Annotated Bibliography

Csatho, B. M., Schenk, A. F., Veen, C. J., & Angelen, J. H. (2014). Laser altimetry reveals complex pattern of Greenland Ice Sheet dynamics. *Proceedings of the National Academy of Sciences, 11*(52), 18478-18483. doi:https://doi.org/10.1073/pnas.1411680112

This article describes a slightly earlier version of the data set I am working with (the dataset was extended to include 2017 data from IceSat after the article was published and now includes more times series; however, the methodologies described here are the same). The field of study here is geology, specifically glaciology of the Greenland Ice Sheet. The article argues that the data shows that dynamic ice loss (above and beyond seasonal melt) is contributing to overall ice loss in Greenland. There are spatial variations to ice loss where some regions show a decreasing in thinning rate over time, while other regions show an increase in thinning rate. In the past, a small number of outlet glaciers were being used to estimate ice loss on the entire island, but this work suggests that these specific glaciers may not be representative of the entire island's thinning rate. By making use of data from all over the island, the authors are able to make a more accurate estimate of thinning and identify its regional variability. The strength of this research is that it provides considerably more data than was previously available for Greenland ice loss. Measuring ice elevations and its changes over time is quite time consuming and expensive to collect data by hand, and more difficult far from the coast. This dataset employs LIDAR data collected from various satellite missions and overflights to provide data not only on the coasts but also in the island's interior. By looking at data from 100,000 locations, this greatly improves the spatial resolution compared to using just four outlet glaciers. The final project will be using the updated version of the same data employed here (it's been expanded to around 150,000 time series). While the entire ice sheet will not be modeled here, data with the improved spatial resolution for a small portion of Greenland over a section of the southern and southeastern portion of the island will be used. At the time this article was published, the authors argued that this section of the island was showing decreased thinning.

Solgaard, A., Kusk, A., Boncori, J. P., Dall, J., Mankoff, K. D., Ahlstrøm, A. P., . . . Fausto, R. S. (2021). *Greenland ice velocity maps from the PROMICE project.* Retrieved from Earth System Science Data: https://essd.copernicus.org/articles/13/3491/2021/

This article models ice sheet velocities around Greenland from 2016 to the present (overlapping with the tail end of my dataset which runs to 2017 in its present form). This study's data increases the spatial resolution of previous studies to provide better spatial resolution of the velocity model. As with the article above, this article is in the field of geology, subfield glaciology, specifically with respect to the Greenland Ice Sheet. Previous work combined optical data with SAR data; this work employs primarily SAR data from satellites providing better coverage and more frequent data collection to provide more better velocity estimates in more locations. One primary goal of this research was to provide continually updated velocity maps of the Greenland Ice Sheet as new data comes in from the satellites. The ability to update velocity maps almost in real time is a powerful tool for scientists monitoring the ice sheet. The use of satellites to increase the spatial and temporal resolution is essential to obtaining more accurate models of ice loss and change over time. The main interest in this analysis is to provide a

point of comparison for the ice loss model to be generated to determine if there is any association with ice sheet velocities and dynamic ice loss. Their error estimation analyses are also of value. The dataset for the final project also contains error estimates which, as noted in the previous article, can vary widely. Particularly their smoothing methods are of interest to me because while most of the time series appears to have relatively small errors, there are some locations where the errors are large due to uneven terrain, and so some smoothing in those locations may be necessary to provide the most stable model.

Anjyo, K., & Lewis, J. P. (2011). RBF interpolation and Gaussian process regression through an RKHS formulation. *Journal of Math-for-Industry, 3*.

This article is about the formulation and equivalence of Radial Basis Function (RBF) interpolation and Gaussian Process regression (GPR). It describes how GPR techniques can be seen as instances of functional regression and how they can be reduced to an identical formulation, differing primarily in their assumptions on when the data locations and values are known, as well as in their deterministic and stochastic perspectives. The document also discusses the scope and effectiveness of RBF and GPR techniques through several applications in computer graphics. Gaussian Process Regression will be the primary method used in the analysis in my final project to generate a map of dynamic ice loss from the available LIDAR data.

Markus, T., Neumann, T., Martino, A., Abdalati, W., Brunt, K., Csatho, B., . . . al., e. (2016). The Ice, Cloud, and land Elevation Satellite-2 (ICESat-2): Science requirements, concept, and implementation. *Remote Sensing of Environment*. doi:http://dx.doi.org/10.1016/j.rse.2016.12.029

This article is about the Ice, Cloud, and land Elevation Satellite-2 (ICESat-2), its science requirements, concept, and implementation. The dataset used in the project will include missions through ICESat-1 and its predecessors. The changes made in the ICESat-2 mission were strongly informed by ICESat-1 data collection. Improvements of collecting data on steeper slopes are particularly important and this information will be used to inform how the data in prior dataset should be cleaned and interpreted in light of known collection errors.

Brenner, A. C., DiMarzio, J. P., & Zwally, H. J. (2007). Precision and Accuracy of Satellite Radar and Laser Altimeter Data Over the Continental Ice Sheets. *IEEE Transactions On Geoscience And Remote Sensing, 45*.

The document is about the precision and accuracy of satellite radar and laser altimeter data over the continental ice sheets. This article provides a general background to the kind of laser altimetry data the final project will be analyzing, and so general considerations of strengths and weaknesses of the data collection technique will inform any analysis of the data. This article will help to provide a general context for that analysis.

Applegate, P. J., Kirchner, N., Stone, E. J., Keller, K., & Greve, R. (2011). Preliminary assessment of model parametric uncertainty in projections of Greenland Ice Sheet behavior. *The Cryosphere Discussions*. doi:doi:10.5194/tcd-5-3175-2011

This article is a discussion paper that assesses the parametric uncertainty in projections of the behavior of the Greenland Ice Sheet. The main finding of the document is that there is a large amount of uncertainty in ice sheet model-based projections of Greenland Ice

Sheet behavior. The range of potential future sea level rise due to model parametric uncertainty is large, with projected values in 2100 AD being 30% or more of the median. This highlights the significant uncertainty in predicting the behavior of the Greenland ice sheet and its contribution to future sea level rise. The study conducted simulations using different parameter combinations and found that the resulting ice volumes varied significantly. Despite the large variation among individual model runs, all of the modeled ice sheets lose mass from 2005 AD onwards, indicating that sea level rise due to enhanced mass loss from the Greenland ice sheet is very likely. The project ice sheet dynamic losses can be compared to predictions from other modeling techniques.

Price, S. F., Hoffman, M. J., Bonin, J. A., Howat, I. M., Neumann, T., Saba, J., . . . al., e. (2017). An ice sheet model validation framework for the Greenland ice sheet. *Geoscientific Model Development, 10*. doi:doi:10.5194/gmd-10-255-2017

The article is about a new ice sheet model validation framework for the Greenland ice sheet. The ice sheet model validation framework uses ICESat altimetry observations and GRACE gravimetry observations for validation. The ICESat observations provide information about the ice sheet surface elevation, while the GRACE observations provide information about the overall mass balance of the ice sheet. These observations are used to compare with model outputs and assess the performance of the ice sheet model. This article will be useful to place the results of the modeling in context and provide an explanation for how the models will be used in future research.

Goelzer, H., Robinson, A., Seroussi, H., & deWal, R. S. (2017). Recent Progress in Greenland Ice Sheet Modelling. *Glaciology And Climate Change*. doi:https://doi.org/10.1007/s40641-017-0073-y

This article is a review of recent advancements in numerical modeling of the dynamics of the Greenland ice sheet, focusing on large-scale modeling, future projections, model parameterizations, paleo applications, and coupling with other Earth system models. The Greenland ice sheet is a major contributor to sea level rise and its potential for irreversible decline has been extensively studied. The dynamics of the Greenland ice sheet are influenced by various factors, including ocean-induced ice melt rates, basal sediment, outlet glacier flow, and thermal regime. Ice sheet models have been developed to simulate the behavior of the Greenland ice sheet and project its future sea level contribution. Observations, including satellite measurements and ice core data, have been used to study the Greenland ice sheet and validate ice sheet models. Recent literature on numerical modeling of the Greenland ice sheet has focused on large-scale modeling, data assimilation techniques, leveraging high-resolution data products, including ice sheets in climate models, and addressing challenges in producing accurate initial conditions. This article will serve to provide background on the ice loss models to be developed in the project.

Bolch, T., Sørensen, L. S., Simonsen, S. B., Mölg, N., & Machguth, H. (2013). Mass loss of Greenland’s glaciers and ice caps 2003–2008 revealed from ICESat laser altimetry data. *Geophysical Research Letters, 40*. doi:doi:10.1002/grl.50270

The document is about the mass loss of Greenland's glaciers and ice caps between 2003 and 2008, as revealed from ICESat laser altimetry data (which is a subset of the time frame to be considered in the project). The article says that the mass changes of land-terminating glaciers are a direct reaction to climate forcing. This means that the changes in mass of these glaciers are directly influenced by changes in climate conditions. As climate conditions change, such as temperature and precipitation, it affects the amount of melting and accumulation of snow and ice on the land-terminating glaciers. This, in turn, leads to changes in the mass of these glaciers. So, climate forcing plays a significant role in determining the mass changes of land-terminating glaciers.

Rignot, E., Broeke, I. V., Monaghan, A., & Lenaerts, J. T. (2011). Acceleration of the contribution of the Greenland and Antarctic ice sheets to sea level rise. *Geophysical Research Letters, 38*. doi:doi:10.1029/2011GL046583

This article discusses the acceleration of the contribution of the Greenland and Antarctic ice sheets to sea level rise. The acceleration rate of ice sheet contribution to sea level rise is 36.3 ± 2 Gt/yr2. This means that the mass loss from the Greenland and Antarctic ice sheets is accelerating at a rate of 36.3 ± 2 gigatons per year squared. This article provides context for the consequences of continues ice loss due to climate change.

Pitcher, L. H., Smith, L. C., Gleason, C. J., & Yang, K. (2016). CryoSheds: a GIS modeling framework for delineating land-ice watersheds for the Greenland Ice Sheet. *GIScience & Remote Sensing*. doi:https://doi.org/10.1080/15481603.2016.1230084

This article is about a GIS modeling framework called CryoSheds that is used to delineate land-ice watersheds for the Greenland Ice Sheet. The CryoSheds modeling framework is a GIS-based tool for generating land-ice watersheds for the Greenland Ice Sheet, providing a standardized approach for cryo-hydrologic watershed delineation of land-terminating outlet glaciers. The choice of watershed delineation technique is important for cryo-hydrologic studies of the GrIS. The Greenland Ice Sheet is experiencing rapid erosion beneath its surface, contributing to increased runoff and mass loss. Subglacial drainage systems beneath the Greenland Ice Sheet are evolving and changing over time, affecting surface water routing and ice sheet stability. Supraglacial streams and rivers efficiently drain meltwater from the Greenland Ice Sheet, impacting its overall mass balance. The Greenland Ice Sheet has a complex network of subglacial and supraglacial drainage systems that can be studied using digital elevation models and remote sensing techniques. Understanding the hydrological processes and dynamics of the Greenland Ice Sheet is crucial for predicting future changes in sea level. This article will be useful in providing a framework for understanding the models ice loss models to be developed in the project and other associated factors that are impacted by or contribute to those ice loss dynamics.

References

Anjyo, K., & Lewis, J. P. (2011). RBF interpolation and Gaussian process regression through an RKHS formulation. *Journal of Math-for-Industry, 3*.

Applegate, P. J., Kirchner, N., Stone, E. J., Keller, K., & Greve, R. (2011). Preliminary assessment of model parametric uncertainty in projections of Greenland Ice Sheet behavior. *The Cryosphere Discussions*. doi:doi:10.5194/tcd-5-3175-2011

Bamber, J. L., Ekholm, S., & Krabill, W. B. (2001). A new, high-resolution digital elevation model of Greenland fully validated with airborne laser altimeter data. *Journal Of Geophysical Research, 106*.

Bjørk, A., Kruse, L., & Michaelsen, P. (2016). GreenlandGlacierNames_GGNv01. doi:https://doi.org/10.6084/m9.figshare.1449148.v2

Bolch, T., Sørensen, L. S., Simonsen, S. B., Mölg, N., & Machguth, H. (2013). Mass loss of Greenland's glaciers and ice caps 2003–2008 revealed from ICESat laser altimetry data. *Geophysical Research Letters, 40*. doi:doi:10.1002/grl.50270

Brenner, A. C., DiMarzio, J. P., & Zwally, H. J. (2007). Precision and Accuracy of Satellite Radar and Laser Altimeter Data Over the Continental Ice Sheets. *IEEE Transactions On Geoscience And Remote Sensing, 45*.

Csatho, B. M., Schenk, A. F., Veen, C. J., & Angelen, J. H. (2014). Laser altimetry reveals complex pattern of Greenland Ice Sheet dynamics. *Proceedings of the National Academy of Sciences, 11*(52), 18478-18483. doi:https://doi.org/10.1073/pnas.1411680112

Goelzer, H., Robinson, A., Seroussi, H., & deWal, R. S. (2017). Recent Progress in Greenland Ice Sheet Modelling. *Glaciology And Climate Change*. doi:https://doi.org/10.1007/s40641-017-0073-y

Hugonnet, R., McNabb, R., Berthier, E., Menounos, B., Nuth, C., Girod, L., . . . Kääb, A. (2021). Accelerated global glacier mass loss in the early twenty-first century. *Nature*. doi:https://doi.org/10.1038/s41586-021-03436-z

Markus, T., Neumann, T., Martino, A., Abdalati, W., Brunt, K., Csatho, B., . . . al., e. (2016). The Ice, Cloud, and land Elevation Satellite-2 (ICESat-2): Science requirements, concept, and implementation. *Remote Sensing of Environment*. doi:http://dx.doi.org/10.1016/j.rse.2016.12.029

Mouginot, J., & Rignot, E. (2019). Glacier catchments/basins for the Greenland Ice Sheet. doi:https://doi.org/10.7280/D1WT11

Pitcher, L. H., Smith, L. C., Gleason, C. J., & Yang, K. (2016). CryoSheds: a GIS modeling framework for delineating land-ice watersheds for the Greenland Ice Sheet. *GIScience & Remote Sensing*. doi:https://doi.org/10.1080/15481603.2016.1230084

Price, S. F., Hoffman, M. J., Bonin, J. A., Howat, I. M., Neumann, T., Saba, J., . . . al., e. (2017). An ice sheet model validation framework for the Greenland ice sheet. *Geoscientific Model Development, 10*. doi:doi:10.5194/gmd-10-255-2017

Rignot, E., Broeke, I. V., Monaghan, A., & Lenaerts, J. T. (2011). Acceleration of the contribution of the Greenland and Antarctic ice sheets to sea level rise. *Geophysical Research Letters, 38*. doi:doi:10.1029/2011GL046583

Simonsen, S. B., Barletta, V. R., Colgan, W. T., & Sørensen, L. S. (2021). Greenland Ice Sheet Mass Balance (1992–2020) From Calibrated Radar Altimetry. *Geophysical Research Letters*. doi:10.1029/2020GL091216

Solgaard, A., Kusk, A., Boncori, J. P., Dall, J., Mankoff, K. D., Ahlstrøm, A. P., . . . Fausto, R. S. (2021). *Greenland ice velocity maps from the PROMICE project.* Retrieved from Earth System Science Data: https://essd.copernicus.org/articles/13/3491/2021/