

Harisankar Manoj<sup>1\*</sup>, Eunsam Cho<sup>2,3</sup>, Bailing Li<sup>2,3</sup>, Carrie Vuyovich<sup>2</sup>, Jennifer M. Jacobs<sup>4,5</sup>, Eunsang Cho<sup>1</sup>

\*Email: harimanoj@txstate.edu

<sup>1</sup>Ingram School of Engineering, Texas State University, San Marcos, TX, USA; <sup>2</sup>Hydrological Sciences Laboratory, NASA Goddard Space Flight Center, Greenbelt, MD, USA; <sup>3</sup>Earth System Science Interdisciplinary Center, University of Maryland, College Park, MD, USA; <sup>4</sup>Department of Civil and Environmental Engineering, University of New Hampshire, Durham, NH, USA; <sup>5</sup>Earth Systems Research Center, Institute for the Study of Earth, Oceans, and Space, University of New Hampshire, Durham, NH, USA

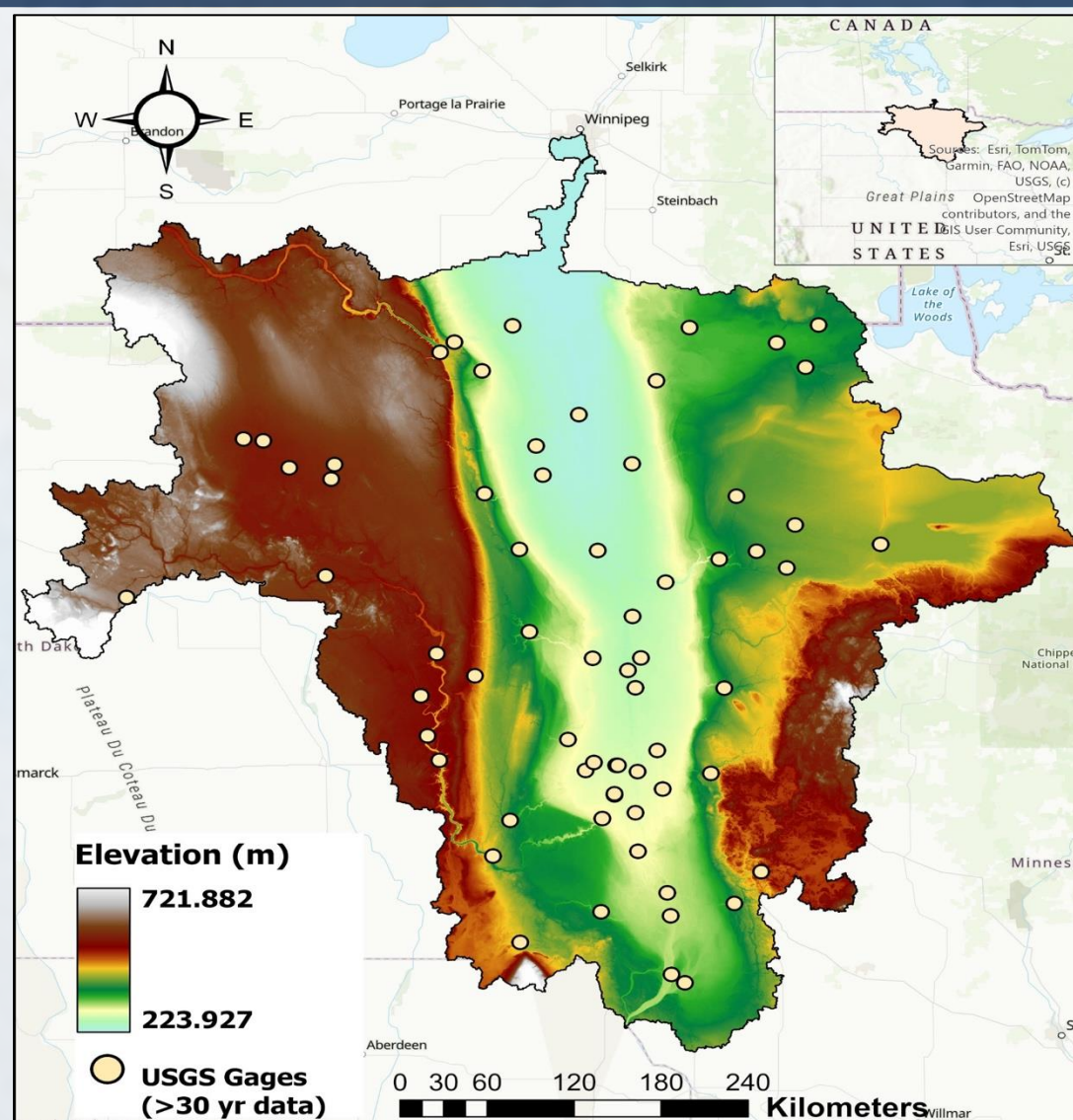
## Motivation and Background

- A deeper understanding of groundwater-runoff interactions is essential for large scale flood generation processes (Taylor et al., 2013; Maxwell and Condon, 2016; Carroll et al., 2019; Brooks et al., 2025)
- Insufficient information on the role of groundwater in the flood events poses a major challenge for accurate forecasting (Koster et al. 2004; Jaeger and Seneviratne, 2011; Diro et al., 2018; Dutra et al., 2013)
- The Red River of the North basin encounters severe floods during spring, driven by rapid snowmelt, rainfall and antecedent conditions (Rasmussen 2016; Stednyk et al., 2016)
- In spring 2013, the flood simulation by the North Central Regional River Forecasting Center (NCRFC) in the Red River shows larger discrepancies in comparison to the USGS observations (S.E. Tuttle et al., 2017)
- This study aims to understand whether incorporating the Gravity Recovery and Climate Experiment (GRACE) derived terrestrial water storage into the Noah Land Surface Model with multi-parameterization options (Noah-MP; Niu et al., 2011; Yang et al., 2011) would improve the runoff simulation in the Red River of the North

### Research Questions:

- Do the GRACE Data Assimilation (DA) simulations substantially differ from the Noah-MP Open Loop (OL) outputs for the study area?
- Does the GRACE DA improve the runoff representation by Noah-MP in comparison with the observed streamflow for a flood year?

## Study Area

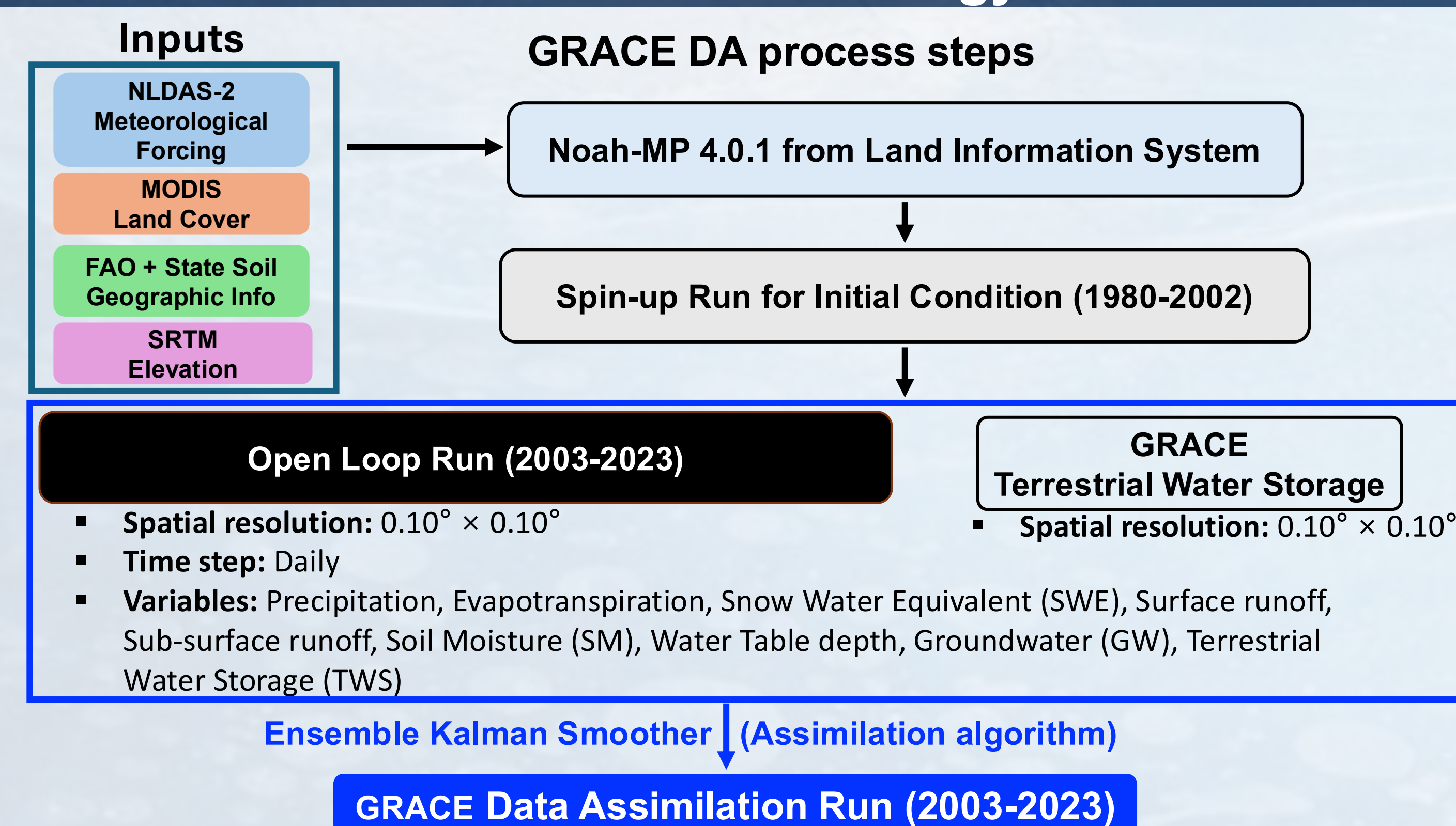


### Red River of the North Basin (RRB)

- Originates near Wahpeton, North Dakota (ND) and flows along the ND-Minnesota border to Lake Winnipeg, Canada
- Drainage area ~ 285,000 km<sup>2</sup>
- 508 mm (20 inches) average annual precipitation, with most rain in summer and heavy snow in winter
- A suitable area to examine the role of antecedent groundwater in the snowmelt flood mechanism
- There are 262 USGS streamflow gages in the basin; 66 gages with ≥30 years of daily streamflow records

Fig. 1. Elevation map showing location of RRB & USGS gages with ≥ 30 yr record

## Data & Methodology



- Noah-MP offers comprehensive representation of basin-scale runoff generation, soil hydrology, and snow processes through its multi-physics framework (Niu et al., 2011; Yang et al., 2011); relevant for RRB floods which depend on spring snow and soil hydrology
- NASA GRACE mission provides extensive terrestrial water storage (TWS) estimates which induces storage corrections and modify the runoff/baseflow partitioning via DA process (Lucey et al., 2020; Giroto et al., 2016; 2018; Rodell et al. 2018; Zaitchik et al., 2008)

## Result 1 : Noah-MP OL run vs DA run Time Series

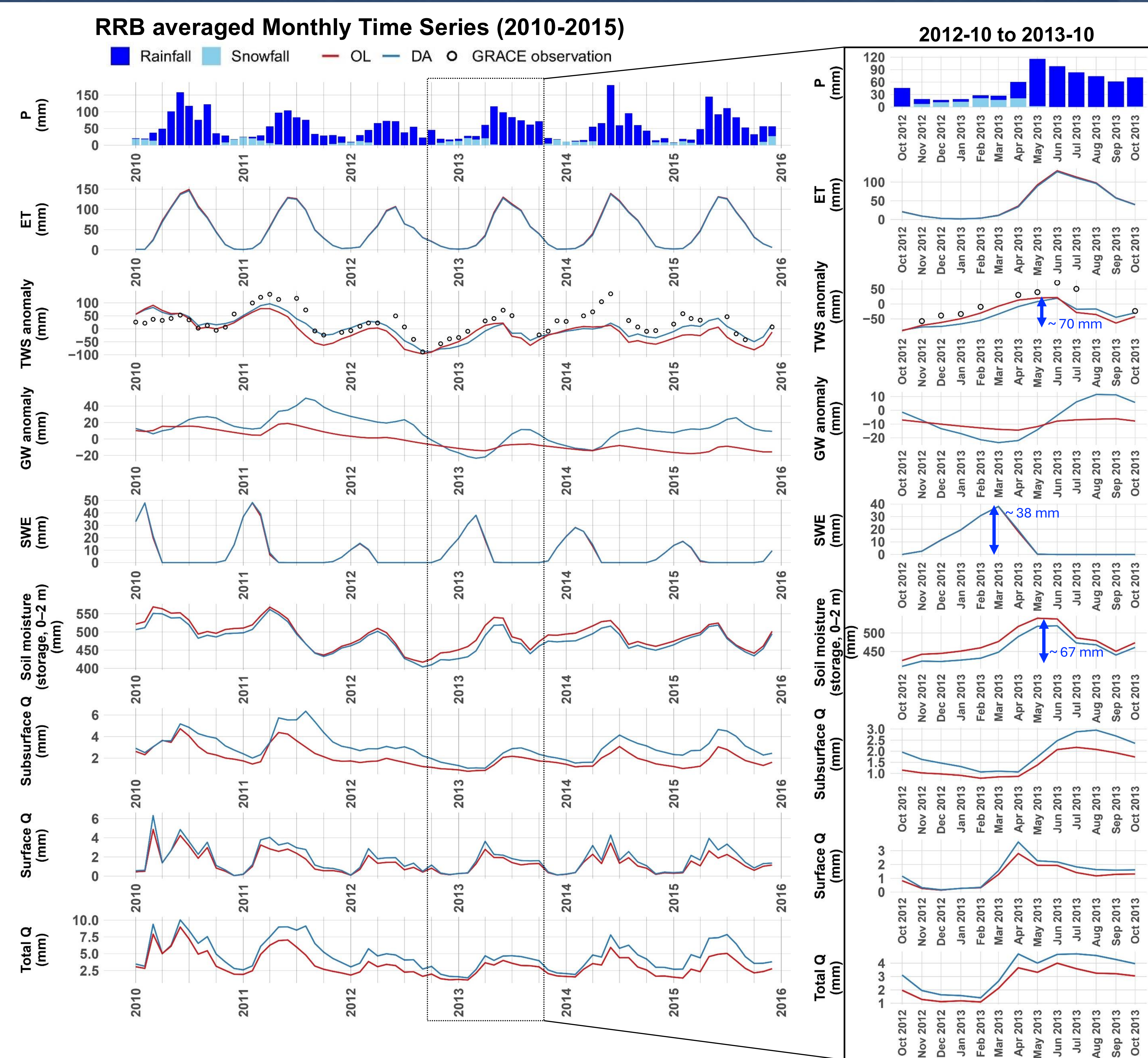


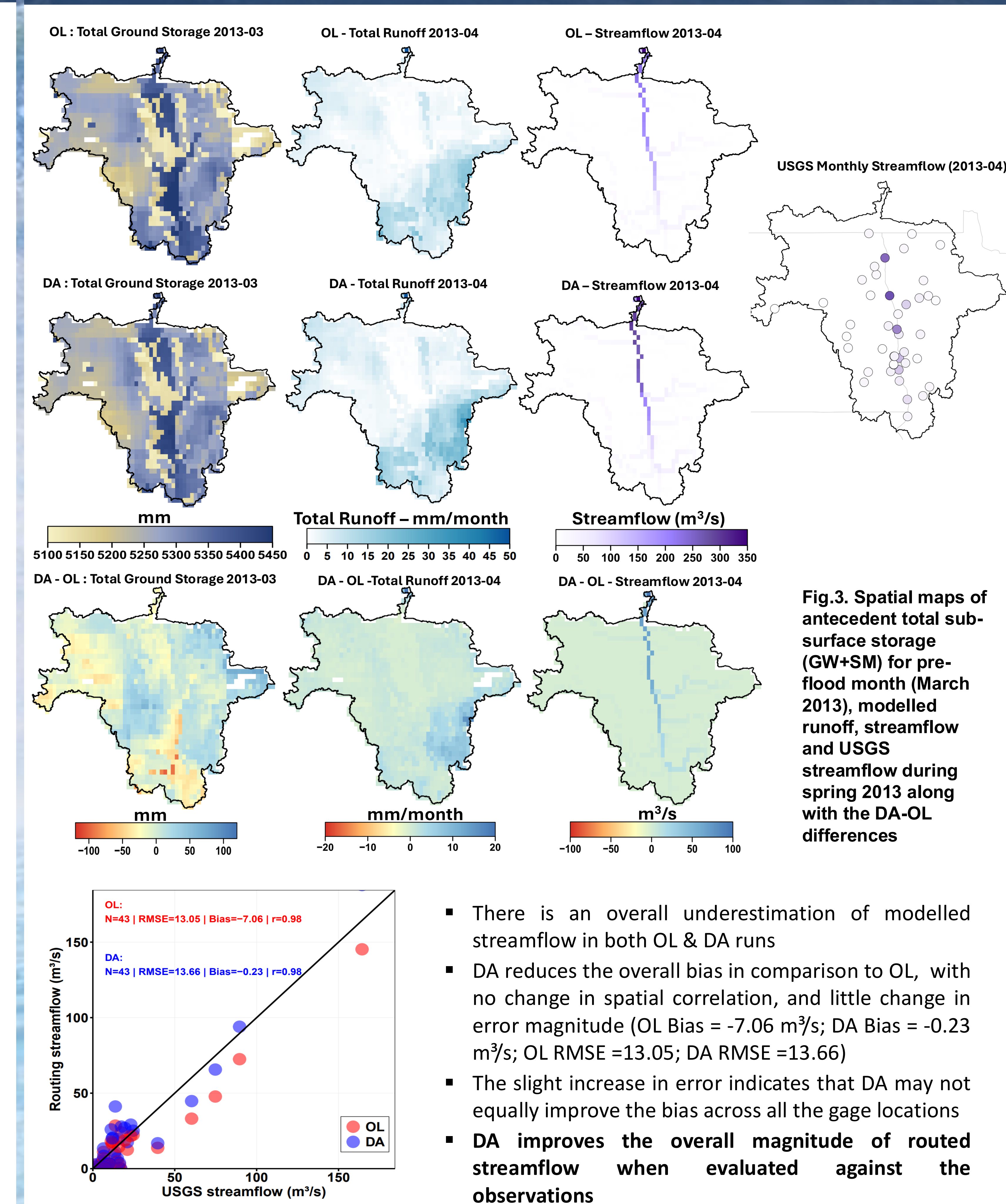
Fig. 2. RRB watershed averaged monthly time series of hydrological variables for the 2010 – 2015 period and the 2013 flood year

- Total soil column storage (0 – 2 m) variations between the 2012-11 and 2013-05 are comparable to the variations in the water inputs (snowmelt and precipitation)
- Most of the input water is stored in the soil layers, with low GW and runoff response
- This could be attributed to higher infiltration and low runoff, when the frozen surface becomes more permeable during spring
- In March 2013, DA process decreases the TWS (-25 mm), which induces a drop in soil moisture (-29 mm), increases in GW storage (+4 mm) and smaller increases in the runoff components (+0.6 mm)
- DA is shifting the water storage more from soil moisture to deeper groundwater
- DA leads to more negative GW anomaly despite small increases in the absolute GW storage

Table 1: RRB watershed averaged monthly values of TWS, soil moisture, SWE, GW, and runoff for 2013 spring months (all values in mm)

|                           | March |             | April |             | May  |            |
|---------------------------|-------|-------------|-------|-------------|------|------------|
|                           | OL    | DA          | OL    | DA          | OL   | DA         |
| Terrestrial Water Storage | 5260  | 5235 (-25)  | 5280  | 5260 (-20)  | 5287 | 5277 (-10) |
| Soil Moisture (storage)   | 477   | 448 (-29)   | 518   | 490 (-28)   | 540  | 518 (-22)  |
| Snow Water Equivalent     | 38    | 38.1 (+0.1) | 18.0  | 19.3 (+1.3) | 0.2  | 0.3 (+0.1) |
| Groundwater               | 4745  | 4749 (+4)   | 4745  | 4751 (+6)   | 4747 | 4759 (+12) |
| Total Runoff              | 2.1   | 2.7 (+0.6)  | 3.7   | 4.7 (+1)    | 3.3  | 4.0 (+0.7) |

## Result 2 : OL & DA runs vs USGS observations for 2013



- There is an overall underestimation of modelled streamflow in both OL & DA runs
- DA reduces the overall bias in comparison to OL, with no change in spatial correlation, and little change in error magnitude (OL Bias = -7.06 m<sup>3</sup>/s; DA Bias = -0.23 m<sup>3</sup>/s; OL RMSE = 13.05; DA RMSE = 13.66)
- The slight increase in error indicates that DA may not equally improve the bias across all the gage locations
- DA improves the overall magnitude of routed streamflow when evaluated against the observations

## Conclusions

- In spring 2013, DA mainly redistributes TWS into groundwater storage (-55 mm TWS, -79 mm soil moisture storage, +22 mm groundwater storage, and +2.3 mm runoff between March and May), with only small increases in runoff
- During spring 2013, the routed streamflow is underestimated, especially during high-flow conditions
- DA produces modest improvements (DA Bias = -0.23 m<sup>3</sup>/s) in modeled streamflow compared to USGS, but skill remains limited at some gauges
- Future work can encompass sub-basin level streamflow validation, testing plausible runoff controls (frozen soil, infiltration, channel gradient), and alternative DA constraints across multiple flood/non-flood years

## Acknowledgements

This research was supported by NASA's Subseasonal-to-Seasonal Hydrometeorological Prediction program (Grant No. 80NSSC24K1278). We thank Dr. Augusto Getirana at NASA GSFC for his support and guidance in applying HYMAP-3. We thank the student members of the Cho Lab, Texas State University for the suggestions, feedback & poster ideas

## References

