3D geodynamic and geomorphic modelling of the Alaska/Aleutian Margin – STEEP and GeoPRISMS

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Key SCD questions addressed:
(2) How does deformation across the subduction plate boundary evolve in space and time, through the seismic cycle and beyond?
(7) What are the feedbacks between surface processes and subduction zone mechanics and dynamics?

Key types of data/infrastructure: coupled three-dimensional geodynamic and geomorphic modelling, topography, seismic stratigraphy, geochronology.

Overview – The Alaska/Aleutian Margin is a premier location in which to investigate subduction related deformation and surface processes:subduction zone feedbacks. Much of what will be investigated here also has direct implications for the Cascadia and the Hikurangi margins, the two other GeoPRISMS SCD focus sites. The Continental Dynamics funded STEEP (ST Elias Erosion-tectonics Project) has already significantly influenced thinking on both deformation styles of flat-slab subduction and interactions between tectonics and erosion at this boundary (Berger et al., 2008; Koons et al., 2010). The GeoPRISMS initiative and the choice of the Alaska/Aleutian Margin as one of the focus sites give us the opportunity to build on the results of STEEP, focusing on higher resolution spatial scales and shorter temporal scales such as a glacial advance and retreat cycles.

Previous results – 3D models of the southern Alaskan orogen (Koons et al., 2010) make robust first-order predictions of style and time of deformation, and illustrate connections between an inlet orogen (the Chugach-St. Elias Mountains), an outlet orogen (Alaska Range), an obliquely convergent lateral orogen (Fairweather Ranges), and subduction basins (Cook Inlet-Copper River basin system) (Fig. 1). The models suggest all of these elements are related to the flat-slab, corner geometry of the Yakutat collision. Additionally, subduction quenching due to rapid advection of cooler material into the orogen produces a high-strength frictional sliver along the subduction interface that controls the position of the inlet orogen. Separation of the inlet and outlet orogens is enhanced by increasing the differences between their respective thermal regimes. At the mesoscale (< 50 km^2), models constrained by observations capture most of the variance in the signal of accretionary tectonics in the southern Alaska plate corner. They predict the formation of strain maxima in the tectonic corner, spatially associated with the Seward Glacier area. Inclusion of natural surface topography and erosion alter these tectonically developed strain patterns and capture the evolution of local topography, observed fault zones, and cooling age patterns. In particular, the models reveal focused uplift that perturbs the thermal structure in the tectonic corner to the east of the present high topography. This pattern of focused strain demonstrates the dominant control of the tectonic geometry on the focusing of strain and the secondary influence of topographic load and erosion.

Opportunities – 3D geodynamic modelling has the potential to bring together a variety of geological and geophysical data and interpretations into an overarching framework that can then be used to constrain ideas and make testable predictions. We identify three topics where geodynamic and coupled geomorphic modelling can address key SCD science questions.

a) *Evolution of deformation in space and time* – With increasingly high resolution data to constrain our models we can expand upon macro- and meso-scale models of the Alaska/Aleutian Margin. Possible modelling targets include the rheological characteristics of the megathrust, thermal evolution of the down going slab and overriding plate, long-term evolution (>10 Ma) of the plate boundary and developing embedded models with higher resolution geological, geophysical and topographic inputs to explore components of the system. We can also now use mesoscale atmospheric models to condition the surface boundary.

b) *Feedbacks between tectonic driven processes and surface processes* – Sophisticated models are available for both crustal and surface processes, however, a complete description of an active landscape requires coupling between them (Koons et al., 2011). At present, available coupling is rudimentary at best. Consideration of temporal and spatial variability in material erodibility is currently lacking in most surface process models. Application of strain-softening material to lithosphere-scale models of the central Southern Alps of New Zealand (Fig. 2) and Namche Barwa in the Eastern Syntaxis of the Himalayan collision illustrate the time dependent variability of material strength fields within actively deforming regions (Koons et al., 2011). Application of strain-softening materials coupled to glacially driven erosion should be a next step in geodynamic/geomorphological models of the SE Alaska margin, facilitated by our established working relationship with the Community Surface Dynamics Modelling System (CSDMS) Group.

c) *Short term vs long term strain* Identification of long period great earthquakes is problematic as on many margins the last event occurred prior to reliable historic records. Although some structures are clearly evident through transitional paleoseismic studies, the signals of many structures reside in the permanent strain fields over the past 10 kyr. As a community we must add to our tools that aid identification of characteristic geological/topographic signals in the landscape that can be used to identify locations of great earthquakes that have occurred outside the historic record. Linking kinematics of the permanent strain field to high-frequency topography using the evolving geomorphic theory of tectonic:surface coupling can provide constraints on timing and location of low-frequency, great earthquakes.

Conclusion – 3D coupled geodynamic/geomorphic modelling will be an important tool for GeoPRISMS to utilise at all three of its focus sites. Models of the Alaska/Aleutian Margin will build on the significant body of modelling work carried out by STEEP. They will focus on shorter spatial and temporal scales, constrained by the large volume of geological and geophysical data available for this margin and be guided by the evolving geomorphic theory.

References:

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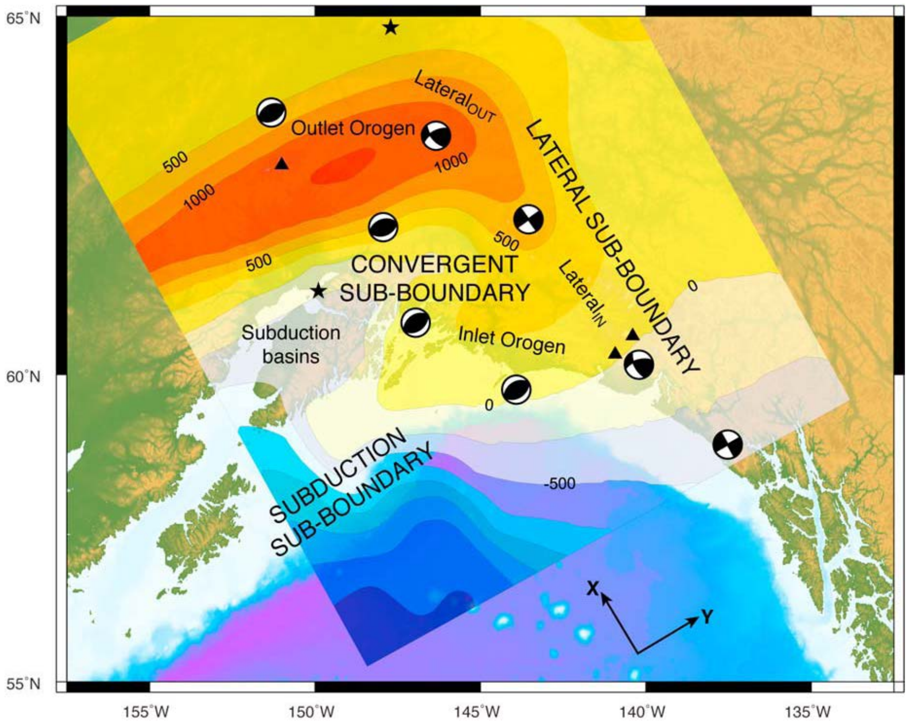

Fig. 1. Diagrammatic sketch of kinematic elements from a 3D geodyanamic model of SE Alaska (Koons et al., 2010). Contours of vertical displacement field in metres. Two orogens form, the Outlet, corresponds to the Alaska Range, and the Inlet, corresponds to the Chugach/St Elias Mountains.

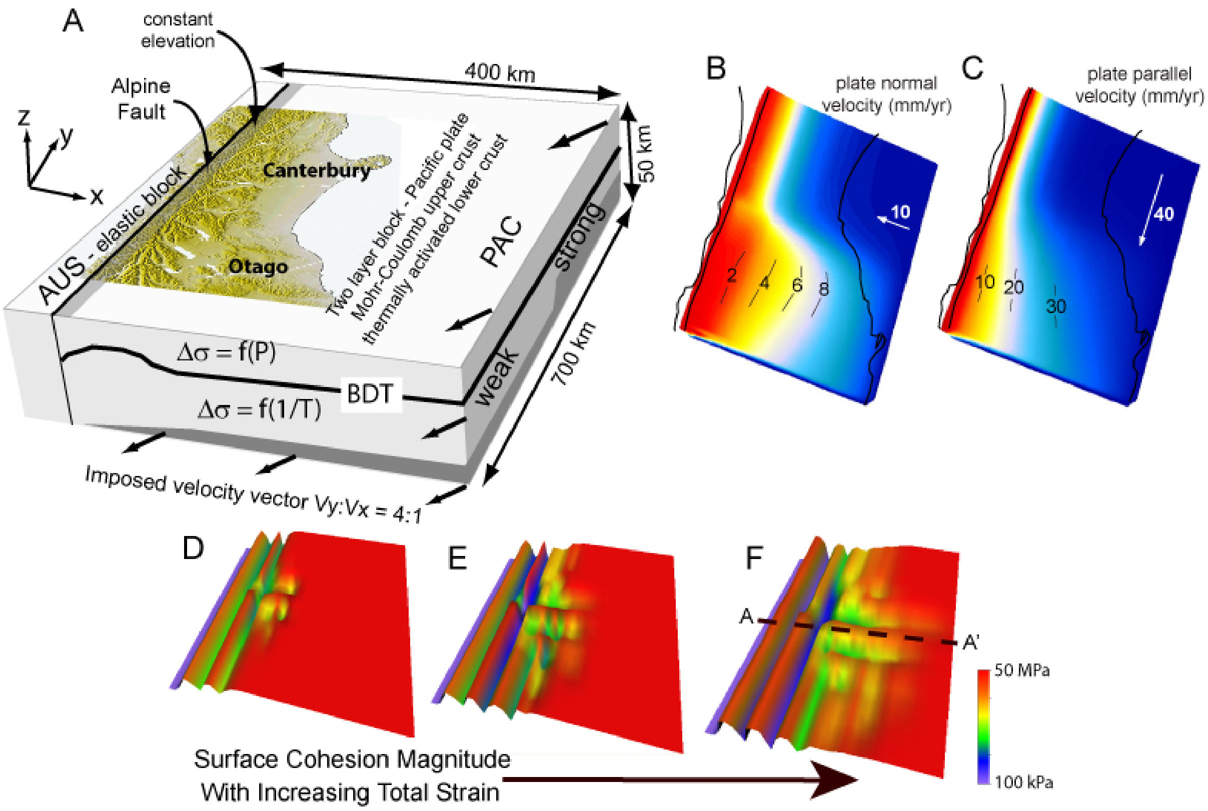

Fig. 2: From Koons et al. (2011). A: Geometry and boundary conditions of Southern Alps model after Upton et al. (2009). B & C: plate normal and perpendicular velocity for model with a time-invariant upper crust. D, E, F: Cohesion with increasing strain for model with time-variant friction and cohesion-softening upper crust (red is intact rock with ϕ=35°C=50 MPa, purple is weakened rock mass with ϕ=15° and C=100 kPa at 3% shear strain).