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The attached proposal is being submitted to you for your consideration by a NOAA Cooperative Institute. Should you recommend funding for this proposal, we request that the funding be transferred through our current NOAA cooperative agreement, # NA17RJ1231. The NOAA contact (described below) for this cooperative agreement should be contacted immediately if this proposal is accepted for funding.

Title of Proposal: Researching Spatial Referencing and National Height Modernization in California

Principal Investigator: Yehuda Bock

Proposal # 2006-3913R1

Period of Performance: 07/01/06 – 06/30/07

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Task #: 2 – Joint NOAA Laboratory/JIMO Programs

Theme: D – R&D on Observations Systems

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California Spatial Reference Center
Statement of Work
Researching Spatial Referencing and National Height Modernization in California
FY2006-2007

Introduction

The Joint Institute of Marine Observations (JIMO) is requesting funding to continue to support the partnership between the National Ocean Service's National Geodetic Survey and the Scripps Institution of Oceanography's California Spatial Reference Center (CSRC) for the purpose of researching spatial referencing and height modernization for the public good. This collaboration between SIO and NGS is for the mutual benefit of both organizations and the American taxpayer. This fundamental research work will provide the basis for public guidelines and procedures, in particular for other states and entities interested in implementing height modernization and spatial reference systems.

Seven specific tasks are budgeted for FY06/07 that encompass the research, information technology, and education and outreach efforts. It is anticipated that additional research will be performed, either as enhancements to the budgeted efforts or as new research efforts, through cooperative agreements with other agencies and organizations.

Background

Modern society is becoming increasingly dependent on geographic data that is accurately and reliably spatially referenced. In response to this increasing demand for dependable spatially referenced data and the decreasing availability of "up-to-date" control (reference) data from the federal government, the California Spatial Reference Center is proposing to perform research that will support the establishment of a modern statewide geodetic control network with at least four geodetic values for each station, each having a stated accuracy – latitude (northings, Y), longitude (eastings, X), height (elevation/orthometric, ellipsoidal), and horizontal velocity. We will investigate and research systematic procedures that minimize the unique challenges within California to maintain control values up to date; i.e., procedures that monitor temporal changes in geodetic coordinates due to tectonic motion, seismic activity, volcanic deformation, and land subsidence. The statewide network will fully utilize the existing continuous GPS (CGPS) and related data processing infrastructure that have been established by a decade of investments, totaling over $50 million, in earthquake-related science. The network not only provides an accurate, consistent foundation for California's spatial referencing needs, but also facilitates the continuation of this vital scientific research. The proposed research will also support the goals of the federal National Height Modernization Program for California, and provide public guidelines for other states.

Research Questions

There are several outstanding research areas related to spatial referencing and height modernization, which we will address in FY2006-2007:

(1) What is the proper observation mix to maintain a modern geodetic control network in a region subject to crustal deformation such as California, and how should these measurements

be optimally combined? Observation types include continuous GPS (CGPS), field GPS surveys at passive monuments, spirit leveling, and gravity surveys.

(2) What is the proper mix of geoid models and local corrector surfaces, in converting from GPS-determined geodetic heights to orthometric heights? What interpolation methods will provide the optimal corrector surfaces?

(3) Can we apply and enhance modern IT methods to provide timely access to geodetic control and height modernization information?

(4) How does one develop and implement a precise GIS for the purposes of geodetic control and height modernization?

Education & Outreach

The outreach effort (**task 1**) continues and expands the efforts of previous years. Specific tasks are: a) keep CSRC members informed through regularly scheduled meetings (two Coordinating Council and four Executive Committee meetings), b) inform others on the objectives and activities of CSRC by participating in meetings (eight local meetings), conducting seminars, and providing presentations (at one convention), c) initiate meetings to improve California's spatial reference system, includes informing and discussing with public agencies (local, state, and federal) the benefits of, and funding needs for a modern California spatial reference system, and (d) conducting two CSRC-related workshops.

Information Technology for Height Modernization

In 2005-2006, we completed version 2.0 of the Pocket GPS Manager (PGM) (Figure 1), and applied it to two CRSC geodetic control and height modernization projects. PGM provides, as a tangible outcome of *research questions 3 and 4*, a modern geodatabase/web-based environment for planning, collecting, analyzing, interpreting, and publishing GPS-based projects. We will continue development of the PGM in 2006-2007, coordinating with Gerry Mader, Neil Weston, and Ronnie Taylor at NGS on a joint effort with PGM/OPUS DB for the Louisiana FEMA project, setting up the PGM Server at NGS Headquarters, and providing training on the use of PGM at NGS for Ronnie Taylor, Kendall Fancher, and Mark Eckl. As part of **task 2**, we will apply after-the-fact, all previous CSRC projects through the PGM process (Figure 2) in order to further expand the California Spatial Reference System (CSRS), which addresses *research question 1*, and create a geolibrary linked to our on-line map interface (SOMI), as part of *research questions 3 and 4*.

Expansion of the CSRS will also contribute to creating a modern crustal motion model for California, the second component of **task 2**. A crustal motion model, such as HTDP produced by the NGS (http://www.ngs.noaa.gov/TOOLS/program_descriptions.html#HTDP), is required for defining and maintaining the CSRS within a region subject to crustal deformation, including steady interseismic motion, occasional earthquake-induced coseismic and postseismic deformation, and possibly transient deformation. This is the key component in providing a timely solution to the "datum" problem in California. The essential problem is that large parts of California's infrastructure are tied to earlier epochs, such as HPGN epoch 1991.35, and it has proven difficult to transform from one epoch to another. The coordinates of a site, say in San Diego today (June 2006), will have moved nearly 0.7m from its 1991.35 values. The second component of task 2 is to develop an updated version of HTDP for California and to make the datum translation tools available in an on-the-fly modern IT environment. This aspect of task 2 addresses *research questions 1, 2, and 4*.

Scripps Orbit and Permanent Array Center (SOPAC)/CSRC is well positioned to develop a crustal motion model for Western North America and to contribute to a new version of HTDP and a new definition of NAD83.

(a) SOPAC and the Jet Propulsion Laboratory (JPL) are producing an operational combined position and velocity solution as part of a multi-year NASA funded project using modern IT methods built upon the extensive data and metadata holdings in the SOPAC database. This solution includes all CGPS sites from geophysical networks in Western North America, including Western Canada, Alaska, and all Plate Boundary Observatory (PBO) sites as they come on line, and currently starts in 1995. (Solutions by SOPAC and JPL go back to 1991, prior to the Landers earthquake, but have not yet been combined.) See http://reason.scign.org/scignDataPortal/. This is the most extensive combined solution available in terms of size of network, and geographic and temporal extent. Both groups are founding members of the IGS and serve as Global Analysis Centers and plan to reprocess their global solutions as well as the Western U.S. solutions and their combination.

(b) Scientists at Scripps (Dave Sandwell, Bridget Smith, Linette Prawirodirjo, and Yehuda Bock) and University of Miami (Shimon Wdowinski) have been working on two crustal motion modeling approaches:

  (i) DEFNODE written by Rob McCaffrey at Rensselaer Polytechnic Institute (RPI) is a program to model elastic lithospheric block rotations and strains, and locking or coseismic slip on block-bounding faults. Block motions are specified by spherical Earth angular velocities (Euler rotation poles) and interseismic backslip is applied along faults that separate blocks, based on the routines of Okada (1985; 1992). The fault model is specified by coordinates of nodes along the fault plane. The parameters are estimated by simulated annealing or grid search. The program can solve for interseismic plate locking or coseismic slip distribution on faults, block (plate) angular velocities, uniform strain rates within blocks, and rotation of GPS velocity solutions relative to a reference frame (Source: http://www.rpi.edu/~mccafr/defnode/). This program has been used in a variety of tectonic setting, for example, in Southern California, the Pacific Northwest, and Sumatra. The first two are directly relevant to the crustal motion model for Western North America.

  (ii) Bridget Smith and Dave Sandwell have developed a viscoelastic model for the San Andreas Fault System. The viscoelastic model accounts for the three dominant processes governing Crustal movements in the period between large earthquakes: elastic strain accumulation of the crust, elastic coseismic displacements, and post-seismic viscous relaxation of the mantle beneath. The viscoelastic model is based on extremely efficient semi-analytic solutions, derived in the Fourier domain, that provide the 3-D displacement response due to an arbitrary distribution of vector body forces (*Smith and Sandwell*, 2004, JGR; *Smith and Sandwell*, 2006, JGR). The restoring force of gravity is included to accurately model vertical deformation. The solution satisfies the zero-traction surface boundary condition and maintains stress and displacement continuity across the base of the plate. With Shimon Wdowinski, we have compared this model to the SCEC III crustal motion model (Figure 3).

Leveraging all of the above, SOPAC will develop for the CSRC a crustal motion model valid for California, in collaboration with Richard Snay and Christopher Pearson at NGS. The main goal is to provide a solution to maintaining a dynamic datum in California, which is subject to crustal motion from a variety of sources, within the framework of the California Spatial Reference System. The final product will be on-the-fly, Web-based tools that will allow conversion between epoch dates for users of the California Real Time Network (CRTN), and for post-

processing. The tools will be fully integrated into the SOPAC/CSRC data portal and accessible through Web Services. CSRC will also be able to maintain and update these tools/models on a regular basis as new data are collected and analyzed, as well as react quickly to irregular but anticipated events such as large earthquakes. The same approach used for California can be applied to other regions of Western North America.

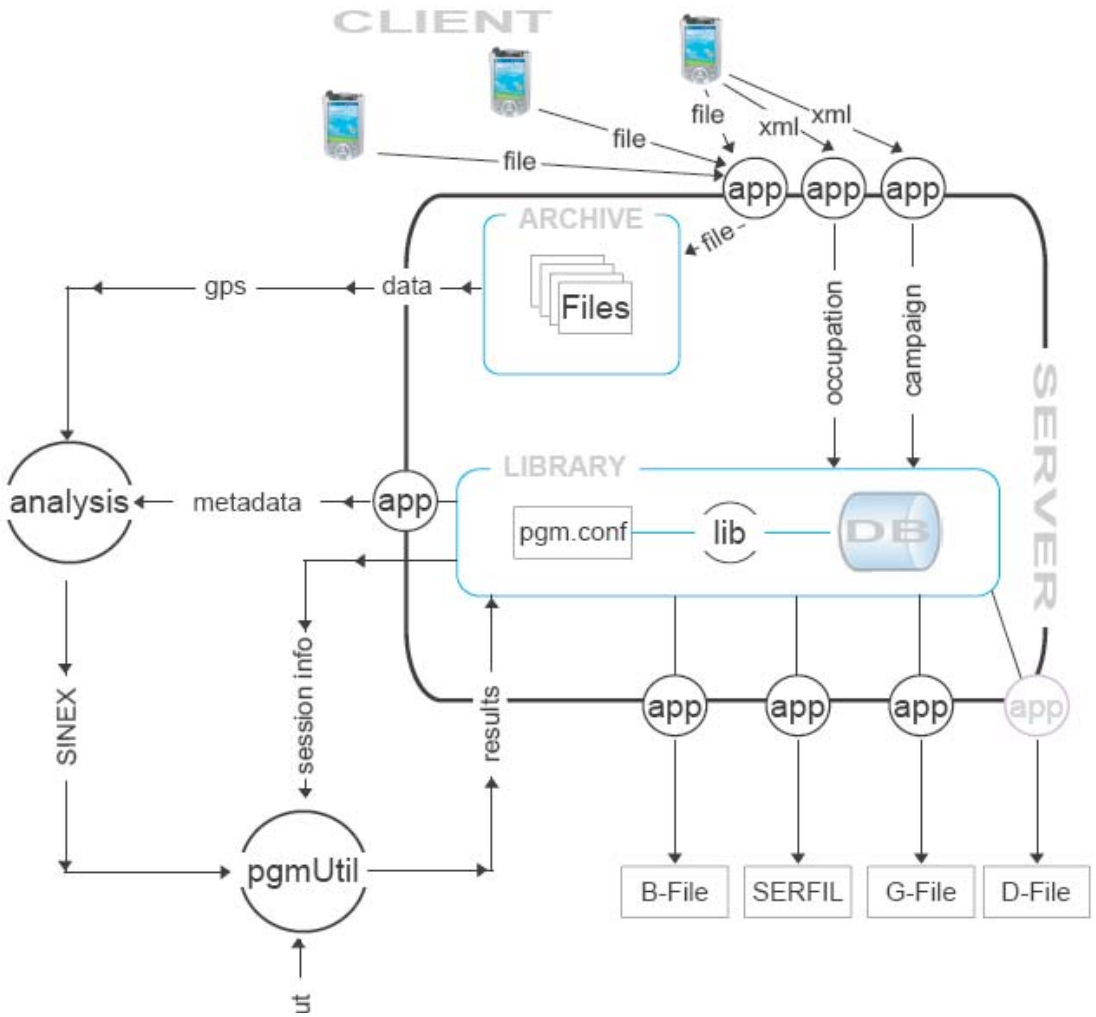

Figure 1. *Schematic of the Pocket GPS Manager*. It provides a modern geodatabase/web-based/distributed GIS environment for planning, collecting, analyzing, interpreting, and publishing GPS-based projects.

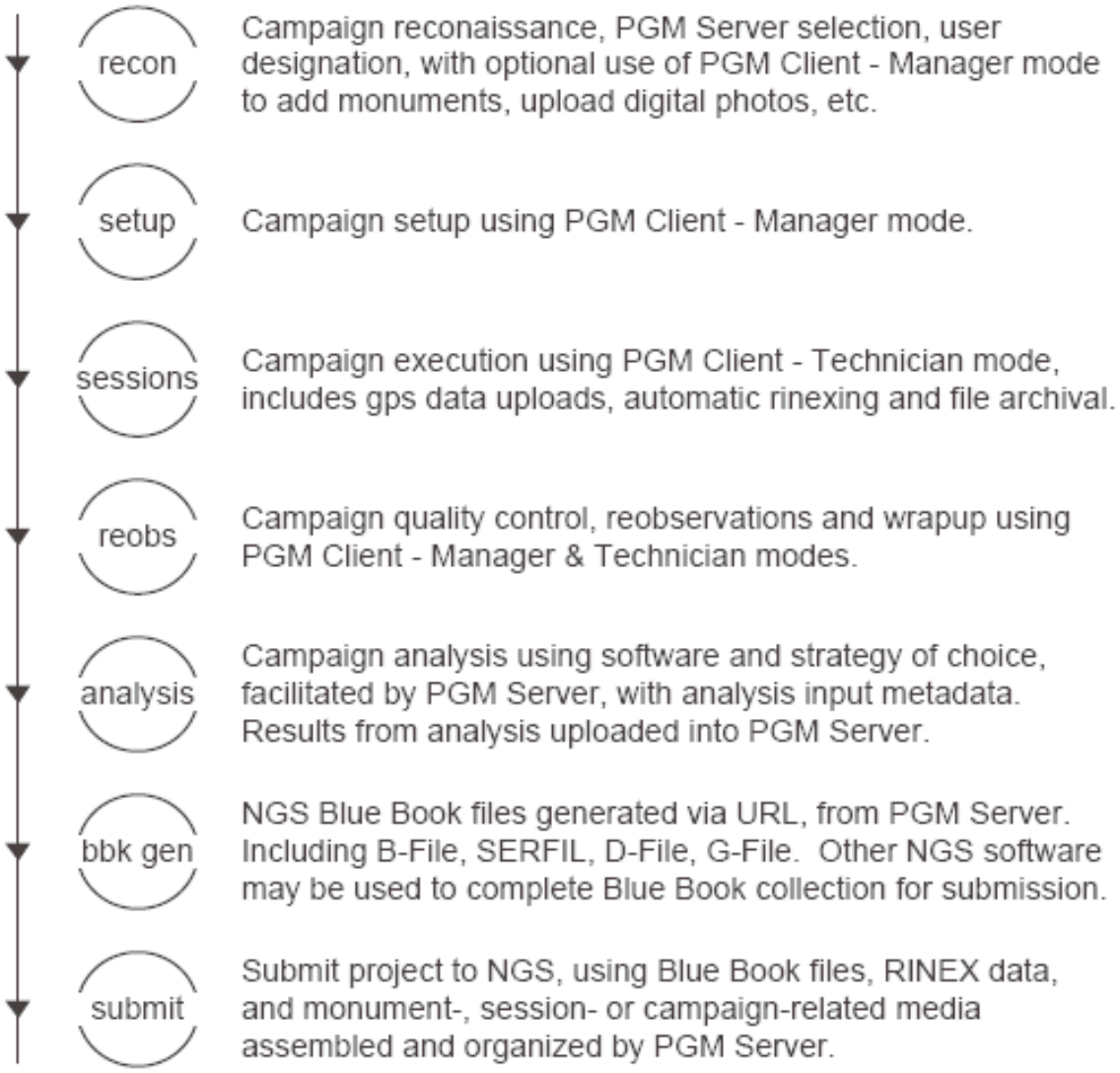

Figure 2. Steps supported in the PGM environment for a GPS campaign (survey).

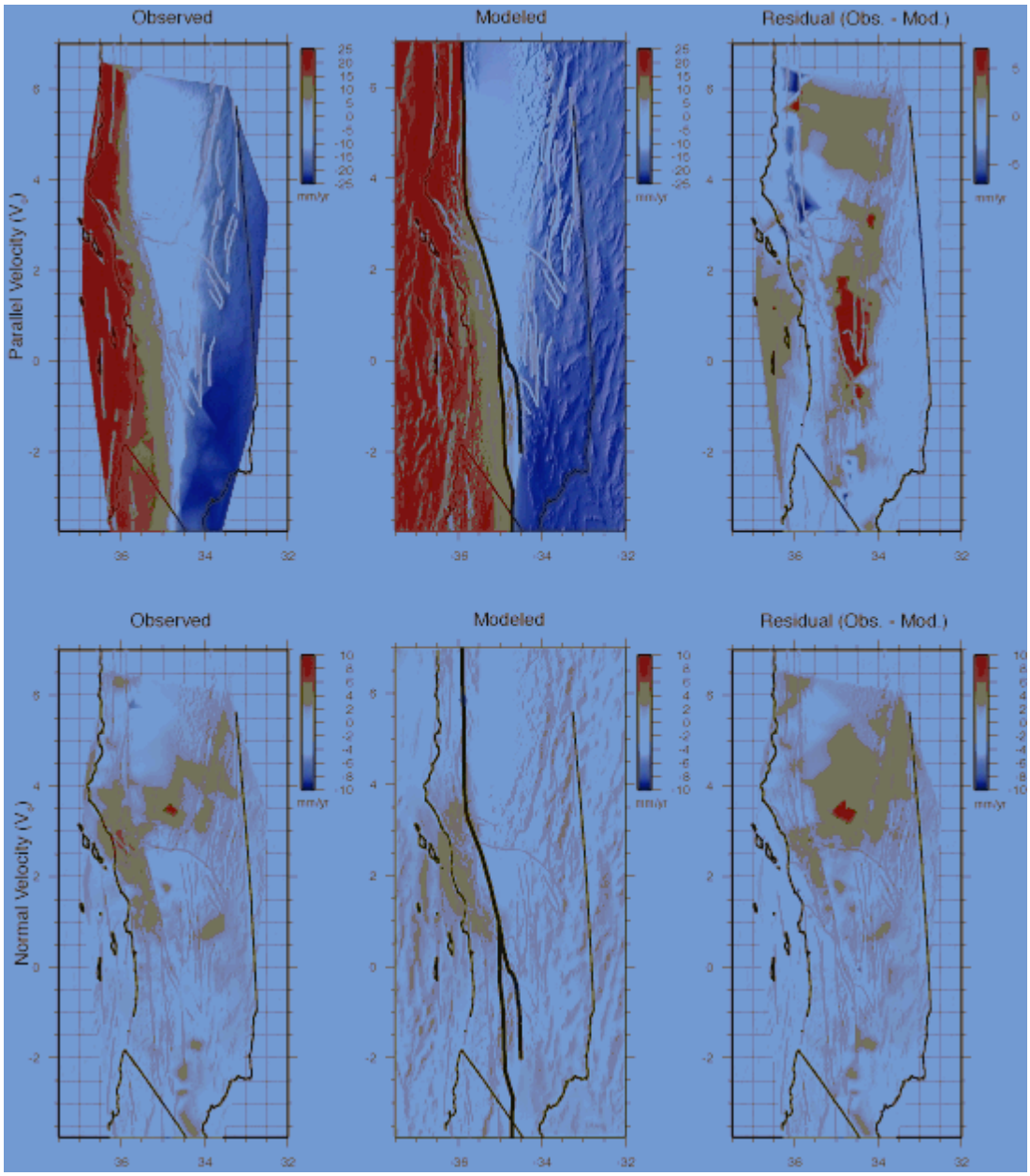

Figure 3. Model of interseismic crustal motion with respect to a North America fixed reference frame, in terms of parallel (upper plots) and normal (lower plots) velocity components. This model was produced by S. Wdowinski, B. Smith, Y. Bock, and D. Sandwell, in a paper recently submitted to the journal *Geology*, titled "Diffuse interseismic deformation across the Pacific-North America plate boundary." The raw observations are from the SCEC Crustal Motion Model 3, and the model is from *Smith and Sandwell* (2004), "A three-dimensional semianalytic viscoelastic model for time-dependent analyses of the earthquake cycle," *Journal of Geophysical Research-Solid Earth*, *109*. We will extend this analysis to all of California as part of **task 2**.

Data Analysis and Interpretation

As in previous years, we've budgeted partial support to operate and maintain CSRC's data portal and continuous GPS infrastructure and to maintain the CSRC geodatabase of active and passive GPS stations (**task 3**). This includes data download, data archive, data analysis, and data interpretation. These activities directly contribute to the California Spatial Reference System (CSRS), and to support *research questions 1, 3, 4.*

To address *all four research questions* we have collected, analyzed, and interpreted data collected in several demonstration projects in California (Figure 4), in support of CSRC's "A Master Plan for a Modern California Geodetic Control Network." In FY2005-2006, we undertook two major height modernization projects, in the northern San Joaquin Valley and in the greater Los Angeles region using the PGM and making use of SOPAC's California Real Time Network (CRTN – http://sopac.ucsd.edu/projects/realtime/). In **task 4**, we propose to establish about 100 passive stations in Sonoma, Napa, Marin, San Mateo, Santa Cruz, and Monterey Counties; and establish orthometric heights on CGPS in the Bay Area. This project, unlike previous projects, will be a hybrid in the sense of investigating how to better integrate CGPS, real-time CGPS, passive monuments, and leveling into the CSRS mosaic, and thus directly address *research question 1*.

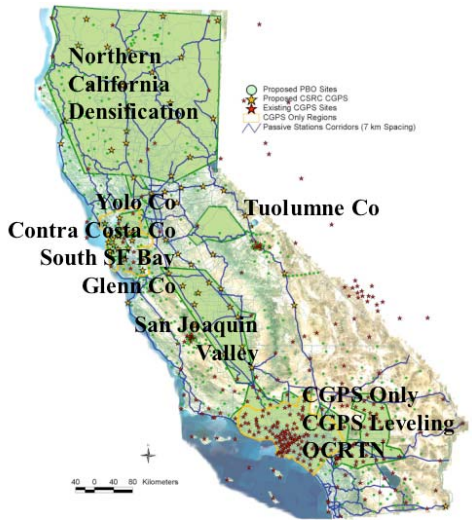

Figure 4. Projects in support of CSRC's Master Plan.

Task 5 will allow CSRC personnel to continue to coordinate permitting and siting activities with the Plate Boundary Observatory (PBO) regional engineers in southern and northern California, in order to meet the scientific objectives of PBO and CSRC. Access to PBO sites is essential in order to accomplish the objectives of the Master Plan.

Improve Geoid Model

As an ongoing effort, discrepancies found between orthometric heights derived from GPS ellipsoidal heights and geoid models, and leveled heights at some stations will need to be understood and research will need to be conducted on the optimal way to improve California's geoid model, in close collaboration with the national effort led by NGS. In **task 6**, we propose an ambitious effort to improve the geoid model for California as expressed in *research question 3*.

As input we will use the NGS-produced Geoid03 gridded binary data file (http://www.ngs.noaa.gov/GEOID/GEOID03/), and the CSRC database of Height Modernization data points including, observed orthometric heights from published benchmarks, derived orthometric heights from GPS campaigns, accuracy estimates of all height values, coordinate location of data points, various metadata for data points (e.g. PID, Station Name, County), and estimated correlation distances for the effective range of geoid corrections.

We will compute weighted corrections from the difference between the observed and derived orthometric heights. Weights will be computed from square root of the sum of the squares of individual accuracy estimates. The corrector surface will be computed from a weighted least

squares adjustment of the weighted corrections, interpolated between data points, and constrained by the correlation distances. The adjustment model will need to be sensitive to surface trends (i.e. regions that have corrections with similar sign and magnitude). The correlation distances might need to lengthen to encompass trending regions, or might need to change due to the original slope of Geoid03. Corrections may not be possible over the entire state, so multiple surfaces may be needed covering individual regions.

The output will include a surface representing the estimated accuracy of existing Geoid03 model in California and a surface representing computed corrections to Geoid03. We will make this model available to the public through gridded binary data files of an improved California geoid, as well as through our on-the-fly geoportal.

Management/Administration

Task 7 provides for the required management and administration of CSRC, including funds to support the activities of CSRC's Executive Manager.

BUDGET BREAKDOWN BY TASK:

Research Effort	Total	CSRC Staff	CSRC Consultants	Contract	Other
1. Education and Outreach	**$38**	$12	$16		$10
2. Information Technology for Height Modernization	**$186**	$175			$11
3. Operations and Maintenance	**$200**	$191			$9
4. Height Modernization Project	**$175**	$6	$20	$145	$4
5. New CGPS, per Master Plan	**$30**	$13	$15		$2
6. Improve Geoid Model	**$130**	$19	$10	$100	$1
7. Management/Administration	**$95**	$79	$15		$1
Total FY06/07	**$854**	**$495**	**$76**	**$245**	**$38**
Percentage FY06/07	***100%***	***57.9%***	***8.9%***	***28.7%***	***4.5%***
			37.6%		

Note: Dollar amounts are in thousands and include indirect costs

Budget Justification

Salary Support

Approximately 58% of the funds requested are for staff salary support at the CSRC research center (includes MPL laboratory support services). There is one Programmer/Analyst (George Wadsworth) assigned 65% effort to the Center and three part-time Programmer/Analysts (Michael Scharber, Paul Jamason, and Ruey-Juin Chang) that have been involved in CSRC activities over the previous years. A portion of Scharber's effort is also dedicated to management duties. We have budgeted 55% for a Staff Research Associate (Linette Prawirodirdjo) to assign with the development of the California crustal deformation model (**task 2**) and 65% effort for a Development Technician (Aaron Enright) for CGPS operations and maintenance (**task 3**). Approximately 33% effort is requested for the Principal Investigator, Yehuda Bock, and 51% effort for a Research Project Assistant/Project Coordinator, Maria Turingan. Salaries for the Project Coordinator are for tasks that will specifically benefit this project such as researching and procuring project materials and coordination of efforts between project partners and collaborators. All monthly salary recharge rates are calculated for actual productive time only and include components for employee benefits, provisions for applicable merit increases, and range adjustments in accordance with the University of California policy.

Professional Services

Approximately 38% of the funds will be outsourced as professional services in support of the research. Three Independent Contractors or Consultants will provide professional services in support of the CSRC goals. In addition, two contracts are planned, one contract for a height modernization project in the Central Coast Area (**task 4**) and a second contract for improvement of the geoid model (**task 6**). Please see the details and the breakdown of the professional services below.

Professional Services- Consultants

John Canas will serve as CSRC's Executive Manager. The other two consultants, Robert Packard and Cecilia Whitaker, are professional land surveyors licensed in California and they will provide expert user advice and recommendations on the CSRC geodetic control network and data dissemination. Because of their unique knowledge and expertise and their past and present performance of providing excellent professional services to the CSRC, we plan to continue to use their services in the upcoming year.

The three Consultants will also provide other services to the CSRC, including professional responsibility for land surveying tasks, as required under state law, and review and oversight of contracted activities. In addition, they will assist in educational and outreach activities and in developing instructional materials on the use of CGPS data for height modernization. All the Consultants have worked for the CSRC on an hourly basis ($50 per hour), therefore the requested amounts are based on historical information of previous services and estimated hours needed to complete the current research. A total of $65,621 is budgeted for the Consultants.

Professional Services- Contracts

The first professional service agreement will allow us to establish about 100 passive stations in the Central Coast area and to establish orthometric heights on CGPS in the Bay Area (**task 4**); we have budgeted $125,087 for this contract. The second professional service agreement will allow us to make improvements to the geoid model (**task 6**); we have budgeted $86,200 for this

second contract. The budgeted amounts are based on estimates of previous professional contracts of equivalent nature.

Supplies and Expenses

Approximately 3% of the budget will be allocated to supplies. Supply and expense items categorized as project specific are for expenses that specifically benefit this project and are reasonable and necessary for the completion of the CSRC objectives. Computing and network supplies include software, manuals, tapes, disks, and miscellaneous items needed to process, store, protect, and disseminate the data. Meeting costs include catering, audio-visual, parking permits, and other miscellaneous charges associated with the Coordinating Council meetings (Northern California and San Diego), Executive Committee meetings, seminars, workshops, and other CSRC meetings pertinent to completing this year's tasks. Telephone, fax, copying, and postage costs are requested based on the number of man months. The amount ($100 per man month) is based on historical usage during past years of this project. IGPP network and computer support charges represent costs necessary to maintain network connectivity for the CSRC staff computers and printers ($225 per man month; no network charge for Research Project Assistant, because this is covered by the IGPP Department).

Travel

Approximately 1% of the budget will be allocated to travel. Travel funds are for project related meetings and fieldwork. The budget amount includes travel to Coordinating Council meetings (Northern California and San Diego), Executive Committee meetings, local meeting, travel to conventions, conferences, seminars, workshops, and other travel directly related to completing the CSRC objectives for FY2006-2007. Funds are requested for **task 1**: two trips related to education and outreach and one trip between San Diego and Washington, DC for the PI and/or CSRC staff to attend meetings with National Geodetic Survey personnel. We estimate two trips to Washington, DC for PGM setup and training at NGS Headquarters (**task 2**). Funds are also requested for travel related to CSRC coordination with PBO (**task 5**).

Budget Summary

Category	**Amount**	**%**
Salaries and Benefits *(includes MPL)*	$494,627	58%
Professional Services	$321,213	38%
Equipment	$0	0%
Supplies	$26,428	3%
Travel	$11,832	1%
Total	**$854,100**	**100%**

Note: Amounts include indirect costs.