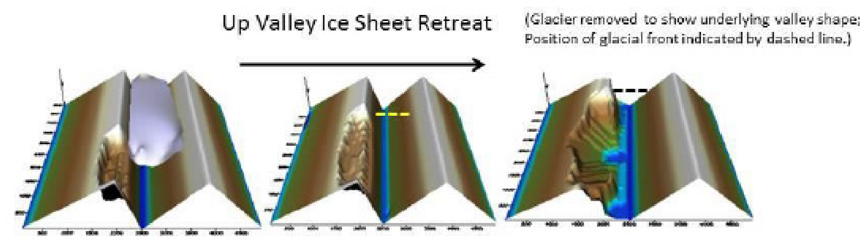
Ferm GeoPRISMS: Retreating Glacier in Homogeneous Valley

Peter Koons (with contributions from Sean Birkel)

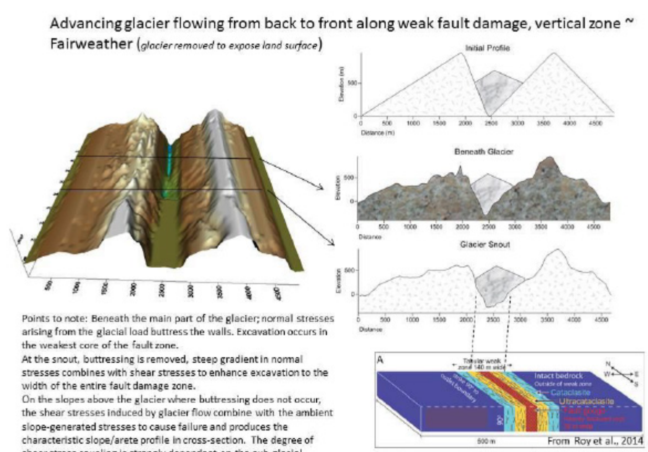
Reduction of ice buttressing constitutes the major influence of glacier wasting. Over steepening at the sides along the valley floor by excavation during advance, together with concomitant reduction of strength due to strain damage, causes valley walls to fail immediately on shallow and deep-seated failure planes, consequently, contributing a large sediment pulse associated with glacial retreat. In the high stress, post -buttress environment, time-dependent strength reduction and pore pressure fluctuation typically leads to landslide decay over centuries following glacier retreat. These regions are particularly susceptible to failure from strength/stress ratio (Σ/τ) perturbations from seismic induced dynamic stress contributions.

Advancing Glacier in a Fault Damage Zone controlled valley (Model Fairweather Fault)

An advancing glacier produces a transient perturbation to the stress state of the bedrock with an increase at the snout of down-valley normal and shear component stresses (σ_{yy}, τ_{yz}) and a steep gradient in the vertical stress (σ_{zz}), both causing a decrease in strength/stress ratio (Σ/τ). Along the valley sides, the transient stress pulse is influenced by the increase in Σ/τ due to the glacial buttress, but, concurrently, valley-parallel shear introduces σ_{yx} and σ_{yy}, reducing Σ/τ. The net Σ/τ pattern is one of failure ($\Sigma/\tau<1$) at the snout where concentrations of glacier induced stresses coincide with topographic stress maxima in a region already close to failure. The result of this stress concentration is to allow significant bulldozing/excavation in front of the snout. This is accompanied by stability on the lower lateral sides of the glacier ($\Sigma/\tau>1$), and failure ($\Sigma/\tau<1$) at the upper margins of the glacial sides.



Retreating Glacier
Notes: Reduction of ice buttressing constitutes the major influence of glacier wasting. Over-steepening at the sides along the valley floor by excavation during advance, together with concomitant reduction of strength due to strain damage, causes valley walls to fail immediately on shallow and deep-seated failure planes. In the high stress, post -buttress environment, time-dependent strength reduction and pore pressure fluctuation typically leads to landslide decay over centuries following glacier retreat. These regions are particularly susceptible to failure from perturbations to the local Strength/Stress ratio from seismic-induced dynamic stress contributions (co-seismic landslides).



Fault damage rheological model for 3D mechanical solution

Some Background to FERM: Current models of Earth surface evolution and of Earth geodynamics have been stunningly successful in producing a general description of topographic development as partial functions of fluid transport and topographic slope. These standard models, which focus on the change of elevation (h) with time (dh/dt), rely on fluid-related erosion laws (fluvial, glacial, coastal) to apportion some fraction of channel incision as a function of fluid flux, with hillslope expressions based primarily on linear and non-linear diffusion laws. A basic limitation in the application of these traditional models arises from the use of multiple, different physical descriptions for the response of any Earth element depending upon the ambient erosion regime. For instance, terrain influenced by fluvial processes is modeled by a different set of mechanics than the same terrain influenced by a topographic slope, or by glacial, or by coastal processes, which in turn differ from the widely-used tectonic descriptions for that same Earth element.

By recognizing that an element of Earth consists of the same material, independently of what processes act on it, we draw together the various physical descriptions of surface evolution and tectonic evolution into a single, Earth-centric framework, the Failure Earth Response Model (FERM), that unifies the physical description of dynamics within and between the geomorphic

and tectonic domains. FERM is constructed on the two, basic assumptions about the three-dimensional stress state and rheological memory:

I) Material displacement, whether tectonic or geomorphic in origin, at or below Earth's surface, is driven by local forces overcoming local resistance;

II) Large displacements, whether tectonic or geomorphic in origin, irreversibly alter Earth material properties enhancing a long term strain memory mapped into the topography. i.e. the earth is a memory material

The FERM formulation with its explicit inclusion of material history, geomorphic and tectonic processes, including seismic accelerations and pore pressure fluctuations, allows closer examination of tectonic:geomorphic interactions and predicts evolutionary trends that differ significantly from the traditional approach.

Contributions from Sean Birkel

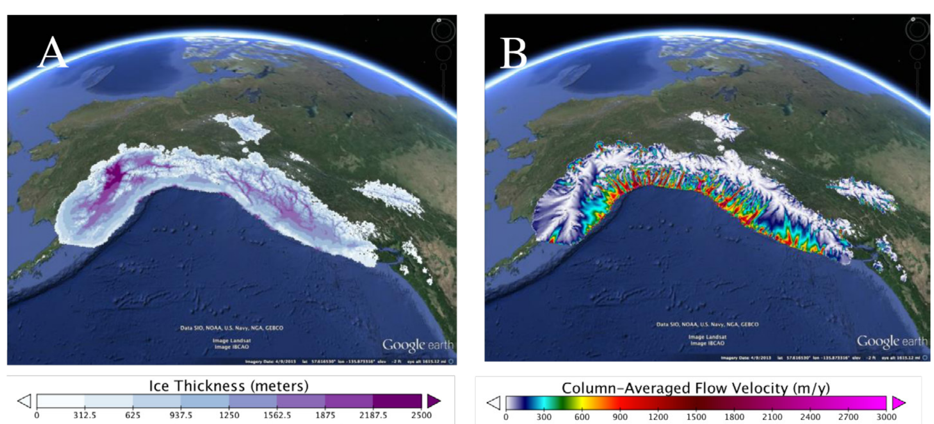
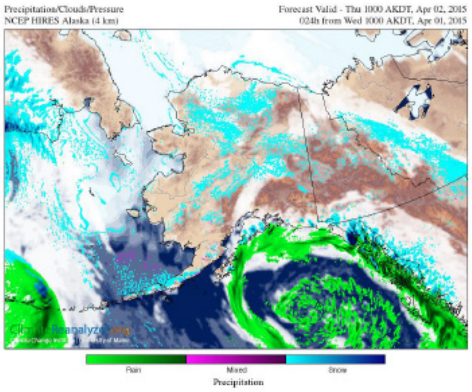


Figure 1. University of Maine Ice Sheet Model (UMISM) simulation of the Cordilleran Ice Sheet during the Last Glacial Maximum (domain excludes the Laurentide Ice Sheet) shown in Google Earth. UMISM calculates both steady state and transient solutions and produces output parameters including ice thickness (A), column-averaged flow velocity (B), basal water production, and bed depression that can be used to derive erosion rates and sediment transport. UMISM solves ice flow using a shallow-ice approximation that ignores longitudinal stresses. Solutions are generally valid to ~ 1 km horizontal grid resolution. The benefit to shallow ice models is that they run orders of magnitude faster than those that incorporate full Stokes solutions. Our strategy is to use UMISM for big picture problem solving, and then to focus on areas of interest using higher order solutions that are possible in software such as FLAC3D. Part of the GeoPRISMS work has involved co-PI Birkel adapting UMISM (a 25-year old Fortran program) to be more readily accessible for student use. This includes the implementation of gridded netCDF output, and improvements to the model preprocessor written in MATLAB.

2A



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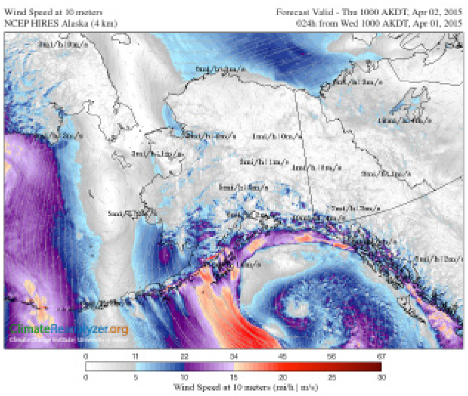

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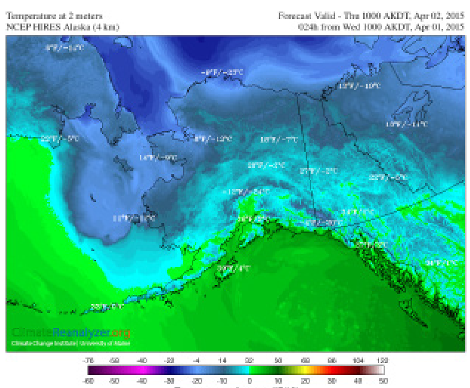
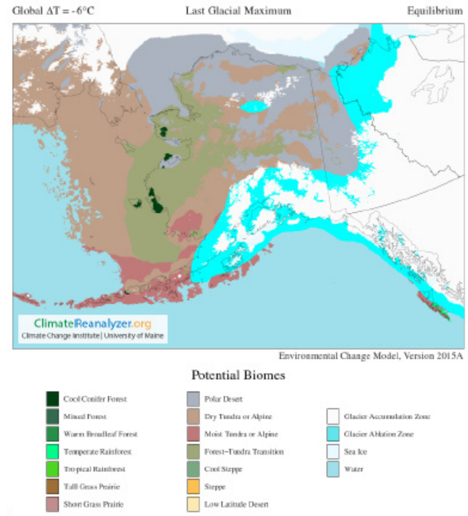


Figure 2. Co-PI Birkel runs a website called Climate Reanalyzer (http://cci-reanalyzer.org), which is a visualization framework for reanalysis, GCM, and weather forecast models. Climate Reanalyzer receives >700 users each day. The website includes daily-updated 48-hour forecast graphics for Alaska from the 4km NCEP NAM-WRF model framework (see [A] precipitation and cloudcover; [B] wind at 10 meters, and [C] temperature at 2-meters). High resolution daily forecast graphics, now archived on our servers for 2013-2014, have provided valuable information about Alaskan climate and the spatial distribution of precipitation that is integral to understanding climate-erosion linkages across the region.

3A



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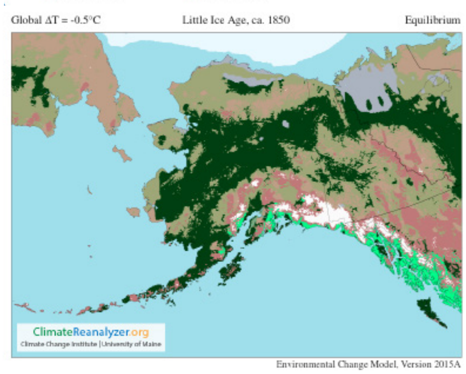

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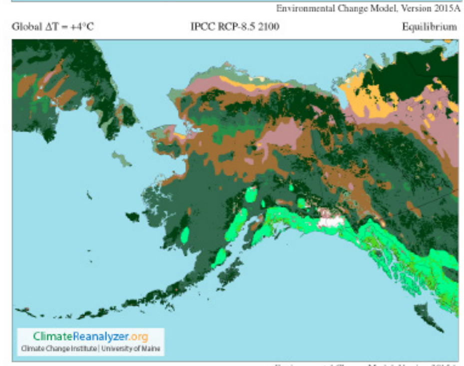

Figure 3. Co-PI Birkel is developing a teaching resource relevant to GeoPRISMS called the Environmental Change Model (ECM) (http://cci-reanalyzer.org/ECM). ECM is a program that estimates snow/ice mass balance and potential biomes across the globe for climate boundary conditions ranging from Last Glacial Maximum (LGM; ~ 20,0000 years ago) to 2100 CE. Using the ECM, students can run simulations to see the equilibrium response of biomes to different climate boundary conditions. Shown below are potential biome solutions for Alaska for the (A) Last Glacial Maximum, (B) Little Ice Age, and (C) 2100 CE. Solutions are calculated from gridded inputs of monthly temperature and precipitation using a degree day solver and biome rubric. Boundary conditions for a given experiment are derived by blending reanalysis (modern climate) and general circulation model (GCM; past/future climate) climatologies. The ratio of reanalysis to past or future climate depends on a user-selected global temperature departure value, ΔT. For the LGM, ΔT = -6 °C; for modern climate, ΔT = 0 °C; for 2100, ΔT = +4 °C. And so on.The mass balance algorithm used in the ECM is also used in the UMaine Ice Sheet Model Alaska simulations. Documentation is available on the website, and a publication is in preparation.