The **L**and c**o**ntinuous **V**ariable **E**stimator for **P**olar-orbiting MODIS and VIIRS data (LoVE-P)

Shunlin Liang

Department of Geographical Sciences
University of Maryland, USA

CISESS 2019

Nov. 12, 2019

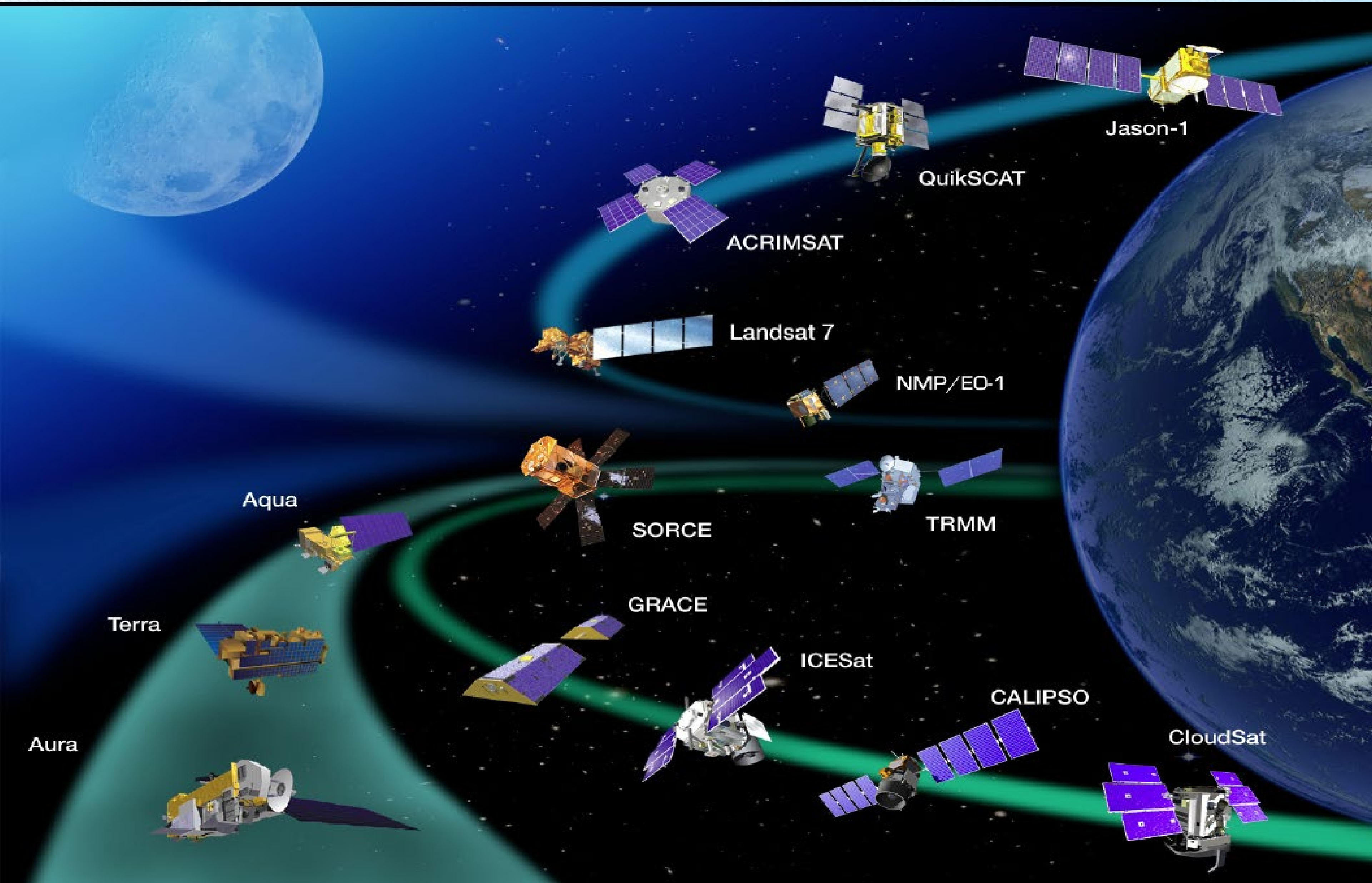
Acknowledgements

Thank many students, colleagues and collaborators for their contributions to this talk

Outline

1. Why do we need a new inversion framework?
2. Overview of the LoVE-P
3. Case studies using MODIS and VIIRS data
4. Concluding remarks

NASA Earth Observing System（EOS）



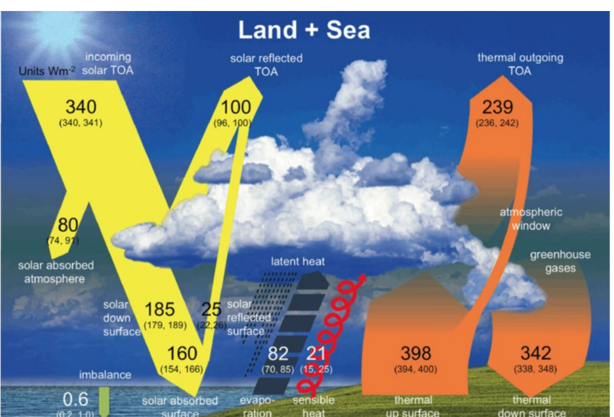
EOS is the first comprehensive mission for monitoring the Earth system

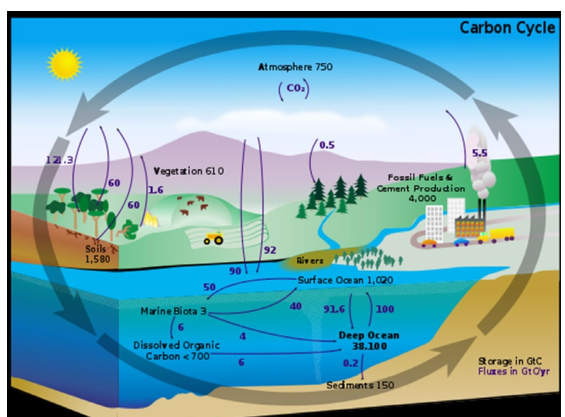
EOS started to convert satellite observations to high-level products

satellite images + high-level products

Earth System Science

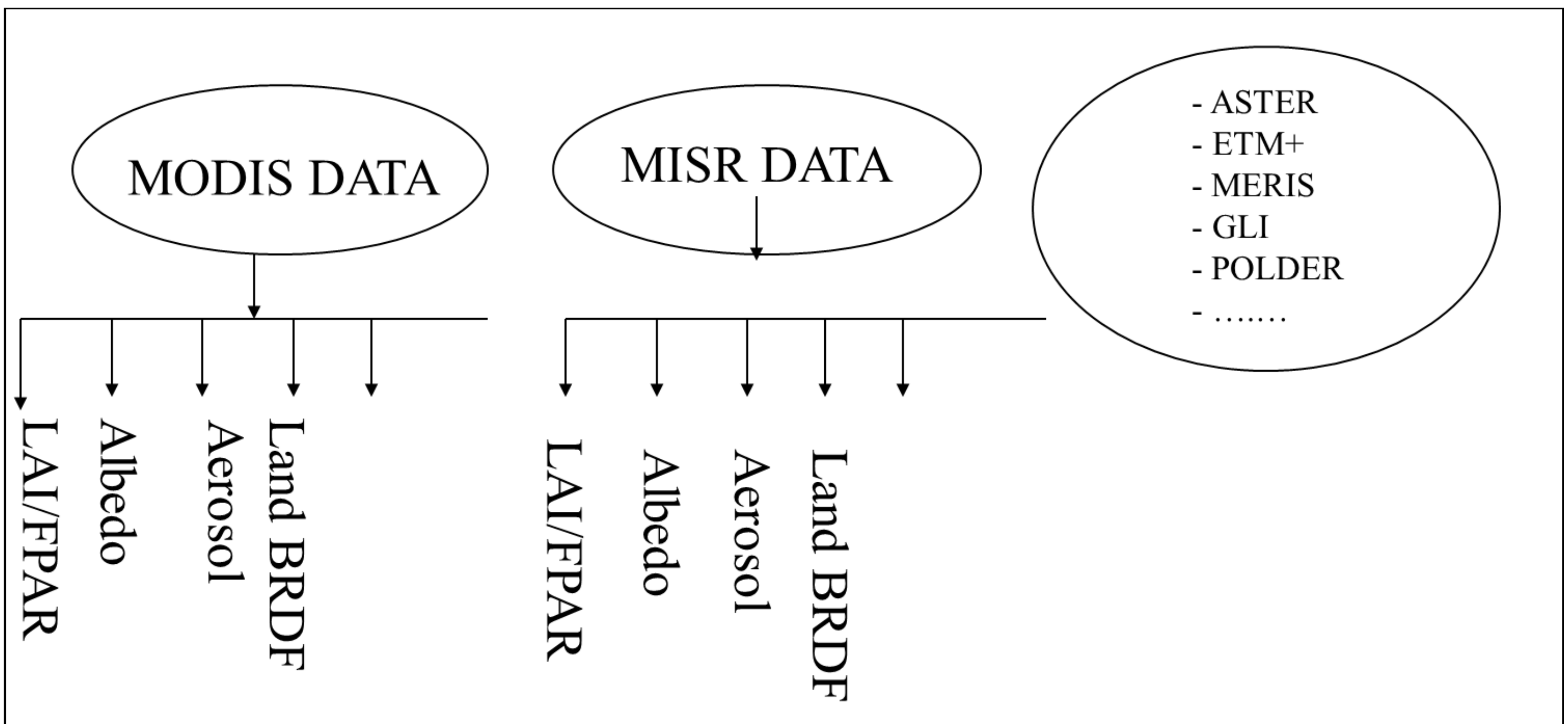
Decision support systems and much wider applications





NASA's approach for generating the EOS high-level products

- Each sensor has a Science Team
- Each PI is responsible for one product algorithm development
- PI passes the science code to the central facility for production



Generic issues of the EOS framework

The EOS framework has been widely accepted by various space agencies. However, there are many issues:

- Same land product generated from different EOS instruments without using the multiple data sources effectively;
- Multiple products from the same sensor by different PIs using different algorithms indepedantly
- Looping requirements and conflicting assumptions;
  - Aerosol retrieval <-> Atmospheric correction <-> surface BRDF
- Only one algorithm for one product;
- Temporal signatures not used effectively;
- Products often spatiotemporally discontinuous and physically inconsistent

Two solutions

One:

Continue to improve the existing framework

Two:

Develop a NEW inversion framework: based on data assimilation

This talk

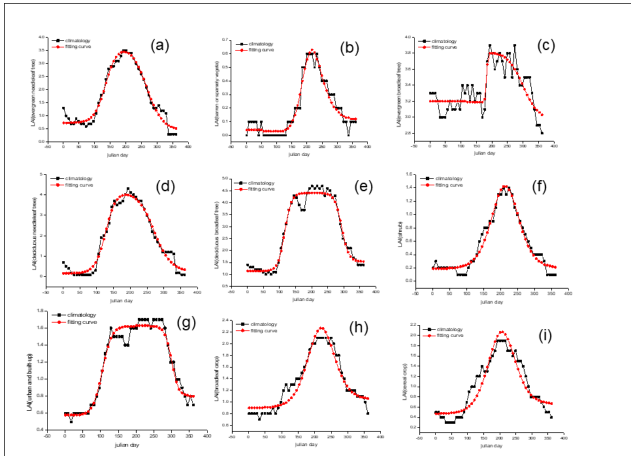
Why is DA a better framework?

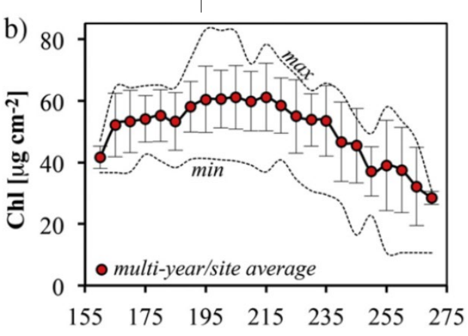
Regularization methods

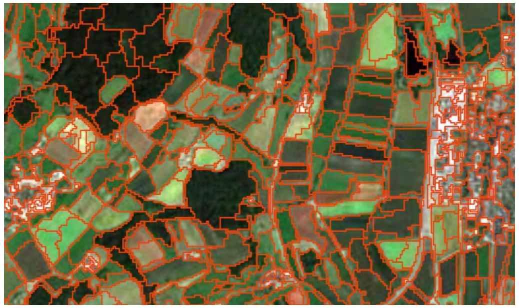
- **Challenges**: ill-posed inversion problem
  - ➢ the number of bands of each pixel always smaller than the number of unknowns
  - ➢ spectral signatures highly correlated

- **Solutions**
  - – A pri... ge
  - ...ts
  - – ...ta

Data Assimilation



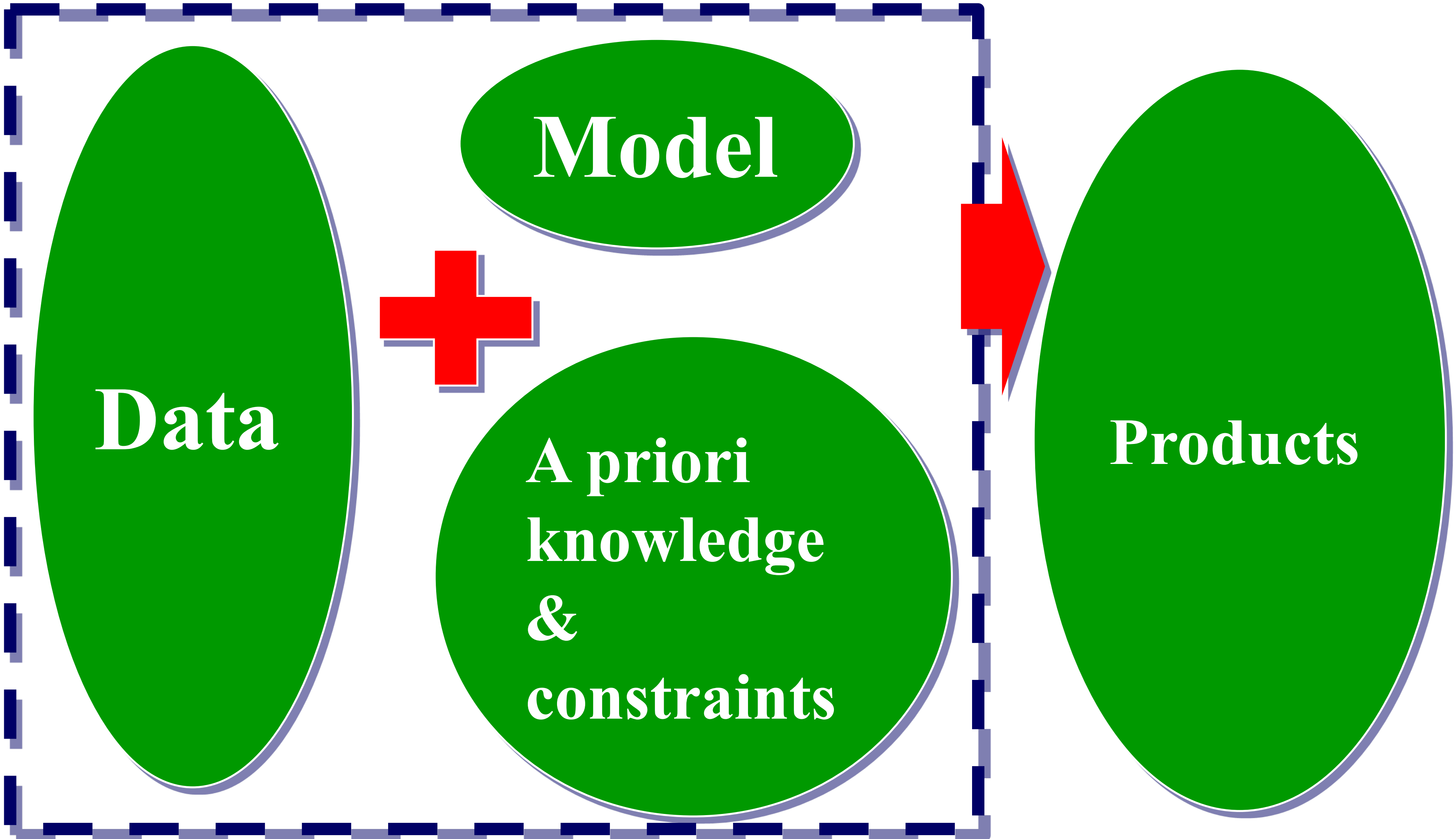




Liang, S., J. Townshend and R. Dickinson, "*Improving Land Surface Products from Multiple EOS Sensors by Developing a Prototype Data Assimilation System*", National Aeronautics and Space Administration (NASA), 4/2004 – 3/2008

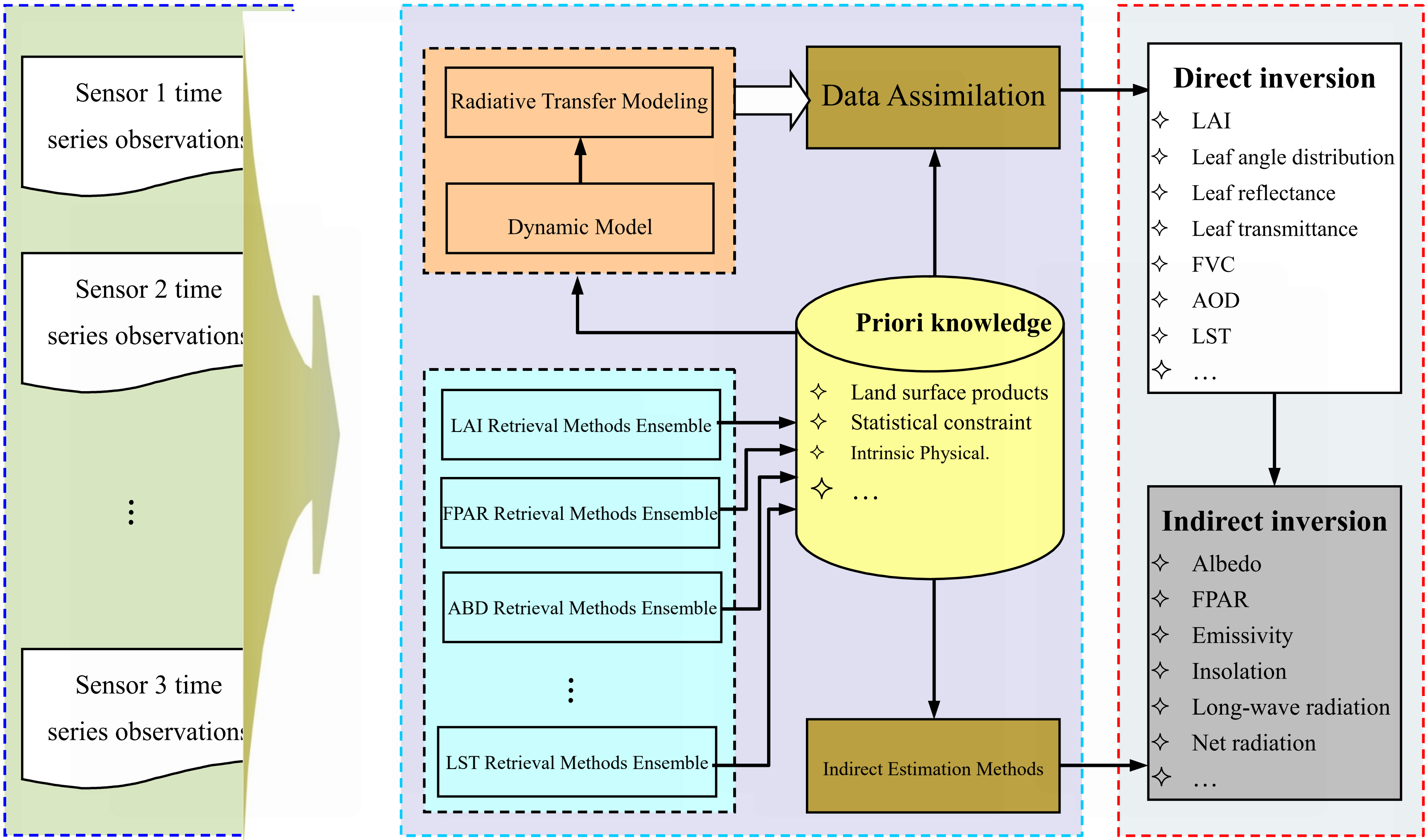
Land continuous Variable Estimator (LoVE)

The new inversion framework is based on data assimilation, characterized by multiple data sources, multiple algorithms, and multiple products

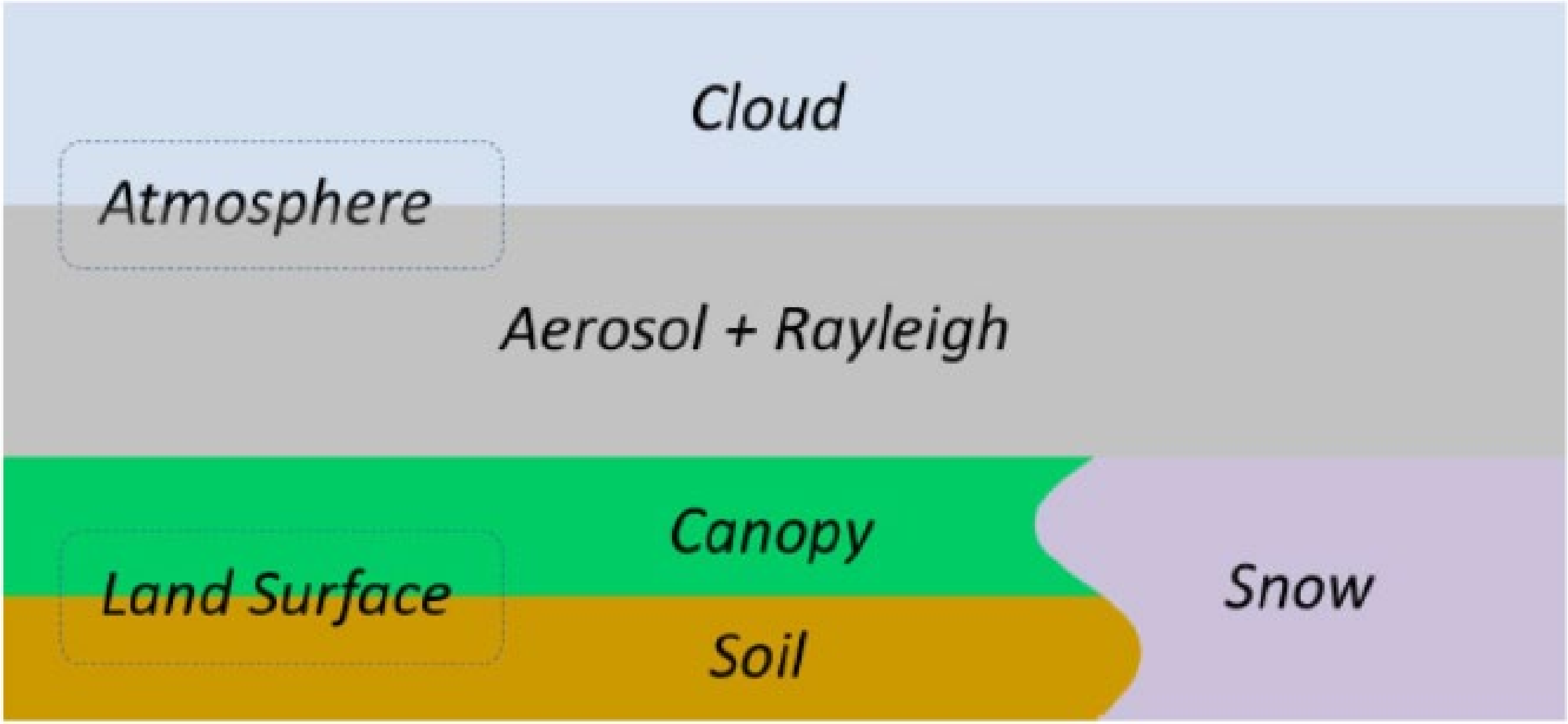


Land continuous Variable Estimator (LoVE)

The new generation of the inversion method is based on data assimilation, characterized by multiple data sources, multiple algorithms, and multiple products

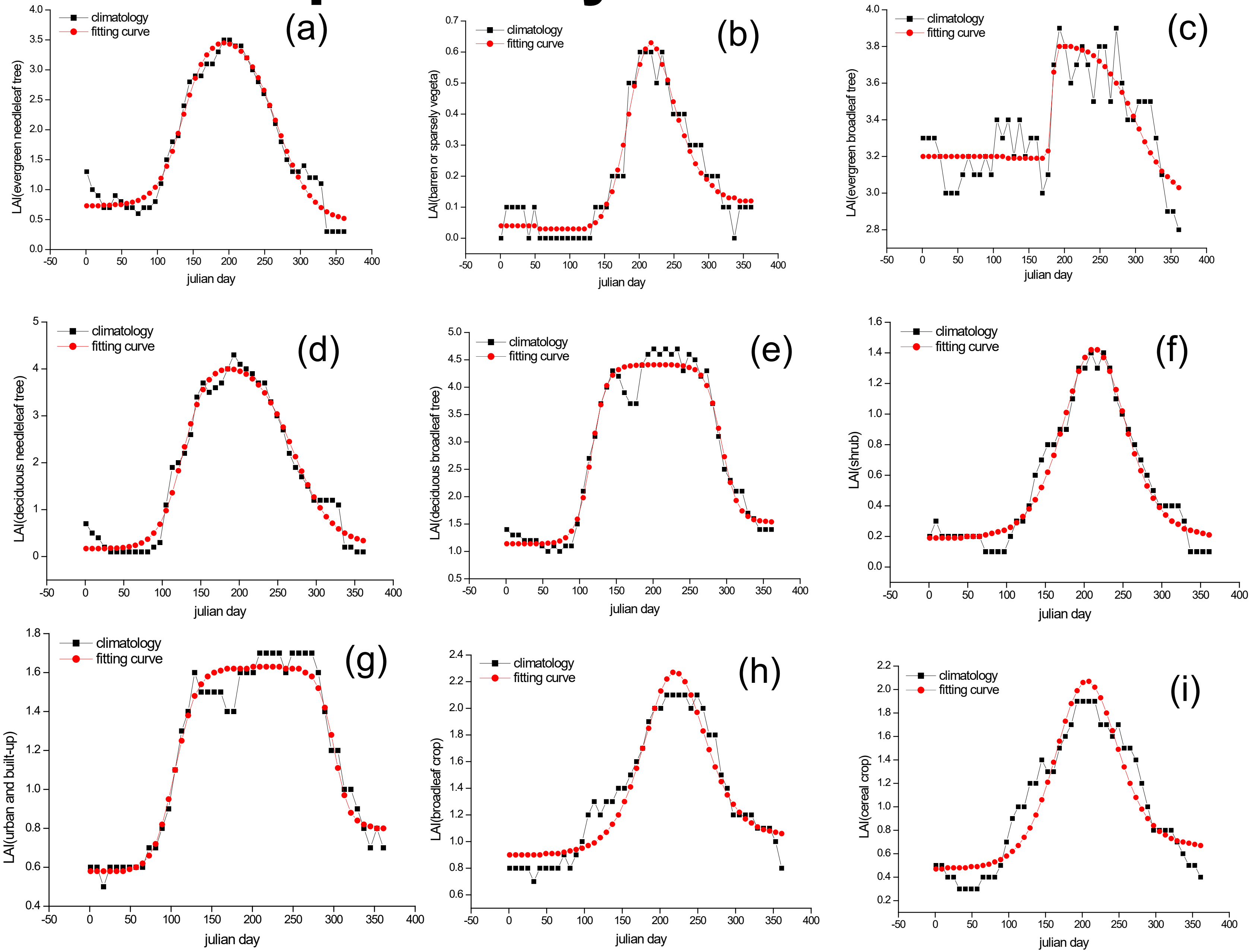


Radiative transfer modeling



Coupled surface–atmosphere system.

Empirical dynamic model



$$X_t = F_t \times X_{t-1} + w_t \tag{1}$$

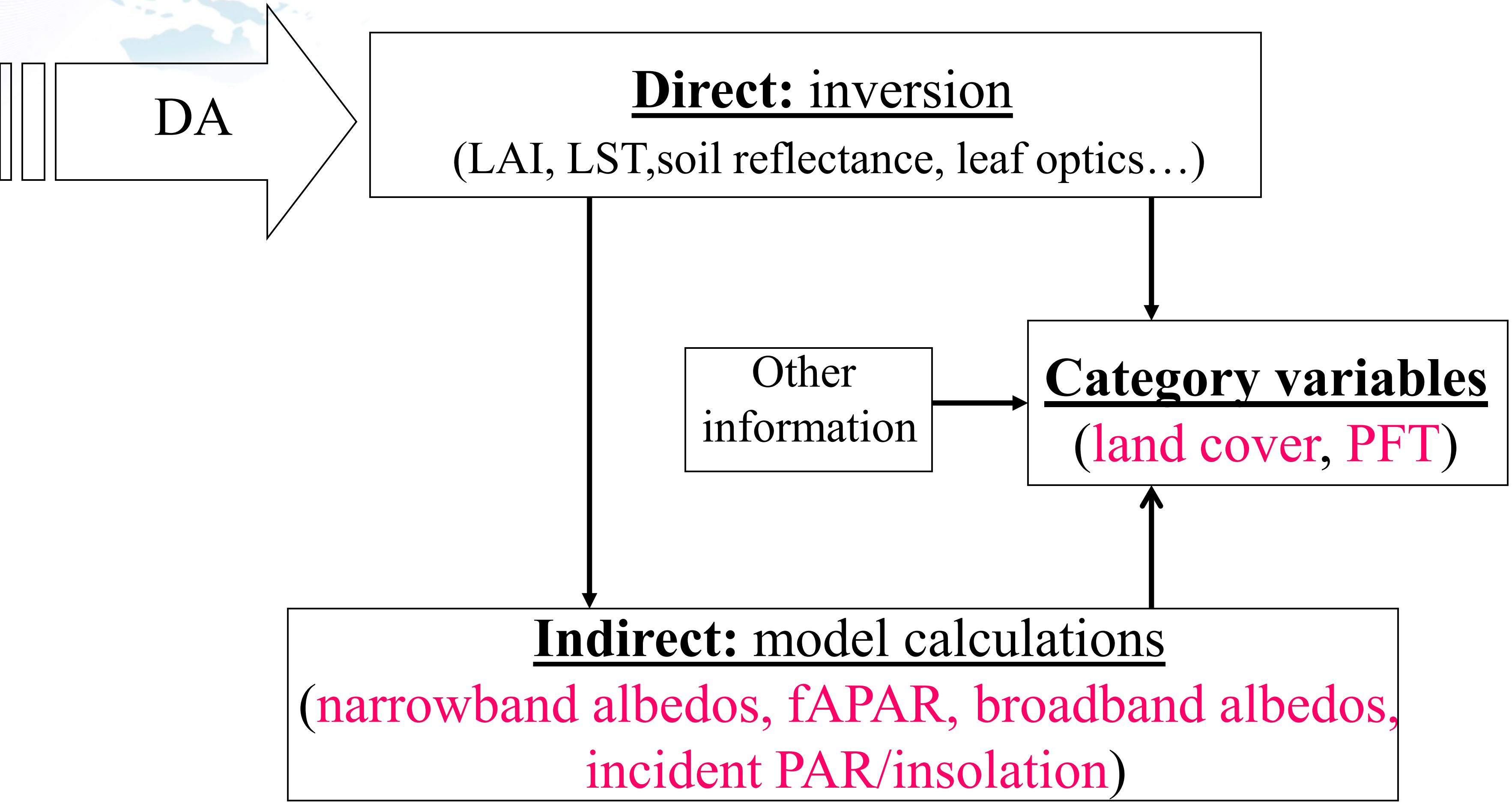
$$F_t(1,1) = 1 + \frac{1}{Z_t + \varepsilon} \times \frac{dZ_t}{dt} \tag{2}$$

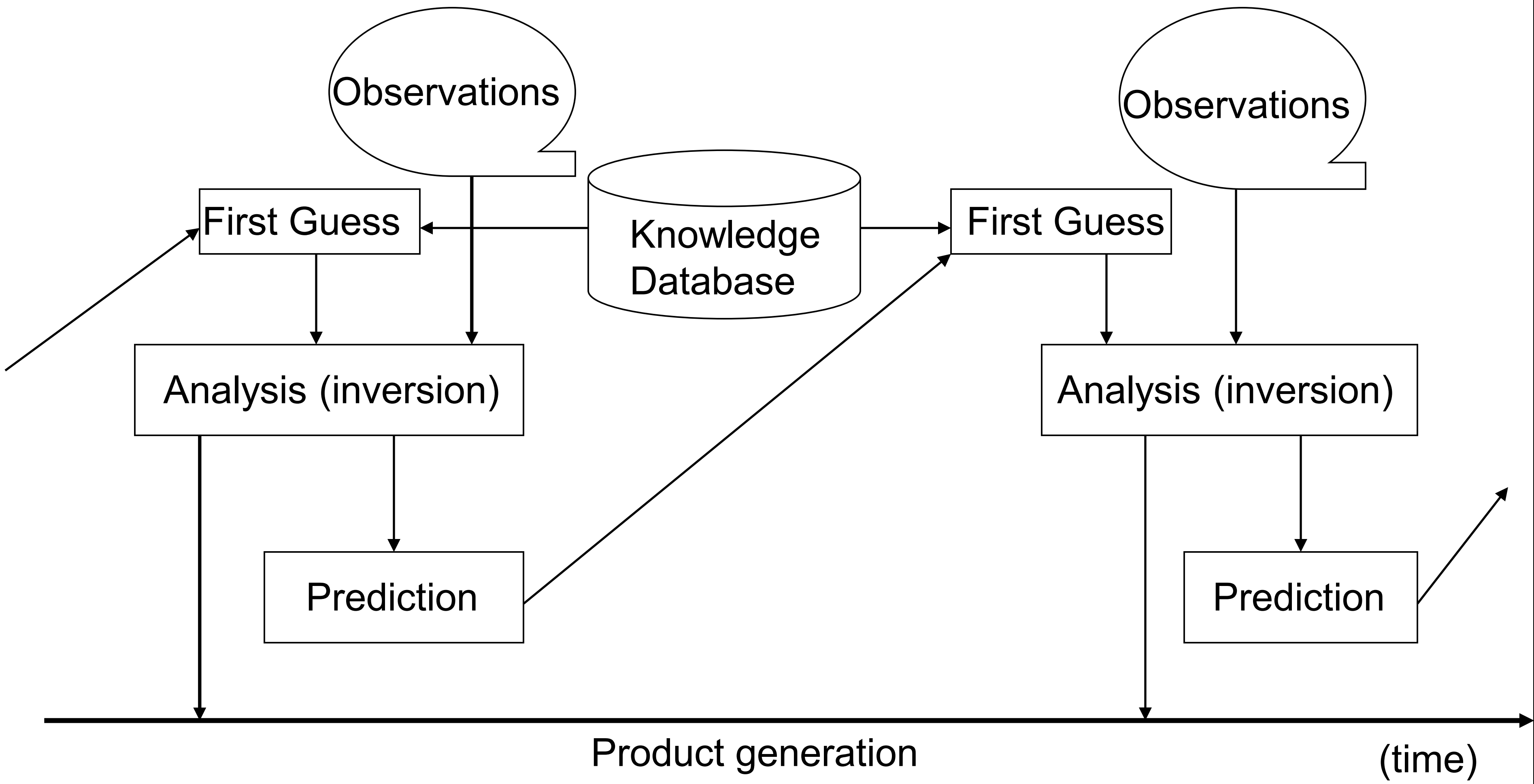
As new observations arrived, the state vector was recursively updated by combining the predictions from the phenology model and the high-quality MODIS reflectance data using the following EnKF analysis equation:

$$A^a = A + A'\hat{A}'^T\hat{H}^T(\hat{H}\hat{A}'\hat{A}'^T\hat{H}^T + R)^{-1}(D - \hat{H}\hat{A}) \tag{3}$$

where $A \in \Re^{n\times N}$ is a matrix containing Nensemble members of the n-dimensional model state vector and $A' \in \Re^{n\times N}$ is the corresponding ensemble perturbation matrix. $\hat{A} \in \Re^{\hat{n}\times N}$ is a

Generating products: direct + indirect





Real-time inversion
Reanalysis

Recent Publications

- <u>**Case 1**</u>: MODIS surface reflectance -> LAI, FAPAR and albedo
  - Xiao, Z.Q., Liang, S., Wang, J.D., Xie, D.H., Song, J.L., & Fensholt, R. (2015). A Framework for Consistent Estimation of Leaf Area Index, Fraction of Absorbed Photosynthetically Active Radiation, and Surface Albedo from MODIS Time-Series Data. *IEEE Transactions on Geoscience and Remote Sensing, 53*, 3178-3197
- <u>**Case 2**</u>: MODIS+VEGETATION+MISR surface reflectance ->LAI, FAPAR, and albedo
  - Ma, H., Liu, Q., Liang, S., & Xiao, Z. (2017). Simultaneous Estimation of Leaf Area Index, Fraction of Absorbed Photosynthetically Active Radiation and Surface Albedo from multiple-Satellite Data. *IEEE Transactions on Geoscience and Remote Sensing, 55*, 4334 - 4354
- <u>**Case 3**</u>: MODIS top-of-atmosphere (TOA) (clear-sky) reflectance->LAI, FAPAR, albedo, PAR/APAR
  - Shi, H., Xiao, Z., Liang, S., & Zhang, X. (2016). Consistent estimation of multiple parameters from MODIS top of atmosphere reflectance data using a coupled soil-canopy-atmosphere radiative transfer model. *Remote Sensing of Environment, 184*, 40-57

Recent Publications – Cont.

- **Case 4**:MODIS TOA (all-sky) reflectance->LAI, FAPAR, albedo, PAR/APAR
  - Shi, H., Xiao, Z., Liang, S., & Ma, H. (2017). A Method for Consistent Estimation of Multiple Land Surface Parameters From MODIS Top-of-Atmosphere Time Series Data. *IEEE Transactions on Geoscience and Remote Sensing*, 55, doi:10.1109/TGRS.2017.2702609
- **Case 5**: MODIS surface reflectance + thermal TOA brightness temperature ->LST + …
  - Ma, H., Liang, S., Xiao, Z., & Shi, H. (2017). Simultaneous inversion of multiple land surface parameters from MODIS optical–thermal observations. *ISPRS Journal of Photogrammetry and Remote Sensing*, 128, 240-254
- **Case 6**: VIIRS surface reflectance + thermal TOA brightness temperature ->LST + …
  - Ma, H., Liang, S., Xiao, Z., & Wang, D. (2018). Simultaneous Estimation of Multiple Land Surface Parameters from VIIRS Optical-Thermal data. *Ieee Geoscience and Remote Sensing Letters, 15*, 151-160

Case 4: Coupled surface + atmosphere

IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING

A Method for Consistent Estimation of Multiple Land Surface Parameters From MODIS Top-of-Atmosphere Time Series Data

Hanyu Shi, Zhiqiang Xiao, Shunlin Liang, *Fellow, IEEE*, and Han Ma

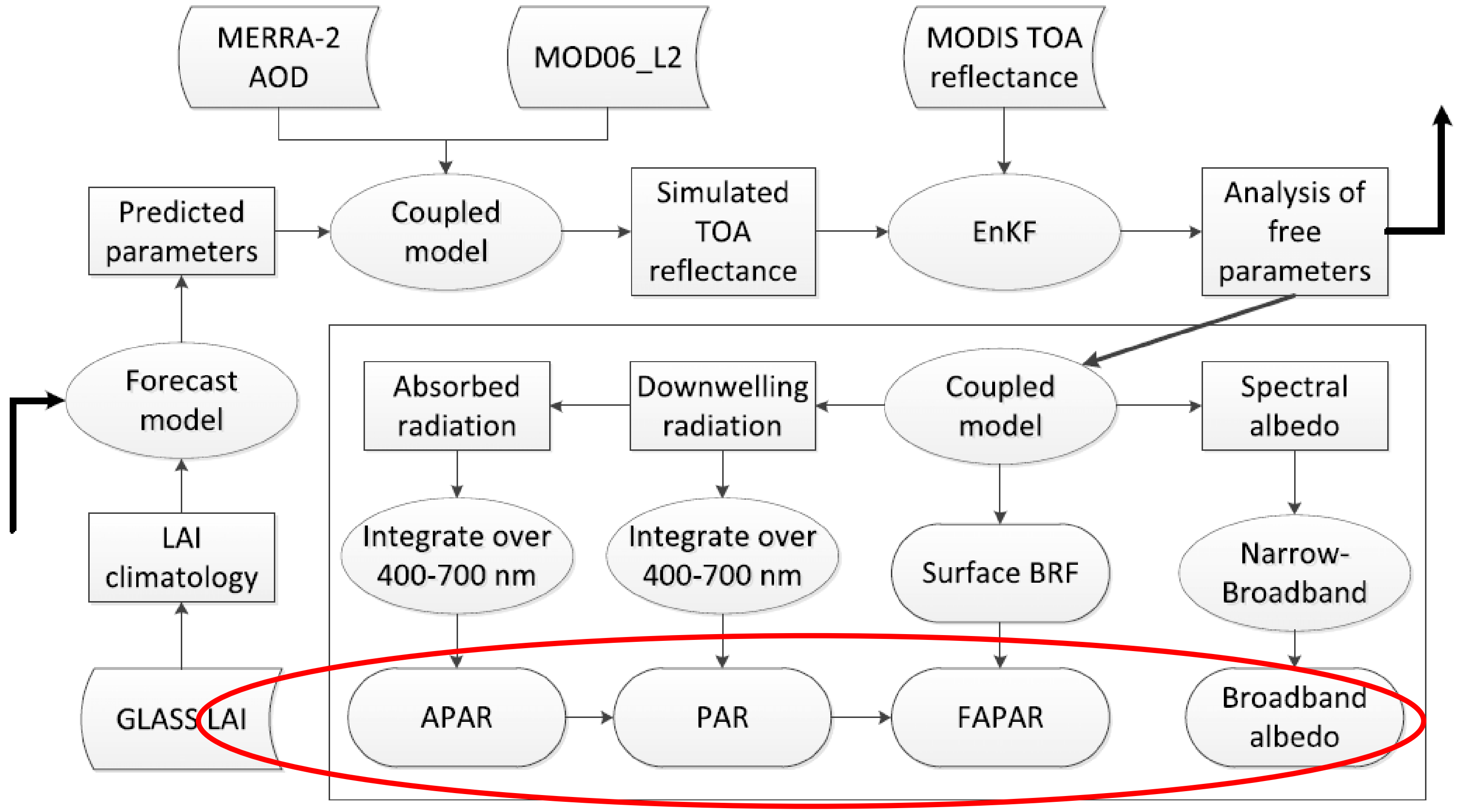
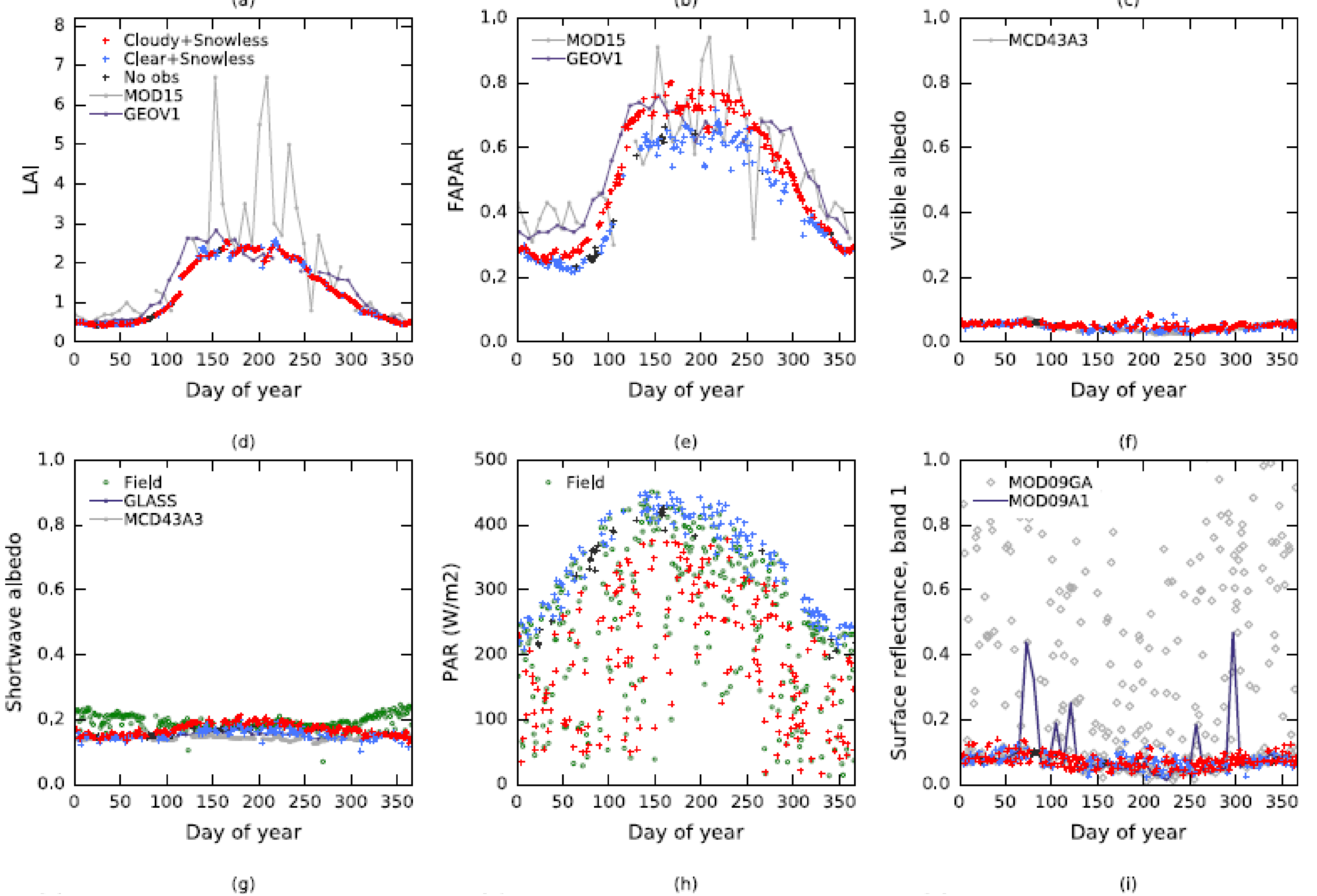


Fig. 1. DA method for consistent estimate multiple land surface parameters from MODIS time series TOA reflectance data.



Goodwin Creek, 2002

Case 5: MODIS (visible-thermal)

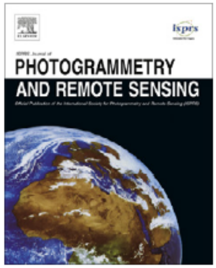
ISPRS Journal of Photogrammetry and Remote Sensing 128 (2017) 240–254

Contents lists available at ScienceDirect

ISPRS Journal of Photogrammetry and Remote Sensing

journal homepage: www.elsevier.com/locate/isprsjprs

ELSEVIER



Simultaneous inversion of multiple land surface parameters from MODIS optical–thermal observations

CrossMark

Han Ma [a], Shunlin Liang [a,b,*], Zhiqiang Xiao [a], Hanyu Shi [a]

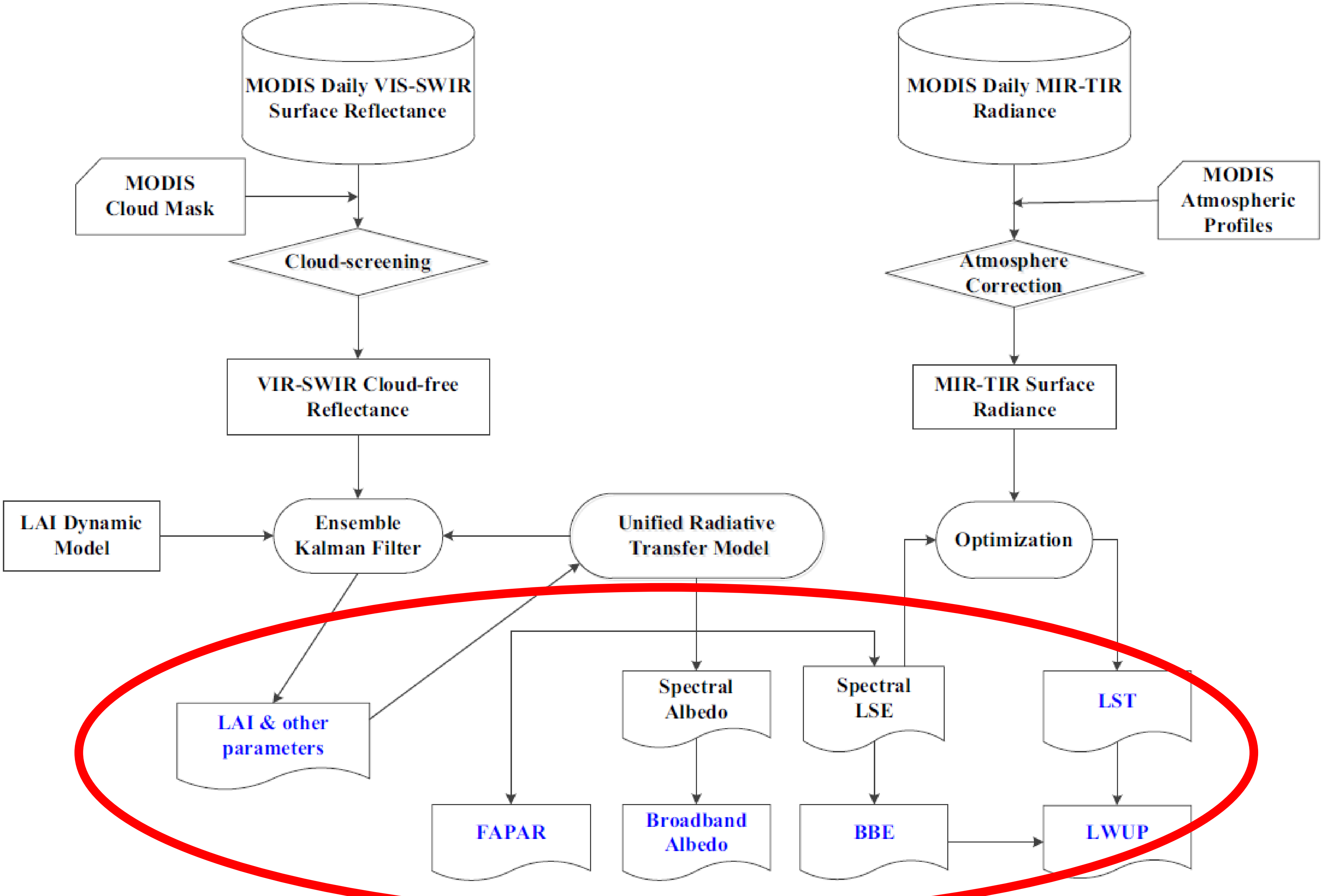
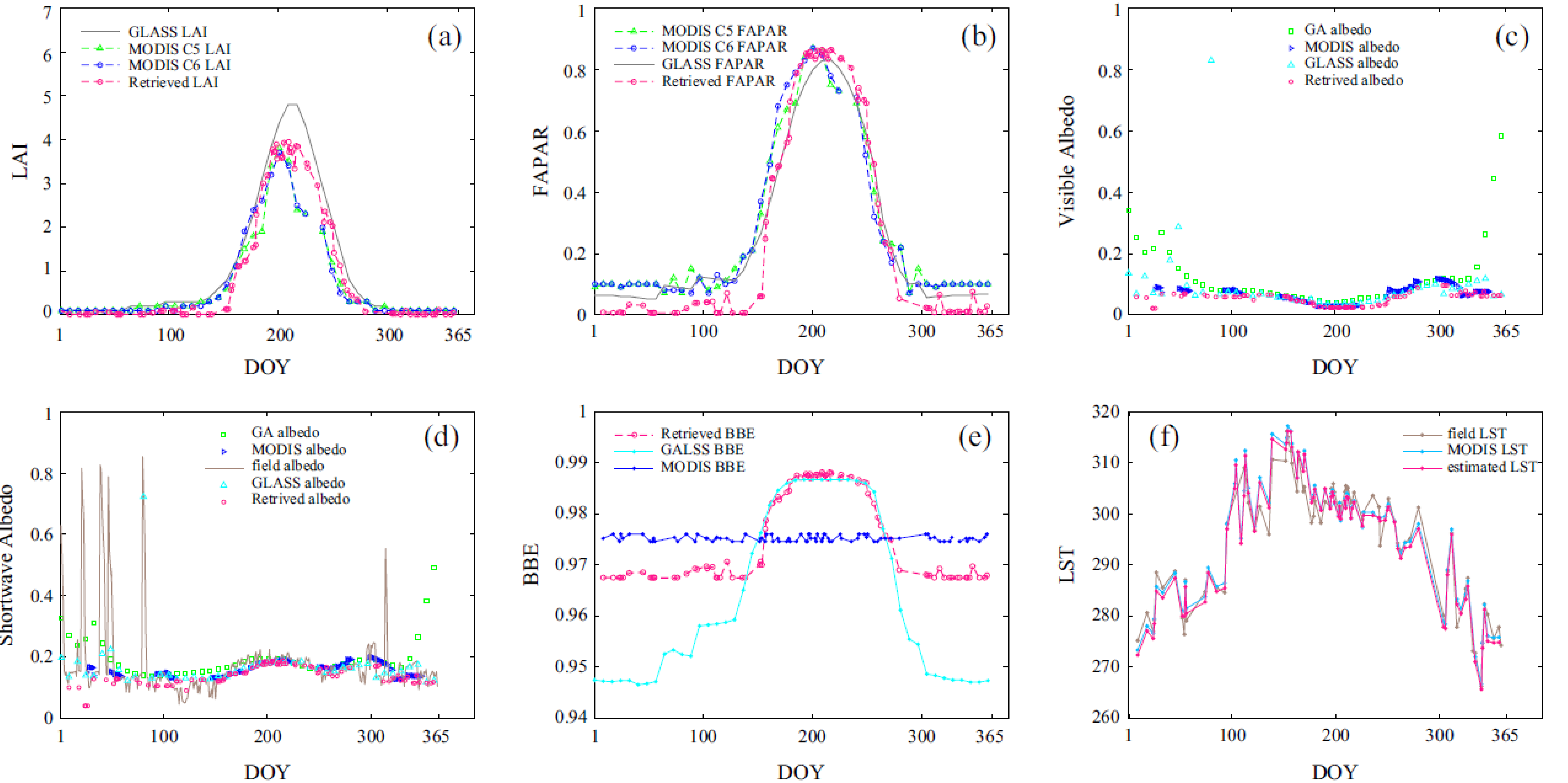
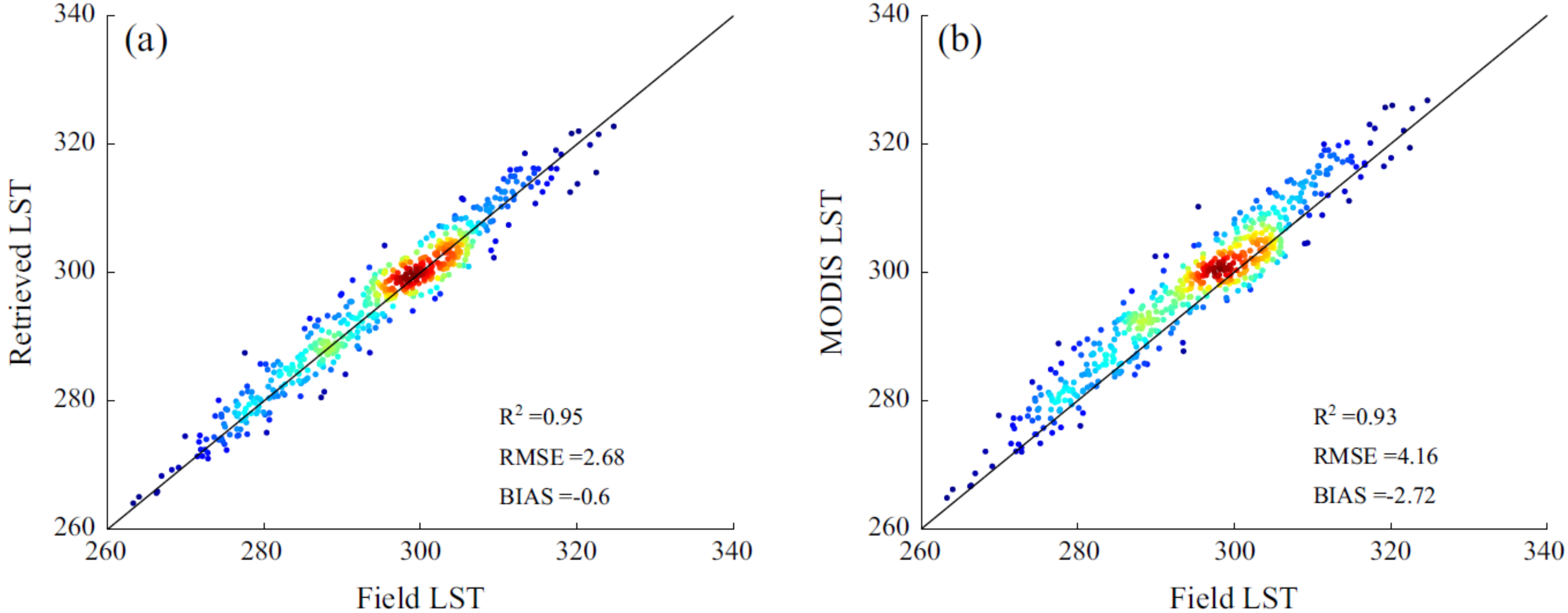


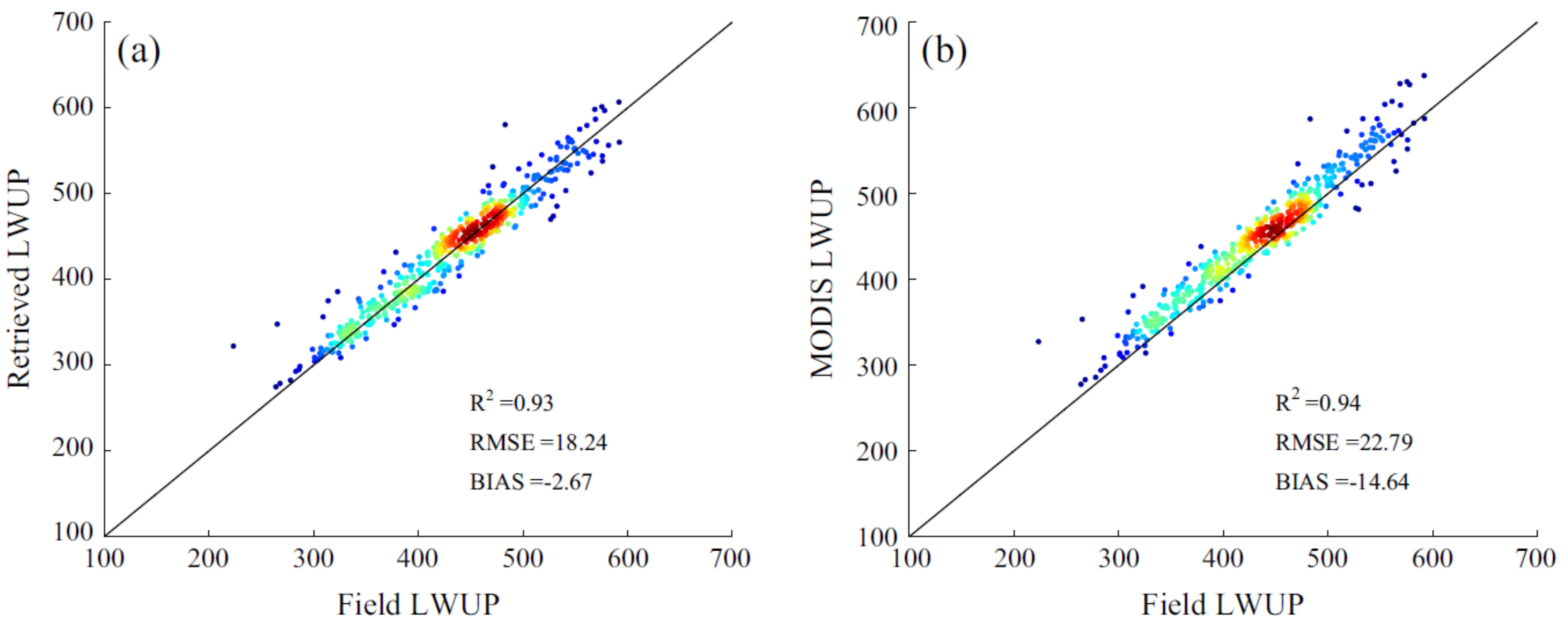
Fig. 1. Flowchart for the multiple land surface parameters unified inversion algorithm.

3



The inverted results are better than the existing satellite products at Bondville, 2005


(a)
Retrieved LST
Field LST
R² =0.95
RMSE =2.68
BIAS =-0.6
(b)
MODIS LST
Field LST
R² =0.93
RMSE =4.16
BIAS =-2.72


(a)
Retrieved LWUP
Field LWUP
R² =0.93
RMSE =18.24
BIAS =-2.67
(b)
MODIS LWUP
Field LWUP
R² =0.94
RMSE =22.79
BIAS =-14.64

Case 6: using VIIRS data

156 IEEE GEOSCIENCE AND REMOTE SENSING LETTERS, VOL. 15, NO. 1, JANUARY 2018

Simultaneous Estimation of Multiple Land-Surface Parameters From VIIRS Optical-Thermal Data

Han Ma, Shunlin Liang, *Fellow, IEEE*, Zhiqiang Xiao, and Dongdong Wang

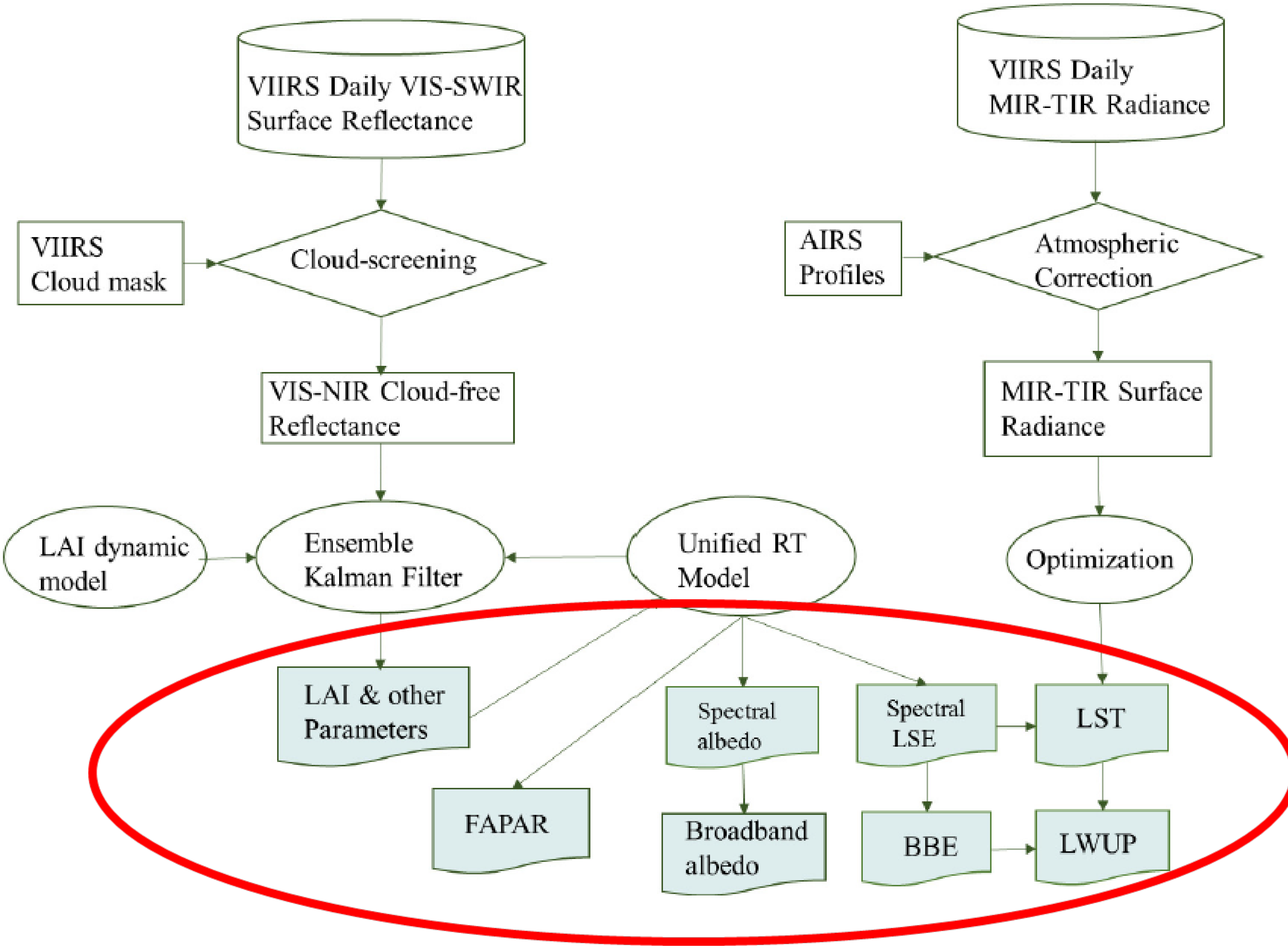


Fig. 1. Flowchart of the unified inversion procedure.

TABLE III

EXPERIMENTS WITH VIIRS BAND COMBINATIONS

Band combination	Bands needed
VIIRS_3i	I1, I2, I3
VIIRS_3m	M5, M7, M10
VIIRS_6m	M3, M4, M5, M7, M8, M10
VIIRS_7m	M3, M4, M5, M7, M8, M10, M11

accounting for the snow-cover fraction. Besides, different band combinations of the VIIRS data were explored, and for the calculation of LAI/FAPAR and albedo, the band combination centered at 0.64/0.67, 0.865, and 1.61 μm was recommended.

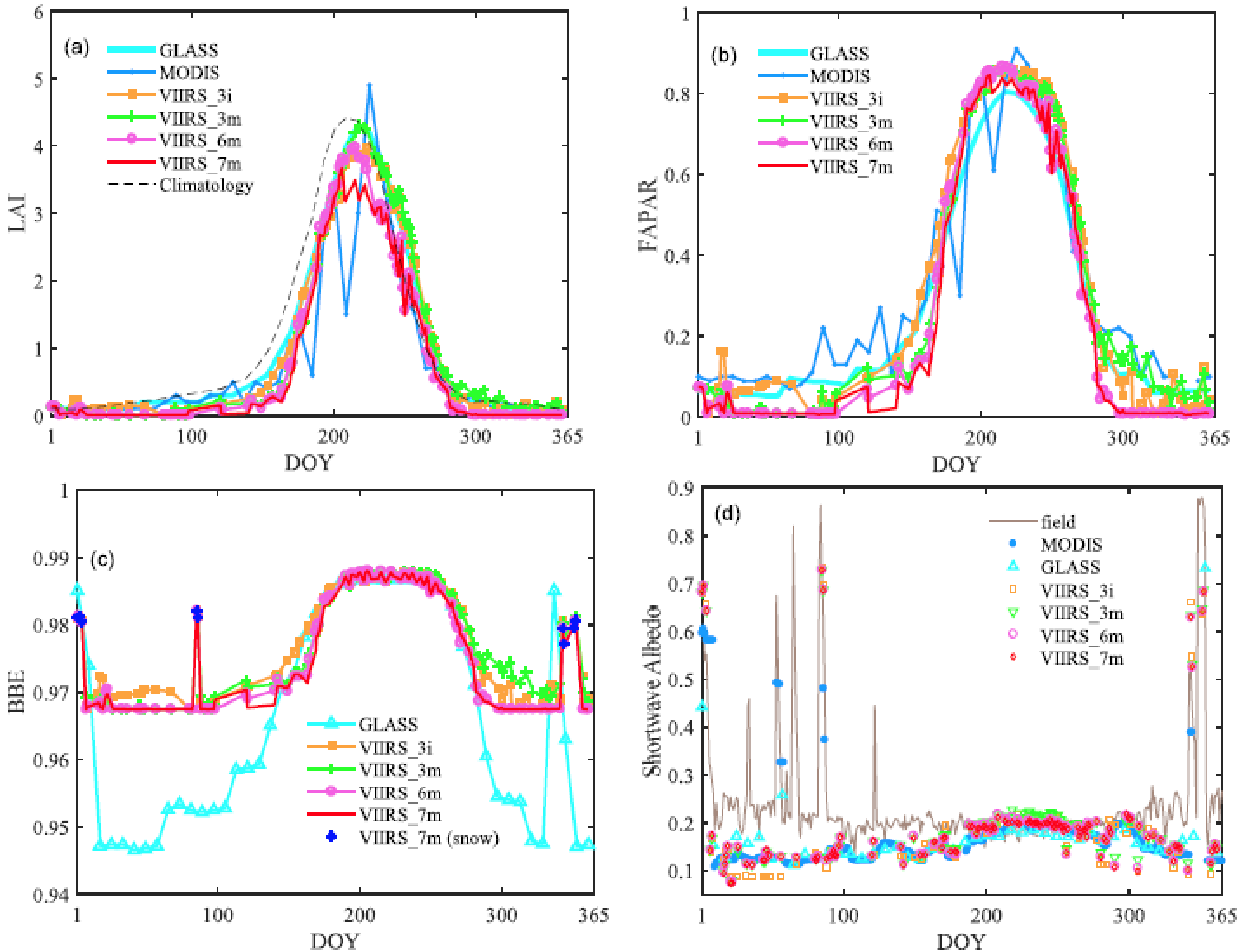


Fig. 2. Time series of (a) LAI, (b) FAPAR, (c) BBE, and (d) shortwave albedo at the SURFRAD BND site in 2013.

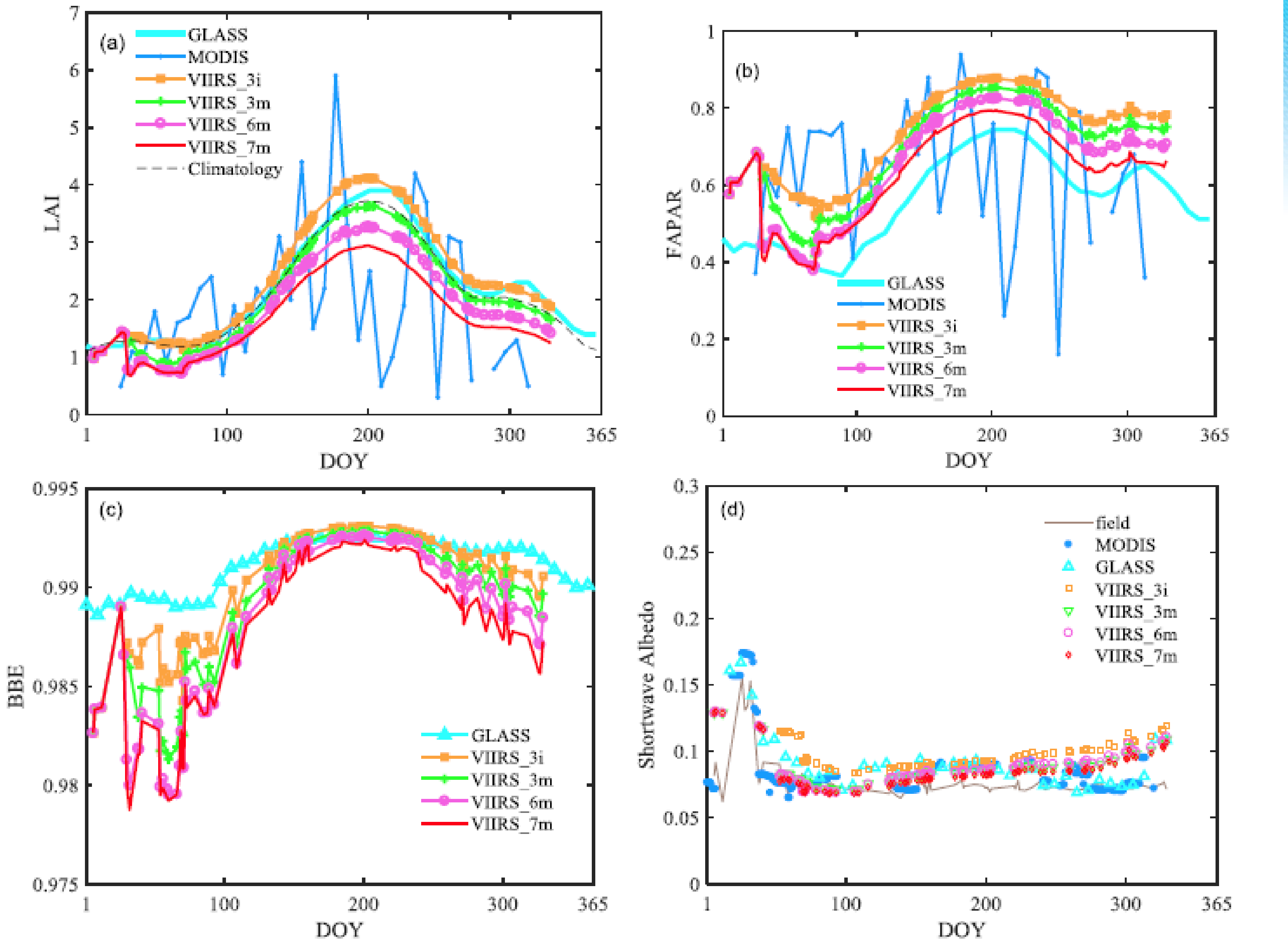


Fig. 3. Time series of (a) LAI, (b) FAPAR, (c) BBE, and (d) shortwave albedo at the Oberbärenburg site in 2014.

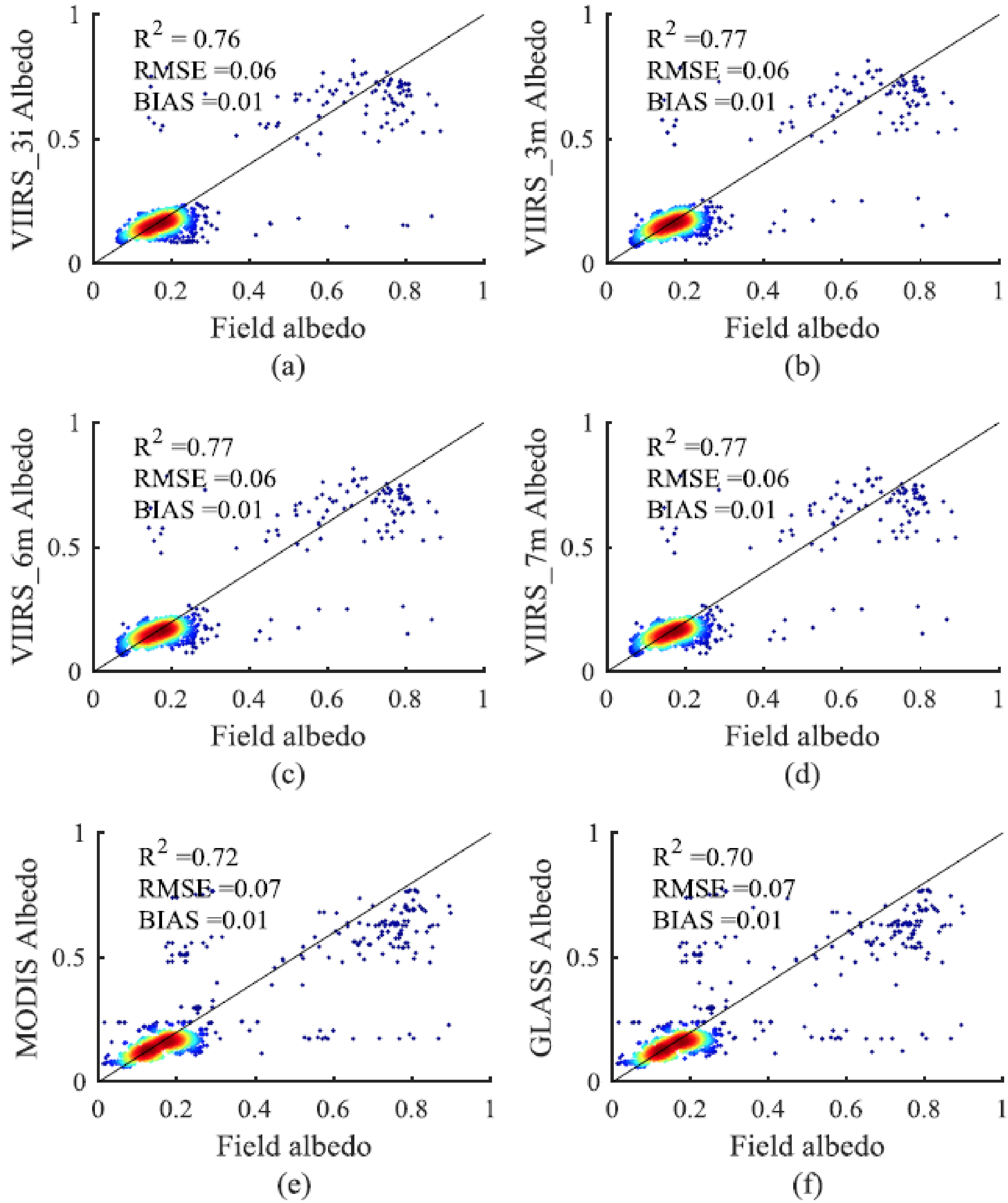


Fig. 5. Scatter plots between field measurements of albedo versus (a) VIIRS_3i, (b) VIIRS_3m, (c) VIIRS_6m, (d) VIIRS_7m, (e) MODIS and (f) GLASS data for the selected site.

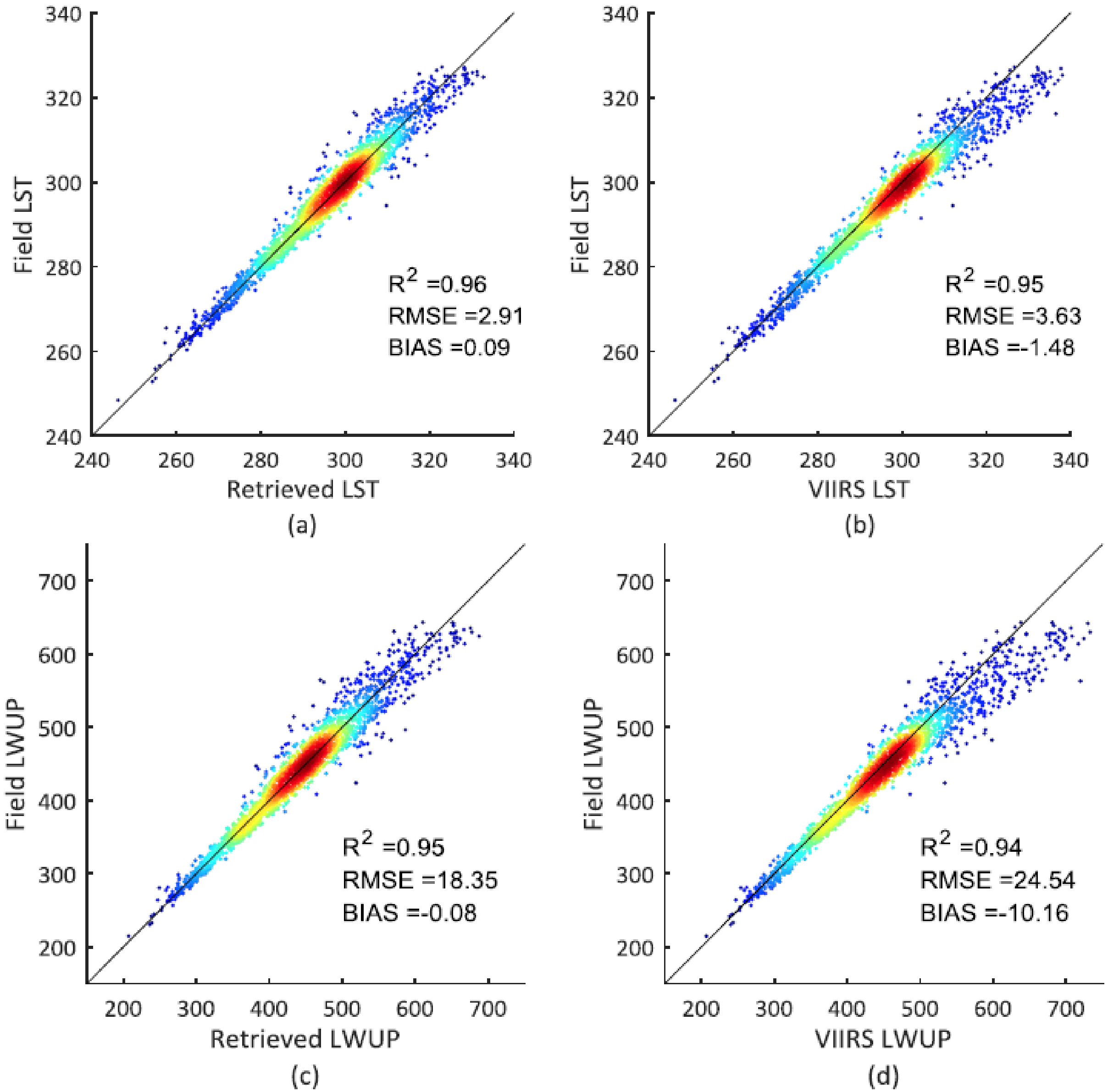


Fig. 6. Scatter density plots between (a) field-measured LST and the retrieved LST, (b) field-measured LST and VIIRS LST product, (c) field-measured LWUP and the retrieved LWUP, and (d) field-measured LST and VIIRS LST product-calculated LWUP.

Concluding remarks

- The current inversion framework was developed in 1980s. It is necessary to explore the new generation of the inversion scheme
- We proposed a new inversion framework (LoVE-P) based on the data assimilation method
- Multiple case studies demonstrated that LoVE-P works very well
- Strengths of the LoVE-P
  - Integration of various regularization methods effectively
  - Estimation of a group of variables simultaneously
  - Spatially and temporally continuous
  - Physically consistent
  - Better or comparable accuracies
  - Suitable for any satellite observations (single or multiple)