# Norske Øer Ice Barrier: A statistical analysis of the increased frequency of breakup

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## 1. Introduction

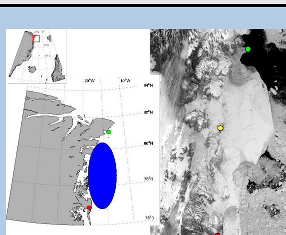


**Figure 1:** *In the lefthand figure, the blue ellipse shows the approximate location of the ice barrier. The right hand figure is a MODIS image of the ice barrier on 15 June 2012; the yellow dot marks Norske Øer. The red dots mark the Danish weather station at Danmarkshavn and the green dots the weather station at Henrik Krøyer Holme.*

Sea ice can potentially exert an important control on the stability of Greenland's outlet glaciers. For example, it can mechanically retard iceberg calving at the terminus. Or it can modulate the delivery of oceanic heat to the terminus, and hence submarine melting, by acting as a rigid cap between the atmosphere and near-terminus ocean waters which damps the circulation. In Northeast Greenland, the Norske Øer Ice Barrier (NØIB) abuts Nioghalvfjerdsfjorden (79N) and Zachariae Isstrøm (ZI), two floating outlets of the Northeast Greenland Ice Stream. Loss of these floating sections might trigger inland migration of the grounding lines, given NEGIS's configuration in a bedrock trough below sea level. NØIB is an extensive region of perennially landfast sea ice whose size varies from year to year, but with complete breakup a rare event. It reportedly broke up in the 1950s[1] and was seen to break up in August, 1997[2]. More recently, the NØIB has broken up during eight of the last ten summers (2002-2005, 2008, and 2010-2012).

The forcings driving the increased frequency of ice barrier breakup are poorly understood, and it is not clear if the breakup is a purely local phenomenon or if its increasing frequency indicates regional changes in East Greenland Current and the Greenland Sea. However, preliminary analysis suggests that increased coastal, surface air temperatures and sea surface temperatures are better explanatory factors of breakup events than other factors with surface air temperatures being the dominant factor.

## 2. Climate and Weather Variables

The epoch studied is 1986 through 2010. For this 25 year period, 24 separate variables are analyzed with a statistical model:

- North Atlantic Oscillation, DJFM & JJA (seasonal)[3]
- Cloud Cover, JJA (seasonal)[4]
- Sea Surface Temperature (SST), monthly averages JJA[5]
- Surface air temperatures at Henrik Krøyer Holme and Danmarkshavn, monthly averages JJA[6,8]
- Positive Degree Days (PDD) at Henrik Krøyer Holme and Danmarkshavn, monthly averages JJA[6,8]
- Surface wind speeds at Henrik Krøyer Holme and Danmarkshavn, monthly averages JJA[6,8]
- Regional cyclones, monthly averages JJA[7,8].

## 3. Logistic Regression Model

Given these climate and weather factors, can we account for when the ice barrier breaks up, i.e., when it is not intact? Furthermore, can we predict when the ice barrier might break up?

Here, the response or dependent variable (DV), intact/not intact, is binary or dichotomous. The independent or explanatory variables (IVs), that are the predictors of the probability of the DV, may be dichotomous or discrete or continuous numerical values. In the case at hand, all the IVs are numerical. Least squares regression is not appropriate when modeling dichotomous response variable for a number of reasons including the fact that the relationship of the DV to the IVs is not linear. A more *generalized linear model* is needed and we use the logisitic regression model.

Odds is defined as,

$$Odds = \frac{Probability\ of\ one\ outcome}{Probability\ of\ the\ other\ outcome} = \frac{P}{1-P}. \tag{1}$$

The general form of the logistic *function* is,

$$g(y) = \frac{e^{a+\beta x}}{1-e^{a+\beta x}} \tag{2}$$

where $g(y)$ is the probability of the ice barrier breaking up, $P(not\,intact)$. We are interested in the *odds* of the breakup so substituting Eq.2 into Eq.1,

$$Odds = \frac{\frac{e^{a+\beta x}}{1-e^{a+\beta x}}}{1-\frac{e^{a+\beta x}}{1-e^{a+\beta x}}}. \tag{3}$$

Finally, we take logarithm of Eq.3,

$$ln(Odds) = a + \beta x \tag{4}$$

which provides a *generalized linear model* suitable for use with a dichotomous, dependent variable[9,10]. If more than one IV is used then $\beta x$ takes the form, $\beta_1 x_1 + \beta_2 x_2 + ... + \beta_n x_n$.

## 4. Analysis

We use the backwards, stepwise strategy to construct a model by including all twenty-four IVs and then, one by one, removing a variable while observing various *goodness-of-fit* criteria. One such criterion is the Akaike Information Criterion (AIC) which is a measure of the *goodness-of-fit* based on the residual deviance — the smaller the AIC value, the better the model. Another criterion is the Area Under Curve (AUC) of the Receiver Operating Characteristics test where the larger the AUC, the better the model. AUC values between 0.9 and 1.0 (ideal) indicate a good model. Additional $\chi^2$ tests, used in conjunction with the AIC and AUC, help determine a *good* model.

The model that best satisfies the various inter-dependent, *goodness-of-fit* criteria is one using the SST for June and the number of PDD for June at Danmarkshavn; the AIC is 16.79 and the AUC is 0.9608. For comparison, if the model used the August average temperature at Danmarkshavn and the July average temperature at Henrik Krøyer Holme, the AIC and AUC would be 22.83 and 0.8646, respectively.

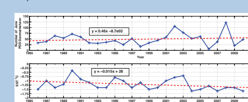


**Figure 2:** *June PDD at Danmarkshavn and regional (81N, 76N, -12W, -20W) June SST.*

In order to test the predictive ability of the model, we created a dataset that did not include the years 2009 and 2010 when the ice barrier was intact and broken up, respectively, and then asked the model to predict the state of the ice barrier for each of the years; the results are below:

**Table 1:** *Logistic Model Predictions.*

| Year | State of NØIB | Probability of Break-up |
|---|---|---|
| 2009 | Not Broken Up | 0.1% |
| 2010 | Broken Up | 44% |

## 5. In Conclusion

All models are a simplification of a complex reality — the one presented is no exception. By objective, statistical measures, it is a good model because it satisfactorily describes how the state of NØIB depends on two climate-related variables. The model is also a reasonably accurate predictor of the future state of the ice barrier. It may be a good causal model as well. However, at least two important pieces of data are missing from the model: quantification of annual meltwater runoff onto the ice barrier and changes in ice thickness. Both are currently being investigated.

## 6. References & Notes

**[1]** Wadhams, P. 1981. The Ice Cover in the Greenland and Norwegian Seas, *Reviews of Geophysics and Space Physics*,**V19, N.3**, 345-393. **[2]** Reeh, N. et al., 2001. Sea ice and the stability of north and northeast Greenland floating glaciers, *Annals of Glaciology*, **33**, 474-480. **[3]** Hurrell, J. and NCAR Staff (Eds.), 19 October 2012. The Climate Data Guide: Hurrell North Atlantic Oscillation (NAO) Index (station-based) `http://climatedataguide.ucar.edu/guidance/hurrell-north-atlantic-oscillation-nao-index-station-based`. **[4]** Simmons, A. et al., 2006. ERA-Interim, *ECMWF Newsletter*, **110**, 26-35. **[5]** NOAA_OI_SST_V2 data provided by NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, `http://www.esrl.noaa.gov/pds/data/gridded/data.noaa.oisst.v2.html`. **[6]** Carstensen, L.S and Jørgensen,B.V., 2011. Weather and Climate Data from Greenland 1958-2010, **DMI Technical Report 11-10**, Copenhagen. **[7]** Serreze, M.C., 2009. Northern Hemisphere Cyclone Locations and Characteristics from NCEP/NCAR Reanalysis Data, *Digital media*, National Snow and Ice Data Center, Boulder, Colorado, USA. **[8]** At this time the data from Henrik Krøyer Holme are incomplete for 2011 and no data are available from either station for 2012. The cyclone dataset ends at December, 2008. **[9]**, Dalgaard, P., 2002. Introductory Statistics with R, Springer. **[10]**, King, W.B., Tutorials, `http://ww2.coastal.edu/kingw/statistics/R-tutorials`.

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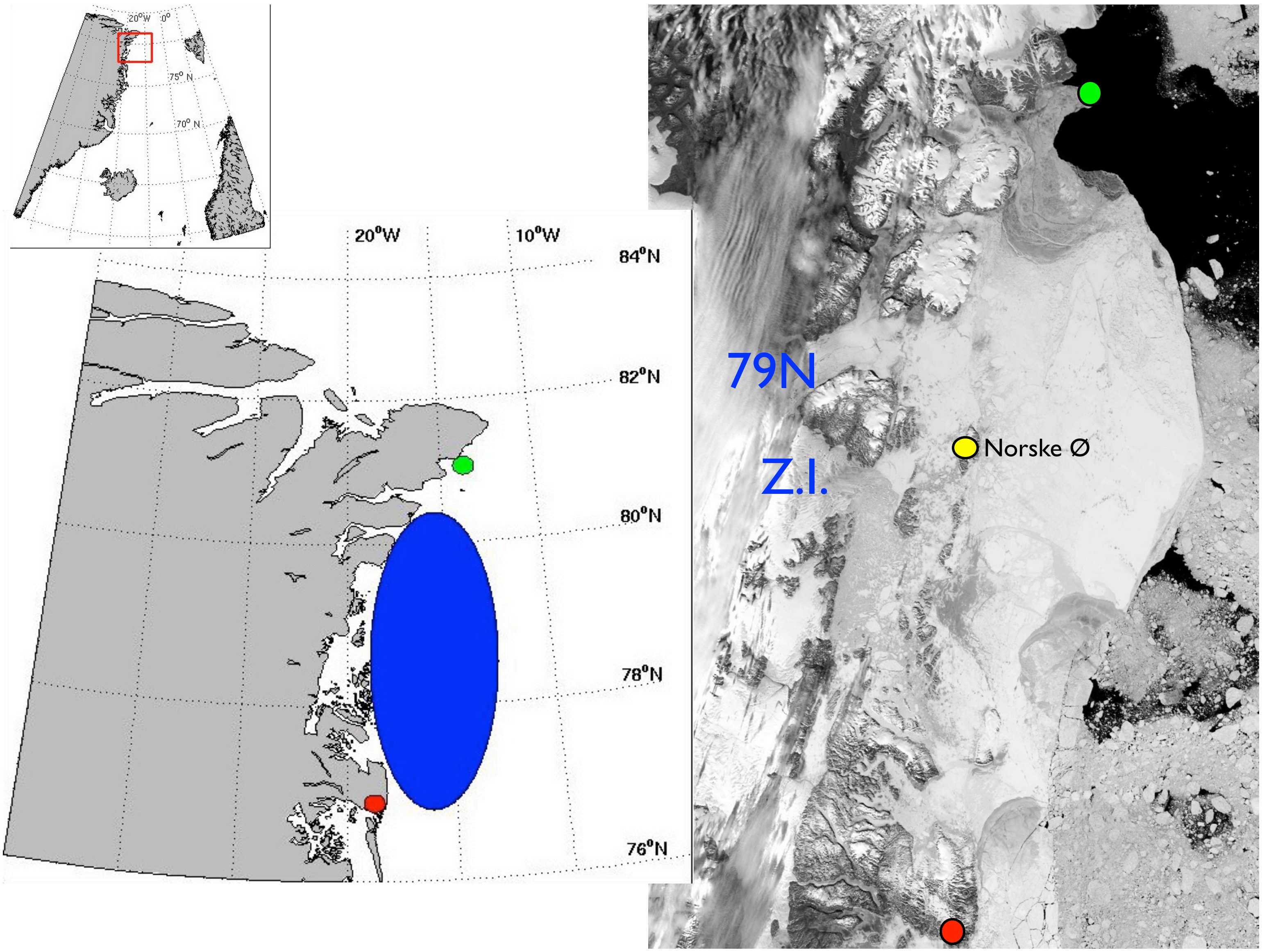
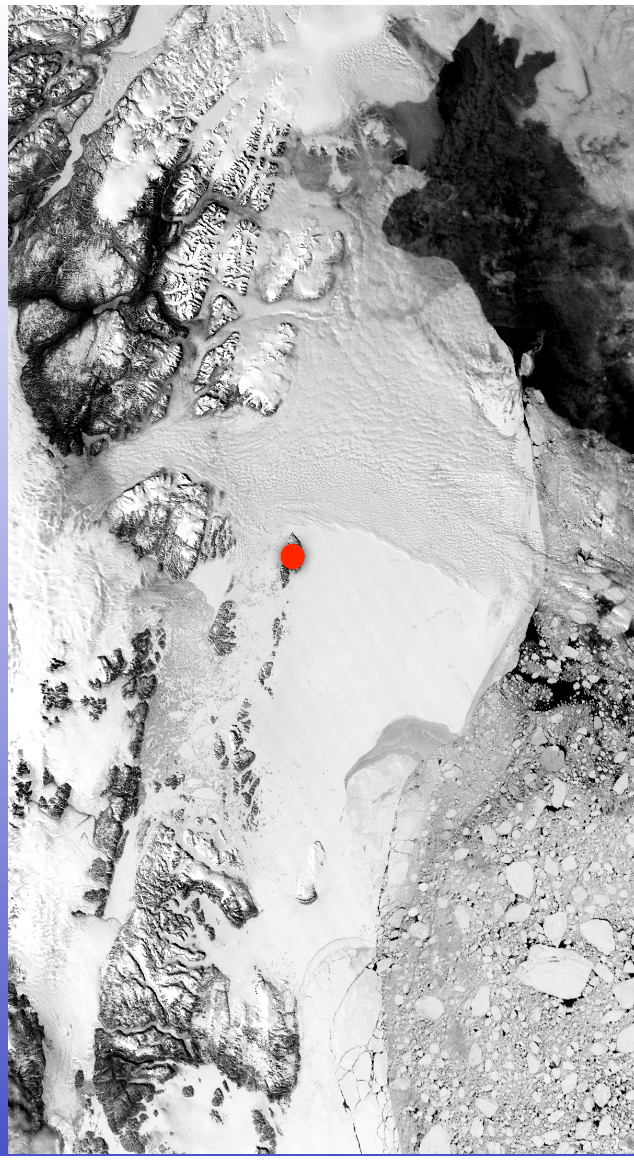
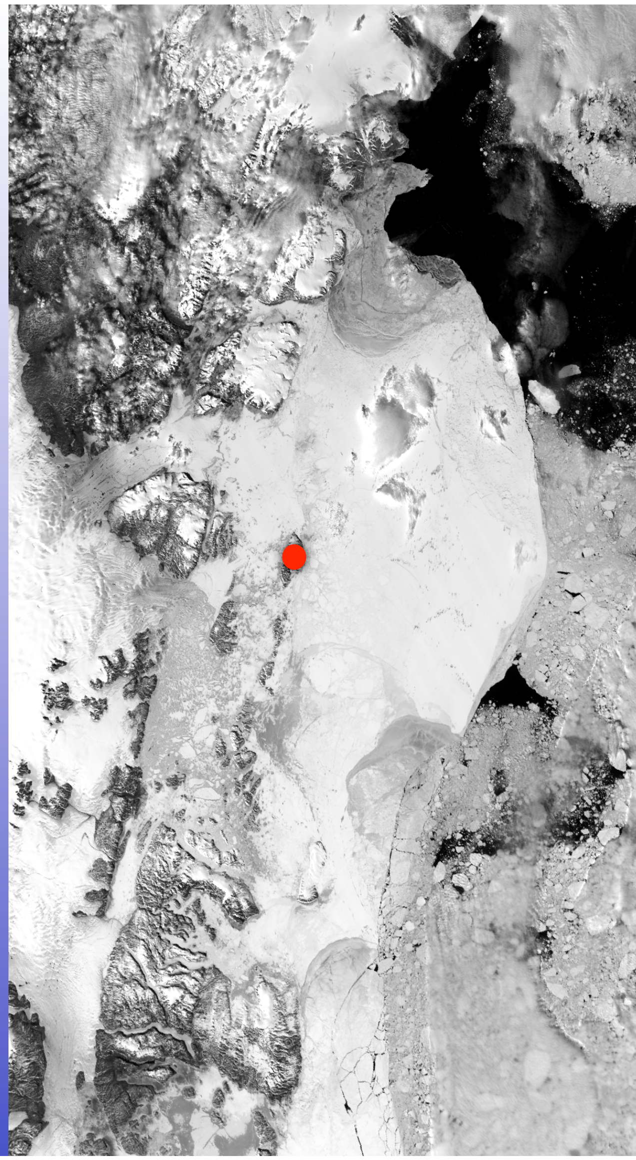


20°W
0°
75° N
70° N
20°W
10°W
84°N
82°N
80°N
78°N
76°N
79N
Z.I.
Norske Ø

5 June 2012





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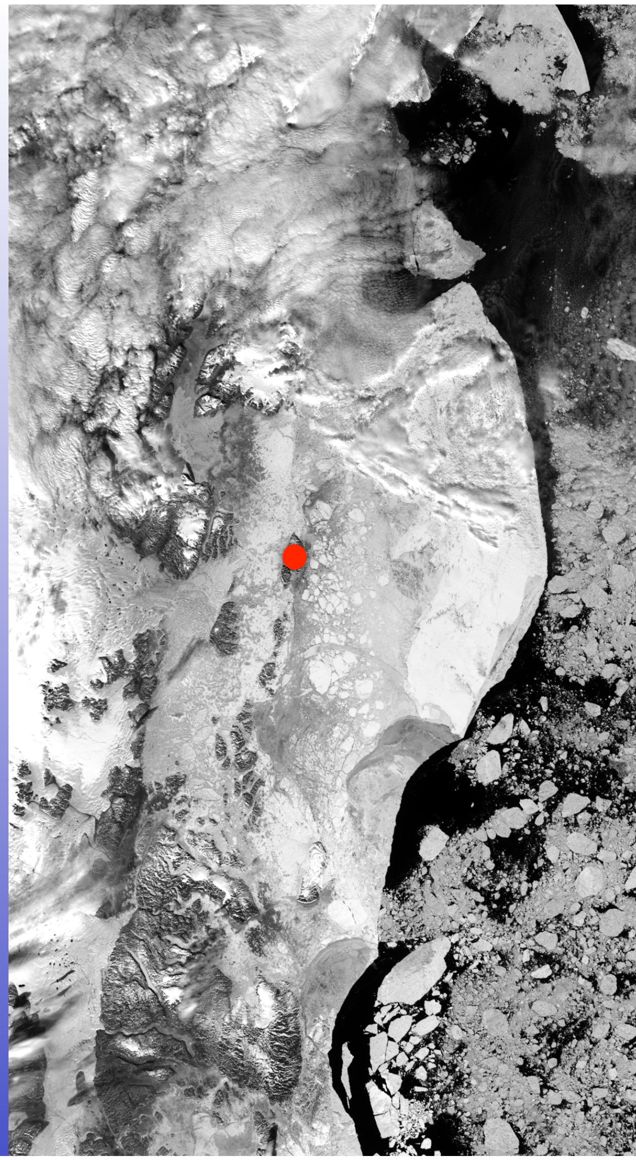

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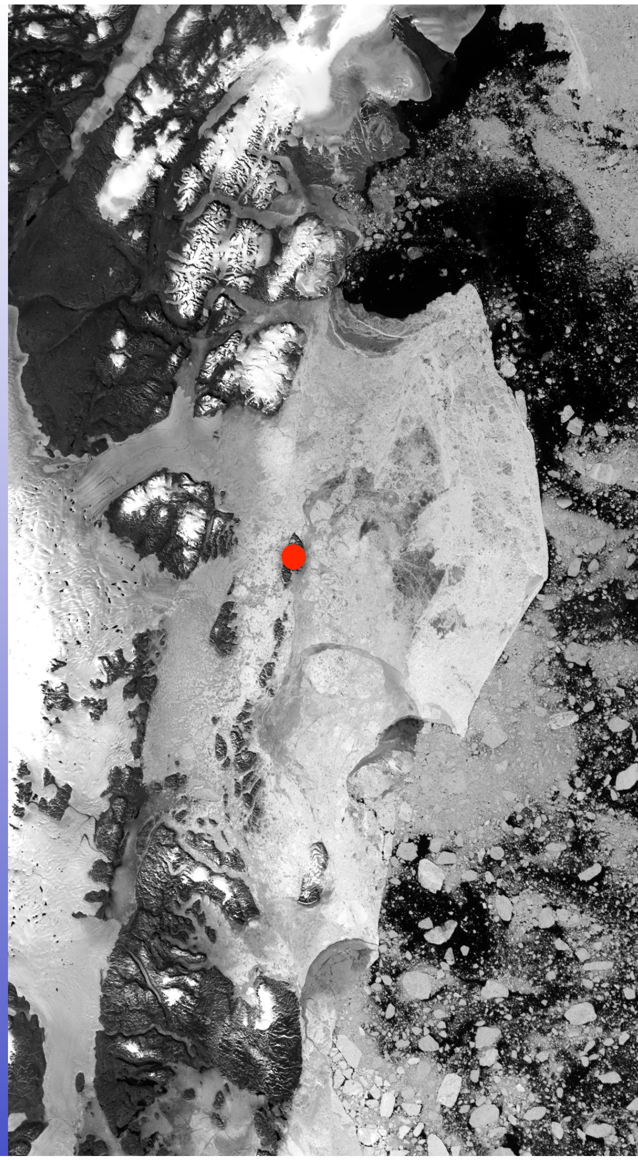

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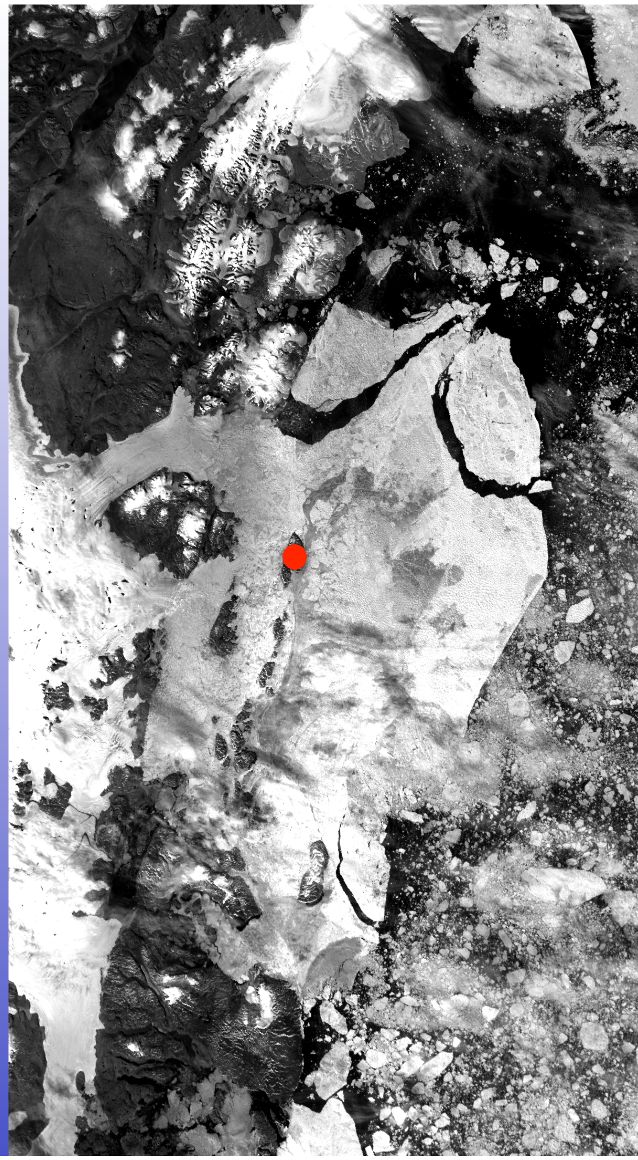

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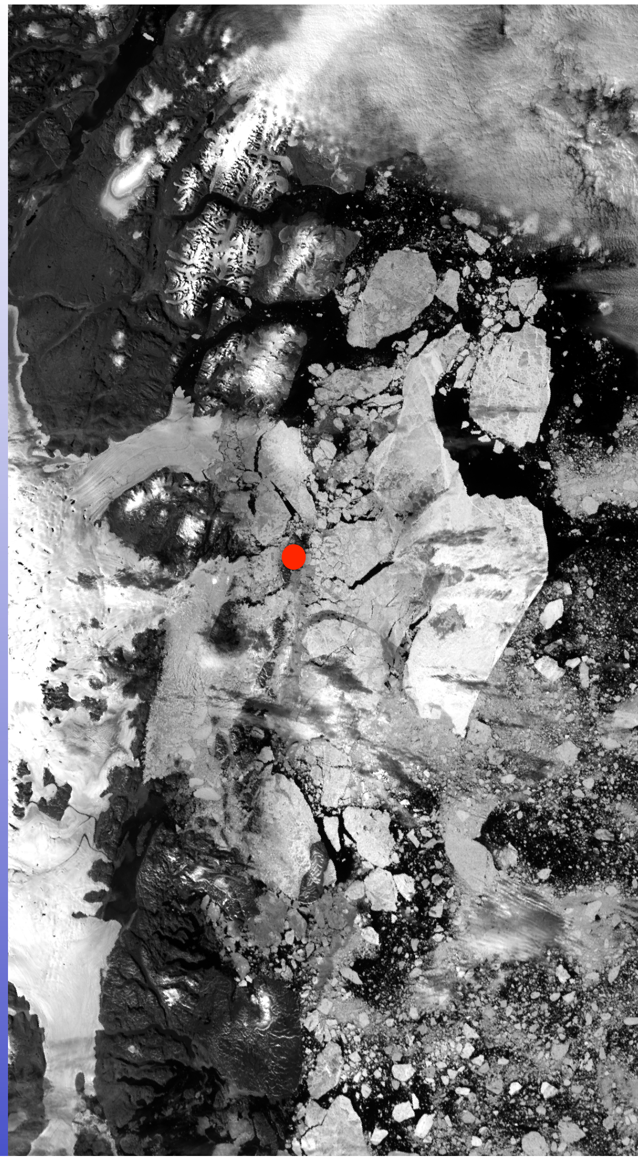

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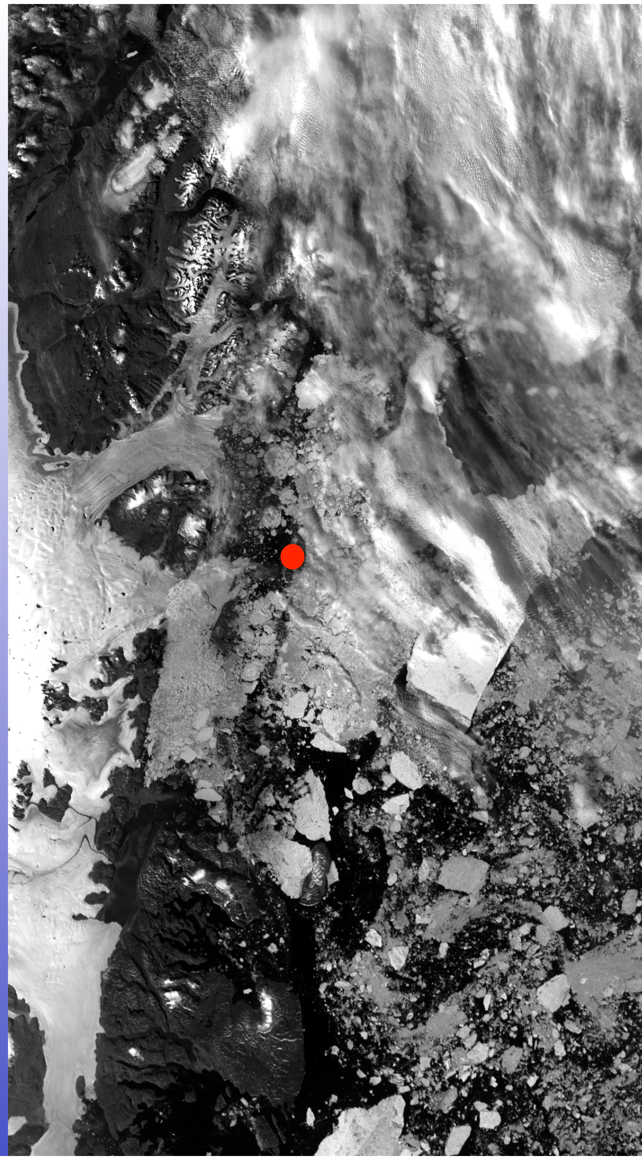

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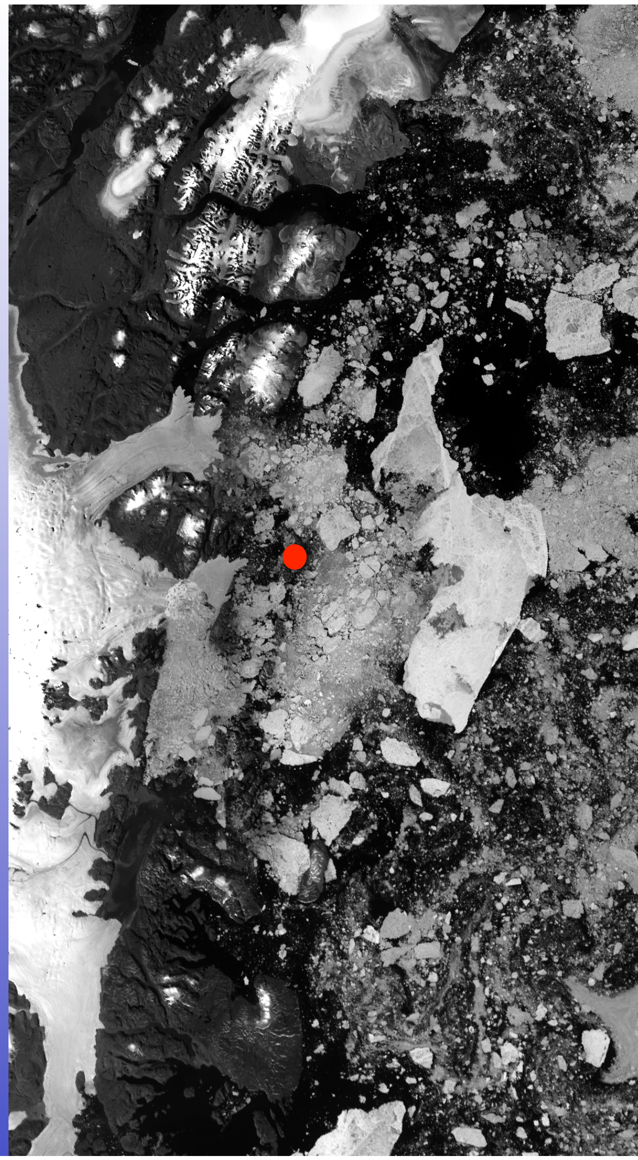

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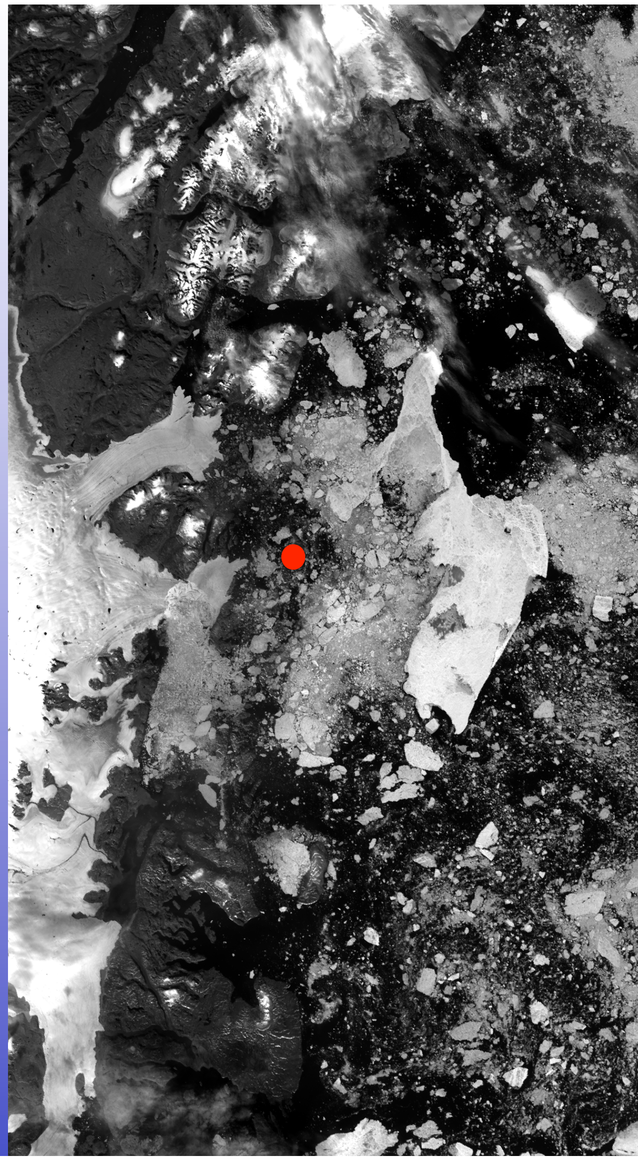

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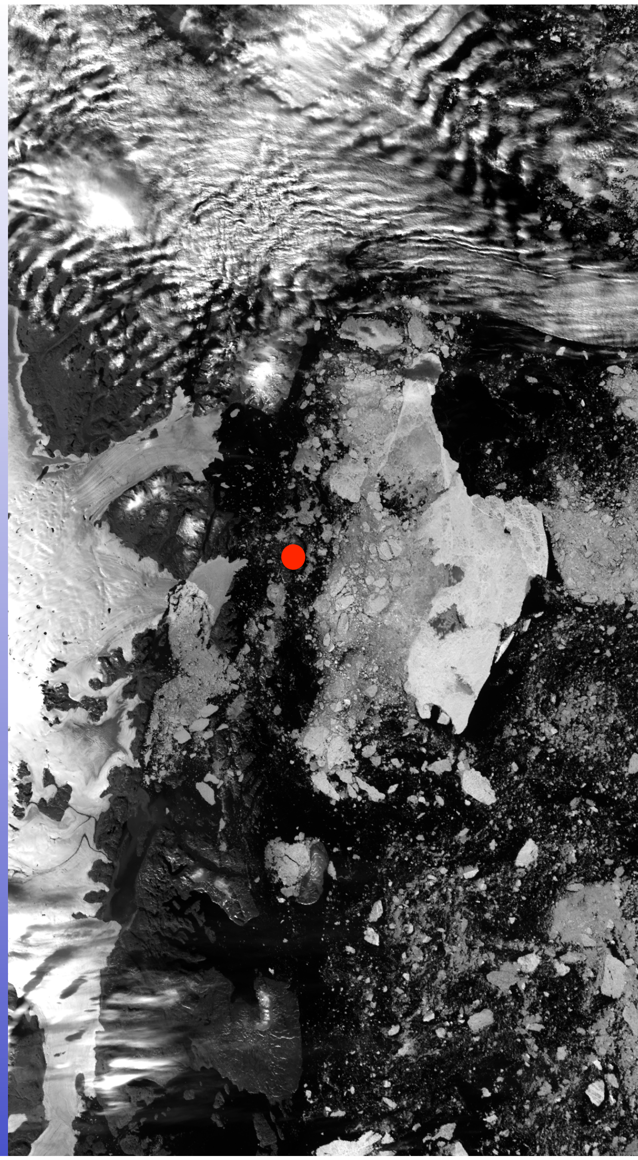

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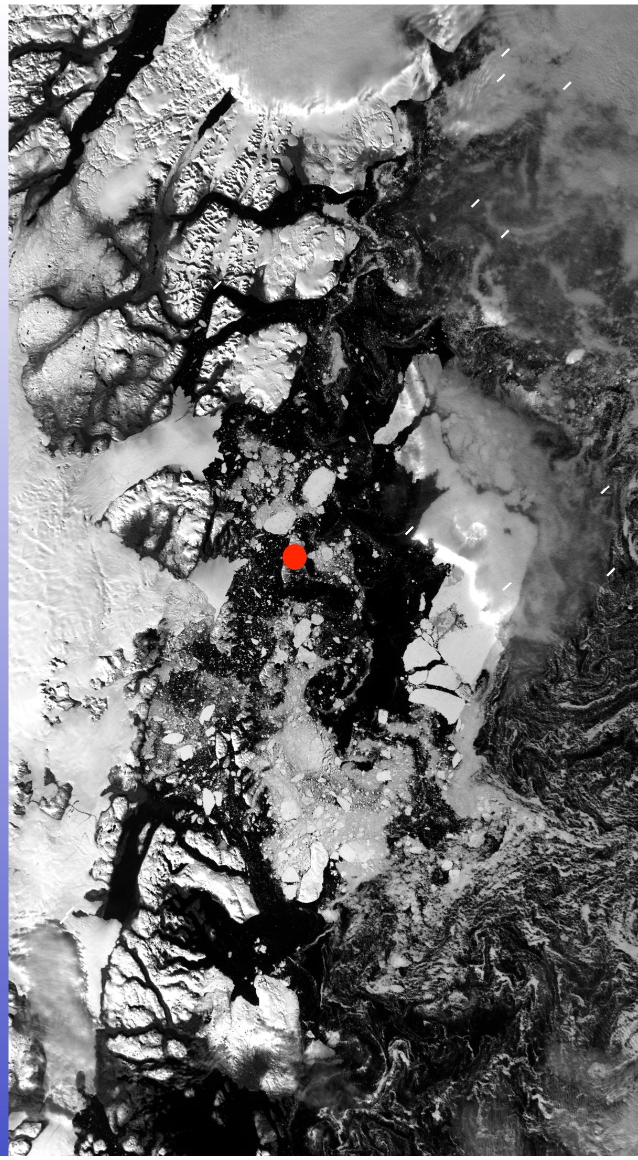

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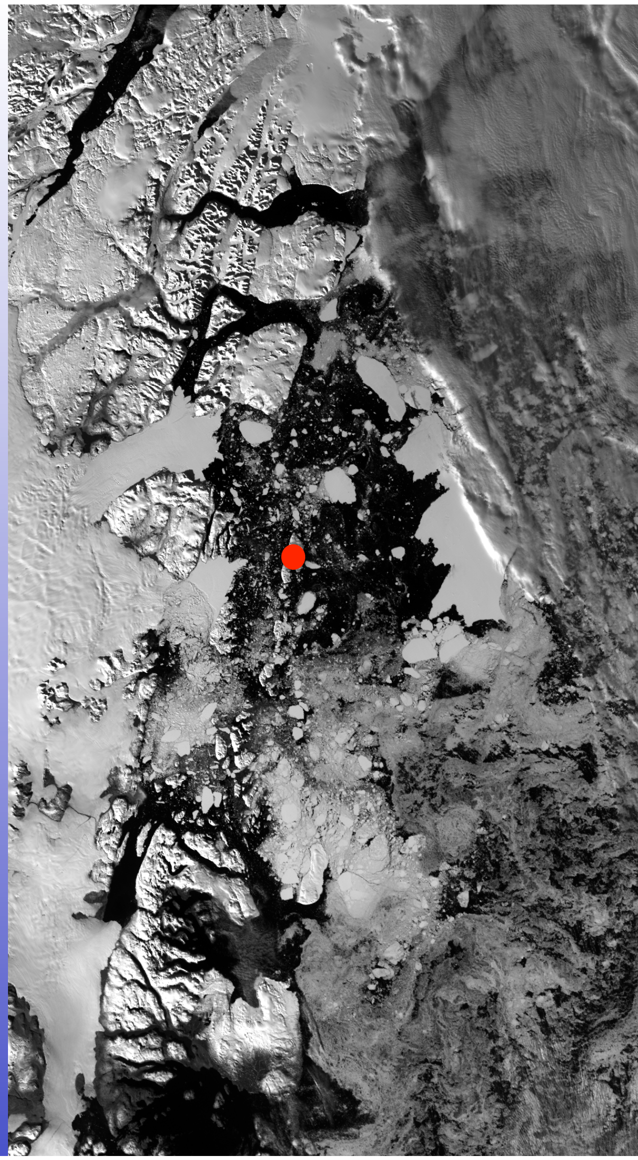

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