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Land information system: An interoperable framework for high resolution land surface modeling

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Abstract

Knowledge of land surface water, energy, and carbon conditions are of critical importance due to their impact on many real world applications such as agricultural production, water resource management, and flood, weather, and climate prediction. Land Information System (LIS) is a software framework that integrates the use of satellite and ground-based observational data along with advanced land surface models and computing tools to accurately characterize land surface states and fluxes. LIS employs the use of scalable, high performance computing and data management technologies to deal with the computational challenges of high resolution land surface modeling. To make the LIS products transparently available to the end users, LIS includes a number of highly interactive visualization components as well. The LIS components are designed using object-oriented principles, with flexible, adaptable interfaces and modular structures for rapid prototyping and development. In addition, the interoperable features in LIS enable the definition, intercomparison, and validation of land surface modeling standards and the reuse of a high quality land surface modeling and computing system.
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1. Introduction

Land surface water, energy, and carbon conditions have profound influences on the overall behavior of the climate systems. A better understanding of these conditions helps in the improved use of natural resources, prevention of adverse impacts, and our adaptation to climate change. Researchers have been involved in integrating land surface simulation, observation, and analysis methods to accurately determine land surface energy and moisture states. Examples of such systems include the 25 km Global Land Data Assimilation System (GLDAS) (Rodell et al., 2004) and the 12.5 km North American Land Data Assimilation System (NLDAS) (Mitchell et al., 2004). Computational limitations in hardware and software have impeded the development and application of such systems at higher spatial resolutions. LIS is a software system that takes advantage of the technological improvements in computing

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and environmental monitoring tools to enable a global high resolution (as high as 1 km) land modeling system. The high resolution modeling capabilities enable LIS to directly ingest the vast array of high resolution observations such as those available from the next generation NASA earth science instruments (Earth Observing System (EOS) Terra and Aqua). The ability to operate at the same fine spatial scales of the atmospheric boundary layer and cloud models also helps in improving water and energy cycle prediction capabilities. In addition to providing a land surface modeling infrastructure, the portable, interoperable design of LIS enables it to be a valuable research tool for land surface researchers and other interdisciplinary scientists.

The land surface modeling infrastructure in LIS consists of several land surface models (LSMs) run typically in a stand-alone manner, using a combination of observationally based precipitation and radiation with downscaled model-based meteorological inputs and many surface parameters. Simulation of land surface processes using these models at high spatial resolution is computationally demanding due to the large number of simulation runs required and the relatively high data density of the LSMs. LIS makes use of the state-of-the-art scalable high performance computing technologies to overcome these challenges. To provide efficient management, storage, and high throughput data access in simulations, LIS employs a number of generic tools to manage the input and output data. To enable the effective use of the system to end users, LIS also provides intuitive web-based interfaces to LIS data and other resources.

Many existing earth science applications, although highly scalable and computationally capable, lack the ability to interoperate with other earth system applications. As a result, the cost of adding new functionalities and adapting the existing systems to function with other applications may be prohibitively high. LIS attempts to achieve code interoperability by applying advanced software engineering concepts in its design. The system is designed as an object-oriented framework that can be shared and reused by scientists and practitioners in the land surface modeling community. LIS provides the use of a complete, usable, and integrated set of high level tools that can be applied without the necessary knowledge of underlying computer hardware or software. The use of object-oriented principles helps in designing LIS to be flexible and extensible, enabling rapid prototyping of new applications into LIS.

In addition to providing an infrastructure to support land surface research and applications activities, LIS has also adopted other earth system modeling standards and conventions, such as the Earth System Modeling Framework (ESMF) (Hill et al., 2004) and Assistance for Land Modeling Activities (ALMA) (ALMA, 2002). ESMF is a system that provides a flexible software infrastructure to foster interoperability, portability, and code reuse in climate, numerical weather prediction, data assimilation, and other earth science applications. ALMA is a land-atmosphere coupling standard that is being developed by the broad land-atmosphere research community. By conforming to the standards laid out by ESMF and ALMA, LIS provides capabilities to interact with other earth system models.

The following sections describe the land modeling and computing tools in LIS, the interoperable features and adoption of earth system modeling standards, and the application of LIS in modeling land surface processes.

6. Summary and future directions

LIS is an evolving framework for high resolution land surface modeling. The use of advanced software engineering concepts in the design of LIS provides a well-defined architecture that allows the rapid specification of numerical models and data products. The interoperable features in LIS allow numerical models to explore various model/observation prediction scenarios for a given application.

In addition to providing a framework for land surface simulation, the flexible design of LIS enables researchers to focus on a wide variety of socially relevant science, education, application, and management issues. The accurate assessment of the spatial and temporal variation of the global land surface water can be used in conjunction with high resolution data obtained from satellites and other sources to improve our understanding of the natural processes. This knowledge can in turn be used for a more efficient management of natural resources. For example, the prediction of variables such as snowpack, amounts of soil moisture, the loss of water into the atmosphere from plants, etc. can be used to manage water in resource-limited areas. Researchers can also perform countless "what-if" studies, such as assessing the impact of landcover changes on climate change.

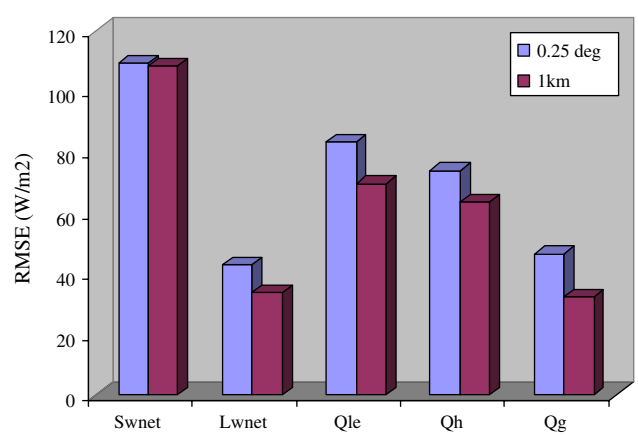

Fig. 13. Comparison of root mean square errors (RMSE) at 25 km and 1 km resolution for the energy fluxes averaged over all LSMs and CEOP sites (Swnet, net shortwave radiation; Lwnet, net longwave radiation; Qle, latent heat flux; Qh, sensible heat flux; Qg, ground heat flux).