LIFE (Linked Institutions for Future Earth)

Fourth Year Report to NSF: 2015-2016

Award Number: 1242458

Lead PI: Efi Foufoula-Georgiou (University of Minnesota)

life

Linked Institutions for Future Earth

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An NSF Science Across Virtual Institutes Program

Drawing upon a decade of national collaborative experience in Earth-science research, the **National Center for Earth-surface Dynamics (NCED)** answered the NSF Science Across Virtual Institutes (SAVI) call for programs that will work to catalyze global research activities efficiently and economically while mentoring and creating international research opportunities for junior researchers.

Linked Institutions for Future Earth (LIFE) aims to create an international network of researchers, institutions, and experimental sites/field observations dedicated to advancing the quantitative predictive understanding of the Earth-surface system. While focusing on two research themes, watershed and deltas, our growing international network of 11 institutions seeks to make research actionable on a global level and to train the next generation of Earth-surface scientists.

University of Minnesota · University of Exeter · The University of Texas at Austin · Science Museum of Minnesota · cima Research Foundation · Illinois · Universidad de la República · IPGP · SAVI NSF Science Across Virtual Institutes · NSF

LIFE interconnected programs:

- •Researcher exchange program
- •Shared and co-mentored postdoctoral researchers
- •International shared graduate degree programs
- •Theme-based focused research (mainly experimental and theoretical) campaigns,
- •International summer institutes for graduate students and young researchers, and
- •Data/model sharing for actionable research
- •Science-to-public international exchange

To get involved, visit www.life.umn.edu

A. ACCOMPLISHMENTS – What was done? What was learned?

1. What are the major goals of the project?

The overarching goal of LIFE (Linked Institutions for Future Earth) is to create an international network of researchers, institutions, and experimental sites/field observations dedicated to advancing the quantitative predictive understanding of the Earth surface system under natural and human-induced change.

LIFE focuses its efforts on research related to Earth surface vulnerability in two key environments: watersheds and deltas, and implements its goals via the following closely linked programs: (1) Researcher exchange, (2) Shared and co-mentored postdoctoral researchers, (3) International shared graduate degree programs, (4) Theme-based focused research (mainly experimental and theoretical) campaigns, (5) International summer institutes for graduate students and young researchers, (6) Data/model sharing for actionable research, and (7) science-to-public international exchange.

2. What was accomplished under these goals (you must provide information for at least one of the 4 categories below)?

2.1. Major international collaborative and educational activities:

In the fourth year of the project, the major activities included:

(1) Continued the "*Distinguished Lecture Series on Earth-Water-Life*" that brought a cadre of international experts to the US for collaboration with researchers and student LIFE participants;

(2) A short course on "*Experiments and Modeling* of Sediment Transport and Land Building Processes", hosted by our LIFE partner Institut de Physique du globe de Paris (IPGP) in Paris in March 2016;

(3) Hosted two IPGP *graduate students* (Julien Renou and Pauline Delorme) at St. Anthony Falls Laboratory;

(4) The *Summer Institute on Earth surface Dynamics* (SIESD-2016) focusing on "Coupled hydro-eco-geomorphologic processes in human dominated landscapes: cascade of changes and the use of modeling for management and decision making" to be hosted at the St. Anthony Falls Laboratory, University of Minnesota on August 11-20, 2016. We had 43 applicants out of whom 10 are international (France, Netherlands, Germany, Italy, and India). The top 2 international applicants will be offered partial travel support from LIFE as needed, to enable their participation.

(5) LIFE-sponsored *Science-on-a-Sphere films* produced by the Science Museum of Minnesota as part of the Great Cities Initiative – these films are showing in several US and international science museums and the NSF-LIFE project is prominently acknowledged. Also, the National Science Foundation (NSF) featured a news article on the *NSF/Belmont Forum Deltas* project (co-sponsored by LIFE) in recognition of *World Oceans Day,* which become the most visited news article of the week (http://www.nsf.gov/discoveries/disc_summ.jsp?cntn_id=138738&org=NSF&from=news);

(6) Organization of *special sessions* at the AGU 2015 (deltas session, and human dominated landscapes session), EGU 2016 (deltas session, and coastal sustainability session) and JpGU 2016 (deltas session) meetings. Some of these sessions are also co-sponsored by the Belmont Forum project BF-DELTAS, "Catalyzing action towards delta sustainability";

(7) Several individual *visits of PIs and students* among LIFE participating institutions.

Some details of these activities are provided below.

Distinguished Lecture series on Earth-Water-Life (EWL): This lecture series is designed to provide a forum for exchange of ideas, learning about the cutting-edge research of international groups affiliated with LIFE, and provide opportunities for students in our mutual programs to explore across-institutions research exchange visits for collaboration towards our LIFE objective of "advance discovery and actionable research in Watersheds and Deltas in a Changing Environment." The invited speakers were in residence for one week at the University of Minnesota. They gave a seminar and met with students and researchers over extended meetings during that week.

Distinguished LIFE Speaker for 2015:

(1) *Alexander Densmore*, Professor, Institute of Hazard, Risk, and Resilience and Department of Geography, Durham University, *Why Fans Matter: Groundwater Abstraction and Decline in Northwestern India* (October 6, 2015)

In addition, LIFE has invited and hosted young researchers to give a talk at St. Anthony Falls Laboratory:

(1) *Sebastien Castelltort*, Department of Earth Sciences, University of Geneva, Switzerland, *River basins as dynamic markers of crustal deformation* (May 22, 2015)

(2) *Ciaran Harman*, Assistant Professor, Department of Geography and Environmental Engineering, Johns Hopkins University, *Transit Time Distributions in a Changing World: New Theory for Understanding and Modeling Hydrologic Transport Under Non-Stationarity* (March 3, 2015)

(3) *Praveen Kumar,* Colonel Harry F. and Frankie M. Lovell Endowed Professor of Civil and Environmental Engineering, Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign, *Water-Food-Climate Squeeze: Can we (Bio)Engineer Our Way Out?* (November 7, 2015) [UIUC is a LIFE partner institution]

(4) *Sarah Ringerud*, Postdoctoral Fellow, NASA Goddard Space Flight Center, *Database Construction for GPM Constellation Precipitation Retrievals Using Core Satellite Combined Microwave Radar-Radiometer Observations* (November 10, 2015) [LIFE expands its reach into remote sensing abilities to monitor hazards from space]

(5) *Pat Hamilton*, Director of Global Change Initiatives, Science Museum of Minnesota, *Visualizing Change – Communicating Environmental Change at Different Scales to Public Audiences* (March 08, 2016) [SMM is a LIFE partner institution]

(6) *Jasper Vrugt*, Associate Professor, Department of Civil and Environmental Engineering, The Henry Samueli School of Engineering, University of California, Irvine, *Markov chain Monte Carlo Simulation Using the DREAM Software Package: Theory, Concepts, and MATLAB Implementation* (March 21, 2016)

IPG Paris short course on Experiments and Modeling of Sediment Transport and Land Building Processes (March, 2016): Professors Paola and Voller continue to establish strong academic and research links with the Institut de Physique du globe de Paris (IPGP). In March 2016, Profs. Paola and Voller offered a one-week short course on the IPGP campus. Eight first year Masters students participated in the graded course. The title of the course was "Experiments and Modeling of Sediment Transport and Land Building Processes." This course involves a relatively unique blend of real time experiments and modeling activities. Our hope is that this course will become a regular offering in the IPGP curriculum and that its format might provide a template for similar courses elsewhere in the LIFE network.

Hosted IPGP graduate students Julien Renou and Pauline Delorme at St. Anthony Falls Laboratory: One requirement of the IPGP masters program is that that registered students undertake a half -year research internship. In this regard form April through August 2015 we hosted Julien Renou (a second year masters student) at the Saint Anthony Falls Laboratory (SAFL). Julien worked closely with PhD students in Prof Paola's group participating in experimental/theoretical research directed at understanding the controls on deltaic geomorphology. Julien was very successful in this endeavor and his report satisfied the requirements for his degree. Our hope is to expand on this success next year and have further intern students at SAFL.

Outside of the IPGP Masters Program, in the Fall of 2015, Prof Paola and Voller hosted the IPGP Advanced PhD student Pauline Delorme at SAFL. Pauline conducted novel experiments related to the building of sediment fans with two grains sizes (gravel and sand). At SAFL she was able to build and analyze experiments on the scale of meters; work that complemented her smaller (cm scale) bench top experiments in Paris. Pauline's research showed (for the conditions studied) a relatively sharp transition between the gravel and sand regimes; an experimental result confirmed with theory and modeling developments. Work is on-going and a publication is expected.

Summer Institute on Earth-surface Dynamics (SIESD) 2016 to be held on August 11-20, 2016 at St. Anthony Falls Laboratory, University of Minnesota: The Summer Institute on Earth-surface Dynamics (SIESD) was designed to engage young scientists in a focused topic in Earth-surface dynamics. This year's SIESD theme focuses on examining the coupled interactions of surface processes in human-dominated landscapes, with the goal of better forecasting the physical and ecological outcomes of implementing different landscape management scenarios. From agricultural fields and urban areas to delta landscapes and coastlines, the vulnerabilities of natural-human systems must be better understood to guide decision-making toward sustainability and resilience. Like previous workshops, SIESD 2016 aims to develop a basic working knowledge of analysis tools that can help us make sense of complex surface systems, including connections between field, laboratory, and modeling. Students will participate in taught classroom sessions, hands-on work with computational tools, field work, and physical experiments that the course participants will help design and run.

Lecturers include several LIFE PIs. 38 students from all over the world have been accepted to the SIESD 2016 after a selection process that includes application and three letters of recommendation.

LIFE-sponsored Science-on-a-Sphere films: In cooperation with the University of Minnesota and the Science Museum of Minnesota, LIFE sponsored four Science-on-a-Sphere videos as part of the Great Cities Initiative.

(1) The Human Era: A World of Changes *featuring Patrick Hamilton (Science Museum of Minnesota) and Chris Paola (University of Minnesota)*

(2) Eating Water: Agriculture and Climate Change *featuring Kate Brauman (University of Minnesota)*

(3) Acidifying Oceans: Oceans and Climate Change *featuring Kevin Theissen (University of St. Thomas)*

(4) Hot Air: Atmosphere and Climate Change *featuring Tracy Twine (University of Minnesota)*

The videos are both in Spanish and English versions and are immediately available for download.

Special sessions at major international meetings: In collaboration with another project (Belmont Forum: DELTAS project) we organized a special sessions in the AGU 2015, EGU 2016 and JpGU 2016 meetings. Special sessions for AGU 2016, EGU 2017 and JpGU 2017 are planned right now.

PI exchanges and Web collaboration ideas: PI Foufoula-Georgiou presented at the AGU 2015, EGU 2016 and JpGU 2016 meetings and met with LIFE partners. PI Chris Paola and Vaughan Voller visited IPGP for the short course in March 2016.

2.2. Significant results:

International research collaborations. Examples include:

(1) Collaboration with University of Padova, Italy (Stefano Lanzoni).

Meandering river dynamics have remained somewhat elusive due to the sparsity of highly-resolved temporal and spatial resolution channel migration data over long times combined with the difficulty of reproducing meandering rivers in laboratory settings. Worldwide Landsat imagery collected every 18 days since 1984 provides a unique opportunity resolve meandering river dynamics over unprecedented spatial scales at sub-annual frequencies. In an effort to gain further insight from this vast data, we have developed a technique for creating annual composite image masks from individual Landsat images, as well as a toolbox called **P**lanform **C**hange **A**na**L**ysis using **M**atlab (PCALM) designed to exploit image-based processing to quantify meandering river dynamics using computationally inexpensive tools. The toolbox is freely available to the community for application to problems focused on understanding meander migration from images.

We applied PCALM to a 1,300 km study reach along the active, meandering Ucayali River in Peru to map planform dynamics annually. *At the reach scale, spatial variability in migration rates was found to be linked to proximity to tributaries which deliver large sediment loads to the river, while temporal variability was observed to be controlled, in part, by the occurrence of cutoffs.* In particular, in 1997 following a massive, triple-lobed cutoff at Masisea, the adjacent reaches of the Ucayali River demonstrated accelerated migration rates both up- and downstream of the cutoff and apparently sparked a cascade of smaller cutoffs downstream. Effects of cutoffs on migration rates remain relatively undocumented, and models of long-time meander migration lack mechanisms to account for this observed effect of cutoff perturbations. Further, analysis of individual bends indicates that a bend's morphodynamic response to cutoff perturbations depends on its pre-cutoff morphology. These results, including the effects of the Masisea cutoff on river width, depth, and migration rate were presented at the 2015 River, Coastal, and Estuary Morphodynamics meeting in Iquitos, Peru.

Publications:

Schwenk, J., S. Lanzoni, and E. Foufoula-Georgiou (2015), "The life of a meander bend: connecting shape and dynamics via analysis of a numerical model", *J. Geophys. Res. Earth Surf.*, *120*(4), 690-710, doi:10.1002/2014JF003252.

Schwenk, J., M. Fratkin, A. Khandelwal, V. Kumar, and E. Foufoula-Georgiou. "Resolving annual planform dynamics using Landsat imagery: the PCALM toolbox." *In Preparation* (plan to submit to *IEEE Transactions on Geoscience and Remote Sensing)*

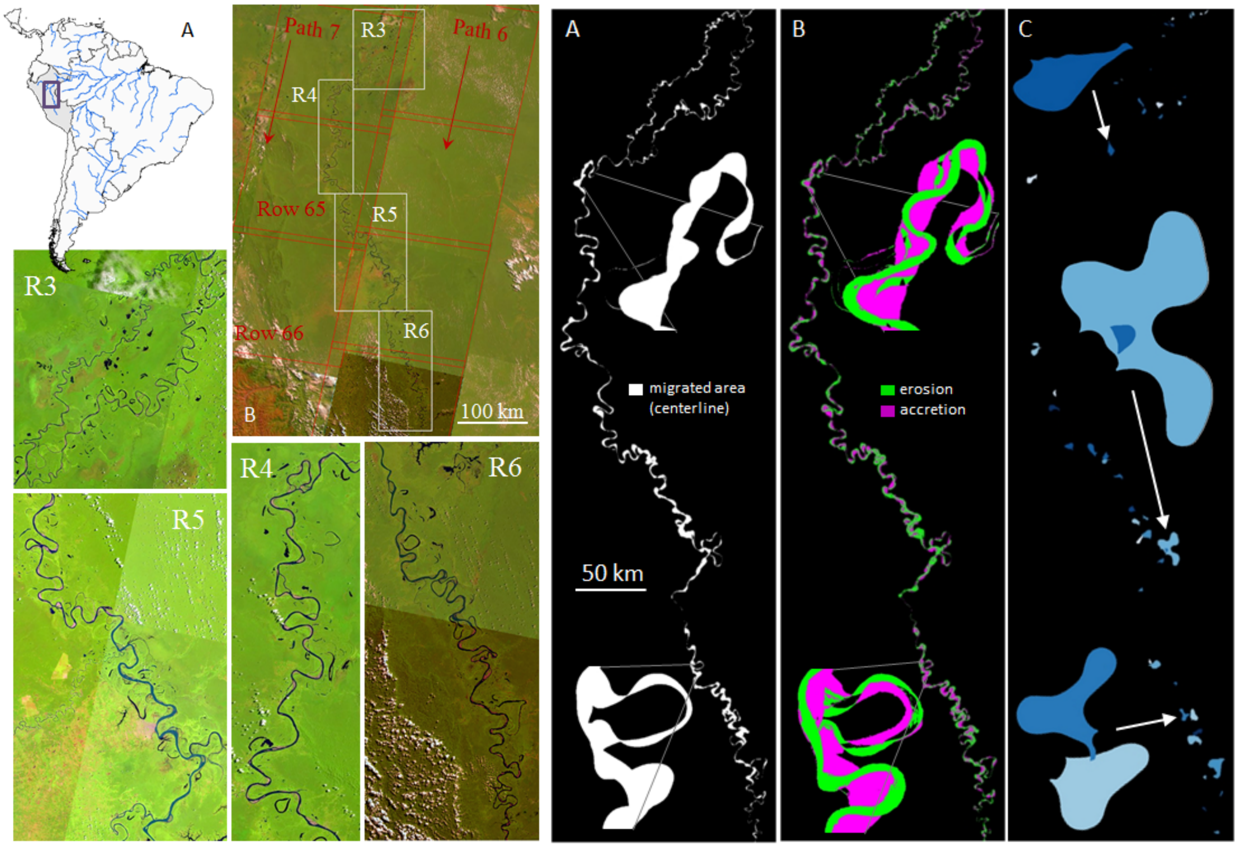

Figure 1. (Left Panels) The extents of the study reach of the Ucayali River within Peru are denoted by a rectangle in (A). A zoomed-in view of the study area is shown in (B), with the four boundary boxes (R1-R4) delineated. The lower portion of the Ucayali's avulsion in the R3 box is considered the main channel, although both branches are retained. The eight Landsat scenes intersecting the R boundary boxes are shown in red and range from Path 7, Row 64 (top left) to Path 6, Row 67 (bottom right). Imagery is the latest available from the Landsat 8 Views collection spanning 2015-2016. (Right Panels) Migrated areas and cutoffs for the full study reach from 1985-2015 are computed using PCALM. Centerline migrated areas are shown in (A) with two zoom views. The scale bar refers to the entire image. Erosion and accretion maps are shown in (B) along with the same zoom views. A pixel may undergo multiple instances of erosion and/or accretion; only the latest occurrence is shown. The 57 cutoffs that occurred from 1985-2015 are shown in (C). Lighter cutoffs occurred nearer 1985, while darker occurred nearer 2015.

(2) Collaboration with the University of Exeter, UK (Liam Reinhardt), Durham University, UK (Alexander L. Densmore), and University of Sheffield, UK (Chris Keylock).

Understanding the processes that drive landscape reorganization in response to changing allogenic forcings, such as climate and tectonics, is key for advancing landscape evolution models, forecasting future landscapes, and deciphering the past from stratigraphic records. There are, however, very few well-documented examples of such landscape-scale geomorphic reorganization. To this goal we conducted a series of experiments in a unique experimental facility (Figure 2, left), where the landscape self-organization to steady state and its reorganization under increased precipitation were extensively monitored. We reveal an emergent "erosional signature" of steady-state landscapes (Figure 2, right) which is scale-dependent and encodes process, and show how its change under increased precipitation (transient-state) captures transitions in geomorphic regimes. Comparing the erosional signatures of the landscape at steady and transient state, we infer the dynamics of reorganization under accelerated erosion, i.e., an enhanced erosion on hillslopes drives a downstream cascade of geomorphic change, triggering a shift in the transport regime in the fluvial regime of the landscape, from supply limited to transport limited.

Experimental Setup **Main Results**

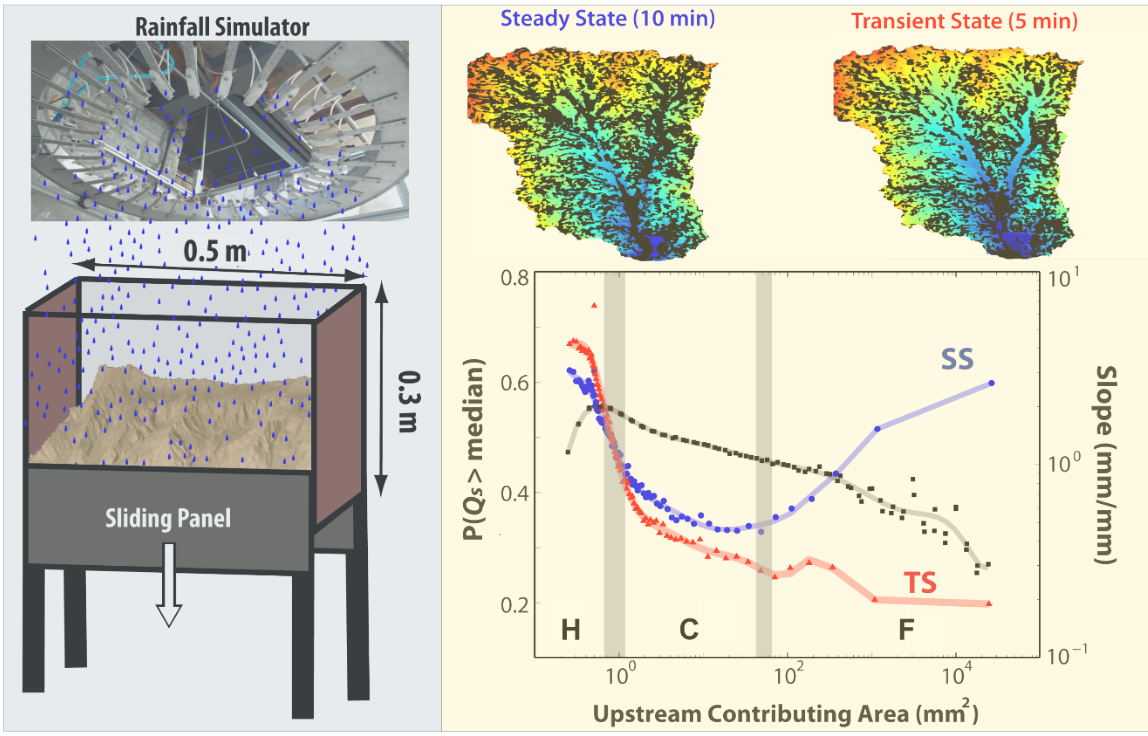

Figure 2. Experimental Setup (Left). Schematic representation of the eXperimental Landscape Evolution (XLE) facility at the St. Anthony Falls Laboratory, University of Minnesota. XLE consists of a 0.5 x 0.5 x 0.3 m^3 erosion box with two opposing sides able to slide up and down at variable rates mimicking changes in the base level. The facility also included a rainfall simulator consisting of 20 ultrafine misting nozzles that are able to generate rain droplet of sizes < 10 mm. The experimental setup is equipped with an advanced laser scanner that can scan the experimental topography at resolution of 0.5 mm in a few seconds. The experimental landscape was evolved under constant uplift, U=20 mm/h, and precipitation intensity, P=45 mm/h until the steady state (SS) was reached, after which the landscape was subjected to a five-fold increase in precipitation intensity, leading to a transient-state (TS). **Main Results (Right).** (Top panel) Mapping on the DEMs of a basin of the landscape the highly eroding pixels (with local volume above the median of $Q_{s,i}$) for SS and TS. (Bottom panel) Fraction of pixels that erode more than the median of the landscape versus upstream contributing area, what we call the E50-area curve. The slope-area curve for SS is also shown on the same plot, depicting the three geomorphic regimes: Hillslopes (H), Coluvial (C) and Fluvial (F). Within the hillslope regime, we observe increased erosion in response to increased precipitation, with this trend inverted within the colluvial regime where erosion systematically decelerates downstream. In the channels, a regime shift from supply-limited to transport-limited is observed, as depicted by the divergence of the E50-area curves in the fluvial part of the landscape.

<u>*Publications*</u>:

Singh, A., L. Reinhardt, and E. Foufoula-Georgiou (2015), Landscape re-organization under changing climatic forcing: results from an experimental landscape, *Water Resour. Res.*, doi:10.1002/2015WR017161.

Tejedor, A., A. Singh, I. Zaliapin, A.L. Densmore and E. Foufoula-Georgiou (2016), Geomorphic reorganization of landscapes under climate change, *Under Review*.

(3) Collaboration with the University of Southampton, UK (Sylvia Szabo, Zoe Matthews, John Dearing, and Robert Nicholls) and United Nations University, Germany (Zita Sebesvari and Fabrice Renaud).

Deltas cover only 1% of the Earth's area, but are home to over 500 million people. Deltas are dynamic systems that are characterised by low elevation, frequent flooding and high biodiversity; and they benefit from high agricultural and fisheries productivity, contributing to regional and global food security. Climate change is leading to higher sea levels, to changes in major river discharge and likely to increases in the frequency of cyclones and coastal storms in many susceptible areas. Collectively, this increases the risk of floods and salinization, often intensified by natural and human-induced land subsidence, and will affect coastal ecosystems and the services they provide. *Semi-arid regions* are home to more than 2 billion people, most of them living in developing countries. Drylands are sensitive to climate change due to the harsh climatic conditions already experienced, and are particularly vulnerable to degradation and desertification, with African dryland populations being most at risk due to the high population density in some localities and low input farming systems. Most dryland areas are projected to warm faster and experience greater relative increases in aridity than more-humid regions, exacerbating these existing climatic sensitivities. Finally, *glaciers and snowpack-dependent river basins* are home to more than one sixth of the world's population, or over 1.2 billion people. They face severe challenges in a warmer climate, including declines in both seasonal snowpacks and glaciers, changes in glacier and snowpack melting, and thus water release, putting additional pressure on dams and groundwater resources. Together, the threats to all three of these climate hotspots (Figure 3) are exacerbated by projected high levels of population growth, directly affecting the lives of local people, and triggering the potential for increased population movement. The climatic impact on these hotspots calls for a substantial investment towards their integrated socio-ecological management, grounded on a better understanding of the biophysical and socio-ecological processes and trade offs underpinning their dynamic ecosystem-service provision and sustainability.

Apart from analyzing and informing social and environmental vulnerabilities in delta regions, one of our goals is to advance the physical classifications of deltas. Our main contributions to this end focus on developing a quantitative understanding of how controlling physical mechanisms of delta formation relate to the channel networks they imprint on the landscape. Advancing the knowledge in this direction paves the way for further progress on quantitative delta classification and understanding process from form. We have studied the isolated effect of sediment composition on network structure by analyzing Delft3D river-dominated deltas (Figure 4, top panels) within the recently introduced graph-theoretic framework for quantifying complexity of delta channel networks. We demonstrate that deltas with coarser incoming sediment (less cohesive) tend to be more complex topologically (increased number of pathways) but simpler dynamically (reduced flux exchange between subnetworks) and that once a morphodynamic steady state is reached, complexity also achieves a steady state. By positioning simulated deltas on the so-called TopoDynamic complexity space and comparing with field deltas (Figure 4), we propose a quantitative framework for exploring complexity toward systematic inference and classification.

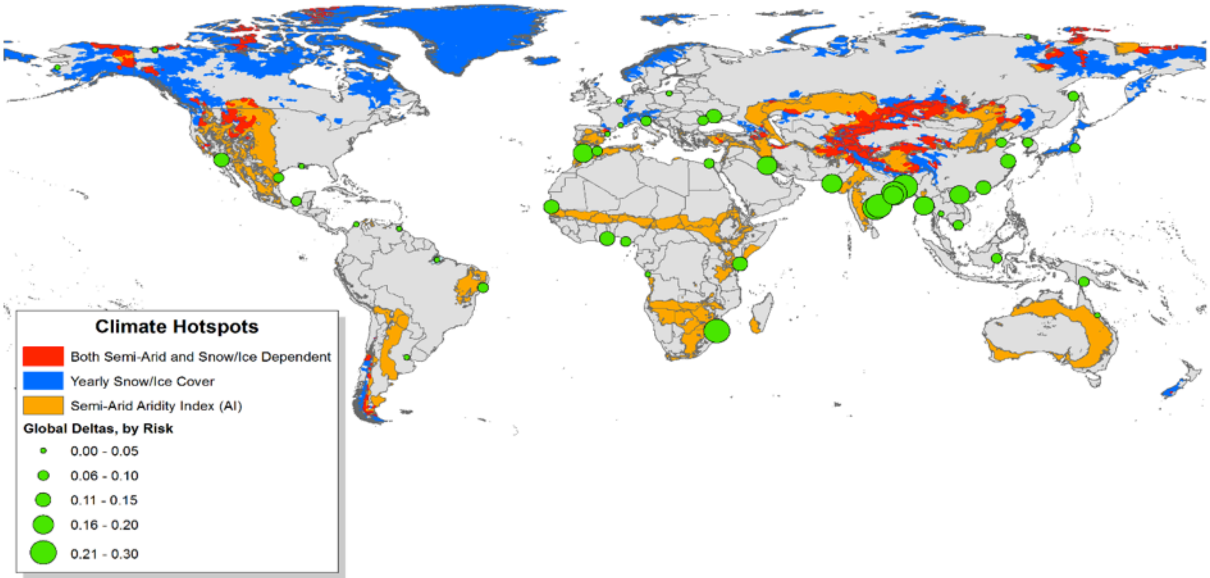

Figure 3. Climate change hotspots requiring focused attention using the Sustainable Development Goals (SDG) indicator framework. The three major types of climate hotspots used in the SDG framework are shown, including: (1) major global delta locations (green dots), varied according to contemporary risk due to sea-level rise and anthropomorphic factors as outlined by *Tessler et al.*, 2015; (2) semi-arid regions (orange) where an Aridity Index (AI) falls between 0.2 and 0.5; (3) snow and ice runoff-dependent basins (blue), defined as basins with average yearly snow/ice cover ≥25%; and (4) overlapping areas with both semi-arid AI and snow/ice runoff dependency (red).

<u>*Publications*</u>:

Tejedor, A., A. Longjas, R. Caldwell, D. A. Edmonds, I. Zaliapin, and E. Foufoula-Georgiou (2016), Quantifying the signature of sediment composition on the topologic and dynamic complexity of river delta channel networks and inferences toward delta classification, *Geophys. Res. Lett.*, *43*, doi:10.1002/2016GL068210.

Brondizio, E., E. Foufoula-Georgiou, S. Szabo, N. Vogt, Z. Sebesvari, F. G. Renaud, A. Newton, E. Anthony, A. V. Mansur, Z. Matthews, S. Hetrick, S. M. Costa, Z. Tessler, A. Tejedor, A. Longjas, J. A. Dearing (2016), Catalyzing action towards the sustainability of deltas, *Current Opinion in Environmental Sustainability*, *19*, 182-194, doi: doi:10.1016/j.cosust.2016.05.001.

Szabo, S., R.J. Nicholls, B. Neumann, F.G. Renaud, Z. Matthews, Z. Sebesvari, A. AghaKouchak, R. Bales, C.W. Ruktanonchai, J. Kloos, E. Foufoula-Georgiou, P. Wester, M. New, J. Rhyner, and C. Hutton (2016), Making SDGs work for climate change hotspots, *Environment: Science and Policy for Sustainable Development*, in revision.

Sebesvari, Z., E. Foufoula-Georgiou, I. Harrison, E.S. Brondizio, T. Bucx, J.A. Dearing, D. Ganguly, T. Ghosh, S.L. Goodbred, M. Hagenlocher, R. Hajra, C. Kuenzer, A.V. Mansur, Z. Matthews, R.J. Nicholls, K. Nielsen, I. Overeem, R. Purvaja, Md.M. Rahman, R. Ramesh, F.G. Renaud, R.S. Robin, B. Subba Reddy, G. Singh, S. Szabo, Z.D. Tessler, C. van de Guchte, N. Vogt, and C.A. Wilson (2016),

Imperatives for sustainable delta futures, *Global Sustainable Development Report (GSDR) 2016 Science Brief*.

Szabo, S., F.G. Renaud, M.S. Hossain, Z. Sebesvari, Z. Matthews, E. Foufoula-Georgiou, and R.J. Nicholls (2015), Sustainable development goals offer new opportunities for tropical delta regions, *Environment: Science and Policy for Sustainable Development*, 57(4), 16-23, doi:10.1080/00139157.2015.1048142, 2015.

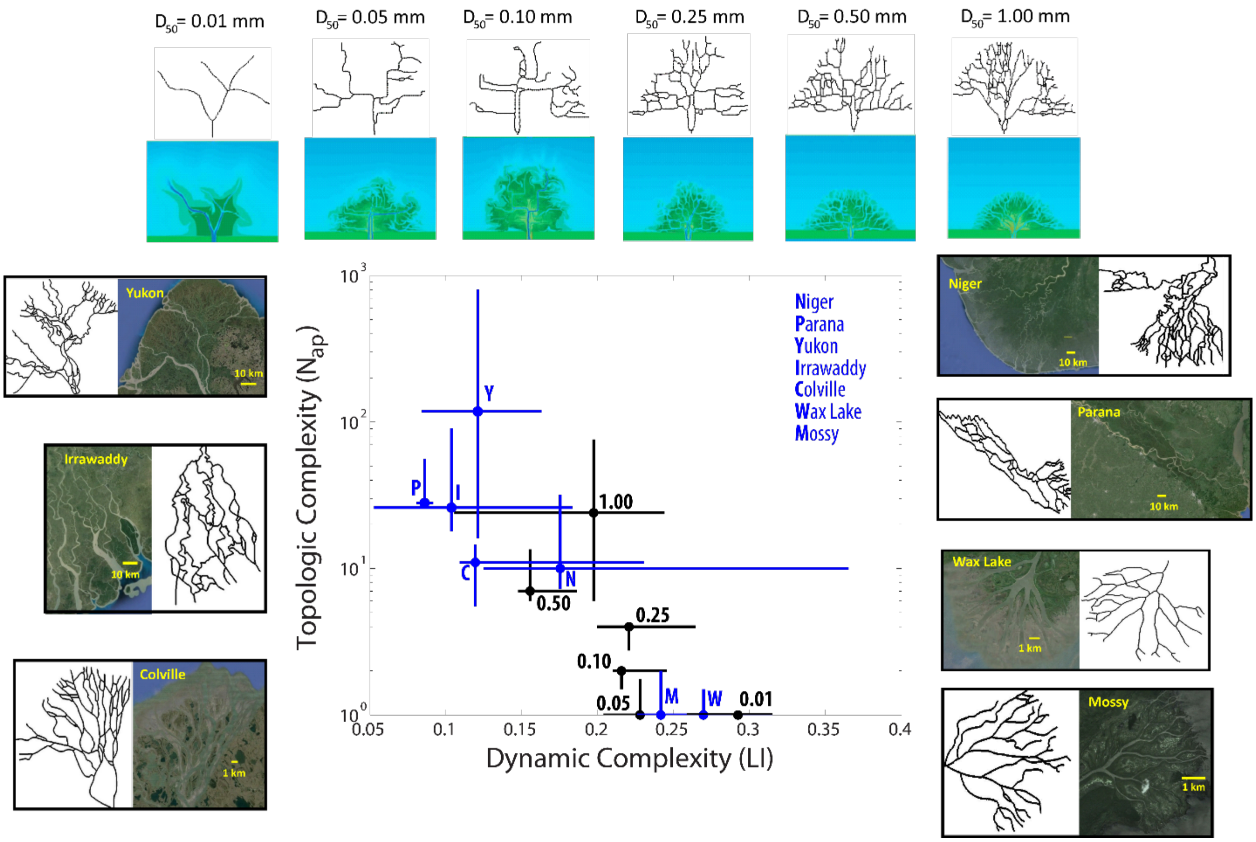

Figure 4. 2D TopoDynamic Space. Combining both the Topological (Number of alternative paths, N_{ap}) and Dynamic (Leakage Index, *LI*) complexity, each delta is positioned uniquely in the TopoDynamic space. Seven field deltas (Niger, Parana, Yukon, Irrawaddy, Colville, Wax Lake and Mossy) and six numerical deltas with different median grain size are displayed. From the numerical deltas we can conclude that fine-grained, cohesive deltas have low topologic complexity and high dynamic complexity. For field deltas, a transition to high topologic complexity and low dynamic complexity is observed as well. The dots correspond to the medians of both parameters, i.e., Number of alternative paths and Leakage Index, while the vertical and horizontal lines span the corresponding 25th up to the 75th percentiles.

(4) Collaboration with University of Padova, Italy (Gianluca Botter)

Climatic trends and anthropogenic changes in land cover and land-use are impacting in complex ways the hydrology and water quality of streams at the field, watershed, and regional scales. In poorly drained agricultural landscapes, subsurface drainage systems have been successful in increasing crop productivity by removing excess soil moisture. However, their hydro-ecological consequences are still debated in view of the observed enhanced rates of nitrate, phosphorus, and pesticides in many streams, as well as altered runoff volumes and timing. In this study we employ the recently developed theory of time-variant travel time distributions within the storage selection function framework to quantify changes in water cycle dynamics resulting from the combined climate and land-use changes. Our results from analysis of a sub-basin in the Minnesota River Basin indicate a significant decrease in the mean travel time of water in the shallow subsurface layer during the growing season under current conditions compared to the pre-1970's conditions. We also find highly damped year-to-year fluctuations in the mean travel time, indicating that the filtering of the natural heterogeneity via the artificially re-wired landscape results in a homogenization of the hydrologic response (Figure 5).

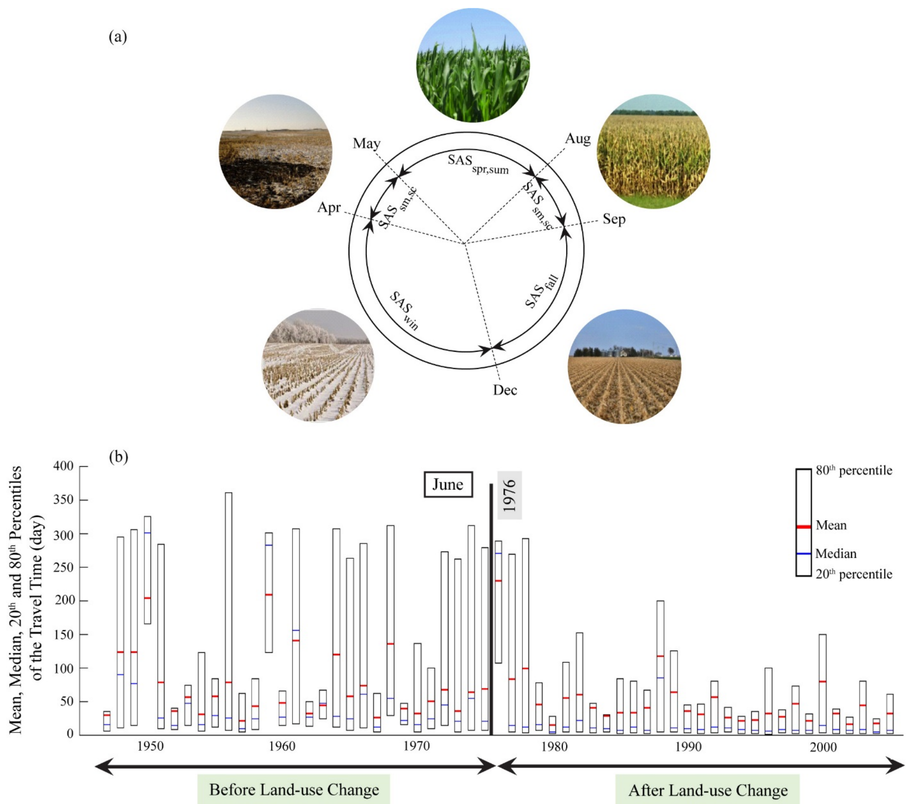

Figure 5. **(a)** Qualitative inference of the type and form of the StorAge Selection (SAS) functions for the winter (SAS_{win}), snowmelt and senescence ($SAS_{sm,sc}$), spring and summer ($SAS_{spr,sum}$), and fall (SAS_{fall}) periods. **(b)** Temporal evolution of the mean, median, 20th and 80th percentiles of the travel time in the month of June. Smaller distance between the mean, and 20th and 80th percentiles of the travel time in the after land-use change period reveals significantly reduced variability in the travel times around the mean.

Publications:

Danesh-Yazdi, M., E. Foufoula-Georgiou, D. L. Karwan, and G. Botter (2016), Inferring Changes in Water Cycle Dynamics of Intensively Managed Landscapes via the Theory of Time-Variant Travel Time Distributions, *Water Resources Research*, *Under Review*.

3. What opportunities for training and professional development has the project provided?

Training has been provided via all LIFE activities, in the following categories:

(1) One-to-one mentoring of students and post-docs by LIFE participating institutions and PIs.
(2) Engagement of students, post-docs, and young PIs into interdisciplinary international research via working group meetings, international visits, short courses, and the Summer Institute on Earth surface Dynamics (SIESD) described above.
(3) Mentoring of the next generation of students not only in research but also in broader impacts is accomplished via including into the SIESD program visits to the Science Museum of Minnesota, joint poster programs with the REU students hosted at the same time at the University of Minnesota (most of them minority students), and lectures on broader impacts and science communication.
(4) Involving students and post-docs in field monitoring studies in the Mekong, Ganges, and Amazon river deltas as part of the BF-DELTAS project.
(5) Providing travel funds from LIFE to young researchers for participation in the SIESD and in international conferences, such as the River, Coastal, and Estuary Morphodynamics (RECM) 2015 conference in Peru.

4. How have the results been disseminated to communities of interest?

The SIESD was announced in EOS, the major outlet for the Geosciences community, and also the Gilbert Club mailing list as it was targeting the whole international community. The IPGP short course was announced via email to the LIFE participating institutions. The National Science Foundation (NSF) featured the NSF/Belmont Forum funded Deltas project in recognition of World Oceans Day (http://www.nsf.gov/discoveries/disc_summ.jsp?cntn_id=138738&org=NSF&from=news).

The LIFE-sponsored Science-on-a-Sphere videos as part of the Great Cities Initiative are posted in the LIFE (http://life.umn.edu/) and in the National Oceanic and Atmospheric Administration (NOAA) websites (http://sos.noaa.gov/Datasets/dataset.php?id=480). The videos are both in Spanish and English versions and are immediately available for download.

5. What do you plan to do during the next reporting period to accomplish the goals?

In Year 5 we will plan the following major activities:

(1) Organize the "Stochastic Transport and Emergent Scaling on the Earth Surface" (STRESS 5) workshop, an international working group meeting to be held at Lake Tahoe, Nevada on Oct. 16-19, 2016.

Connectivity And Graph Theory In Earth-Surface Dynamics: Studying Process, Form And Vulnerability To Change: Networks and graphs provide a framework that allows a convenient representation of interrelations in complex systems by mapping interactions among a large number of individual components and studying their feedbacks and dynamics: nodes (vertices) identify the elements of the system and links (edges) represent the presence or strength of a relationship among those elements. Such network-type representations are common in hydrology, geomorphology, ecology, population dynamics, plant physiology, soil science, food webs, epidemiology, social sciences and transportation, to name a few. Graph theory provides a formal framework by which to study networks. The STRESS 5 workshop focuses on exploring innovative ways for studying a suite of hydro-geomorpho-ecological problems in earth surface dynamics via graph and information theoretic approaches by exploring structural (spatially explicit) connectivity or process-based connectivity. Of special interest is the understanding of how connectivity relates to system response to change (system vulnerability), methodologies for quantifying system complexity, system typology via metrics that capture how relevant physics are projected into patterns, as well as information theoretic concepts for unraveling nonlinear dependencies and strengths among processes.

This working group meeting aims to bring together hydrologists, geomorphologists, ecologists/biologists, as well as dynamical system theorists to brainstorm ideas on how theoretical frameworks from network dynamics and graph theory can be used to advance our understanding of many complex natural systems around us undergoing change. Through this workshop, we also aim to establish a sustained international research collaboration with other European Union-funded research groups such as: (a). CONNECTEUR (Connecting European Connectivity Research) http://connecteur.info/, and (b). CAOS (Catchments As Organized Systems) http://www.caos-project.de/.

CONNECTIVITY AND GRAPH THEORY IN EARTH-SURFACE DYNAMICS:

STUDYING PROCESS, FORM AND VULNERABILITY TO CHANGE

Oct.16-19,2016
Lake Tahoe

Supported by

Networks and graphs provide a framework that allows a convenient representation of interrelations in complex systems by mapping interactions among a large number of individual components and studying their feedbacks and dynamics: nodes (vertices) identify the elements of the system and links (edges) represent the presence or strength of a relationship among those elements. Such network-type representations are common in hydrology, geomorphology, ecology, population dynamics, plant physiology, soil science, food webs, epidemiology, social sciences and transportation, to name a few. Graph theory provides a formal framework by which to study networks.

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This working group meeting aims to bring together hydrologists, geomorphologists, ecologists/biologists, as well as dynamical system theorists to brainstorm ideas on how theoretical frameworks from network dynamics and graph theory can be used to advance our understanding of many complex natural systems around us undergoing change. This is the second working group sponsored by an international virtual institute funded by NSF, Linked Institutions for Future Earth (LIFE). It is also co-sponsored by the Belmont Forum project BF-DELTAS, and by the National Center for Earth-surface Dynamics (NCED2).

For more information please contact the organizers: Rina Schumer (rina.schumer@dri.edu), and Efi Foufoula-Georgiou (efi@umn.edu)

(2) First "LIFE-ECOPOTENTIAL" Meeting on Ecosystem Management of Protected Areas, and NSF-EU cooperation meeting, University of California, Irvine, November 14-17, 2016

The scope of this meeting is to bring together two projects of global reach funded by NSF (LIFE) and EU-Horizon 2020 (ECOPOTENTIAL) to coordinate scientific, programmatic, observational, and educational activities towards an accelerated understanding of earth surface processes and ecosystems as complex social, hydrological, and geo-biological systems undergoing change under climate and human stressors.   It aims to establish a long-term institutional partnership for scientific and educational exchange.

(3) Accelerate collaboration with the Ecosystem Services For Poverty Alleviation (ESPA) Deltas project by participating in their final UK event: "The Sustainable Development Goals and Deltas", to be held on November 22-23, 2016.

(4) Beyond the strong and strengthening relationship with IPGP, we are also looking at forging similar links with other institutions. For example, this June 2016, Voller will visit the University of Montenegro and work with Igor Vusanovic (the Dean of Engineering) to explore how the educational and research models developed at IPGP might be used to inform ongoing efforts in Montenegro directed at mitigation of coastline erosion.

(5) Advance and expand research collaborations on the two specific themes in LIFE:

(a) ***Deltas and coastal areas:*** Collaboration with University of Southampton, UK (S. Szabo, Z. Matthews, R.J. Nicholls), and United Nations University, Germany (F. Renaud and Z. Sebesvari) on Delta Sustainability. New collaboration with the EU-Horizon 2020 project ECOPOTENTIAL partners towards the eco-hydrology of wetlands and protected areas.

(b) ***Watersheds:*** Collaboration with University of Padova (Stefano Lanzoni, Gianluca Botter) on meandering rivers and watershed flux modeling; Collaboration with Antonio Parodi CIMA and Antonello Provenzale – (University of Genova) on hydro-meteorological extremes and societal impacts; Collaboration with the European Union-funded project DRIHM (Distributed Research Infrastructure for HydroMeteorology) on predicting weather and climate and their impacts on the watershed environment, including floods and landslides.

<u>B. PRODUCTS</u> – What has the project produced?

1. Dissertation

Czuba, J. A. (2016), “A Network-Based Framework for Hydro-Geomorphic Modeling and Decision Support with Application to Space-Time Sediment Dynamics, Identifying Vulnerabilities, and Hotspots of Change”, Doctoral Dissertation, University of Minnesota, pp. 172.

2. Publications

Brondizio, E., E. Foufoula-Georgiou, S. Szabo, N. Vogt, Z. Sebesvari, F. G. Renaud, A. Newton, E. Anthony, A. V. Mansur, Z. Matthews, S. Hetrick, S. M. Costa, Z. Tessler, A. Tejedor, A. Longjas, and J. A. Dearing (2016), “Catalyzing action towards the sustainability of deltas”, *Current Opinion in Environmental Sustainability*, *19*, 182-194, doi: doi:10.1016/j.cosust.2016.05.001.

Czuba, J. A., and E. Foufoula-Georgiou (2015), “Dynamic connectivity in a fluvial network for identifying hotspots of geomorphic change”, *Water Resour. Res.*, *51*, 1401–1421, doi:10.1002/2014WR016139.

Danesh-Yazdi, M., E. Foufoula-Georgiou, D. L. Karwan, and G. Botter (2016), Inferring Changes in Water Cycle Dynamics of Intensively Managed Landscapes via the Theory of Time-Variant Travel Time Distributions, *Water Resources Research*, *Under Review*.

Ebtehaj, A. M., E. Foufoula-Georgiou, G. Lerman, and R. L. Bras (2015), “Compressive Earth observatory: An insight from AIRS/AMSU retrievals”, *Geophys. Res. Lett.*, *42*, 362–369, doi:10.1002/2014GL062711.

Ebtehaj, A.M., R.L. Bras, and E. Foufoula-Georgiou (2015), “Shrunken locally linear embedding for passive microwave retrieval of precipitation”, *IEEE Trans. on Geosci. and Remote Sens.*, *53*(7), 3720-3736, doi:10.1109/TGRS.2014.2382436.

Fan, N., A. Singh, M. Guala, E. Foufoula-Georgiou, and B. Wu (2016), “Exploring a semimechanistic Episodic Langevin model for bed load transport: Emergence of normal and anomalous advection and diffusion regimes”, *Water Resour. Res.*, doi:10.1002/2015WR018023.

Foufoula-Georgiou, E., Z. Takbiri, J.A. Czuba, and J. Schwenk (2015), “The change of nature and the nature of change in agricultural landscapes: Hydrologic regime shifts modulate ecological transitions”, *Water Resour. Res.*, *51*(8), 6649-6671, doi:10.1002/2015WR017637.

Gangodagamage, C., E. Foufoula-Georgiou, S.P. Brumby, R. Chartrand, A. Koltunov, D. Liu, M. Cai, and S.L. Ustin (2016), “Wavelet-compressed representation of landscapes for hydrologic and geomorphologic applications”, *IEEE Geoscience and Remote Sensing Letters*, *13*(4), 480-484, doi:10.1109/LGRS.2015.2513011.

Hansen, A.T., J.A. Czuba, J. Schwenk, A. Longjas, M. Danesh-Yazdi, D. Hornbach, and E. Foufoula-Georgiou (2016), "Coupling freshwater mussel ecology and river dynamics using a simplified dynamic interaction model", *Freshwater Science*, *35*(1), 200-215, doi:10.1086/684223.

Kuenzer, C., I. Klein, T. Ullmann, E. Foufoula-Georgiou, R. Baumhauer, and S. Dech (2015), "Remote Sensing of River Delta Inundation: exploiting the Potential of coarse spatial Resolution, temporally-dense MODIS Time Series", *Remote Sens.*, *7*, 8516-8542, doi:10.3390/rs70708516.

Pelletier, J.D., A.B. Murray, J.L. Pierce, P.R. Bierman, D.D. Breshears, B.T. Crosby, M. Ellis, E. Foufoula-Georgiou, A.M. Heimsath, C. Houser, N. Lancaster, M. Marani, D.J. Merritts, L.J. Moore, J.L. Pederson, M.J. Poulos, T.M. Rittenour, J.C. Rowland, P. Ruggiero, D.J. Ward, A.D. Wickert, and E.M. Yager (2015), "Forecasting the response of Earth's surface to future climatic and land-use changes: A review of methods and research needs", *Earth's Future*, *3*, doi:10.1002/2014EF000290.

Schwenk, J., S. Lanzoni, and E. Foufoula-Georgiou (2015), "The life of a meander bend: connecting shape and dynamics via analysis of a numerical model", *J. Geophys. Res. Earth Surf.*, *120*(4), 690-710, doi:10.1002/2014JF003252.

Schwenk, J., M. Fratkin, A. Khandelwal, V. Kumar, and E. Foufoula-Georgiou. "Resolving annual planform dynamics using Landsat imagery: the PCALM toolbox." *In Preparation* (plan to submit to *IEEE Transactions on Geoscience and Remote Sensing)*

Sebesvari, Z., E. Foufoula-Georgiou, I. Harrison, E.S. Brondizio, T. Bucx, J.A. Dearing, D. Ganguly, T. Ghosh, S.L. Goodbred, M. Hagenlocher, R. Hajra, C. Kuenzer, A.V. Mansur, Z. Matthews, R.J. Nicholls, K. Nielsen, I. Overeem, R. Purvaja, Md.M. Rahman, R. Ramesh, F.G. Renaud, R.S. Robin, B. Subba Reddy, G. Singh, S. Szabo, Z.D. Tessler, C. van de Guchte, N. Vogt, and C.A. Wilson (2016), "Imperatives for sustainable delta futures", *Global Sustainable Development Report (GSDR) 2016 Science Brief.*

Singh, A., L. Reinhardt, and E. Foufoula-Georgiou (2015), "Landscape re-organization under changing climatic forcing: results from an experimental landscape", *Water Resour. Res.*, doi:10.1002/2015WR017161.

Szabo, S., F. Renaud, S. Hossain, Z. Sebesvári, Z. Matthews, E. Foufoula-Georgiou, and R.J. Nicholls (2015), "New opportunities for tropical delta regions offered by the proposed Sustainable Development Goals", *Environment: Science and Policy for Sustainable Development*, *57*(4), doi:10.1080/00139157.2015.1048142.

Szabo, S., E. Brondizio, F.G. Renaud, S. Hetrick, R. J. Nicholls, Z. Matthews, Z. Tessler, A. Tejedor, Z. Sebesvari, E. Foufoula-Georgiou, S. da Costa, and J. A. Dearing (2016), "Population dynamics, delta vulnerability and environmental change: comparison of the Mekong, Ganges-Brahmaputra and Amazon delta regions", *Sustainability Science*, doi: 10.1007/s11625-016-0372-6.

Tejedor, A., A. Longjas, I. Zaliapin and E. Foufoula-Georgiou (2015), "Delta channel networks: 1. A graph-theoretic approach for studying connectivity and steady-state transport on deltaic surfaces", *Water Resour. Res.*, doi: 10.1002/2014WR016577.

Tejedor, A., A. Longjas, I. Zaliapin and E. Foufoula-Georgiou (2015), "Delta channel networks: 2. Metrics of topologic and dynamic complexity for delta comparison, physical inference and vulnerability assessment", *Water Resour. Res.*, doi: 10.1002/2014WR016604.

Tejedor, A., A. Longjas, R. Caldwell, D. A. Edmonds, I. Zaliapin, and E. Foufoula-Georgiou (2016), "Quantifying the signature of sediment composition on the topologic and dynamic complexity of river delta channel networks and inferences toward delta classification", *Geophys. Res. Lett.*, *43*, doi:10.1002/2016GL068210.

Tessler, Z.D., C.J. Vorosmarty, M. Grossberg, I. Gladkova, H. Aizenman, J. Syvitski, and E. Foufoula-Georgiou (2015), "Profiling risk and sustainability in coastal deltas of the world", *Science*, *349*(6248), 638-643, doi:10.1126/science.aab3574.

3. Presentations

Danesh-Yazdi, M., E. Foufoula-Georgiou, and D. L. Karwan (2015), "Interplay of climate and land-use change on transport dynamics of intensively managed landscapes: a catchment travel time distribution analysis", H11I-1457, AGU Fall Meeting, San Francisco, California, 14-18 December.

Czuba, J. A., E. Foufoula-Georgiou, A. T. Hansen, J. C. Finlay, and P. R. Wilcock (2015), "A Network-Based Approach for Modeling Water, Sediment, and Nutrient Dynamics: Guiding Watershed Management Through a Systems Perspective ", H12C-01, AGU Fall Meeting, San Francisco, California, 14-18 December. [**INVITED**]

Czuba, J. A., E. Foufoula-Georgiou, K. B. Gran, P. Belmont, and P. R. Wilcock (2015), "Near-Channel Sediment Sources Now Dominate in Many Agricultural Landscapes: The Emergence of River-Network Models to Guide Watershed Management ", EP24B-03, AGU Fall Meeting, San Francisco, California, 14-18 December. [**INVITED**]

Ebtehaj, A., E. Foufoula-Georgiou, and R. L. Bras (2015), "Rainfall Microwave Spectral Atoms: A New Class of Bayesian Algorithms for Passive Retrieval", H11O-07, AGU Fall Meeting, San Francisco, California, 14-18 December.

Foufoula-Georgiou, E., A. M. Ebtehaj, and R. Bras (2015), "A Novel Bayesian algorithm for Microwave Retrieval of Precipitation from Space: Applications in Snow and Coastal Hydrology", EGU2015-7585, EGU General Assembly, Vienna, Austria, 12-17 April. [**SOLICITED**]

Foufoula-Georgiou, E., J. Schwenk, and A. Tejedor (2015), "Perspective – Open problems in earth surface dynamics require innovative new methodologies from graph theory and non-linear analysis", EGU2015-8805, EGU General Assembly, Vienna, Austria, 12-17 April.

Foufoula-Georgiou, E., J. A. Czuba, P. Belmont, P. R. Wilcock, K. B. Gran, and P. Kumar (2015), "Climate and Humans as Amplifiers of Hydro-Ecologic Change: Science and Policy Implications for Intensively Managed Landscapes", H33O-02, AGU Fall Meeting, San Francisco, California, 14-18 December. [**INVITED**]

Foufoula-Georgiou, E., and A. Ebtehaj (2015), "Resolving Extreme Rainfall from Space: A New Class of Algorithms for Precipitation Retrieval and Data Fusion/Assimilation with Emphasis on Extremes over Complex Terrain and Coastal Areas", NH42A-02, AGU Fall Meeting, San Francisco, California, 14-18 December. [**INVITED**]

Foufoula-Georgiou, E. (2016), "Climate and Humans as Amplifiers of Hydro-Ecologic Change: Science and Policy Implications for Intensively Managed Landscapes", Robert E. Horton Lecture, AMS Annual Meeting, New Orleans, Louisiana, 10-14 Jan. [**AWARDEE**]

Foufoula-Georgiou, E., and M. Ebtehaj (2016), "Resolving extreme rainfall from space: a new class of algorithms for precipitation retrieval over radiometrically complex terrain and coastal areas", EGU2016-18518, EGU General Assembly, Vienna, Austria, 17-22 April. [**SOLICITED**]

Foufoula-Georgiou, E., A. Tejedor and A. Longjas (2016), "Delta channel network complexity for quantitative delta classification and vulnerability assessment", HCG11-09, JpGU Meeting, Chiba City, Japan, 22-26 May.

Hansen, A., J.C. Finlay, J.A. Czuba, C. Dolph, and E. Foufoula-Georgiou (2015), "Assessing Wetland Effects on Nitrogen Reduction within a Fluvial Network Perspective: A Combined Field and Modeling Approach", B53H-02, AGU Fall Meeting, San Francisco, California, 14-18 December.

Longjas, A., A. Tejedor, I. Zaliapin, and E. Foufoula-Georgiou (2015), "Vulnerability maps of deltas: quantifying how network connectivity modulates upstream change to the shoreline", CSDMS Annual Meeting, Boulder, Colorado, 26-29 May.

Longjas, A., A. Tejedor, and E. Foufoula-Georgiou (2016), "An entropy-based quantification of channel network complexity", CSDMS-SEN Annual Meeting, Boulder, Colorado, 17-19 May.

Schwenk, J., and E. Foufoula-Georgiou (2015), "Nonlocal effects of local cutoff disturbances along the meandering Ucayali River in Peru", EP53D-05, AGU Fall Meeting, San Francisco, California, 14-18 December.

Schwenk, J., and Efi-Foufoula Georgiou (2015), "Accelerated migration rates downstream of a human-induced cutoff in the Ucayali River, Peru." *9th Symposium on River, Coastline, and Estuary Morphodynamics*. Iquitos, Peru, 30 August – 3 September.

Singh, A., A. Tejedor, I. Zaliapin, L. Reinhardt, and E. Foufoula-Georgiou (2015), "Experimental evidence of dynamic re-organization of evolving landscapes under changing climatic forcing", EGU2015-8726, EGU General Assembly, Vienna, Austria, 12-17 April.

Singh, A., A. Tejedor, I. Zaliapin, L. Reinhardt, and E. Foufoula-Georgiou (2015), "Experimental evidence of reorganizing landscape under changing climatic forcing", NG23B-1786, AGU Fall Meeting, San Francisco, California, 14-18 December.

Singh, A., A. Tejedor, A. Densmore, and E. Foufoula-Georgiou (2016), "Landscape response to climate change: quantifying a regime shift in transport processes at the onset of re-organization", EGU2016-10233, EGU General Assembly, Vienna, Austria, 17-22 April.

Singh, A., A. Tejedor, J.-L. Grimaud, and E. Foufoula-Georgiou (2016), "Experimental investigation of the effect of climate change and tectonic anisotropy on landscape evolution", CSDMS-SEN Annual Meeting, Boulder, Colorado, 17-19 May.

Singh, A., A. Tejedor, C. Keylock, I. Zaliapin, and E. Foufoula-Georgiou (2016), "Landscape evolution and re-organization under steady and transient states: results from an experimental investigation", 31st IUGG Conference on Mathematical Geophysics, Paris, 6-10 June.

Takbiri, Z., A. Ebtehaj, and E. Foufoula-Georgiou (2015), "Microwave Signatures of Inundation Area", H13H-1658, AGU Fall Meeting, San Francisco, California, 14-18 December.

Tejedor, A., A. Longjas, I. Zaliapin, and E. Foufoula-Georgiou (2015), "A graph-theoretic approach to River Deltas: Studying complexity, universality, and vulnerability to change", EGU General Assembly, Vienna, Austria, 12-17 April.

Tejedor, A., A. Longjas, I. Zaliapin, and E. Foufoula-Georgiou (2015), "A graph-theoretic approach to Studying Deltaic Systems: Quantifying Complexity and Self-Organization", CSDMS Annual Meeting, Boulder, Colorado, 26-29 May.

Tejedor, A., A. Longjas, I. Zaliapin, J. Syvitski, and E. Foufoula-Georgiou (2015), "Complexity and Robustness of Deltaic systems: A graph-theoretic approach", INQUA, Japan.

Tejedor, A., A. Longjas, R. Caldwell, D. A. Edmonds, I. Zaliapin, and E. Foufoula-Georgiou (2015), "Moving beyond the Galloway diagrams for delta classification: Connecting morphodynamic and sediment-mechanistic properties with metrics of delta channel network topology and dynamics", GC44C-03, AGU Fall Meeting, San Francisco, California, 14-18 December.

Tejedor, A., A. Longjas, R. Caldwell, D. Edmonds, I. Zaliapin, and E. Foufoula-Georgiou (2016), "Moving beyond the Galloway diagrams for delta classification: A graph-theoretic approach", EGU General Assembly, Vienna, Austria, 17-22 April.

Tejedor, A., A. Longjas, I. Zaliapin, and E. Foufoula-Georgiou (2016), "An entropy-based quantification of delta channel network complexity", Workshop on Information Theory and the Earth Sciences, Schneefernerhaus, Germany, 25-27 April.

Tejedor, A., A. Longjas, and E. Foufoula-Georgiou (2016), "Quantifying delta complexity toward inference and classification", CSDMS-SEN Annual Meeting, Boulder, Colorado, 17-19 May.

Tejedor, A., A. Longjas, I. Zaliapin, and E. Foufoula-Georgiou (2016), "A graph-theoretic approach to infer process from form in deltaic systems", 31st IUGG Conference on Mathematical Geophysics, Paris, 6-10 June.

Tessler, Z.D., C.J. Vorosmarty, M. Grossberg, I. Gladkova, H. Aizenman, J. P. Syvitski, and E. Foufoula-Georgiou (2015), "The Geophysical, Anthropogenic, and Social Dimensions of Delta Risk: Estimating Contemporary and Future Risks at the Global Scale" GC44C-01, AGU Fall Meeting, San Francisco California, 14-18 December. [**INVITED**]

4. Technologies or techniques

Not applicable.

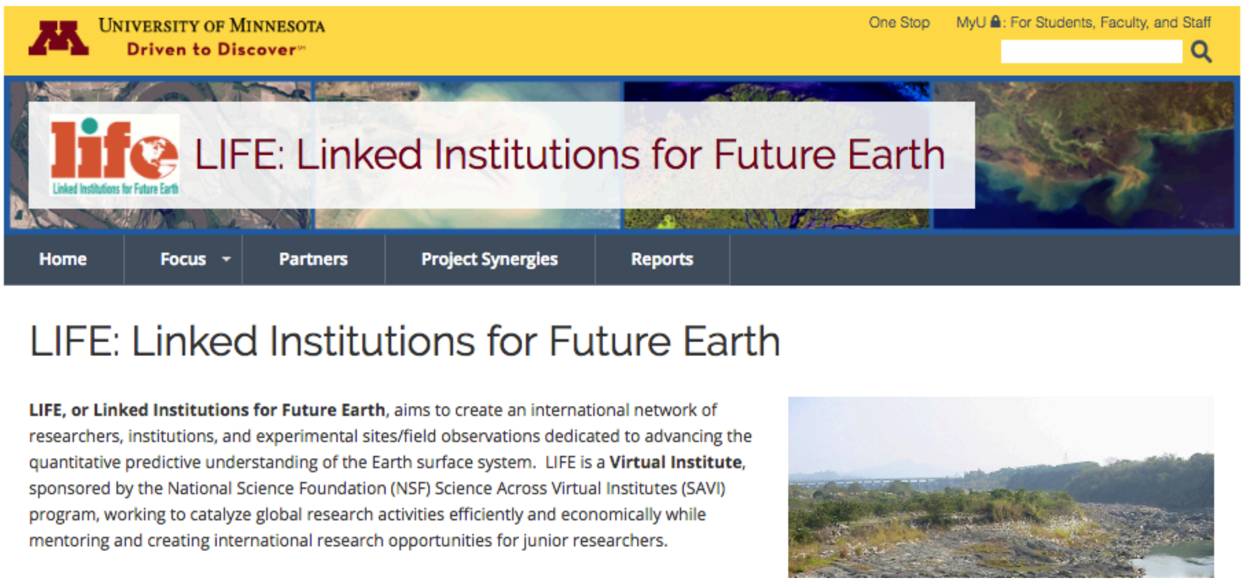
5. Inventions, patent applications, and/or licenses

Not applicable.

6. Websites

We have revamped our project web site, which we will update regularly and populate with our publications, presentations and products.

http://life.umn.edu/



7. Other products, such as data or databases, physical collections, audio or video products, software or NetWare, models, educational aids or curricula, instruments, or equipment

The data produced by LIFE will be handled in the same way as the NCED data, that is, stored in an easy to access format in the NCED web site and available to the research community at large and the public. Currently, discussions are taking place with SEAD (Sustainable Environment- Actionable Data) at the University of Michigan to mainstream and improve the storage and retrieval of the NCED2 and LIFE data and use them as demonstration case studies. A preliminary such case study with NCED data has already been developed.

Supporting Files

You may upload pdf files with images, tables, charts, or other graphics in support of this section. You may upload up to 4 pdf files with a maximum file size of 5 MB each. Description (required if uploading a file).

C. PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS – Who has been involved?

1. What individuals have worked on the project?

People that have contributed to the LIFE project by exchanging research ideas:

Efi Foufoula-Georgiou (University of Minnesota)

Chris Paola (University of Minnesota)

Vaughan Voller (University of Minnesota)

William Dietrich (University of California, Berkeley)

Paola Passalacqua (University of Texas, Austin)

Praveen Kumar (University of Illinois, Urbana-Champaign)

Patrick Hamilton (Science Museum of Minnesota)

Vladimir Nikora (University of Aberdeen, UK)

Liam Reinhardt (University of Exeter, UK)

Francois Metivier (IPGP, France)

Antonio Parodi (CIMA Research Foundation, Italy)

Daniel Conde (Universidad de la Republica, Uruguay)

Cristian Escauriaza (Pontifica Universidad Catolica de Chile)

Rina Schumer (Desert Research Institute, Reno)

Lauren Larsen (University of California, Berkeley)

Chris Keylock (University of Sheffield, UK)

Stefano Lanzoni (University of Padova, Italy)

Gianluca Botter (University of Padova, Italy)

David Mohrig (University of Texas, Austin)

Arvind Singh (University of Central Florida)

Barbara Burkholder (University of Minnesota)

Diana Dalbotten (University of Minnesota)

Antonello Provenzale (CNR, Rome, Italy)

2. What other organizations have been involved as partners?

None entered.

3. Have other collaborators or contacts been involved?

Yes.

D. IMPACT – What is the impact of the project? How has it contributed?

1. What is the impact on the development of the principal discipline(s) of the project?

LIFE Research advances understanding of deltas and watersheds that spans the disciplines of geomorphology, hydrology, river biology, ecology, water resources engineering, and socio-economic sciences. The researches of the PIs have contributed original ideas to: (1) River Meandering, (2) Landscape organization under changing climatic forcing, (3) Analyzing and informing social and environmental vulnerabilities in delta regions, and advancing physical classifications of deltas, and (4) Inferring changes in Water Cycle Dynamics of Intensively Managed Landscapes via the Theory of Time-Variant Travel Time Distributions.

2. What is the impact on other disciplines?

The two research themes of LIFE (quantifying vulnerability and resilience of watersheds, coastal areas, and deltas in a changing environment) are by nature multi-disciplinary (hydrology, geomorphology, ecology, engineering, social sciences). The quantitative frameworks developed by life PIs can be used for analysis in other disciplines.

3. What is the impact on the development of human resources?

The LIFE project is a collaboration of several, international and diverse teams of specialists with expertise in the geosciences and engineering. Students and young researchers are exposed to an interdisciplinary approach to scientific research and a combination of theoretical approaches, models, fieldwork and survey-based analyses. Special emphasis on broader impacts and in bridging research, education, and science-policy that affects society is embedded in all activities of LIFE.

The Science Museum of Minnesota (SMM), a LIFE partner, is featuring an exhibit called "Future Earth" where the impacts of humans on the future of our resources are explained for the public. With financial support from LIFE, SMM produced four "Science-on-a-Sphere" films as part of the Great Cities Initiative. The videos are both in Spanish and English versions and are immediately available for download.

4. What is the impact on physical resources that form infrastructure?

LIFE uses extensively the experimental laboratories in the U.S. and abroad (the St. Anthony Falls Laboratory at the University of Minnesota and the laboratory facilities at IPGP, France) for both education and research. In subsequent years more facilities will be engaged in the projects both in collaborative research and training.

5. What is the impact on institutional resources that form infrastructure?

Not applicable.

6. What is the impact on information resources that form infrastructure?

Not applicable.

7. What is the impact on technology transfer?

Not applicable.

8. What is the impact on society beyond science and technology?

Delta and watershed research is immediately relevant to the livelihood of people that live there and the goods that they produce. Our research findings are expected to play a major role in informing management and policy decisions in watersheds and deltas undergoing change.

E. CHANGES/PROBLEMS

1. Changes in approach and reasons for change

None

2. Actual or Anticipated problems or delays and actions or plans to resolve them

None

3. Changes that have significant impact on expenditures

None

4. Significant changes in use or care of human subjects

None

5. Significant changes in use or care of vertebrate animals

None

6. Significant changes in use or care of biohazards

None

SPECIAL REQUIREMENTS

None