Including Water Management in Large Scale Models:

a workshop co-sponsored by the Global Land/Atmosphere System Study Panel (GLASS) & the GEWEX Hydroclimatology Panel (GHP), Gif-sur-Yvette, France, 28-30 September 2016

Large-scale modelling of groundwater resources:

insight from the comparison of models and in-situ observations

The Chronicles Consortium*

*** Richard Taylor, UCL (richard.taylor@ucl.ac.uk)**

artesian borehole, Singida (central Tanzania)

The Chronicles Consortium

Multi-Decadal Groundwater Levels in Africa

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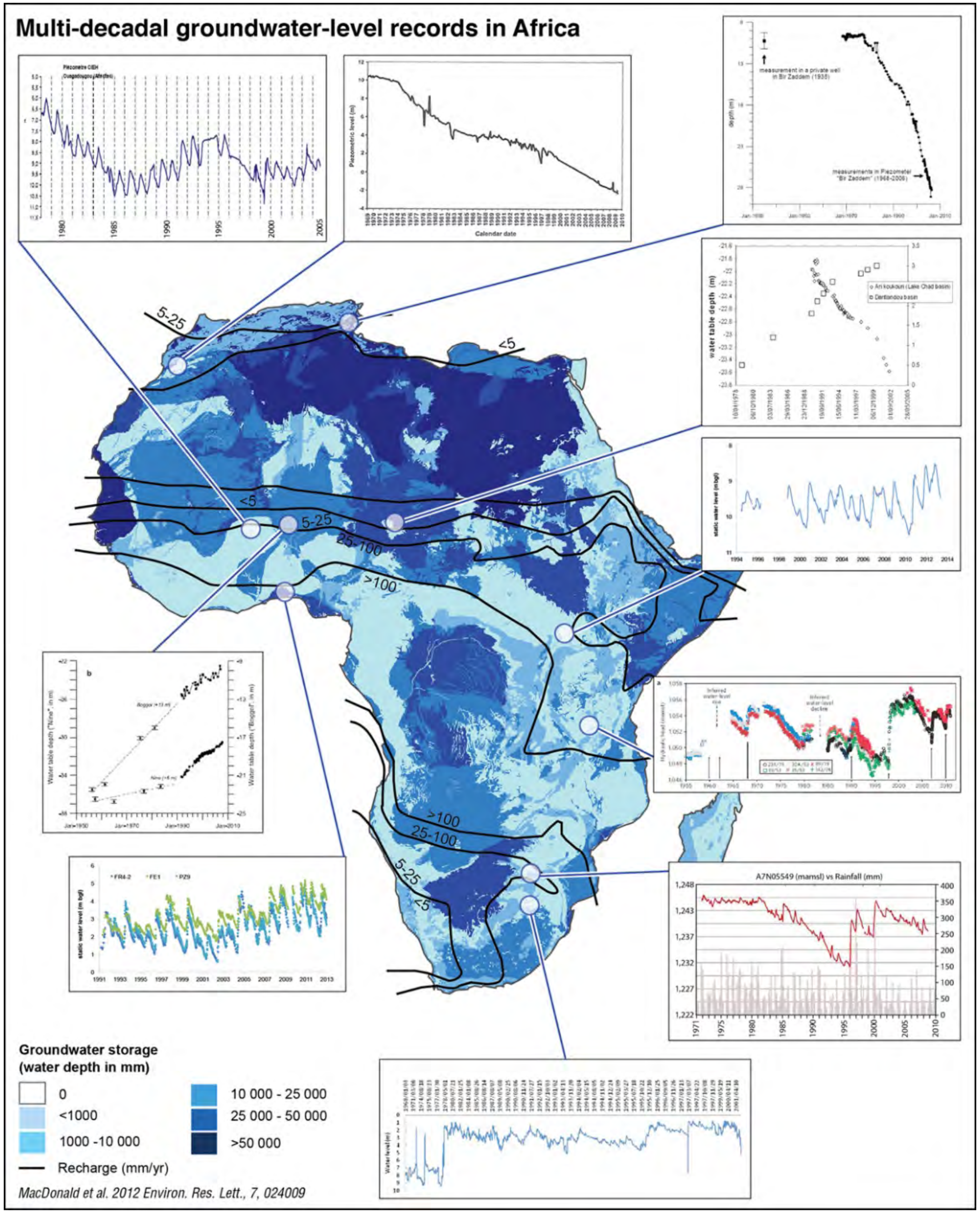

A pan-African inter-comparison of groundwater recharge from *in-situ* observations and large-scale models

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Groundwater Futures in Sub-Saharan Africa

Developing the scientific basis and participatory management processes by which groundwater resources can be used sustainably for poverty alleviation.

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growing dependence on groundwater

Dependence on groundwater is growing globally to sustain and amplify the production of food through irrigation and the provision of safe drinking water

Why Africa? – home to the world's most variable freshwater resources, the highest rates of population growth, lowest rates of per capita food production, and lowest proportions of national populations with access to safe water

SUSTAINABLE DEVELOPMENT GOALS

- **groundwater is a fundamental component of the global hydrological system but inadequately represented in large-scale models despite recognition by GCOS & GEWEX of the influence of groundwater on the global climate system through surface moisture and energy budgets**

large-scale groundwater-fed irrigation (Zambia)

reconciling large-scale models to observations

UCL

- large-scale models (LSMs, GHMs) are, with a few exceptions (*e.g.* WaterGAP), uncalibrated
- lack of *in situ* hydrological observations beyond river discharge leads to 'equifinality' (non-uniqueness) in the development of large-scale models

- evolution of large-scale models toward 'hyperresolutions' requires revision of model structures to explicitly represent *subgrid* hydrological processes – the understanding of which is informed by *in situ* observations

large-scale models and hydrological process

- **large-scale models mostly* disregard focused recharge - leakage from surface waters such as ephemeral streams - yet this is the dominant pathway of groundwater replenishment occurs in dryland regions** ***except WaterGAP*

ephemeral stream flow in central Tanzania during 2015-16 El Niño

model – observation inter-comparison

collation of observational data addresses the key challenge of groundwater data scarcity raised by GCOS and GEWEX and has the potential:

1. **to evaluate the performance of large-scale models to simulate terrestrial water balances – addressing the problem of equifinality - and to estimate groundwater recharge; and**
2. **to inform the development of more robust large-scale models that simulate critical groundwater processes (*e.g.* focused recharge)**

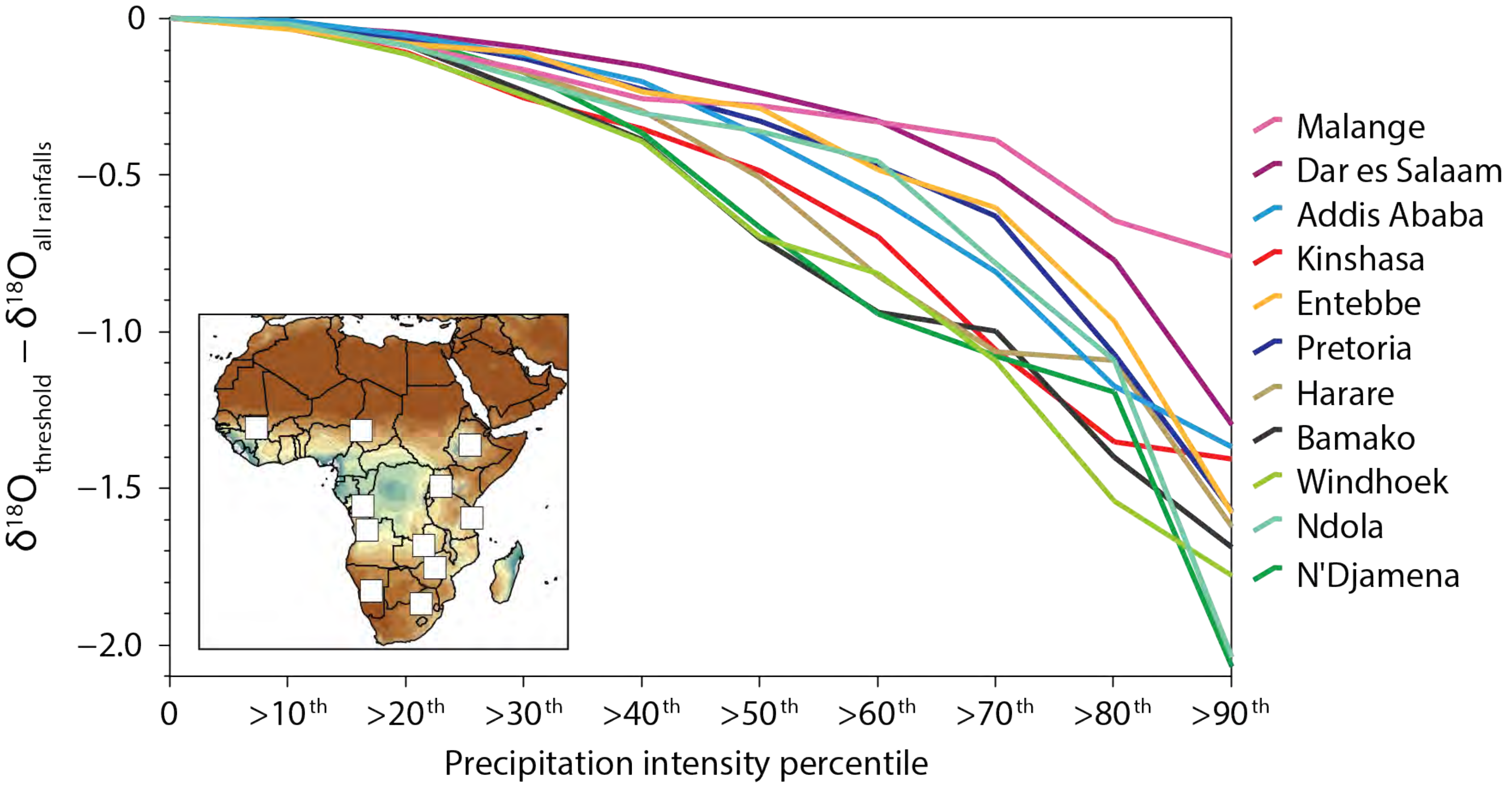
observations: multi-decadal GWL records

collation of multi-decadal, *in situ* (piezometric) records of groundwater levels across Africa under *The Chronicles Consortium*

Location	No.	Geology	Climate	Duration
Benin	8	Quaternary sands Continentale Terminale	humid	1991-present
Burkina Faso	2	weathered crystalline rock Continentale Terminale	semi-arid	1978-present
Chad	15	Quaternary sediments	arid	1968-1989
Ghana	1	Quaternary sediments	humid	1976-present
Morocco	25	Plio-Quaternary sediments	arid	1970-present
Niger	50	Quaternary sediments	semi-arid	1987-present
South Africa	21	weathered crystalline rock limestone	semi-arid	1970-present
Tanzania	1	weathered crystalline rock	semi-arid	1954-present
Tunisia	70	Quaternary sediments	semi-arid	1969-present
Uganda	5	weathered crystalline rock	humid	1998-present

observations of stable-isotope tracers

"amount effect" enables the use of rainfall-groundwater stable-isotope (^{18}O:^{16}O) "pairings" to trace the intensity of rainfall to groundwater recharge



potential stable-isotope 'pairings' in Africa

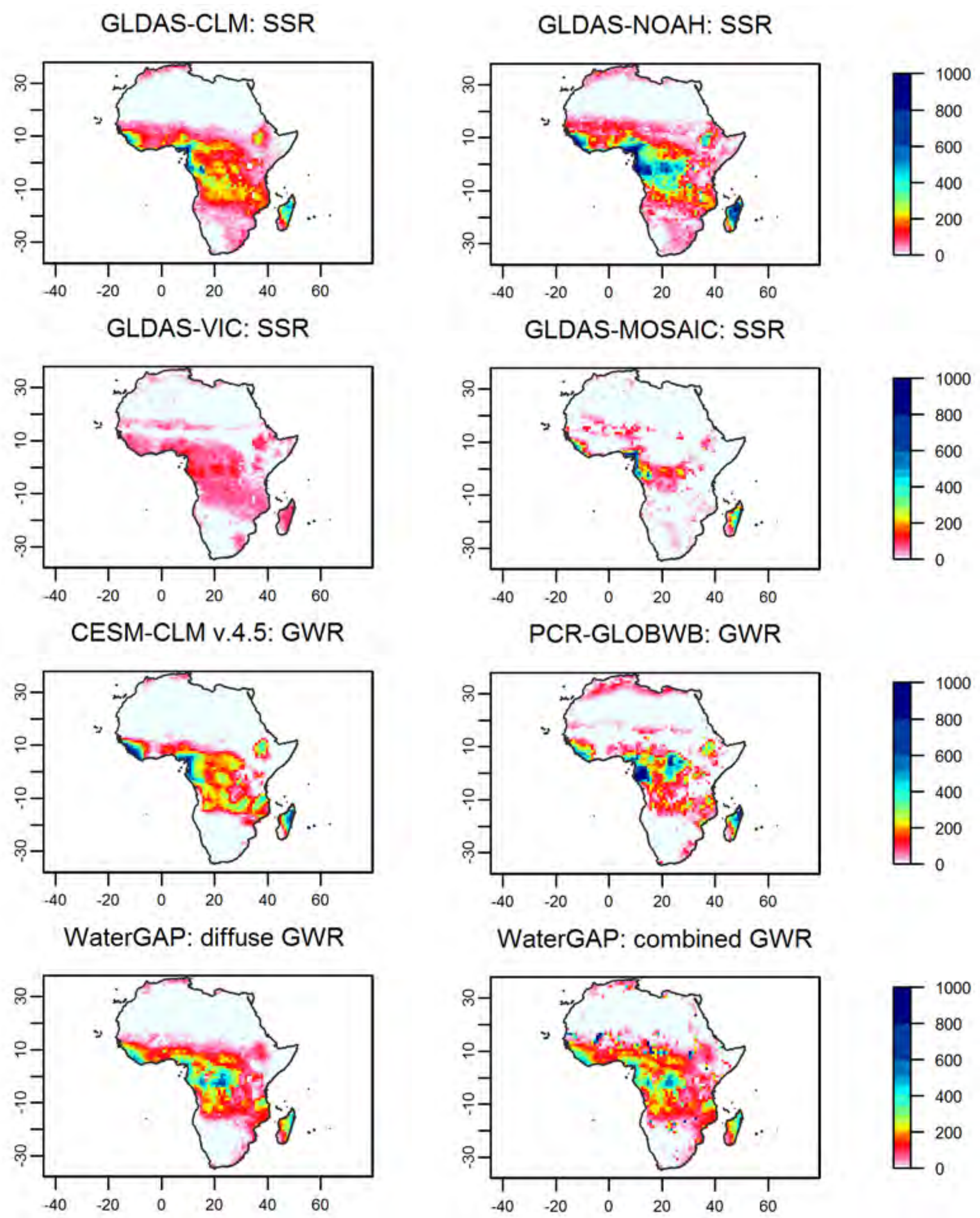
Location	P samples	P period	Mean annual P	GW samples
Addis Ababa	299 (296)	1961-2009	1100	13
Bamako	147 (140)	1962-1998	920	10
Dar es Salaam	125 (117)	1960-1973	1140	9
Entebbe	197 (192)	1960-2006	1570	56 (IAEA TWIN)
Harare	257 (192)	1960-2003	890	none within 100 km
Kinshasa	60 (59)	1961-1968	1380	none within 100 km
Malange	330 (204)	1961-2009	1140	none within 100 km
Ndola	143 (133)	1968-2009	1210	none within 100 km
N'Djamena	86 (75)	1963-1995	550	320 (IAEA TWIN)
Pretoria	245 (168)	1958-2001	680	none within 100 km
Windhoek	141 (97)	1961-2001	360	1 (IAEA TWIN)

Land Surface Models (LSMs) / Global Hydrological Models (GHMs)

groundwater recharge (subsurface runoff) estimates from 7 global-scale models: 2 GHMs (WaterGAP, PCR-GLOBWB) and 5 LSMs (CESM-CLM4.5 & NASA's GLDAS LSMs: CLM , NOAH, VIC, MOSAIC)

Model	Grid	Precipitation	Output
CLM2.0	1°	CMAP	SSR
NOAH	1°	CMAP	SSR
VIC	1°	CMAP	SSR
MOSAIC	1°	CMAP	SSR
CLM4.5	0.5°	CRU-NCEP (v.5)	GWR (diffuse only)
PCR-GLOBWB	0.5°	WFDEI	GWR (diffuse only)
WaterGAP	0.5°	CRU TS 3.23	GWR (diffuse only)
WaterGAP	0.5°	CRU TS 3.23	GWR (diffuse-focused)

mapping simulated SSR & GWR

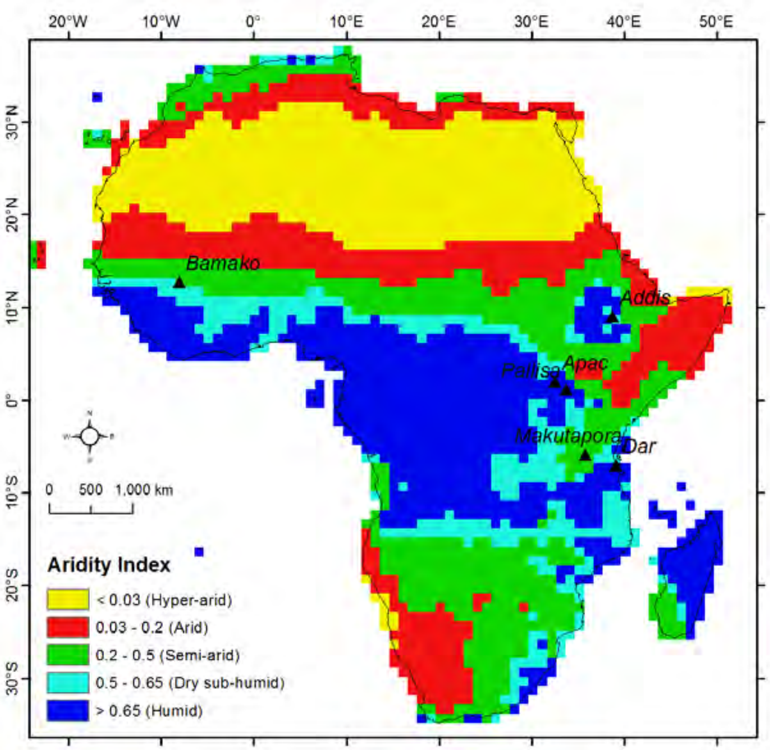


- substantial variations in the magnitude and distribution of mean annual SSR & groundwater recharge (GWR)

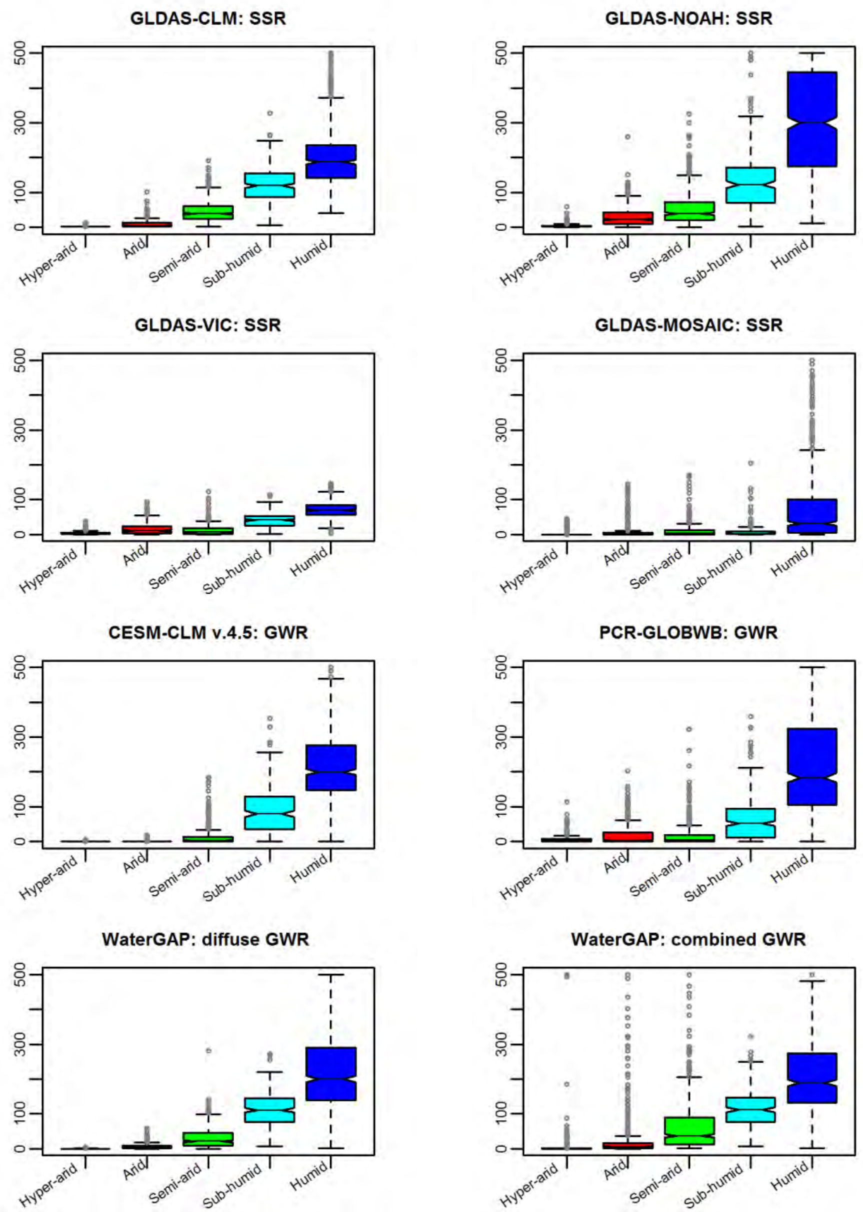
- spatial extent & magnitude of recharge in semi-arid regions increase from WaterGAP (diffuse only) to WaterGAP (diffuse-focused)

simulated SSR & GWR grouped by climate

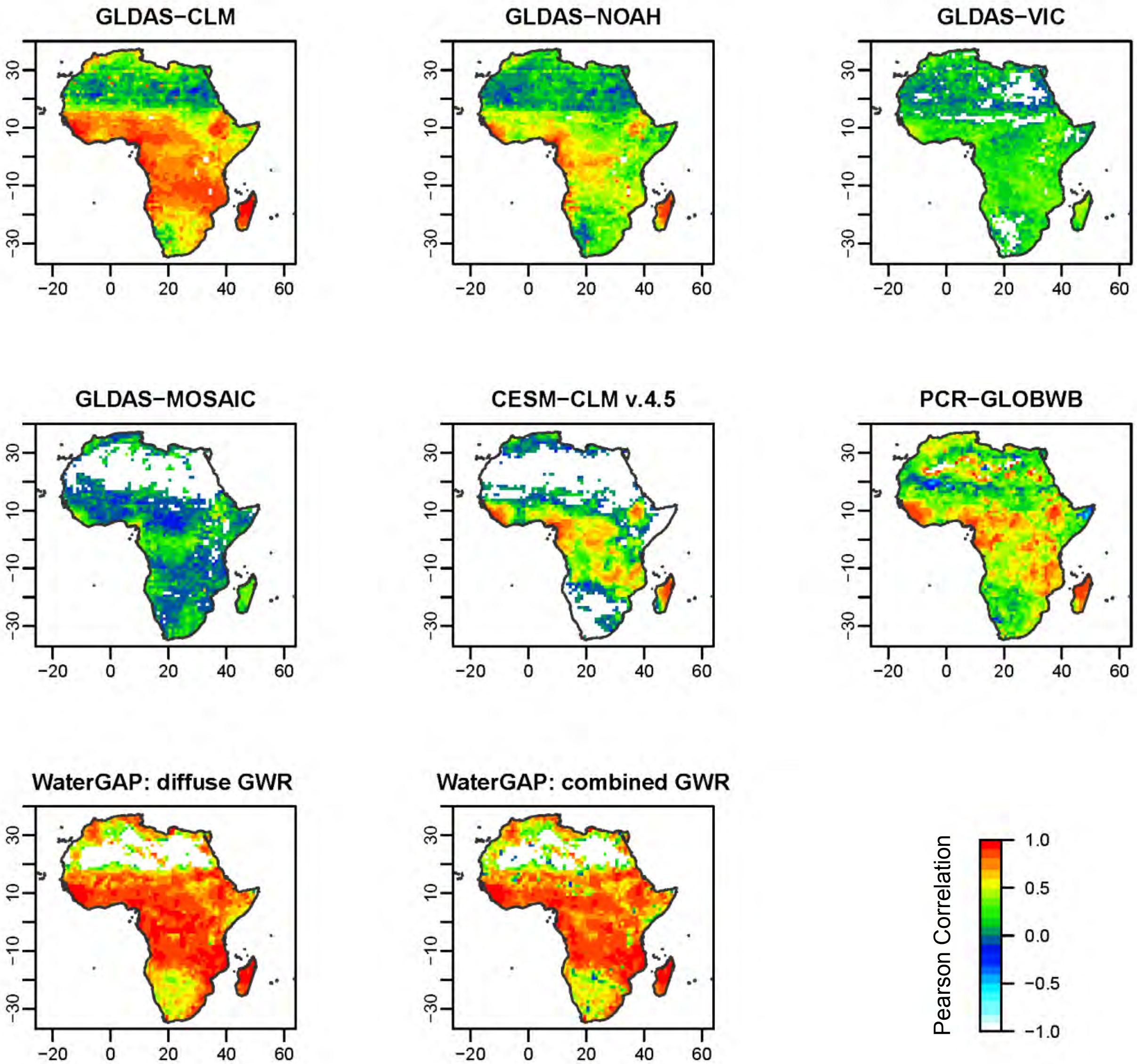
- simulated recharge in semi-arid regions increases with the inclusion of focused recharge in WaterGAP



CGIAR Aridity Index



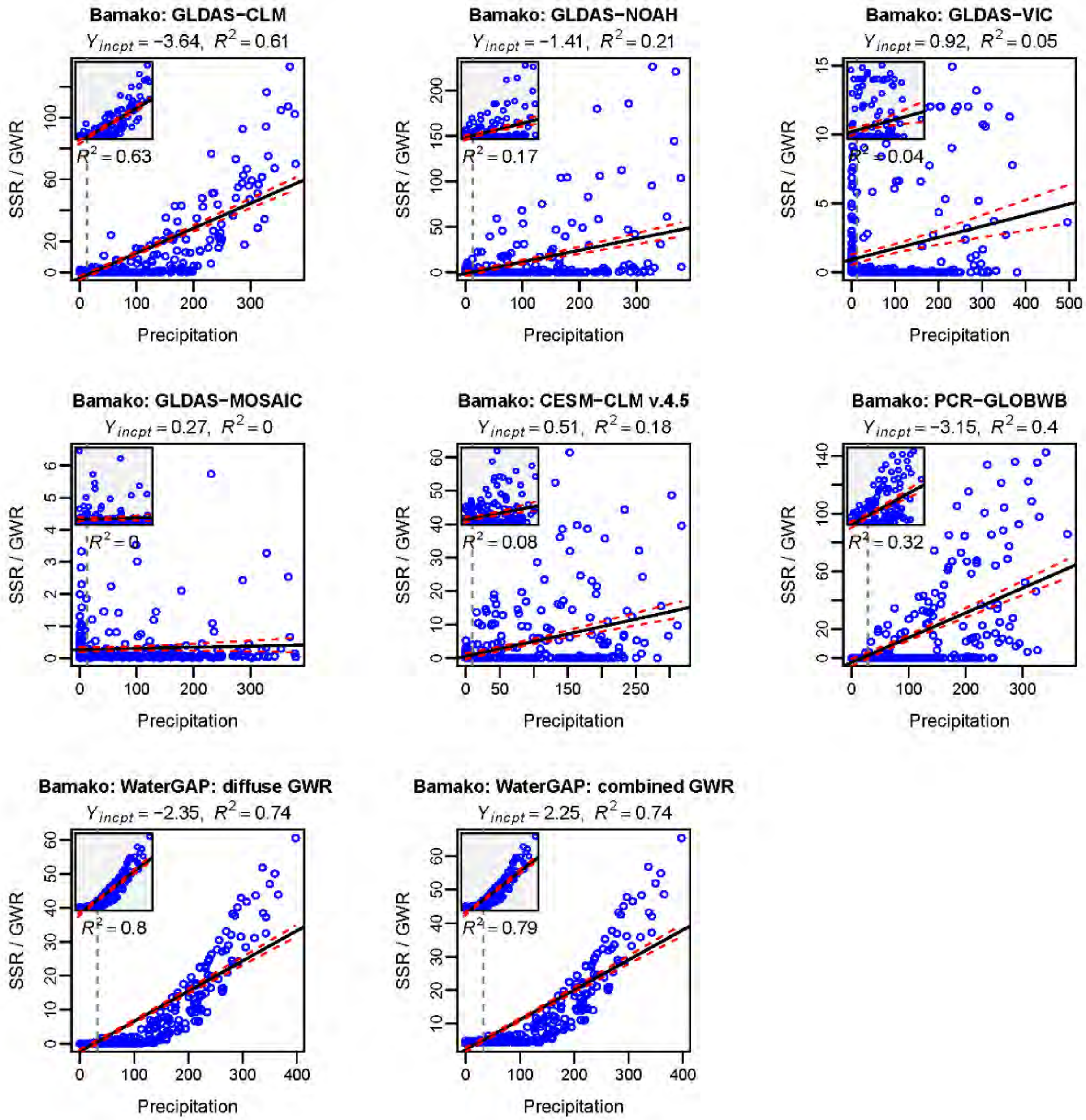
correlation of simulated GWR/SSR and precip



- precipitation and simulated GWR / SSR are strongly correlated in GLDAS-CLM and WaterGAP
- weaker correlations in GLDAS VIC and MOSAIC explained by very low, estimated SSR

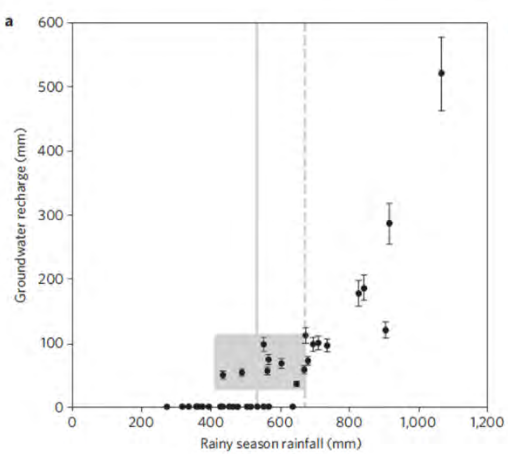
semi-arid: Bamako (isotope pairing)

Bamako (Mali)

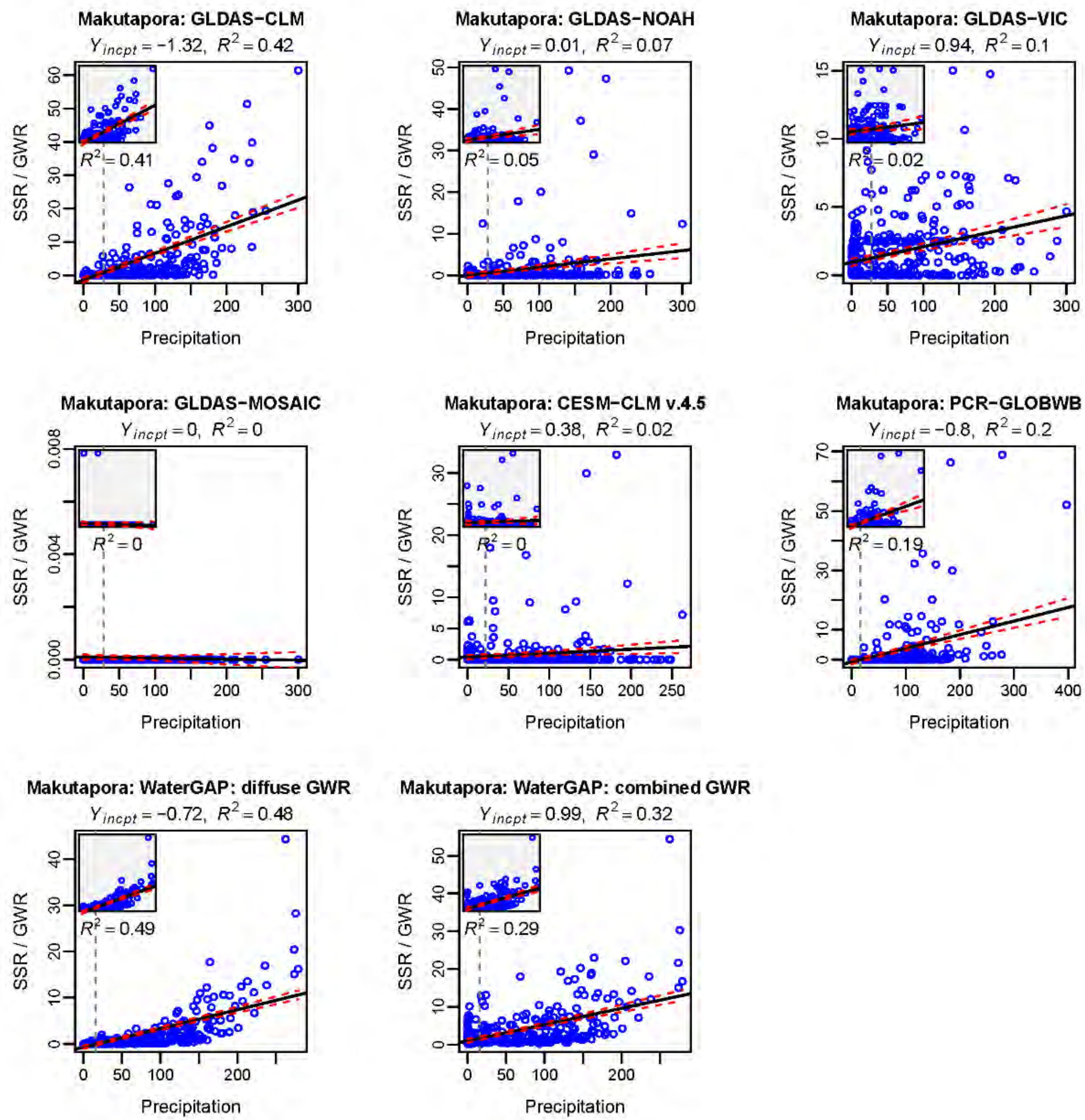


semi-arid: Makutapora (piezometry)

Makutapora (Tanzania)

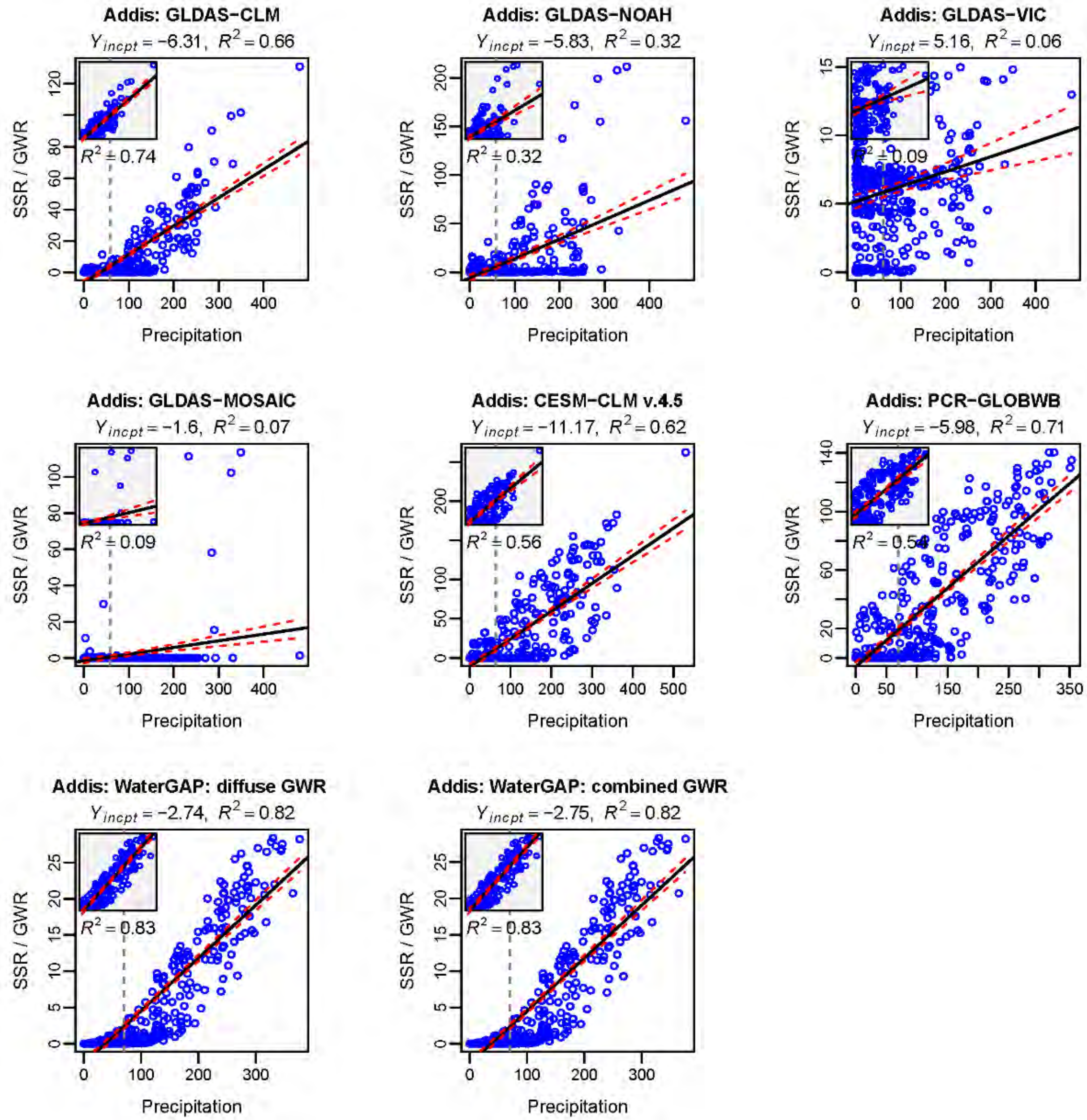


Taylor et al. (2013)



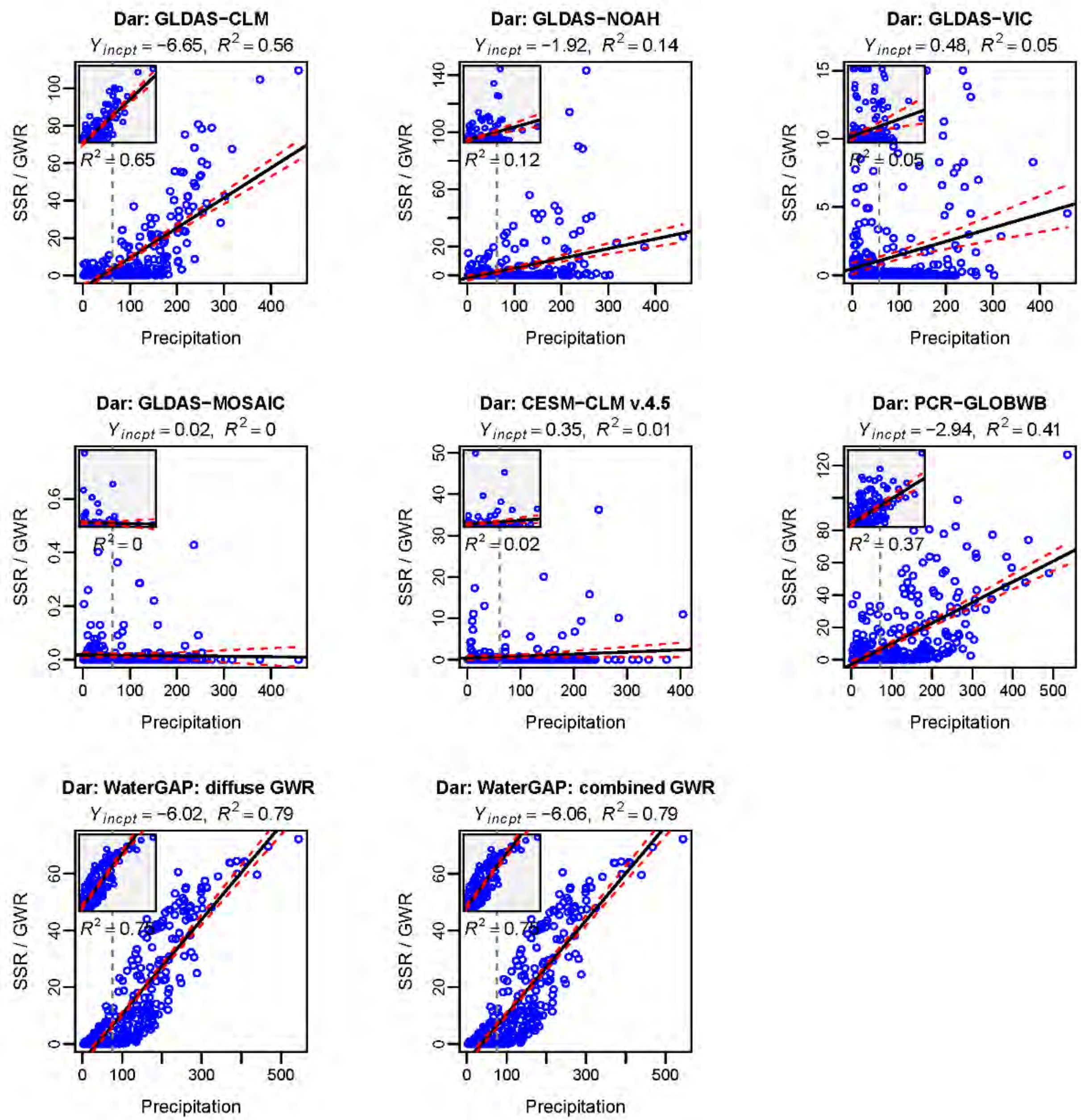
humid: Addis Ababa (isotope pairing)

Addis Ababa (Ethiopia)



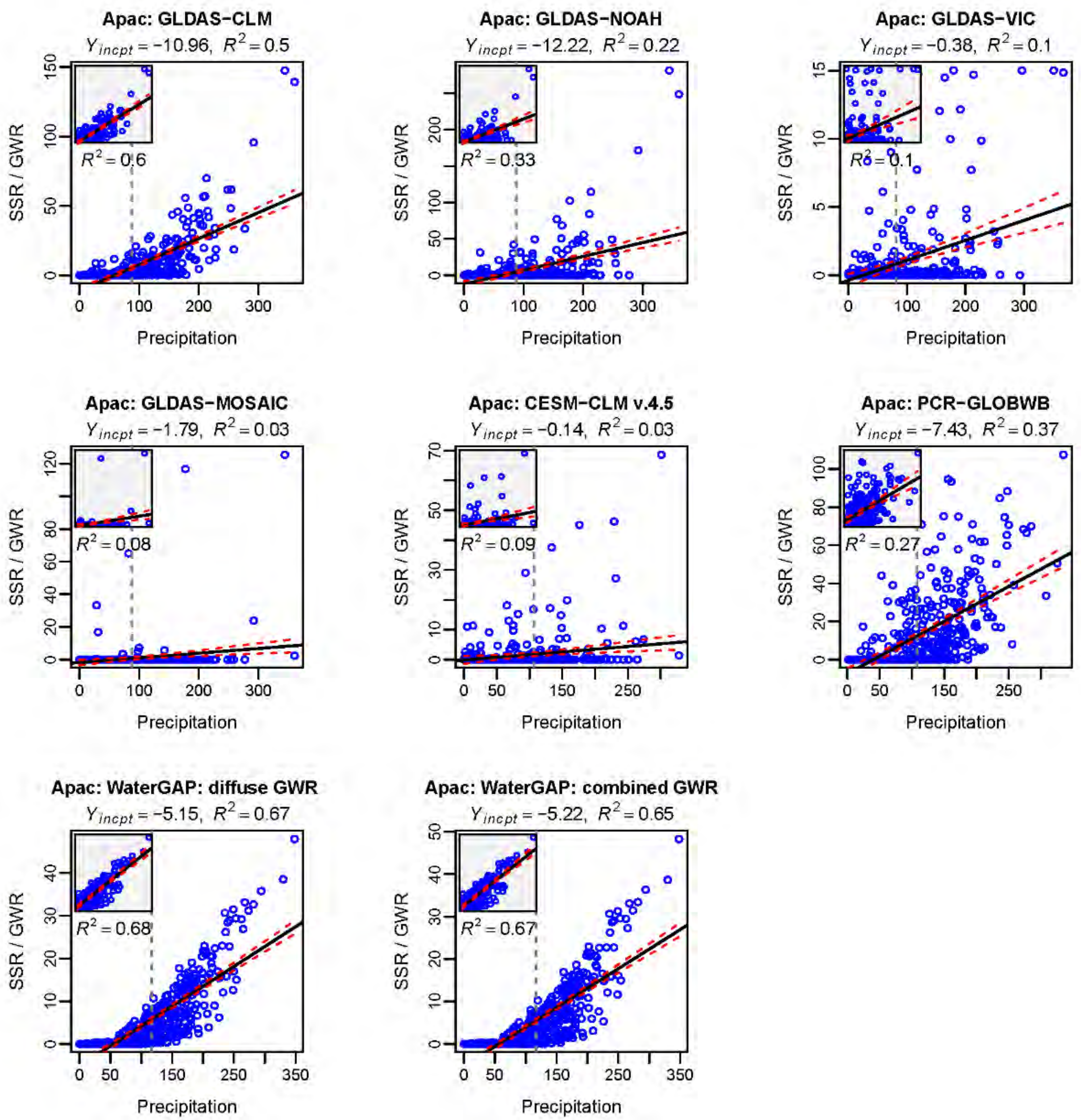
humid: Dar es Salaam (isotope pairing)

Dar e Salaam (Tanzania)



Humid: Apac (piezometry)

Apac (Uganda)



preliminary outcomes of inter-comparison in Africa

- spatial extent and magnitude of simulated GWR & SSR vary substantially among large-scale models; in semi-arid regions, simulated estimates of GWR & SSR are substantially less in large-scale models disregarding focused recharge

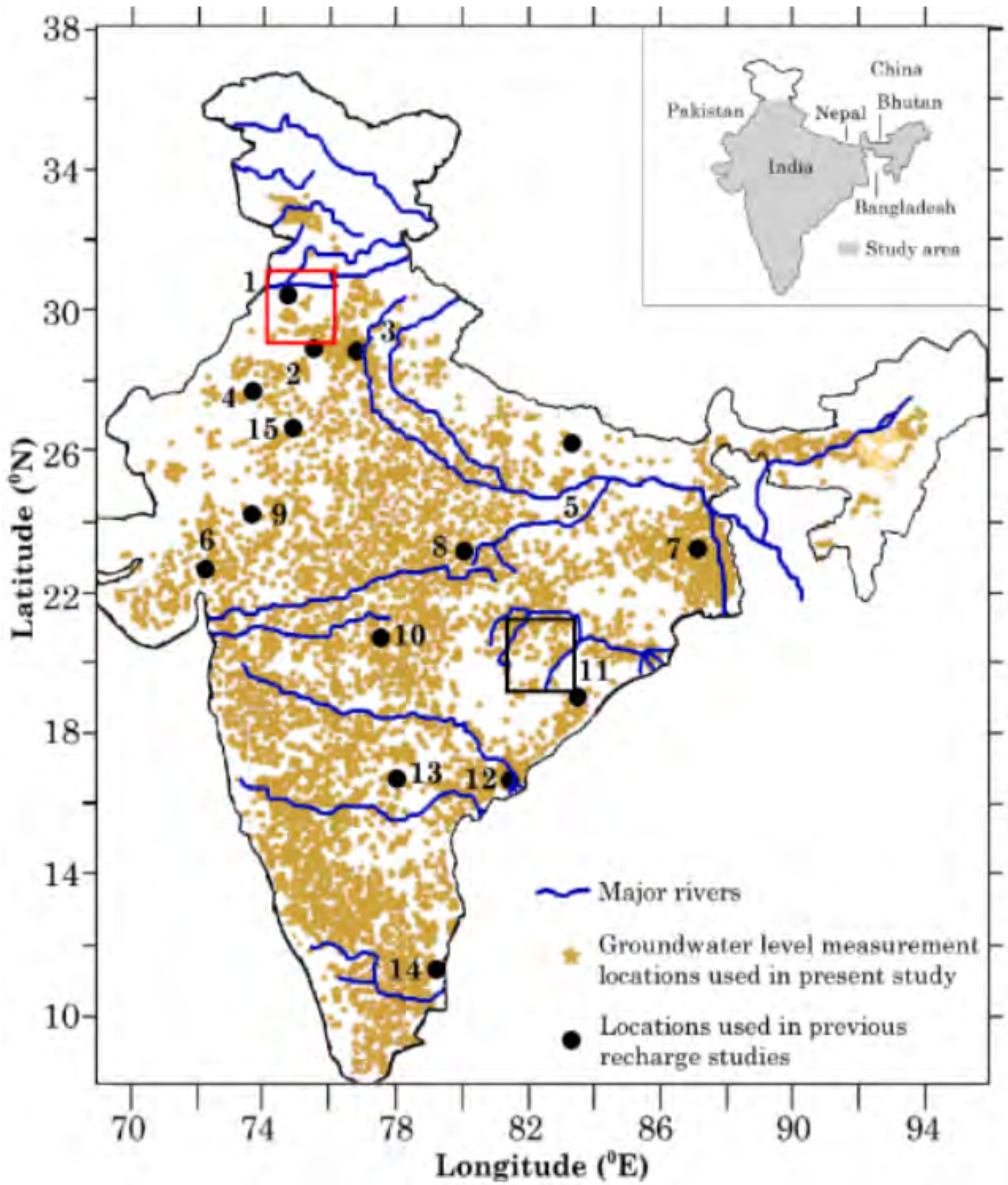
- non-linearity, evident in the relationship between simulated GWR & SSR and precipitation (GLDAS-CLM, WaterGAP), is consistent with piezometric & isotopic observations

- simulated GWR & SSR and precipitation correlate well for some models (GLDAS-CLM, WaterGAP) but are very weakly correlated in others (GLDAS-VIC, MOSAIC)

addendum: inter-comparison from India

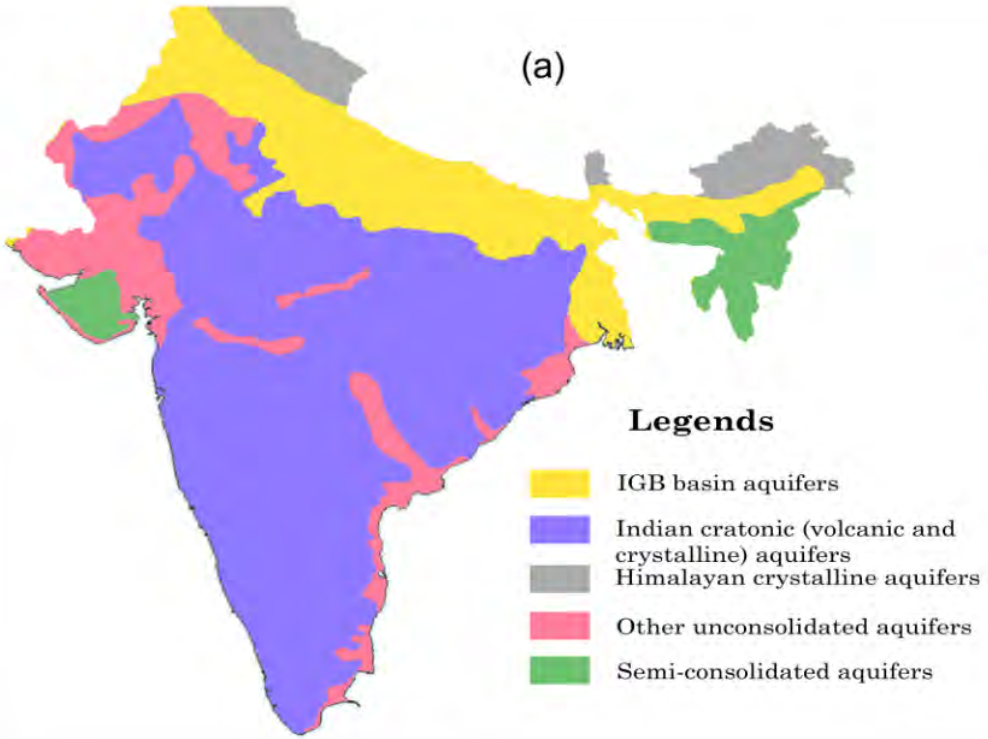
- database of ~5500 seasonal (quarterly) groundwater-level records across India from 2007 to 2011

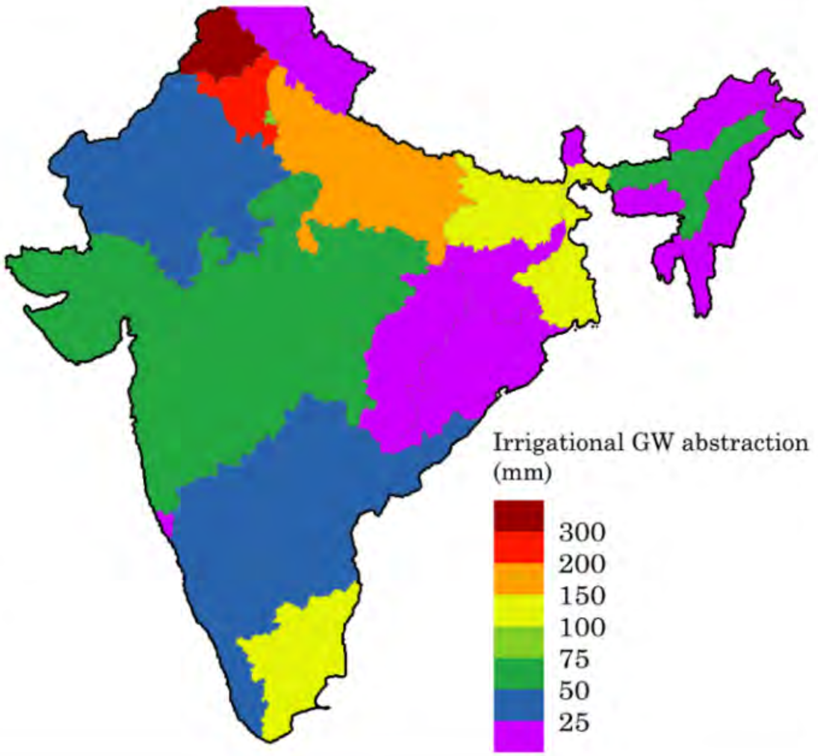
- estimated recharge from water-level fluctuations compared to mean of 3 GLDAS LSMs (CLM, VIC, NOAH) and PCR-GLOBWB (with & without water management)



hydrogeological context in India

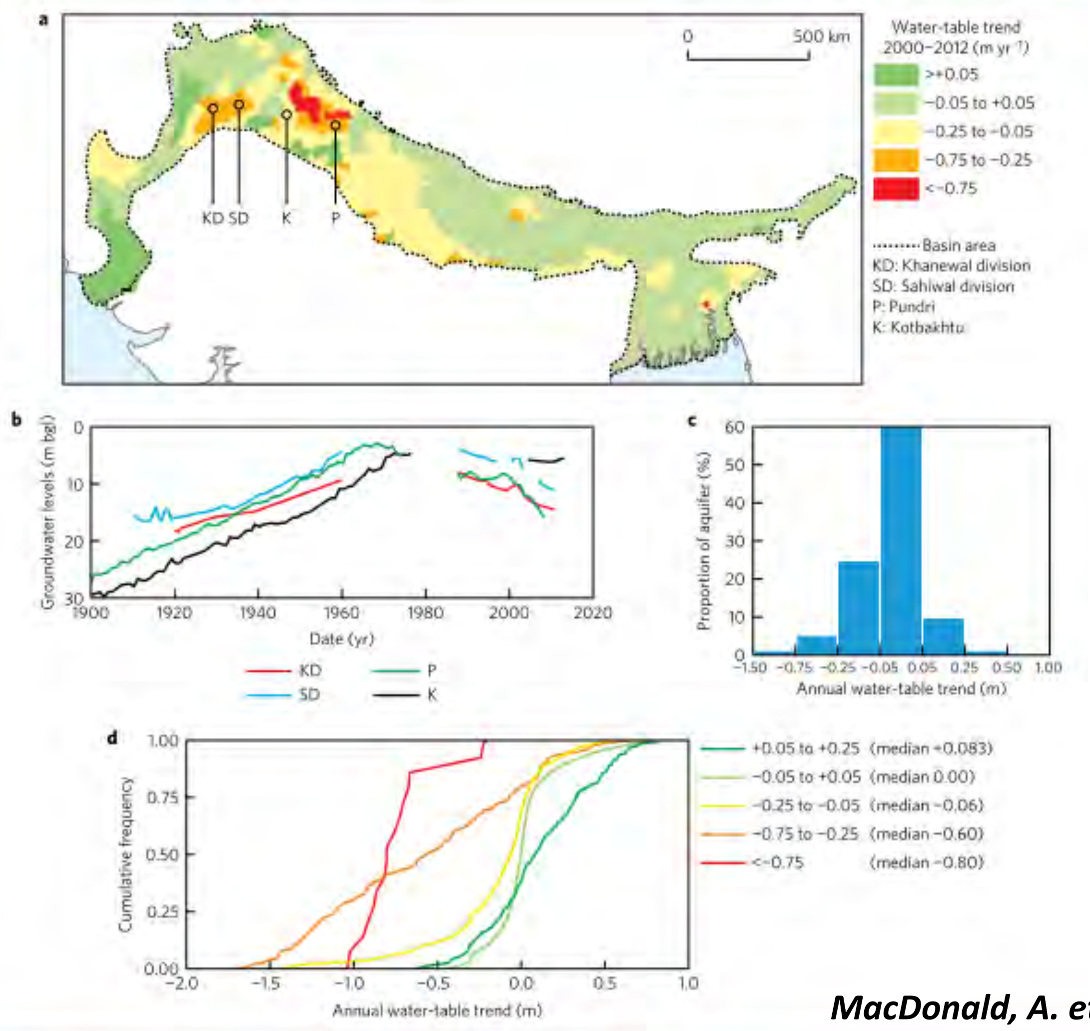
- **distribution of aquifer types and human use of groundwater**





human influences on groundwater in India

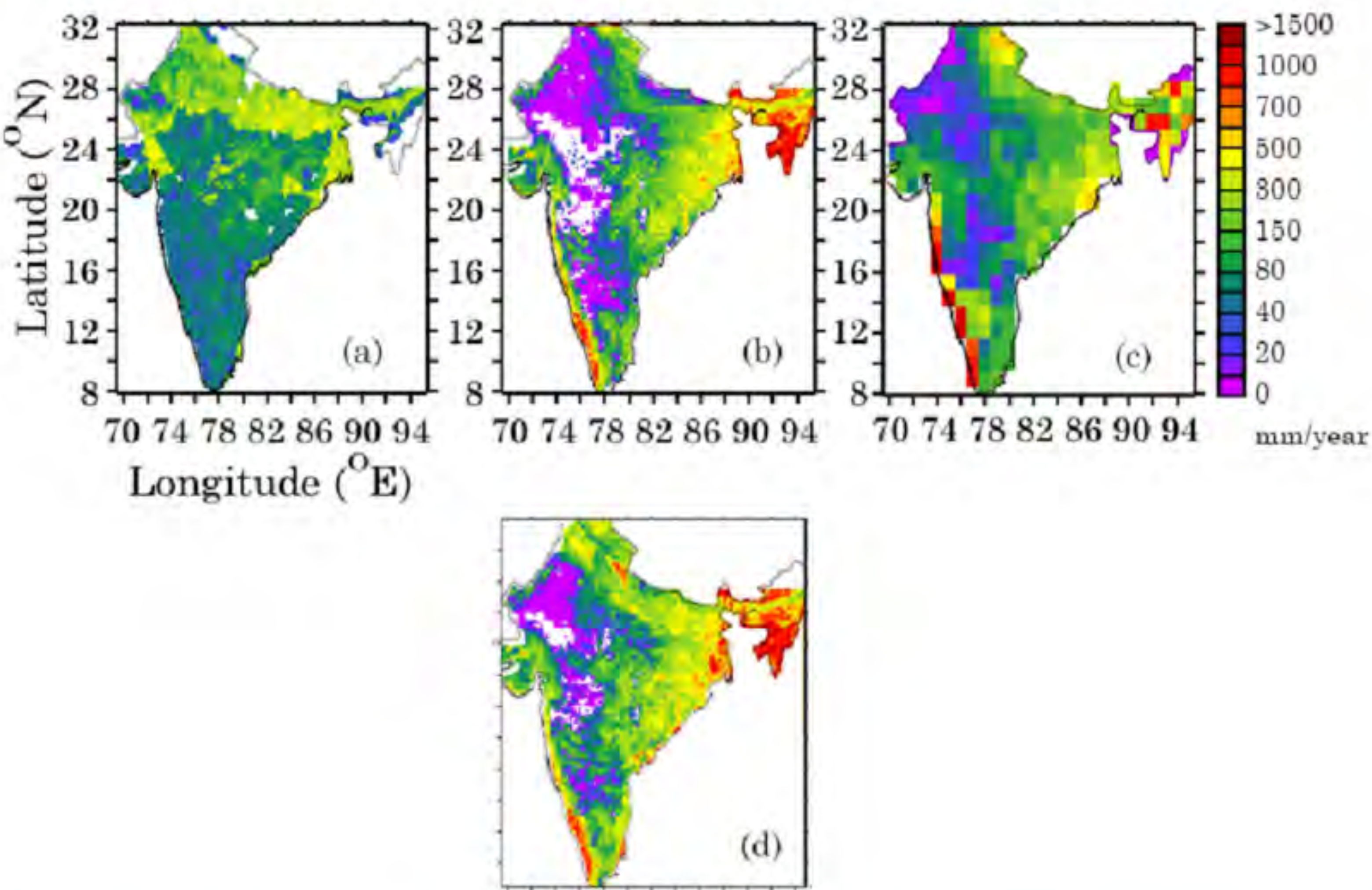
- **human influences on terrestrial hydrology in India have a very long history…**



MacDonald, A. et al. 2016. Nature Geoscience, NGEO2791.

recharge inter-comparison in India

- **very substantial differences among “observed” recharge from piezometry (a), PCR-GLOBWB – natural (b), 3 GLDAS LSMs (c), and PCR-GLOBWB – water management (d)**



recharge inter-comparison in India

- **inclusion of human withdrawals for irrigation and return flows in PCR-GLOBWB amplifies simulated recharge in the Indo-Gangetic Basin but do not address substantial discrepancy with "observed recharge"**

PCR-GLOBWB (water management) - PCR-GLOBWB (natural)