are associated with strong variations in materials properties (such as jumps in viscosity over many orders of magnitude) making the problems highly ill-conditioned. CIG has pursued a multiple approach to bring useful software to the community. The first is a collaboration with the developers of deal.II, a finite element library with a wide range of functionality in Adaptive Mesh Refinement (AMR), through the creation of a geodynamics AMR test suite. We currently have tutorials for Stokes flow and mantle convection but will soon release examples in magma migration and viscoelastic deformation. We have also pursued a research strategy with the Institute of Computational Science and Engineering (ICES) at the University of Texas, Austin through which we have recently demonstrated global mantle convection problems having resolutions as fine as 1 km while scaling on tens of thousands of computational cores (processors). In terms of resolution and scalability, the applications are far-reaching for all of geodynamics.

An entirely different strategy that CIG has pursued for the community has been the development and maintenance of Science Gateways to allow users to initiate and monitor simulations on the TeraGrid (the current incarnation of the NSF supercomputer centers and a powerful resource that is under-utilized by the geosciences community). One portal applicable to the MARGINS community is CIG's computational seismology gateway in which users can simulate seismic wave propagation in fully three-dimensional earth models using the versatile Specfem3D code. On the web, users can select the seismic sources and stations (with the data automatically retrieved), select the earth model, start the simulation on a remote parallel computer, and later download the results in the popular SAC format. A beta version allows users to upload their own 3D earth model.

The MARGINS community is encouraged to use CIG software, interact with the developers and oversight committees, and join a working group. We hold several specialized training workshops for both the geodynamics and larger earth science communities. The stand-alone codes can be downloaded as tar files by users to build on their own cluster or as executable binaries that run on a desktop for training and testing. If users do not have a large computer, our major codes are preinstalled on the NSF TeraGrid and CIG has a large community allocation of computational cycles that we can reallocate. Advanced users can download the latest versions of software from our repository or browse our code line by line through the web. Detailed user manuals with technical background, tutorials and benchmarks are available for all codes. For those wanting to actively participate, we have working groups for the subdisciplines of geodynamics, a wide variety of list-servs, and we sponsor several workshops per year. All of the material described here is available through our web site at http://geodynamics.org.

CSDMS and What it Means in the MARGINS context

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CSDMS, pronounced "Systems", stands for the Community Surface Dynamics Modeling System. CSDMS deals with the Earth's surface—the dynamic interface between the lithosphere, hydrosphere, cryosphere, and atmosphere. CSDMS is the virtual home for a diverse community of experts who foster and promote the modeling of earth surface processes, with emphasis on the movement of fluids, sediment and solutes in landscapes, seascapes and their sedimentary basins. In essence CSDMS is about glaciers, floods, deltas, coastal erosion, climate impacts, underwater avalanches, tropical reefs, ocean storms, and much more.

CSDMS includes an open library or repository of useful, vetted, surface dynamic models, along with appropriate databases and numerical tools. The growing library provides access and information on more than 100 models, along with their metadata. The CSDMS Integration Facility in Boulder presently offers 200,000 lines of code. CSDMS's data repository deals with model initializations and boundary conditions; benchmarking data for stand-alone models; and data structures for system framework validation.

CSDMS Integration Facility as supported by the Cyberinformatics and Numerics Working Group provides the "Middleware" to couple models and data systems. CSDMS uses the "Common Component Architecture" to allow components to be combined and integrated for enhanced functionality on high-performance computing systems. "BABEL" is used as the language interoperability compiler that automatically generates the glue code that is necessary for components written in different open-source languages to communicate, including C, C++, Fortran (all years), Java and Python. CSDMS uses as its Interface Standard "OpenMI", to define the rules and supporting infrastructure for how a component must be written or refactored in order for it to more easily exchange data with other components that adhere to the same standard. The OpenMI Standard supports two-way links where the involved models mutually depend on calculation results from each other, allowing models to run asynchronously, and represent data on different geometries (grids).

CSDMS offers software products of interest to academia, government and industry, through its Education and Knowledge Transfer Working Group, that in turn is supported by an Industrial Consortium involving energy and environmental companies, and a CSDMS Interagency

Committee with representatives from NSF, ARO, ACE, ONR, NASA, NOAA, USGS, USDA, EPA, NPS, and DOE/INL. This knowledge transfer effort closely follows the products developed by each of the Environmental Working Groups (Terrestrial; Coastal; Marine) and Focus Research Groups (Chesapeake; Hydrology; Carbonate). Together the CSDMS "virtual" community includes 250 experts (as of Feb 1, 2009) from 22 countries who are advancing the field of Quantitative Geoscience.

CSDMS also provides a concerted effort to help the surface dynamic disciplines take advantage of High Performance Computing (HPC). The CSDMS chain of HPC clusters includes a dedicated Tier 3 CSDMS cluster (512 cores, >6 Tflops), connected to Tier 2 Front Range HPC (7000 cores, >100 Tflops), with plans for linkage to a regional Tier 1 Petascale (>100,000 cores, 2-4 Pflops) system.

As a community effort, CSDMS: 1) ensures continuity and project robustness beyond individual projects; 2) cuts redundancy since open-source models can be built upon on already existing concepts, algorithms and code; 3) allows scientists to engage with software engineers, helping to bridge the cultural and, often, institutional gap between these teams; and 4) offers transparency that promotes user participation, better testing, more robust models and more acceptance of the results.

CSDMS addresses the challenging problems of surface-dynamic systems: self-organization, localization, thresholds, strong linkages across environments, scale invariance, and interwoven biology and geochemistry. CSDMS supports the following imperatives in Earth Science research:

1. discovery, use, and conservation of natural resources;
2. characterization and mitigation of natural hazards;
3. geotechnical support of commercial and infrastructure development;
4. stewardship of the environment; and
5. terrestrial surveillance for global security.

CSDMS partners with related computational and scientific programs to eliminate duplication of effort and to provide an intellectually stimulating environment. To date, partners on the computational side include: ESMF, CCA, OpenMI, CSTMS, CCMP, OMS (Object Modeling System); and with the following observational or field programs: MARGINS, Taiwan CSTS, CCMP, CZO, CUAHSI, NCED, LOICZ, NEON, NOPP, NCALM, Carbonate FRG, RCEM. While this alphabet soup seems daunting, each of these large programs commands infrastructure that supports focused research teams that claim with good evidence to be transformative to national interests within their research disciplines.

To date, CSDMS has focused its attention to the MARGINS Source-to-Sink Initiative. The S2S focus on how "tectonics, climate, sea level and human disturbances regulate the production, transfer and storage of sediment and solutes from their sources to their sinks" is completely in line with the grand challenges of CSDMS. The S2S interests in sediment budgets, canyons, shoreline migration, organic fluxes, incised valleys, clinoforms, and siliciclastic-carbonate interactions, are all aspects that the CSDMS community is helping to address through integrated models and the CSDMS Working Groups or Focus Research Groups. S2S offers CSDMS the potential of an integrated database from which to validate coupled models working through the CSDMS framework. CSDMS needs environmentally integrated databases that involve gridded data that represent a time-dependent multidimensional parameter space, from which 1D, 2D and 3D simulations can be validated.

A community challenge is to ensure good cross-fertilization of ideas and needs. A modeling study might require a CSDMS field program to sample in a prescribed manner, so as to best exercise the model's predictive capabilities in both time and space. S2S field-based studies might otherwise work to economize their research funds and thus sample in a manner to maximize the information needed to uncover the geological history of their area of interest. The two sampling approaches might be very different in where or when observations are made. Indeed the field sites themselves might be different, chosen to reflect the unique criteria of each community. Yet even with little consensus, both communities offer much to the other and strongly support the efforts of one another. As extension of the MARGINS program is discussed this support will undoubtedly be tapped.

Enhance Your Broader Impacts

A range of programs and resources is available to help investigators enhance the impact and educational reach of their MARGINS-funded research.

- MARGINS Post-Doctoral program: Entrain early-career scientists in your research (see box on page 10)
- Research Experience for Undergraduates (REU): NSF solicitation 07-569, http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=5517
- Research Experience for Teachers (RET): NSF solicitation 05-047, http://www.nsf.gov/pubs/2005/nsf05047/nsf05047.jsp
- Submit a new one-page research Nugget (http://www.nsf-margins.org/Nuggets_Public/nuggets_public.html)
- Participate in the MARGINS mini-lesson program: Use and evaluate a broad range of teacher-ready MARGINS mini-lessons in your undergraduate classroom (http://serc.carleton.edu/margins/topic.html)
- Encourage your students to enter the MARGINS Student Prize (http://www.nsf-margins.org/AGU2008/PastPres.html)

MARGINS Education and Outreach
http://www.nsf-margins.org/EPO/index.html