Submarine Groundwater Discharge: Linking the Continental and Oceanic Hydrospheres

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EarthScope Theme: Hydrosphere, Cryosphere, and Atmosphere
GeoPRISMS Theme: Mechanisms and Consequences of Fluid Exchange Between the Earth, Oceans, and Atmosphere

Summary
Onshore-offshore groundwater flow occurs over many temporal and spatial scales along the continental margin [*Younger, 1996; Moore, 1996; Cohen et al., 2010*], with significant implications for society (water supply) and a wide range of coastal ecosystems [Fig. 1] [*Moore, 2010*]. Observations document submarine discharge of fresh and saline groundwater along the entire US East Coast margin, exiting the seafloor from meters to nearly 100 km offshore [*Hathaway et al., 1979*]. Measurements and models show that modern processes (e.g., rainfall, tidal loading) can affect these flow systems locally and rapidly [Fig. 1] [*Michael et al., 2005; Taniguchi et al., 2006; Wilson and Gardner, 2006*], but also that long-term processes (e.g., sea-level change, glaciation) can affect these systems at a regional scale [Figs. 2,3][*Cohen et al., 2010; DeFoor et al., 2011*]. Many offshore flow systems are believed to be out of equilibrium with modern sea level and topography conditions and thus record previous conditions [*Person et al., 2003, Marksamer et al., 2007*]. Assessing the controls on submarine groundwater systems and their variations in time has important implications for understanding linkages between onshore and offshore flow systems, ocean chemical budgets, and human water supply [*Edmunds, 2001; Li et al., 1999; Slomp and van Cappellen, 2004*]. Accurate assessment of these systems: (1) requires detailed stratigraphic knowledge; (2) is a problem addressable along the US East Coast (a GeoPRISMS primary site); and (3) has societal relevance. These systems also link geological and climatological impacts that bridge EarthScope and GeoPRISMS and tie directly to the hydrosphere aspects of EarthScope and GeoPRISMS.

Scientific Addressability
Existing well and geophysical data provide ample information on the general distribution of offshore freshwater along the US East Coast margin [*Hathaway et al., 1979*]. Modeling studies of submarine groundwater systems constrain the basic behavior of many of these flow systems and submarine groundwater discharge, but they also indicate the importance of linking the long-term geologic evolution with the hydrologic cycle. The timing and type of sediments being shed from the continent and deposited on the shelf affects the pore pressure regime and the stratigraphic architecture, both of which affect the flow regime. Therefore it is crucial to understand the sediment inputs to the system over time, which is affected by the tectonic history of the continent and the structure of the margin. In addition, glacial history greatly affects subsurface hydrology along the margin due to its impact of fluid pressure [*Marksamer et al., 2007; Cohen et al., 2010*], but it also has topographic affects due to loading and flexure of the lithosphere [*Lemieux et al., 2008*]. This latter component is not well constrained but could be through EarthScope research that would feed into coupled ice sheet-sedimentation-fluid flow models [e.g., *Wolinsky, 2009*].

The low salinity of submarine groundwater presents an electrically resistive target that is suitable for geophysical imaging using controlled source electromagnetic (CSEM) technology developed during the past decade for offshore hydrocarbon exploration [e.g., *Key, 2011*]. Although this technology has not been applied to submarine groundwater study previously, an analogous well-tested application is CSEM mapping of resistive gas hydrate on the continental shelves [e.g., *Weitemeyer et al., 2011*]. CSEM mapping would provide vital constraints on the spatial distribution and concentration of submarine fresh water that could be integrated with seismic images of the stratigraphic architecture. CSEM imaging could also be used to map the lateral extent of groundwater identified from drilling studies.

Study Sites

Understanding large, offshore, non-equilibrium freshwater distributions requires knowledge of the emplacement mechanisms for the water in these systems and an understanding of the factors that have controlled these emplacement mechanisms through time [Figs. 1,2]. We propose two separate study areas to look at different temporal and spatial scales and at different driving mechanisms. The first study region is the New England continental shelf offshore Massachusetts and the second is the South Atlantic Bight offshore South Carolina. Models of the onshore-offshore hydrology offshore New England suggest that significant volumes of water are stored offshore and that glacial loading and sea level have impacted the long-term storage and discharge of continental freshwater into the ocean [Fig. 3][*Cohen et al., 2010*]. A combined EarthScope-GeoPRISMS study could help image the stratigraphy of the shelf, thus defining the hydrologic connectivity but also the deep earth structure that has affected the large-scale flexure and topography, which also influences the shallow fluid flow regime. CSEM studies will help define the distribution of this onshore-offshore freshwater resource. Thus we can address linkages between the cryosphere and the hydrosphere at the onshore-offshore transition.

The South Atlantic Bight study site provides an alternate end-member location with a very active modern, nearshore submarine groundwater discharge system. *Evans and Lizarralde* [2003] conclude that stratigraphically-controlled permeability enhancement has led to focused submarine groundwater discharge in the South Atlantic Bight. Offshore stratigraphy places important controls on the distribution, volumes, and recharge and discharge rates of freshwater in offshore environments. *Wilson et al*. [*2011*] show that nearshore (marsh) discharge in this region is tidally modulated, but also that stratigraphic distribution affects how the flow system responds to high-frequency water-level perturbations. The links between multi-scale flow processes, with temporal scales ranging from hours for tides to 100 ky for sea-level fluctuation, are very poorly constrained and depend strongly on an accurate understanding of stratigraphy and basin history. We have something like a zeroth-order understanding of these controls. A detailed study of stratigraphy and fluid type (freshwater, saltwater) through geophysics (seismic, CSEM) coupled with high-resolution monitoring of surface hydrology and subsurface hydrology and water chemistry will facilitate our ability to constrain linkages between fluid flux, local topography, and climate (rainfall) [Fig. 1] but also can be linked with continental controls of the stratigraphy linked to sediment flux from the Appalachians.

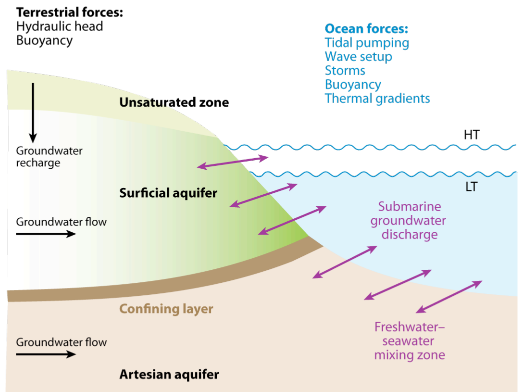

Fig. 1. Conceptual model of submarine groundwater discharge showing geologic components and terrestrial and oceanic forces. Figure from Moore [2010].

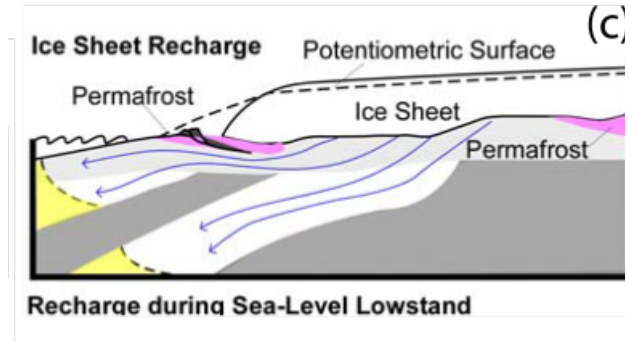

Fig 2. Example of impacts of glacial loading on submarine groundwater systems (blue arrows) including extending the freshwater zone and changing location and chemistry of SGD.

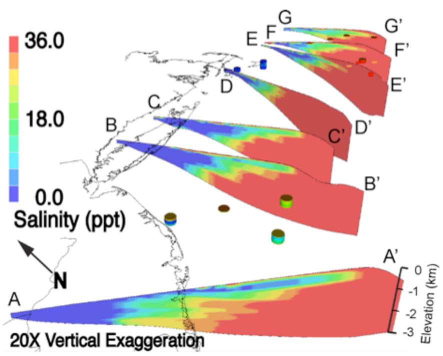

Fig. 3. Simulated salinity (in parts per thousand) along cross sections extracted from the three-dimensional finite element model of the Atlantic continental shelf. Cylinders depict concentration of offshore AMCOR, COST and ODP wells (well radii not to scale). The wells were raised 500 m above the sea floor in this image, so that the cross sections would not obscure them. Figure from Cohen et al. [2010].

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