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Preface

"Earth observation for land–atmosphere interaction science"

D. Fernández-Prieto[1], J. Kesselmeier[2], M. Ellis[3], M. Marconcini[4], A. Reissell[5], and T. Suni[5]

[1]European Space Agency, ESRIN, Via Galileo Galilei, 00044, Frascati, Italy
[2]Max Planck Institute for Chemistry, Hahn-Meitner-Weg 1 55128 Mainz
[3]BGS Science Programme, UK
[4]Deutsches Zentrum für Luft- und Raumfahrt (DLR), German Aerospace Center, Oberpfaffenhofen, 82234 Wessling, Germany
[5]iLEAPS International Project Office (iLEAPS IPO), Department of Physics, P.O. Box 48, 00014 University of Helsinki, Finland

Correspondence to: D. Fernández-Prieto (diego.fernandez@esa.int)

1 Introduction

Land–atmosphere interactions include a variety of complex processes and feedbacks between radiative, hydrological, and biogeochemical processes resulting in critical exchanges of energy and matter that influence the overall Earth system and its climate. The observation, understanding and prediction of such processes from local to global scales represent a major scientific challenge that requires multidisciplinary scientific effort and international coordination involving different scientific communities and technologies.

The study of land–atmosphere interactions has been hindered in the past by the lack of suitable data at the required spatial and temporal scales. Over the last few years, Earth observation (EO) data integrated with in situ networks and suitable models have demonstrated the potential to become a major tool for observing key variables and characterising the main processes governing land–atmosphere interactions at global to local scales. In the next few years the capabilities of monitoring land surface and atmosphere will be further improved by the increasing number of advanced EO missions to be launched by space agencies. The full exploitation of such increasing multi-mission observational capacity requires harmonised research efforts involving both EO and Earth system scientists, modellers, and institutions to develop novel observations and robust biophysical products to be effectively integrated with in situ data and within appropriate coupled models.

In this context, in 2010, the European Space Agency (ESA), iLEAPS (the Integrated Land Ecosystem–Atmosphere Processes Study of the International Geosphere-Biosphere Programme, IGBP) and the European Geoscience Union (EGU) organised an international conference on *EO for Land–Atmosphere Interaction Science* at the ESA centre in Frascati (Italy). The conference, attracting almost 200 scientists worldwide, aimed at bringing together the EO and Earth system communities, as well as scientific institutions and space agencies involved in the observation, characterisation and forecasting of land–atmosphere interactions and their impacts. In particular, the event presented a unique opportunity to facilitate the communications and scientific exchanges among these different communities in order to enhance the coordination of specific scientific efforts and advocate for a common view of major scientific needs and priority areas for the future.

As a synthesis of these recent advances, this special issue entitled "Earth observation and land–atmosphere interactions science" collects some of the works presented at the above conference and gathers a number of scientific results demonstrating the potential and exploring the limits of EO technology as a key tool to advance our current knowledge on land–atmosphere processes at different scales in space and time.

After an overview of the main scientific challenges in land–atmosphere interactions today (Sect. 2), the scientific advances reported in the papers of this special issue will be briefly summarised in Sect. 3. Section 4 will provide an outlook to future opportunities.

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2 Current scientific challenges in land–atmosphere interactions science

The overall goal of iLEAPS is to enhance the understanding of how interacting physical, chemical and biological processes transport and transform energy and matter through the land–atmosphere interface, particularly emphasising interactions and feedbacks at all scales, from past to future and from local to global. iLEAPS studies the implications of transport and transformation processes at the land–atmosphere interface for Earth system dynamics from two main perspectives: (1) land–atmosphere interactions crucial for global radiative forcing and the Earth system, and (2) solution-oriented research for sustainable development.

The iLEAPS community has always invested in creating new ways to observe and model the land–atmosphere continuum: observation systems have developed to networks of long-term flux stations and large-scale land–atmosphere observation platforms and, more recently, to combining remote sensing techniques with ground observations (Baldocchi et al., 2005; Hari et al. 2009; Guenther et al., 2011; de Leeuw et al., 2011; Jung et al., 2011). Remote sensing and other Earth system observation techniques combined with modelling have become an indispensable tool in iLEAPS research regarding all the major research topics such as aerosol dynamics, atmospheric composition, and land cover and land use change. In addition to purely natural land–atmosphere interactions, human influence has always been an important part of iLEAPS science. In its effort to integrate the human and natural contributions to radiative forcing and important feedback mechanisms, iLEAPS will require realistic estimates of land use and anthropogenic emissions resulting from population increase, migration patterns, food production allocation, land management practices, energy production, industrial development, and urbanisation. EO offers completely new, efficient possibilities to monitor and observe these phenomena from the regional to the global scale and, especially, in areas unattainable by traditional observation techniques, such as large areas in Africa, Asia, Latin America, and Eurasia – where iLEAPS is planning to start new regional nodes.

Important initiatives requiring a strong emphasis on Earth observation include (but are not restricted to) the IGAC/WMO/iLEAPS initiative on Fire in the Earth system; the GLP/iLEAPS initiative on Interactions among Managed Ecosystems, Climate, and Societies (IMECS); the ESA-iLEAPS project on remote sensing in the boreal zone (ALANIS); the Pan-Eurasian Experiment (PEEX) on forcing and feedback mechanisms in the Pan-Eurasian Arctic and boreal regions, combining ground-based, airborne and satellite observations together with global and regional models and socioeconomic analysis to study forcing and feedback mechanisms in the changing climate; and, finally, the Remote sensing in the Aerosols, Clouds, Precipitation, Climate initiative (Sat-ACPC). The scope of iLEAPS research for the next years will include the following four themes:

- [Focus 1.] Interactions between climate change, extreme events, and the Earth system. This focus will include the hydrological cycle and associated processes, biogeochemical feedbacks, biosphere–aerosol–cloud–precipitation interactions, and regional and global perspectives of all of these topics.
- [Focus 2.] Land–atmosphere exchange of reactive, long-lived compounds, and aerosols. This focus will cover greenhouse gases (long- and short-lived), non-radiatively active reactive trace gases, evolution of aerosols, and industrial and urban emissions.
- [Focus 3.] Transfer of material and energy in the ecosystem–atmosphere system: Observation, theory, and modelling. This focus is especially dependent on remote sensing and other Earth observation techniques. It involves ground-based Earth system observation system; observational networks; expanding the use of advanced tracers, remote sensing and airborne measurements; boundary layer dynamics (energy, mass, biosphere–atmosphere interactions, atmospheric chemistry, and aerosols); and integrative biosphere–atmosphere model evaluation.
- [Focus 4.] Understanding the dynamic properties of the human-dominated environments. This theme looks at the human–natural system interface as well as mostly human-dominated ecosystems and concentrates, among other issues, on interactions among managed environments, climate, and societies; how human drivers are altering ecosystem–atmosphere coupling (land use, irrigation, fertilisation, grazing, urbanisation, etc.); complex dynamics modelling among human and natural systems; assessing food and fresh water security (effects of climate, management, socioeconomic aspects); and changes in ecosystem services.

3 Advances on the use of EO technology for land–atmosphere interactions science

This section provides an overview of the different papers collected in this special issue. They provide a good panorama of some of the recent scientific efforts carried out by the international scientific community to advance our understanding of land–atmosphere interactions by exploiting the advantages of EO technology. It is worth nothing that the discussion below provides only a partial view of the current state of the art, as the discussion is mainly focused on the papers included in this special issue. In fact, many important parameters, observations and open scientific issues are not tackled in detail. However, the sample of works included in this issue provides an excellent showcase of some of the main areas of research where the community is focusing its efforts at the present time.

Wild fires, the impacts of their emissions into the atmosphere as well as the post-fire vegetation processes leading to recovery represent a key component of land–atmosphere interactions where EO may make an important contribution. Several papers address this topic in this special issue from different perspectives. For example, A. Ito (Ito, 2012) made use of different satellite geo-information products (burned area, active fire, land cover and MIRS derived plume injection heights) and biochemical and aerosol chemical transport models to estimate biomass burning emissions from fires in Siberia and to assess the relative importance of biomass burning sources of soluble iron compared to those from dust sources into the oceans. This work demonstrates that extreme fire events contribute significantly (10–60 %) to the deposition of soluble iron to downwind regions over the western North Pacific Ocean. The impact of wildfires, in particular the western Russia fires starting in late July of 2010, was investigated in Mei et al. (2012). In particular, the study analysed the transport trajectory and impacts of the Russian wildfires using the aerosol optical depth (AOD) images retrieved from MODIS data. Also, Ozone Monitoring Instrument (OMI) data were used to measure the associated trace gases (NO_2 and SO_2) and CO_2 as well as the vertical distribution of AOD data retrieved from Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) into a chemical transport model. Kaiser et al. (2012) also focus their analysis on the Russian fires in the summer of 2010. In particular, their work demonstrates the potential use of the Global Fire Assimilation System (GFASv1.0) to calculate biomass burning emissions by assimilating Fire Radiative Power (FRP) observations from the MODIS instruments on board the Terra and Aqua satellites. Looking at post-fire vegetation processes, Bastos et al. (2012) make use of NDVI VEGETATION data to assess the accuracy of a vegetation recovery model over two selected areas in Portugal affected by two large wildfire events in the fire seasons of 2003 and 2005, respectively. The analysis indicates that fire damage is a determinant factor of regeneration.

Aerosols represent another important area where EO technology may make a significant contribution to land–atmosphere interactions science. In this context, the recent eruption of the Eyjafjallajökull Volcano starting on 14 April 2010 resulted in a significant spreading of volcanic ash over most parts of Europe, impacting the air traffic for weeks. Gao et al. (2012) demonstrate the use of ground-based in situ measurements, lidar-based remote sensing and airborne in situ measurements to identify the volcanic origin of detected aerosols in Slovenia and simulate the airflow trajectories explaining the arrival of the air masses containing volcanic ash to Slovenia. Also, the role of salt lakes and salty soils in the production of volatile halogenated organohalogens (VOX), which can affect the ozone layer of the stratosphere and play a key role in the production of aerosols, is investigated in Kotte et al. (2012). In particular, a remote sensing based analysis was performed in the southern Aral Sea basin, providing information on major soil types as well as their extent and spatial and temporal evolution. MODIS time series and supervised image classification have been used to compute daily production rates for trans-1,2-dichloroethene (DCE).

Methane emissions have been also addressed in this special issue. In particular, Ito and Inatomi (2012) assess the global terrestrial budget of methane (CH_4) using a process-based biogeochemical model (VISIT). In this context, satellite EO data have been used for deriving soil properties (i.e., International Satellite Land Surface Climatology Project Initiative II), seasonal change in the inundated wetlands (i.e., SSM/I), paddy field distribution (i.e., MODIS). CH_4 flows were estimated at $0.5°\times0.5°$resolution from 1901 to 2009. Results indicate that sources and sinks are distributed highly heterogeneously over the Earth's land surface. The trend of increasing net terrestrial sources and its relationship with temperature variability imply that terrestrial CH_4 feedbacks will play an increasingly important role as a result of future climatic change. Also, Bartsch et al. (2012) present an assessment of the capability of active microwave sensors to derive inundation dynamics and wetland extent as a key factor controlling methane emissions, both in nature and in the parameterisations used in large-scale land surface and climate models.

The carbon cycle represents another key topic in land–atmosphere interaction science. This topic has been addressed by Kaiser at al. (2012) and Kaminski et al. (2012). The former report on a comparison of different leaf area index (LAI) satellite based products (from MODIS and CYCLOPES) with model simulations derived from land surface modelling (i.e., ISBA-A-gs and the ORCHIDEE models) showing their main advantages and drawbacks to describe the interannual and the seasonal variability of monthly LAI values. The latter demonstrate consistent assimilation at global scale of the fraction of absorbed photosynthetically active radiation (FAPAR) derived from the satellites (MERIS) into the terrestrial BETHY (Biosphere Energy Transfer Hydrology) model, where the global MERIS FAPAR product and atmospheric CO_2 (derived from in situ data) are used simultaneously. The assimilation improves the match with independent observations.

One of the main advantages of EO is the potential to collect information on the global scale, allowing in situ data to be complemented. An example of this capacity is presented in Fröhlich-Nowoisky et al. (2012). This paper addresses the existence of different biogeographic regions in the atmosphere. In situ air filter samples were collected at continental, coastal, and marine locations in tropical, mid-latitude, and sub-polar regions around the world. Global atmospheric transport model simulations have been run with climatological sea surface temperatures derived from AVHRR and online calculation of atmospheric dynamics. Results assess the difference between the "blue ocean" and "green ocean" regimes in the formation of clouds and precipitation and suggest that air flow patterns and the global atmospheric circulation are important for the evolution of microbial ecology and for the understanding of global changes in biodiversity.

The problem of assimilation of EO data into land surface models, potential opportunities and benefits as well as main drawbacks and limitations have been addressed in several papers in this special issue. For example, Dieye et al. (2012) made use of Land Cover and Land Use (LCLU) classification of multi-temporal Landsat satellite data to assess the sensitivity of soil organic carbon (SOC) modelled by the Global Ensemble Biogeochemical Modelling System (GEMS). The experiments carried out over Senegal assessed the SOC uncertainty due to satellite classification errors. The study demonstrates a significant dependency not only on the LCLU classification errors but also on where the LCLU classes occur relative to the other GEMS model inputs. Also, Barbu et al. (2011) provide an assessment of the benefits obtained from and the challenges to be faced to assimilate satellite derived soil wet index and leaf area index in land surface models. The study demonstrates that a significant improvement of around 13 % of the root-zone soil water content is obtained by assimilating dimensionless root-zone SWI data while a lower impact is observed when assimilating in situ data. This work highlights the importance of the assimilation design on the quality of the analysis.

Understanding radiation balance and heat fluxes represents another major scientific challenge where observations from space may provide a significant advantage at local, regional and global scales. This multi-scale capacity offered by different EO sensors and missions provides an opportunity to advance the understanding of land surface processes. In this context, satellite information has been used (Brunsell and Anderson, 2012) to study how the multi-scale spatial structure of land surface heterogeneity impacts the relationships and feedbacks between land surface conditions, mass and energy exchanges between the surface and the atmosphere. Using data from Landsat, MODIS and GOES satellites, this work aids in identifying the dominant cross-scale nature of local to regional biosphere–atmosphere interactions. As another example, reanalysis and observational data covering 1979–2008 were used by Kharyutkina et al. (2012) in the Asian territory of Russia to study the variability of spatial–temporal distribution of temperature and radiative balances components. The study showed an increase of back Earth atmosphere shortwave radiation since the 1990s as well as a downward trend of radiative balance.

Also, surface emission and deposition fluxes of reactive nitrogen compounds have been studied by Delon et al. (2012) at five sites of West Africa during the period 2002 to 2007. The study used a combination of data from different sources including surface measurements, satellite and modelling to document the atmospheric nitrogen cycle in tropical regions to overcome the scarcity of available data from the African continent. In particular, global biomass burning inventories for NOx and NH_3 using the L3JRC burnt area product based on the SPOT-VGT vegetation satellite has been used. Also, the Global Land Cover (GLC) vegetation map along with the satellite based meteorological data were used to provide the conditions needed to run the ISBA model.

Finally, in Bontemps et al. (2012) the potential offered by satellite based global land cover characterisation (GlobCover based on MERIS data) is analysed as a tool to provide basic information to land–atmosphere interaction process studies and climate modellers.

4 Final remarks

This special issue aims at providing an overview of some of the current developments in the use of EO for land–atmosphere interactions. It does not provide an exhaustive but only a partial view of key aspects where EO data may contribute to this important area of Earth science. Key conclusions drawn from the analysis of various papers included in this special issue and some remarks for future work are outlined below.

This special issue underlines that an integrated approach to observe and characterise land–atmosphere interactions with all its components will be fundamental to ensure effective computation of the different fluxes and components of various interactions between land and atmosphere. In the near future, this interdisciplinary collaboration, the dialogue between the EO and the Earth system science modellers, and a more holistic approach to face land–atmosphere science will be fundamental to progress in different areas pointed out in Sect. 2.

Contributions included in this issue also highlight the large number of methods, techniques and products that have been developed by the EO community. In this context, promoting inter-comparison exercises providing a clear understanding of the validity ranges, uncertainties and limitations of algorithms and retrieved data products is a major need for the future. In this respect it is worth noting the international coordination efforts carried out in the context of iLEAPS and space agencies to assess and compare different EO-based products and data sets, hence contributing to promotion and facilitation of the understanding and acceptance by the research community.

Furthermore, dedicated multi-scale data analysis experiments studying the inter-scale relationships between point measurements on the ground – including very tall towers bridging the gap between surface layer and airborne measurements, airborne data sets and observations retrieved at different scales and resolutions from satellites – need to be promoted. A better understanding of the multi-scale inconsistencies between the biophysical processes measured in situ and the final observations and data products obtained from satellites at different resolutions from local to global scales will open new opportunities to develop enhanced methods, algorithms and data products. Reducing multi-scale inconsistencies between in situ observations and different scale EO-based data products is a major requirement to ensure an effective dialogue between the models characterising biophysical processes and the geo-information retrieved from satellites.

The capacity of currently available missions is being complemented by a new generation of scientific and operational satellites that will offer new opportunities for science and operational applications. However, it will still be necessary to further understand the full potential of these novel missions that in many cases are based on new technologies. Further research will be required to maximise the scientific impact of those missions as well as to generate robust and enhanced data products that address current gaps in observations. This growing observational capacity is also increasing the need for dedicated research efforts aimed at exploring the potential for the synergic exploitation of the different and complementary capacities offered by these new sensors. Multi-mission approaches that exploit synergies among different missions and data sets need to be further promoted.

Finally, it is worth emphasising the need for internationally coordinated efforts for the development of long-term consistent data records governing the land–atmosphere interactions that may exploit the increasing archives of EO data.

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