LIFE (Linked Institutions for Future Earth)

Third Year Report to NSF: 2014-2015

Award Number: 1242458

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Linked Institutions for Future Earth

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 third year of the project, the major activities included:

(1) Initiated 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 **"**Geomorphodynamics", hosted by our LIFE partner IPG in Paris in June 2015;

(3) MOU between the University of Minnesota and the Institute of Physics of the Globe, Paris (IPGP);

(4) Special volume in *Water Resources Research* for research presented at the LIFE sponsored international working group meeting called "Stochastic Transport and Emergent Scaling on the Earth Surface" (STRESS);

(5) The Summer Institute on Earth surface Dynamics (SIESD-2015) focusing on "Self-organization in landscapes and its residue in the stratigraphic record" to be hosted at Tulane University on July 27-August 5, 2015;

(6) Organization of special sessions at the "Deltas in Times of Climate Change II" International Conference in Rotterdam, Netherlands (August 2014);

(7) Active collaboration between the international Belmont Forum DELTAS project and US researchers on delta sustainability;

(8) 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: 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.

The invited speakers in this series include:

(1) *Sanjeev Gupta,* Professor of Earth Science, Department of Earth Science and Engineering, Imperial College, *Ancient Rivers, Ancient Civilizations, Present Water: Water and Life through Time in NW India* (Nov 18, 2014).

(2) *Rina Schumer*, Associate Research Professor, Desert Research Institute, *Real and Apparent Changes in Erosion and Deposition Rates Through Time* (Sept. 30, 2014).

(3) *Cristian Escauriaza*, Assistant Professor, Department of Hydraulic and Environmental Engineering, Pontificia Universidad Catolica de Chile, *Complex Interactions of Turbulent Flows and Geochemical Processes in a High-Andean Watershed* (Sep. 9, 2014).

(4) *Paola Passalacqua*, Assistant Professor, Department of Civil, Architectural and Environmental Engineering, University of Texas at Austin, *The Delta Connectome: Structure and Transport Dynamics of Delta Networks Across Scales* (May 6, 2014).

(5) *Francois Metivier*, Professor and Coordinator of the French Chinese International Laboratory on Sediment Transport and Landscape Dynamics, *Alluvial Fan Dynamics: Insight from Sandpiles, the Tianshan Piedmont and the Kosi River Megafan* (April 8, 2014).

(6) *Laurel Larsen*, Assistant Professor in Physical Geography, University of California-Berkeley, *Biogeochemistry as a Geomorphic Agent in Aquatic Landscapes* (March 25, 2014).

(7) *Chris Keylock*, Associate Editor, Water Resources Research, Prize Senior Lecturer, Sheffield Fluid Mechanics Group, Department of Civil and Structural Engineering, University of Sheffield, *The Velocity-intermittency Structure of Ideal and Natural Turbulent Flows* (March 11, 2014).

(8) *Alex Densmore,* Professor, Department of Geography, Durham University (postponed for October 13, 2015).

In addition, LIFE also hosted international researcher *Sebastien Castelltort*, Department of Earth Sciences, University of Geneva, Switzerland, *River basins as dynamic markers of crustal deformation* (May 22, 2015).

IPG Paris short course on Geomorphodynamics (June, 2015): Faculty (Paola and Voller) from the University of Minnesota taught a short course at IPGP in June 2015 on Geomorphodynamics. This one-week course involved a combination of theory, modeling and experiments focused on sediment fan building dynamics. IPGP researches made available state of the art table top sediment transport experiments. Graduate students from both IPGP, University of Berkeley, and the University of Minnesota participated.

MOU between the University of Minnesota and the Institute of Physics of the Globe, Paris (IPGP): This year our key LIFE effort was devoted toward putting into place and MOU between the University of Minnesota and the Institute of Physics of the Globe, Paris (IPGP) - a leading organization in Europe focused on LIFE research initiatives. This MOU formalizes the exchange of researchers and students between IPGP and the University of Minnesota.

Faculty across the Earth Science and Civil, Environmental and Geo- engineering departments at the University of Minnesota have proposed 10 graduate projects to fulfill the 3-6 month research internship requirement in the Masters programs managed by the IPGP. Despite the short lead time, to date one Masters students Julien Renou has taken up a 6 month residence at the SAFL lab in the University of Minnesota working on understanding the influence of wave motions on sediment delta building. The other nine project proposals are still active and the expectancy is that, given a longer lead time, more of these will be filled by next year's batch of IPGP Masters students.

Special WRR Volume based on the STRESS working group meeting sponsored by LIFE: A special issue in Water Resources Research "*Connectivity, Non-Linearity, and Regime Transitions in Future Earthscapes"* is already available. The published articles precipitated from discussions at the STRESS 4 (Stochastic Transport and Emergent Scaling on the Earth's surface) working group meeting held at Lake Tahoe, Nevada on April 2013.

Summer Institute on Earth-surface Dynamics (SIESD): July 27 - August 5, 2015 in Tulane University (New Orleans): The National Center for Earth-surface Dynamics (NCED2) is proud to provide ongoing support for the 7th annual Summer Institute for Earth-surface Dynamics. The SIESD engages graduate students and young researchers in interdisciplinary investigation of Earth-surface processes based on integration of theory, physical experiments, fieldwork and numerical modeling. This year's theme is on "Self-organization in landscapes and its residue in the stratigraphic record" and aims to develop a basic working knowledge of analysis tools that can help us make sense of complex surface systems and their depositional records, and begin to make predictions in both realms. We will focus on building connections: between surface and subsurface, between field and laboratory, and among physical biological and geochemical processes.

Lecturers include several LIFE PIs. 40 students from all over the world have been accepted to the SIESD 2015 after a selection process that includes application and three letters of recommendation.

Special sessions at major international meetings: In collaboration with another project (Belmont Forum: DELTAS project) we organized a special session and a Deltas-in-Practice workshop at the "Deltas in Times of Climate Change II" meeting in Rotterdam, Netherlands, Sept, 2014. Special sessions for AGU 2015 and EGU 2016 are planned right now.

PI exchanges and Web collaboration ideas: PI Efi Foufoula-Georgiou visited University of Southampton in Aug 2014 to collaborate with Profs. John Dearing and Robert Nicholls on depositional systems. Foufoula-Georgiou presented at the EGU 2015 meeting and met with LIFE partners attending EGU. PI Voller visited researchers at the University Warsaw and the Technical University of Warsaw to continue projects related to the mathematics of fractional Stefan problems arising in non-locally driven moving boundaries in earth surface dynamics. PI Chris Paola visited IPGP for the short course in June 2014 and June 2015.

2.2. Significant results:

International research collaborations. Examples include:

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

The life of a meander bend: connecting shape and dynamics via analysis of a numerical model

Understanding meandering river dynamics is important for a host of engineering and geologic applications. Most work to date has considered the dynamics of the whole river, e.g., average river sinuosity, but not much the dynamics of individual meander bend evolutions. We have introduced a new tool for identifying and extracting the lives of these individual meander bends, dubbed "atoms" and have explored (via numerical modeling and some observations) the question as to whether the static geometry of the meander cutoffs (oxbow lakes) can reveal the story of their growth from inception to cutoff. We find that before cutoffs, the intrinsic model dynamics invariably simulate a prototypical cutoff atom shape we dub *simple*. Once perturbations from cutoffs occur, two other archetypal cutoff planform shapes emerge called *long* and *round* that are distinguished by a stretching along their long and perpendicular axes, respectively (see Figure 1). Three measures of meander migration—growth rate, average migration rate, and centroid migration rate—are introduced to capture the dynamic lives of individual bends and reveal that similar cutoff atom geometries share similar dynamic histories. Specifically, *simples* are seen to have the highest growth and average migration rates, followed by *rounds*, and finally *longs*. Using the maximum average migration rate as a metric describing an atom's dynamic past, we show a strong connection between it and two metrics of cutoff geometry. *This result suggests both that early formative dynamics may be inferred from static cutoff planforms and that there exists a critical period early in a meander bend's life when its dynamic trajectory is most sensitive to cutoff perturbations.*

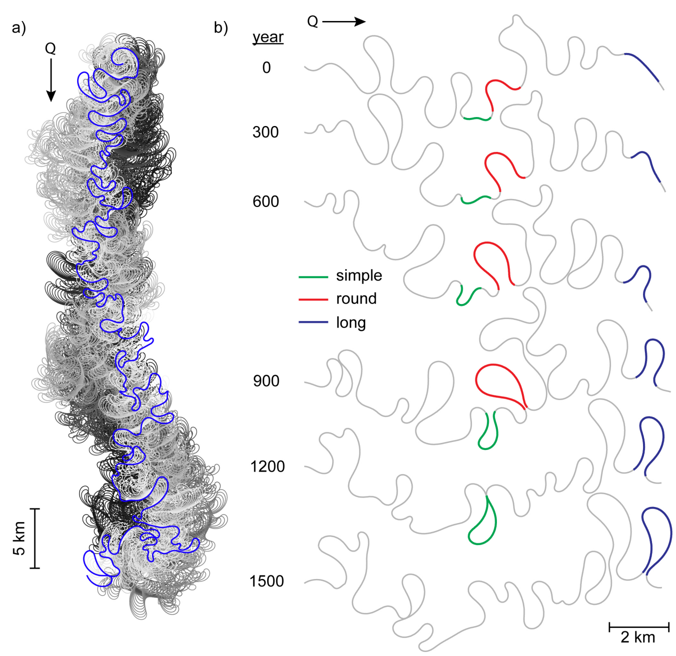

Figure 1. Results of the long-term simulated meandering river. (a) 30,000 years of modeled centerline realizations. Older centerlines are darker; the blue centerline shows t=30,000 years. The upstream boundary condition fixes the first centerline node in place, leading to the formation of the spiral pattern at the upstream boundary. No restrictions are placed on the downstream node so the river may migrate freely. (b) A reach of simulated centerline selected shows the growth and cutoff of all three atom types. Realizations are 300 years apart. Note the complex multilobe meander that starts as double lobed but develops a third lobe before cutting off between 900 and 1200 years.

(2) Collaboration with the University of Exeter, UK (Liam Reinhardt).

Landscape reorganization under changing climatic forcing: Results from an experimental landscape

Understanding how landscapes respond to climate change in terms of macro-scale (average topographic features) and micro-scale (landform re-organization) is of interest both for deciphering past climates from today's landscapes and for predicting future landscapes in view of recent climatic trends.
Although several studies have addressed macro-scale response, only a few have focused on quantifying smaller-scale basin re-organization. To that goal, we conducted a series of controlled laboratory experiments where a self-organized complete drainage network emerged under constant precipitation and uplift dynamics (Figure 2). Once steady state was achieved, the landscape was subjected to a five-fold increase in precipitation (transient state). Throughout the evolution, high resolution spatio-temporal topographic data in the form of digital elevation models were collected. The steady state landscape was shown to possess three distinct geomorphic regimes (unchannelized hillslopes, debris-dominated channels, and fluvially-dominated channels). During transient state, landscape re-organization was observed to be driven by hillslopes via accelerated erosion, ridge lowering, channel widening, and reduction of basin relief as opposed to channel base-level reduction. Quantitative metrics on which these conclusions were based included slope-area curve, correlation analysis of spatial and temporal elevation increments, and wavelet spectral analysis of the evolving landscapes. *Our results highlight that landscape re-organization in response to increased precipitation seems to follow "an arrow of scale": major elevation change initiates at the hillslope scale driving erosional regime change at intermediate scales and further cascading to geomorphic changes at the channel scale as time evolves.*

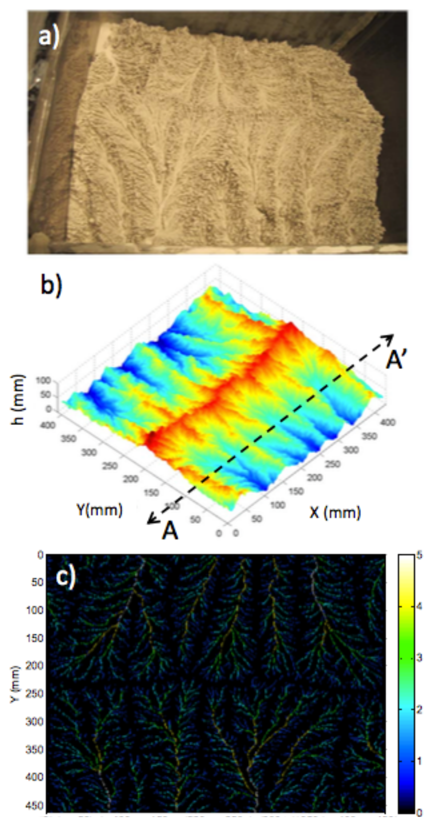

Figure 2. Photograph (a) and the DEM (b) of the evolved landscape at the steady state obtained from the eXperimental Landscape Evolution (XLE) facility at the St. Anthony Falls laboratory of University of Minnesota. The river network at the steady state extracted from the DEM at steady state is shown in (c) with the color bar

indicating Strahler channel order. Notice the 5th order channels present in the drainage basins.

(3) Collaboration with the University of Sheffield, UK (Chris Keylock).

The complexity and non-linearity of gravel bed river topography

The self-organized geometrical and dynamic structure of bedforms in a channel is important for estimating sediment transport as well as inferring river biotic life and nutrient/pollutant cycling. Yet, not much data are available from actual stream observations as this requires extensive bathymetric data. Here, we analyzed the nonlinear nature of gravel bed elevation data series obtained in a large scale flume facility for four different discharges, including spatial transect series and temporal series at a fixed location. *The goals are to infer the degree of complexity, to assess the scales and features in the signals that mostly contribute to this complexity, and to discern the difference in the manner in which this complexity is expressed in time and space.* An important and novel dimension is the adoption of a recently introduced approach to surrogate data generation, namely the gradual wavelet reconstruction (GWR) methodology, which produces partially linearized counterparts of the original series that preserve an increasing degree of the underlying nonlinear structure in the original data, while randomizing the rest. This allows us to discern the difference in the manner in which the nonlinear asymmetry is expressed in the temporal and spatial data series. Our analysis revealed that the complexity of both spatial and temporal series increases with discharge and that the nature of their nonlinearity is quantitatively and qualitatively different. *For the spatial series, asymmetry is expressed at large scales and is shown to result from the organization of intermediate scale features. In contrast, asymmetry in the temporal series is a smaller-scale phenomenon. We posited that this space-time difference is a consequence of the scale-dependent propagating velocity of topographic features.*

(4) Collaboration with the University of Southampton, (Sylvia Szabo, Zoe Matthews, John Dearing, and Robert Nicholls).

Population dynamics in the context of environmental sustainability: the Mekong delta

Tropical delta regions experience complex population dynamics, which are strongly influenced by socio-economic and environmental factors. They are subject to increasing pressure from relative sea level rise, and because of human alterations of these low elevation landscapes they are becoming more and more vulnerable to extreme floods, storms, surges, and salinity intrusion. In this context, understanding population dynamics in delta regions is crucial for ensuring efficient policy planning and progress towards social and ecological sustainability. Here we focus on examining population dynamics in the Ganges-Brahmaputra, Mekong and Amazon deltas. Analysis of the components of population change is undertaken in the context of environmental factors affecting the demographic landscape of the three regions, and makes use of multiple data sources, including census data, the United Nations cities database, and Demographic and Health Surveys. *The results of the analysis suggest that the Mekong delta region shows the lowest fertility rates and experiences the most rapidly ageing population. The results further show that mortality trends are strongly influenced by environmental factors, including natural hazards, which affect life expectancy through both direct and indirect effects.* Finally, urbanisation and migration dynamics will arguably be the most important factors influencing population change in the three delta regions in the years to come. Policy implications of the results are discussed in the context of sustainable development.

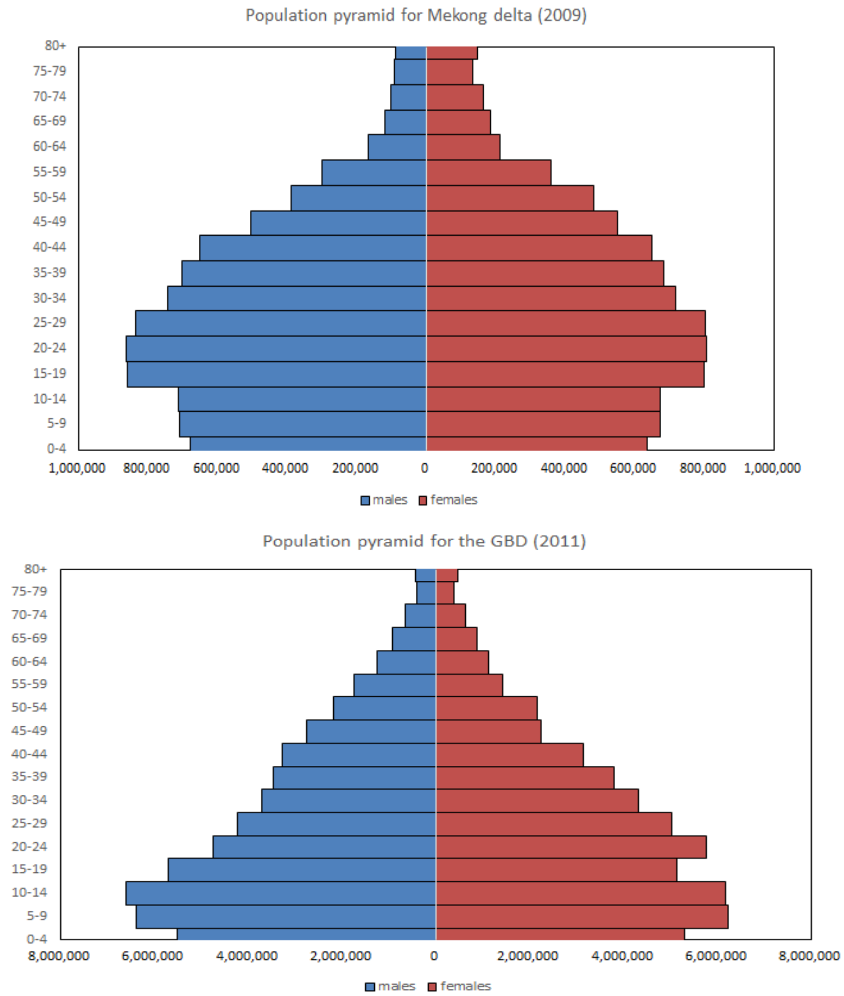

Figure 3. Population pyramid for the (a). Mekong Delta (2009) and (b). Ganges – Brahmaputra – Meghna (2011).

Apart from social vulnerability, deltas exhibit significant vulnerability in terms of how their water and sediment fluxes are distributed to the shoreline and affected by upstream human actions and climate, thus limiting new land building. To enable quantifying such vulnerabilities, a new framework for delta network connectivity analysis was recently introduced based on spectral graph theory. The framework allows computation of topologic and dynamic metrics on each delta and analysis of their response to change.

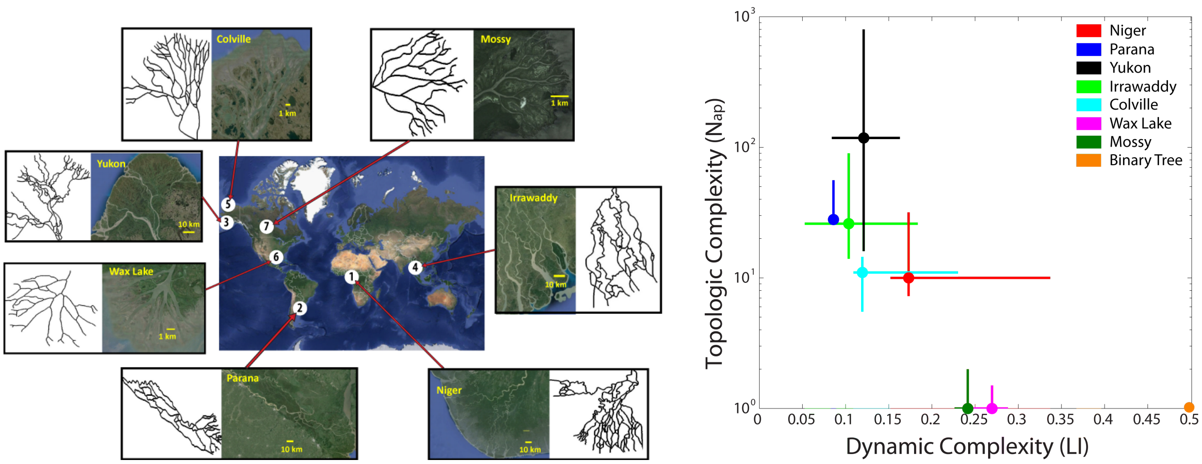

Figure 4. (left) Location of seven deltas and their corresponding channel networks numbered according to size (largest to smallest area). We used the Smart and Moruzzi [1971] networks for (1) Niger, (2) Parana, (3) Yukon, (4) Irrawaddy, and (5) Colville Deltas. For (6) Wax Lake we used the network extracted by Edmonds et al. [2011]. We have extracted the network of (7) Mossy from Google Earth. Satellite images are copyrighted by Digital Globe Inc. 2014. (right) Topo-dynamic complexity space for deltas. The x-axis corresponds to the dynamic exchange of the different subnetworks measured by the Leakage Index (*LI*), and the y-axis corresponds to the topologic complexity measured by the Number of alternative paths from apex to outlet (N_{ap}). Each colored cross corresponds to a different delta, and the orange dot corresponds to a binary tree. The vertical (horizontal) component of each cross runs from the 25th until the 75th percentile of the Number of alternative paths (Leakage Index).

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 PIs
(2) Engagement of students, post-docs, and young PIs into interdisciplinary research via the 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.

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. Several news pieces have appeared around the world (for example in the LOICZ newsletter) about the DELTAS project.

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

In Year 4 we will plan the following major activities:

(1) Organize the STRESS 5 workshop at University of California, Berkeley tentatively scheduled around Oct. – Nov. 2015. We considered an international destination for STRESS 5 but the expense for the US participants is prohibitive, while LIFE can compensate partial travel for the international participants to the US. Preliminary work on agenda and invitees is in place.

(2) Establish a sustained international research collaboration with other European Union-funded research groups such as:

(a) CONNECTEUR (Connecting European Connectivity Research) http://connecteur.info/
(b) CAOS (Catchments As Organized Systems) http://www.caos-project.de/

(3) Bring together international researchers in the rapidly emerging field of "*Network analysis for Earth Sciences*"

(4) Advance collaborations on two specific themes in LIFE:
(a) ***Deltas:*** 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.

(b) ***Watersheds:*** Collaboration with University of Padova (Stefano Lanzoni, Gianluca Botter) on Meandering rivers; Collaboration with Antonio Parodi CIMA and Antonello Provenzale – (University of Genova); 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.

(5) Teach the short course on "Geomorphodynamics" in 2016, this time we hope with increased participation of US LIFE supported students. In addition to arrive at a complete exchange we are planning to send US students for research visits to IPGP and have IPGP faculty teach courses in the US, the joint LIFE/NCED supported summer institute would be an ideal venue for this.

(6) To further cement the MOU efforts, a short course is to be taught by Subir Banerjee at IPGP later this summer and a research visit of IPGP PhD student Pauline Delorme to SAFL in the fall of 2015.

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

1. Publications

Keylock, C., A. Singh, J.G. Venditti, and E. Foufoula-Georgiou (2014), Robust classification for the joint velocity-intermittency structure of turbulent flow over fixed and mobile bedforms, *Earth Surf. Process. Landforms*, 39(15), 1717-1728, doi: 10.1002/esp.3550.

Keylock, C.J., A. Singh, and E. Foufoula-Georgiou (2014), The complexity of gravel bed river topography examined with gradual wavelet reconstruction, *J. Geophys. Res. Earth Surf.*, 119(3), 682-700, doi:10.1002/2013JF002999.

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 Sensing*.

Hansen, A.T., J.A. Czuba, J. Schwenk, A. Longjas, M. Danesh-Yazdi, D. Hornbach, and E. Foufoula-Georgiou (2015), Coupling freshwater mussel ecology and river dynamics using a simplified dynamic interaction model, *Freshwater Science*, in revision.

Fan, N., D. Zhong, B. Wu, E. Foufoula-Georgiou, and M. Guala (2014), A mechanistic-stochastic formulation of bed load particle motions: From individual particle forces to the Fokker-Planck equation under low transport rates, *J. Geophys. Res. Earth Surf.*, 119(3), 464-482, doi:10.1002/2013JF002823.

Ning, L., F. P. Carli, A. M. Ebtehaj, E. Foufoula-Georgiou, and T. T. Georgiou (2014), Coping with model error in variational data assimilation using optimal mass transport, *Water Resour. Res.*, 50, 5817–5830, doi:10.1002/ 2013WR014966.

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.

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.

Tejedor, A., A. Longjas, I. Zaliapin and E. Foufoula-Georgiou (2015a), "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 (2015b), "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.

2. Presentations

Voller, V.R., and C. Paola (2014), Reduced Complexity Modeling (RCM): toward more use of less, Geophysical Research Abstracts, Vol. 16, EGU2014-7693, EGU General Assembly, Vienna, Austria, 27 April – 2 May.

Jerolmack, D., F. Falcini, C. Paola , and V. Voller (2014), Evaluating the influence of heterogeneity length scale on long profile landscape signals, Geophysical Research Abstracts, Vol. 16, EGU2014-7281, EGU General Assembly, Vienna, Austria, 27 April – 2 May.

Czuba, J.A., and E. Foufoula-Georgiou (2014), Assessing river basin resilience to natural and human disturbances, Institute on the Environment Sustainability Symposium, St. Paul, Minnesota, 11 April.

Czuba, J.A. and E. Foufoula-Georgiou (2014), Network Dynamic Connectivity for Identifying Hotspots of Fluvial Geomorphic Change, AGU Fall Meeting, San Francisco, California, 15-19 December.

Danesh-Yazdi, M., A. Tejedor, and E. Foufoula-Georgiou (2014), Self-dissimilar Landscapes: Probing into Causes and Consequences via Multi-scale Analysis and Synthesis, AGU Fall Meeting, San Francisco, California, 15-19 December.

Ebtehaj, M., E. Foufoula-Georgiou, and R. Bras (2014), A New Framework for Robust Retrieval and Fusion of Active/Passive Multi-Sensor Precipitation, AGU Fall Meeting, San Francisco, California, 15-19 December.

Foufoula-Georgiou, E., J. Czuba, and I. Zaliapin (2014), Dynamic connectivity and response to change in a river network: what can be learned for managing river basins?, EGU2014-14510, HS1.1, EGU General Assembly, Vienna, Austria, 27 April – 2 May [**INVITED**].

Foufoula-Georgiou, **E.** and M. Ebtehaj (2014), From Rainfall Downscaling to Rainfall Retrieval: Inverse Problems of Similar Nature, EGU General Assembly, Vienna, Austria, 27 April – 2 May [**INVITED**].

Foufoula-Georgiou, E. (2014), Belmont Forum Deltas Project (BF-DELTAS) – to sustain the resilience of deltas, Deltas in Times of Climate Change II International Conference, Rotterdam, Netherlands, 24-26 September.

Foufoula-Georgiou, E., A. M. Ebtehaj and Z. Tessler (2014), Satellite Rainfall Retrieval Over Coastal Zones, Deltas in Times of Climate Change II International Conference, Rotterdam, Netherlands, 24-26 September.

Foufoula-Georgiou, E., A. Tejedor, A. Longjas, I. Overeem, F. Renaud and J. Dearing (2014), Constructing vulnerability maps of material and energy pathways in deltas, Deltas in Times of Climate Change II International Conference, Rotterdam, Netherlands, 24-26 September.

Foufoula-Georgiou, E. (2014), Mathematical Hydrology and Vulnerability Science: the come-back of a systems approach for Sustainability, AGU Fall Meeting, San Francisco, California, 15-19 December [**INVITED**].

Foufoula-Georgiou, E., A. Tejedor, A. Longjas, and I. Zaliapin (2014), "Quantitative Metrics of Robustness in River Deltas", AGU Fall meeting, San Francisco, California, 15-19 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.

Harrison, I.J., E. Foufoula-Georgiou, and B. Burkholder (2014), Catalyzing action towards sustainability of deltaic systems in collaboration with colleagues in the Belmont Forum DELTAS project. IUCN World Congress on Protected Areas. Stream 4: Supporting Human Life. November 18, 2014.

Longjas, A., A. Tejedor, I. Zaliapin, S. Ambroj, and E. Foufoula-Georgiou (2014), Network Robustness: the whole story, AGU Fall Meeting, San Francisco, California, 15-19 December.

Longjas, A., V. Voller, N. Filipovitch, K. Hill, C. Paola, and E. Foufoula-Georgiou (2014), **"**What might rice piles tell us about non-local sediment transport?", AGU Meeting, San Francisco, California, 15-19 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.

Schwenk, J., E. Foufoula-Georgiou, and S. Lanzoni (2014), Revisiting nonlinearity in meandering river planform dynamics using Gradual Wavelet Reconstruction, AGU Fall Meeting, San Francisco, California, 15-19 December.

Singh, A., A. Tejedor, I. Zaliapin, L. Reinhardt, and E. Foufoula-Georgiou (2014), Emergent reorganization of an evolving experimental landscape under changing climatic forcing, AGU Fall Meeting, San Francisco, California, 15-19 December.

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.

Tejedor, A., A. Longjas, I. Zaliapin, and E. Foufoula-Georgiou (2014), Defining network robustness using a dual connectivity perspective, 30th IUGG Mathematical Geophysics, Merida, Mexico, 2-6 June.

Tejedor, A., A. Longjas, I. Zaliapin, and E. Foufoula-Georgiou (2014), Network topology, Transport dynamics, and Vulnerability Analysis in River Deltas: A Graph-Theoretic Approach, AGU Fall Meeting, San Francisco, California, 15-19 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.

Tessler, Z., C. Vörösmarty, E. Foufoula-Georgiou, and M. Ebtehaj (2014), Spatial and temporal patterns of rainfall and inundation in the Amazon, Ganges, and Mekong deltas, Deltas in Times of Climate Change II International Conference, Rotterdam, Netherlands, 24-26 September.

Zanardo, S., A. Hilberts, E. Foufoula-Georgiou, and W. Dietrich (2014), Emergent phase shift between diurnal transpiration maxima and stream flow minima during base flow as diagnostic of eco-hydrologic interactions in landscapes, EGU General Assembly, Vienna, Austria, 27 April – 2 May.

3. Technologies or techniques

Not applicable.

4. Inventions, patent applications, and/or licenses

Not applicable.

5. Websites

We have developed a web site for the project, which we will update regularly and populate with our publications, presentations and products: http://www.life.umn.edu

6. 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)

Barbara Burkholder (University of Minnesota)

Diana Dalbotten (University of Minnesota)

Debra Pierzina (University of Minnesota)

Arvind Singh (University of Central Florida)

Praveen Kumar (Univ. of Illinois)

Rina Schumer (Desert Research Institute, Reno)

Patrick Hamilton (Science Museum of Minnesota)

Francois Metivier (IPG Paris)

Vladimir Nikora (University of Aberdeen)

Antonio Parodi (CIMA Research Foundation, Italy)

Cristian Escauriaza (Pontifica Universidad Catolica de Chile)

David Mohrig (University of Texas, Austin)

Paola Passalacqua (University of Texas, Austin)

Lauren Larsen (University of California, Berkeley)

Chris Keylock (University of Sheffield, UK)

Stefano Lanzoni (University of Padova, 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) Complexity of gravel bed river topography with gradual wavelet reconstruction, and (4) Population dynamics in the context of environmental sustainability (Mekong delta).

2. What is the impact on other disciplines?

The two research themes of LIFE (quantifying vulnerability and resilience of watersheds 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.

The Science Museum of Minnesota, a LIFE partner, is already featuring an exhibit called "Future Earth" where the impacts of humans on the future of our resources are explained for the public.

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 IPG, Paris) 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