High-Resolution PyGLDA-based Hydrological Data Assimilation to Reveal Added Values of Future NGGM and MAGIC Satellite Gravity Products

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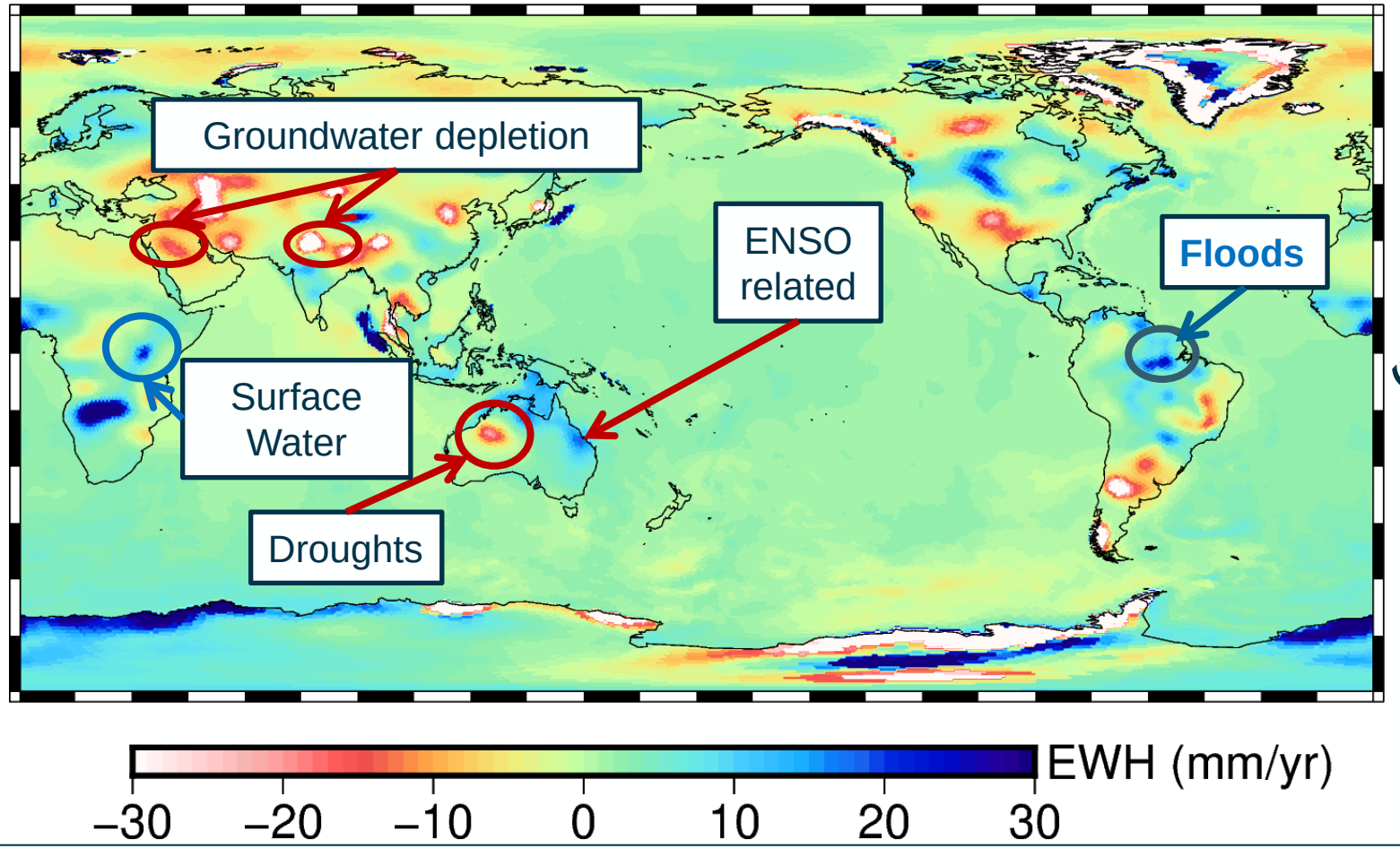
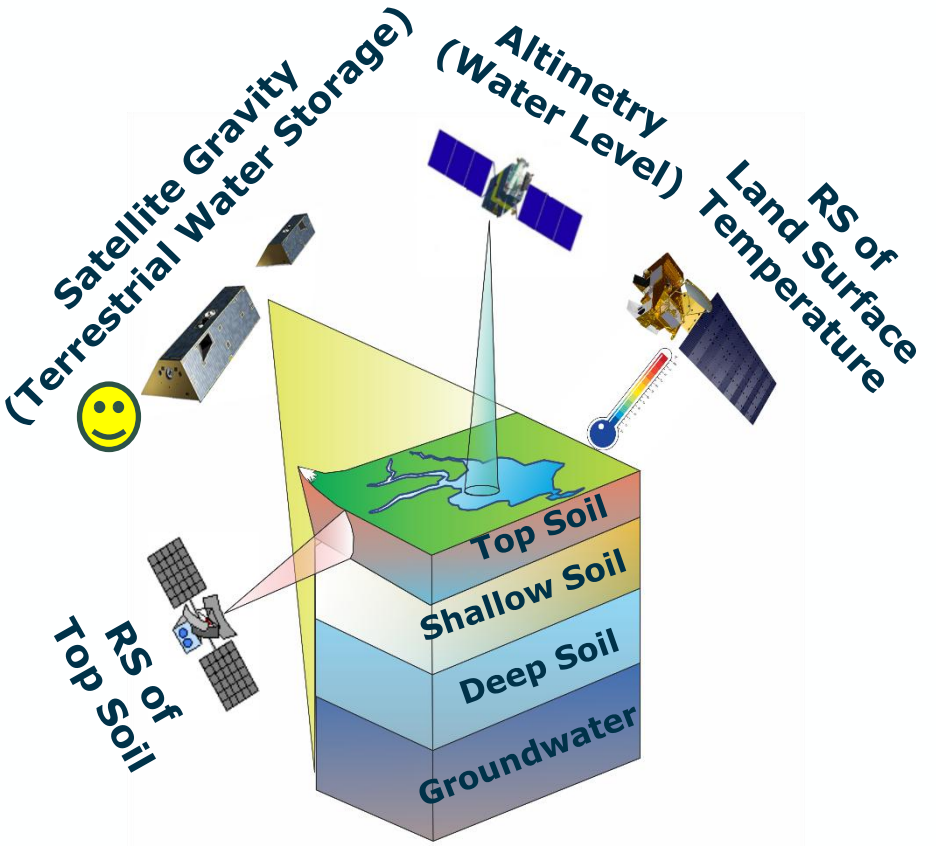
ESA Living Planet Symposium 2025, Vienna

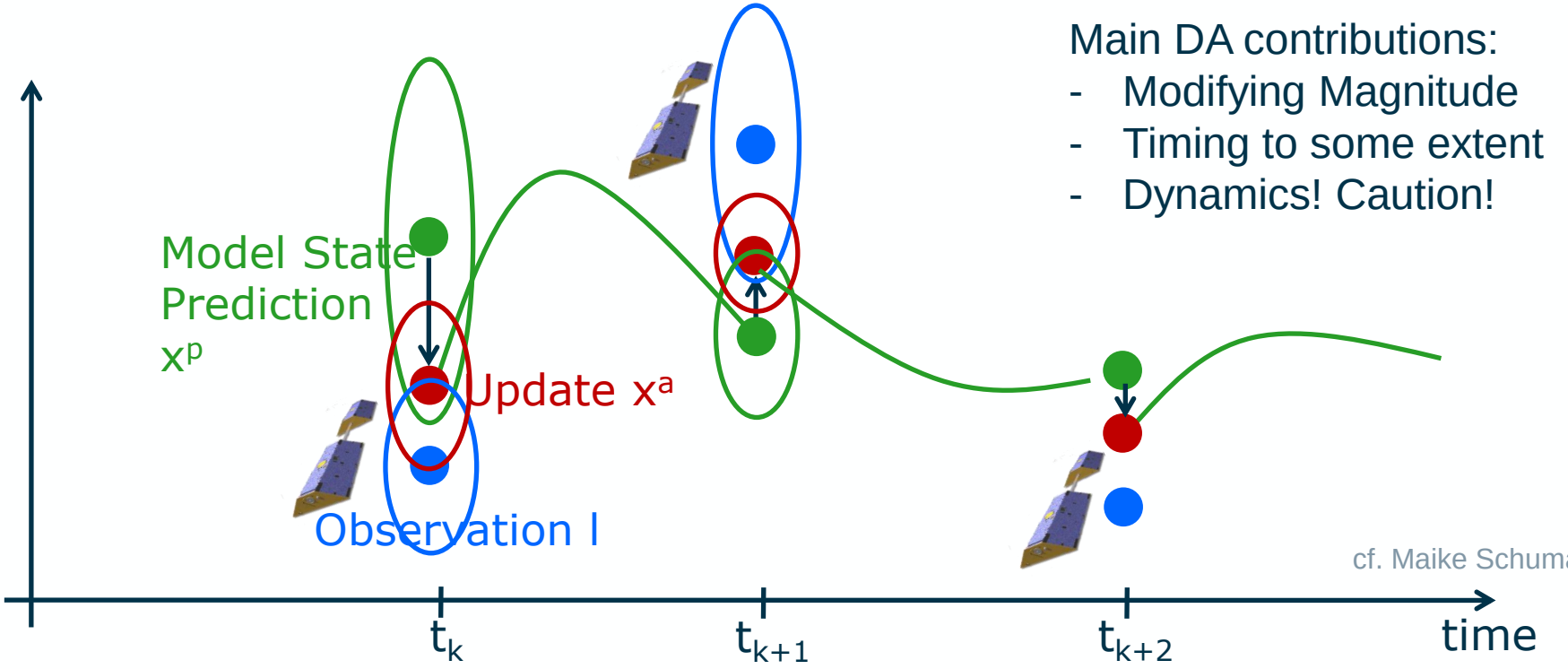
Background: Time-Variable Gravity

What we have now: GRACE and GRACE-FO have been used in many applications related to geophysics, hydrology and water resources, and climate.





Sequential TWS Data Assimilation (DA)



Main DA contributions:
- Modifying Magnitude
- Timing to some extent
- Dynamics! Caution!

cf. Maike Schumacher

Cost function

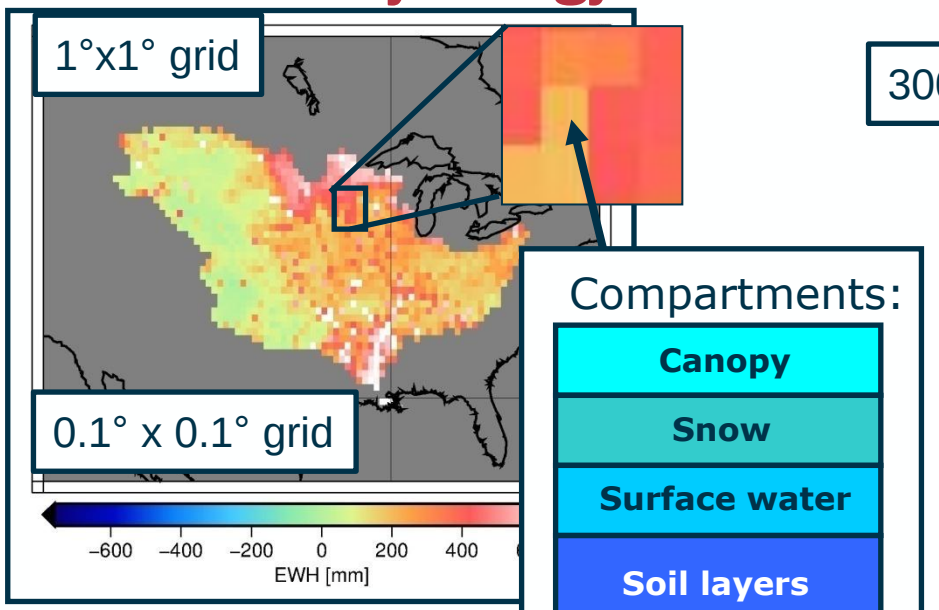
Distance between data and update

$$J(x) = (x - x^p)(C_{xx}^p)^{-1}(x - x^p) + (f(x) - l)\Sigma_{ll}^{-1}(f(x) - l) \quad \text{... min.}$$

Distance between model prediction and update

Technical Considerations of TWS DA

W3RA Global Hydrology Model



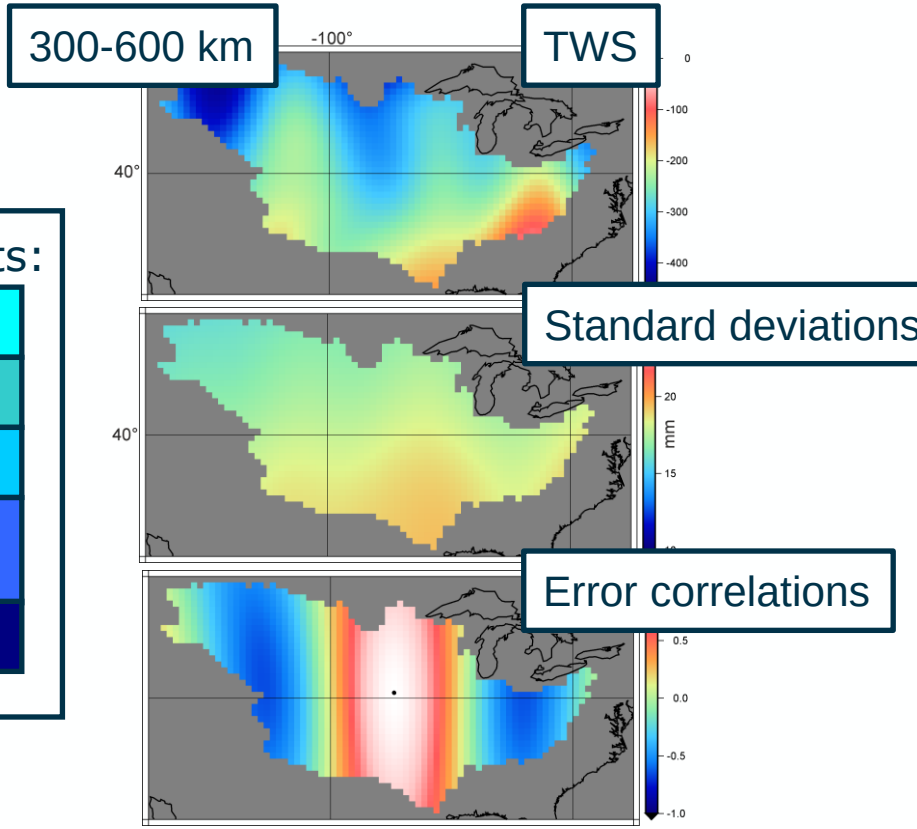
Compartments:

- Canopy
- Snow
- Surface water
- Soil layers
- Groundwater

*** 1 ° TWS updates 100s of model states!**

Model (Storage) Outputs
- Uncertainty of Input Fields
- Imperfect Model Parameters

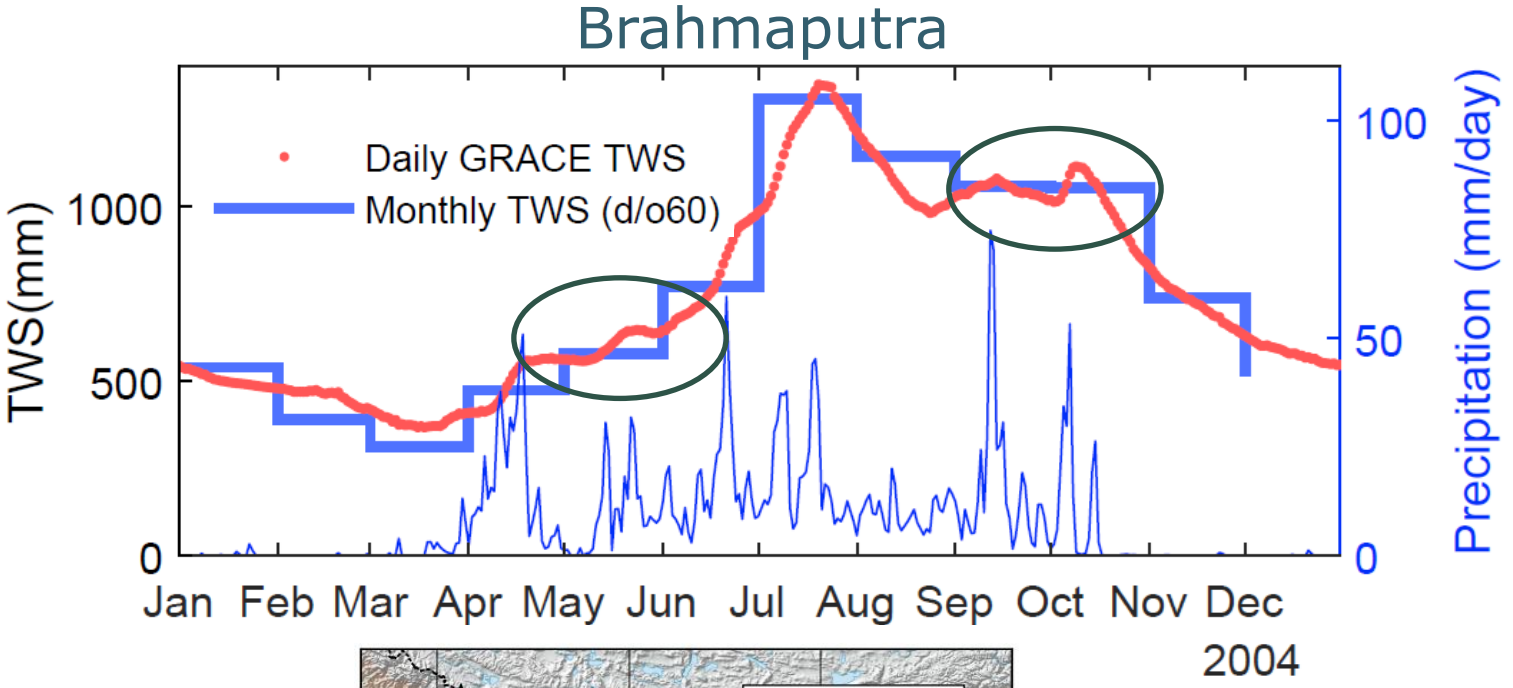
Real GRACE Example

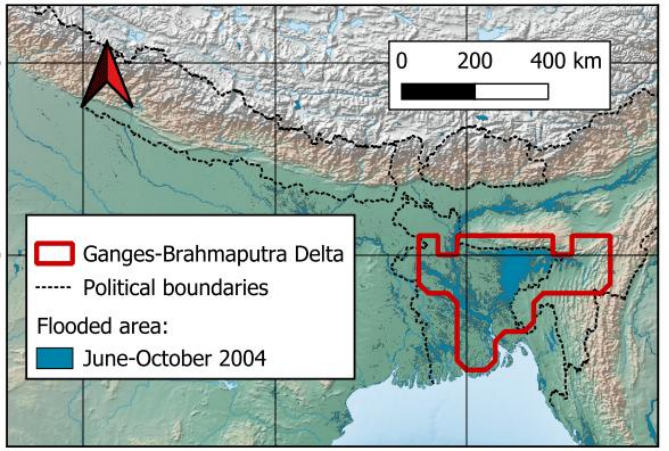


Gravity-derived TWS Observations + Uncertainty Schumacher et al. 2016-JoG

*** Gravity-based TWS constrains horizontal and vertical sum of model simulations → Better (Real) Spatial Resolution and Lower Uncertainty are desired**
*** Less filtering → Less Leakage and error patterns close to normal distribution are easier to be handled in operational applications**

Technical Considerations of TWS DA





During epochs that gravity-based TWS are available, they can be used to update model states → Hydrological applications desire:

- **Better (Real) Temporal Resolution**
- **Stable few-day solutions**
- **Realistic level of noise to avoid disturbing temporal dynamics of hydrological processes**
- **Low latency**

Retegui-Schiettekatte et al. 2025-STOTEN. Assessing daily GRACE Data Assimilation during flood events of the Brahmaputra River Basin

Assessing the contribution of future gravity missions

Future missions and main objectives

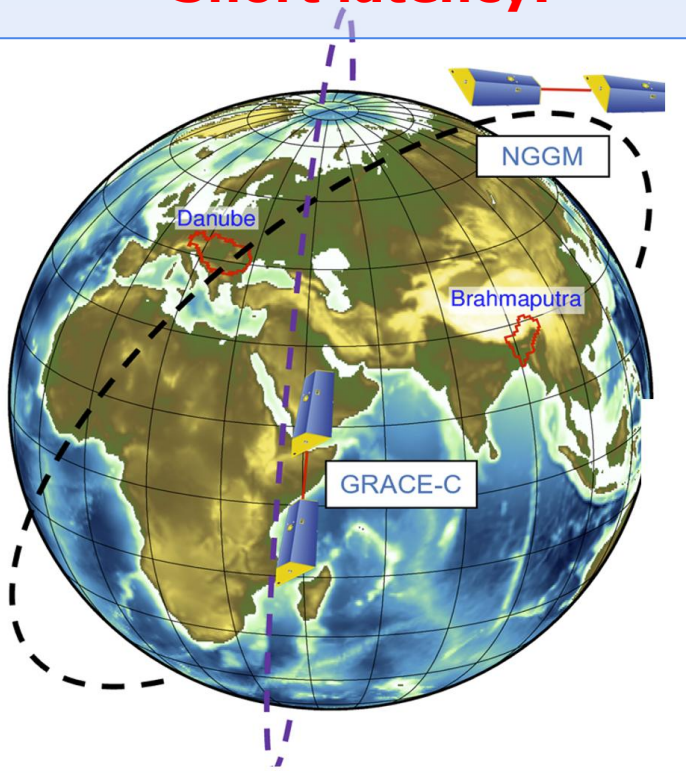
MAGIC includes a Bender double-pair constellation, realized in a staggered manner:

- ➔ Pair 1 (P1) **GRACE-C**: NASA/DLR program: polar orbit
- ➔ Pair 2 (P2) **NGGM** : ESA project: inclined orbit
- ➔ Few years of combined operations for MAGIC

- ➔ extend the time series,
- ➔ enhance the spatial and temporal resolutions,
- ➔ reduce the latency in data availability,
- ➔ reduce the uncertainty.

New scientific applications and **New operational services**!

5-day and **monthly satellite only data**! **Short latency!**



Assessing the contribution of future gravity missions

SING: Studying the Impact of NGGM and MAGIC missions : KO-September 2024, Duration: 18 months

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Sébastien Fourest

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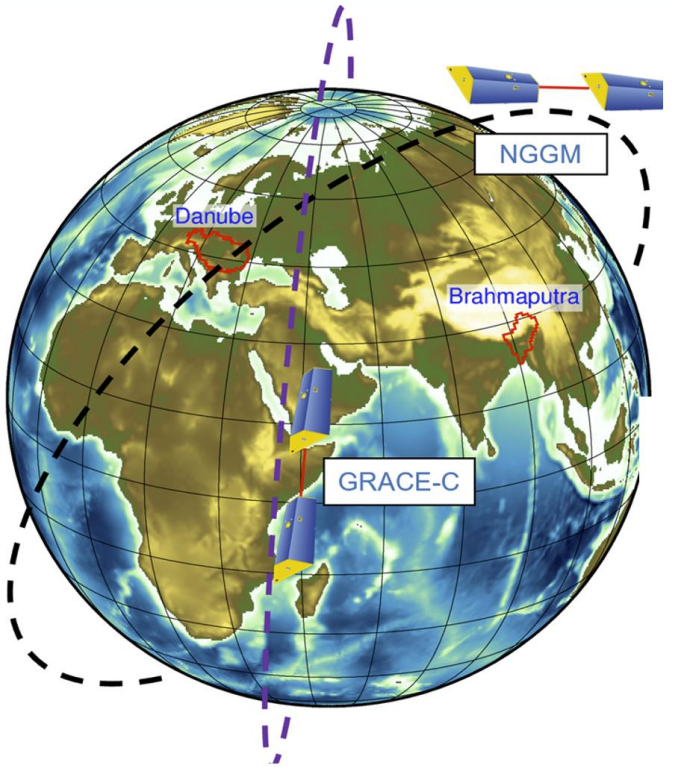

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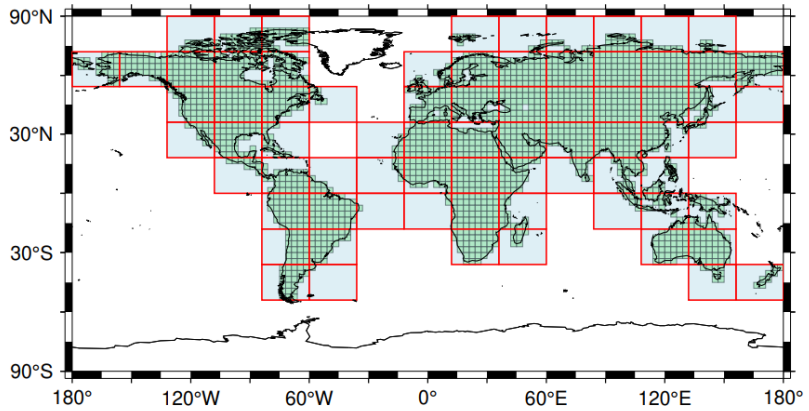
High Resolution Global Data Assimilation

PyGLDA: efficient global land DA

- Towards operational satellite gravity DA
- Full error covariance consideration
- Numerically optimized DA
- Efficient patch-wise implementation
- **10 km resolution**
- **Sub-weekly & monthly** DA



PyGLDA Software

SCAN ME

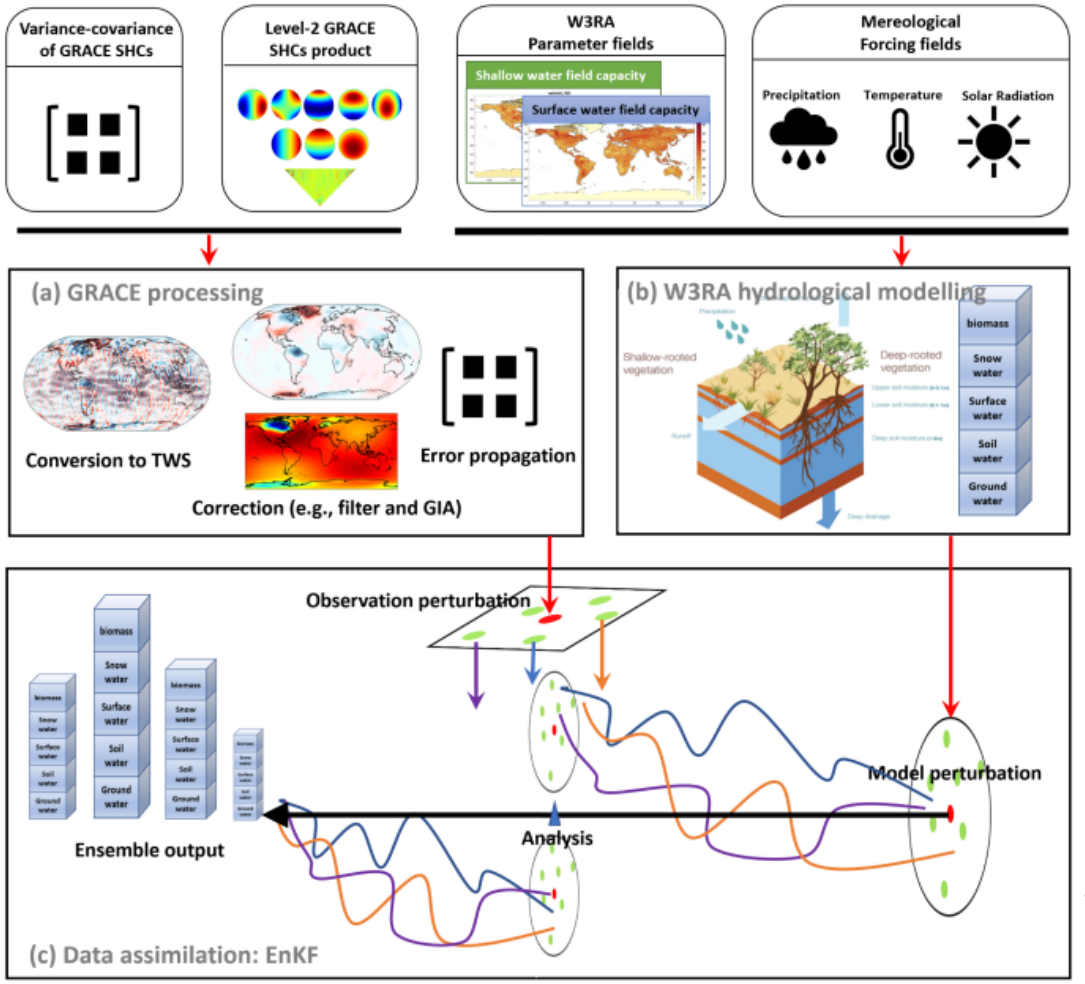
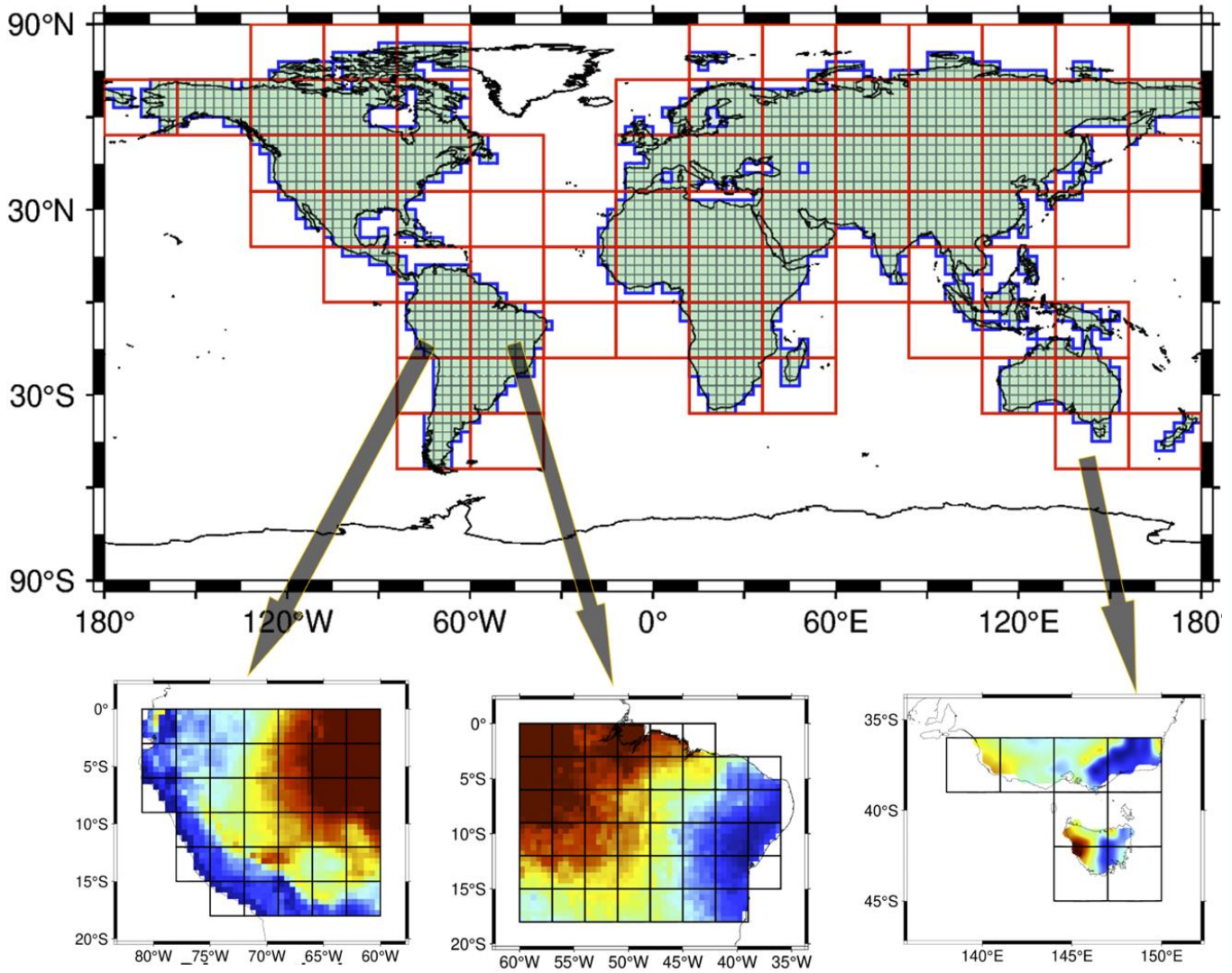


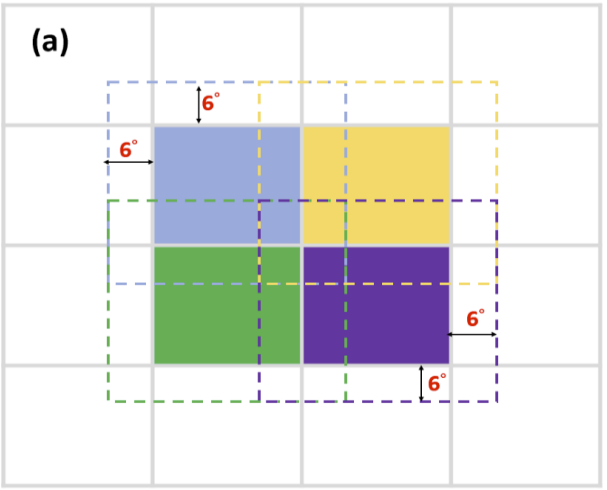
Figure 1. An overview of PyGLDA structure that mainly consists of three modules: (a) GRACE processing, (b) W3RA GHM (van Dijk, 2010) and (c) Data Assimilation (DA).

Yang, F., Schumacher, M., Retegui-Schiettekatte, L., van Dijk, A. I. J. M., and Forootan, E.: PyGLDA: a fine-scale Python-based Global Land Data Assimilation system for integrating satellite gravity data into hydrological models, Geosci. Model Dev. Discuss. https://doi.org/10.5194/gmd-2024-125

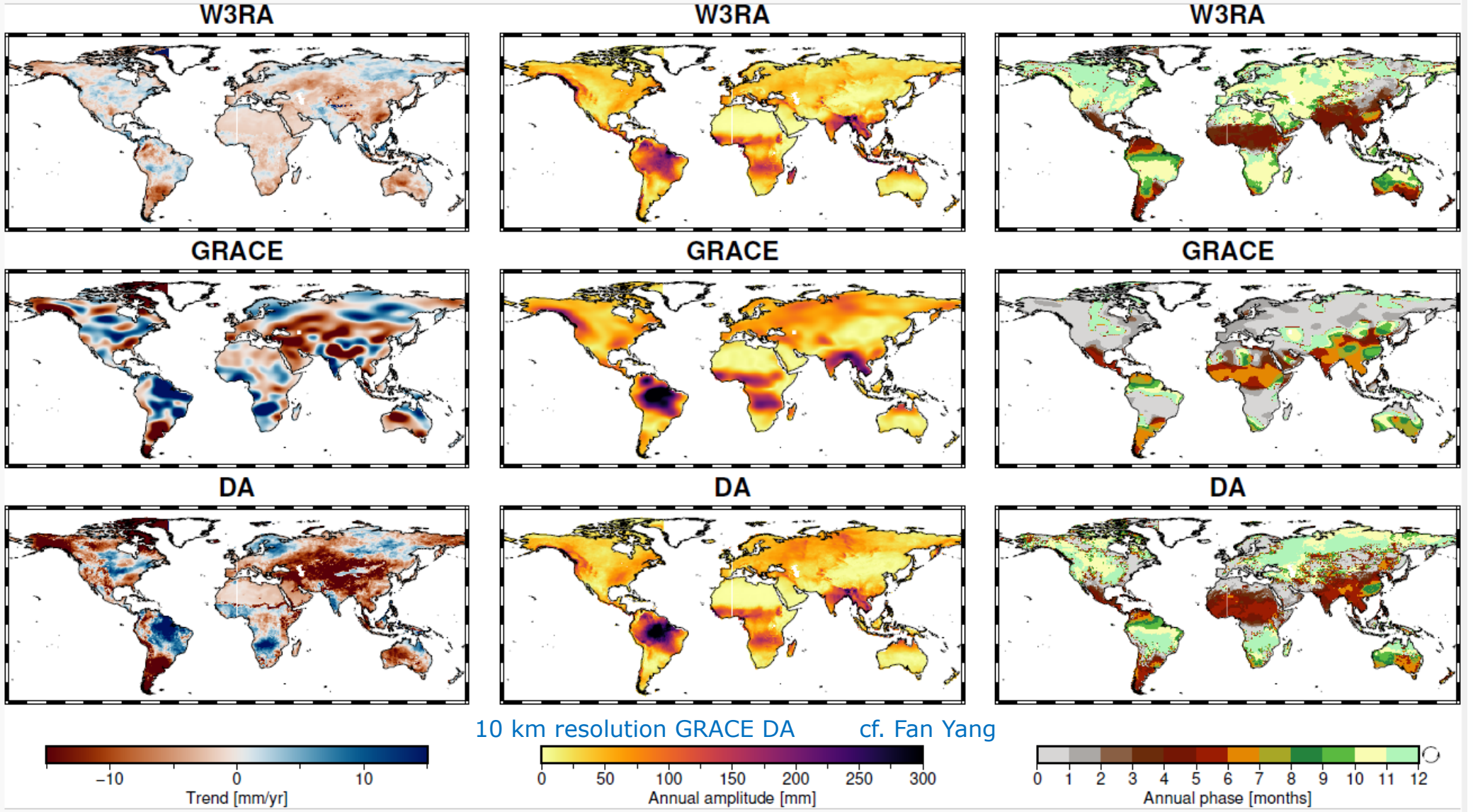
Relevance of TWS Observations to Hydrology



Patch-wise implementation to deal with limited computational memory



Global Data Assimilation of GRACE and GRACE-FO



Current TWS data can only modify the large-scale features! The detailed variability is introduced by model after DA!

A double-loop framework for gravity simulation and DA

Data: ESA ESM.2

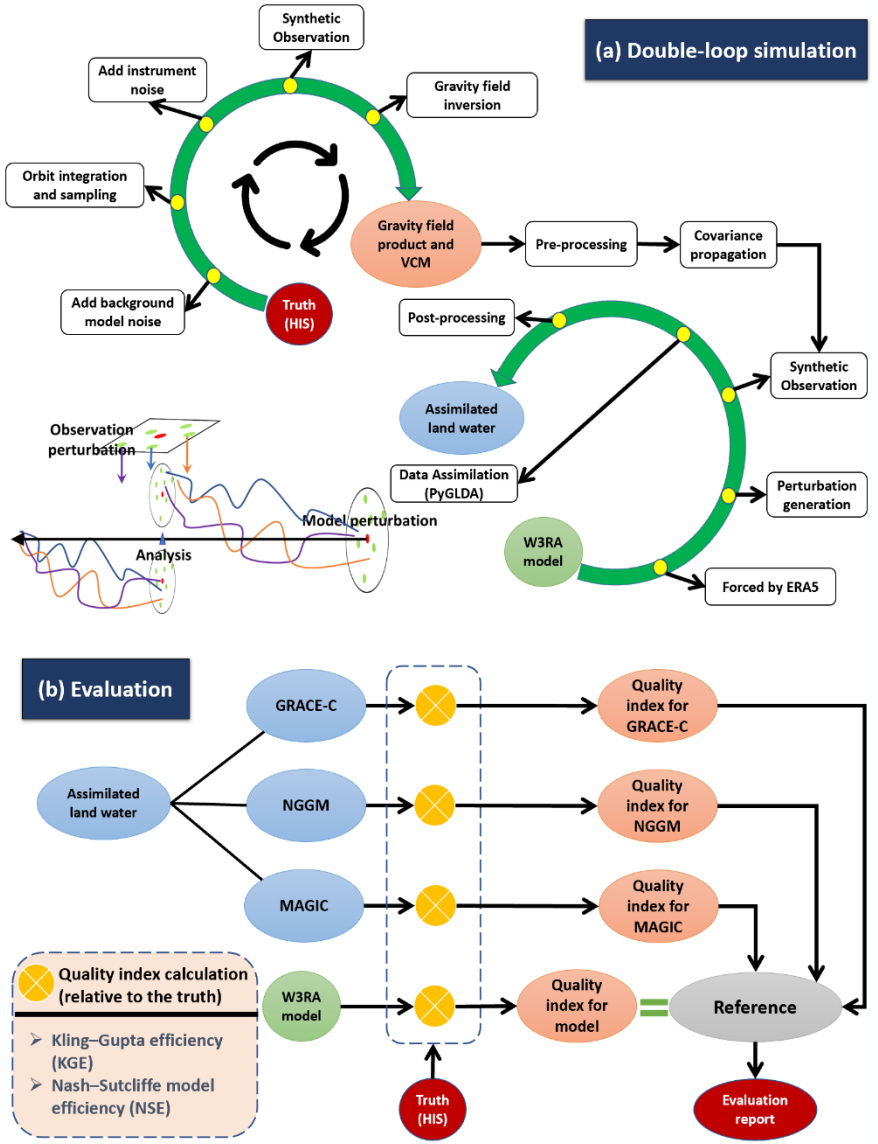
GRACE-C
NGGM
MAGIC
+
Full VCM

DA: PyGLDA

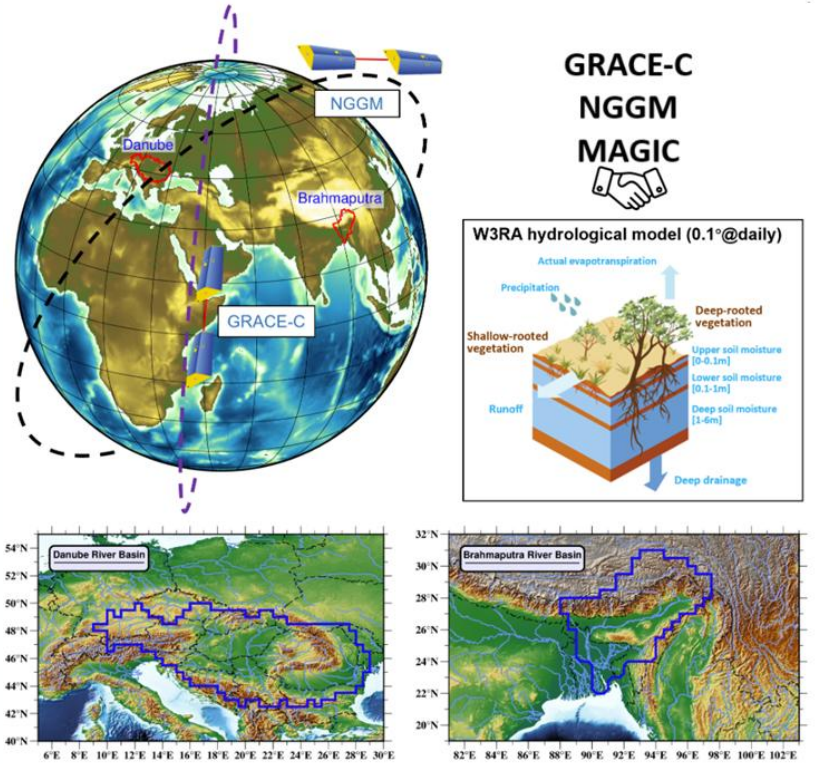
Filtered solutions

Propagated filtered VCM

Comparison with synthetic truth: HIS of ESA ESM.2

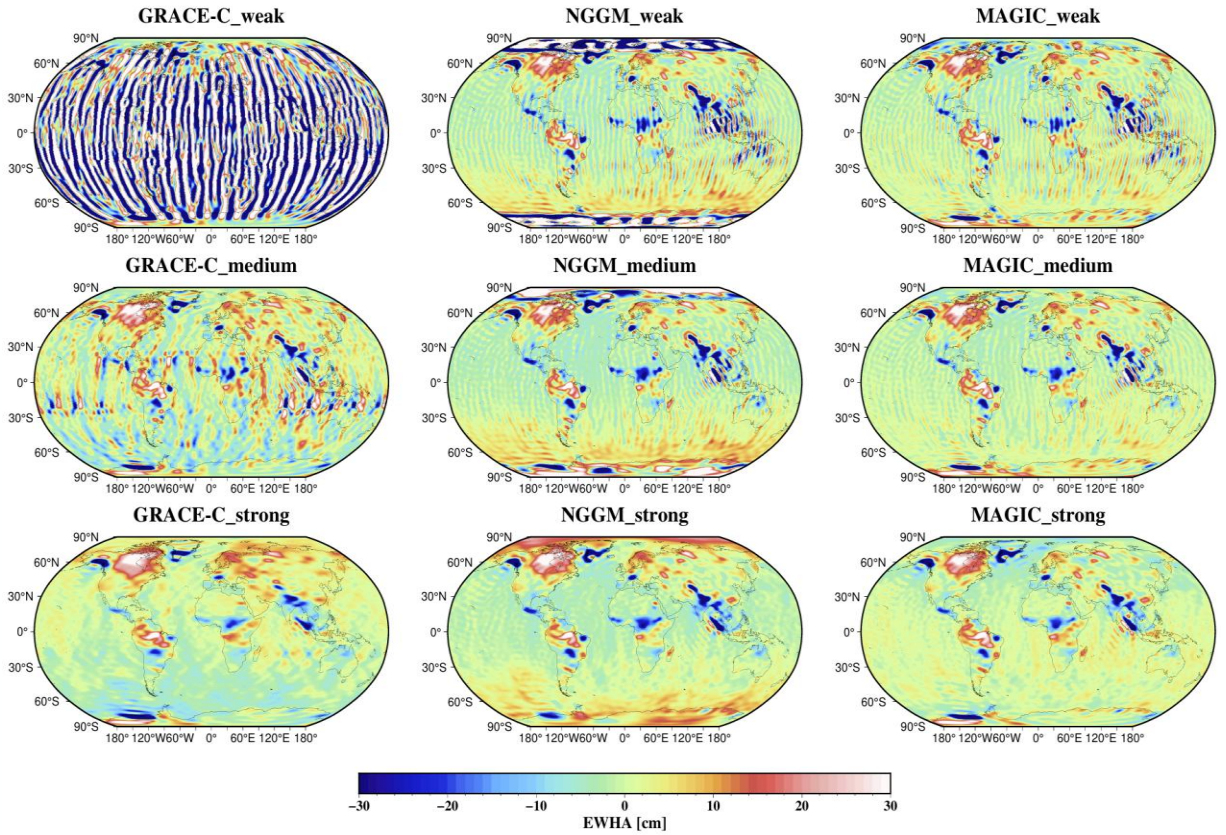


DA Experiments based on 5-day Solutions

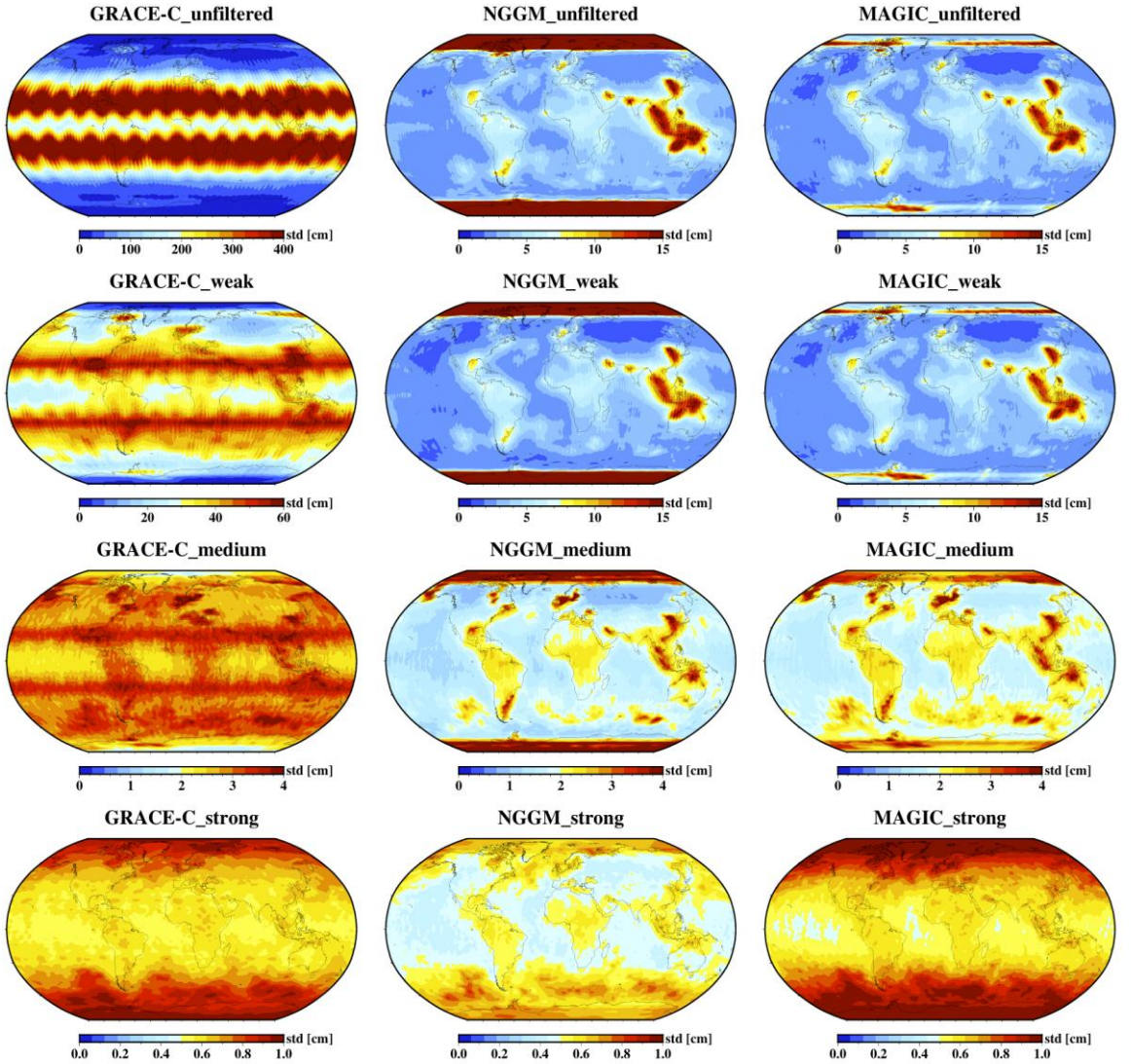


Signal and noise in 5-day GRACE-C, NGGM, and MAGIC

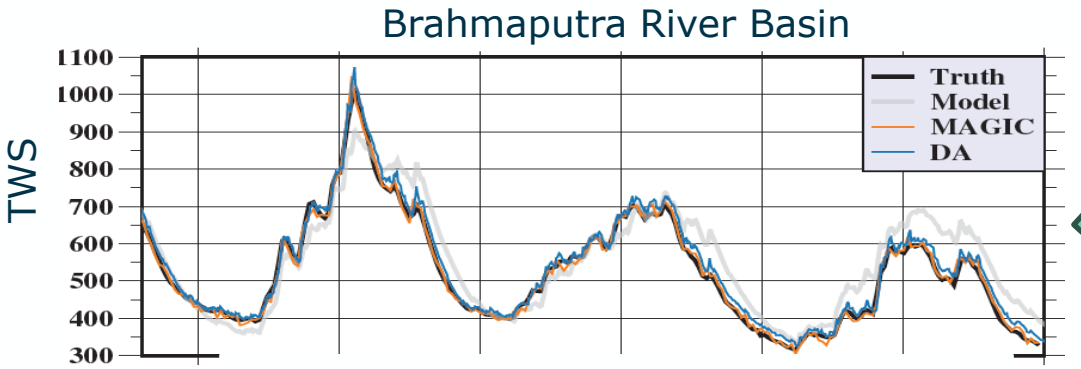
Signal

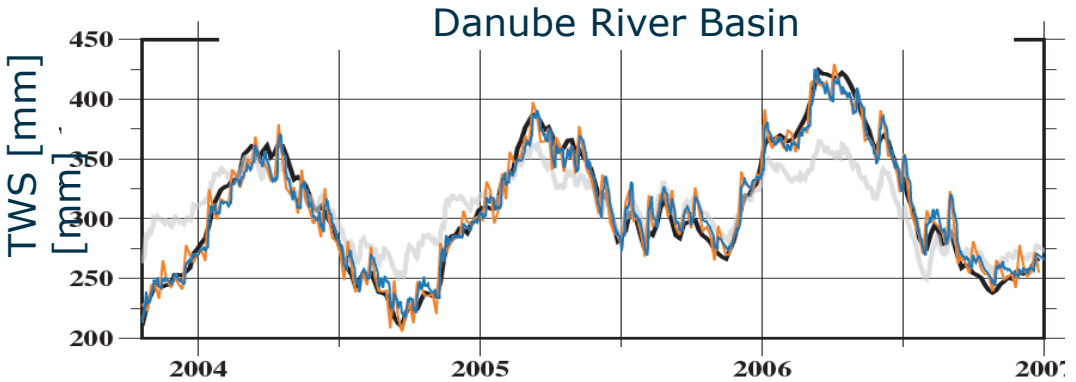


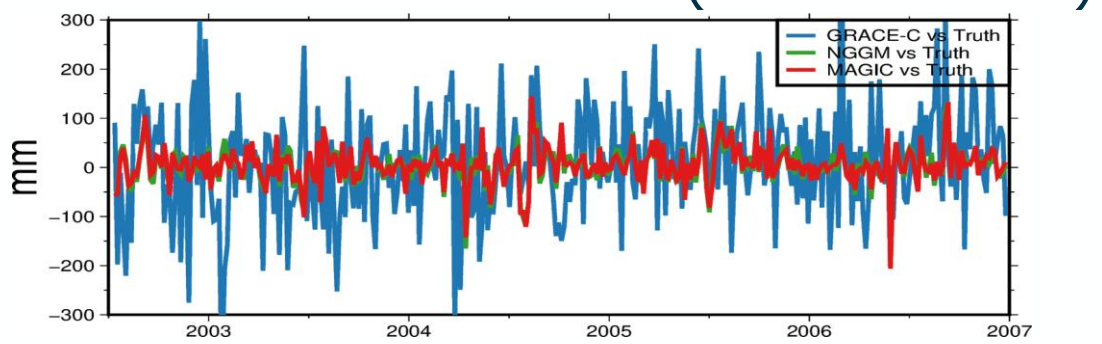
Noise

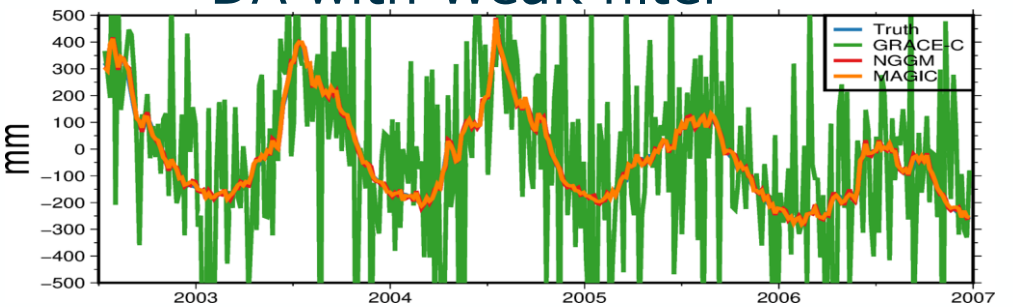


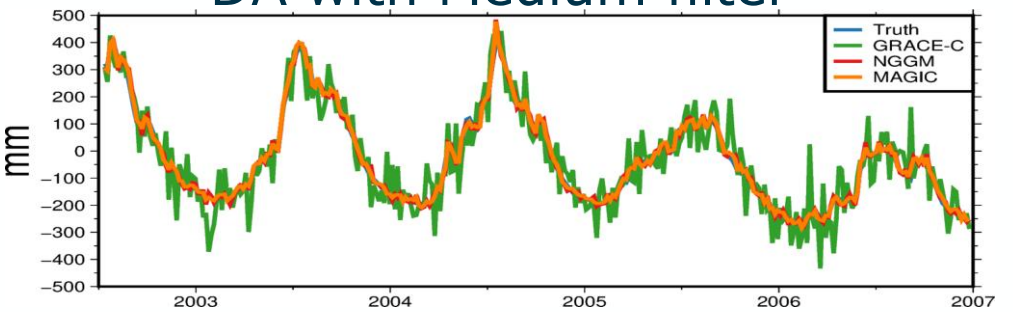
Results of the 5-day DA in Danube and Brahmaputra

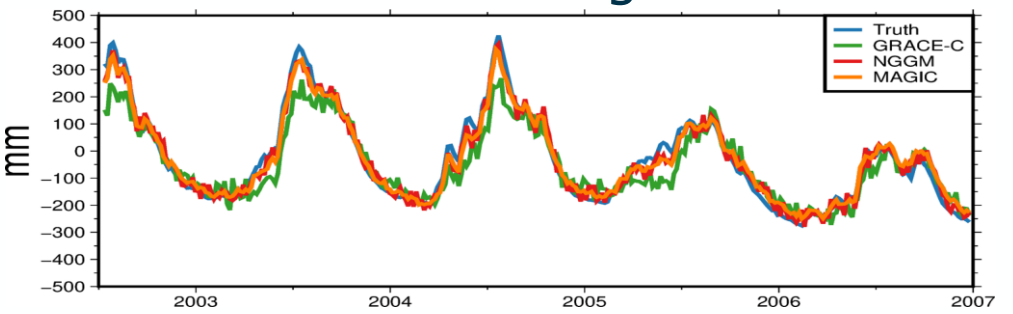






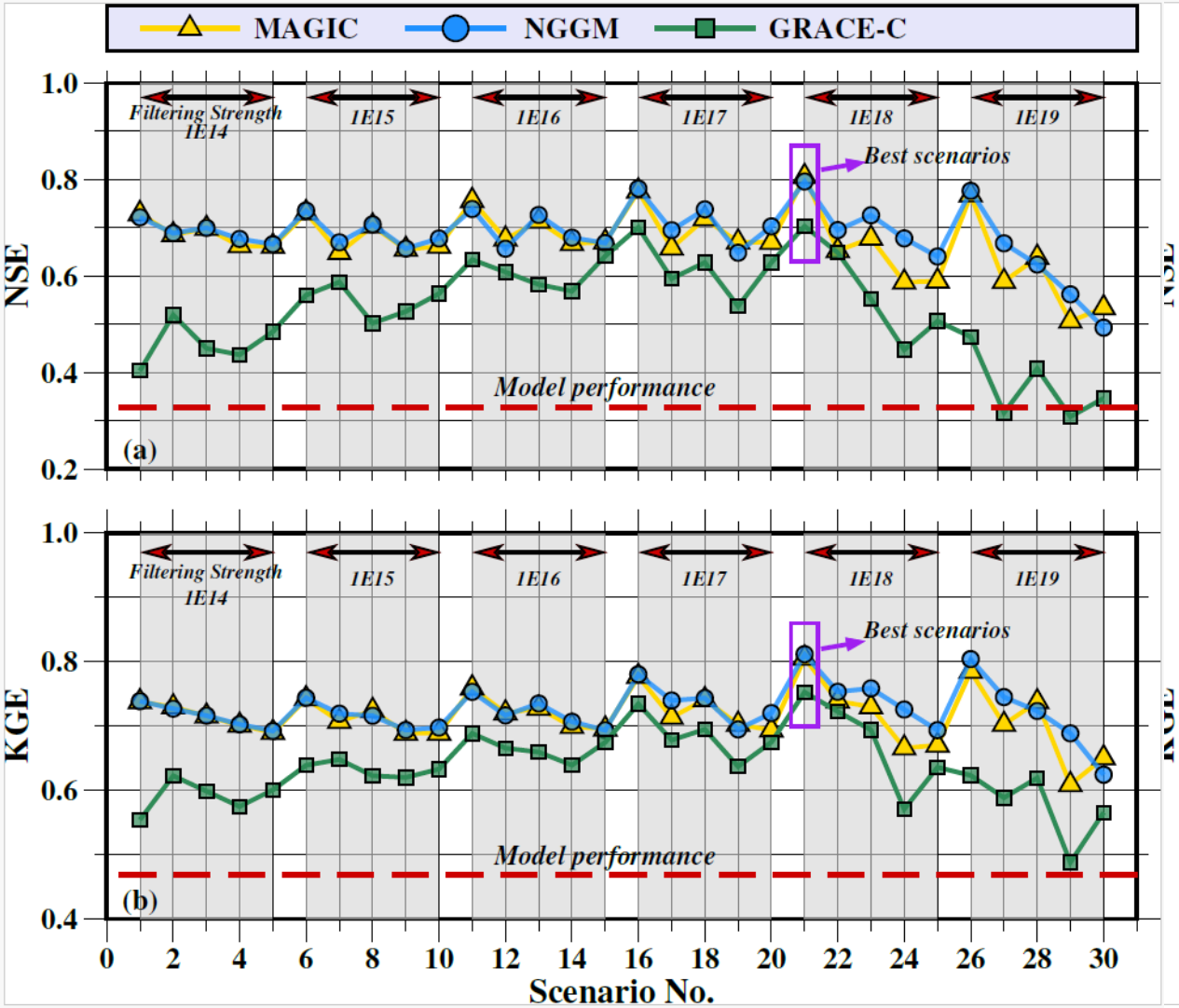




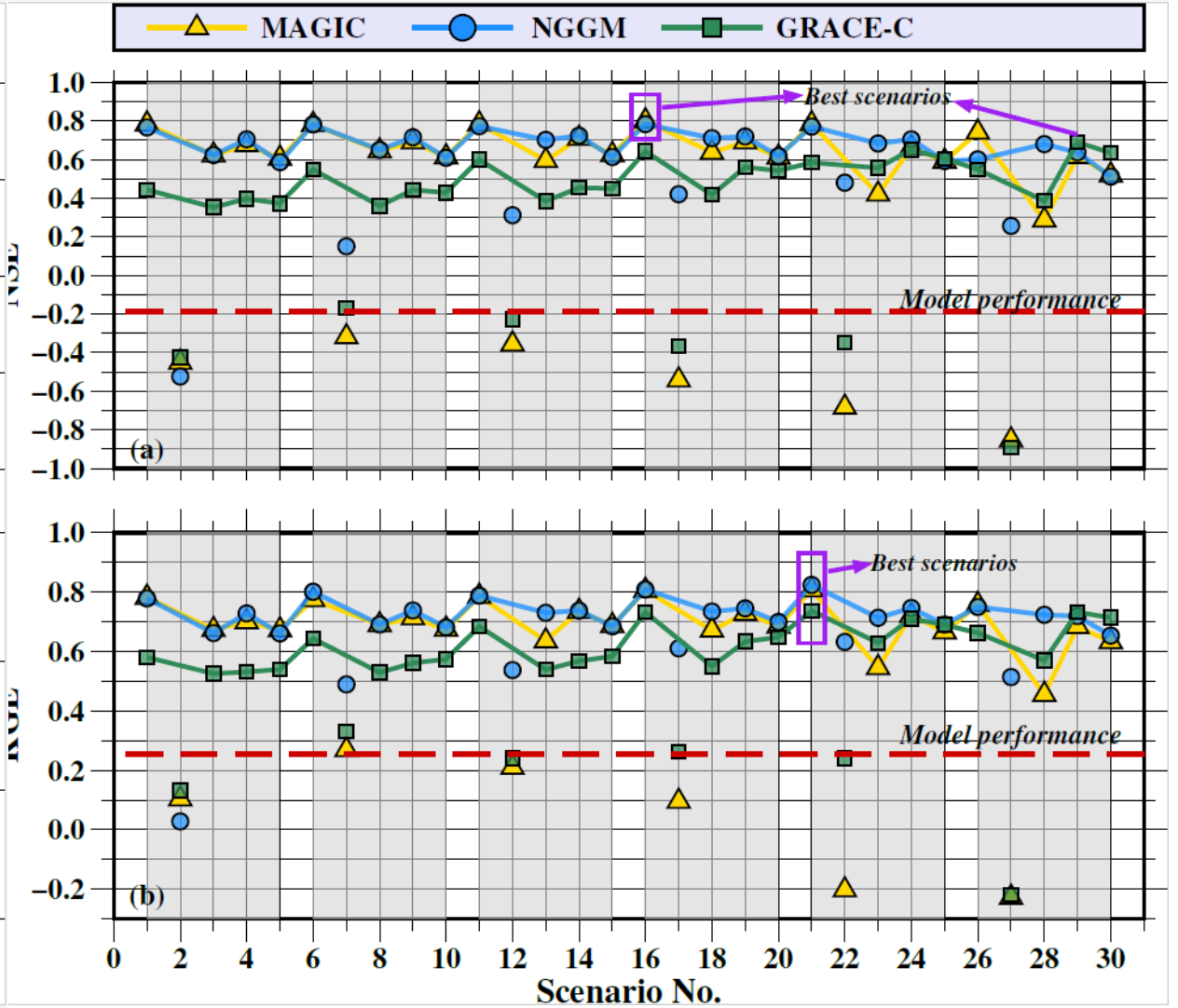


180 DA experiments to assess the contribution of future gravity missions: 3 missions * 6 filters * 5 grids * 2 basins

Brahmaputra River Basin



Danube River Basin



Conclusions & Outlooks

Conclusions:

180 sets of 5 day DA experiments are performed for a 10 km resolution hydrological model: 2 climatologically different basins, 3 missions, 5 DA resolutions, & 6 filtering strengths. Results compared to GRACE-C:

- **NGGM and MAGIC require much weaker filters, thus, exhibiting smaller leakage effects**
- **NGGM and MAGIC are better suited for representing sub-monthly to seasonal water storage variations**
- **High resolution DA experiments get higher benefit from the better resolution and low uncertainty of NGGM and MAGIC**

Outlooks:

- **Contributions of 5-day DA during flood events will be investigated**
- **Assessment of contribution at various time-scale will be assessed**
- **Disaggregation of TWS into individual water storage will be examined**

More updates will come soon in the context of SING project

The work presented here was performed as part of the SING project
"NGGM and MAGIC Science and Applications Impact Study,"
ESA Contract No. 4000145265/24/NL/SC, funded by the European Space Agency.

Thank You!

SING

PyGLDA

AAU-Geodesy