Enabling worldwide access to climate simulation data: the earth system grid (ESG)

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Abstract. With support from the U.S. Department of Energy’s Scientific Discover Through Advanced Computing (SciDAC) program, we have developed and deployed the Earth System Grid (ESG) to make climate simulation data easily accessible to the global climate modelling and analysis community. ESG currently has 2500 registered users and manages 160 TB of data in archives distributed around the nation. From this past year alone, more than 200 scientific journal articles have been published from analyses of data delivered by the ESG.

1. Introduction
The U.S. Department of Energy’s (DOE) investment in climate change research is broad, spanning model development, climate change simulation, model intercomparisons, observational programs, and supporting infrastructure for the Intergovernmental Panel on Climate Change (IPCC) [15]. Increasingly, climate change research is data intensive, involving the analysis and intercomparison of simulation and observation data from many sources. Continued scientific progress depends upon powerful, effective enabling technologies that allow the core climate science community to coherently manage and publish a diverse collection of what in a few years will be petascale data, such that a broad, global community can access and analyze it.
DOE’s SciDAC program brought major advances in not only climate modeling (via the Community Climate System Model – CCSM - [8] effort) but—equally importantly—in the management and sharing of distributed terascale data, via the Earth System Grid (ESG) project [6, 7, 11]. The multidisciplinary ESG team developed and delivered a production environment that serves a worldwide community with climate data from multiple climate model sources (e.g., CCSM, PCM, IPCC), ocean model data (e.g., POP), CCSM source code distribution, and analysis and visualization tools. Data holdings are distributed across multiple sites including LANL, LBNL, LLNL, NCAR, and ORNL. ESG also operates a dedicated portal that supports the IPCC community in the development of its 4th Assessment Report (AR4) [14]. The ESG enterprise now supports 2500 registered users from around the globe; manages over 160 TB of data, models, and tools; and has delivered more than 100 TB of data to its users. It is estimated that over 200 scientific publications focused upon the analysis of the IPCC data alone have been authored.

2. An Overview of ESG
ESG is a large, production, distributed system – a DataGrid - with primary access points via two web portals: one for general climate research data and another dedicated to the IPCC activity.

![Figure 1: ESG Portal](image)

Users of the ESG portal first undergo a registration process, where they are made known to the system and granted various privileges and access to data collections. The main portal page, shown in Figure 1, provides news, status, and live monitoring of the ESG. Once logged in, users may either search or browse ESG catalogs to locate desired datasets, with the option of browsing both collection-level and file/usage-level metadata. Based on this perusal of the catalogs, users may gather a collection of files into a “DataCart” or request an “aggregation,” which allows them to request a specific set of variables subject to a spatiotemporal constraint. Selected data may then be downloaded to the user’s system, including datasets that are on deep storage at multiple sites behind security firewalls. Group-based authorization mechanisms allow the ESG administrators to control which users can access which data. Behind all of this exists a collection of ESG management and data publishing tools, along with large-scale data transport tools. The ESG system includes a metrics-gathering capability that keeps track of user activity. Interactive displays as well as reports allow us to track what data is downloaded, how often, and by whom.

ESG’s convenient portal interface, flexible group-authorization capabilities, and metric collection facilities combine to provide an attractive mechanism for delivering tools and data of interest to the climate community, and subsets thereof. Thus, the general ESG portal now provides access not only to over 130 TB of PCM, CCSM, and POP ocean model data, but also to the CCSM model itself,
initialization datasets, and analysis and visualization tools—along with metrics concerning the use of those components. It has begun to evolve into what the community has sometimes termed a “science gateway” [20]. ESG, in its current realization, is the result of the large-scale integration of many different information technologies originating from both the Grid community and the business world at large. Two separate systems were architected and deployed out of this common set of technologies to fulfill two separate sets of requirements. The distributed ESG system, centered around the NCAR ESG portal [11], addresses CCSM, PCM, POP, and related tools, while a dedicated IPCC system embodied in the LLNL/PCMDI ESG portal [17] focuses on providing access to IPCC data.

The ESG data portal (hosted at NCAR) is the center of a distributed Grid system spanning multiple data centers across the nation (see Figure 1). The system provides authenticated, access-controlled, seamless access to over 130 TB of Climate Model data (comprising CCSM, PCM and POP data holdings) and related analysis and visualization software, stored on online disk farms and deep archives across a number of centers. Since going into production in the summer of 2004, over two thousand users have registered and have accessed over 20 TB of data corresponding to approximately 58,000 files. A parallel ESG data portal was established at LLNL specifically to serve climate model data for the IPCC AR4, a comprehensive scientific assessment of the current understanding of climate change. Although serving the international IPCC process was not in our original project plan, we embraced the opportunity and redeployed a dedicated system for this purpose. Approximately 30 TB of data from 23 different models were processed to a common metadata convention and subsequently served to a community of over 500 users, who have so far downloaded 80 TB of data.

3. Current ESG Technologies and Services

The current portfolio of ESG operational data services spans multiple domains including metadata, security, data transport, data aggregation and subsetting, usage metrics, and services monitoring. A high-level illustration of its current architecture is show below in Figure 2.

ESG system security employs the Grid Security Infrastructure (GSI) [21] for service-level authentication and messaging encryption and integrity. An ESG-specific user interface and backend component allows users to register and be affiliated with one or more groups that entitle them to access specific logical resources. Automatically generated user certificates, issued by the ESG Certificate Authority, are stored in a MyProxy [1] repository for easy, web-based retrieval.

Metadata services are based on two complementary technologies. A flexible, object-oriented hierarchical schema is used to capture climate model metadata describing logical concepts such as model ensembles, simulations, and datasets, with all associated detailed information. These data are
stored in a central metadata catalog maintained in a relational database. Additionally, a system of distributed, cross-updating Replica Location Service (RLS) [5] nodes are used to keep track of the physical location of the (perhaps multiple copies of) actual data files accessible through the system. Browseable metadata catalogs conforming to THREDDS [10] are generated automatically from the logical metadata and RLS system. Data transfer and ultimate delivery to the user are also accomplished via a set of integrated software components. The Storage Resource Manager (SRM) [4, 18] in connection with DataMover [19] is used to allow massive, reliable, seamless transfer of data from heterogeneous deep storage repositories (e.g., NERSC and ORNL HPSS, NCAR MSS) to a central system disk cache. SRM employs GSI for security and GridFTP [13] for high-speed data transfer. Data from the system cache, and from distributed, stand-alone online disk farms, is delivered to the user via HTTP by means of a lightweight middleware component based on central authorization and limited lifetime tokens via the Lightweight HTTP Authorized File System (LAHFS) [16]. Finally DataMover Light (DLM) is an easily deployable Java client that interacts with both SRM and LAHFS to allow one-click execution of multiple file transfers directly to the user desktop.

ESG also includes virtual data services, which allow the presentation of a collection of related data files as a single aggregated dataset, and data subsetting, which allows the user to select and download only the data hyperslab of interest. Data subsetting on an aggregation is accomplished by the OPeNDAP-G [2, 3, 12] server, an extension of the OPeNDAP specification commonly used in the geoscientific community to the realm of Grid technologies (GSI and GridFTP). All ESG data services (metadata, data transfer, data aggregation and subsetting) are continuously monitored by a system of daemon programs conforming to the Web Services Resource Framework (WSRF) specification, which provide immediate notification via email to ESG administrators in case of service interruption. User activity spanning all available services is logged in detail for auditing and analysis purposes.

Finally, all technologies mentioned above are integrated into a cohesive architecture and made available to the user via web portal software that is built in Java upon the Tomcat servlet engine and Struts web framework technologies. The two currently deployed web portals constitute the main entry points into the ESG system and allow data users and data providers to access the spectrum of ESG high-level data services for publication, search and discovery, description, download, aggregation, and subsetting.

4. Additional Impacts and Conclusions

In the process of realizing these new production capabilities for climate research, we developed a next-generation system where existing emerging technologies were harnessed and new ones developed. As we have pursued our scientific objectives, we have strived to innovate in partnership with others such that we contribute technology and knowledge back to the wider community. The development of a next-generation OPeNDAP-G server is a good example of this. OPeNDAP [2, 9, 12] is a remote data access framework that is widely used in the geosciences and we created a next-generation framework aimed at modularity, performance, and the ability to use multiple transport protocols (e.g., HTTP, GridFTP). This technology was developed in concert with the core OPeNDAP team and the technology has now been moved back into the community distribution. Another good example of this was ESG’s requirements analysis and subsequent development of a user registration and credential management component which has subsequently been packaged and distributed by the NSF NMI GRIDS Center as the Portal-based User Registration System (PURSE) [3]. ESG collaborators have also worked together to contribute to the development of the Global Organization for Earth System Science Portals (GO-ESSP) [6], an international group that meets annually to develop strategies and relationships that promote interoperability and shared development.

ESG has made a major step forward in terms of our ability to deliver climate model data to a global community. Even so, much remains to be done if we are to respond adequately to the challenges of future petascale climate simulation research. Over the next few years we expect to see modeling activities that produce data at annual volumes comparable to everything ESG currently provides access to. Primary drivers for future capabilities include the 2010 IPCC 5th Assessment Report, an aggressive campaign supported by DOE’s Climate Science Computational End Station (CCES), and ongoing developments and experiments in climate modeling overall.
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