INVESTIGATING FLOW VARIABILITY OF HELHEIM GLACIER AND POTENTIAL CORRELATIONS WITH OCEANIC FORCINGS

Steven Foga[1], Leigh A. Stearns[2], C.J. van der Veen[1]
[1]University of Kansas, Department of Geography, 1475 Jayhawk Blvd., Lawrence, KS 66045
[2]University of Kansas, Department of Geology, 1475 Jayhawk Blvd., Lawrence, KS 66045

Introduction

Fast-flowing outlet glaciers are efficient conduits for the transport of mass from an ice sheet's interior to the ocean. Changes in the flow dynamics of these glaciers will have significant impacts on ice sheet mass balance and sea level. Helheim Glacier, East Greenland, is a large tidewater outlet glacier that has undergone dynamic changes in its flow behavior over the past 10 years. While the greatest changes occur at the marine margin of Helheim Glacier, the physical processes that drive these changes are poorly understood. These processes are partially driven by surface melt due to atmospheric forcing and oceanic variability. The ice mélange, a mixture of sea ice and icebergs that aggregates at the front of the glacier, may be an important link between glacier flow and oceanic forcings. The mélange may provide stability to the terminus through backpressure that regulates calving. However, the role that the mélange and terminus play in the stability of ice flow is not well understood.

The main objectives of this research project are:
1) to investigate the spatial pattern of glacier acceleration and iceberg calving;
2) to evaluate the influence that mélange extent has on calving frequency and extent.

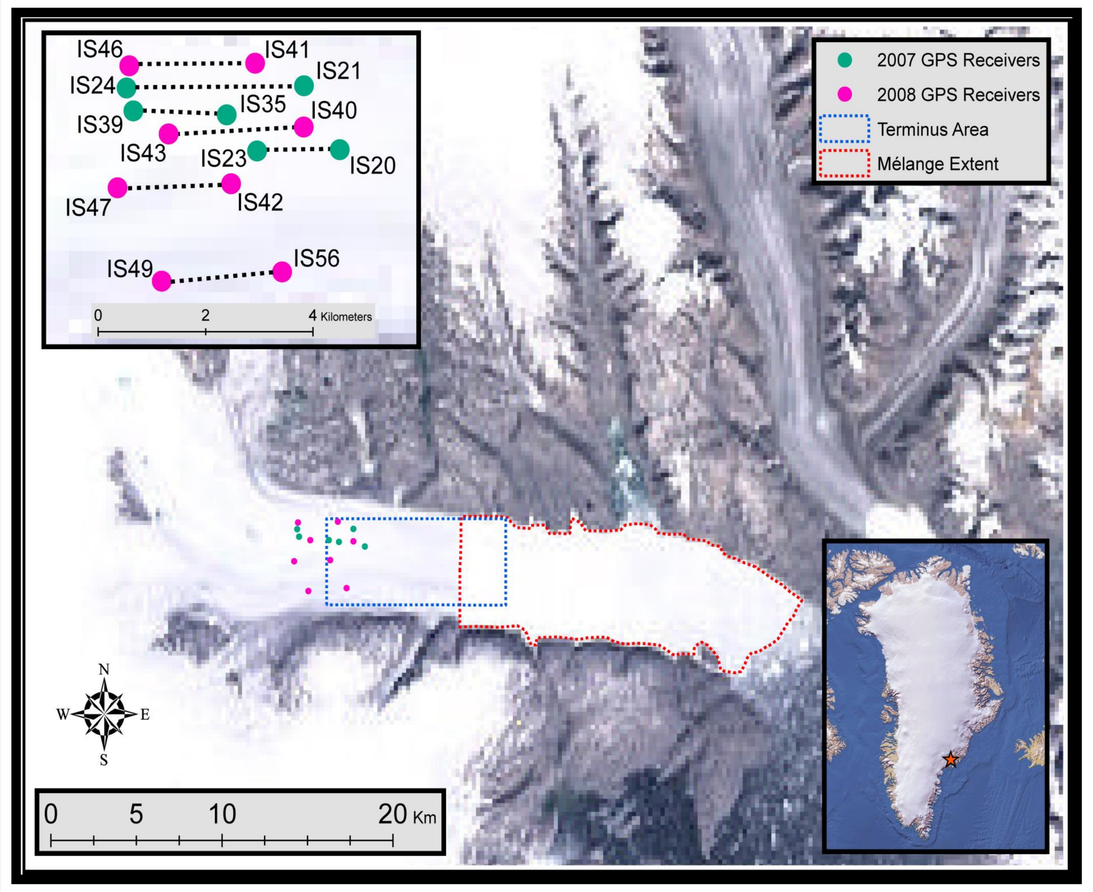

Figure 1: Map of the Helheim Glacier study area. MODIS imagery was analyzed for the mélange (red) and terminus (blue) areas. Locations of GPS receivers deployed in June of 2007 (pink) and 2008 (green) are shown as points.

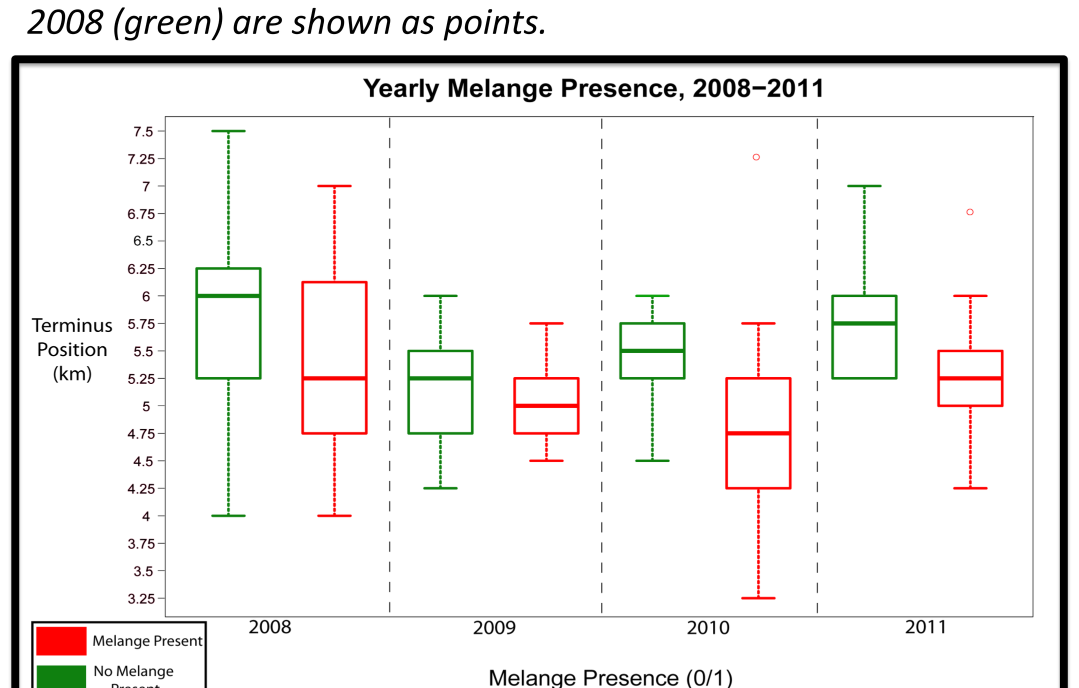

Figure 2: Range of the terminus length each year, visualized through box-and-whisker plots. Yearly terminus extent data is split between mélange presence (red) and no mélange presence (green).

Methods

We use a combination of field measurements (GPS) and satellite remote sensing techniques to construct a daily time-series of terminus length, mélange extent and ice flow variability during the summer of 2007 and 2008. Variations in mélange extent and rigidity are likely modulated by atmospheric, oceanic and glaciological processes. In this analysis, mélange extent is considered either complete (> 10 km long), or partial (<10 km long). This mélange classification is based on the observation that the Helheim mélange does not undergo small changes in extent because of the fjord geometry. Additionally, a binary classification (full or partial extent) allowed us to include partially-cloudy images in our analysis.

The terminus and mélange data were derived from bands 1 and 2 of the Moderate Resolution Image Spectroradiometer (MODIS), which collects images on a daily basis with a ground resolution of 250 meters. These measurements were verified with higher-resolution imagery, such as ASTER (15m) and Landsat ETM+ (30m).

1) **Terminus area** - We created an automated program in R to digitize each 250 m cell and determine the terminus edge. A GUI-based program allows a user to quickly correct any errors in cell characterization **(Figure 3)**.
2) **Terminus length** - We manually measured the terminus length for each day – from the western edge of study area to the center of the terminus **(Figure 1)**. We determined calving events based upon the reduction in terminus length between one observation and the next **(Figures 5 and 6)**.
3) **Mélange extent** - We manually measured the mélange extent, then categorized it with a binary classification: 0 = 0-10 kilometers in length; 1 = 10+ kilometers in length **(Figure 8)**.
4) **Flow dynamics** - We used daily position estimates from GPS receivers that were deployed on Helheim Glacier in 2007 and 2008 to investigate patterns of longitudinal strain in relation to calving events.

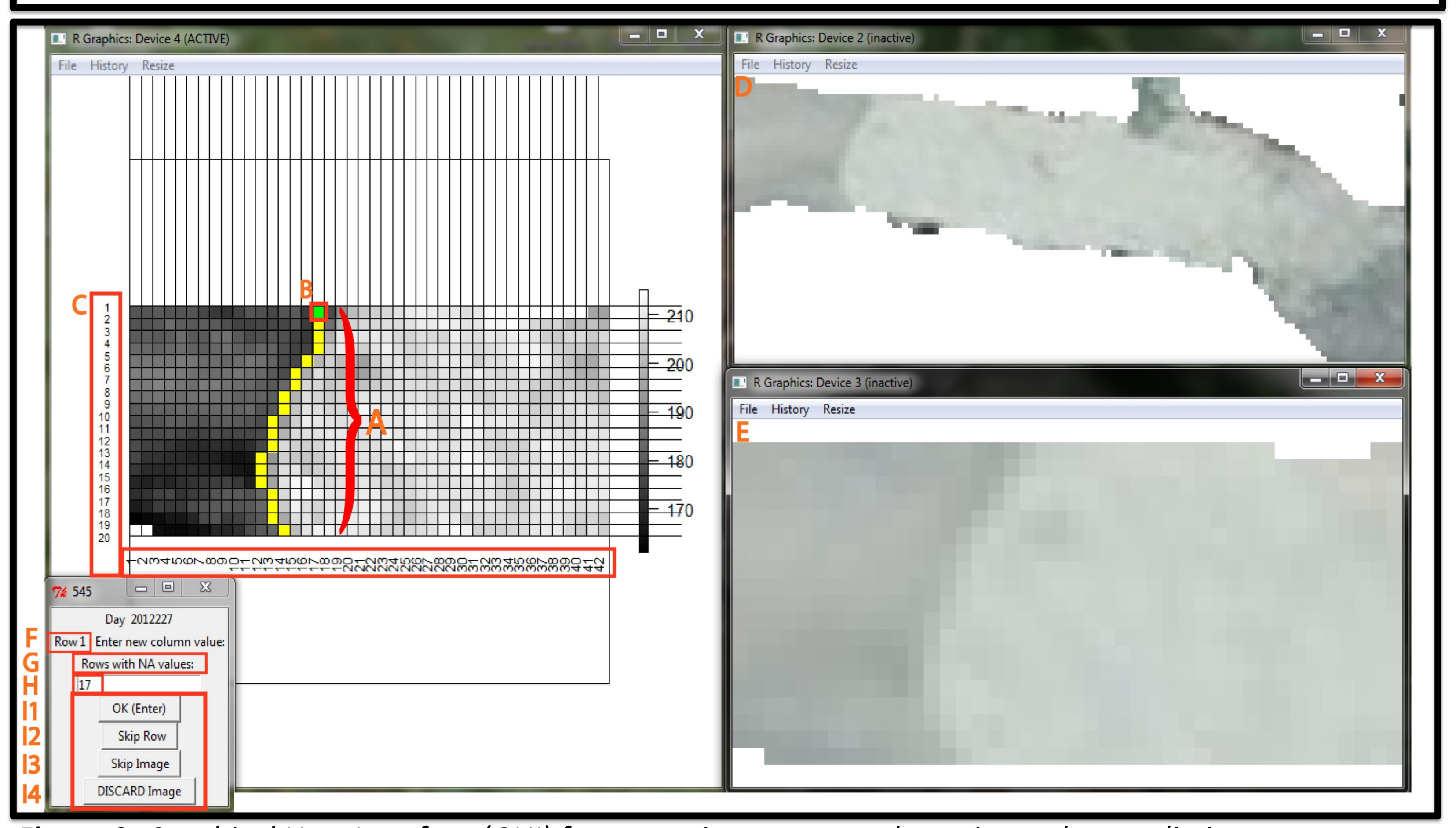

Figure 3: Graphical User Interface (GUI) for correcting automated terminus edge predictions.

*A. Yellow pixels indicate location of predicted terminus edge // B. Current row (always shown as green) // C. Row/column indexes for each image // D. Overview of entire study area (with all bands plotted) // E. Overview of clipped study area (with all bands plotted) // F. Current row // G Index value of rows with NA values // H. Current value, which can be changed to a new value // **I1. OK (Enter):** Enter new value, advance to next row // **I2. Skip Row:** Value looks fine, advance to next row // **I3. Skip Image:** Entire image looks fine, advance to next image // **I4. DISCARD Image:** Substantial cloud cover and/or bad data, mark all values as NA, advance to next image*

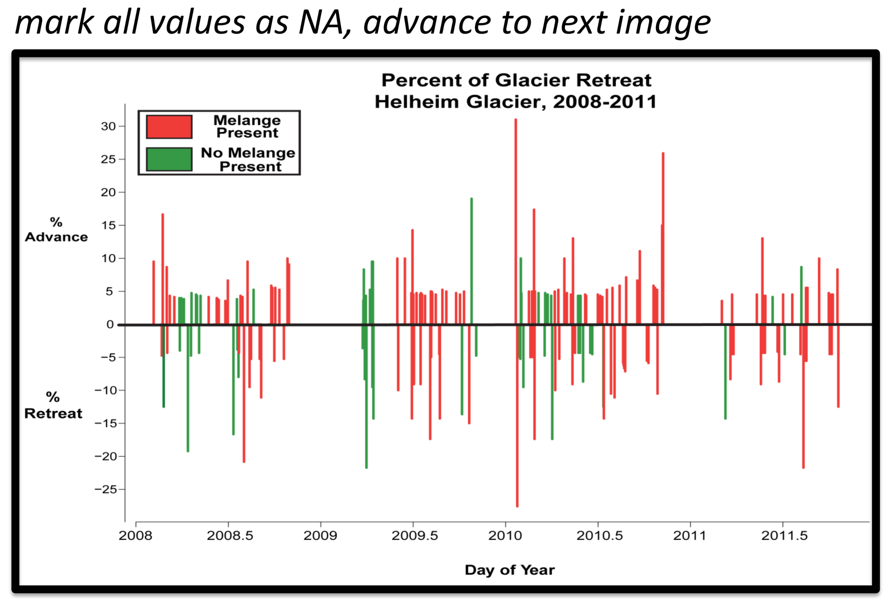

Figure 4: Distribution of mélange presence relative to the percent of advance or retreat of the glacier terminus.

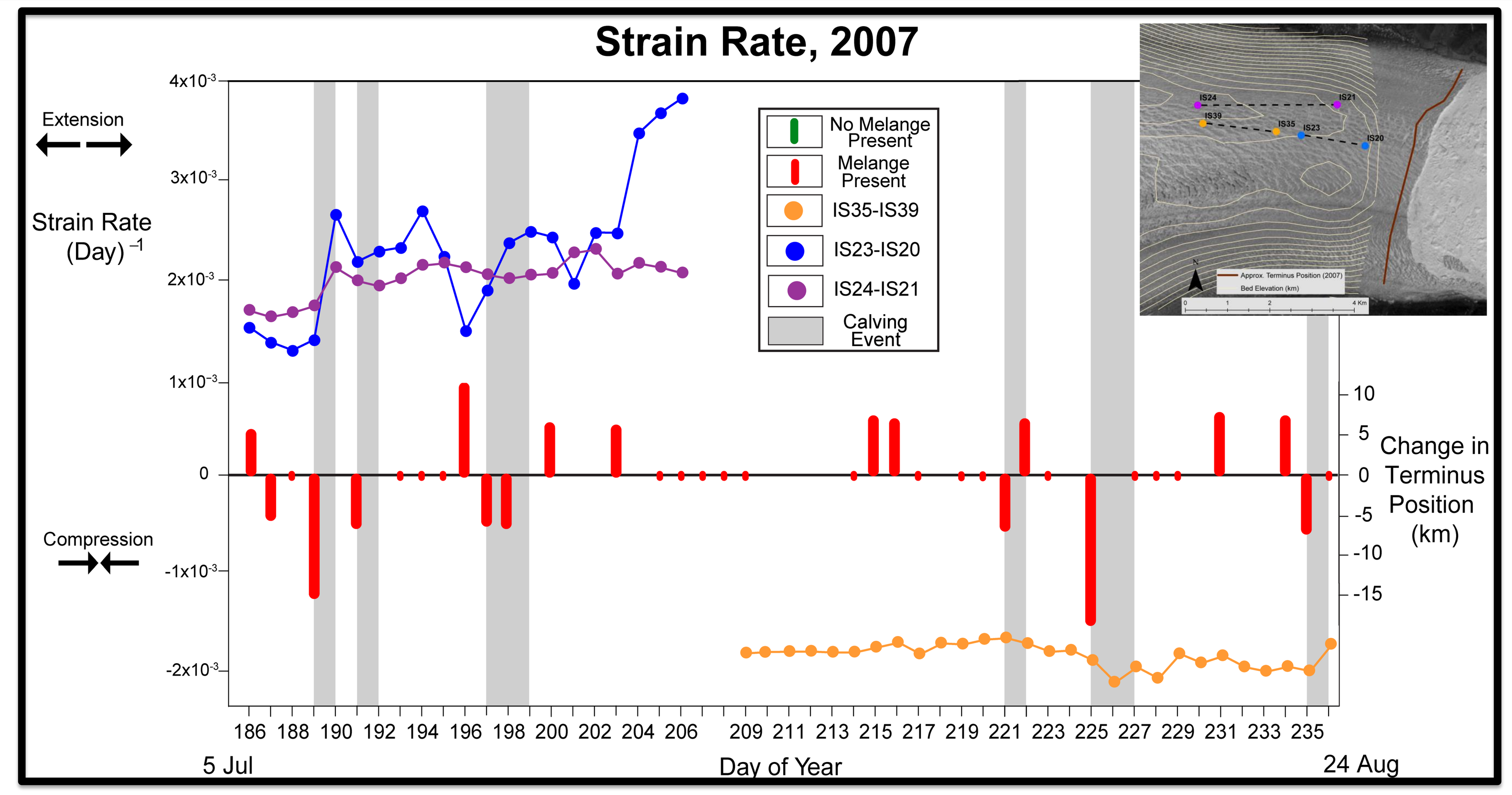

Figure 5: Summer 2007 strain rates (5 July 2007 to 24 August 2007) along with calving events, change in terminus position and mélange presence.

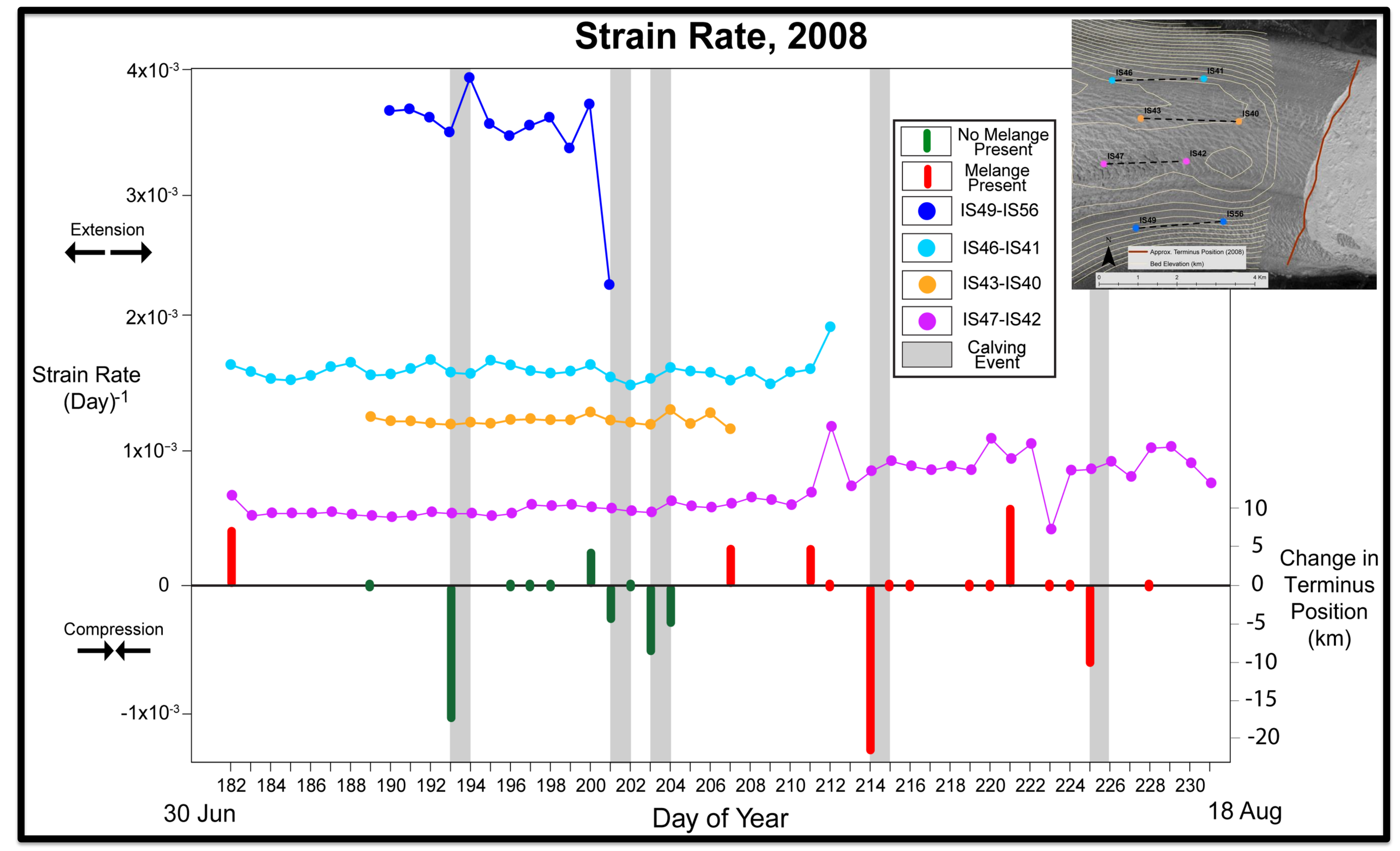

Figure 6: Summer 2008 strain rates (30 June 2008 to 18 August 2008) along with calving events, change in terminus position and mélange presence.

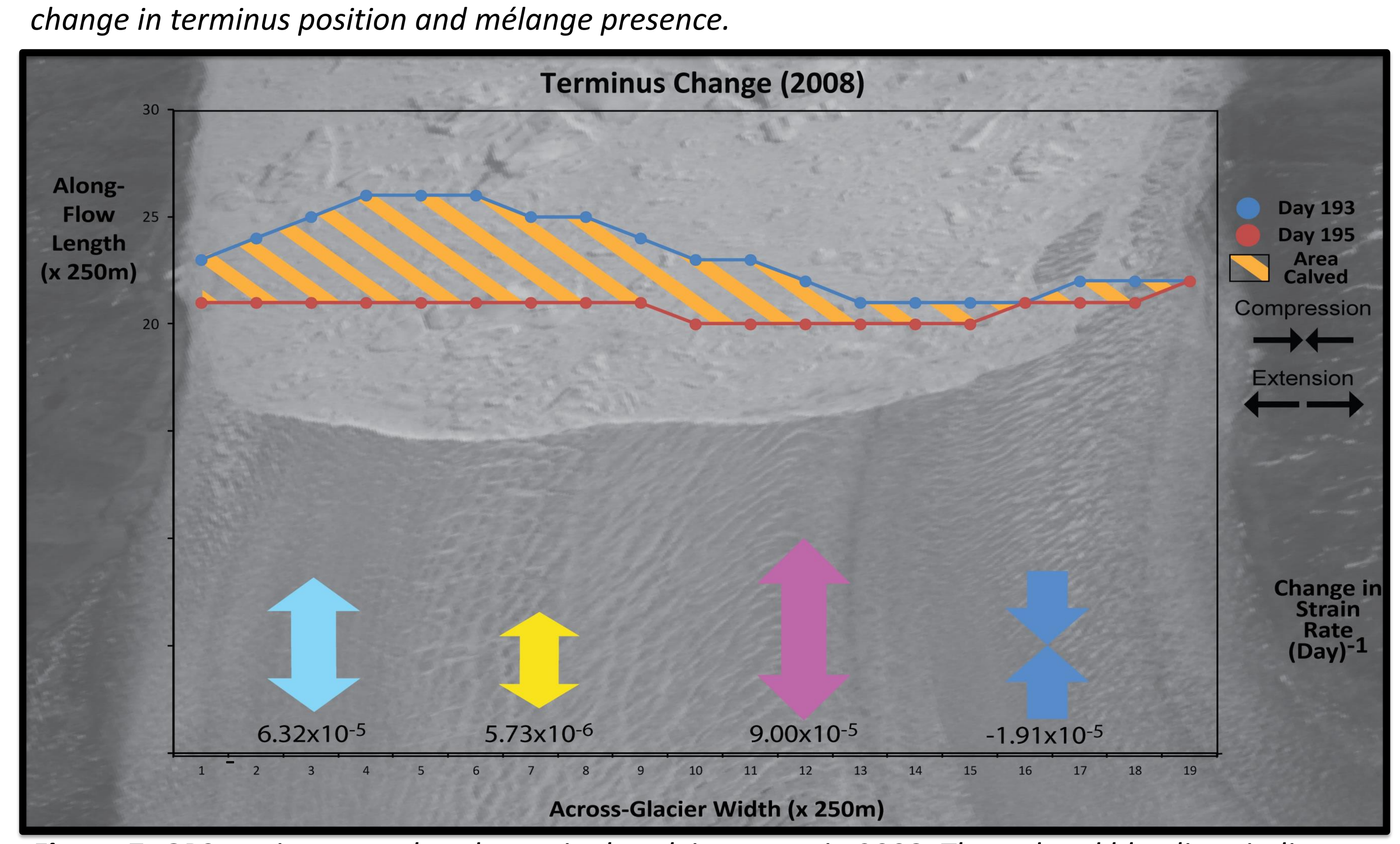

Figure 7: GPS strain rates related to a single calving event in 2008. The red and blue lines indicate terminus position on days 193 (blue) and 195 (red); 12 sq. km. were lost to calving between these two days. Extension occurs across the main trunk of the terminus, directly up-glacier from the large calving events. However the magnitude of extension and retreat are not correlated. Compression occurs along a flowline far removed from the calving location.

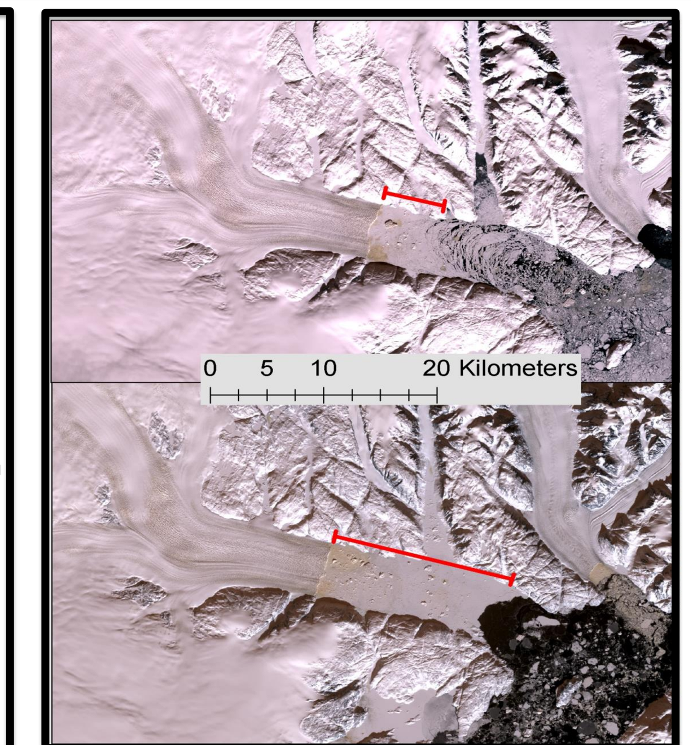

Figure 8: The length of the mélange must be at least 10 kilometers or greater to be considered present. The mélange is ~8 km in the top image (partially present), and is ~17 km in the bottom image (completely present).

Results

1) Based upon the results of a binary logistic regression test, mélange presence is not a strong predictor of calving events. While the regression model strongly predicts the calving events being more frequent during mélange presence (93%), it does not accurately predict calving when mélange is not present (19%).
2) There is a greater overall mélange presence during the study period than an absence of mélange. **(Figures 2 and 4)**.
3) Mélange presence and/or absence is not correlated with glacier advance or calving events **(Figures 4, 5 and 6)**.
4) For each year, the mean, upper quartile and maximum terminus lengths are greater when mélange is absent than when mélange is present **(Figure 2)**.
5) Calving events correspond with some of the increase in strain rates. During a given calving event, some of the GPS receivers experience no increase or decrease in strain rate during a given calving event, while others respond to the same calving event **(Figures 5 and 6)**.
6) In 2008, the increase in strain of the southernmost receiver pair responded accordingly to an uneven calving event **(Figure 7)**.

Conclusions

1) The mélange length extends as calving events occur, but it's impact on glacier dynamics is still uncertain.
2) Calving events do not always involve the entire terminus, which can impact the rate of deformation along a corresponding upstream flow line.
3) Measuring the terminus area is more effective than using a single vector measurement, as it provides greater detail into the dynamics of the glacier. Calving events do not always occur at the center of the glacier terminus, and mass loss can be calculated more accurately with more data points.

Future Goals

1) Extend our record of terminus area and mélange extent to include data between 2002 and 2012.
2) Use the relative brightness of icebergs and sea ice in satellite imagery to investigate mélange strength and rheology throughout a season.
3) Complete a similar analysis on Rink Isbrae and surrounding glaciers.

Acknowledgments

Grant: NSF ARC 0909373
Bed topography provided by the Center for Remote Sensing of Ice Sheets (CReSIS)