Automating Ice On/Off Dates Using Remote Sensing

GEOM4009 Team Report

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Introduction

The Ottawa Riverkeeper is a non-profit organization that is dedicated to protecting the ecological health of the Ottawa River Basin. Through largely community-based efforts, this group engages in several valuable initiatives that help protect the watershed and spread awareness across a wide range of people. Among these, the Watershed Health Assessment and Monitoring program (WHAM) stands out as it involves continuous monitoring through 14 key indicators of watershed health.

One of these indicators is *Ice On/Off* which is a temporal analysis of ice formation and breakup across waterbodies in the area. Ice cover is an important health indicator, as it drives chemical, biological, and physical processes that affect the watershed. In the context of climate change and warming temperatures, understanding these changes is critical, not only for scientific research but also to mitigate risks to those who rely on accurate information for safe ice use. Within this project, three ice cover classifications are defined: ‘Ice On’, indicating total ice coverage, ‘Ice Off’, indicating ice-free waters, and ‘Ice Cover’ which refers to partial ice cover.

Currently, the Ottawa Riverkeeper's ice monitoring efforts rely on public observations, which are recorded manually (e.g. photos) and published online. While this approach provides an estimate of ice on/off dates, it lacks efficiency for continuous monitoring. To improve this, a member of the organization, Liam Nguyen, proposed the development of a tool that automates ice monitoring through remotely sensed satellite imagery. Liam Nguyen is a scientist with the Ottawa Riverkeeper who specializes in analyzing climate data to mitigate the effects of extreme rainfall and flooding, ensuring preparedness for extreme weather events. Over the course of this semester, our group has worked closely with Liam to develop such a tool. Key requirements included accessing satellite imagery for a given waterbody and date range, calculating ice coverage for every image, and summarizing the results in tables and summary graphs.

Overall, this project yielded two Python scripts that use Landsat-9 and Sentinel-1 data acquired from the Google Earth Engine (GEE) Data Catalog. GEE served as the primary analytical platform for the project. Additionally, all waterbodies used in this analysis were included in a shapefile provided by Liam and the Ottawa Riverkeeper. This shapefile was uploaded to Google Earth Engine as a public asset, where it can be used within the developed tool or incorporated into future iterations

Workflow

The functionality of the final products are as follows:

1. Initialize the user's GEE project
    a. Associated function: gee_initialize()

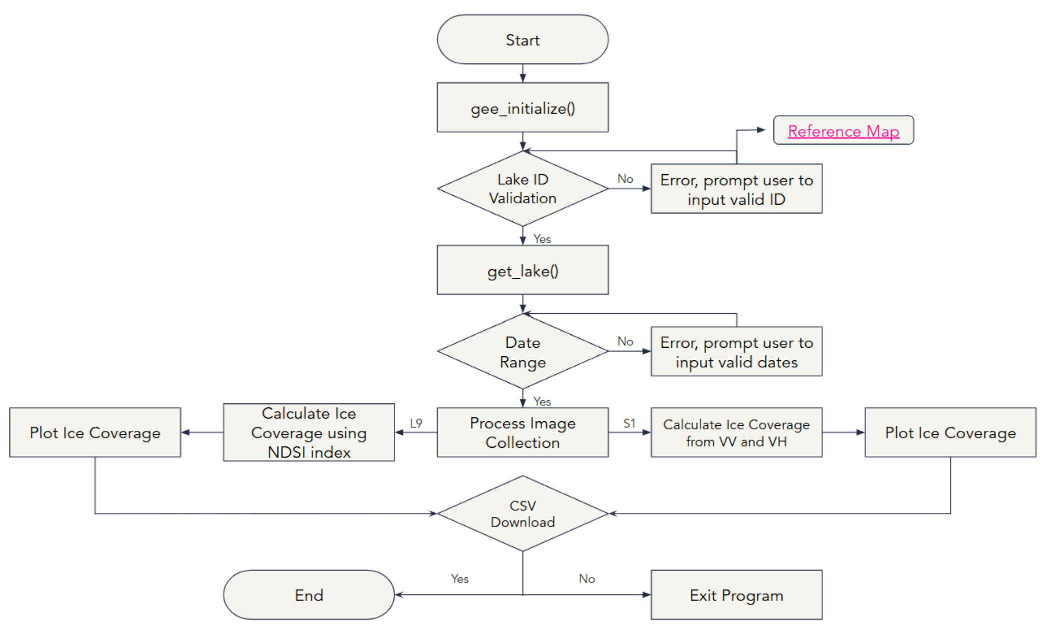
2. Define the user-selected waterbody and date range
    a. Associated functions: get_lake(), validate_lake()

3. Collect and filter imagery
    a. Associated functions (Landsat 9):
        i. get_imagery(), aoi_CloudCover_L9(), L9_CloudMask()
    b. Associated functions (Sentinel-1):
        i. process_image_collection(), toNatural(), toDB(), RefinedLee(), dynamic_threshold()

4. Calculate ice coverage
    a. Associated functions (Landsat 9):
        i. get_IceCoverage()
    b. Associated functions (Sentinel-1):
        i. calculate_ice_coverage()

5. Tabulate and plot ice coverage
    a. Associated functions: plot_ice_coverage(), prompt_download()

Flowchart:



Note: In the current product, the Landsat 9 and Sentinel-1 workflows are independent of one another.

Discussion

Challenges and Limitations

While this project successfully met its objective of automating ice on/off dates, certain limitations are worth noting. Regarding the Landsat 9 approach, data availability proved to be a considerable challenge. Because this workflow is heavily dependent on a clear view of the area of interest (AOI), it applies stringent image filters. These include an AOI-specific cloud filter that sets a 10% cloud limit, as well as a coverage filter that discards all images that do not fully contain the AOI. As a result, analyses conducted during cloudy periods or over large waterbodies may yield a limited number of useable images.

This issue is especially prevalent given the size of certain features in the provided waterbody dataset. For example, the Ottawa River is represented as a single feature spanning from Arnprior to North Bay. In contrast, Landsat 9 images measure approximately 183 km by 170 km, meaning this feature will consistently fall outside the bounds of any single image. While this issue is less severe for Sentinel-1 data, where images collected in the interferometric wide (IW) mode have a width of roughly 250 km, it still poses a challenge for large waterbodies.

Another challenge encountered in the Landsat 9 workflow involved ice thresholding. In the final product, ice is identified using a Normalized Difference Snow Index (NDSI), which was selected after comparisons with the Normalized Difference Water Index (NDWI). During the tests, NDWI generally produced more similar values between ice and water, making the NDSI the more reliable choice. Nevertheless, other indices may still offer more accurate results. Given that most of the effort during this project was focused on structuring and developing the scripts, less time was dedicated to researching optimal indices. Therefore, refining this approach may be a potential area of improvement for future work.

While Sentinel-1 SAR data provides advantages for ice detection, such as its all-weather capability and ability to penetrate clouds, it does present certain limitations. One notable challenge is speckle noise, which can distort ice coverage estimates if not properly filtered. Despite the use of the Refined Lee filter, residual noise can still lead to inaccuracies or the drastic fluctuation in ice coverage percentages. Additionally, the dynamic thresholding approach, while effective, can struggle with edge situations like mixed ice-water conditions, or misidentify non-ice features as ice, especially during transitional periods. These challenges highlight the need for improved processing methods to maximize Sentinel-1's potential for monitoring ice coverage.

Client Interactions

As mentioned above, this project was proposed and guided by Liam Nguyen, a scientist with the Ottawa Riverkeeper. In the early phases, meetings were held every couple of weeks via zoom to discuss the project's objectives, refine the scope, and to provide progress updates. As the term progressed, communication shifted primarily to email, through which progress updates and feedback were exchanged. Close interaction with Liam was a valuable asset to this project, as his feedback helped ensure that the team's progress and focus aligned with the project's objectives and offered useful suggestions to refine the final product.

Future Work

Looking ahead, there are several ways one might consider improving the current tools for future work. Regarding the Landsat 9 script, broadening data sources would increase data availability, particularly during cloudy periods or over large waterbodies. Incorporating data from previous Landsat missions would be an ideal way to do this, given their similar bands and cloud masking capabilities. Moreover, further exploring spectral indices, or developing a customized one, could improve the accuracy of differentiating ice and water.

Future improvements to the Sentinel-1 workflow could focus on enhancing the robustness and accuracy of the analysis. Refining speckle filtering techniques is important to minimize residual noise and improve the reliability of the ice coverage estimates. Integrating temporal smoothing methods or moving averages could address sudden fluctuation and provide a more consistent depiction of seasonal trends. Additionally, the incorporation of ancillary data, such as temperature records or wind speed might help enhance the accuracy of ice detection during transitional periods.

Another possible improvement to this product could involve widening its application. While the current tools focus their analysis on individual waterbodies, including multiple waterbodies would provide a broader understanding of freeze/thaw patterns in the Ottawa River Watershed. This could be done by iterating through all the waterbodies included within an image collection and returning their collective ice cover percentage.

Finally, improving the visualization of results would significantly improve these tools' usability. For example, including an option to download the imagery used in the analysis would allow the user to personally verify the tool's output. Expanding on this, adding a functionality to display the imagery for a specific date would make this verification process more effective, significantly improving the products interpretability.

Conclusion

Overall, this project has been a successful and informative endeavour. The Landsat 9 workflow successfully automated the process of monitoring ice on/off dates, offering a potential contribution to the Ottawa Riverkeeper's Ice On/Off initiative. While Sentinel-1 approach was able to capture general temporal patterns of ice formation and breakup, further refinements to speckle filtering and smoothing are needed to achieve accurate ice cover assessments. Nevertheless, this work has established a good methodological baseline for future improvements and research.

This project has been a valuable experience, not only in managing and executing a large, coding-based workflow, but also in applying it to a real-world scenario through hands-on experience with an external client. Moving forward, the tools and knowledge gained here will help support future research in both coding and remote sensing applications.

Acknowledgements/Sources

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We also acknowledge Liam Nguyen, who initially proposed this project to the GEOM 4009 class. Liam worked closely with our team throughout the term, offering thoughtful suggestions and guidance. His support provided a clear sense of direction, ensuring that the team's efforts were focused on elements that aligned with the project's overarching goals.

In addition to the contributions of supporting individuals, this project leveraged several online resources. A particularly valuable resource was Stack Overflow, a discussion forum widely used among programmers. This platform provided guidance on code structure, syntax, and methodological approaches to coding challenges. Much of the code used in this project was informed by answered found here.

Another critical resource was the Google Earth Engine (GEE) platform. The GEE data catalogue not only provided foundational satellite-derived datasets for this project but also includes useful band information which was helpful for image filtering and thresholding. Additionally, GEE provides tutorials and guides that were frequently consulted in their official developer documentation.

Finally, ChatGPT played a role in answering technical questions related to Python syntax, code structuring, and general programming logic. This platform was particularly helpful for code troubleshooting given its ability to quickly provide guidance, reducing the need for extensive web searches.