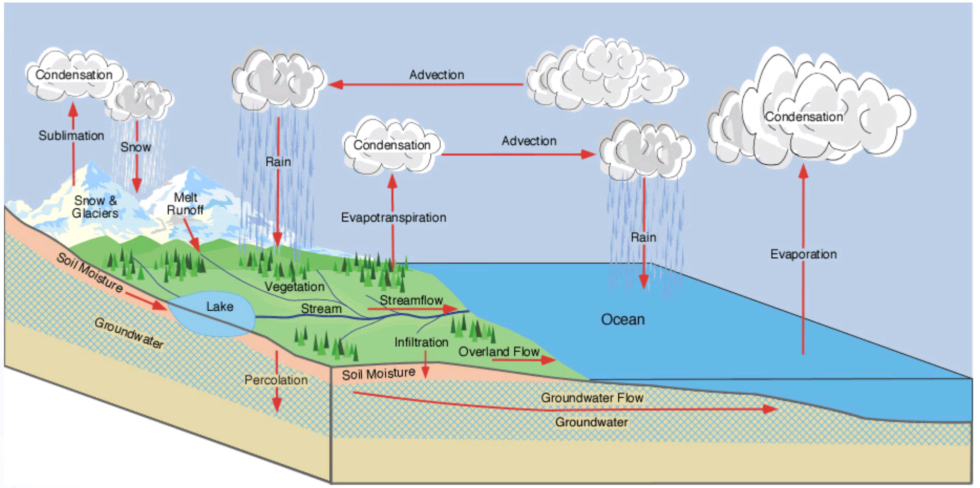


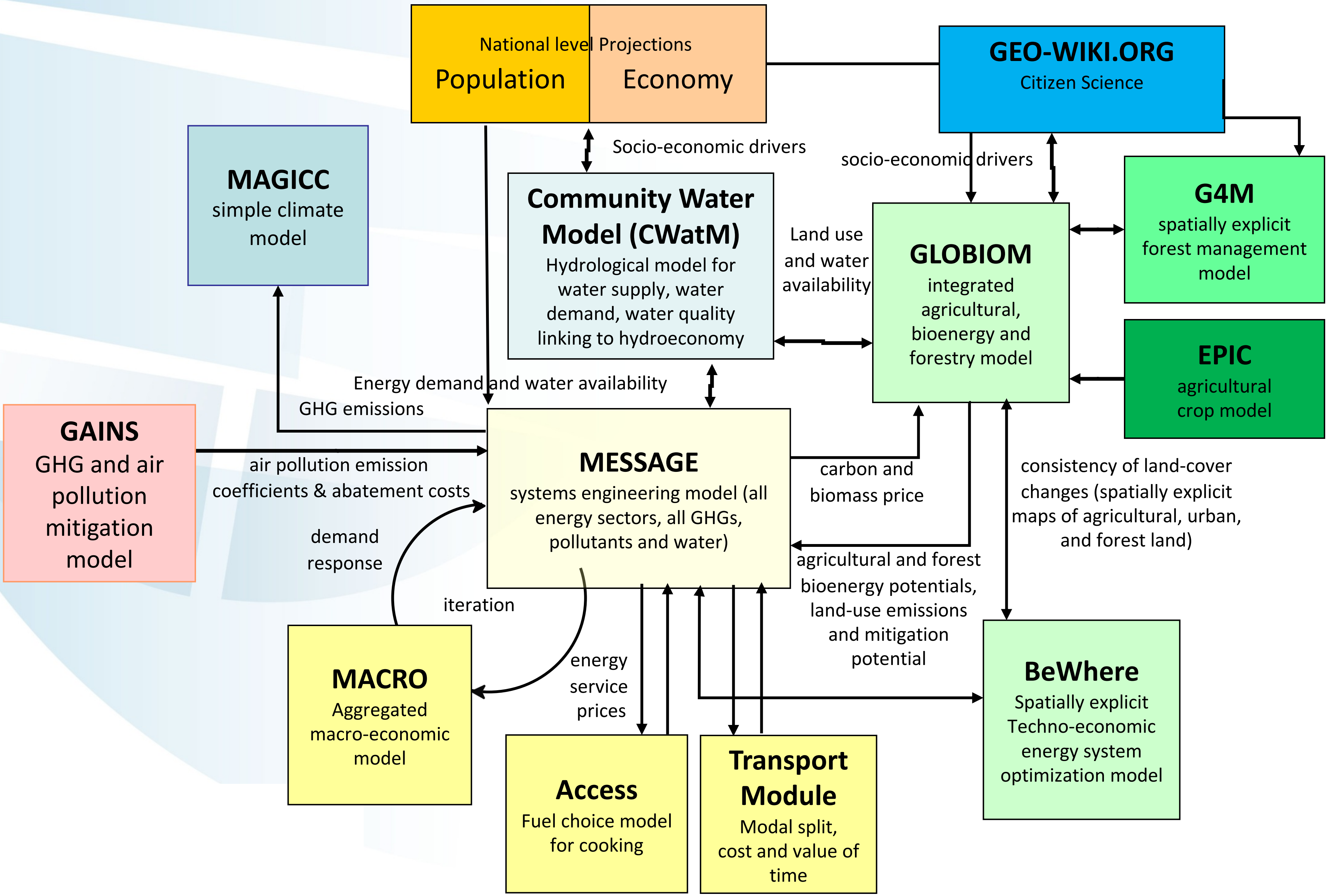
State of knowledge of land management impacts on water and climate

Yoshihide Wada

Director of Water Program, International Institute for Applied Systems Analysis (IIASA)
Professor of Global Water and Food Security, Utrecht University
Governors of World Water Council (WWC)
wada@iiasa.ac.at

16-20 September 2019
Impacts of Land Use and Land Management on Earth System Evolution, Biogeochemical Cycles, Extremes and Inter-Sectoral Dynamics
Snowmass, CO, USA

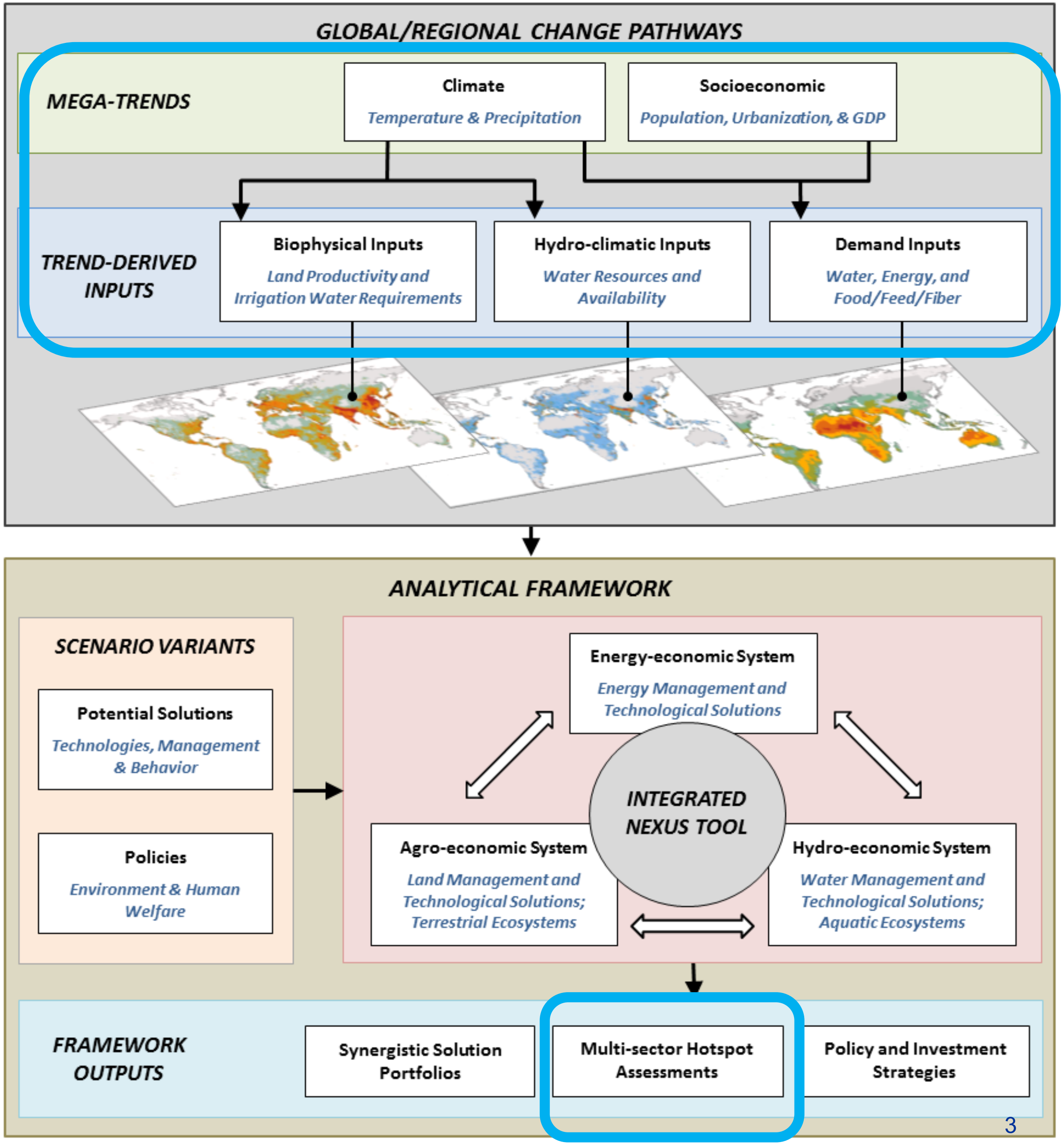
IIASA Integrated Assessment Framework (offline/online)



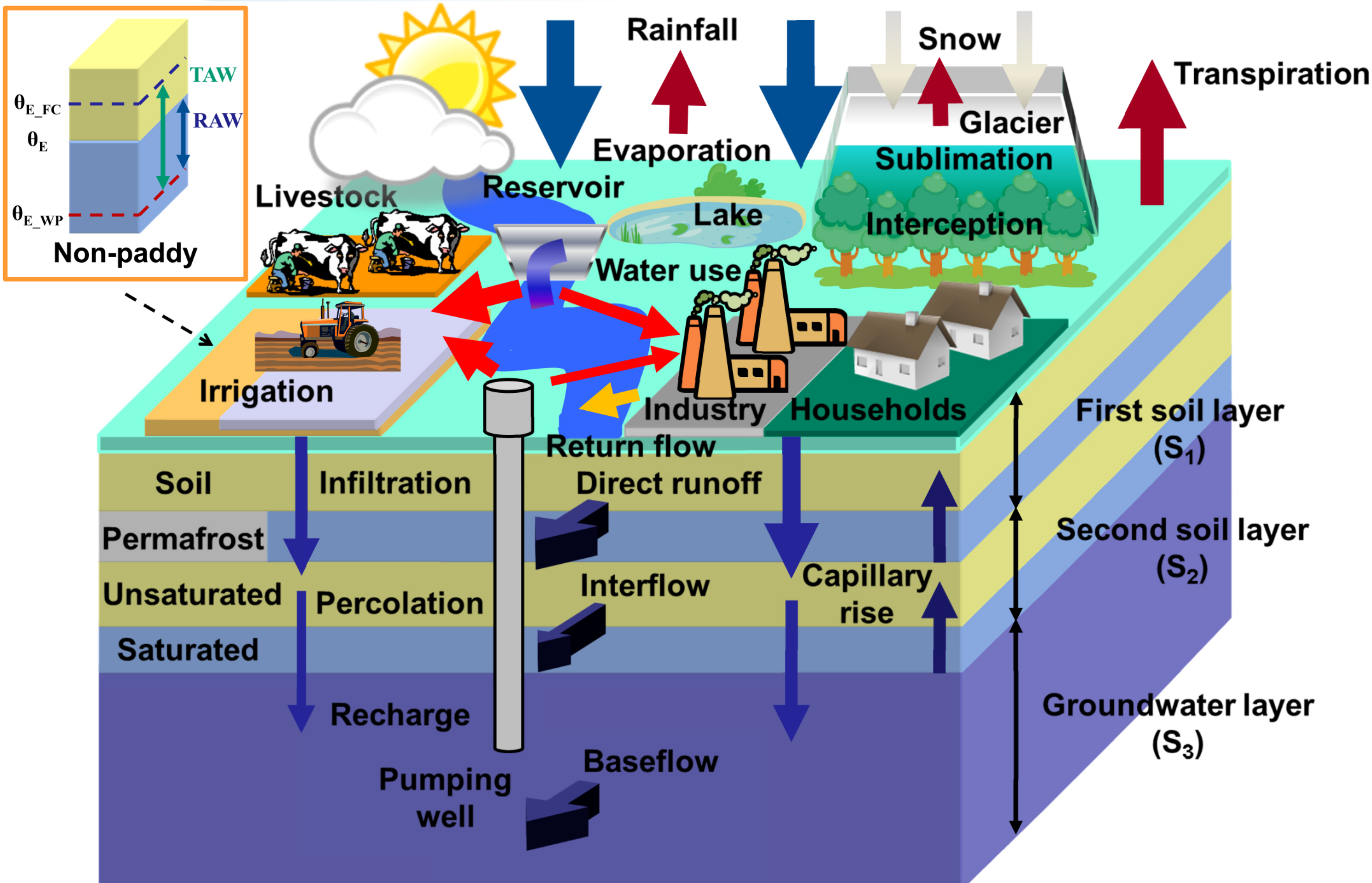
Modeling framework

- Inputs

- Outputs

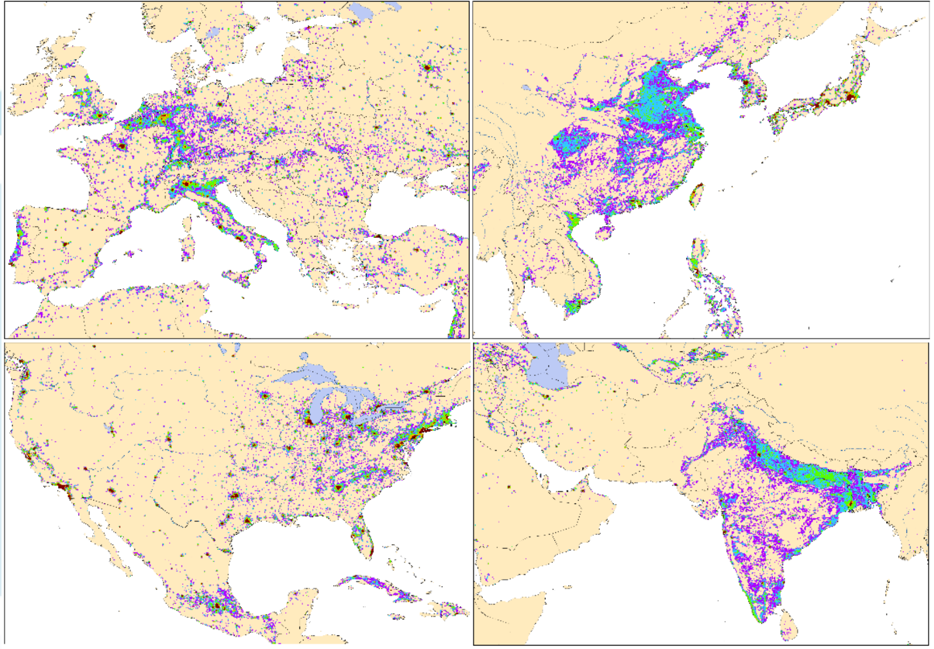


Community Water Model (CWatM) for global to regional scales
Open source; https://cwatm.iiasa.ac.at/index.html



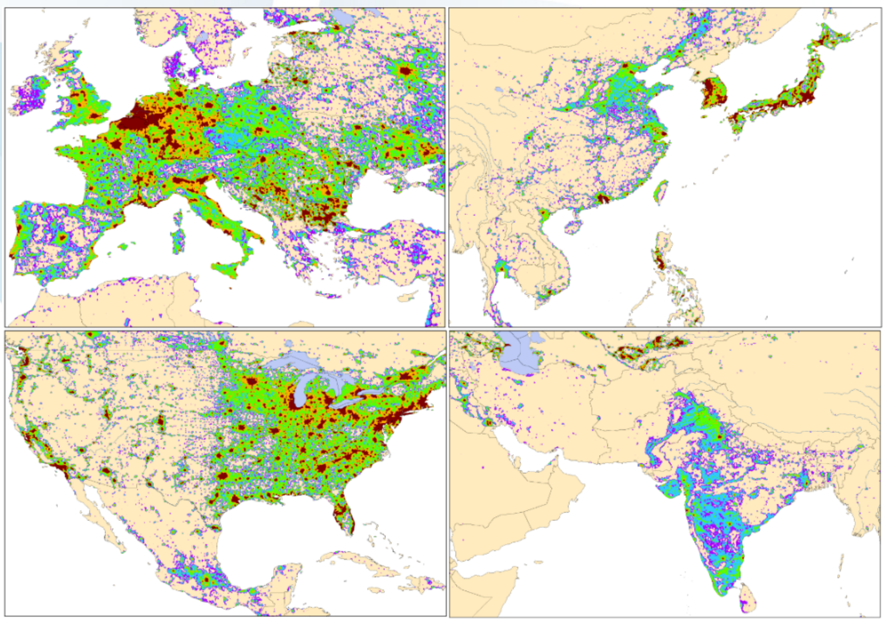
Burek et al. (2019; GMD)

Hydrology and water use simulation based on land use, GDP, population and other socio-economic data (50km => 10km grid)



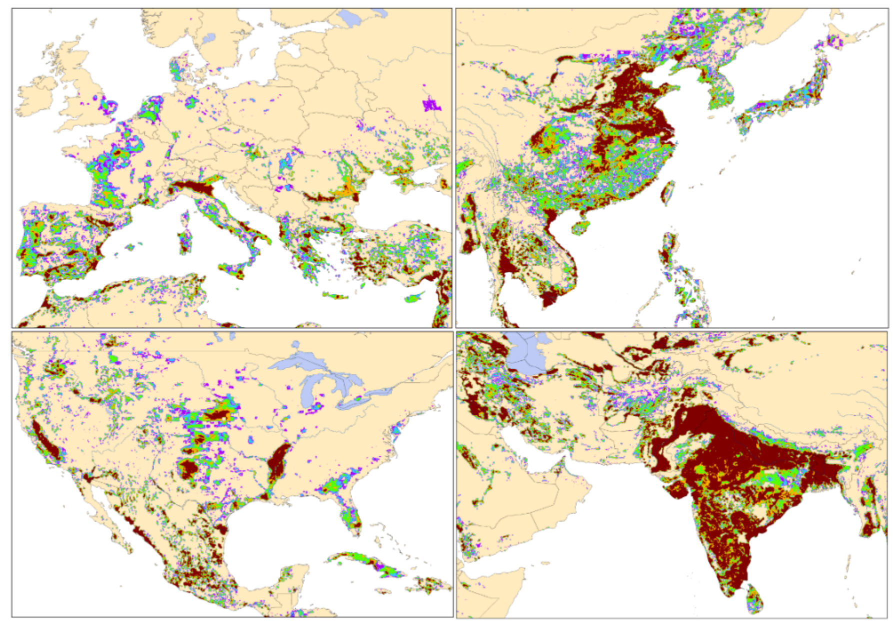
Domestic water use [million cubic meter per year]

0 - 0.5 | 0.5 - 1 | 1 - 2 | 2 - 5 | 5 - 10 | > 10



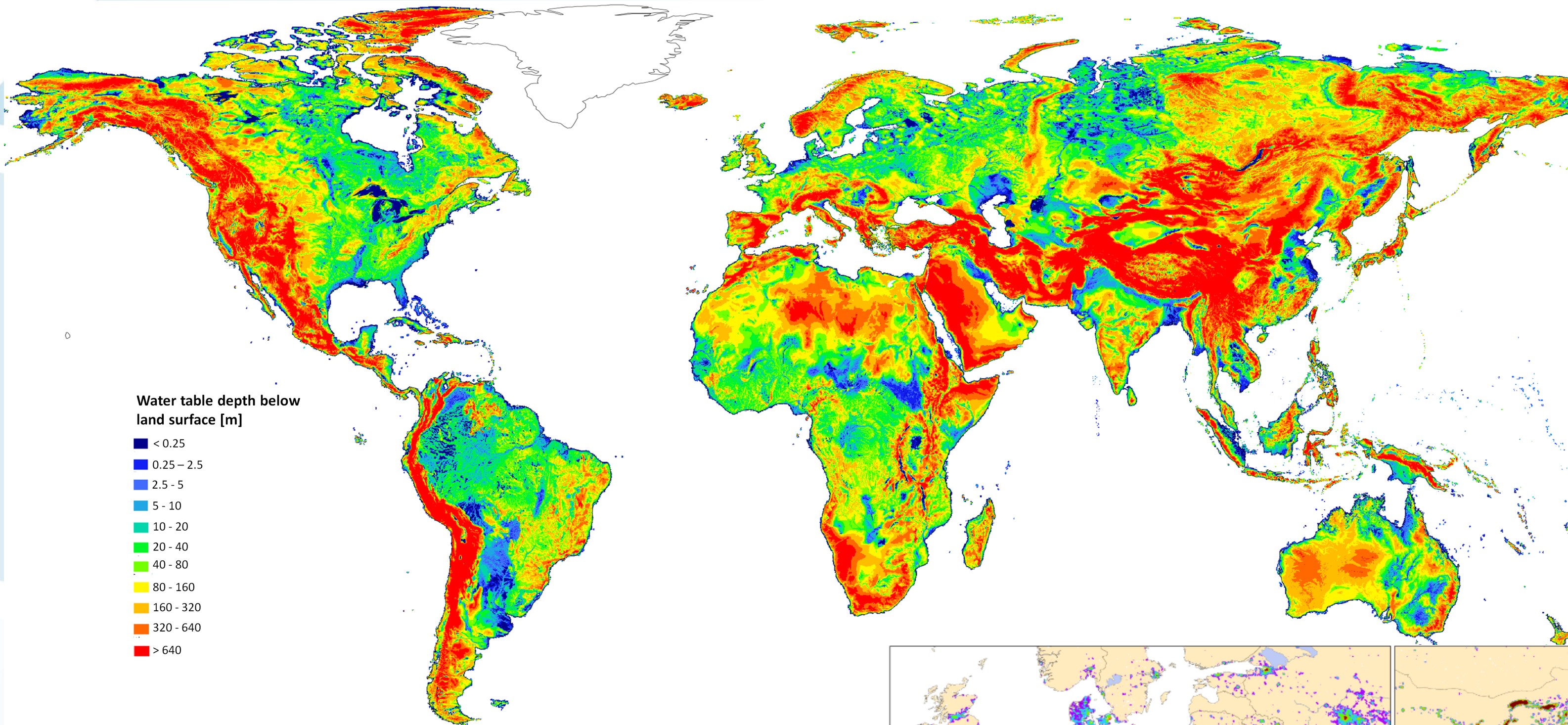
Industrial water use [million cubic meter per year]

0 - 0.5 | 0.5 - 1 | 1 - 2 | 2 - 5 | 5 - 10 | > 10



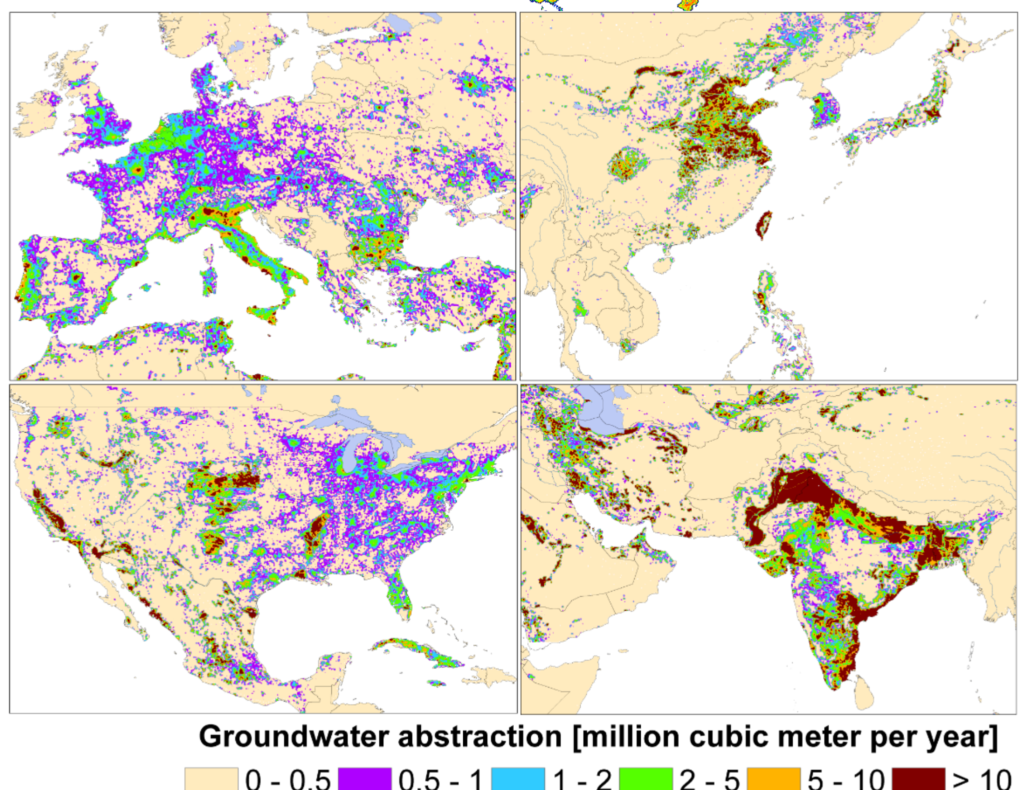
Irrigation water use [million cubic meter per year]

0 - 0.5 | 0.5 - 1 | 1 - 2 | 2 - 5 | 5 - 10 | > 10



Groundwater level
[De Graaf et al., 2014; HESS]

Groundwater representation including lateral fluxes



Groundwater pumping
[Wada et al., 2016; JAMES]

ISIMIP-ISIpedia; https://www.isimip.org/

climate projections
RCP scenarios from CMIP & CORDEX archives

Socio-economic input
SSP scenarios

Impact models global & regional

agriculture	water
biomes	Forests
coastal infrastructure	health
fisheries	energy
agro-economics	permafrost

- Synthesis of impacts at different levels of global warming
- Quantification of uncertainties
- Model improvement
- Cross-sectoral interactions
- Cross-scale intercomparison
- Focus topics (e.g. extreme events, adaptation)

ISIMIP Fast Track (2012-2014)
ISIMIP 2a (2014-2016)
ISIMIP 2b (2016-2019)
ISIMIP 3 (2020-)

ISIMIP Inter-Sectoral Impact Model Intercomparison Project

ABOUT GETTING STARTED PROTOCOL IMPACT MODELS

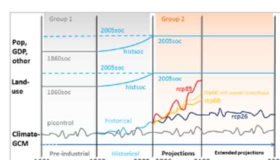
The Inter-Sectoral Impact Model Intercomparison Project

ISIMIP offers a framework for consistently projecting the impacts of climate change across affected sectors and spatial scales. An international network of climate-impact modellers contribute to a comprehensive and consistent picture of the world under different climate-change scenarios.

READ MORE

NEWS

Key insights from ISIpedia stakeholder workshops
June 12, 2019
The ISIpedia Stakeholder Engagement Team (SET) conducted two workshops where ISIMIP modellers and ...



Extended ISIMIP2b protocol released
Feb. 28, 2019
A new version of the ISIMIP2b protocol has been released and can be found here ...

Registration for cross-sectoral ISIMIP workshop in June now open!
Feb. 27, 2019
You can now register for the next cross-sectoral ISIMIP workshop ...

ISIMIP IN NUMBERS

53
ISIMIP2b output data sets
Impact models with ISIMIP2b simulations available on our DKRZ server.

84
ISIMIP2a output data sets
Impact models with ISIMIP2a simulations available on our DKRZ server.

dataset	Data category	Meteorological forcing GSWP3	PGMFD	WFDEI	Citation
FLUXNET-MTE	Diagnostic				Jung *et al* (2009)
GETA 2.0	Diagnostic				Ambrose and Sterling (2014)
GLEAM V3.1A	Diagnostic				Martens *et al* (2016)
MODIS Global ET	Diagnostic				Mu *et al* (2011)
PM-MU-LANDFLUX	Diagnostic				Vinukollu *et al* (2011)
PML-CSIRO	Diagnostic				Zhang *et al* (2016)
PT-FI-LANDFLUX	Diagnostic				Fisher *et al* (2008)
SEBS-LANDFLUX	Diagnostic				Su (2001)
WANG-ET	Diagnostic				Wang *et al* (2010a, b)
WB-MTE	Diagnostic				Zeng *et al* (2014)
WECANN	Diagnostic				Alemohammad *et al* (2016)
HBV-SIMREG	E2O			x	Beck *et al* (2016)
HTESSEL	E2O			x	Balsamo *et al* (2011)
JULES	E2O			x	Best *et al* (2011)
LISFLOOD	E2O			x	Burek *et al* (2013)
ORCHIDEE	E2O			x	Krinner *et al* (2005)
PCR-GLOBWB	E2O			x	Wada *et al* (2014)
SURFEX-TRIP	E2O			x	Oki and Sud (1998)
W3RA	E2O			x	van Dijk *et al* (2013)
WaterGAP3	E2O			x	Eisner (2016)
CLM-CROP[a]	ISIMIP agriculture			x	Drewniak *et al* (2013)
EPIC-BOKU[a]	ISIMIP agriculture	x	x	x	Williams (1995), Izaurralde *et al* (2006)
EPIC-IIASA[a]	ISIMIP agriculture			x	Balkovič *et al* (2014)
EPIC-TAMU[a]	ISIMIP agriculture			x	Kiniry *et al* (1995)
GEPIC[a]	ISIMIP agriculture			x	Liu *et al* (2007), Folberth *et al* (2012)
LPJ-GUESS[a]	ISIMIP agriculture	x			
LPJmL[a]	ISIMIP agriculture				
ORCHIDEE-CROP[a]	ISIMIP agriculture	x			
PAPSIM[a]	ISIMIP agriculture				
PDSSAT[a]	ISIMIP agriculture				
PEGASUS[a]	ISIMIP agriculture				
PEPIC[a]	ISIMIP agriculture	x			
CARAIB[c]	ISIMIP biomes	x			
DLEM[c]	ISIMIP biomes	x			
JULES-B1	ISIMIP biomes	x			
LPJ-GUESS	ISIMIP biomes	x			
ORCHIDEE	ISIMIP biomes	x			
VEGAS[c]	ISIMIP biomes	x			
VISIT	ISIMIP biomes	x			
CLM	ISIMIP global water	x			
DBH	ISIMIP global water	x			
H08	ISIMIP global water	x			
JULES-W1	ISIMIP global water	x			
LPJmL	ISIMIP global water	x			
MATSIRO	ISIMIP global water	x			
MPI-HM	ISIMIP global water	x			
PCR-GLOBWB	ISIMIP global water	x			
SWBM	ISIMIP global water	x			
VIC	ISIMIP global water	x			
WaterGAP2	ISIMIP global water	x			
ERA-Interim/Land	Land Reanalyses				
MERRA-2	Land Reanalyses				
LandFlux-EVAL[b]	Composite[b]				

IOP Publishing   *Environ. Res. Lett.* 13 (2018) 075001   https://doi.org/10.1088/1748-9326/aac4bb

Environmental Research Letters

LETTER

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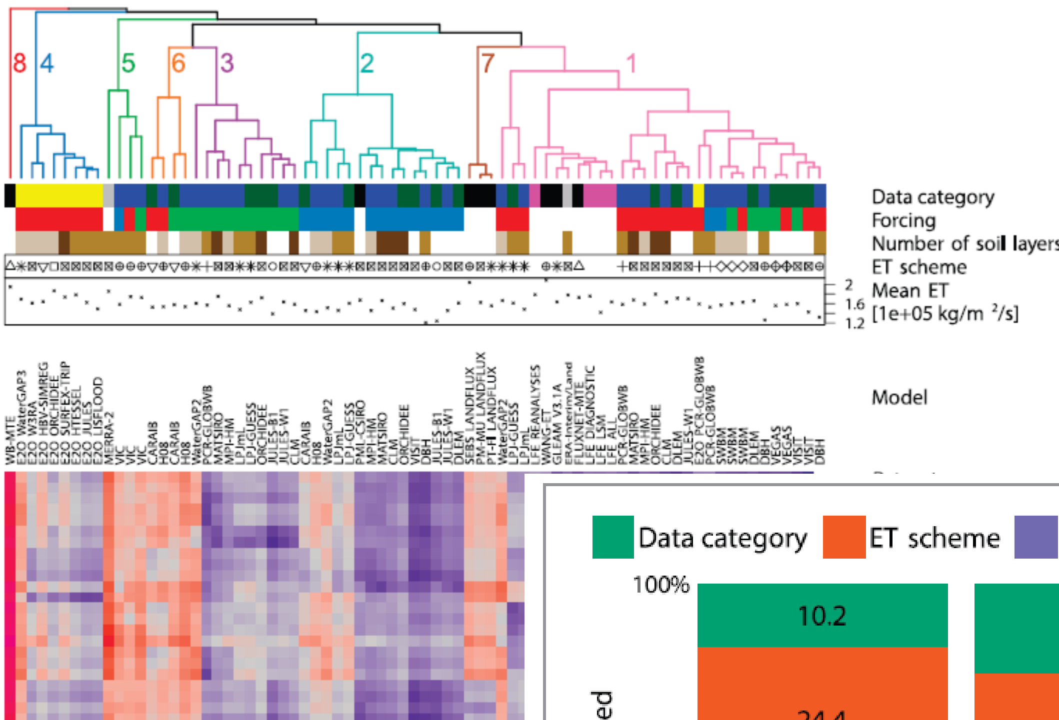
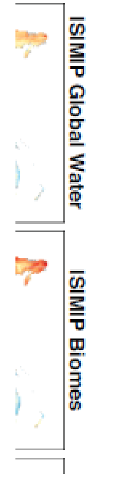
Evapotranspiration simulations in ISIMIP2a—Evaluation of spatio-temporal characteristics with a comprehensive ensemble of independent datasets

Richard Wartenburger[1,37], Sonia I Seneviratne[1], Martin Hirschi[1], Jinfeng Chang[24,30], Philippe Ciais[24], Delphine Deryng[2,3], Joshua Elliott[26], Christian Folberth[9], Simon N Gosling[20], Lukas Gudmundsson[1], Alexandra-Jane Henrot[14], Thomas Hickler[29,25], Akihiko Ito[23], Nikolay Khabarov[4], Hyungjun Kim[22], Guoyong Leng[8], Junguo Liu[12,4], Xingcai Liu[7], Yoshimitsu Masaki[18], Catherine Morfopoulos[28], Christoph Müller[17], Hannes Müller Schmied[5,6], Kazuya Nishina[16], Rene Orth[31,34], Yadu Pokhrel[13], Thomas A M Pugh[10,11], Yusuke Satoh[4], Sibyll Schaphoff[17], Erwin Schmid[19], Justin Sheffield[32,33], Tobias Stacke[15], Joerg Steinkamp[36], Qiuhong Tang[7], Wim Thiery[1,35], Yoshihide Wada[4], Xuhui Wang[24], Graham P Weedon[21], Hong Yang[27] and Tian Zhou[8]

1 Institute for Atmospheric and Climate Science, ETH Zurich, Universitaetstrasse 16, CH-8092 Zurich, Switzerland
2 Climate Analytics, 10969 Berlin, Germany

Euclidean distance matrices





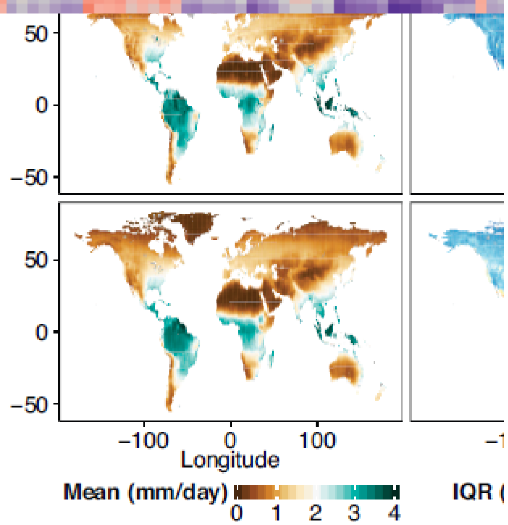


Figure 1. Temporal averages (1989–2005 time period)
QCDs (right) of ET_{tot} grouped by data category (rows).
MODIS Global ET and WECANN (which have been ex
shown.

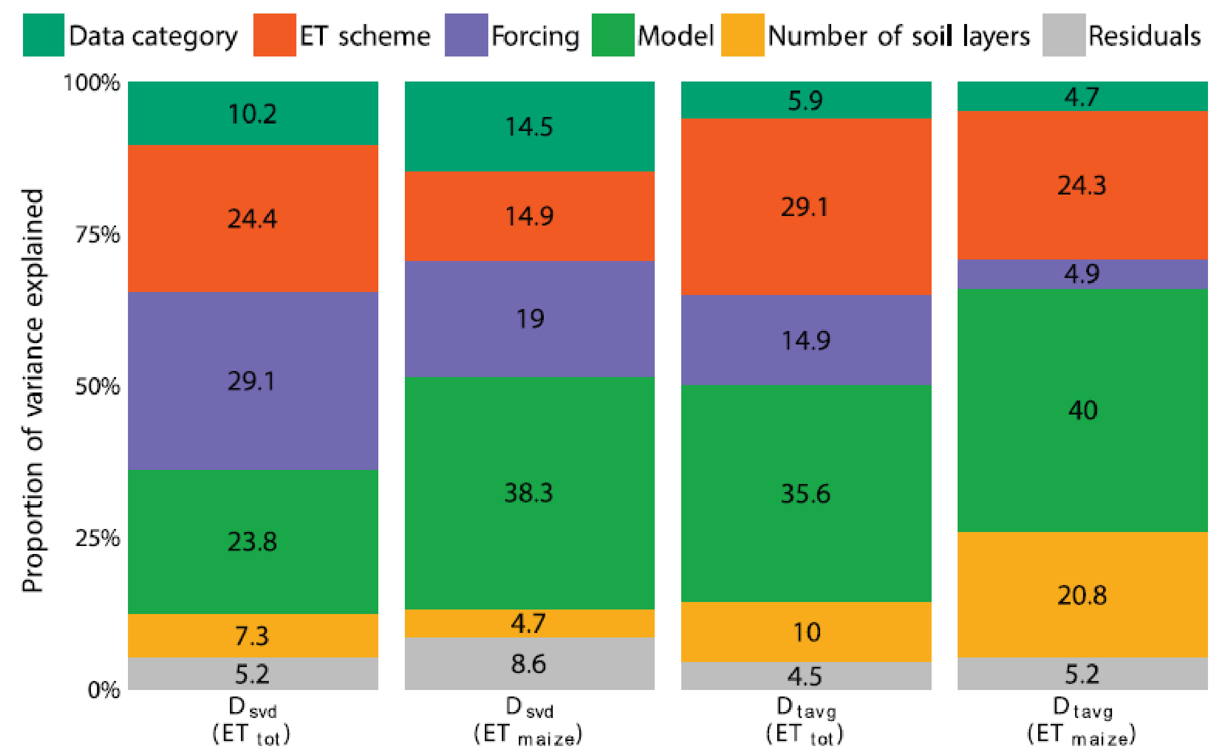


Figure 4. Fraction of variance in D_{svd} (representing spatio-temporal variabilities) and D_{tavg} (representing spatial variabilities) for both ET_{tot} and ET_{maize} explained by different factors (coloured shading and numbers [%]). Also shown is the proportion of unexplained variance (grey shading).

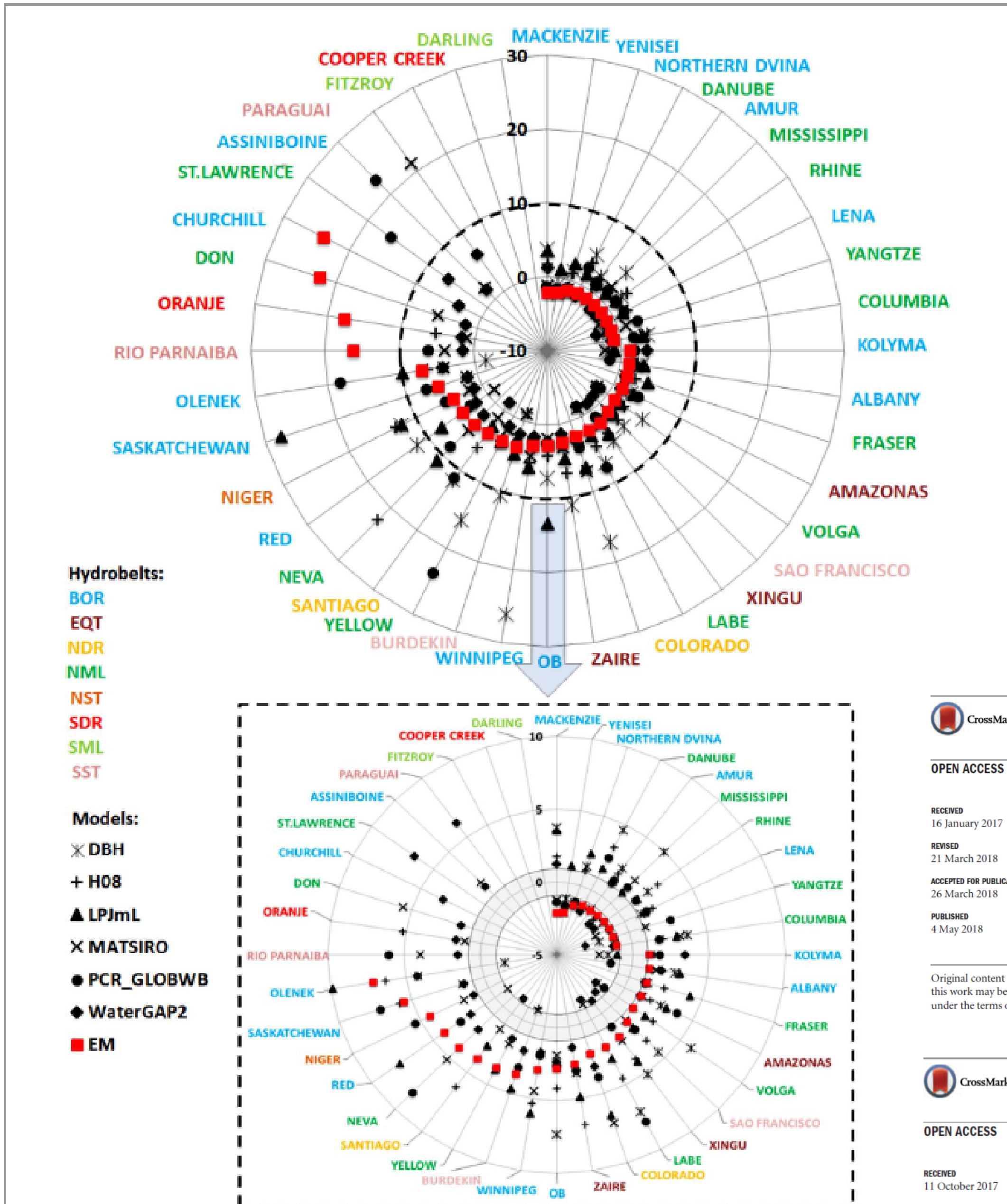


Figure 2. Catchments ranked clockwise (starting with Mackenzie) according to the IPE score for the ensemble mean (EM, IPE scores range between (−1, −∞] and [1, +∞). The bottom panel focuses on IPE≤10, with the range (−1,1) in grey the boundary of performance improvements (IPE ≤ −1) or loss (IPE ≥ 1) relative to the naïve benchmark model. Catc are colored by hydrobelts (BOR = boreal, NML = northern mid-latitude, NDR = northern dry, NST = northern subtro equatorial, SML= southern mid-latitude, SDR= southern dry and SST = southern subtropical).

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LETTER

Human impact parameterizations in global hydrological models improve estimates of monthly discharges and hydrological extremes: a multi-model validation study

T I E Veldkamp[1,9,13], F Zhao[2], P J Ward[1], H de Moel[1], J C J H Aerts[1,3], H Müller Schmied[4,5], F T Portmann[4], Y Masaki[6], Y Pokhrel[7], X Liu[8], Y Satoh[9], D Gerten[2,10], S N Gosling[11], J Zaherpour[11] and Y Wada[9,12]

1 Institute for Environmental Studies (IVM), VU Amsterdam, the Netherlands
2 Potsdam Institute for Climate Impact Research, Potsdam, Germany
3 Department of Geography, University of California, Santa Barbara, Santa Barbara, United States of America
4 Institute of Physical Geography, Goethe-University Frankfurt, Frankfurt, Germany
5 Senckenberg Biodiversity and Climate Research Centre (SBiK-F), Frankfurt, Germany

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LETTER

Worldwide evaluation of mean and extreme runoff from six global-scale hydrological models that account for human impacts

Jamal Zaherpour[1,19], Simon N Gosling[1], Nick Mount[1], Hannes Müller Schmied[2,3], Ted I E Veldkamp[4,18], Rutger Dankers[5], Stephanie Eisner[6], Dieter Gerten[7,8], Lukas Gudmundsson[9], Ingjerd Haddeland[10], Naota Hanasaki[11], Hyungjun Kim[12], Guoyong Leng[13], Junguo Liu[14], Yoshimitsu Masaki[15], Taikan Oki[12,16], Yadu Pokhrel[17], Yusuke Satoh[18], Jacob Schewe[7] and Yoshihide Wada[18]

1 School of Geography, University of Nottingham, Nottingham NG7 2RD, United Kingdom
2 Institute of Physical Geography, Goethe-University, Frankfurt, Germany
3 Senckenberg Biodiversity and Climate Research Centre (SBiK-F), Frankfurt, Germany

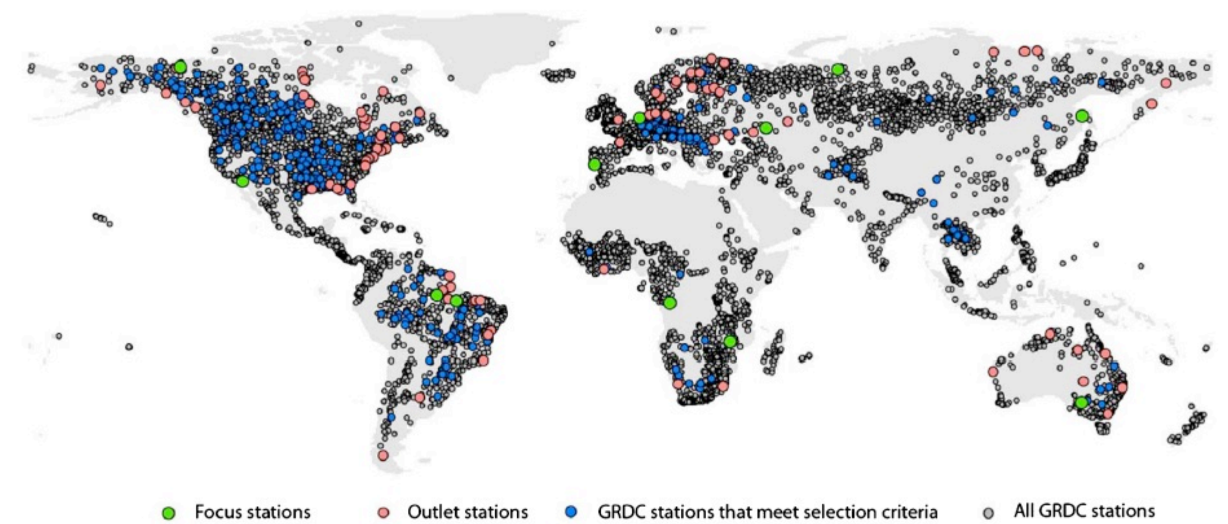


Figure 2. The spatial distribution of GRDC stations used for this study. Each dot shows a GRDC station ($n = 9051$) from the station catalogue. Blue dots indicate all GRDC stations ($n = 471$) that meet the selection criteria, whereas the red dots refer to the stations ($n = 92$) that are located at the outlet of a catchment. The green dots indicate those stations ($n = 12$) that were selected for detailed analyses.

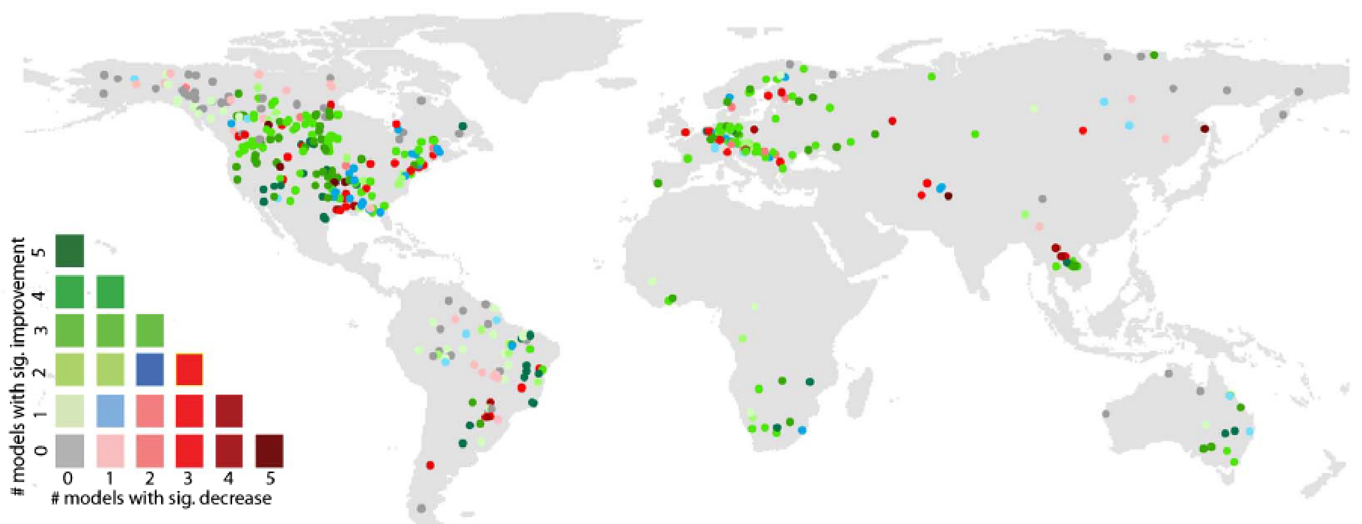
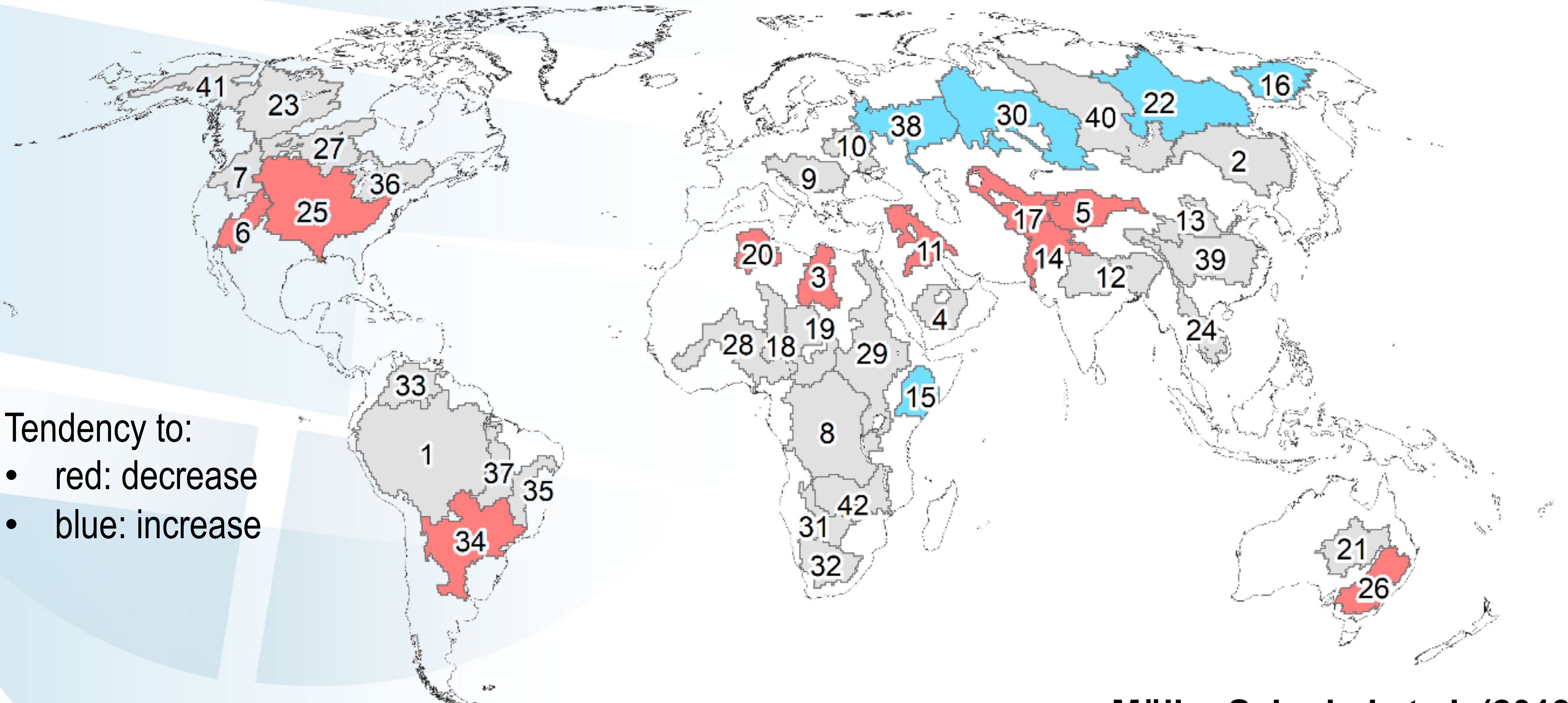


Figure 4. The number of GHMs with a significant improvement or deterioration in overall hydrological performance (KGE) due to the inclusion of HIP. The figures for the underlying KGE sub-parameters (bias ratio, variability ratio, correlation coefficient) are presented in supplementary figure 1; supplementary figure 2 shows the KGE performance values per GHM under HIP conditions.

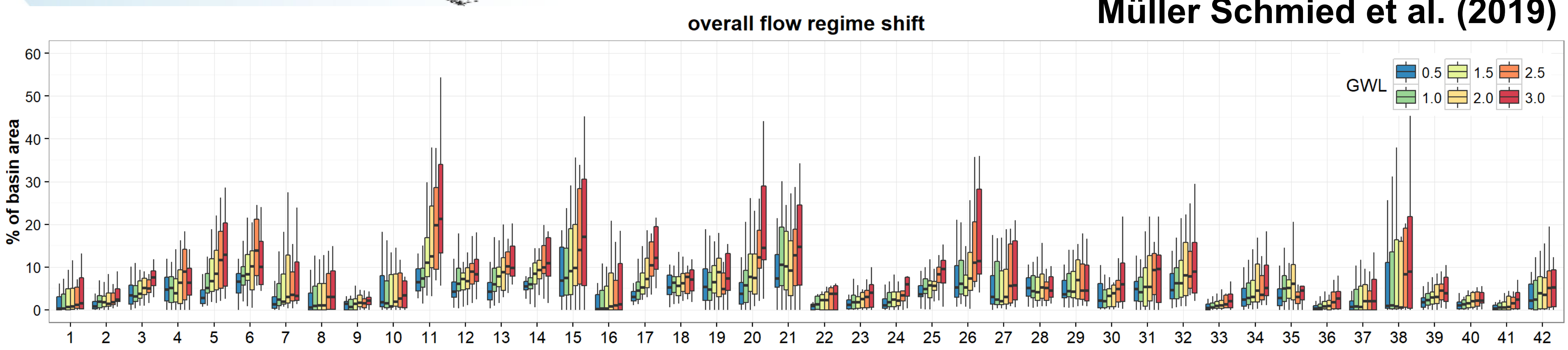
How would large river basins be affected at different global warming levels? % of river basin area affected

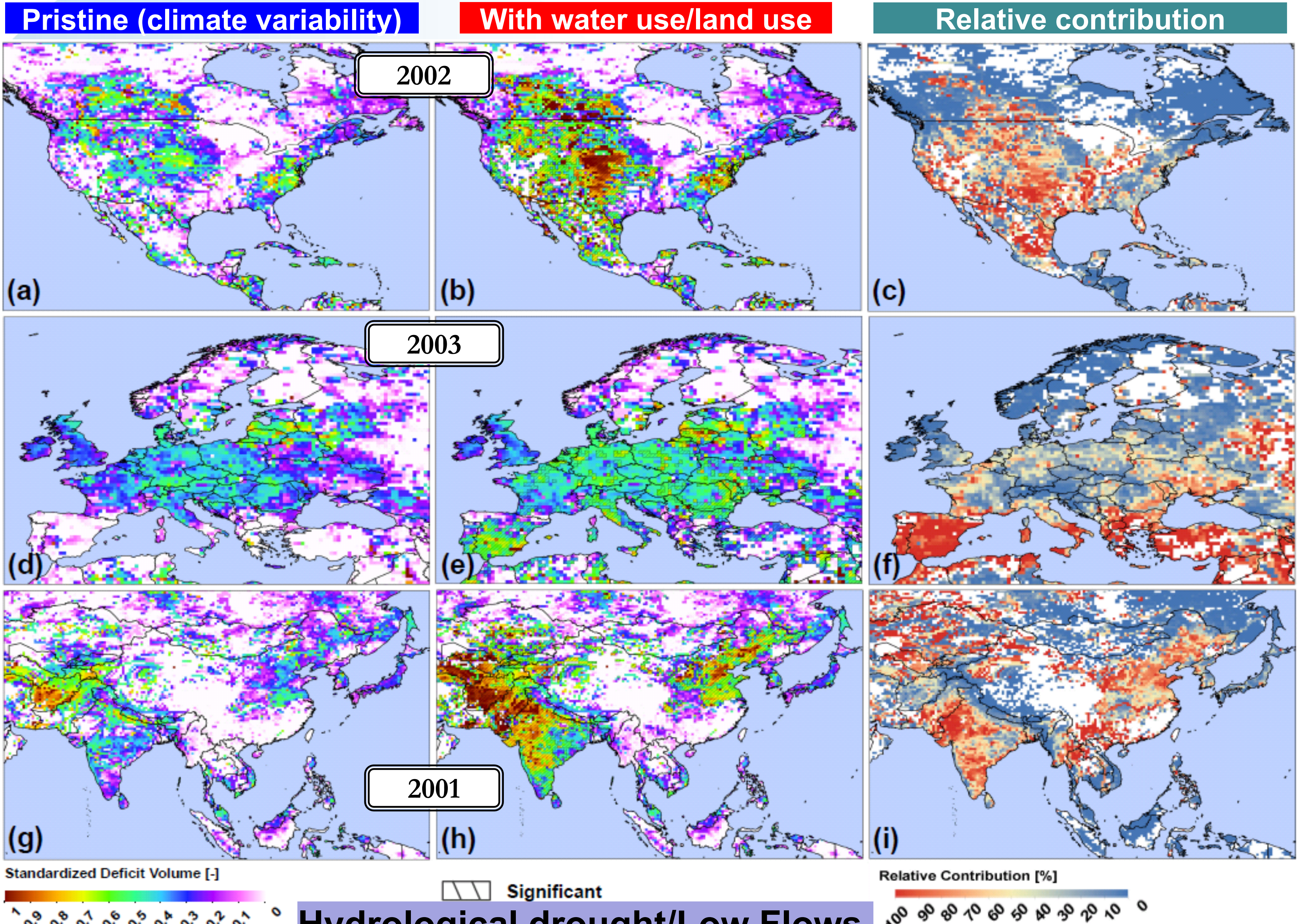


Tendency to:

- red: decrease
- blue: increase

Müller Schmied et al. (2019)





Hydrological drought/Low Flows

Wada et al. (2014; ERL)

Future Irrigation Water Demand Comparison (IWD)

- Future IWD is subject to large uncertainties due to anticipated climate change, i.e. increasing temperature and changing precipitation patterns.

- How climate change affects future IWD on currently irrigated areas by the end of this century?

- How certain are we? Where are the sources of the uncertainties in projected IWD?

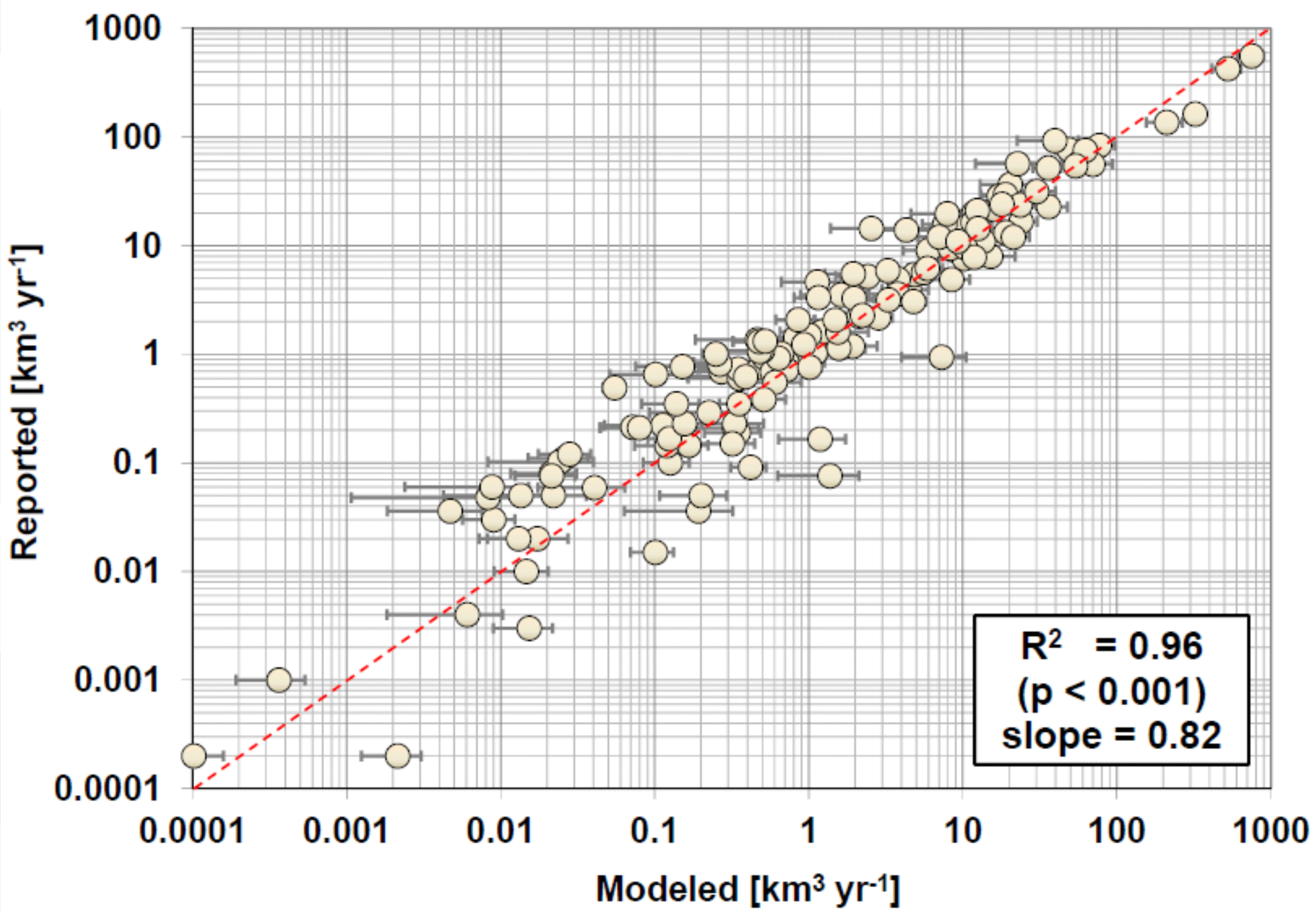
Methods (LPJmL~CO_2 fertilization effect and no socio-economic change):

Global Hydrological Models (GHMs):
H08, LPJmL, MPI-HM, PCR-GLOBWB, VIC, WaterGAP, WBMplus

Global Climate Models (GCMs):
HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, GFDL-ESM2M, NorESM1-M
(0.5 degree, bias-corrected; Hempel et al. [2013])

Representative Concentration Pathways (RCPs): 2.6, 4.5, 6.0, 8.5
Simulation period: 1971-2099
Outputs: Irrigation water demand (IWD), Irrigation water consumption (IWC)
(Potential demand and consumption)

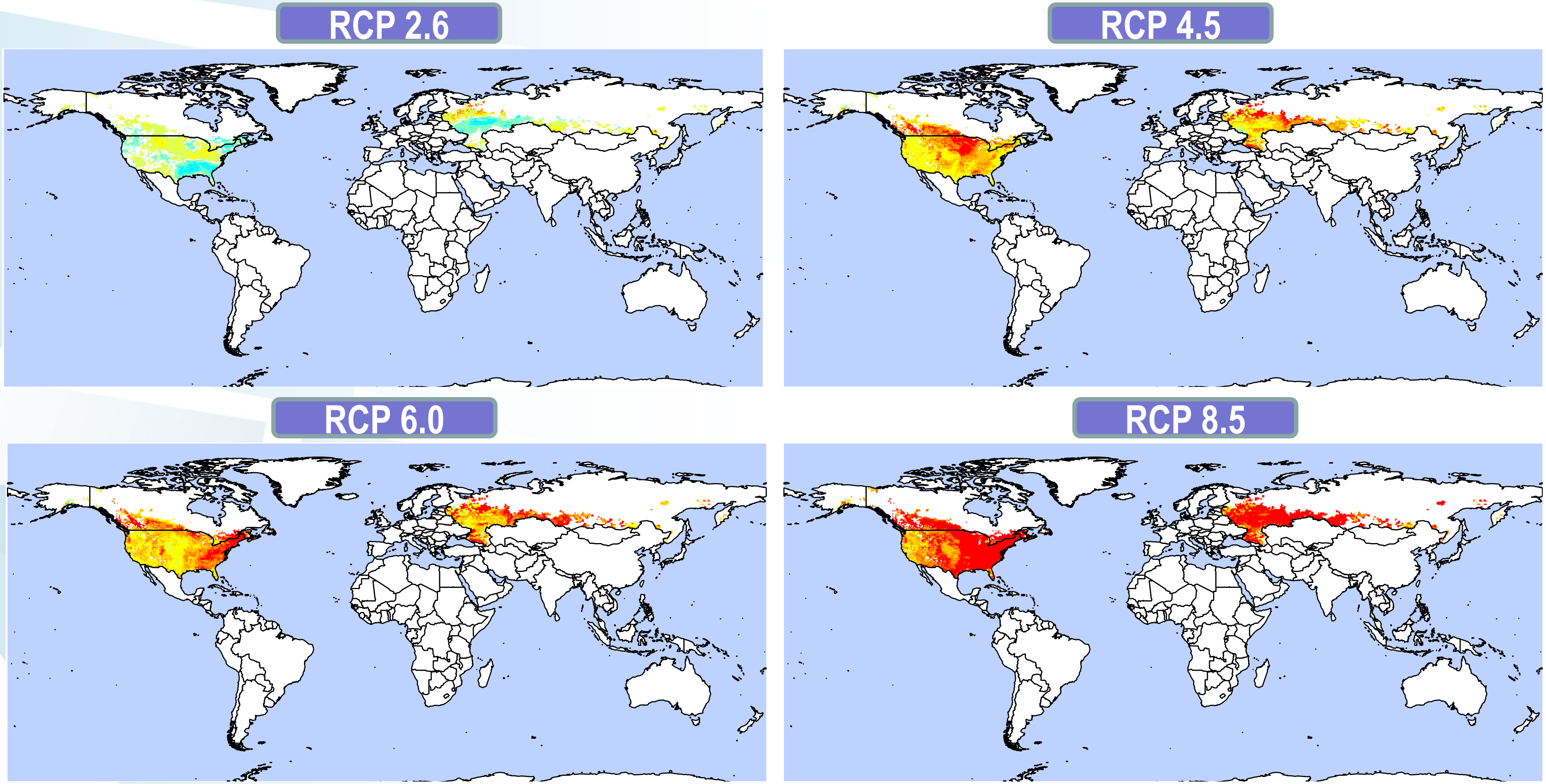
Validation: Present Irrigation Water Demand

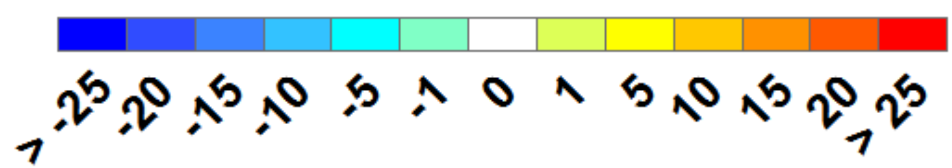


Reported: FAO AQUASTAT database (2000)
Modeled: Ensemble mean (all GHMs, all GCMs) over the period 1980-2010
Error bars show standard deviation among all simulation.

Simulated ensemble mean slightly overestimates IWD, but compares well with reported value for most of countries (N = 212).

Future IWD (ensemble mean) - spatial





Relative increase compared to the present-day condition (2000), i.e. mean of 1980-2010

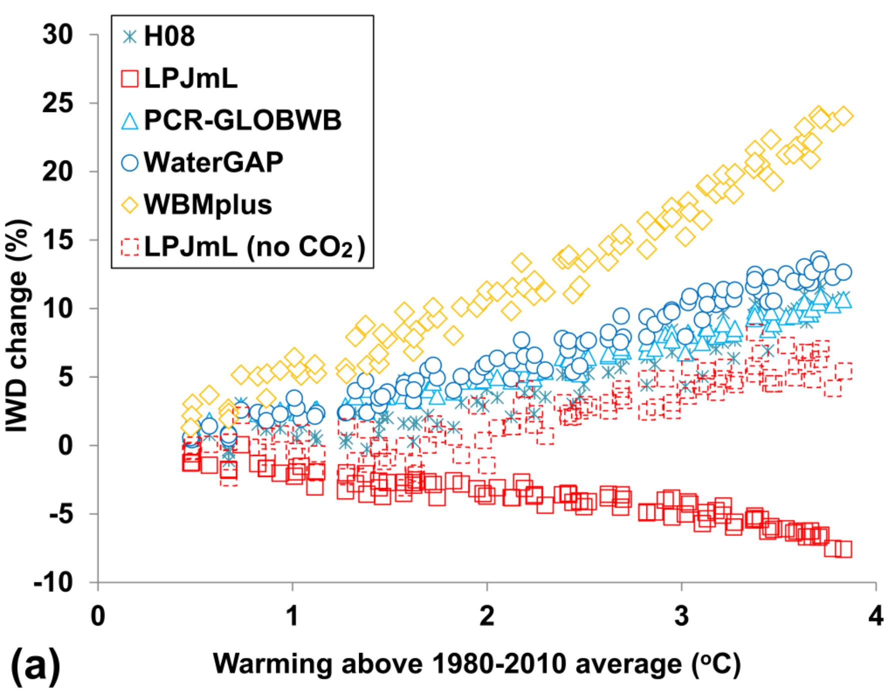
[end of this century (2085), i.e. mean of 2069-2099]

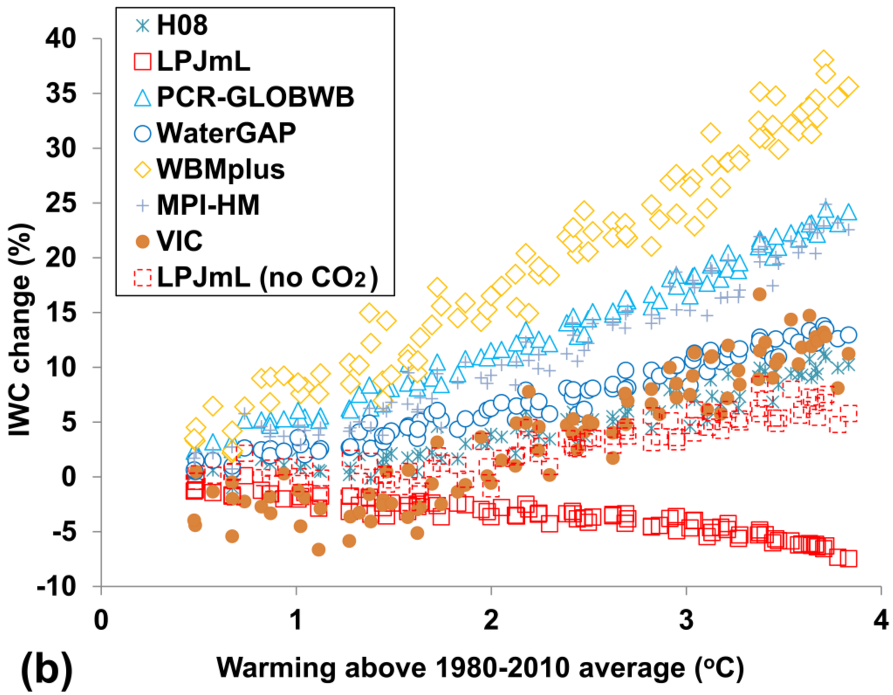
%

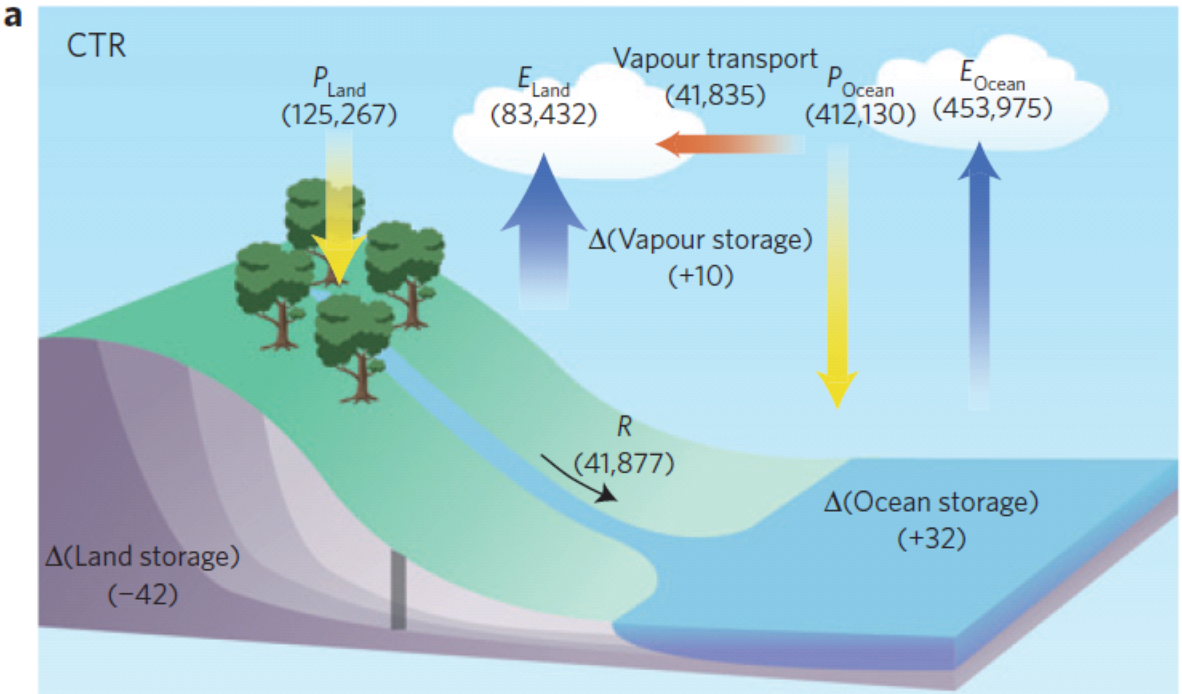
IIASA

Wada et al. (2013; GRL)

Model-specific Trends in Future IWD

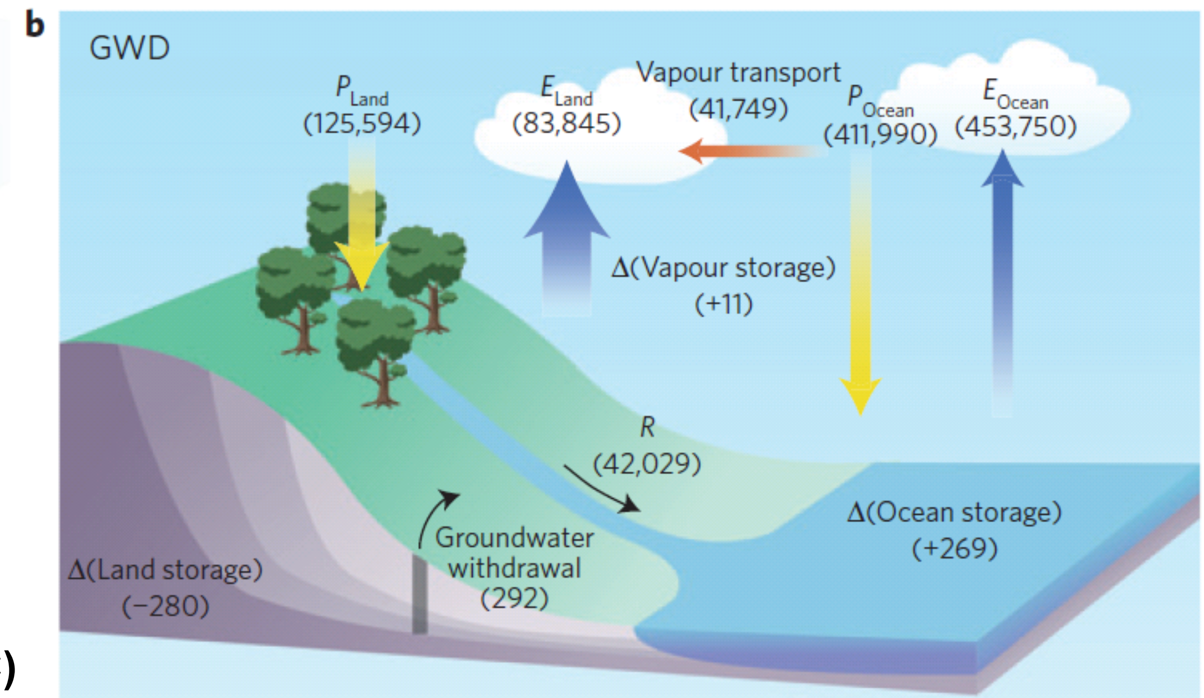






NCAR CESM (CAM4 + CLM4+POP2)

Impacts of groundwater pumping on land and ocean budget



Wada, Lo, et al. (2017; NCC)

Global mean annual water budget over the land and ocean (1900-2000 average; km^3/yr)

	Precipitation (P)	Runoff (R)	Evaporation (E)	Total storage change (ΔS)	Precipitation minus evaporation	Atmospheric water vapour change
Land				$P-R-E$	$P-E$	
(1) GWD	125,594	42,029	83,845	−280	41,749	-
(2) CTR	125,267	41,877	83,432	−42	41,835	-
(3) GWD-CTR	+327	+152	+413	−238	−86	-
Ocean				$P+R-E$	$P-E$	-
(1) GWD	411,990	42,029	453,750	+269	−41,760	-
(2) CTR	412,130	41,877	453,975	+32	−41,845	-
(3) GWD-CTR	−140	+152	−225	+237	+85	-
Global						
(1) GWD	-	-	-	-	-	+11
(2) CTR	-	-	-	-	-	+10

Summary

- Land use including agriculture is a key variable for hydrology and increasing impacts on water over last decades

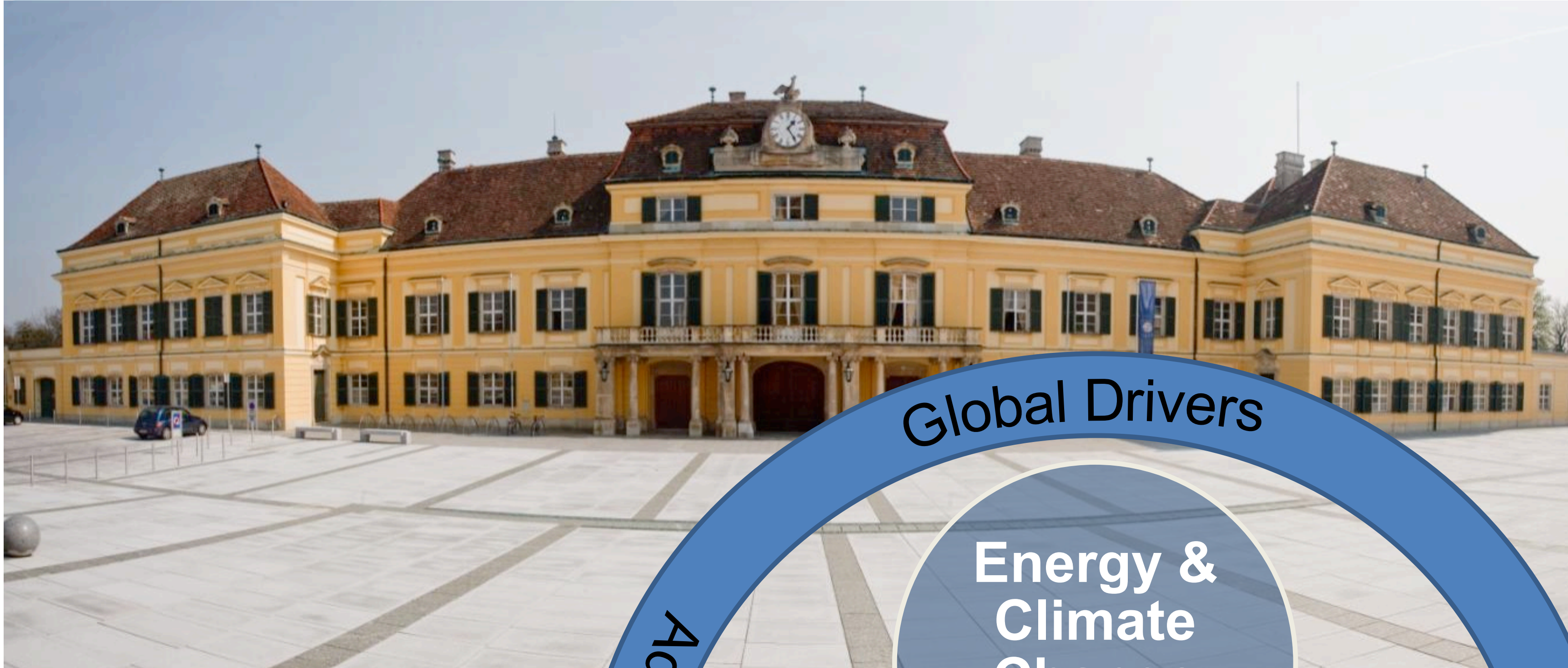
- Simulated water fluxes by hydrological models are largely affected by land use data (>20%) – satellite or model driven land use data vary

- Land use-groundwater-climate interactions are getting more attentions and more research needed

- Urban areas need better focus (P, ET, R)

- Dynamic simulation of coupled land-atmospheric system is still challenging and sensitive to the choice of modeling algorithm and assumptions

- The boundary between land surface models and hydrological models are less obvious – where are we heading?



IIASA - RESEARCH FOR A CHANGING WORLD