Resilience to Extreme Events in Social Ecological Systems of the Lake Champlain Basin

(Basin Resilience to Extreme Events, BREE)

Fig. 1 Tropical Storm Irene floods a Vermont stream, 2011, G. Miller

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BREE Overarching Research Question

What are properties within the Lake Champlain Basin that drive hydrologic and nutrient responses to extreme events, and what are strategies for increasing resilience to protect water quality in the social ecological system?

BREE IAM Research Question

What strategies for resilience can be implemented to manage the risk from extreme events and what are the trade-offs for prioritizing public sector investments?

"Resilience" Assessment in Social Ecological Systems (SES)

Resilience refers precisely to **the magnitude of disturbance that can be absorbed before a system changes to a radically different state, as well as the capacity to self-organize and the capacity for adaptation to emerging circumstances** (Carpenter et al., 2001, Folke, 2006, Berkes et al., 2008)

Hypothesis: **A loss of resilience can trigger critical transitions in SES that induce the state variables in the system to be abruptly tipped into a different state**

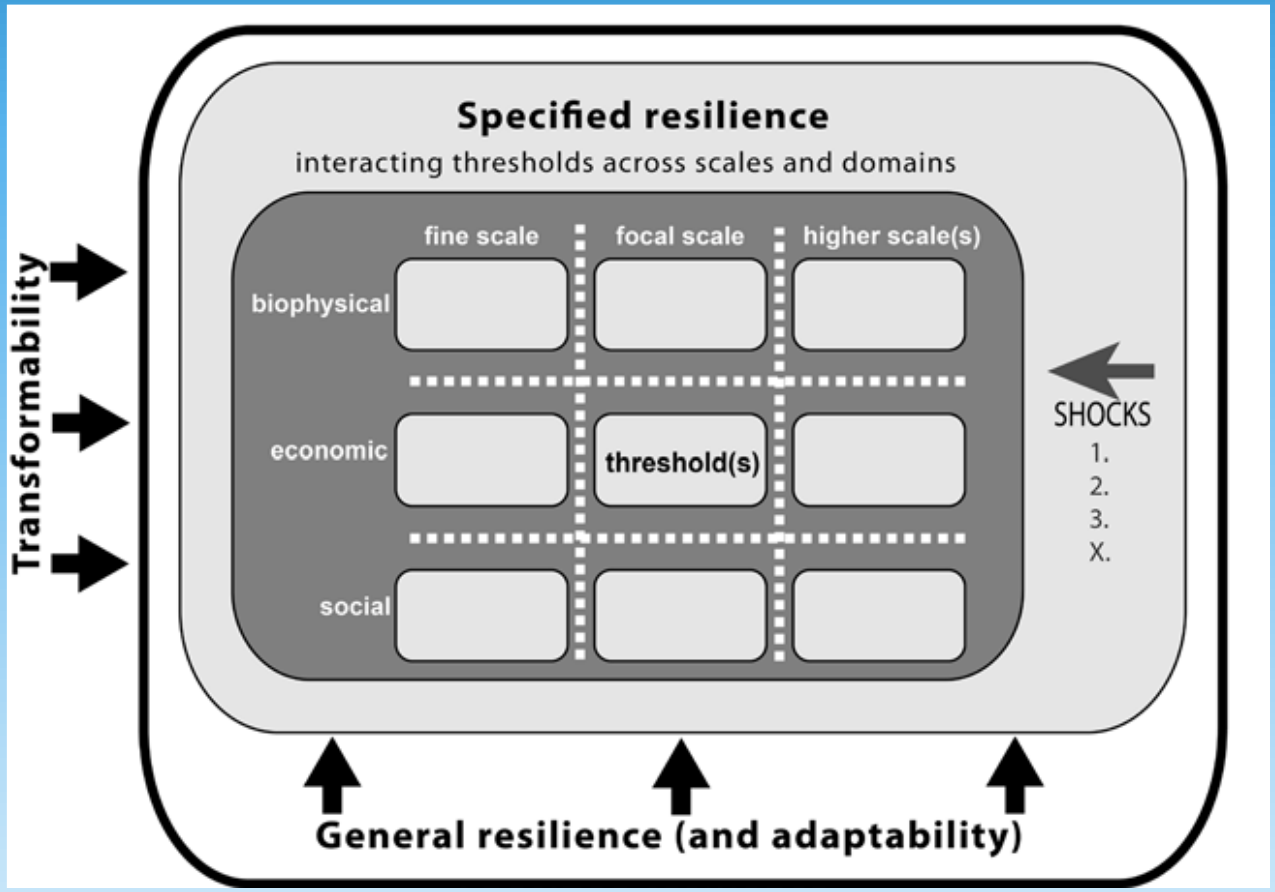


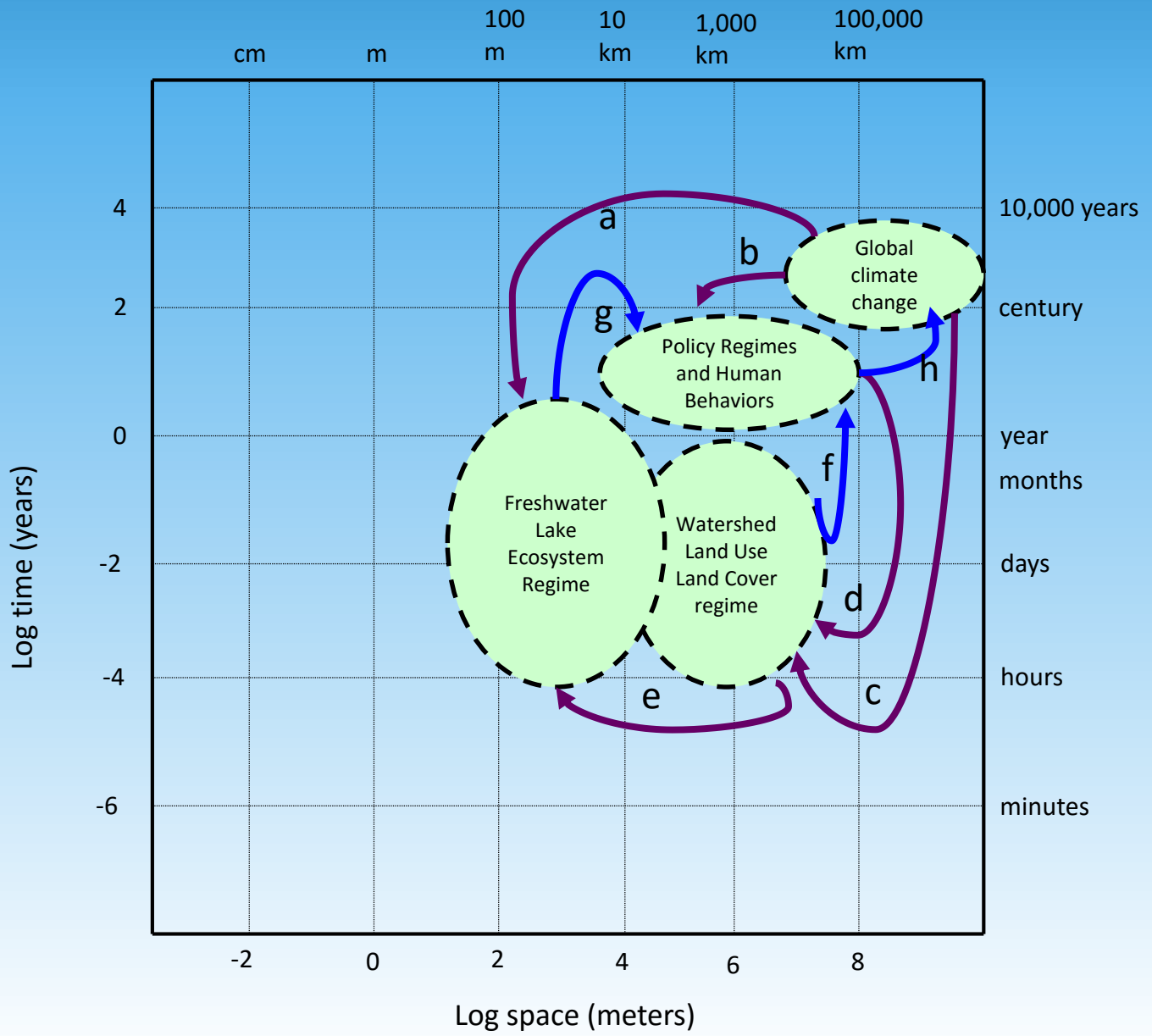
Figure 11: Specified Resilience, General Resilience, and Transformability

These are different but interacting capacities of the system. Assessing a system's resilience requires an accounting of all three.

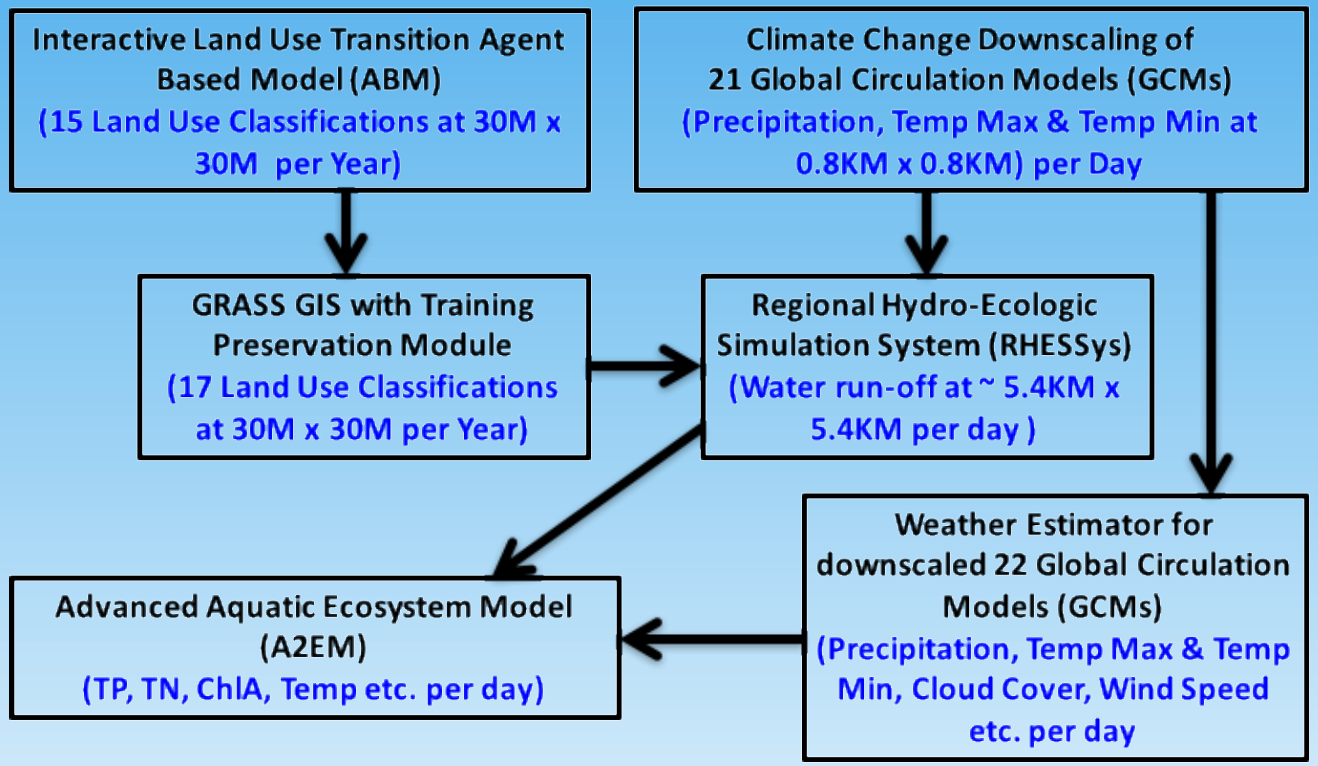
Walker and Salt (2012)

IAM framework to assess resilience of LCB SES

When exposed to exogenous shocks (e.g. extreme events) or endogenous surprises (e.g., ecological collapse), SES do not necessarily go through gradual change, but rather critical transitions (tipping points and thresholds) may cause abrupt "regime" shifts



IAM V1.0: High Resolution Forecasting of Global Climate Change Impacts on Watersheds and Lakes: Integrating Climate, Land-Use, Hydrological and Limnology Models



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Coupled impacts of climate and land use change across a river–lake continuum: insights from an integrated assessment model of Lake Champlain's Missisquoi Basin, 2000–2040

Asim Zia[1,2,3,4], Arne Bomblies[4,5,6], Andrew W Schroth[7], Christopher Koliba[1,4], Peter D F Isles[8], Yushiou Tsai[5], Ibrahim N Mohammed[6], Gabriela Bucini[6], Patrick J Clemins[2,6], Scott Turnbull[6], Morgan Rodgers[6], Ahmed Hamed[6], Brian Beckage[9], Jonathan Winter[10], Carol Adair[3], Gillian L Galford[4,8], Donna Rizzo[4,5] and Judith Van Houten[6,10]

IAM V1.2: Feed-forward enabled with 3 RCPs, 4 GCMs and 4 "refined" Land Use scenarios, Missisquoi 2000-2100

Understanding Lags, Thresholds and Cross Scale Dynamics in Social Ecological Systems: Cascading Impacts of Climate and Land Use Adaptation on Missisiquoi Bay, 2000-2100

Asim Zia[a,b,c,d,*], Andrew W. Schroth[e], Patrick J. Clemins[b,h], Christopher Koliba[a,d], Arne Bomblies[d,f,h], Brian Beckage[i], Peter D.F. Isles[g], Yushiou Tsai[h], Ibrahim N. Mohammed[h], Gabriela Bucini[h], Scott Turnbull[h], Morgan Rodgers[h], Jory Hecht[h], Jonathan Winter[j], Carol Adair[g], Donna Rizzo[d,f], Judith Van Houten[h, l]

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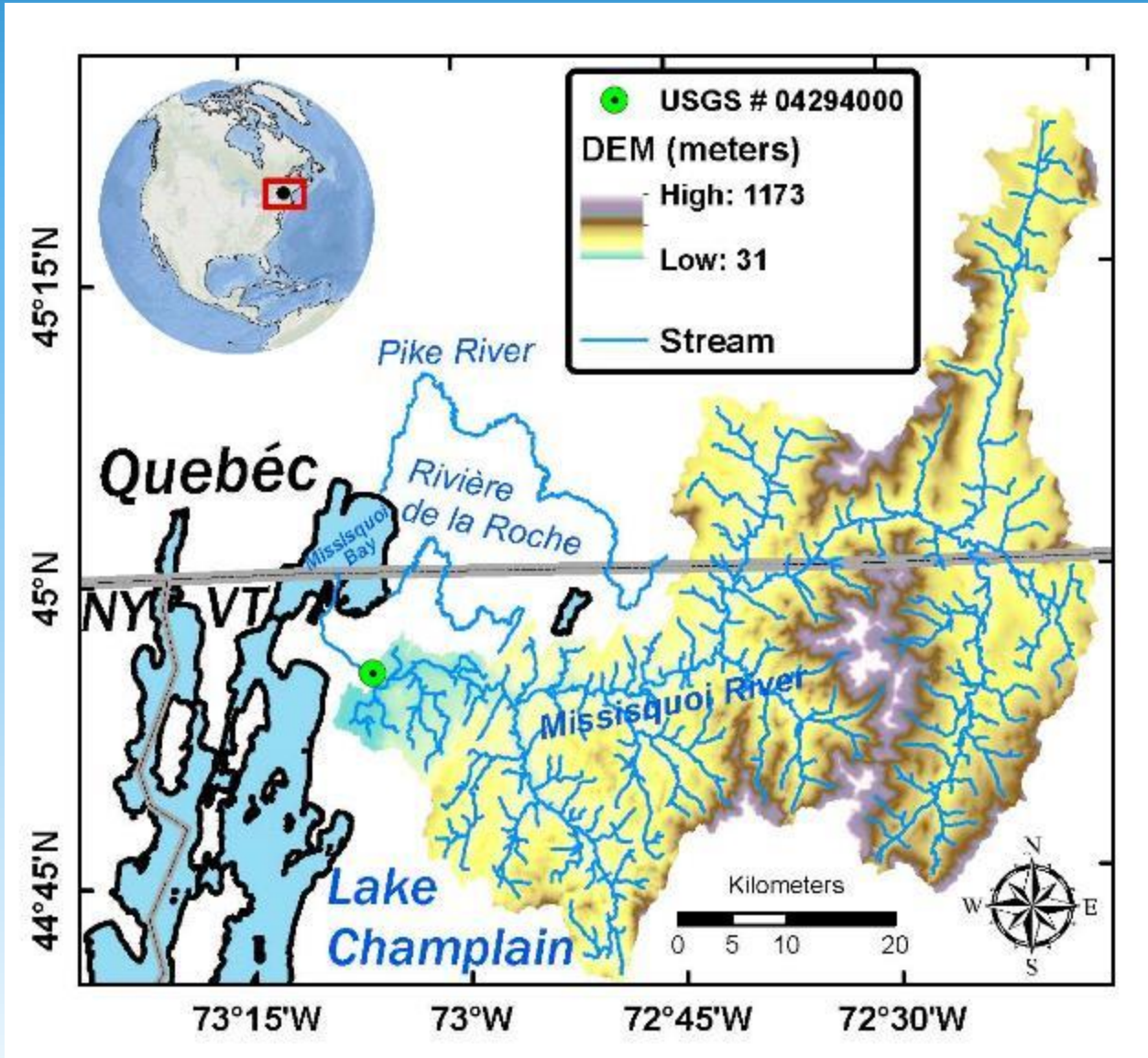
- Target Journals: PNAS, Ecology and Society etc.

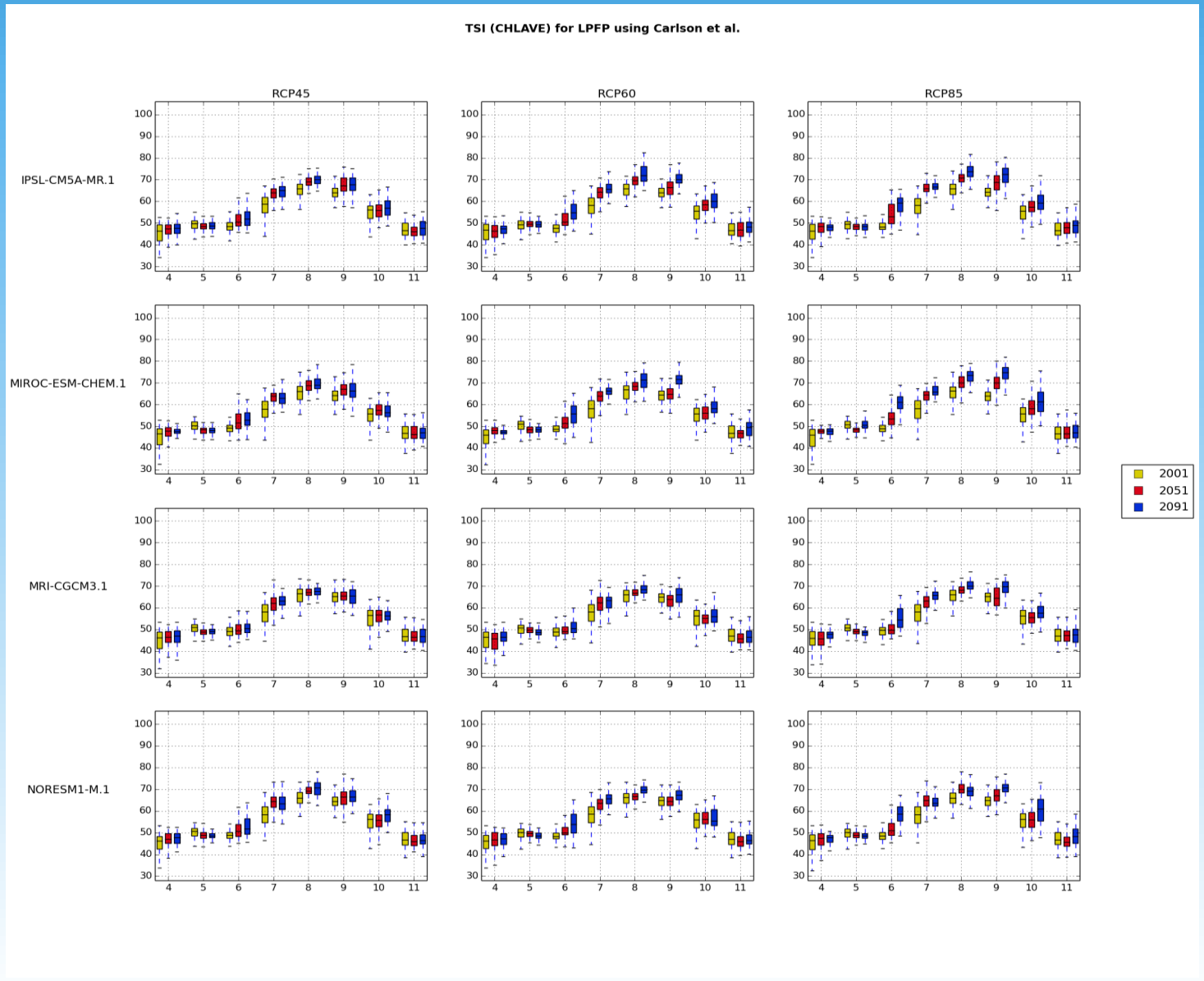
"EXTREME" SCENARIO SETTINGS

- **THREE "extreme" Climate Scenarios**: RCP 4.5; RCP 6.0 and RCP 8.5
  - Four extreme GCMs (Warm: miroc-esm-chem; Cool: mri-cgcm3.1; Wet: noresm1-m.1; Dry: ipsl-cm5a-mr.1) are used for three RCP scenarios.
- **FOUR "extreme" LULCC ABM Scenarios**: BAU, Pro-forest, Pro-Ag, Urbanization

Situated in Social Ecological Systems (SES) theoretical and empirical framework, this paper addresses the following question : **How do lags, inertia and thresholds (phase transitions) affect the evolution of state variables in Mississquoi Basin SES that interact across multiple scales of space and time ?**

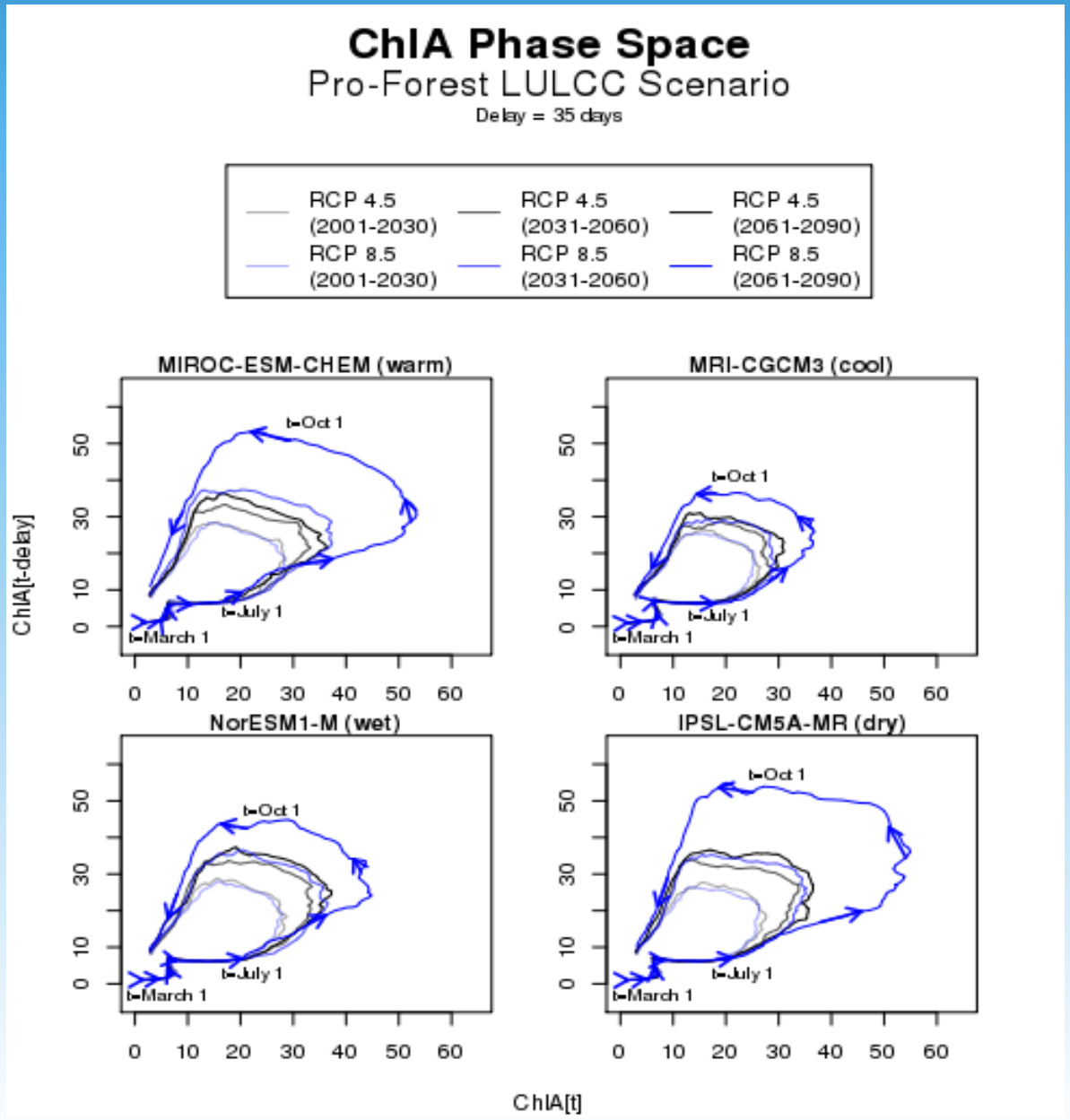


Projected Carlson's tropic state index for decadal averages (2001-11, 2051-61, 2091-2101) for the 'pro-forest scenario' under warm, wet, dry, and cool GCM ensembles. State transitions from meso to eutrophic occur at TSI 50, and from eutrophic to hypereutrophic conditions at TSI 70 with this metric.



At monthly scale, eutrophic regime will likely expand to June, July and October, while hyper-eutrophic regime will likely replace eutrophic regime in July and August

Projected Phase Transitions in CHLA Concentrations under four GCMs x 2 RCPs for pro-forest land management scenario



The width of the "basin of the attraction" will likely expand under "worst-case climate scenario" (RCP 8.5), shifting the lake regimes from meso-trophic (CHLA<20) to eutrophic (CHLA 21-40) and hyper-eutrophic (CHLA>40) in summer and fall

IAM V1.1: Feed-forward enabled with 4 RCPs, 5 GCMs, 4 land management and TP reduction scenarios for Missisquoi, 2000-2050

Accelerating Climate Change Will Limit Adaptation Options for Water Quality Management

Asim Zia[1,2,3,4,*], Andrew W. Schroth[5], Christopher Koliba[1,4], Arne Bomblies[4,6,8], Peter D.F. Isles[7], Yushiou Tsai[8], Ibrahim N. Mohammed[8], Gabriela Bucini[8], Patrick Clemins[2,8], Scott Turnbull[8], Morgan Rodgers[8], Jory Hecht[8], Brian Beckage[9], Jonathan Winter[10], Carol Adair[4,7], Donna Rizzo[4,6], Judith Van Houten[8, 11]

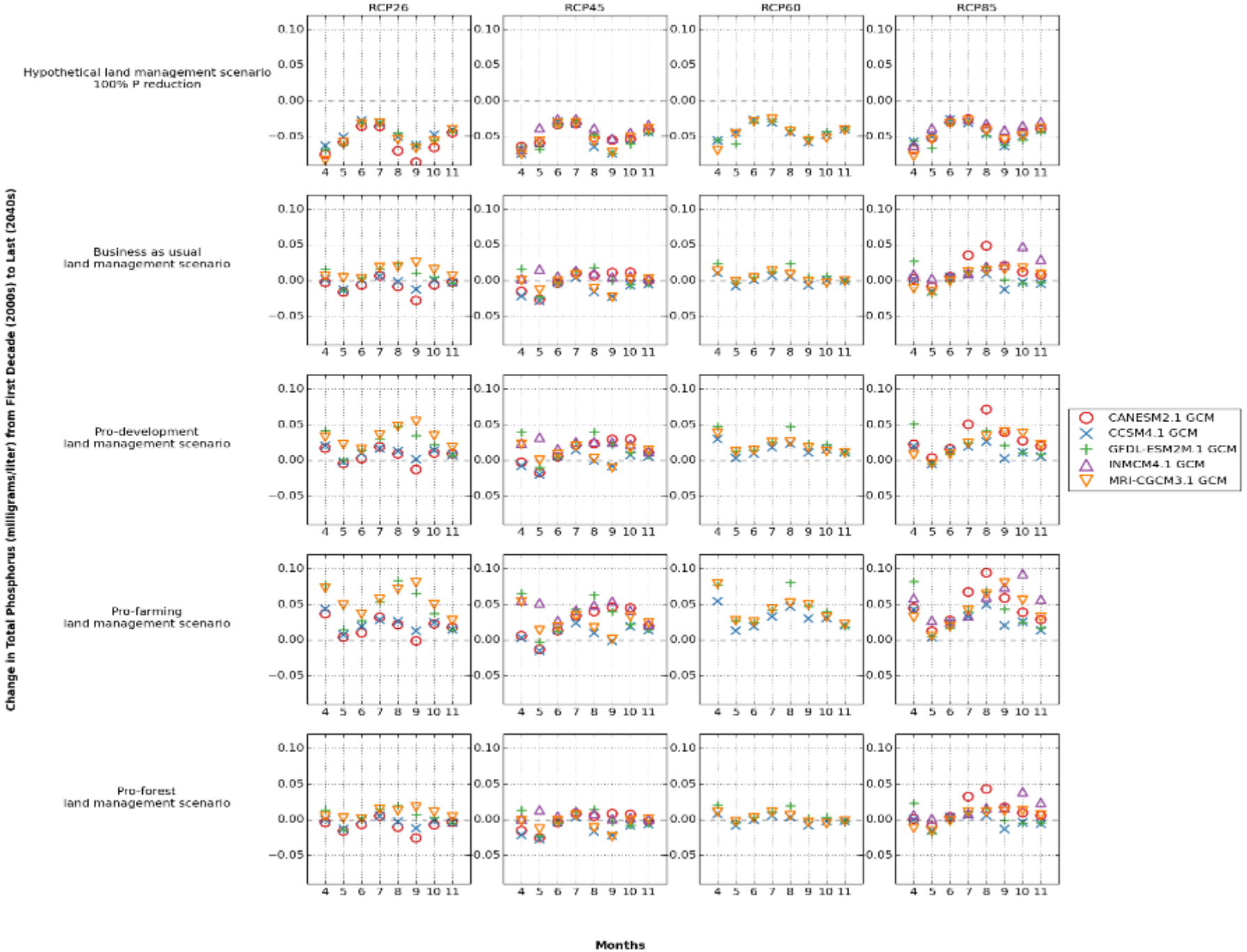
- Target Journals: Nature Climate Change, PNAS, etc.

"Ensemble Method" of Scenario Settings Used for Cascading IAM Version 1.1 Missisquoi Runs, 2000-2050

- **Four Climate Scenarios**: RCP 2.6, RCP 4.5; RCP 6.0 and RCP 8.5
  - Ensemble of five GCMs that are among the best to replicate North-Eastern US climatic conditions identified by Thibeault, J.M. and Seth, A., 2015. Toward the credibility of Northeast United States summer precipitation projections in CMIP5 and NARCCAP simulations. *Journal of Geophysical Research: Atmospheres*, *120*(19).

- **FOUR LULCC ABM Scenarios "Refined"**: BAU, Pro-forest, Pro-Ag, Urbanization

- **Hypothetical TP reduction scenarios**
  - 100% TP reduction from 2016-2050 scenario (ex-Secretary Ag scenario)
  - 90%, 85%, 80%, 70%...0% scenario runs (in progress)
  - Monte Carlo analysis on TP flux regression equations driving the Limnotech Model (in progress)
- **Remaining settings are similar to IAM Version 1.0** (e.g. no additional changes in model settings and calibration)


RCP26
RCP45
RCP60
RCP85
Hypothetical land management scenario
100% P reduction
Business as usual
land management scenario
Pro-development
land management scenario
Pro-farming
land management scenario
Pro-forest
land management scenario
Change in Total Phosphorus (milligrams/liter) from First Decade (2000s) to Last (2040s)
Months
CANESM2.1 GCM
CCSM4.1 GCM
GFDL-ESM2M.1 GCM
INMCM4.1 GCM
MRI-CGCM3.1 GCM

BREE IAM Model Structure

Intellectual merit: Exploration of SES couplings and feedbacks through novel application of deep learning and agent cognition!

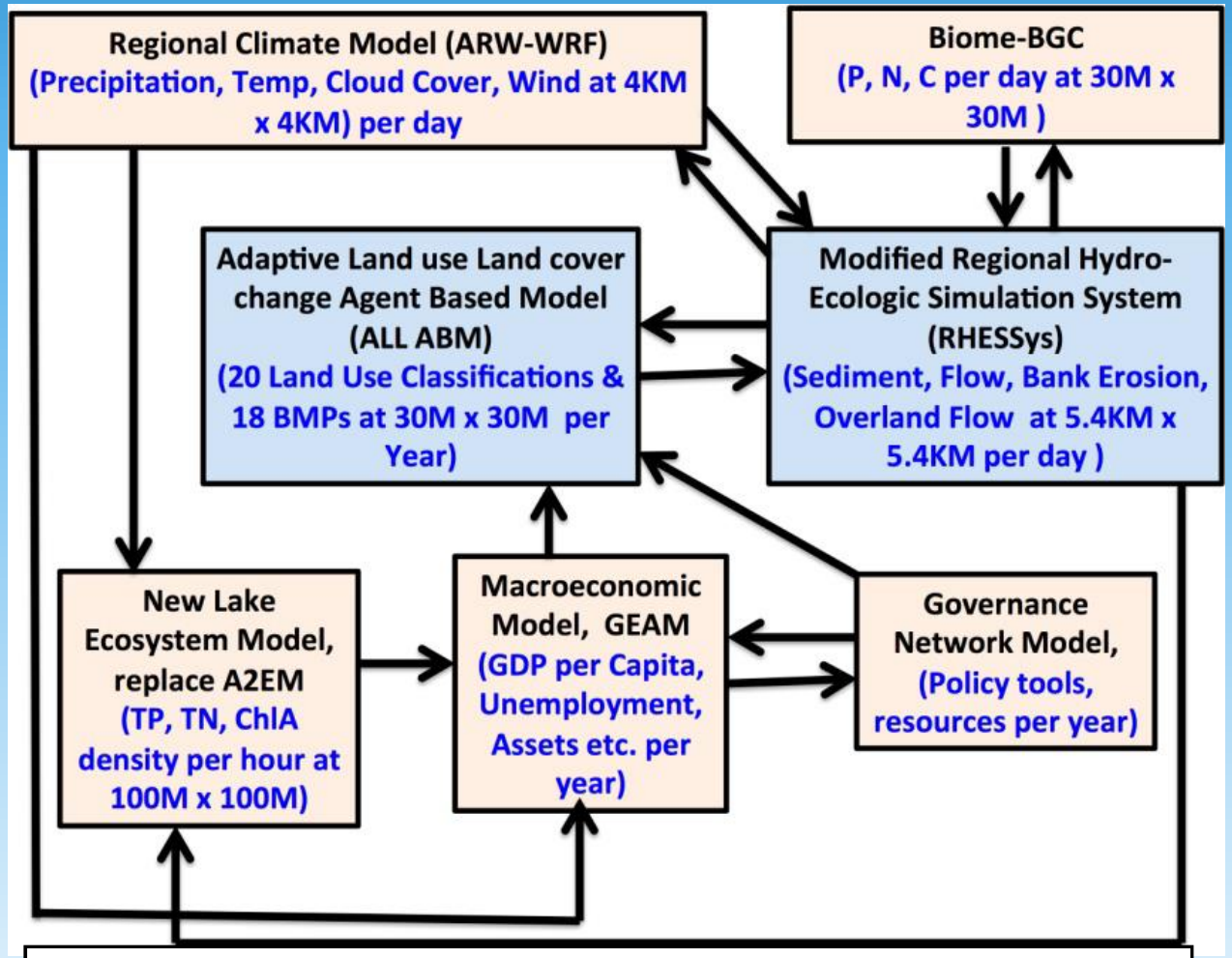


Figure 7: The BREE Integrated Assessment Model (IAM) of coupled social ecological systems for understanding the cascading impacts of climate change induced extreme events at watershed scales; tan = new model; blue = expanded existing model; WRF: Weather Research and Forecasting; ALL: Adaptive Landuse Land cover agent based model: GEAM: General Equilibrium Analysis Model