Research Statement

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Summary

Remote sensing images have been accumulating dramatically in the past decades through many recent space missions, including the Gaofen satellite series launched by China. The proliferation of remote sensing images lays the foundation for a better understanding of ocean-land and ice-ocean interactions. The recent development of deep learning enables us to maximize the utilization of abundant remote sensing imagery and provide new insights into the complex coupling system of Earth, for instance, how glaciers respond to the ongoing warming of the climate. In the current context of global warming, the coastal regions become vulnerable to sea level rise. The declining mass balance of the world's ice sheets and glaciers represents the largest source of sea level rise occurring since the 1900s, with losses from mountain glaciers, the Greenland Ice Sheet (GrIS), and the Antarctic Ice Sheet (AIS) representing 41%, 25%, and 4% of total sea level rise respectively (IPCC, 2021). Outlet glacier termini are highly sensitive to climate changes and are key to understanding the ice-ocean interaction. The high manual practice of digitizing terminus traces challenges a better constraint of ice-ocean interaction and leads to large ranges in published sea-level rise projections over the coming century. My current research integrates deep learning applications in remote sensing and big-data analysis to better understand ice-ocean interaction.

Past and Current Work

In a pilot study, I automatically delineated the calving front of the largest glacier in Greenland, Jakobshavn Isbræ, from multi-temporal TerraSAR-X (TSX) images using deep learning Zhang et al. (2019). The automatically delineated terminus traces are often indistinguishable from manually-created ones, deviating by 5.5 pixels (38 meters). Moreover, such a promising performance shows the network's robustness to various weather conditions such as changes in snow cover and wetness. However, the method is limited to a specific dataset (TSX images) and a particular study area (Jakobshavn Isbræ), which is not general enough to be applied to multi-sensor remote sensing images over various glaciers with diverse textures and contexts. In the second study, I solved this limitation and improved the accuracy, generalization, and robustness of the deep-learning-based method (Zhang et al., 2021). By training the network with two glaciers and applying it to the third one, I proved the spatial transferability of the deep learning method. Additionally, I successfully integrated seven remote sensing datasets and proved the feasibility of using multi-sensor remote sensing imagery. Overall, we demonstrated the method's high generalization to various glacier targets and data types, laying the foundation for applying deep learning methods to all glaciers using multi-sensor remote sensing images.

My current work focuses on applying the deep learning method to all the glaciers in Greenland. While deep learning methods have shown great potential to automate the terminus delineation, none involve sufficient quality control and automation to enable DL applications to "Big Data" problems in glaciology. When processing a substantial amount of images, any manual step in the pipeline requires intense effort and significantly slows progress. This necessitates improved automation in the pipeline that spans from data collection to quality control and quantifying data uncertainties, which previous studies have lacked. Additionally, applying deep learning to the existing and substantial volume of images requires the network to have a high level of generalization, comparable to the diversity found in all of the images. In this study, I build a fully automated, deep-learning-based pipeline that can continuously produce terminus traces from multi-sensor remote sensing images. I also substantially generalize the deep learning method by leveraging almost all existing manually-picked terminus traces to the training set so that it can tackle diverse conditions of "Big Data." Finally, I produce 279,177 terminus traces for 295 outlet glaciers in Greenland with controlled quality and uncertainties, providing the most comprehensive terminus dataset for Greenland.

New Research Directions

In the future, I will take advantage of the compresive terminus dataset derived from the current study, letting the data shed light into controlling mechanisms of terminus variations. Specifically, The approach is to conduct time series clustering to find the spatio-tempoal correlation at seasonal and inter-annual time scales. The clustering results will yield several glacier types. Within each type, we will investigate the primary controlling factors based on the similarity of other glaciological setting such as bathymetry and atmospheric forcing like surface melting. Finally, we will use Ice Sheet System Model (ISSM) to simulate the controlling factors for various glacier types. This study will bring new insights into the mechanism of ice-ocean interaction, and therefore, could benefit the community for better projecting sea-level rise.

I will also continue to apply the deep learning methods to other glacial regions including Antarctica and mountain glaciers in China. Owing to the spatial transferibility of deep learning and the maturity of the method, these applications will be straightforward, and thus can be turn into initial research projects for junior graduate students, providing them oppotunities to have a preliminary understanding of scientific research and gain knowledge in deep learning technology and remote sensing.

My research interests extend beyond ice-ocean interactions as I am also attracted to applying deep learning to broader Earth sciences. In addition, I plan to seek collaborative relationship with ocean scientist to better monitor the changes of coastal regions and better understand the coupling system between land and ocean, especially with in the Great Bay Area.

References

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