Geophysical Research Abstracts
Vol. 17, EGU2015-7706, 2015
EGU General Assembly 2015

A graph-theoretic approach to River Deltas: Studying complexity, universality, and vulnerability to change.

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River deltas are landforms with complex channel networks that deliver water, sediment and nutrient fluxes from rivers to oceans or inland water bodies via multiple pathways. Most of the deltas are subject to anthropogenic and natural perturbations causing topological and dynamical changes in the delta structure and function. We present a quantitative framework based on spectral graph theory within which a systematic study of the topology, transport dynamics and response to change of river deltas can be performed, as well as computation of sub-networks (from apex to shoreline outlets), and contributing/nourishing areas. We introduce metrics of topologic and dynamic complexity and define a multidimensional complexity space where each delta projects. By analysis of seven deltas of different morphodynamic and environmental settings, we report a surprising power law relationship between sub-network size and its dynamic exchange with surrounding sub-networks within the deltaic system. The exponent of the relationship is universal (predicting that a sub-network twice as large leaks out to other sub-networks only 1.3 times its total flux) and the pre-exponent depends on the topologic complexity of the delta network as a whole, i.e. the ensemble of the interacting sub-sub-networks. We also use the developed framework to construct vulnerability maps that quantify the relative change of sediment and water delivery to the shoreline outlets in response to possible perturbations in hundreds of upstream links. This enables us to evaluate which links (hotspots) and what management scenarios would most influence flux delivery to the outlets, paving the way for systematically examining how local or spatially distributed delta interventions can be studied within a systems approach for delta sustainability.