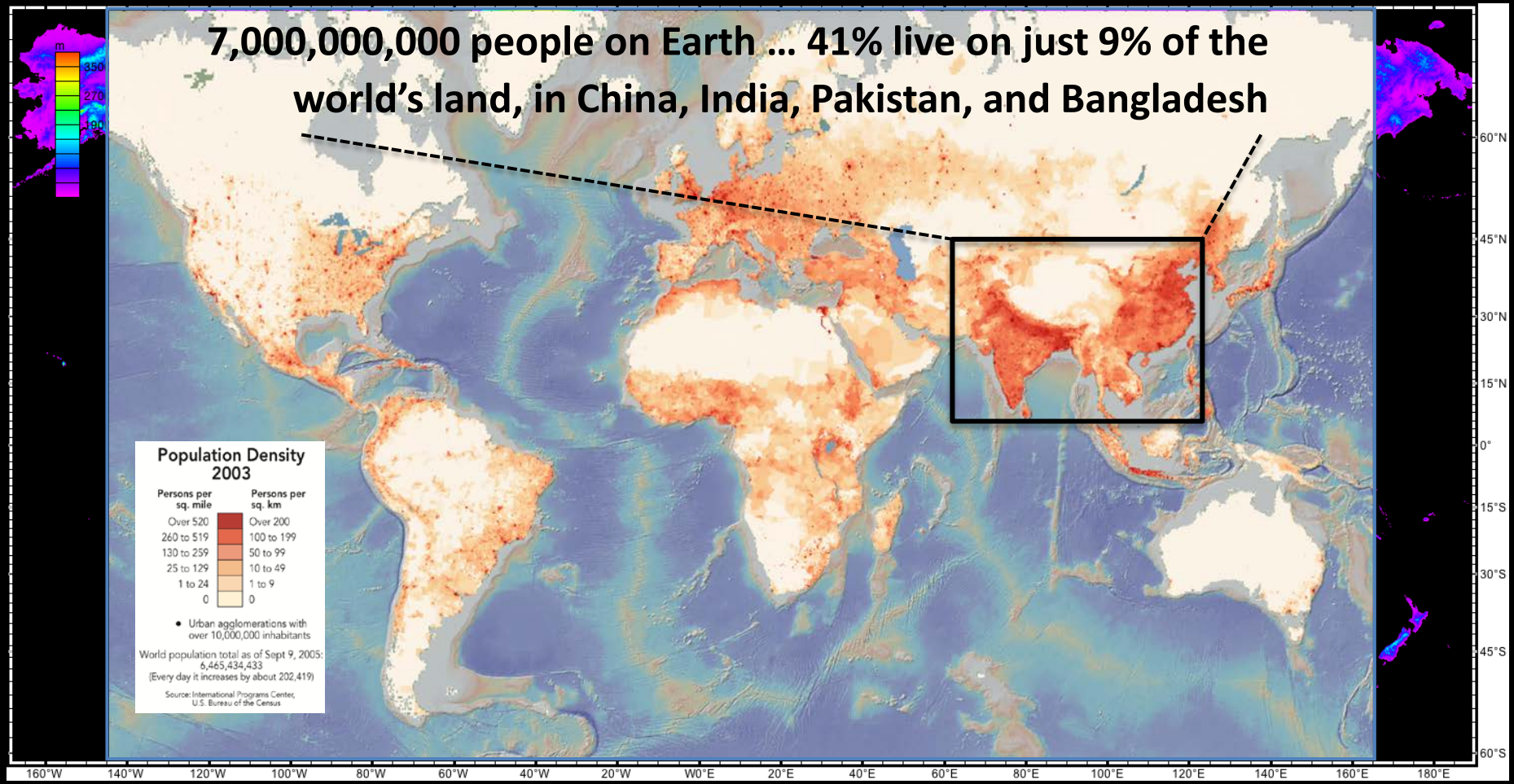
Environmental stress and human migration in a low-lying developing nation: Co-evolving natural and human landscapes in Bangladesh

OXFAM Bangladesh - Climate Change canvas, by students at Charupeeth School of Fine Art, Jessore, Bangladesh

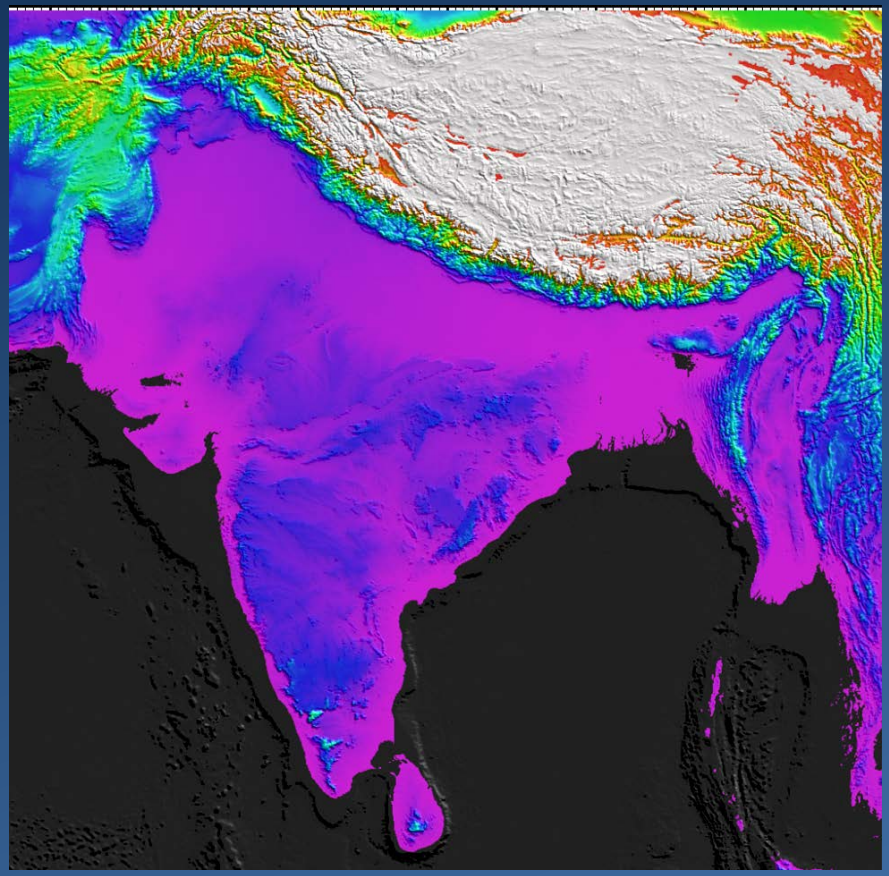
VANDERBILT UNIVERSITY

COLUMBIA UNIVERSITY IN THE CITY OF NEW YORK

Human-environment coupling …

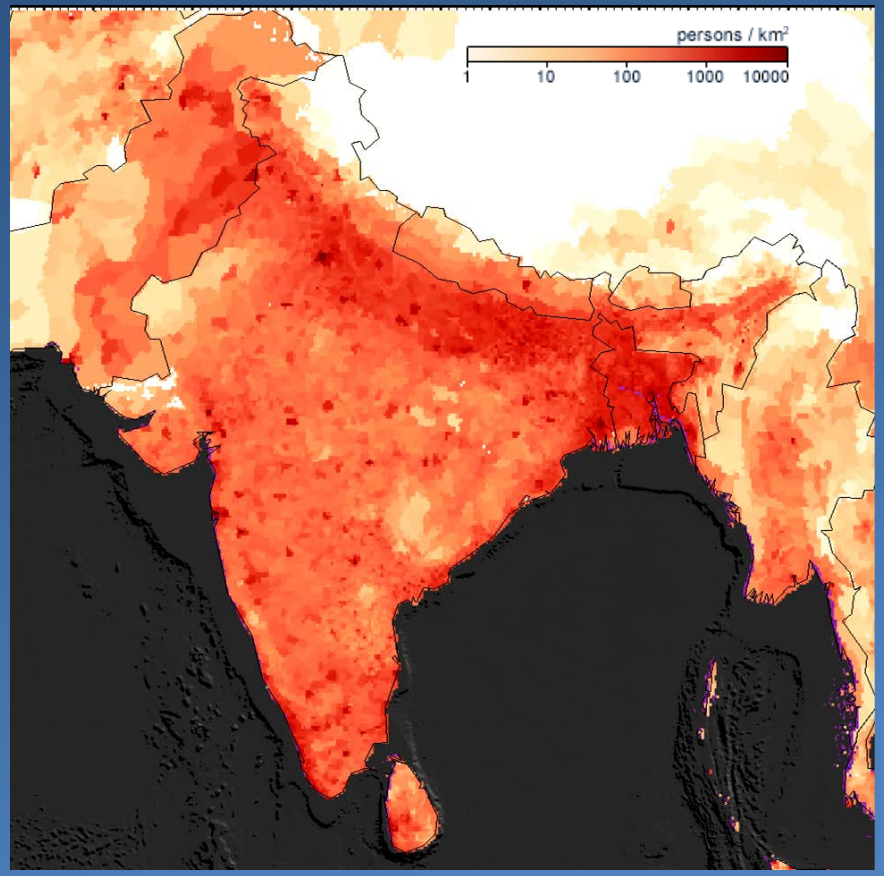


Defining characteristics of the region …



Topography → Precipitation
Sediment

Water resources
Fertile landscapes → People



nature geoscience

PROGRESS ARTICLE

PUBLISHED ONLINE: 20 SEPTEMBER 2009 | DOI: 10.1038/NGEO629

Sinking deltas due to human activities

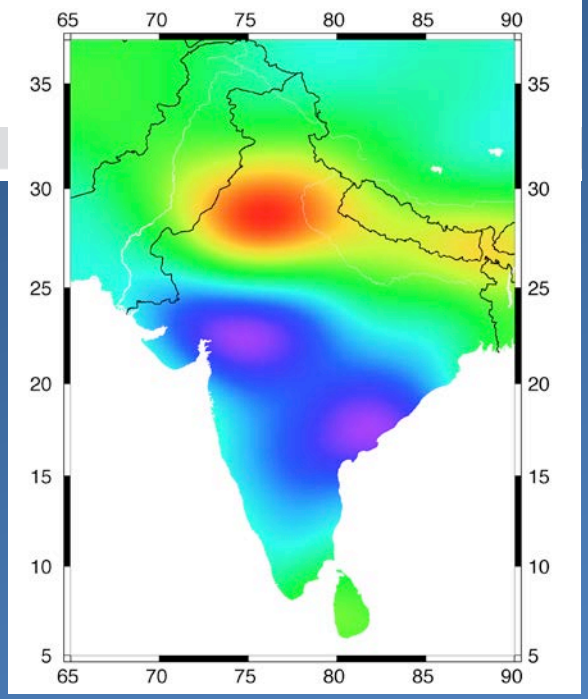
James P. M. Syvitski[1]*, Albert J. Kettner[1], Irina Overeem[1], Eric W. H. Hutton[1], Mark T. Hannon[1], G. Robert Brakenridge[2], John Day[3], Charles Vörösmarty[4], Yoshiki Saito[5], Liviu Giosan[6] and Robert J. Nicholls[7]

Regionally intense environmental issues …

Satellite-based estimates of groundwater depletion in India

Matthew Rodell[1], Isabella Velicogna[2,3,4] & James S. Famiglietti[2]

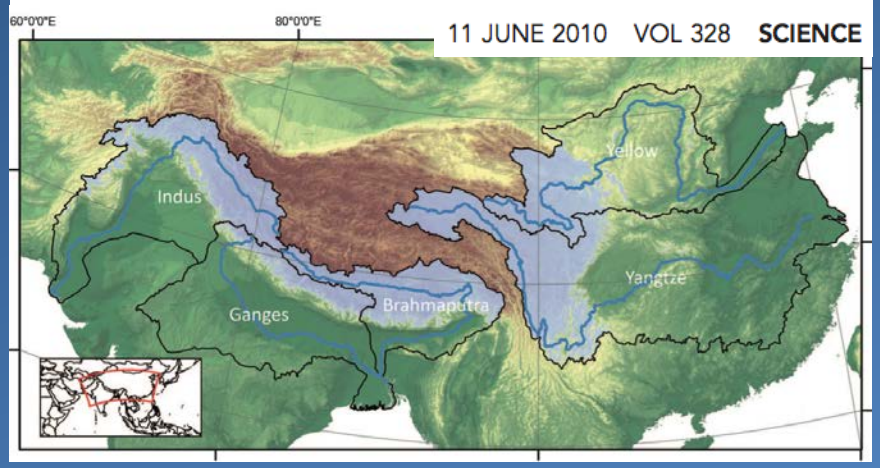
Vol 460 | 20 August 2009 | doi:10.1038/nature08238



Climate Change Will Affect the Asian Water Towers

Walter W. Immerzeel,[1,2]* Ludovicus P. H. van Beek,[2] Marc F. P. Bierkens[2,3]

11 JUNE 2010 VOL 328 SCIENCE



The Climate-Security Nexus

Sherri Goodman, General Counsel for Center for U.S. Naval Analyses:

"The construct of global climate change as a threat multiplier is an important insight because it recognizes that the effects of climate change play out in complex ways, carrying the potential to result in multiple chronic conditions"

U.S. Senator John W. Warner:

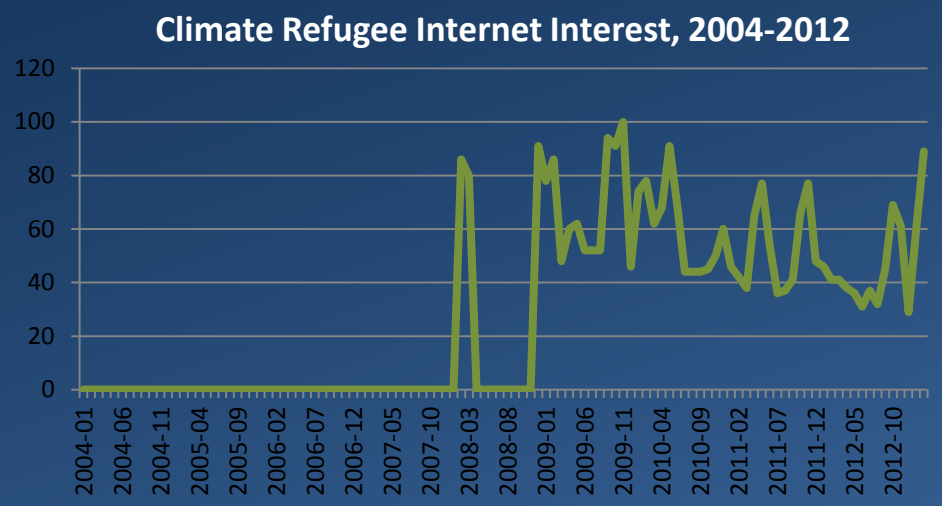
"There is very clearly a nexus between climate change consequences and the military roles and missions of our forces in the years to come"

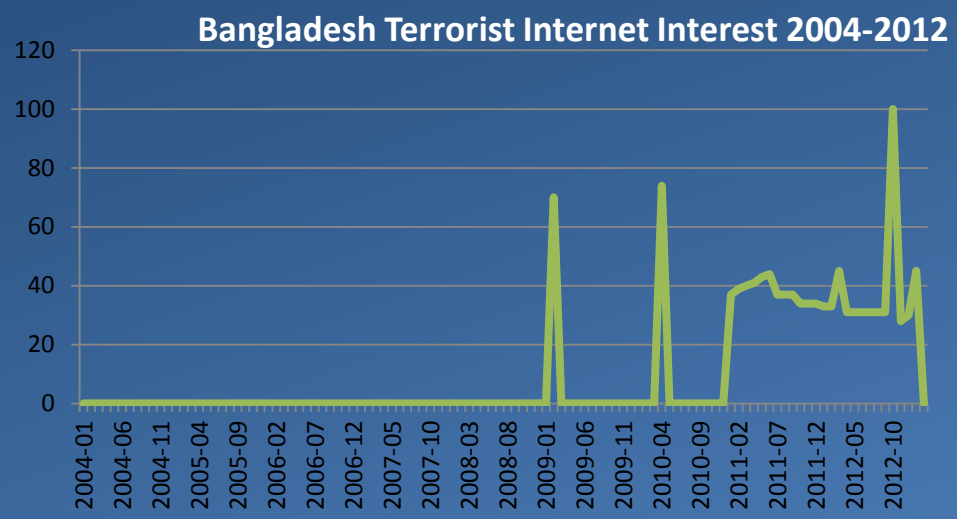
U.N. Security Council:

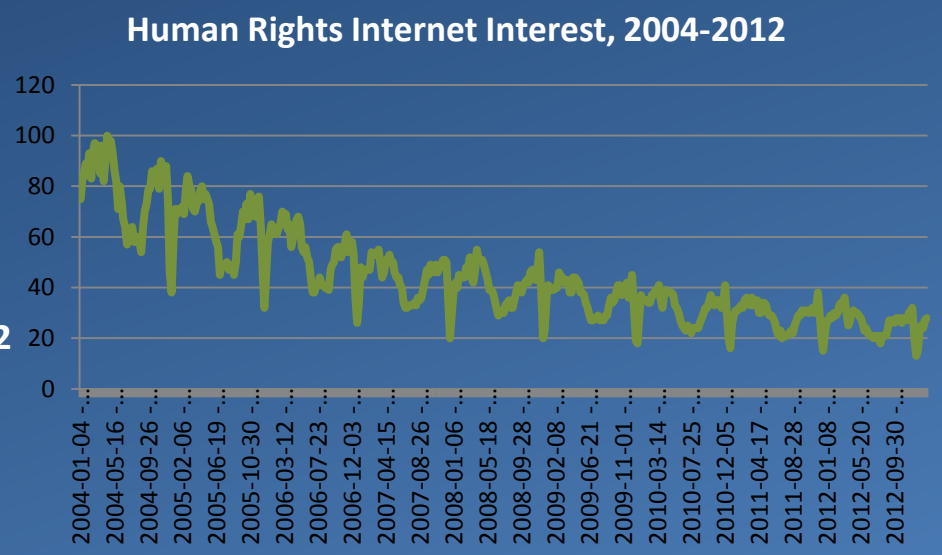
"Adverse effects of climate change might aggravate threats to international peace and security"

Compelling ... but untested. Certainly not understood.

Public Interest in Climate Refugees and Bangladesh Terrorists







Compiled from Google® search statistics

A. What is the MURI project trying to accomplish (scientific objective and technical approach)?

As a heavily populated, low-lying coastal nation, Bangladesh supports a mobile but adaptive population that is susceptible to numerous natural hazards, including widespread flooding, riverbank erosion, groundwater and soil salinization, land loss from sea level rise, and recurrent cyclones and storm surges.

Within this context we seek to couple the human-social dimensions of migration behavior with a realistic understanding of the physical environment and its modification by humans, particularly where these facets intersect in profound and unpredictable ways.

We bring together social scientists, physical scientists, and engineers to investigate the critical interactions between natural and human systems that motivate the movement of large numbers of people (*e.g.*, migration) using an ***Integrated Social, Environmental, and Engineering (ISEE)* framework.**

Particular goals of the project are to understand:

(1) the social, political, economic, and environmental factors that most affect resilience of households, communities, and the physical landscape;
(2) the different strategies that sustain resilience, including adaptive measures such as migration
(3) the environmental factors that affect household decisions to migrate permanently;
(4) how these factors differ within and across diverse social and environmental landscapes; and
(5) how these variables interact and co-evolve to define the changing relationship between humans and their environment.

B. List of MURI team members and their professional qualifications, institutions and numbers of post docs and graduate students

PRINCIPAL INVESTIGATORS

Vanderbilt University (8 PIs)

Steven Goodbred – coastal landscape dynamics, sediment transport
Brooke Ackerly – human rights, social justice, environmental ethics
Jonathan Gilligan – science policy, risk management, agent-based modeling
Mark Abkowitz – hazard risk management, transportation engineering
John Ayers – geochemistry of water and soils; environmental sustainability
Katharine Donato – population and society, migration, demography
David Furbish – fluid transport, physical sediment transport
George Hornberger – hydrogeology, groundwater resources, science policy

Columbia University (3 PIs)

Christopher Small – remote sensing, population and environment
Michael Steckler – geophysics, margin tectonics and subsidence
Leonardo Seeber – paleoseismology, earthquake risk

Post-docs: (3 women)

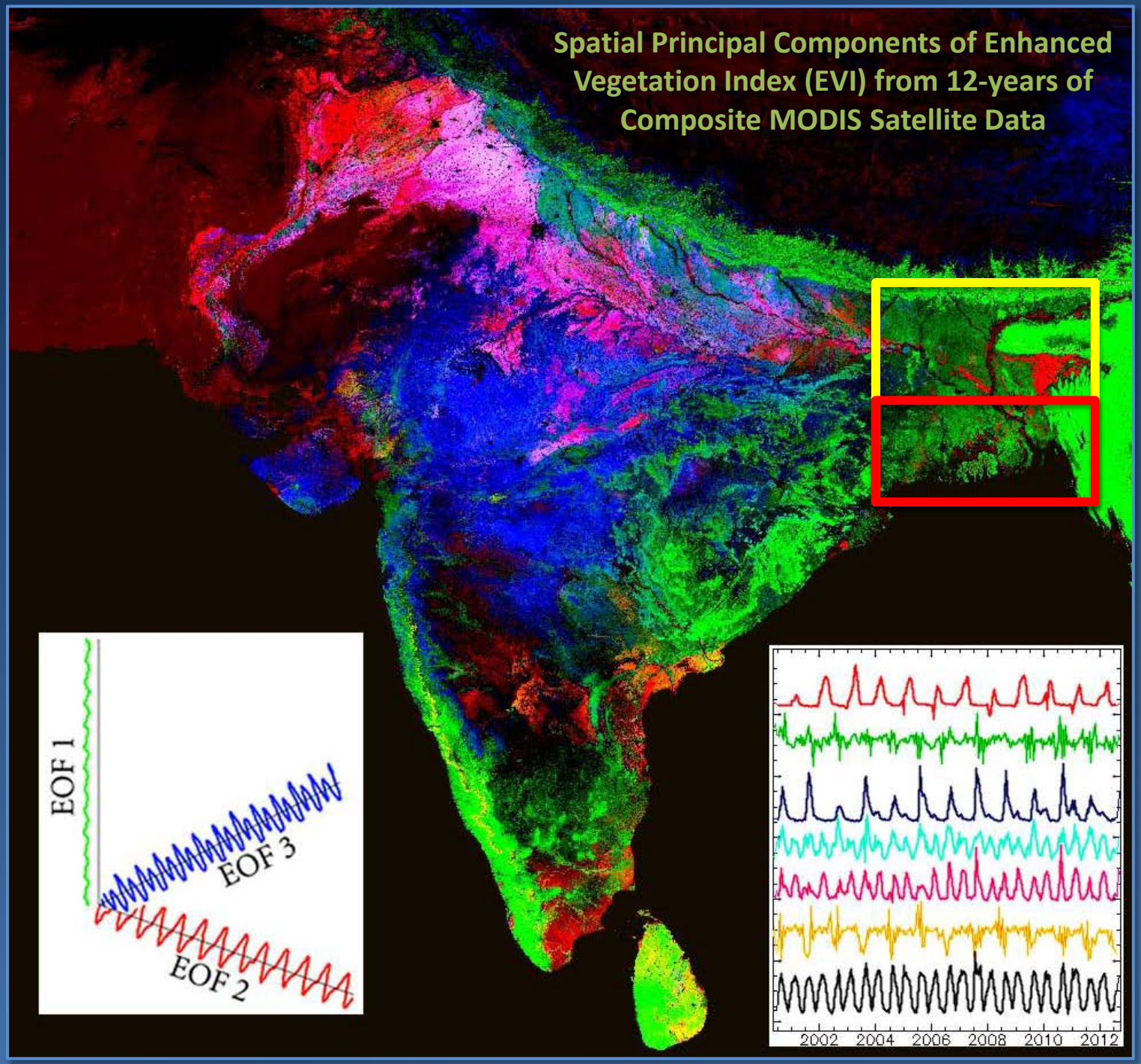
Janey Camp (GIS, risk management), **Amanda Carrico** (psychology, behavioral theory), **Carol Wilson** (coastal evolution)

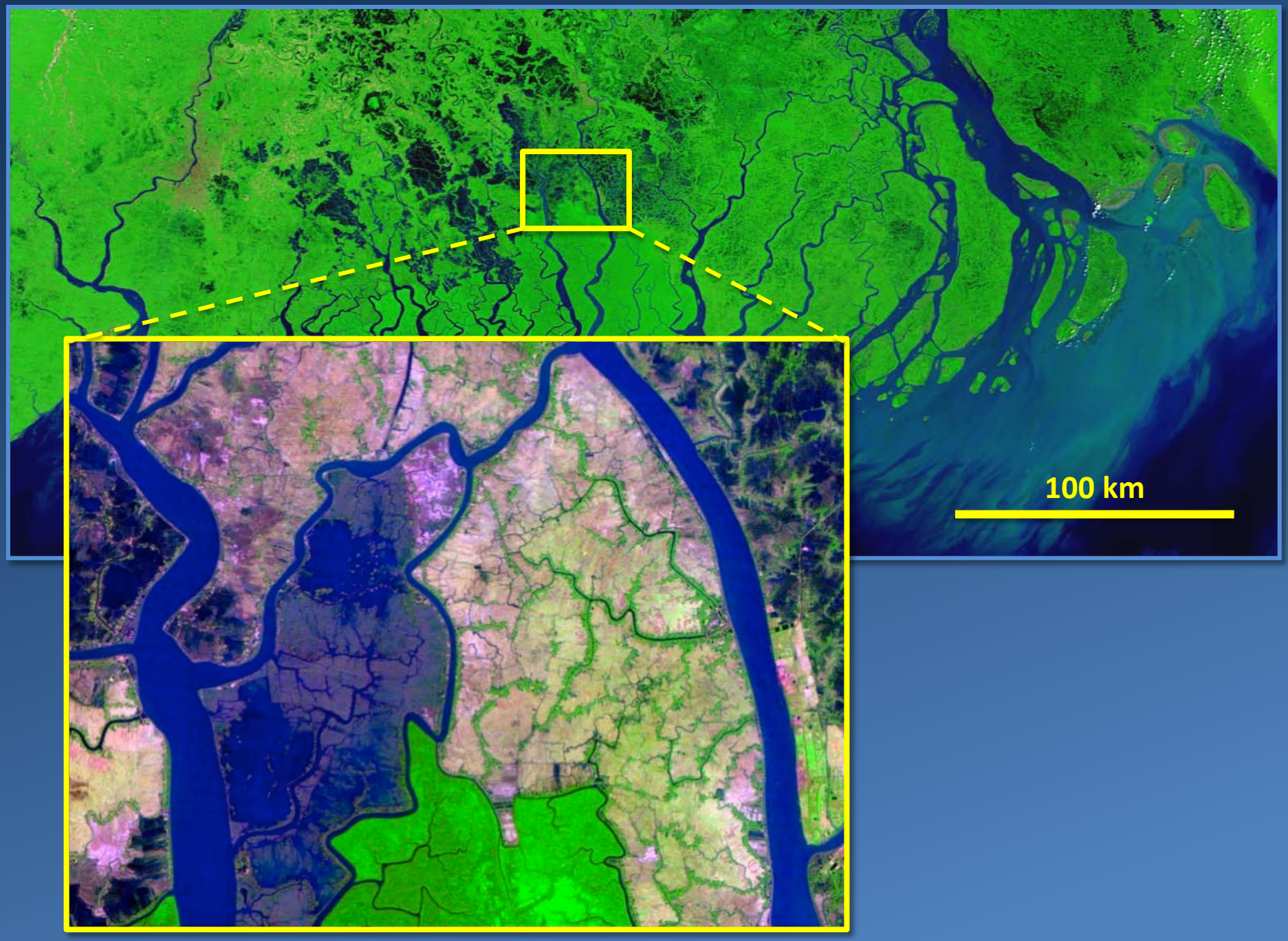
Graduate Students: (4 PhD; 5 MS; 4 women)

Bhumika Piya, John Nay, Anna Carella, Laura Benneyworth, Chris Tasich, Scott Worland, David Fry, Leslie Auerbach, Greg George

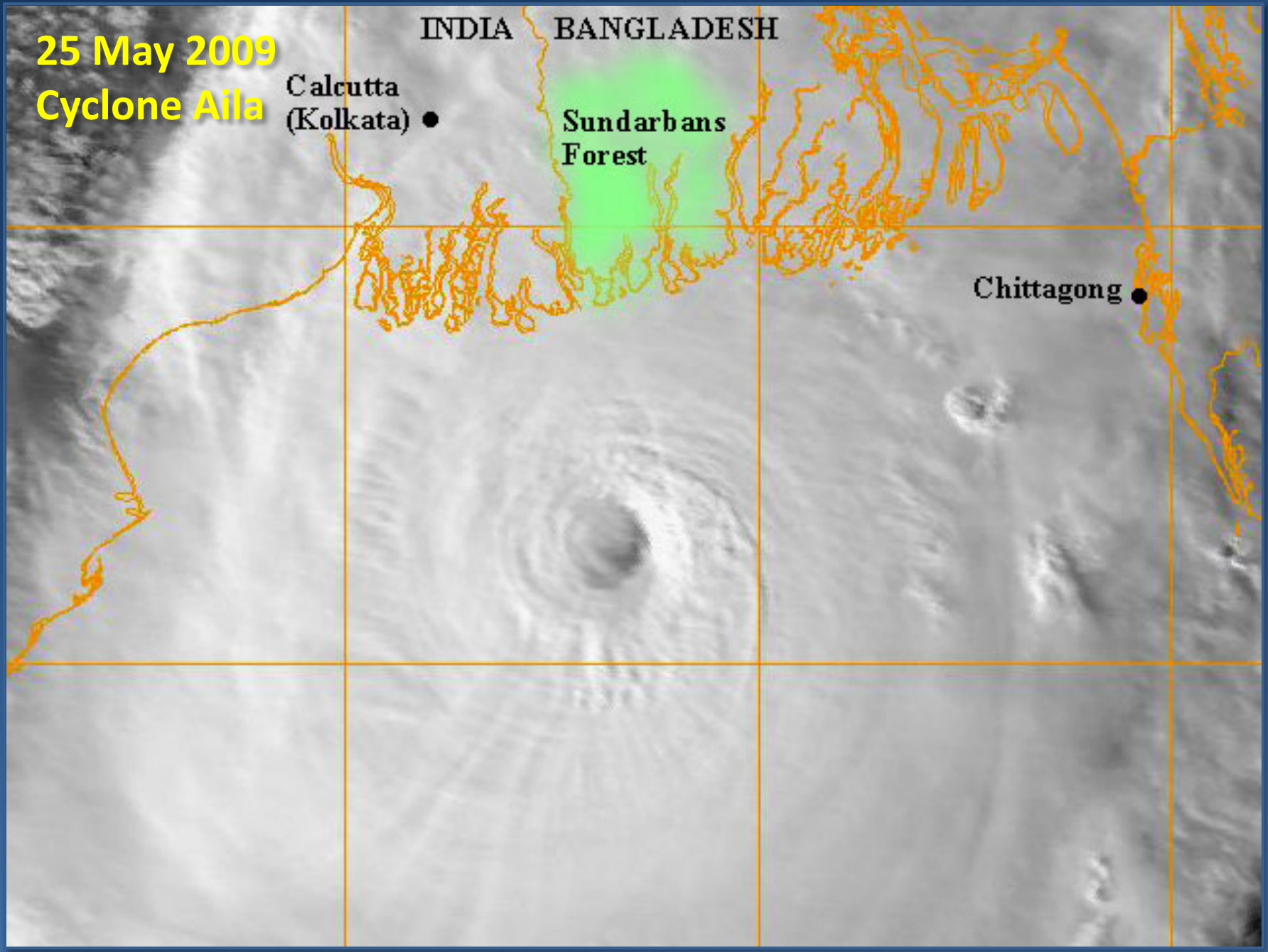
IN-COUNTRY PARTNERS

Dhaka University
Khulna University
Jahangirnagar University
… many others


Spatial Principal Components of Enhanced Vegetation Index (EVI) from 12-years of Composite MODIS Satellite Data
EOF 1
EOF 3
EOF 2
2002
2004
2006
2008
2010
2012


100 km

10/14/2008
2001
2013
14 Oct 2008
Image © 2013 DigitalGlobe
1691 m
Google earth
45 Q 748807.20 m E 2494200.35 m N elev 0 m eye alt 7.30 km

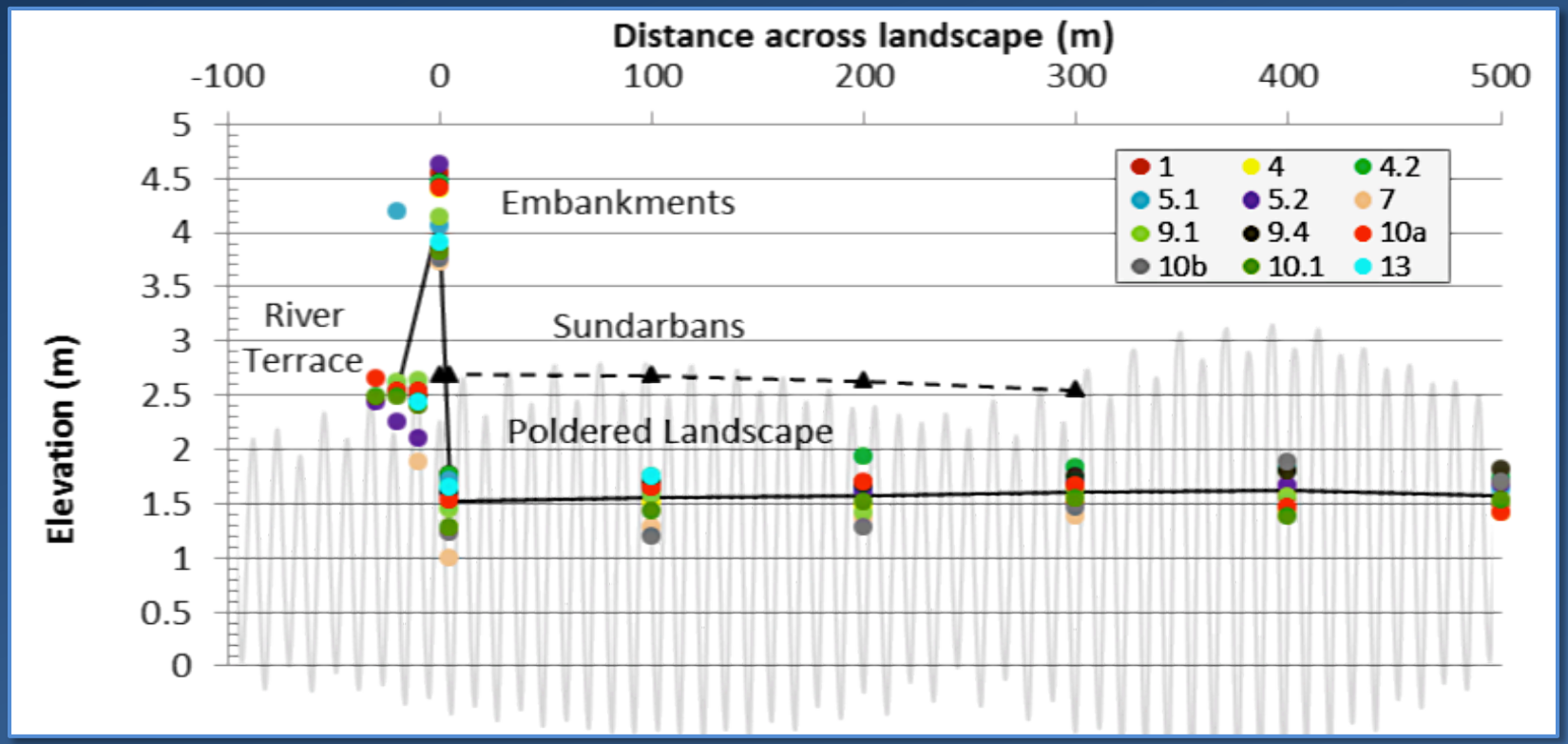

25 May 2009
Cyclone Aila
INDIA
BANGLADESH
Calcutta
(Kolkata)
Sundarbans
Forest
Chittagong

11/4/2010
2001
2013
04 Nov 2010
Image © 2013 DigitalGlobe
1691 m
Google earth
Imagery Date: 11/4/2010 45 Q 751195.64 m E 2494253.06 m N elev 5 m eye alt 7.30 km

2/11/2011
N
Image © 2013 DigitalGlobe
87 m
Google earth
Imagery Date: 11/4/2010 45 Q 749938.53 m E 2489860.62 m N elev 4 m eye alt 367 m

Long-term effect of embankment construction/human modification
NET ELEVATION LOSS INSIDE POLDERED AREAS

Benevolent intervention … slow, permanent strain



- Polders are 1.0-1.5 m below natural landsurface
- Equivalent to ~2 cm/yr of effective RSL rise over last 50 yrs
- Natural landscape floods on 1/3 of tides to 20 cm depth;
- Poldered landscape flooded 100% of tides to 2 m deep.

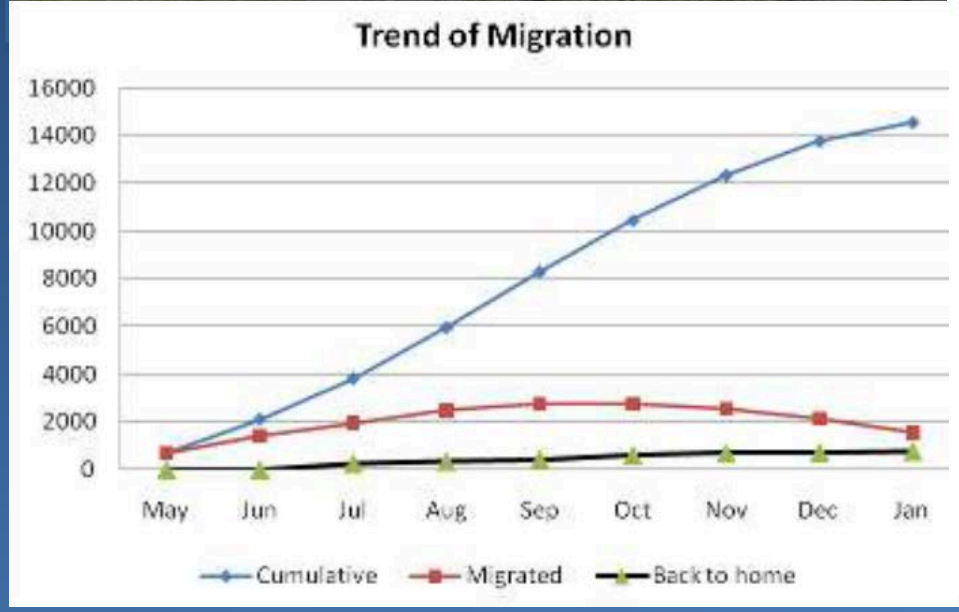
12/2/2011
2001
2013
02 Dec 2011
Image © 2013 DigitalGlobe
1691 m
Google earth
Imagery Date: 12/2/2011 45 Q 753001.85 m E 2490765.74 m N elev 3 m eye alt 7.30 km

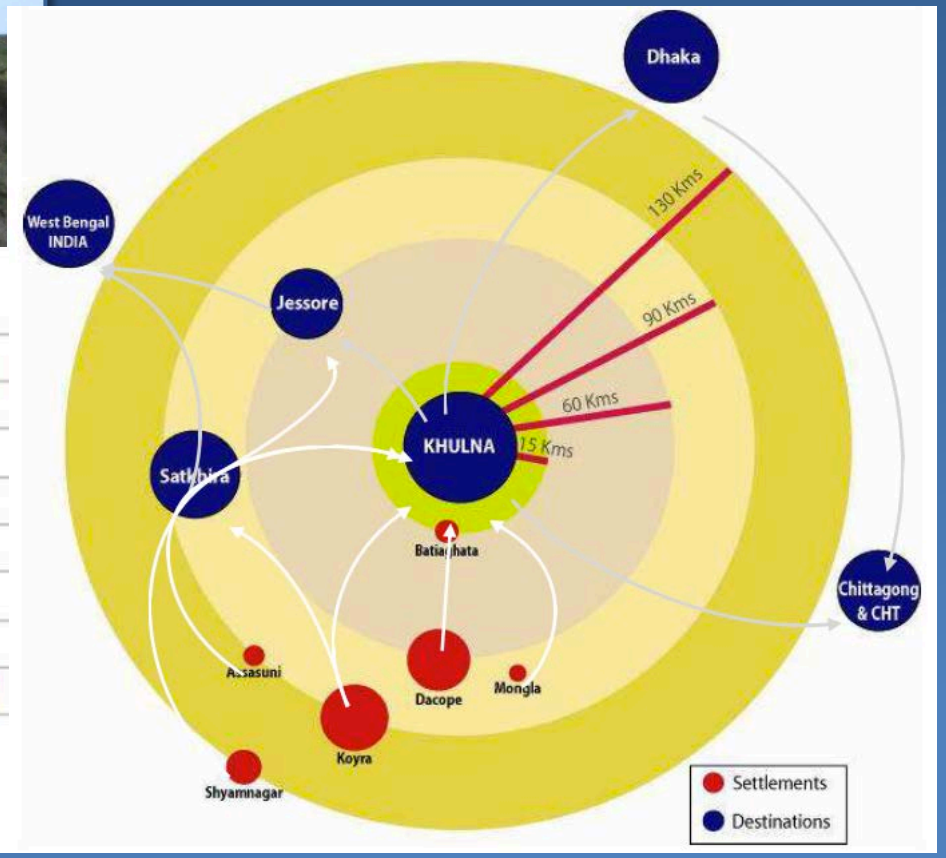
4/7/2013
2001
2013
07 Apr 2013
N
Image © 2013 DigitalGlobe
1691 m
Google earth
Imagery Date: 4/7/2013 45 Q 750974.06 m E 2494218.76 m N elev 2 m eye alt 7.30 km

50,000 displaced by post-storm flooding, homes destroyed or flooded

15,000 migrants (~30%), mostly to nearby cities, mostly temporarily

LESSON – question not why did they go, it is why they did not, how did they persevere, what was their strategy …





Climate Refugees ?

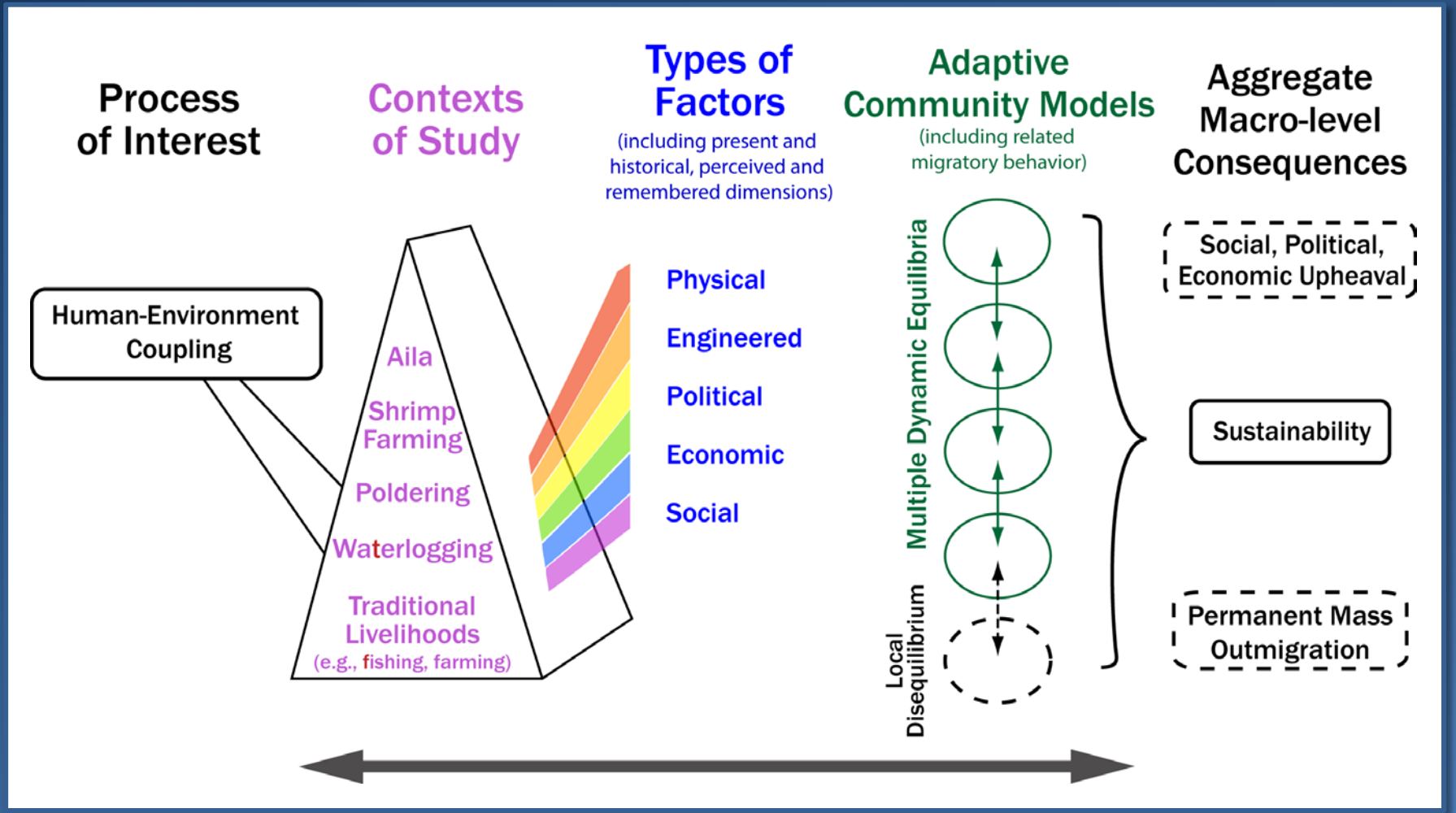
"Floods and other weather-related disasters have caused nearly 10 million people to migrate from Bangladesh to India over the past two decades, creating immense population pressures … the climate refugee problem will intensify as global warming increases, potentially yielding between 150 million and 200 million refugees"
– Center for American Progress

"Just as the environment is only one among many factors that drive migration, migration is also only one among many possible responses to environmental change." — IOM

Walsham, M. *Assessing the evidence: Environment, climate change, and migration in Bangladesh.* (International Organization for Migration 2010)

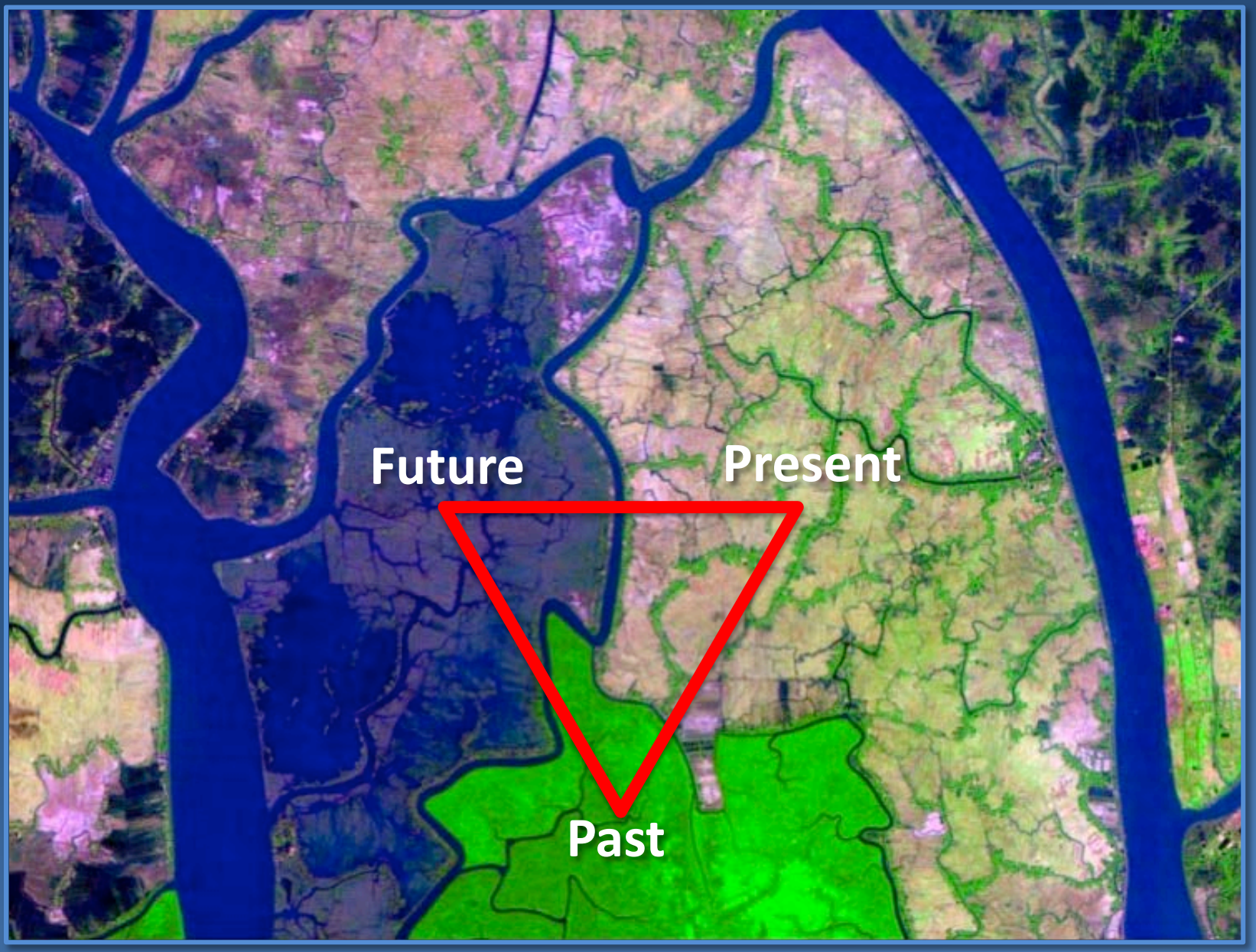
MIGRATION – PUSH vs. PULL factors

ISEE: Integrated Social, Environmental, and Engineering framework

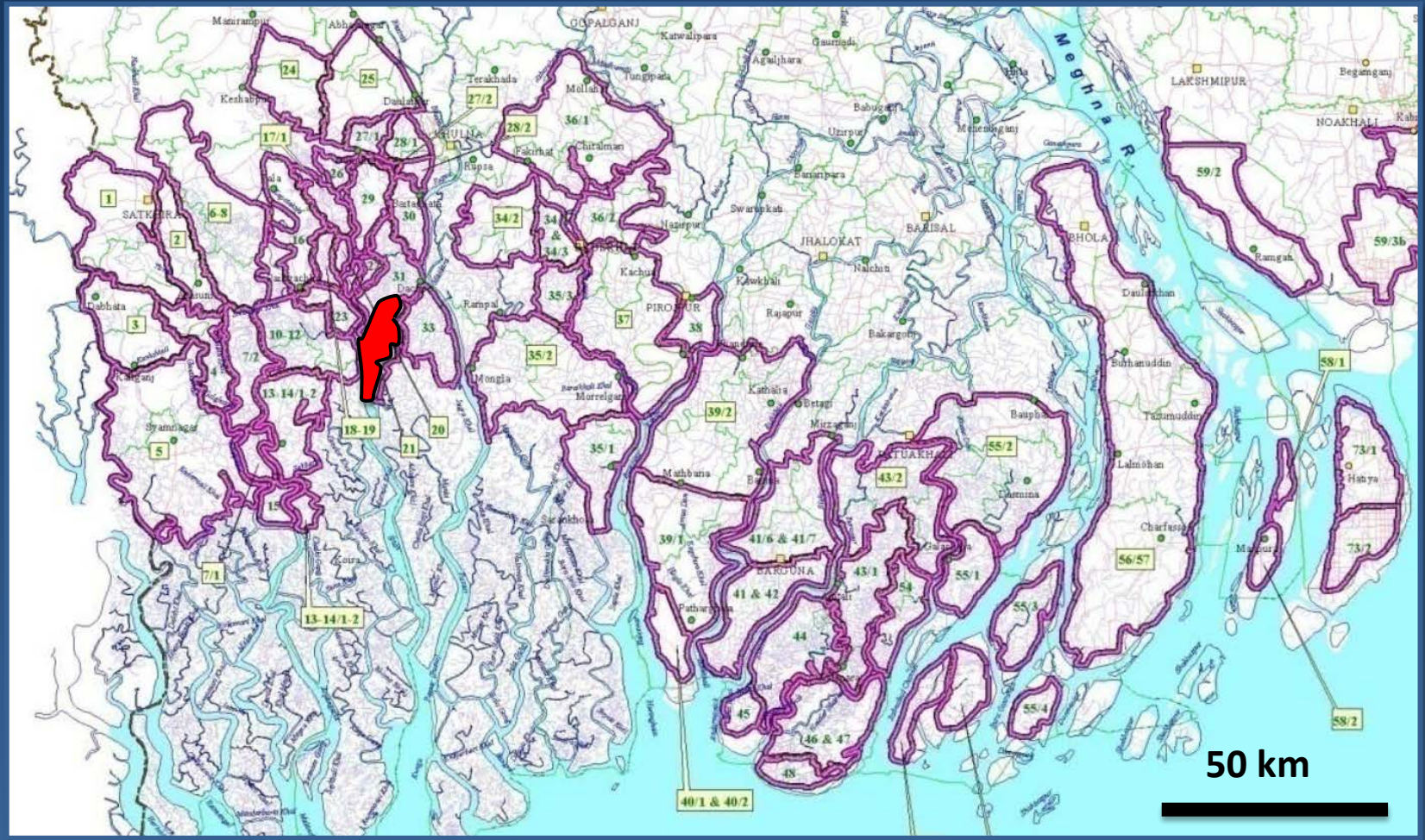


Turning the conceptual system into research questions …

Multiple Dynamic Equilibria

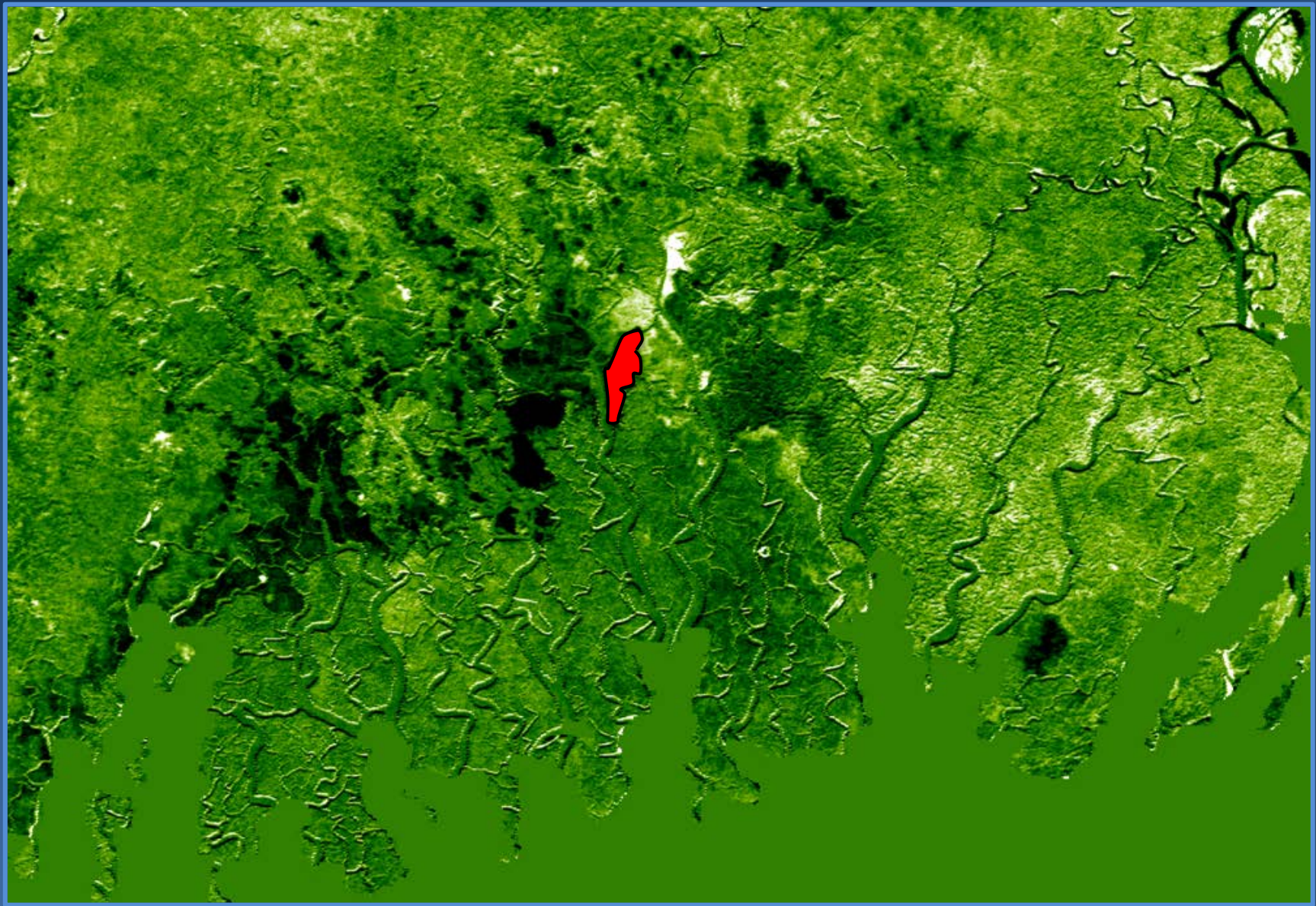

Future
Present
Past

Polder System of Bangladesh

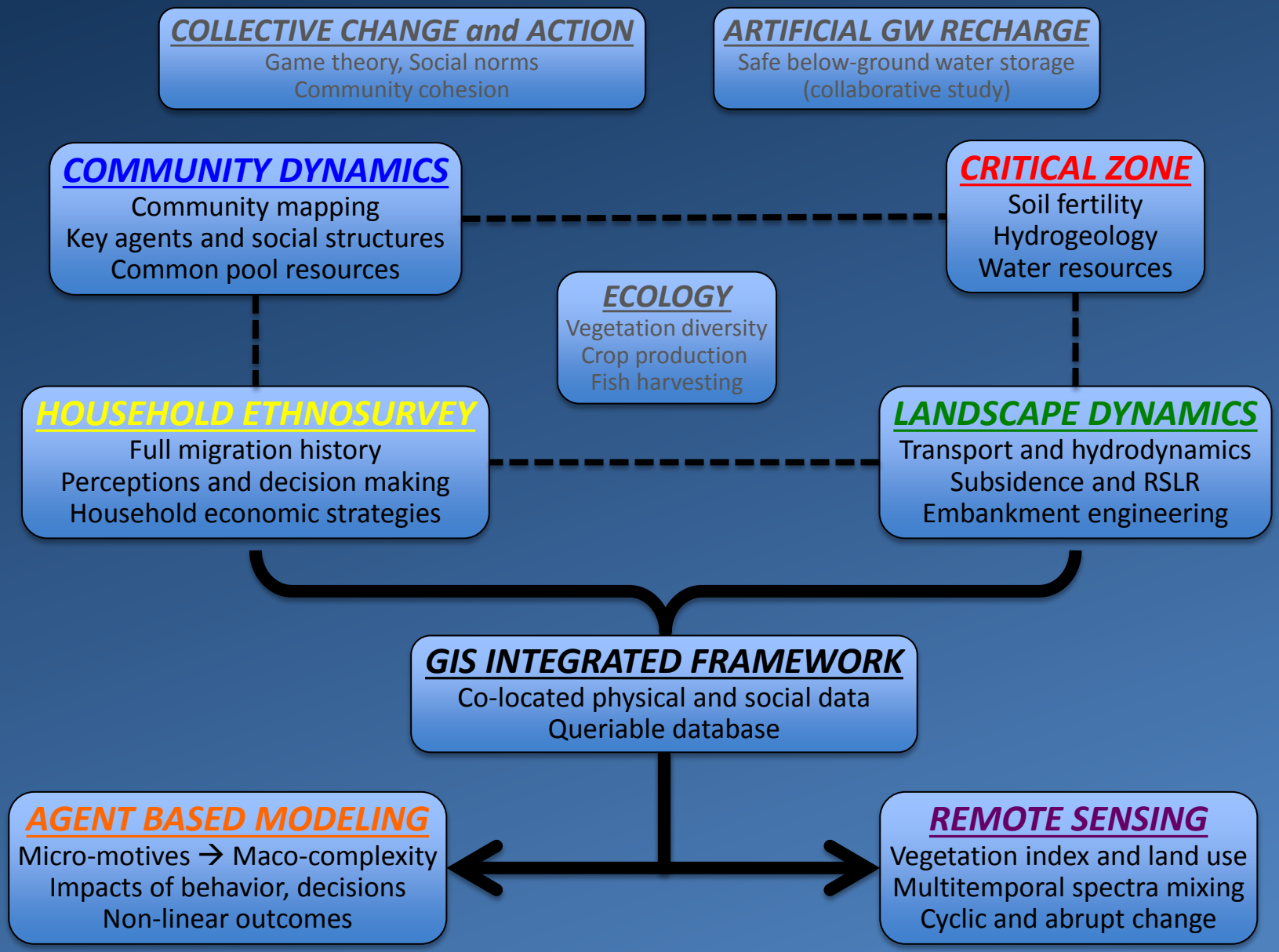


World Bank - $400M loan to Bangladesh for Phase 1 Embankment Restoration Project

Net Decadal Change in Vegetation



Project Research Structure



C. Project scientific issues: Underlying scientific principles, prior state-of-the-art advances that favored a multidisciplinary approach, scientific barriers, potential scientific advances:

One of the only research groups to integrate social, physical, and engineering sciences for understanding the complex interface between humans and environment, using diverse methodologies including field-based, theoretcal, and experimental approaches. Project stands to establish a new approach to study coupled human-environment interactions and develop new paradigms on

D. Scientific accomplishments to date and what have we learned?

(examples)

- **Documented and quantified previously unrecognized areas of land that lie below sea-level within the world's largest and most densely-populated delta system.**
- **Determined causes and consequences of major embankment failures during cyclone, accounting for displacement of 50,000 people.**
- **Document the important role of leadership and power structure in determining local resilience to flooding disaster (in both + and – manners)**
- **Established working hypothesis that multiple sources of livelihood enhances resilience in the face of environmental strain and disasters.**
- **"Migration" is abundant but varied, and appears to be an opportunity structure**
- **Widespread failure of engineering aid structures; need new strategy.**

E. Do you foresee any potential breakthroughs in this research?

We foresee establishing a new framework and integrative approach for studying complex human-environment relationships with regard to social outcomes of migration, upheaval, and sustainability. Strong field-based observation and theory will be coupled with computational models of scenario outcomes. To date no similar or otherwise adequate approach exists.

F. Why is this an important area of research? –

Persistent and significant environmental change, now and into the future, is widely held to be a trigger of civil unrest and migration, which are recurring stresses in developing nations. This research will test this assertion, and more importantly investigate how humans and environment are coupled during times of change and how stresses are manifested in stability and resilience of large populations.

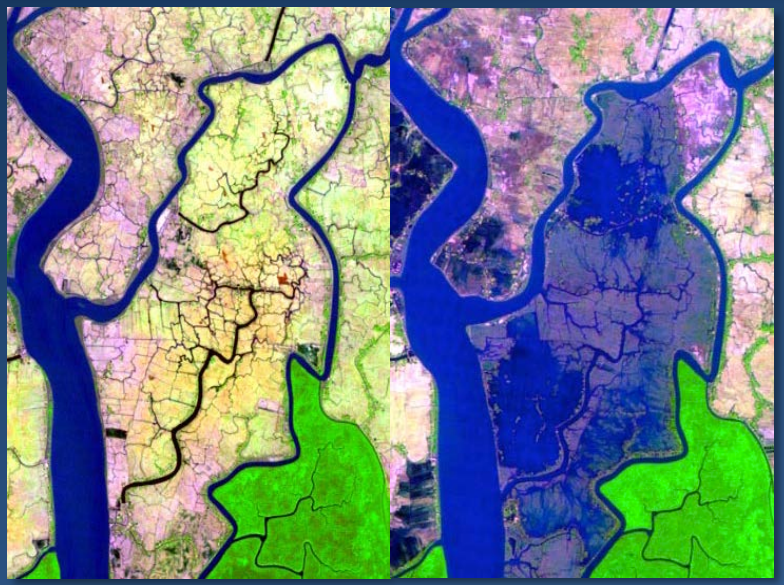
G. Overall budget dollars, year by year (planned or actual)

$1.5M/yr; 2 yrs completed; 1 yr + 2 yr option remaining

H. Dates, locations, overall results of major reviews or meetings.

- **Regular team meetings and internal workshops;**
- **Results presented at major conferences – 2012 American Geophysical Union; 2013 Joint Chapman/Penrose Conference on Coastal Management; 2013 Bangladesh Development Initiative**

Environmental Stress and Human Migration in a Low-lying Developing Nation: A Comparison of Co-evolving Natural and Human Landscapes in Bangladesh



STUDY AREA:

1989 Landsat (left);

2009 Landsat, post-cyclone (right)

Objectives:

- Identify social and environmental factors most important in supporting stability or motivating decisions to migrate;
- Determine how factors differ within and across social and physical landscapes;
- Assess how factors, and related social-environmental interactions, are likely to evolve under a variety of scenarios.

Key Findings:

- Region experienced 2-3 cm/yr of RSLR for past 50 years related to embanking.
- Study area was intertidal for 2 years following 5 major embankment breaches.
- Resilience to strain based in community inter-dependence and diverse livelihoods.

Principal Investigator:

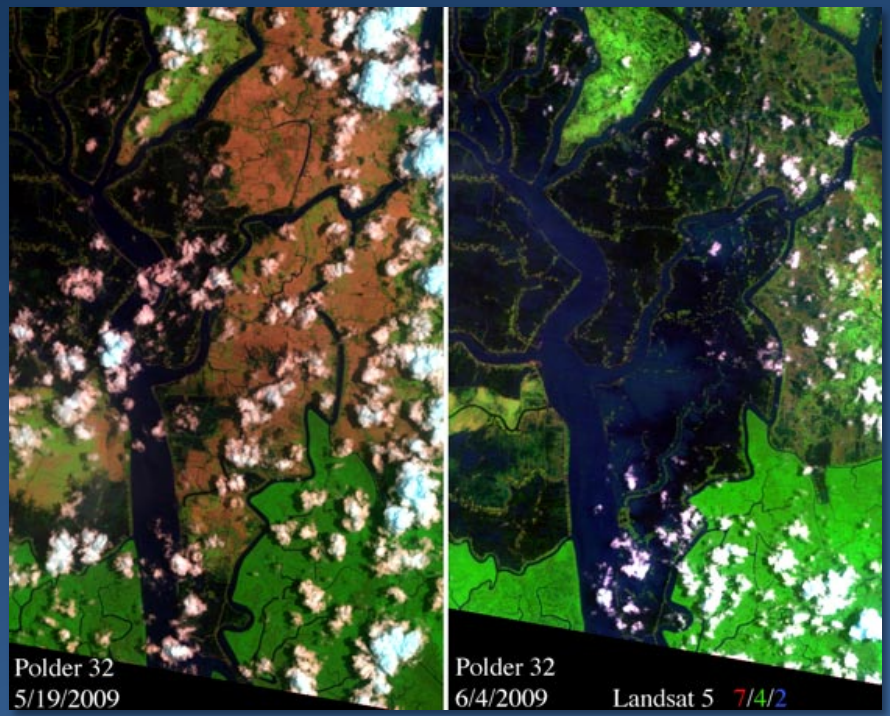
- Steven Goodbred, Jr. (Vanderbilt Univ.)

Approach:

- Transdisciplinary project framework, Integrated Social, Environmental, and Engineering (ISEE) model for study of human-environment coupling.
- Jointly conducted, mixed-method, social and physical science field campaigns.
- Remote sensing of landscape changes and evaluation through GIS database.

Remote Sensing and Spatiotemporal Analysis of Land Cover

Lamont-Doherty Earth Observatory
Columbia University | Earth Institute



Objectives:

- Characterize spatial and temporal changes in land cover for southern Ganges-Brahmaputra delta over the past 12 years.
- Identify abrupt changes in temporal cycles of agriculture aquaculture and flooding.
- Map spatial variations in both cyclic and abrupt changes.

Key Achievements:

- Mapped vegetation phenology and potential flooding cyclicity for southern delta @ 250m resolution 2000-2012.
- Acquired full Landsat and PALSAR archives for Polder 32 Currently processing both for seasonal & interannual spatiotemporal analysis.

Co-Investigator:

- Christopher Small, LDEO Columbia Univ.

Approach:

- Multiscale, multitemporal spectra mixture modeling.
- Combined Empirical Orthogonal Function Analysis and temporal mixture modeling.

Multi-Community Qualitative Study ISEE Bangladesh

Revolutionary Research . . . Relevant Results

VANDERBILT UNIVERSITY

Women after seasonal mapping participatory rapid appraisal

Objectives:

- Assess PRA methods for gathering data on community livelihoods, mobility, common pool resources, and other political variables.
- Identify key physical, engineered, social, economic, and political factors contributing to community stability and instability.
- Assess potential for scaling multi-method methodology. "Proof of Concept"

Key Achievements:

- Identified and generated hypotheses about key physical, engineered, social, economic, and political variables.

Principal Investigator:

- Brooke Ackerly (*Political Science, Vanderbilt)*

Approach:

- Multi-method qualitative research
  1. Key Informant Interviews
  2. Participatory Rapid Appraisal
  3. Focus Group Discussion

The Bangladesh Environment and Migration Survey (BEMS)

Objectives:

- To understand patterns and processes of internal and international migration in contemporary Bangladesh with a special emphasis on how environmental stressors affects migration patterns in southwest Bangladesh

Key Achievements to Date:

- Designed BEMS household and community survey instruments
- Developed BEMS interviewer training manual
- Developed BEMS research protocol
- Selected BEMS pilot sites
- Received IRB Approval from Vanderbilt

Investigators

Katharine Donato, Amanda Carrico, Bhumika Piya

Approach:

- Implement an ethnosurvey to randomly selected households in select communities to collect data about demographics, economic activity, assets, livelihoods, internal and international migration, access to services, access to food and water, nutrition, health, social networks, and perceptions and responses to environmental change
- Implement a community survey to local leaders to understand the economic, political, social and historical dimensions of study sites

Experimental Methods to Understand Factors of Collective Action

Objectives:

- Identify individual (decision processes and preferences), social (cohesion and goals), and local institutional (norms and policy) factors that facilitate/inhibit collective action for maintenance of drinking water infrastructure.
- Understand and improve project delivery.
- Test hypotheses generated by Rapid Qualitative Methods sub-project regarding social cohesion and collective action.

Key findings from preliminary research at 17 water project sites:

- Social variables, NGO project delivery, and local project management practices are key variables in successful long-term project maintenance.

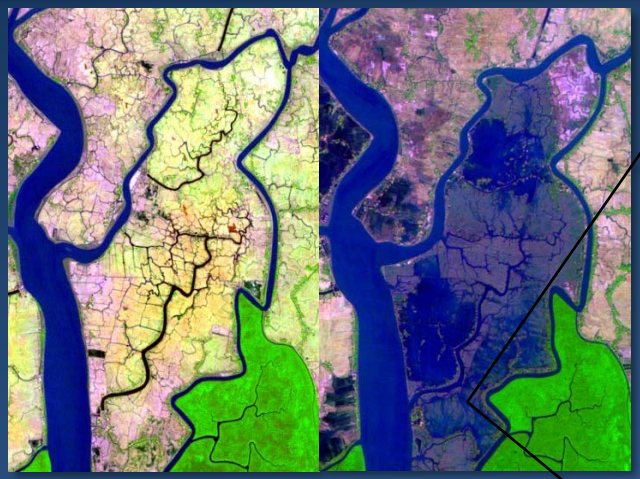
Principal Investigators:

- Brooke Ackerly and Cecilia Mo (VU)

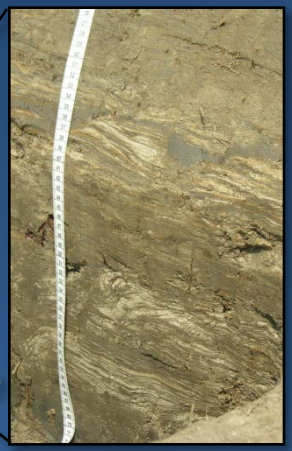
Approach:

- Preliminary research (May 2013).
- Ethnography of project delivery.
- Experimental social science (economic games and randomized controlled trial interventions).
- Household survey.
- Agent-based modeling.

Contrasting pristine and human-modified environments: severe long-term consequences from coastal embankments



1989 image (left) and 2009 post-cyclone image (right) showing tidal inundation



70 cm thick tidal splay deposit

Objectives:

- Identify processes/conditions that define the relationship between tides, sea level, and sediment accretion in human-modified & pristine regions of lower delta plain
- Determine impacts and recovery of landscape by Cyclone Aila and post-storm processes

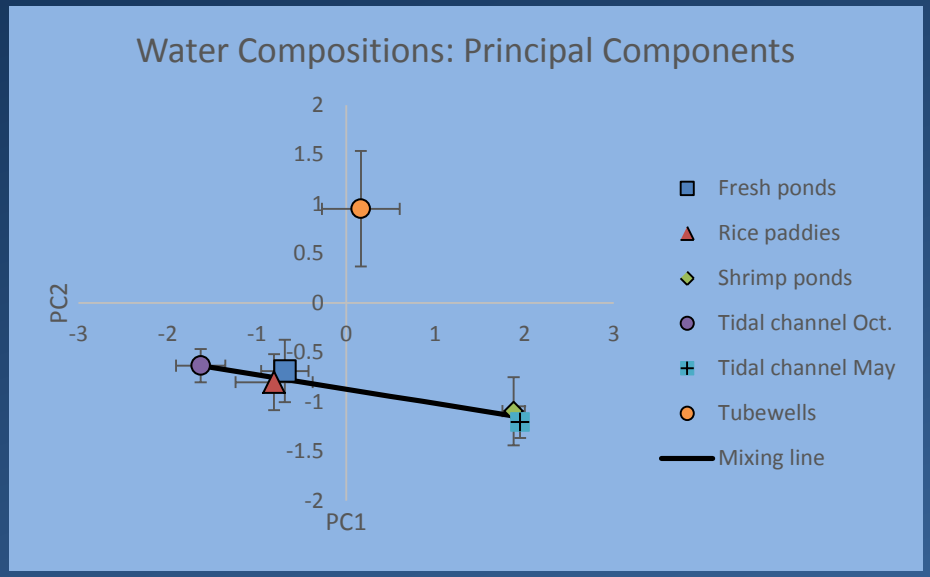
Key Findings:

- Poldered landsurface 1.0-1.5 m below adjacent river bank terraces and MHW
- 5 major breaches of embankment, all along reaches of channel bank erosion
- Landsurface intertidal for 2 years, led to 10-80 cm of tidal splay deposition

Approach:

- Develop conceptual model of lower delta plain which balances relative sea level with sediment accretion, subsidence, compaction and eustatic sea level
- Measure sediment accretion, compaction, subsidence and sea level with field instrument deployments
- Complete GPS elevation survey

Sources of Salinity in Drinking Water and Soil



Objectives:

- To identify the source of salinity in drinking water and soil and in a representative polder in southwestern Bangladesh.
- Identify areas where salinities exceed safe drinking water limits and are high enough to reduce crop yields.

Key Achievements To Date:

- Surface waters are mixtures of meteoric water and salts from soil, often exceed safe limits for salinity.
- Shrimp ponds sourced from tidal channel water in dry season, but have higher Dissolved Organic Carbon (DOC).
- Shallow groundwater has high spatial and compositional variability, but little or no seasonal variation, suggesting low recharge rates and slow flow.
- Groundwater often exceeds safe limits for salinity and As.
- Groundwater is mixture of seawater and meteoric water, but with high DOC possibly sourced from shrimp ponds.
- High DOC may be cause of Fe oxyhydroxide reduction, which adds As to groundwater but causes sulfide precipitation.

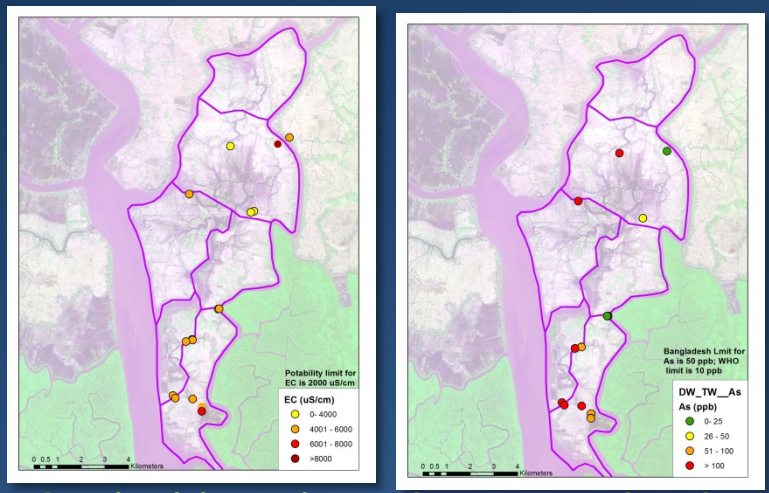
Principal Investigator:

- John C. Ayers, EES, Vanderbilt University

Approach:

- Collect water samples from rice paddies and from all water types.
- Analyze water samples by ICP-OES, IC, and TOC and identify mixing trends.
- Characterize subsurface salinity through electromagnetic surveying.
- Collect soil samples and measure salt contents using XRF (bulk composition) and analysis of soil extracts by ICP and IC.

Integrated Assessment of Factors Affecting Water Security in Rural Southwestern Bangladesh



Conductivity and arsenic concentrations in tubewell drinking water sources

Objectives:

Identify factors affecting water security in coastal Bangladesh by evaluating water use and quality in the Polder 32 area, and evaluating land use changes over time; asses the utility of applying a water security index on a local and regional scale, and develop a method of incorporating biophysical and socioeconomic parameters.

Key Findings:

- None of the tubewells used for drinking met the minimum level for potability for conductivity; many exceeded criterion for As
- Levels of access to safe drinking water locally is inconsistent with national MDGs
- Residents use a mixture of drinking water sources, depending on season

Investigator:

- Laura Benneyworth, Vanderbilt Center for Environmental Management

Approach:

- Collect drinking water samples; assess electrical conductivity and arsenic quality; compare to relevant criteria
- Perform spatial and temporal analyses of data using GIS
- Evaluate land use change with Landsat imagery
- Analyze water quality and socioeconomic data on water access to develop water security index for Polder 32; test regionally

GIS-based Visualization and Integration of ISEE Knowledgebase and Datasets

Objectives:

- To evaluate the capabilities and effectiveness of field data collection using handheld mobile devices (i.e., Nexus 10 tablets) in Bangladesh
  - Collect location information automatically
  - Provide more efficient form of data collection including photos, infrastructure information and interview logs

Key Achievements to Date:

- Designed forms to be used in data collection on GPS-enabled Nexus tablets
- Tested and utilized Garmin-GLO devices to secure accurate GPS location
- Collected data on infrastructure systems and components (Feb 13) and social team research
- Uploaded and began analyzing data

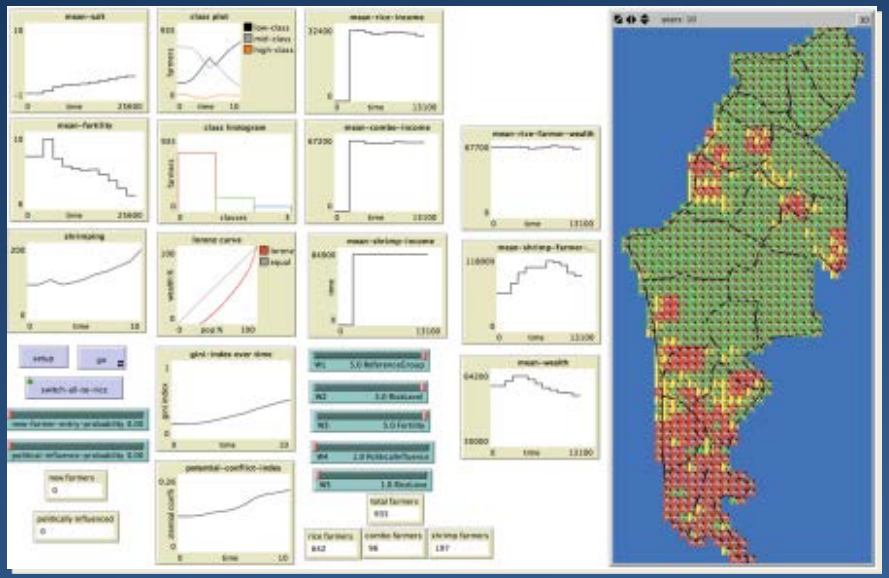
Investigators

Janey Camp, Mark Abkowitz, Lindsey Langsdon, Jason Abkowitz, John Nay

Approach:

- Investigate options for developing forms for data collection and crowdsourcing techniques on mobile devices
- Design research questions and forms for use in field data collection in Bangladesh
- Utilize forms in field, test GLO devices for GPS accuracy compared to handheld GPS receivers
- Troubleshoot and then train other project team members in use of devices and forms

Computational Models of Resilience and Stability



Objectives:

- Identify social and environmental factors most important for supporting stability.
- Generate and test hypotheses about individual and household processes that could generate observed phenomena at the community level.
- Explore implications of plausible local scenarios for regional stability.

Main Achievements:

- Developed modeling approach to connect hypothetical individual-level decisions to community-level phenomena.
- Implemented a schematic model to examine the implications of different assumptions about individual behavior.

Principal Investigator:

- Jonathan Gilligan (Vanderbilt University)

Approach:

- Complex systems, bottom-up modeling.
- Qualitative, schematic modeling:
  - Simple micro-motives to qualitatively reproduce observed macro-complexity.
- Quantitative, empirical modeling:
  - Detailed individual/household data to reproduce observed phenomena.