Water: Macro-scale process-based modeling of water

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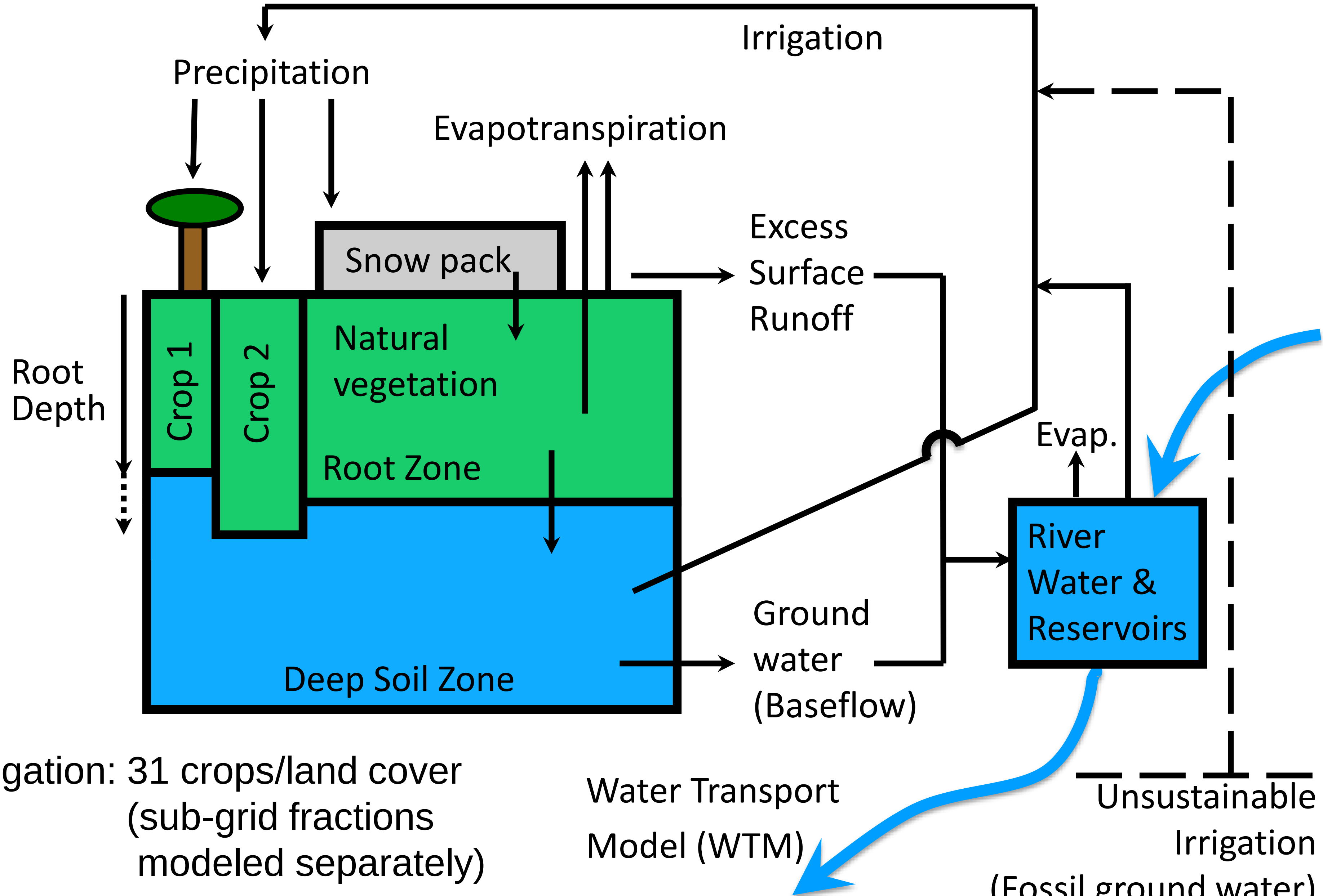
OUTLINE

1. Framework & methods
2. Context & questions
3. Some Outcomes
4. Relevance to IAMs

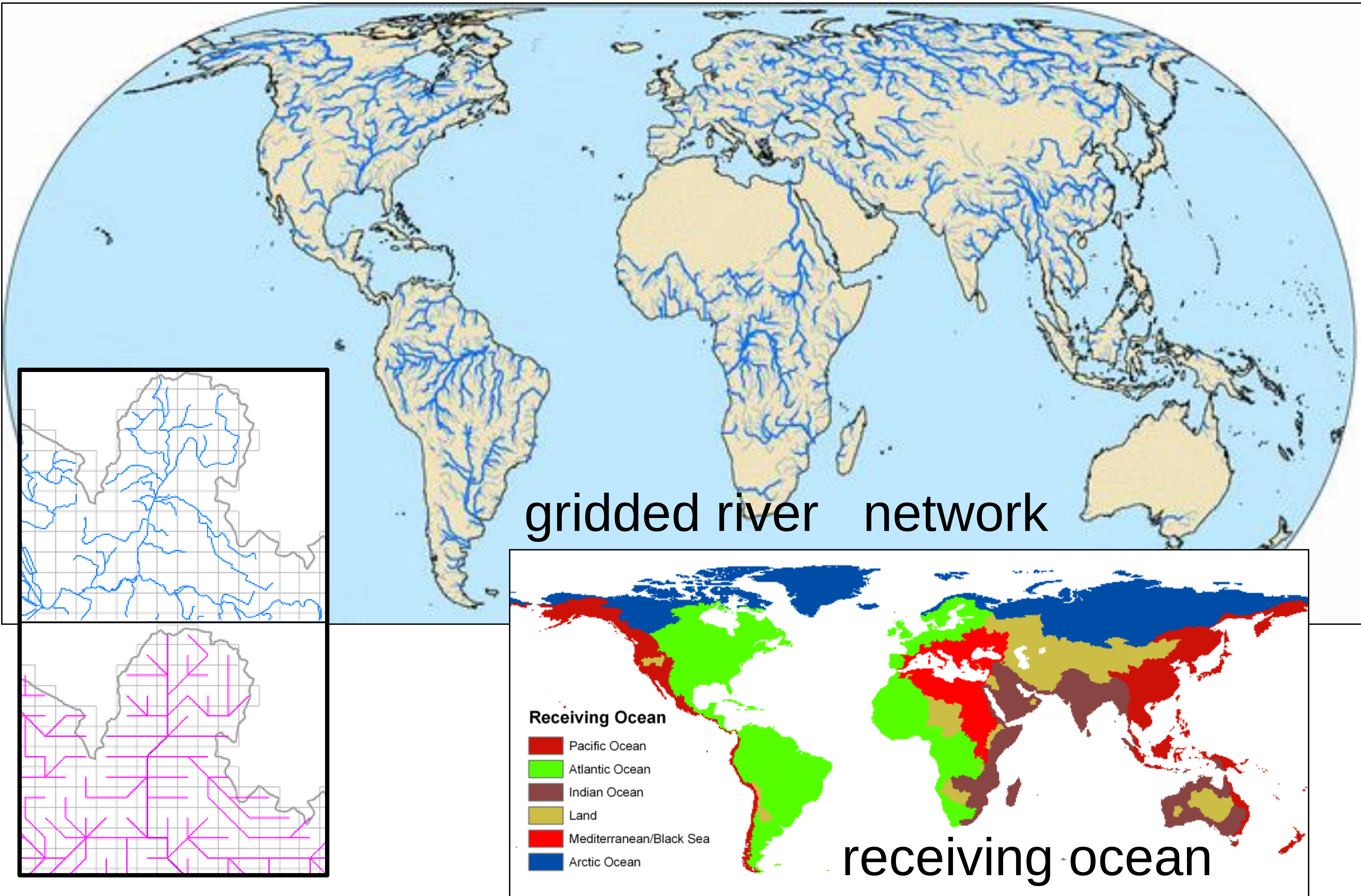
1. Framework & methods

(UNH) Water Balance Model Structure - Single Grid Cell



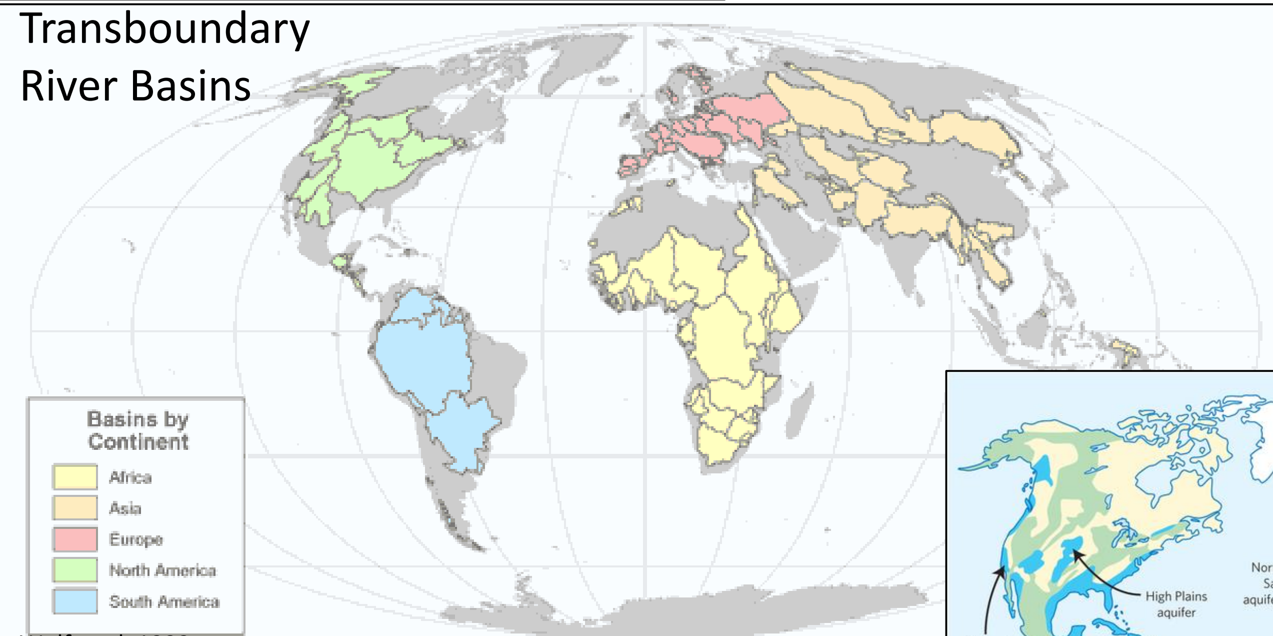
Irrigation: 31 crops/land cover
(sub-grid fractions
modeled separately)

Horizontal Water Transport



1. Framework & methods

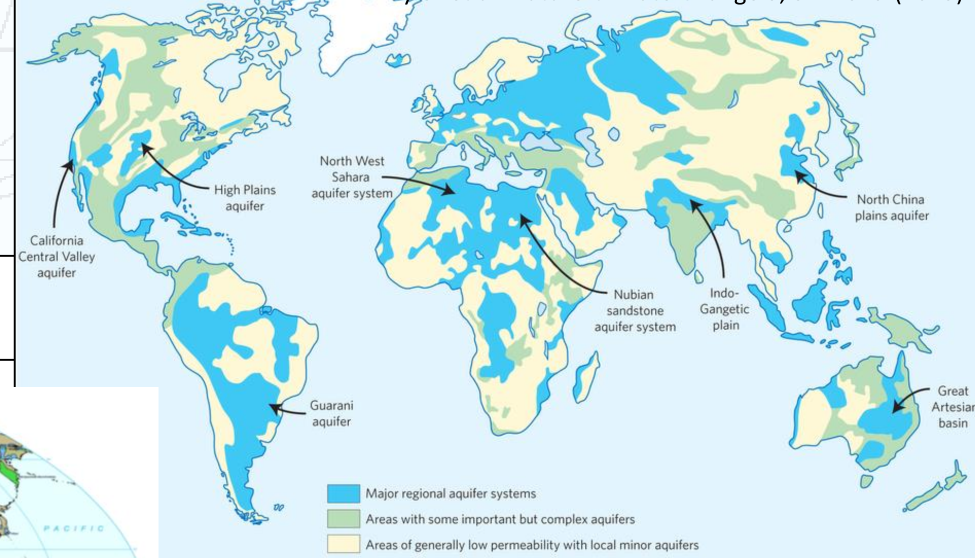
Transboundary
River Basins

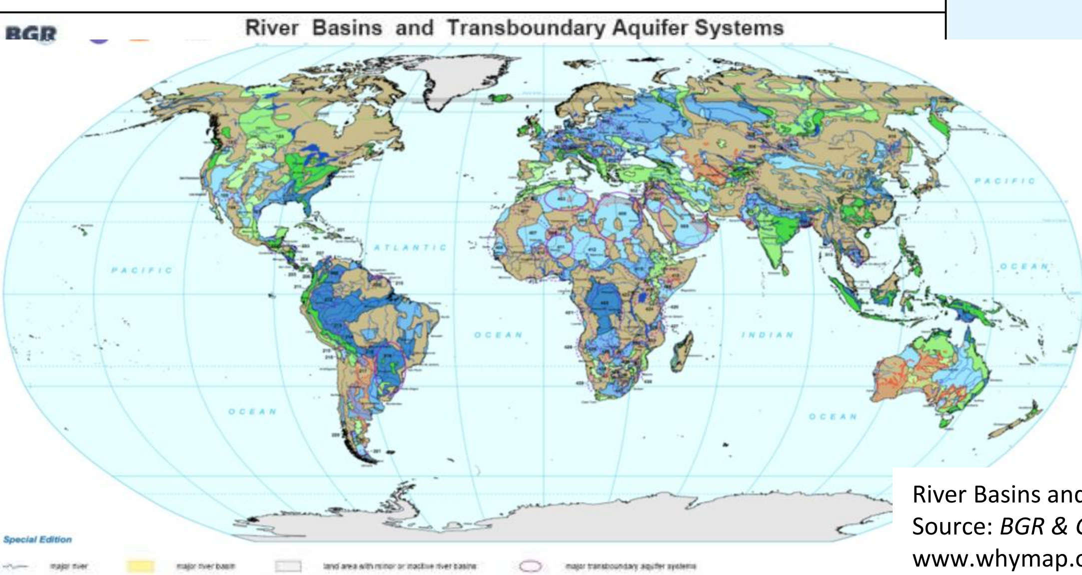


Wolf et al. 1999
transboundarywaters.orst.edu/publications/atlas/atlas_html/interagree.html

Global Aquifers
(simplified)

Taylor et al. Nature Climate Change 3, 322–329 (2013)

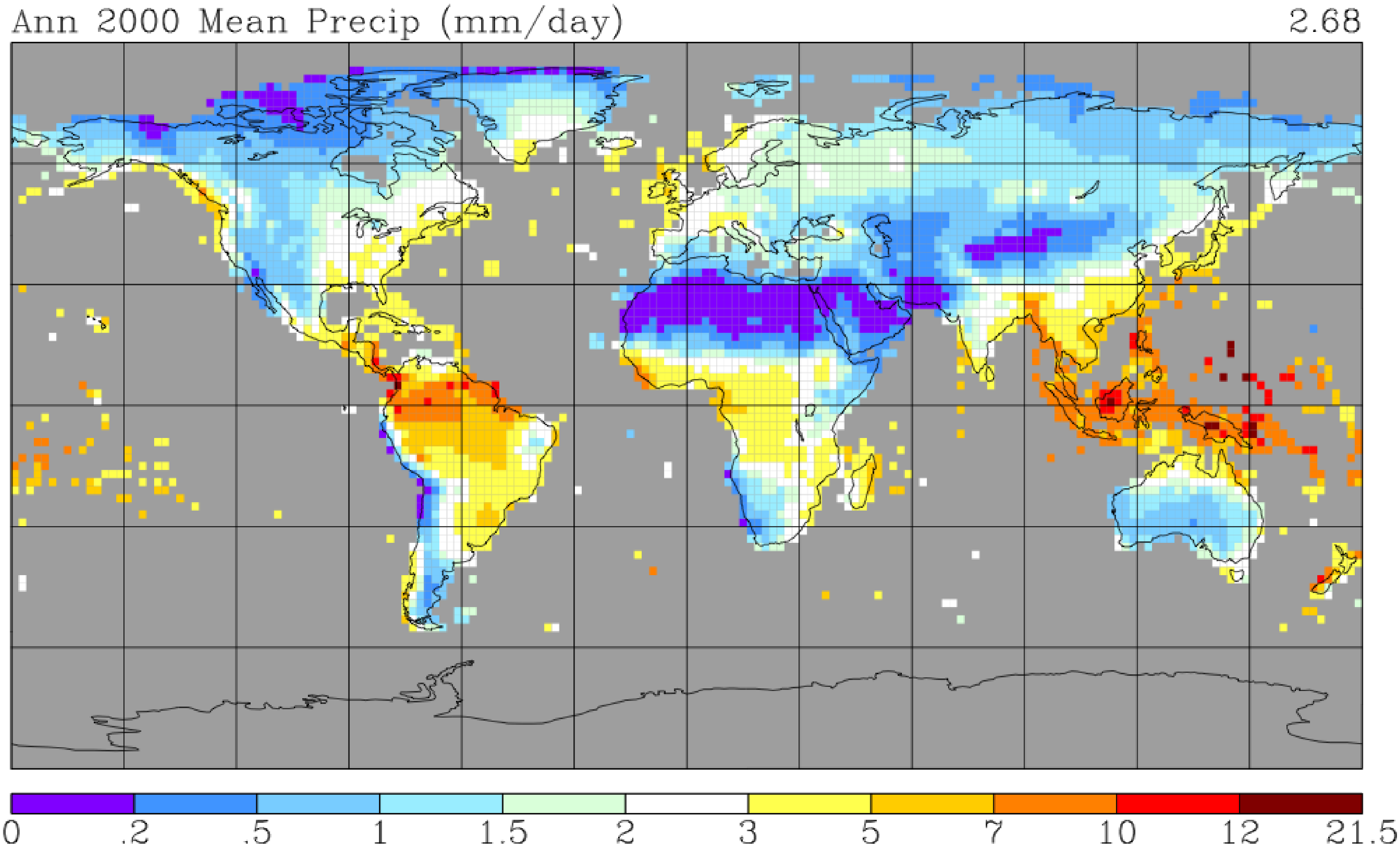




River Basins and Transboundary Aquifer Systems
Source: *BGR & GRDC*
www.whymap.org/whymap/EN/Downloads/Global_maps/globalmaps_node_en.html

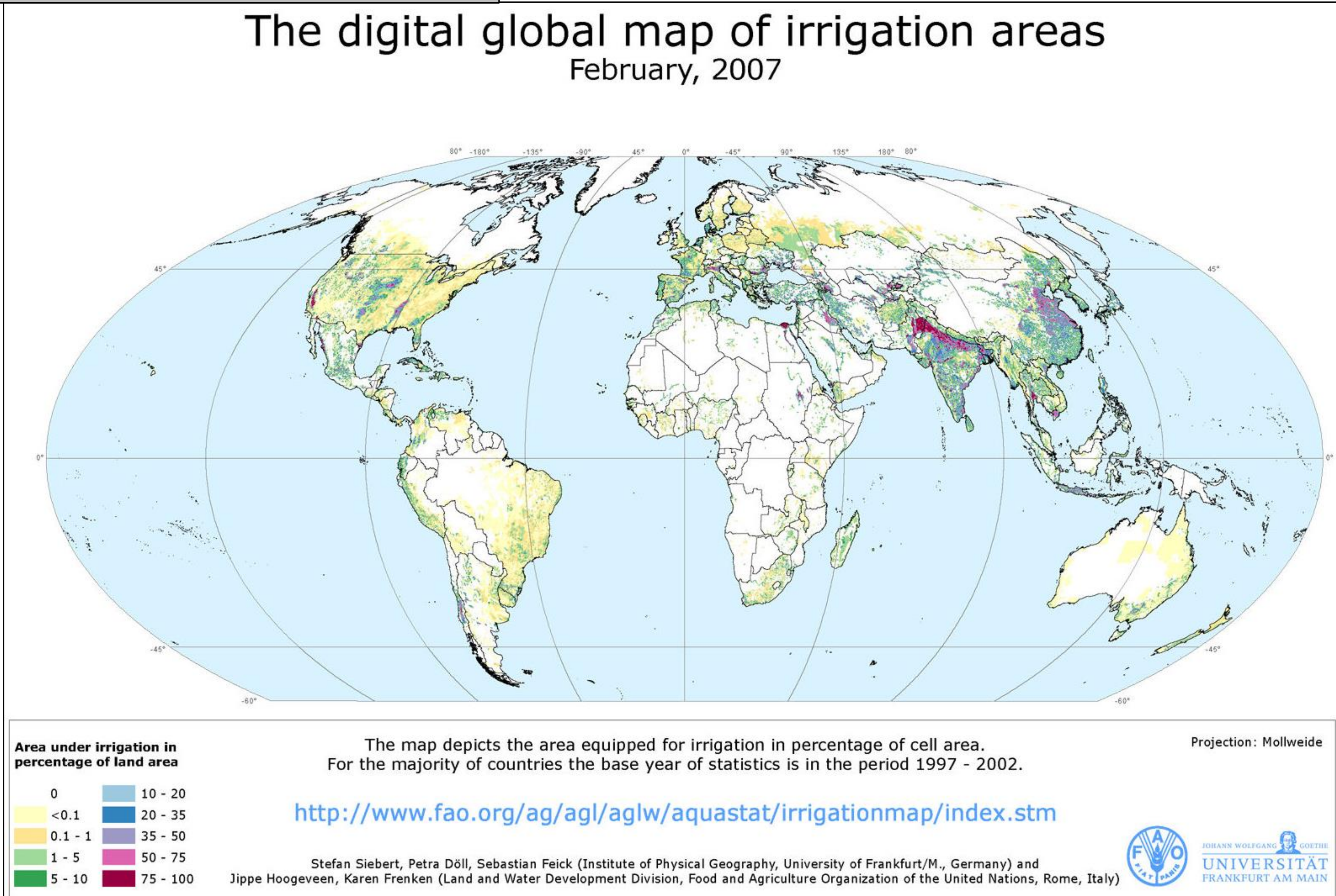
1. Framework & methods

Precipitation Data (CRU TS 2.0)

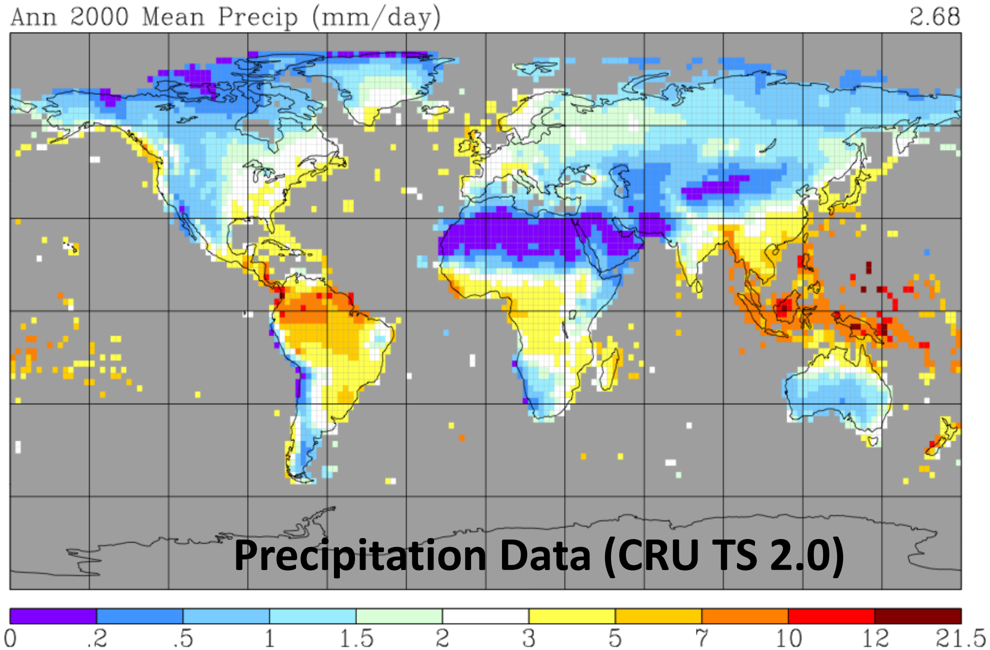


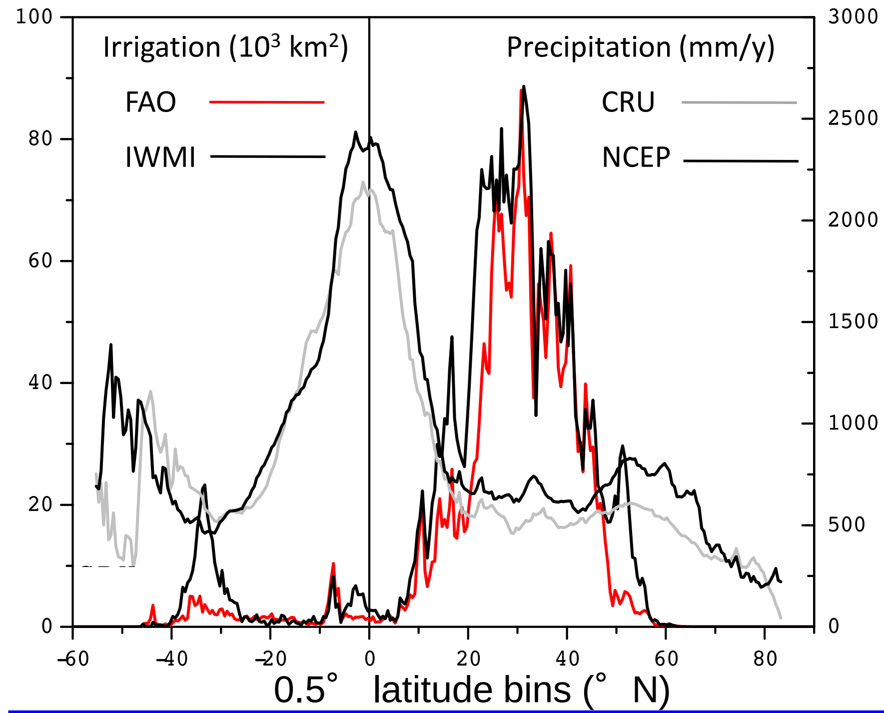
Map source: http://data.giss.nasa.gov/cgi-bin/precipcru

1. Framework & methods

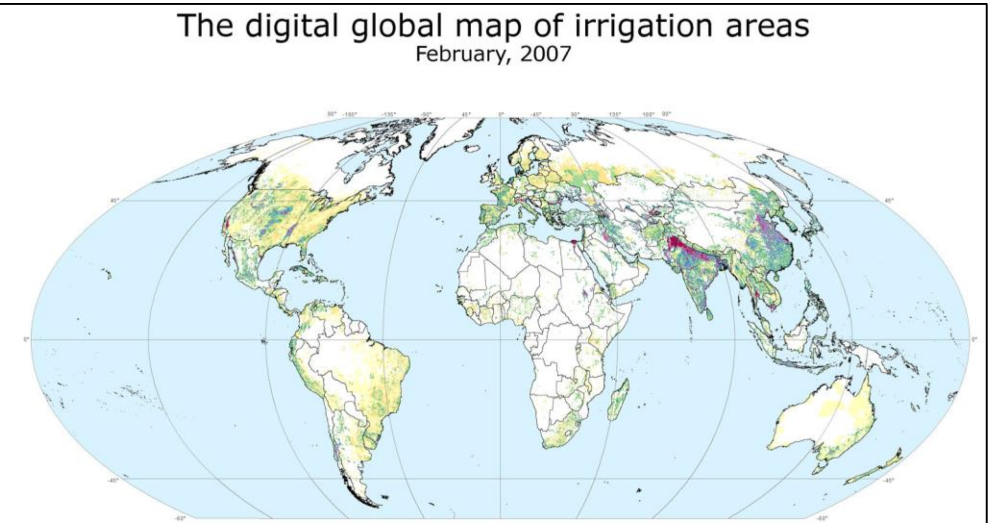


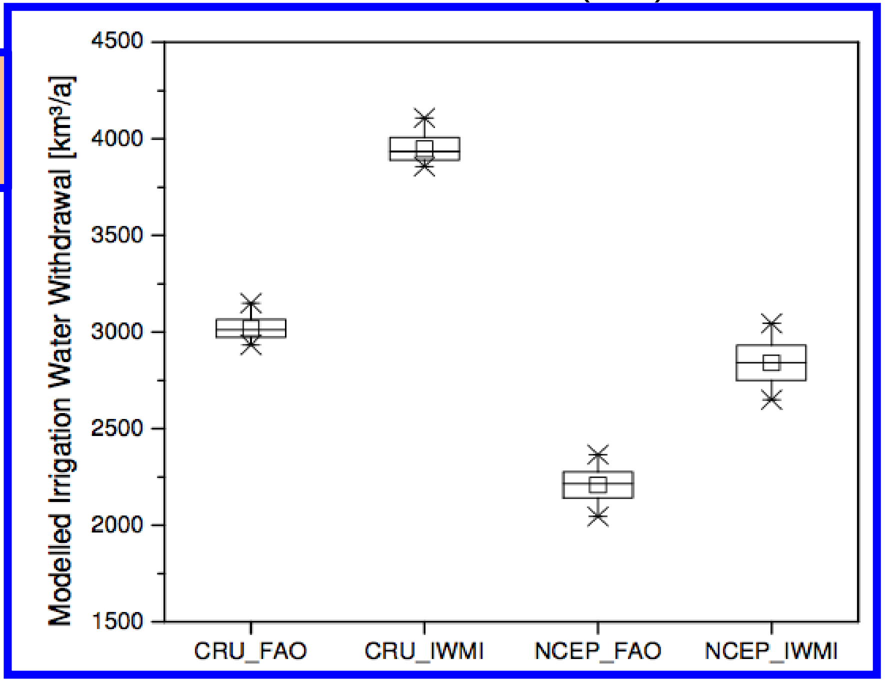
1. Framework & methods





variation in 2 input datasets led to ~2000 km³/y range in modeled demand for irrigation water.





Wisser et al. 2008 *GRL*

1. Framework & methods

Reservoirs

Small

- Supply ~40% of irrigated areas in India.
- Increasingly considered an important option to increase food security.
- Store local runoff: capacity ~1000 m^3.
- Irrigated area: 5-50 ha.

Wisser et al. 2010.

J. Hydrology

Large

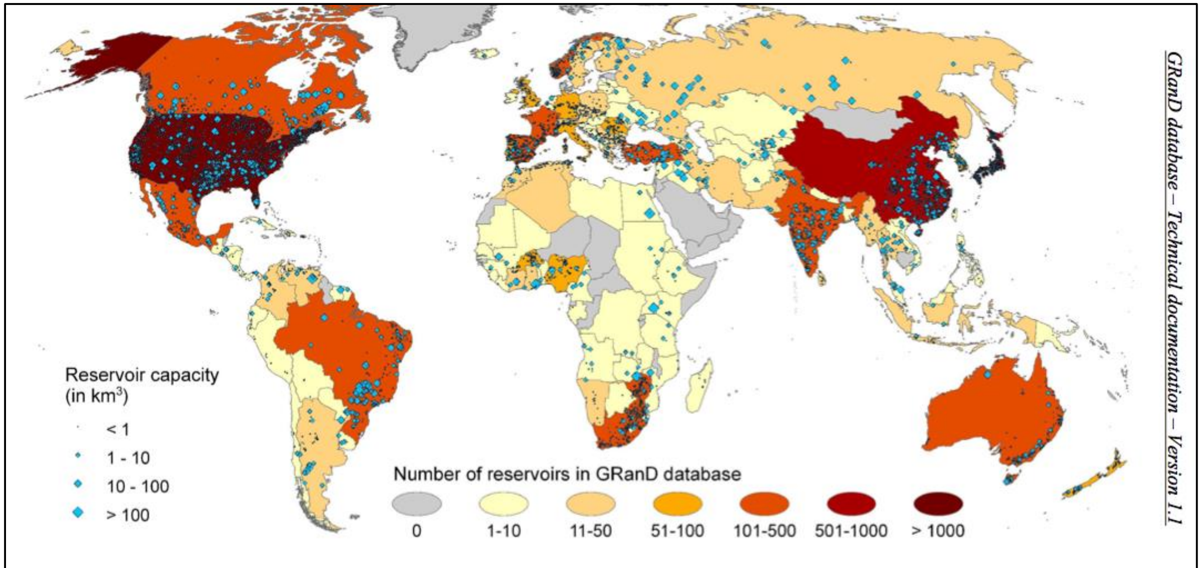


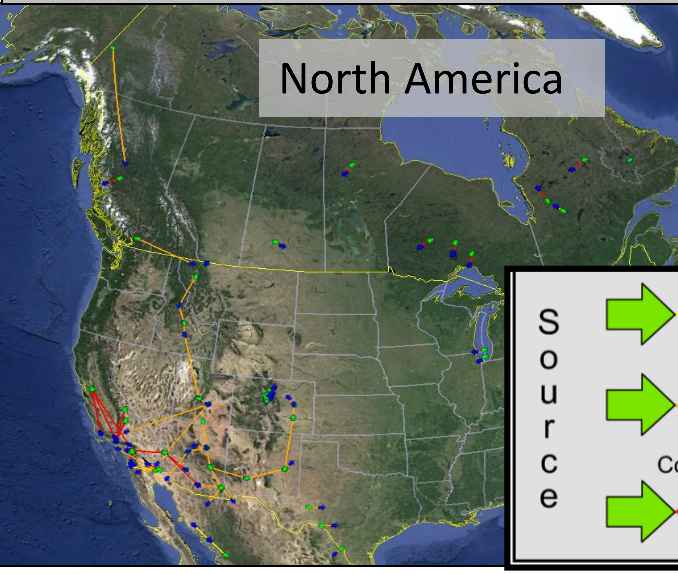
Figure 1: Global distribution (by country) of large reservoirs in GRanD database.

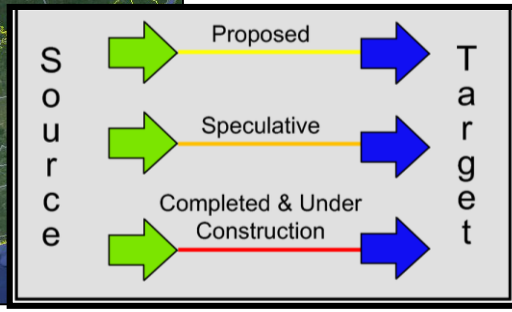
Large dam/reservoir database (GRanD; Lehner et al. 2011; *n~6500*)
hydropower; flood control; irrigation; navigation
http://www.gwsp.org/85.html

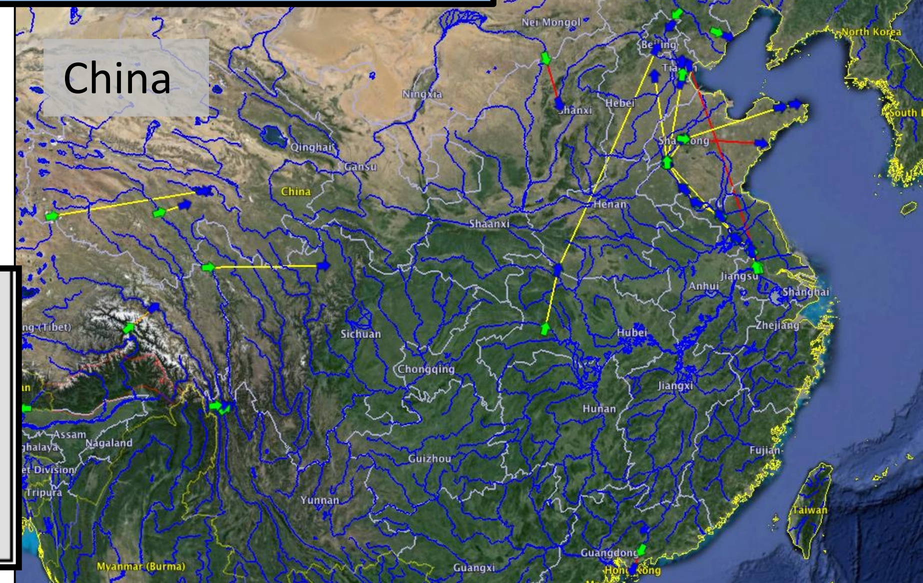
US National Inventory of Dams

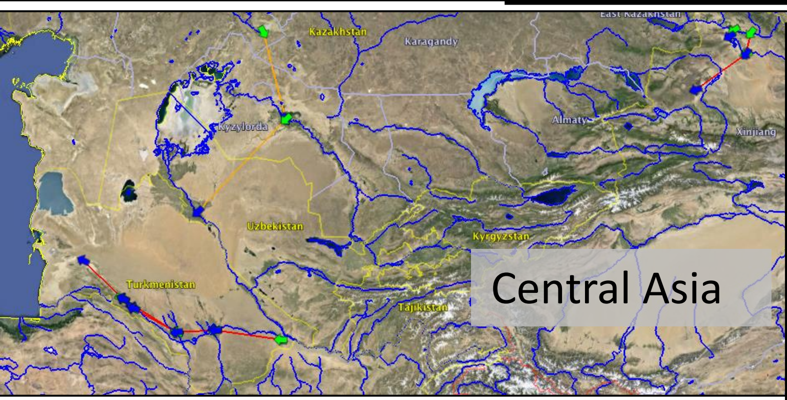
1. Framework & methods

Inter-basin water transfers

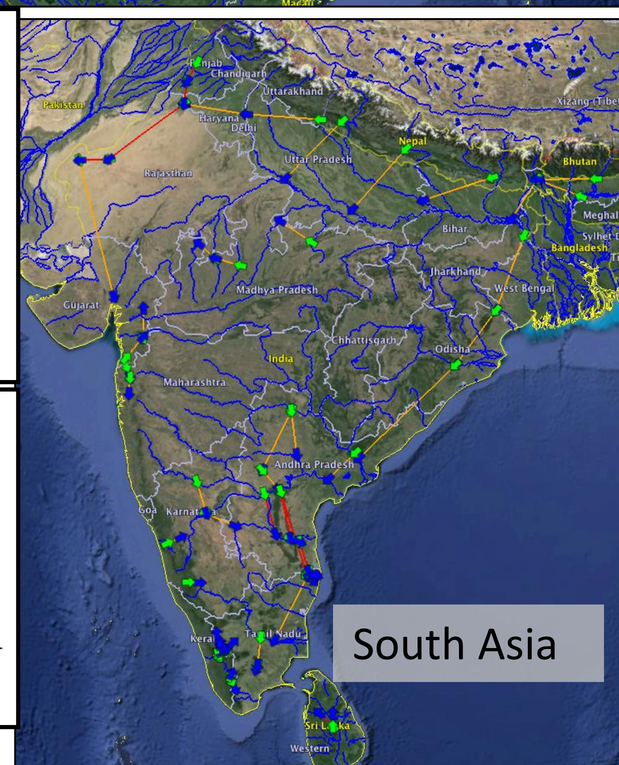


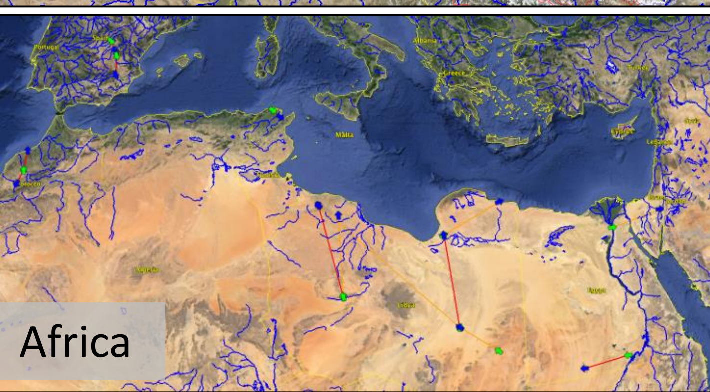






Continent	Count
Africa	13
Australia	3
Eurasia	80
North America	57
South America	11
Total	**164**

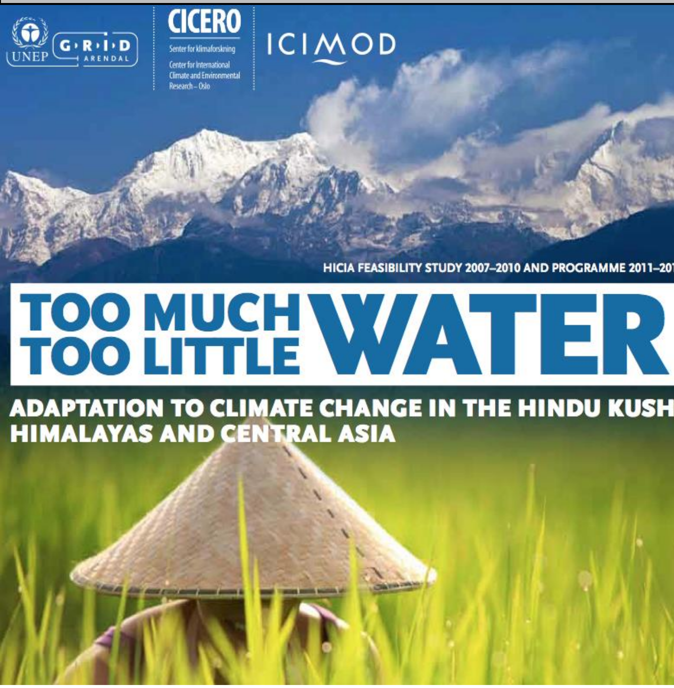


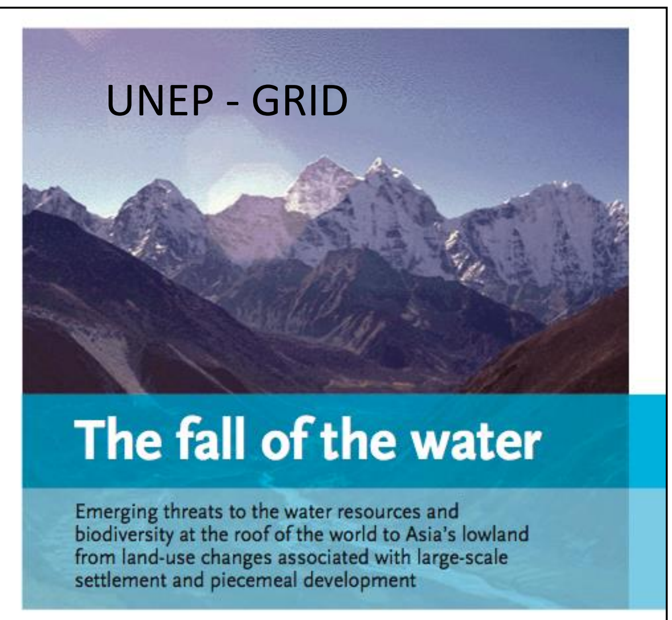


Status	Count
Completed	65
Under Construction	5
Proposed	21
Speculative	73
Total	**164**

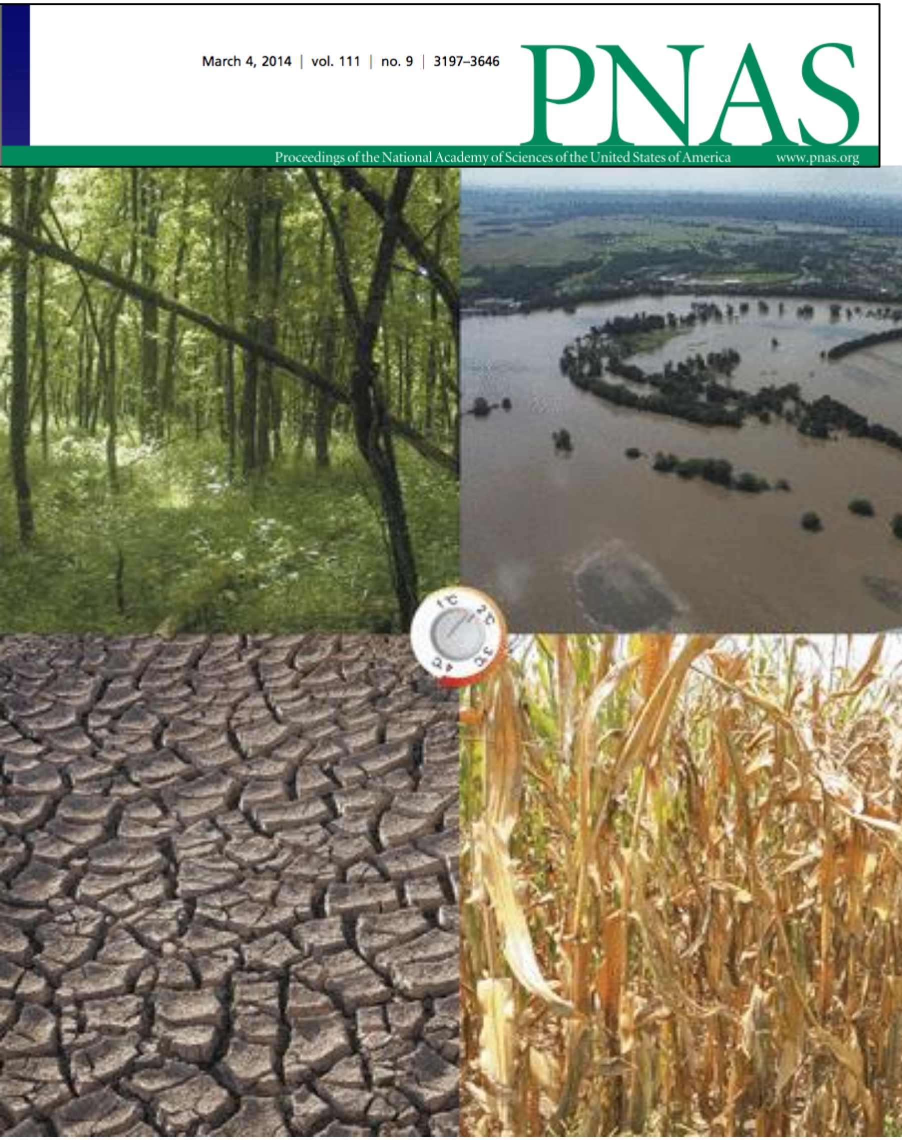
R Lammers (UNH) ms in prep.

2. Context & Questions





2. Context & Questions



8 related research articles

The Inter-Sectoral Impact Model Intercomparison Project (ISI–MIP): Project framework

Lila Warszawski, Katja Frieler[1], Veronika Huber, Franziska Piontek, Olivia Serdeczny, and Jacob Schewe

Potsdam Institute for Climate Impact Research, 14412 Potsdam, Germany

Table 1. Participating impact models

Model (source)	Sector
LPJmL (15, 16)	Water/agriculture/ biomes
JULES (17, 18)	Water/biomes
VIC (19)	Water
H08 (20)	
WaterGAP (21)	
MacPDM.09 (22)	
WBM (23)	
MPI–HM (24)	
PCR–GLOBWB (25)	
MATSIRO (26)	
DBH (27)	
ORCHIDEE (28)	Biomes
Hybrid4 (29)	
SDGVM (30)	
JeDi (31)	
VISIT (32)	

Table 1. Participating impact models

Model (source)	Sector
VISIT (32)	
GEPIC (33)	Agriculture
EPIC (34)	
pDSSAT (35)	
PEGASUS (36)	
GAEZ-IMAGE (37)	
LPJ-GUESS (38)	
MARA (39)	Health (malaria)
Umea statistical model (40)	
LMM 205 (41)	
MIASMA (42)	
VECTRI (43)	
DIVA (44)	Coastal infrastructure
AIM (45)	(Agro-) economic effects
ENVISAGE (46)	
EPPA (47)	
GTEM (48)	
FARM (49)	
MAGNET (50)	
GCAM (51)	
GLOBIOM (51)	
IMPACT (53)	
MAgPIE (54)	

2. Context & Questions

The Predictability of Rainfall over the Greater Horn of Africa. Part I: Prediction of Seasonal Rainfall

SHARON E. NICHOLSON

J. Hydrometeorology, 2014, 15:1011-1027

Are people more interested in how much water they will have in the next rainy season, or in predictions for 2100?

Response of snow-dependent hydrologic extremes to continued global warming

nature climate change LETTERS
PUBLISHED ONLINE: 11 NOVEMBER 2012 | DOI: 10.1038/NCLIMATE1732

Noah S. Diffenbaugh[1]*, Martin Scherer[1] and Moetasim Ashfaq[2]

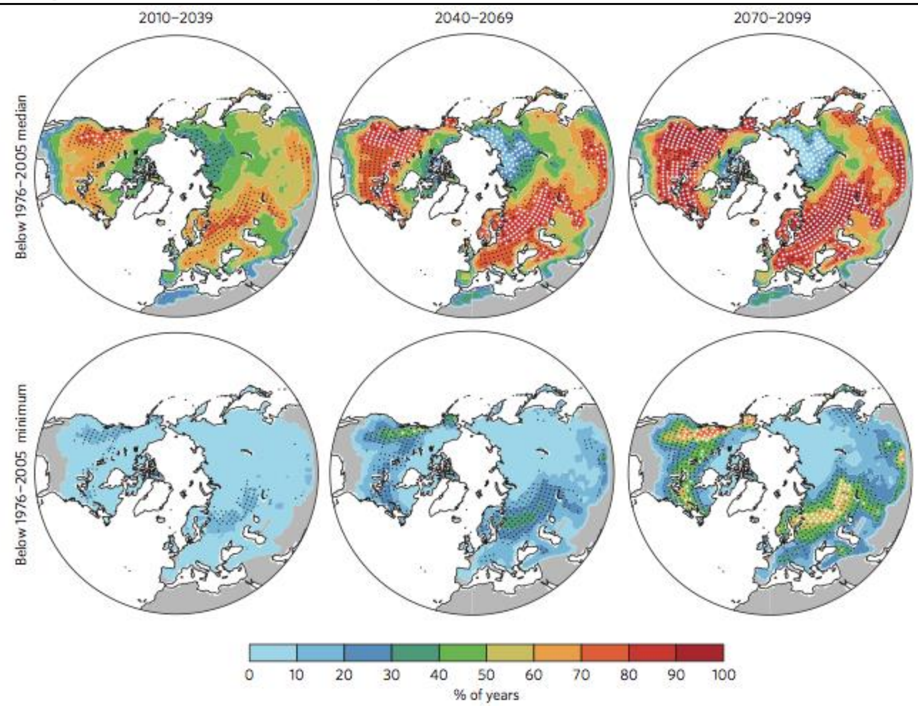


Figure 2 | Emergence of low and extremely low snow years in the twenty-first century. Percentage of years with accumulated March SWE below the simulated 1976–2005 median (top) or minimum (bottom) in three periods of RCP 8.5 (56 realizations from 26 models; Supplementary Table S1). Following ref. 21, stippling indicates areas where the magnitude of the multi-model ensemble mean occurrence divided by the multi-model standard deviation of occurrence exceeds 1.0 (black symbols) or 2.0 (white symbols). Grey denotes areas where at least half of the realizations have a median (top) or minimum (bottom) March SWE of zero in the 1976–2005 period.

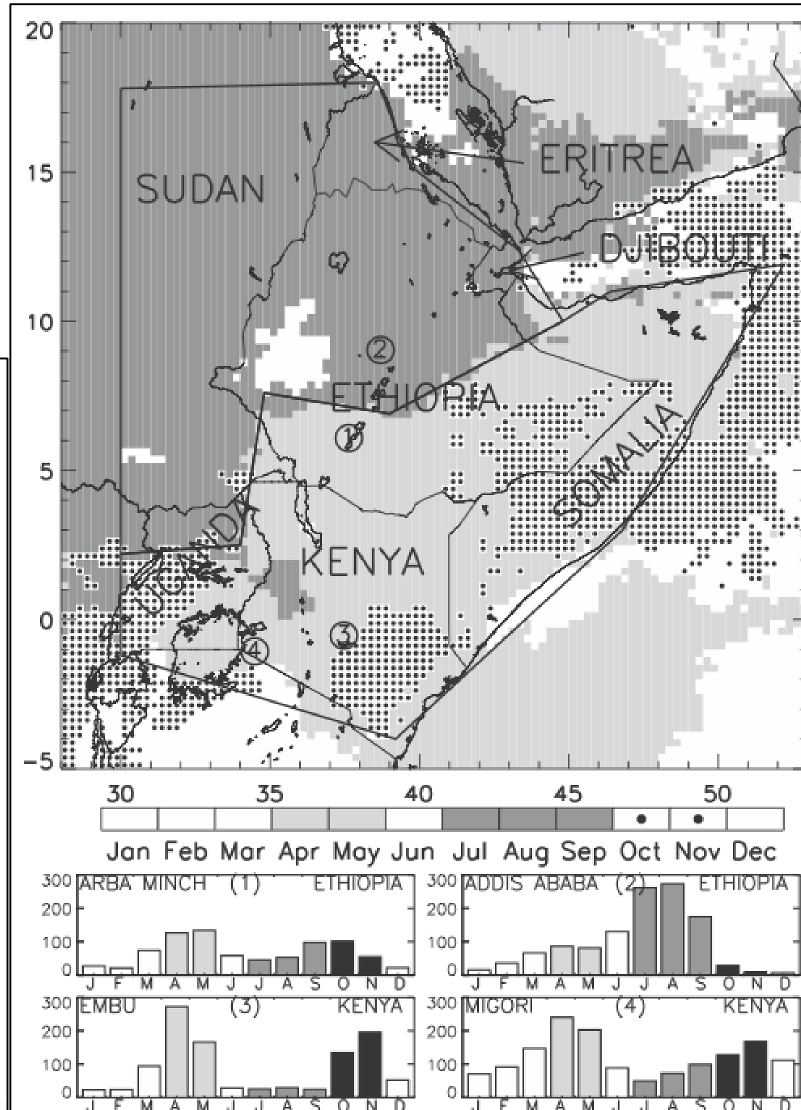


FIG. 1. (top) Month of rainfall maximum and area rainfall divisions (defined by numbers with circles 1–4). (bottom four panels) Monthly rainfall (mm) at typical stations: Arba Minch, Addis Ababa, Embu, and Migori.

2. Context & Questions

WATER RESOURCES RESEARCH, VOL. 47, W05301, doi:10.1029/2010WR010090, 2011

Hyperresolution global land surface modeling: Meeting a grand challenge for monitoring Earth's terrestrial water

Eric F. Wood,[1] Joshua K. Roundy,[1] Tara J. Troy,[1] L. P. H. van Beek,[2] Marc F. P. Bierkens,[2,3] Eleanor Blyth,[4] Ad de Roo,[5] Petra Döll,[6] Mike Ek,[7] James Famiglietti,[8] David Gochis,[9] Nick van de Giesen,[10] Paul Houser,[11] Peter R. Jaffé,[1] Stefan Kollet,[12] Bernhard Lehner,[13] Dennis P. Lettenmaier,[14] Christa Peters-Lidard,[15] Murugesu Sivapalan,[16] Justin Sheffield,[1] Andrew Wade,[17] and Paul Whitehead[18]

The never-ending quest for higher spatial resolution.

i.e., global 1-km modeling

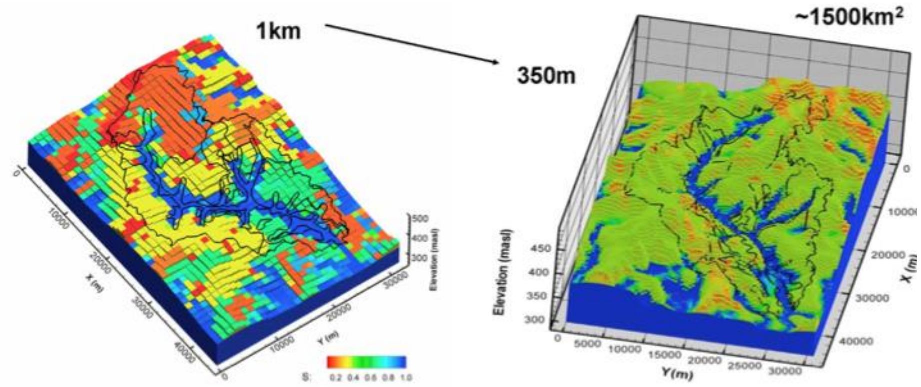


Figure 1. Higher-resolution modeling leads to better spatial representation of saturated and nonsaturated areas, with implications for runoff generation, biogeochemical cycling, and land-atmosphere interactions. Soil moisture simulations on the Little Washita showing the impact that the resolution has on its estimation

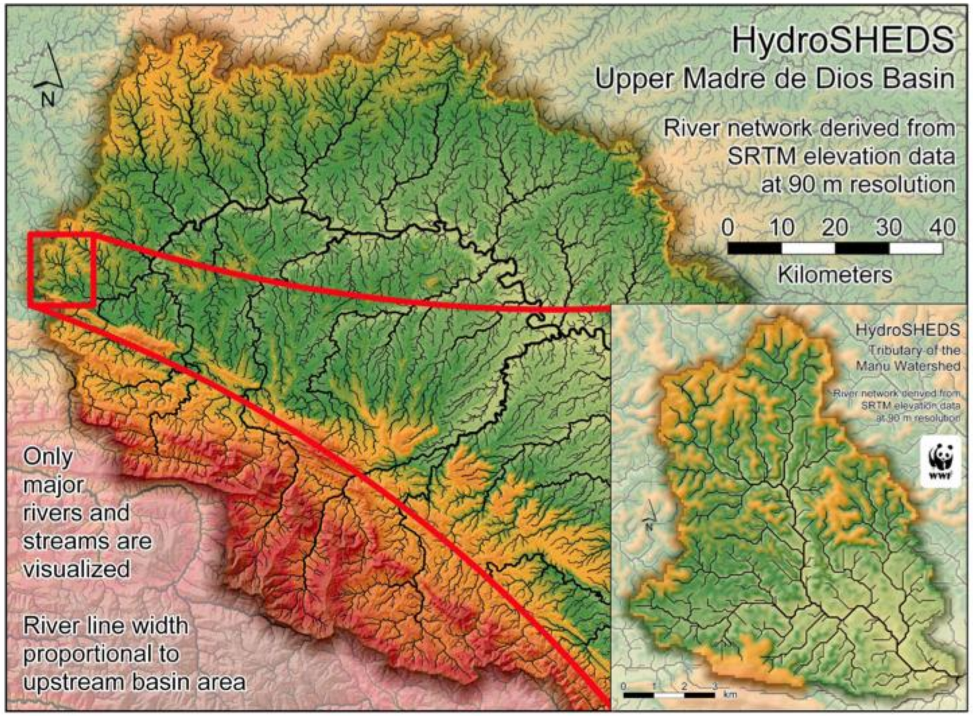
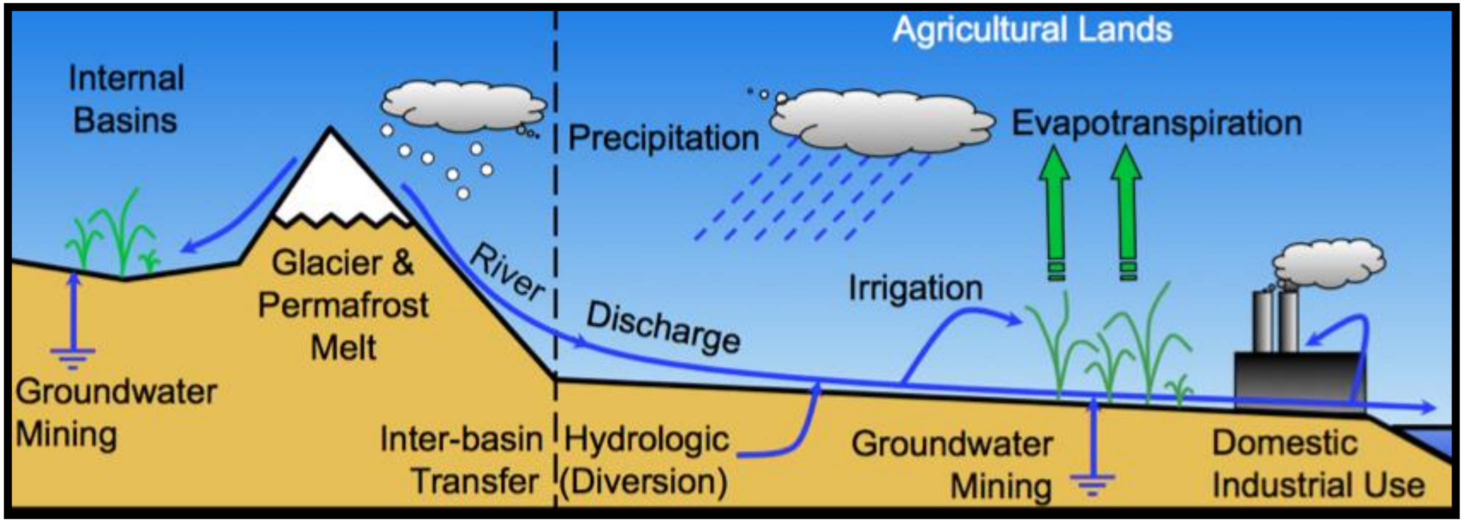


Figure 3. HydroSHEDS, an example of a global data set that will be needed for a hyperresolution hydrologic model. The data set consists of elevation, stream networks, watershed boundaries, drainage directions, and ancillary data layers such as flow accumulations, distances, and river topology at various resolutions from approximately 90 m to 10 km and is based on data from NASA's Shuttle Radar Topography Mission.

2. Context & Questions

Crops, climate, canals, and the cryosphere in Asia – changing water resources around the earth's third pole

- ***Univ. New Hampshire*** *Water balance and crop yield modeling*
- ***Boston University*** – *Economic modeling; land use analysis and remote sensing*
- ***Penn State University*** *Economic modeling*
- ***Univ. Alaska-Fairbanks*** *Cryosphere modeling*



1. Water and Climate*:* What are potential impacts of climate change on water supply in Asia?

2. Water and Food: What are present relative contributions of local surface water, upstream runoff, and deep groundwater to water resources for food production and how will these relative contributions evolve? What are potential impacts of major inter-basin transfers and improvements in irrigation and crop water use efficiency?

3. Water, Climate, and Sustainability*:* How will food and water pricing respond, and with what impacts on trade in food and virtual water, on water engineering efforts, on partitioning of water resources for agriculture, industrial, and municipal/domestic use, and on water resource policies?

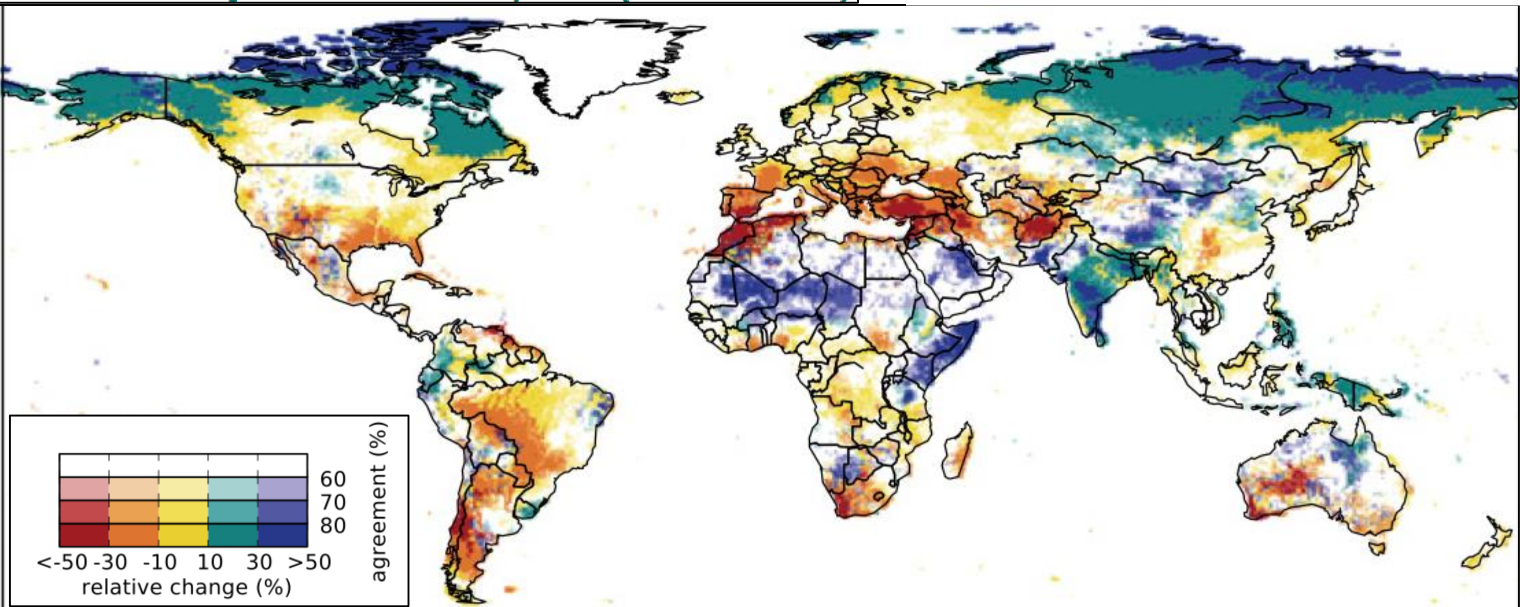
NSF Water, Sustainability, and Climate project

3. Outcomes

The Inter-Sectoral Impact Model Intercomparison Project (ISI–MIP)

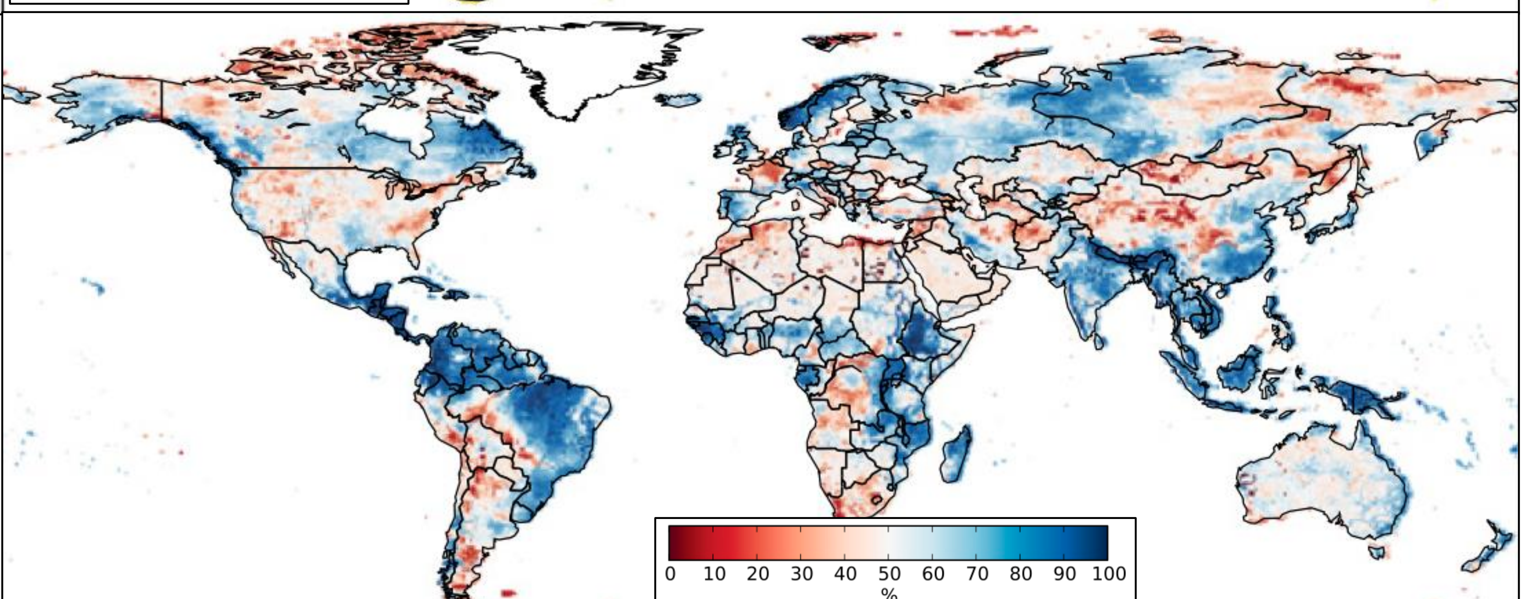
Multimodel assessment of water scarcity under climate change PNAS, 2014, 111, 3245–3250

Jacob Schewe[a,1], Jens Heinke[a,b], Dieter Gerten[a], Ingjerd Haddeland[c], Nigel W. Arnell[d], Douglas B. Clark[e], Rutger Dankers[f], Stephanie Eisner[g], Balázs M. Fekete[h], Felipe J. Colón-González[i], Simon N. Gosling[j], Hyungjun Kim[k], Xingcai Liu[l], Yoshimitsu Masaki[m], Felix T. Portmann[n,o], Yusuke Satoh[p], Tobias Stacke[q], Qiuhong Tang[l], Yoshihide Wada[r], Dominik Wisser[s], Torsten Albrecht[a], Katja Frieler[a], Franziska Piontek[a], Lila Warszawski[a], and Pavel Kabat[t,u]



Change (relative to present) in annual discharge at 2°C under RCP8.5.

Colors show multimodel mean change, and saturation shows the agreement on the sign of change across all GHM–GCM combinations

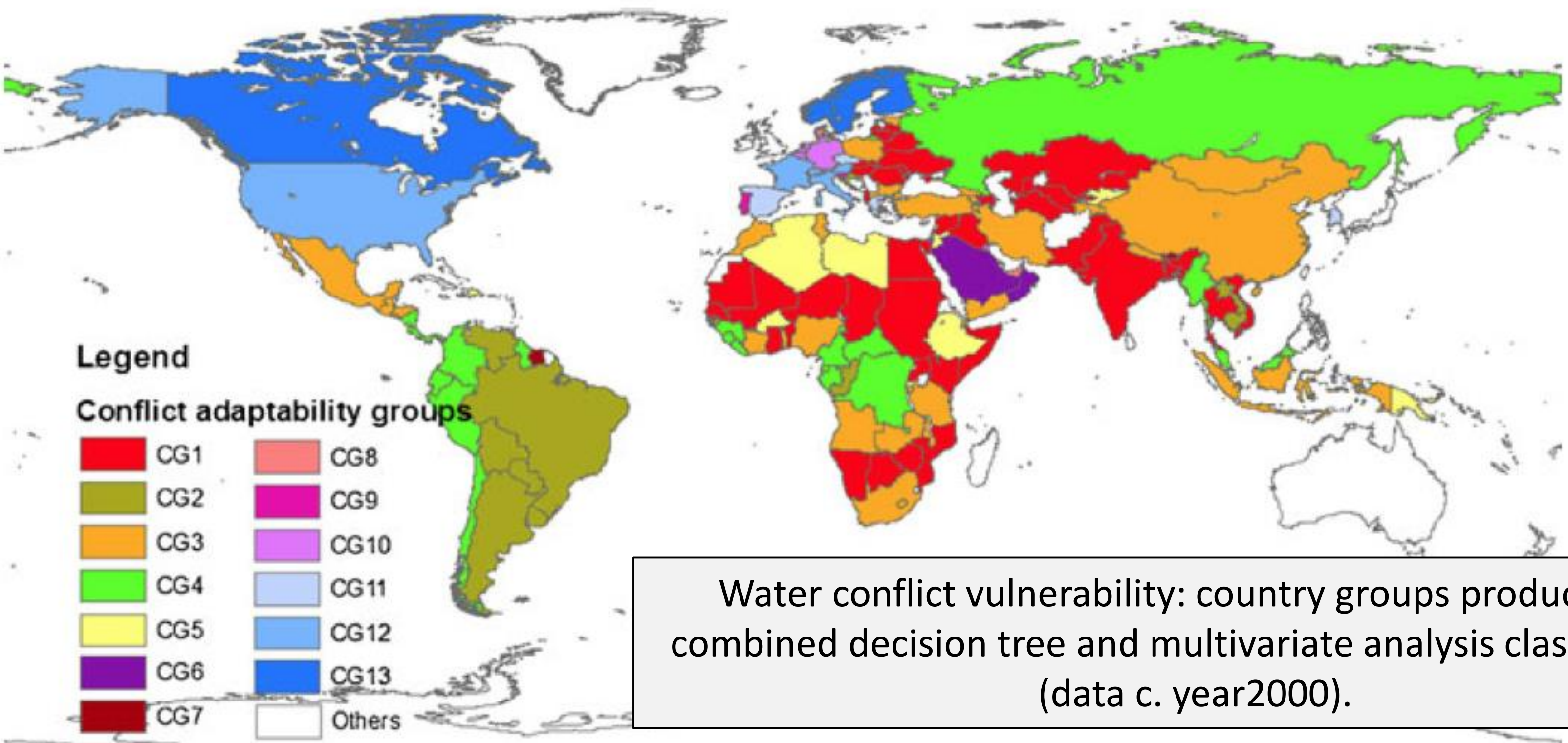


Ratio of GCM variance to total variance.

In red areas Global Hydrological Model variance predominates.

In blue areas Global Climate Model variance predominates.

3. Outcomes



Water conflict vulnerability: country groups produced by combined decision tree and multivariate analysis classification (data c. year2000).

group	groundwater dependency	external water dependency	water resources	income
1	low	HIGH	low	low
2	low	HIGH	HIGH	low
3	low	low	low	low
4	low	low	HIGH	low
5	HIGH	low	low	moderate
6	HIGH	low	low	moderate
7	HIGH	low	HIGH	low
8	HIGH	low	low	HIGH
9	low	HIGH	low	moderate
10	low	HIGH	low	HIGH
11	low	low	low	moderate
12	low	low	low	HIGH
13	low	low	HIGH	HIGH

Water Resour Manage (2014) 28:169–184
DOI 10.1007/s11269-013-0478-x

Water Conflict Risk due to Water Resource Availability and Unequal Distribution

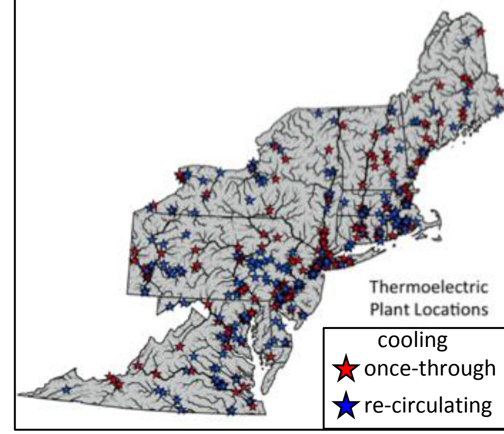
N. K. Gunasekara • S. Kazama • D. Yamazaki • T. Oki

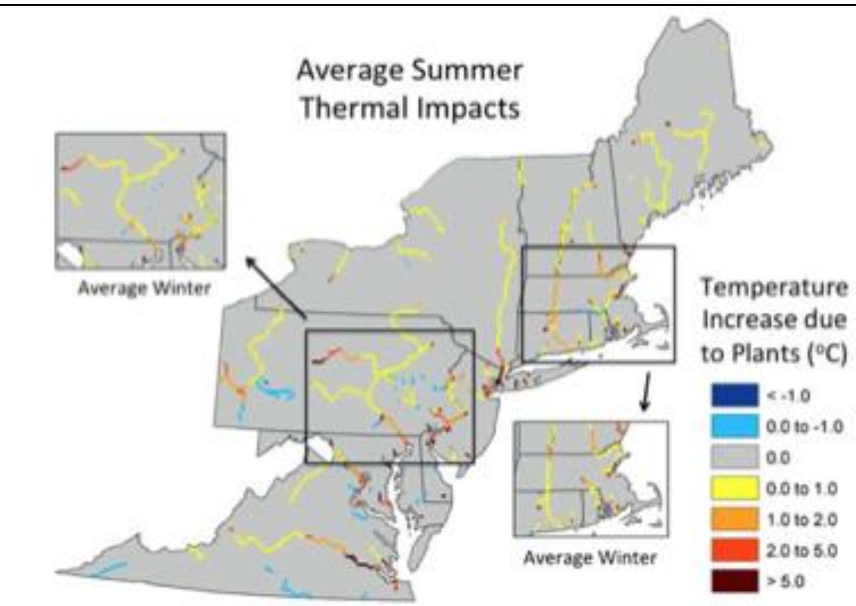
3. Outcomes

OPEN ACCESS
IOP Publishing — Environmental Research Letters
Environ. Res. Lett. 8 (2013) 025010 (10pp) — doi:10.1088/1748-9326/8/2/025010

Horizontal cooling towers: riverine ecosystem services and the fate of thermoelectric heat in the contemporary Northeast US

Robert J Stewart[1], Wilfred M Wollheim[1,2], Ariel Miara[3], Charles J Vörösmarty[3,4], Balazs Fekete[3,4], Richard B Lammers[1] and Bernice Rosenzweig[3]

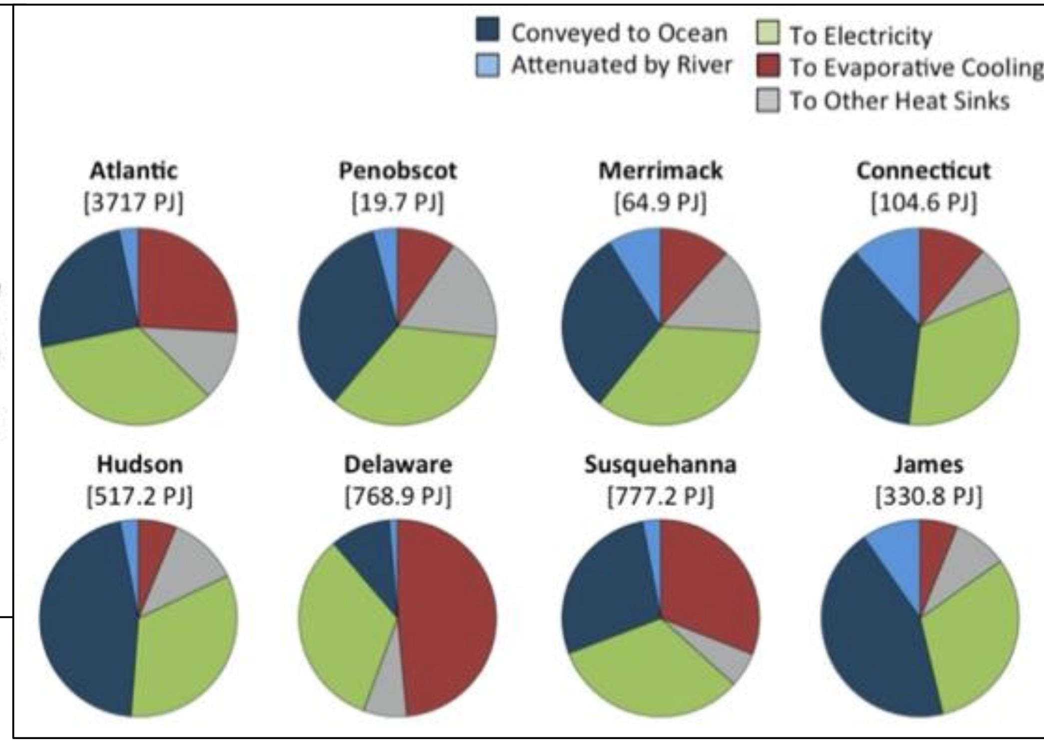




Increase in average summer water temperatures (2000–2010) due to thermal pollution from power plants.

Callout boxes show results for average winter conditions in selected regions.

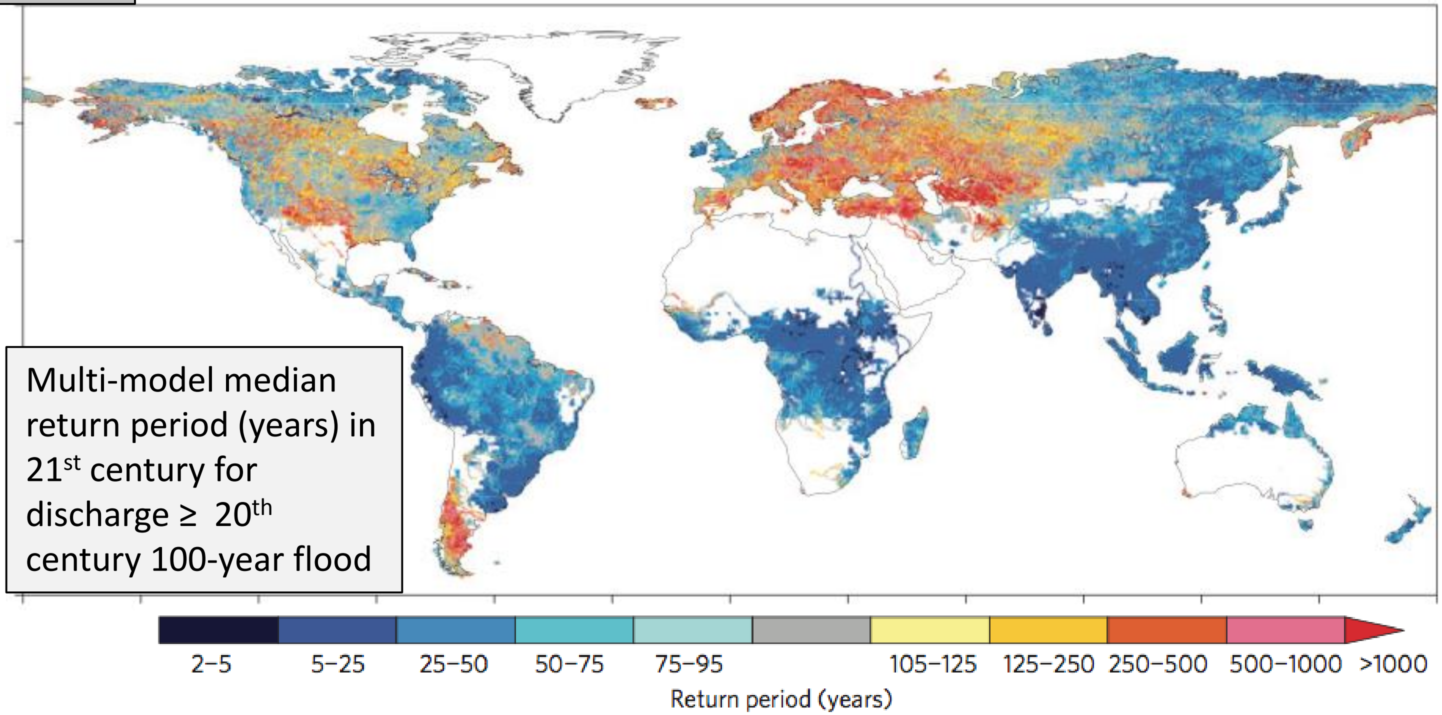
Temperature increases due to plants are more widespread in the summer because waste heat inputs are dissipated more quickly in the winter.

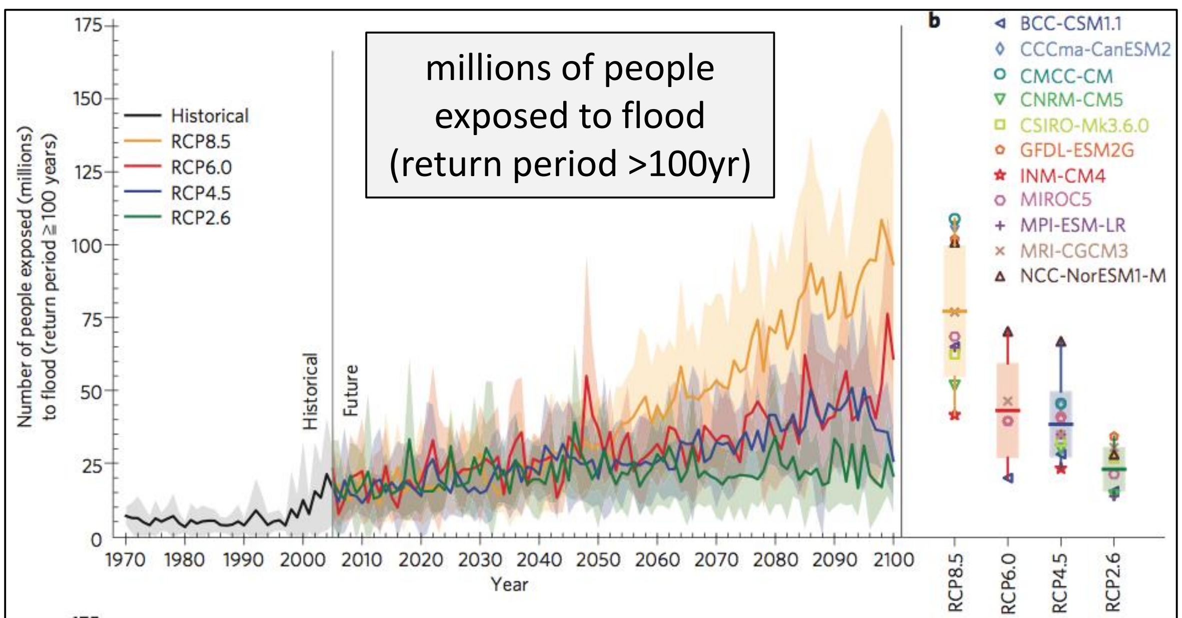


Allocation of total heat (in petajoules) generated in freshwater thermoelectric power plants during electricity production at selected basins.

3. Outcomes

Hirabayashi *et al* (2013) Global flood risk under climate change, *Nature Climate Change*

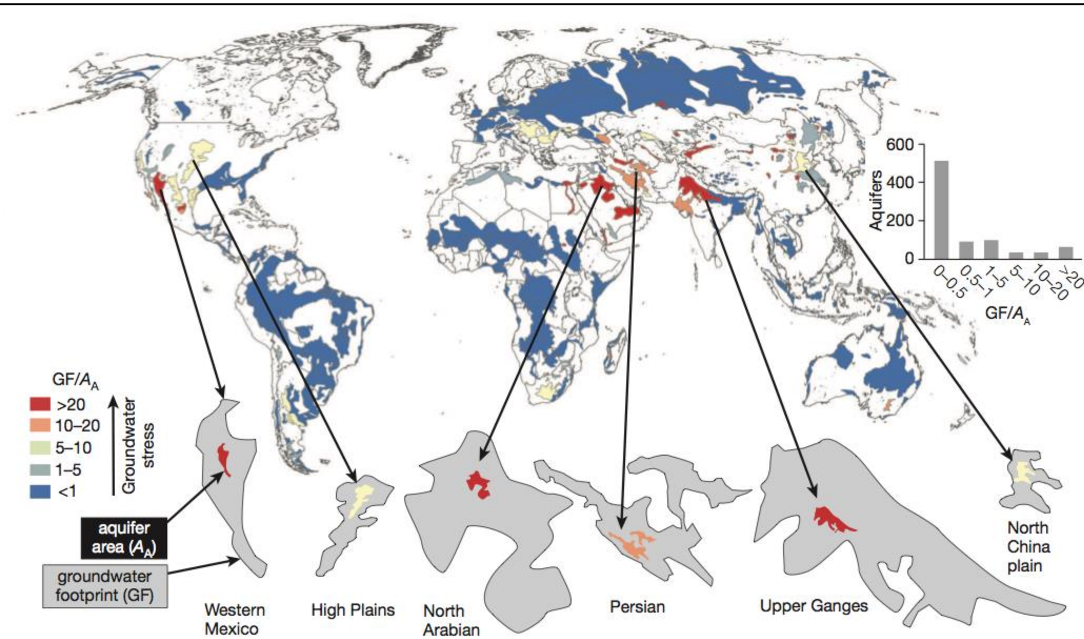




3. Outcomes

Water balance of global aquifers revealed by groundwater footprint

Tom Gleeson[1], Yoshihide Wada[2], Marc F. P. Bierkens[2,3] & Ludovicus P. H. van Beek[2]



Groundwater footprints of aquifers that are important to agriculture are significantly larger than their geographic areas. Aquifers are major groundwater basins with recharge of .>2 mm yr. At the bottom of the figure, the areas of the six aquifers (Western Mexico, High Plains, North Arabian, Persian, Upper Ganges and North China plain) are shown at the same scale as the global map; the surrounding grey areas indicate the groundwater footprint proportionally at the same scale. The ratio GF/AA indicates widespread stress of groundwater resources and/or groundwater-dependent ecosystems. Inset, histogram showing that GF is less than AA for most aquifers.

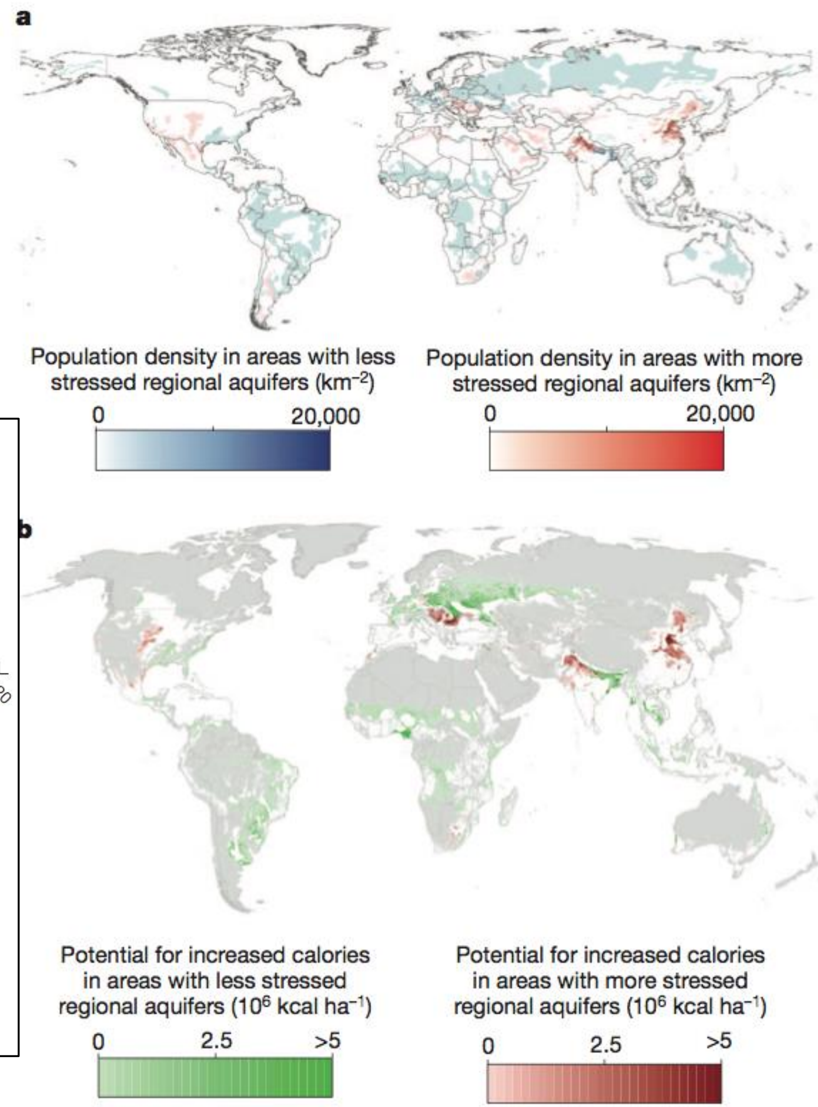
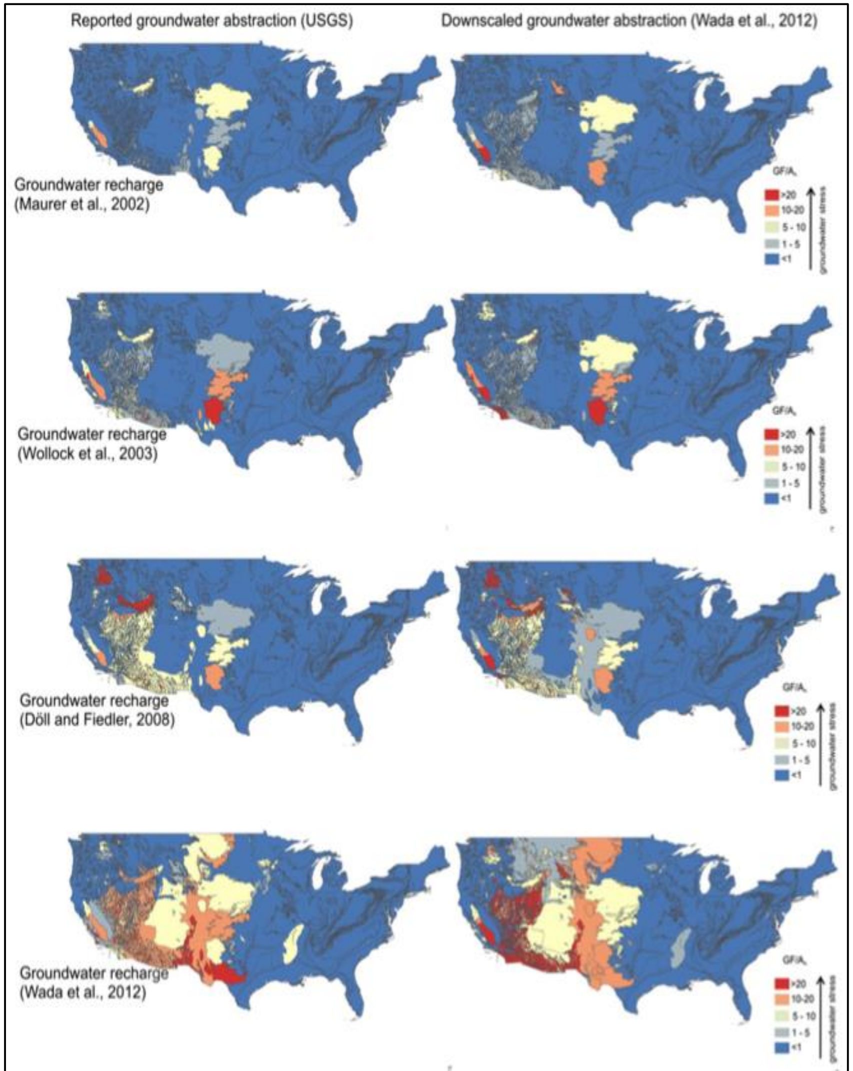


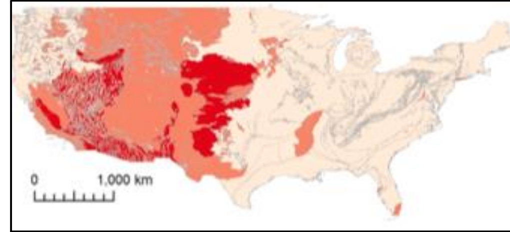
Figure 2 | Groundwater stress may be affecting ~1.7 billion people and could limit the potential to increase agricultural production. The ratio GF/A_A is used to differentiate areas with less groundwater stress (GF/$A_A < 1$) and more groundwater stress (GF/$A_A > 1$). **a**, Population densities, derived from the gridded population of the world for year 2000 (ref. 29). Areas that do not have underlying regional aquifers, or that have very low population density are shown in white. **b**, Potential for increased calories (see main text). Some areas with potential new calories[15] coincide with stressed aquifers and some areas coincide with aquifers that are less stressed. Areas with potential new calories that are not underlain by a regional aquifer are shown in white.

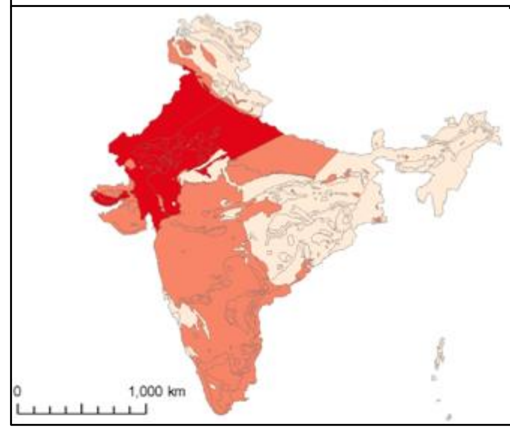
3. Outcomes

Gleeson & Wada, *ERL* 2013

Assessing regional groundwater stress for nations using multiple data sources with the groundwater footprint





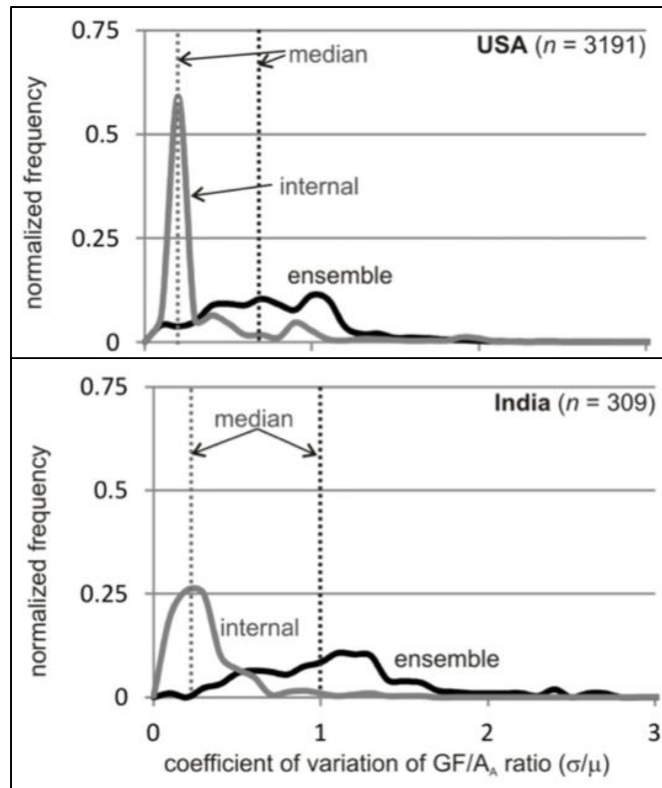


GF (groundwater footprint) = $\frac{\text{gw withdrawal}}{\text{gw net recharge}} \cdot \text{Area}$

A_A = aquifer known area

Aquifer stressed (GF/A_A >1) for:

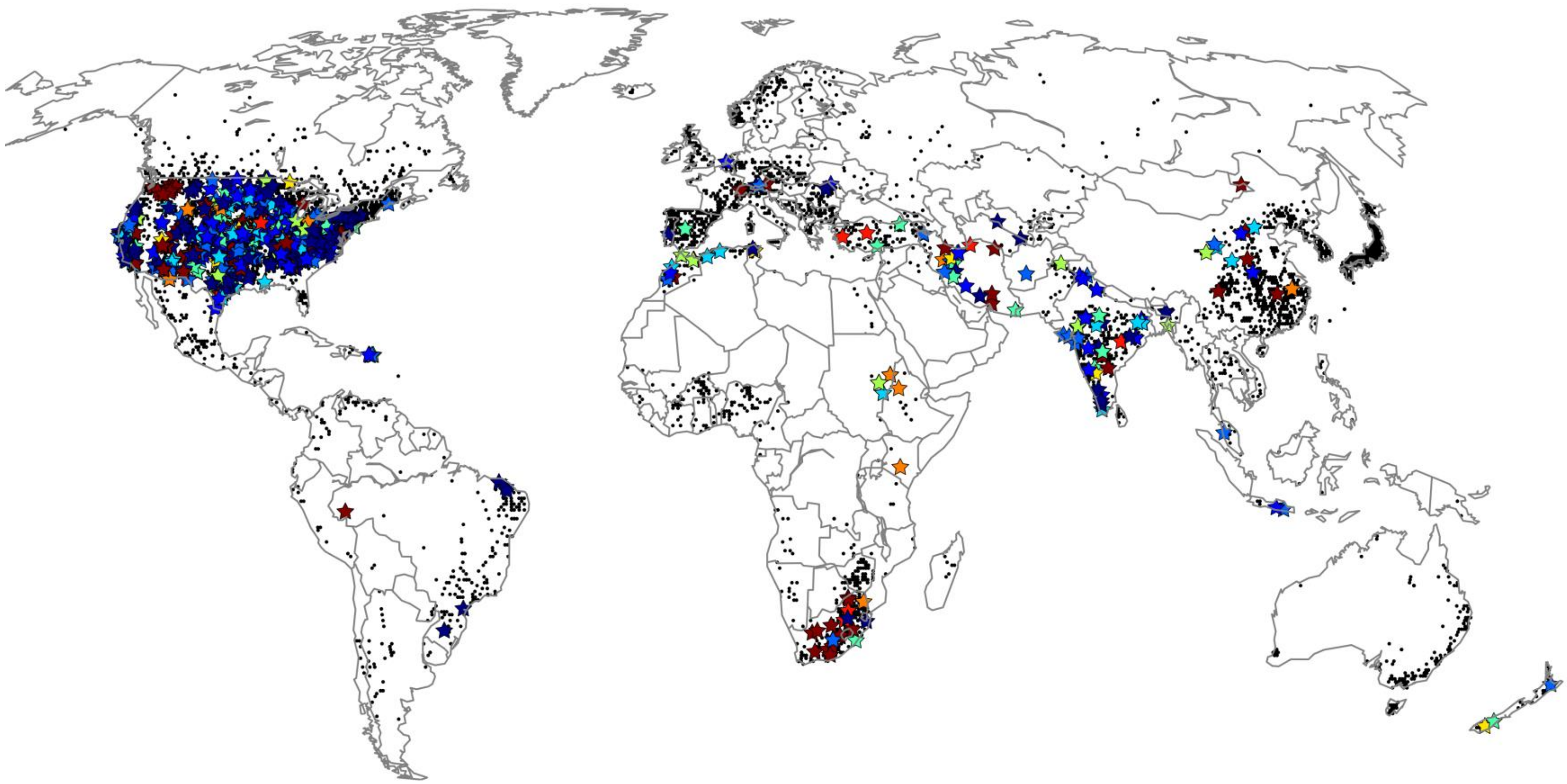
- ALL combinations of input data
- SOME combinations of input data
- NO combinations of input data



ensemble uncertainty 2-5x internal uncertainty

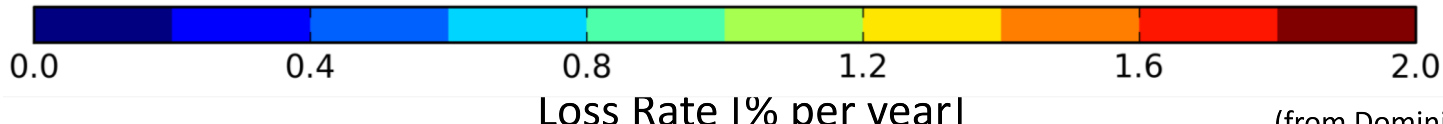
3. Outcomes

Dwindling Storage in Reservoirs



• Reservoirs in GRanD database

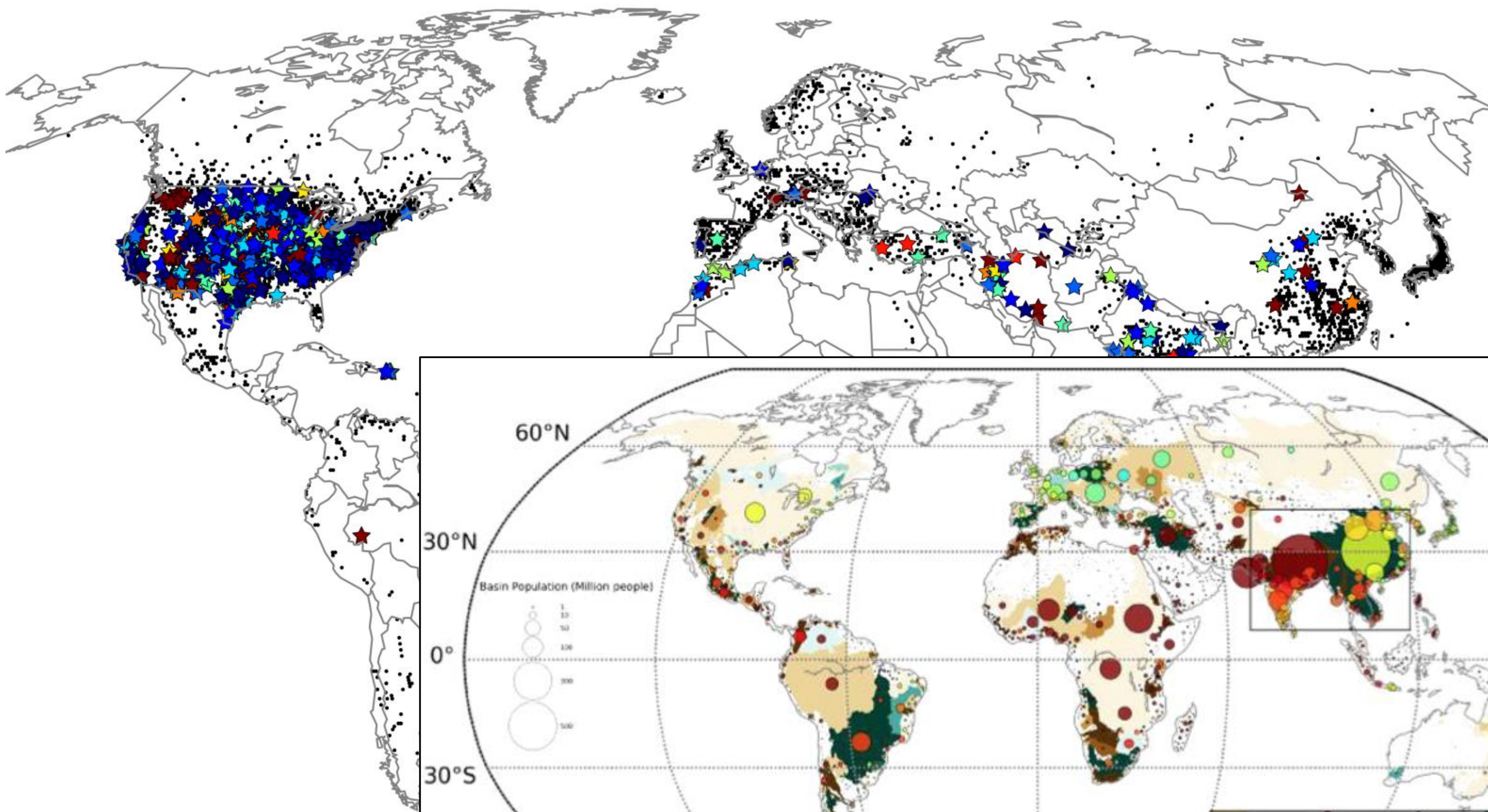
★Reported reservoir capacity loss rates due to sedimentation

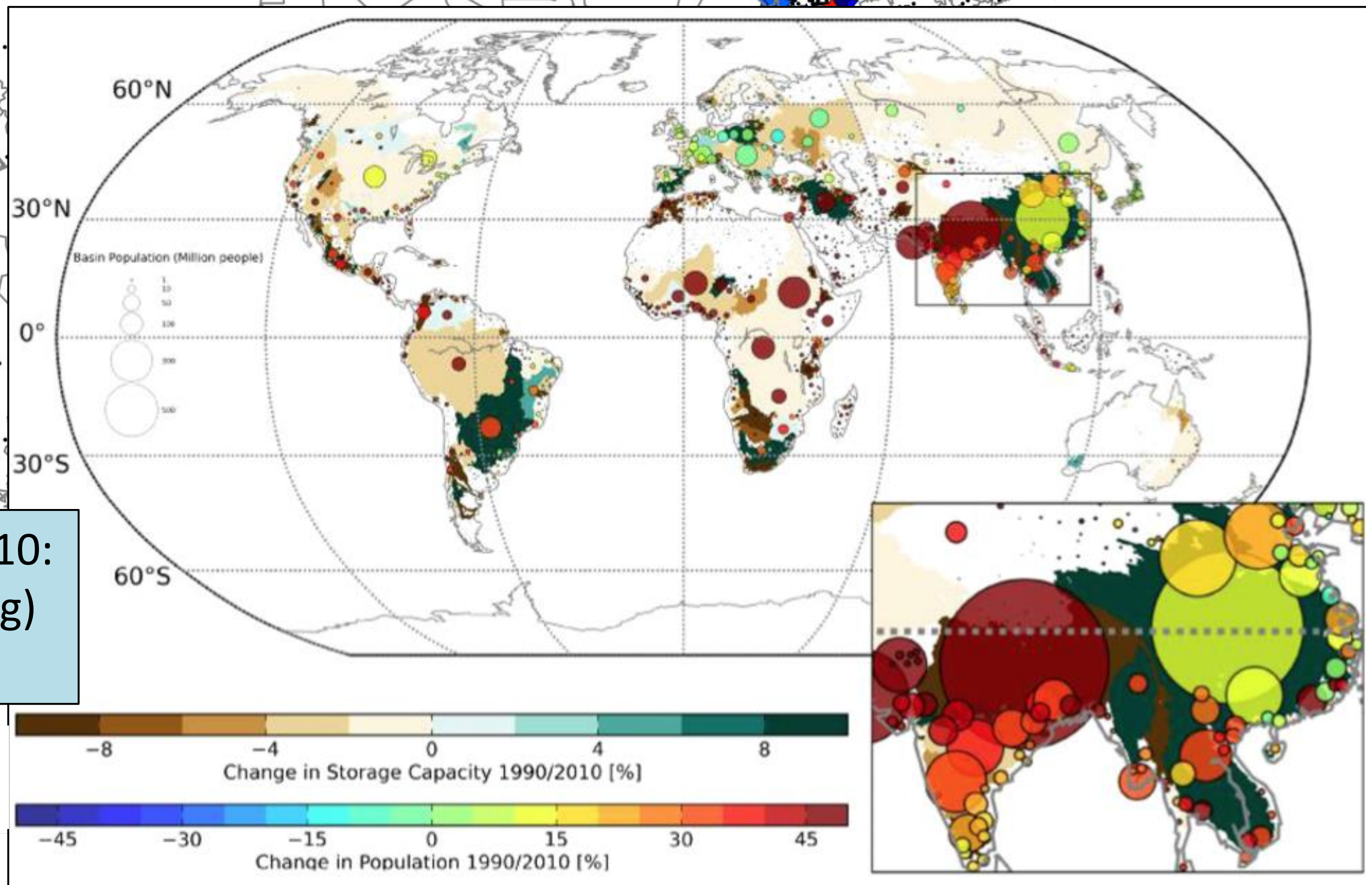


(from Dominik Wisser, Bonn U)

3. Outcomes

Dwindling Storage in Reservoirs



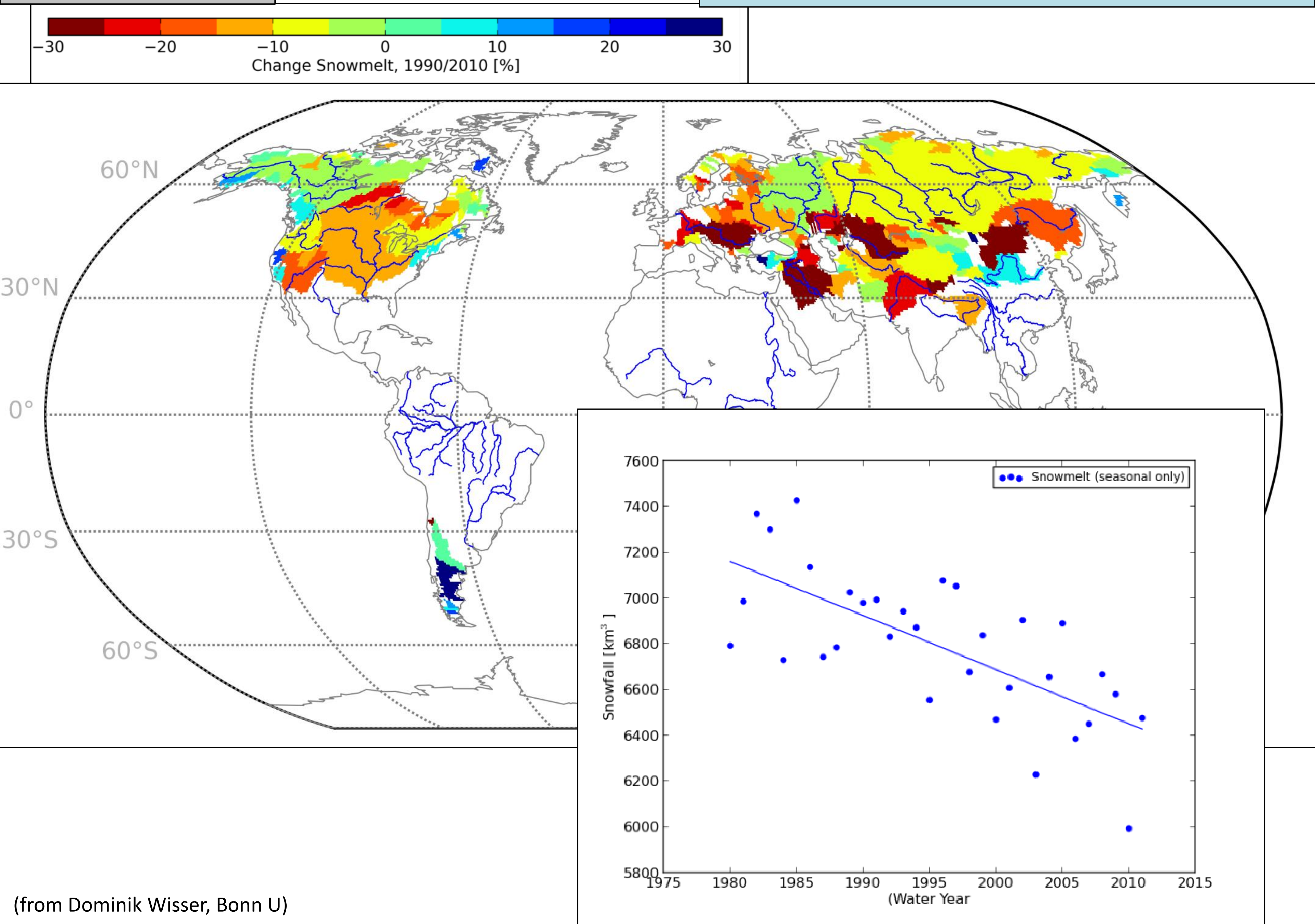


river basin change 1990-2010:

- reservoir capacity (shading)
- population (filled circles)

Wisser et al. 2013 *WRR*

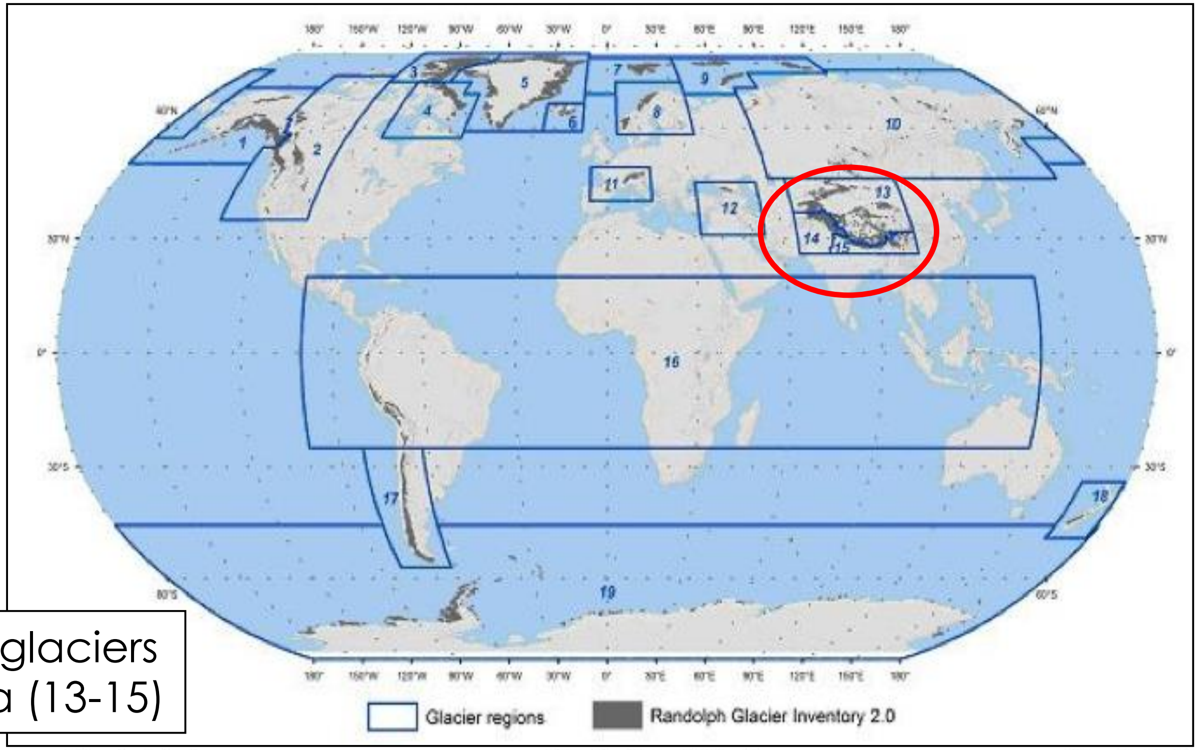
Dwindling Storage in Snow



(from Dominik Wisser, Bonn U)

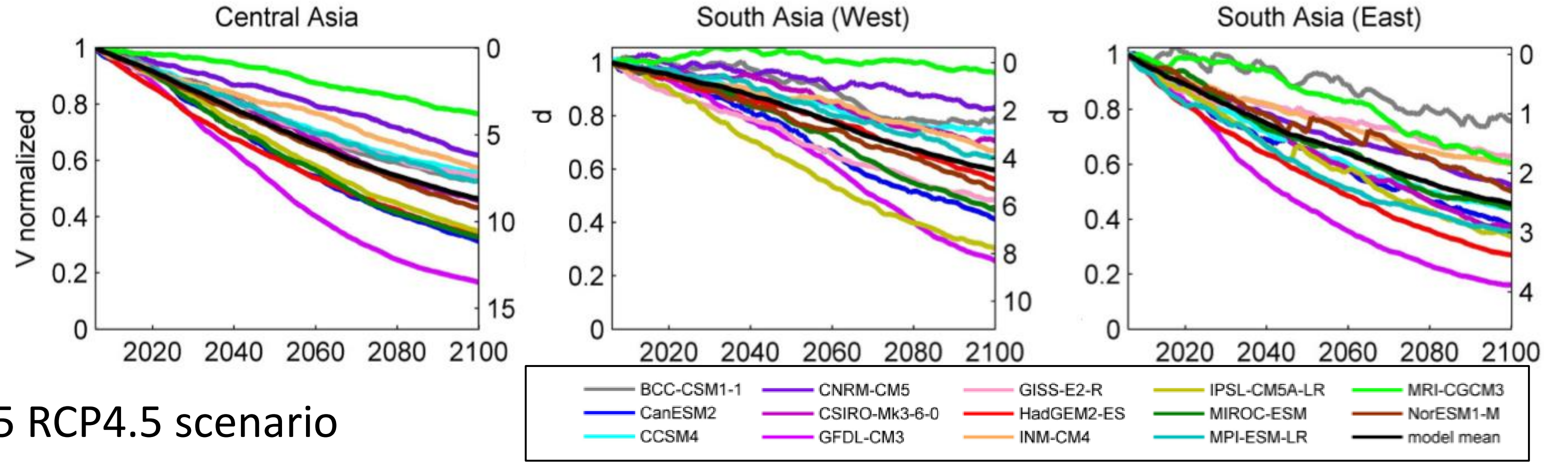
3. Outcomes Coupling WBM & Glacier Mass Balance Modeling

Radic et al. (*Climate Dynamics, 2013*)



About 80,000 glaciers in Central Asia (13-15)

glacier annual volume

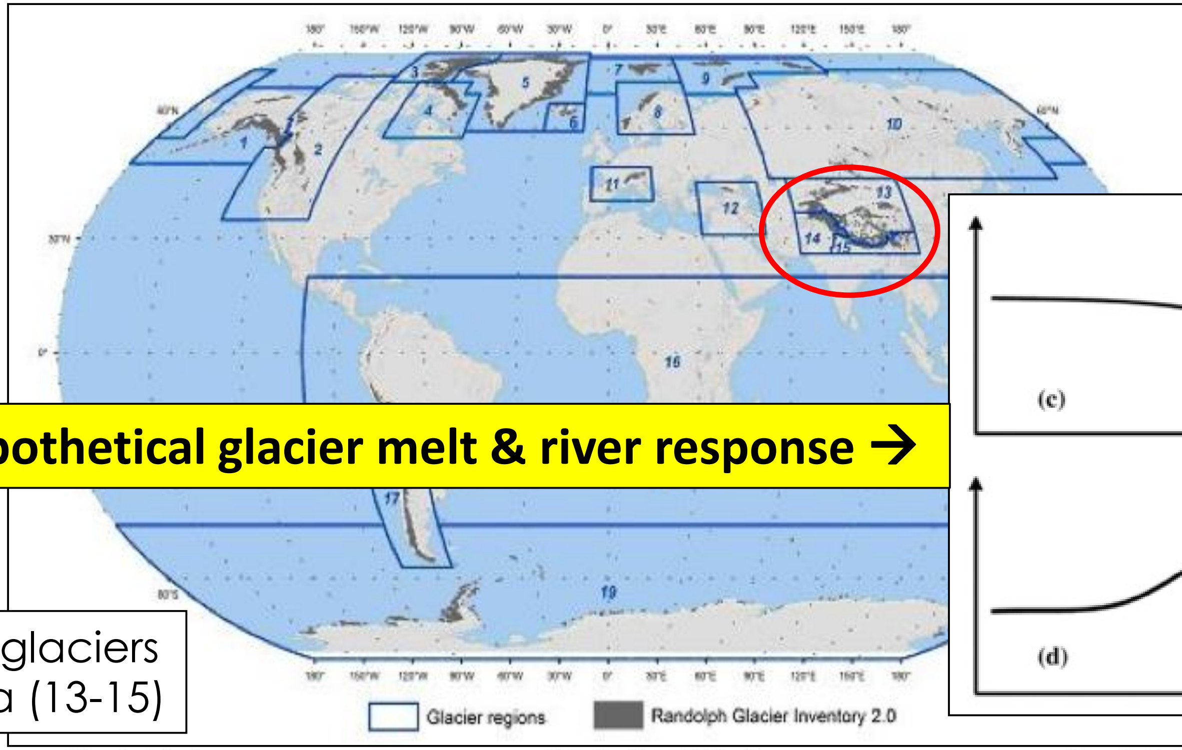


glacier melt sea-level equiv. (mm)

IPCC AR5 RCP4.5 scenario

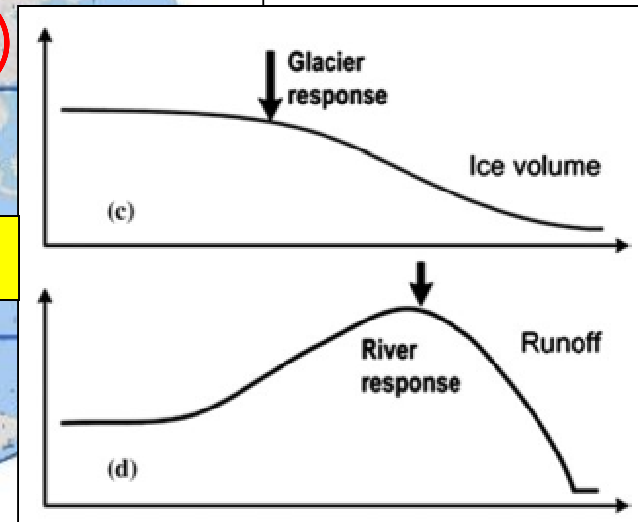
3. Outcomes Coupling WBM & Glacier Mass Balance Modeling

Radic et al. (*Climate Dynamics, 2013*)



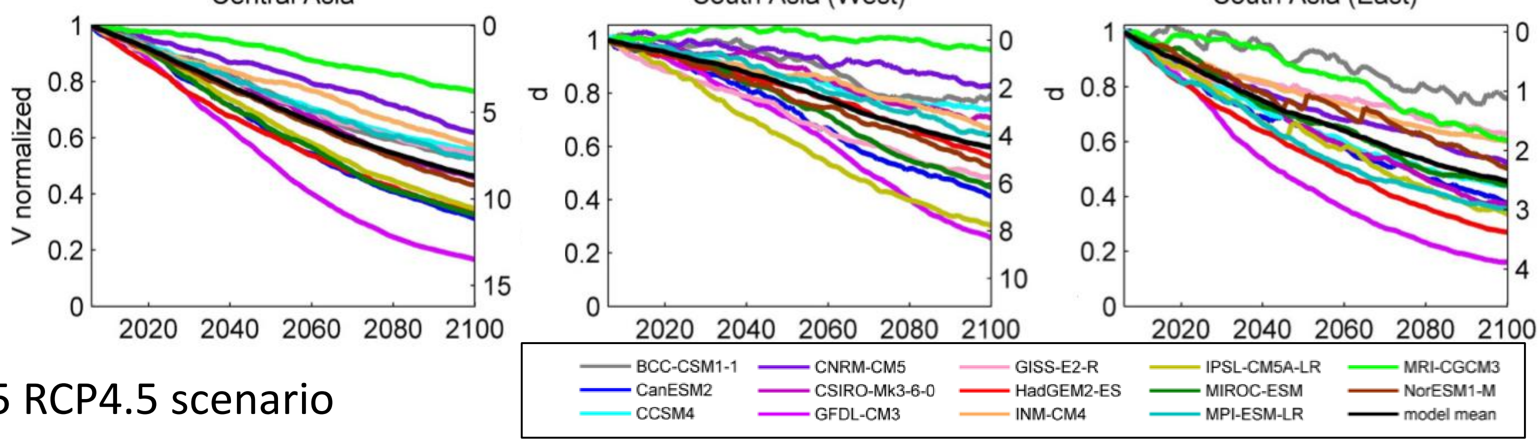
About 80,000 glaciers in Central Asia (13-15)

Hypothetical glacier melt & river response →



Xu et al. (2009)

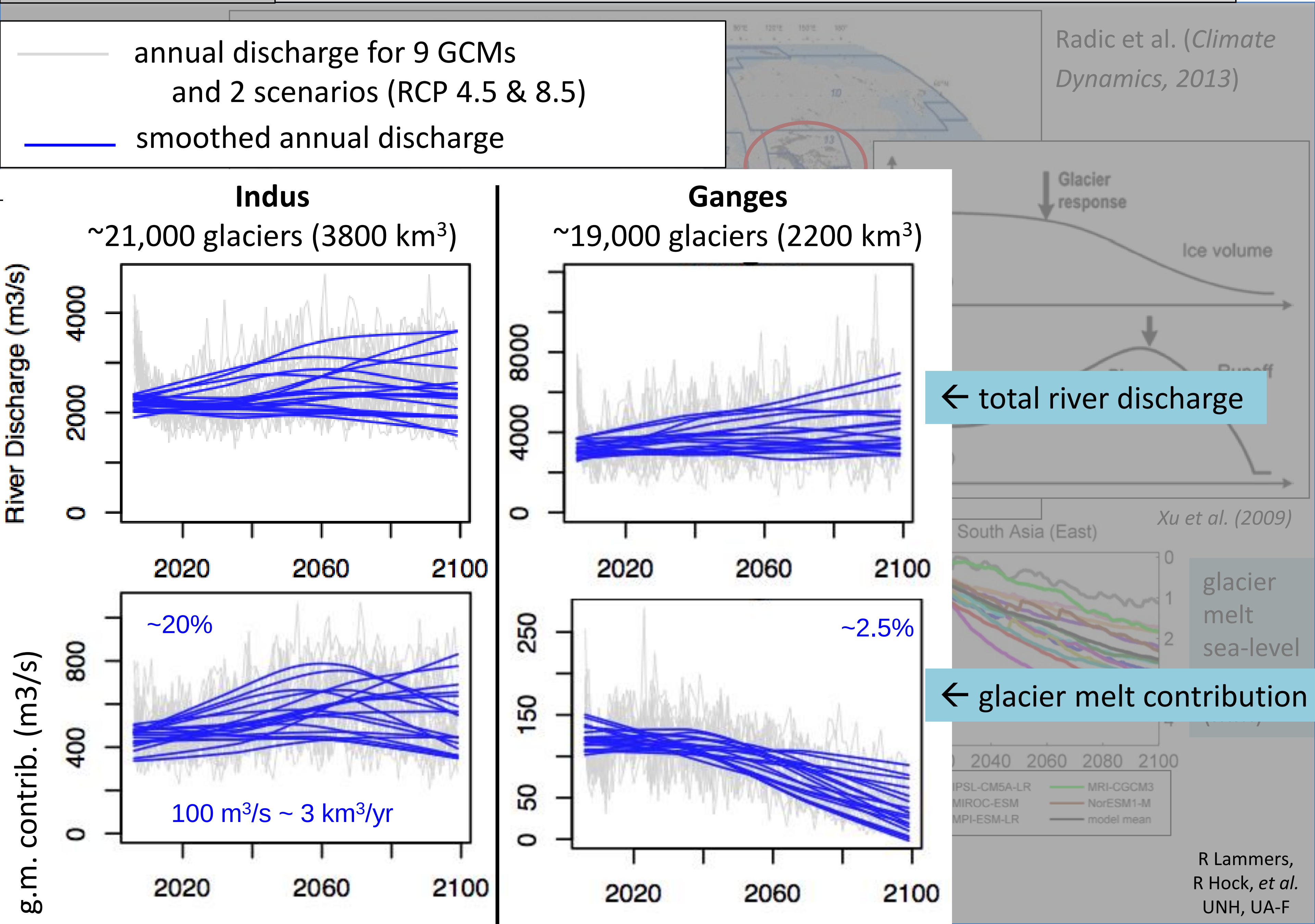
glacier annual volume



glacier melt sea-level equiv. (mm)

IPCC AR5 RCP4.5 scenario

3. Outcomes | Coupling WBM & Glacier Mass Balance Modeling

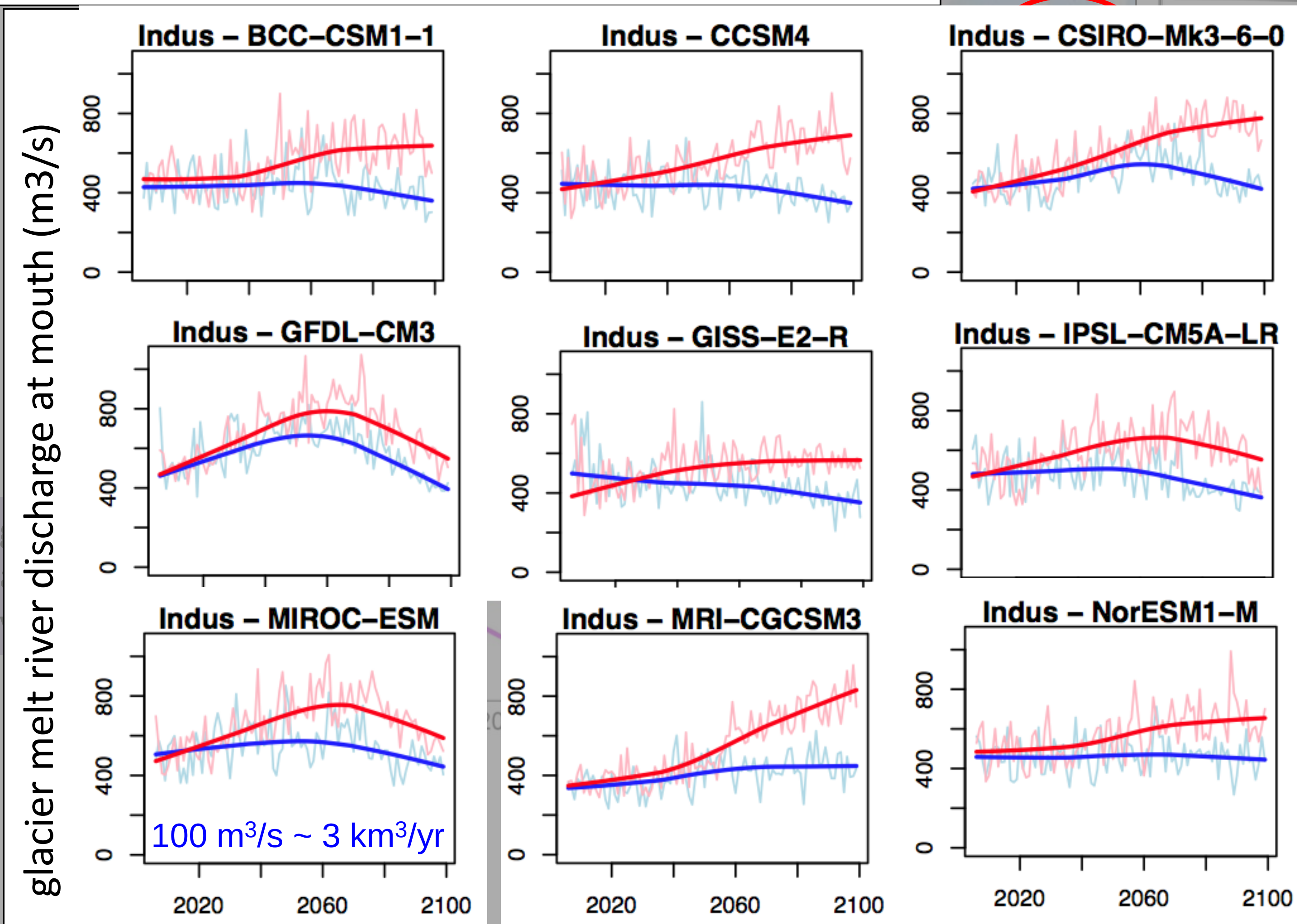


R Lammers,
R Hock, *et al.*
UNH, UA-F

3. Outcomes Coupling WBM & Glacier Mass Balance Modeling

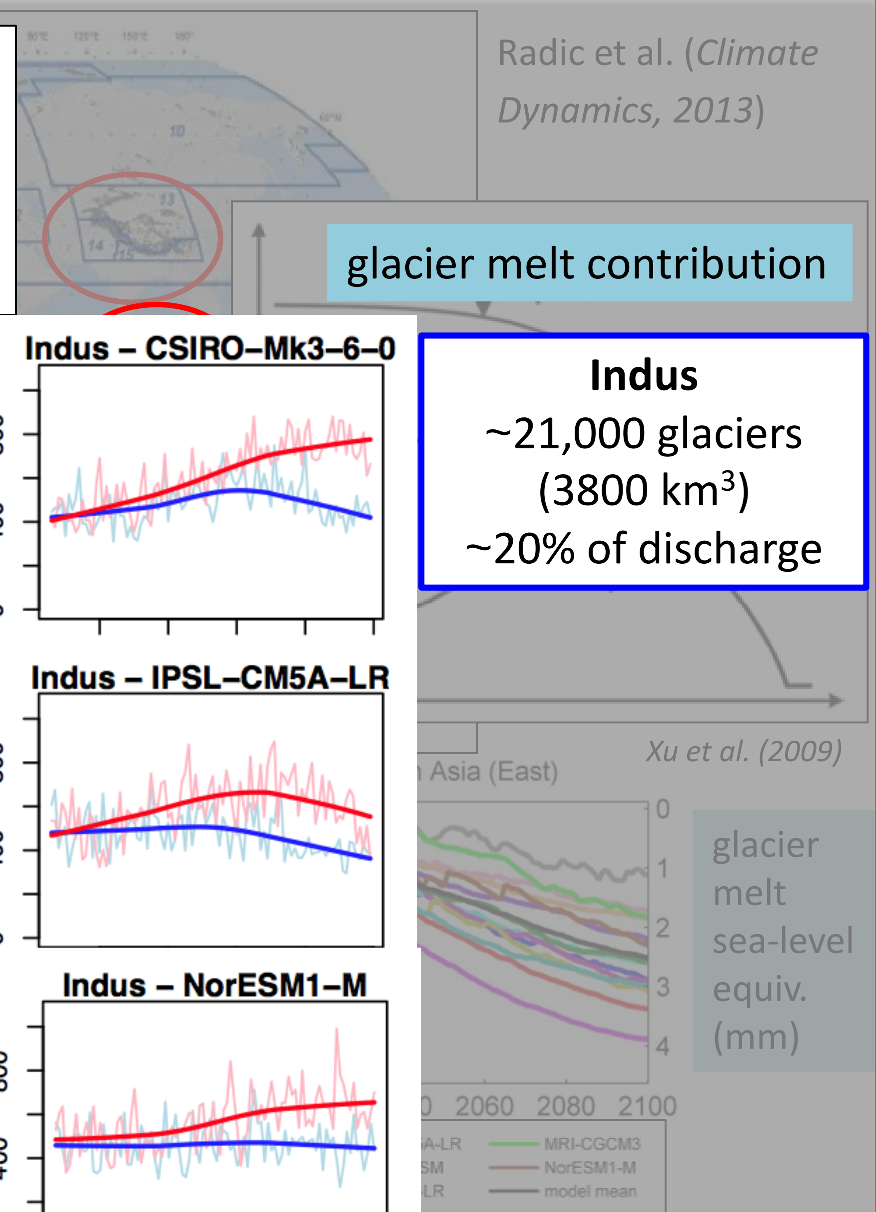
Indus River annual discharge for 9 GCMs and 2 scenarios (RCP 4.5 & 8.5)

smoothed annual discharge (RCP 4.5 & 8.5)



Indus
~21,000 glaciers
(3800 km³)
~20% of discharge

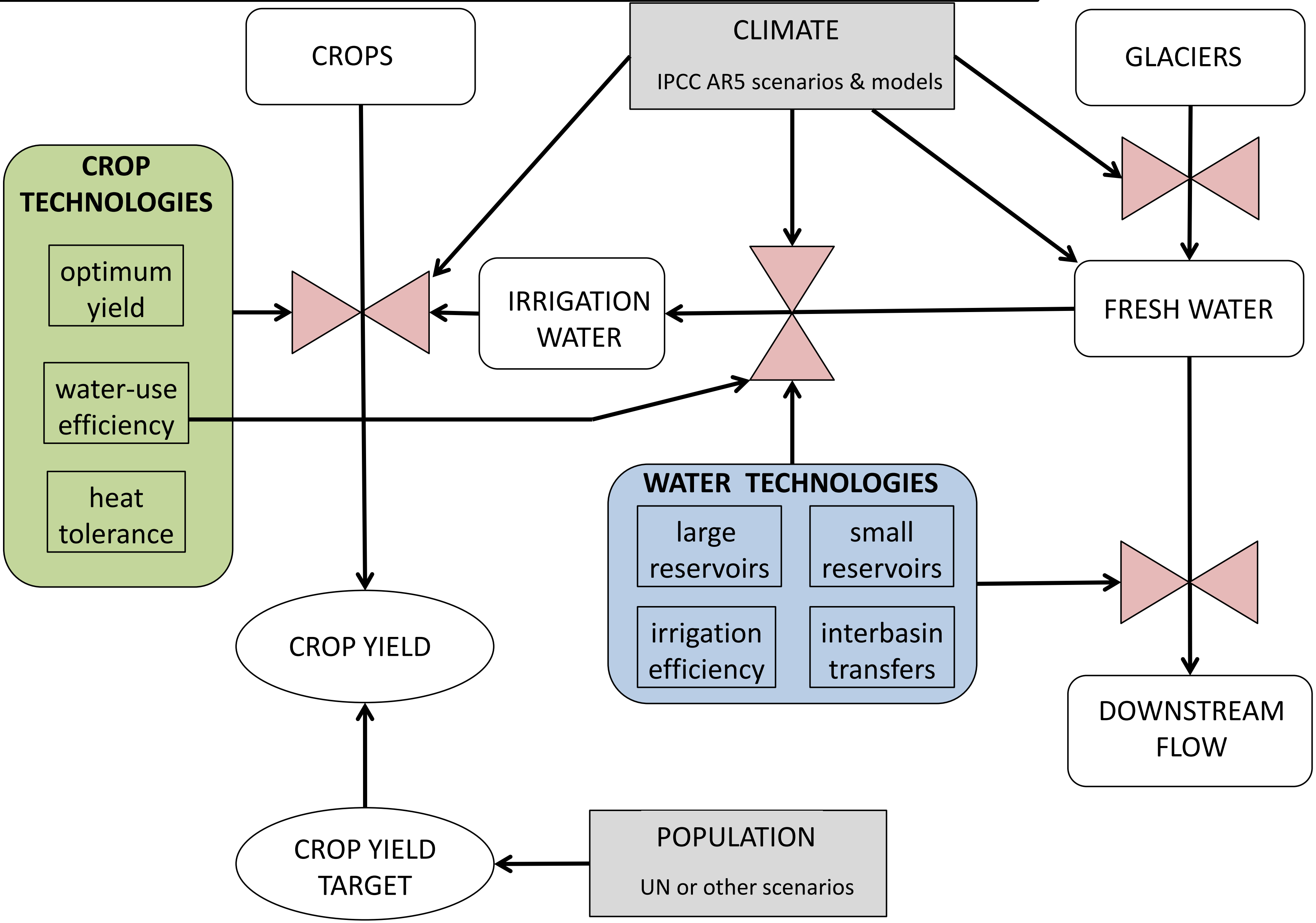
Radic et al. (*Climate Dynamics, 2013*)



R Lammers,
R Hock, *et al.*
UNH, UA-F

4. Relevance to IAMs

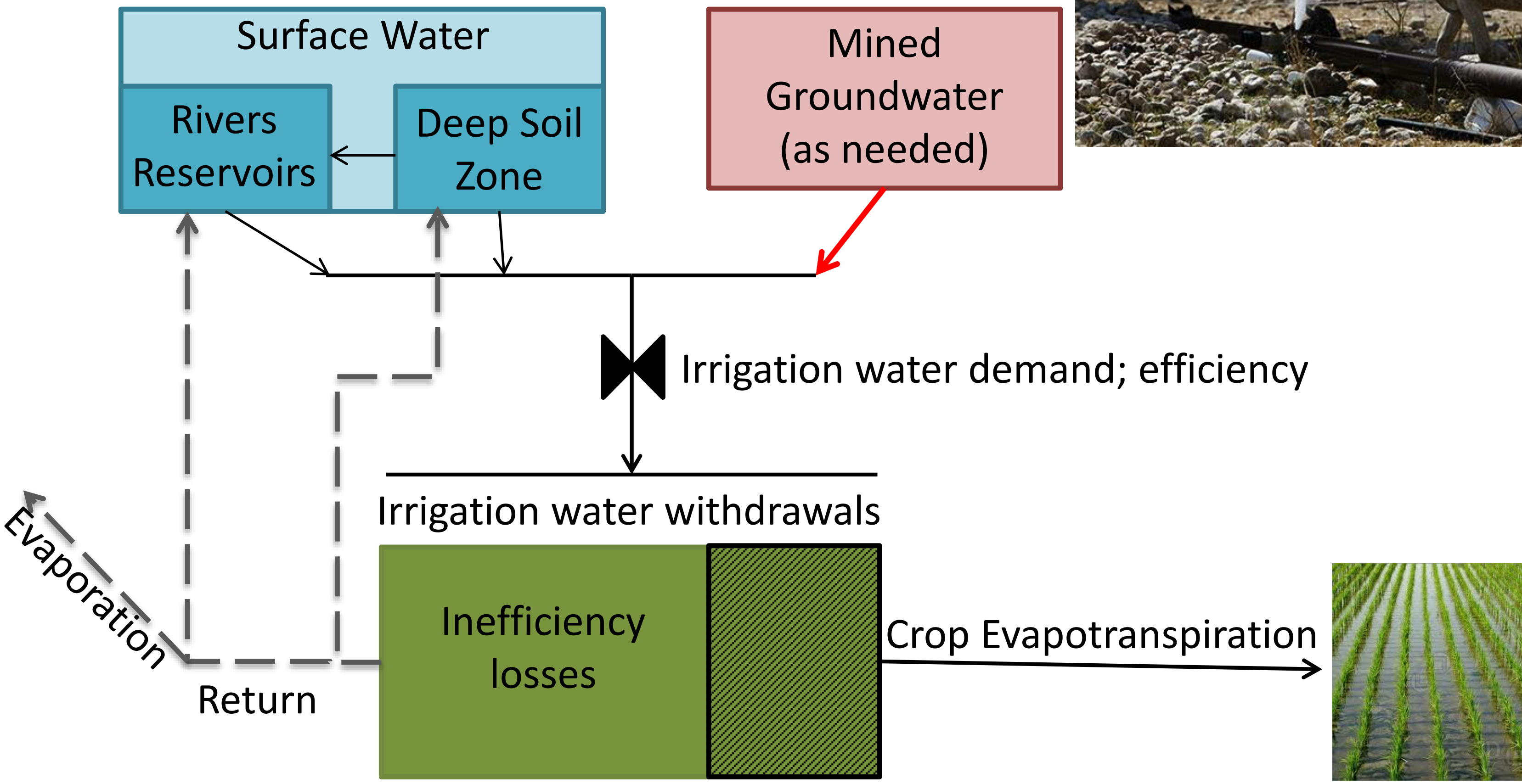
How can ‘technologies’ improve water supply & crop yield?



3. Outcomes

Improving irrigation efficiency

India's irrigation efficiency (FAO) = 0.34
Irrigation water withdrawal = demand ÷ 0.34

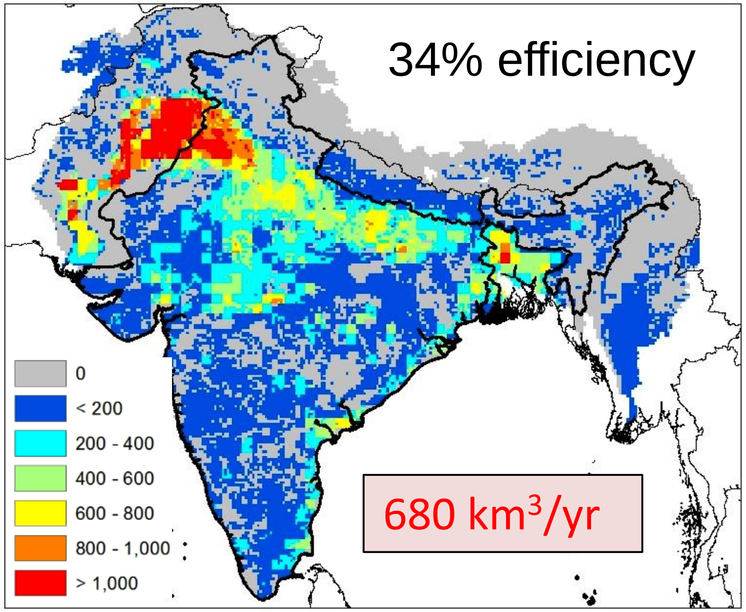


D Grogan
et al.
UNH

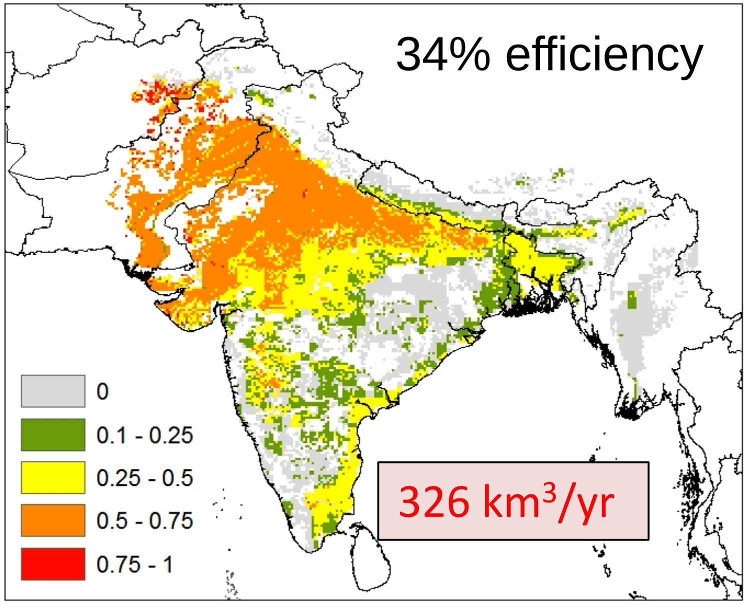
3. Outcomes

Irrigation, mined groundwater fraction of demand (c.2000)

irrigation water demand (mm/y)



Mined groundwater (MGW) fraction of demand



MGW = 48% of demand

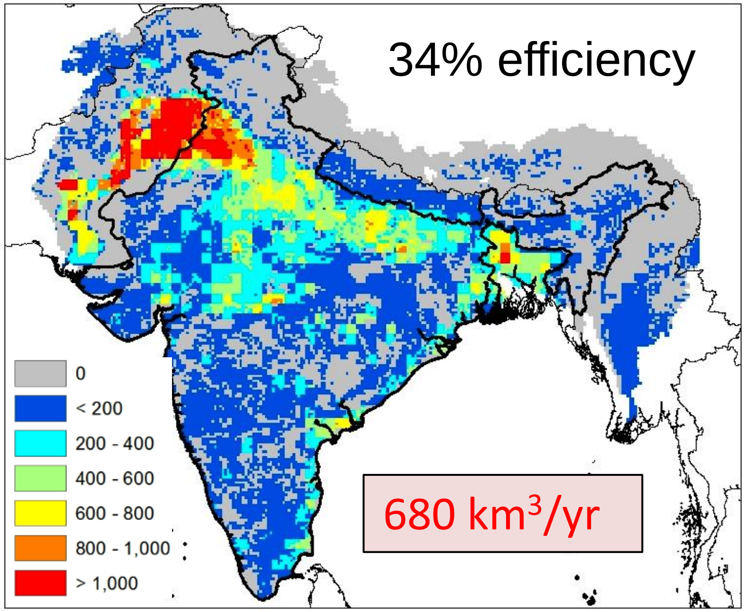
D Grogan *et al.* UNH

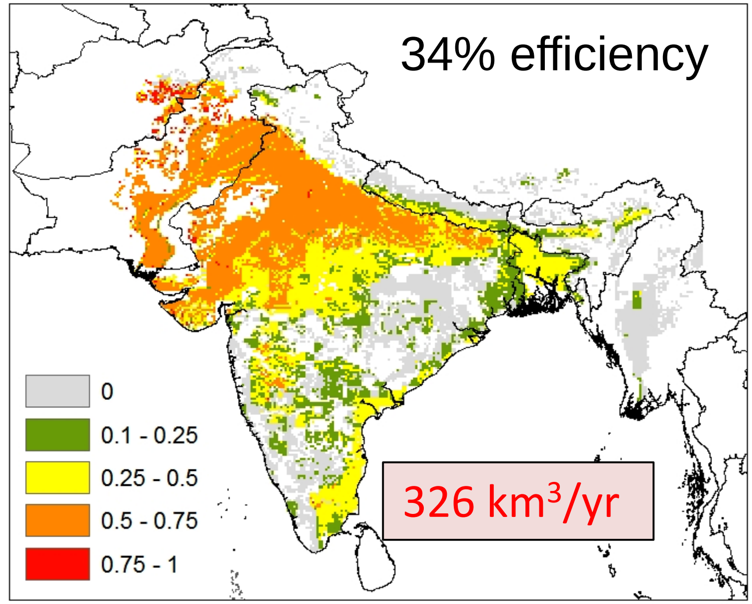
3. Outcomes

Irrigation, mined groundwater fraction of demand (c.2000)

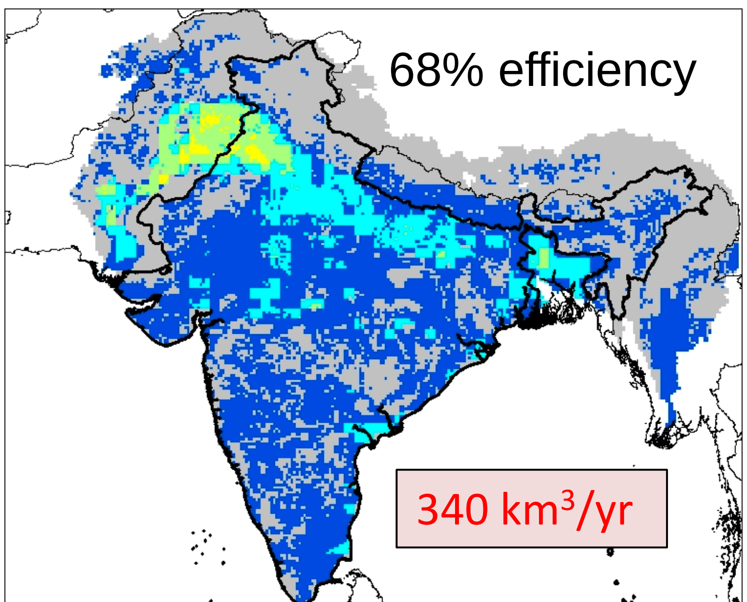
irrigation water demand (mm/y)

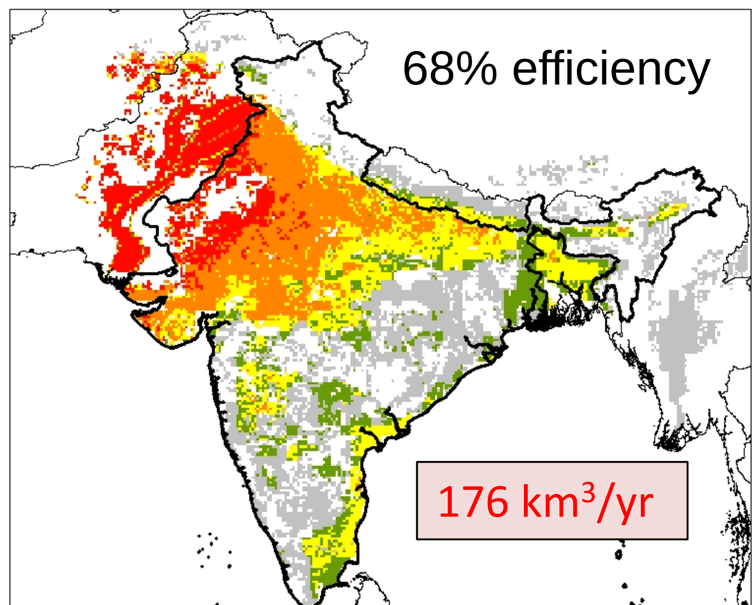
Mined groundwater (MGW) fraction of demand





MGW = 48% of demand





MGW = 52% of demand

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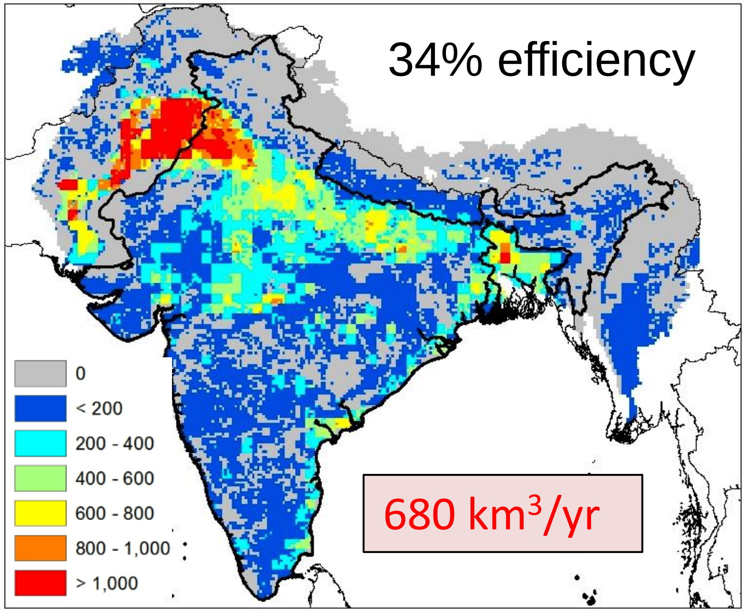
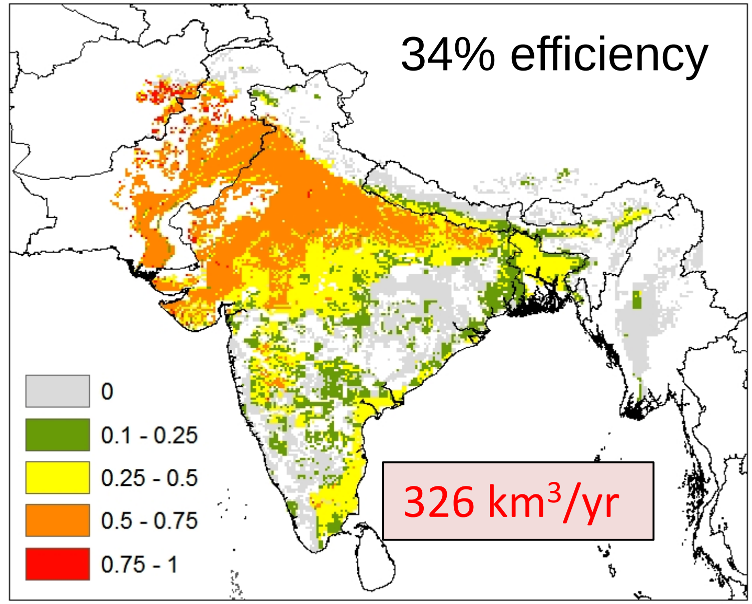
3. Outcomes

Irrigation, mined groundwater fraction of demand (c.2000)

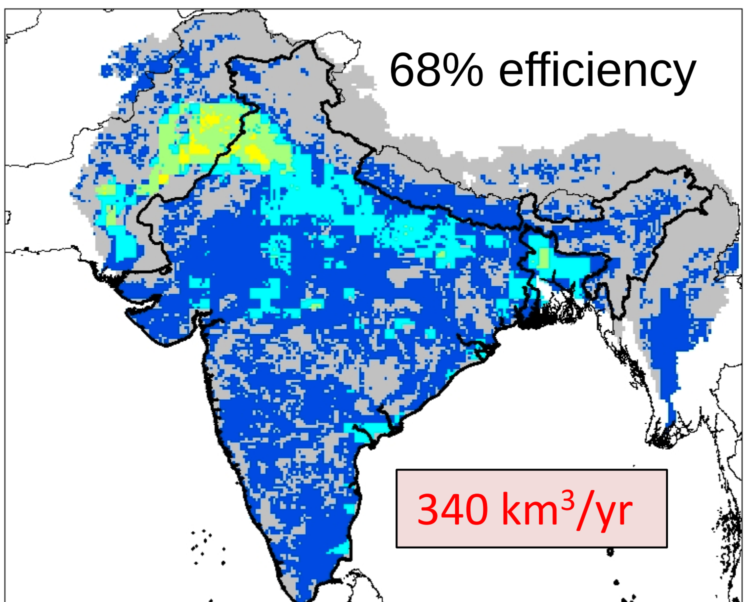
irrigation water demand (mm/y)

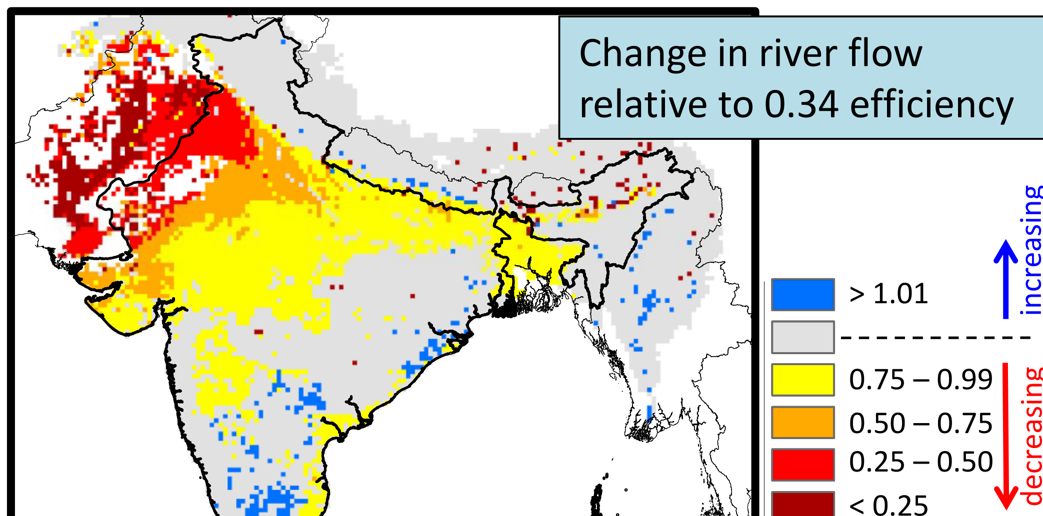


Mined groundwater (MGW) fraction of demand



MGW = 48% of demand





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Chair: Karen Fisher-Vanden

Tuesday:

1:00 PM	Energy: Empirical estimates of impacts: Ian Sue Wing
1:30 PM	Water: Process modeling of water: Steve Frolking
2:00 PM	Water: Pat Reed
2:30 PM	DISCUSSION: ENERGY & WATER IMPACTS
3:00 PM	BREAK
3:30 PM	Adaptation for city infrastructure: Paul Kirshen
4:00 PM	Sea Level: Sea level rise: Bob Kopp
4:30 PM	Extreme Events: Carolyn Kousky
5:00 PM	DISCUSSION: Cities, Sea Level, and Extreme Events

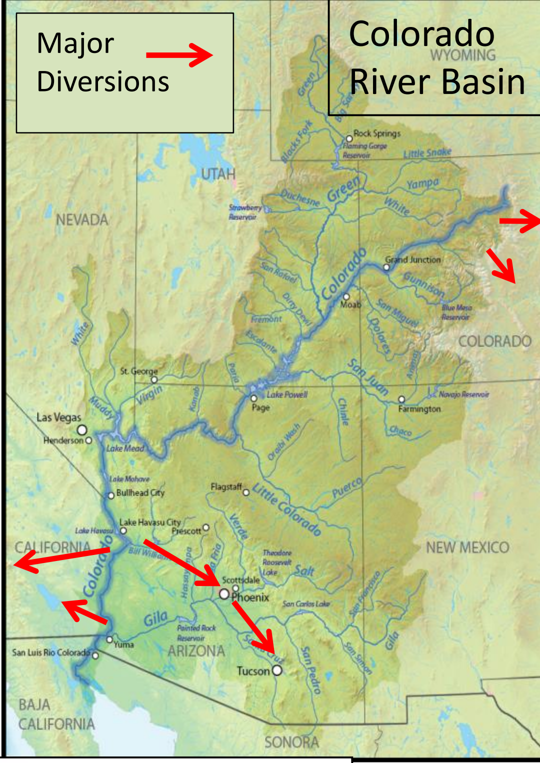
As you can see, you are scheduled to speak in the session I am chairing titled, "The State of the Art in Understanding Potential Climate Impacts and Adaptation," on Tuesday afternoon (July 22nd) and Wednesday morning (July 23rd). As the title suggests, the purpose of this session is to provide an overview of the state-of-the-art in empirical and process modeling work on climate impacts and adaption in six sectors (energy, water, city infrastructure, sea level rise, extreme events, and agriculture). ***In addition to providing a short summary of the state-of-the-art in your assigned sector, if would be great if you could provide some thoughts on how the findings from these studies could inform integrated assessment models, if possible. We are hoping that speakers will provide a good survey of the work being done in the field and won't focus their talks solely on their own work.*** We realize that this is a lot to cover in the time allotted, but we are hoping that speakers will keep their ***presentations to 20 minutes, with 10 minutes for Q&A***. We will then be opening the floor to further discussion after the set of presentations.

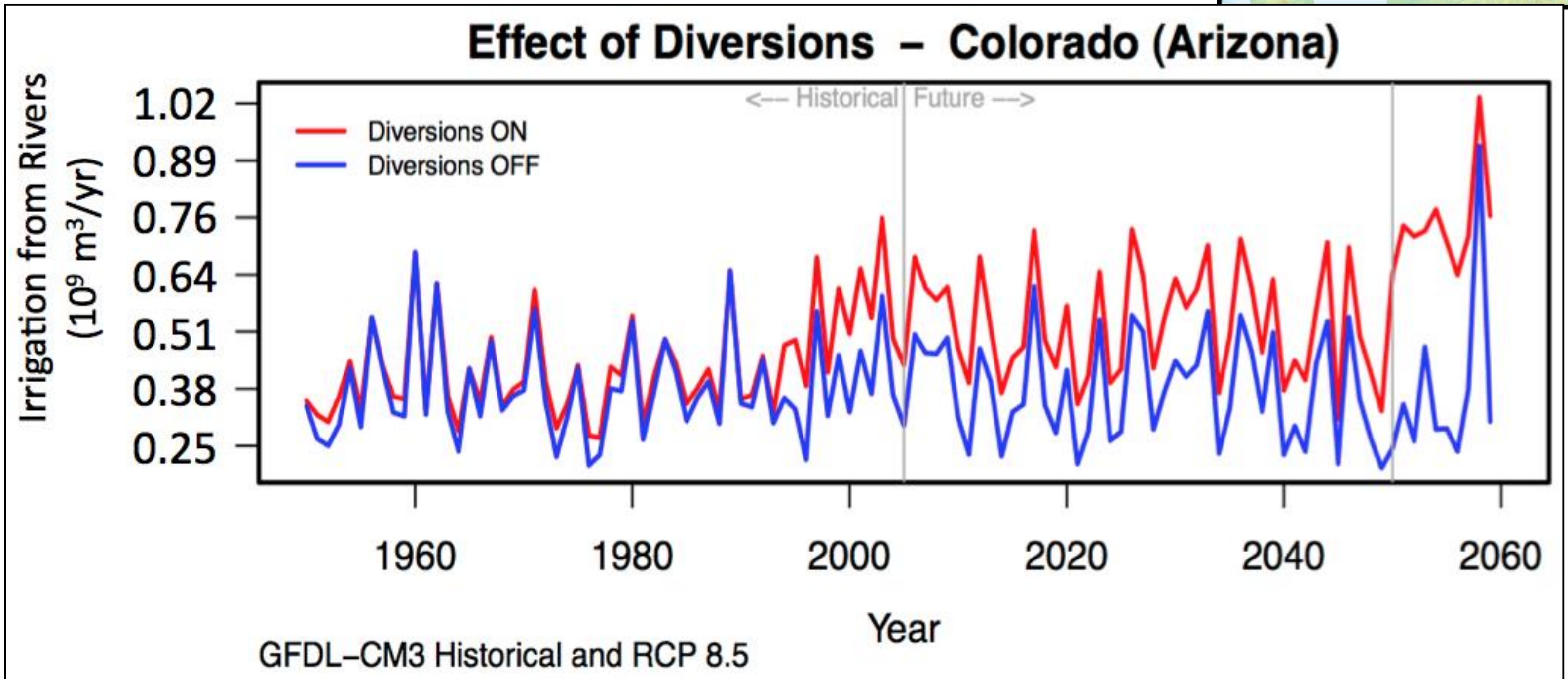
3. Outcomes Interbasin Water Transfers

Includes: Reservoirs and Irrigation. Irrigation water applied with 100% efficiency (no loss back to system).

With and Without Inter-basin Transfers (Diversions).

When Diversions turned on (red line) more water is abstracted from rivers for irrigation.

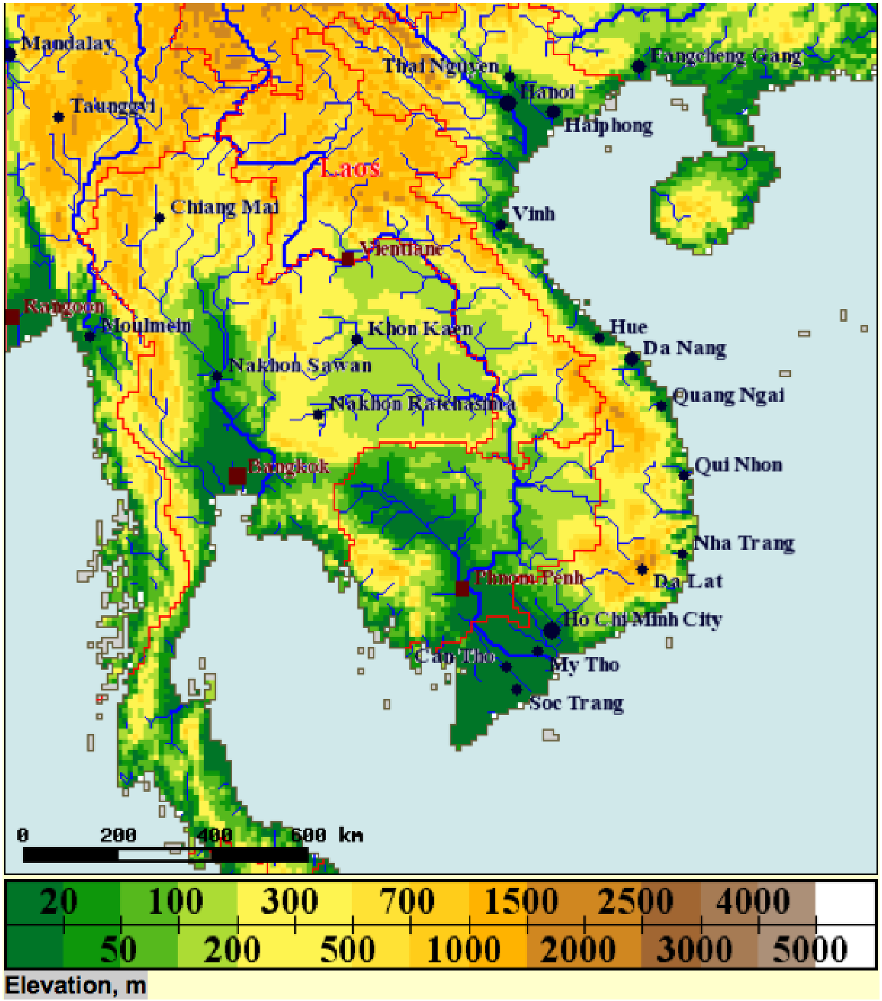




1. Framework & methods

Geophysical

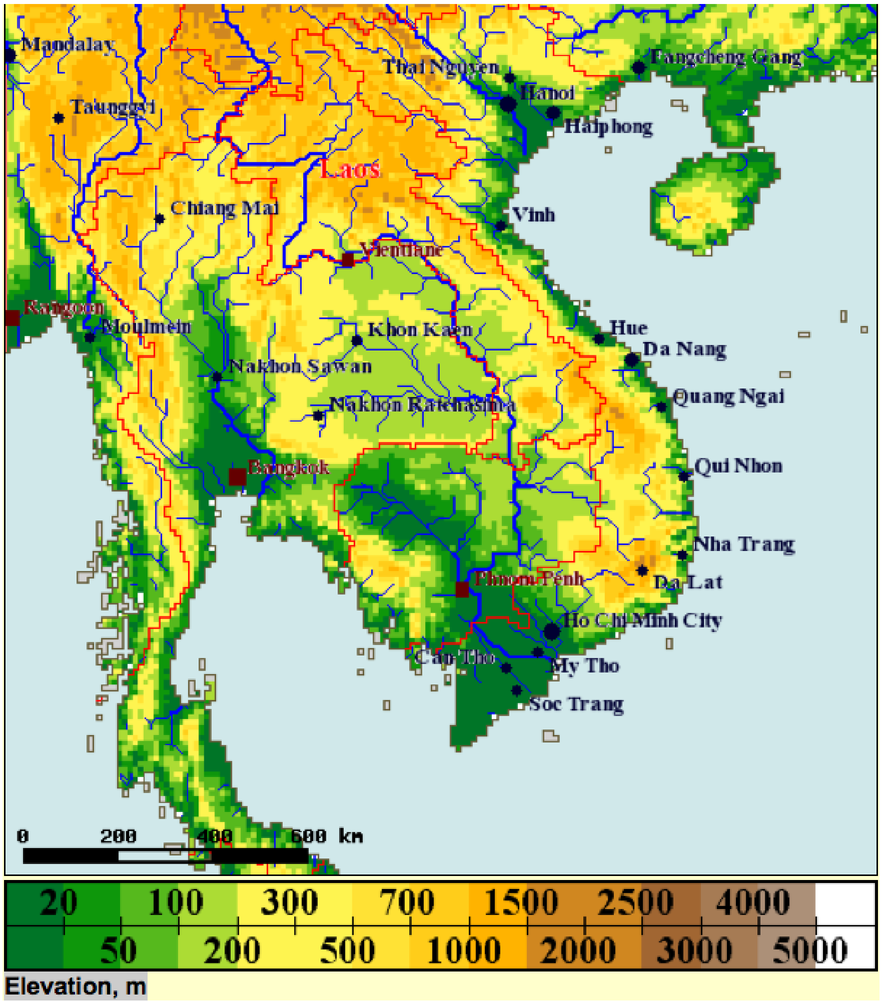
Water flows downhill!



1. Framework & methods

Geophysical

Water flows downhill!



Socio-Economic

Unless it doesn't!

South-to-North Water Transfer Canal, China

Water flows up-money?