Improve the performance of the Noah-MP model by hybridizing data assimilation and machine learning

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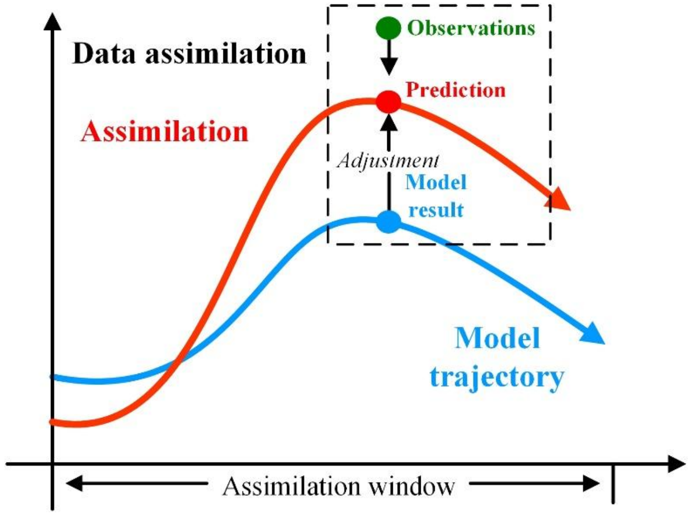
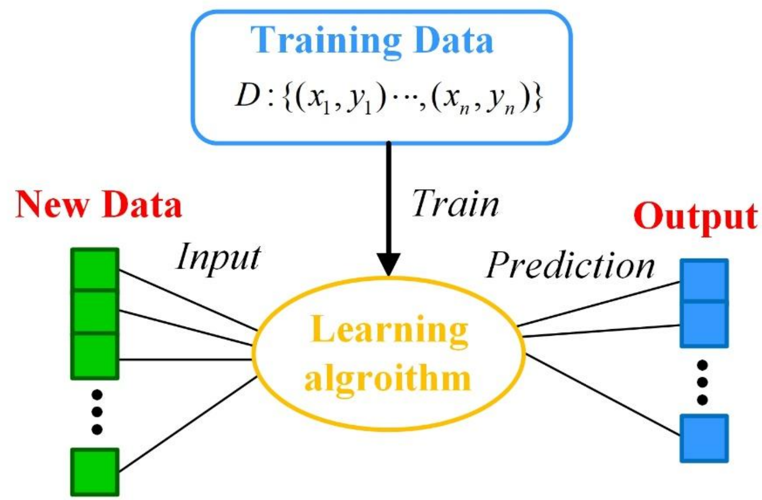
Introduction



Data assimilation (DA) methods merge the observations with physical models to optimally retrieve the model state variables and parameters, ultimately improving model prediction accuracy.

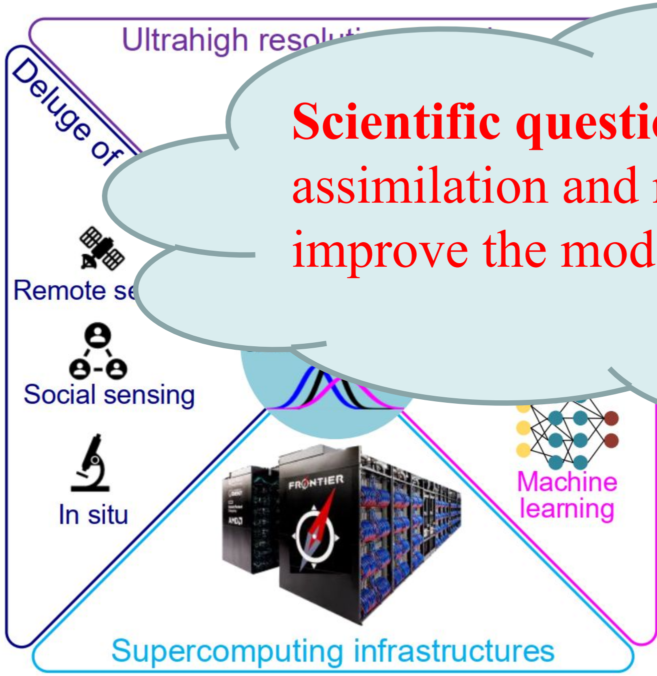
Machine learning (ML) is a data-driven method based on data, which tries to retrieve main features and variable relationships from data.



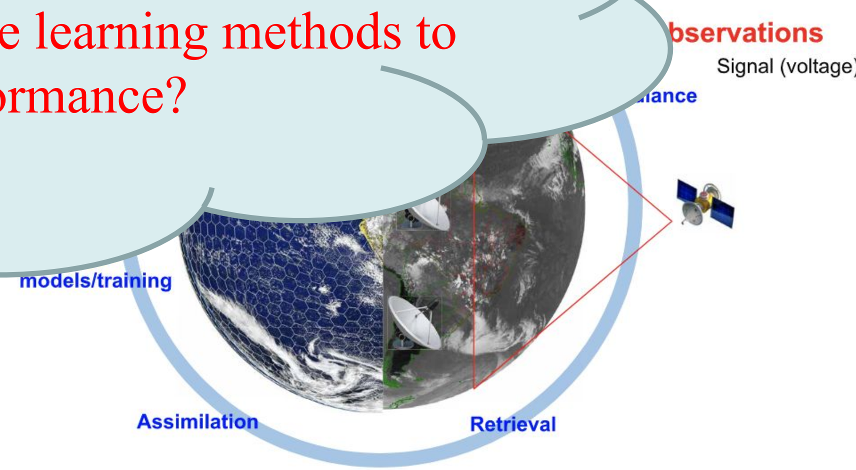
Introduction

Hybrid modeling refers to the dynamic coupling of machine learning methods and data assimilation systems using advanced supercomputing equipment, and the mutual integration of Earth system models and Earth observation data (remote sensing and station observations).

Scientific question: How to take advantage of data assimilation and machine learning methods to improve the model performance?

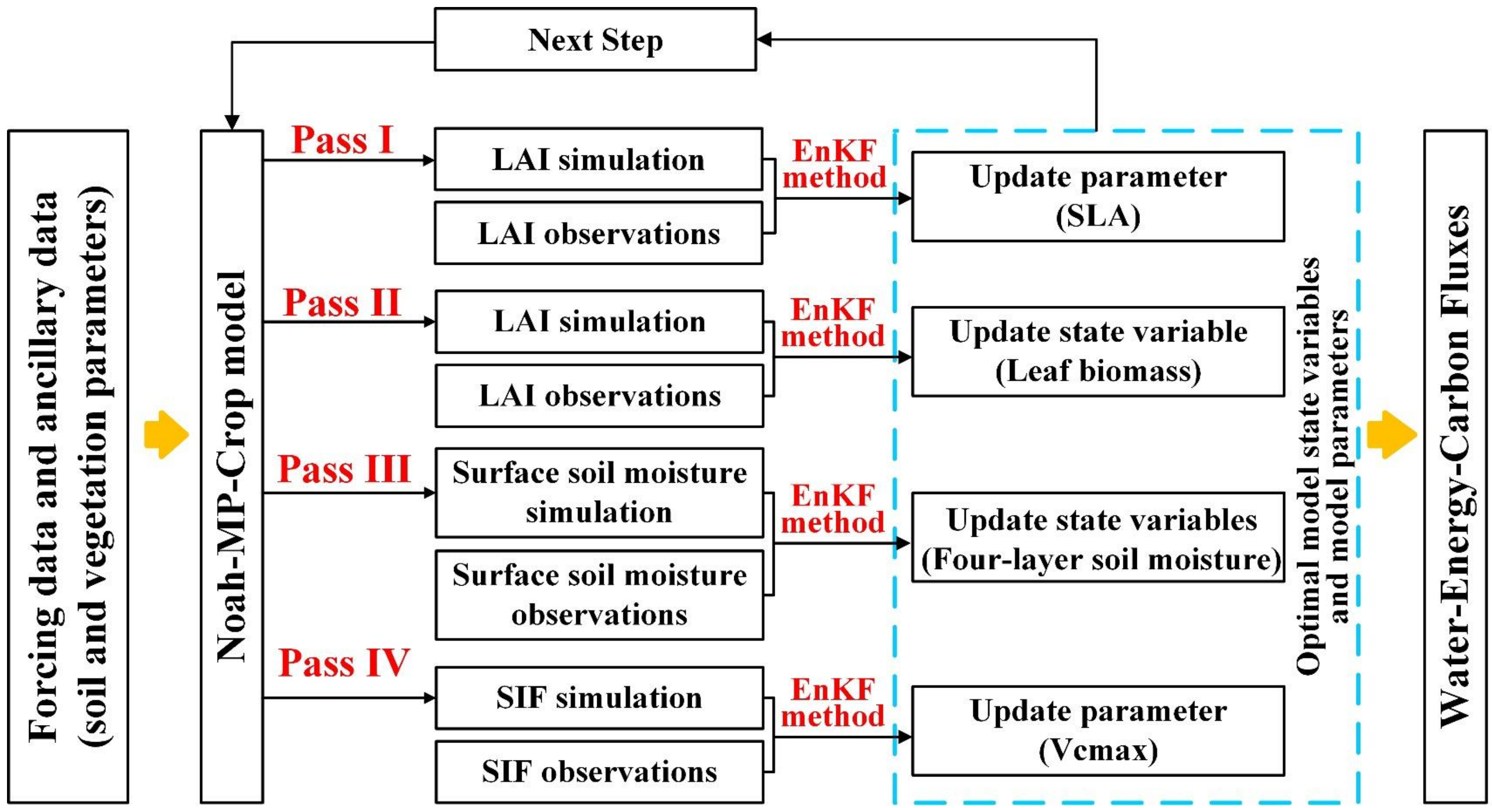


(Li et al., 2023, Nature Reviews Earth & Environment)



(Gettelman et al., 2022, Science Advances)

Methodology



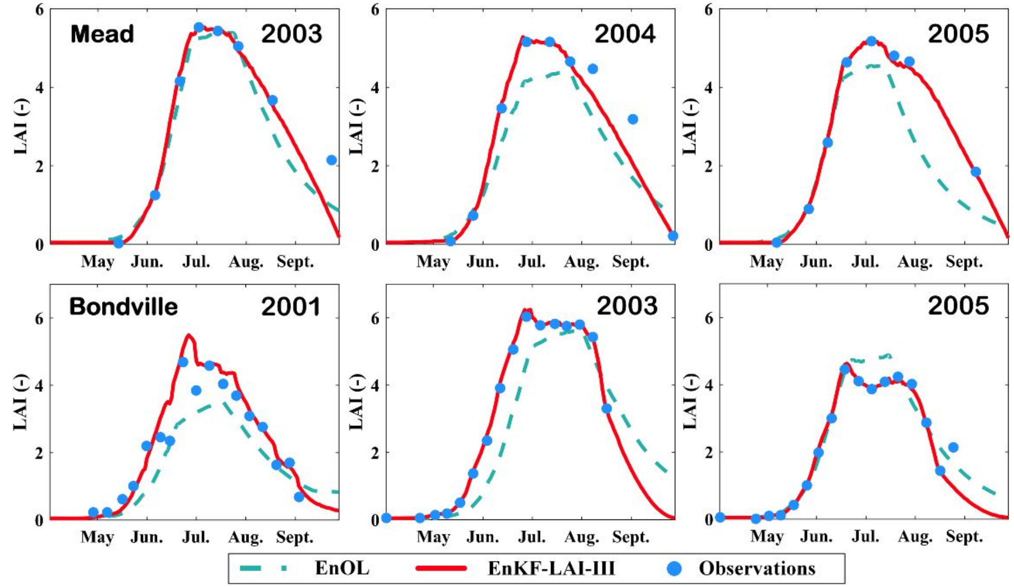
Flowchart of the multipass land data assimilation scheme.

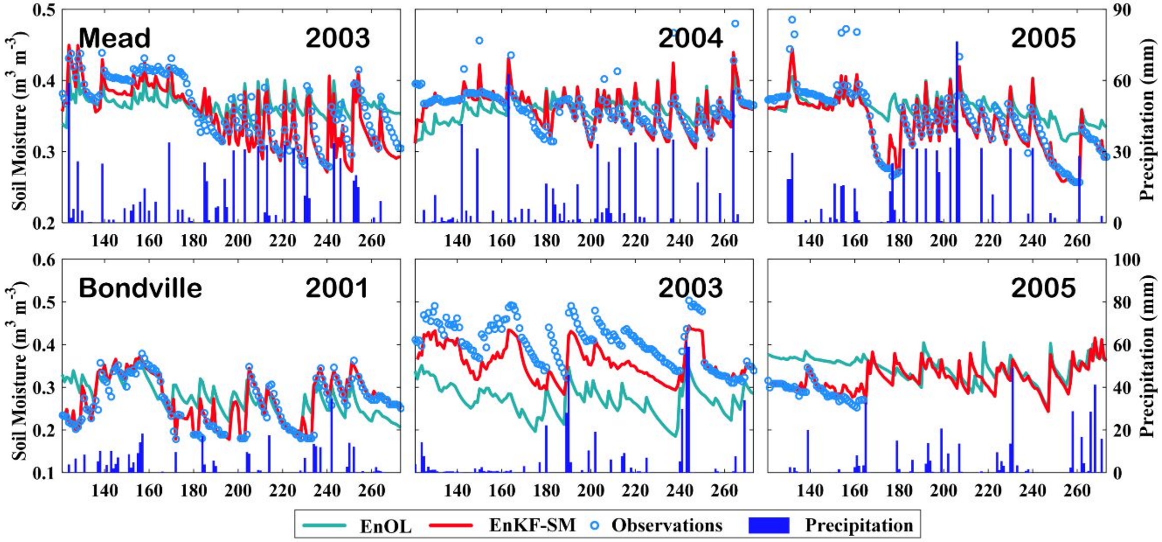
Tongren Xu, Fei Chen, and Xinlei He*, et al., *JAMES*, 2021

Results

The estimation of LAI and soil moisture

Comparisons of the LAI values estimated from EnKF and open loop (EnOL) with the observations at the Mead and Bondville sites.

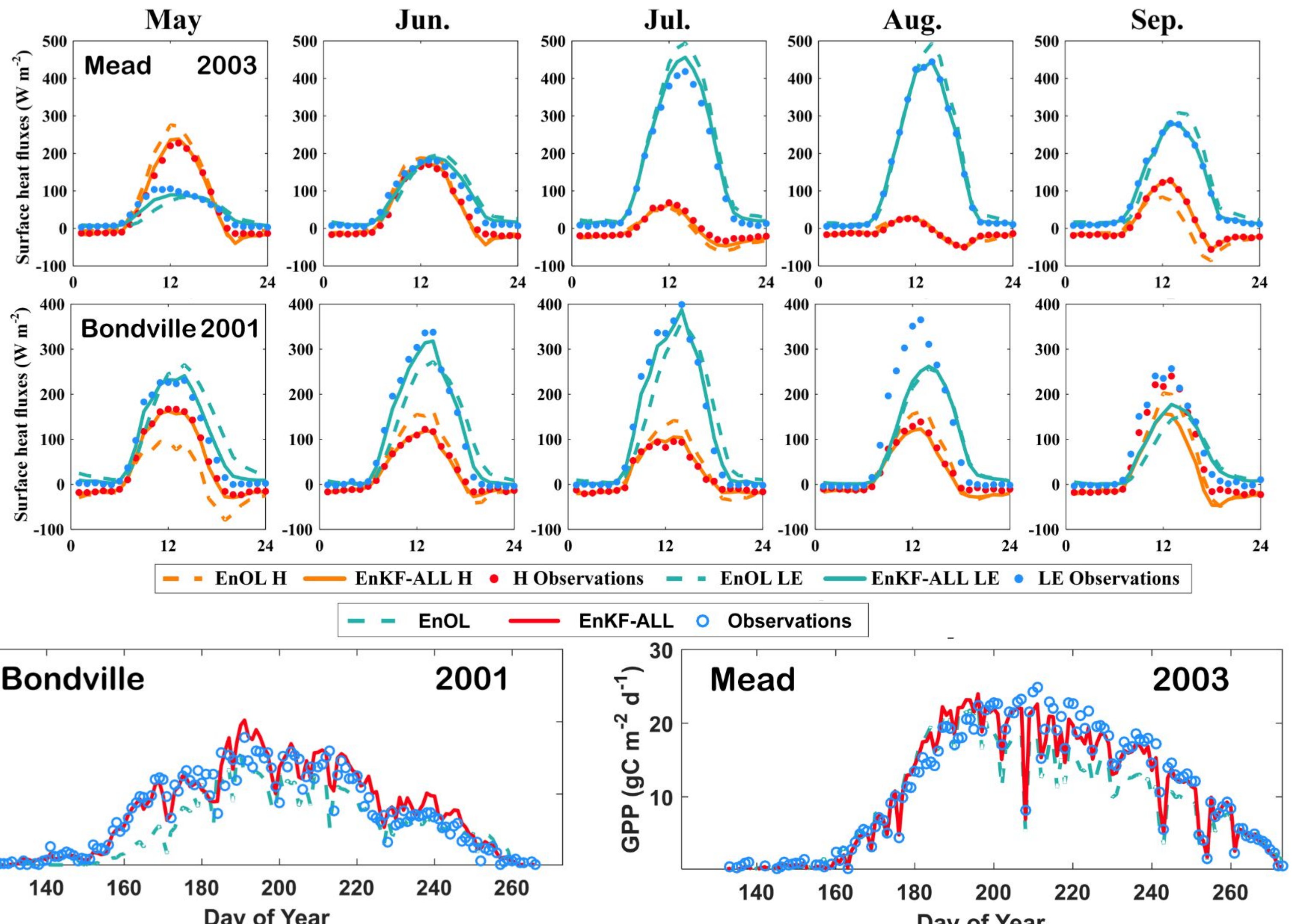




Daily averaged soil moisture (0–10 cm) estimates from EnKF and open loop (EnOL) versus ground measurements at the Mead and Bondville sites.

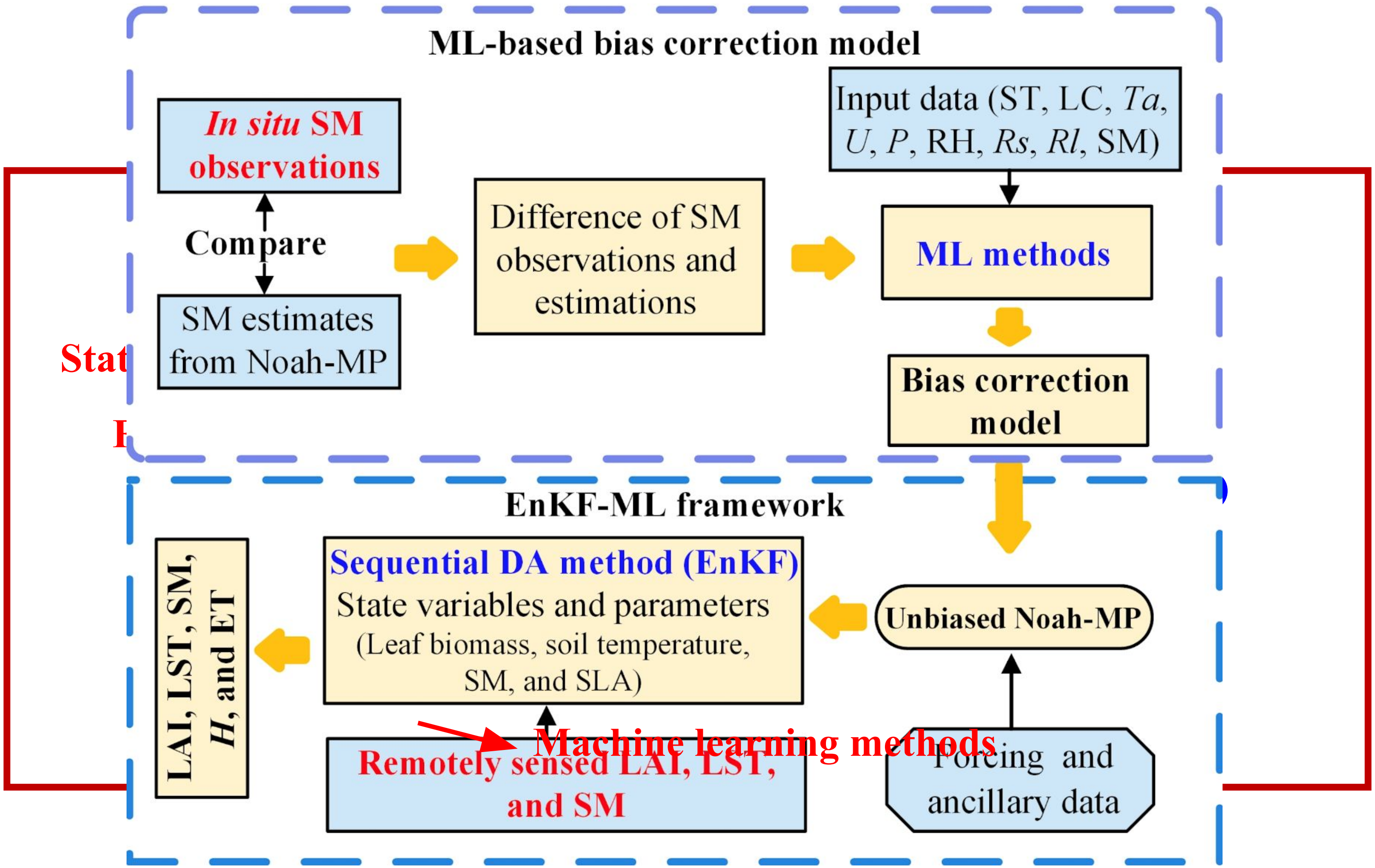
Results

The estimation of sensible and latent heat fluxes and GPP



The time series of modeled sensible and latent heat fluxes and GPP at the Mead and Bondville sites.

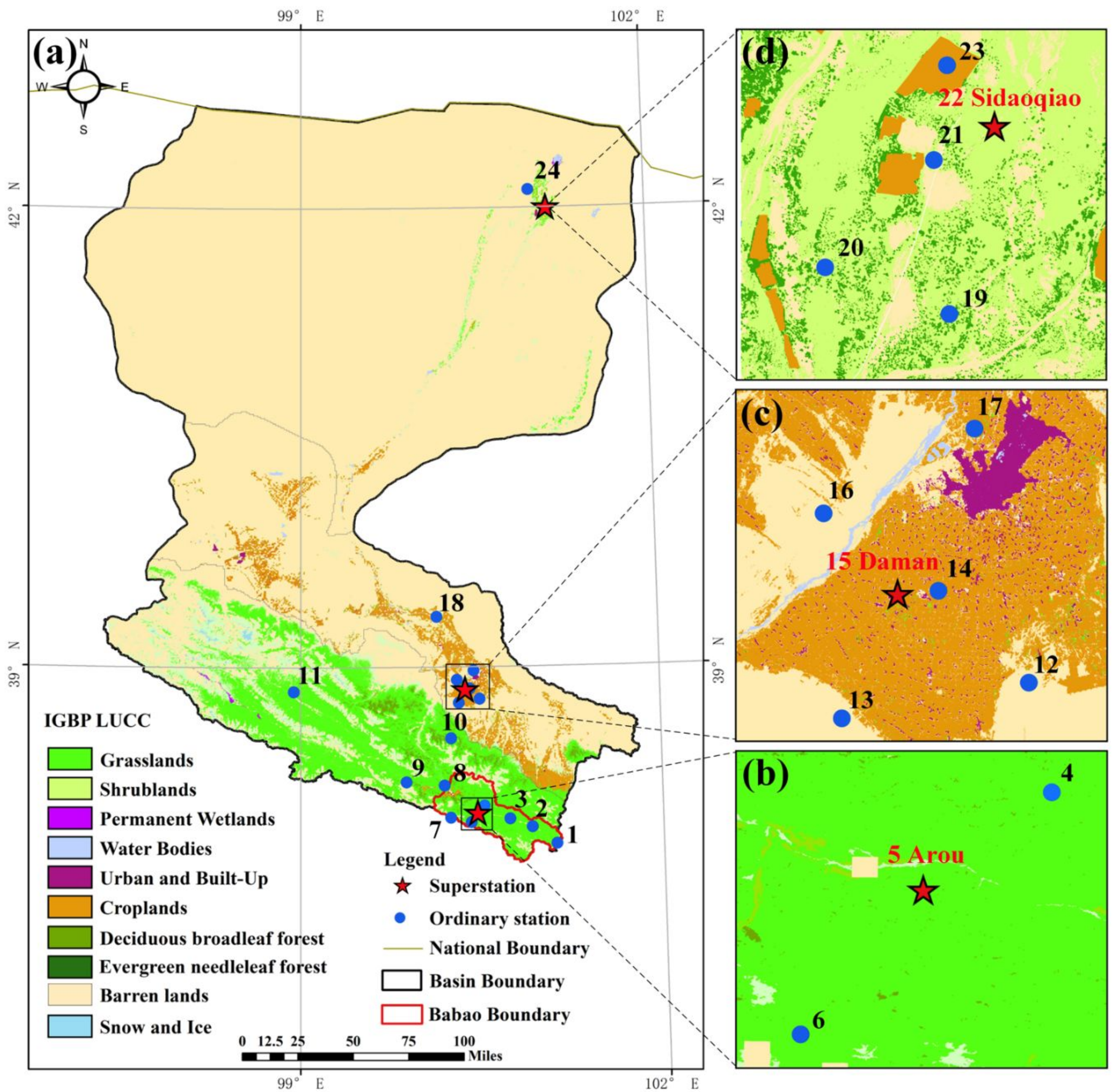
Methodology



Schematic diagram of the developed EnKF-ML framework

Xinlei He, et al., *AWM*, 2022

Study Location



Heihe River Basin (HRB) in Northwestern China

Land Cover of HRB:

Upstream :
Alpine meadow,
Qinghai spruce

Midstream :
Cropland, Desert

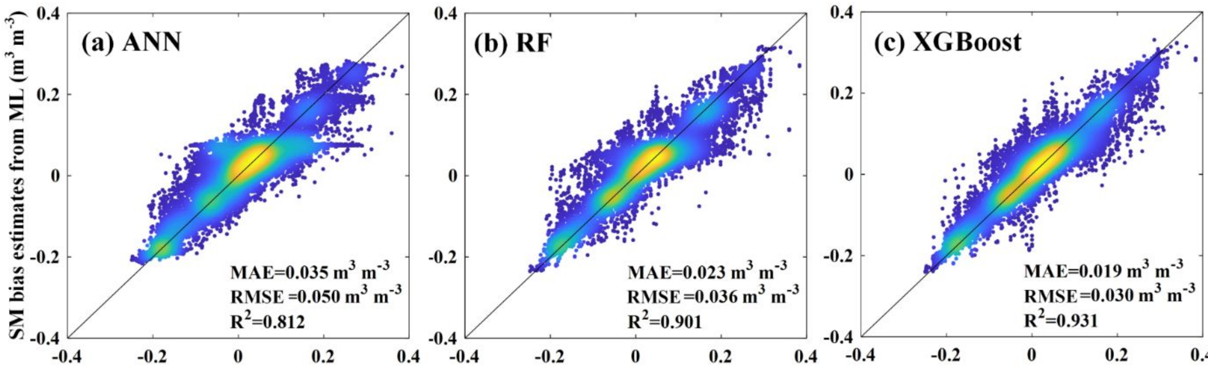
Downstream:
Riparian Forest, Desert

Liu et al. (2018, VZJ)

Xu et al. (2020, AFM)

Results

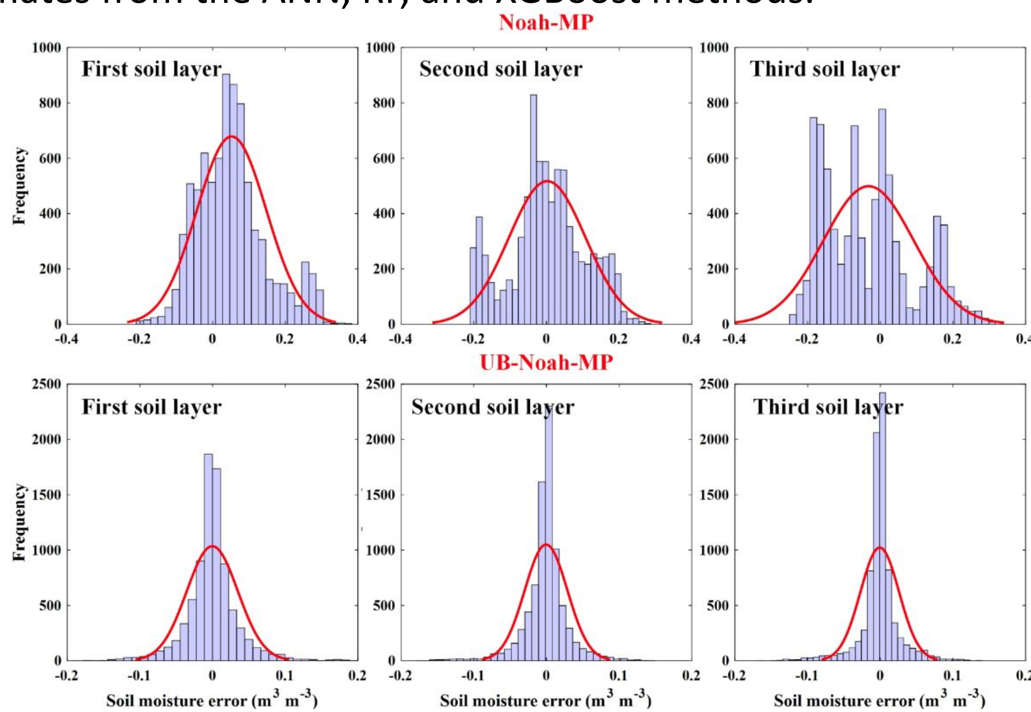
Soil moisture bias correction:



Ten-fold validation

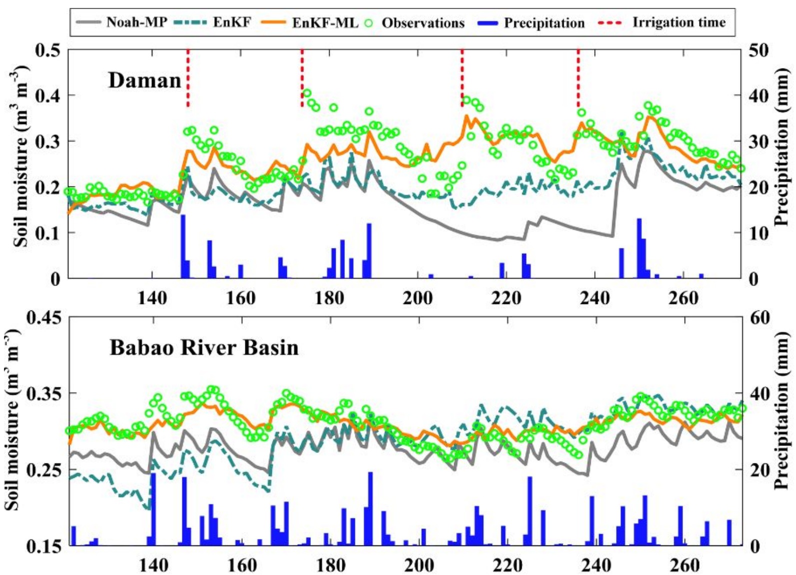
Comparison of soil moisture bias estimates from the ANN, RF, and XGBoost methods.

Frequency histogram of the soil moisture errors from Noah-MP (top row) and unbiased Noah-MP (UB-Noah-MP) (bottom row) at the 24 sites.

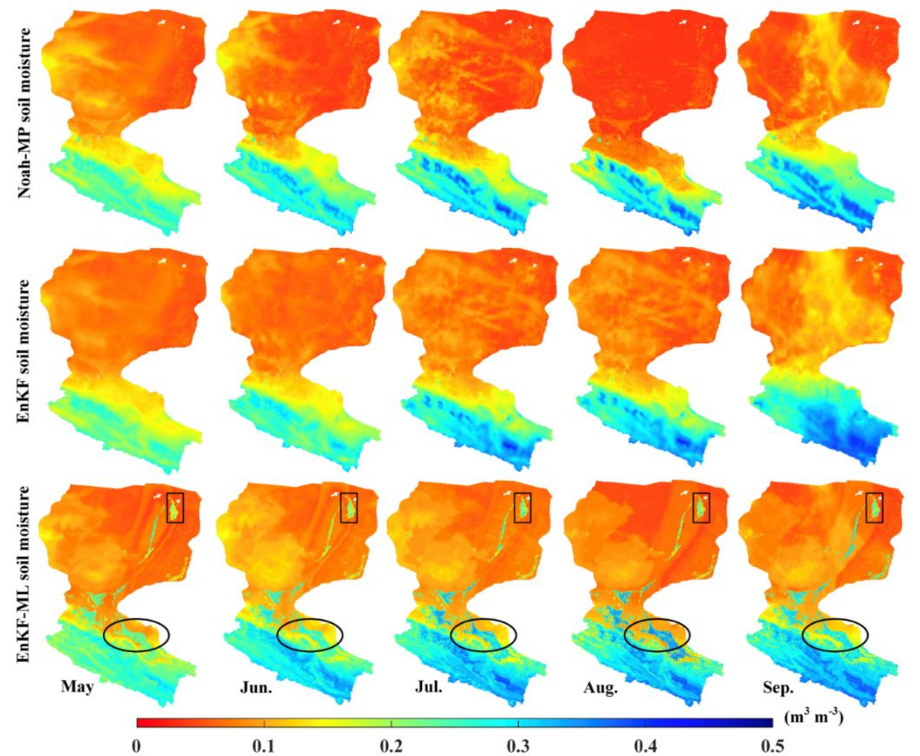


Results

The estimation of soil moisture



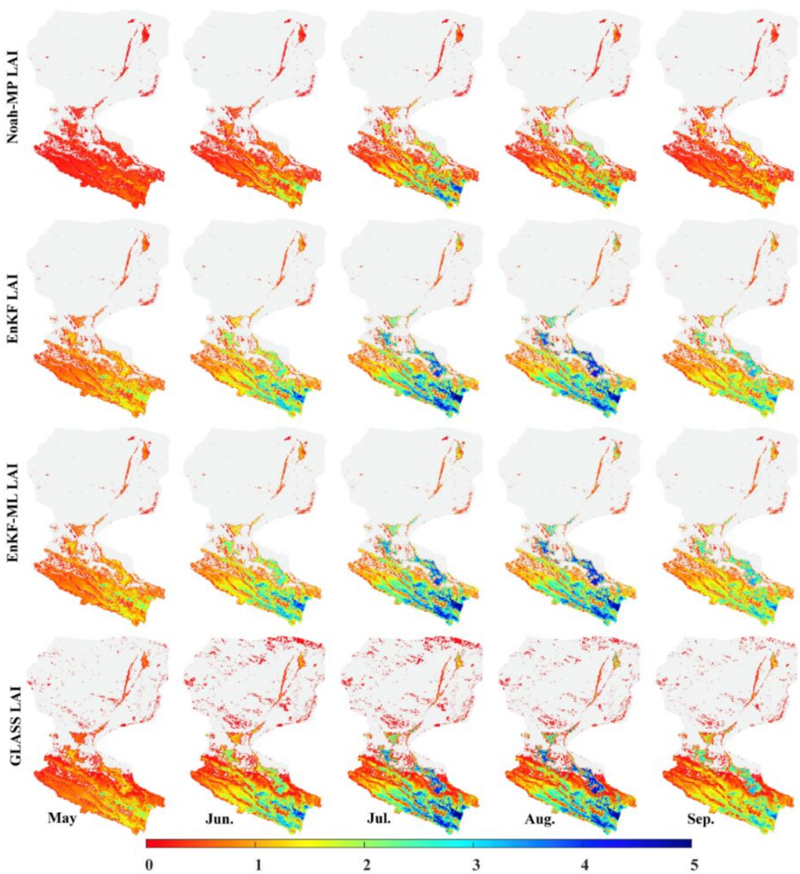
Daily first layer soil moisture estimates from Noah-MP (gray solid lines), EnKF (green dashed lines), and EnKF-ML (orange solid lines) at the Daman site and Babao River Basin in 2015.



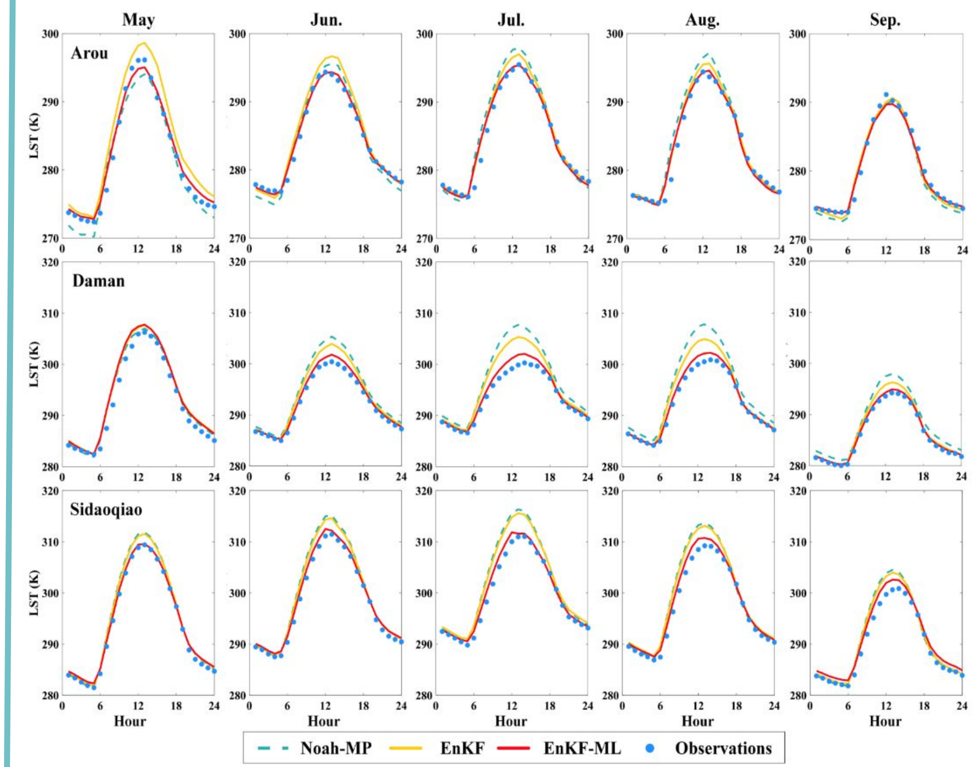
Spatial patterns of monthly mean soil moisture estimate from Noah-MP (first row), EnKF (second row), and EnKF-ML (third row) over the HRB during May–September, 2015.

Results

The estimation of LAI and LST



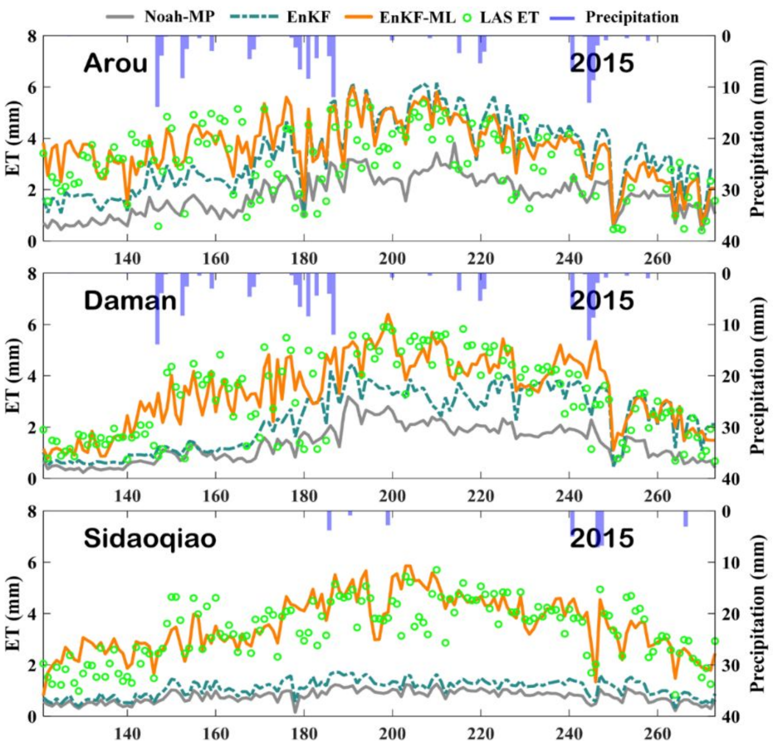
Monthly mean LAI estimates from the Noah-MP, EnKF, and EnKF-ML methods and GLASS LAI over the HRB in 2015.



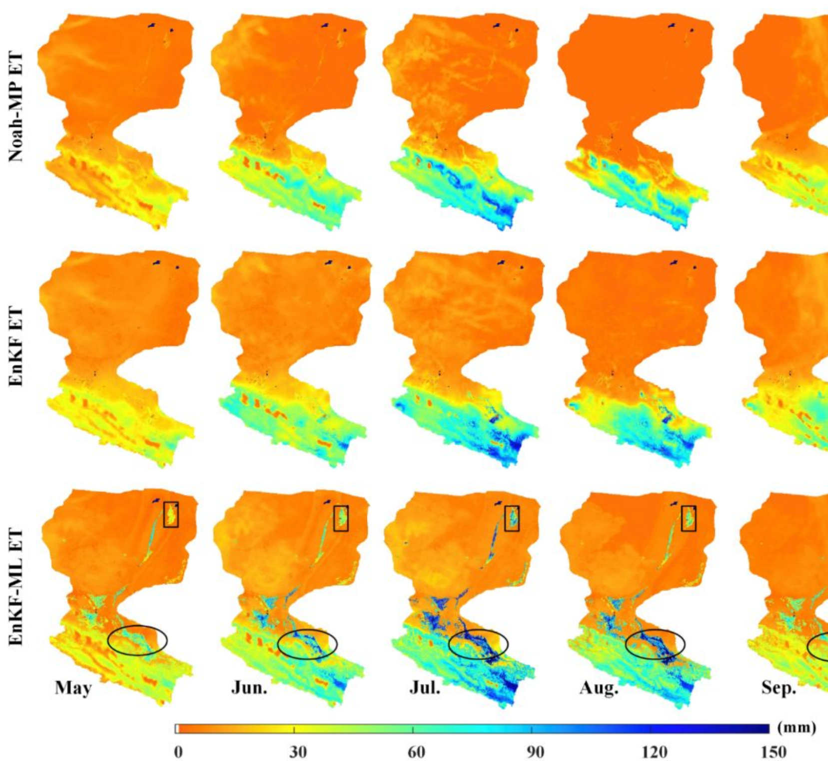
Monthly mean diurnal cycle of the LST estimates from the Noah-MP, EnKF, and EnKF-ML methods and corresponding observations at the Arou, Daman, and Sidaoqiao sites

Results

▯ The estimation of evapotranspiration

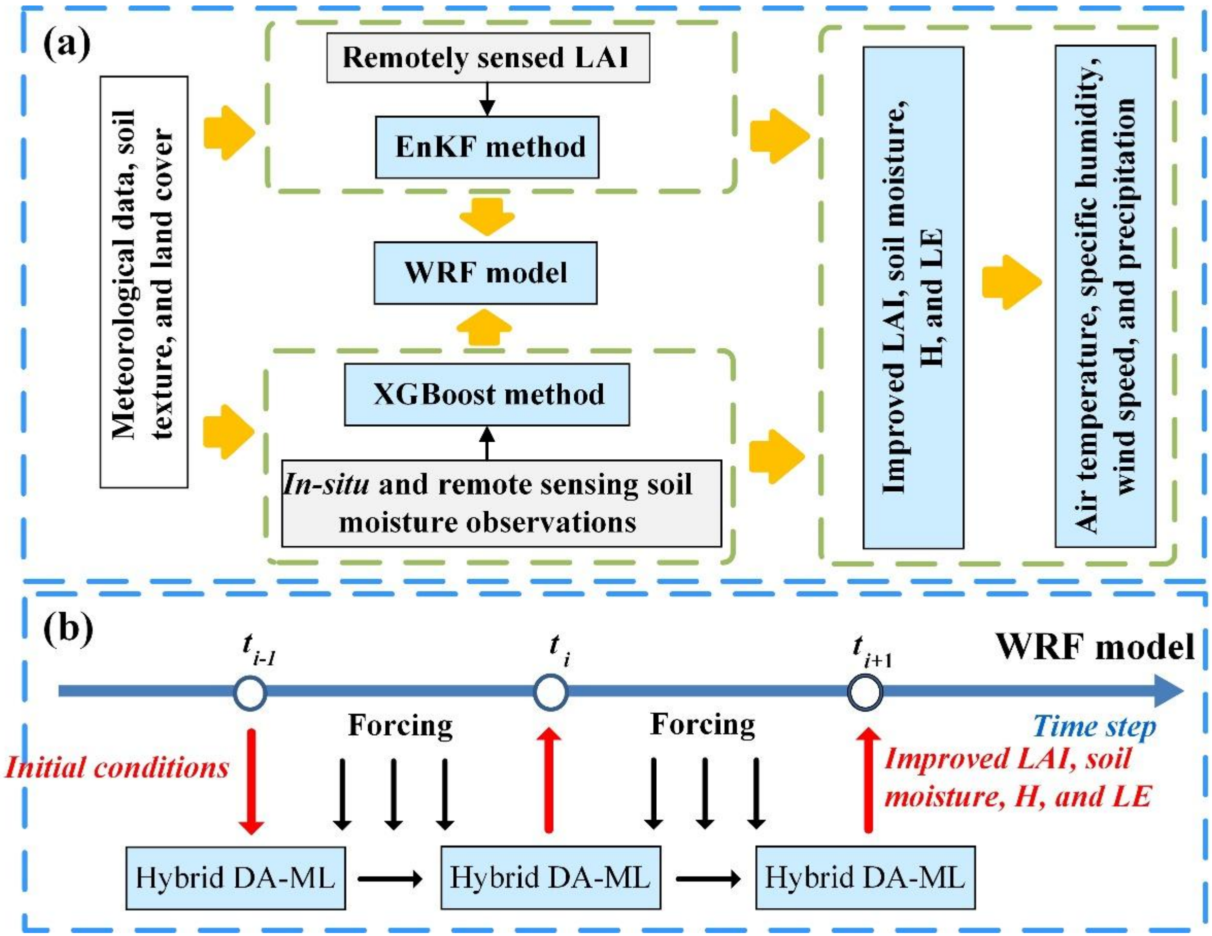


Time series of daily ET estimates from Noah-MP (gray solid lines), EnKF (green dashed lines), and EnKF-ML (orange solid lines) at the Arou, Daman, and Sidaoqiao sites in DOYs 121-273, 2015.



The ET estimates from the Noah-MP (first row), EnKF (second row), and EnKF-ML (third row) approaches over the HRB during May–September, 2015.

Methodology

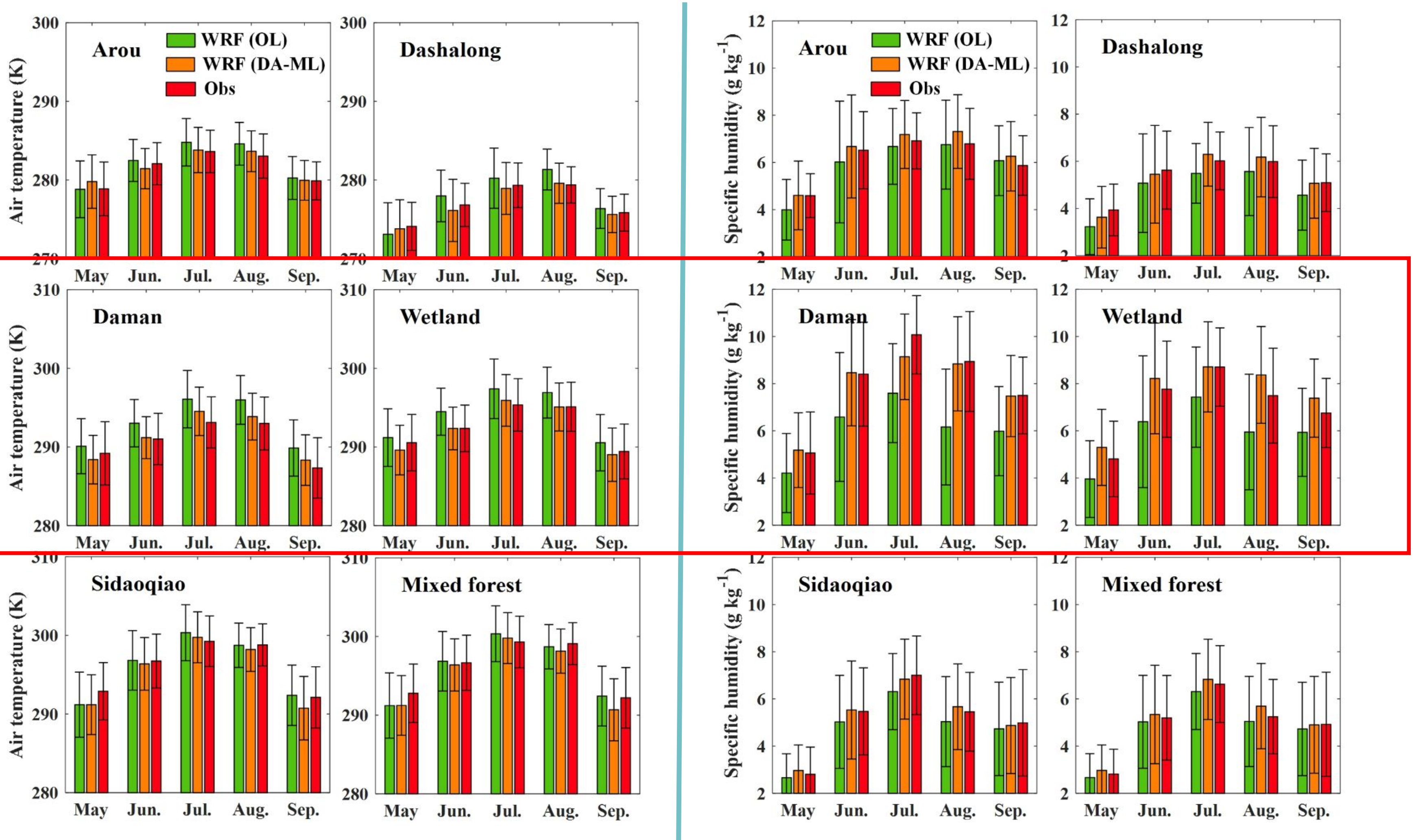


The flowchart of the coupling with the WRF model.

Xinlei He, et al., *HESS*, 2023

Results

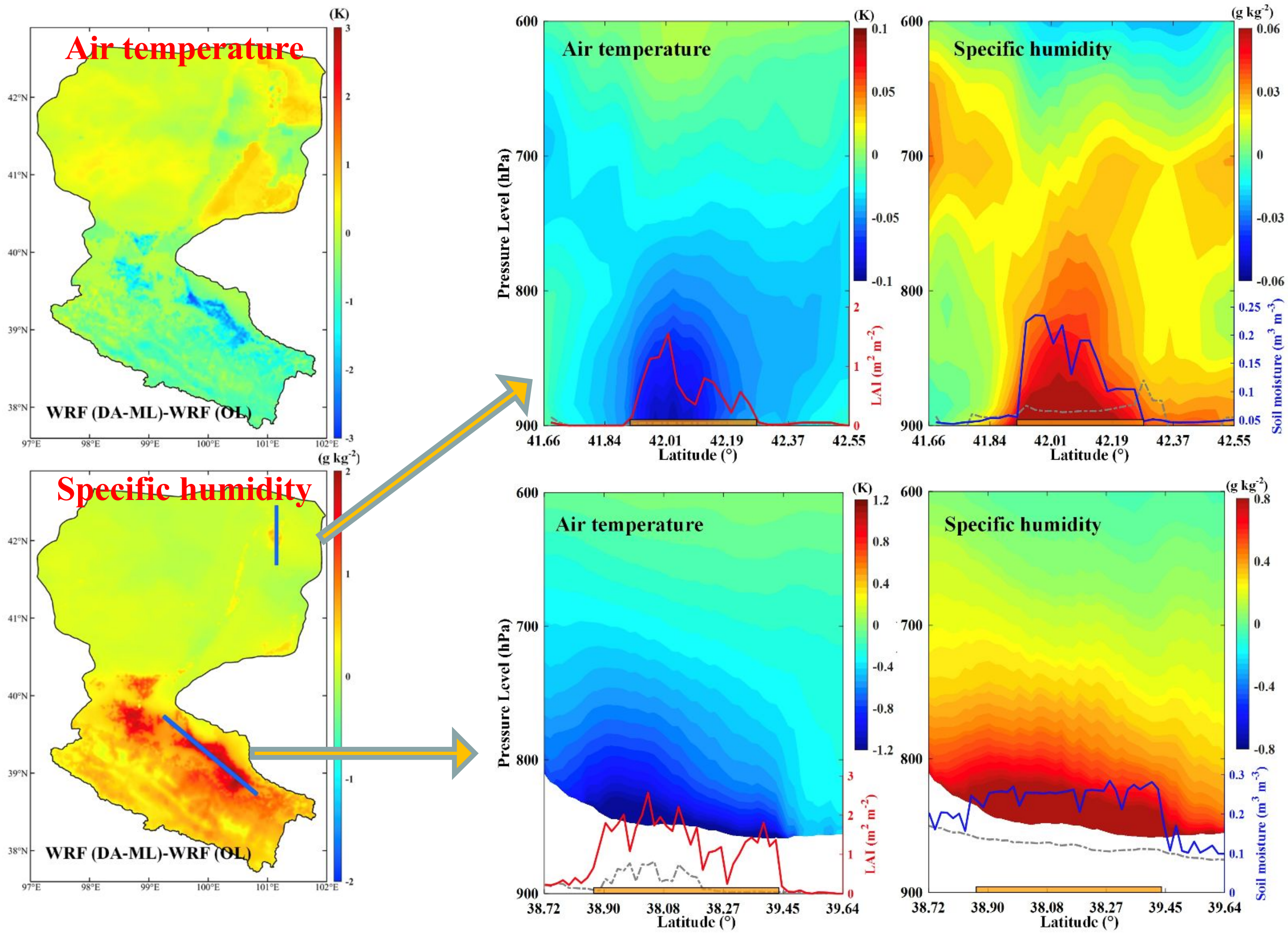
- **The estimation of air temperature and specific humidity**



Monthly averaged air temperature and specific humidity simulations from the WRF and WRF (DA-ML) versus the observations at six sites in 2015.

Results

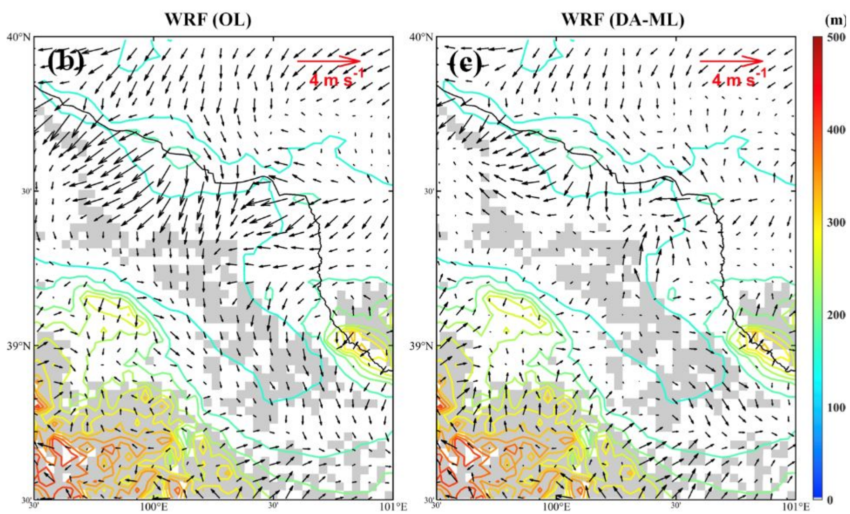
▯ The estimation of air temperature and specific humidity



The improved simulations of LAI, soil moisture, and ET make the oasis a typical "wet island" and "cold island" compared to the surrounding desert.

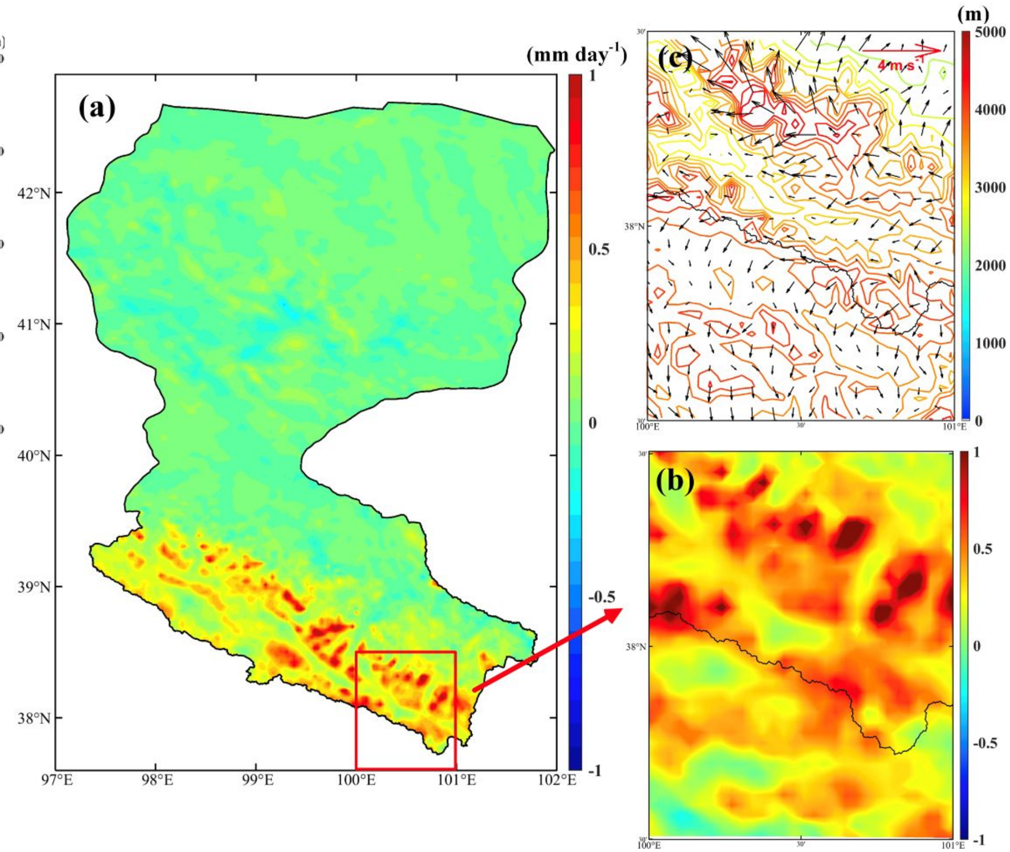
Results

▯ The estimation of wind speed and precipitation



Wind vectors at 10 from WRF (OL) and WRF (DA-ML) in the midstream oasis.

The irrigation and vegetation growth in the midstream oasis produces a wind shield effect.



Precipitation [WRF (DA-ML) minus WRF (OL)].

WRF (DA-ML) enhances the estimation of precipitation in the southeastern part of the HRB. The increase in precipitation is mainly concentrated on windward slopes compared to valleys.

Conclusions

- The joint assimilation of LAI, soil moisture, and SIF is demonstrated to be effective in constraining the model state variables (i.e., leaf biomass and SM) and optimizing parameters (i.e., SLA and Vcmax) and improving the estimation of H, LE, and GPP.

- The XGBoost method can correct the bias of SM estimates from Noah-MP. The assimilation of remotely sensed LAI, LST, and SM into the unbiased Noah-MP model can improve LAI, LST, SM, and ET estimates.

- The WRF (DA-ML) method can integrate remotely sensed leaf area index (LAI), multi-source soil moisture (SM) observations, and land surface models (LSMs) to accurately describe regional climate and land–atmosphere interactions.

References

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Thanks for attention