Comparing Observed and Predicted Hourly Arctic Coastal Erosion Rates, Alaska

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Abstract

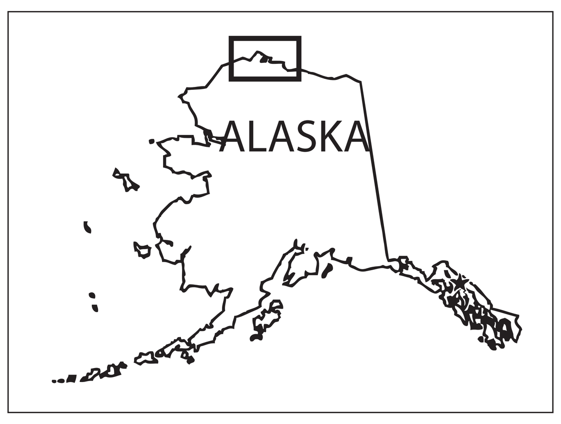
In Arctic landscapes, modern surface warming has significantly altered geomorphic process rates. Along the Beaufort Sea coastline bounding Alaska's North Slope, the mean annual coastal erosion rate has doubled from ~7 m/yr for 1955-1979 to ~14 m/yr for 2002-2007. Locally the erosion rate reaches 30 m/yr. A robust understanding of the processes that govern the rate of erosion is required in order to predict the response of the coast and its adjacent landscape to a rapidly changing climate, with implications for sediment and carbon fluxes, oilfield infrastructure, and animal habitat.

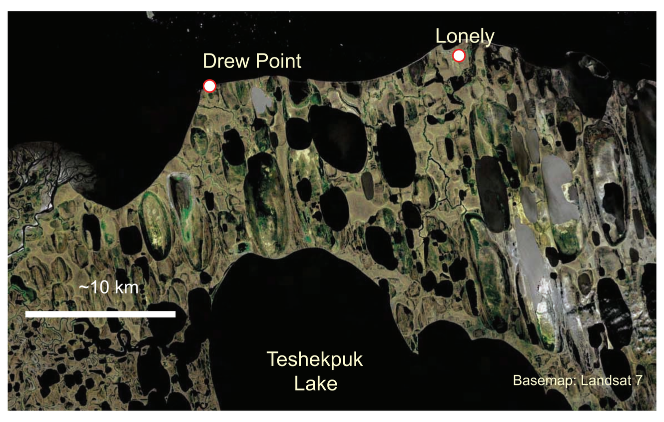
On the Beaufort Sea coast, bluffs in regions of ice-rich silt-dominated permafrost are abundant. This type of coast is vulnerable to rapid erosion due to its high ice content and the small grain size of bluff sediment. The bluff material at our study site near Drew Point is 64% ice, making the bluff susceptible to thermal erosion. Liberated sediment is removed from the system in suspension and does not form sheltering beaches or barrier islands which would provide a negative feedback to erosion. During the sea ice-free season, relatively warm waters abut the bluff and ocean water melts a notch into the 4-m tall bluffs. The bluffs ultimately fail by the toppling of polygonal blocks bounded by mechanically weak ice-wedges that are spaced roughly 10-20 m apart. The blocks then temporarily armor the coast against further attack.

We have developed a numerical model that captures the observed style of coastal erosion over a land to ocean cross section. It requires local meteorology and wave field to determine the instantaneous erosion rate. We must specify a model to calculate the instantaneous erosion rate. We present short-term erosion rates estimated from timelapse imagery. We compare these erosion rates with measured environmental conditions that drive three models of erosion. Observed and predicted erosion rates are comparable for a small subset of competing erosion models.

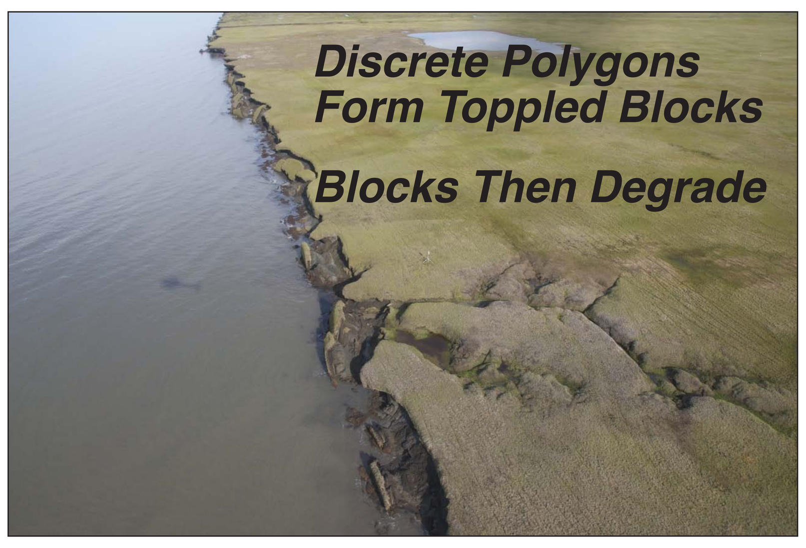
Field Site

The field site is located in the northern National Petroleum Reserve - Alaska. At the site the coast is characterized by ~3-4 m high ice-rich permafrost bluffs.



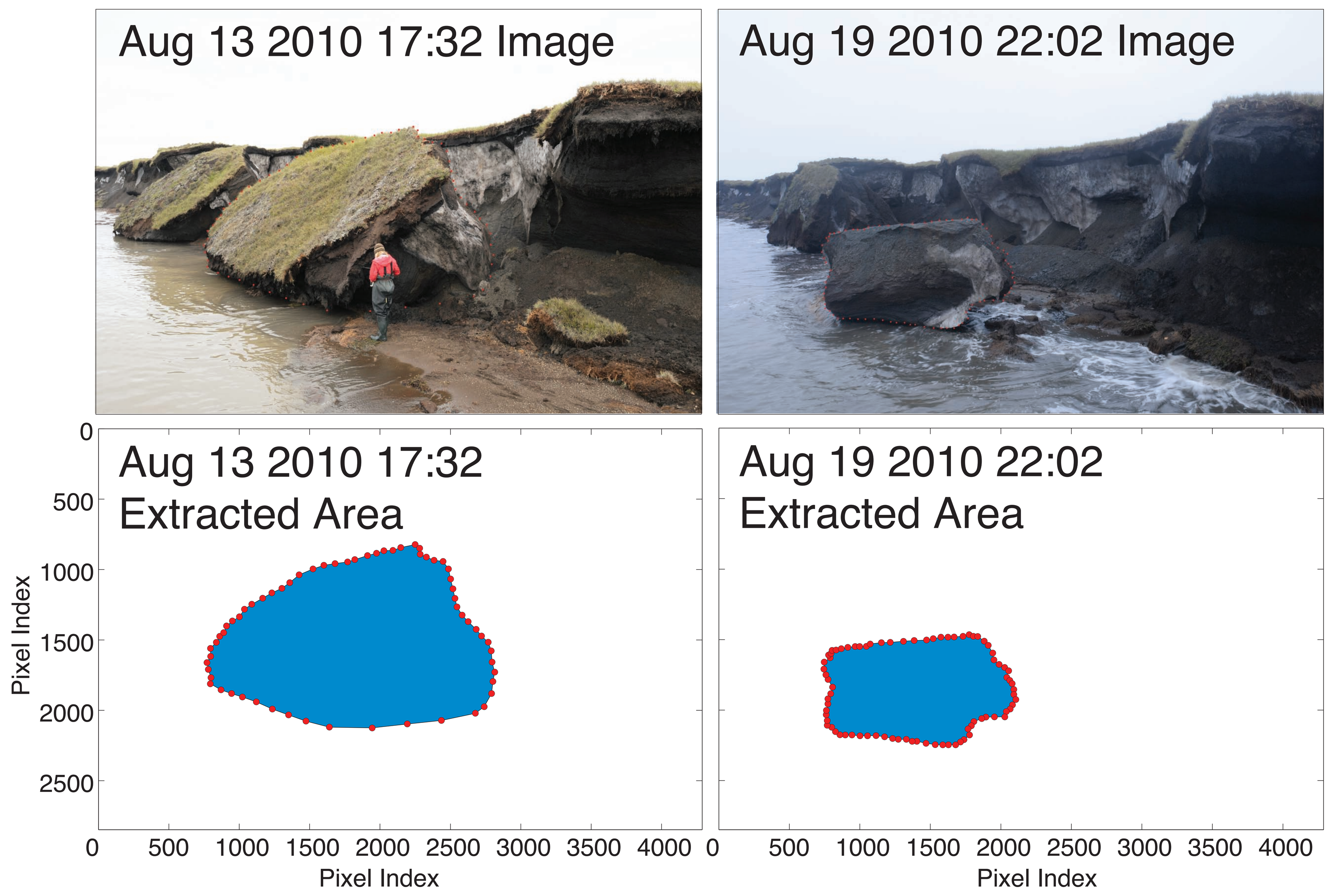


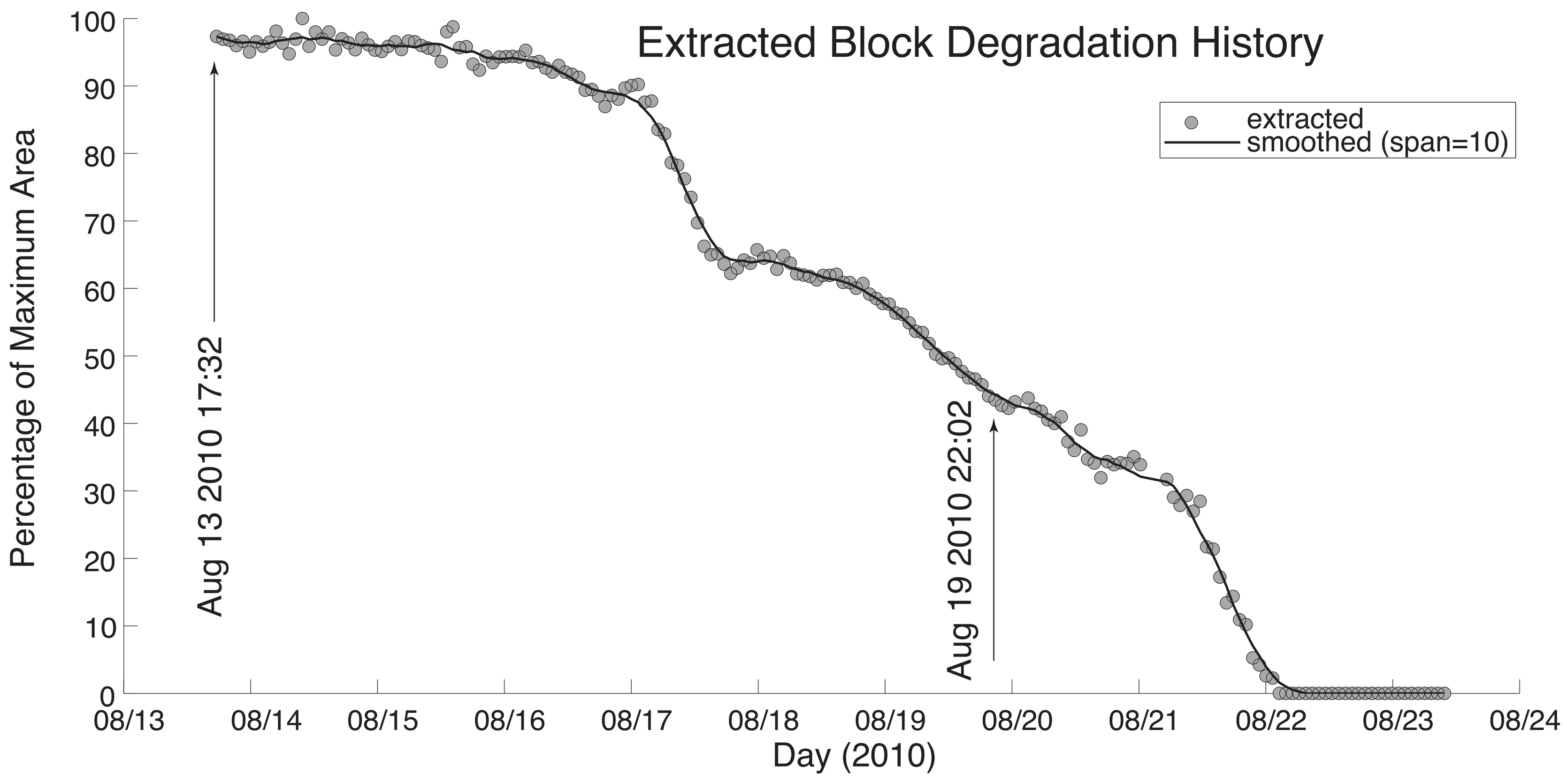
Field Photos



Time Lapse Imagery

Extracting Erosion Rate Proxies from Time Lapse Photography





Erosion Models

Russel-Head

Empirical Iceberg melting rule that describes erosion rate as a power law function of the water temperature

$$M=\alpha(T_s-\delta)^\beta$$

M, melt rate
T_s, Temperature of Water [°C]
α, δ, β, Emperical Constants

In the Russel-Head formulation:

$\alpha = 2.08 \times 10^{-7}$
$\delta = 1.5$
$\beta = -1.8$ °C

Kubat/White

Modified Iceberg Melting Rule that explicitly considers the wave field characteristics

$$V_m = 0.00146\left(\frac{R}{H}\right)^{0.2} \frac{H}{\tau}\Delta T$$

V_m, melt rate in m/day
R, roughness height of water (10 cm)
H, wave height
τ, wave period
ΔT, temperature difference between water and ice

$$V^*_m=\beta V_m$$

$$\beta = \frac{L\rho_{ice}W}{L\rho_{ice}W + \rho_{bulk}c_{p,bulk}\Delta T}$$

β, modification factor
W, ice content
ρ_{ice}, ρ_{bulk}, density of ice and bulk material (kg/m³)
L, Latent heat (J/kg)
$C_{p,bulk}$, bulk heat capacity (J/(kg °C)

Wave Power

Wave Power represents the flux of energy carried by the wave. It is the product of energy density and group wave speed.

$$\omega=\frac{\rho g^{3/2}}{8} H^2 h^{1/2}$$

ω, Wave Power [J /(m² s)]
ρ, Density of the water
H, Wave height
h, Water depth

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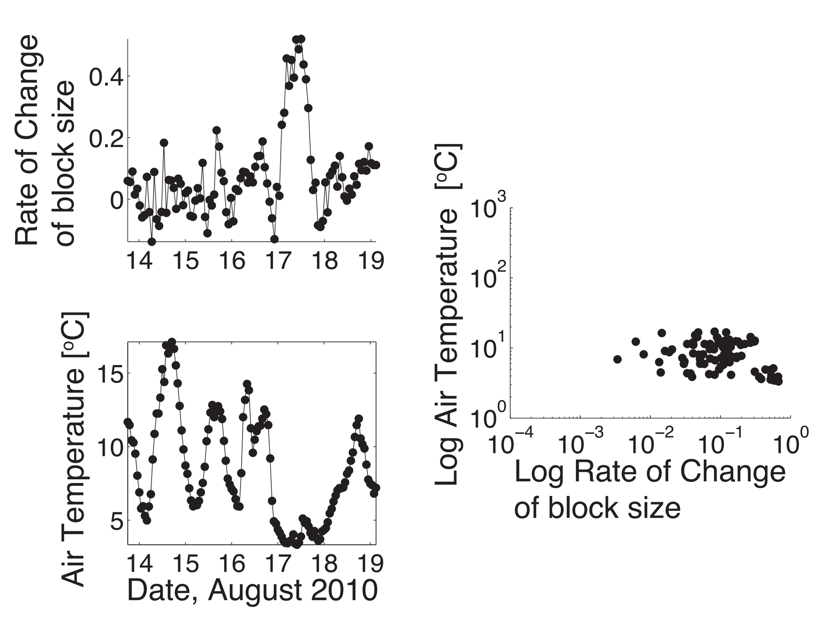
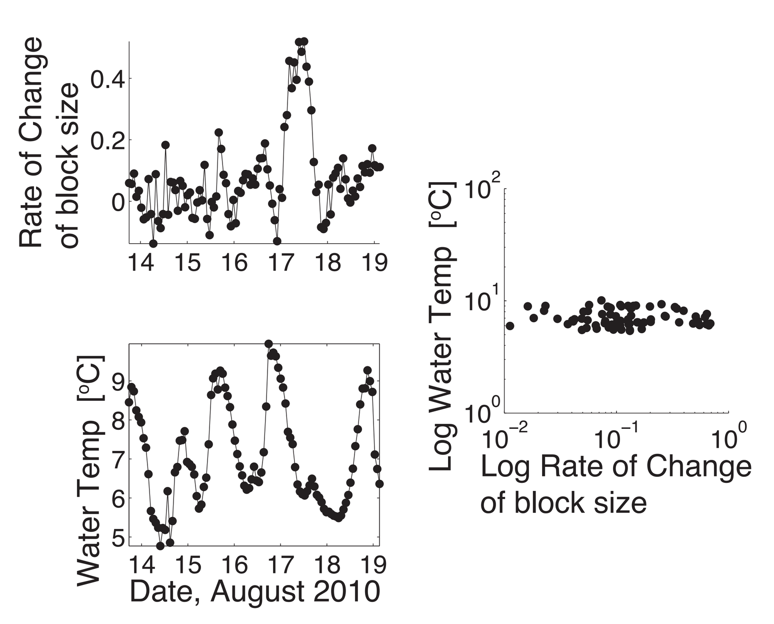
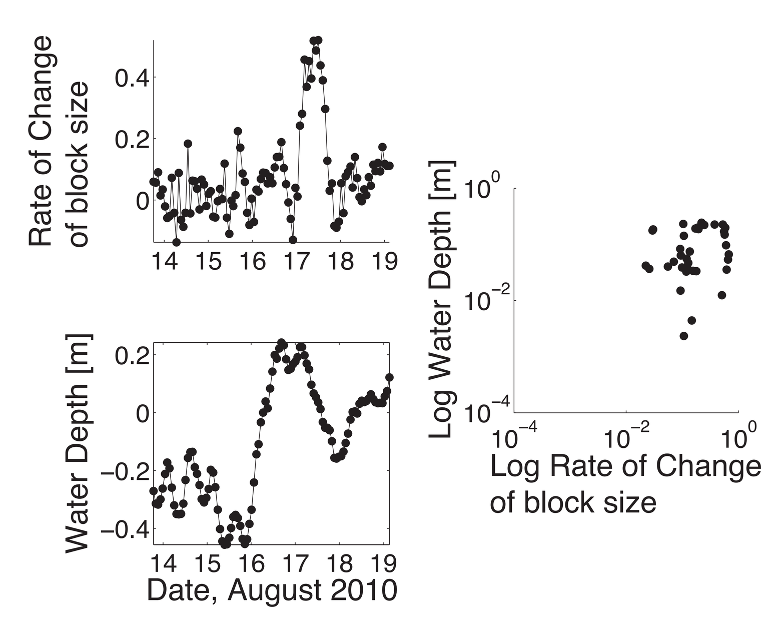
Air Temperature



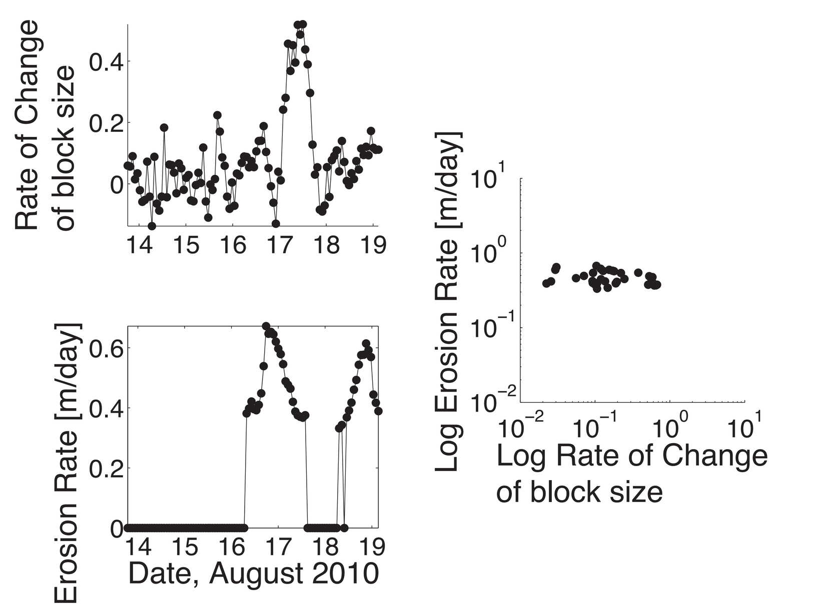
Water Temperature



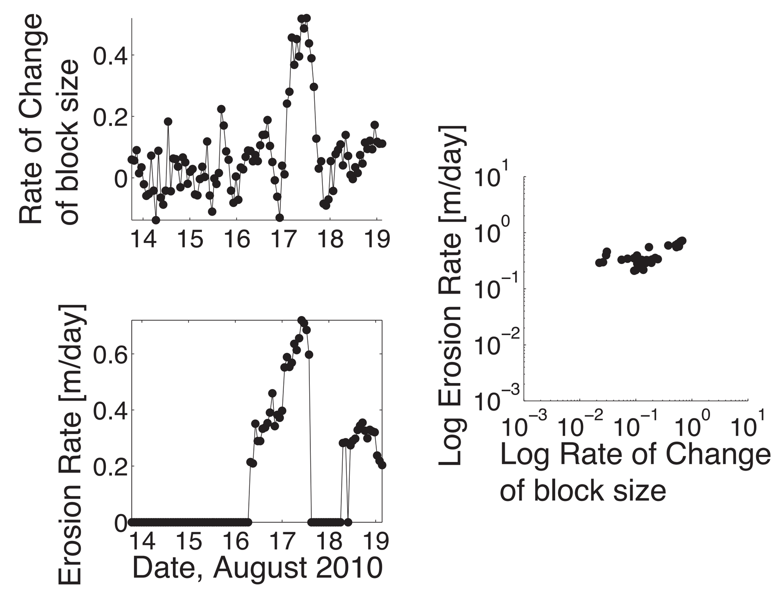
Water Depth



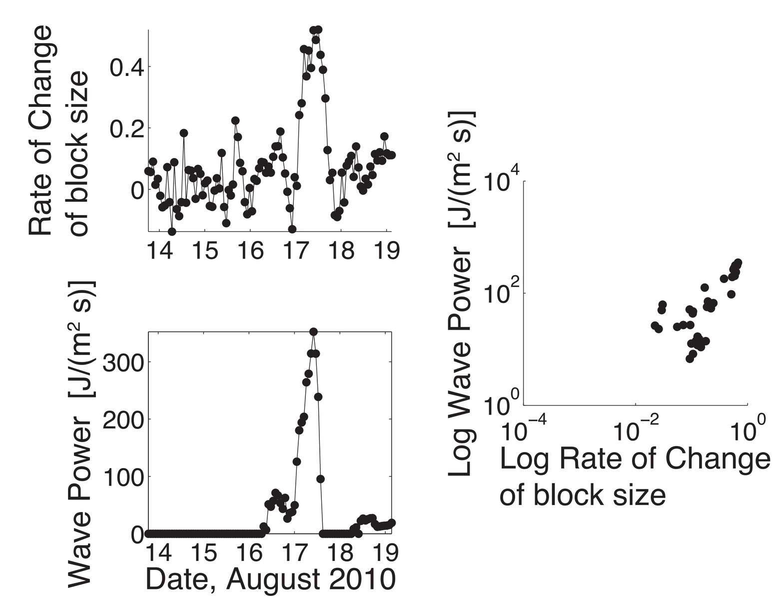
Russel-Head Erosion Model



Kubat/White Erosion Model



Wave Power



Conclusions

-Russel-Head erosion model does not compare well to observed erosion rate.

-Both Kubat/White and Wave power models compare well to observations.

Future Directions

-Continue to explore different erosion models and compare with observations.

-Isolate thermal and mechanical components of instantaneous erosion rate.

-Apply instantaneous erosion rate models to the coastal erosion model. Compare observed and predicted rate of erosion over the timeperiod of remote sensing observations.

-Use the coastal erosion model to explore effects of different conditions on the rate of erosion including increases in the duration of sea-ice free conditions, warming ocean temperatures, and changes in storm frequencies.

References

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