Enhanced Estimation of Land Surface Moisture and Heat Fluxes by Coupling Water and Energy Balance Models

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INTRODUCTION

The land surface is a key component of climate system. It controls the partitioning of available energy at the surface between sensible and latent heat, and partitioning of available water between evaporation and runoff. Determination of energy and water exchange between the land surface and atmosphere is the primary objective of land surface models in many fields such as hydrology, climatology and meteorology.

The Water and energy cycles are intrinsically coupled trough the moisture flux from the surface to the atmosphere. This mass flux (**evapotranspiration***) represents a heat exchange as latent heat flux, coupling water and energy balance equation [1].

"In situ" measurements of heat and moisture fluxes are costly and therefore are applicable only to local scales and cannot be extended to large areas [2]. A suitable alternative to "in situ" measurement of land surface fluxes is utilizing the remote sensing observations. Among the numerous techniques developed to make quantitative estimates of surface, data assimilation (DA) techniques (e.g., variational data assimilation (VDA)), have gained substantial success in recent years. The VDA techniques estimate unknown parameters of land surface fluxes by assimilating remotely sensed observations of land surface state variables within the physical land surface models [3], [4].

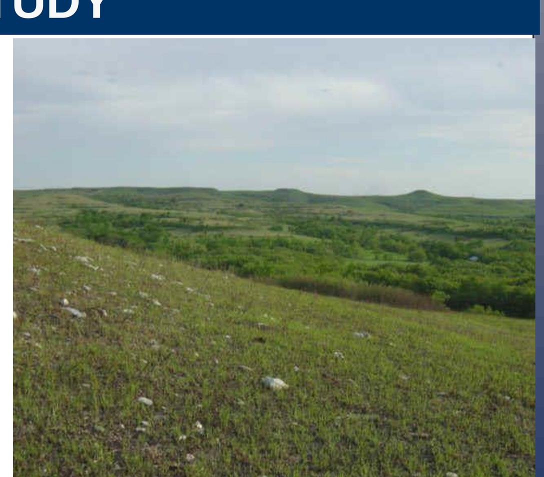
In this study, we apply the VDA technique to retrieve the key unknown parameters of the land surface by assimilating land surface state variables. The surface energy balance (SEB) is coupled with surface water balance (SWB) through evapotranspiration flux.

OBJECTIVE

Accurate prediction of the closure relation between water balance and energy balance equations, unknown parameters and flux components of both equations.

CASE STUDY

- ✓ FIFE (First ISLSCP Field Experiment)
- ✓ Grassland site near Manhattan, Kansas
- ✓ Summer 1987 (Julian days 148–243, covered by three assimilation periods)



METODOLOGY

➢ Surface Energy Balance (SEB)

The SEB describes the partitioning of incoming net radiation (R_n) into sensible (**H**), latent (**LE**), and ground heat flux (**G**) components as:

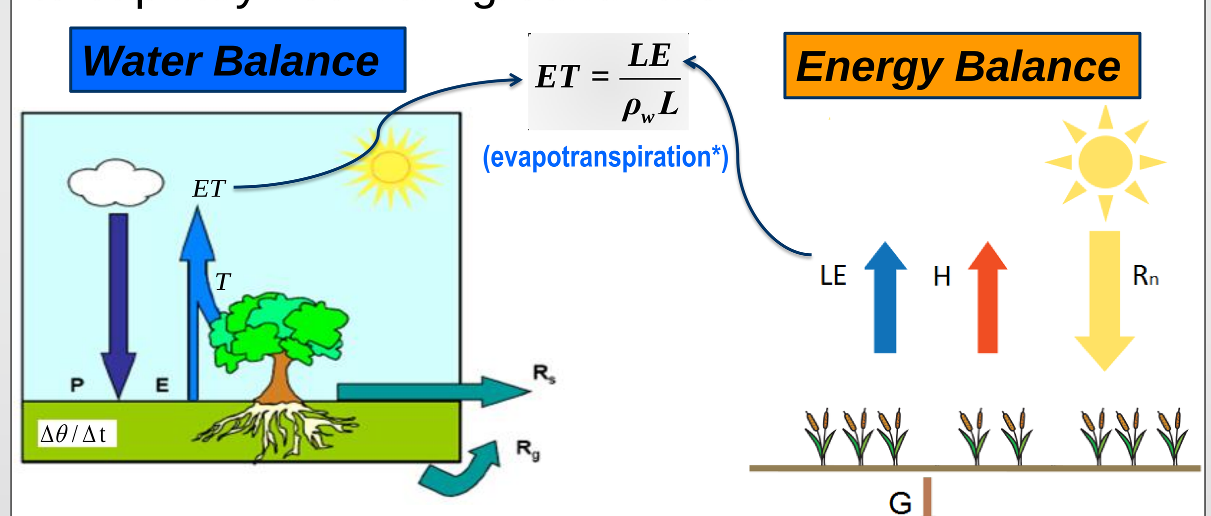
$$R_n = H + LE + G$$

➢ Surface Water Balance (SWB)

$$l\frac{d\theta}{dt} = P - ET - R_{off}$$

θ is water content storage and $d\theta/dt$ shows the rate of change in the water content within the active soil layer (l),

P *is precipitation rate,* ***ET*** is the evapotranspiration (sum of evaporation from soil and transpiration from canopy) rate and **Q** represents combined losses due to surface runoff and drainage and upward transport due to capillary rise from groundwater.



➢ Variational Data Assimilation (VDA)

The VDA approach is based on the minimization of the cost function, **J**, which represents the aggregated errors on state estimation (**X**) with respect to observations, X_{obs}, and parameters estimation (**Y**) with respect to "prior" values **Y'**:

$$J = \int_{t_1}^{t_2} (X - X_{obs})^T C_X^{-1} (X - X_{obs}) dt +$$
$$(Y - Y')^T C_Y^{-1} (Y - Y') + \int_{t_1}^{t_2} \lambda^T \left[\frac{dX}{dt} - F(X,Y)\right] dt$$

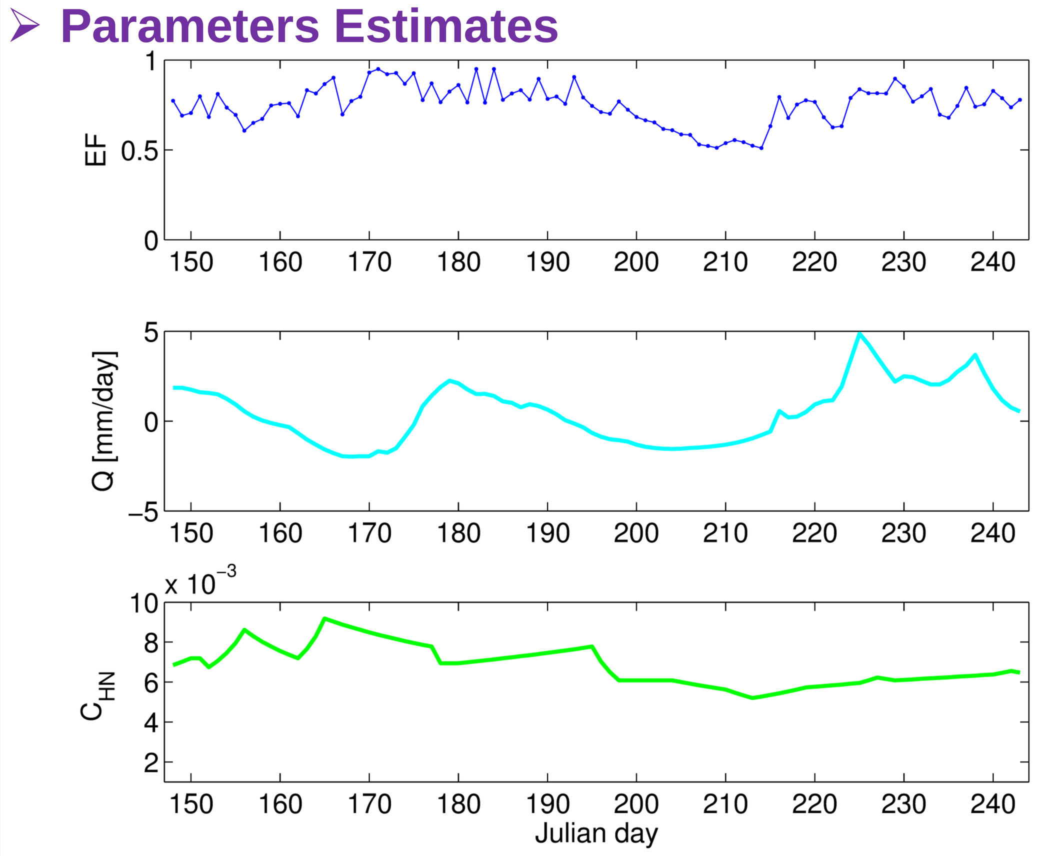
- ✓ **State Variable**: land surface temperature (**T**) and water content (**θ**)
- ✓ **Unknown Parameter**: **EF** (evaporative fraction), **Q** (combined surface runoff, drainage and capillary rise) and monthly C_{HN} (bulk heat transfer coefficient)
- ✓ **Physical Constraint**: heat diffusion equation and water balance equation

The optimal values of unknown parameters are found by minimizing the cost function → $\delta J = 0$

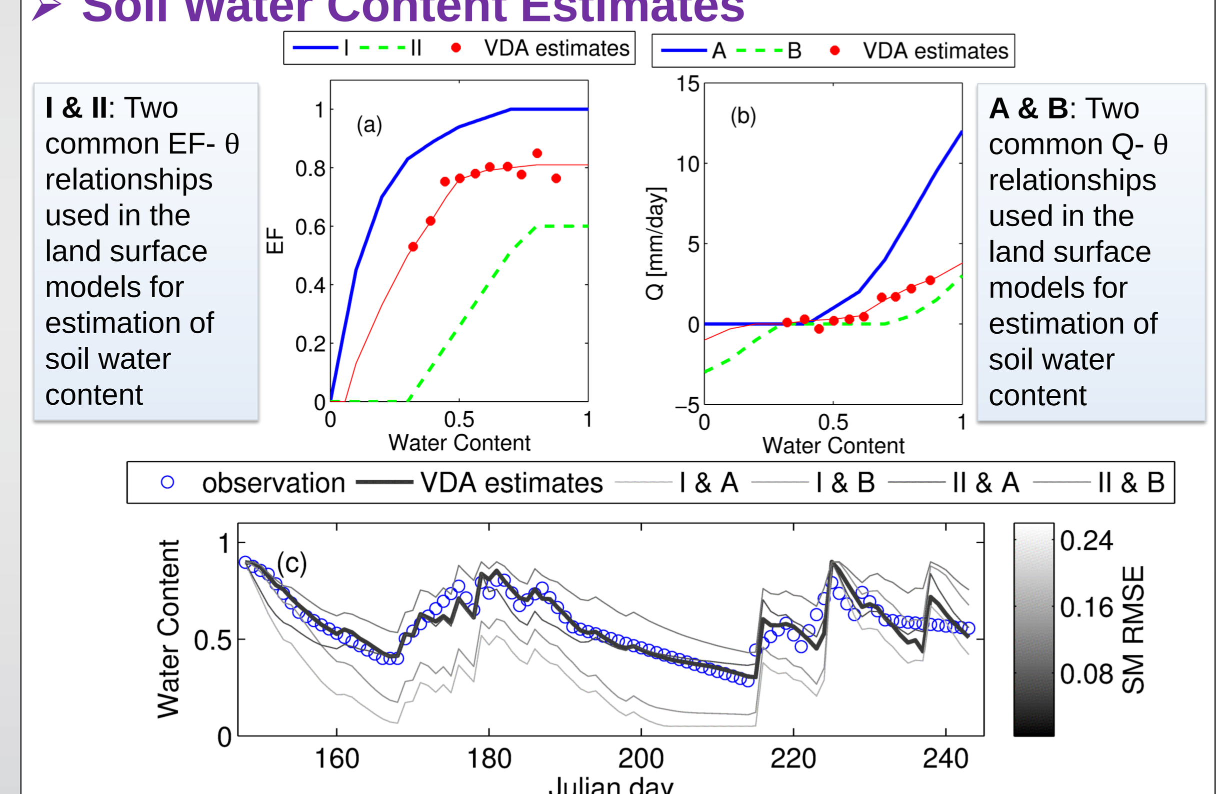
Setting δJ to zero leads to the set of Euler-Lagrange equations as well as a set of equations for updating prior value of parameters.

RESULTS

➢ Parameters Estimates



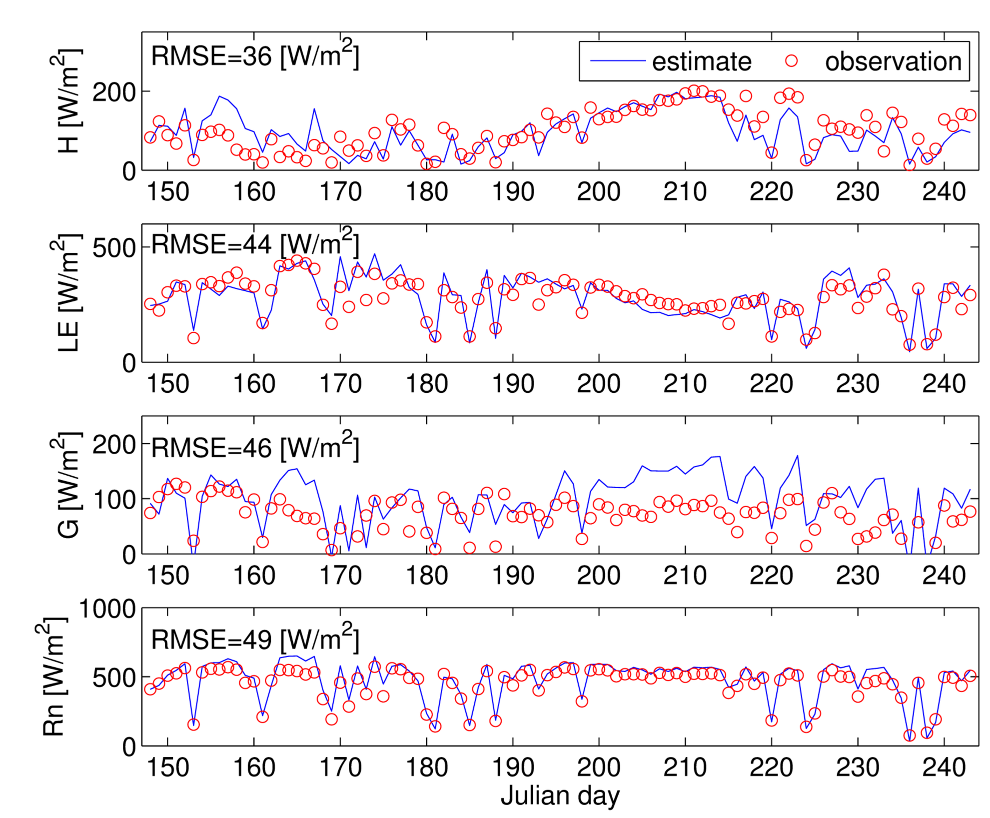
➢ Soil Water Content Estimates



Comparison of misfit between retrieved and observed θ:

- ✓ Less RMSE obtained when EF-θ and Q-θ relationships that obtained from VDA approach are used
- ✓ indicate the importance of accurate representation of EF-θ and Q-θ relationships in land surface models and the need for techniques that provide accurate estimates of these relationships from state observations

➢ Land Surface Fluxes estimates



The retrieved values of land surface fluxes are **in good agreement with observations** in terms of both magnitude and day-to-day dynamics.

CONCLUSION

In this study the VDA technique is applied to retrieve the key unknown parameters of the land surface energy and water balance equations by assimilating land surface state variables (*i.e.*, land surface temperature and water content). The surface energy balance (SEB) is coupled with surface water balance (SWB) through evapotranspiration flux. This coupling makes SEB and SWB to operate in a consistent and dynamic way and provide means to more accurate prediction of the closure relation between water balance and energy balance equations, unknown parameters and flux components of both equations. Small root mean squared error between observed and estimated θ from VDA estimates in comparison with those of SWB estimates (using common combinations of *EF*-θ and *Q*-θ relationships) reveals the importance of using VDA-proposed *EF*-θ and *Q*-θ relationships in land surface model. The retrieved values of land surface fluxes (i.e., Sensible (H), Latent(LE), Ground, and net radiation (R_n)) are in good agreement with observations in terms of both magnitude and day-to-day dynamics. This indicates that VDA is able to use the information in LST dynamics to partition available energy among the turbulent heat fluxes.

REFERENCE

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