LIFE (Linked Institutions for Future Earth)

Fifth Year Report to NSF: 2016-2017

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Lead PI: Efi Foufoula-Georgiou (University of California, Irvine)

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 interna-tional network of 11 institutions seeks to make research actionable on a global level and to train the next generation of Earth-surface scientists.

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 fifth year of the project, the major activities included:

(1) 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.

(2) 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;

(3) 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 May/June 2017. Professors Paola and Voller offered a one-week short course on the IPGP campus.

(4) The *Summer Institute on Earth surface Dynamics* (SIESD 2017) focusing on "Investigating scale in earth-surface systems to better inform predictions" to be hosted at the St. Anthony Falls Laboratory, University of Minnesota on August 10-19, 2017. Approximately 40 students from all over the world have been accepted to the SIESD 2017 and the top 2 international applicants will be offered partial travel support from LIFE as needed, to enable their participation.

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

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

Some details of these activities are provided below.

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

The meeting was organized by Lead PI Efi Foufoula-Georgiou (UCI), Antonello Provenzale (CNR, Italy), Travis Huxman (UCI), Matthew Bracken (UCI), and Kailen Mooney (UCI).

The other participants were Ghada El Serafy (DELTARES, Netherlands), Constantin Cazacu (University of Bucharest, Romania), Herman Hummel (NIOZ, Netherlands), Amy Hansen (University of Minnesota), Megan Lulow (UCI), Michael O'Connell (Irvine Ranch Conservancy), Anthony Longjas (UCI), Kristen Davis (UCI), Soroosh Sorooshian (UCI), Klaus Fraedrich (Max Planck Inst Hamburg*),* Ian Harrison (Conservation International), Kristin Byrd (USGS, Menlo Park), Henry (Hank) Loescher (NEON and INSTAAR), and David M. Theobald (Conservation Science Partners, USA).

The meeting brought together experts working on protected area design and management, ecosystem processes, landscape connectivity, adaptive planning, climate change, ecosystem benefit analysis, and the application of satellite information for ecosystem monitoring and biodiversity conservation. Some of the questions that were discussed are the following:

Science: What is the state-of-knowledge on protected areas and other ecological reserves?

- What are the ongoing changes in the environments of protected areas and how can we quantify them?
- What is the effect of extreme events on eco-hydrosystems, especially in protected areas?
- How can we quantify uncertainties in future projections of ecosystem conditions?
- How can we upscale (and is it possible to upscale) the information from local ecosystems in protected areas to obtain information at regional/continental scale?
- What new types of RS and in situ data are becoming available?
- What data and models are needed to fully represent the geosphere-biosphere-climate interactions

characterizing natural ecosystems?
- Can we define hotspots of "climate change impact" for ecosystems?

Policy: What are the opportunities for influencing management and policy of protected areas and other ecological reserves?

- How does location, connectivity, and size of protected areas affect their ecological functionality, benefits, and sustainability?
- What protected area designs function better under climate and landscape change scenarios?
- How do we measure the value of protected areas for conservation and for services? Do protected areas provide services that are not available elsewhere?
- How to plan adaptively for a post 2020 strategy on nature?
- How to use science to influence policy and management? How do we communicate uncertainties to policy and decision makers?
- What is the role of citizen science?

(2) 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 California, Irvine. They gave a seminar and met with students and researchers over extended meetings during that week.

Distinguished LIFE Speakers for 2017:

1. ***Gianluca Botter**,* Associate Professor, University of Padova, Italy, “*Streamflow Regimes: Drivers, Classification & Implications*” (April 5, 2017).
2. ***Praveen Kumar**,* Colonel Harry & Frankie Lovell Endowed Professor, University of Illinois Urbana-Champaign, “Advancing Food-Energy-Water Sustainability Through Critical Zone Science”, (March 24, 2017).

In addition, LIFE partially supported invited speakers to give a talk at the University of California, Irvine:

1. ***Paolo D'Odorico***, Ernest H. Ern Professor, University of Virginia, “*Globalization of Water Through Trade & Transnational Investments*” (September 23, 2016).
2. ***Ciaran Harman***, Assistant Professor, Johns Hopkins University, “*A Unified Approach to Hydrologic Flow & Transport in The Critical Zone*” (October 21, 2016).
3. ***Giuliano Di Baldassarre***, Professor Uppsala University, Sweden, “*Hydrological Extremes in the Anthropocene*” (October 28, 2016).
4. ***Grey Nearing***, Research Scientist, Hydrological Sciences Lab, NASA Goddard and Faculty at University of Maryland, “*The Science of Complex Systems*” (November 4, 2016).
5. ***Fred Ogden***, Professor of Engineering and Roy & Caryl Cline Endowed Chair of Engineering University of Wyoming, “*The Generalized Moisture Content Equation: Implications for Hyper-Resolution Modeling of the Hydrological Cycle over Large Domains*” (November 10, 2016).

6. ***Aaron Packman***, Professor, Northwestern University, "*Solute-Particle-Biofilm Interactions: Ubiquitous Controls on Physical-Biological Dynamics*" (December 2, 2016).
7. ***Gabriel Katul***, Professor, Duke University, "*Co-spectral Budgets Link Energy Distributions in Eddies to Bulk Flow Properties in Hydrology & Micrometeorology*" (January 13, 2017).
8. ***Luigia Brandimarte***, Associate Professor, KTH Royal Institute of Technology, Sweden, "*Simple probabilistic methods for the design of hydraulic structures: Applications to bridge scour and flood protection*" (February 3, 2017).
9. ***Peter Troch,*** Professor & Agnese Haury Endowed Chair in Environment, Hydrology & Water Resources University of Arizona, "Catchment Co-evolution: A Useful Framework for Improving Predictions of Hydrological Change?" (March 10, 2017).

(3) IPG Paris short course on Experiments and Modeling of Sediment Transport and Land Building Processes (May/June, 2017): Professors Paola and Voller continue to establish strong academic and research links with the Institut de Physique du globe de Paris (IPGP). In May/June 2017, Profs. Paola and Voller offered a one-week short course on the IPGP campus. 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.

(4) Summer Institute on Earth-surface Dynamics (SIESD) 2017 to be held on August 10-19, 2017 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. Drawing on NCED's approach of integrating theory, laboratory experiments, numerical modeling, and fieldwork, this two-week institute combines lectures with practical experiences in the laboratory and the field. This year's SIESD theme focuses on investigating scale in earth-surface systems to better inform predictions. Scale is a fundamental attribute in how earth-surface systems operate and how we (scientists) study and understand them. The 2017 SIESD will concentrate on system behaviors that emerge from the interaction of processes operating at different spatial and temporal scales. Human activities, as a principal source of change, are included and introduce dimensions of scale that are unparalleled in geologic history. The themes of scale at SIESD will focus on two main applications: earthcasting – the simulation of large-scale earth-system interactions; and river deltas – a nexus of climate, land, ocean, and society. Like previous workshops, SIESD 2017 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. Approximately 40 students from all over the world have been accepted to the SIESD 2017 after a selection process that includes application and three letters of recommendation.

(5) Special sessions at major international meetings: In collaboration with another project (Belmont Forum: DELTAS project) we organized special sessions in the AGU 2016 and EGU 2016 meetings. Special sessions for AGU 2017, EGU 2018 and JpGU 2018 are planned right now.

(6) PI exchanges and Web collaboration ideas: PI Foufoula-Georgiou presented at the AGU 2016 and EGU 2017 meetings and met with LIFE partners. As part of the LIFE supported research, PI Foufoula-Georgiou was invited to present a talk at the *Mathematical Approach To Climate Change Impacts Workshop* 2017 hosted by the Istituto Nazionale di Alta Matematica (INdAM) in Rome, Italy from March

13 - 17, 2017. She gave a talk entitled, “Reduced Complexity Modeling of eco-hydrologic change in intensively managed landscapes”. PIs Chris Paola and Vaughan Voller visited IPGP for the short course in May-June 2017.

The following international collaborators visited PI Foufoula-Georgiou at UC Irvine:

(1) Gianluca Botter visited to finalize work on “Reducing Aggregation Bias of Water and Solute Travel Times in Heterogeneous Catchments via a Time-Variant Lagrangian Transport Formulation”. The work was eventually published in Geophysical Research Letters.
(2) Stefano Lanzoni (University of Padova, Italy) visited to discuss new ideas on proposing a new metric for Braiding Index based on entropy.
(3) Jean-Louis Grimaud (MINES ParisTech, France) visited and discussed on precipitation driven knickpoints.

Diogo Bolster (University of Notre Dame) visited PI Voller at the St. Anthony Falls Laboratory, University of Minnesota last March 2017 to discuss work on flows in heterogeneous porous media.

2.2. Significant results:

International research collaborations. Examples include:

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

Dynamics of meandering rivers and inferring geomorphic processes from patterns

Meandering river planform evolution is driven by the interaction of local nonlinear hydro-morphodynamic processes and by threshold-type nonlinear dynamics via cutoffs. Understanding if and how these “process or dynamic nonlinearities” show up in the static geometry of river planforms (“form nonlinearity”) is important as it can provide the basis of inferring dynamics from static images, and deciphering changes in forcing (natural or anthropogenic) by observing changes in planforms. But *are dynamic nonlinearities encoded in the static meander planform geometries?* Previous attempts have found at most a weak signature of these dynamic nonlinearities in static meander planform morphologies. Using powerful analysis and detection methodologies, our work has unambiguously showed that the spatial structure of meandering centerlines does indeed encode dynamic nonlinearities (see Figure 1). We demonstrated this finding both in numerically simulated meandering rivers and in three natural rivers. Cutoffs were found to obscure the imprint of the dynamic nonlinearities of the governing morphodynamic processes, but they were also shown to act as a local source of nonlinearity themselves by rearranging the meander train and introducing small scales into the centerline. The degree of nonlinearity (DNL) was measured for two meandering rivers in the Minnesota River Basin. Both the Watonwan and Blue Earth Rivers saw an overall decline in DNL from 1938 to 2008, reflecting a shift in the driving dynamics (i.e., climate and land use changes), direct channel modifications such as channel straightening, and the occurrence of 36 cutoffs over the time period (*Schwenk et al*., 2016).

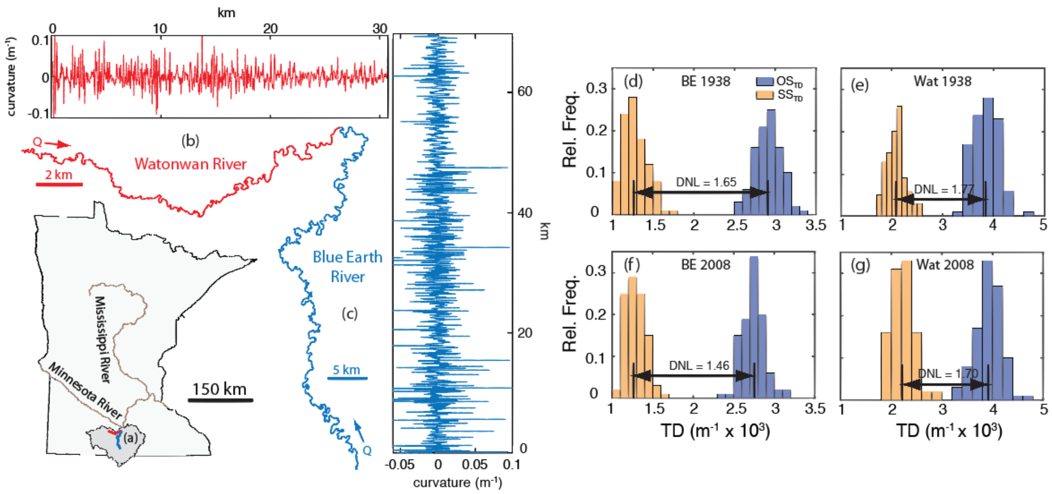

Figure 1. Left panel: the locations of the Blue Earth (in red) and Watonwan (in blue) rivers are shown within the Greater Blue Earth Basin (a) in Minnesota, USA. In (c) and (d), the 2008 Watonwan River and 2008 Blue Earth centerlines are shown in more detail along with their curvature series. As shown, both rivers flow to the same location but note the different scales for each. Right panel: the degree of nonlinearity (DNL) is shown for each river in 1938 and 2008. The degree of nonlinearity (DNL) is defined as the distance between the means (vertical black lines) of the OS_{TD} and SS_{TD} distributions. See *Schwenk and Foufoula-Georgiou* (2017) for the formulation of the DNL.

The need to monitor the ever-changing meandering rivers at high spatio-temporal resolutions is imperative in the quest to understand the role of climatic and human influences on planform adjustments. This was not possible before based on sparse areal photographs or field surveys, but becomes feasible now with the ability to observe landscapes from space. *However, efficiently extracting meandering river planform changes over large spatial domains and with high enough temporal resolution from satellite images, now available globally, presents multiple challenges.* Our work addressed these challenges using Landsat imagery and introduced a set of innovate and efficient methods to map and measure spatial and temporal planform changes including local and average widths, centerline migrated areas and rates, erosion and accretion, and cutoffs (*Schwenk et al*., 2017). The methods have been assembled in a freely-available, comprehensive toolbox called River Morphodynamics from Analysis of Planforms (RivMAP). As a proof-of-concept, the RivMAP toolbox was applied to over 1,300 km of the actively-migrating and predominately meandering Ucayali River in Peru (see Figure 2).

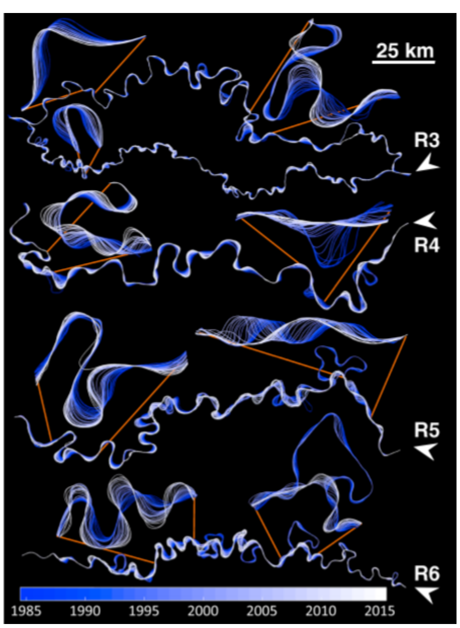

Figure 2. Centerlines obtained from Landsat-derived single-thread channel masks using RivMAP are shown for the study regions of the Ucayali. North arrows also indicate the direction of flow which travels from R6 to R3. Zoom views highlight some of the complex migration patterns and cutoffs along the Ucayali River. The total centerline length each year is approximately 1500 km including both branches in R3. Flow travels from R6 to R3.

Landsat 5 and 7 images collected from 1985-2015 were classified with a supervised classifier, and annual composite images were created that are shown to resolve bankfull channel and bar morphologies. We found that sediment flux, cutoffs, and climate simultaneously act as controls on migration rates and cannot be parsed without the high spatiotemporal analysis performed by this research. We also analyzed 13 meander cutoffs and found that cutoffs perturb river morphodynamics by accelerating migration rates (11/13 cutoffs) and widening the channel (8/13) both up- and downstream of the cutoff (*Schwenk and Foufoula-Georgiou*, 2016). The downstream distance of accelerated migration was found to scale with the length of river removed due to cutoff, presenting new challenges in modeling and prediction of rivers' self-adjustments to perturbations with implications for river and floodplain management.

Publications:

Schwenk, J., A. Khandelwal, M. Fratkin, V. Kumar, and E. Foufoula-Georgiou (2017), "High spatio-temporal resolution of river planform dynamics from Landsat: the RivMAP toolbox and results from the Ucayali River", *Earth and Space Science, 4,* 46-75, doi: 10.1002/2016EA000196.

Schwenk, J., and E. Foufoula-Georgiou (2016), "Meander cutoffs nonlocally accelerate upstream and downstream migration and channel widening", *Geophysical Research Letters*, 43, 12,4370-12,445, doi:10.1002/2016GL071670.

Schwenk, J., and E. Foufoula-Georgiou (2017), "Are process nonlinearities encoded in meandering river planform morphology?", *JGR Earth Surface*, Accepted.

(2) Collaboration with the University of Exeter, UK (Liam Reinhardt), Durham University, UK (Alexander L. Densmore), University of Sheffield, UK (Chris Keylock), and MINES ParisTech, France (Jean-Louis Grimaud).

Geomorphic reorganization of landscapes under climate change

Afforded by the unique experimental landscape that provided a detailed space-time recording of erosional fluxes (every 5 mins, at more than 800,000 pixels and over several hours), we have shown for the first time that there exists a hierarchical pattern of erosion namely, that hillslopes and fluvial channels erode more than the landscape-median while parts of the colluvial regime erode less than the median (geomorphic regimes are quantified via the typical slope-area curve). This erosional pattern apparently contradicts the possibility of maintaining the statistical properties of a steady state landscape, such as invariant total relief or stationary slope-area curves. The missing factor needed to reconcile these ostensible discrepancies is the dynamic character of the landforms at Steady State (SS). Thus, asserting that hillslopes are more likely to erode is not equivalent to stating that fixed locations in the landscape are also more likely to erode, because pixels can evolve through different geomorphic regimes (see Fig. 3).

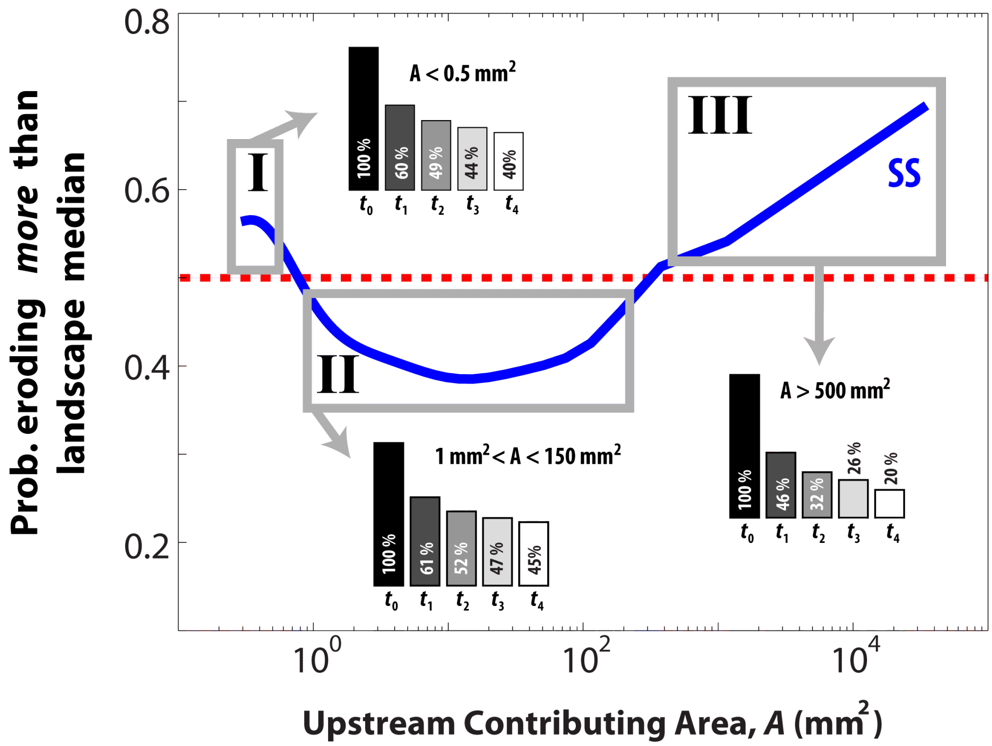

Figure 3. Dynamic Landforms at Steady State. The shape of the E50-area curve (blue curve) reveals that the likelihood of eroding more (or less) than the median of the landscape is nonlinearly related to the upstream contributing area, *A*. We examine the dynamic nature of steady-state landscapes within three ranges of upstream contributing areas: (I) $A < 0.5\text{mm}^2$, with a higher likelihood of eroding more than the median of the landscape; (II) $1\ \text{mm}^2 < A < 150\ \text{mm}^2$, with a lower likelihood of eroding more than the landscape median; (III) $A > 500\ \text{mm}^2$, with a higher likelihood of eroding more than the landscape median. We identify at a given time (t_0) the location of all the pixels on the landscape within each of the three ranges defined above (100%). For each subsequent topography (measured 5 min apart), we compute the percentage of pixels on those locations, which are still characterized by *A* in the same interval as initially defined. The inset plots show that, in each area range, a significant percentage of pixels change their upstream contributing areas over time, illustrating the dynamic nature of steady-state landscapes.

We show that the E50-area curve admits a characteristic shape which is not a horizontal line at 0.5, as would be expected for landscapes that are at a SS with random internal dynamics. Rather it is a bend-shaped curve that captures the hierarchical erosional dynamics of SS landscapes. Under increased precipitation by five-fold (Transient State -TS), we characterize the drastic changes in shape of the E50-area curve, which keeps track of the major landscape reorganization as it starts on its way towards a new equilibrium state. Finally, we document the changes in the longitudinal river profiles during the Transient State, i.e. with increasing rainfall intensity, revealing the formation of knickpoints at certain confluences where large discontinuities in the ratio Qs/Qw are observed (see Fig. 4).

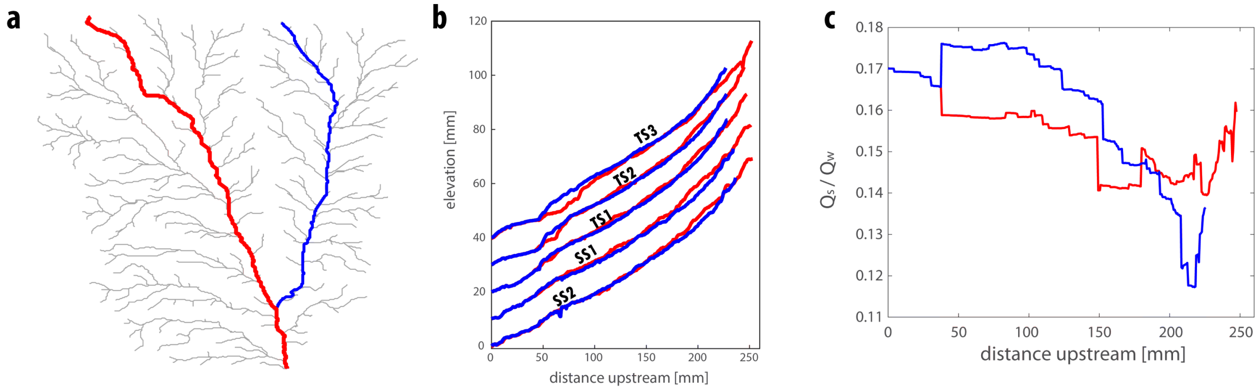

Figure 4. Precipitation driven Knickpoints (a) River network of the largest basin of the experimental landscape. **(b)** Longitudinal river profiles of the two channels highlighted in red and blue on the channel network computed every five minutes starting at Steady State conditions (SS2), and following their temporal evolution during the transient state (TS) generated by a maintained increase of rainfall intensity by five-fold. A knickpoint is generated at the junction of both (red and blue) channels during the first five minutes of the transient state (TS1). The knickpoint advects upstream faster on the red channel, being almost fixed in place on the blue channel as time proceeds (TS2, TS3). **(c)** Sediment to water discharge ratio computed along the river profiles highlighted in (**a**) during TS1. A fairly large discontinuity in the ratios is observed at the junction. We hypothesize that the higher ratio upstream channel generated the knickpoint due to the reduction of river incision caused by a substantial increase of transported sediment load during the onset of TS. Once the knickpoint is generated, it advects faster along the channel where the ratio Qs/Qw is smaller.

Publications:

Tejedor, A., A. Singh, I. Zaliapin, A.L. Densmore and E. Foufoula-Georgiou (2017), Geomorphic reorganization of landscapes under climate change, *Under Review in Science Advances*.

Singh, A., A. Tejedor, JL Grimaud and E. Foufoula-Georgiou. Experimental evidence of landscape reorganization under changing external forcing: implications to climate driven knickpoints. In: *EGU*, Vienna, April 2017.

Singh, A., A. Tejedor, J.L.Grimaud I. Zaliapin, and E. Foufoula-Georgiou. Quantifying the scale- and process-dependent reorganization of landscape under climatic change: inferences from an experimental landscape. In: *Fall AGU Meeting*, San Francisco, December 2016.

(3) Collaboration with the Ecole Polytechnique Federale de Lausanne, Switzerland (Andrea Rinaldo).

Entropy and Optimality in River Deltas

River deltas are critically important Earthscapes at the land water interface supporting dense populations and diverse ecosystems, while also providing disproportionally high food and energy resources. Yet, deltas are sinking at alarming rates due to sea level rise, local subsidence, and reduced sediment supply. Resilience to these perturbations depends on the structure of the deltaic channel network that ultimately dictates how water, sediment, and nutrients are spread over the delta surface. To date, however, a unified theory explaining how deltas self-organize to optimally distribute water and sediment up to the shoreline remains elusive. By defining a suitable Nonlocal Entropy Rate (based information theory concepts) and by analyzing data from field (Fig. 5) and simulated deltas (Fig. 6), we suggest that delta networks achieve configurations wherein the diversity of flux delivery to the shoreline is maximized. We suggest that prograding deltas attain dynamically accessible optima of the flux distributions for each configuration of their channel networks, thus effectively decoupling evolutionary timescales of geomorphology and hydrology. When interpreted in terms of delta resilience, high nonlocal Entropy Rate configurations reflect an increased ability to withstand perturbations but also suggest that the distributive mechanism responsible for dampening the perturbations, when exceeds a certain intensity threshold, might lead to catastrophic events.

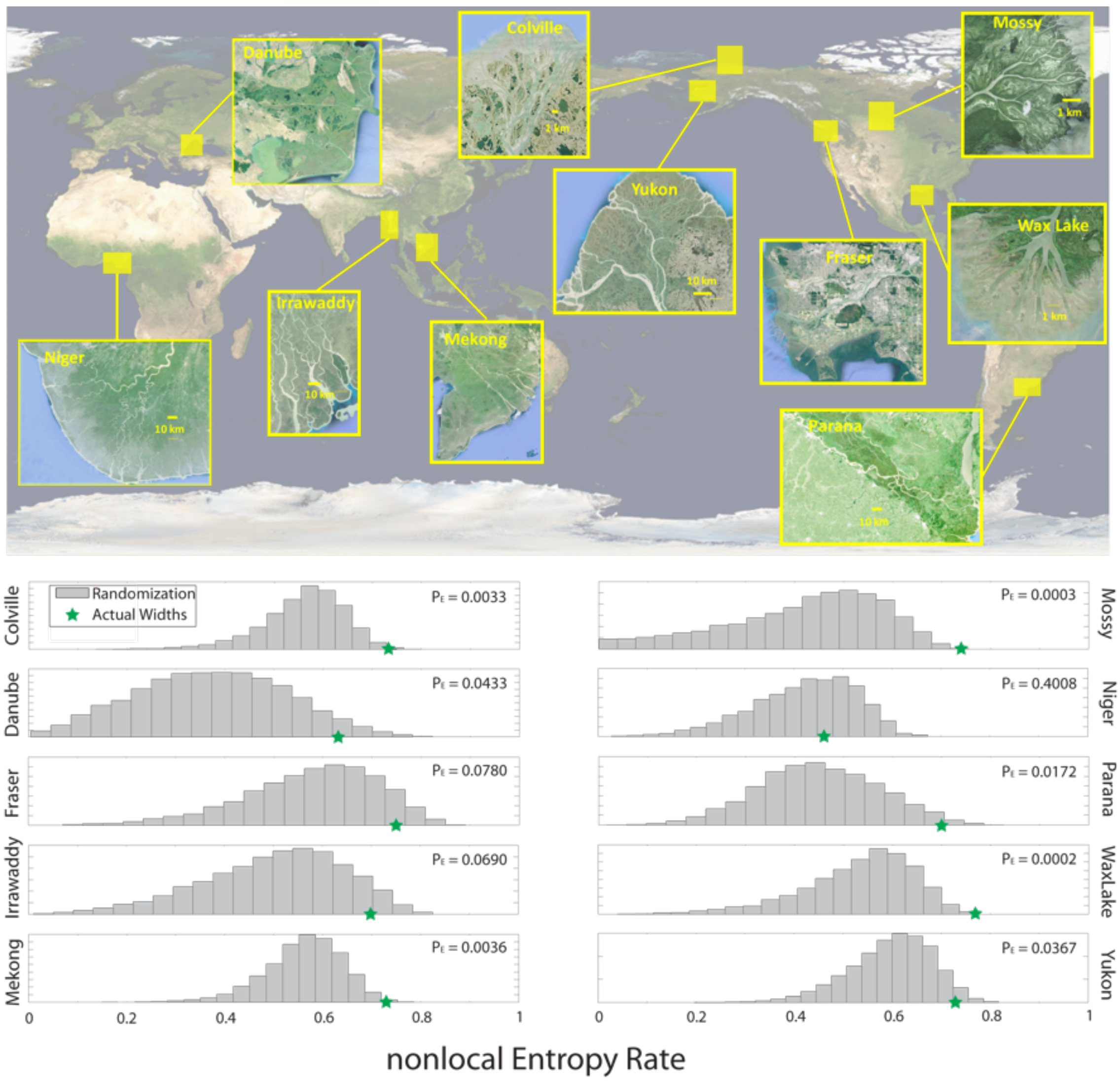

Figure 5. Nonlocal Entropy Rate for ten field deltas. Green stars represent the values of nonlocal Entropy Rate computed for ten field deltas, using channel width (extracted from Landsat) as proxy for flux partition in bifurcations. For comparison and as a null hypothesis, we have computed for each delta the values of nonlocal Entropy Rate when the flux partition is randomized. The results of 10^5 randomizations are displayed for each delta as histograms. It is observed that nine out of the ten deltas analyzed exhibit a maximal value of nonlocal Entropy Rate, supporting the hypothesis that deltas self-organize to maximize the diversity in delivering fluxes to the shoreline.

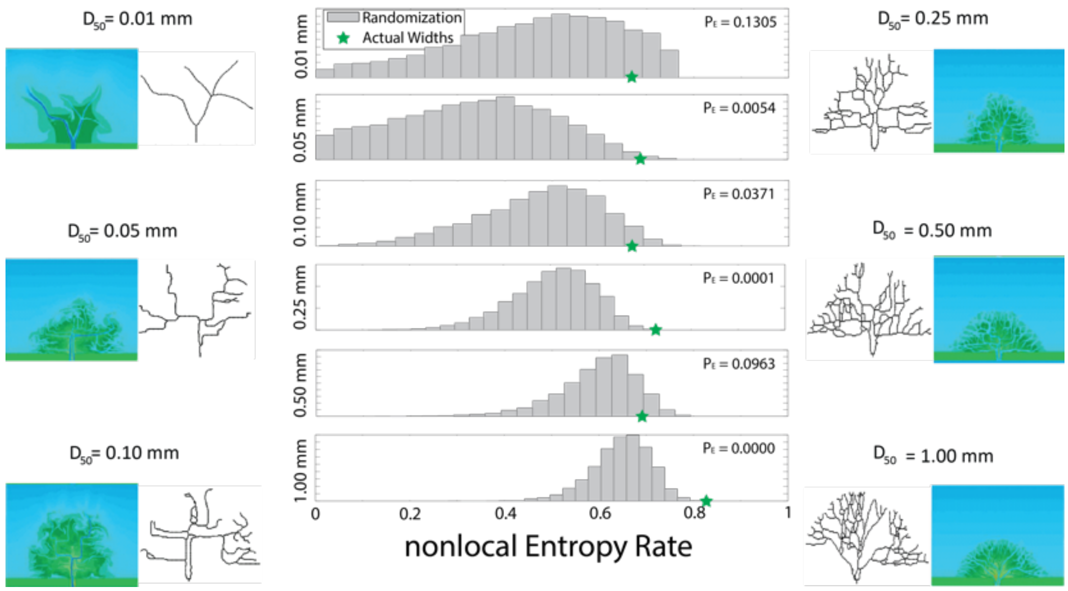

Figure 6. Nonlocal Entropy Rate for simulated deltas. We examine the nonlocal Entropy Rate of numerically simulated deltas obtained by the Delft3D model. The simulated deltas are river dominated, with no vegetation, and with a lognormal distribution of incoming sediment size with median grain-size D_{50} varying from 0.01 to 1.0 mm and the same variance in the log space. Similar to the analysis conducted for the field deltas, green stars represent the values of nonlocal Entropy Rate using channel width (extracted from simulations) as proxy for flux partition in each bifurcation. Five out of six deltas analyzed exhibit a maximal value of nonlocal Entropy Rate.

Publications:

Tejedor, A., A. Longjas, D. Edmonds, I. Zaliapin, T. Georgiou, A. Rinaldo and E. Foufoula-Georgiou. Entropy and Optimality in River Deltas, *Under Review in PNAS*.

Tejedor, A., A. Longjas, and E. Foufoula-Georgiou. Is there a self-organization principle of river deltas? In: *EGU*, Vienna, April 2017.

Tejedor, A., A. Longjas and E. Foufoula-Georgiou. River delta self-organization via entropy rate analysis. In: *Fall AGU Meeting*, San Francisco, December 2016.

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

Reducing Aggregation Bias of Water and Solute Travel Times in Heterogeneous Catchments via a Time-Variant Lagrangian Transport Formulation

Anthropogenic changes in land cover and land use in the Midwestern U.S. since the 1970's have imposed contrasting spatial heterogeneities that are impacting in complex ways the residence and travel time of water in catchments (*Danesh-Yazdi et al.*, 2016). Although detailed transport models with a large number of parameters might explain some physical processes of interest at the field scale, provided that enough observations are available for attribution of cause and effect, they are infeasible at the large watershed scale. The absence of rigorous data and theories for extrapolating information from the field to the larger scales necessitates developing reduced-complexity frameworks that are still able to explain the spatial heterogeneity and process complexity in real-world catchments. *In this study, we examined the ability of* *the lumped stochastic Lagrangian formulation for water and solute transport in providing reliable estimates of the mean travel time (MTT) in spatially heterogeneous catchments* (*Danesh-Yazdi et al*., 2017).

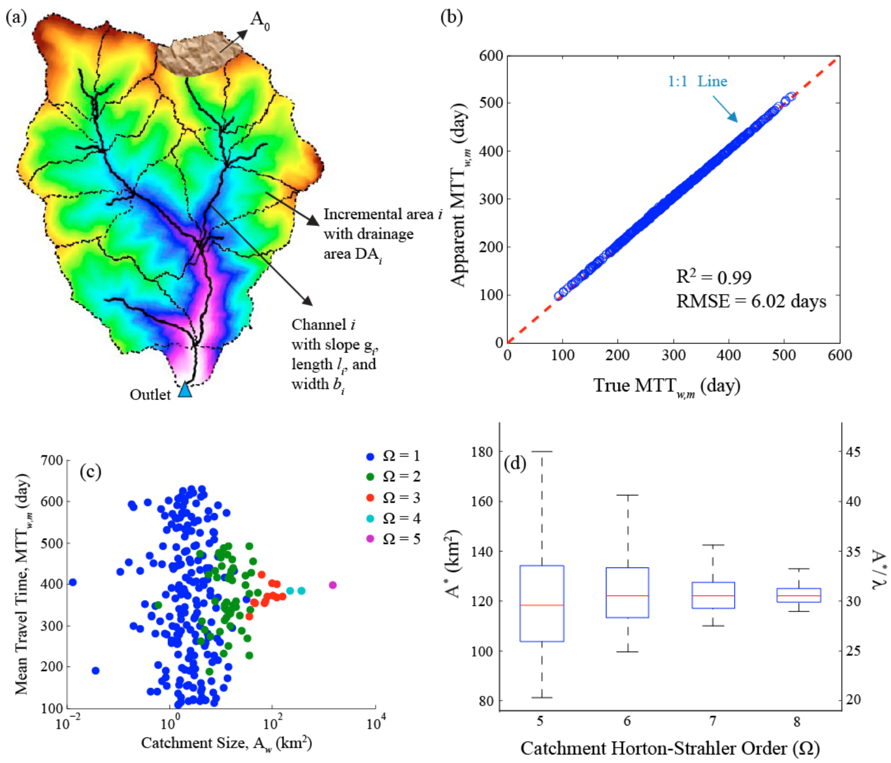

Figure 7. Effect of spatial heterogeneity on the scale of the aggregated time-variant travel time distribution (TTD). (a) Schematic of a catchment decomposition into incremental areas (IAs), each IA represented by a single storage model. (b) Comparison of the apparent MTT (computed using the aggregated fluxes of the catchment and a time-varying lumped Langrangian formulation) with the true MTT (computed using the fluxes of the individual IAs) in a two reservoir system under the random age sampling assumption. (c) Emergence of a characteristic scale (A^*) at which the aggregation effects of spatial heterogeneity vanish. (d) A^* versus catchment maximum Horton-Strahler order (Ω) for 1000 realizations of Tokunaga trees with parameters $a = 1.1$, $c = 2$, and mean incremental area $\lambda = 3$ km^2. The median of A^*/λ, i.e., A^*_{med}/λ, takes place at almost the same magnitude in catchments with different orders, while its variance decreases as the catchment's order increases.

Via numerical simulations of heterogeneous catchments, *we showed that a time-varying travel time distribution (TTD) formulation results in MTTs that are not significantly biased to the aggregation of spatial heterogeneity under different age sampling assumptions*. This finding reinforces the importance of such a time-variant lumped formalism to appropriately predict the catchment's mean transport time scales without the need to explicitly characterize and embed the small-scale spatial heterogeneity. *Although significant variability of MTT exists at small spatial scales, we showed that there exists a characteristic spatial scale (A^*) above which the MTT converges to a constant value not influenced by the aggregation of spatial heterogeneity*. *The ratio between the characteristic scale A^* and the mean incremental area of* *the basin was also shown to be on average independent of the river network topology and spatial arrangement of incremental areas*. The above findings have practical implications pertaining to data measurements in the field and inferences that can be made on transport time scales and mixing processes across spatial scales. Specifically, if the interest is to understand the functioning of a large catchment, collecting data at scales smaller than A^* does not allow extrapolation to estimate the MTT at larger scales. However, the MTT estimated via a time-variant Lagrangian transport formulation and for scales comparable to A^* is not significantly influenced by aggregation effects, allowing thus reliable interpretation and inference at the catchment scale.

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*, *52,* doi:10.1002/2016WR019091.

Danesh-Yazdi, M., G. Botter, and E. Foufoula-Georgiou (2017), Time-Variant Lagrangian Transport Formulation Reduces Aggregation Bias of Water and Solute Mean Travel Time in Heterogeneous Catchments, *Geophys. Res. Lett.,* 44, doi:10.1002/2017GL073827.

Danesh-Yazdi, M., A. Tejedor, and E. Foufoula-Georgiou (2017), Self-Dissimilar Landscapes: Revealing the Signature of Geologic Constraints on Landscape Dissection via Topologic and Multi-Scale Analysis, *Geomorphology*, Accepted.

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.

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 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 6 we will plan the following major activities:

(1) Organize the *"Stochastic Transport and Emergent Scaling on the Earth Surface"* (STRESS 5) workshop, which is 5th in a series of workshops aiming to increase international collaboration on a focused topic. The 2017 topic is on connectivity in earth surface dynamics and vulnerability assessment in coupled earth surface processes.

(2) Organize the *second "LIFE-ECOPOTENTIAL" Meeting* on Ecosystem Management of Protected Areas, and NSF-EU cooperation meeting. The first LIFE-ECOPOTENTIAL meeting was organized on November 15-17, 2016 at UCI with the goal of bringing 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. The scope to establish a long-term institutional partnership for scientific and educational exchange.

(3) Continue the "*Distinguished Lecture Series on Earth-Water-Life*". This lecture series was introduced four years ago 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."

(4) Short and long term visits of research collaborators. For the following year we plan visits of several researchers, including: (1) *Stefano Lanzoni* (Professor, University of Padova) to work on river meandering dynamics as inferred from high resolution long-term records of Landsat images. (2) *Chris Keylock* (Prize Senior Lecturer, University of Sheffield) to advance joint work on landscape evolution using the extensive data we have collected on the eXperimental Landscape Evolution (XLE) facility where different uplift and precipitation rates were applied and high resolution scanned topographies recorded; (3) *Jean-Louis Grimaud* (Assistant Professor, Mines ParisTech) to continue work on quantifying how knickpoints in rivers can result from climate perturbations which alter transport dynamics in the river network; (4) *François Métivier* (Professor, IPGP) to visit and collaborate with PIs Paola and Voller at SAFL; (5) support the exchange of several students and young researchers from partner institutions.

(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.

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

1. Dissertations

Czuba, Jonathan (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", University of Minnesota, http://hdl.handle.net/11299/181713.

Danesh-Yazdi, Mohammad (2017), "Inferring the Impacts of Anthropogenic Changes and Catchment Spatial Heterogeneity on the Water Cycle Dynamics and Transport Time Scales", University of Minnesota, http://hdl.handle.net/11299/185617.

Schwenk, Jon (2016) "Meandering rivers: interpreting dynamics from planform geometry and the secret lives of migrating meanders", University of Minnesota, http://hdl.handle.net/11299/183333.

2. Publications

Belmont, P., and E. Foufoula-Georgiou (2017), Solving water quality problems in agricultural landscapes: new approaches for these nonlinear, multiprocess, multiscale systems, *Water Resources Research, 53*, 2585-2590, doi: 10.1002/2017WR020839

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., E. Foufoula-Georgiou, K.B. Gran, P. Belmont, and P.R. Wilcock (2017), Interplay between spatially-explicit sediment sourcing, hierarchical river-network structure, and in-channel bed-material sediment transport and storage dynamics, *Journal of Geophysical Research – Earth Surface*, *122*(5), 1090-1120, doi:10.1002/2016JF003965.

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*, *52,* doi:10.1002/2016WR019091.

Danesh-Yazdi, M., G. Botter, and E. Foufoula-Georgiou (2017), Time-Variant Lagrangian Transport Formulation Reduces Aggregation Bias of Water and Solute Mean Travel Time in Heterogeneous Catchments, *Geophys. Res. Lett.,* 44, doi:10.1002/2017GL073827.

Danesh-Yazdi, M., A. Tejedor, and E. Foufoula-Georgiou (2017), Self-Dissimilar Landscapes: Revealing the Signature of Geologic Constraints on Landscape Dissection via Topologic and Multi-Scale Analysis, *Geomorphology*, Accepted.

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., P. Belmont, P. Wilcock, K. Gran, J. C. Finlay, P. Kumar, J. A. Czuba, J. Schwenk, and Z. Takbiri (2016), Comment on "Climate and agricultural land use change impacts on streamflow in the upper midwestern United States" by Satish C. Gupta et al., *Water Resources Research*, 52, 7536–7539, doi:10.1002/2015WR018494.

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.

Hajra, R., S. Szabo, Z. Tessler, T. Ghosh, Z. Matthews, and E. Foufoula-Georgiou (2017), "Unravelling the association between the impact of natural hazards and household poverty: evidence from the Indian Sundurban delta", *Sustainability Science*, doi:10.1007/s11625-016-0420-2.

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.

Kelly, S., Z. Takbiri, P. Belmont, and E. Foufoula-Georgiou (2017), "Human amplified changes in precipitation-runoff patterns in large river basins of the Midwestern United States", *Hydrology and Earth System Sciences*, In Revision, doi:10.5194/hess-2017-133.

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Schwenk, J., A. Khandelwal, M. Fratkin, V. Kumar, and E. Foufoula-Georgiou (2017), "High spatio-temporal resolution of river planform dynamics from Landsat: the RivMAP toolbox and results from the Ucayali River", *Earth and Space Science, 4,* 46-75, doi: 10.1002/2016EA000196.

Schwenk, J., and E. Foufoula-Georgiou (2016), "Meander cutoffs nonlocally accelerate upstream and downstream migration and channel widening", *Geophysical Research Letters*, 43, 12,4370-12,445, doi:10.1002/2016GL071670.

Schwenk, J., and E. Foufoula-Georgiou (2017), "Are process nonlinearities encoded in meandering river planform morphology?", *JGR Earth Surface*, Accepted.

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., 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.

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*, 58:6, 24-33, doi: 10.1080/00139157.2016.1209016.

Takbiri, Z., A. M. Ebtehaj, and E. Foufoula-Georgiou, A Multi-sensor Data-driven methodology for all-sky Passive Microwave Inundation Retrieval, In Review, *Hydrology and Earth System Sciences*.

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.

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Tejedor, A., A. Singh, I. Zaliapin, A.L. Densmore, and E. Foufoula-Georgiou, Geomorphic Reorganization of Landscapes under Climate Change, In Review, Science Advances.

3. Presentations

Czuba, J.A., A. T. Hansen, E. Foufoula-Georgiou, and J. C. Finlay (2016), "Contextualizing Wetlands within a River-Network Perspective for Assessing Nitrate Removal at the Watershed Scale", H42G-05, AGU Fall Meeting, San Francisco.

Danesh-Yazdi, M., E. Foufoula-Georgiou and G. Botter (2016), "Accounting for catchment spatial heterogeneity via a time-variant Lagrangian transport formulation in estimating water and solute travel time distributions", B32A-04, AGU Fall Meeting, San Francisco.

Ebtehaj, A., and E. Foufoula-Georgiou (2016), "Towards better understanding of high-mountain cryosphere changes using GPM data: A Joint Snowfall and Snow-cover Passive Microwave Retrieval Algorithm", H23F-1608, AGU Fall Meeting, San Francisco.

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.

Foufoula-Georgiou, E., Z. D. Tessler, E. Brondizio, I. Overeem, F. Renaud, Z. Sebesvari, R.J. Nicholls, and E. Anthony (2016), "Catalyzing action towards the sustainability of deltas: deltas as integrated socio-ecological systems and sentinels of regional and global change" GC33E-01, AGU Fall Meeting, San Francisco [**INVITED**].

Guala, M., A. Singh, E. Wong, and E. Foufoula-Georgiou (2016), "Scaling and normalization of river bathymetry spectra and bedform velocity" EP53E-1031, AGU Fall Meeting, San Francisco.

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.

Marra, W.A., A. Tejedor, E. A. Addink, E. Foufoula-Georgiou, and M. G. Kleinhans (2016), "Connectivity of Multi-Channel Fluvial Systems: A Comparison of Topology Metrics for Braided Rivers and Delta Networks" EP53A-0930, AGU Fall Meeting, San Francisco.

Papalexiou, S.M., A. AghaKouchak, and E. Foufoula-Georgiou (2016), "A global assessment of changes in extreme daily maximum temperature", GC11B-1150, AGU Fall Meeting, San Francisco.

Papalexiou, S.M., E. Foufoula-Georgiou, and A. AghaKouchack (2017), "Watch the tail! A story on extreme hourly precipitation", EGU2017-10444-1, EGU General Assembly, Vienna, Austria.

Schwenk, S., A. Khandelwal, M. Fratkin, V. Kumar, and E. Foufoula-Georgiou (2016), "The Secret Lives of Migrating Rivers" EP51A-0882, AGU Fall Meeting, San Francisco.

Schwenk, J., A. Khandelwal, M. Fratkin, V. Kumar, and E. Foufoula-Georgiou (2017), "River morphodynamics from space: the Landsat frontier", EGU2017-11858, EGU General Assembly, Vienna, Austria.

Schwenk, J., and E. Foufoula-Georgiou (2017), "A case of self-perturbation: channel responses to meander cutoffs in the Ucayali River, Peru", EGU2017-11817, EGU General Assembly, Vienna, Austria.

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.

Singh, A., A. Tejedor, J.-L. Grimaud, I. Zaliapin, and E. Foufoula-Georgiou (2016), "Quantifying the scale- and process- dependent reorganization of landscape under climatic change: inferences from an experimental landscape" EP32A-08, AGU Fall Meeting, San Francisco.

Singh A., A. Tejedor, J.-L. Grimaud, and Efi Foufoula-Georgiou (2017), "Experimental evidence of landscape reorganization under changing external forcing: implications to climate-driven knickpoints", EGU2017-17359-1, EGU General Assembly, Vienna, Austria.

Takbiri, Z., A. Ebtehaj, and E. Foufoula-Georgiou (2016), "Inundation Retrieval Using Passive Microwave Observations", H23F-1624, AGU Fall Meeting, San Francisco.

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.

Tejedor, A, A. Longjas, and E. Foufoula-Georgiou (2016), "River delta self-organization via entropy rate analysis" EP53A-0931, AGU Fall Meeting, San Francisco.

Tejedor, A., A. Longjas, and E. Foufoula-Georgiou (2017), "Is there a self-organization principle of river deltas?", EGU2017-11531, EGU General Assembly, Vienna, Austria.

Wu, Z., E. Foufoula-Georgiou, M. Guala, X. Fu, and G. Wang (2016), "A New Lagrangian Formulation of Bedload Transport Guided by Ensemble Statistics of Particle Velocities and Accelerations", EP53E-1018, AGU Fall Meeting, San Francisco.

Wu, Z., E. Foufoula-Georgiou, G. Parker, A. Singh, X. Fu, and G. Wang (2017), "Burial effects on bedload tracer transport", EGU2017-2677, EGU General Assembly, Vienna, Austria.

4. Technologies or techniques

Not applicable.

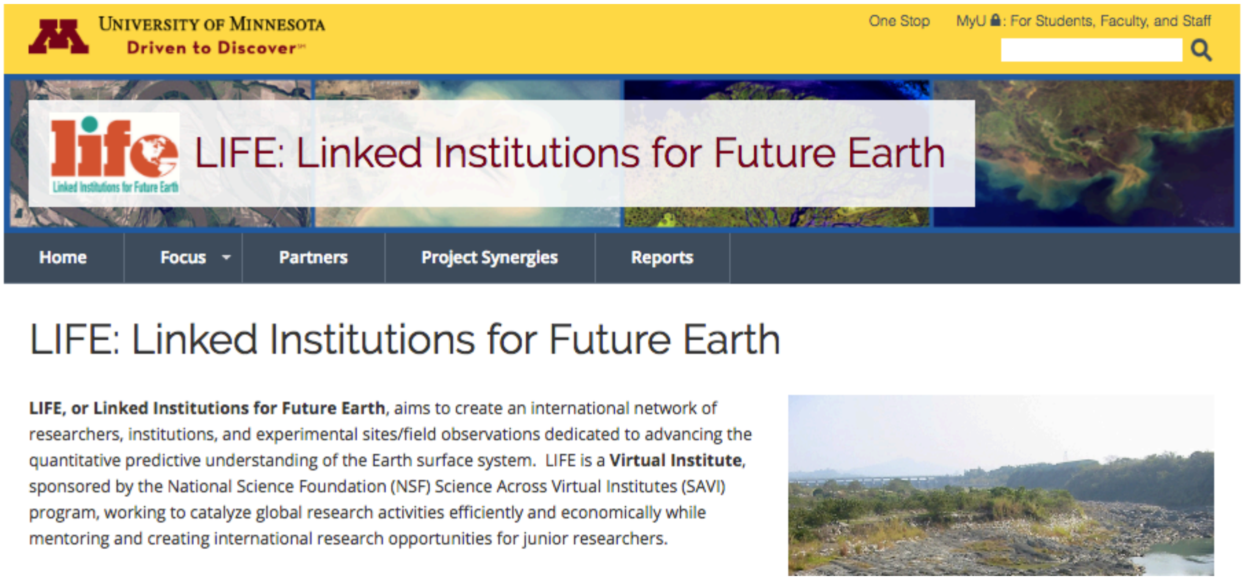
5. Inventions, patent applications, and/or licenses

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 California, Irvine)

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) Geomorphic reorganization of landscapes under climate change, (3) Entropy and Optimality in River Deltas, and (4) Reducing Aggregation Bias of Water and Solute Travel Times in Heterogeneous Catchments via a Time-Variant Lagrangian Transport Formulation.

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