remote sensing

Editorial

Editorial for the Special Issue "Assimilation of Remote Sensing Data into Earth System Models"

Jean-Christophe Calvet [1,*], Patricia de Rosnay [2,*] and Stephen G. Penny [3,4,*]

1 CNRM, Université de Toulouse, Météo-France, CNRS, 31057 Toulouse, France
2 European Centre for Medium-Range Weather Forecasts (ECMWF), Reading RG2 9AX, UK
3 Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, CO 80309, USA
4 Physical Sciences Division (PSD), Earth System Research Laboratory (ESRL), National Oceanic and Atmospheric Administration (NOAA), Boulder, CO 80305-3328, USA
* Correspondence: jean-christophe.calvet@meteo.fr (J.-C.C.); patricia.rosnay@ecmwf.int (P.d.R.); steve.penny@noaa.gov (S.G.P.)

Received: 17 September 2019; Accepted: 18 September 2019; Published: 19 September 2019

Abstract: This Special Issue is a collection of papers reporting research on various aspects of coupled data assimilation in Earth system models. It includes contributions presenting recent progress in ocean–atmosphere, land–atmosphere, and soil–vegetation data assimilation.

Keywords: data assimilation; Earth system models; atmospheric models; ocean models; land surface models

1. Introduction

A transition is currently occurring in multiple fields in the Earth sciences towards an integrated Earth system approach, with applications including numerical weather prediction, hydrological forecasting, climate impact studies, ocean dynamics estimation and monitoring, carbon cycle monitoring. These approaches rely on coupled modeling techniques, using Earth system models (ESMs) that account for an increased level of complexity of (coupled) processes and interactions between atmosphere, ocean, sea ice, and terrestrial surfaces [1]. A crucial component of Earth system approaches is the development of coupled data assimilation (CDA) of satellite observations to ensure consistent initialization at the interface between the different subsystems [2]. For example, a coupled ocean–atmosphere data assimilation system ensures consistent sea surface temperature and near-surface atmospheric conditions [3], and coupled land–atmosphere assimilation produces consistent soil moisture and air temperature analyses [4].

There is a large range of CDA approaches, from weakly coupled (coupled forecast model but separate analyses) to strongly coupled assimilation (single cost function and control vector). Intermediate levels of coupling (quasi-CDA) allow observations in one subsystem to provide increments in other subsystems [5]. CDA development in ESMs will open possibilities to further exploit satellite observations that are sensitive to both the lowest levels of the atmosphere and the underlying system (land, urban surfaces, ocean, or sea ice).

The integration of satellite-derived observations into ESMs or into ESM modules can also help minimize modeling uncertainties [6,7]. The assimilation of new remote sensing products is expected to benefit a wide range of applications, including weather, subseasonal to seasonal (S2S), seasonal and interannual climate prediction, and climate reanalysis [8,9]. Satellite-derived climate data records of essential climate variables are now available for the different components of the Earth system, including terrestrial and ocean surfaces.

2. Overview of Contributions

The contributions reported in this Special Issue include key aspects of CDA involving several components of ESMs: ocean–atmosphere interactions, land–atmosphere interactions including hydrological processes, and interactions within the soil–plant system.

2.1. Ocean–Atmosphere Data Assimilation

In this Special Issue, state-of-the-art developments in operational coupled ocean–atmosphere developments are presented by Browne et al. [10]. Recent advances in Earth system components assimilation are presented, including (1) assimilation of Global Positioning System (GPS) radio occultation (RO) in atmospheric models (Banos et al. [11]) as well as (2) sea level interpolation using an analog data assimilation approach to improve high resolution current representation in ocean general circulation models (Lguensat et al. [12]). Assimilation of observations from the Tropical Rainfall Measuring Mission (TRMM) and the Integrated Multi-satellitE Retrievals for Global Precipitation Measurement (GPM IMERG) is also investigated by Yi et al. [13]. A consistent benefit of atmospheric assimilation is shown on both atmosphere and hydrological components.

2.2. Land–Atmosphere Data Assimilation

This Special Issue also addresses the relationship between soil moisture and different land surface–atmosphere fields (precipitation, surface air temperature, total cloud cover, and total water storage) and Pangaluru et al. [14] show that assimilation of Advanced Microwave Scanning Radiometer for Earth Observing System (AMSR-E) over India improves their consistency. Furthermore, Yi et al. [15] compare the use of different precipitation products in the hydrological modeling of the Wangjiaba (WJB) watershed in China with the Soil Moisture Active and Passive (SMAP) data used to validate soil moisture. They show that although in situ precipitation reports provide the most reliable local information, precipitation from numerical weather prediction models provides the gridded and future information necessary for flood forecasting. With the paper of Massari et al. [16], this Special Issue further studies the strong physical connection between soil moisture dynamics and rainfall. This work shows that in Mediterranean areas, correction of precipitation is most relevant for high flow representation, whereas soil moisture assimilation brings slightly more benefit in low flow conditions.

2.3. Soil–Vegetation Data Assimilation

Drought propagation from soil moisture to vegetation dynamics is investigated by Sawada [17] using a newly developed eco-hydrological land reanalysis. Results from Leroux et al. [18] show a positive impact of the joint assimilation of leaf area index (LAI) and surface soil moisture in a global Land Data Assimilation System (LDAS-Monde) over the Euro-Mediterranean area. Vegetation sun-induced fluorescence (SIF) is used as an independent observational system to validate the added value of the assimilation. The work of Albergel et al. [19] published in this Special Issue confirms the positive impact of soil moisture and LAI joint assimilation over the contiguous United States. They point out that soil moisture and LAI satellite observations assimilated in LDAS-Monde for reanalysis purposes have the potential to be used to monitor extreme events such as agricultural droughts.

3. Conclusions

Going towards strongly coupled data assimilation involving all Earth system components is a subject of active research. This Special Issue shows that a lot of progress is being made in the ocean–atmosphere domain, but also over land. As atmospheric models now tend to address subkilometric scales, assimilating high spatial resolution satellite data into the land surface models used in atmospheric models is critical. This evolution is also challenging for hydrological modeling.

Author Contributions: The three authors contributed equally to all aspects of this editorial.

Acknowledgments: The Guest Editors would like to thank the authors who contributed to this Special Issue and the reviewers who dedicated their time and provided the authors with valuable and constructive recommendations. They would also like to thank the editorial team of Remote Sensing for their support.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Balsamo, G.; Agustì-Panareda, A.; Albergel, C.; Arduini, G.; Beljaars, A.; Bidlot, J.; Bousserez, N.; Boussetta, S.; Brown, A.; Buizza, R.; et al. Satellite and in situ observations for advancing global Earth surface modelling: A review. *Remote Sens.* **2018**, *10*, 2038. [CrossRef]
2. Mulholland, D.P.; Laloyaux, P.; Haines, K.; Alonso Balmaseda, M. Origin and impact of initialization shocks in coupled atmosphere-ocean forecasts. *Mon. Weather Rev.* **2015**, *143*, 4631–4644. [CrossRef]
3. Laloyaux, P.; Balmaseda, M.; Dee, D.; Mogensen, K.; Janssen, P. A coupled data assimilation system for climate reanalysis. *Q. J. R. Meteorol. Soc.* **2016**, *142*, 65–78. [CrossRef]
4. De Rosnay, P.; Balsamo, G.; Albergel, C.; Muñoz-Sabater, J.; Isaksen, L. Initialisation of land surface variables for numerical weather prediction. *Surv. Geophys.* **2014**, *35*, 607–621. [CrossRef]
5. Penny, S.G.; Akella, S.; Alves, O.; Bishop, C.; Buehner, M.; Chevallier, M.; Counillon, F.; Draper, C.; Frolov, S.; Fujii, Y.; et al. *Coupled Data Assimilation for Integrated Earth System Analysis and Prediction: Goals, Challenges and Recommendations*; Technical Report; World Meteorological Organisation: Geneva, Switzerland, 2017.
6. Reichle, R.H.; Koster, R.D.; Liu, P.; Mahanama, S.P.P.; Njoku, E.G.; Owe, M. Comparison and assimilation of global soil moisture retrievals from the Advanced Microwave Scanning Radiometer for the Earth Observing System (AMSR-E) and the Scanning Multichannel Microwave Radiometer (SMMR). *J. Geophys. Res.* **2007**, 112. [CrossRef]
7. Barbu, A.L.; Calvet, J.-C.; Mahfouf, J.-F.; Albergel, C.; Lafont, S. Assimilation of Soil Wetness Index and Leaf Area Index into the ISBA-A-gs land surface model: Grassland case study. *Biogeosciences* **2011**, *8*, 1971–1986. [CrossRef]
8. Dee, D.P. The ERA-Interim reanalysis: Configuration and performance of the data assimilation system. *Q. J. R. Meteorol. Soc.* **2011**, *137*, 553–597. [CrossRef]
9. Hersbach, H.; de Rosnay, P.; Bell, B.; Schepers, D.; Simmons, A.; Soci, C.; Abdalla, S.; Alonso-Balmaseda, M.; Balsamo, G.; Bechtold, P.; et al. Operational global reanalysis: Progress, future directions and synergies with NWP. *ERA Report Series* **2018**, *27*, 65.
10. Browne, P.A.; de Rosnay, P.; Zuo, H.; Bennett, A.; Dawson, A. Weakly Coupled Ocean–Atmosphere Data Assimilation in the ECMWF NWP System. *Remote Sens.* **2019**, *11*, 234. [CrossRef]
11. Banos, I.H.; Sapucci, L.F.; Cucurull, L.; Bastarz, C.F.; Silveira, B.B. Assimilation of GPSRO Bending Angle Profiles into the Brazilian Global Atmospheric Model. *Remote Sens.* **2019**, *11*, 256. [CrossRef]
12. Lguensat, R.; Viet, P.H.; Sun, M.; Chen, G.; Fenglin, T.; Chapron, B.; Fablet, R. Data-Driven Interpolation of Sea Level Anomalies Using Analog Data Assimilation. *Remote Sens.* **2019**, *11*, 858. [CrossRef]
13. Yi, L.; Zhang, W.; Wang, K. Evaluation of Heavy Precipitation Simulated by the WRF Model Using 4D-Var Data Assimilation with TRMM 3B42 and GPM IMERG over the Huaihe River Basin, China. *Remote Sens.* **2018**, *10*, 646. [CrossRef]
14. Pangaluru, K.; Velicogna, I.; Mohajerani, Y.; Ciracì, E.; Charakola, S.; Basha, G.; Rao, S.V.B. Soil Moisture Variability in India: Relationship of Land Surface–Atmosphere Fields Using Maximum Covariance Analysis. *Remote Sens.* **2019**, *11*, 335. [CrossRef]
15. Yi, L.; Zhang, W.; Li, X. Assessing Hydrological Modelling Driven by Different Precipitation Datasets via the SMAP Soil Moisture Product and Gauged Streamflow Data. *Remote Sens.* **2018**, *10*, 1872. [CrossRef]
16. Massari, C.; Camici, S.; Ciabatta, L.; Brocca, L. Exploiting Satellite-Based Surface Soil Moisture for Flood Forecasting in the Mediterranean Area: State Update Versus Rainfall Correction. *Remote Sens.* **2018**, *10*, 292. [CrossRef]
17. Sawada, Y. Quantifying Drought Propagation from Soil Moisture to Vegetation Dynamics Using a Newly Developed Ecohydrological Land Reanalysis. *Remote Sens.* **2018**, *10*, 1197. [CrossRef]

18. Leroux, D.J.; Calvet, J.-C.; Munier, S.; Albergel, C. Using satellite-derived vegetation products to evaluate LDAS-Monde over the Euro-Mediterranean area. *Remote Sens.* **2018**, *10*, 1199. [CrossRef]
19. Albergel, C.; Munier, S.; Bocher, A.; Bonan, B.; Zheng, Y.; Draper, C.; Leroux, D.J.; Calvet, J.-C. LDAS-Monde Sequential Assimilation of Satellite Derived Observations Applied to the Contiguous US: An ERA-5 Driven Reanalysis of the Land Surface Variables. *Remote Sens.* **2018**, *10*, 1627. [CrossRef]