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# FINAL REPORT TO NASA

## FOR THE PERIOD

September 1, 1995 - August 31, 1997

## AND PROPOSED WORK

## FOR THE PERIOD

September 1, 1997 - August 31, 1998

# AIRBORNE LASER ALTIMETRIC MONITORING OF THE RAPID EVOLUTION OF TOPOGRAPHY IN THE LONG VALLEY, CA CALDERA

Proposal Submitted Jointly by Scripps Institution of Oceanography
and the University of Colorado, Boulder

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## Introduction:

A consortium of investigators from several universities and Government agencies have conducted a series of aircraft topographic surveys over the Long Valley caldera, California. The region has a geologic history of extensive volcanism, and its central dome has recently been undergoing resurgent uplift episodes of up to 4 cm per year, a deformation rate that is still continuing. These surveys were conducted from the NASA WFF T39 jet aircraft, outfitted with a nadir-profiling altimetric laser (ATLAS), a GPS guidance system for in-flight precision navigation, two P-code GPS receivers, a Litton LTN92 inertial unit for attitude determination, and both video and still-frame aerial cameras. In addition, two base-station GPS receivers were deployed for post-flightdifferential navigation, complementing the permanent GPS station operated onthe resurgent dome by JPL, and a kinematic automobile survey of roads crossing the area was conducted, thereby complementing the JPL kinematic GPS surveys of some of the same roads. Precision flying yielded multiple profiles along nearly identical paths, including crossing profiles over selected locations within the caldera and calibration flightsover Mono Lake, and Lake Crowley. Data from the most recent survey in 1995 are at this time still being reduced, but the standard error of the mean is very low (< 3 mm), due to the high number of crossover points. We thus intend to evaluate the technique for measuring systematic changes in the dome height over time.

## Results:

At the University of Colorado, our work to date involved research in two areas:

1) Development of evolutionary programming/genetic algorithm techniques to invert models for ground deformation processes for volcanic sources of inflation and more general earthquake sources. Major activities in this project have involved 1) analysis of the existing geophysical data base for active processes within Long Valley, particularly including leveling data, two-color geodolite data; 2) integration of the existing data set with airborne altimetric data collected during the summer of 1992 and the experiment planned under this proposal; and 3) modeling and Interpretation of all data obtained in both the previous flight experiments and the proposed flight experiment, together with data from all other sources. It was found that the pattern of inflation within the caldera reflects magmatic injection processes that have been operating from 1980- present, i.e., inflation centered on the resurgent dome of several cm per year. It has been of great interest, however, to ascertain by means of modeling exercises whether primary magmatic injection will be at shallow levels within the caldera (< 6 km) or deeper (> 7 km). This information will be of great value in helping to assess the level of volcanic risk due to the possiblity of an eruption within the caldera.

The genetic algorithm, coded into the C programming language, has successfully inverted synthetic data with noise for a 20 km x 20 km area. In addition to uplift observations, data can also be used in the form of horizontal and vertical motions at both simple GPS locations and along two color laser geodimeter lines. Errors in the four parameters of location and inflation volume are about 11% for small data sets, when standard deviations in observations are on the order of 1 cm. Types of models that can be used include several (~3) Mogi spheres, and several (~3) faults. Other sources that have been coded include ellipsoids and dikes. Advances in the GA techniques include multipoint crossover, dynamic mutation rates and population size, and windowing techniques. Typical computation times range from 20 to 2200 minutes on a SUN Sparc 10.

The link between the genetic algorithm inversion algorithm (which appears completely ready) and the forward model of magma and fault displacements was completed. A stripped-down version of the forward model is being used for initial tests of their combined performance. Fabricated data will be used again to test the combined model. The final step was a connection between the GA inversion routine and the full forward model, with preliminary data tests using synthetic data. In the absence of reliable, high precision laser ranging data, we have used more conventional terrestrial data with the GA routine. Publications detailing these results have been written and submitted.

2) Development and modeling of Synthetic Aperature Radare Interferometry techniques to investigate topographic alteration and change. In addition to our work on GA inversions for laser altimetry in Long Valley, wealso assembled the software necessary to process Synthetic Aperture Radar Interferometry data, using codes obtained from the Jet Propulsion Laboratory. We are using a 27 Gbyte disk array and a SUN Sparc Ultra computer with 16 parallel processors and 2 Gbytes of RAM, to among other things, form images of deformation along the San Andreas fault system. Once these and other images were constructed and refined, we began modeling the deformation using both elastic and the viscoelastic modeling codes developed here, and available at (ftp: /fractal/users/ftp/pub/Viscocodes). Although there exist other software packages such as IDL that are capable of handling SAR images, they are not designed to work in interferometric mode, which is necessary to image surface deformation. While this represented a new direction for us, it has been quite compatible with our work on topography and surface change, in that SAR derived deformation data has been collected for the Long Valley area, and is currently being proposed for use in monitoring deformation on a variety of volcanoes throughout the United States and the world. This work has resulted in a number of exciting InSAR images, together with interpretations, that form the central core for the Ph.D. dissertation of Paul Vincent.

**Results from InSAR Data Processing:**

Southern San Andreas Fault / Durmid Hill: We processed the raw deformation and topography interferometric pair data sets for the Salton Sea/Durmid Hill region into flattened (orbital geometry-induced fringes removed) interferograms. We successfully unwrapped the flattened topography pair and removed the topography fringes derived from the topo pair from the deformation pair to isolate the deformation signal. A deformation signal (SAF creep NW of and possible uplift at, Durmid Hill) is evident in the deformation pair even before the topography is removed. Results will be presented at the Fall '98 AGU meeting in San Francisco.

Landers/Big Bear, CA region: We processed the deformation and topography pairs into flatted interferograms. We successfully unwrapped the topo pair and removed topography from the deformation pair. Results will be presented at Fall '98 AGU meeting in San Francisco.

San Francisco Bay region (San Andreas and Hayward Faults): Deformation and topography pairs were processed and topography was successfully removed from the defomation pair yielding an unambiguous creep signal accross the Hayward Fault. These results were presented at the Fall '97 AGU meeting in San Francisco.

San Juan Bautista region (San Andreas Fault): A deformation pair was processed (~2 years temporal baseline), but unfortunately the interferogram was mostly decorrelated due to vegetation.

Greenland: We have processed the deformation and topography pairs into flattened interferograms. We had some difficulty unwrapping the topo interferogram but finally succeeded, isolating crustal deformation due to ice loading. We have five years separate orbits in the deformation pair which shows ~50% correlation--this has never been done before to the best of our knowledge.

## InSAR Modeling Results

Landers 1992 Earthquake Coseismic Deformation: We have modeled and created synthetic interferograms using two different slip distribution models. The first is the seismic frequency inversion of Cotton and Campillo (1995) and the second is the geodetic inversion of Hudnut, et al. (1994). Both inversions yielded a synthetic interferogram which resembles the actual interferogram from Massonnet (Nature cover page). Neither slip model matches the data perfectly but the geodetic inversion slip model produces a better match to the data. These modeling results were presented at the Fall '97 AGU meeting in San Francisco. Further results will be presented at Fall '98 AGU meeting in San Francisco.

San Francisco Bay Faults: All the known major faults numbering ~15 in the Bay region (including the San Andreas and Hayward faults) were modeled using the geodetic inversion of Lienkaemper, et al. (1991) and synthetic interferograms were created and compared to the data processed for this region (see above). Synthetic interferograms were calculated for the Hayward Fault alone and also with all the other faults included, demonstrating a better match to the data when all faults are included in the modeled strain field. Note: recently published analysis of other InSAR data of the same region includes only models of the Hayward fault alone. Results were presented at Fall, 1997 AGU meeting in San Francisco.

**Papers and Abstracts Acknowledging Grant**

**Abstracts supported in whole or in part by grant:**

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