SCEC 2003 PROGRESS REPORT

IMPLEMENTATION OF THE SCEC COMMUNITY VERTICAL MOTION MAP†
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DEVELOPMENT OF A COMMUNITY VERTICAL MOTION MAP OF SOUTHERN CALIFORNIA†
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Introduction

For the 2003 cycle of SCEC funding, two separate proposals relating to the development and implementation of the SCEC Community Vertical Motion Map were submitted to the SCEC panel for consideration. It was suggested that the two research groups work together to design, develop, and begin to populate an initial version of the SCEC Community Vertical Motion Map. This report presents the results of this collaboration, details the progress made toward the development of a Community Motion Map, and outlines plans for continued development and population of the vertical motion database.

Understanding the vertical component of crustal motion is important in regions of complex faulting and distributed deformation such as occurs across the active Pacific – North America plate boundary through southern California. Vertical motions directly measure reverse displacement common to both exposed and blind faults that threaten the urban region (e.g. Dolan et al., 1997; Oskin et al., 2000; Grant et al., 1999; Huftile and Yeats, 1996). Moreover, documentation of distributed vertical deformation is critical to understanding kinematic compatibility of conjugate fault systems common to southern California Additionally, the ongoing revolution in satellite geodesy has progressed to the point where precise records of present-day vertical motion are within reach, while the emerging combination of GPS with radar interferometry offers tremendous spatial coverage of absolute surface motions (Gundmedsson et al., 2002). These advances in modern vertical motions will be represented in version 4.0 of the SCEC Crustal Motion Map that will incorporate vertical motions. One challenge in analyzing these new geodetic data is to deconvolve tectonic signals from non-tectonic ones. A detailed long-term geologic record of crustal deformation is invaluable to this effort.

In response to this emerging need, we have designed, implemented, and partially populated a geologic vertical motion database (GVMD) and vertical motion map utility for southern California. This database and map utility will provides a long-term regional geologic vertical motion baseline centered at the 10^5 year-timescale. The database design has been purposefully left flexible to allow integration into other ongoing geodatabase projects within SCEC, such as the Community Fault Model, and the Fault Activity Database, but provides a unique set of data not currently being compiled within any of the other projects. This database will be of particular interest with the implementation of the SCEC Community Block Model to analyze and interpret long-term vertical uplift rates of tectonic blocks within southern California.

Results

Our efforts this year were focused on three distinct phases of Community Vertical Motion Map development: 1) Design of the database structure for storing, retrieving, and analyzing vertical uplift data; 2) Programmatic development of the database, database procedural tools, and user interface; and 3) Population of the database with actual geologic vertical uplift data. Each of these three facets of the project is discussed below.

Design

During the past year, we have successfully designed a database structure to store, query, and analyze geologic vertical uplift data, as well as a user interface to perform these functions. The database design aspects were the most significant achievement of the project, and form the basis for fairly expedient expansion of the database to

† This progress report also contains significant contributions from SURE Interns Nick Campagna at UCSB and Danielle Verdugo at SDSU.

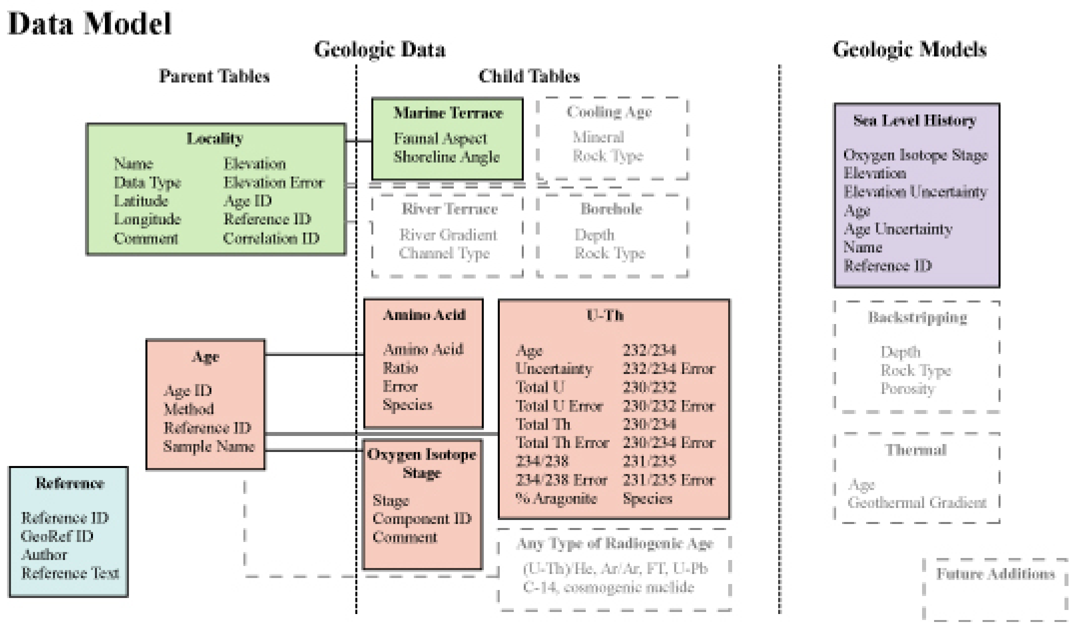


Figure 1. Preliminary data model for the SCEC Community Vertical Motion Database. Colored tables indicate implemented portions of the database using marine terraces as an example dataset. Tables on the left, called 'parent' tables, contain information that is generic to all data types. 'Child' tables 'inherit' all of the qualities of their parents, thus they contain both generic data and type specific data. This data model thus allows a set up generic procedures to calculate uplift rates for a wide variety of geologic and geochronologic data types, will still preserving the data type-specific information that provides justification and explanation for the geologic interpretations made within the data structure. Geologic models, on the right, allow users to select various reference frames relevant to calculating uplift rates; in this example, several eustatic sea level curves are available to users for calculating marine terrace uplift rates.

contain a wide variety of geological data types, while retaining the ability to preserve the potentially significant quantity of actual data (geochemistry or geochronologic data, survey data, paleontology data) required to make a geological assessment of vertical motion at a particular point. Such a database structure has been designed using the concept of ‘inheritance’ within an object-oriented database program (discussed in greater detail below). The concept of ‘inheritance’ exploits the fact that many data types may share common features (for geologic data, location, age, and reference may be common features), as well as having features unique to that particular data type. A ‘parent’ table within the database contains all of the common features to the many data types; ‘child’ tables ‘inherit’ these features, while having unique features of their own. The end practical result is that, through an appropriate attribution of features within a ‘parent’ type, many data types can be simultaneously queried for calculation of vertical uplift rates, while the geological data supporting the ‘parent’ data can be stored within the ‘children’ for later analysis and observation (Fig. 1).

This database design makes the vertical motion database useful both to the geodynamicist, who may wish to calculate geological vertical uplift rates across the whole of southern California in as time-efficient manner as possible, as well as the researcher interested in Quaternary uplift of marine terraces, who may wish to query the specific species of coral used to determine a U-Th disequilibrium age for a particular terrace.

In addition to this advance in geological database design, it was also determined that the vertical uplift rates should be calculated on-the-fly, when requested by the user, rather than being pre-determined results waiting for user retrieval. In part this stems from significant issues related to the selection of a vertical reference frame, and the difficulties in reliably comparing uplift rates from marine terraces, where modern sea level is the reference frame, to fluvial terraces, where some past base level is the reference frame, to thermochronologic data, where a given thermal level in the crust is the past reference. To make these issues as apparent to the user as possible, it was decided to allow the user to control the selection of reference frames for each available data type, and in cases where it was appropriate, to allow the user to select from multiple reference frames for a particular data type. A design for interactive processing of data within the vertical motion database was conceived utilizing procedural query language within the database itself (discussed below), and implemented for a set of data within the database (Fig. 2).

The implementation of this interactive processing scheme provides the end user the ability to select from two separate models of sea level history for southern California when calculating vertical uplift rates based on marine terrace data. Although this is a small step in the overall implementation of the complete vertical motion database, the effectiveness of the procedural language at processing there requests performs two important tasks; 1) the overhead in making uplift calculations is moved from the client side to the server side, thus eliminating a significant amount of communication bandwidth, and 2) effectively involves the end-user in the interpretation and analysis of the vertical motion data.

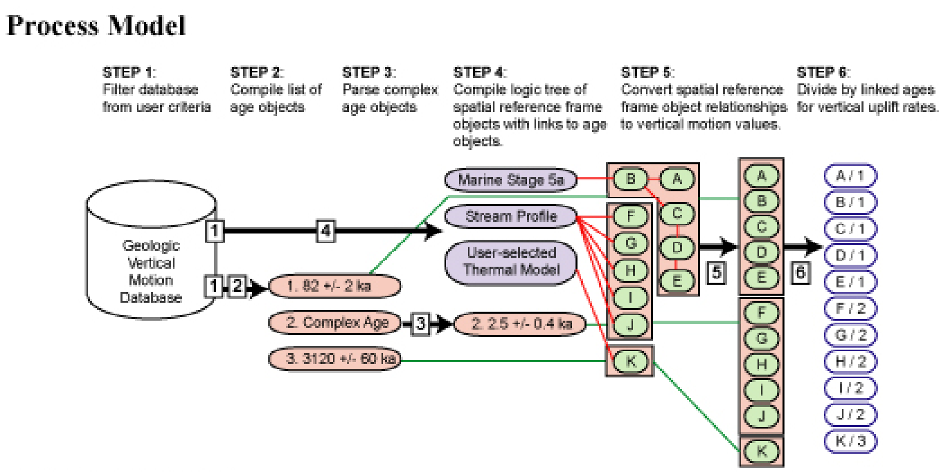
Finally, we wished to present the vertical uplift data on a map view that could be interactively queried by the user for data selection by region or area prior to presenting the user with various data processing options, as described above. Modifications to an existing Internet Map Server were viewed as the most effective means to achieve this design goal.

Development

Following the design portion of the project we attempted to develop the geologic vertical motion database. Based on recommendations from the Community Fault Model project, we selected PostgreSQL as the most appropriate database for our needs. This Open Source software is object-oriented, allows complicated database procedures, such as recursion and transactions necessary to our database model, offers an extension, called PostGIS to natively support geographic data objects, and supports the implementation of a variety of internal procedural languages, including native PL/PGSQL, Perl, and Python, for custom modification and development of database procedures. Within this framework, parent-child table relationships were constructed to support point data relevant to vertical uplift, age data relevant to uplift rates, and reference data relevant to the origin of the other data. Tables representing various vertical datum scenarios were also developed. Customized procedures were designed in the native PL/PGSQL language to select data and calculate uplift rates based on key identifiers for each data point stored in the database.

A web-based interface to provide the user with a graphical means to select and query the data was developed utilizing ArcIMS, a commercial Internet Map Server available from ESRI. The prevalence of ESRI products in the academic work environment, and the fact that ESRI shapefiles are a *de facto* (but not exclusive) standard in distributing geographic data made this selection a natural fit. Customized tools were added to the standard ArcIMS interface environment to provide specific capabilities related to the vertical motion database. In particular, these include the ability to extract key identifier information from user-selected objects in the graphical interface to the backend PostgreSQL database for data processing. Communication between ArcIMS and the PostgreSQL database was implemented in JavaScript and PHP (PHP Hypertext Processor). PHP generated web pages also provide the user-interactive reference frame selection capabilities described above. The web-based interface was implemented on an Apache web server integrated with Java, Tomcat, and PHP. A 2.8 GHz Dell Pentium 4 running Windows XP provides the development environment and acts as the test server. ArcIMS was installed onto this server. PostgreSQL is installed on a Sun Ultra 60 running Solaris 8 (Fig. 3).

Initial testing of the database indicates that the solution is robust and effective. User selection of data within ArcIMS, interactive reference frame selection, and data processing within the PostgreSQL



Processed Data Example

	Longitude (°W)	Latitude (°N)	Present Elevation (m)	Past Elevation (m)	Age (ka)	Uplift Rate (mm/yr)	References (GeoRef ID)
Locality 1	118.36454	34.22335	30 ± 2	+6	125	0.24 ± 0.016	1997-048251
Locality 2	118.36332	34.2243	25 ± 2	+6	125	0.20 ± 0.016	1998-056332

Figure 2. Process model of the geologic vertical motion database showing how geologic relationships are processed to calculate vertical uplift rates. Lower table provides an example of the current output from the vertical motion database.

database were all successfully implemented. Data return is currently limited to a web-based table.

Population

To test the design and development of the geologic vertical motion database, we populated the database with geological data relevant to the uplift of marine terraces along the coast of southern California. Data relevant to the current elevation of the marine terrace, the age of the marine terrace, and references for this data were compiled and entered into the database. Additionally, as much data as could be retrieved was assembled for each data point; thus, all isotopic ratios for U-Th series dates were compiled; species and amino acid ratios were compiled for each amino acid racemization age determination, etc. To date, marine terrace data has been compiled for San Diego County, the Malibu Coast, the Santa Barbara and Ventura Coast, and Cayucos, as well as several of the Channel Islands (Fig. 4).

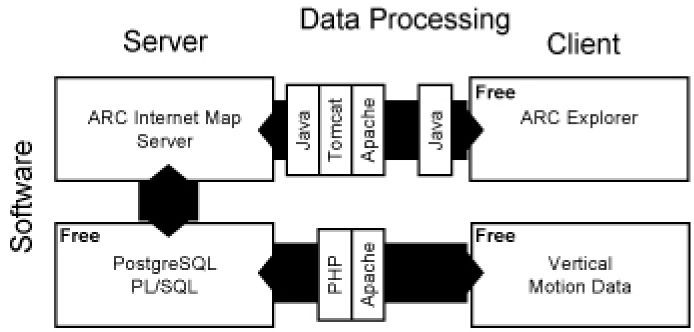


Figure 3. Several software components were integrated to create the vertical motion database and user interface. Data tables were planned and populated in PostgreSQL, an open-source object-relational database. Custom PostgreSQL functions were programmed in PL/SQL to query complex geologic data and calculate uplift rates. A web-based user interface was created integrating ArcIMS, a java-based commercial map data server, dynamic HTML, and custom PHP scripts.

Discussion

Over the course of the past year, we have designed, developed, and tested a model for an interactive Community Vertical Motion Map. The model design contains several features previously unimplemented in geologic databases, and which greatly enhance the utility, flexibility, and completeness of the database. The overall model design should prove readily expandable to a broad range of vertical uplift motion data, and is flexible enough to contain other types of geologic data, if so needed. Procedural queries within the database provide a means to calculate vertical uplift rates from geological data on-the-fly, utilizing user-specified reference frames and models. Calculation speeds are rapid enough, given the present database size, to perform these operations in real-time. The development was achieved using Open Source database products already in use among the SCEC database development community.

A web-based Internet Map Server has been implemented to serve the vertical uplift utility to the scientific community. The Internet Map Server is based on an industry standard, and was customized to meet the needs of this specific project. Communications between the graphical user-interface and the vertical motion database were developed utilizing PHP, and the database was populated with several hundred data points representing vertical geologic uplift data related to marine terraces along the coast line of southern California. Testing of the database was successful to the present point of development.

This database model and graphical user interface, with user-specified processing stream, is a new and unique development in the storage and analysis of geological data, and provides a conceptual model for the development of future geological database projects. The success of database design, development, and implementation to this point warrant continued development of the database, and expansion into other vertical motion data types. The data will be significant interest to the Community Block Model program, and will provide a complementary data suite to the SCEC Fault Activity Database. Comparison of vertical geologic uplift rates derived from this database with geodetic observations of vertical motions will be particularly worthwhile, especially in light of recent controversies regarding the compatibility and comparability of horizontal fault slip rates and geodetic velocities.

Future Research Directions

There are several directions in which we feel that the achievements of the past year can be built on. Primarily, we would like to see the Vertical Motion Database continue to be populated with geological uplift data. This includes, but is not limited to, continuation of marine terrace data, addition of fluvial terrace data, and addition of low-temperature thermochronologic data. Programatically, we would like to replace our customized procedural

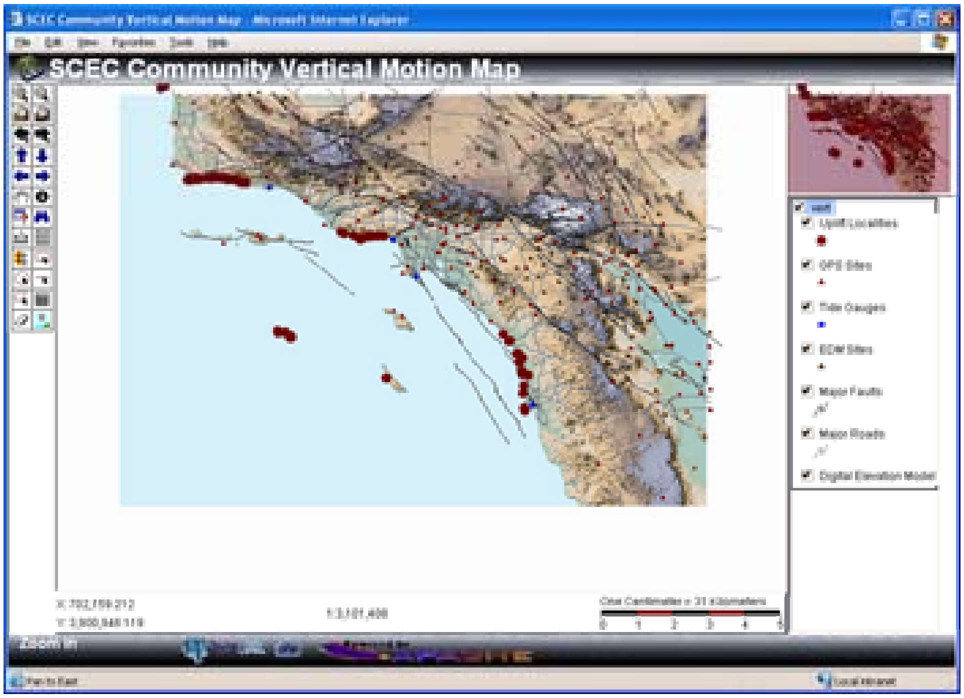


Figure 4. Screen capture of the ArcIMS graphical web interface to the SCEC Vertical Motion Database. Red dots represent marine terraces that have been populated into the database. Legend indicates the wide variety of additional data that can be incorporated into the web-based interface. Lowermost button in the right hand column at the right side of the map display is a customized to initiate calculation and display of vertical motion data**.**

queries in the database, currently written in PL/PGSQL, with a more modern, object oriented language, such as Perl or Python. Implementation of versioning within the database to track changes is also a priority in the next iteration of the database. Other key concerns are a 'digest' function to allow user access to the detailed data stored in the database, which is not currently accessible through the user-interface, and implementation of output functions such that the vertical uplift rates can be distributed in formats compatible with most GIS programs and spreadsheets.

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