imagery

- From over 100,000 UAV photos collected during the field campaigns, we use a subset over key areas to manually interpret the landcover type.
- Vidoes and off-nadir photos proved to be the most useful for vegetation type identification
- The digital elevation models (DEMs) and point clouds produced during orthomosaicking have the potential to be used for automated vegetation height detection.
- Even at 2-10 cm resolution, manually detecting water between gaps in leaves or stalks proved difficult, and ground-based observation is still the most effective method for determing inundation extent.

[VIDEO] https://www.youtube.com/embed/_NpiAV6v724?feature=oembed&fs=1&modestbranding=1&rel=0&showinfo=0
Above: sampling gases and chemistry from an inflatable boat

Above: flying over a logjam in a delta lake inlet

Sorry but time is up!

CV

Ethan D. Kyzivat

Curriculum Vitae

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Studying arctic hydrological environments using remote sensing.

Education

Ph.D. Brown University Department of Earth, Environmental & (exp. Aug 2022)

Planetary Sciences

Institute at Brown for Environment & Society

Adviser: Laurence C. Smith

M.S. Brown University Department of Earth, Environmental & (May 2019)

Planetary Sciences

B.S. Yale University Physics major, with distinction (2015)

Energy Studies Program, Yale Climate & Energy Institute

Louis Sudler Prize in the Performing and Creative Arts, nominee

Research experience

Graduate student researcher, Brown dept. of Earth Science (2017-present)

NASA Jet Propulsion Laboratory, January 2019

Workshops attended

Introduction to GIPSY-X (2019)

GPS processing software led by Dr. Willly Bertiger, Pasadena, CA

8th Annual Spatial Statistical Modeling of Stream Networks Workshop, Boise, ID (2019)

USFS/NOAA Instructors: Dr. Erin Peterson, Dr. Jay Ver Hoef, Dr. Dan Isaak

Geo-Computation and Environmental Analysis Workshop (2016)

Yale Center for Research Computing, Instructor: Dr. Giuseppe Amatulli

One-week introduction to Bash, GDAL, Python, R, Grass, QGIS, OS-GEO

Service and outreach

University:

Graduate Council, Brown Graduate School (2019-present)

Speaker and 3D map contributor: Anthropocene exhibit, Brown Science Center (2018-2019)

Graduate Library Advisory Committee, Brown University (2017-present)

Vartan-Gregorian Elementary School geoscience teaching and lesson planning (2017-present)

Science Olympiads, design remote sensing exam for high school competition (2017-present)

SPLASH at Yale: gave lectures to high school students on data science and on jazz (2015)

Seed to Salad: taught classes on sustainability at Yale farm for third-grade students (2014)

Professional Community:

Expert review for IPCC Special Report on the Ocean and Cryosphere in a Changing Climate (2018)

Local Community:

Board member, Jazz Haven (2015-2017)

Board member, Yale Undergraduate Jazz Collective (2011-2013)

Affiliations

American Meteorological Society, student member (2017-present)

American Geophysical Union, student member (2018-present)

Professional Certifications

Wilderness First Responder (SOLO) (2018-2021)

Remote Pilot (FAA) (2018-2020)

ABSTRACT

Wetlands are the largest environmental sources of methane, and interannual changes in wetland methane fluxes explain most of the variability in the global flux. Despite their importance, global wetland maps, a key component of methane models, are inaccurate for at least three reasons: (1) Their temporal variability is poorly suited for static maps: (2) Optical remote sensing cannot penetrate foliage, making water hard to identify: and (3) satellites cannot resolve their fine-scale features. Furthermore, small, unmapped water bodies may emit methane disproportionately to their size due their shallow depths inhibiting bacterial oxidation from the water column and their large perimeter: volume ratios, which introduce the potential for organic matter input and plant-mediated fluxes from shorelines. However, in boreal regions, there is conflicting evidence on the effects of water body size on methane and carbon dioxide fluxes. Here, we measure methane emissions in lakes and wetlands in an Arctic-Boreal delta and compare to open water and vegetated area with the goal of improving methane emission estimates in this region.

We expect small, shallow, and vegetated wetlands to produce more methane than those bordering deeper lakes. To test this hypothesis, we map wetlands in the Peace-Athabasca Delta, a 5,000 km2 inland delta in northern Alberta, Canada containing abundant open and vegetated wetlands. We use airborne remote sensing from three sources: (1) High-resolution (<5 cm pixel) unmanned aerial vehicle (UAV) imagery, (2) Coincident L-band synthetic aperture radar (SAR) from NASA's UAVSAR airborne imaging system, and (3) 2017 AirSWOT Ka-band interferometric SAR with color-infrared imagery. With a wavelength of 23.8 cm, UAVSAR L-band returns are ideal for mapping vegetated wetlands due to double-bounce backscatter between vegetation and the water surface. Combining two field campaigns of flux chamber gas sampling from over twenty lakes, walked shoreline surveys, and over 70 thousand UAV photos, we present a collection of wetland maps and a methodology for efficiently mapping them from UAV. We then upscale methane and carbon dioxide emissions to the scale of the delta and compare to existing estimates. These results will help improve greenhouse gas emission estimates for boreal zone wetlands.

REFERENCES

References:

Hess, L. L., John M. Melack, and D. S. Simonett. 1990. “Radar Detection of Flooding beneath the Canopy a Review.” International Journal of Remote Sensing 11(7):1313–25.

Ethan D. Kyzivat, Laurence C. Smith, Lincoln H Pitcher, Jessica V. Fayne, Sarah W. Cooley, Matthew G. Cooper, Simon N. Topp, Theodore Langhorst, Merritt E. Harlan, Christopher Horvat, Colin J. Gleason, and Tamlin M. Pavelsky. 2019. “A High-Resolution Airborne Color-Infrared Camera Water Mask for the NASA ABoVE Campaign.” Remote Sensing 11. doi.org/10.3390/rs11182163 (http://doi.org/10.3390/rs11182163)

Laanbroek, Hendrikus J. 2009. “Methane Emission from Natural Wetlands: Interplay between Emergent Macrophytes and Soil Microbial Processes. A Mini-Review.” doi.org/10.1093/aob/mcp201 (http://doi.org/10.1093/aob/mcp201)

Code references:

Github and Matlab file exchange: PixelClassifier (https://github.com/HMS-IDAC/PixelClassifier)and ENVI file reader/writer (https://www.mathworks.com/matlabcentral/fileexchange/27172-envi-file-reader-writer)

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SWITCH TEMPLATE