Land Data Assimilation in China: A review

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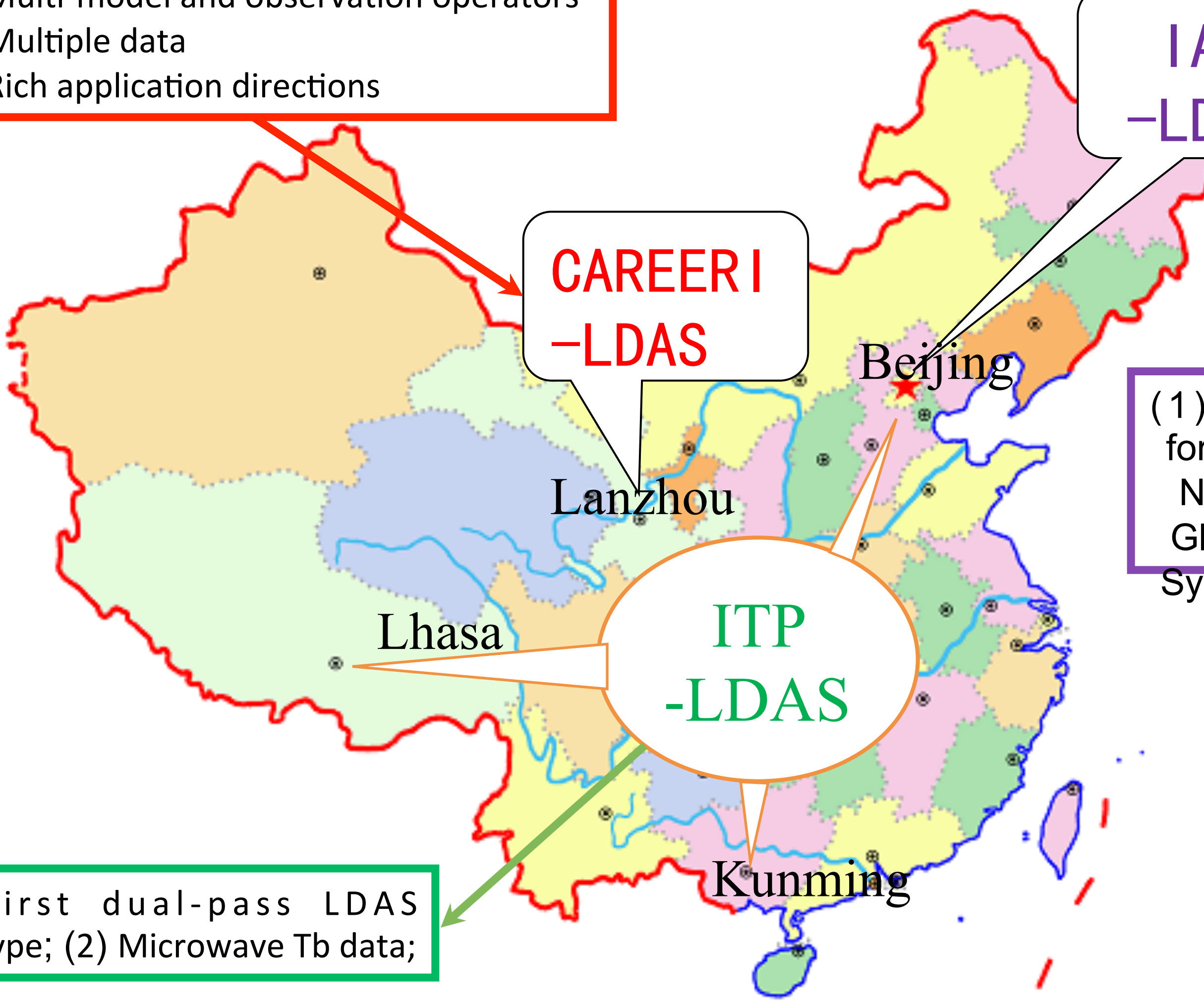
Contents

1. Data assimilation in China: a quick review

LDAS sisters and developers in China

(1) First LDAS in China
(2) Multi-model and observation operators
(3) Multiple data
(4) Rich application directions



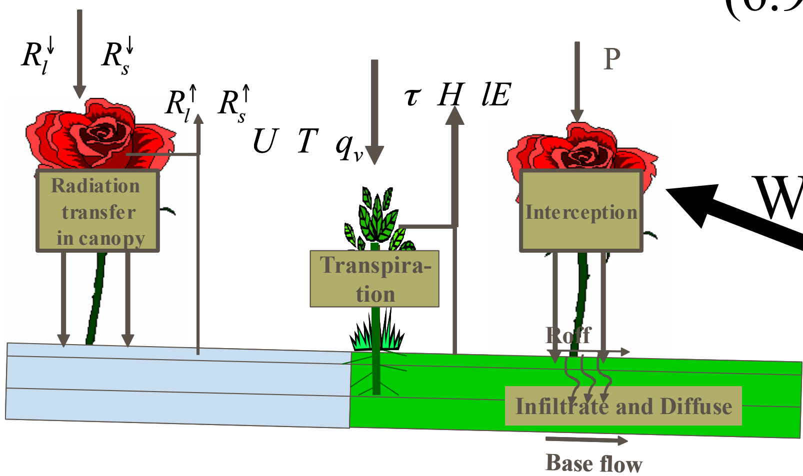
(1) Operational weather forecast (2) Dual-pass LDAS; (3) Novel assimilation; (4) The Global Microwave Land Data System;

(1) First dual-pass LDAS prototype; (2) Microwave Tb data;

From Prof. Kun Yang

Dual-pass LDAS at ITP: (1) first dual-pass LDAS prototype; (2) model operator: SiB2; (3) microwave Tb data

LSM



TMI/AMSR/AMSR-E
(6.9/10.6 and 18.7 GHz)

Tb_{obs}

Wsfc

Minimization scheme
$F(Tb_{obs}-Tb_{sim})$

Tb_{sim}

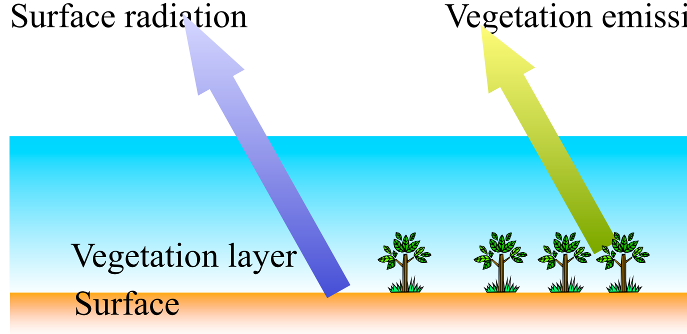
Tg, Tc, Wsfc

$$T_{bp} = T_g(1-\Gamma_p)\exp(-\tau_c) + T_c(1-\omega)[1-\exp(-\tau_c)][1+\Gamma_p \exp(-\tau_c)],$$

Surface radiation

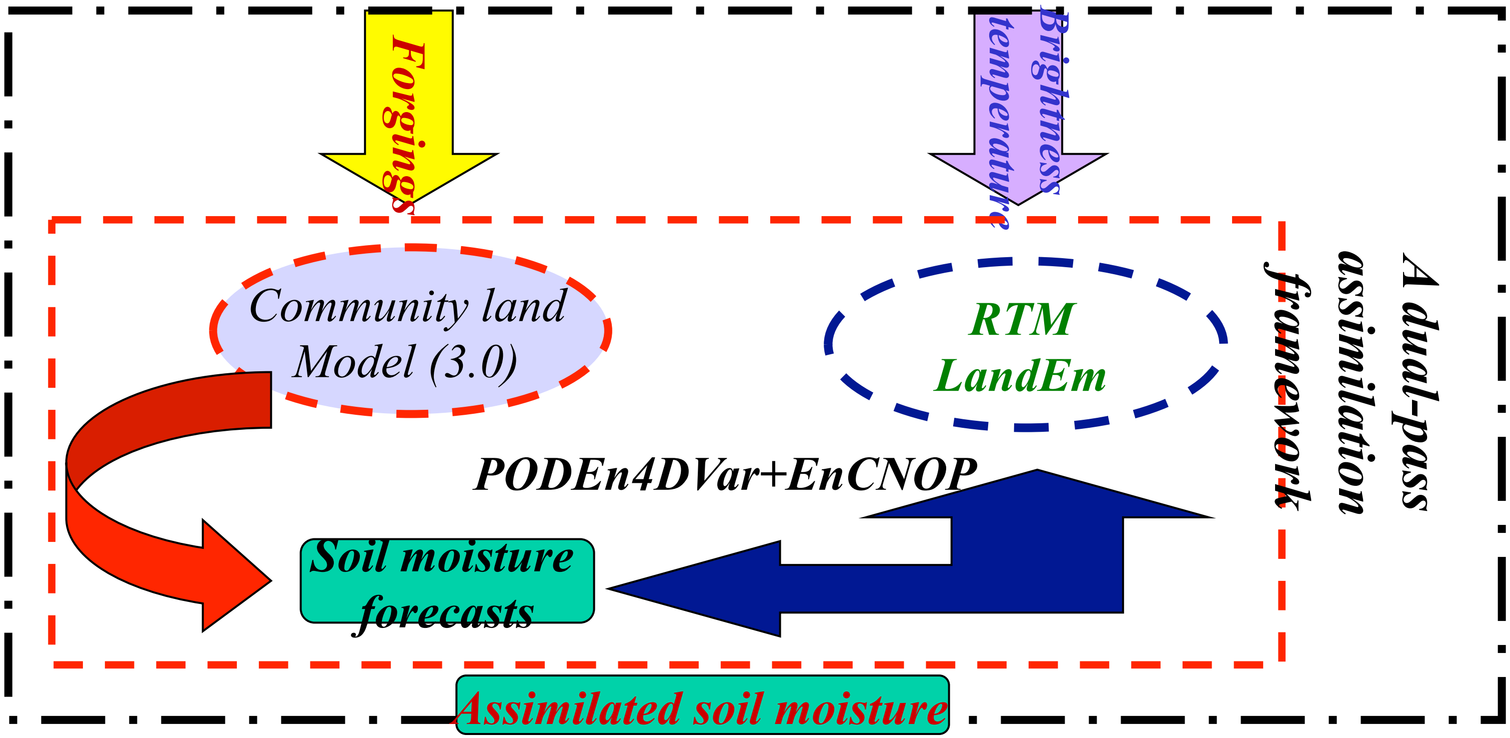
Vegetation emission

RTE



Yang et al., 2007, JMSJ;
Qin et al., 2009, JGR
Yang et al., 2009, J. Hydrometeorology
Yang et al., 2016, J Hydrology

The Global Microwave Land Data System at ITP: (1) dual-pass LDAS; (2) Novel assimilation

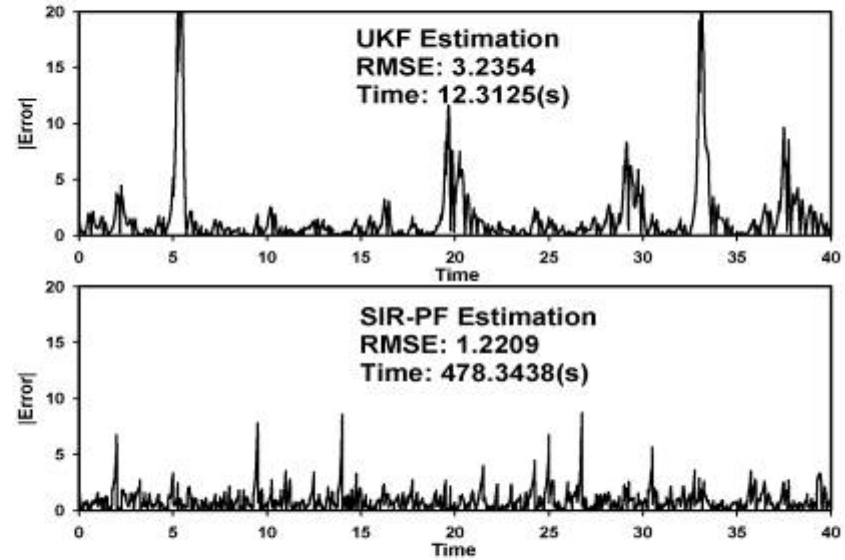


- A Dual-pass Assimilation-Calibration strategy (Tian et al., 2009, JGR)
- A POD-based ensemble 4DVar method (Tian et al., 2010,Tellus-A; 2008, JGR)
- A EnCNOP-P parameter calibration method (Tian et al.,2010, WRR)
- A BMA-based observation operator framework (Tian et al., 2011, JGR)

2. Data assimilation method development

Comparisons of nonlinear non-Gaussian filtering algorithms

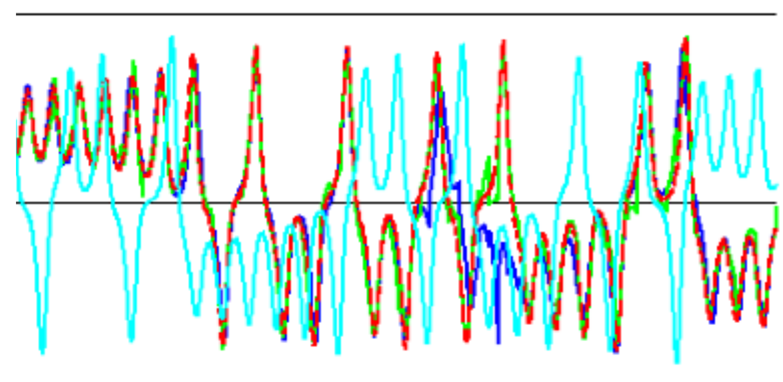
- UKF is a good choice in nonlinear Gaussian problems;
- The performance of the Kalman filter depends on the accurate estimation of system and observation error;
- For nonlinear non-Gaussian Problem, the best option is particle filter;
- Balance between calculation accuracy, numerical stability and computational efficiency.



Accuracy and computation cost (VIC model)

Table of the algorithms, the mean of the RMSE and the error standard deviations for experiment A calculated over 100 independent runs with $\Delta t_{obs}=0.1$

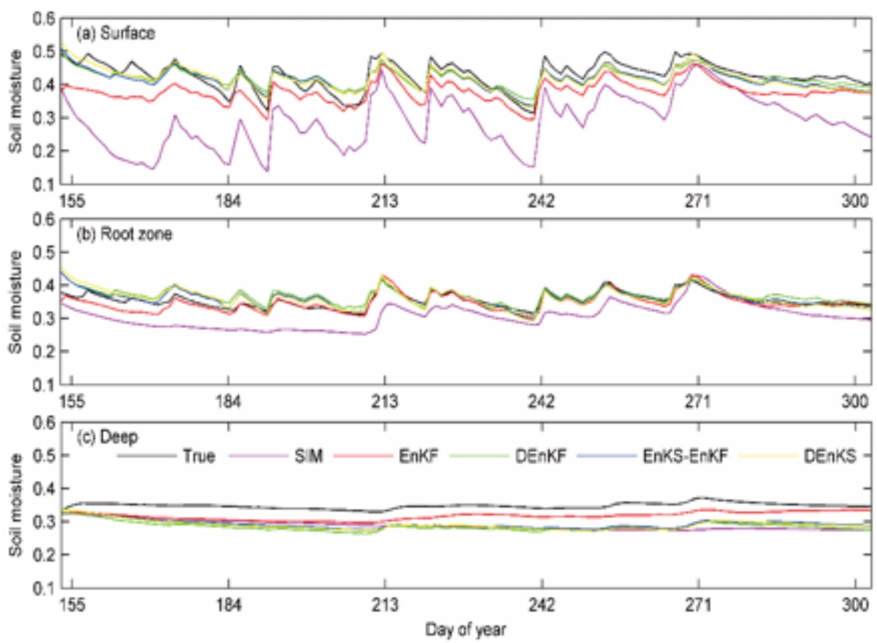
Algorithm	x		y		z	
	RMSE	S.D.	RMSE	S.D.	RMSE	S.D.
Unscented Kalman filter (UKF)	1.157	1.340	1.872	2.319	1.667	2.082
Ensemble Kalman filter (EnKF)	1.102	1.421	1.811	2.433	1.663	2.176
Particle filter (SIR-PF)	1.179	1.298	1.909	2.254	1.724	2.029
Unscented particle filter (UPF)	1.076	1.270	2.022	2.194	1.799	1.677



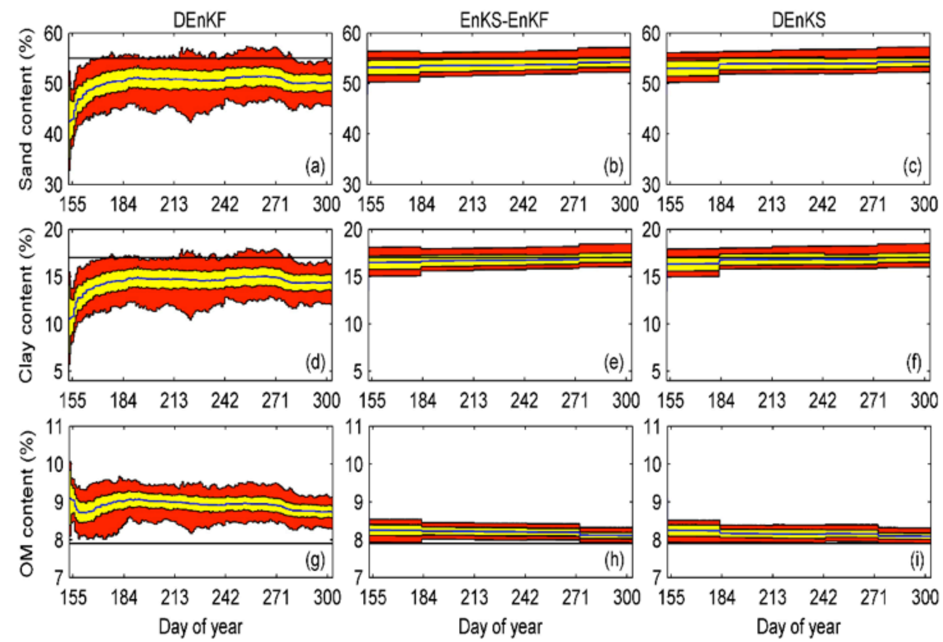
Han & Li, 2008. Remote Sensing of Environment

Dual Ensemble Kalman Smoother for simultaneous estimation of soil moisture and soil properties

Soil moisture



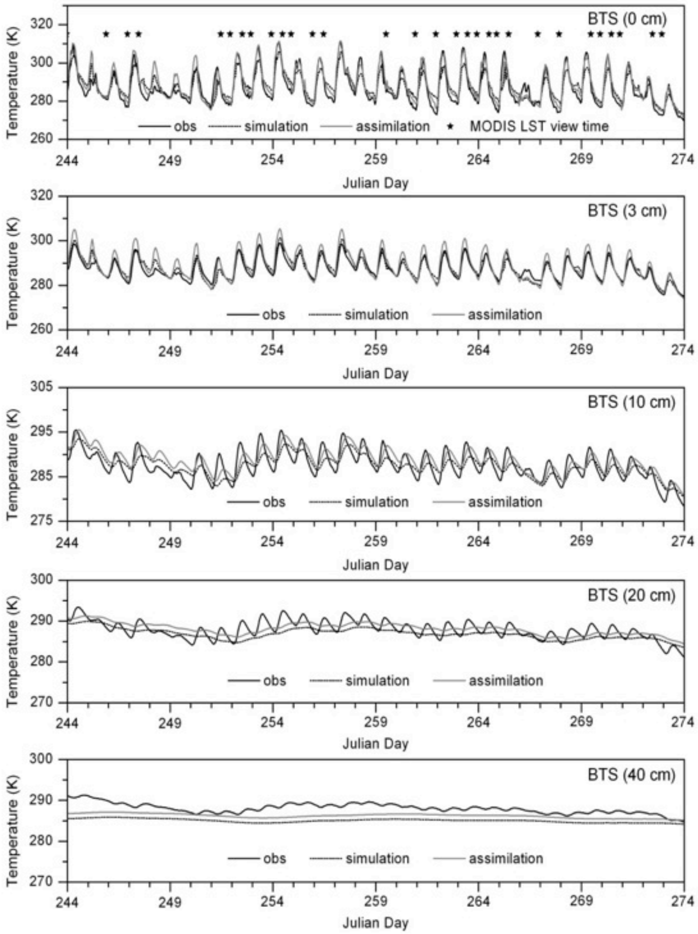
Soil properties



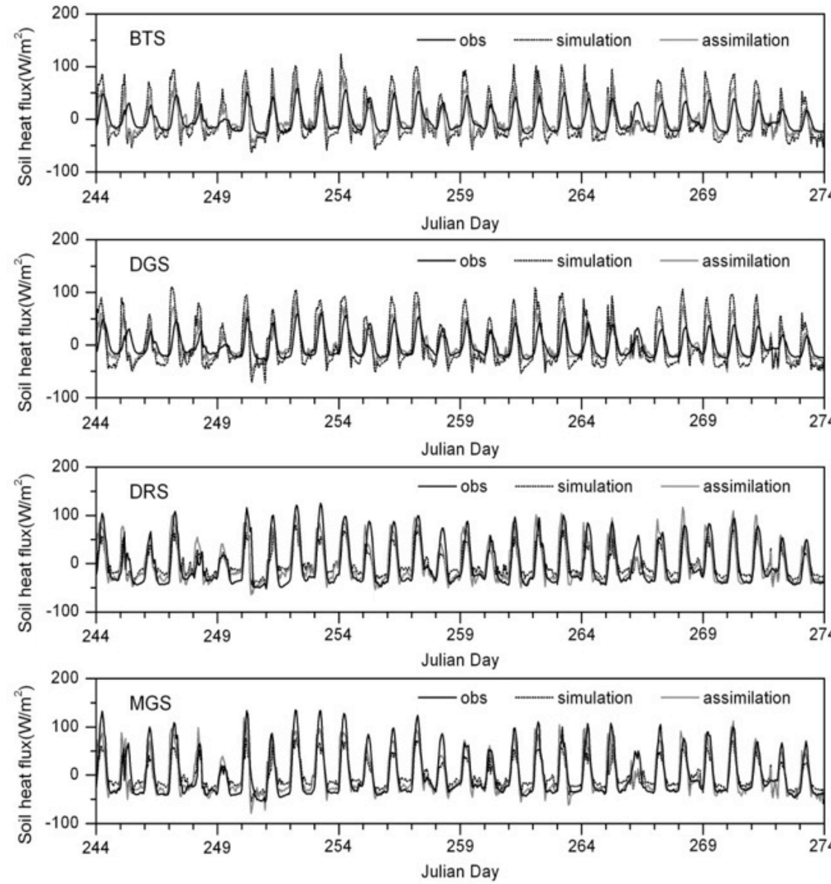
	Surface(5cm)			Root-zone(20cm)			Deep(80cm)		
	24h	72h	240h	24h	72h	240h	24h	72h	240h
EnKF	0.059	0.070	0.093	0.042	0.051	0.072	0.019	0.025	0.046
DEnKF	0.044	0.047	0.054	0.037	0.036	0.042	0.064	0.043	0.015
EnKF-EnKS	0.039	0.041	0.045	0.028	0.031	0.037	0.054	0.062	0.067
DEnKS	0.035	0.038	0.040	0.025	0.028	0.032	0.052	0.057	0.060

Chu et al., 2015, SCIENCE CHINA Earth Sciences; Chen et al., 2015, Advances in Water Resources

Assimilating the MODIS LST Products



Assimilating the MODIS LST products at CEOP Mongolian reference (Sep 1-30,), the estimation of land surface temperature can increase 2K averagely



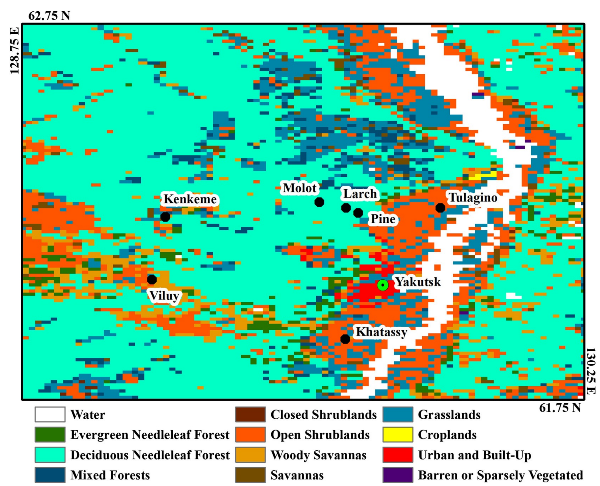
Ground flux (simulated and assimilated)

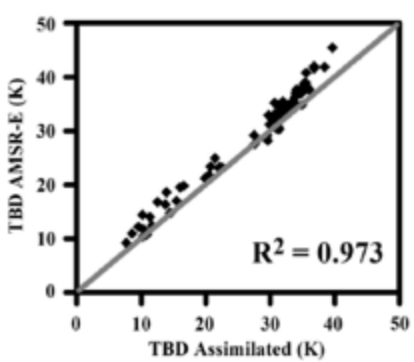
	BTS	DGS	DRS	MGS
simulation	32.421	33.293	27.625	25.824
assimilation	19.649	19.671	25.436	23.578

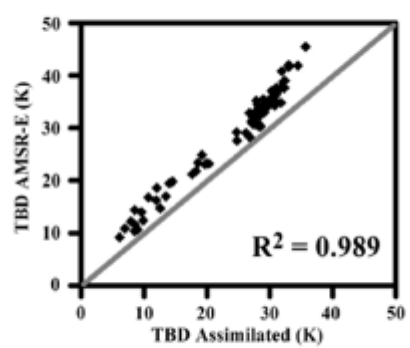
Huang CL, Li X, Lu L, 2008b, Retrieving soil temperature profile by assimilating MODIS LST products with ensemble Kalman filter. Remote Sensing of Environment.

One-dimensional experiment of assimilating AMSR-E data for snow state estimation

- Data: CEOP Siberia reference; Land model: CoLM; Radiative transfer model of snow: MEMLS







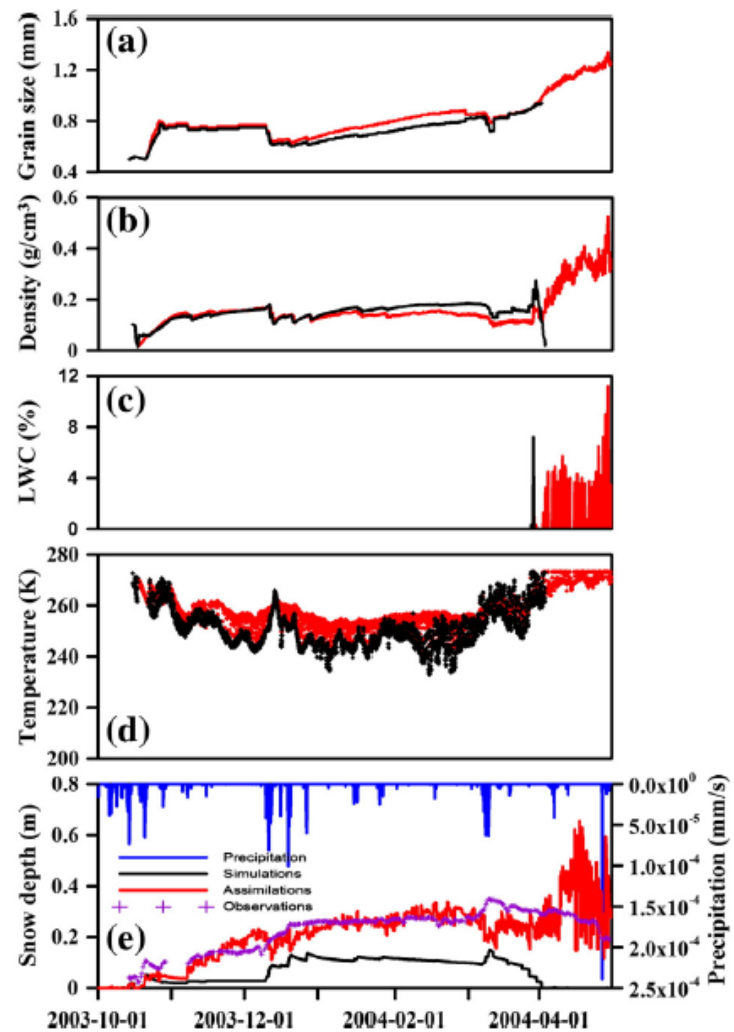
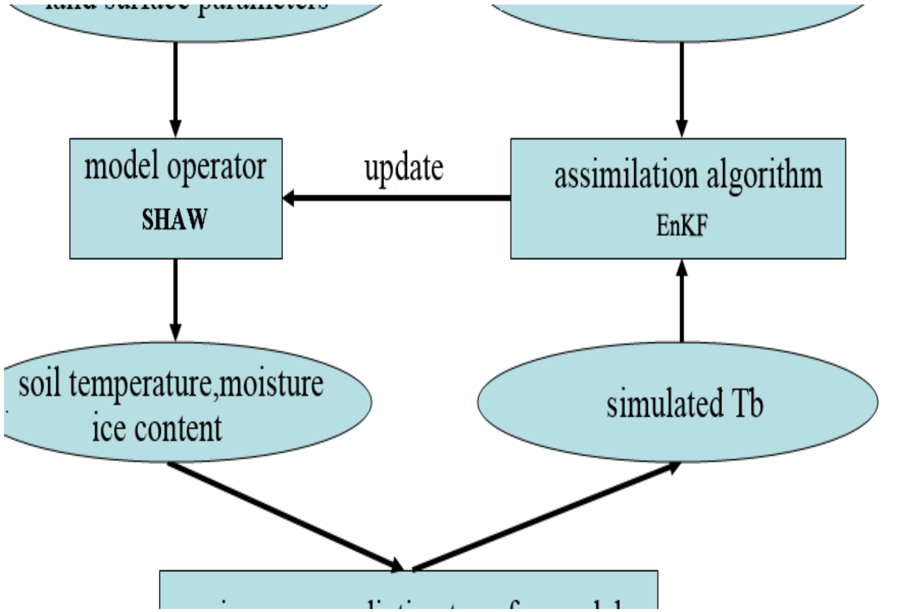


Fig. 4. Snow variables from simulations and assimilations at Larch station. (a) Snow grain size, (b) snow density, (c) liquid water content, (d) snow temperature, and (e) snow depth as well as the precipitation.

Che et al., 2014, RSE

Assimilating SSM/I brightness temperature for active layer soil temperature estimation

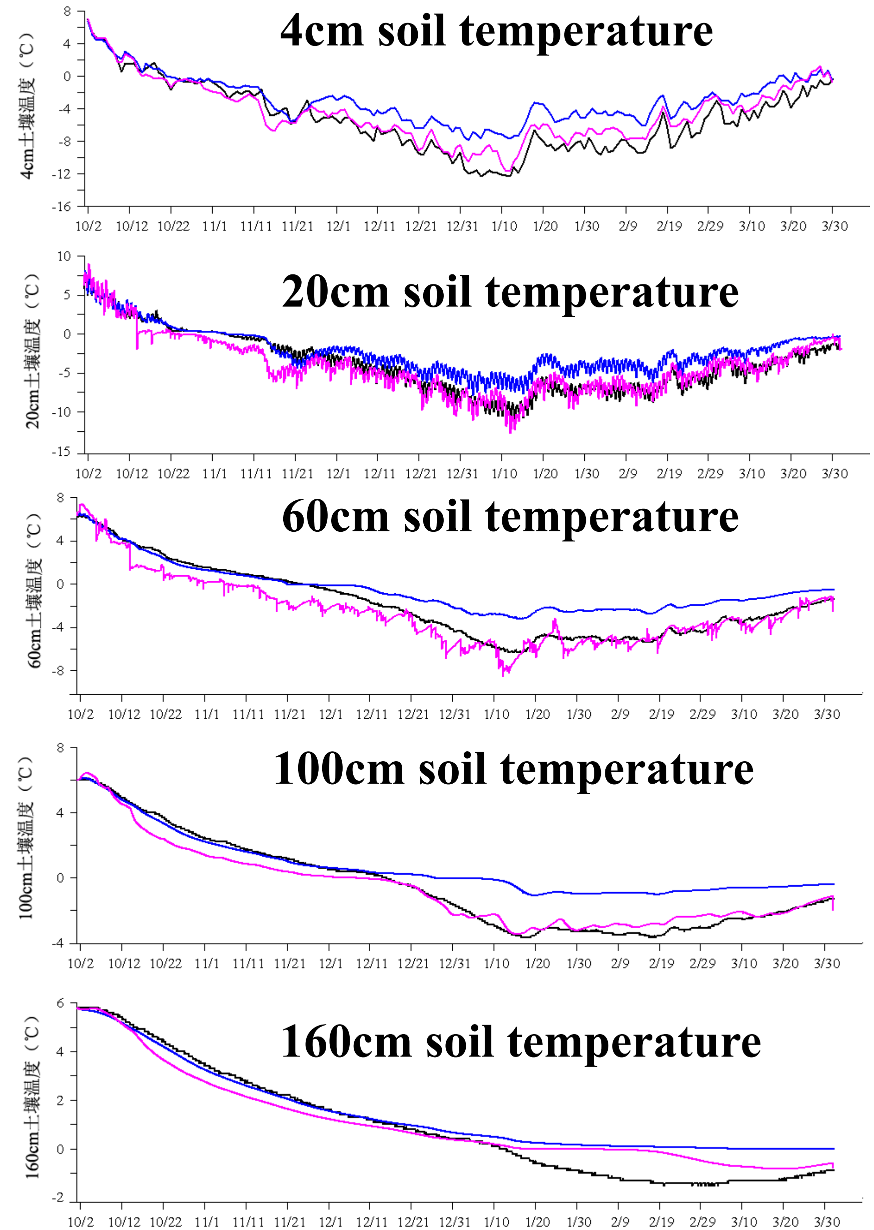


A frozen soil model is used as dynamic model

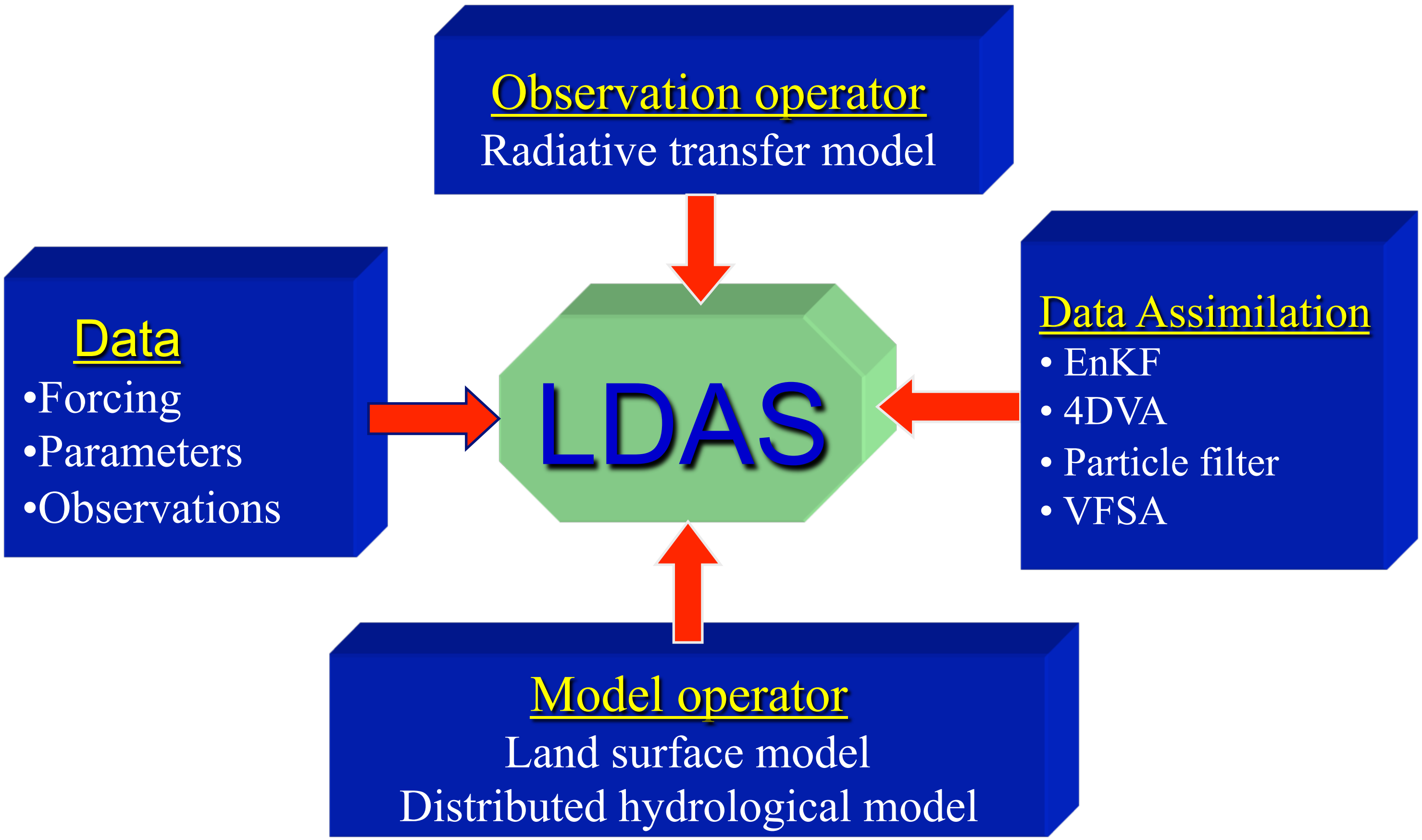
$$T_{eff}(t) = T_g(0,t) + \frac{1}{\kappa_e \sec\theta_t} \cdot \left(\frac{\partial T_t(z,t)}{\partial z} \right)_{z=0}$$

Radiative transfer of microwave signal by considering frozen soil scattering darkening

Jin & Li, 2009, Science China Earth Sciences



3. Chinese Land Data Assimilation System



Li et al., 2007, Progress in Natural Science; Huang & Li, 2008a, Remote Sensing of Environment
Huang et al., 2012, IEEE Transactions on Geoscience and Remote Sensing

Framework of Chinese Land Data Assimilation System (CLDAS)

Input

RS Data
- MODIS LST
- MODIS LAI
- MODIS SCA
- AMSR-E TB

Model Parameters
- BNU Soil Texture
- CAREERI Land cover Map

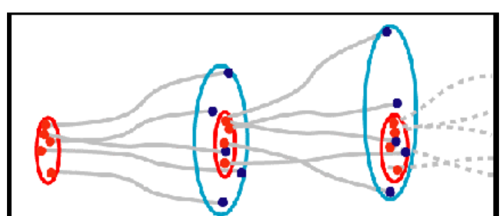
Forcing
- GLDAS Forcing
- ITPCAS Forcing

Models

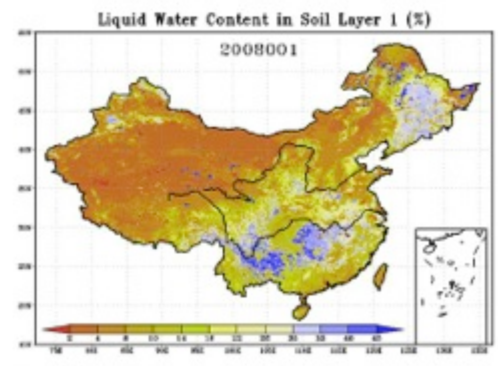
PM-RTM
- Soil (thaw/freeze)
- Snow
- Water

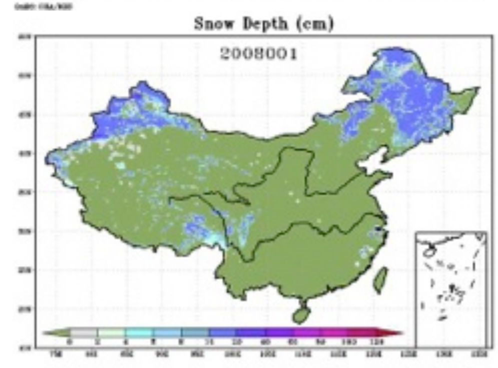
LSM
- CoLM

DA Algorithm
- EnKF

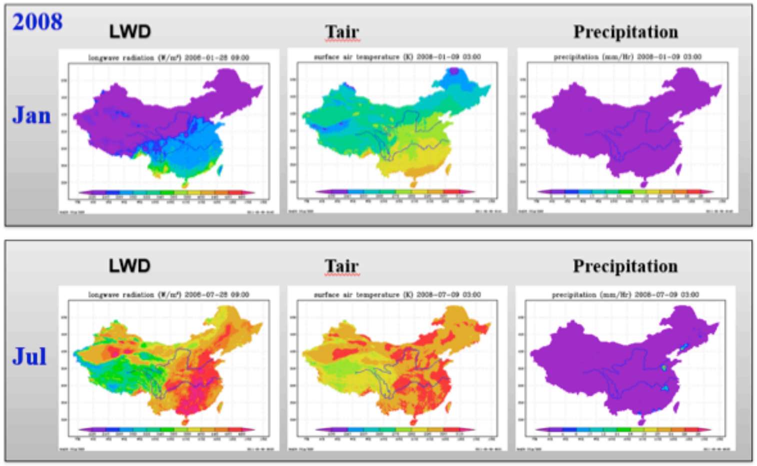


Output
- Soil Moisture
- Soil Temperature
- Surface fluxes
- Snow

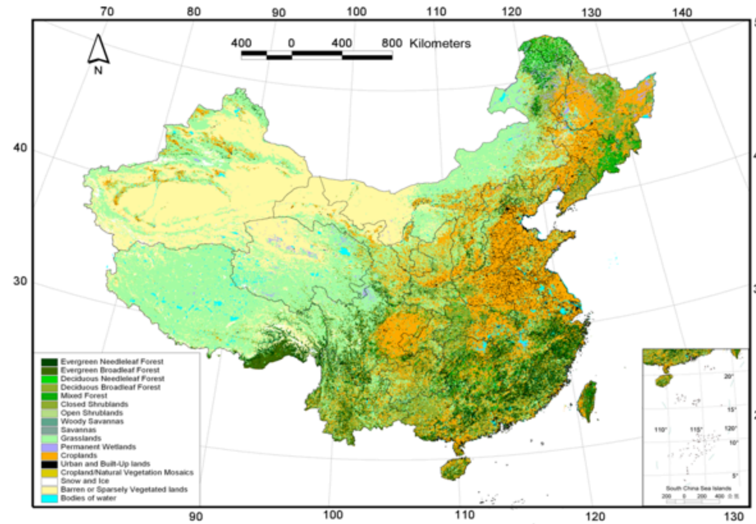




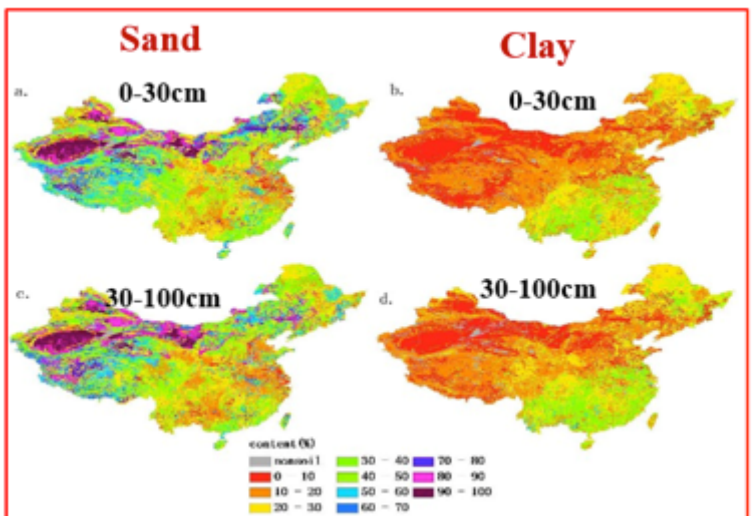
Data sets used in the Chinese Data Assimilation System



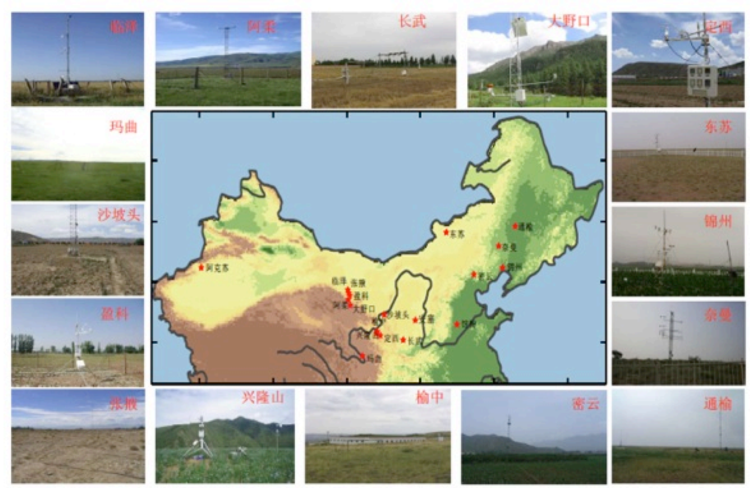
ITPCAS forcing data (0.1degree, 3hour), Chen et al., 2011, JGR



Land cover and vegetation data
Ran et al., 2012, IJGIS

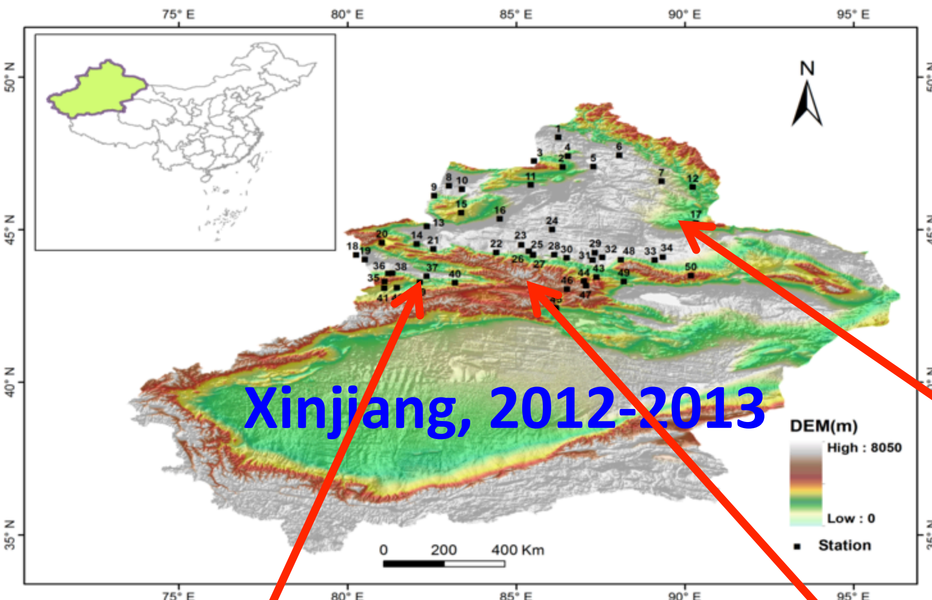


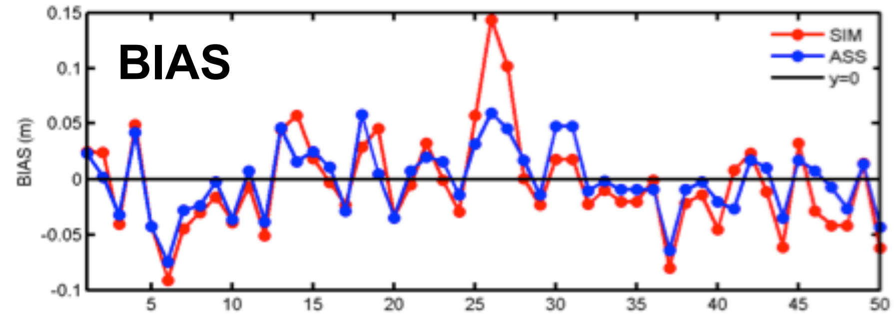
Soil texture data, Shangguan et al., 2012, Geoderma;
Dai et al., 2013, JHM

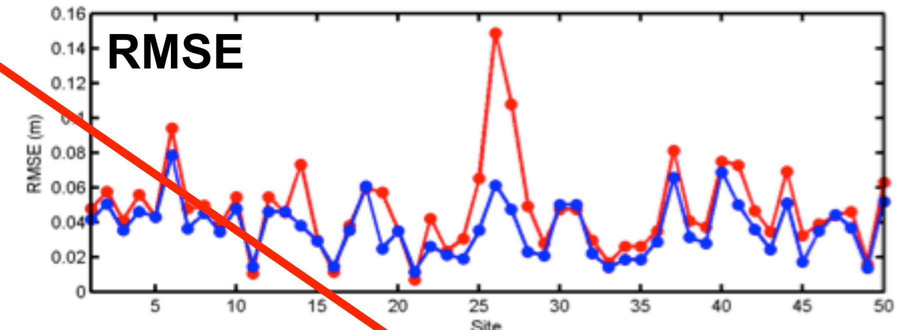


Validation data, different sources

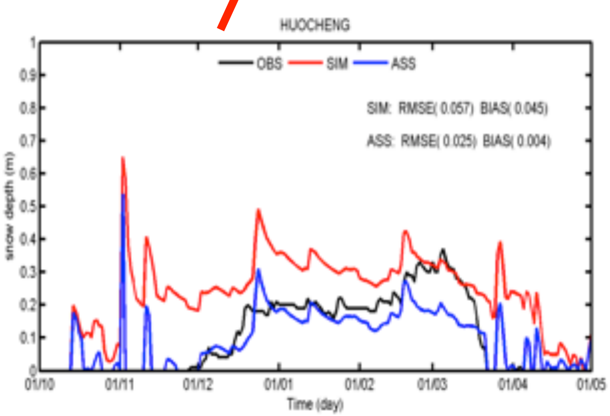
Assimilating MODIS Snow Cover Products into Land Surface Model: A Case Study in Northern Xinjiang, China

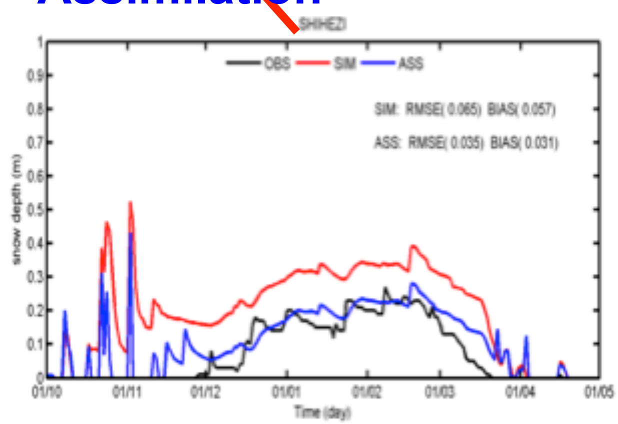


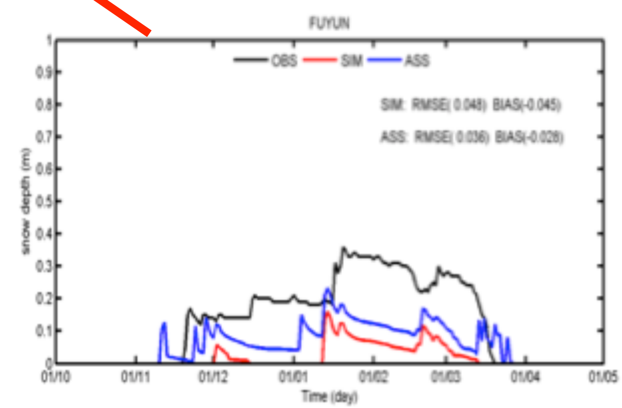




Observation Simulation Assimilation







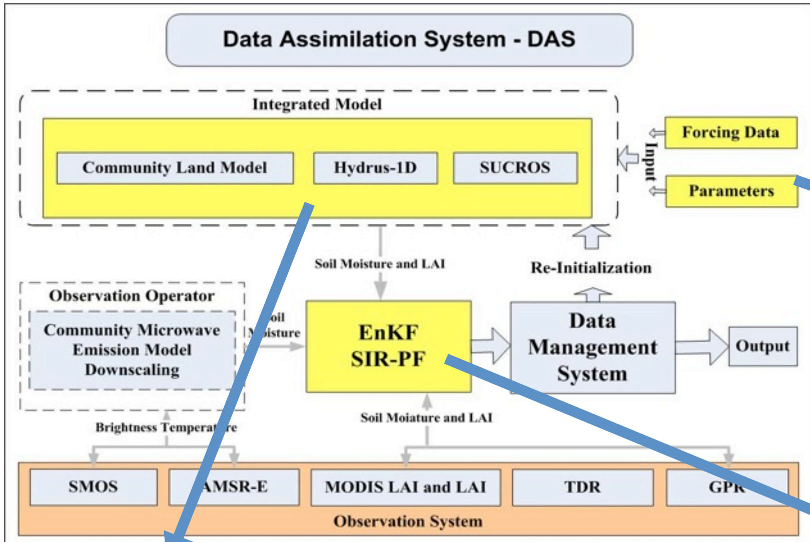
Snow Depth Evolution

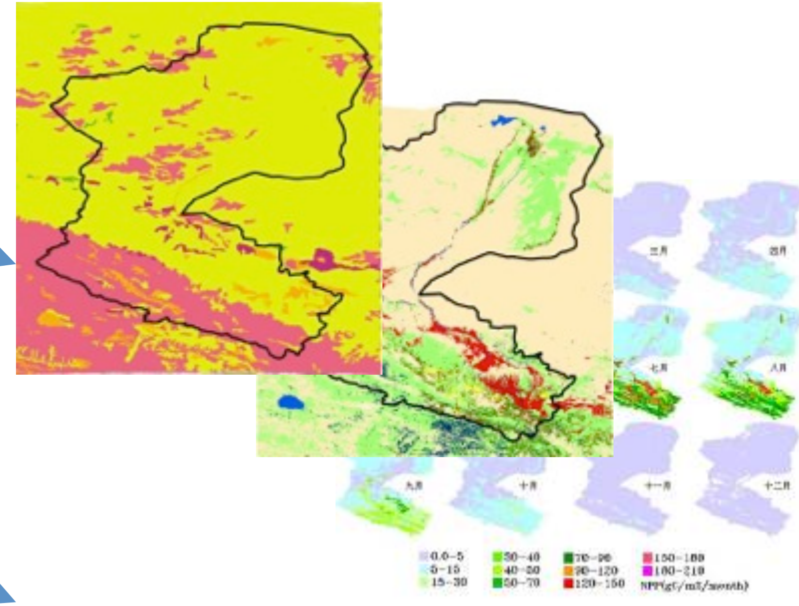
Summary on CLDAS

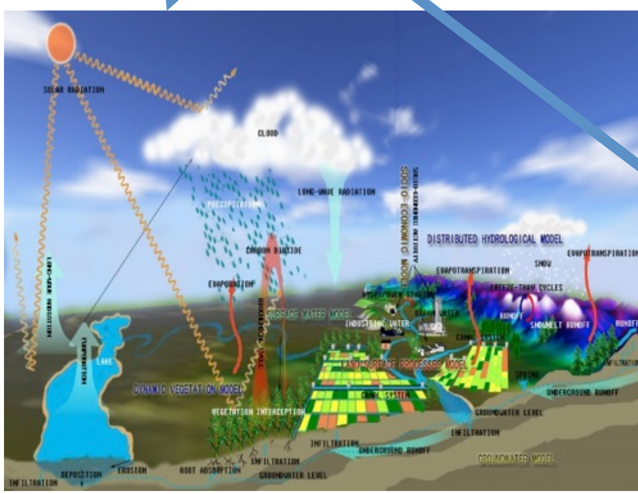
- A multivariate, multi-source, and multi-purpose LDAS of China has been developed by a joint effort of different institutions.
- Various kinds of remote sensing data and data products can be operationally assimilated.
- DA results have been preliminarily validated.
- Results have not been published, data have not been published as well, systematic validation is still required.

4. Catchment Scale Eco-Hydrological Data Assimilation

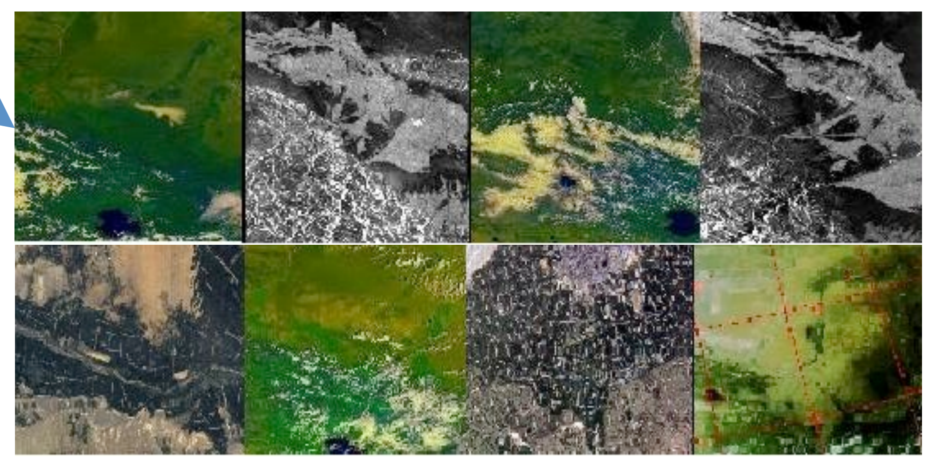
A catchment scale eco-hydrological data assimilation system







$$p(\mathbf{x}_k \mid \mathbf{y}_k) = \frac{p(\mathbf{y}_k \mid \mathbf{x}_k)\, p(\mathbf{x}_k \mid \mathbf{y}_{k-1})}{p(\mathbf{y}_k \mid \mathbf{y}_{k-1})}$$



Han et al., 2012, Hydrology and Earth System Sciences
Han et al., 2013, Vadose Zone Journal
Han et al., 2014, Water Resources Research
Han et al., 2015, PloS One; Han et al., 2015, HESS
Han et al., 2015, Geoscientific Model Development

HiWATER: An eco-hydrological experiment designed from an interdisciplinary perspective addresses problems including **heterogeneity, scaling, uncertainty**, and closing water cycle at the watershed scale.

HEIHE WATERSHED ALLIED TELEMETRY EXPERIMENTAL RESEARCH (HiWATER)

Scientific Objectives and Experimental Design

BY XIN LI, GUODONG CHENG, SHAOMIN LIU, QING XIAO, MINGGUO MA, RUI JIN, TAO CHE, QINHUO LIU, WEIZHEN WANG, YUAN QI, JIANGUANG WEN, HONGYI LI, GAOFENG ZHU, JIANWEN GUO, YOUHUA RAN, SHUOGUO WANG, ZHONGLI ZHU, JIAN ZHOU, XIAOLI HU, AND ZIWEI XU

An eco-hydrological experiment designed from an interdisciplinary perspective addresses problems including heterogeneity, scaling, uncertainty, and closing water cycle at the watershed scale.

A major research plan entitled "Integrated research on the eco-hydrological process of the Heihe River Basin" (hereafter referred to as the Heihe Plan) was launched by the National Natural Science Foundation of China (NSFC) in 2010. The scientific objectives of the Heihe Plan is to reveal the processes and mechanisms of the eco-hydrological system in an inland river basin at different scales (e.g., leaf, individual plant, community, landscape, and watershed scales); to improve the research capabilities and predictability of the evolution of hydrological, ecological, and economic systems; to determine the responses of eco-hydrological processes to climate change and human activities; and to provide fundamental theory and technical support for water security, ecological security, and sustainable development in inland river basins. Eventually, the implementation of the Heihe Plan will establish a research platform that integrates the observation, data management, and model simulation of both physical and socioeconomic processes to foster twenty-first-century watershed science in China.

The Heihe River basin (HRB) in the arid region of northwest China has been selected as an experimental watershed to carry out this research plan. This area was selected because, first, the HRB is a typical inland river basin (endorheic basin). Inland river basins occupy approximately 11.4% of world's land

AFFILIATIONS: X. Li, Cheng, Ma, Jin, Che, W. Wang, Qi, H. Li, G. Zhu, Guo, Ran, S. Wang, Zhou, and Hu—Cold and Arid Regions Environmental and Engineering Research Institute, Chinese Academy of Sciences, Lanzhou, China; S. Liu, Z. Zhu, and Xu—State Key Laboratory of Remote Sensing Science, School of Geography and Remote Sensing Science, Beijing Normal University, Beijing, China; Xiao, Q. Liu, and Wen—State Key Laboratory of Remote Sensing Science, Institute of Remote Sensing Applications, Chinese Academy of Sciences, Beijing, China
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The abstract for this article can be found in this issue, following the table of contents.

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In final form 27 November 2012
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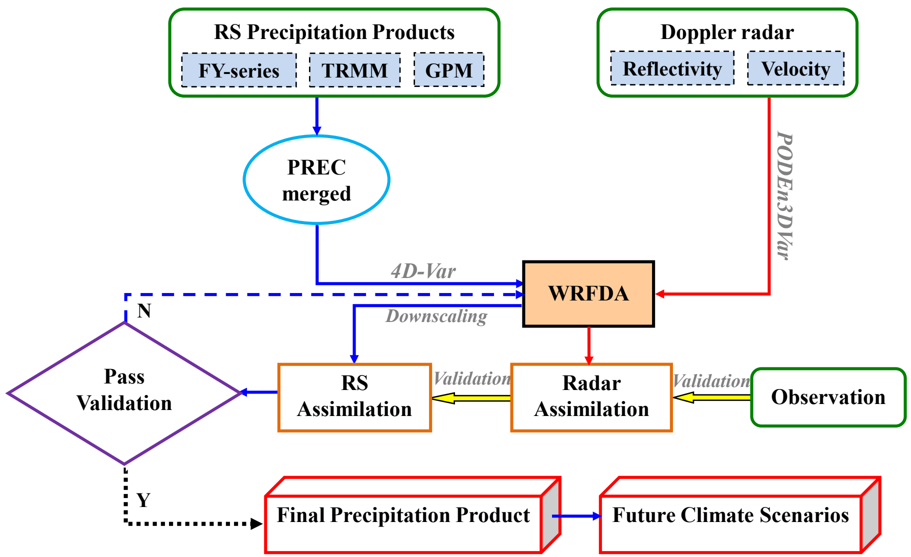
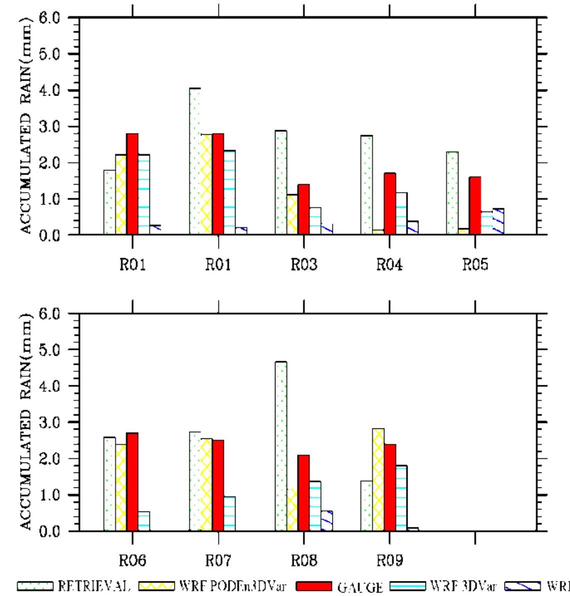
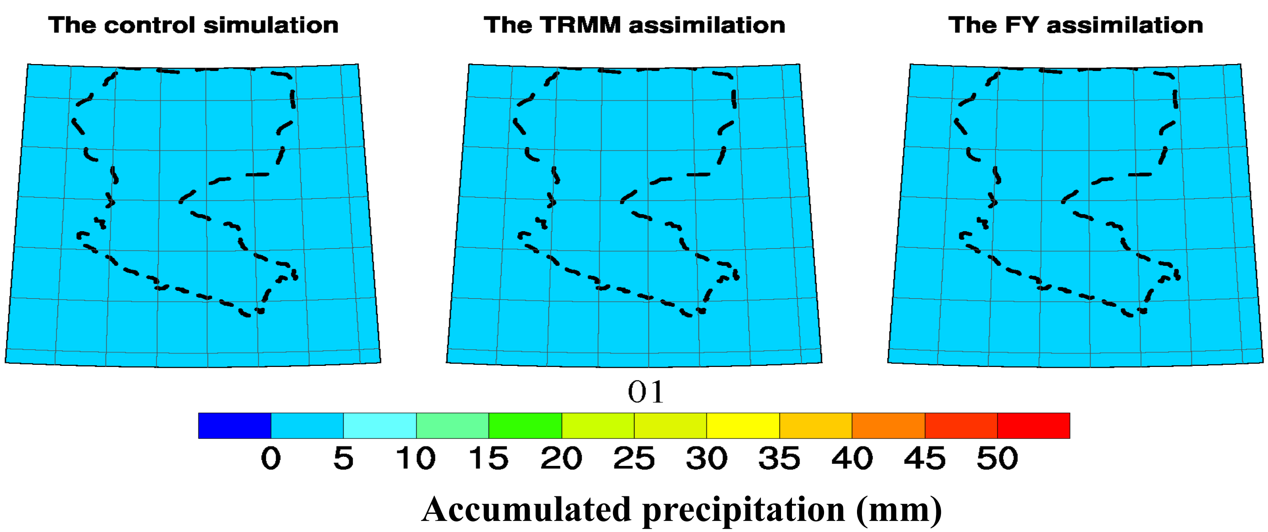
Data information system: http://heihedata.org/hiwater
More information:
http:// hiwater.westgis.ac.cn/

Li et al., *BAMS*, 2013

High-resolution precipitation data by data assimilation at Heihe river basin



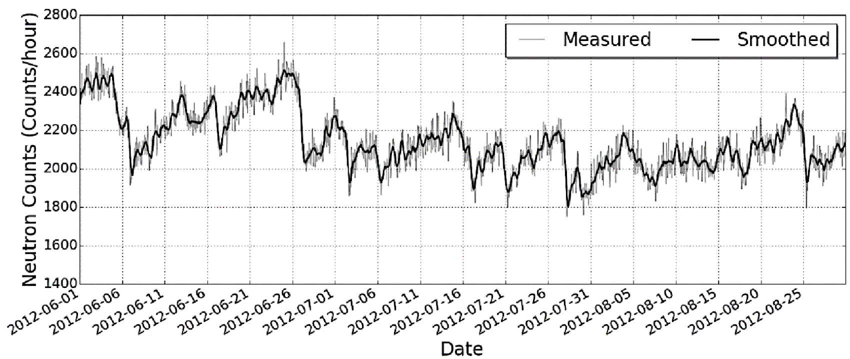




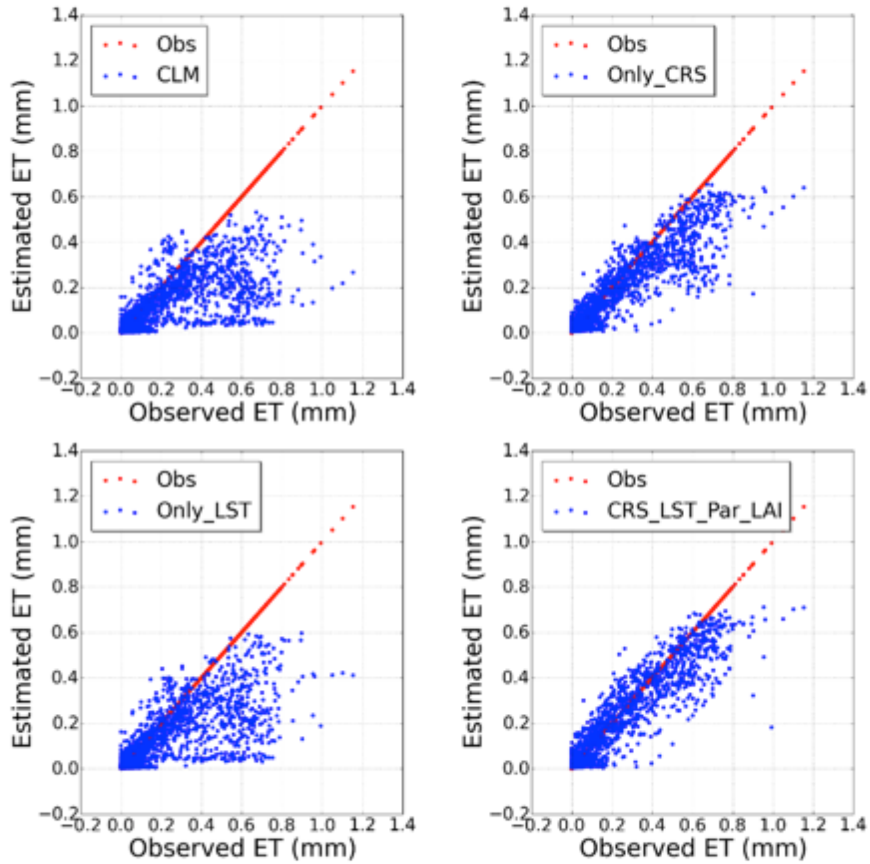
Pan et al., 2012, Journal of Geophysical Research: Atmospheres; Pan et al., 2014, Journal of Hydrometeorology; Pan et al., 2015, Remote Sensing

Joint assimilation of cosmic-ray and land surface temperature at Heihe river basin

- Cosmic Ray measures the 12 cm~76 cm soil moisture in a 300 m radius (non-invasive, intermediate scale)

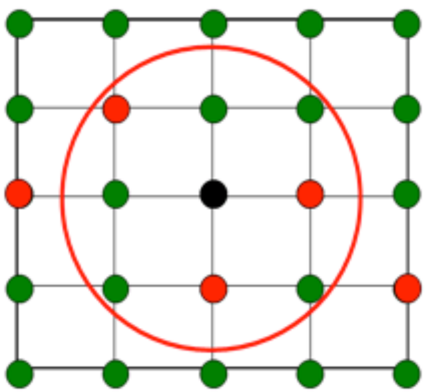


Highlight,: a Cosmic-ray forward model was used as an observation operator



Han et al., 2015, Hydrology and Earth System Sciences

An improved observation localization strategy in data assimilation by incorporating Geostatistics



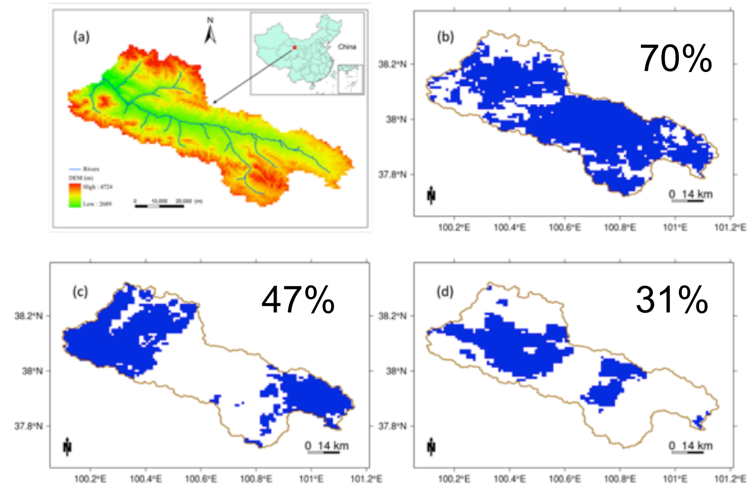
$$\gamma(h) = c_0 + c\left(h/a^*\left(1.5 - 0.5^*(h/a)^2\right)\right) \quad \text{spherical} \quad (1)$$

$$\gamma(h) = c_0 + c(1 - \exp(-3h/a)) \quad \text{exponential} \quad (2)$$

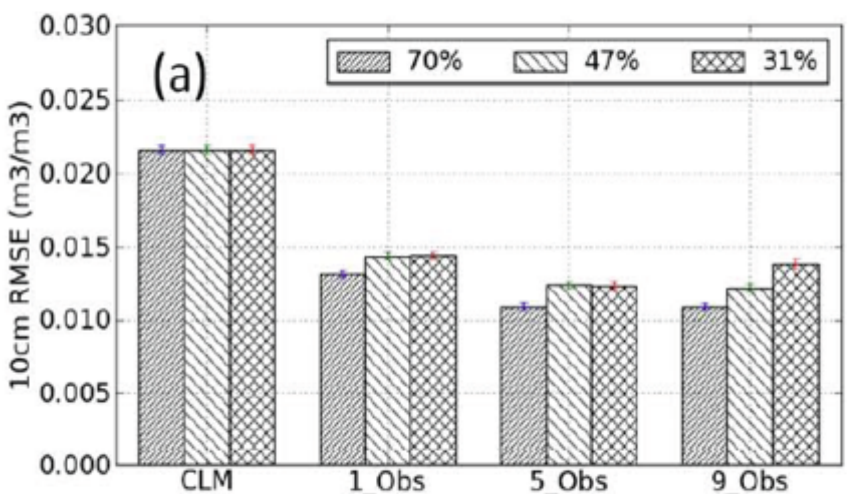
$$\gamma(h) = c_0 + c\left(1 - \exp\left(-\left(3h^2/a^2\right)\right)\right) \quad \text{Gaussian} \quad (3)$$

$$\gamma(h) = c_0 + c\left(\frac{1}{2^{\upsilon-1}\Gamma(\upsilon)}\left(\frac{2\upsilon^{1/2}h}{a}\right)^{\upsilon} K_{\upsilon}\left(\frac{2\upsilon^{1/2}h}{a}\right)\right) \quad \text{Matern} \quad (4)$$

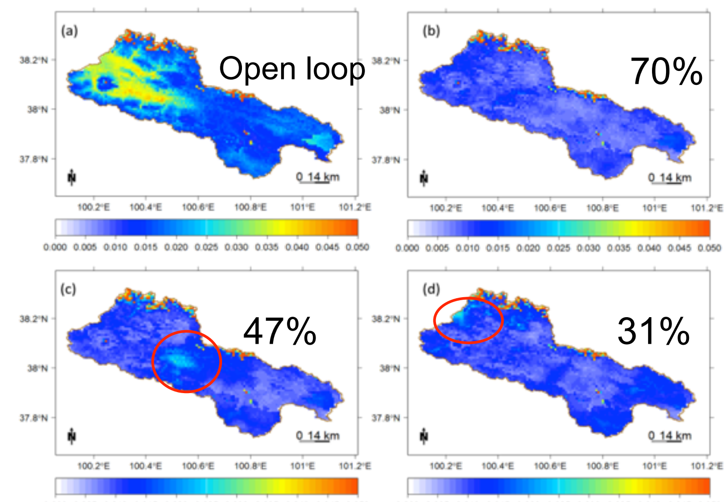
LETKF & localization



Observational coverages



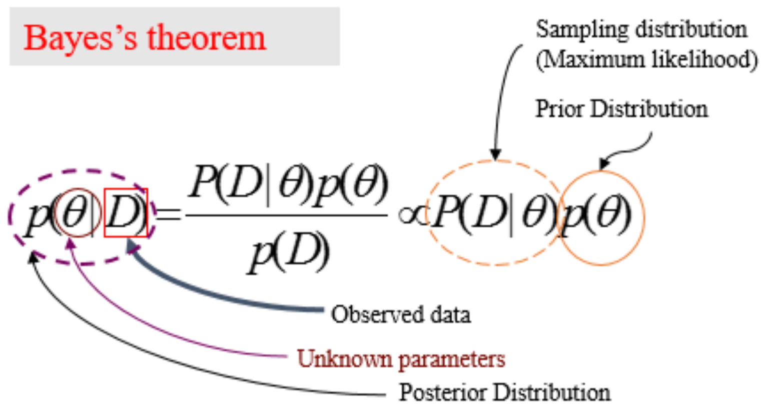
Mean basin scale soil moisture RMSE values

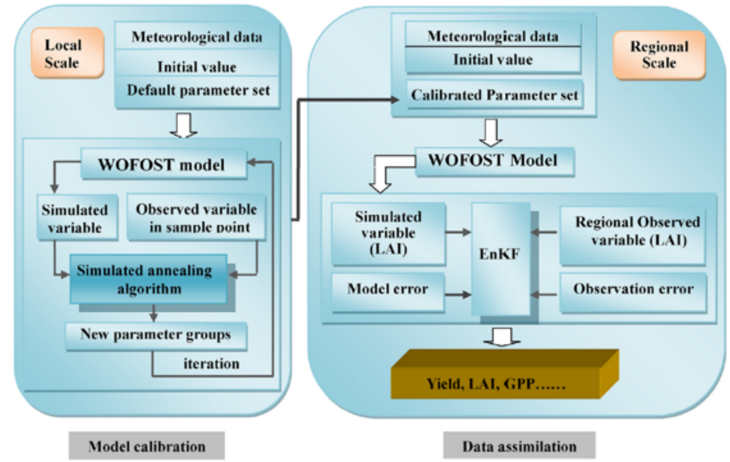


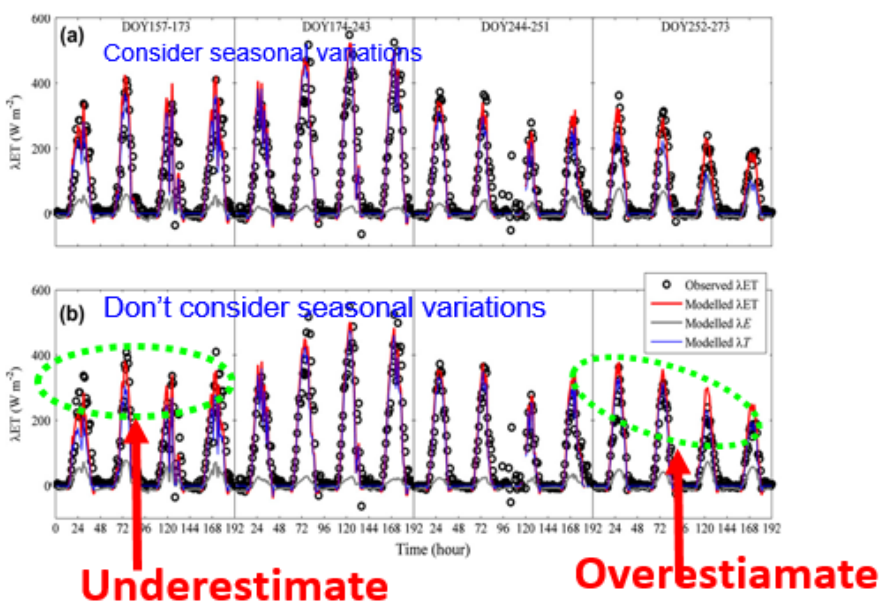
10 cm depth soil moisture RMSE

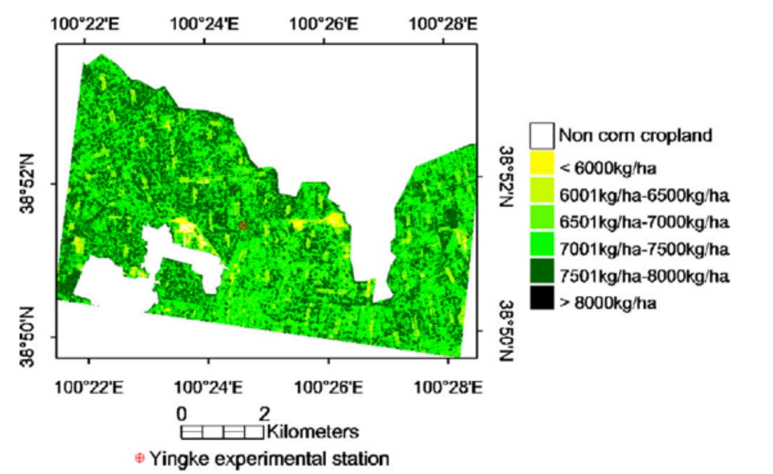
Han et al., 2012, Hydrology and Earth System Sciences; Han et al., 2015, PLoS One

Ecological data assimilation system at catchment-scale









Crop yield estimation by assimilating LAI into crop growth model

Zhu et al., 2010, HESS; Zhu et al., 2011, Tree Physiology; Zhu et al., 2014, Geoscientific Model Development

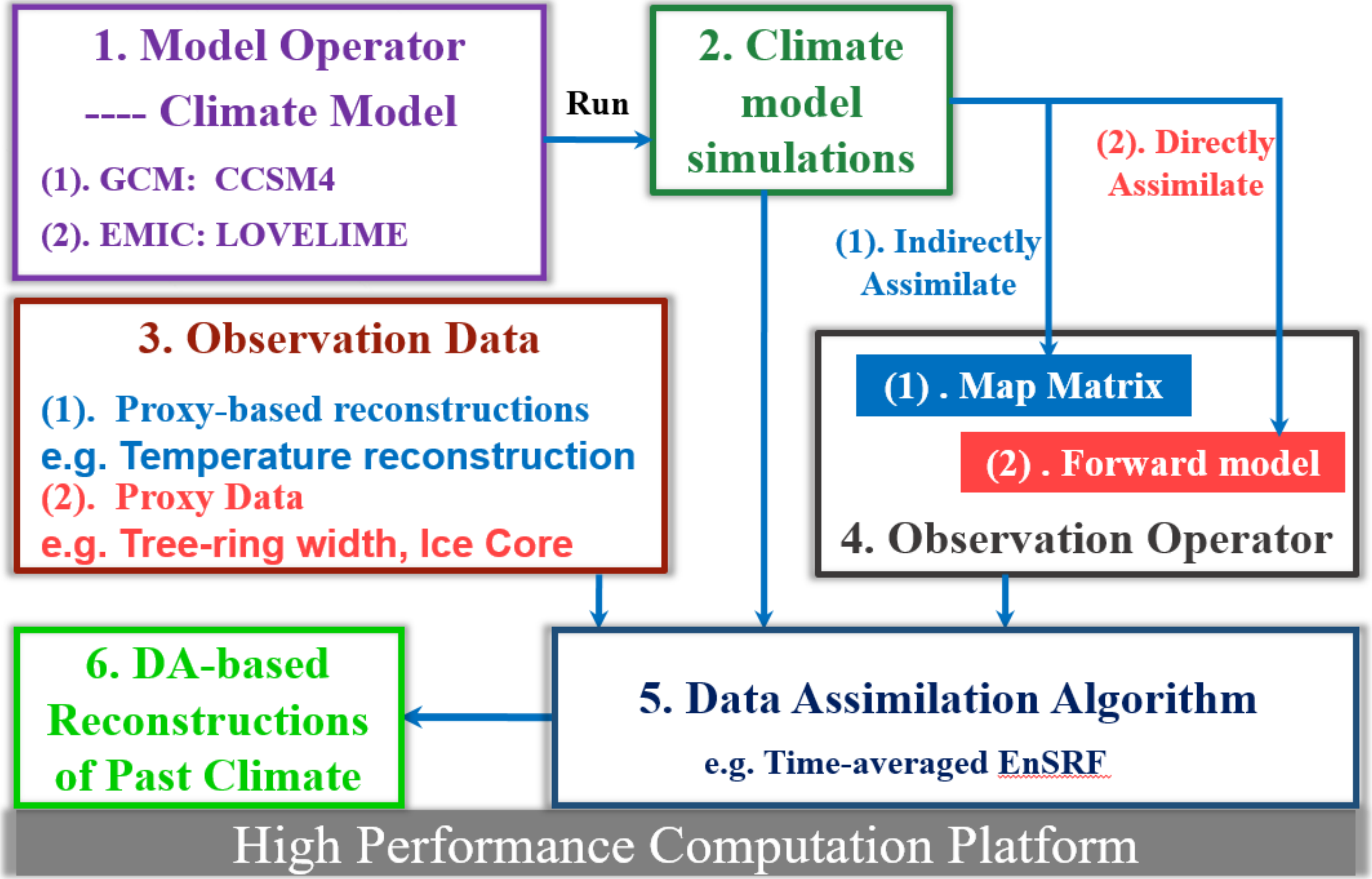
Wang et al., 2013, EMS;
Wang et al., 2013, European Journal of Agronomy

Summary on catchment scale DAS

- A high-resolution, multivariate, and multi-source data assimilation system of the Heihe River Basin has been developed.
- Synthetic and true-data experiments have been conducted.
- Observational data and data products are plentiful but many of them have not been used yet.
- The objective is to improve the predictability and observability of watershed ecohydrology as well as operational usability such as irrigation scheduling and groundwater pumping.

5. Ongoing projects

Paleoclimate data assimilation--scheme description



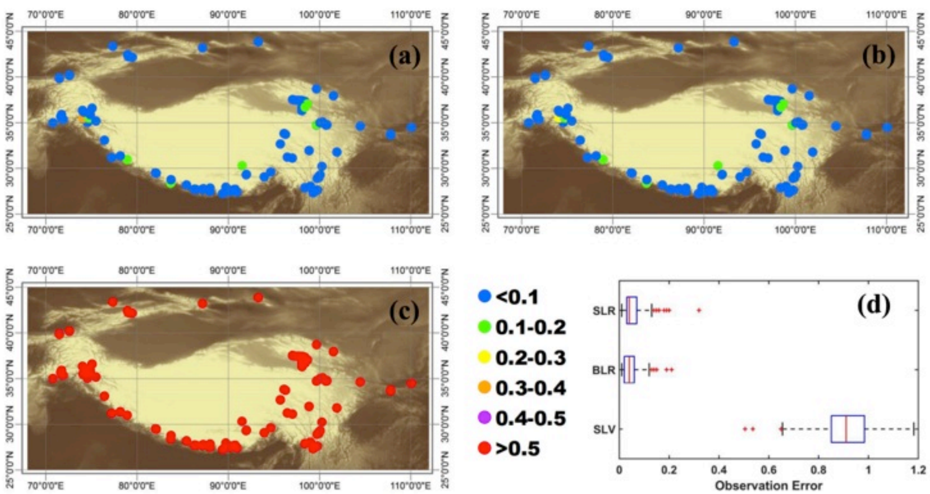
Fang & Li, 2016, SCIENCE CHINA Earth Sciences

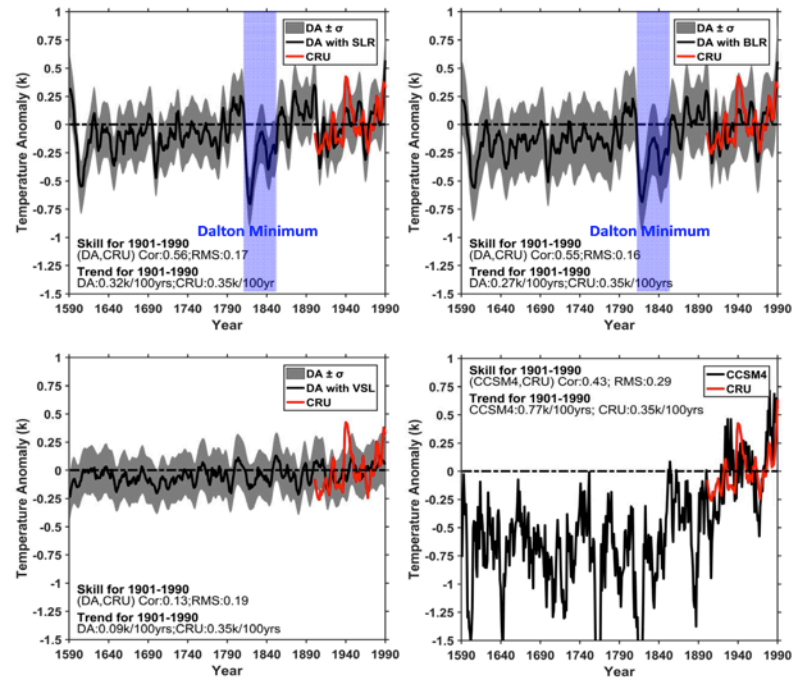
Temperature reanalysis over high-Asia through assimilating tree-ring widths chronologies

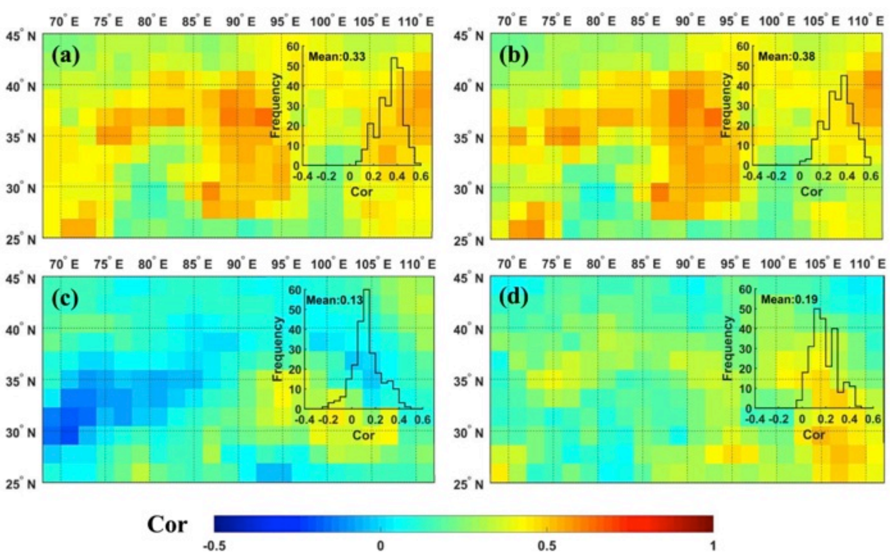
Data assimilation method: Time-averaged EnSRF

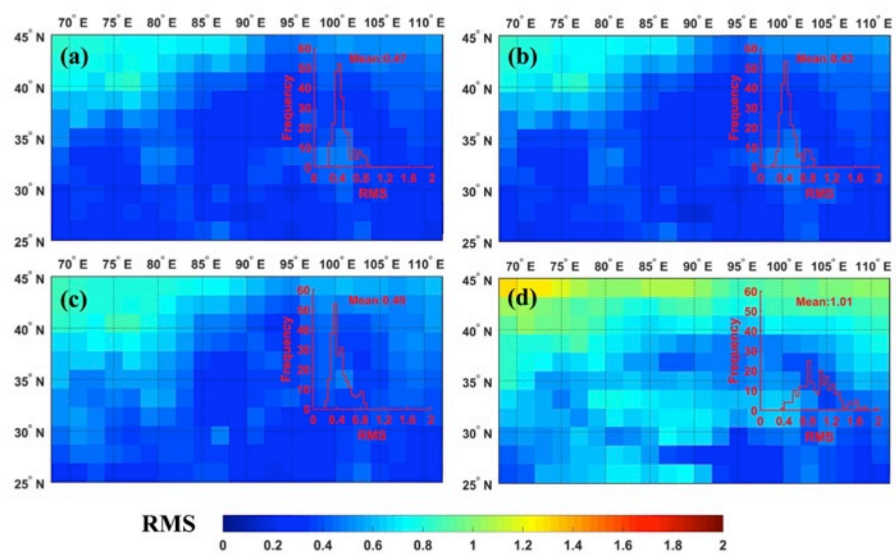
Observation: 61 tree-ring widths chronologies

Observation operator: VS-Lite, SLR, BLR









6. Summary

- Large scale and catchment scale DASs that truly assimilate various kinds of remote sensing observations have been developed.
- Integration
  - Multivariate, multi-source data assimilation
  - Eco-hydrology applications
  - Paleoclimate reconstruction
  - Historical LUCC reconstruction
- Next step efforts
  - System refinement and validation
  - Operational application in ecohydrological forecasting and water resource management

CAS-CEOP and CAHMDA-IV Workshop, Lhasa, China, July 19-21, 2010


陆面数据同化培训与研讨会
第二届中科院陆面数据同化研讨会 2013.4.27, 北京
第 三 届 陆 面 数 据 同 化 培 训 班
第三届中科院陆面数据同化研讨会 2014.10月，北京

The 7th International Workshop on Catchment Hydrological Modeling and Data Assimilation (CAHMDA-VII)

Aug 20-24, 2017, Xi'an, China

Co-sponsored by
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Thank you !


The 2nd Summer School on Land Surface Observing, Modeling and Data Assimilation
July 13-16, 2010
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2010.7.13-16