Predicting Arctic Methane Seeps via Satellite Imagery

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1 Introduction

The arctic has seen significant warming and releases of greenhouse gases in the past few decades. Methane is 28 times more potent as a greenhouse gas than CO_2; it is seeping from the permafrost region through diffuse bio-decomposition of previously frozen material, and leaking from concentrated geological deposits. Arctic geological methane deposits are estimated to include 240 times the methane currently in the atmosphere [1]. To date, researchers have been unable to quantify the aggregate leakage rate from these deposits into the atmosphere and predict how it might change with increasing temperatures. We aim to apply machine learning methods to study the extent of this climate hazard and inform the deployment of mitigation strategies. By combining a computer vision-assisted analysis of satellite data with targeted field measurements, we seek to (1) determine the number of concentrated methane seeps, (2) estimate their flow rates, and (3) understand how they change with increasing temperatures.

Identifying methane seeps via direct imaging of the CH_4 absorption spectra is challenging. However, visual, thermal and Synthetic Aperture Radar (SAR) proxy signals demarcate several reported categories of concentrated methane release sources, such arctic lakes, seabed clathrate releases, and methane hills. Faster permafrost thaw beneath arctic lakes causes anomalous freezing patterns that can be seen from satellites, creating a signal that is readily detected with computer vision techniques [2].

2 Remote Methane Detection

Methane is an odourless, colorless gas that has a narrow absorption spectra in in the mid-infrared range, making it non-trivial to detect with standard remote sensing instruments. A small amount of ground truth data from these methane releases has been collected in field by geologists. In addition, NASA's ABOVE initiative collects data from methane sensors mounted on an airplane in sub regions of Alaska. While it is possible to use modified airplane flyovers to map larger areas, the permafrost represents 9% of Earth's surface, and seeps are unevenly distributed within that region, making a localized-sensing approach or manual field measurements prohibitive from both a cost and emissions perspective. There are two satellites in orbit equipped with the specialized instruments to detect methane directly: Sentinel-5P has instrumentation with great sensitivity, but with a resolution on the order of several kilometers; GHGSat's Claire conversely has a 50-meter resolution but its sensitivity is above the threshold typical for flow rates in the permafrost. The seeps of interest are therefore undetectable by existing space-based remote sensing solutions.

Without the ability to directly detect these permafrost methane seeps locally or remotely, we focus on indirect detection methods. Specifically, we seek to identify methane released underneath arctic lakes, where sufficient flow rates lead to abnormal freezing patterns in the winter. This phenomenon yields a distinct visual, thermal and SAR signature. The broader spectrum of this indirect signal allows detection via imaging from existing low-earth orbit satellite swarms.

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3 Methods

Due to the limited number of known locations of methane-seeping lakes, we propose a semi-supervised anomaly detection approach. We propose to:

1. Acquire satellite data with that meet the necessary resolution and quality requirements:
    (a) Spatial resolution: anomalous features may be only a few meters across in the winter
    (b) Temporal resolution: to detect seeps, we need a small number of clear summer and winter images. To determine flow rates, we need to capture a high frequency of images during freeze and thaw season.
    (c) Quality control: regions of interest must be relatively cloud free with minimal shadows and artifacts.
2. Identify bodies of water using classical remote sensing techniques, such as NDWI threshold, pixel-wise cross entropy and random forests, and appropriate filtering. Sentinel-2 data is suitable for this task due to its relatively high spatial resolution (most bands of interest are 10m), a reasonable temporal resolution (constellation revisit time is 5 days), and a robust QA-band for cloud masking. In our experiments, simple techniques performed well in summer months, but occasionally misclassified ice as water. Combining NDWI and a pixel-wise max entropy classifier improved performance, although we still noticed noise in the classification process, suggesting that additional human verification may be required.
3. Separate saline bodies, lakes, glaciers and rivers, as those all have different freezing patterns. For the Alaska region, we have found the vector lake dataset [3] to be suitable for imaging data from 2018-19. The dataset includes 294,273 manually verified lake contours that have been identified from digital elevation mapping, normalization for shadows via through various sensors, and cleaning using edge detection. This dataset could be use to train a classifier which minimizes manual intervention for the rest of the arctic region.
4. Compile a time-series of freezing-state cloudless images from the arctic fall and spring for target lakes from Planet Labs RGB & NIR satellite imagery.
5. Find "unusual freezing in lakes" using a clustering approach. Due to a lack of true positives, we must rely on proxy features to cluster lakes in a given latitude band and identify outliers for manual review. We consider an intermediate feature representation of a convolutional neural network trained to predict arctic lake degradation to produce time-series embeddings for each lake, and employ hierarchical clustering followed by manual re-clustering.
6. Estimate flow rates through features such as sizes and changes in the unfrozen region of the lake over time, lake depth, temperatures, precipitation, etc.
7. Separate concentrated methane releases from other similar freeze disturbers such as hot springs through thermal imaging.
8. Finally, track the methane from these releases over years and correlate with arctic temperatures.

Delineating freezing patterns and cloud obfuscation (steps 3-5 above) can be augmented with SAR C-band datasets, which show promise in estimating diffuse methane emissions[5] and floating ice regimes [4] in arctic lakes.

4 Conclusion

Machine learning and computer vision are useful tools in quantifying concentrated methane emissions from arctic lakes. Although our work focuses on lakes, the proposed approach can be generalized to other concentrated methane releases, such as river methane seeps, releases from arctic seabed [6] and Pingos (large hills) that have filled with methane reported in the Yamal and Gadal peninsulas. It is important to know whether these phenomena are fairly isolated geologies or widespread effects with significant contribution to the global methane cycle and develop cost-effective mitigation methods such as converting methane into CO_2 to produce energy and reduce 96% of its harmful potential. Since the region of interest is 9% of the earth's surface, sparsely populated, with difficult transportation options, and with unevenly spread geologies of interest, sophisticated satellite data analysis could be a valuable tool in understanding the changing arctic.

References

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