Using sea level histories to constrain fluviodeltaic evolution: An integrated approach connecting glacial cycling to global climate shifts

Motivation

While a suite of parameters play a role in river delta formation, studies show that sea-level change constitutes an essential driving agent for fluvial and deltaic evolution. Sea-level fluctuations adjust shorelines, which in turn control fluvial system channel length and number of distributary channels. Previous research has investigated the relation between fluviodeltaic systems and sea-level change by creating theoretical models for timing the response of rivers to sea-level rise or fall *Swenson* [2005] and for quantifying aggradation or progradation rates according to sea level, using these rates to predict river avulsion and large-scale branching *Jerolmack* [2009]. Moreover, a connection has been established between the geographic variability of post-glacial sea level rise and the delta type formation in a regional study of the western Siberian Arctic coast *Whitehouse et al.* [2007].

Understanding the influence of sea level on fluvial systems is of interest to a range of fields. Most directly, stratigraphers and sedimentologists can utilize this information in geological interpretations of ancient river deposits in order to infer paleo sea-level histories. The response of deltaic systems to sea-level rise is also of critical importance to civil planners today in terms of predicting and managing fluvial fluctuations near urban populations. Furthermore, a more complete understanding of fluvial response to sea level can elucidate changes in the global ocean chemistry cycle, as sediment dispersion in river deltas constitutes nearly all terrestrial input of nutrients to shallow marine environments. Biotic processes and burial on the continental margin, controlled by this influx of nutrients, have direct ties to global atmospheric chemistry. Through the connection of sea level to rivers it is possible to place the impact of ice age cycling on local fluvial environments into a global-scale picture of the Earth's climate cycle.

Proposal: I propose to couple a state-of-the-art model of sea level change incorporating glacial isostatic adjustment over the last glacial cycle *Dalca et al.* [2013] to a surface process model of fluviodeltaic development in order to investigate modern delta evolutionary trajectories and to compare these against a global database of delta morphologies.

Nearly all previous theoretical investigations exploring the impact of sea level on delta morphology employ overly simplistic models of sea level change, controlling shoreline evolution with a globally uniform (i.e eustatic) sea level history. However, sea level change since the last glacial maximum is characterized by a complex spatial geometry and temporal history reflecting surface mass (ice sheets and ocean) load variation over glacial cycles. Therefore, to quantify delta morphological response it is necessary to consider local sea level over the full time history of fluvial evolution. Using the post-glacial sea level model in conjunction with a surface process model predicting fluvial properties, such as avulsion and branching, it will be possible to track river delta evolution and test theoretical hypotheses on fluvial response to sea-level against present day delta morphologies. A better constraint on how deltaic systems evolved in response to ice age cycles will, in turn, enable us to quantify changes in sediment flux and burial in oceans over these same periods. These influx changes will then permit us to link glacial cycles to ocean, and, thus, atmospheric chemistry, as terrigenous nutrients play a major role in the shallow marine geochemical cycle.

Methods

Glacio-isostatic adjustment models of sea level change consider deformational, rotational and gravitational perturbations to the Earth associated with ice growth and ablation. These models incorporate viscoelastic deformation of the solid Earth, time-varying shoreline geometries and perimeters of grounded or marine-based ice sheets, feedback of the Earth rotation vector, and the redistribution, through erosion and deposition, of sediment *Dalca et al.* [2013]. Two inputs are required: (1) an Earth structure model with either a depth varying viscosity of the mantle, or, in more complex regions, the 3-D mantle viscosity field, along with the thickness of the elastic lithosphere and crust; and (2) the space-time geometry of ice sheet history. The solution of the governing sea level equation is achieved iteratively such that final topography matches present day topography, yielding a full gravitationally self-consistent reconstruction of sea level (and topography) changes over the past 120 kyr.

I will perform sea-level simulations under the guidance of Prof. Jerry Mitrovica and couple the output to a surface process model of fluviodeltaic systems developed by Prof. Taylor Perron (MIT) in order to examine modern world deltas and assess their developmental dependence on spatially accurate sea level fluctuation. Through Prof. Perron's supervision, I will access a modern database of delta characteristics with information such as the number and width of distributary channels, deltaic gradient, and sediment discharge, using a classification system to categorize this global database of deltas. I will then explore whether there is a significant global correlation between delta type and the local sea level history predicted by the glacioisostatic adjustment modeling.

I envision this project as the first step in a larger scale Earth systems project, which ultimately seeks to comprehend how ice age cycles are reflected in ocean geochemical shifts through the intermediary continental margin. The same sea level models constructed for delta analysis may be utilized to quantify the time and space-varying inundation and exposure of continental shelves over ice age cycle history. Using results from the delta project, it will be possible to quantify fluctuations in riverine chemistry input due to sea level change. In collaboration with Prof. David Johnston, I will construct box models that realistically quantify shifts in shallow marine chemistry cycles due to sea-level controlled depths and shorelines, in addition to fluctuating terrigenous nutrient influx.

Broader Impact

The proposed project enables the advancement of scientific knowledge by establishing constraints on fluviodeltaic evolution through sea level history. These findings allow the investigation of both past and future: building a framework for geological interpretations of ancient fluvial systems while providing a measure of sensitivity of rivers to sea level change with implications for future predictions. Ultimately this project seeks to address the impact of ice age cycles as feedback on the climate system by quantifying the control of sea level on ocean chemistry cycles. These proposed investigations, focusing on coupling local processes to the global climate system, are thus of key importance to both the scientific and broader community.

References

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