Exploring the controls on permafrost coastal bluff retreat rate, North Slope, Alaska

Barnhart, Katherine R. [1], Anderson, Robert S. [1,2], Overeem, Irina [2], Wobus, Cameron [3,4], Clow, Gary D.[5]

[1]Department of Geological Sciences, University of Colorado, Boulder [2]Institute of Arctic and Alpine Research, University of Colorado, Boulder
[3]Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder, CO
[4]Stratus Consulting, Inc., Boulder, CO [5]United States Geological Survey, Lakewood, CO

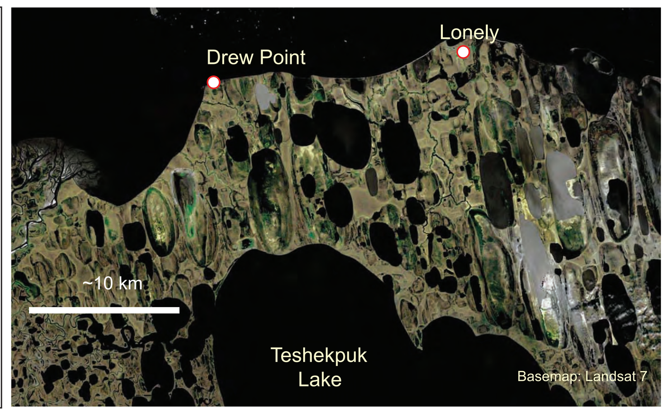
Abstract

The arctic is a region where modern surface warming has had significant effects on geomorphological processes. 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 (Mars and Houseknecht, 2007). Locally the erosion rate can reach 30 m/yr, with short term rates that are far greater than this. A robust understanding of the processes that control the rate of coastal erosion is required to predict response to a rapidly changing climate, with implications for sediment and carbon fluxes, oil field infrastructure, and animal habitat.

We model the evolution of the permafrost bluffs on the North Slope, constrained by time-lapse imagery, and by measurements of both the oceanic and atmospheric setting. During the sea ice-free season, relatively warm waters melt a notch into the ice-rich silt that comprises the bluffs. The bluffs ultimately fail by toppling of polygonal blocks bounded by mechanically weak ice-wedges. The toppled blocks then temporarily armor the coast against further attack. The annual retreat rate is controlled by the length of the sea ice-free season, water and air temperatures, and the wave history. Our model is forced by air temperature, water temperature, water level, and wave period, and is validated using field and remote sensing observations over a variety of timescales. The model is then used to explore the expected changes in coastal retreat rates for various climate change scenarios that include increases in the duration of sea-ice free conditions, warming ocean temperatures, and changes in storm frequencies.

Field Site

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



Time Lapse Imagery

Modified Iceberg Melting Rule

The iceberg melting rule of White et al. (1980) and Kubat et al. (2007) is modified based on the thermal properties of the permafrost.

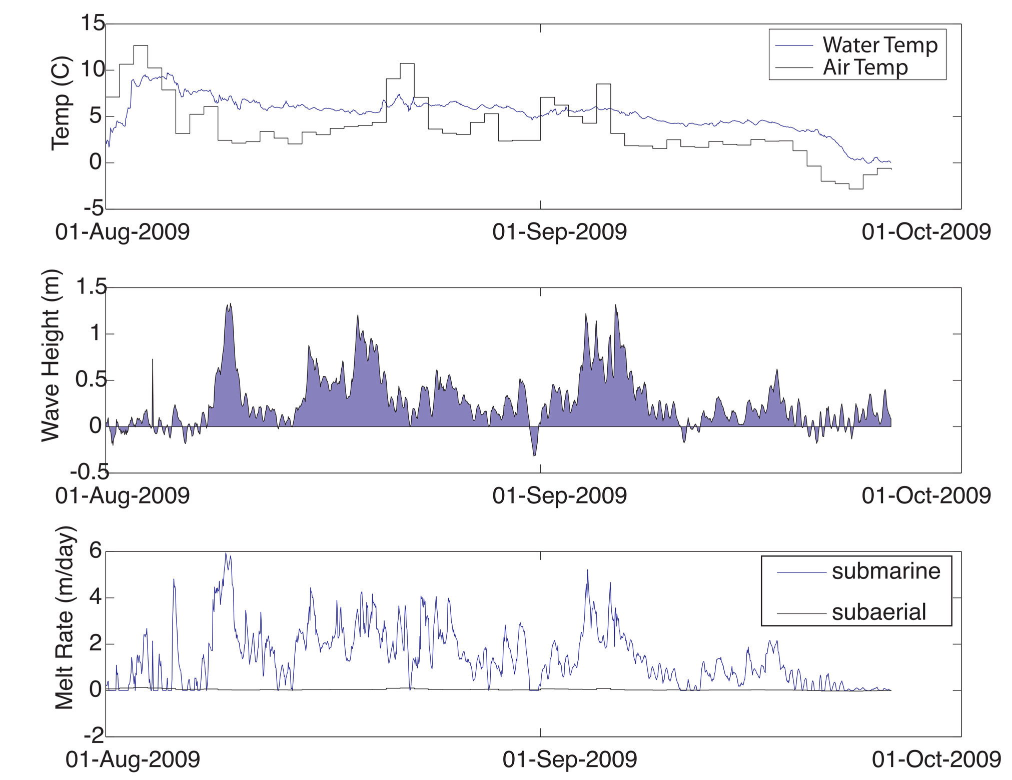
$$V_m = 0.00146\left(\frac{R}{H}\right)^{0.2}\frac{H}{\tau}\Delta T$$

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

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

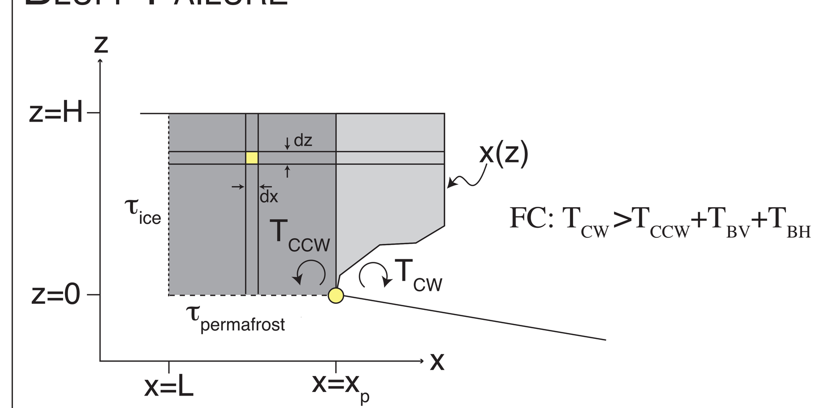
$$\beta = \frac{L\rho_{ice}W}{L\rho_{ice}W + \rho_{bulk}c_{p,bulk}\Delta T}$$

β, modification factor
W, ice content
ρ_{ice}, ρ_{bulk}, density of ice and bulk material (kg/m^3)
L, Latent heat (J/kg)
$C_{p,bulk}$, bulk heat capacity (J/(kg °C)



Torque Balance

Bluff Failure

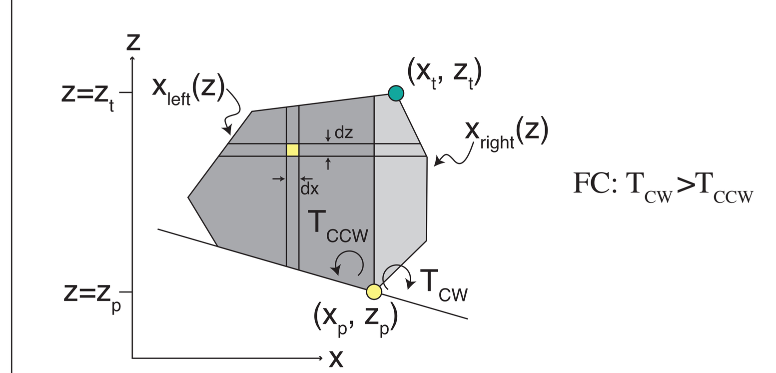


FC: $T_{CW} > T_{CCW} + T_{BV} + T_{BH}$

$$T_{CW} = \int_0^H \int_{x_p}^{x(z)} \rho g(x_p - x(z))\,dx\,dz \qquad T_{BH} = \int_L^{x_p} \tau_{permafrost}(x - x_p)\,dx$$

$$T_{CCW} = \int_0^H \int_L^{x_p} \rho g(x - x_p)\,dx\,dz \qquad T_{BV} = \int_0^H \tau_{ice}(L - x_p)\,dz$$

Block Topple

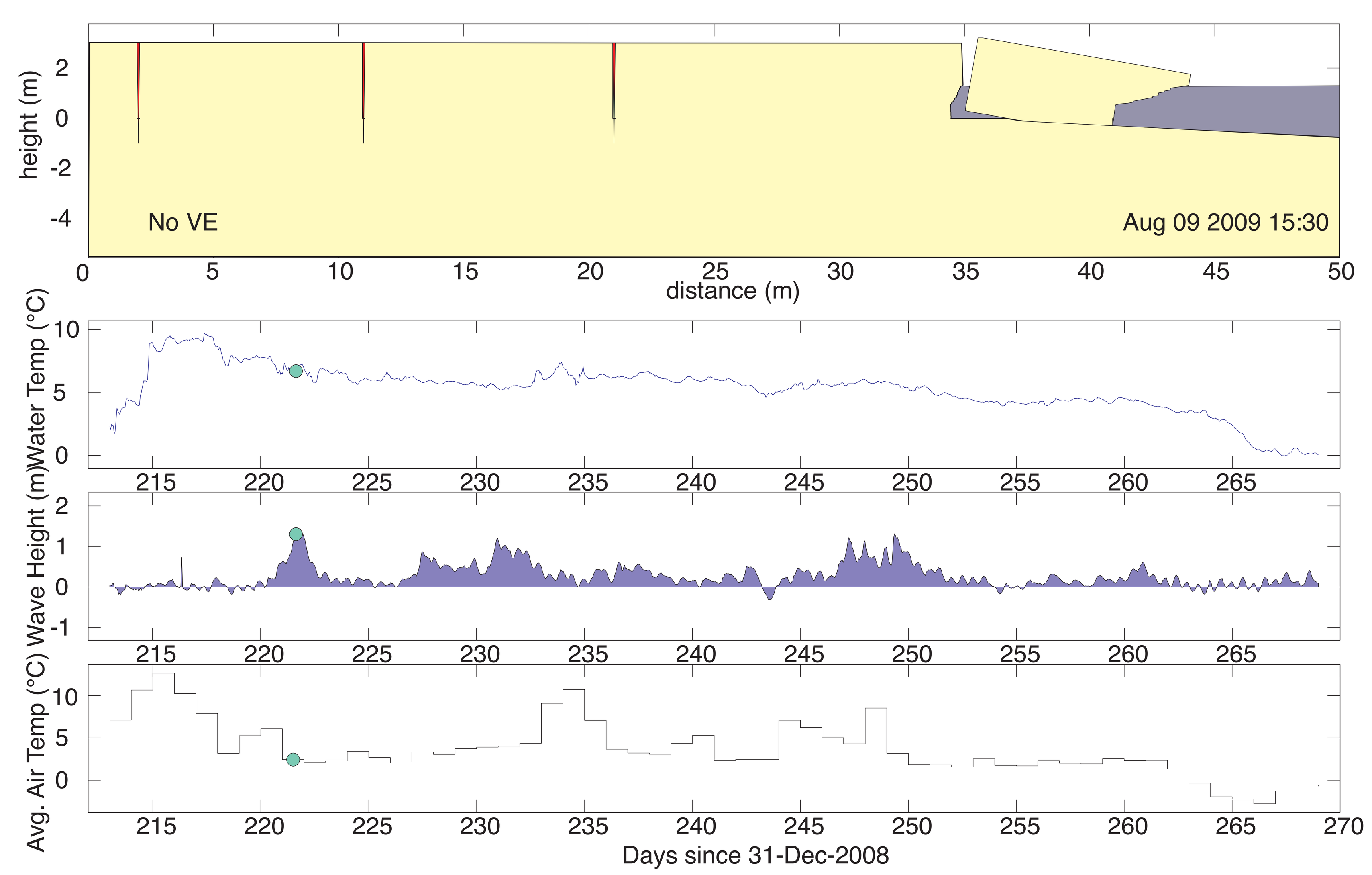


FC: $T_{CW} > T_{CCW}$

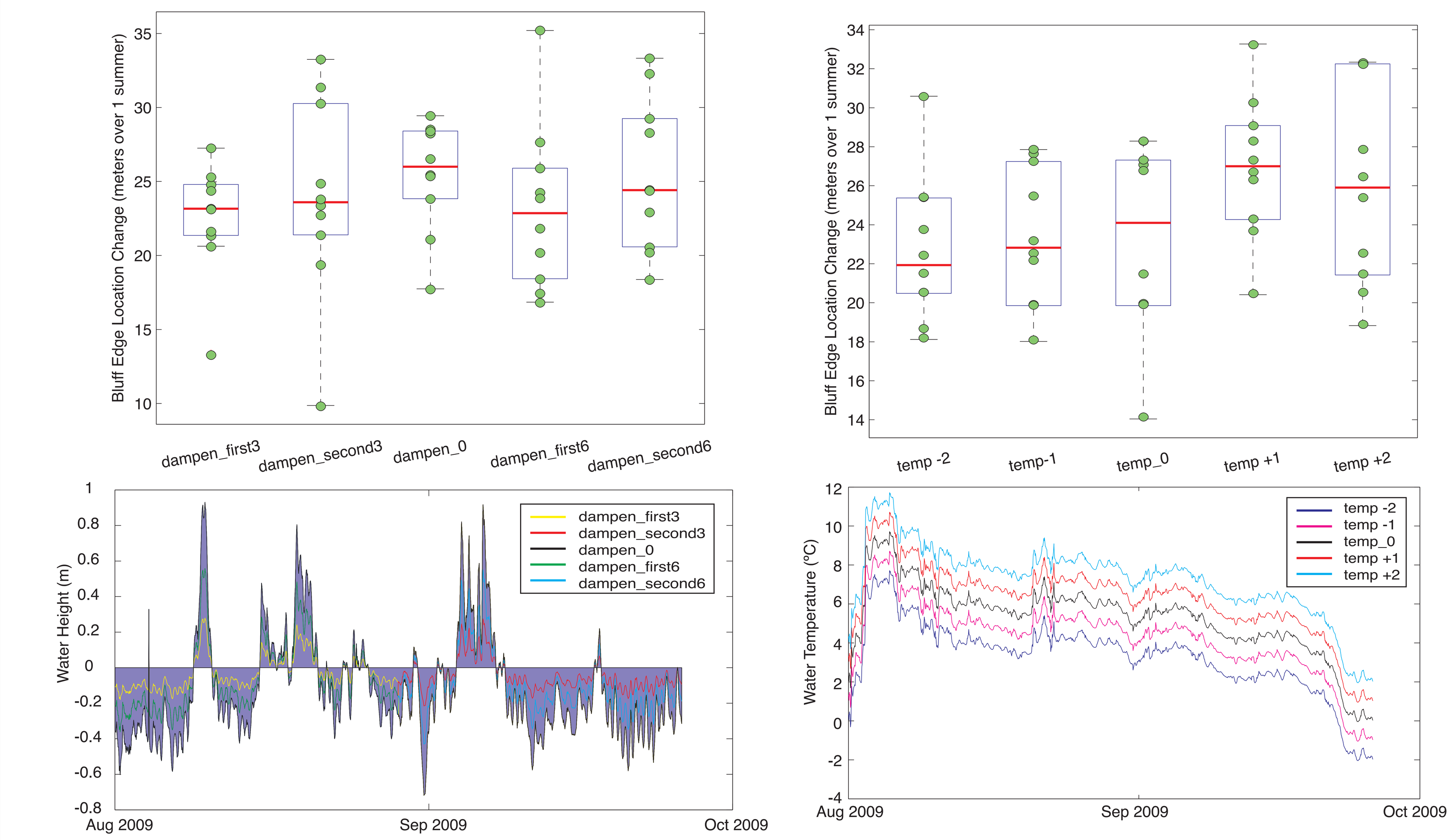
$$T_{CW} = \int_{z_p}^{z_t} \int_{x_p}^{x_{right}(z)} \rho g(x_p - x_{right}(z))\,dx\,dz$$

$$T_{CCW} = \int_{z_p}^{z_t} \int_{x_p}^{x_{left}(z)} \rho g(x_p - x_{left}(z))\,dx\,dz$$

Model Example



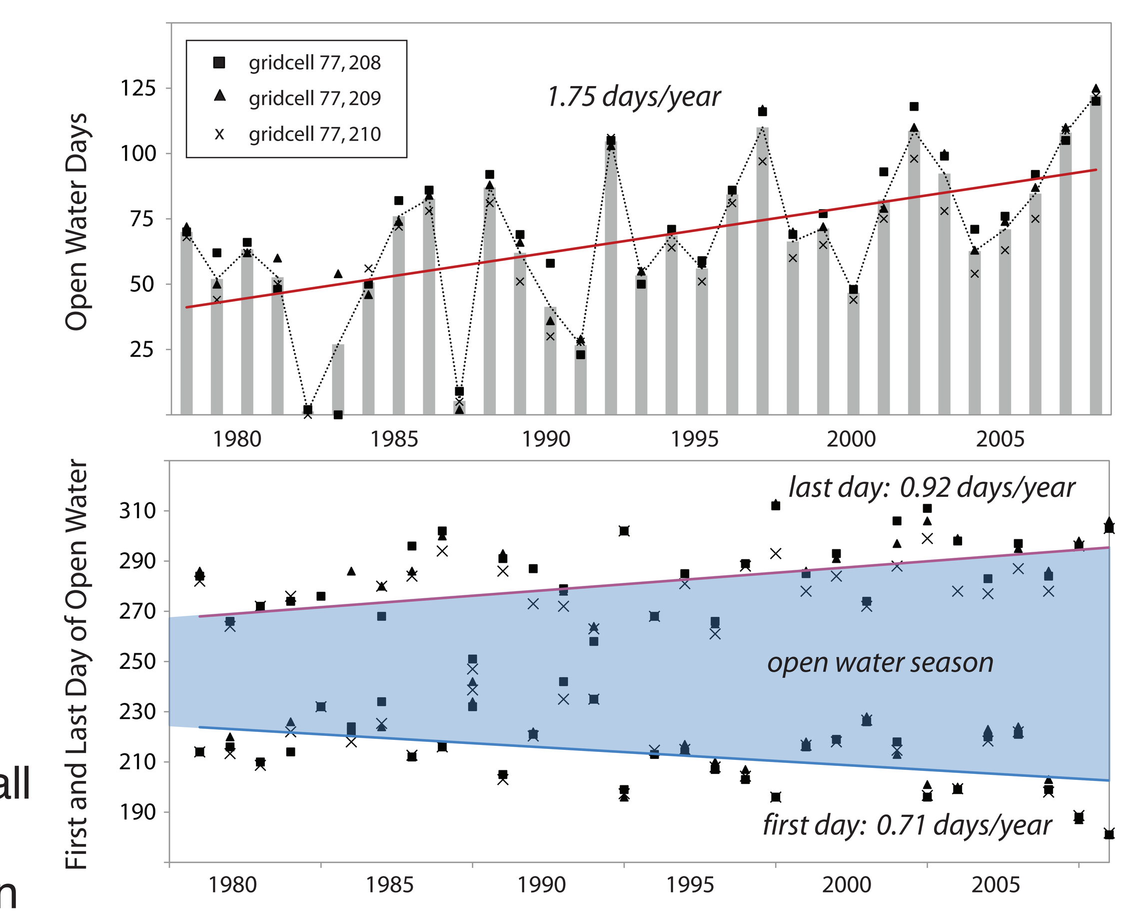
Preliminary Results



Future Directions

Explore the effects of a variety of scenarios on the retreat rate

- Increasing average sea surface temperatures
- Changing storm patterns
- Extending the duration of the sea-ice free season
  - Both into summer and fall
  - Tie surface water temperature to solar radiation
  - Simulate storms stochastically



Identify relationships between observations and forcing parameters
- wind, water level and wave heights
- SST and radiation

References

Kubat, I., Sayed, M., Savage, S., Carrieres, T., and Crocker, G. (2007) An Operational Iceberg Deterioration Model. Proceedings of the Sixteenth (2007) International Offshore and Polar Engineering Conference. Paper 2007-JSC-409, 2007-07-01.
Mars, J. C., and Houseknecht, D. W. (2007) Quantitative remote sensing study indicated doubling of coastal erosion rate in past 50 yr along a segment of the Arctic coast of Alaska. Geology v. 35; no. 7; p. 583-586.
White, F. M., Spaulding, M. L., and Gominho, L. (1980) Theoretical estimates of the various mechanisms involved in iceberg deterioration in the open ocean environment. Rep. CG-D-62-80, U.S. Coast Guard, Washington, D. C. 126 pp.

Acknowledgements

Adam LeWinter and EIS for time-lapse camera field support.
USGS and BLM for helicopter support.
Tim Stanton at NPS

Funding From ONR and NOPP