Smoothed Particle Hydrodynamics at the coastal interface of Earth, ocean, and ice

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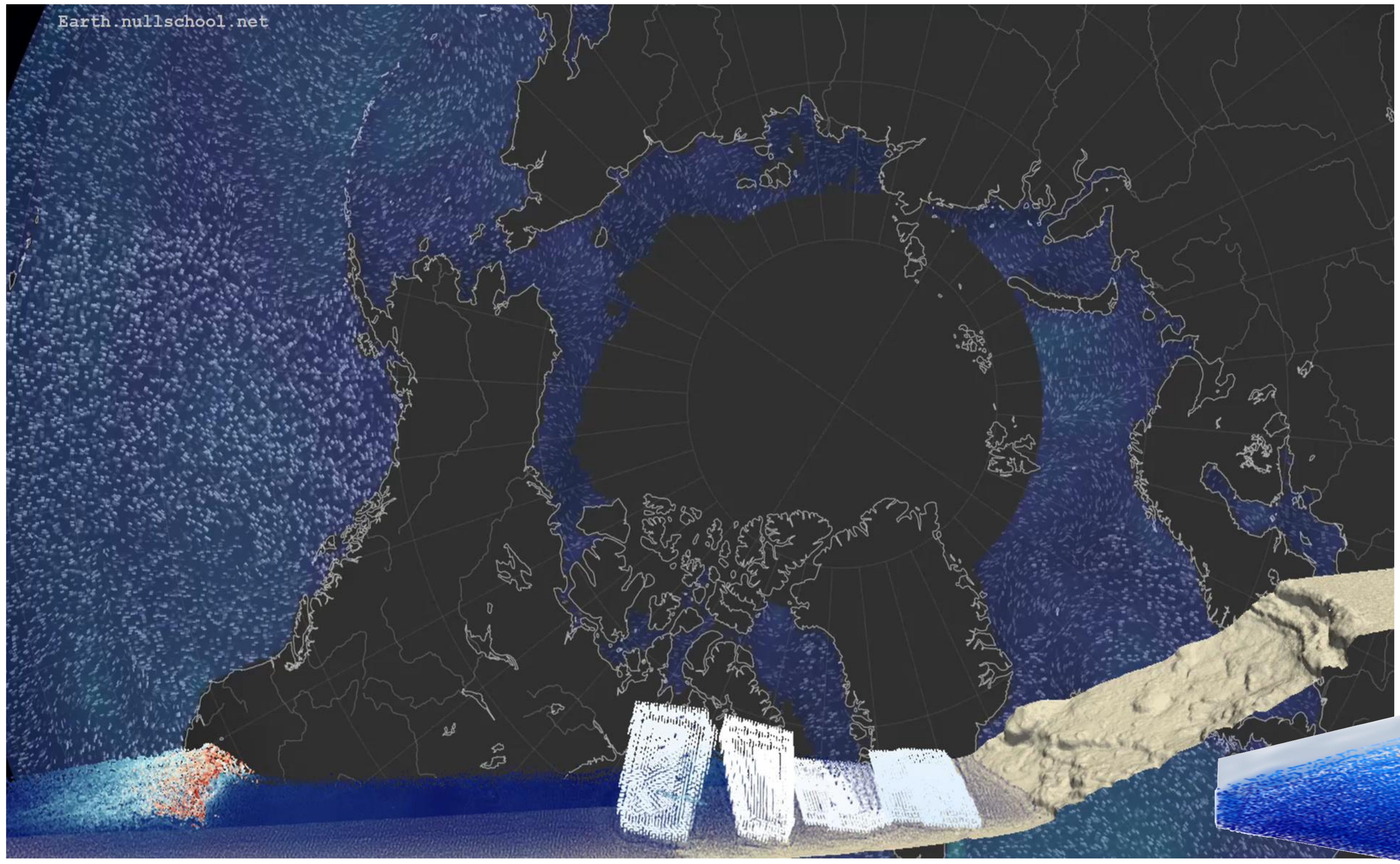
A Multiscale Problem



Abstract

Particle-based methods in computational fluid dynamics are capable of characterizing the propagation of the inertial terms and complex behavior of a fluid in low-viscosity systems onto an interface with highly viscous or solid materials, providing a high resolution window into fluid dynamics within environments that are fundamentally defined by fluid-solid interaction. The rate limiting feedbacks of wave action, erosion and sediment transport are a multiscale problem, involving kilometer-scale climate forcing and local, submeter Earth responses. We use real-world inputs of dynamic water levels at the mesoscale to drive local particle-based wave solutions towards natural coastal landforms effectively coupling the multiscale transfer of forces produced by topographic relief, wave action and ice collisions. 3D temporal solutions of nearshore currents at multiple scales make it possible to handle the specifics of fluid-solid interactions as the basis for training algorithms and subsequent expansion to larger regions.

Overview

>Coastal erosion is a multiscale problem where kilometer scale environmental forcings exploit sub-meter localized weaknesses to effect a great deal of morphological change.

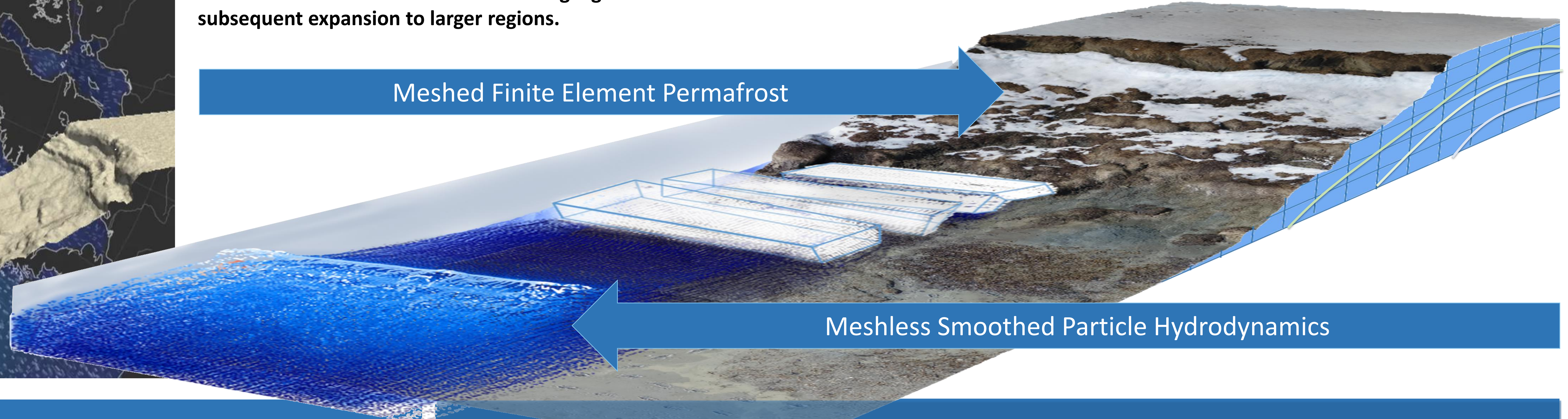
>Rapid erosion of Arctic permafrost coast due to a warming Arctic environment represents the greatest change to Earth's surface in the last 15,000 years.

>This coastal retreat presents an existential hazard to coastal ecosystems, communities and infrastructure across the Arctic.

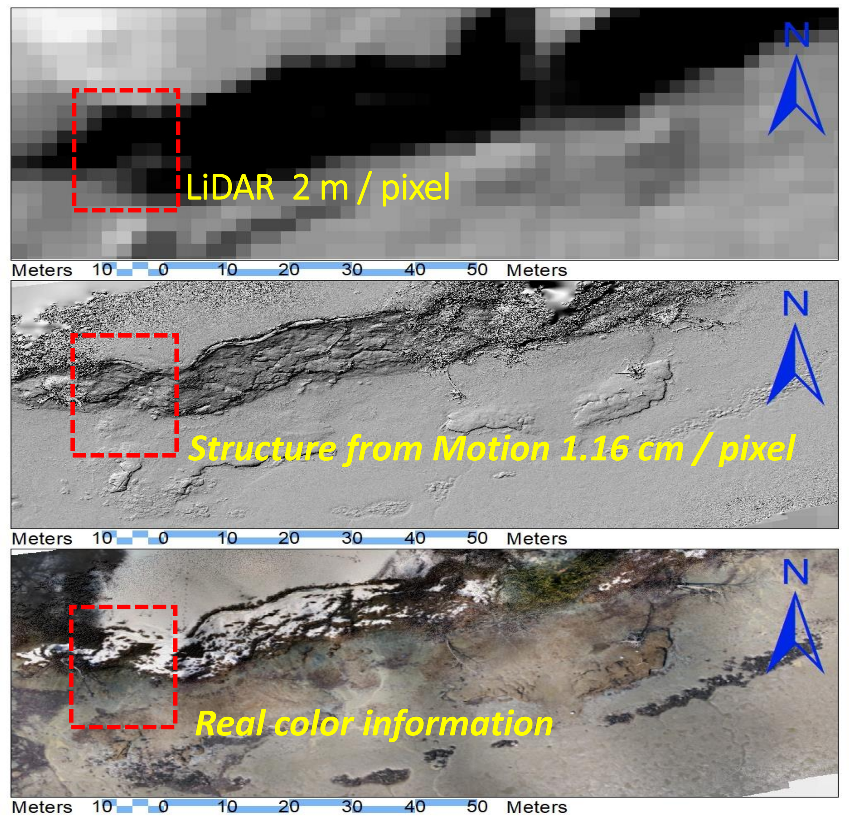
>The primary drivers of coastal permafrost erosion have long been recognized as products of increasing regional air and ocean temperatures and associated, increasing wave energies along bluffs (e.g. Novikova et al., 2018).

>Permafrost erosion is highly episodic with 40% of erosion occurring during less than 5% of the sea ice-free season (Barnhart et al., 2014). These episodes are directly related to complex nearshore wave events and fluid-solid interactions at the interface of land and sea not easily captured with traditional modeling methods.

> Our Geodynamics facility has developed GPU-accelerated software for modeling fluid-solid dynamics of ice/ocean/atmosphere environments via coupling of SPH and FEM.

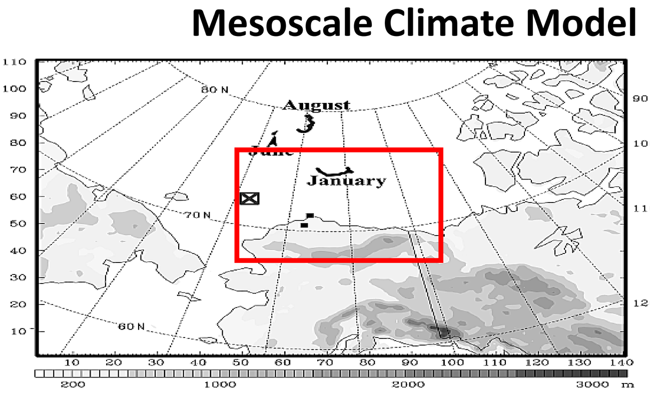


High-resolution surface products obtained by *Structure from Motion* capture natural coastal landforms

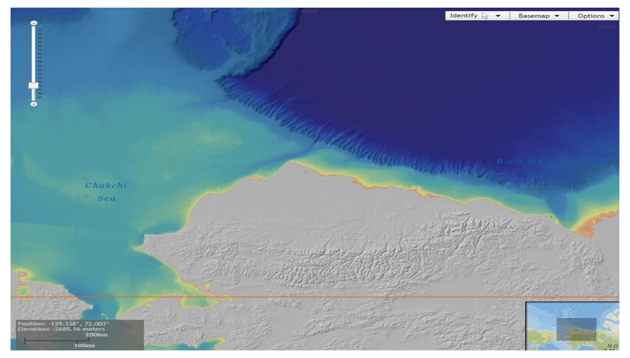


Mesoscale modeling of both atmospheric and oceanic forcings drive localized solutions

Mesoscale Climate Model



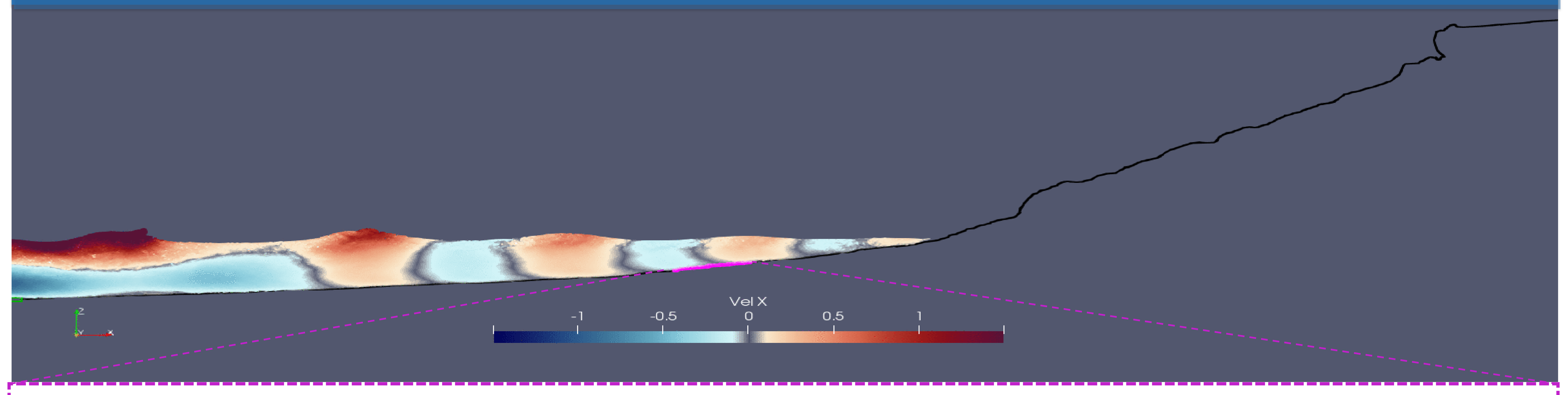
Mesoscale Ocean Model

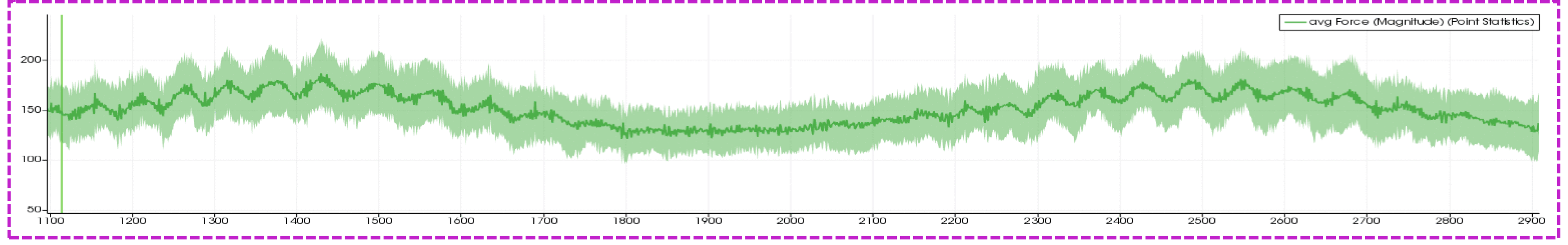


From off shore

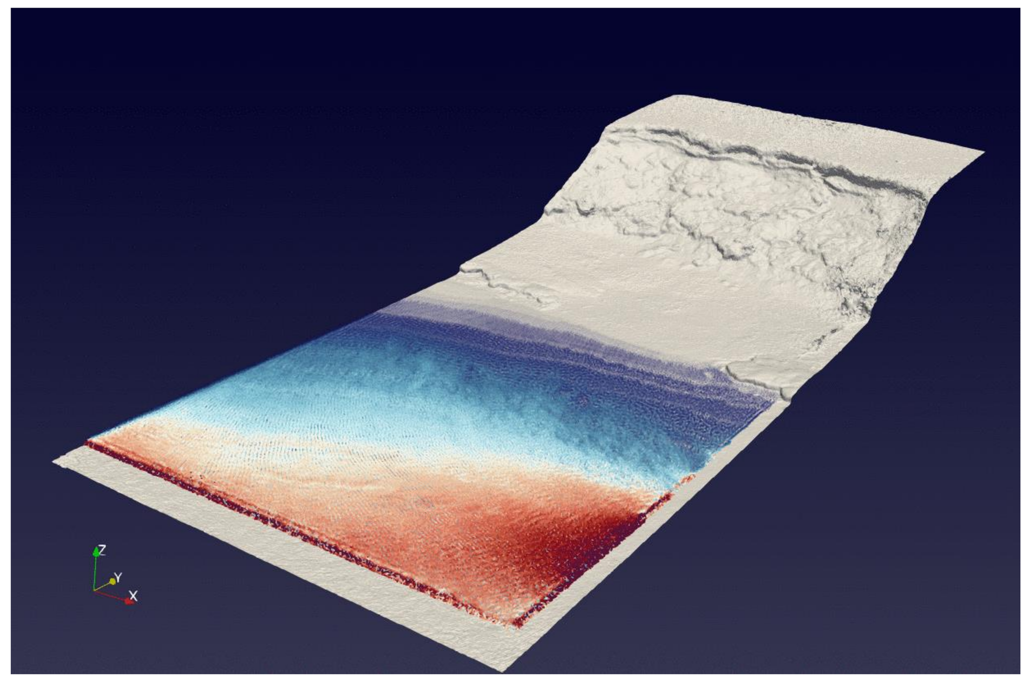
To on land

Particle based methods allow for the propagation of inertial terms and the breaking of waves





Hybrid Modeling



>Captures complex fluid-solid interactions critical to sediment-transport and niche erosion.

>*Physics-Based Model:* we have coupled a 3D meshed finite element solid (FEM) with a meshless Smoothed Particle Hydrodynamics fluid (SPH) model.

>The SPH model (DualSPHysics, Crespo et al., 2015). approximates the 3D Navier Stokes equations using millions of particles at centimeter spacing to calculate forces associated with coastal wave impacts. The high resolution of SPH permits us to model the complex ocean-sea ice-permafrost bluff interactions. Mesoscale ocean condition and regional wave models inform the transition from deep-water to shallow-water conditions (e.g. Telemac3D, Moulinec et al., 2011).

>Our FEM model solves for earth response to static and dynamic stresses with material properties defined by the transient thermal dependence of permafrost strength in a warming regional climate. Mesoscale climate modeling of surface temperature and precipitation conditions inform fluctuations in material strengths (e.g. Polar WRF, Bromwich et al., 2009).

Future Work

Machine learning application for a predictive understanding of multiscale coastal change

The physics based numerical modeling described here provides a strong foundation for the training of machine-learning algorithms when paired with remote sensing , field data, and analysis of predictive variables such as topology and transient environmental conditions.

References

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Acknowledgements

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