



## Assimilation of groundwater level and cosmic-ray neutron sensor soil moisture measurements into integrated terrestrial system models for better predictions

Fang Li

Energie & Umwelt / Energy & Environment  
Band / Volume 650  
ISBN 978-3-95806-796-7

Forschungszentrum Jülich GmbH  
Institut für Bio- und Geowissenschaften (IBG)  
Agrosphäre (IBG-3)

# **Assimilation of groundwater level and cosmic-ray neutron sensor soil moisture measurements into integrated terrestrial system models for better predictions**

Fang Li

Schriften des Forschungszentrums Jülich  
Reihe Energie & Umwelt / Energy & Environment

Band / Volume 650

---

ISSN 1866-1793

ISBN 978-3-95806-796-7

## Contents

|  |    |
|--|----|
| Contents .....   | i  |
| List of Figures.....   | iv |
| List of Tables.....  | xi |
| List of Acronyms .....   | xv |
| Abstract.....  | 1  |
| Zusammenfassung.....   | 3  |
| Chapter 1: Introduction .....  | 5  |
| Chapter 2: Theory, methods and materials .....   | 15 |
| 2.1 Integrated terrestrial systems model TSMP .....  | 15 |
| 2.1.1 Land surface model Community Land Model (CLM), version 3.5.....  | 15 |
| 2.1.2 Subsurface hydrological model ParFlow .....  | 18 |
| 2.1.3 Coupling interface OASIS-MCT .....   | 20 |
| 2.2 Data assimilation .....  | 20 |
| 2.2.1 Ensemble Kalman Filter (EnKF) .....  | 20 |
| 2.2.2 Localized Ensemble Kalman Filter (LEnKF) .....   | 23 |
| 2.2.3 TSMP-PDAF .....  | 24 |
| 2.3 Study area and hydrological measurements.....  | 26 |
| Chapter 3: Water table depth assimilation in integrated terrestrial system models at the larger catchment scale..... | 29 |
| 3.1 Introduction .....   | 29 |
| 3.2 Materials and methods.....   | 31 |
| 3.2.1 Study area and data .....  | 31 |
| 3.2.2 Model description (TSMP) .....   | 35 |
| 3.2.3 LEnKF methodology .....  | 38 |
| 3.2.4 Assimilation methodology .....   | 41 |
| 3.3 Experimental setup .....   | 42 |
| 3.3.1 Ensemble generation and simulations .....  | 42 |
| 3.3.2 Selection criteria for assimilated sites.....  | 44 |
| 3.3.3 Evaluation of model performance.....   | 45 |

|  |     |
|--|-----|
| 3.4 Results and discussion.....  | 47  |
| 3.4.1 Water table depth .....  | 47  |
| 3.4.2 Soil moisture.....   | 53  |
| 3.4.3 Discussion.....  | 55  |
| 3.5 Conclusions.....   | 57  |
| Chapter 4: Can a sparse network of cosmic ray neutron sensors improve soil moisture and evapotranspiration estimation at the larger catchment scale? ..... | 58  |
| 4.1 Introduction.....  | 58  |
| 4.2 Materials and methods.....   | 60  |
| 4.2.1 Study area .....   | 60  |
| 4.2.2 Terrestrial System Modeling Platform (TSMP).....   | 61  |
| 4.2.3 Data .....   | 63  |
| 4.2.4 Data assimilation methodology.....   | 66  |
| 4.3 Model and experiment setup .....   | 69  |
| 4.3.1 TSMP-PDAF setup.....   | 69  |
| 4.3.2 Ensemble generation.....   | 70  |
| 4.3.3 Setup of the DA Experiments .....  | 71  |
| 4.3.4 Evaluation of model performance.....   | 72  |
| 4.4 Results.....   | 74  |
| 4.4.1 Soil moisture data assimilation general results .....  | 74  |
| 4.4.2 Jackknife simulations.....   | 76  |
| 4.4.3 Temporal evolution of parameter estimates and parameter verification.....  | 78  |
| 4.4.4 Evapotranspiration and discharge .....   | 81  |
| 4.4.5 Discussion.....  | 85  |
| 4.5 Conclusions.....   | 89  |
| Appendix A .....   | 90  |
| Chapter 5: A new approach for joint assimilation of cosmic-ray neutron soil moisture and groundwater level data into an integrated terrestrial model.....  | 100 |
| 5.1 Introduction .....   | 100 |

|  |     |
|--|-----|
| 5.2 Materials and methods.....   | 104 |
| 5.2.1 Study area .....   | 104 |
| 5.2.2 Terrestrial System Modeling Platform (TSMP) .....                              | 105 |
| 5.2.3 Model input data and measurements.....   | 107 |
| 5.2.4 Data assimilation: localized EnKF.....   | 110 |
| 5.3 Model and Experiment Setup .....   | 113 |
| 5.3.1 Ensemble generation.....   | 113 |
| 5.3.2 Setup of data assimilation experiments.....                                    | 115 |
| 5.3.3 Evaluation of model performance.....   | 116 |
| 5.4 Results.....   | 117 |
| 5.4.1 Univariate data assimilation of soil moisture.....                             | 117 |
| 5.4.2 Univariate data assimilation of groundwater level.....                         | 119 |
| 5.4.3 Multivariate data assimilation of groundwater level and soil moisture.....     | 122 |
| 5.4.4 Influence of $K_3$ updates on simulations.....                                 | 129 |
| 5.5 Discussions.....   | 131 |
| 5.5.1 Strengths and limitations of new multivariate data assimilation approach ..... | 131 |
| 5.5.2 Uncertainties and potential improvement .....                                  | 133 |
| 5.6 Conclusions .....  | 135 |
| Appendix B .....   | 136 |
| Chapter 6: Summary and outlook .....   | 151 |
| Bibliography .....   | 159 |
| Acknowledgements.....  | 171 |

Energie & Umwelt / Energy & Environment  
Band / Volume 650  
ISBN 978-3-95806-796-7