PROJECT SUMMARY

Workshops for Establishing a Stable North American Reference Frame (SNARF) to Enable Geophysical and Geodetic Studies with EarthScope

The geodetic results of the Plate Boundary Observatory (PBO) must be defined in a terrestrial reference frame. This frame requires the definition of its scale, its origin, and the orientation of the coordinate axes, as well as precise models of the dynamic Earth. UNAVCO has formed the Stable North American Reference Frame (SNARF) working group to define the reference frame to be used for PBO. This proposal will fund three SNARF workshops to develop the reference frame and to educate the community about it.

Intellectual merit: The SNARF working group is comprised of geodesists with expertise in both developing and testing reference frames. The group has significant links to developers of the international terrestrial frame and the national geodetic surveys of the U.S. and Canada. Accurate realization of the terrestrial reference frame will enable a more robust determination of strains and strain-rates, and provide a common framework for comparison of geodetic solutions and geophysical models, for combinations of network solutions, and for publication of station velocities. We will provide tools and products for performing model calculations and model-data comparisons in the EarthScope reference frame.

Broader impacts: The EarthScope initiative will significantly broaden the community using geodetic techniques to study the Pacific-North American plate boundary. It is thus essential that the SNARF working group not only develop an accurate and stable reference frame, but that the use of that reference frame be properly described to this larger scientific community. The working group will publish SNARF in a refereed journal. Educational information on using the frame correctly will also be available online.

Project Description

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BACKGROUND

Introduction

The Plate Boundary Observatory (PBO) is a geodetic observatory designed to study the three-dimensional strain field resulting from deformation across the active boundary zone between the Pacific and North American plates in the western United States (http://www.EarthScope.org). Arrays of Global Positioning System (GPS) receivers will be deployed to measure the strain field on timescales of days in order to understand plate driving forces, the spatial distribution of plate-boundary deformation and how the plate boundary evolved.

The plate boundary strain field will primarily be derived from GPS instrumentation. The strain field will be built on GPS measurements of position and velocity. These positions and velocities are defined in a *terrestrial reference frame*. A terrestrial reference frame requires the definition of its scale, its origin, the orientation of the coordinate axes, and the evolution of these quantities in time. For the geodesist, the frame is fundamental – measurements made at different times cannot be compared unless you are able to define them in the same reference frame. An accurate and stable definition of the reference frame is particularly critical for PBO because reference frame errors can be manifested as many of the things that PBO is looking for: state and time-dependent strain phenomena, local and large-scale vertical signals, rotations, etc. For example, if two geodetic solutions of overlapping regions are combined without appropriate attention given to reference frame issues, the resulting solution will likely contain spurious signals that could be misinterpreted as strain. As we begin to build the EarthScope facility, PBO must prepare a reference frame in which to define all EarthScope GPS products. Its development must also include an assessment of its uncertainties

Reference Frames

One of the main tasks of modern space geodesy is to define and maintain the global terrestrial reference frame. Today, this frame (the International Terrestrial Reference Frame or ITRF) is computed by the Institut Géographique National in Paris. The definitions of orientation, scale, and origin, and their evolution in time, are made after careful discussion and debate between space geodesists specializing in the various geodetic techniques (GPS, VLBI, SLR, DORIS). The frame itself is based on global geodetic observations that are made on nearly all tectonic plates. The current ITRF (ITRF2000) was released in March, 2001 [*Altamimi et al*., 2002]. It is the most extensive and accurate terrestrial reference frame ever developed and includes positions and velocities for about 800 stations located at about 500 sites. Nevertheless, ITRF is not accurate enough for EarthScope. For example, because of the time needed to develop the frame, ITRF2000 only includes data through the year 2000 and is already out of date. Because of its global nature, the ITRF does not incorporate the complexities of the Pacific-North American interaction.

Whereas ITRF is a Earth-fixed (no-net global rotation) frame, the frame that is of most interest to geophysicists is a plate-fixed frame. The natural frame for EarthScope is a North America fixed frame. For completeness and flexibility, a Pacific-fixed frame should also be made available. Immediate applications of such plate-fixed frames include (1) identification of stable plate interiors and assessment of intra-plate deformation, (2) assessment of where the plate boundary deformation zone begins, (3) rigorous accounting for precisely where the full relative North America-Pacific plate motion is accommodated between the stable plate interiors, and (4) unambiguous determination of block rotations in the plate boundary zone relative to the far field (stable North America). While the geophysical community relies completely on the ITRF to analyze GPS data, the development of terrestrial reference frames has gone on "behind the scenes." The science goals of EarthScope require that we develop a terrestrial reference frame that is optimal for EarthScope. It is also critical that we assess the uncertainties in this frame.

Defining a Reference Frame for EarthScope

The Stable North America Reference Frame (SNARF) Working Group (WG) was formed at the request of the UNAVCO president and board to develop an appropriate reference frame for EarthScope. It works cooperatively with the International Association for Geodesy (IAG) subcommission on the North American Reference Frame (NAREF).

The initial task for the SNARF WG will be to design an appropriate ideal reference system. This includes discussion of philosophy, axioms, and models. Many of the WG members were heavily involved in developing ITRF2000, so are familiar with the relevant questions of defining a reference frame. As space geodetic systems have improved in accuracy and observation periods have been extended to decades, it has become clear that the typical definition of a reference frame (position and linear velocities) is incomplete. For EarthScope, the WG will extend our discussions to both characterizations of site motions (e.g. seasonal signals) and deformation models (e.g. postglacial rebound and loading).

After decisions are made regarding the definition of the frame, the WG must take on the task of developing a realization of the frame. This means, in practice, defining a set of geodetic stations with good geographical distribution, long measurement histories, the strong support of geodetic agencies to maintain them, as well as being located on the stable portion of the North American plate. Many of our WG members routinely analyze GPS data from North America as part of their geodetic network analyses (BARGEN, PANGA, SCIGN, CORS). Thus, we have a strong database of existing measurements to guide our decisions. We can also draw from the expertise of our WG in terms of GPS software differences (GIPSY, Bernese, GAMIT) and combining the position measurements in a consistent way (MIT and Nevada-Reno IGS Associate Analysis Centers). Software to define an angular velocity vector for North America can easily be adopted from the work of various members of the WG.

A preliminary SNARF will be released for testing by the WG in mid-1994. Since most data centers now impose a reference frame after the GPS observations are analyzed, it will be relatively straight-forward for the WG to compute SNARF solutions for 5+ years at many of the reference frame sites. We will compare various realizations (i.e. adding and substracting reference stations) to assess its stability.

Our goal is to release the first official SNARF by Fall 2004. This reference frame will also include with it procedures that enable and facilitate its correct realization by users. This is a critical function of the WG. Despite the fact that the international geodetic community works very hard to develop accurate and stable reference frames, it is equally important that the proper use of that reference frame be conveyed to the user community. This is even more so for EarthScope, because the EarthScope community is much broader than the space geodetic community that has traditionally developed and used terrestrial reference frames. Specifically, this frame's relation to ITRF must be explicitly communicated. Transformations between SNARF and other reference frames must be posted in an easily accessible manner (e.g. UNAVCO website). Software to allow users to estimate angular velocities and various plate-fixed quantities must also be made available. Given the synergy between PBO and existing national geodetic agencies in the U.S. and Canada, the SNARF WG will maximize consistency with established conventions, particularly those in use by those national geodetic agencies, provided such choices do not compromise accuracy.

In order to clearly define SNARF, a comprehensive final report will be written. This report will include the motivation for defining its axioms, an assessment of its accuracy, with recommendations for further development and continuing maintenance. The SNARF results must also be summarized in a manner appropriate for publication in a refereed journal.

WORK PLAN

We are requesting funding from NSF for three workshops to support the development and definition of SNARF for EarthScope. We currently envision having all workshops in Boulder at the UNAVCO facility. The location is central, which reduces travel costs, and allows the participation of key UNAVCO employees (UNAVCO Facility Director Chuck Meertens, and PBO Director Mike Jackson). UNAVCO can also provide conference facilities at no charge to this grant. Although we may attempt to combine one of the workshops with another meeting (e.g. the CGS-AGU Spring Meeting in 2004), we believe the WG is better served by having concentrated workshops where the members are not distracted by preparations for other meetings. JPL has also offered to host one of the workshops and would provide workshop facilities at no charge.

We anticipate that workshops will cover 1.5 days. The initial workshop (tentatively scheduled for mid-January 2004) will be an organizational workshop to assign priorities, identify problems to be solved. Tasks must be itemized and subgroups of the main WG must be assigned to work on these tasks. Some of the issues to be discussed will be disseminated through e-mail in Fall 2003. This will allow various members to perform preliminary studies. A second workshop will be used to finalize the preliminary SNARF. A third and final workshop will be used to define the official SNARF, prepare the final report, and make plans for publication of SNARF in a refereed publication. For planning purposes, two SNARF workshops are scheduled for 2004 and one is scheduled for 2005.

PERSONNEL

The current members of the SNARF WG are experienced both in developing and using terrestrial reference frames. The current (Geoff Blewitt) and past (Kristine Larson) chairs of the IERS committee on the ITRF datum that produced ITRF2000 are both SNARF members. Members Don

Argus and Tom Herring also contributed to the development of ITRF2000; specifically Argus was responsible for choosing stable sites that defined the rotational datum for ITRF2000. Jim Davis and Jerry Mitrovica have extensive experience working in postglacial rebound models and measurements, which will be important for defining the vertical datum. Eric Calais and Tim Dixon have worked on both inter- and intra-plate deformation studies in the past decade.

The SNARF WG also includes members (Frank Webb, Meghan Miller, Rick Bennett) who operate geodetic networks and thus have a significant amount of experience in defining the reference frame on a daily basis. We further include members with direct ties to the geodetic surveys of Canada (Mike Craymer) and the U.S. (Richard Snay). Craymer provides an additional link through his North American reference frame committee that reports to the International Association of Geodesy.

SNARF Committee Members:

Geoff Blewitt (Chair), University of Nevada-Reno. Coordinate specifications and recommendations.

Jim Davis (Co-chair and co-PI), Smithsonian Center for Astrophysics. Coordinate specifications and recommendations.

Jerry Mitrovica, University of Toronto, Reference frame - PGR models. Site selection.

Don Argus, JPL, Reference frame - origin and tectonics. Site selection.

Tim Dixon, University of Miami, Reference frame – North Ameican plate stability. Site selection.

Tom Herring, MIT, Reference frame - global GPS & ITRF. Site selection.

David Lavallee, University of Nevada-Reno, Reference frame - global GPS & GPSVEL. Site selection.

Mike Craymer, Natural Resources Canada, Testing & Application to NAREF (Bernese, GAMIT, GIPSY).

Rick Bennett, Smithsonian Center for Astrophysics, Testing & Application to BARGEN (GAMIT).

Frank Webb, JPL, Testing & Application to SCIGN (GIPSY).

Meghan Miller, Central Washington University, Testing & Application to PANGA (GIPSY).

Richard Snay, NGS (NOAA), NAREF and national geodetic agencies.

Eric Calais, Purdue University, Intra-plate deformation.

Kristine Larson (PI), University of Colorado-Boulder, Relative Pacific-North America plate motion.

PROJECT MANAGEMENT AND DISSEMINATION OF RESULTS

The PI of this grant will report to NSF. The SNARF committee itself also reports to UNAVCO and the IAG subcommission on NAREF.

UNAVCO Inc. will provide financial oversight for the grant, and will organize travel for the WG.

Results of the SNARF WG will be published in a refereed journal. Software developed to use the frame and extensive frame descriptions for the user community will be posted at the UNAVCO website.