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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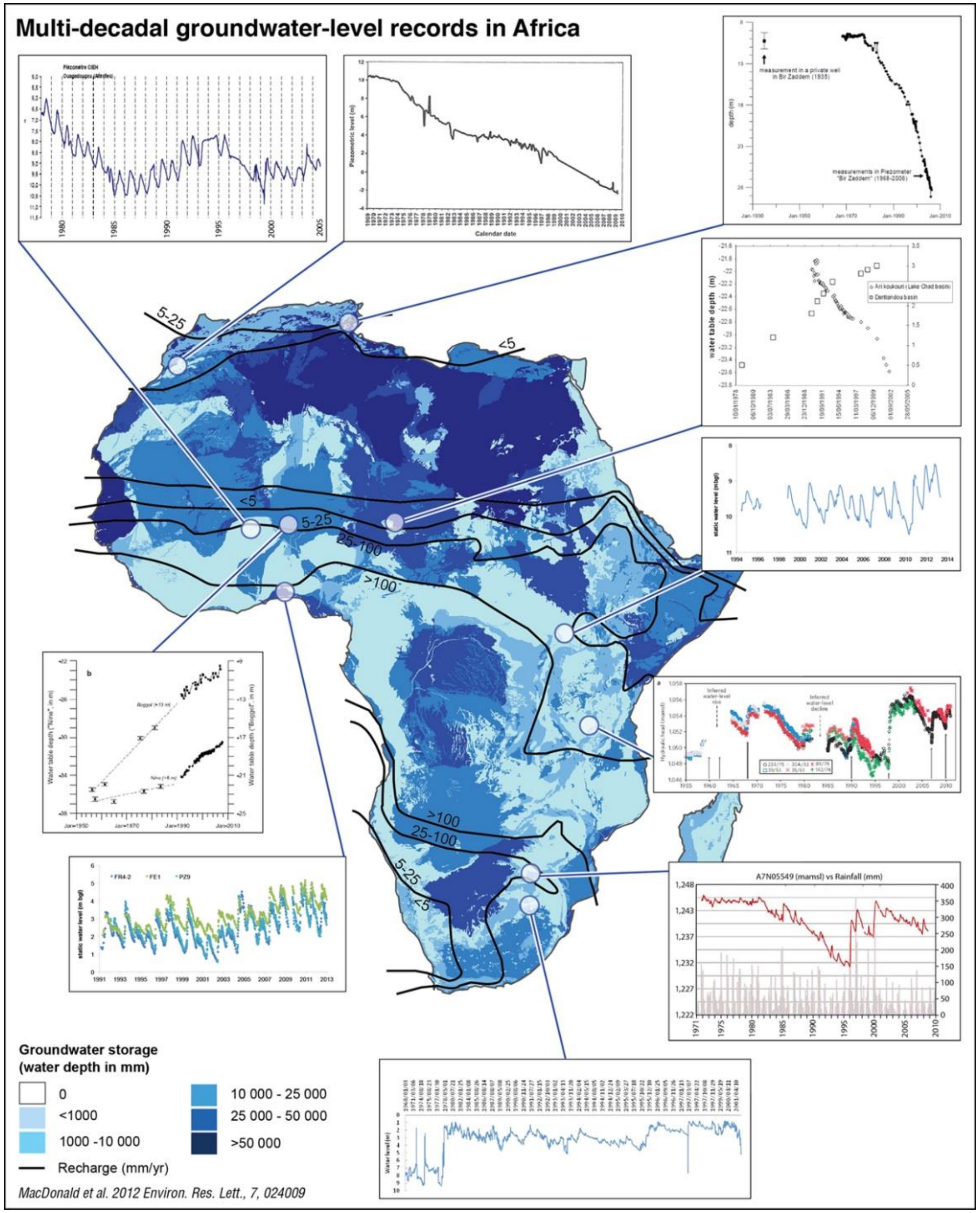

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A pan-African inter-comparison of groundwater recharge from *in-situ* observations and large-scale models

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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 <u>world's most variable freshwater resources</u>, the <u>highest rates of population growth</u>, <u>lowest rates of per capita food production</u>, and <u>lowest proportions of national populations with access to safe water</u>

- **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

- 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**

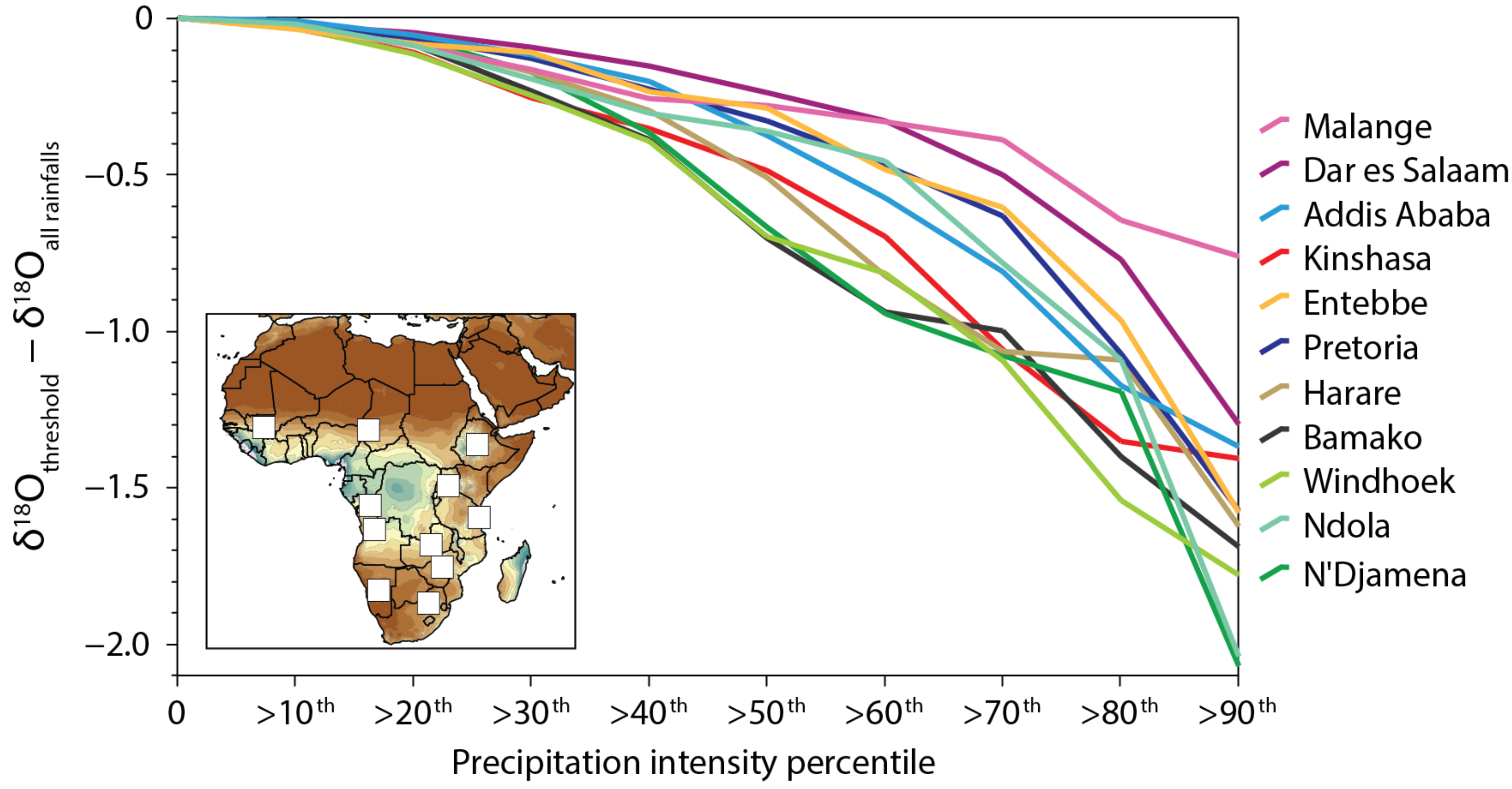
2. **to inform the development of more robust large-scale models that simulate critical groundwater processes (*e.g.* focused recharge)**

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

"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

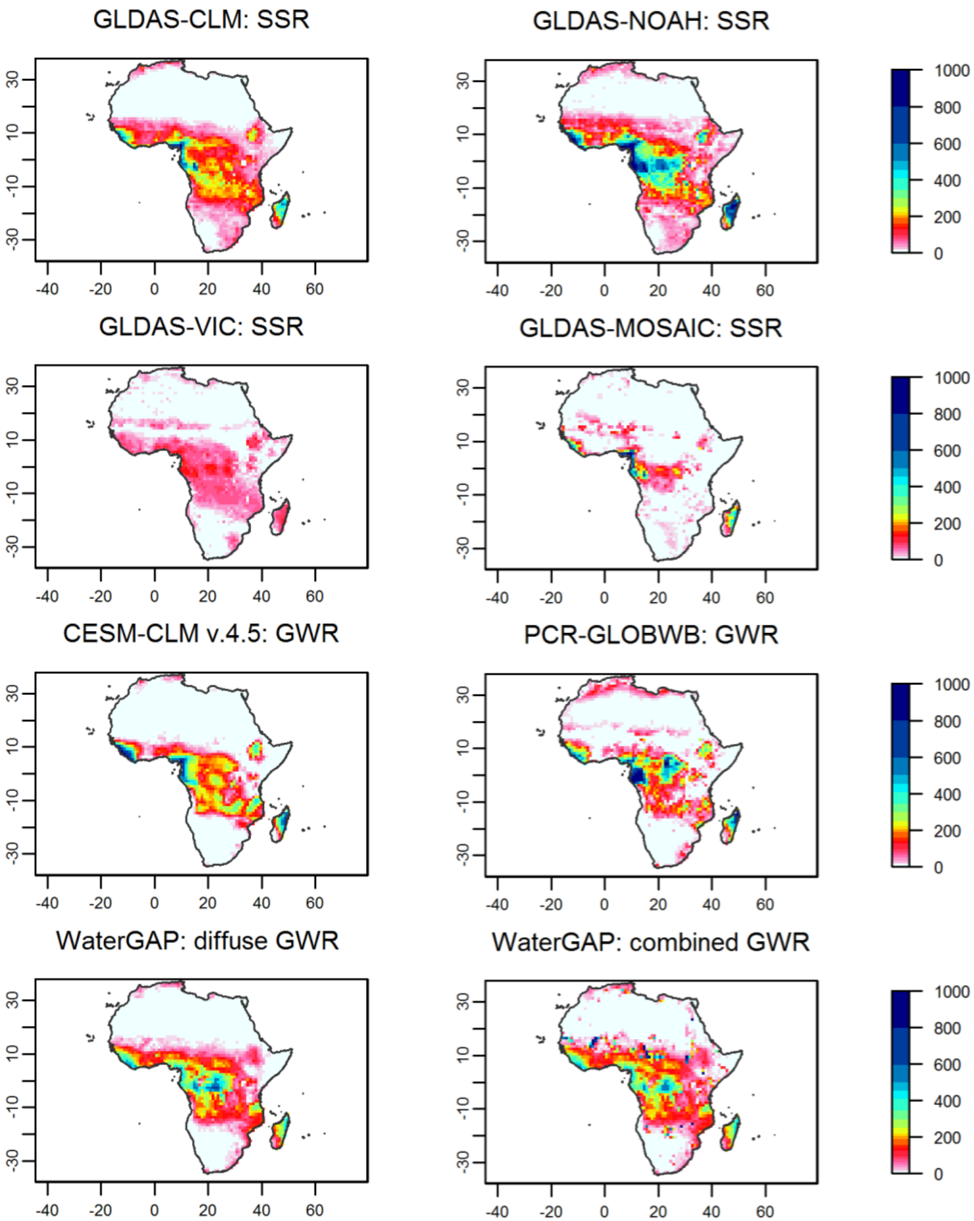
Location	P samples	P period	Mean annual P	GW samples
Addis Ababa	299 (296)	1961-2009	1100	13
Bamako	147 (140)	1962-1998	920	10
Dar es Salaam	125 (117)	1960-1973	1140	9
Entebbe	197 (192)	1960-2006	1570	56 (IAEA TWIN)
Harare	257 (192)	1960-2003	890	none within 100 km
Kinshasa	60 (59)	1961-1968	1380	none 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

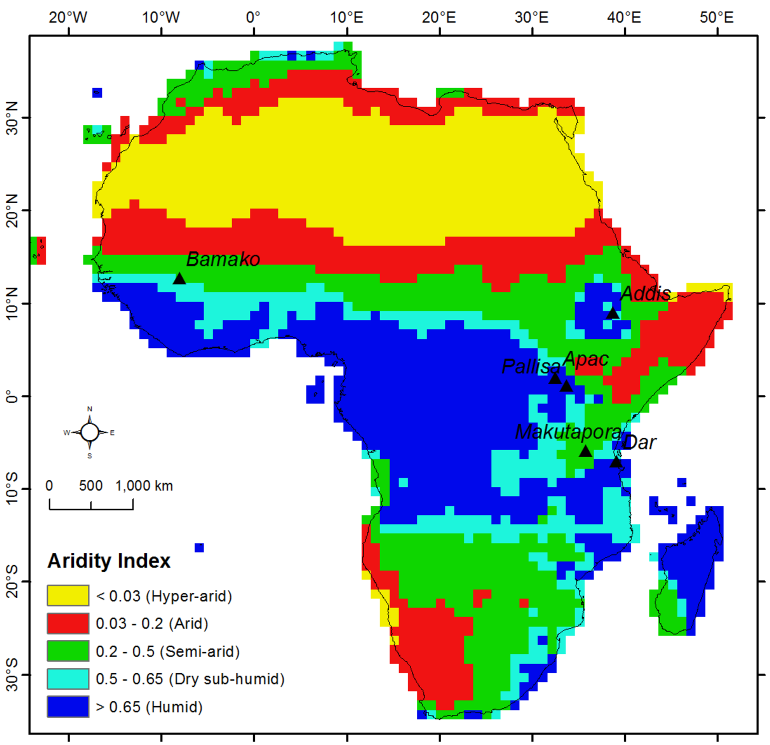


- substantial variations in the magnitude and distribution of mean annual SSR & groundwater recharge (GWR)

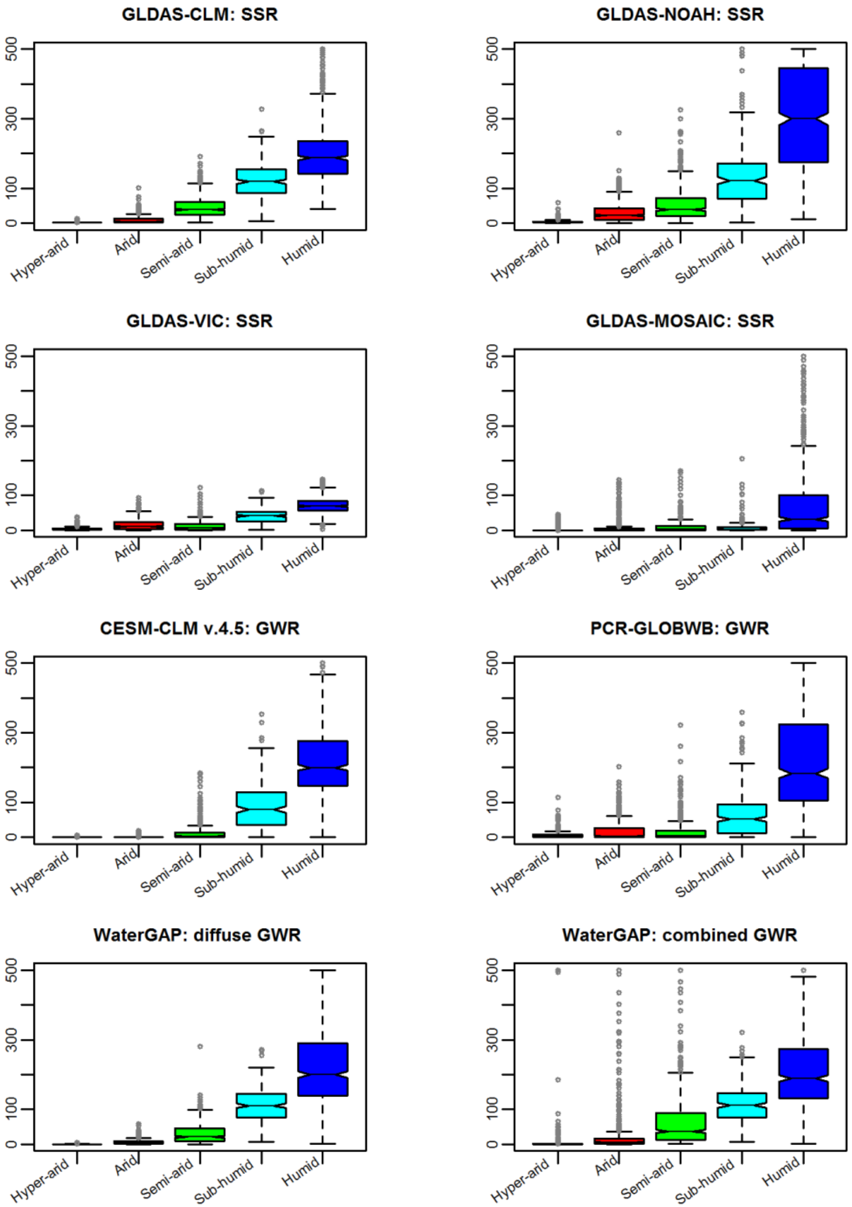
- spatial extent & magnitude of recharge in semi-arid regions increase from WaterGAP (<u>diffuse only</u>) to WaterGAP (<u>diffuse-focused</u>)

simulated SSR & GWR grouped by climate

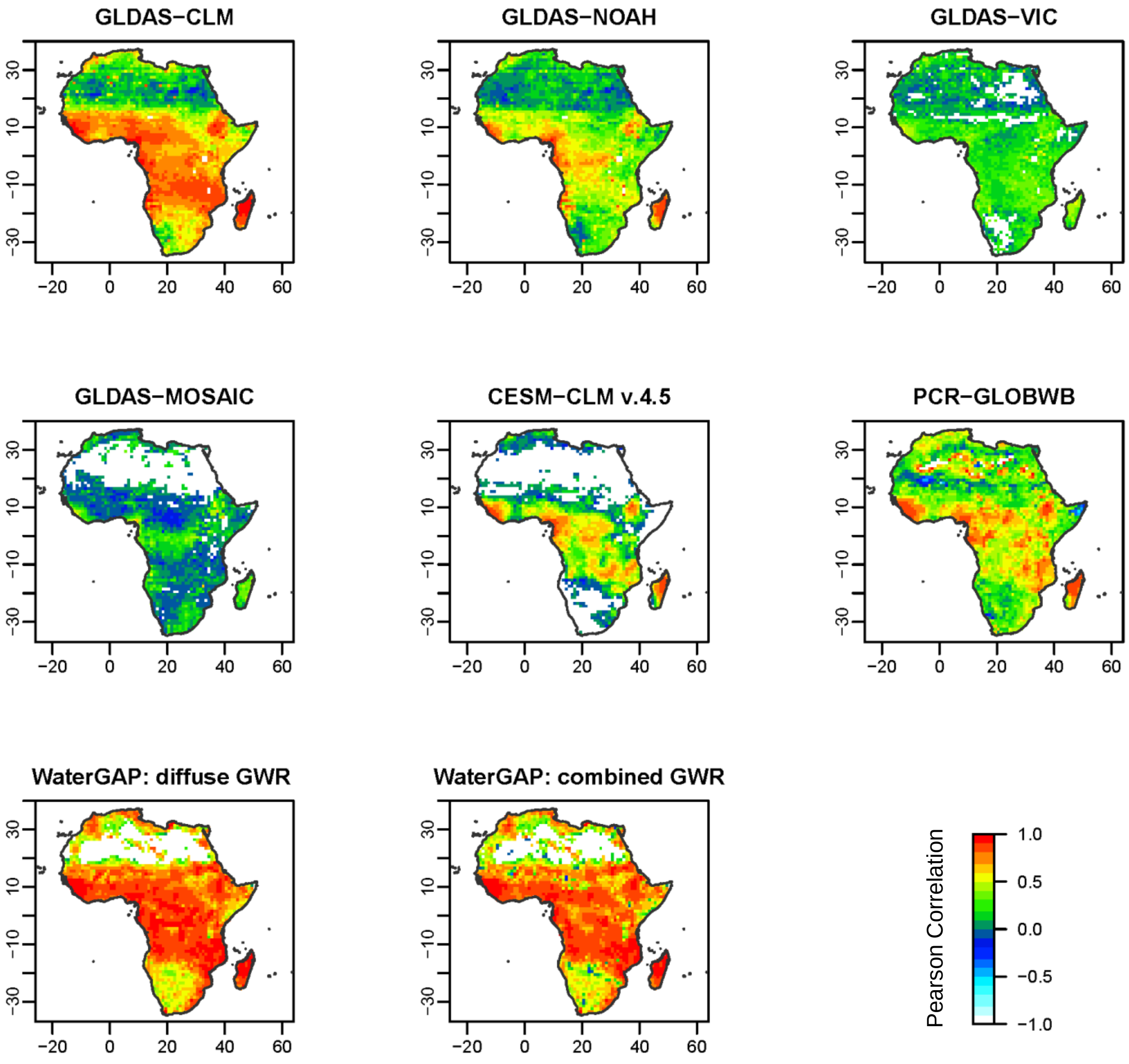
- simulated recharge in semi-arid regions increases with the inclusion of focused recharge in WaterGAP



CGIAR Aridity Index



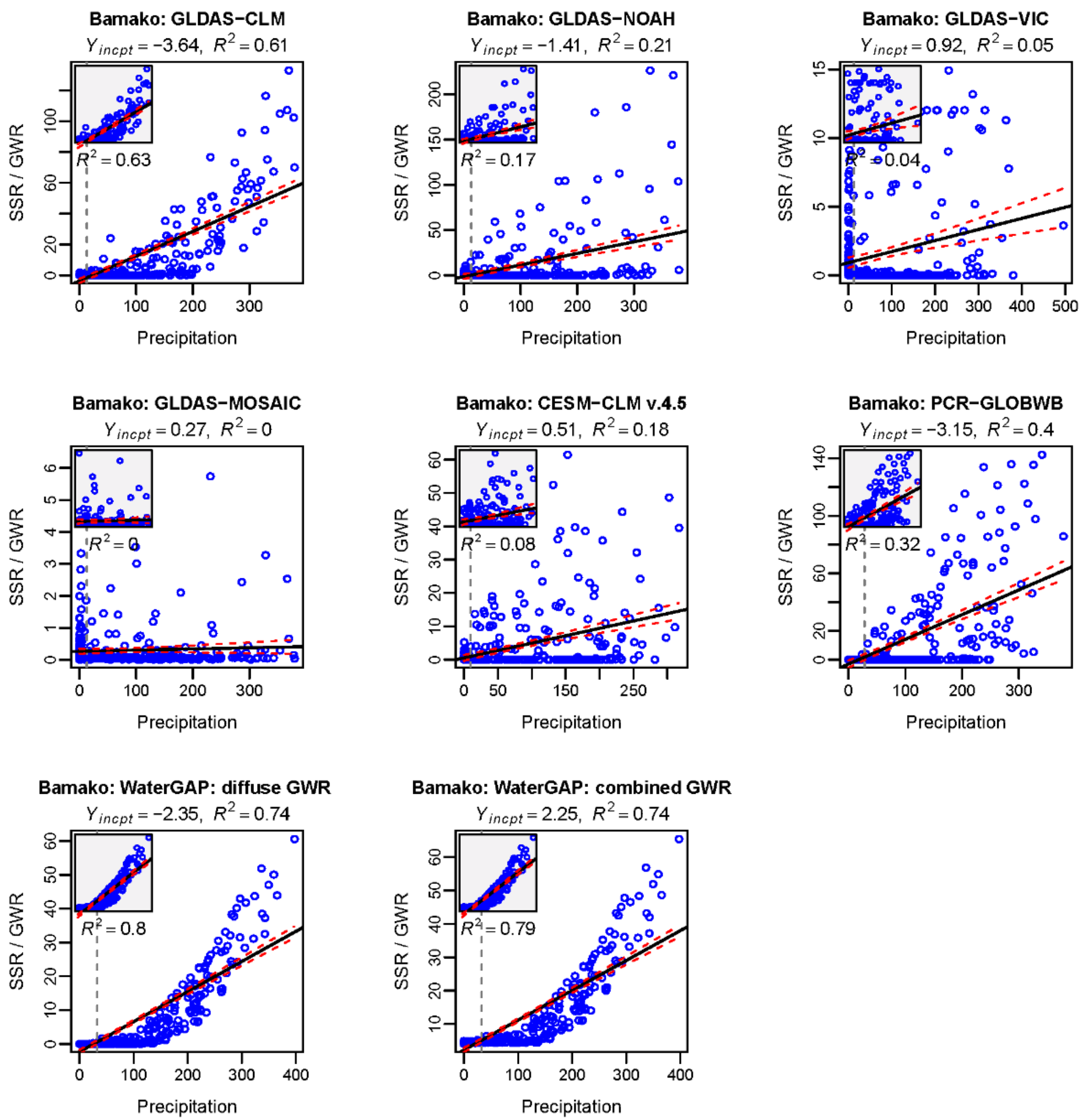
correlation of simulated GWR/SSR and precip



- 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

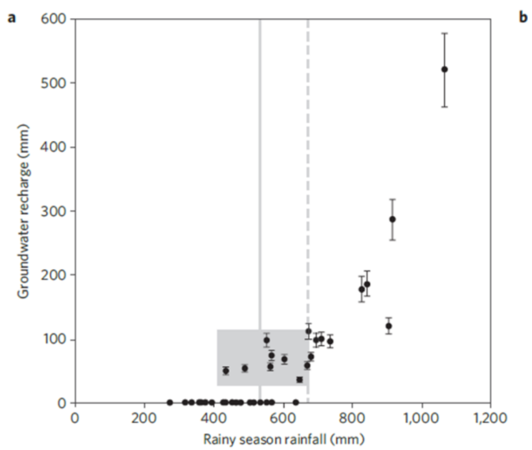
semi-arid: Bamako (isotope pairing)

Bamako (Mali)

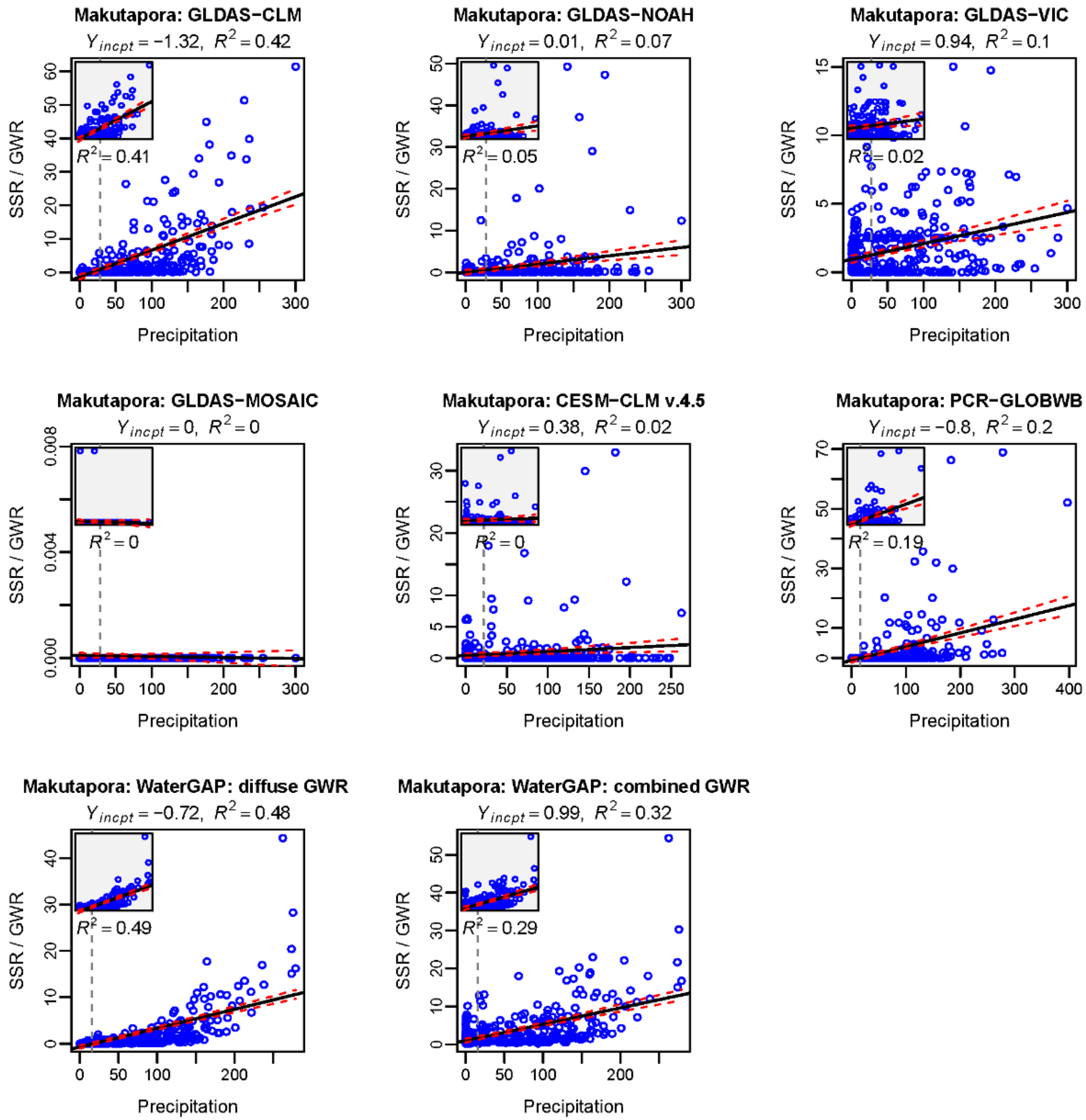


semi-arid: Makutapora (piezometry)

Makutapora (Tanzania)

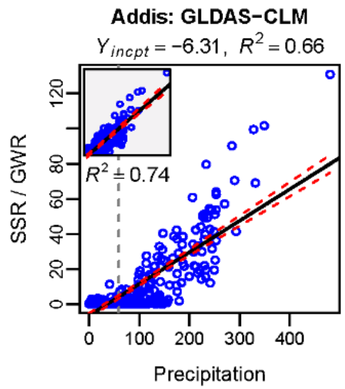


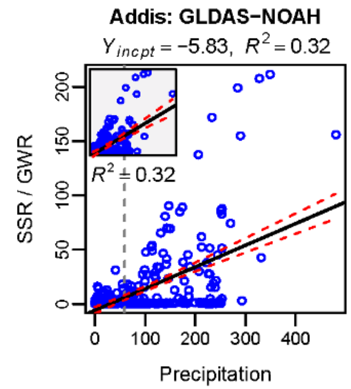
Taylor et al. (2013)

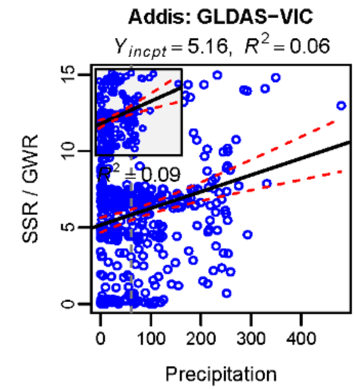


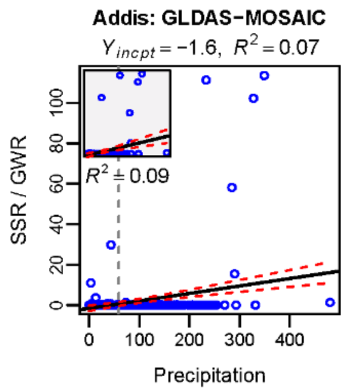
humid: Addis Ababa (isotope pairing)

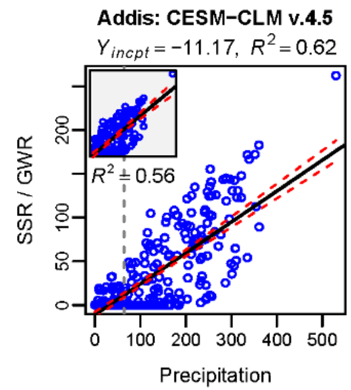
Addis Ababa (Ethiopia)

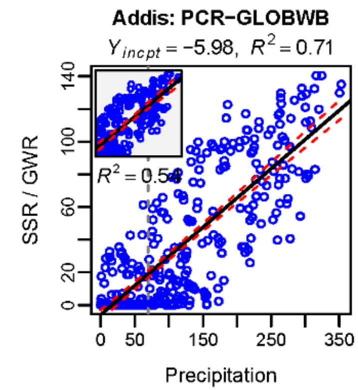


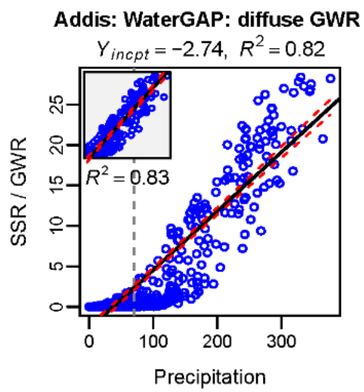


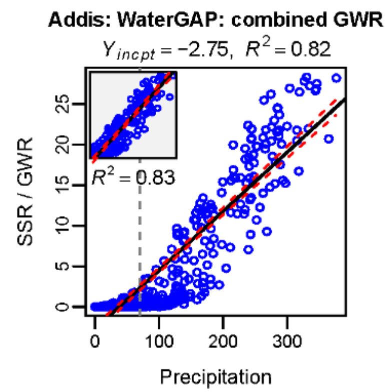






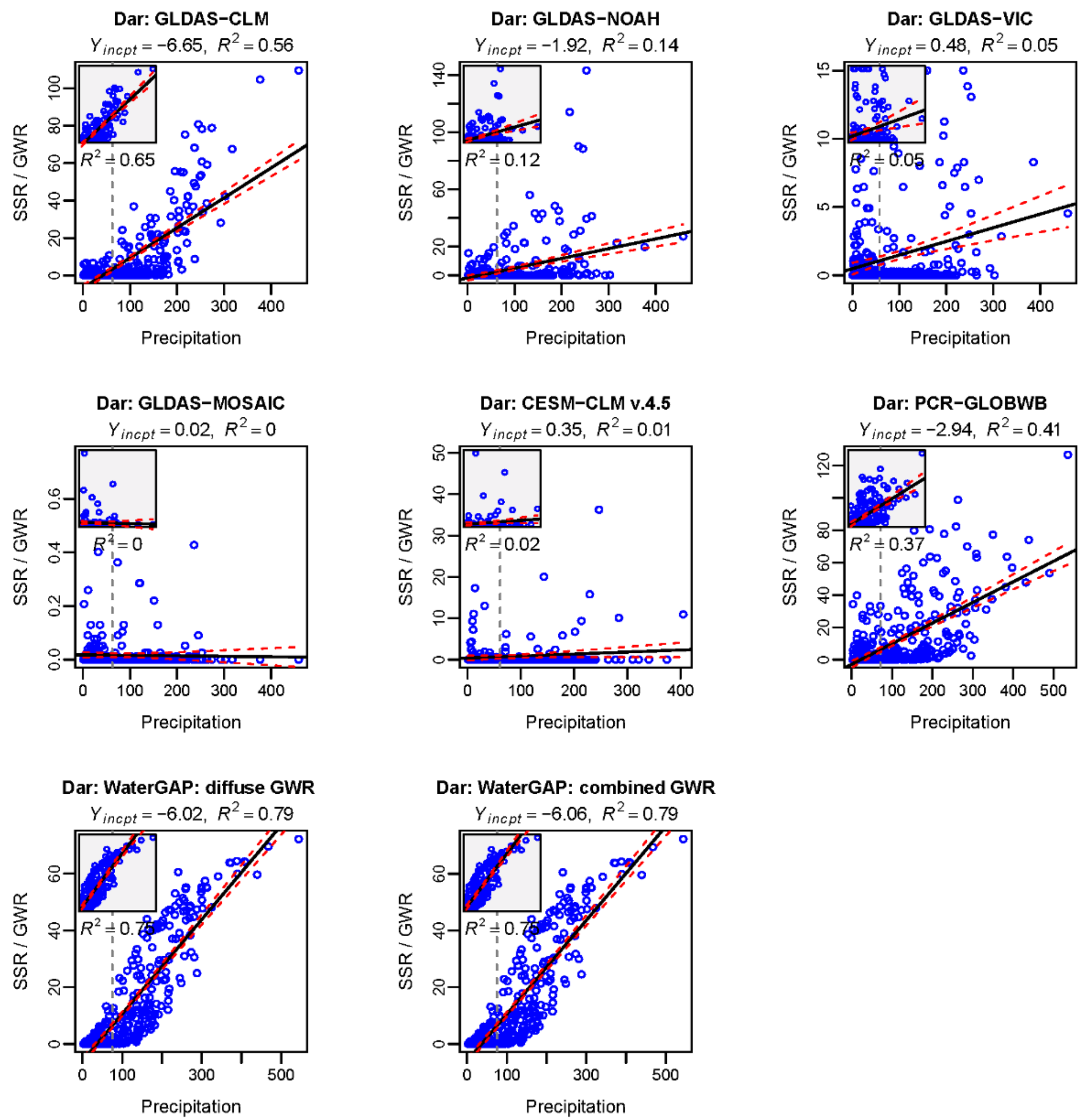






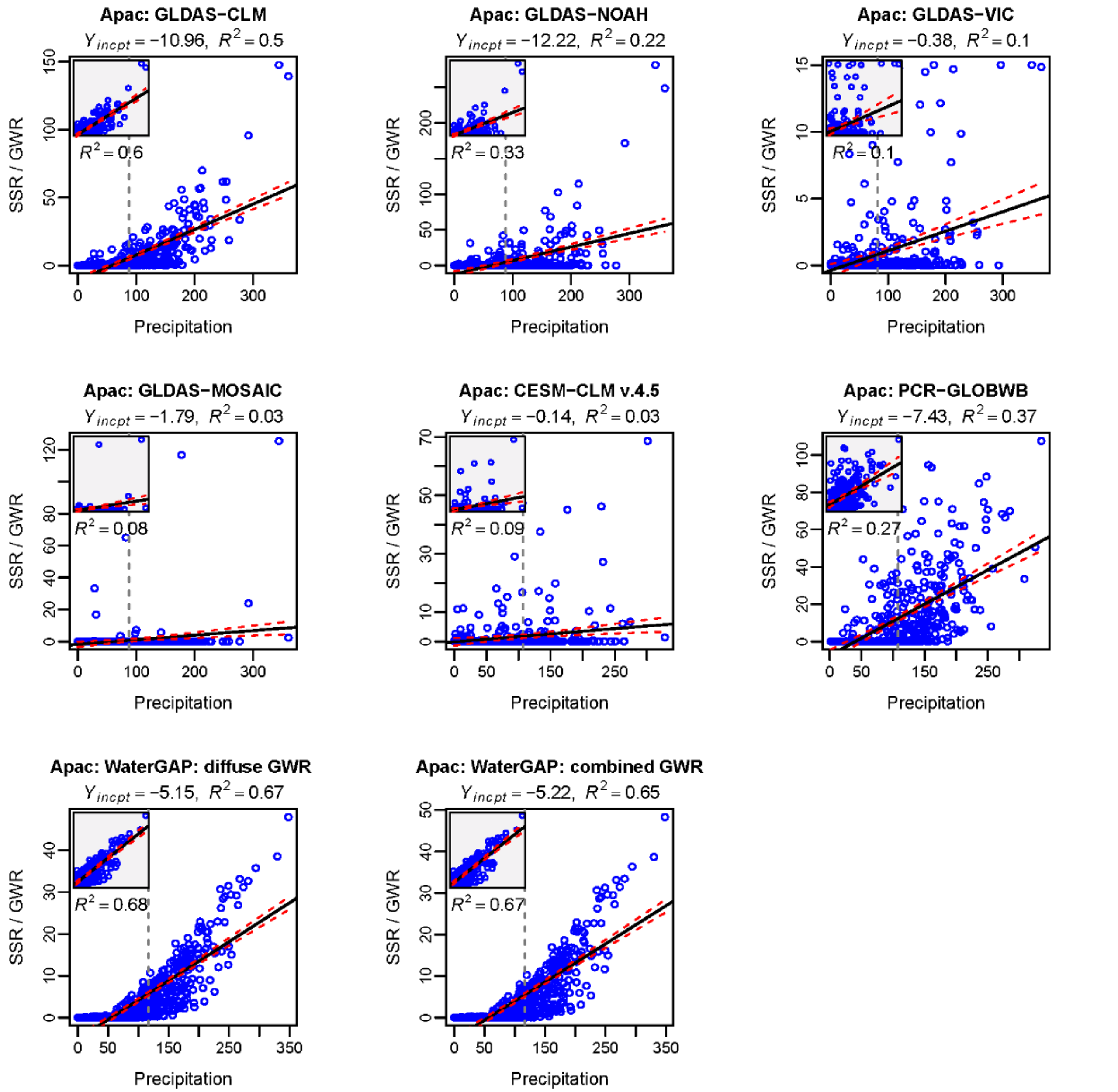
humid: Dar es Salaam (isotope pairing)

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

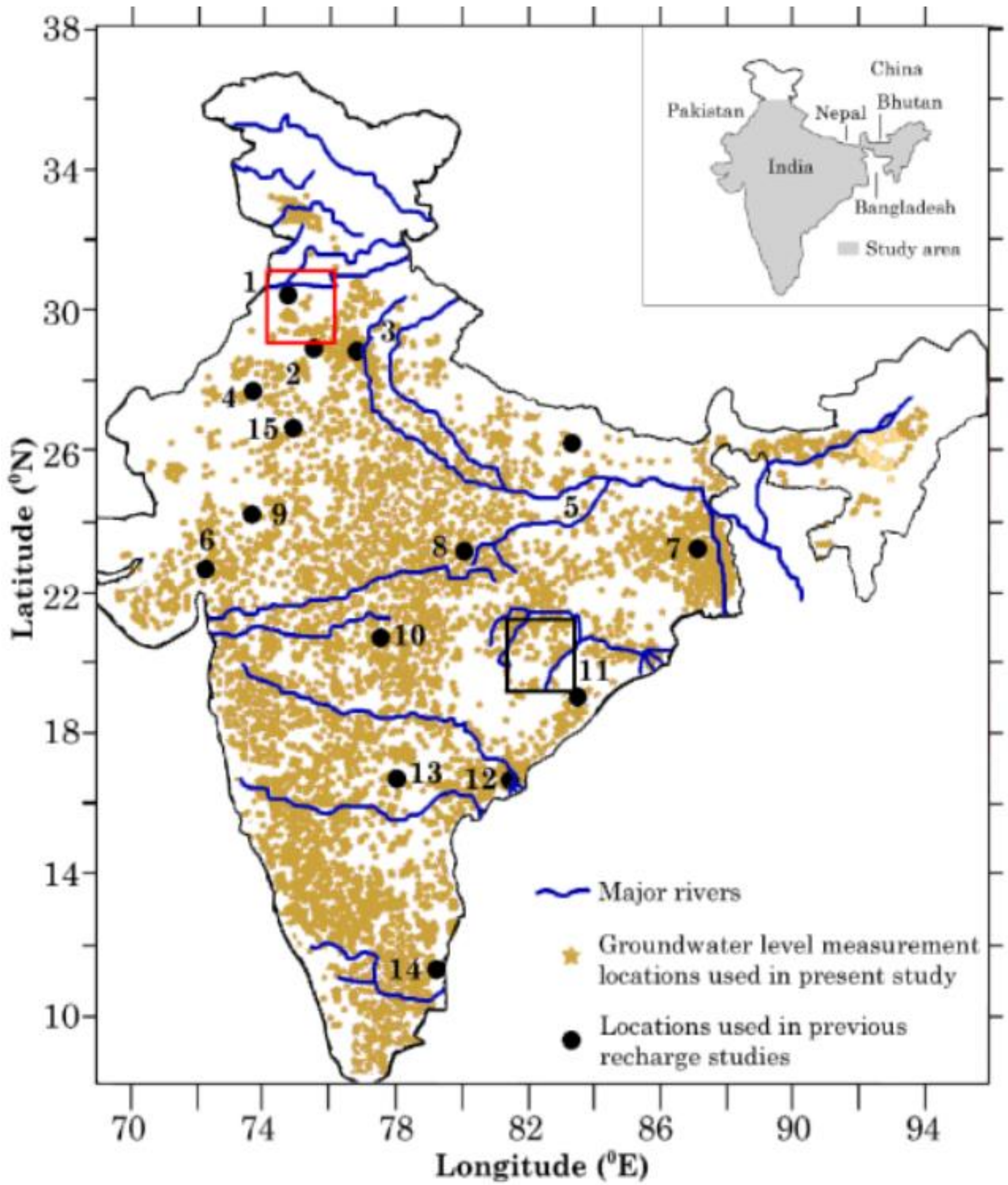
- non-linearity, evident in the relationship between simulated GWR & SSR and precipitation (GLDAS-CLM, WaterGAP), is consistent with piezometric & isotopic observations

- 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

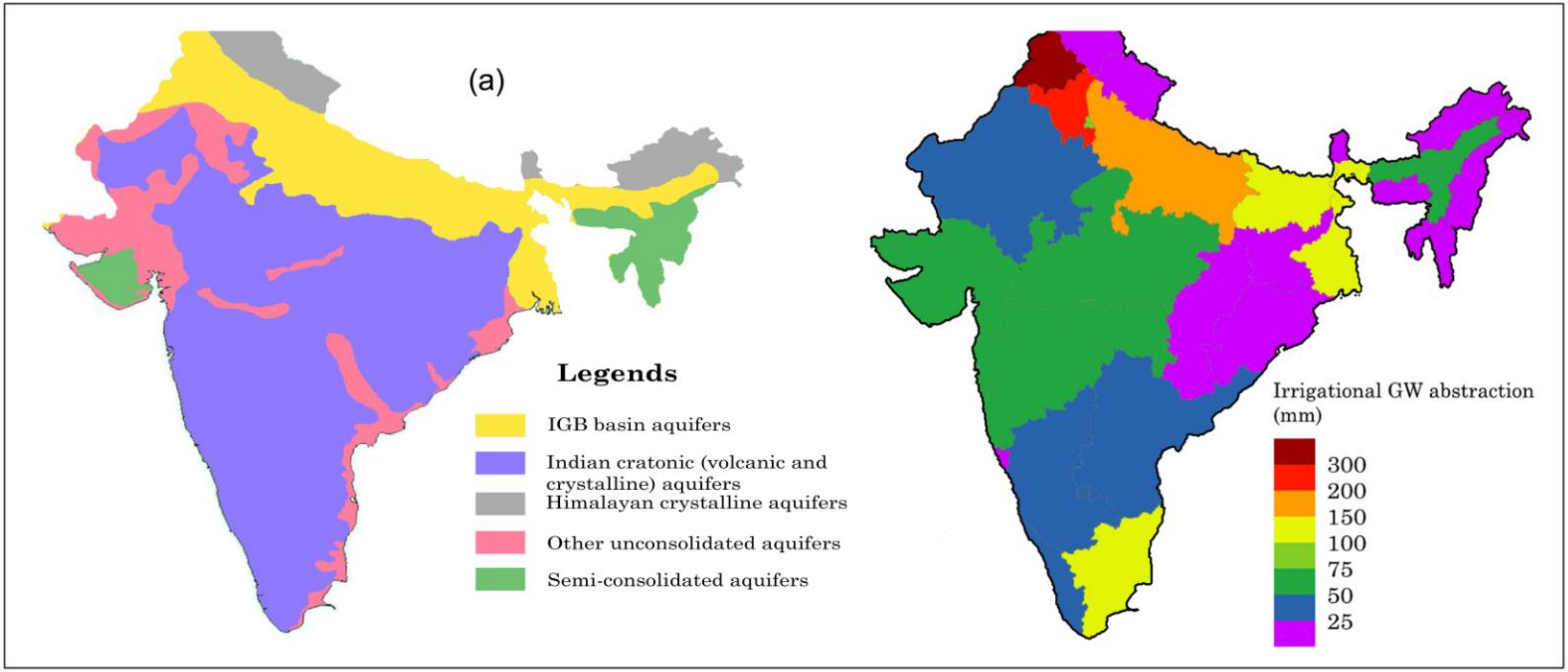
- database of ~5500 seasonal (quarterly) groundwater-level records across India from 2007 to 2011

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



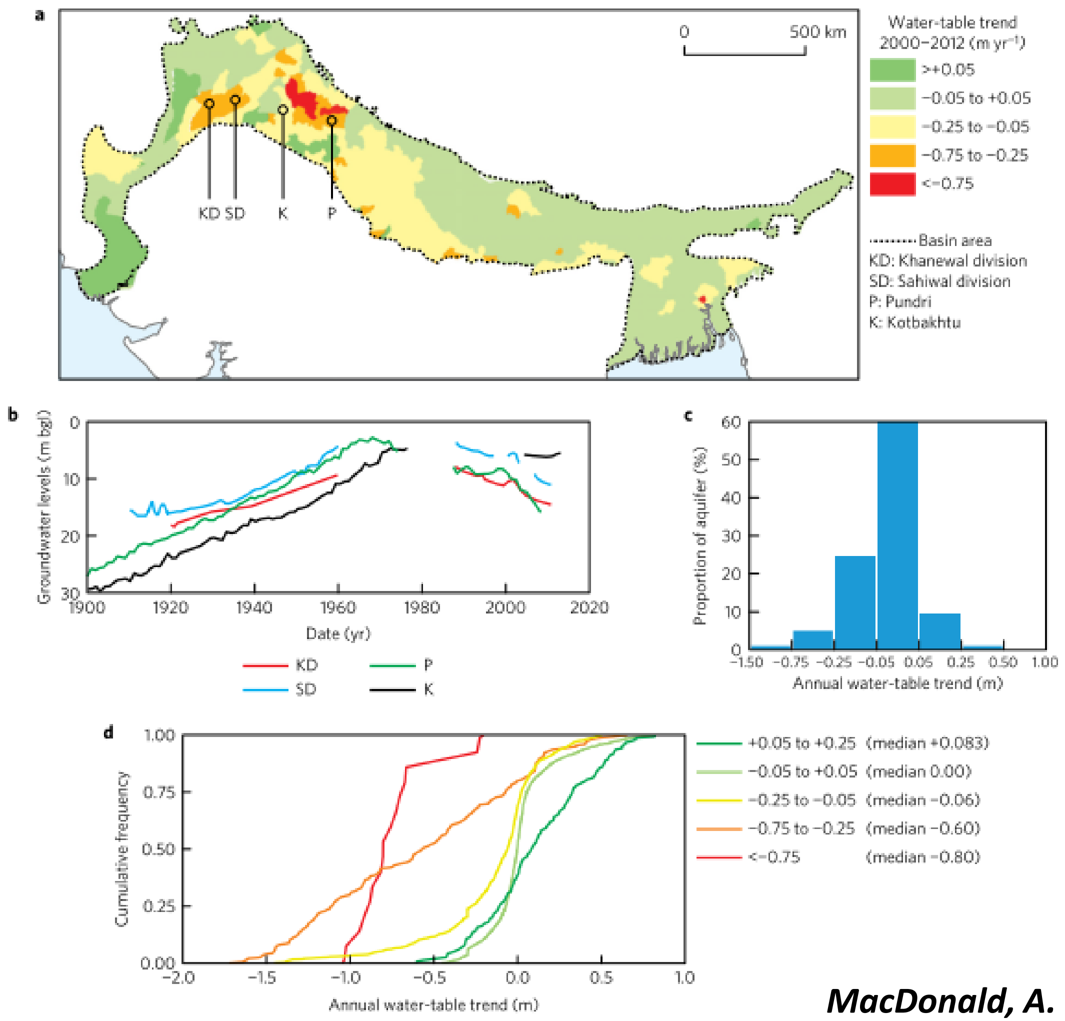
hydrogeological context in India

- distribution of aquifer types and human use of groundwater



human influences on groundwater in India

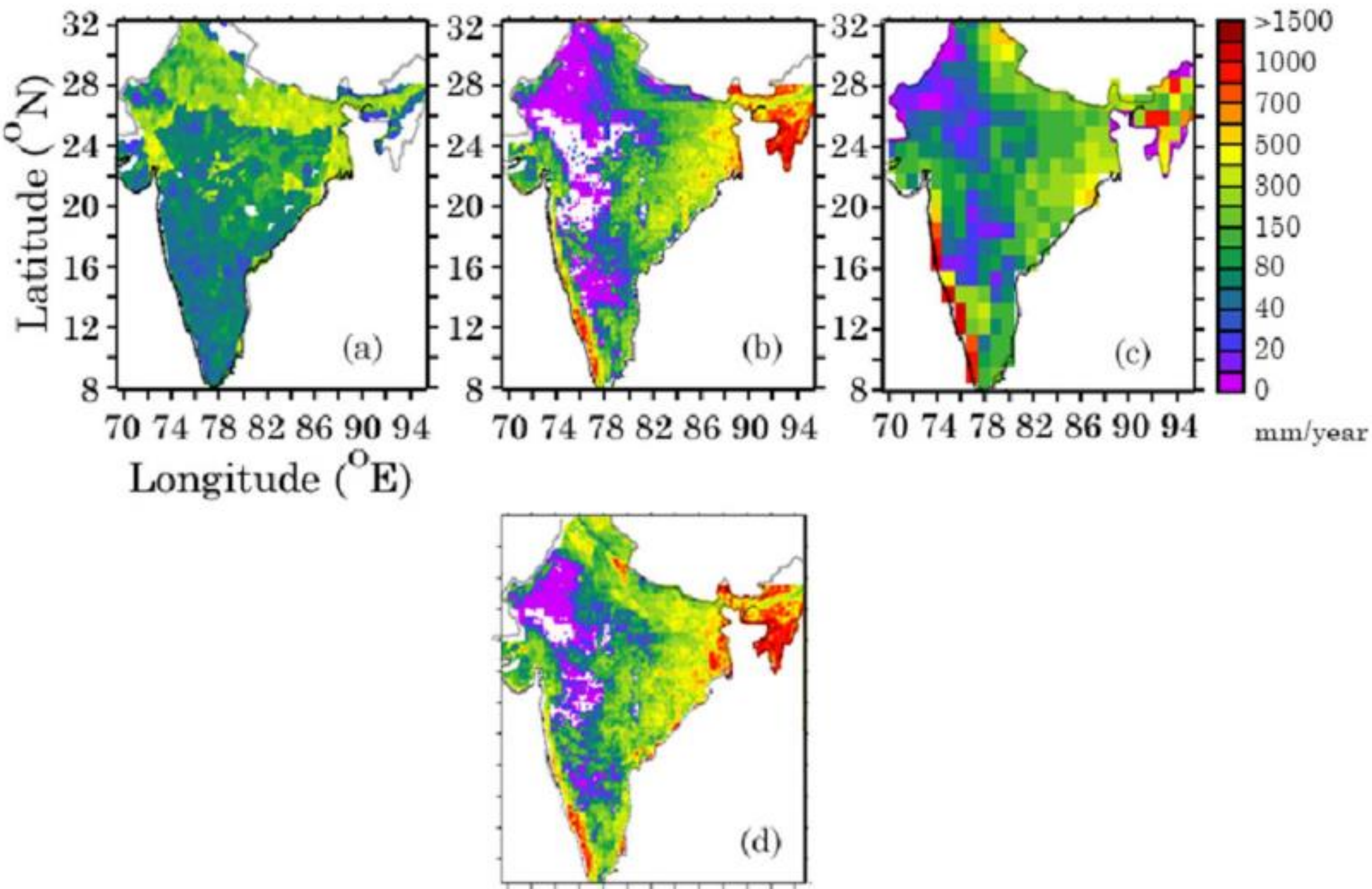
- **human influences on terrestrial hydrology in India have a very long history…**



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)