Cyberinfrastructure for Remote Sensing of Ice Sheets

Dr. Linda Hayden, Dr. Geoffrey Fox, and Dr. Prasad Gogineni

Abstract— Science and engineering research and education are foundational drivers of Cyberinfrastructure. Understanding the relationship between sea level rise and melting ice sheets is the application domain of this project. It is an issue of global importance, especially for the populations living in coastal regions. Scientists are in need of computationally intensive tools and models that will help them measure and predict the response of ice sheets to climate change. To address the Cyberinfrastructure challenges presented immediately by the Center for Remote Sensing of Ice Sheets (CReSIS) and the polar science community in general, the Cyberinfrastructure Center for Polar Science (CICPS), with experts in Polar Science, Remote Sensing and Cyberinfrastructure, has been established. This center includes the University of Kansas (KU), the lead CReSIS institution; Indiana University (IU), which is internationally known for its broad expertise in research and infrastructure for eScience; and Elizabeth City State University (ECSU), a founding member of CReSIS with a center of excellence in remote sensing. CICPS includes CReSIS institutions as collaborators and will drive PolarGrid to meet their goals while using the best-known technologies. ,Founded with the vision that Cyberinfrastructure will have a profound impact on polar science, CICPS is committed to the effort needed to build the portal, workflow and Grid (Web) services that are required to make PolarGrid real. This paper describes the set of CICPS projects that are being implemented and proposed. The first of these projects is an NSF CI-TEAM project (PI: Hayden, Co-PIs: Fox and Gogineni), "Cyberinfrastructure for Remote Sensing of Ice Sheets," which establishs a virtual classroom environment and a CReSIS Science Gateway for TeraGrid working with IU, Minority-Serving Institution Cyberinfrastructure Empowerment Coalition (MSI-CIEC), and TeraGrid. The second project, called PolarGrid (PI: Fox, Co-PIs: Hayden and Gogineni), as proposed, deploys the Cyberinfrastructure which provides the polar community with a state-of-the-art computing facility to process the large volumes of data to be collected by CReSIS field operations and support large-scale ice-sheet models. PolarGrid will follow modern open data access standards so that raw, processed and simulated data can be archived outside PolarGrid by and for the full science community.

Index Terms— CI-TEAM, Ice Sheets, Polar Science, Cyberinfrastructure

1 Introduction

Recent polar satellite observations show disintegration of ice shelves in West Antarctica and speed-up of several glaciers in southern Greenland. The great ice sheets in Antarctica and Greenland interact with the global climate in a complex manner, and the impact on global sea level of their retreat would be profound. Most of the existing ice-sheet models, including those used by the Intergovernmental Panel on Climate Change (IPCC), cannot explain the rapid changes being observed. The Center for Remote Sensing of Ice Sheets (CReSIS) is developing new technologies to perform 3-D characterization of ice sheets to understand the physics of rapid changes, and develop models to explain observed changes and predict future behavior. In particular, CReSIS has demonstrated that Synthetic Aperture Radar (SAR) can image the beds of ice sheets. This will enable a new generation of high resolution ice-sheet models with realistic boundary conditions, but it will require distributed Cyberinfrastructure to gather and process data, and assimilate them with large simulations. We propose a sophisticated Cyberinfrastructure instrument that will both enable the crucial ice-sheet science and educate and train a diverse workforce in both Polar Science and Cyberinfrastructure.

We have formed the Cyberinfrastructure Center for Polar Science (CICPS) with experts in Polar Science, Remote Sensing and Cyberinfrastructure. This center includes the University of Kansas (KU), the lead CReSIS institution; Indiana University (IU), which is internationally known for its broad expertise in research and infrastructure for eScience; and Elizabeth City State University (ECSU), a founding member of CReSIS with a center of excellence in remote sensing. CICPS includes CReSIS institutions as collaborators and will drive PolarGrid to meet their goals while using the best-known technologies. Impressive institutional commitments include a new building and faculty lines at ECSU, and resources and system support from IU. We also commit the substantial initial effort needed to build the portal, workflow, and Grid (Web) services that are required to make PolarGrid real.

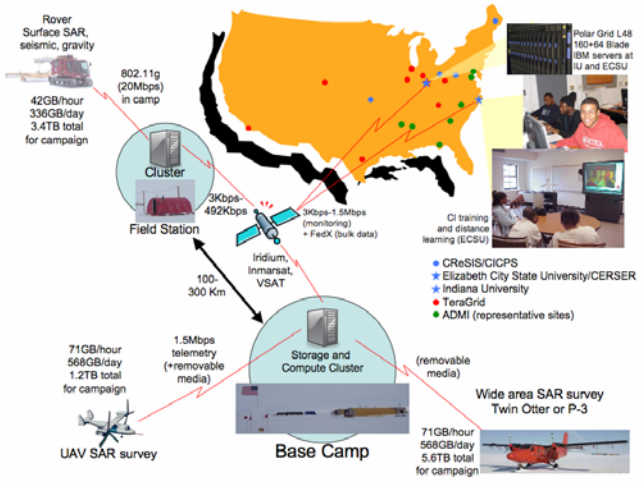

Fig.1. PolarGrid's major components and concept of operations.

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CICPS is founded with the vision that Cyberinfrastructure will have a profound impact on polar science. We will realize this vision through a set of projects that are of the highest quality in all dimensions: Polar Science, Computer Science, Cyberinfrastructure, and EOT (education, outreach and training). The first of these projects is an NSF CI-TEAM project (PI: Hayden, Co-PIs: Fox and Gogineni), "Cyberinfrastructure for Remote Sensing of Ice Sheets," which will establish a CReSIS Science Gateway for TeraGrid working with IU, Minority-Serving Institution Cyberinfrastructure Empowerment Coalition (MSI-CIEC), and TeraGrid.

The second project, as proposed, will deploy the Cyberinfrastructure, called PolarGrid, needed to support polar science and, in particular, the field research program of CReSIS. The major components, including field, base and core systems, are depicted in **Figure 1**.

In past years, most of the data collected in the polar regions were not processed in real time. Instead, data were shipped to computing facilities in the continental US and analyzed well after collection. Real-time processing and data analysis are urgently needed, both in the field and at supporting computing centers, to adjust collection strategies in response to new information contained in the data. The polar community must have access to a state-of-the-art computing facility to process the large volumes of data to be collected by the polar community in 2007-08 as a part of the International Polar Year (IPY) activities, and to support large-scale ice-sheet models.

2 NSF CI-TEAM PROJECT

The vision and goals of the NSF CI-TEAM project, "Cyberinfrastructure for Remote Sensing of Ice Sheets," are based on the fact that "educational settings, audiences, and goals are too important to be adequately addressed as afterthoughts or add-ons to CyberInfrastructure projects and, instead, must be treated as high priorities integrated in a project's overall design" [12]. As such, the NSF CI-TEAM project aggressively engages computer science and engineering students from five minority universities in the Grid, remote sensing, and CReSIS training, seminars, workshops and classes.

ECSU will establish a minimal Grid configuration and a virtual classroom environment with broadcast and receiving capabilities. With regards to the Grid, access will be implemented through web and research portals for use of computational and data resources. The portals will be customized with educational and science interfaces while still allowing access to large amounts of data. The virtual classroom configuration will consist of a Polycom 8000S system with 14-kHz wideband audio, 2 channels of 14-kHz audio, standalone audio conferencing phone, IP (H.232 and SIP) interfaces and Global Management System collaborative communications. The system will have standards compliance for traversing NATs and firewalls. Existing plasma display units will be connected to the 8000S system. For receiving at the partner institutions, VIAVideo for desktop PCs will be provided to allow point-to-point connectivity. ConferenceXP by Microsoft will also be offered as an option for partner institutions.

The CReSIS Education Program benefits significantly from the implementation of the NSF CI-TEAM project. The network proposed supports a number of objectives outlined in the CReSIS Strategic and Implementation Plan including: *CReSIS Objective B: To integrate center research to enhance undergraduate curricula and involve undergraduate students in research; and CReSIS Objective G: Assure that graduate students receive the necessary courses and training opportunities to succeed in their research endeavors.*

The Association of Computer and Information Science/Engineering Departments at Minority Institutions (ADMI) (http://cerser.ecsu.edu/admi2006/purp_gls.html) was founded in August 1989. Represented on the Board of ADMI are Spelman College, Mississippi Valley State University, North Carolina Central University, ECSU, Howard University, Jackson State University, University of the District of Columbia, Hampton University, Fisk University and Florida A&M University. ADMI was established as a national organization dedicated to exploring and providing remedies to the educational issues in computer/infor-mation science and computer engineering that confront minority institutions of higher learning. ADMI goals include:

* Support research initiatives and their continuation at member minority institutions.

* Serve as an advocate/lobbyist for minority institutions interest at funding agency forums, both public and private.

* Exchange information and educational training techniques.

* Identify and seek viable solutions to problems relevant to the disciplines.

* Exchange information and ideas for improving the quality and effectiveness of computer science and engineering at minority institutions.

* Work for the continued development of excellent teaching, state-of-the-art curriculum, research, and equipment enhancement.

* Strive for increased support of the continued, professional advancement of faculty.

* Solicit and assist in the soliciting of funds for achieving the above stated objectives.

ADMI's role in the proposed ECSU Grid project will be to establish capability within their institutions to allow students and faculty to participate in the virtual workshops, training and courses. In addition, students from the ADMI institutions will participate in an 8-week Grid technology workshop to be conducted during the summers at ECSU.

With particular attention to the current and next generation of traditionally underrepresented minority scientists engineers and educators, the NSF CI-TEAM project prepares students with the knowledge and skills necessary to conduct interdisciplinary research in areas including Cyberinfrastructure, remote sensing, engineering and modeling related to glaciers and ice sheets.

3 POLARGRID

While there is considerable evidence now that fast glacial changes occur and have occurred in the past, there is no consensus yet regarding how this takes place. Better understanding will only come from an ambitious campaign to collect more data, and develop new and better models using such data. The National Science Foundation established CReSIS in 2005 for just this purpose. Major advancement in the quantity and quality of data about polar ice sheets is an important objective of the 2008 and 2009 field data campaigns in which new measurement techniques will multiply the quantities of data available to the polar research community. The field program will consist of coordinated satellite, airborne and in situ measurements. Satellite data acquisitions are being planned as a part of the Global Interagency IPY Polar Snapshot Year (GIIPSY) [7]. The field program includes plans to perform airborne measurements to collect data over an area of 200 km x 200 km with grid spacing of 5-10 km and a 20 km x 20 km area with grid spacing of 1 km or less, and

surface-based observations including ice cores, seismics and fine-resolution radars.

CReSIS science research presents a substantial challenge for PolarGrid. The traditional view regarding the relationship of polar ice sheets and climate has been that polar ice sheets respond slowly to changes in climate. Most existing models, including those used by the IPCC, predict only a small contribution from Greenland and Antarctica to global sea level over the next century [11]. However, evidence for active ice sheets, both present-day and in the past, has mounted, and we now understand that large ice sheets can undergo rapid changes [10]. For example, analysis of deep-sea sediment cores has revealed major oscillations in the Laurentide Ice Sheet volume, believed to be associated with surges of the Hudson Bay lobe [5]. During meltwater pulse 1A, *ca*. 14,000 years B.P., sea levels rose about 20 m over a period of 400 years at an average rate of 5 cm/yr [8] compared to the rate of rise of 1-2 mm/yr during the 20th century [6].

The observed rapid changes cannot be explained by conventional models, and thus critically important predictions about the future responses of polar ice sheets to climate change are certain to be wrong in potentially disastrous ways. The existing models are based on a shallow-ice approximation in which driving forces are balanced by friction at the glacier bed. The models incorporate basal sliding where the bed is lubricated or for deformation of a soft sediment layer. However, they do not fully capture the controlling dynamics of ice streams and outlet glaciers, and do not allow for rapid along-flow propagation of force perturbations, including those resulting from removal of peripheral ice shelves.

SAR imaging of the ice-bed interface has the potential to make a significant contribution to glaciology by providing insights regarding the conditions at this critical boundary, including terrain relief and roughness as well as presence and distribution of liquid water. However, SAR image formation is computationally intensive. While the raw radar data, called phase histories, can be collected and stored for post-processing analysis, the image formation process requires a significant amount of signal processing, regardless of whether it is done in real-time or in post-processing. SAR imaging of the ice-bed interface through 3-km thick ice may require iterative focusing to compensate for the unknown variability in the electrical properties of the intervening ice.

Initial CReSIS SAR data collection flights may produce in excess of 6 million complex samples per second per receiver channel. A single 5-hour flight mission could collect as much as one terabyte of raw SAR data. Table 1 shows estimated data volume that CReSIS plans to collect during the 2008 and 2009 field seasons.

Polar science is an exemplar of the type of science that will benefit from an advanced Cyberinfrastructure. Cyberinfrastructure enables a dynamic Data-Information-Knowledge pipeline accelerating new scientific discovery. This will result in better quality predictions rendered in shorter periods of time. Some of the hardware acquisitions will be quite novel to meet the challenges of operating an IT infrastructure in the polar regions.

The impact of the “data deluge” has motivated substantial progress in the areas of data management, real-time sensors and data assimilation algorithms. Other important general Grid research areas of relevance to PolarGrid include scientific gateways [9] to manage the use of Grid-based services. A critical matter is the development of tools that enable polar scientists to make use of sophisticated supercomputers and Grid computing systems without first having to develop deep expertise in computational science themselves. The PolarGrid implementation and development will focus on the following key areas sketched in Figure 1.

a) Field data collection systems to be taken with Polar Science researchers as they collect data.

b) A base camp 64-core cluster, allowing near real-time analysis of radar data by the polar field teams.

c) A large 17 Teraflops cluster, to be integrated with the NSF-funded TeraGrid, to serve the polar research community in final processing of data and supporting simulations. This is split between IU and ECSU to support research and education/training respectively.

d) The implementation of new improvements to the speed and capabilities of ice sheet models, and implementation of web portals to make the data, data products, and resources easily accessible to the polar research community.

e) An educational videoconferencing Grid to support educational activities.

We propose two sets of field and base camp equipment, to simultaneously support operations in the Arctic and Antarctic. An initial prototype system from IU’s commitment will be used to confirm the design of the production expedition Grids. It will be used later in other applications where we face similar power and bandwidth challenges.

IU will lead the design and development of PolarGrid software based on their experience with the Common Instrument Middleware Architecture (CIMA) [1] [2], the Linked Environments for Atmospheric Discovery (LEAD) [3], and QuakeSim [4] projects which cover key areas of remote instruments, sensors, Geographical Information Systems (GIS), simulation, and data assimilation. The entire new area of eScience, in which IU is a leader, aims to develop tools by collaboration between computer and discipline scientists to put the tools needed to rapidly make new discoveries into the hands of discipline scientists.

4 Conclusions

The PolarGrid we propose will transform the capabilities of US polar researchers by enabling them to process and evaluate data as they are collected. This capability is achieved through a combination of laptop computers carried by researchers as they collect data in the field, a 64-core computer cluster to be added to the polar research base camp, and a larger cluster located in the continental US for final data processing and modeling work. The 64-core base camp computer cluster is a system sufficiently powerful that just half a decade ago it might have been considered a university's major supercomputer. This system must be deployed in the field; much of the data will be collected with Synthetic Aperture Radars (SAR) and will require considerable post-processing; and low network bandwidth between the polar regions and larger supercomputer facilities will preclude real-time supercomputing at centers such as the TeraGrid. However, there will be considerable post-collection analysis and scientific investigation on the collected data that will require the resources of the TeraGrid.

Video conferencing hardware and an educational grid is also included as a part of this project to aid in the dissemination of new research findings to students, particularly from traditionally underserved groups, at our partner institutions.

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