Geomorphology xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph

The Delta Connectome: A network-based framework for studying connectivity in river deltas

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ARTICLE INFO

Article history:
Received 14 September 2015
Received in revised form 17 March 2016
Accepted 4 April 2016
Available online xxxx

Keywords:
Deltas
Distributary networks
Topology
Graph
Connectivity
Hydrodynamics
Morphodynamics

ABSTRACT

Many deltas, including the Mississippi River Delta, have been losing land at fast rates compromising the safety and sustainability of their ecosystems. Knowledge of delta vulnerability has raised global concern and stimulated active interdisciplinary research as deltas are densely populated landscapes, rich in agriculture, fisheries, oil and gas, and important means for navigation.

There are many ways of looking at this problem which all contribute to a deeper understanding of the functioning of coastal systems. One aspect that has been overlooked thus far, yet fundamental for advancing delta science is *connectivity*, both physical (how different portions of the system interact with each other) as well as conceptual (pathways of process coupling).

In this paper, I propose a framework called *Delta Connectome* for studying connectivity in river deltas based on different representations of a delta as a network. After analyzing the classic network representation as a set of nodes (e.g., bifurcations and junctions or regions with distinct physical or statistical behavior) and links (e.g., channels), I show that from connectivity considerations the delta emerges as a leaky network that continuously exchanges fluxes of matter, energy, and information with its surroundings and evolves over time. I explore each network representation and show through several examples how quantifying connectivity can bring to light aspects of deltaic systems so far unexplored and yet fundamental to understanding system functioning and informing coastal management and restoration. This paper serves both as an introduction to the Delta Connectome framework as well as a review of recent applications of the concepts of network and connectivity to deltaic systems within the Connectome framework.

1. Introduction: why study connectivity in deltaic systems?

Deltaic systems show tremendous variability of shape and structure (Fig. 1); their location, at the boundary between land and water, makes them prone to dynamic spatial and temporal disruptions due to environmental factors such as waves, wind, and tides. The relevance of deltaic systems goes well beyond aesthetics; home to wetlands and hotspots of biological productivity, deltas are ideal environments for fish and agricultural productivity, oil and gas resources, and navigation pathways. It is natural that because of all these factors and a tendency for people to settle in fertile soils in proximity of sources of water, deltas are home to >500 million inhabitants (Giosan et al., 2014).

International attention has been recently focused on deltaic systems; their low elevation gradients and the natural and anthropogenic subsidence they are subject to (Syvitski et al., 2009) make them vulnerable to relative sea-level rise (actual sea level plus subsidence) (Horton et al., 2014; Jevrejeva et al., 2014), raising concern in numerous areas of the world, including the Mississippi River delta and the highly populated South Asian deltas (Ericson et al., 2006).

Experiments have shown that under the right conditions deltas are able to match forcings such as sea-level rise. For example, an increase in sea level does not necessarily cause shoreline retreat (land loss) and aggradation of the delta top is possible as long as enough sediment is supplied to the system (Helland-Hansen and Martinsen, 1996; Muto, 2001; Carvajal et al., 2009; Martin et al., 2009; Sverre et al., 2009; Paola et al., 2011).

Why then are so many deltaic systems in danger? The tremendous development of dams and reservoirs in many parts of the world contributes to the sinking of many deltaic systems (Giosan et al., 2014). Flood management interventions, such as the construction of levees, and cutting of channel networks into wetlands for transport and draining further exacerbate this problem. For example in the Mississippi River delta, a lowland system where connectivity of channel and floodplains should be high (Fryirs, 2013), the construction of levees has contributed

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http://dx.doi.org/10.1016/j.geomorph.2016.04.001
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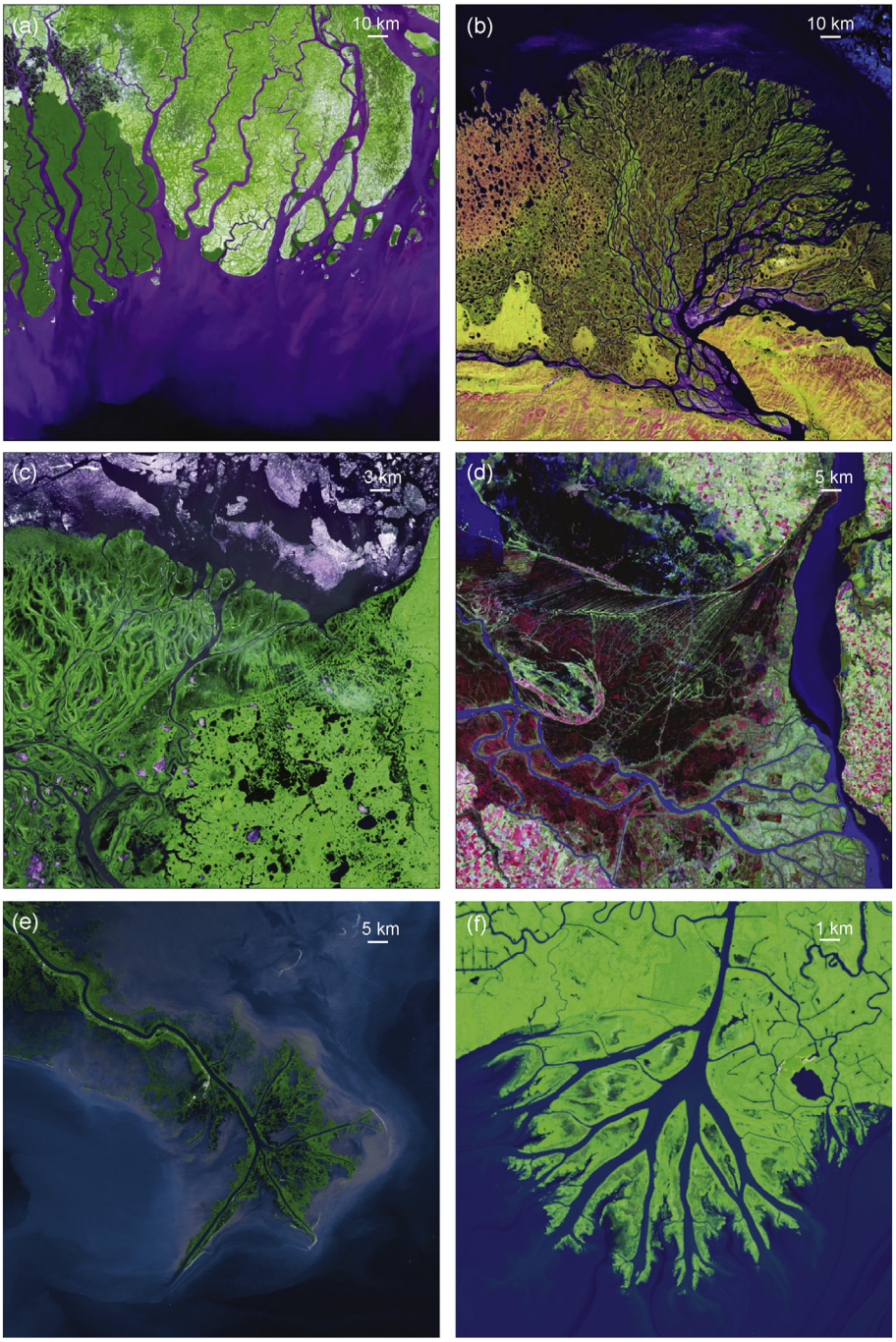

Fig. 1. Examples of delta systems. (a) Portion of the Ganges-Brahmaputra-Meghna Delta; (b) Lena Delta; (c) Yukon Delta; (d) Parana Delta; (e) Mississippi River Delta; (f) Wax Lake Delta. Images from NASA Visible Earth.

to the loss of 1/3 of the land since colonization (Craig et al., 1979; Gagliano et al., 1981; Kesel, 1989; Day et al., 2000; Day et al., 2007) as sediment is routed to the Gulf of Mexico by a very efficient pipe flow (Falcini and Jerolmack, 2010; Paola et al., 2011; Falcini et al., 2012). Problems related to anthropogenic structures are not unique to the Mississippi River delta; for example, in the Ganges-Brahmaputra-Meghna delta (GBMD) increasing inundation has been recently attributed to the amplification of the tidal signal due to the construction of embankments (Pethick and Orford, 2013) and high subsidence rates have been measured at aquaculture facilities in the Yellow River delta (Higgins et al., 2013). Engineered flood protections disconnect the river from its floodplain resulting in increased vulnerability of delta systems (Temmerman and Kirwan, 2015).

There are several ways to understand delta processes and response to perturbations; efforts have been focused on numerical (e.g., Seybold et al., 2007, 2009; Geleynse et al., 2010; Rowland et al., 2010; Sassi et al., 2012; Liang et al., 2015b) and experimental modeling (e.g., Hoyal and Sheets, 2009; Kim et al., 2009; Martin et al., 2009; Reitz et al., 2010) as well as on the analysis of field observations (e.g., Shaw and Mohrig, 2014; Shaw et al., 2013) and of remotely sensed imagery (e.g., Brakenridge et al., 2013; Passalacqua et al., 2013; Geleynse et al., 2015) to gain an understanding of delta formation and evolution under a suite of initial and boundary conditions. Most of this research, though, has focused on one specific portion of the system, for example channels or islands, without quantifying their connectivity (Hiatt and Passalacqua, 2015).

Please cite this article as: Passalacqua, P., The Delta Connectome: A network-based framework for studying connectivity in river deltas, Geomorphology (2016), http://dx.doi.org/10.1016/j.geomorph.2016.04.001