XVIII
World Water Congress
International Water Resources Association (IWRA)

GRACE satellite-based estimation of groundwater storage changes and water balance analysis for the Haihe River Basin

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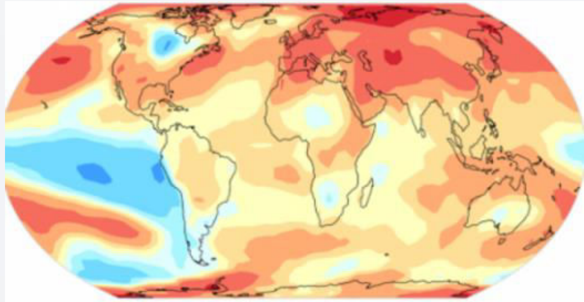
第18届
世界水资源大会
水与万物：
人与自然和谐共生

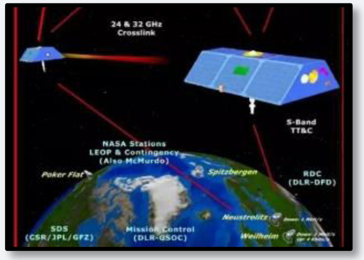
Content

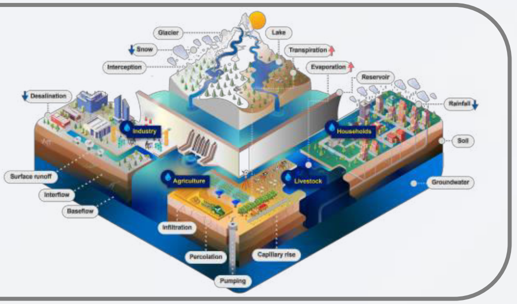
Introduction

Climatic change



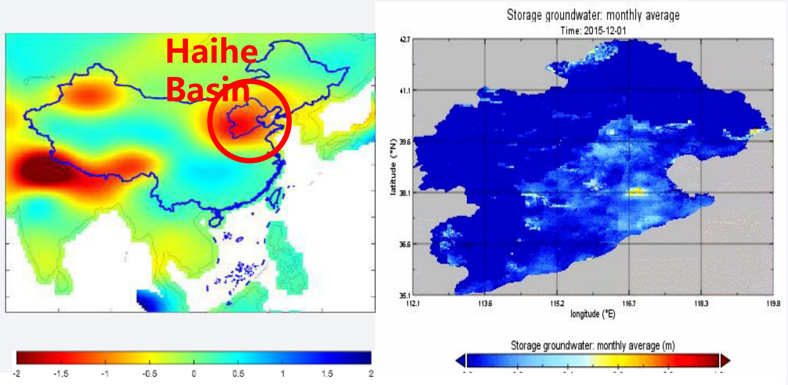
Water supply and use structure





changed

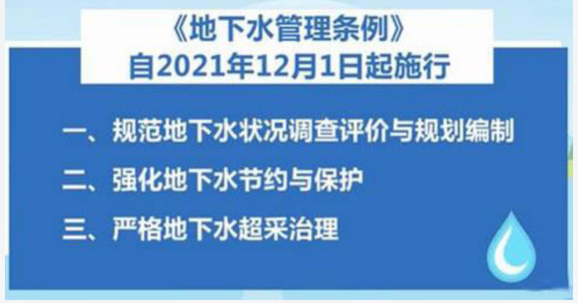
influenced



groundwater storage changes

South-to-North Water Diversion

Reductions in groundwater withdrawals



《地下水管理条例》
自2021年12月1日起施行

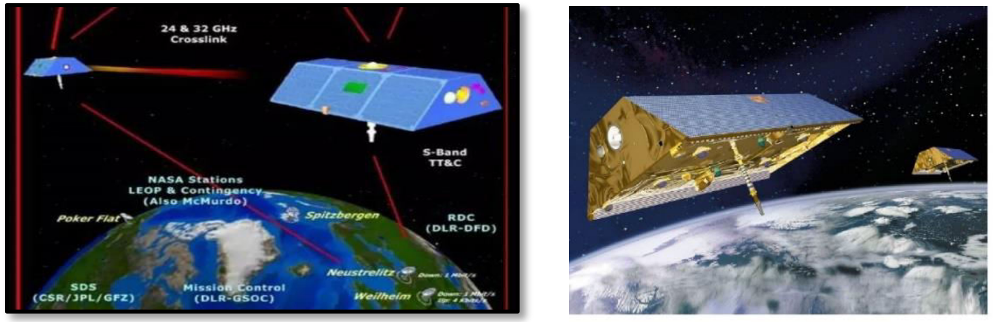
一、规范地下水状况调查评价与规划编制
二、强化地下水节约与保护
三、严格地下水超采治理

Reliable monitoring of regional GWS changes serves as a basis for water security and strategic groundwater reserves

Introduction

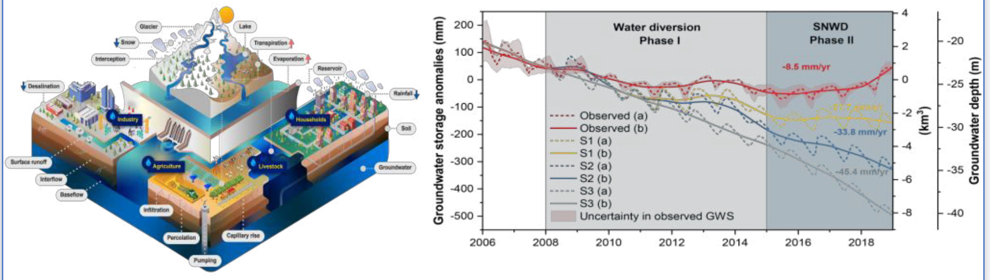
- ☐ Traditional approaches of calculating GWS changes over large areas using in-situ groundwater level measurements and specific yield/storage coefficients may be subject to large uncertainties due to large spatiotemporal variability in those variables and parameters
- ☐ Here we compare different methods of processing GRACE signals and use four GRACE products to estimate changes in total water storage (TWS) and GWS in the HRB from 2003 to 2022

Gravity satellite monitoring of groundwater storage changes



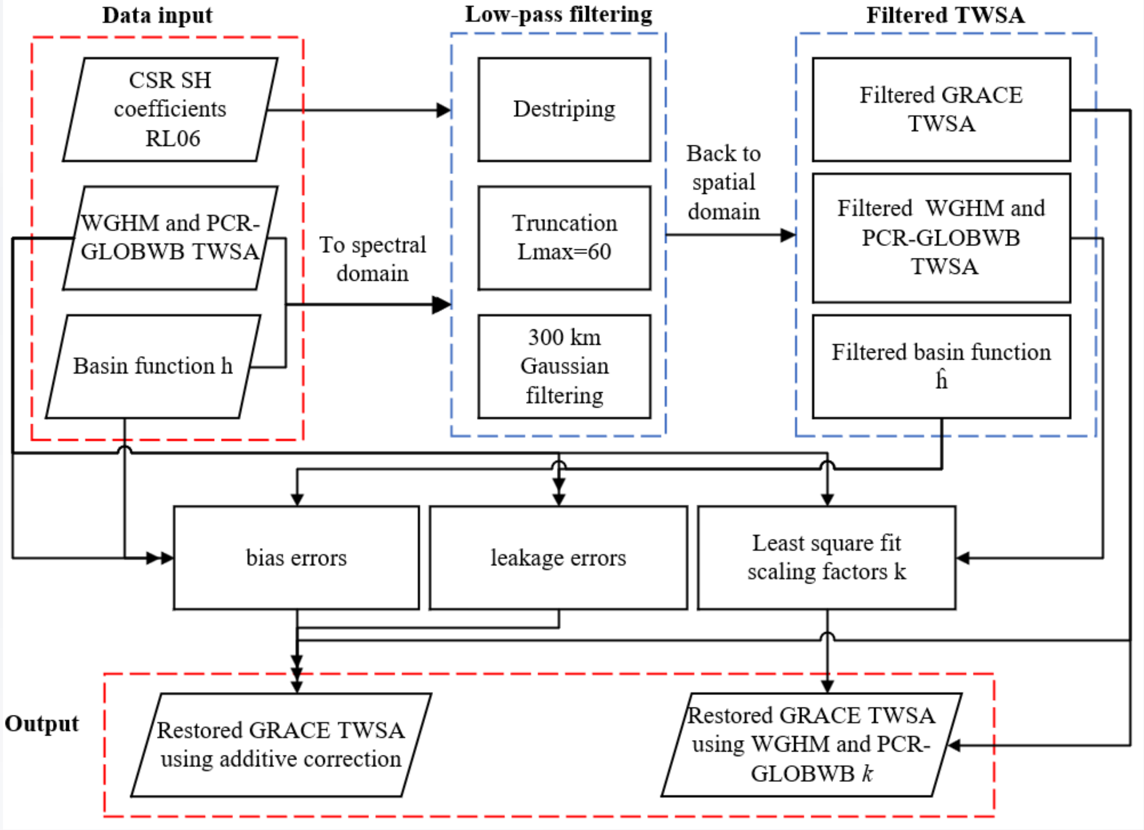
Long et al. *Journal of Hydraulic Engineering*, 2023

Simulation prediction of groundwater storage change



Yang and Long et al. *Water Resources Research*, 2022

Methods and Data



Data input

CSR SH coefficients RL06

WGHM and PCR-GLOBWB TWSA

Basin function h

To spectral domain

Low-pass filtering

Destriping

Truncation Lmax=60

300 km Gaussian filtering

Back to spatial domain

Filtered TWSA

Filtered GRACE TWSA

Filtered WGHM and PCR-GLOBWB TWSA

Filtered basin function ĥ

bias errors

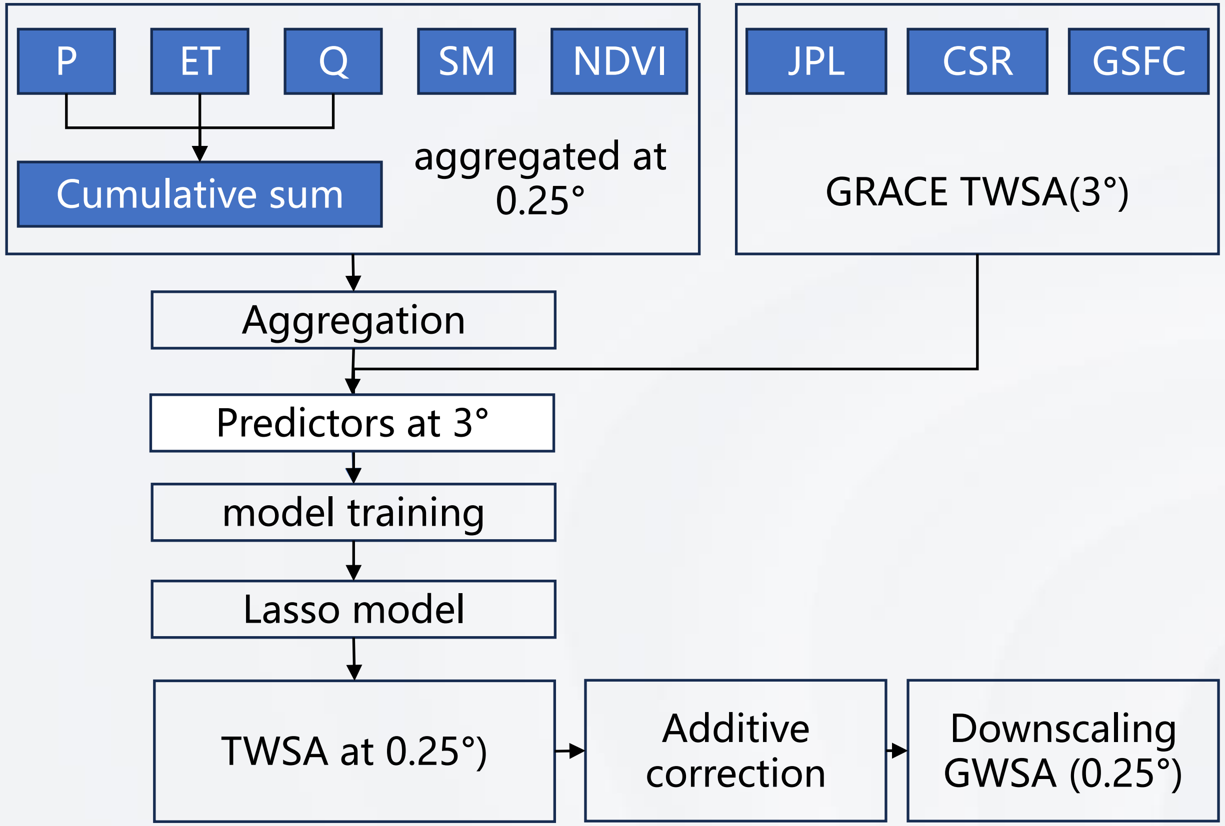
leakage errors

Least square fit scaling factors k

Output

Restored GRACE TWSA using additive correction

Restored GRACE TWSA using WGHM and PCR-GLOBWB *k*



P

ET

Q

SM

NDVI

Cumulative sum

aggregated at 0.25°

JPL

CSR

GSFC

GRACE TWSA(3°)

Aggregation

Predictors at 3°

model training

Lasso model

TWSA at 0.25°)

Additive correction

Downscaling GWSA (0.25°)

Flowchart of the derivation of scaling factors to restore GRACE TWS anomaly signals

Flowchart of the GRACE downscaling method

Methods and Data

Downscaling GWS based on Lasso (Least absolute shrinkage and selection operator) algorithm

$$\mathrm{TWSA} = \beta_0 + \beta_1 \mathrm{ET} + \beta_2 \mathrm{ET}_{\mathrm{acc}} + \beta_3 \mathrm{P} + \beta_4 \mathrm{P}_{\mathrm{acc}} + \beta_5 \mathrm{Q} + \beta_6 \mathrm{Q}_{\mathrm{acc}} + \beta_7 \mathrm{NDVI} + \beta_8 \mathrm{SM}$$

$$\hat{\beta}^{\mathrm{lasso}} = \mathrm{argmin}_{\beta} \Sigma_{i=1}^{n} \left(y_i - \beta_0 - \Sigma_{j=1}^{p} \beta_j x_{ij} \right)^2 + \boldsymbol{\lambda} \boldsymbol{\Sigma}_{\boldsymbol{j=1}}^{\boldsymbol{p}} |\boldsymbol{\beta}_{\boldsymbol{j}}|$$

Advantage: automatic screening of feature variables reduces overfitting

List of the data sets used in this study:

Variable	Data Set	Spatial Resolution	Time Resolution	Period	Data Source
TWSA	RL06 Mascon products from JPL, CSR and GSFC	3°	1 month	2002/04–2022/11	https://grace.jpl.nasa.gov https://www2.csr.utexas.edu https://earth.gsfc.nasa.gov/
evapotranspiration(ET)	GLEAM v3.6b	0.25°	1 month	2003/01–2022/12	http://www.gleam.eu
precipitation(P)	IMERG v06	0.1°	1 month	2000/06–2022/11	https://gpm.nasa.gov/data/imerg
runoff(Q)	GLDAS v2.2 CLSM	0.25°	1 day	2003/02–2022/12	https://disc.gsfc.nasa.gov
NDVI	MODIS NDVI v6.1	0.05°	1 month	2000/02–2022/11	https://search.earthdata.nasa.gov
soil water storage(SM)	GLDAS v2.1 Noah	0.25°	1 month	2000/01–2022/12	https://disc.gsfc.nasa.gov

Methods and Data

CWatM- MODFLOW Model

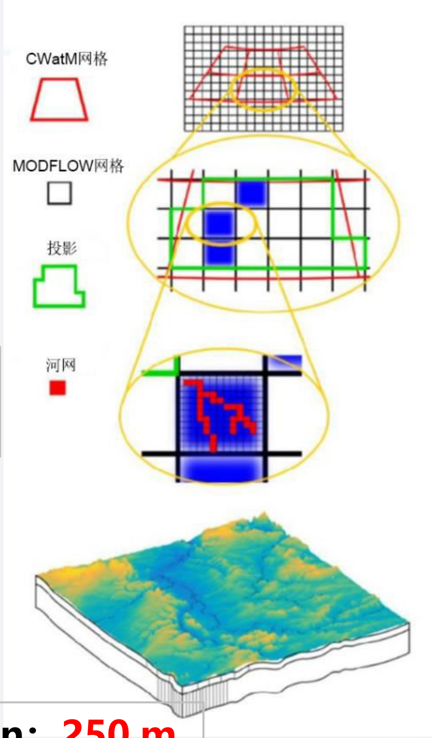
Coupling in different coordinate systems

CWatM spatial resolution: 1000 m

CWatM and MODFLOW grid matching

MODFLOW spatial resolution : 500 m

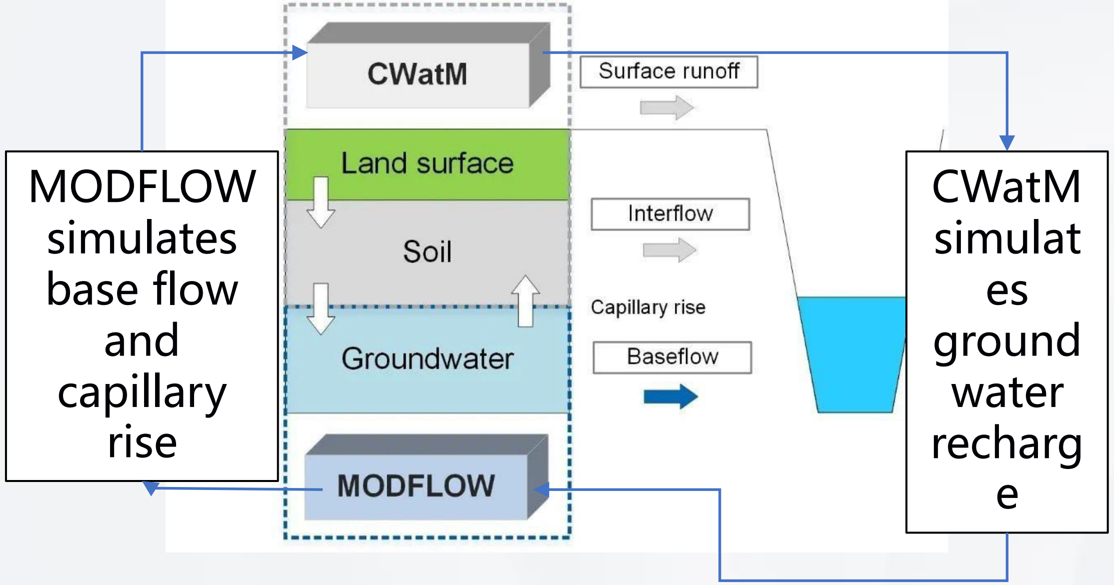
Channel network in MODFLOW cell grid



River Network Spatial Resolution: 250 m

Coupling of surface and subsurface hydrological processes

$$S_s \frac{\partial h}{\partial t} = \frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right) - W$$



MODFLOW simulates base flow and capillary rise

CWatM simulates groundwater recharge

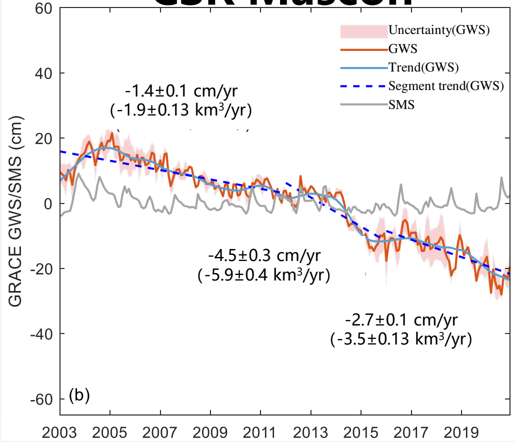
Setting up MODFLOW-NWT with a higher spatial resolution and coupling it with CWatM through the discrete unit grid projection correspondence

Implementing a high-resolution surface hydrological model, can describe the movement of groundwater and capture key hydrological processes in greater detail

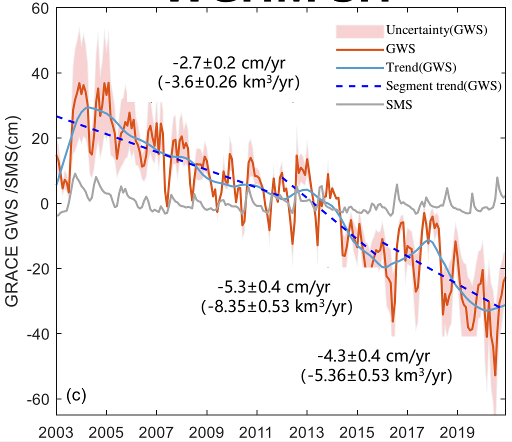
Result

GWS estimation using multiple GRACE products

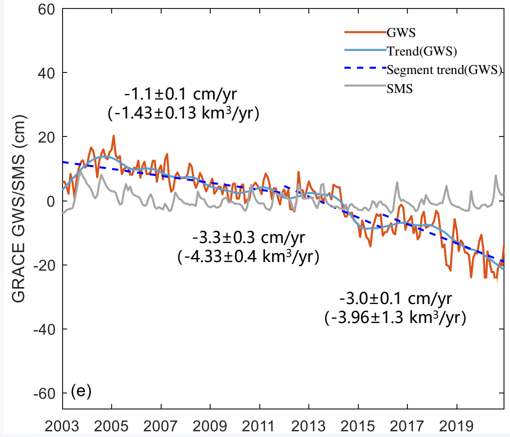
Average of JPL and CSR Mascon



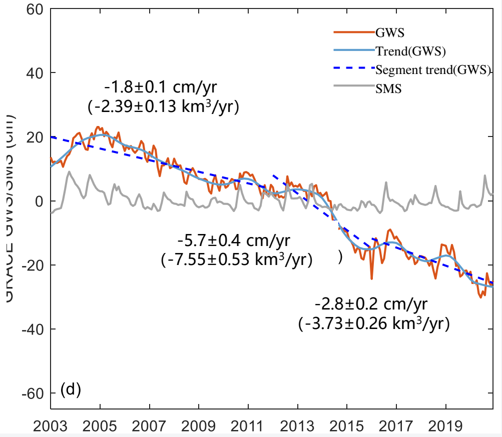
Average of CLM and WGHM SH



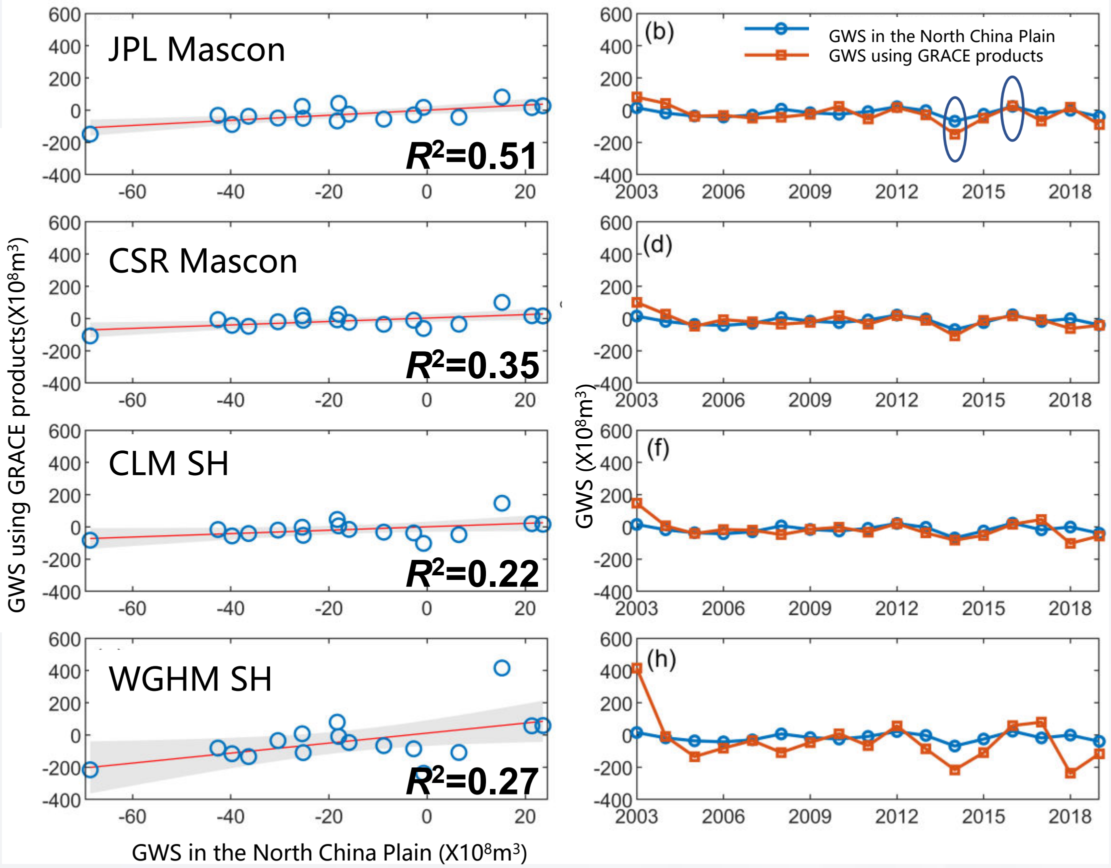
CSR Mascon



JPL Mascon



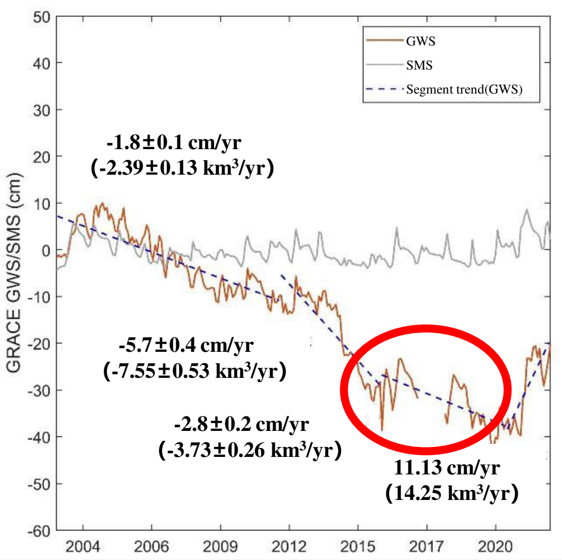
Validation of results

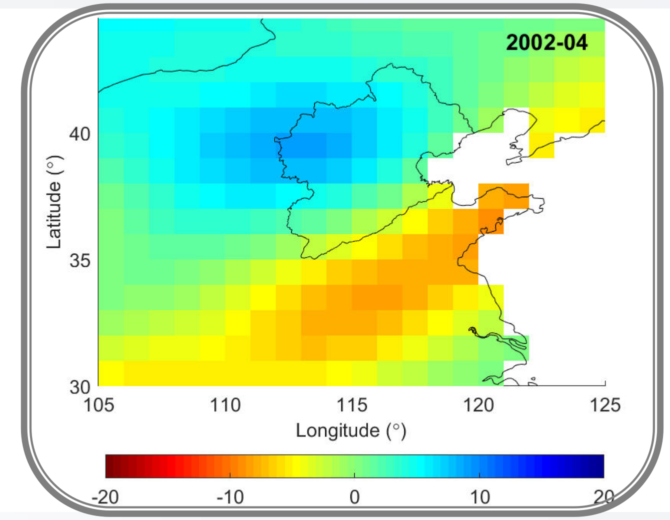


***R^2* of GWS in the North China Plain retrieved from JPL Mascon is the best**

[Long et al. *JHE*, 2023]

Result





Over the past two decades GWS in the HRB generally shows a downward trend at three distinct stages

- **2003–2011: -1.8±0.1 cm/yr (-2.39±0.13 km^3/yr)**
- **2012–2015: -5.7±0.4 cm/yr (-7.55±0.53 km^3/yr)**
- **2016–2020: -2.8±0.2 cm/yr (-3.73±0.26 km^3/yr)**

- **In 2021, GWS has been largely recovered by ~16 billion m^3, due to higher than normal precipitation up to 830 mm/yr across the HRB and policy on restrictions of groundwater abstractions**
- **the increase in GWS from the early nine months in 2022 has ceased**

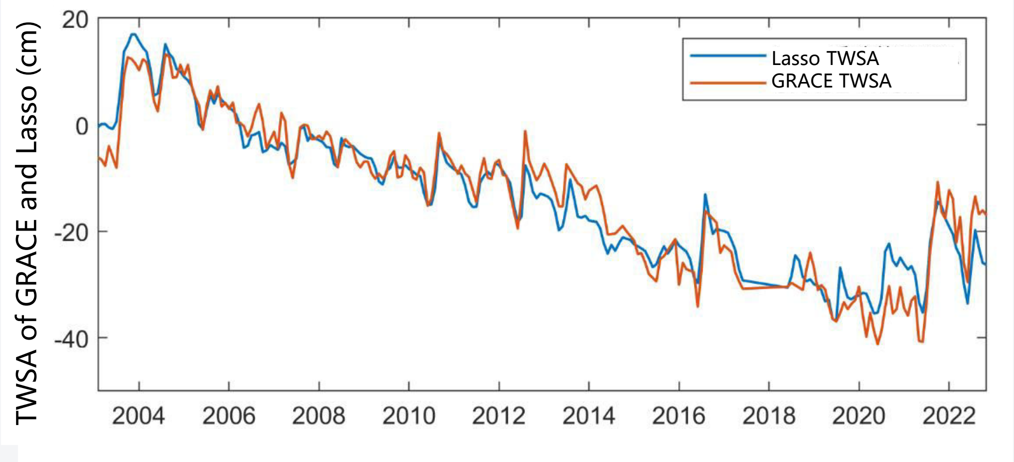
There is still a long way to go for GWS recovery and comprehensive treatment of groundwater overexploitation in the North China Plain

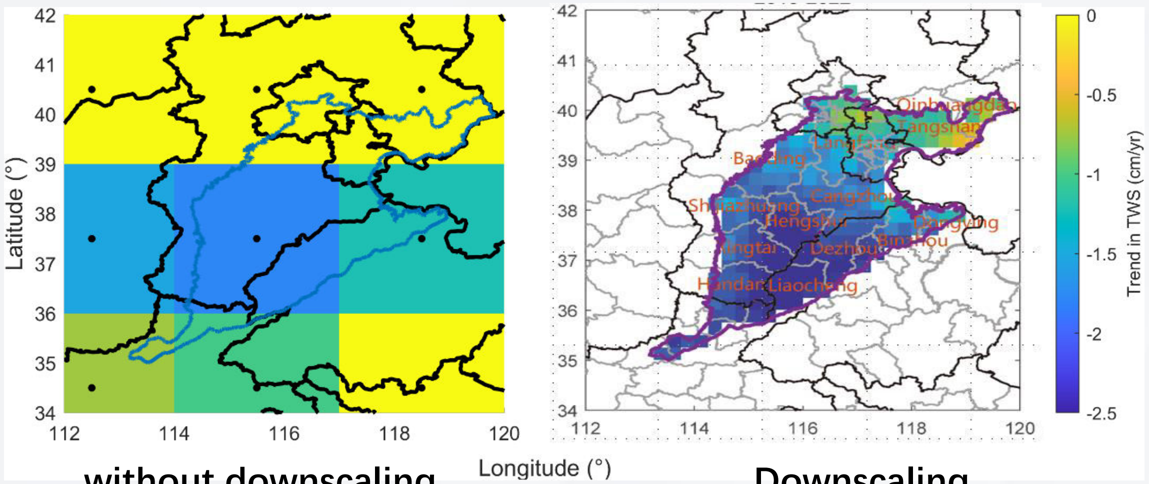
[Long et al. *JHE*, 2023]

Result

Results of downscaled GWS

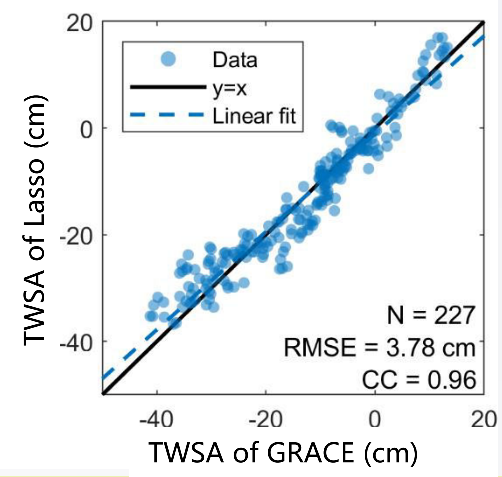
Downscaled TWSA using Lasso model is highly correlated with the measured groundwater level and GRACE TWSA (*R* = 0.96; *RMSE* = 3.78 cm)





without downscaling

Downscaling



- Downscaled GRACE TWSA for the NCP provides a higher spatial resolution compared to the original GRACE data.
- Downscaled TWSA in the NCP has been refined from a coarse resolution of 3°×3° (approximately 300 kilometers) to a higher resolution of 0.25°×0.25° (about 27 kilometers).

Result

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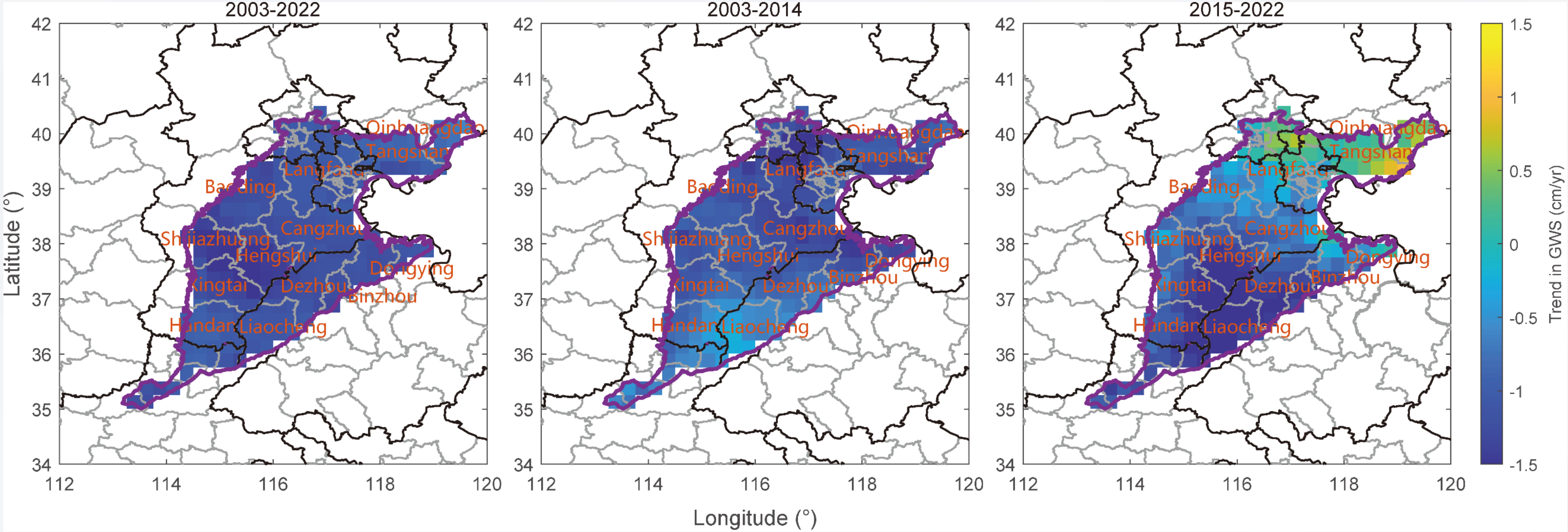
Results of downscaled GWS



Downscaled GWS trends in the NCP in different periods

- Analysis of GWS in the NCP from 2003 to 2022 indicates an overall downward trend in groundwater levels. Among all locations within the NCP, the area near Hengshui City experienced the most substantial decline in GWS.
- After the South-to-North Water Diversion delivered water, the northern part of the NCP experienced a rising trend in groundwater reserves, while the overall trend in the southern region continued to decline.

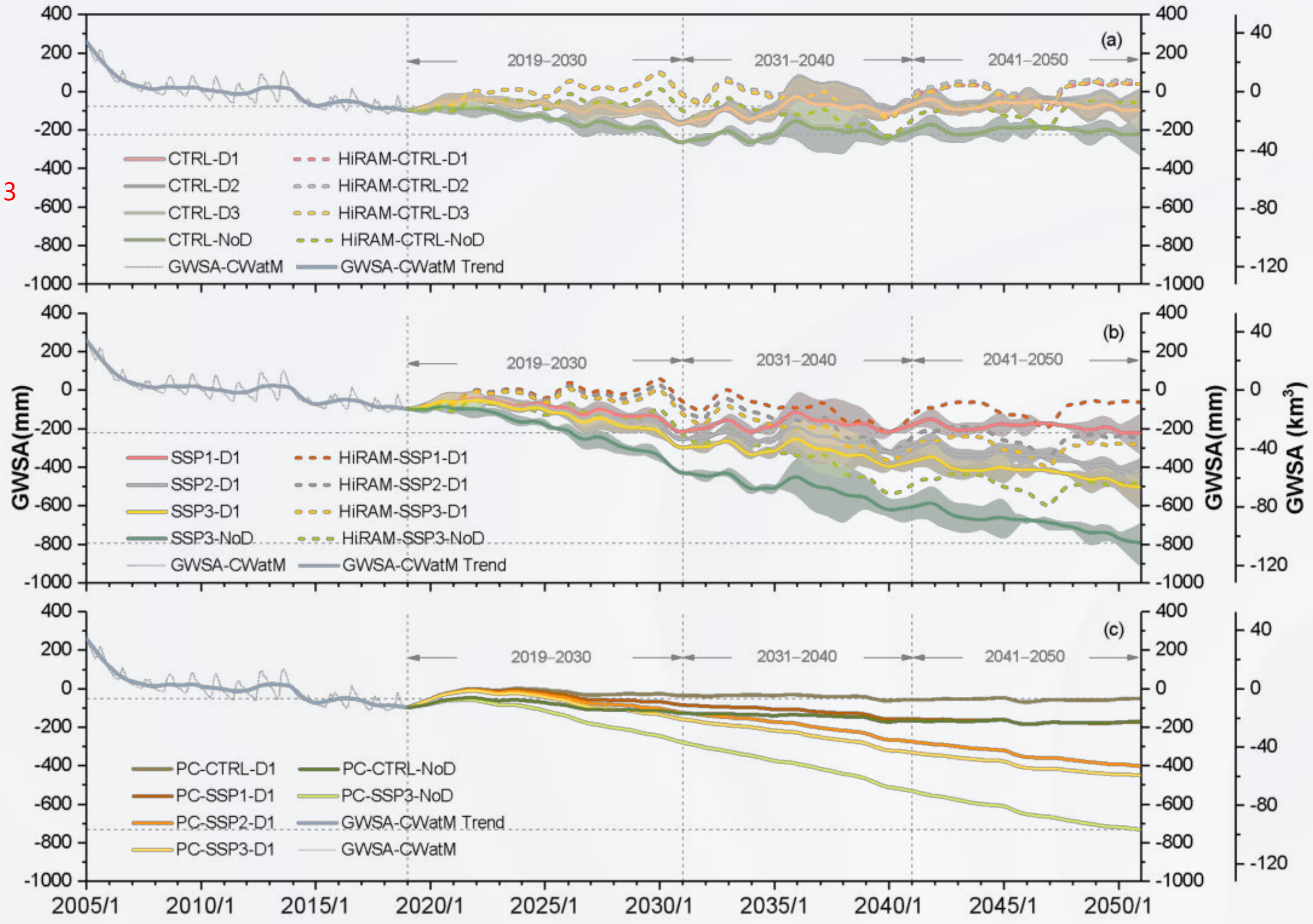
Result

Estimated changes in GWS in the NCP under future climate and water use scenarios

group	scene	Changes in groundwater storage from 2019 to 2050(mm [km³])
CTRL	CMIP6-CTRL-D1	1.0 (0.1)
	CMIP6-CTRL-D2	21.4 (2.8)
	CMIP6-CTRL-D3	3.0 (0.4)
	CMIP6-CTRL-NoD	-122.7(-16.2)
SSP	CMIP6-SSP1-D1	-123.2 (-16.2)
	CMIP6-SSP2-D1	-337.0 (-44.4)
	CMIP6-SSP3-D1	-405.9 (-53.5)
	CMIP6-SSP3-NoD	-695.3 (-91.7)
PC	PC-CTRL-D1	46.7 (6.2)
	PC-SSP1-D1	-73.7 (-9.7)
	PC-SSP2-D1	-302.3 (-39.8)
	PC-SSP3-D1	-351.4 (-46.3)
	PC-SSP3-NoD	-632.4 (-83.4)
	PC-CTRL-NoD	-70.8 (-9.3)

~20 km³

~ 90 km³



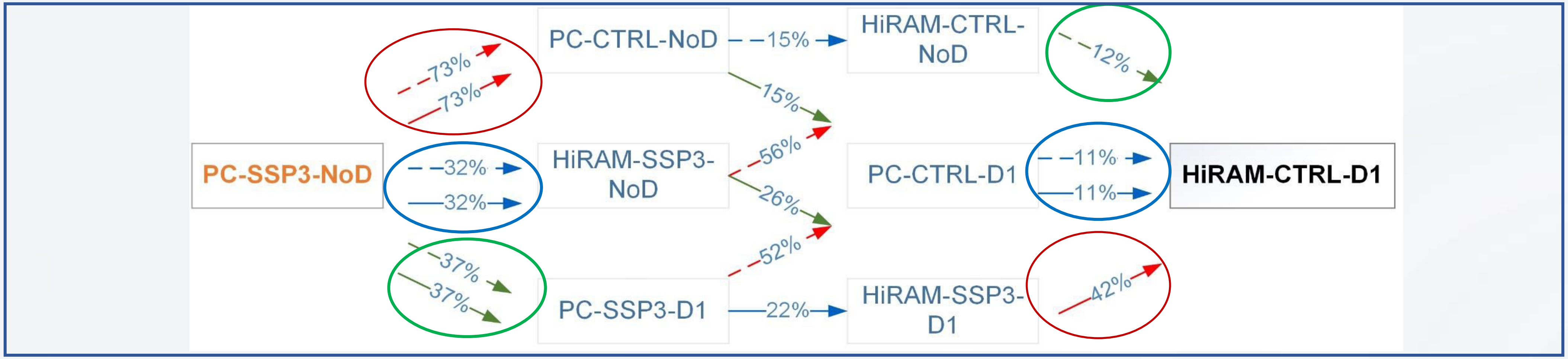
Under the normal-flow year conditions, water use reduction, and water diversion, the groundwater storage in the NCP is projected to remain relatively stable compared to the levels observed in 2019 by the year 2050.

[Yang and Long et al. *WRR*, 2022]

Result

Quantifying the contribution of different factors to GWS in the NCP

Contributions of water use (red lines), water diversion (green lines), and precipitation (blue lines) to groundwater recovery.



- **From 2019 to 2050, water use and water diversion emerge as the primary drivers influencing GWS.**
- **Water reduction, water diversion, and precipitation collectively account for up to 73%, 37%, and 32% of the stability of groundwater levels, respectively.**
- **As future water management practices entail a reduction in irrigation water and an increase in the proportion of domestic and industrial water use, the role of water diversion is expected to become increasingly prominent.**

[Yang and Long et al. *WRR*, 2022]

Summary

- Here we compare different methods of processing GRACE signals and use four GRACE products to estimate changes in total water storage (TWS) and GWS in the HRB from 2003 to 2022. The downscaled GRACE TWSA for the NCP provides a higher spatial resolution compared to the original GRACE data.
- This study aims to simulate and project GWS in the NCP during 2005–2050 by incorporating effects of water diversion, water use, and climate variability.
- This study highlights the contributions of different management strategies toward sustainable GWS and the importance of water conservation along with diversions.

Reference:

1. Yang, W., Long, D., Scanlon, B. R., Burek, P., Zhang, C., Han, Z., et al. (2022). Human intervention will stabilize groundwater storage across the North China Plain. Water Resources Research, 58, e2021WR030884.
2. LONG D, YANG W, SUN Z, et al. GRACE satellite-based estimation of groundwater storage changes and water balance analysis for the Haihe River Basin[J]. Journal of Hydraulic Engineering,2023,54(03):255-267.DOI:10.13243/j.cnki.slxb.20220743.

Thanks for your attention