NASA GEODYNAMICS PROGRAM INVESTIGATIONS

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Summaries

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Program Overview

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EARTH DYNAMICS PROGRAM

Atmospheric Excitation of Changes in Earth Rotation and Polar Motion

Dr. Richard D. Rosen, Atmospheric and Environmental Research, Inc.

The objective of this investigation is to develop a time-series of global atmospheric motion and mass fields through April 1984 to compare with changes in length of day and polar motion.

Work dealing with Earth rotation will include the following: 1) Computation of atmospheric angular momentum through April, 1984. Atmospheric data will be obtained approximately every six months to update the existing time series of ψ_3 values. 2) Comparisons of ψ_3 values with variations in length of day obtained by several groups utilizing B.I.H., lunar laser ranging, VLBI, or Lageos measurements. This will include the removal of atmospheric "noise" so that it will be possible to investigate and determine the other geophysical phenomena involved in the processes responsible for long-term changes in length of day. 3) Computation of atmospheric excitation of polar motion using daily fields of atmospheric winds and pressures for a short test period. If the results are encouraging, daily calculations will be extended over a longer period to be able to examine the forcing of the annual and Chandler wobbles, in addition to higher frequency nutations.

Earth Rotation and Planetary Motion Studies with Lunar Laser Ranging and Lageos Data

Dr. Peter J. Shelus, McDonald Observatory, The University of Texas at Austin

The investigation will continue work in the derivation of Earth rotation and polar motion parameters, station coordinates, and baselines and will study methods for determining judicial points of laser ranging telescopes to coordinate reference frame ties. Recent capabilities have been developed to simultaneously reduce LLR and Lageos data to maximize the advantages inherent in each data type and minimize the disadvantages. With respect to the Lageos observation type, the contamination of the orbit model from unmodelable secular drift cannot be separated from the axial rotation of the Earth. This study will continue to develop, improve, and apply joint solutions to lunar/Lageos Earth rotation parameters of the highest quality with a minimum turnaround time and continue cooperative efforts in the international sphere via programs such as EROLD and MERIT.

Study of the Use of Laser Ranging and Very Long Baseline Interferometry Data in the Routine Rapid Determination of Earth Orientation Parameters

Dennis D. McCarthy, U.S. Naval Observatory

The primary objective of this investigation is the determination of the standard UT1-UTC time scale and polar variations by use of laser ranging and VLBI techniques in conjunction with more classical methods. These data will be published weekly with roughly a 15-day delay from the latest observations available, and will be available through the Data Information System (DIS).

Observations from USNO instruments (the PZT's and CERI), Doppler Motion Service (DPMS), Lageos, LLR, and VLBI will be collected and fed into a filtering routine which smooths each component separately, determining a weight for each from the rms of the fit of the particular series being processed.

Small gaps in data are filled by a Lagrange interpolation scheme. The smoothed, weighted, complete series are then treated as variations in local reference vector components measured in a Conventional Inertial reference system and combined into a uniform series which can be used to calculate polar coordinates and UT1-UTC.

A secondary benefit of this effort will be to contribute to the long-term improvement of the current geocentric coordinate system. This will be accomplished through the evaluation of the systematic differences between individual contributors determined by the routine intercomparison of observations.

Analysis of Variable Earth Rotation for Geophysical Sources

Charles F. Yoder, Jet Propulsion Laboratory

The investigation will study variations in Earth rotation by removing meteorological variations and examining geophysical factors in the residue. The first task shall be to study the dynamic modeling used to reduce Lageos data to determine if important effects have been omitted or mismodeled. The second task shall be to compare ocean tidal models of Swederski and Parke and estimate error sources arising from the Circum-Antartic current. The third major task shall be to estimate the meteorological contributions to the tidal constituents. Besides perturbing the Lageos orbit, meteorological effects may also perturb the semi-annual forced nutation. This research will determine whether a comparison of Lageos derived UT1 and laser ranging UT1 can be used to separate the component of UT1 driven by angular momentum exchange from the component caused by dynamical changes in the Earth's principal moment of inertia. If this separation is possible, then it shall be possible to derive a record which can be used to study the role of atmospheric circulation on UT1.

Lunar Laser Ranging Data Analysis and Modeling

Dr. James G. Williams, Jet Propulsion Laboratory

This investigation will continue analysis of lunar laser ranging data to provide estimates of tidal components, UT, station coordinates, and GM to model the Earth-Moon system at the 2-5 cm level.

First year tasks include continued solutions for GM of the Earth, McDonald LLR coordinates and the M_2 tide using new data. The Earth tide perturbations will be split into diurnal and semidiurnal components in an attempt to separate them in the solutions. Corrections will be applied to the McDonald coordinates for nominal values of continental drift. The software will be upgraded with a new polynomial for the right ascension of the mean Sun. Power spectra of the residuals will be examined for the nearly diurnal free wobble. The lunar orbit and physical librations will be numerically integrated as significant improvements in the initial values become available. Orbit and libration partials will be similarly generated as needed.

The long term goal is to generate a model comparable in accuracy to the 3-5 cm range data expected in the future.

Analysis of Lunar Laser Ranging Data for Earth Dynamics Applications

Dr. Irwin I. Shapiro, Massachusetts Institute of Technology

This investigation will continue and extend analysis of lunar laser ranging observations to provide UT, polar motion, nutation, rotation rate, GM, and tides for use in geophysical studies. Lunar ranging data obtained by the McDonald Observatory, the McDonald Laser Ranging Station (MLRS), and the Orroral Lunar Ranging Station over the period 1970 to 1986 will be utilized.

To obtain the most accurate estimates of Earth rotation parameters the M.I.T. Planetary Ephemeris Program (PEP) will be used to simultaneously solve for a large number of parameters, including tabular values that describe continuous piecewise linear representations of UT1 and the two components of Earth rotation. Daily estimates of range residuals will be combined with those of the piecewise linear model and smoothed to produce continuous values of UT1 and pole position. This process will be repeated until convergence is achieved.

Using the lunar orbit and rotation models developed from analysis of the McDonald date, PEP will be used to calculated theoretical values of the Orroral ranging observations. Comparison of theoretical and observed data will be used to improve estimates of Orroral station coordinates.

Current efforts to compare LLR estimates of Universal Time and polar motion with those obtained by satellite Doppler, SLR, VLBI, and classical optical techniques will be expanded, especially in regard to VLBI data.

Study of the Earth-Moon System by Lunar Laser Data Analysis

Dr. Odile Calame, C.E.R.G.A./G.R.G.S., France

This investigation will continue polar motion and Earth rotation studies based on lunar laser ranging data. The main objectives are: 1) determination of a basic network of improved coordinates for the LLR stations to use in benchmarks, in linkage with the Lageos coodinate system, to be related to the conventional celestial and terrestrial reference frames; and the possible determination of the time variations of these coordinate sets; 2) determination of the three parameters (UT1 and polar motion) of the Earth rotation, by combined analysis of LLR and Lageos data; 3) improvements of knowledge for the physical parameters affecting the dynamics of the Earth-Moon system and the various motions of the lunar reflectors with respect to the terrestrial stations; 4) construction of a new improved lunar ephemersis and lunar libration model, by simultaneous numerical integration process in an homogenous systems, and 5) improvement of the determination of the tidal dissipation effects in the lunar orbit and consequently in the Earth's rotation.

Measurement of Contemporary Tectonic Plate Motions by Very Long Baseline Interferometry

Dr. Thomas A. Clark, NASA, Goddard Space Flight Center

This investigation will study north-south VLBI baselines to determine both components of polar motion, uncorrupted by UT-1 variations. These observations will be coordinated with the NGS POLARIS measurement program so that meaningful intercomparisons can be made of results obtained on radically different baselines.

The investigators will also provide various support functions related to pre-observation VLBI planning activities. Covariance analyses will be performed to test various schedules for their ability to deliver the desired results as well as for their immunity to various categories of systematic errors. Studies will also be made of suitable radio sources in the southern celestial hemisphere and to identify extragalactic radio sources suitable for use on longer baselines.

The Thermal Structure of Convection with Large Viscosity Variations

S.F. Daly, Jet Propulsion Laboratory

Using numerical techniques, this investigation has studied the properties of convection in a plane layer with temperature and depth dependent viscosities over a large parameter range. When both top and bottom boundaries are stress free, two dimensional finite difference models with viscosity variations up to 10^3 demonstrate that the cold high viscosity top boundary layer has a dramatic effect on the cell aspect ratio and vertical convective flow structure. Horizontal wavelengths that are large compared to the thickness of the convective layer cool the interior of the convecting fluid more efficiently than do wavelengths which are on the order of the depth of the layer. Viscosity variations across the top thermal boundary layer result in significant differences between the interior temperature, surface deformation and gravity anomalies associated with constant and variable viscosity convection. Numerical experiments have now been run up to viscosity variations of 10^5 using a mean field approach. Excellent agreement between this approximation and the recent laboratory experiments of Richter and Nataf (private communication) has been reached. Both numerical and laboratory experiments indicate that the Nusselt number - Rayleigh number relationship can be properly scaled to include the effects of viscosity variation. Also the interior isothermal temperature is increasingly offset with increasing viscosity variation. This interior offset is shown to reach an equilibrium value as the Rayleigh number is increased for a given value of the viscosity ratio. An understanding of the physical properties of such idealized systems is an important step toward understanding how solid state convection within the Earth's mantle controls its thermal and chemical state including the formation and structure of the lithosphere.

Estimation of Solid Earth/Ocean Tide Parameters from Satellite Tracking

T.L. Felsentreger, NASA, Goddard Space Flight Center

The objective of this study is to estimate improved low degree and order ocean/solid Earth tidal parameters for the M_2 and other constituents. The present-day tidal acceleration of the Moon will be derived.

Observational data consisting of laser and electronic observations will be analyzed to compute precision mean orbital elements over time spans of hundreds of days. The satellites to be considered in these analyses are Starlette, GEOS-3, Lageos, GEOS-1, GEOS-2 and Seasat. In the case of Starlette, a new high degree and order sepcially tailored gravity model will be used in the production of the mean elements which will be significantly more accurate than previously available elements. Similar improvements are anticipated for the GEOS-3 elements.

Two techniques will be employed for the estimation of the tidal parameters. The first technique involves the analysis of the evolution of the mean elements, and has been used extensively by the investigators in previous works. A new method for estimating the tidal parameters directly from the tracking data in the orbit determination process will also be employed. This affords an intercomparison of the results obtained in the two approaches.

Measurement of Earth Tides at NASA Tracking Stations

William E. Farrell, System, Science and Software

The principal objectives of this study are: 1) To calculate vertical tidal displacements and accelerations (ocean load tide plus body tide) as a function of time at the various NASA tracking stations, and 2) To provide a global Earth tide data base for constructing global models of the principal ocean tide constituents.

The need to implement the Earth tide program arises from the increasingly stringent positional accuracy required of Earth based observation stations. Since body tides cause vertical displacements of 30 cm, and ocean load tides have displacements of up to 3 cm, it is becoming more and more important to have accurate tide models to account for these effects. Our understanding of Earth tides has increased greatly in the past five years. This new understanding of the tides, along with improved models of the elastic structure of the Earth, end of the tides in the ocean is such that theoretical predictions are probably accurate to within a few centimeters.

Effects of the Ocean on Polar Motion

Dr. Steven R. Dickman, SUNY - Binghamton

The objective of this research is a more complete and advanced understanding of effects of the oceans on Earth's polar motion. The research will focus on investigating the possibility of a free wobble of the oceans, the conditions under which it can exist, its probable nature, and its effects on Earth's rotation. Such a wobble would be continually excited as the Earth rotates and might explain the existence and characteristics of the long-period component of polar motion known as the Markowitz wobble, the long-term modulation observed in the Chandler wobble amplitude, and non-equilibrium properties of the pole tide (which would contribute to the observed Chandler period, and Chandler decay).

Oceanic wobble will be investigated in two stages. During the first stage he inertial tensor of non-global oceans on a spheroidal Earth will be analytically calculated; then, the inertia tensor associated with a fluid ocean's response to its own wobble will be derived, extending the theory to deformable oceans. In the second stage the coupling of the oceanic wobble to the underlying solid Earth will be explored extensively; comparisons with actual polar motion data will be made.

Lunar Laser Ranging Data Analysis and Modeling

Dr. James G. Williams, Dr. Jean O. Dickey, Dr. Charles F. Yoder, Jet Propulsion Laboratory

This investigation will continue anlaysis of lunar laser ranging data to provide improved estimates of GM_{EARTH}, geocentric station location, tidal components and to support Earth rotation studies (external to this work) through improved modeling, analysis and generation of residuals for long data spans. The ultimate goal is the modeling of the Earth-Moon system at the 3-5 cm level.

First year tasks include continued solutions for improved values of GM_{EARTH}, McDonald coordinates (and other sites is available), Earth's luni-solar precession and the M_2 tide. General software improvements will be made that involve bias determinations of four spans of McDonald data, the correction (IAU, 1979) to the equation for the right ascension of the mean sun and solution capability for 18.6 year nutation term. Corrections will be applied to the McDonald coordinates for nominal values of continental drift. Orbit and libration partials will be generated as needed.

In the second year, remodeling of the Earth tides may allow measurement of two tidal components (diurnal and semi-diurnal) instead of the present one. The weighting of data of widely different instrumental weights and locations will be optimized. The power spectra of the residuals will be examined for the nearly diurnal free wobble due to the Earth's fluid core. A lunar ephemeris will be generated for the MERIT campaign. The long term goal is to generate modeling at least comparable in accuracy to the 3-5 cm range data expected in the future.

Advanced Studies for the Geodynamics Program

Dr. Ivan I. Mueller, The Ohio State Univeristy

A common requirement for all geodynamic investigations is a well-defined coordinate system attached to the Earth in some prescribed way, as well as a well-defined quasi-inertial coordinate system in which the motions of the terrestrial system can be monitored, traditionally through precession, nutation, polar motion and sidereal rotation.

This investigation is evaluating the geodynamic requirements and the problems encountered when establishing coordinate systems for the non-rigid Earth. Early results indicate that the reference frames of the future will have to be established, maintained and made accessible to the public by international services which, for practical reasons, will have access to the actual observations (SLR, LLR, VLBI, etc.) in some compacted form only (e.g., repeatedly determined station coordinates, baselines or pole coordinates). Various alternatives, their advantages and disadvantages are being examined, with special attention paid to the forthcoming MERIT main campaign to commence in the 1983-85 time frame. One of the objectives of the MERIT campaign is to establish the modus operandi for the future service.

Measurement of a Baseline to High Precision Using VLBI

Dr. K.J. Johnston, Naval Research Laboratory

This investigation will use a series of VLBI experiments between Haystack/Westford and Maryland Point Observatory to evaluate methods for determining a baseline to very high precision. VLBI data acquired on a monthly or bimonthly basis will be analyzed. These experiments will allow the testing and evaluation of atmospheric and ionospheric delay calibration, instrumental delay calibration, deformations in the antenna structures, and geophysical models which predict such effects on Earth tides to high accuracy. The VLBI observables may also be utilized to calculate geophysical parameters such as UT1, etc.

Geophysical Interpretation of Spatial Geodetic Data

Dr. B. Lago, CNES-GRGS, France

This investigation will combine SLR, LLR, and VLBI data with Doppler and altimeter parameters to determine the position of the pole and the geophysical effects of seismic and atmospheric sources of excitation. It will determine tidal parameters (coefficients and phase lag of ocean tides and phase lag of Earth tide) and study dissipation of the Earth-Moon system. The investigators will make an improved model of global gravitation and the geophysical interpretation of long wavelengths of the geoid.

Data acquired from a laser station on Tahiti and other sites will be used to detect elastic and possibly the viscoelastic strains due to earthquakes generated at the boundaries of the Pacific plate.

Contribution of G.R.G.S. to a Crustal Dynamics Program Based on Satellite Laser Ranging

Dr. F. Barlier, C.E.R.G.A., France

The goals of this investigation are the following: 1) establishment of a worldwide reference system; 2) analysis of constraints imposed by a long-lived operational system on the determination of Earth rotation parameters based on SLR techniques; and 3) determination of total parameters from combined observations of Starlette and Lageos. In order to establish a global geodetic network, observations of Lageos, Starlette and GEOS-3 by laser techniques at Grasse and San Fernando will be used. The results will be compared to those obtained by different techniques (SLR, LLR, Doppler) by different programs and authors, in different systems (NWL-9-D, MEDOC, GEM 10B, SAO IV, GRIM 2 and 3). Since it is essential that Earth rotational data be homogeneous over the term, it is necessary to be able to recompute new series of results with a minimum of effort when the number of stations varies and when changing from one Earth model to another. The investigators will attempt to develop the needed algorithms. Long range analysis to determine tides and zonal harmonics will be accomplished by using a mixed method that combines both analytical and numerical approaches. The variations of each orbital element is a sum of short periodic terms, long periodic terms and secular terms. If the short periodic terms can be eliminated, differential equations of averaged elements can be developed. A particular effort will be made to describe charge drag and other non-gravitational forces.

Studies of Polar Motion, Earth Rotation and Plate Motions

Dr. W. Jason Morgan, Princeton University

This investigation consists of two parts; first, a study of polar motion and variations in Earth rotation, and second, a study of plate rigidity and plate motions. The study of polar motion and variations in rotation and their correlation with other geophysical phenomena, such as atmospheric motions and earthquakes, will be carried out at Princeton University. They will undertake the following five goals: 1) extend the knowledge of meteorological effects on polar motion. This will be accomplished by comparing both the five-day averaged pole positions determined by Lageos and the VLBI pole positions (when available) with the expected polar motion forced by the atmosphere, as calculated using post-1976 global atmospheric data; 2) verify and extend current theoretical understanding of the effect of earthquakes on polar motion; 3) investigate the fortnightly and monthly tidally induced variations in Earth rotation using LLR, Lageos and VLBI pole positions and UT variations, and global atmospheric data; 4) search for the existence of a theoretically predicated (but as yet unobserved) free core nutation; and 5) use Lageos and VLBI pole positions to compute the polar motion-induced deformation of the Earth's surface. Plate rigidity will be tested by computing baselines between stations on the same plate, primarily using sites on the Pacific and North America, and data for which both stations observed the same pass. Plate motion will be studied by applying the same technique to station pairs on the Pacific, Nazca, and South American plates. Routinely determined station coordinates will be examined by all SLR and VLBI sites on all plates, to compare with models of expected plate motion.

Earth Dynamics Analyses

William M. Kaula, University of California

The objective of this investigation is to explain the longer wavelength ($\gtrsim$1000 km) variations of the Earth's gravity field as the consequence of mantle convection and its interaction with the lithosphere and crust.

The correlation of gravity field features with plate tectonic features (most notably the positives over subduction zones) indicates that the causes of gravity field are largely dynamic. Other relevant surface fields are the plate velocities, the topography, and heat flow. From spherical harmonic representations of these data, the momentum, energy, and Poisson equations are integrated downward into the mantle. At each level, the fields are mapped, and the non-linear terms are calculated and harmonically analyzed to continue the integration. For this integration, the distribution of energy sources and compositional variations as well as the thermal and rheological parameters must be described. By such criteria as the diminution of the gravity and toroidal velocity fields with depth it is planned to determine the optimum set: most notably, the effective viscosity and temperature dependence thereof for the lithosphere. At a later stage, it is planned to determine the distribution of energy sources and density variations in the mantle by an inverse theory treatment.

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Study of the Effect of Inner Core, Fluid Core, and Oceans on Earth Rotation, Nutation and Polar Motion

C.F. Yoder, Jet Propulsion Laboratory

The main focus of this investigation is to examine the complex interaction of pressure, gravity, and the Earth's magnetic field in the Earth's core and how it may influence the dynamical motion of the Earth. Present efforts are aimed toward completing research on the free motions of the Earth's inner core and possible excitation mechanisms. The outstanding problems include the estimation of the solid core relaxation time or equivalent viscosity and the hydromagnetic inner core-fluid core couple.

Three-Dimensional Modeling of Post-Seismic Polar Motion

Martin A. Slade and Arthur Raefsky, Jet Propulsion Laboratory

The objective of this research is the numerical modeling of post-seismic motions surrounding a fault in a three-dimensional spherical Earth in order to examine the importance of such motions in exciting the Chandler Wobble. The role of the rheology and viscosity structure of the upper mantle also being examined, both from the excitation viewpoint and from the perspective of understanding what geodetic measurements after a large earthquake would elucidate concerning the lithosphere and asthenosphere.

The code for doing this modeling is quite complicated and thus needs careful testing. The data handling to describe the problem to the code, and to interpret the results obtained, is laborious and also subject to error. In order to check that all stages of this process were correct, a test case of a strike-slip fault was chosen to test all these aspects. The general character of the solution is known analytically for a dislocation in a half-space. The non-Newtonian rheology solution was, by itself, of sufficient interest to make such a solution worthwhile.

The fault is straight, finite in length, and embedded in a heterogeneous upper mantle. The varying parameter is viscosity as a function of depth, with the thinning of the lithosphere appearing under the fault. The time dependent deformations and stress are plotted at the free surface and at varying depths. The code required some restructuring to address the 5.565 megabytes of virtual memory necessary for this problem, which has 960 elements, 1326 nodes, 2970 equations, and 610,821 terms in the stiffness matrix. Larger three-dimensional problems will require major changes in data handling, and the most efficient way to do this is being studied.

The rheology assumed in the problem included both non-Newtonian and linear Maxwellian. For the linear case, the results are being compared to Yang and Toksoz (1981). The time dependence of the horizontal motions will distinguish power-law non-Newtonian from linear rheology. The vertical motions are smaller in magnitude than the horizontal motions, and harder to measure, but they are also more sensitive to the spatial distrubution of the vicosity.

The next stage will be placing this fault into a spherical Earth model.

Thermal Isostasy in the World's Oceans

Dr. Gerald Schubert, University of California

The primary objective of this research is to determine the thermomechanical structure of the oceanic upper mantle by using the information contained in measurements of geoid height, seafloor depth, and heat flow. The investigators have found a nearly linear decrease in geoid height with age, for ages less than about 80 million years, in large areas of the North Atlantic, South Atlantic and Southeast Indian Oceans. The investigators will examine the change in geoid height with age for two additional areas in the Indian Ocean. The observed geoid height-age relation is a direct measure of the gravitational sliding force on the plates. The geoid-age, depth-age, and heat flow-age data will be investigated using a cooling plate model to infer the thermal properties of the lithosphere. The three data bases for the entire North Pacific will be analyzed in greater detail to characterize the heat sources (e.g., small scale convection beneath the plates and isolated plumes beneath swells) that are responsible for the flattening of the averaged depth-age and geoid height-age relations. The geoid height-age relation for a nonsymmetric spreading ridge from Seasat radar altimeter measurements across a number of fracture zones in the North Pacific will be estimated.

A Study of the Effects of Moving: Continental Wakes

E. M. Parmentier, Brown University

The purpose of this investigation is to study geoid lows and anomalously shallow sea floors that occur behind drifting continents such as south of India, southwest of Australia, and east of North and South America. There is no corresponding geoid low along the western margin of Africa and Europe, continents thought to be moving slowly relative to the underlying mantle. If only harmonics 4-10 are considered, continental wakes are all characterized by geoid lows of 20-40 meters. Residual depth anomalies occur in association with the geoid lows defining the wakes of North America, South America, and Australia. These depth anomalies show that sea floor in these areas is shallow relative to normal sea floor of the same age. Residual depth data are not presently available for the area of the Indian ocean geoid low.

Several differences between the oceanic and continental upper mantle may be important for creating continental wakes and suggest several conceptual models for the formation of wakes. The greatest amplitude geoid low on the Earth occurs south of India. Work in progress includes a seismic velocity study of the mantle beneath this Indian Ocean low to look for possible structural features which may be associated with the source of the anomaly.

CRUSTAL DYNAMICS PROGRAM

SAFE II

Dr. Christopher H. Scholz, Lamont-Doherty Geological Observatory, Columbia University

The object of this investigation is to study movement along the San Andreas Fault. The Crustal Dynamics Project has established a stable baseline that indicates that deformation in California is not restricted to a narrow zone near the San Andreas Fault. To determine how that deformation is distributed, the project plans to continue to measure the SAFE baseline with laser ranging systems, while tying the two endpoints with strategically located intermediate stations along several routes, using the mobile VLBI and laser. Based on geological studies, the area can be divided into three tectonically distinct regions: 1) northern and central California, where it is a zone of subparallel strike-slip faults some 100 km wide, 2) the region of the big bend in the San Andreas Fault, where it is a complex zone of north-south compression coupled with both strike-slip and thrust faulting some 150-200 km wide, and 3) a southern zone where it is again a system of subparallel strike-slip faults distributed over a wide zone. Since the deformation across the plate boundary is likely to be distributed differently in these three zones, this investigation will study links between the SAFE endpoints using intermediate points along three routes, one crossing each of these regions.

CD-034

VLBI Determination and Interpretation of Relative Motions Within a Network of Sites in North America and Europe

Dr. Irwin I. Shapiro, Massachusetts Institute of Technology

This investigation will analyze VLBI observations from antennas in North America and Europe to aid in the understanding of forces that govern plate tectonics and to illuminate possible relationships between plate motions and earthquakes. It is hoped to achieve, on average, an accuracy in the determination of rates of change of baseline length to 1 cm/yr (five standard deviations), or better, with a temporal resolution of five years, or better.

Plate Motions and Deformations from Geologic and Geodetic Data

Dr. J. Bernard Minster and Dr. Thomas H. Jordan
Systems, Science, and Software — Scripps Institute of Oceanography

Global plate-motion models will be used to predict the relative-motion vectors between proposed project sites and their uncertainties. The model Relative Motion 2 (RM2) will be augmented with several smaller plates, and numerical experiments will be conducted to assess possible sources of bias in RM2. Plate tectonic boundary conditions will be used in conjunction with other geological constraints to develop models of base-line changes in western North America.

The study will devise algorithms for the inversion of Project acquired data to determine models of network deformation as a function of time. Various models will be formulated that rest on geologically realistic hypotheses regarding the grouping of sites on tectonic blocks and constraining the temporal variability of motions among blocks. These algorithms will be applied to the analyses and interpretation of Project acquired geodetic data.

Interpretation of Crustal Deformation Data in Southern California

Dr. John B. Rundle, Sandia National Laboratories

An investigation and analysis of southern California crustal deformation data will be performed. The principle deformation data will be obtained by VLBI and TLRS techniques and from the U.S. Geological Survey.

The prime objective of this investigation will be to determine whether it is possible to refine either the Kosloff-type model or the Rundle-Thatcher Model so that agreement between the data is achieved. Both models offer specific predictions on how the data in various locations are related to each other spatially and temporally, and these predictions will be tested. Other objectives include the use of deformation data to analyze the constitutive behavior of Earth materials at depth. The investigators will also obtain information on the physics of fault gorge behavior. This should be especially interesting in areas like the Imperial Valley which often display aseismic fault creep behavior. The study will determine if the observed local strain field is consistent with the local geology and tectonics. The results will be compared to tide gauge data to determine its reliability as a measure of "absolute" deformation. The investigators hope to see if exposed rocks that originated at a depth of 1-10 km can be used to support the Rundle-Thatcher model, and if strain data can be related temporally and spatially to seismicity, gravity changes and well water changes in the area. And finally, the study will analyze the VLBI data to see if it is consistent with other land-based data, e.g., geodolite, leveling, and tide gauges.

CD-001

Determination of the Large-Scale Crustal Motion of Australia by Satellite Laser Ranging

Dr. Artur Stolz, University of New South Wales, Australia

This investigation will evaluate the attainable accuracy of the satellite laser ranging solutions for the relative position of stations, determine the large-scale deformation of the Australian plate, and measure the relative motions of plates in the Australasian region.

Two methods will be used in order to determine the time variation of the Orroral-Yarragadee baseline. First, a number of consecutive passes of Lageos, tracked simultaneously from Orroral and Yarragadee will be analyzed by the multi-arc method. Second, the baseline determinations, obtained from several consecutively (but not necessarily simultaneously) observed 1-day long orbital arcs will be averaged.

Australia/NASA Crustal Deformation Program Using VLBI Techniques

Dr. Artur Stolz, University of New South Wales, Australia

The principal objective of this investigation is to perform a pilot experiment to operate various sizes of antennas in order to involve the Australian geodynamics community in VLBI. The desired results are to measure baselines in the range of 300-2500 km between Australian sites to an accuracy of 10 cm. Four main investigations are planned that will utilize available antennas across Australia to form a VLBI array. They are: 1) to provide maps of a selection of the stronger extra-galactic and galactic radio sources; 2) to search for compact components in extra-galactic and galactic radio sources; 3) to provide radio source positions of astrometric quality for selection of southern hemisphere radio sources; and 4) to provide baseline sector measurements with an accuracy of about 10 cm for selected baselines.

While Australia is relatively aseismic, there are regions of concentrated activity that indicate stress accumulation, presumably associated with the northward motion of the plate. Fault-plane solutions of some of these events and in-situ stress-strain measurements indicate different directions of the principal stress orientation for different regions of the continent. This may suggest that the plate as a whole may be subject to deformation. It is planned therefore to analyse both relative motions between the plates in the Australian region and the deformation within the Australian plate. Since Australia is less seismic than other continents, it provides a stable platform from which to verify the long-term reliability of the geodetic relative position determination processes using the new space techniques.

Tectonic, Seismic and Geodetic Studies of the Gulf and Peninsula of California

Dr. Gordon Ness, Western Oregon State College

These investigators will conduct geophysical and geodetic studies of the Gulf of California and adjacent land masses and will analyze intersite baseline information to determine the neotectonic pattern of the Gulf of California fault system.

Utilizing Mexican seismometer station data, in conjunction with Worldwide Standard Seismic Network data, the measured baseline displacements will be related to activity along specific faults. The seismic data will be examined in detail to relate waveform characteristics to crustal structure, rheology and slip rates. Marine geophysical data already obtained jointly by the Mexican General Directorate of Oceanography and Oregon State University will be used to accurately map, at reconnaissance scale, the tectonic features of the Gulf of California and to locate active and recently active transform faults, transform fault extensions and fault blocks.

A Program in Crustal Dynamic and Earthquake Research

Dr. Alfonso Lopez Arroyo, Instituto Geografico Nacional, Spain

This investigation will use the Madrid DSN station to observe plate movement and deformation in connection with VLBI observatories in Europe and North America. Geophysical and geodetic observations are planned to study both the complex geometry and dynamics of the area. The study will investigate the possibility of stress migration and analyze its relationship to seismicity. The study will also include an analysis of baselines between European and American antennas, to measure deformation of the Iberian Peninsular against Central Europe and the average motion of America with respect to Eurasia and to monitor seismic activity in this region.

The baseline data will be analyzed jointly with data derived from other programs. They results will be integrated into a general interpretation of the whole Mediterranean area, under the coordination of the working group of the European Geoscientists for the Establishment of Networks for Earthquake Research.

North American Plate Deformation in Canada

Dr. Anthony Lambert, Dept. of Energy, Mines and Resources, Canada

This investigation will study plate deformation between the east and west coasts of Canada; it will also study deformation near Alaska and intercompare Canadian and U.S. VLBI systems. One objective of the study will be to obtain preliminary estimates of deformation at parts of the western boundary of the North American plate in Canada and Alaska and the plate interior, using two stations on the Canadian Shield as a reference. A second objective is to determine any systematic errors in the Canadian and U.S. VLBI data reduction procedures by comparing results over selected baselines in Canada. The investigation is expected to provide: 1) preliminary constraints on plate boundary deformation in the southeast Alaska/southwest Yukon region for seismic risk assessment, and 2) preliminary data on the relative stability of the Canadian Cordillera, and the Canadian Shield.

Present Relative Plate Motions of the Nazca and South America Plates and Internal Plate Deformations of the Andean Region

Dr. Edgar Kausel, University of Chile, Chile

This investigation will study regional deformations and strain accumulations related to large earthquakes along the western coast of South America. Baselines between stations located at Easter Island and San Felix Island and along the coast of South America will be used to determine relative plate tectonic motions between the Nazca plate and South American plate.

A combination of the results obtained from the measurement of the relative motion between the Nazca and South American plates and the observation of deformation of the South American plate will give some information regarding the levels of tectonic motion released in earthquakes. The results may also reveal information on aseismic slip along the Benioff zone.

Improvements in Benchmark Stability for Precision Tilt Measurements of Crustal Dynamics

Jonathan Berger and Frank Wyatt, Scripps Institution of Oceanography

A review of the strain measurements made at the Cecil and Ida Green Pinon Flat Observatory over the past seven years show that, with care, surface strain measurements can be made to resolve seismotectonic phenomena including normal secular strain of 10^{-7}/yr, dislocations from nearby earthquakes, and possibly post-earthquake strain. The results confirm that the crust acts elastically at least for periods between those of the tides and seismic waves. Comparisons between secular strain observations and geodetically determined strain shows general agreement but significant discrepancies perhaps reflect the results of temporal aliasing in the geodetic measurements, or spatial inhomogeneities in the regional strain field.

Neotectonics of the Northern Caribbean Plate Boundary Zone - A Study in Hispaniola

Dr. Kevin Burke, State University of New York at Albany

Photointerpretation and field mapping of Hispaniola will be used to study the nature of continental-style interplate deformation occurring within the North American-Caribbean plate boundary zone (PBZ).

Initial work will determine whether the model of shear zone evolution that has emerged as a good way of describing Jamaican neotectonics is applicable in Hispaniola. The emphasis of the study is to gain a detailed understanding of faulting over the last 25 m.y.

Structural and Tectonic Evolution of the North Anatolian Fault: A Pilot Study in Synthetic Integration of Field Investigations and Landsat Interpretation in the Evolution of Intracontinental Plate Boundaries.

Dr. John F. Dewey, State University of New York at Albany

This investigation will study the North Anatolian Transform Fault (NATF). The field work is yielding information on the history of the fault at both its eastern and western ends and has shown that a particularly critical direction for the investigation to take is to study the complementary East Anatolian Transform Fault (EATF). The studies in this investigation will help to achieve an understanding of the evolution of the structure and tectonics of intracontinental transform fault systems.

Empirical Strain Modeling and Verification of Space Geodetic Information

John L. Fanselow, Jet Propulsion Laboratory

The purpose of the task described here is the derivation of empirical crustal strain models from on-going VLBI observations in California. The goals have been set by this investigating team:

1. Definition of VLBI baseline data set. By examination of the spatial and temporal distribution of refined baseline determination, baseline "epochs" for the purpose of subsequent interpretation and modeling will be determined.

2. Assembly of general least-squares parameter estimation software for strain-displacement solutions. We plan to draw heavily on existing VLBI software so that the thrust of the work in this area will be the implementation of strain models, not code development.

3. "Zeroth-order" single block strain model solution. In addition to providing an average measure of the rate of secular strain accumulation over the whole region covered by the VLBI network, careful evaluation of the misfit data to this model will guide us in the next phase of model development.

4. Spatially resolved strain model. Within the confines of the available VLBI data set, we will attempt to model a number of subregions, solving for separate components of strain and relative displacements. This type of modeling has potential for the detection of strain localization within the network.

Because the anticipated motions of interest are nearly comparable in size to the measurement errors it will be important to include the level of meaningful resolution implicity in the model derivation. It is also intended to develop the analysis/modeling utility in such a manner that improved and/or supplemental baseline data provided by additional multiple visits to remote sites in the VLBI network can be efficiently incorporated into pre-existing models.

Seismic Wave Velocity Structure in the Downgoing Slab and the Olivine - Spinel Phase Change

Dr. Peter Molnar and Dr. S. Roecker, Massachusetts Institute of Technology

This investigation is a systematic study of the seismic wave velocity structure in the downgoing slab in a subduction zone. The main goal is to determine if the Olivine-Spinel phase change occurs at a shallower depth in the slab than in the surrounding mantle, and if so, the degree to which the phase boundary is elevated. The plan is to study numerous numerical experiments using synthetic data generated with ray tracing programs and different assumed velocity, earthquake and station distributions. From the numerical experiments, the investigators hope to be able to determine if a sufficiently good study of the velocity structure in the slab can be made. These numerical experiments are necessary to evaluate the methods being used, the reliability of the results, the accuracy of the arrival times that are needed, etc. If the results of the numerical experiments are encouraging, the study will proceed with a detailed study of the Japanese region, and in particular of Southwest Japan where in the extension of the Izu-Bonin arc there are many earthquakes between 200 and 500 km depth.

Late Cenozoic Tectonics of the Basin and Range Province

Dr. Paul D. Lowman, Jr., NASA, Goddard Space Flight Center

This investigation is utilizing aerial and satellite image data and data from field studies to analyze the Late Cenozoic tectonic setting of the Basin and Range Province. This includes determining if and when the faults in the region have undergone slip and recognizing the resulting features produced by that slip. The results may aid in elucidating patterns of stress propagation throughout the region and their relationship to the San Andreas fault system.

Seismicity and Active Tectonics of the Andes and the Origin of the Altiplano

Dr. Peter Molnar, Massachusetts Institute of Technology

This investigation will study in detail the seismicity and the faulting processes of shallow earthquakes in order to understand how the crust deforms. The tectonic regions of interest are the Antiplano and the Andes. The study includes making a thorough analysis of Landsat imagery of the Andes in order to map, insofar as possible, the surface expression of active faulting and deformation. Progress is occurring in calculating the relative positions and velocities of the Nazca (or Farallon) and South America plates at different times since the late Cretaceous. Ultimately, the study is interested in evaluating the general structure and tectonics of Andean margins and their relation to tectonics of convergent plate boundaries.

Development of Techniques to Reduce the Error in VLBI Determinations of Transcontinental and Intercontinental Baseline Lengths to Less than One Centimeter

Dr. Alan E.E. Rogers, Northeast Radio Observatory Corp.

This investigation will test an experimental procedure for resolving the X-band phase ambiguity in VLBI. The S/X receiver phase and group delays will first be analyzed using the Crustal Dynamics Project CALC/SOLV software developed at GSFC. Similar but independent software developed at the Haystack Observatory will be used for consistency checks. The ambiguity function for the residual phase delays will be derived using software to be developed at the Haystack Observatory. In this way a baseline offset to the group delay solution will be derived.

It is expected that the combination of improvements in the observing strategy, ionospheric and atmospheric calibration along with the use of phase delay observables will reduce the 3 sigma baseline length errors to less than one centimeter. If the use of phase delay observables work as expected, sufficient precision (better than 1 msec) will be obtained to allow study of the ultimate limits on accuracy imposed by the atmosphere.

Improving the VLBI Reference Frame

Dr. David B. Shaffer, Phoenix Corporation

This effort will be devoted to the development of an improved catalog of compact radio sources. Weak sources, well within the capability of the Mark III VLBI system, are often more compact and simpler than stronger sources. While it is possible to identify candidate compact sources by their radio spectrum, the only way to determine their structure is by actual VLBI observations. The delay and delay rate data will be used to determine the positions of new sources. Visibility amplitude and phases from all CDP VLBI observations will be used to determine the structure of the sources. The investigators will determine relative structure at 2.3 GHz and 8.4 GHz, and determine the structure on all size scales, so that long and short baseline observations will be properly referenced to the VLBI frame. Phase-closure mapping techniques now running on the GSFC HP-1000 computer will be used. The investigators will deliver maps of sources to the Project and provide delay and delay rate corrections for VLBI observations. The structure information will be put into the source catalog file.

Satellite Laser and VLBI Technique Validation Through Intercomparison of Vector Baselines

Mr. James Ryan, NASA, Goddard Space Flight Center

This investigation will intercompare laser ranging and VLBI baselines to validate the methods for baseline détermination. The validation will be achieved by: 1) identifying those baselines and experiments for which laser-VLBI intercomparisons are possible and working with the Project to assure that intercomparisons are specifically considered as the laser and VLBI deployment schedules are formulated; 2) carrying out at least one intensive one-month laser-VLBI experiment, designed and optimized for intercomparison; 3) obtaining the laser and VLBI data for the intercomparisons and reducing the two data sets separately; 4) carrying out a "blind" intercomparison of the laser and VLBI results; and 5) examining the intercomparison results to identify systematic differences and to identify inadequacies in either system.

Simultaneous Adjustment of Spatial and Terrestrial Geodetic Data

Dr. V. Ashkinaze, University of Nottingham, England

This study will investigate optimum methods of combining and simultaneously adjusting spatial and terrestrial data to determine the contribution of the various observational techniques to the final accuracies of the baselines between the observing stations. It will assist the European investigators in determining the relative positional accuracies which have been achieved by various combinations of observational techniques.

The classical 2-dimensional geodetic computation techniques, based on a reference ellipsoid, are no longer appropriate to the solution of a system combining space and terrestrial data. These techniques do not fully exploit spatial contributions to the network, such as Doppler and VLBI observations. A new computer program developed at the University of Nottingham will be used to process observation data obtained during the Joint European Observation Campaign.

Inherent Accuracy of the Water Vapor Radiometry Technique

George M. Resch and R.B. Miller, Jet Propuslion Laboratory

This investigation is a joint effort with the Goddard Space Flight Center to test water vapor radiometer (WVR) performance. During 1981, two of the new water vapor radiometers were run side-by-side with both instruments observing the zenith. The difference in their outputs is then an estimate of the lower bound on the absolute accuracy of the WVR technique that we use to estimate path delay corrections. In the second test, the two WVRs were used to observe the zenith but also were separated by distances of approximately 0.7, 3, 7, 15, and 20-km. Knowing the level of intrinsic difference between the instruments means it is then possible to estimate horizontal gradients in the distribution of water vapor. In the third test, the output from the WVRs were compared with the residual phase from a connected element interferometer (i.e. the very large array in New Mexico). Data has been acquired from each of these tests and is being analyzed. The investigation is analyzing data that involves the determination of both 'dry' an 'wet' atmospheric delay. Measurement of the 'wet' delay with high accuracy (i.e., better than 1 cm) will be used to evaluate the performance of the new set of water vapor radiometers.

Very Long Baseline Interferometric Geodesy with GPS Satellites

C. C. Counselman III , Massachusetts Institute of Technology

In principle, very-long-baseline interferometry (VLBI) observations of Earth satellites can yield determinations of baseline vectors on the ground, up to several thousand kilometers in length, that are just as accurate as those obtainable from VLBI observations of extragalactic objects. This investigation will perform experiments to validate this principle. These experiments would employ the Mark III VLBI data acquisition systems at Haystack Observatory, the Owens Valley Radio Observatory, the Harvard Radio Astronomy Station, and the National Radio Astronomy Observatory (NRAO). Special, small antennas and receivers would be placed at these sites to enable VLBI observations of the GPS satellites to be made concurently with the observations of extragalactic radio sources. The orbits of the satellites would be determined using observations from the first three sites listed. Observations of the satellites from NRAO, combined with those from another site, would be used to determine the corresponding baseline vector, which would be compared with the one determined from the observations of the extragalactic sources.

GPS Satellite Orbit Determination Using the Reconstructed Carrier Phase Method for Teaching

Peter L. Bender, Joint Institute for Laboratory Astrophysics, University of Colorado and National Bureau of Standards

Earlier work indicated that the reconstructed carrier phase method could be used with signals from the GPS satellites to determine geodetic baselines accurately with very short measurement time per site. Improved estimates of the expected accuracy were then obtained by using what is called a modified worst case analysis. This approach allows for the fact that the main expected measurement errors are likely to have correlation times which are comparable with the observation period. With an estimated difference of 1 cm rms for the water vapor radiometer errors at 2 sites 50 km apart, the baseline between them can be determined to about 1 cm for the horizontal components and 2 cm for the vertical. It also was found that measurements once per day with the same accuracy can be carried out in most parts of the world with just the first 6 satellites, which already are up.

The other part of the initial study was a preliminary investigation of what can be learned about episodic crustal movements by combining GPS measurements with the use of ground techniques. The main emphasis was on possible future networks of instruments designed to detect whether irregular motions occur near the fault trace during periods of minutes to days before a large earthquake in California. The principal ground instruments considered have been laser distance measuring instruments, improved borehole tiltmeters, long baseline liquid tiltmeters, improved gravimeters, and dilatometers. Present work on a number of these instruments has been reviewed recently. In order to evaluate the usefulness of GPS displacement measurements, when added to local tilt, strain, or gravity change measurements, several models of the possible patterns of episodic motions as a function of position have to be introduced. Attention was focused on the experimental tests which are needed in the next 3 years in order to define the probable value of adding fixed GPS receivers at a substantial number of sites.

Recent work under the new investigation has been directed toward the GPS satellite orbit determination problem. Geometrical arguments indicated that about 20 cm accuracy could be achieved for the horizontal coordinates of the GPS satellites if accurate observations of their signals were made from somewhere between 12 and 20 well-distributed sites around the world. With this orbital accuracy, the corresponding contribution to the error budget for determining a 1000 km baseline with GPS geodetic receivers would be only 1 cm. Also, the GPS signals could be recorded on altimeter satellites such as TOPEX, and used to determine their radial coordinates with high accuracy.

Results have been obtained for the case of 18 GPS satellites being tracked from a particular set of 20 ground stations. It was assumed that the station positions were known to 3 cm in each coordinate from laser ranging and VLBI measurements under the Crustal Dynamics Project, and that water vapor radiometers were used at each site to reduce the GPS range measurement uncertainty to 1 cm. The uncertainty in the radiation pressure force on each satellite was modeled as an unknown thrust in each direction, and uncertainties in the gravitational field also were included. The results demonstrated that the desired 20 cm accuracy for the GPS horizontal coordinates could indeed be achieved by using 4 to 6 hours of tracking data.

Series-GPS Portable Radio Geodesy

P.F. MacDoran, D.J. Spitzmesser and L.A. Buennagel, Jet Propulsion Laboratory

The challenge of high accuracy geodesy at low cost on scales of 2 to 200 km can be met by the use of satellites as radio sources because of their high signal strengths (10^6 stronger than quasars). The satellites of the Global Positioning System (GPS) offer an important new geodetic resource making possible a highly accurate portable radio geodetic system. A concept called Satellite Emission Radio Interferometric Earth Surveying (SERIES) makes use of GPS radio transmissions without knowledge of the coded sequence of transmissions. Three dimensional baseline precision of 0.5 to 3 cm can be achieved with only a few minutes of on-site data acquisition. In the original SERIES implementation, the GPS was to serve as an incoherent noise-like illuminator of an Earth-based interferometer with signal detection accomplished by cross-correlation. A challenge noted in that design concerned the ability to simultaneously estimate ionospheric effects and baseline errors. To solve this parameter separability issue, the properties of the GPS signal structure have been exploited to make direct measurement of the ionosphere and perform one-way ranging from a single station. SERIES activities have focused on the implementation of a pair of proof-of-concept stations using lightweight 1.5 m dish antennas. Techniques are also available for the use of an omnidirectional antenna and a crystal oscillator while still retaining the SERIES advantage of single station, pseudo-ranging with centimeter precision. Preliminary results of ionospheric calibration have shown a precision of 10^{15} el/m^2 with 1 sec. averaging (1.6 cm path calibration). Independent accuracy assessments appear favorable relative to mapped VHF Faraday Rotation ionospheric observations. Two station differenced one-way ranging to measure baselines have begun.

Methods have also been devised to adapt existing Transit satellite Doppler positioning equipment to use the GPS satellite signals with relatively few changes to existing equipment. Doppler-GPS adapted equipment should exhibit superior performance on much shorter time scales than presently available using the Transit satellites.

Tectonic Deformation in Southern California

Dr. David D. Jackson, Institute of Geophysics and Planetary Physics, University of California

This investigation will study ongoing horizontal tectonic displacements in California using a combination of data from VLBI, SLR and conventional survey techniques of trilateration and triangulation. Quantitative analysis of VLBI and SLR will be used to determine displacement rates. Alternative tectonic models, such as uniform shear strain over a broad zone, block motion of microplates along known fault boundaries, and displacements at depth on strike slip faults, will be constructed. Both conventional and space geodetic data will be used to estimate the parameters in the various models, and statistical tests will be made to identify the models. Consistency testing will incorporate examination of baselines measured by redundant techniques to test their claimed accuracy, and testing by repeated baseline observations will look for evidence of correlation with potential sources of systematic error.

During the first year, emphasis will be on interpreting conventional geodetic data and establishing basis for intercomparing VLBI, SLR, and conventional data. As more VLBI and SLR data becomes available, the emphasis will shift to combined interpretation of conventional and space geodetic data. Finally, the combined data will be interpreted to give estimates for tectonic motions in California.

New Zealand/NASA Cooperative Crustal Deformation Program

Dr. R. I. Walcott, Geophysics Division, DSIR, New Zealand

This investigation will measure coastal deformation in New Zealand and study the relative movement of the Australian and Pacific plates. This boundary extends through New Zealand as a westward facing subduction zone under the North Island with associated back-arc spreading in the Taupo rift. As part of the New Zealand Earth Deformation Program begun in 1975, eight 40 km wide belts of first-order trilateration and triangulation have been, or are being established. Sites within each of the Earth Deformation Survey belts are planned to be occupied by laser systems and reoccupied after a period of 5 to 10 years. The initial occupation is expected to provide data to improve the adjustment of the surveys and, in particular to provide control on scale and azimuth. The reoccupation is expected to give accurate estimates of the motions of the occupied sites in the intervening period and control on the displacement vectors that will permit greatly increased accuracy in the determination of displacements and strains in the EDS stations.

Crustal Dynamics of the Eastern Mediterranean

Dr. Max Wyss, Cooperative Institute for Research in Environmental Sciences, University of Colorado

This investigation is a multidisciplinary study of the crustal dynamics in the Eastern Mediterranean which will include the following analyses: 1) evaluation of plate motions in this complex area with respect to Wetzell, FGR, 2) measurement of crustal deformation of Western Crete to determine per-, co- and post-seismic deformations near the plate boundary of the Hellenic arc, 3) determination of vertical movement on Crete by repeated precise gravity observations, 4) determination of vertical movement on Crete by mean sea level measurements, and 5) derivation of vertical movement for Crete during the Holocene time by detailed dating of marine terraces by the amino acid and C^{14} methods. By integrating the results of these different studies, a fairly detailed understanding of the Cretan plate deformation and the regional tectonic setting of the plates in the area will be obtained. Together with the seismic monitoring already in progress, a better assessment of the earthquake hazard in the area may be obtained.

This work is planned as a collaboration between the University of Colorado and Greek scientists. It is designed to fit into the Greek national research efforts and to complement plans by European geodesists to use space techniques for studies of the tectonic movements in the Eastern Mediterranean.

Strategies for Satellite Laser Ranging to Investigate Crustal Movements as Related in Particular to the Eurasian Lithospheric Plate.

Dr. Leendert Aardoom, Delft University of Technology, Netherlands

This investigation will essentially be a continuation of a data use investigation, "Precision and reliability of relative station determinations in selected areas with a view to investigating the potential of detecting relative station displacements", being carried out in the framework of the Lageos project. The area presently selected is the western part of the Eurasian lithospheric plate. The specific area of interest is the boundary between the Eurasian and the African plate along the Mediterranean area. The main objective of the investigation is to conceive, develop and apply satellite laser ranging strategies, aimed at the establishment of a basic geodetic network, to be used in subsequent stages to detect and monitor crustal motions in the area selected. The study will attempt to optimize the strategies such that the crustal motions are most reliably determined.

Intraplate Deformation, Stress in the Lithosphere and the Driving Mechanism for Plate Motions

Dr. Bradford H. Hager, California Institute of Technology

This investigation will determine large scale intraplate strains from changes in baseline lengths and will calculate the state of lithospheric stress using three-dimensional finite element methods. The stresses will be calculated by treating the lithosphere as a thin (spherical) elastic shell loaded by the tractions obtained from a fluid dynamical model. The results will be used to recommend Project sites for measurements of intraplate strain. Regions where high strain is expected will be identified early in the study. The models will be extended to include the possible effects of mantle plumes and active ledges. Areas where strain measurements will most readily discriminate between driving force models will be identified. The stress models will be compared to the strain observations to determine the effective viscosity of the lithosphere and constrain the plate driving mechanism.

The Interpretation of Crustal Dynamics Data in Terms of Plate Motions and Regional Deformation Near Plate Boundaries

Dr. Sean Carl Solomon, Massachusetts Institute of Technology

Time rates of change in vector baselines measured by the Crustal Dynamics Project will be used as primary constraints on quantitative models of plate motion and lithospheric deformation. Modeling of regional deformation will also make use of existing standard geodetic data, in-situ stress measurements, earthquake mechanisms and geological indicators of deformation where available.

A major focus will be on the relative motion between the Pacific and North American plates and the nature of deformation in the western United States. The investigation will begin with the development of a regional model to identify significant parameters in reproducing project-measured changes, deformation and state of stress. The model will be based on a finite element grid system to calculate individually the contribution to the stress field from a variety of sources. The transient motions due to earthquakes will also be calculated and used to compare with measured changes in the California baselines.

The time-dependent deformation near the Alaskan portion of the North American and Pacific plate boundary will also be investigated. Using Project data, a mean convergent velocity and relative vertical displacement among the Alaskan stations will be determined. Existing finite element models of post-seismic deformation along the Pacific-North American plate boundary in the Alaskan region will be tested against these new data.

The relative plate motion between Eurasian and North American and betwen the Nazca and South American plates will also be determined, subject to the availability of data. In South American, objectives include a determination of the thickness of the continental lithosphere and the geometry of the subducting slab; a test of geological models for the rates of crustal shortening and uplift of the Andes; and estimates of the internal rigidity of the Nazca and South America plates and the direction of any migration of great earthquakes along the plate boundary.

Displacement, Strain and Relative Plate Motion in the Africa/Arabia/Anatolia/Eurasia Plate System: Synthesis of Landsat and Ground Studies with VLBI Data

Dr. John F. Dewey, State University of New York

This investigation will continue field studies of the North Anatolian and East Anatolian Transform Faults, using Landsat images. The image data will be used to study plate movements in the vicinity of the Anatolian Triple Junction using baseline data obtained by the European consortium. The Anatolian Plate is a fascinating analog of the western U.S. in several ways. The North Anatolian Fault is a lengthy, highly seismic transform fault well-exposed on land on both sides, very similar to the San Andreas Fault. Preliminary information suggests that the East Anatolian convergent zone may be one of the best areas in the world to study the geometry and kinematics of continental convergence and its relation to regional seismicity.

The following are the goals of this investigation: 1) The elucidation of a longer, more significant history of earthquake behavior along the selected segments of the EATF and NATF. The investigators hope to obtain more reliable estimates of recurrence interval, displacement per event, and magnitude of past earthquakes, thereby refining and extending their present capabilities for assessing seismic risk. 2) The study will assess the conditions, motions, mechanisms and evolution of the earthquake faulting process at the surface and at depth. 3) The data accumulated by this study will be used to assess how fault zone structures and fault rock textures relate to strain accumulation and release that is associated with earthquake rupture.

SLR/VLBI Investigation of Regional Lithospheric Deformation and Contemporary Plate Motions

Dr. Seth Stein, Northwestern University

This investigation will study regional deformation in the Basin and Range Province by combining SLR/VLBI observations with field geology. This will provide an excellent opportunity to compare short and long term deformation at a diffuse tectonic boundary.

The specific scientific targets for study of Great Basin kinematics include the following: 1) determination of the mean extension rate across the entire Great Basin (EW baseline near 39^{o}N) and detection of differential extension rates across the Great Basin in at least three domains, 2) correlation of lateral variations in extension rates with seismic data to evaluate the kinematic significance of belts of maximum seismicity near the western and eastern margins of the Great Basin, 3) detection of displacement, especially of spatial differences in uplift rate as they may relate to horizontal extension rates and seismicity, 4) comparison of the distribution of instantaneous displacement rates by NASA ranging with those estimated by fault scarp studies for Holocene and Pleistocene times to estimate secular changes in rates and loci of displacement and 5) assessment from goals 1 and 2 whether shallow aseismic creep is likely to be an important deformation mechanism in Great Basin tectonics.

Conduct Crustal Dynamics Investigations Along the Eurasian-African Plate Boundary

Dr. Peter Wilson, Institut fur Angewandte Geodasic, Federal Republic of Germany

Using both laser ranging and VLBI techniques, the Sonderforschungsbereich 78 will conduct a detailed investigation of the dynamic changes encountered at the crustal plate boundaries in the Mediterranian. Initial work will concentrate efforts in the East Mediterranean, especially linking the Hellenic Arc with Northern Greece, North and northwest Anatolia and Egypt, and Central Europe. Later work may extend eastwards to connect the East Anatolian Fault Zone, Cyprus, and the Jordan Rift. Westward, the observations should be extended to include all Mediterranean plate boundaries out to the Azores.

Contributions of GRGS to Crustal Dynamics by VLBI Techniques

Mr. Claude Boucher, GRGS/IGN, France

This investigation will equip the EISCAT (European Incoherent Scatterometer) radio observatory in northern Sweden with VLBI equipment and use it in the global program of VLBI observatory operations. EISCAT is in the far north of Sweden, and its regular participation in the global program is desirable for its contribution to European plate stability measurements, measurements of glacial rebound of the Fennoscandian region, and measurements in the global polar motion network. One (or two) antenna at EISCAT will be modified to work in S- and X-band (2 GHz and 8 GHz) and the following equipment will be added: appropriate receivers, Mark II (or Mark III) recording equipment and interfaces; and accurate atomic time standards (H maser).

Determination of Worldwide Tectonic Plate Motions and Large Scale Intra-Plate Distortions

Dr. Peter L. Bender, Joint Institute for Laboratory Astrophysics, University of Colorado and National Bureau of Standards

The main objective of this investigation is to obtain new information on the present rates of worldwide plate tectonic motions and large scale distortions within the plates. The investigation will be using station positions derived by NASA from both Lageos ranging and VLBI data.

The investigators will look for deviations of relative station displacements as a function of time from a model such as RM-2 of Minster and Jordan (1979), which describes the long-term average motions over the last 3 million years, with the assumption that the plates are rigid up to within a few hundred kilometers of the boundaries. For significant deviations from such a model, an effort will be made to make reasonable modifications to the model and fit the appropriate parameters to the data followed by an interpretation of the results in terms of geophysical phenomena.

Finite Element Studies of the Surface Strain Field Adjacent to the San Andreas Fault

Dr. Donald L. Turcotte, Cornell University

This investigation is studying the scale length of strain accumulation normal to the San Andreas fault. Simple order of magnitude calculations indicate that strain can only accumulate over a distance of a few tens of kilometers. This result is consistent with both the coseismic strain associated with the 1906 San Francisco earthquake and measurements of subsequent strain accumulation.

This narrow band of strain accumulation has important implications regarding mechanisms of deformation at depth. Initial results include the derivation of a simple analytical model that shows the observations can be explained by a three layer rheological model. A near surface elastic layer exhibits stick slip behavior at the fault. This layer has a thickness of about 10 km. Beneath this elastic layer is a thin viscous layer at intermediate crustal depths. This intermediate layer has a thickness of a few kilometers and may be the same layer along which the allochthonous behavior of the southern Appalachians occurs. Beneath this viscous layer is a second elastic layer associated with the lower crust and upper mantle. This second elastic layer exhibits free sliding on the fault.

Geophysical Study of the Structure and Processes of the Continental Convergence Zones Alpine-Himalayan Belt

Dr. M. Nafi Toksoz, Massachusetts Institute of Technology

This investigation is performing a detailed geophysical study, using Earth-based and satellite data, of the Alpine-Himalayan belt. The work will aid in the understanding of the processes and consequences of continental collisions. The collision zones of India and Eurasia (Himalayas and Tibet) and Arabia and Eurasia (Zagros Ranges, Iran and Turkey) will be studied in detail. Satellite gravity and magnetic data will be combined with ground based seismic and other geophysical data to determine the structure and properties of these collision zones. Significant new information (seismic, gravity, magnetic, and geochemical and geologic data) are now becoming available from Chinese studies in Tibet. These new data greatly enhance the data base for this study.

Using surface and subsurface structure and properties as constraints, thermal and deformation models of the collision zones will be calculated using finite difference and finite element techniques. These models will help identify the processes involved in the evolution of these major tectonic features.

Global Study of the Time Evolution of the Lithosphere Using GEOS-3 and Seasat Altimeters

Dr. Micheline C. Roufosse, Smithsonian Astrophysical Observatory

Radar altimeter data derived from the GEOS-3 and Seasat satellites will be used to investigate the mechanical properties of the lithosphere and the influence of plate velocity on these properties.

Using the thin elastic plate model developed by McKenzie and Bowin or an Airy model of crustal thickening, these investigators are studying the relationship between geoid heights derived from the GEOS-3 altimeter and ocean bathymetry for several features in oceanic regions, mostly the Central Pacific and the South Atlantic. The study is calculating a series of theoretical admittance functions in wavenumber space with flexural-rigidity values for the thin elastic plate model and plate thickness values. These functions are Fourier transformed into normal space and convolved with the bathymetry constructed rigorously along the sub-satellite position in order to obtain a theoretical geoid to be compared with the observed geoid. The value of the flexural rigidity that best reproduces the wavelength and intensity of the observed signal is selected as representative of the area.

The method described above will be used to study the time evolution and obtain a three-dimensional picture of the lithosphere for all oceans. Many different sites locations will be examined, spanning a wide range of posibilities for the age, formation, and evolution of the load and for the age of the underlying lithosphere.

Models for Rupture Mechanics of Plate Boundaries and Crustal Deformation

Dr. Amos M. Nur, Stanford University

This investigation will develop a general model for the mechanics of plate boundary rupture -- including the seismic rupture in its upper part, and the aseismic yielding in the lower part of the lithosphere. The model will involve the time history of slip and the migration of slip zone boundaries on the plate boundary, derived from dislocation and crack mechanics, creep rheology of rocks, and observations of fault patterns, multiple faults, and pull apart basins. The results will consist of theoretical patterns of large scale, time dependent deformation fields near plate boundaries related to the occurrence of large earthquakes. The results will provide guidelines for the kind of geodetic, gravimetric and large scale strain measurements to be undertaken by NASA around active major plate boundaries and several hundred kilometers along and away from these boundaries.

Models of Coseismic and Post-Seismic Deformation and Studies of Regional Seismicity

Steven C. Cohen, NASA, Goddard Space Flight Center

This study involves the ongoing development of a model for post seismic deformation and stressing of the crust and subcrustal layers of the Earth. The model attributes these deformations to viscoelastic relaxation of the lower lithosphere and asthenosphere following an earthquake. The essential features of the theoretical and numerical structure are the representation of the Earth as a multiple layer medium with depth dependent rheological properties and the representation of the fault as a slip plane. Illustrative calculations have been made for the case of strike-slip faulting in an elastic upper layer of a three-layer Earth. Below the upper elastic and brittle lithosphere layer is a linear viscoelastic solid layer representing the lower lithosphere and below that a Maxwell viscoelastic fluid representing the asthenosphere. The rheological model incorporates many features expected to be found in the Earth including a lower lithosphere which allows for both time-dependent viscoelastic flow and permanent elastic support of a portion of applied stress (on the time scale of the earthquake cycle) and an asthenosphere which has even smaller viscosity and more fluid-like behavior. The model also allows for horizontal variations in elastic and viscous properties as well as thrust faulting but these have not yet been included in numerical simulations.

Detailed calculations using the finite element method reveal that appreciable postseismic displacements (> 1 cm) may be expected to develop over time following a major earthquake at distances up to several hundred kilometers from the fault. The predicted displacements are significantly greater than those derived from simpler two-layer models and indicate the possibility for appreciable displacement even when the top of the asthenosphere is several tens of kilometers below the surface. The analysis of the magnitude and width of the corresponding change in the deviatoric stress field is now underway.

The Seismotectonics of Plate Boundaries

J. Berger, J.N. Brune, J. Goodkind, F. Wyatt, D.C. Agnew, and C. Beaumont, University of California, Dalhousie University, Canada

This investigation team has conducted research over the past seven years in both instrument development and observation analysis on the seismotectonics of southern California and the northern Gulf of California. This broad-based study has three major elements. The study has made strain accumulation measurements to evaluate the relationship between stress accumulation and seismic vs. aseismic strain changes. It included the instrument development of a superconducting gravimeter (which more correctly could be categorized under the advanced studies area of the program). The investigation also provided a framework for the study of Earth tides. All three of the studies focus on the seismotectonics of the North American - Pacific plate boundary. The strain measurements were made in this region, the gravimeter was tested in this region, and the Earth tidal studies were related to the possible effects of loading and their relationship to the seismicity of the region.

Studies of Crustal Movement Measurement Techniques

P.L. Bender and D.R. Larden, Joint Institute for Laboratory Astrophysics, National Bureau of Standards and University of Colorado

This investigation has been working during the last five years on evaluating and comparing various proposed methods for measuring crustal movements. The main emphasis has been on trying to understand the various sources of systematic errors which affect the different techniques, and the practical problems involved in using them in the field. Related work sponsored mainly by NBS involved evaluating the complementary scientific results that could be expected if increased efforts were made to develop improved ground measurement techniques.

The studies related to the Lageos mission investigations were aimed mainly at determining the importance of different factors in limiting the accuracy of world-wide station positions. Biases and other types of persistent systematic errors are the main concern for the future usefulness of data being taken now. If sufficient efforts are made to overcome these measurement errors, then limitations on other sources of information on the gravity field beyond that obtainable from fitting the Lageos orbit may limit the position accuracy for widely separated stations to about 3 cm in each coordinate. In addition, refraction and ocean tide model errors need to be considered carefully. Some simulations of the accuracy achievable for determining shorter baselines in California also have been done.

The current efforts are concentrating on studies of weather limitations and station location geometry effects on the accuracy expected from Lageos ranging. The main factor determining the number of worldwide fixed stations required may be the need to monitor short-period variations in the Earth's rotation rate accurately enough so that positional results from the high-mobility stations aren't substantially degraded. In the future, the investigators may work with other groups on analyzing their results, particularly with the objective of trying to find ways to improve the level of confidence in the important geophysical conclusion which will be drawn from the data.

Testing of Hypotheses in Crustal Dynamics Using VLBI and SLR Data from California

Dr. G. Peter Bird, University of California

This study will analyze and determine the rheology of the crust and upper mantle in California through numerical modeling. At present there are four different models of upper-mantle flow, and each implies a different pattern of drag in the crust. Using a data set of baseline changes determined by SLR and VLBI methods, each model which is consistent with geology, will be geographically extended to include all existing or planned stations relevant to California. Next, the predicted (anelastic) relative motions will be corrected for elastic strain changes in the measurement period, using elastic dislocation models for the relative displacements caused by differences between actual fault locking or slip and average rates. Finally, a maximum - likelihood criterion will be used to select the best model, given all that can be estimated about measurement errors. The calculations will be performed once in 1982 to identify which measurements would be most valuable in 1983-86. In 1986, the elastic corrections and model evaluations will be repeated, to take advantage of the complete dataset. Results of this project will give an empirical characterization of crustal and fault-zone rheologies which will advance tectonophysics in general and earthquake studies in particular. The project will also help to determine the general form of upper mantle tectonics beneath California and contribute to understanding of its thermal history. Finally, the selected optimal model will yield an improved map on long-term seismic hazards in California.

Towards a Statistical Understanding of Tectonic Motions

Dr. Ducan Carr Agnew, Scripps Institution of Oceanography

This investigation will apply statistical time series analysis methods to the study of irregularities in regional crustal deformation. Existing data show that these irregular motions are statistically like a random walk and are dominated by very low frequencies, showing a long-term persistance. Methods of analyses will be investigated and applied to Crustal Dynamics Project data, deformation data from the U.S. Geological Survey, and the continuous records from the Pinon Flat Geophysical Observatory. Specific areas of investigation and application will include how best to determine and describe very low frequency deformation on the basis of a sparse data set, what procedures can be used for the detection of anomalies in a time series with long-term persistance, and how to correlate deformation data meaningfully with other measures of tectonic activity, such as seismicity. Additionally, the study will attempt to determine the limits that irregular tectonic motion place on the ability to measure steady plate motion or other trends in a regional deformation. This will involve comparing data of different length baselines to estimate the wavenumber spectrum of deformation and determining what the spectrum implies about appropriate lengths for deformation measurements. The study plans to determine the time interval needed to measure deformation. The investigators hope to discern whether polar motion diverges at low frequencies and whether it defines a preferred reference frame. By determining this, they may estimate the limits on the irregularities in the pole path and their impact on detecting anomalies in polar motion.

The Interpretation of Crustal Dynamics Data in Terms of Plate Motions and Regional Deformation Near Plate Boundaries

Dr. Sean Carl Solomon, Massachusetts Institute of Technology

This investigation will interpret data for plate motions between the North American, Eurasian, Pacific, Nazca, and South American plates, and for plate deformation near active margins. The first step will be the development of a regional model to determine which parameters are most important in reproducing observed deformation and state of stress. These parameters will be incorporated into future models of global stress fields and generalized to other regions where similar deformation is observed. The western U.S. will be the prime subject for detailed study of the global stress field interaction with large regions of internal deformation. The next phase of the investigation will entail the integration of these data sets with finite element models of lithospheric deformation to test hypotheses about plate driving forces and the mechanical properties of the lithosphere and asthenosphere.

The investigators have developed and are continuing to develop finite-element computational techniques to model intraplate stress and the time-dependent deformation and stress in the lithosphere following a large earthquake. Work to date has shown that the results of such calculations are sensitive to the assumed forces acting on the plates and to the assumed mechanical properties of the lithosphere and asthenosphere. It is expected that measurements to an accuracy of 1 cm/yr of changes in intercontinental baselines and in regional baselines in areas of active tectonic deformation, will in concert with proper theroretical models, permit a new understanding both of plate driving forces and of crustal and mantle rheology.

VLBI Measurements in Alaska to Determine Plate Convergence, Intraplate Deformation, and Possible Coseismic Displacements

Dr. Tracy Johnson, Lamont - Doherty Geological Observatory, Columbia University

Repeated baseline measurements between sites in Alaska and other locations will be used to determine relative Pacific -North American plate motion and any spatial or temporal variations, to study internal deformation in continental Alaska, and possibly measure coseismic deformation during an earthquake. Changes in baselines would help establish the degree to which strain release is partitioned between the continental and oceanic plates and would provide a check on seismically determined deformation for the presence of substantial aseismic slip. Continental to oceanic strain release is important for estimating recurrence intervals, future seismic gaps, and evaluating other geophysical phenomena such as changes in the Chandler wobble.

Alaska is composed largely of a group of micro-continental plates which have accreted into the edge of the North American craton. The sutures form weak zones. From south to north, broadly defined deformation zones can be delineated by the Border Ranges, the Denali fault system, the Keltag fault, and the Brooks Range. In southeastern Alaska, the Fairweather and other fault systems define another series of accreted terranes. Although seismic coverage in northern Alaska is incomplete, it appears that an active rift is forming from west to east, south of the Brooks Range. The VLBI sites are optimally oriented to measure these internal deformations, as the baselines are located in areas between which deformation is likely to be most rapid.

Measurement of Crustal Motion in the United States Using Laser Tracking Observations

Ronald Kolenkiewicz, NASA, Goddard Space Flight Center

The objective of this analysis is to improve the knowledge and understanding of the regional deformation in the Western United States and of the relative tectonic plate motion and boundary characteristics of the North American and Pacific tectonic plates. Specific studies include: 1) analysis of the baselines between lasers in Boulder, Colorado; Fort Davis, Texas; Greenbelt, Maryland; and Trinidad and Roswell, New Mexico. This will establish the precision of the lasers for determining the baselines in which there is no significant motion expected. 2) analysis of baselines between Otay Mountain, California; Bear Lake, Utah; Goldstone, California; Owens Valley, California; Vandenberg AFB, California; Yuma, Vernal, Flagstaff, Gallup, Mount Hopkins, Magdalina, Santa Rosalia, San Felipe, La Paz, Los Moches, and Guaymas, Arizona with respect to base stations in Mexico and the United States. 3) Measurement of the baseline and relative height variations between Monument Peak and Quincy, California, to extend the measurements made during the SAFE program.

The main analysis tool to be used will be the GEODYN orbit determination system, which possesses the capability to estimate station locations from multiple arcs of data from several different satellites simultaneously, as well as to adjust both components of the polar motion. The orbit perturbation model can include the geopotential to degree and order 50, atmospheric drag, solar radiation pressures, direct and tidal luni-solar perturbations and those due to the planets. Force model characteristics can also be adjusted simultaneously with orbit and station location parameters to refine the orbit perturbation model.

Networks for Earthquake Research

Dr. Hans-Gert Kahle, Huebwiessenstrasse, Switzerland

This project is an integral part of the joint European, long-term investigation program of crustal dynamic processes along the Alpine-Mediterranean plate boundary zones. The emphasis of this study is on earthquake interpretation and will involve modeling of earthquake mechanisms which are connected to the relative plate motions in the zone of contact between the Adriatic promontory and the European foreland. The investigation will assess the kinematics and dynamics of the Alpine area by terrestrial and space related methods. The terrestrial measurements include: repeated precise levelings, detailed gravity surveys, in-site stress measurements, deep-seismic soundings, seismic surface-wave observations, fault-plane solutions of earthquakes, geodetic-astronomical zenith camera observations, and tilt measurements with water-tube tiltmeters. The space related techniques involve Doppler measurements, SLR, and VLBI. The results of the investigation should increase the knowledge of earthquake episodes and their mechanisms in the realm of the northern (Alpine) limit of the Adriatic promontory. The study results will also provide a quantitative assessment of horizontal and vertical displacements which will help to evaluate the potential of crustal hazards in this area.

Modeling of Tectonophysical Distortion from Measurements of Long-Baseline Geodetic Data and other Geophysical Parameters

Dr. James H. Whitcomb, University of Colorado

The objectives of this investigation are to model the tectonic stress -strain rheology of the plate boundary region in the western United States and correlate the long-baseline geodetic data and models with other geophysical parameters in the region. Projected improvements in the performance of the geodetic systems should enable the mapping of dilatant crustal zones by means of monitoring the distortion gravity gradient during vertical distortion episodes. The anticipated results of this study are a better understanding of the plate motion rates and the state of stress in the Earth's crust in the western United States. A direct application of the study results may lead to an increased understanding of the earthquake process and earthquake hazards.

Study of Geophysical Mechanisms of Recent Crustal Movements Affecting Scandinavian Tied Space Geodetic Baselines

Dr. Allen Joel Anderson, University of Colorado and The University of Uppsala

This investigation deals with the study of geophysical mechanisms responsible for spatial variations in the precise space geodetic baselines tied to the Scandinavian Region. The mechanisms to be studied include: plate and intraplate motion processes and their relationhips with the Northern European and Euroasian crustal areas; global isostatic rebound and subsidences; and regional seismicity of old fault zones, grabens, and areas of accumulated crustal stress. Data types to be included in the investigation include: Scandinavian baselines using the EISCAT antenna facilities; tidal loading measurements (recording gravimeters) and precision geodetic geodimeter surveys of space geodetic observation sites and other regions within Scandinavia; regional seismicity and focal mechanism studies; precision satellite Doppler translocation network measurements within Scandinavia; and European satellite laser ranging data.

Finite Element Modeling of Crustal Strain

Dr. Gregory A. Lyzenga, Jet Propulsion Laboratory

Numerical modeling of the tectonic structure and rheology of the southern California crust and upper mantle will be conducted employing finite elements methods. The models produced will analyze the following: 1) the spatial and temporal dependence of regional strains determined by space and conventional geodesy, 2) the correlation between their models and other models of observed "uncompensated" topography and geophysical/geological evidence for lateral inhomogeneities, 3) the correlation between vertical and horizontal tectonics zones including horizontal crustal detachment, offset of the San Andreas fault at depth, and upper mantle non-uniformity, and 4) the problems of pre-seismic strain accumulation, and the effects of model rheology and structure on precursory signatures where significant earthquakes or aseismic strain events can provide model-constraining data.

The same numerical methods will be employed to treat the crustal deformation information made available through VLBI and TLRS observations near other plate boundaries, chiefly from the circum-Pacific belt. Geodetic data will be used from different types of plate boundary regions in order to constraint finite element models of large scale structure and dynamic properties. These modeling efforts will be directed toward explaining topographic and gravity profiles, as well as toward elucidating the nature of driving and coupling forces at the selected boundaries.

Satellite Laser Ranging Applications to Crustal Dynamics

Dr. Bryon D. Tapley, The University of Texas at Austin

The primary objectives of this research are continued application of satellite laser ranging to the precise determination of TLRS coordinates, global laser stations network coordinates, global baselines between geodetic markers, polar motion, length of day and UT1. Intercomparison of satellite laser results with VLBI, LLR, and satellite Doppler techniques and interpretation of results in terms of geophysical signal and the characteristics of the error sources associated with the SLR techniques will also be analyzed.

A fundamental requirement for achieving these objectives is the ability to determine precise orbits for Lageos, Starlette and other geodetic satellites. The University of Texas Orbit Processor (UTOPIA) will be used for the orbit determination. To alleviate deficiencies in the model, investigations will be conducted to obtain the following: improvements in the range measurement model through evaluation of mean station coordinates, Earth tides, tectonic plate motion, polar motion, and relations between reference frames and tropospheric refraction models. Improvements in the satellite force model will be sought through more accurate values for gravity spherical harmonic coefficients, and other parameters such as lunar, solar and planetary forces, solid Earth tides, ocean tides, general relativity, radiation pressure, drag and empirical or unmodeled forces. The study hopes to bring an improved understanding of the effects of reference frame selection and the relations with other reference frames as well as improving the accuracy of the geodetic and geophysical parameters and improved accuracy in the solution methods.

Determination of the Relative Horizontal and Vertical Motions of Stations in the Laser Tracking Network

David E. Smith, NASA Goddard Space Flight Center

The major objectives of this research are to determine the rates of change of baseline length between all major stations of the laser tracking network, the stability of these rates (data permitting), the stability of the heights of the major laser stations above a reference surface and the significance of any variations. The secondary objective is to apply laser tracking to the determination of polar motion and Earth rotation. This will include formulating estimates of GM (the product of the Earth's mass and gravitational constant) at regular intervals and developing improved geodetic techniques for estimating baselines, stations heights and Earth rotation parameters.

This research effort will produce monthly estimates of baseline length and station heights for all stations in the laser tracking network from which sufficient data are available. Polar motion and length-of-day values will be resolved at 5 day intervals and estimates of GM will be made annually. These results will be made available to each investigator in the Crustal Dynamics Project on a timely basis.

Center of Mass Laser Teaching Station Coordinate Determination and Lithospheric Plate Motion Investigation

James G. Marsh, NASA, Goddard Space Flight Center

The objective of this investigation is to determine the center of mass coordinates of global laser ranging stations, and compare results with those obtained by other methods. The investigators will assess the ability to measure plate tectonic motions by making detailed analyses, study specific analysis of relative plate motion of the tracking sites using yearly coordinate solutions for the lasers, and compare currently available relative motion plate tectonic models derived from groundbased measurements with satellite derived quantities. They will verify software, assess dynamic and measurement model accuracy, and execute calibration activities for a (36, 36) or higher gravity model. The accuracy of solar radiation pressure and atmospheric drag models will be established. The accuracy of station coordinates and other error sources affecting ephemeris computation will be investigated. Laser data from European sites will be evaluated and validated for data noise, range biases, and timing errors. A set of the most accurate orbit elements using the most recent geodynamical models and computational procedures will be published periodically.

Studies of Continental Deformation, Plate Motion and Polar Motion using Geodetic Data from Space Techniques

Dr. Richard J. O'Connell, Harvard University

This investigation will integrate an analysis of baseline data and other geophysical measurements to study plate deformation. Seismic, gravity and heat flow data and numerical modeling of the deformation of the lithosphere will be used to investigate large scale deformation and smaller scale lithospheric deformation, with special reference to the western U.S. Activities include investigating the response of the lithosphere to unhomogeneous stress distributions resulting from plate motion and determining intraplate deformation from baseline lengths changes. Since the most densely instrumented region during the lifetime of this program will be the western United States, the deformation of this region will be modeled.

Excitation of the Chandler Wobble by seismic and aseismic events will be investigated by calculation of the polar motion expected to be caused by large earthquakes on plate boundaries. This will involve separating crustal deformation from polar motion in the data and the elimination (as much as possible) of the atmospherically forced annual motion.

Space Based Measurements of Crustal Deformation in the U.S.: Interpretation in Light of Other Geodetic, Geophysical, and Geological Information.

Dr. Jack Oliver, Cornell University

This investigation will use VLBI and laser ranging data together with ground based geodetic measurements to better define contemporary deformation near the active plate boundary in western U.S. and to define possible internal deformation of the North American continental lithosphere. The study will incorporate other relevant geophysical and geological information with the crustal movement measurements to further the understanding of earthquakes, volcanic activity and geodynamic processes in general.

The first part of the study will concentrate on deformation in southern California. A massive re-leveling program was undertaken in 1978 throughout a large area of southern California. These re-leveling measurements provide information on regional deformation for the same time period as covered by NASA measurements. Procedures and criteria for identifying systematic errors and near surface non-tectonic movements, and separating them from tectonic deformation will be used to evaluate the most recent re-leveling measurements in southern California.

Other problems to be addressed include plate boundary deformation in Alaska, historic deformation near the Rio Grande Rift, contemporary uplift of the Appalachian Mountains, and discrepancies between leveling and tide gauge data along the U.S. East Coast.

Correlation of Data on Strain Accumulation Adjacent to the San Andreas Fault with Available Models.

Dr. Donald L. Turcotte, Cornell University

Cyclic accumulation of strain associated with great earthquakes in the San Andreas Fault will be studied using numerical modeling. Alternative models are now available to compare with available data. These models depend critically on the rheology of the fault zone and on the amount of viscous damping of surface strain that occurs within the atmosphere below the surface plates and within the crust.

In addition, the distribution of strain across the western United States will be studied to determine whether the Eastern United States behaves as a rigid plate. Changes in length will be analysed to determine the origin of the associated change in stress.

Contribution of Shanghai Observatory to Crustal Dynamics for the Period 1982-1986

Ye Shu-Hua, Shanghai Observatory, Peoples Republic of China

This investigation includes the following activities: 1) The inter-comparison of VLBI and SLR data collected by NASA and CERTI will be compared to Doppler tracking data and classical optical observations provided by other agencies to estimate their accuracies, to detect possible systematic errors, and to explore the sources of these errors; 2) an analysis of the variations of short period terms of polar motion and UT1; and 3) evaluation of possible correlations between Earth rotation, earthquakes, atmospheric and oceanic circulations, solar bursts and other related phenomena.

Modeling of Tectonophysical Distortion from Measurements of Long-Baseline Geodetic Data and other Geophysical Parameters

James N. Whitcomb, CIRES, University of Colorado

This investigation's work will include continuation of the construction of strain models of the fault system in Southern California using two-dimensional finite element techniques. In this manner, it is hoped to realistically investigate the range of possible tectonophysical models which satisfy the geodetic data for the region. Three-dimensional techniques, if found to be relevant and practical, may also be employed. These models will be investigated with special emphasis as to the effect of the Big Bend region of the San Andreas fault and the behavior of other geophysical data including gravity.

Finite Element Investigation of Lithosphere Tectonics

Dr. H.J. Melosh, State University of New York at Stony Brook

The coseismic displacements accompanying an earthquake on a long strike slip fault are well described by an elastic screw dislocation model. Following the earthquake the resulting shear stresses begin to relax in the asthenosphere and further deformation may be observed at the Earth's surface. The ultimate result of this relaxation is to propagate the displacements initially localized along the fault to great distances from the fault zone.

This situation has been modeled in detail using a finite element numerical computer code. The fault is introduced into the model by means of a "split node" technique. The fault is displaced at $t = 0$ and held fixed thereafter. The lithosphere is treated elastically throughout the computation while the asthenosphere is Maxwell viscoelastic. The asthenosphere follows either a newtonian ($n=1$) or non-newtonian ($n=3$) creep law. A variety of runs were performed for different fault depths, asthenosphere thickness, and mesosphere viscosity. The newtonian results show that after about one Maxwell time displacements propagate away from the fault following a diffusion law, $x \sim t^{1/2}$, and stresses at the rupture zone die away exponentially. These results are in good agreement with other numerical computations.

The non-newtonian runs show that the relevant time scale is also one Maxwell time, where the effective viscosity is determined by the average stress drop on the fault. Displacements propagate away from the fault following a $x \sim t^{1/6}$ relation. The newtonian and non-newtonian results are nearly indistinguishable if time is rescaled by a power rule. These results agree qualitatively with results found for dip slip earthquakes in a non-newtonian rheology.

GEOPOTENTIAL RESEARCH PROGRAM

Gravity Model Improvement For Lageos

Francis J. Lerch, NASA, Goddard Space Flight Center

A refined gravity field model, Goddard Earth Model GEM-L2, has been derived using the Lageos orbital data yielding better baseline measurements for the analysis of tectonic plate motion. This field also contributes to an improved understanding of long wavelength features, such as sea slope across broad ocean basins, through its significant improvement of the long wavelength geoid (through degree and order 4). The geoid for these terms has an accuracy estimated at ± 8 cm in GEM-L2. GEM-L2 as in all recent Goddard Earth Models, heavily relies on the precise near-Earth satellite laser ranging data, in this case provided by NASA's Crustal Dynamics Program. Two and a half years of Lageos laser data acquired from over 20 well-distributed stations were combined with the existing data from the best satellite-derived model, GEM-9, to develop the new Lageos model. Testing shows that the Lageos gravity field error at long wavelengths is less than half that for GEM-9. Independent tests using well determined longitude accelerations of 24-hour satellites have verified the improved accuracy of the new model. A comparison of global laser "base" stations from independent data sets of alternating 15 day data segments over the 2 1/2 years of Lageos show total interstation positioning to ± 1.6 cm when using this new field. The same comparison using the 1979 versus the 1980 Lageos data yields ± 5.2 cm; this difference in agreement (1.6 vs. 5.2 cm) may reflect the tectonic motion which has occurred between these chronologically distinguishable data sets. Five day polar motion values with a precision of 10 cm and A1-UT1 values accurate to better than 1 msec have been derived in the solution. The adjustment of these parameters are necessary to achieve the accurate stations and geopotential results of GEM-L2.

The Relationship Between Gravity and Bathymetry in the Pacific Ocean

A.B. Watts, Lamont-Doherty Geological Observatory

This investigation has made significant progress in the understanding of long wavelength gravity and topography anomalies in the Pacific ocean and the plan form and scale of mantle convection. All available gravity anomaly, bathymetry, magnetic anomaly, and geoid data have been used to obtain smoothed values of gravity and topography anomalies over the Pacific ocean basin. The preliminary results of this analysis have been accepted for publication in NATURE (McKenzie, Watts, Parsons and Roufousse, 1980). This analysis has shown that there is a good correlation between geoid and topography anomalies over the central Pacific ocean basin. The pattern of geoid and topography anomalies trends generally parallel to the absolute motion direction of the Pacific plate. We have shown that this pattern can be explained by simple models in which the plan form of convection consists not of rolls but of three-dimensional rising and sinking jets, elongated in the direction of Pacific plate motion. The spacing between the maxima and minima of the geoid and topography anomalies is about 1500 km, suggesting a small scale of convection occurring in the mantle.

This study plans to complete an analysis of gravity anomaly, bathymetry, magnetic anomaly, seismic reflection and geoid data over the Pacific ocean. They will then interpolate the resulting gravity anomalies and residual depth anomalies (observed topography data corrected for the effects of age and sediment loading) onto an equal area grid and analyze the relationship between gravity field and residual depth as a function of wavelength using the Fast Fourier transform. The resulting observed transfer function between gravity field and residual depth will then be compared to calculated transfer functions based on different numerical models of convection in the mantle. These studies should greatly add to our knowledge of the plan form as well as viscosity structure of convection in the Earth's mantle.

Gravity Field Improvement

Richard H. Rapp, The Ohio State University

This investigation is researching the Earth's gravity field. The following specific topics are currently under study:

1. The Current Status of the $1^o \times 1^o$ Anomaly Field - This study's effort has continued to provide the most up to date $1^o \times 1^o$ data set as possible. The next update will contain some significantly changed anomalies in several areas, but especially Africa where some problem areas have been previously indentified, through altimeter and SST analyses.

2. Improved 5^o Anomaly Prediction Techniques - This study has improved the standard procedure for estimating 5^o equal area anomalies from $1^o \times 1^o$ data. This improvement includes proper weighting for 1^o blocks of different areas; consideration of the elevation of the known and unknown $1^o \times 1^o$ blocks, and the incorporation of local covariance function comparisons between the old and new. Comparisons between the old and new procedures show substantial improvement in areas of sparse data and widely varying topography.

3. The Indirect Effect on Geoid Undulations - Research has been carried out to quantify the indirect effect in specific regions of the world. Various models for the terrain correction were assumed to find a total correction to current methods being used for geoid computation. The corrections found are considerably larger than those described in the literature.

4. Gravity Field Monitoring - Efforts have been made to compare some of the recent gravity field models. This information led to a combination solution with SEASAT and terrestrial gravity data yielding a set of potential coefficients to degree 180. This field will be compared to the GEM 10C field and other similar fields.

Dynamic Processes of Convergent Plate Margins

David C. McAdoo, NASA, Goddard Space Flight Center

It is generally accepted that relative geoid highs over subduction zones are due to positive mass anomalies in the subducting slabs. Mass anomalies inferred from the observed geoid highs are generally less than those predicted by thermal models thereby implying that slab anomalies are, in part, regionally compensated. This investigation is developing a model of induced corner flow in the mantle to describe this regional compensation. The initial model results in the form of geoid slope profiles are being compared with profiles of geoid slopes derived from Seasat data and global gravity models. Qualitative agreement is shown for the case of non-Newtonian induced flow. In the Newtonian case induced surface deformation gives rise to a relative geoid low which obliterates the high due to the slab alone. Early study results indicate that in some subduction zones (for example Aleutian arc) the mass void of the trench proper does not substantially compensate positive anomalies within the slab and that gravitationally apparent density anomalies in the slab are concentrated at depth-perhaps extending to greater depths than the seismically defined Benioff zone. To the extent to which it is applicable, this model also indicates that the degree of partial compensation should decrease with increasing slab dip angle. This sort of negative correlation can be demonstrated globally.

Interpretation and Delineation of the Earth's Gravity Field

Bruce D. Marsh, The Johns Hopkins University

The gravity field of the central Pacific area has been studied using measurements acquired with satellite-to-satellite tracking (SST). Because the low degree and order (≤ 12) gravity field is known well, this has been assumed as the reference field in computing the orbits. The resulting accelerations reflect the field above the 12th degree and order. This field shows a dominant wavelength of about 2,000 km, often with positive anomalies associated with residual depth anomalies. Significant new anomalies appear near the East Pacific Rise trending in the ridge direction and continuing through North America. Recently additional data have been simlarly reduced to produce a map which correlates closely with the newest GEM model, the GEOS geoid, and with the SEASAT geoid. This is the first time such close agreement has been achieved between these independent data sets. The implications of the six major positive anomalies in this area is emphasized in a model of heat transfer between the lithosphere, small scale upper mantle convection and/or plume convection.

Altimetry Data and the Deep Structure of Subduction Zones

Dr. Glyn M. Jones, Texas A&M University

GEOS-3 altimetry profiles crossing trench/island-arc/back-arc systems typically exhibit a long-wavelength (4000-5000 km), large-amplitude (5-60 meters) increase in geoidal height over these regions. The isostatic component of the geoid due to variations in ocean floor topography has been calculated for several trench systems and is in the range 5-25 meters. Subtraction of this component from the altimetric geoid leaves a residual long-wavelength geoid anomaly of 0-40 meters to be attributed to deeper structure. The residual geoid anomaly appears to systematically decrease in amplitude as the age of the associated back-arc basin increases.

These data are being used to construct numerical models of flow and temperature in subduction zones with a view to obtaining a better understanding of the deep structure of these regions and to address the question of the depth to which the return flow extends. Initial results obtained using a simple Newtonian model show a broad zone of downwelling centered on the trench and predict geoid anomalies an order of magnitude larger than those actually observed. Models involving a temperature- and pressure-dependent viscosity should reduce the amount of mantle material entrained with the downgoing slab and thereby reduce the predicted geoid anomaly to more reasonable levels.

Development of a Superconducting Tensor Gravity Gradiometer

Ho Jung Paik, University of Maryland

The purpose of this study is to develop a three-axis superconducting gravity gradiometer. The long-range goal of this program is to combine the proven superconducting technology with improved geometries of the instrument in order to (1) improve the gradient sensitivity to approximately 10^{-4} E (Eotvos - 10^{-9} s^{-2}) for an integration time of 3 seconds and (2) achieve a three-axis instrument which measures all five independent components of the gravity gradient tensor simultaneously. Such an instrument, when developed, could be flown in an orbiting satellite to obtain an improved gravity map of the Earth.

The superconducting gravity gradiometers currently under development are technological offsprings of the cryogenic gravitational radiation detector project (for the NSF) which started at Stanford University in 1969. During the period 1970-74, a sensitive superconducting accelerometer was developed to detect very small oscillations of a large aluminum bar (1 $\sim$ 5 tons) induced supposedly by pulses of cosmic gravitational radiation. In 1975, work began at Stanford University to combine a pair of the tested superconducting accelerometers in a differencing mode and achieve a sensitive single-axis gravity gradiometer. Two versions of superconducting gravity gradiometers operating on different principles of common mode balance have been constructed and tested. The University of Maryland program of the three-axis superconducting gravity gradiometer development started in 1979 for the NASA Geodynamics Program.

Satellite Geopotential Anomalies: Global Distribution and Relation to Surface Data

Herbert V. Frey, NASA Goddard Space Flight Center

To date no quantitative analysis of the global distribution of satellite-derived geopotential anomalies and their relations to major geologic and tectonic data sets has been performed. Qualitative comparisons using map overlays have shown intriguing relations between POGO magnetic anomalies and GEM 10B higher order free-air gravity anomalies, as well as between these geopotential signatures and major tectonic boundaries as represented by rifts and sutures.

This investigation will further study these broadscale anomalies, using improved gravity models and Magsat magnetic anomaly data, and to explore the significance of their distribution across the globe through qualitative comparison with three other global data sets. The study will evaluate the feasibility of more quantitative statistical correlation of these data with surface geologic and geophysical information, and the possibility of developing a broadscale classification of the lithosphere based on these correlations.

The Age of Satellite-Observed Magnetic and Gravity Anomalies Using Paleo-Reconstructions

Herbert V. Frey, NASA Goddard Space Flight Center

The purpose of this study is to examine the patterns of broadscale magnetic and gravity anomalies as they might have existed in the early Mesozoic era, before the breakup of Pangaea. By examining the continuity or lack of continuity across now-rifted margins, it is hoped to gain a greater understanding of the age of geopotential anomalies and to identify which, if any, anomalies might predate the breakup of Pangaea. This, in turn, will contribute to understanding the nature of large-scale magnetic and gravity anomalies and their relationship with the deep roots of continents and lithospheric evolution.

Magnetic Field Measurements and Interpretation

Robert A. Langel, Goddard Space Flight Center

An initial selection of Magsat data has been utilized to derive a series of magnetic field models. In addition to representing the core field well at the Magsat epoch, these models have been used to study the spectra of the field to aid in separating core and crustal fields.

To model the field over longer time spans, and to provide a larger temporal data base for predicting the field, Magsat data was combined with pre-Magsat data from both satellite and surface measurements to derive a time dependent representation for the period 1960-1980. Surface data utilized in such models often has a very large contribution from local crustal sources which has not been accounted for. Because of the combination of satellites and surface data, this study's models are able to include a solution representing the anomaly fields at observatories. Use of this technique improves not only the field representation but also the prediction ability of the resulting models.

Preliminary examination of Magsat vector data indicates that it has the accuracy necessary to detect anomaly fields. The vector data will be utilized to infer the presence or absence of a remanent component in the anomaly field.

MAGSAT INVESTIGATIONS

From: R. Langel, "Magsat Scientific Investigations" Johns Hopkins APL Technical Digest, July-September, 1980, Vol. 1, No. 3, pp. 216-218.

David R. Barraclough, Institute of Geological Sciences, United Kingdom

Spherical Harmonic Representation of the Main Geomagnetic Field for World Charting and Investigation of Some Fundamental Problems of Physics and Geophysics.

Produce an accurate model of the main geomagnetic field, together with reliable estimates of the accuracy of coefficients.

Charles R. Bentley, University of Wisconsin

Investigation of Antarctic Crust and Upper Mantle Using Magsat and Other Geophysical Data.

Using Magsat data, devise a general framework for the structure of Antarctica into which more specific and local measurements can be integrated.

Edward R. Benton, University of Colorado

Geomagnetic Field Forecasting and Fluid Dynamics of the Core.

Adjust the gauss coefficients of the main field model of the Magsat data set to satisfy dynamic constraints; use Magsat data to test the ability to forecast the structure of the internal geomagnetic field.

B.N. Bhargava, Indian Institute for Geomagnetism

Magsat for Geomagnetic Studies in the Indian Region.

Prepare a regional geomagnetic reference field and magnetic anomaly maps over Indian and neighboring regions: (a) to gain a clearer understanding of secondary effect features and the variability of the dawn/dusk field, and (b) to study in detail the equatorial electrojet and transient variations.

Robert F. Brammer, The Analytic Sciences Corporation (TASC)

Satellite Magnetic and Gravity Investigation of the Eastern Indian Ocean.

Produce magnetic anomaly maps of the Indian Ocean; quantify the comparison between Magsat data and GEOS-3 gravity data; interpret the magnetic data using ancillary data.

J. Ronald Burrows, National Research Council of Canada

Studies of High-Latitude Current Systems Using Magsat Vector Data.

Understand the physical processes that control the high-latitude current systems; improve the confidence level in studies of internal field sources.

Robert S. Carmichael, University of Iowa

Use of Magsat Anomaly Data for Crustal Structure and Mineral Resources in the U.S. Midcontinent.

Analyze Magsat anomaly data to synthesize a total geologic model and interpret crustal geology in the midcontinent region; contribue to the interpretation and calculation of the depth of the Curie isotherm.

Richard L. Coles, Energy, Mines and Resources, Canada

The Reduction, Verification and Interpretation of Magsat Magnetic Data over Canada.

Select quiet-time data; correct Magsat data for disturbance fields and apply the routines; compared Magsat and vector airborne data; combine Magsat and aircraft data of magnetic anomalies; produce regional interpretations relating to earth structure.

James C. Dooley, Bureau of Mineral Resources, Australia

Magsat Data, the Regional Magnetic Field, and the Crustal Structure of Australia and Antarctica.

Incorporate Magsat data into regional magnetic field charts to improve their accuracy; determine if differences exist in temperature-depth curves for different tectonic areas; study the boundaries between major tectonic blocks and between continental and oceanic crust; determine Curie point depth and crustal magnetization for Antarctica.

Naoshi Fukushima, Geophysics, Research Laboratory, Japan

Proposal from Japanese National Team for Magsat Project.

Analyze the regional geomagnetic field around Japan and Japanese Antarctica; study the contributions to magnetic variations by electric currents and hydromagnetic waves in and above the ionosphere.

Paolo Gasparini, Osservatorio Vesuviano, Italy

Crustal Structures under the Active Volcanic Areas of Central and Eastern Miditerranean.

Calculate the depth of the Curie temperature for the Meditteranean area and relate to areas of volcanic activity; investigate the Italian and Tyrrhenian anomaly.

Bruce P. Gibbs, Business and Technological Systems, Incorporated

Geomagnetic Field Modeling by Optimal Recursive Filtering.

Produce a state vector to predict field values for several years beyond the Magsat mode; obtain optimal estimates of field values throughout the 1900-1980 period.

M.R. Godivier, Office de la Recherche Scientifique et Technique, Outremer (ORSTOM), France

Magnetic Anomaly of Bangui.

Improve the explanation of the cause of the Bangui anomaly, using Magsat data, other magnetic data, and gravity, seismic, and heat flow data.

Stephen E. Haggerty, University of Massachusetts

The Mineralogy of Global Magnetic Anomalies.

Interpret Magsat data to locate mafic and ultramafic source rocks and lineament expressions of anomalies that can be correlated with crustal of upper mantle depths; determine mineral stabilities pertinent to magnetic anomalies to ascertain the magnetic properties of metamorphic rocks.

D.H. Hall, University of Manitoba, Canada

Identification of the Magnetic Signatures of Lithostratographic and Structural Elements in the Canadian Shield Using Magnetic Anomalies and Data from Individual Tracks from Magsat.

Confirm and extend the model for crust mantle magnetization.

Christopher G.A. Harrison, University of Miami

Investigations of Medium Wavelength Magnetic Anomalies in the Eastern Pacific Using Magsat Data.

Determine the relationship of magnetic anomalies with surface geological features.

David A. Hastings, U.S. Geological Survey, EROS Data Center

An Investigastion of Matsat and Complementary Data Emphasizing Precambrian Shields and Adjacent Areas of West Africa and South America.

Determine the Magsat magnetic signatures; synthesize Magsat and other data with mineral resources data globally.

John F. Hermance, Brown University

Electromagnetic Deep-Probing (100-1000 km) of the Earth's Interior from Artificial Satellites; Constraints on the Regional Emplacement of Crustal Resources.

Evaluate the applicability of electromagnetic deep-sounding experiments using natural sources in the magnetosphere.

William J. Hinze, Purdue University

Application of Magsat to Lithospheric Modeling in South America: Part I -Processing and Interpretation of Magnetic and Gravity Anomaly Data.

Use magnetic anomalies to develop lithospheric models to determine the properties of principal tectonic features; correlate magnetic anomalies of South America with those of adjacent continental areas to attempt to reconstruct Gondwanaland (see Keller below).

B. David Johnson, Macquarie University, Australia

An Investigation of the Crustal Properties of Australia and Surrounding Regions Derived from Interpretation of Magsat Anomaly Field Data.

Produce a map of surface magnetization to understand the evolution of the crust and to aid in mineral exploration.

G.R. Keller, The University of Texas at El Paso

Application of Magsat to Lithospheric Modeling in South America: Part II -Synthesis of Geologic and Seismic Data for Development of Integrated Crustal Models.

Provide models of the seismic velocity structure of the lithosphere (see Hinze above).

David M. Klumpar, The University of Texas at Dallas

Investigation of the Effeccts of External Current systems on the Magsat Data Utilizing Grid Cell Modeling Techniques.

Apply a modeling procedure to the vector Magsat data in order to separate the terrestrial component from that due to extraterrestrial sources.

John L. LaBrecque, Lamont-Doherty Geological Observatory

Analysis of Intermediate-Wavelength Magnetic Anomalies over the Oceans in Magsat and Sea Surface Data.

Determine the distribution of intermediate wavelength magnetic anomalies of lithospheric origin in the oceans, the extent to which Magsat describes the distribution, and the cause of these anomalies.

Jean-Louis LeMouel, Institut de Physique du Globe de Paris, France

Magsat Investigations Consortium.

Reduce Magsat vector data for a global analytic field model and constant altitude field maps; compare Magsat data to regional studies; study features of the core field; correlate globally and regionally Magsat and gravimetric data.

Michael A. Mayhew, Business and Technological Systems, Incorporated

Magsat Anomaly Field Inversion and Interpretation for the U.S.

Construct a regional crrustal temperature/heat flow model based on a developed magnetization model, heat flow/production data, and spectral estimates of the Curie depth.

Michael A. Mayhew, Business and Technological Systems, Incorporated

Equivalent Source Modeling of the Main Field Using Magsat Data.

Model the core field; compute equivalent spherical harmonic coefficients for comparison with other field models; examine the spectral content of the core field.

Igor I. Gil Pacca, Instituto Astronomico e Geofisico -- UPS, Brazil

Structure, Composition, and Thermal State of the Crust in Brazil.

Construct preliminary crustal models in the Brazilian territory; point out possible variations in crustal structure among different geological provinces.

Thomas A. Potemra, The Johns Hopkins University Applied Physics Laboratory

A Proposal for the Investigation of Magsat and Triad Magnetometer Data to Provide Corrective Information on High-Latitude External Fields.

Identify and evaluate high-latitude external fields from the comparison of data acquired by the Magsat and Triad spacecraft that can be used to improve geomagnetic field models.

Robert D. Regan, Phoenix Corporation

Improved Definition of Crustal Magnetic Anomalies in Magsat Data.

Develop an improved method for the identification of magnetic anomalies of crustal origin in satellite data by defining better and removing the most persistent external field effects.

David P. Stern, NASA/Goddard Space Flight Center

Study of Enhanced Errors and of the Secular Magnetic Variation Using Magsat Models and Those Derived in Pogo Surveys.

Estimate the secular variation over the period 1965-80 by removing mathematical instability based upon scalar field intensity alone.

David W. Strangway, University of Toronto, Canada

Proposal to Analyze the Magnetic Anomaly Maps from Magsat over Portions of the Canadian and Other Shields.

Examine the expected difference between the Grenville and Superior provinces.

Ihn Jae Won, North Carolina State University

Compatibility Study of the Magsat Data and Aeromagnetic Data in the Eastern Piedmont of the U.S.

Evaluate the compatibility between the Magsat and aeromagnetic data in the eastern North Carolina Piedmont.

LAGEOS INVESTIGATIONS

PLATE TECTONICS

W. Jason Morgan, Princeton University

Lageos Study of Polar Motion, Plate Rigidity and Plate Motions.

L. Aardoom, Delft University of Technology, Netherlands

Precision and Reliability Station Determination in Selected Areas with a View of Investigating the Potentiality to Detect Relative Station Displacements.

David E. Smith, Goddard Space Flight Center

Measurement of Fault Motion in the Western United States.

Peter L. Bender, National Bureau of Standards

Determination of Worldwide Mobile Station Positions and Geodynamics Reference System.

H. James Dorman, University of Texas, Galveston

Earth Strain Measurements With the Transportable Laser Ranging System: Field Techniques and Planning.

POLAR MOTION/EARTH ROTATION

Henry F. Fliegel, Jet Propulsion Laboratory

Earth Rotation Parameters from Lageos and Lunar Laser Ranging (LLR) Data.

Richard D. Rosen, Environmental Research and Technology Inc.

Earth-Atmosphere Momentum Exchange and Lageos-Determined Rotation Rates.

Byron D. Tapley, University of Texas, Austin

Solid Earth Dynamics Using Lageos Range Observations.

Deiter Lelgeman, Satellitengeodasie der Technischen Universitat, West Germany

Determination of Polar Motion and Earth Rotation from Lageos Data.

F. Nouel, Groupe de Recherches de Geodesie Spatiale, France

Comparative Studies of Polar Motion by Laser and Doppler Techniques.

David E. Smith, Goddard Space Flight Center

Determination of Polar Motion and Earth Rotation from Lageos Data.

Irwin I. Shapior, Massachusetts Institute of Technology

Validation, Intercomparison, and Use of Laser Ranging and Radio Interferometric Data for the Determination of Geophysical Parameters.

Ivan I. Mueller, Ohio State University

Utilization of Range and Range Difference Observations in Geodynamics.

D. McCarthy, U.S. Naval Observatory

A Proposal for Comparison of Earth Rotation Parameters Derived by Satellite Laser Ranging and Radio Interferometric Techniques.

EARTH ELASTICITY AND GRAVITY FIELDS

A. Cazenave, Groupe de Recherches de Geodesie Spatiale, Toulouse, France

Use of Artificial Satellite Laser Data for Tidal Studies.

Clyde C. Goad, National Oceanic and Atmospheric Administration

The Value of Q at Tidal Frequencies Obtained from Laser Tracking of Lageos and Other Geodetic Satellites.

W.T. Wells, EG&G/Washington Analytical Services

Gravity Model Improvement Using Laser Data.

ORBIT ANALYSIS

E.M. Gaposchkin, Smithsonian Astrophysical Observatory

Analyze Satellite Tracking Laser Data in Order to Study Satellite Ephemerides, Solid-Earth and Ocean Tides and Laser System Performance.

F. Barlier, Groupe de Recherches de Geodesie Spatiale, France

Investigation of Lageos Laser Data at GRGS/Grasse.

Arthur J. Meadows, University of Leicester

Development of a New British Orbital Analysis Program.

M. Lefebvre, Group de Recherches de Geodesie Spatiale, France

Tentative Determination of General Relativity B Coefficient Using Secular Variations of Perigee of Laser Satellites.

Chreston F. Martin, EG&G/Washington Analytical Services

Study of Relativistic Effects on Lageos Orbit Determination and Parameter Estimations.

Peter J. Dunn, EG&G/Washington Analytical Services

Studies of Atmospheric Refraction Effects on Laser Data.

Ronald G. Williamson, EG&G/Washington Analytical Services

Tracking Station Coordinate Determination and Lithospheric Plate Motion Investigation.