Watershed Hydrology in Earth-Human Dialogue

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Seminar on November 07, 2016
LRES/MSU

Outline

- **Background**: classic watershed modeling
- ~~Watershed-scale modeling~~
- ~~Watershed data analysis~~
- **Modeling beyond watersheds**
- **Future research**
- **Summary**

Classic definition of watershed

Everyone lives in a watershed

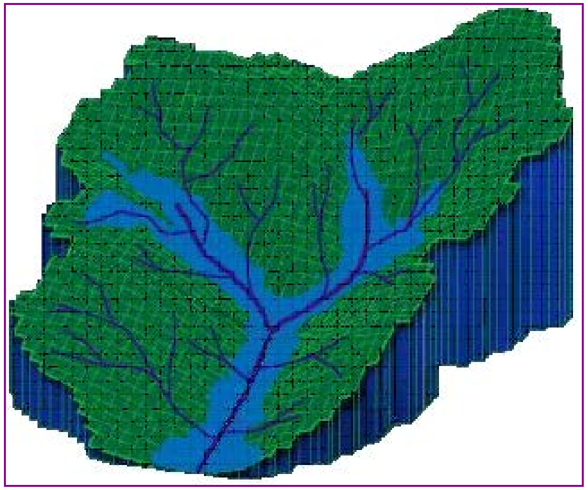
- A watershed is t … common **waterway**, suc … ary, wetland, aquifer, or even the ocea … EPA)

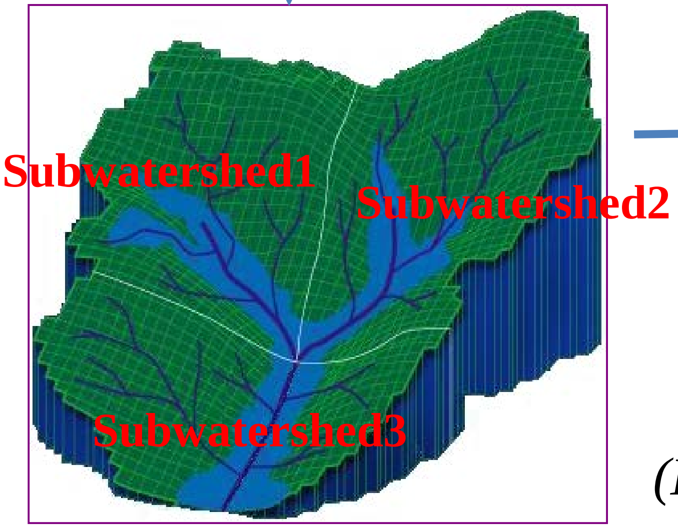
Watershed is NOT just about water

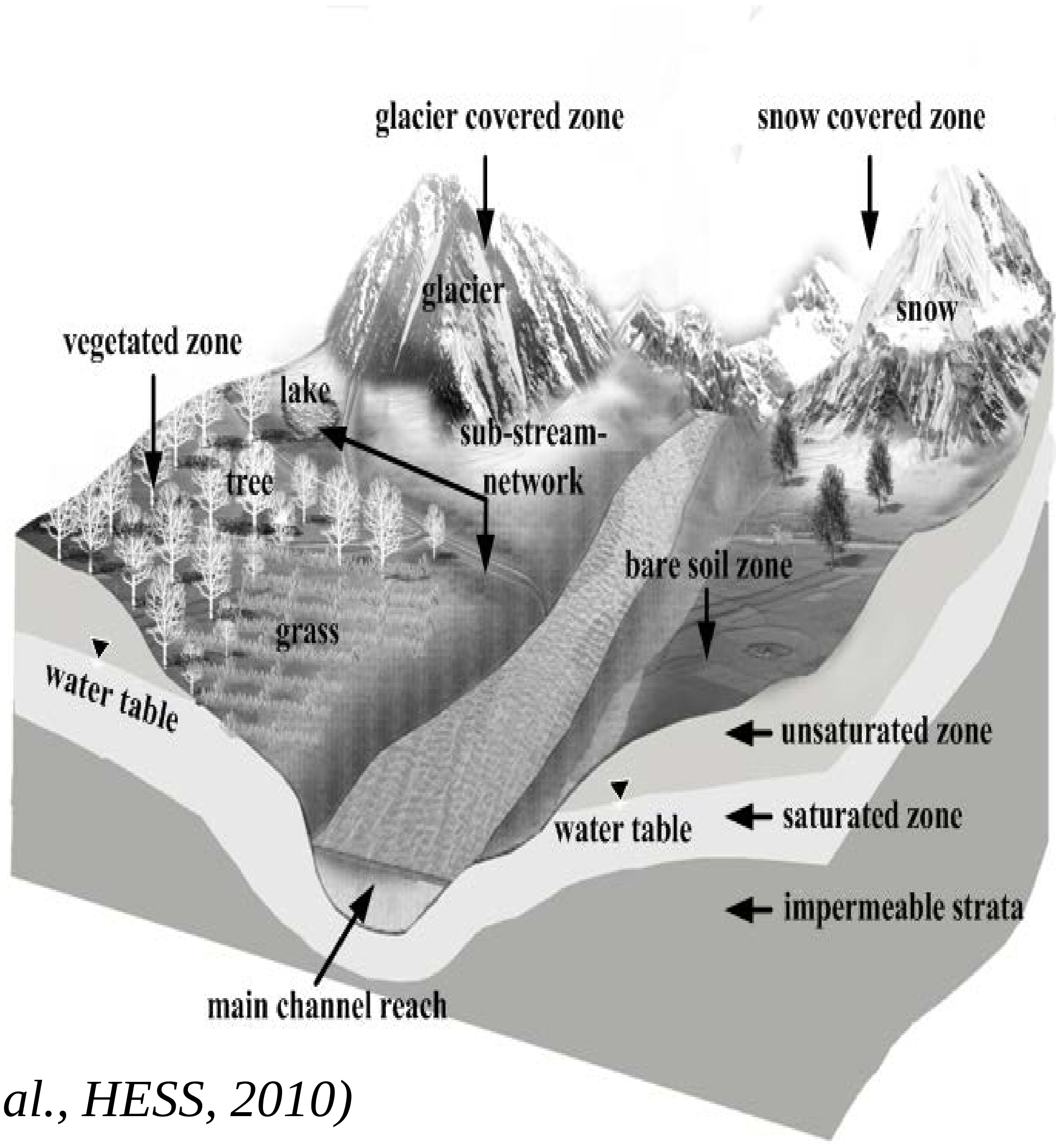
- A watershed is that **area** of land, a bounded hydrologic system, within w … are inextricably linked by their … and where, as **humans** settled, simpl … demanded that they become part of a community (John W. Powell)

Classic watershed modeling

-- Spatial heterogeneity within watersheds



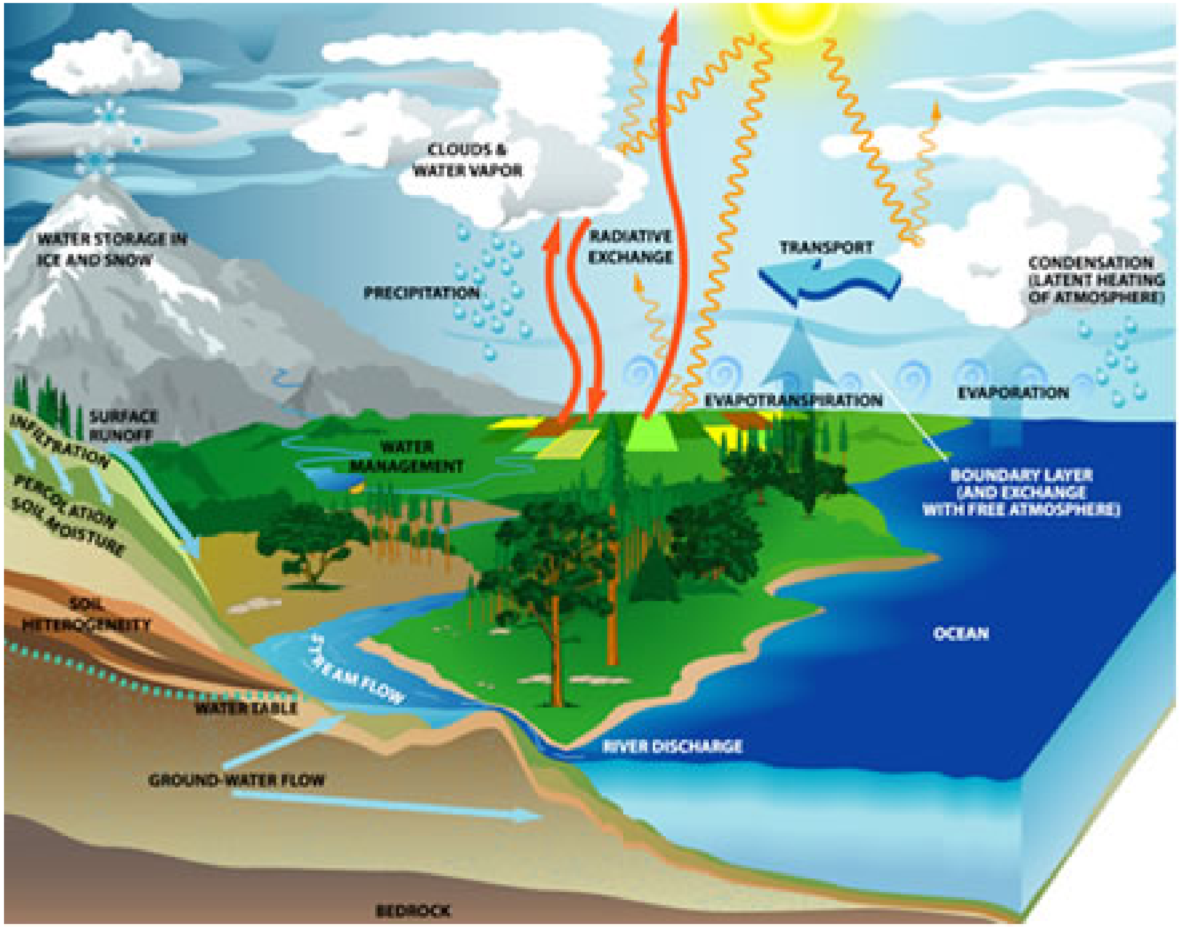




(Li et al., HESS, 2010)

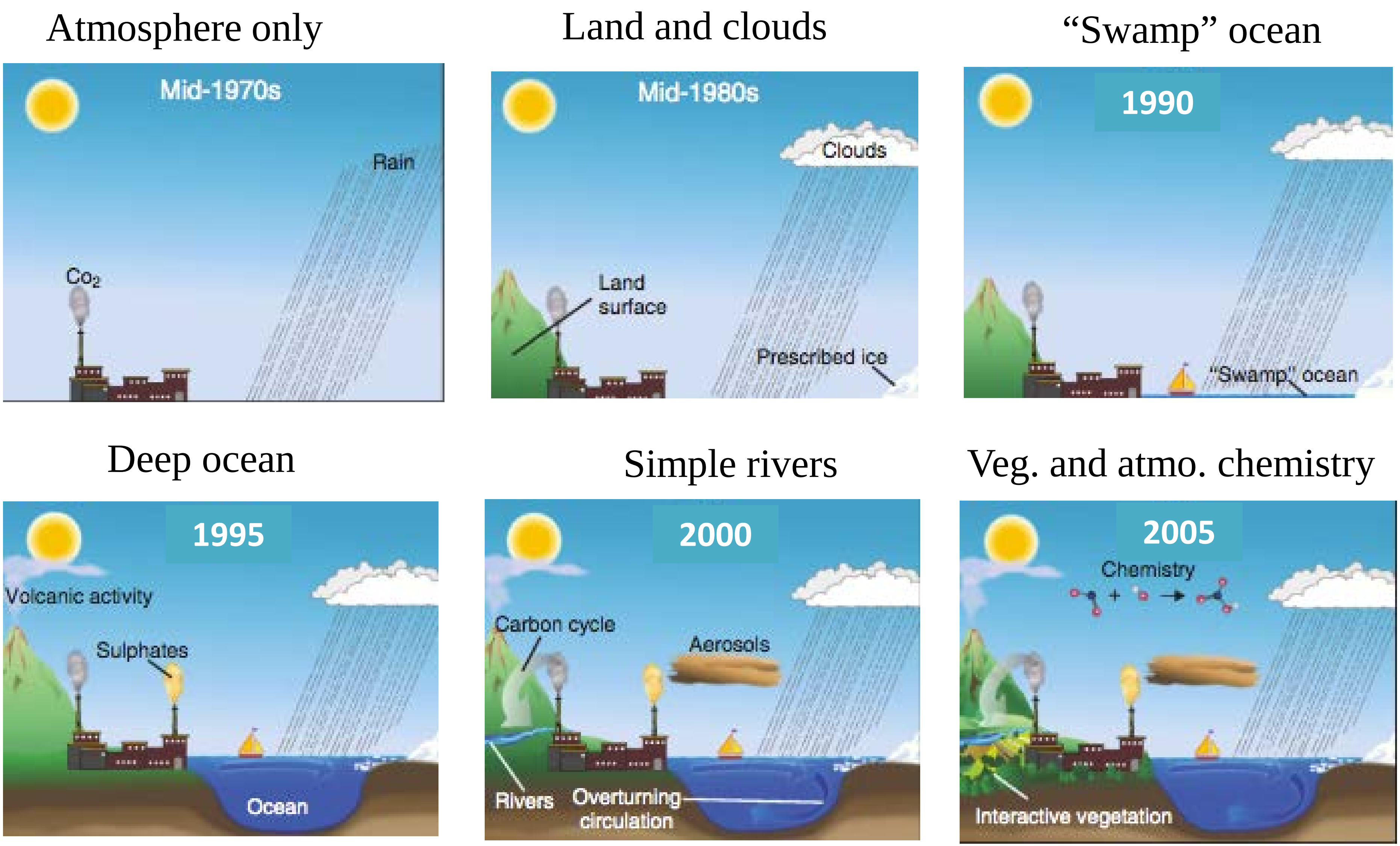
(Li et al., WRR, 2011) *(Li et al., JOH, 2012)*

Moving beyond watersheds
– An Earth-Human system perspective



http://science.nasa.gov

Current Earth system models lack of physical representation of rivers



Processes in generations of GCMs, from P. Edwards, 2011, WIREs Climate Change

Current status of river representation in earth system models

***Typical example**:*

River Transport Model (RTM)

in Community Land Model (CLM, v4.0 and v4.5)

- Oversimplification of important riverine dynamics (e.g., River Transport Model in Community Earth System Model)
  - Lack of sub-grid heterogeneity representation
  - Assuming constant, globally uniform channel velocity
- No representation of human impacts
- No representation of riverine energy and biogeochemistry

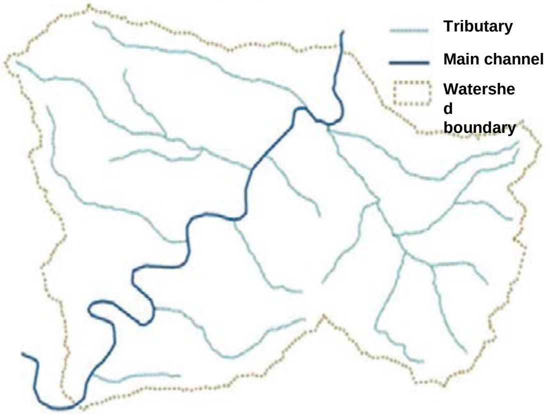
Outline

- **Background**: classic watershed mode
- **Modeling beyond watersheds**
  - Improving riverine dynamics
  - Incorporating human component
  - Using model as a tool to answer questions
- **Future vision**
- **Summary**

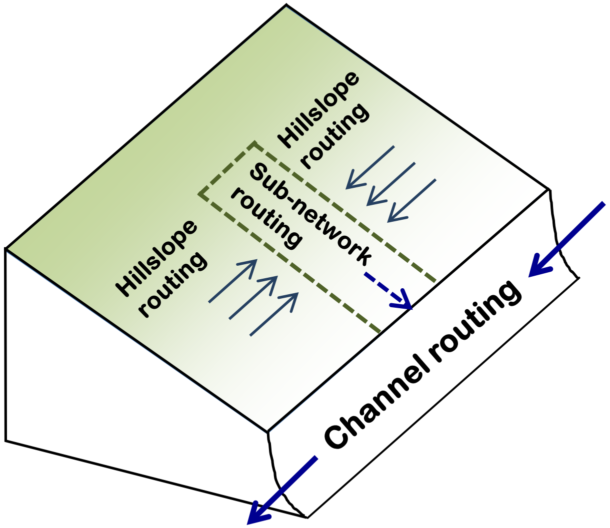
Improving river representation in ESMs to help better understand and predict climate change dynamics

Scale adaptive river transport

Real River Network



Conceptualized River Network

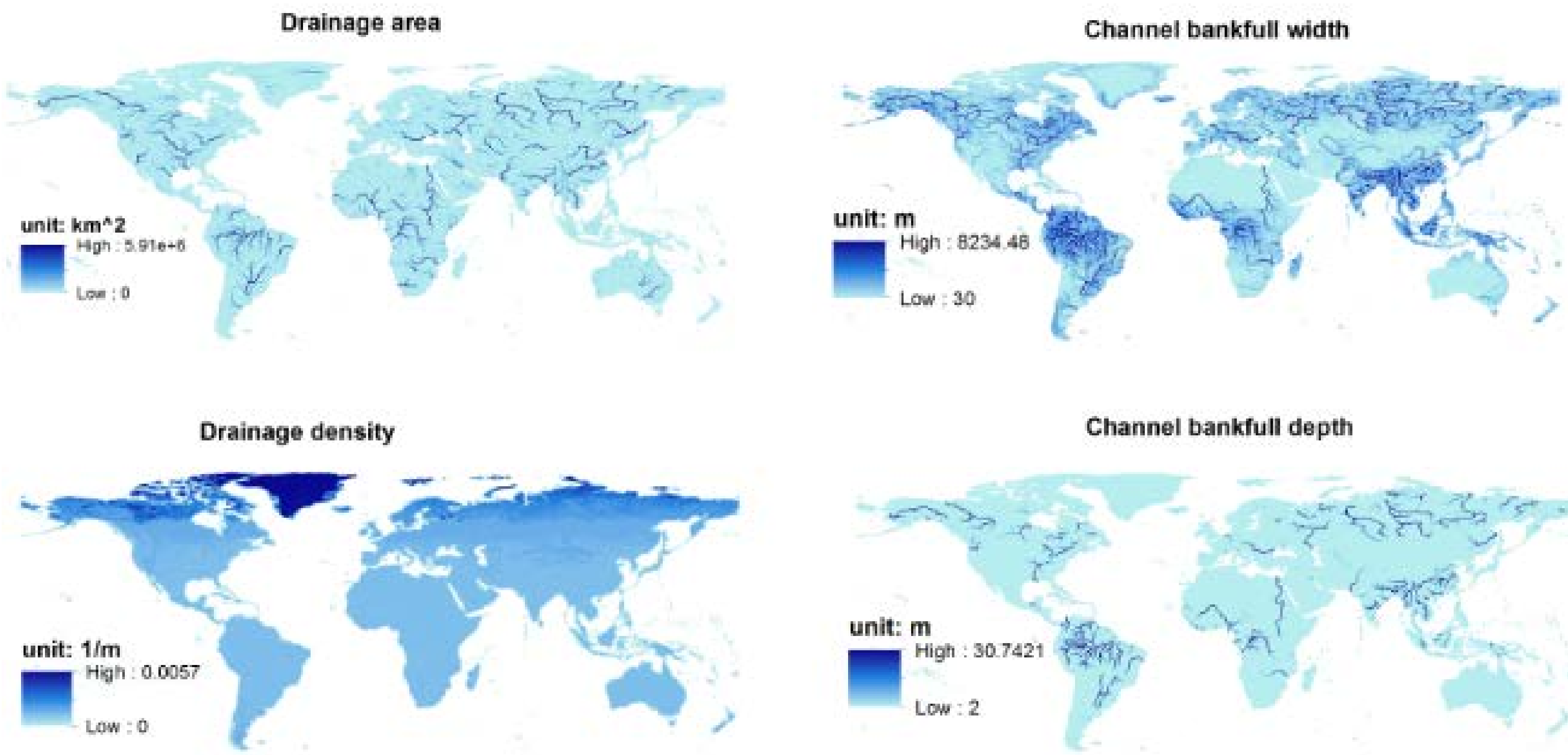


Model for Scale-Adaptive River Transport (MOSART)

- **Hillslope routing:**
  - Account for impacts of overland flow on soil erosion, nutrient loading, etc.
- **Sub-network routing:**
  - Scale adaptive across different resolutions to reduce scale dependence
- **Main channel routing:**
  - Explicit estimation of in-stream conditions (velocity, water depth, etc.)
- **Model streamflow and stream temperature**
  - Being extended to include river biogeochemistry

(Li et al. 2013; 2015 JHM; Li et al. 2016 JAMES)

A comprehensive global hydrography database
To support application of MOSART

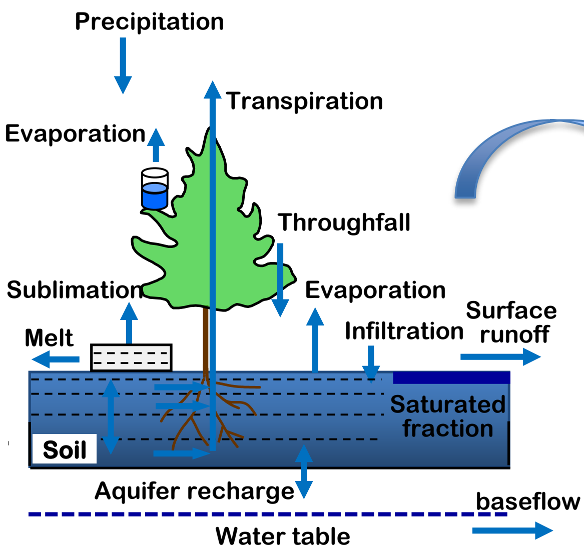


All parameters available at

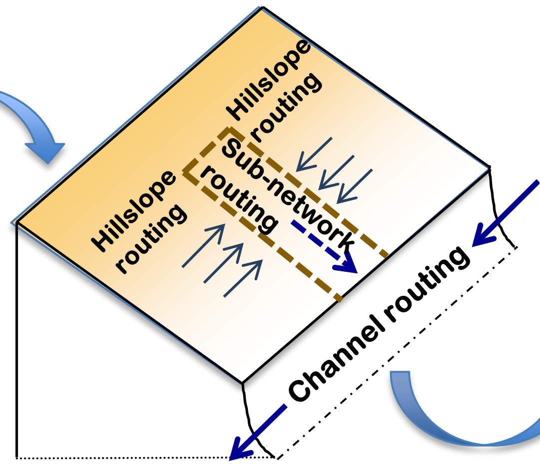
1/16, 1/10, 1/8, ¼, ½, 1 and 2 degree resolutions

Coupling MOSART to Community Land Model

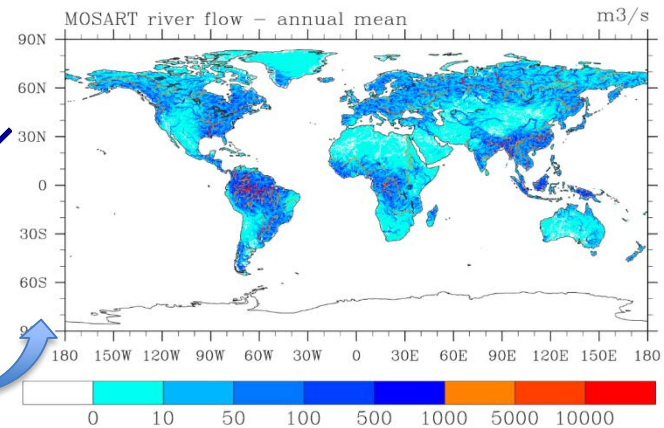
CLM Hydrology



MOSART

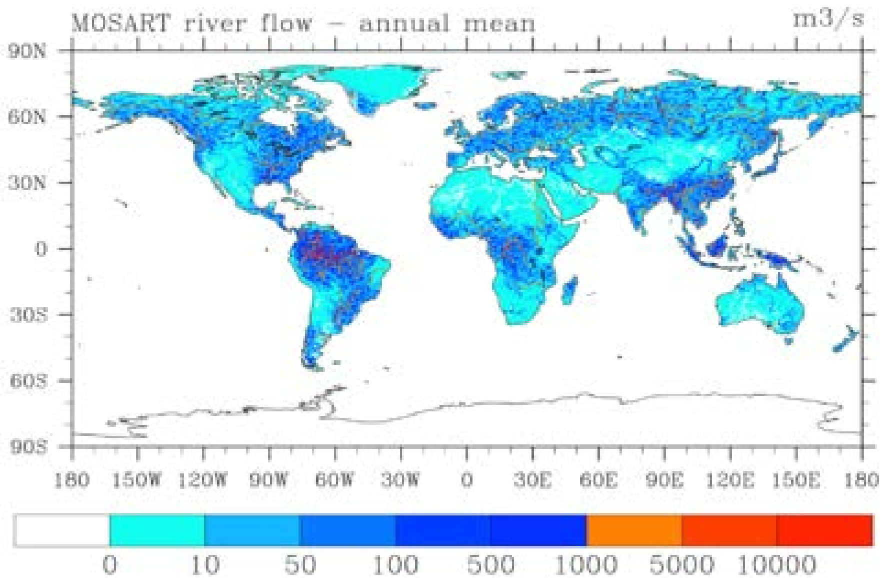


Coupled CLM-MOSART Simulation

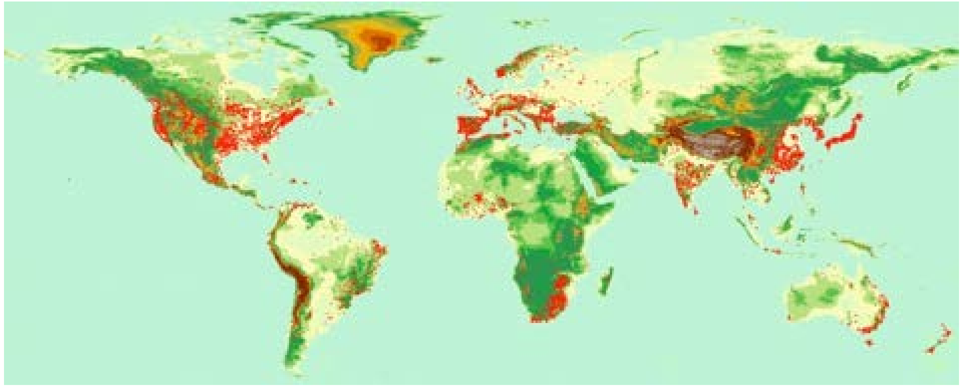


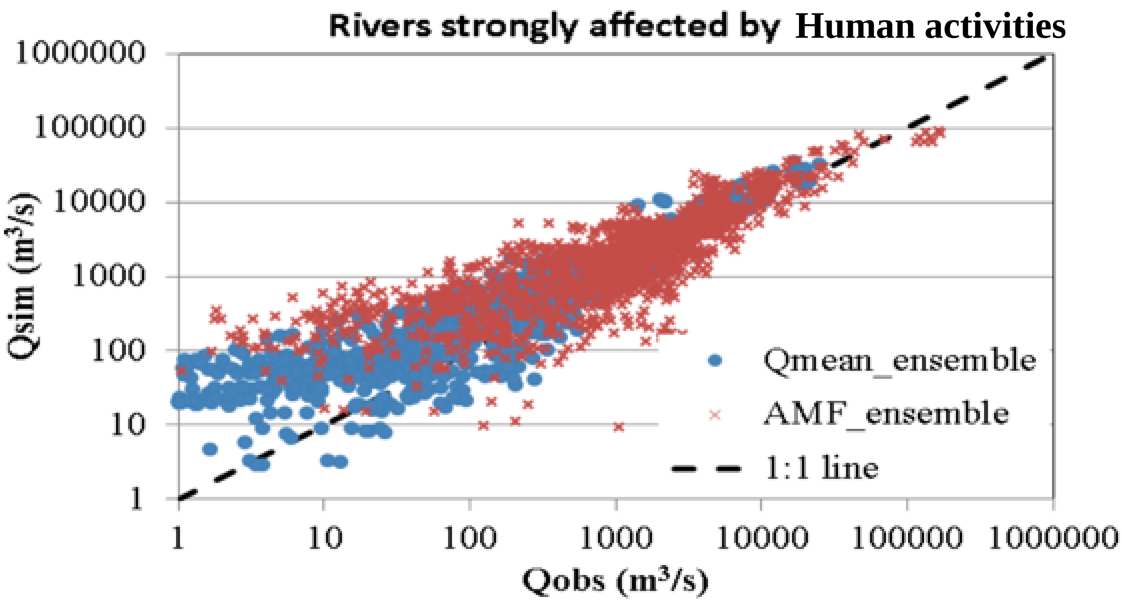
(Li et al., JHM, 2015)

Large human influence on streamflow

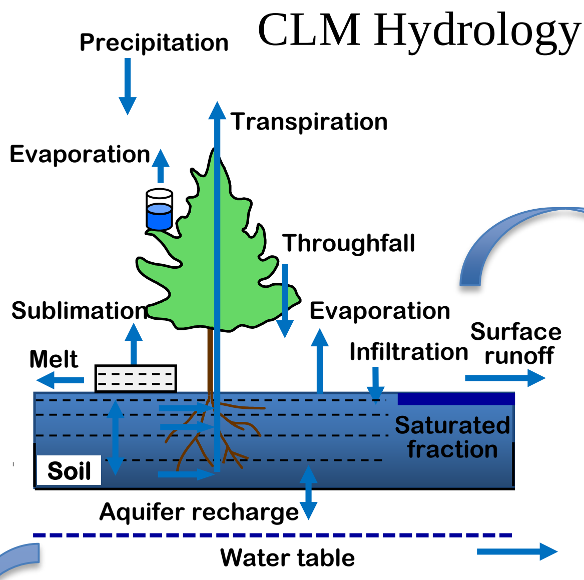


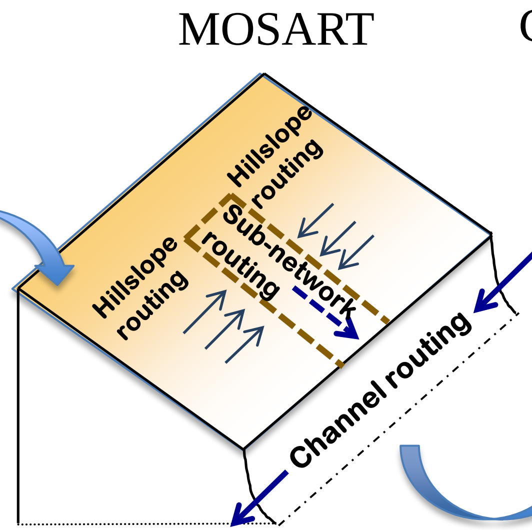
Global distribution of dams

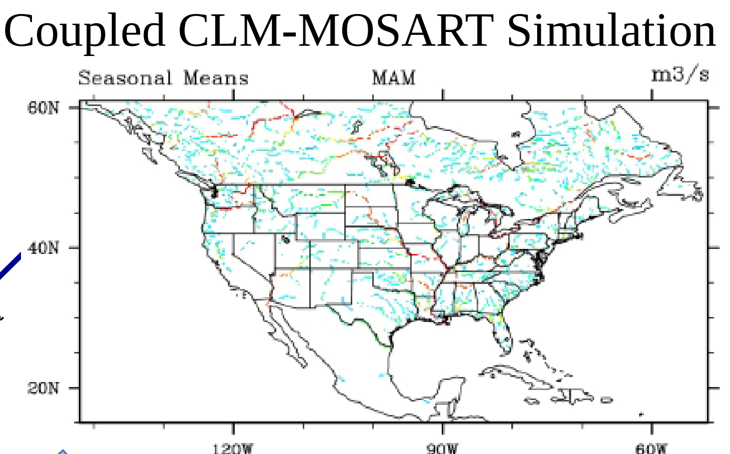




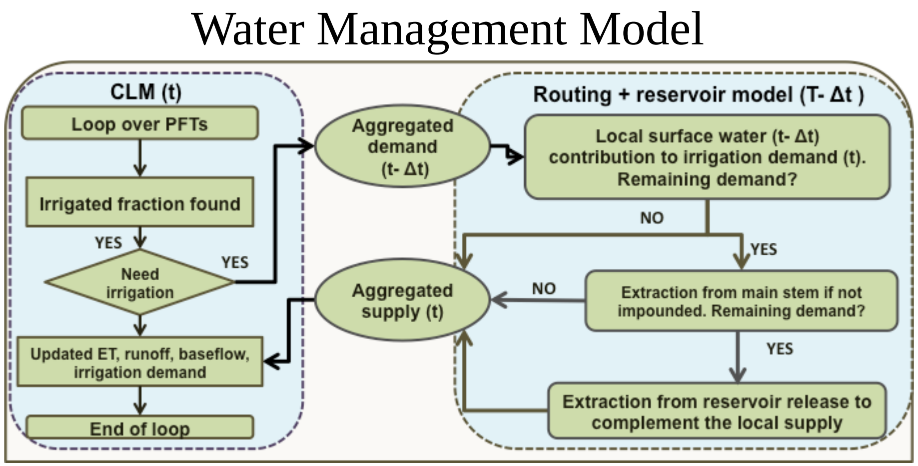
Adding human component to river modeling
-- An Earth-Human modeling framework







Irrigation water demand



Reservoir operations

(Voisin et al., HESS, 2013; Li et al., JAMES, 2015)

Two characteristics of water management

Local water extraction:
reduce flow year round

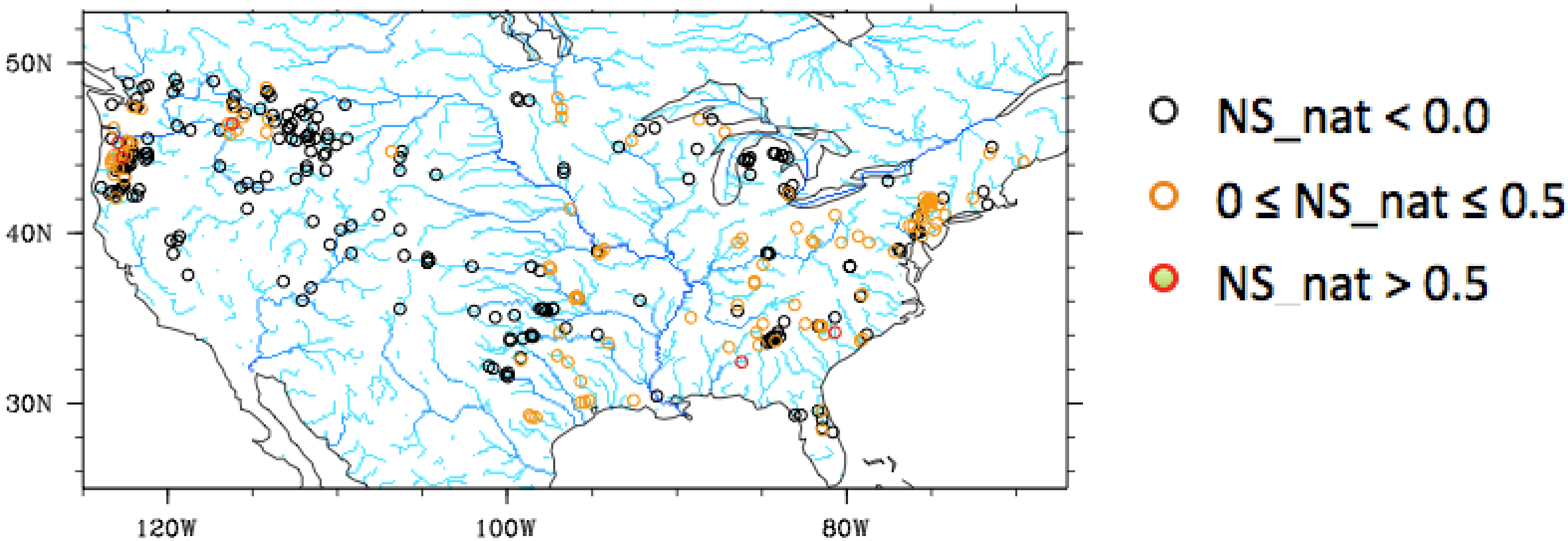
Reservoir operations:
enhance summer low flow

Modeling water management in the US rivers

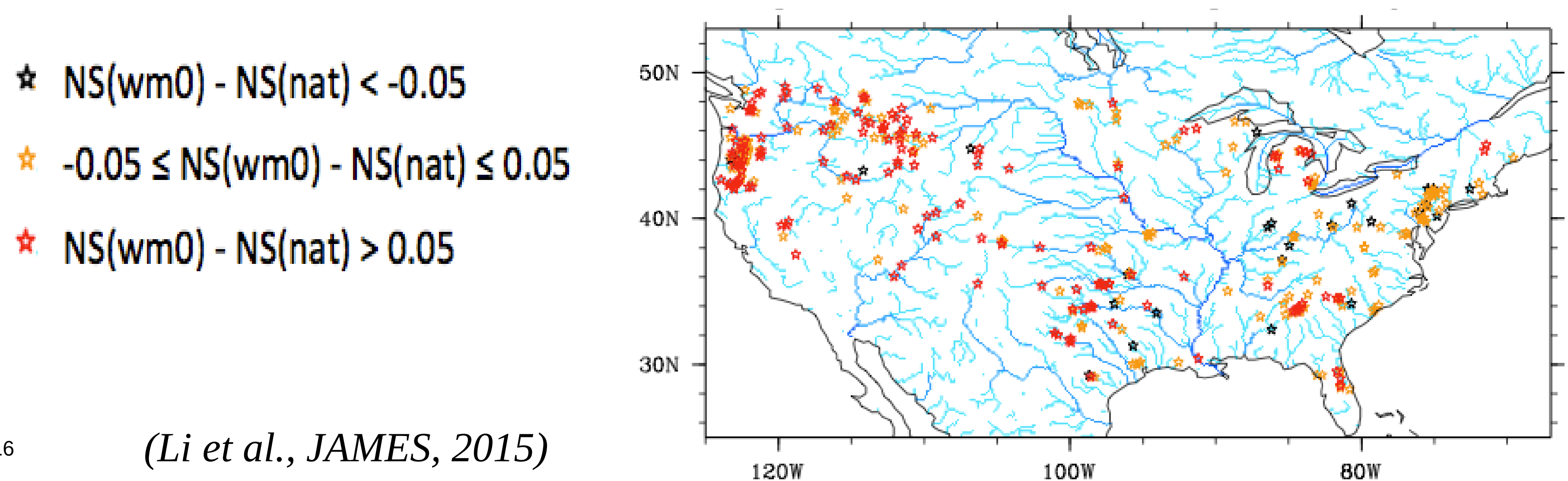
- A total of 1839 reservoirs in the US are represented

Adding water management leads to improved streamflow simulation

NS coeff. w/o WM

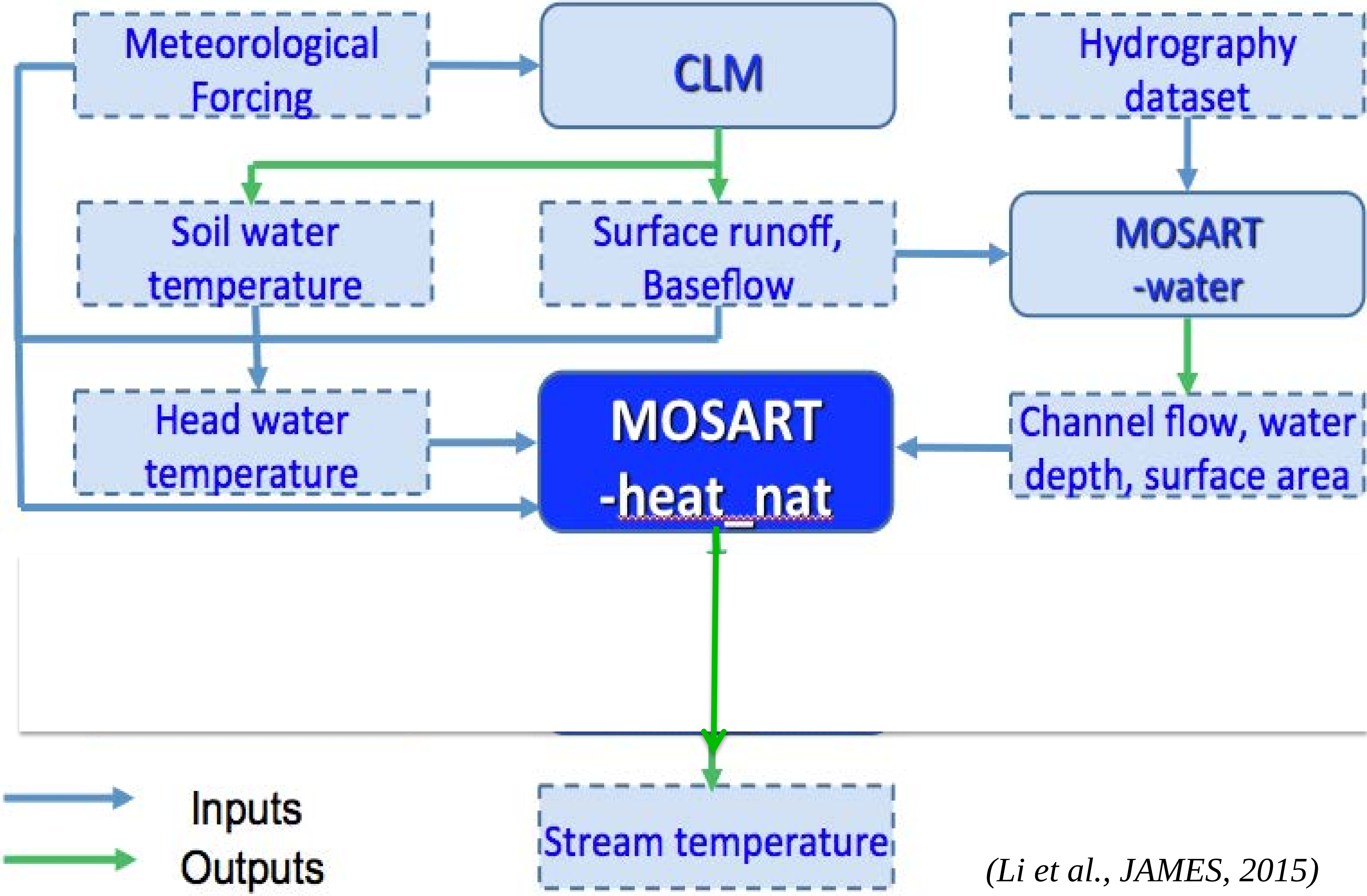


Change of NS coeff. After including WM module



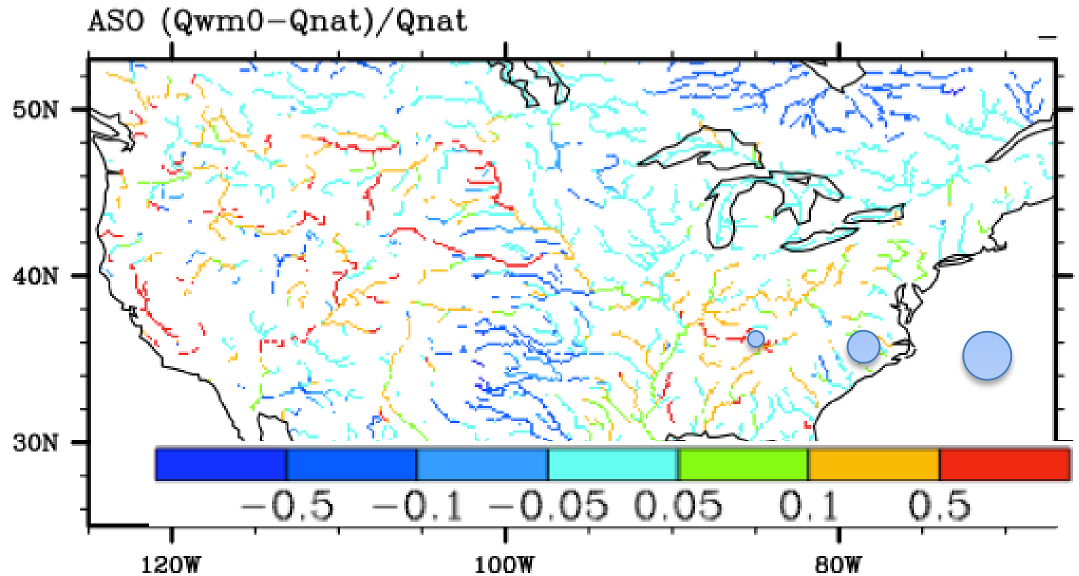
(Li et al., JAMES, 2015)

Riverine transform & transport of energy
– An Earth-Human modeling framework



(Li et al., JAMES, 2015)

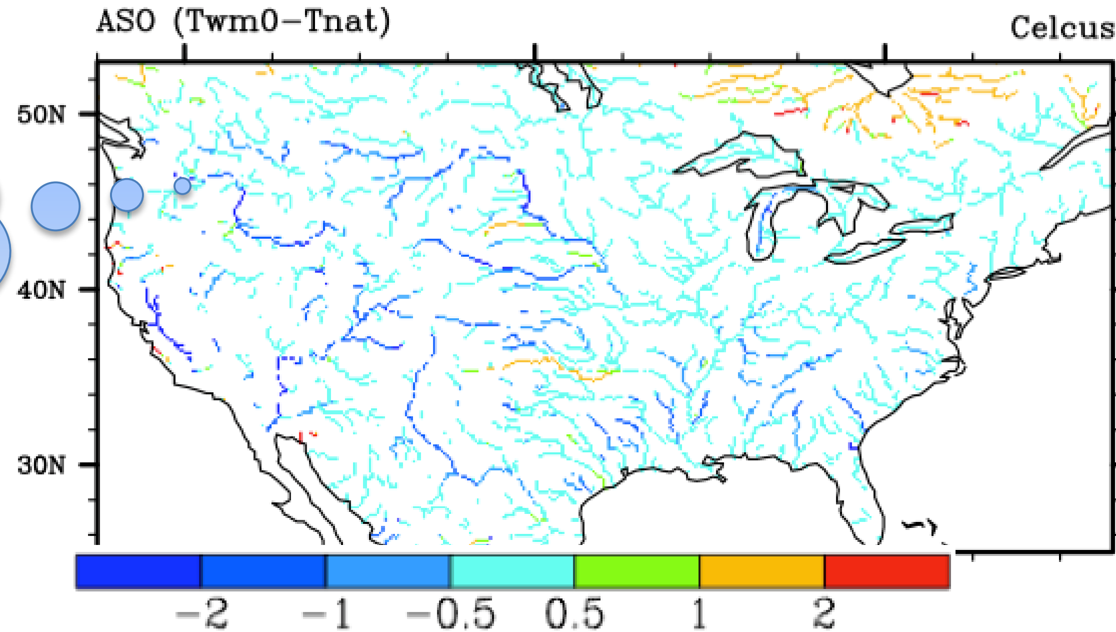
Riverine transform & transport of energy
-- Effects of reservoir regulation in large rivers



Aug., Sept. and Oct. (ASO) as a low flow season with high temperature

Increasing of flow by dam regulation

Decreasing of water temp.

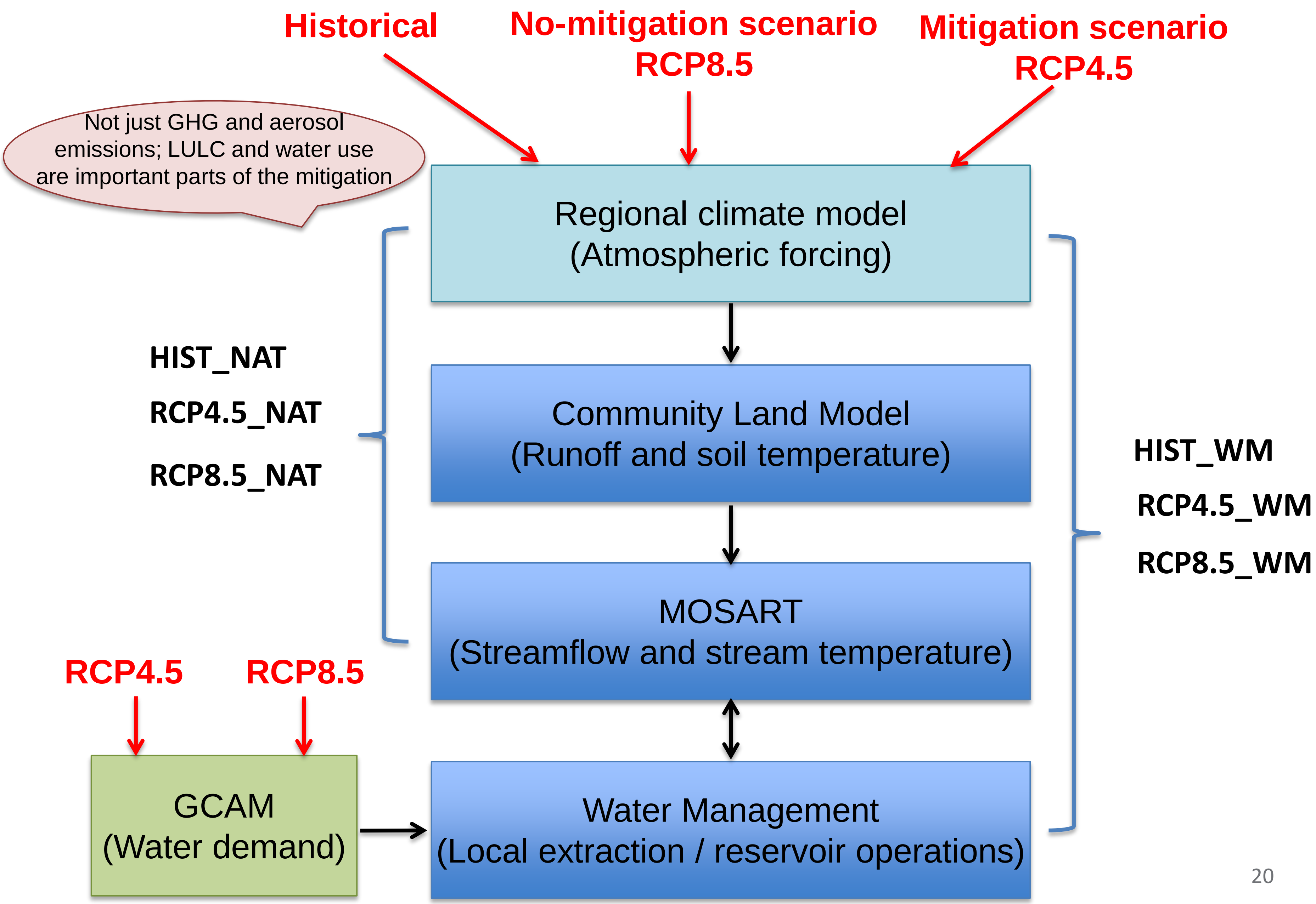


(Li et al., JAMES, 2015)

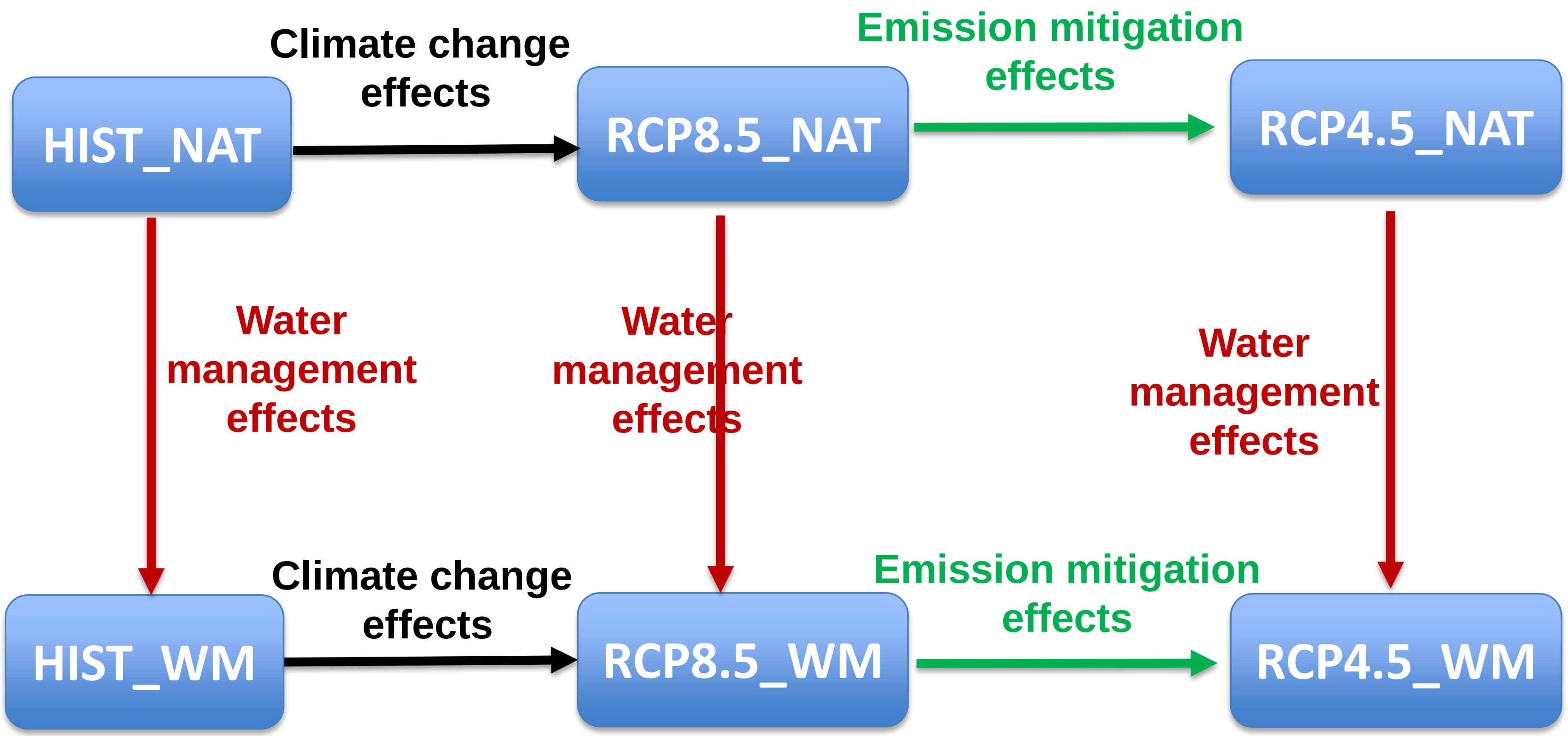
Science questions

- How does climate change influence water, energy, and their connections?
- How does human intervention (mitigation, adaptation, and management) alter climate change impacts?
- What are the regional characteristics of the above impacts and their drivers?

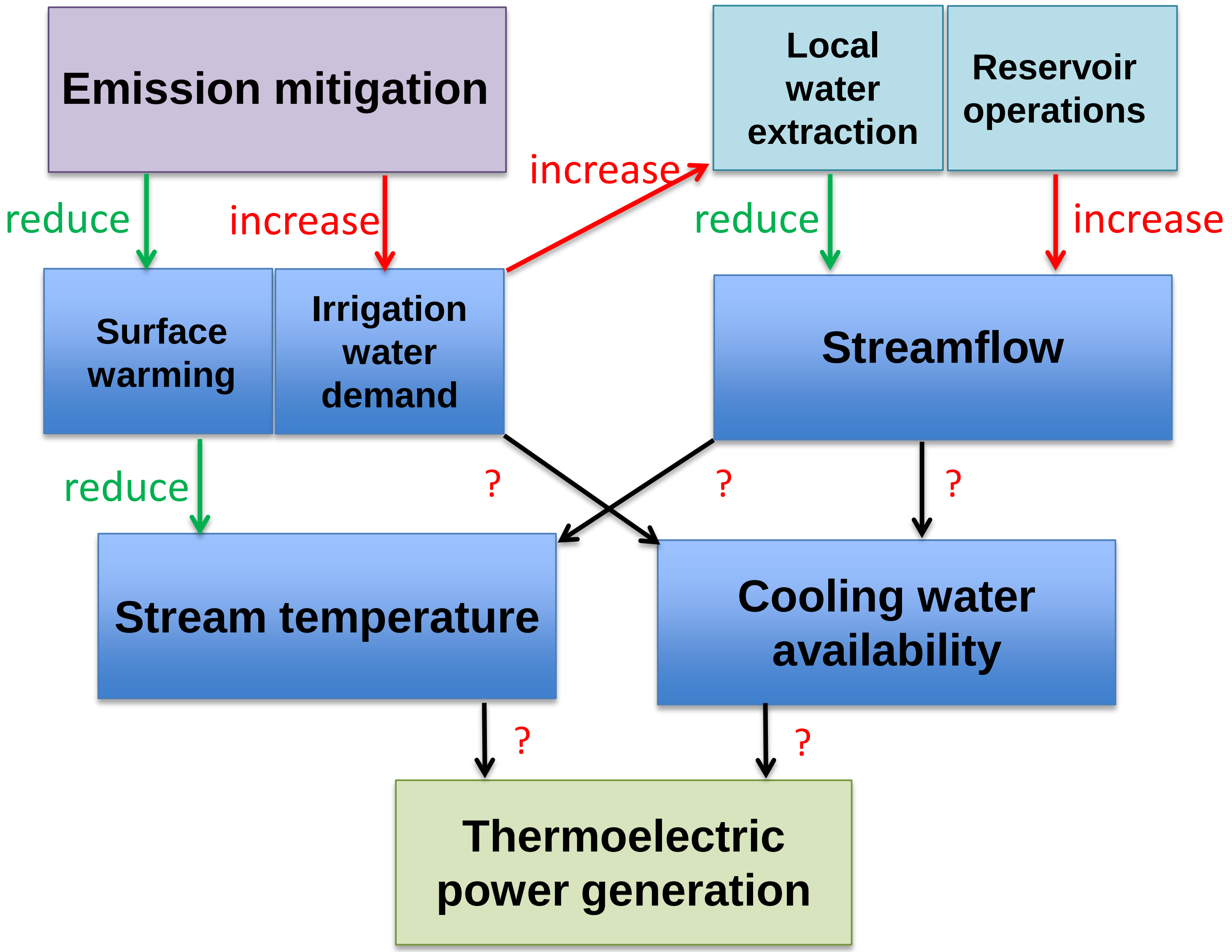
Numerical experiments



Effects of climate change & mitigation

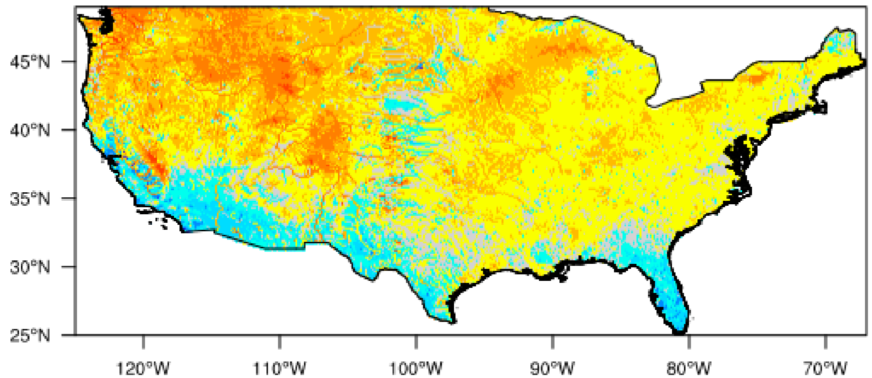


Climate change impacts: emission mitigation vs. water management

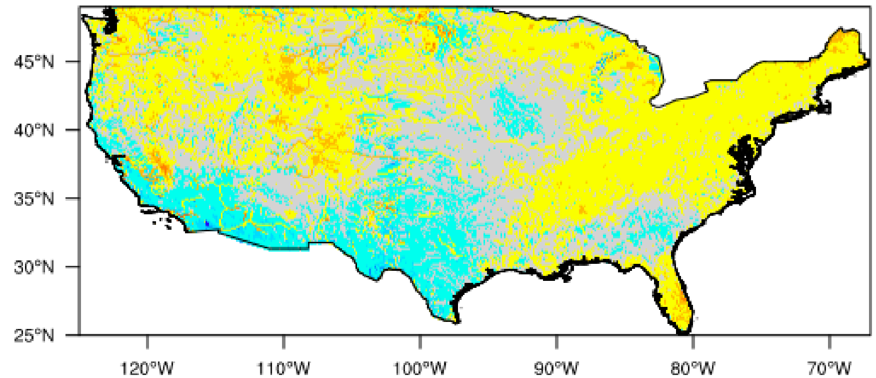


Changes in stream temperature

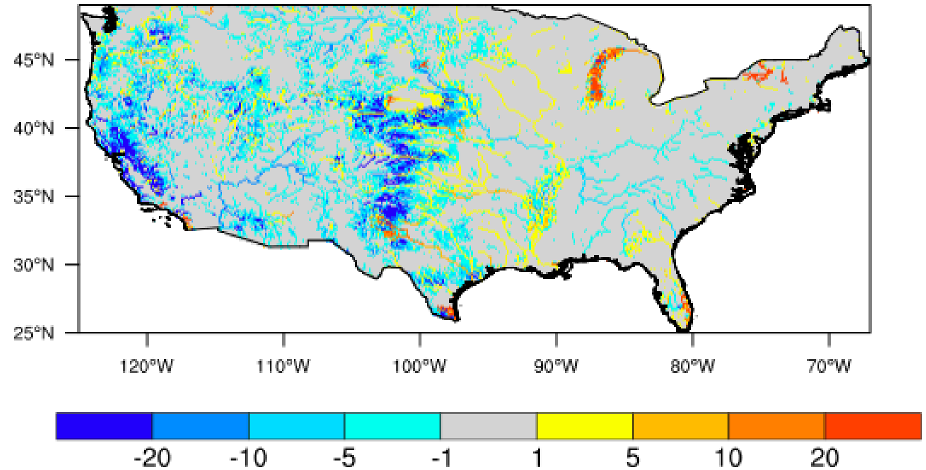
Climate change effects (future minus historical)



Emission mitigation effects (RCP8.5 minus RCP4.5)



Water management effects (with_WM minus without_WM)

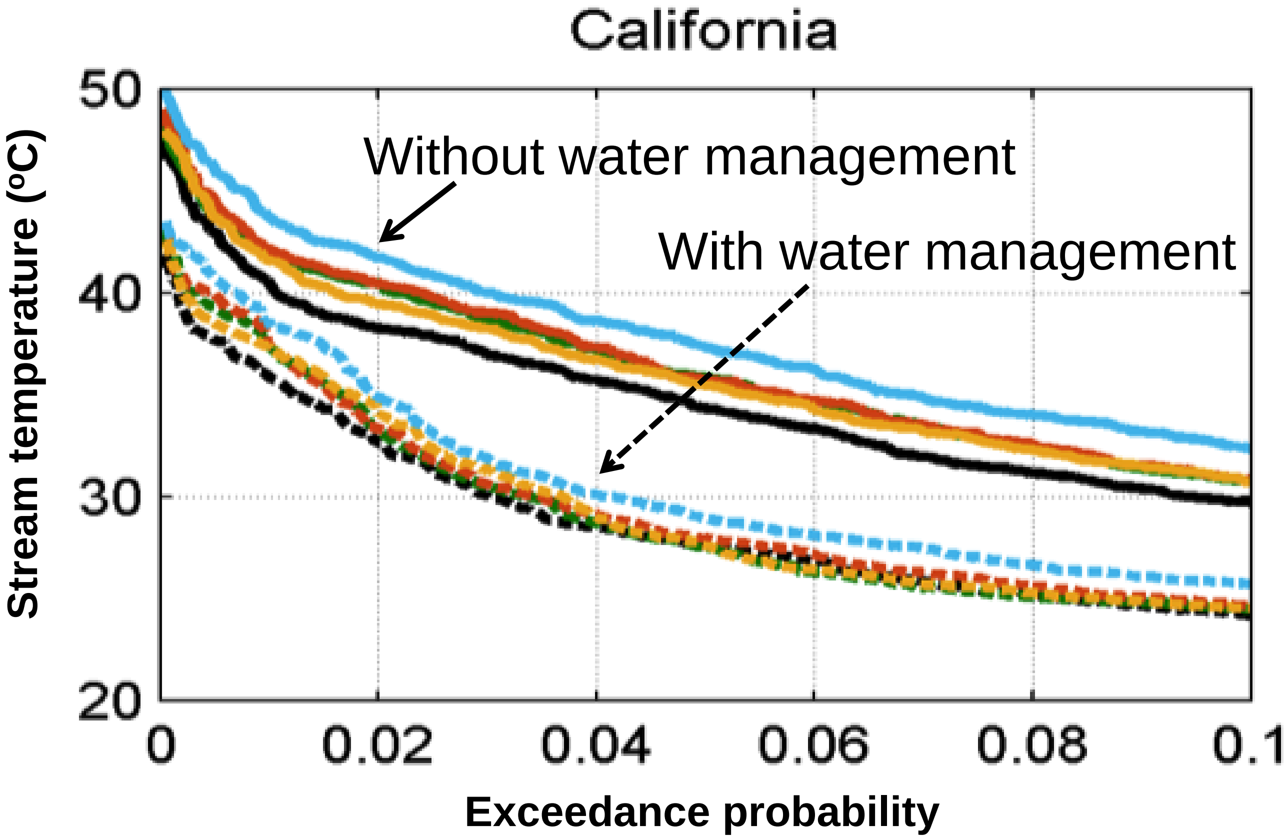


% change in seasonal amplitude

Likelihood of extreme high stream temperature

- Water management substantially reduces the likelihood of extreme high stream temperature in western river basins by enhancing summer low flows

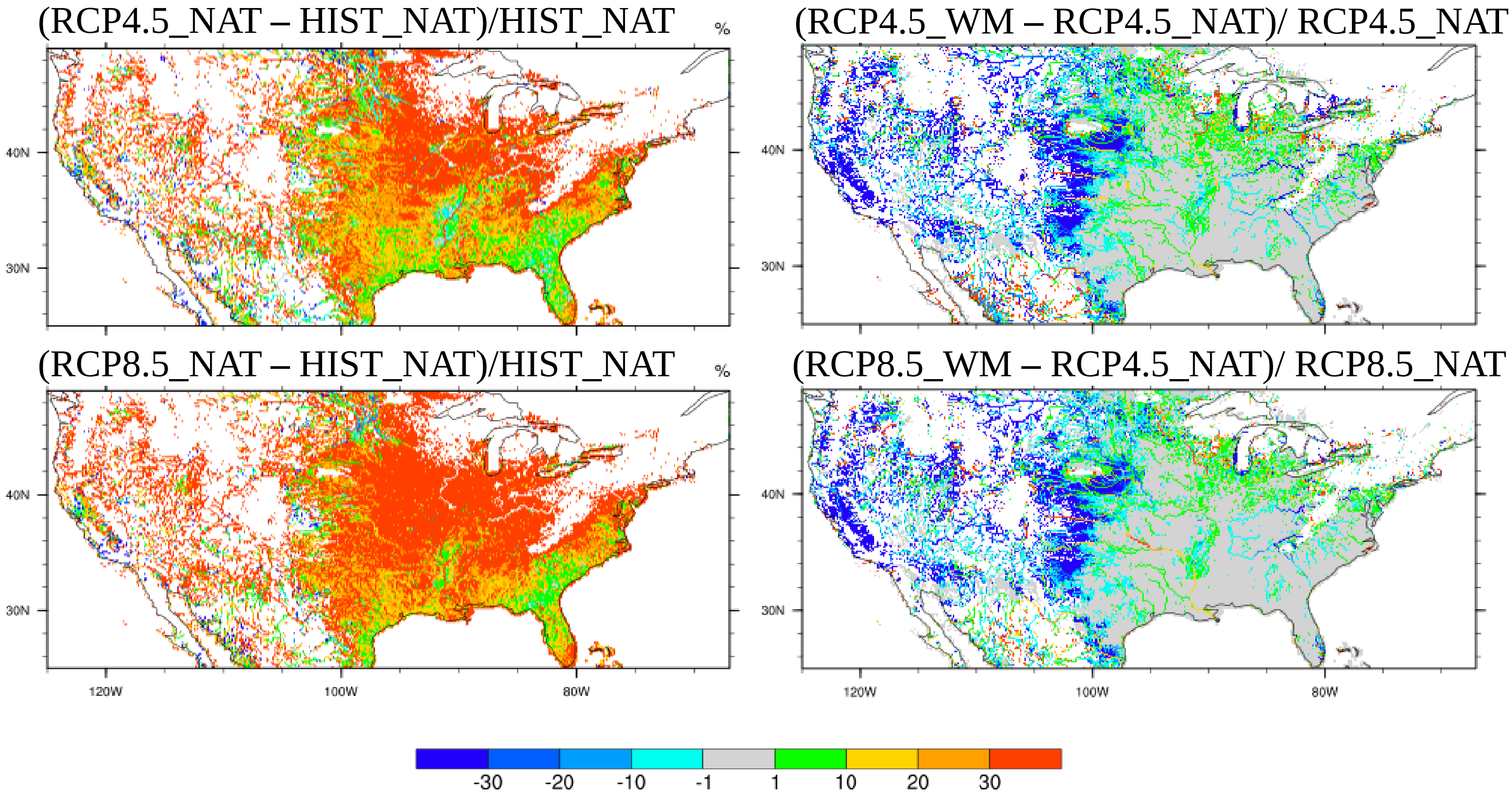
Exceedance Probability of high stream temperature



Frequency changes for stream temperature > 27ºC

Water management reduces exceedance frequency

Emission mitigation reduces exceedance frequency



% change in number of hours with stream temperature > 27ºC

Impacts of stream temperature on thermoelectric power production

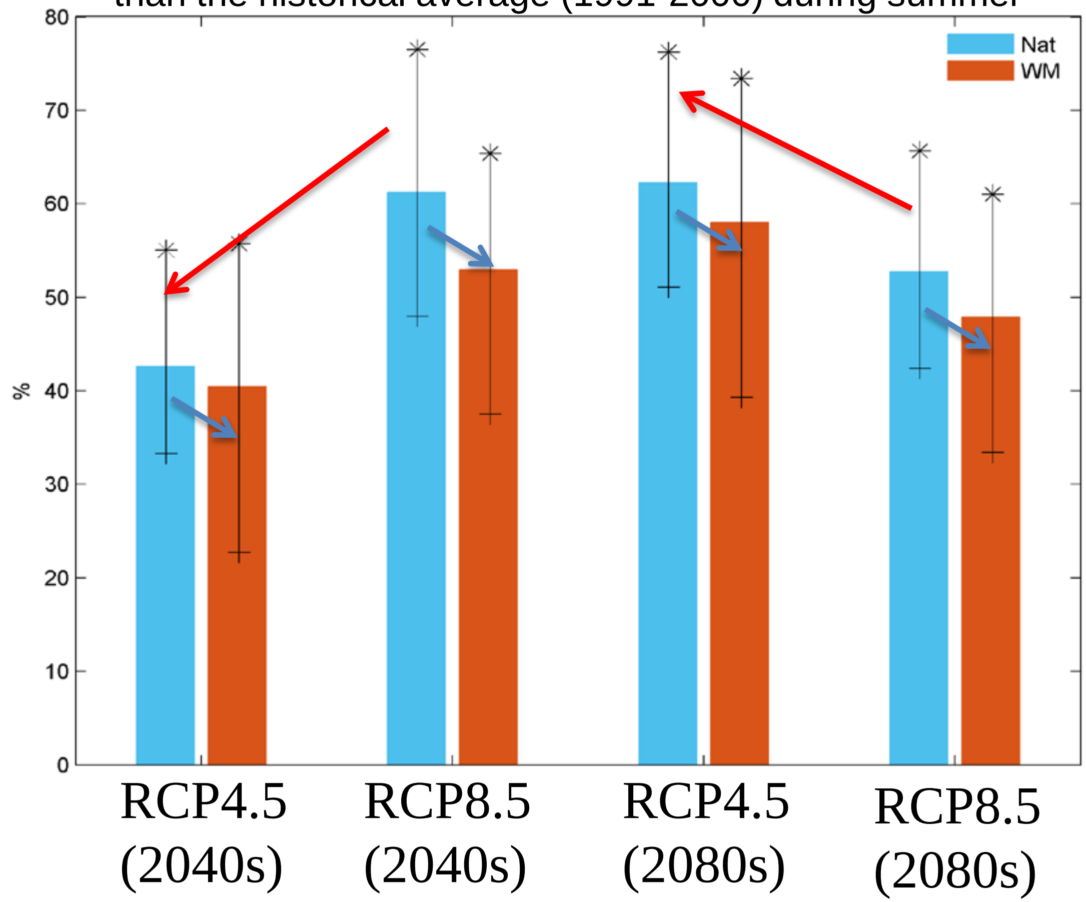
- Estimated based on 177 once-through power plants, which account for about 76% of once-through thermoelectric power plants in the US
- Both emission mitigation and water management reduce power loss from climate change at similar level

Loss (%)	RCP4.5_NAT	RCP8.5_NAT	RCP4.5_WM	RCP8.5_WM
2040s	10.6	11.1	10.0	10.5
2080s	14.0	15.1	13.3	14.4

Impacts of cooling water availability on thermoelectric power production

- There is no consistent difference in cooling water availability between RCP4.5 and RCP8.5 due to large inter-decadal variability in precipitation
- Water management consistently alleviates the duration of low water availability by 5%-14%

Percentage of time when projected inflows (2040s and 2080s) are lower than the historical average (1991-2000) during summer



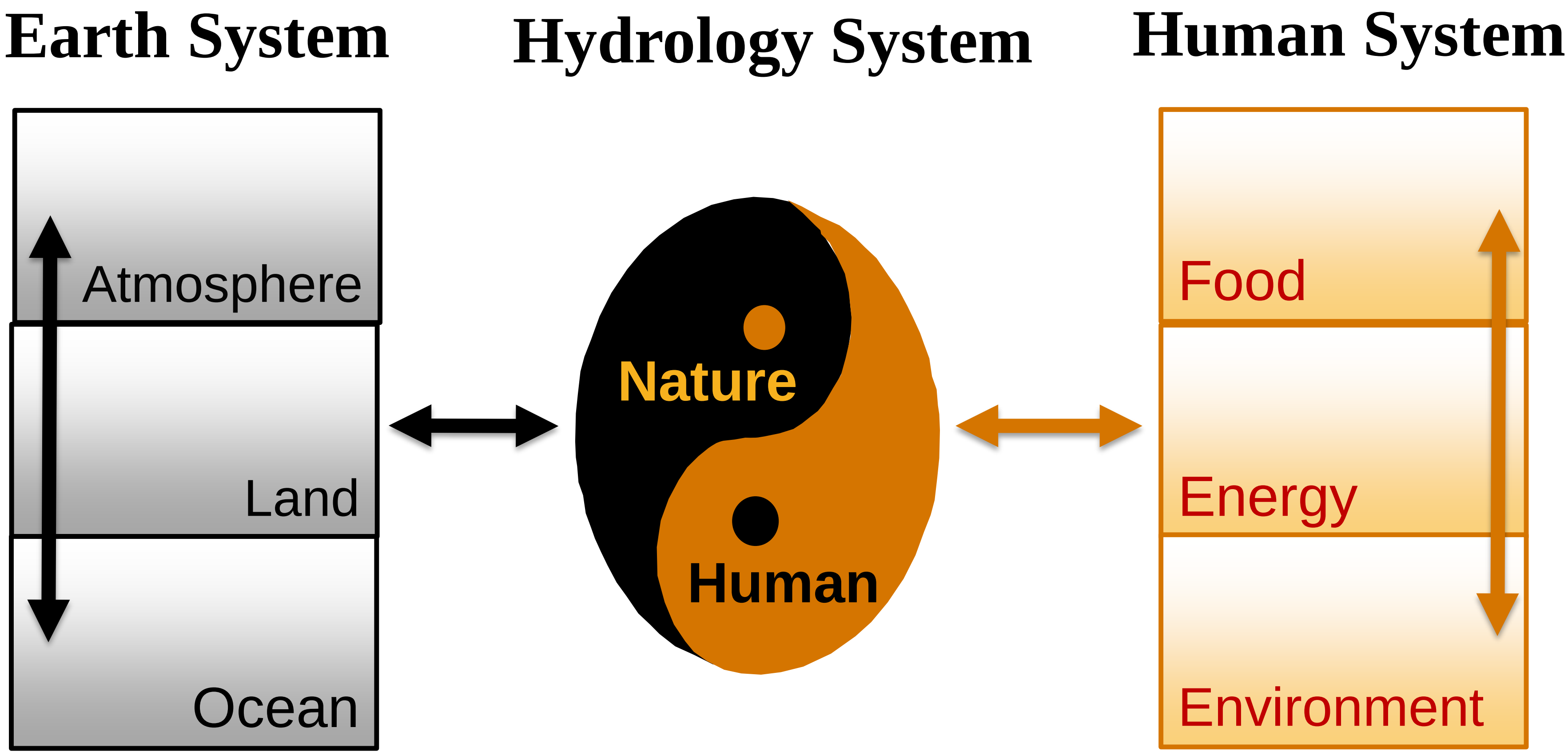
Answers to science questions

- *How does climate change influence water, energy, and their connections?*
  - Warming increases stream temperature – reduces thermoelectric power generation
  - Warming has variable effects on regional precipitation and cooling water availability
- *How does human intervention (mitigation, adaptation, and management) alter climate change impacts?*
  - Emission mitigation reduces warming, but its impacts on regional water availability are variable
  - Water management consistently alleviates high stream temperature and reduces thermoelectric power generation loss
- *What are the regional characteristics of the above impacts and their drivers?*
  - Regional drivers: local water extraction, reservoir regulations, and water demand
  - Impacts of different scenarios must account for LULC and water use

Outline

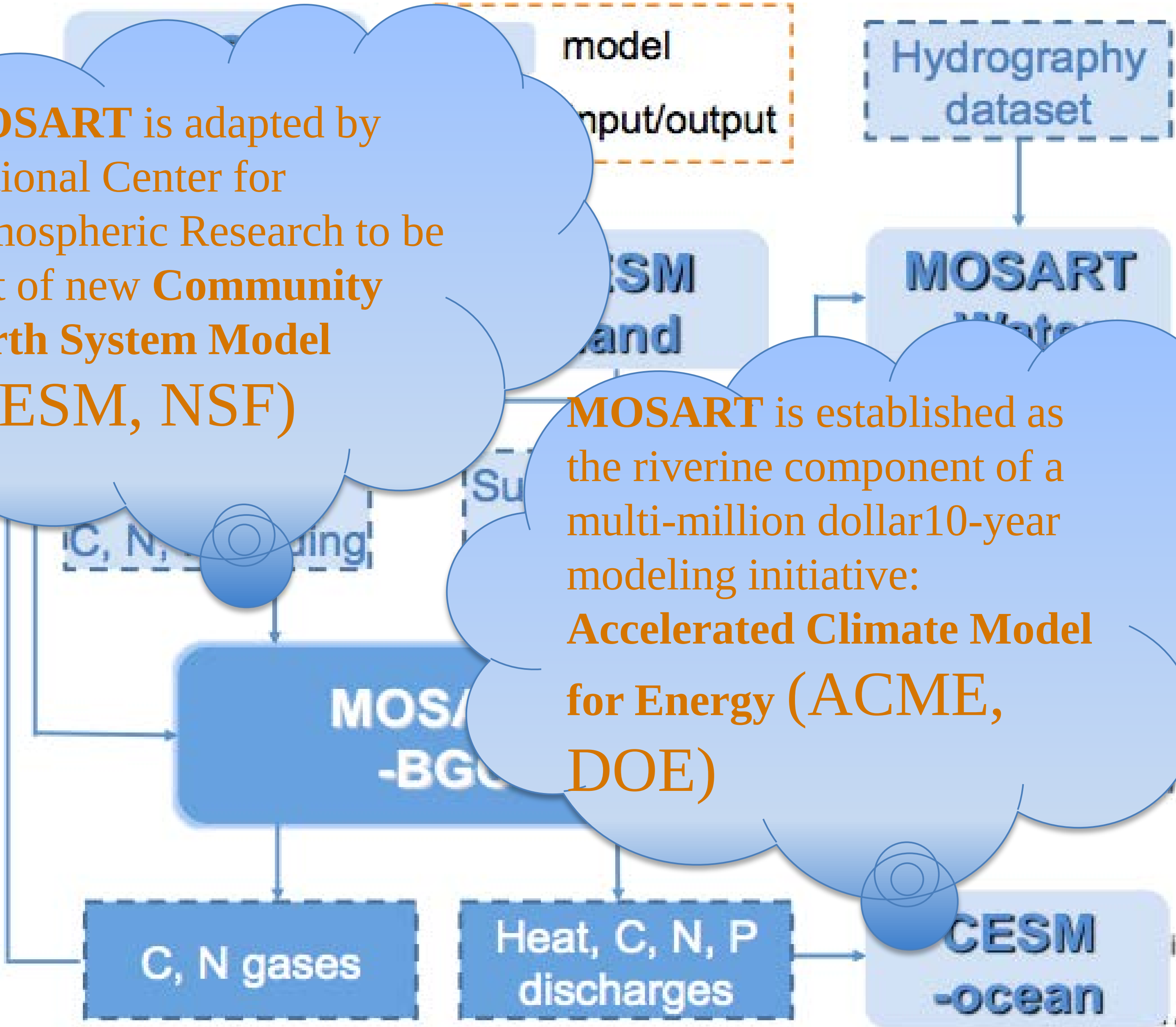
- Background: Classic watershed modeling
- Modeling beyond watersheds
- Future research
- Summary

Future research
– overarching goal



Understand and predict multiscale nonlinear system behaviors of water-food-energy-environment nexus and their feedbacks to climate change dynamics

Future research



MOSART is adapted by National Center for Atmospheric Research to be part of new **Community Earth System Model** (CESM, NSF)

MOSART is established as the riverine component of a multi-million dollar10-year modeling initiative: **Accelerated Climate Model for Energy** (ACME, DOE)

Future research

Wenhua Wan

Visiting student from Tsinghua University, China

Working on hydrological drought under climate change and human interventions

Future research

Yuan (Navy) Zhuang

Visiting student from Tsinghua University, China

Working on global streamflow and temperature simulations under future climate, socio-economic and technologic scenarios

Future research

Wondmagegn (Wondie) Yigzaw

Ph.D., Tennessee Tech University

Working on reservoir stratification module within MOSART

Future research

Man Gao

Visiting student from Hohai University, China

Working on meta-analysis of macro-pore flow

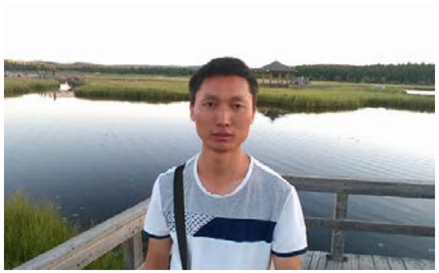
Future research

Dengfeng Liu

Ph.D., Tsinghua University

Working on modeling and data analysis of macro-pore flow

Summary



Watershed scale

Nature

Earth

Human

Human

Small scale

Regional scale or larger

Watershed hydrology beyond "watersheds"

Watershed boundaries adapted in CESM

Geosci. Model Dev., 7, 947–963, 2014
www.geosci-model-dev.net/7/947/2014/
doi:10.5194/gmd-7-947-2014

Geoscientific Model Development
Open Access

A subbasin-based framework to represent land surface processes in an Earth system model

T. K. Tesfa[1], H.-Y. Li[1], L. R. Leung[1], M. Huang[1], Y. Ke[2], Y. Sun[3], and Y. Liu[1]

Grid-based representation (CLM) Subbasin-based representation (DCLM)