Version 1

Geodetic Network Standards and Procedures

This document describes the standards and procedures of the U.S. Geological Survey's (USGS) Earthquake Hazards Program (EHP) for operations and data availability for geodetic networks operated or supported by the EHP. The overall priorities for these operations fall into two broad categories:

- Long-term monitoring of interseismic deformation for dynamic seismic hazard assessment and investigation of fault creep and transient phenomena
- Use of real-time and near real-time data for earthquake likelihood forecasting, earthquake early warning, rapid response, and assessment of immediate postseismic motion

The Earthquake Hazards Reduction Act (P.L. 95–124 as amended) gives the USGS the Federal responsibility for providing notifications of earthquakes and its reauthorization in 2000 established the ANSS to modernize and expand the Nation's earthquake monitoring infrastructure in order to improve the delivery of earthquake information to users.

The use of geodetic data for earthquake-related research, monitoring, and response is an evolving field, and standards for EHP and university-based operations supported by the EHP evolve in parallel to capitalize on new capabilities. Realizing efficiencies in network operations will allow for resources to focus on developing and implementing new technologies and pursuing new applications for geodetic data. Some changes from past procedures are described in the Standards and Procedures section below in light of these issues.

The convergence between CGPS and seismic networks highlight the need for greater standardization (in quality control, latency, up-time, processing strategies, minimum precision, data formats, and other aspects). Such standardization could pave the way for future formal inclusion of CGPS networks into EHP's Advanced National Seismic System (ANSS). To this end, EHP and operators of supported geodetic networks that produce real-time GPS data should collaborate in the following ways in the coming years.

- Develop policy documents to establish forward-looking standards and procedures.
- Carry out systematic testing and comparison of processing strategies, algorithms that use real-time position streams and implementation of real-time and near real-time GPS in the context of earthquake early warning and rapid response.
- Increase network resiliency to ensure data availability in the seconds to hours after an earthquake.
- Explore co-locating seismic and geodetic instrumentation at monitoring sites.
- Develop capability for operational alerts for transient deformation.

The number of GPS stations streaming high-rate data in real time continues to grow, and a range of processing strategies and algorithms that use the resulting position streams for monitoring and response are under development and testing. These advances necessitate new infrastructure requirements, for telemetry, power at sites, and computing resources. Efforts that further the incorporation of real-time geodetic data into operational tools for earthquake likelihood forecasting, earthquake early warning, rapid response, and other post-earthquake situational awareness products are envisioned in coming years. Possible actions include hardening data acquisition systems; establishing robust real-time data exchange; development, evaluation, and implementation of real-time data processing strategies; and real-time data analysis that provides required input for operational alert systems.

Alinement array operations could be improved by establishing a limited number of new or replacement sites to monitor fault slip. New or replacement sites should focus on defining the presence or absence of fault creep, or the distribution of creep rates, along major faults in the San Francisco Bay Area,

particularly in locations that currently lack well-constrained surface creep rate estimates. If new arrays are installed, those sites would initially need to be measured more frequently to expedite the estimate of the initial creep rate and to gauge the background "noise".

Standards and Procedures

1. Site maintenance and quality control

Network operators should monitor data for anomalous signals that might indicate problems at a site. If such a problem is detected, it should be addressed in a timely manner and station logs/metadata updated accordingly. Quality control statistics may address, but are not limited to, data completeness (e.g., missing epochs, cycle slips), data acquisition latency, GPS multipath, and signal-to-noise.

2. Network websites are to include:

- A map of EHP-supported stations accompanied by a table providing the following information for each station:
- Station name
- Station ID (if different from station name)
- Station location (city, state)
- Station longitude (degrees E), latitude (degrees N), elevation (m)
- Instrument type
- Installation date (enter "planned" if applicable)
- Sampling rate(s)
- Telemetry type
- Field survey or data download frequency (for data not streamed in real time)
- Network name
- List of any co-located instrumentation

3. Metadata

Station information and full metadata must be publically available through a website maintained by the network operator; proposals must include a link to this website. Metadata updates due to changes at the sites must be provided within 1 week of the corresponding site activity. The following tables outline minimum required metadata with example entries. Formatting as noted below is NOT required; it is recommended that all site data components be referenced to Site Code. Note: For CGPS stations, metadata should be provided using the IGS site log format.

Site information:

Site name	**Site code**	**Network Name**	**Site Type**	**Monument description**	**Install date**	**Data archive**	**Co-Located Instruments**
CSU Northridge	CSN1	SCIGN	Continuously operating GPS	Wyatt driven-braced	4/27/1996	UNAVCO	none

Site location information:

City	**County**	**State**	**Latitude, deg N**	**Longitude, deg E**	**Elevation, m**
Northridge	Los Angeles	CA	34.25355	-118.52381	261.4312

Data acquisition information for continuously recorded data:

Sample interval (sec)	Data acquisition method (download or telemetered)	Telemetry type	Real-time stream available?
30	telemetered	Ethernet Freewave	no

Additional location information for GPS stations (to be provided in IGS08 reference frame):

X coordinate, m	Y coordinate, m	Z coordinate, m
-2520226.1	-4637082.18	3569875.5

Instrument information for GPS stations, one line with date for each equipment change:

Date	Receiver manufacturer and type	Receiver S/N	Antenna manufacturer and type	Antenna S/N	Antenna Height, m
4/27/1996	ROGUE SNR-8000	T-389	AOAD/M_T	276	0.0814
8/14/1998	ASHTECH Z-XII3	LP03106	as above	as above	as above
5/13/1999	ASHTECH Z-XII3	LP02792	as above	as above	as above
1/16/2009	TRIMBLE NETRS	4811147009	as above	as above	as above

4. Data archiving

Data obtained at least daily (through real-time telemetry or automated remote downloads) must be archived daily. Data collected and/or downloaded less frequently than once per day must be archived within 3 months of data retrieval. For GPS data, raw and RINEX files must be archived. At a minimum, RINEX files must be available in a public archive. Raw GPS data may be made available upon request; such requests must be filled within two weeks. Operator websites must clearly indicate how to obtain both RINEX and raw GPS data. Minimum sampling rate for archived GPS data is 1 sample/30 sec. Network operators must ensure that RINEX header information is complete and correct. Network operators who maintain their own publically available data centers should also participate in the Geodesy Seamless Archive (GSAC) to promote ease of data discovery and broad use of these data. Network operators who do not operate their own publically accessible, routinely updated archive must archive their data at UNAVCO.

5. Processing and analysis of non-telemetered GPS data

Data for all USGS EHP-supported stations whose data are not generally available daily (manually downloaded) must be processed to produce daily three-component position estimates in a routine and timely manner. Positions should be provided in IGS08 (or newer, if available) and North America-fixed reference frames. Position time series for each station, along with derived quantities, must be posted in graphical and numerical form (downloadable as ascii files) on the website maintained by the network operator. Uncertainties must be provided both for individual position estimates and for derived quantities. At minimum, derived quantities include velocities and offsets (for earthquakes and equipment changes). Coseismic offset estimates must be provided within 1 week of data acquisition following the earthquake and must be accompanied by the earthquake name (if any), date, time, magnitude, and updated time series plots with label indicating earthquake. Operators are encouraged to include estimates and uncertainties for seasonal, postseismic, transient, and other terms as needed to improve velocity estimation and noise characterization. Units for data and derived quantities, as well as time-tag conventions, should be clearly stated. Documentation of processing strategy, reference frame realization,

regional filtering, and methods for producing derived quantities must be provided on the website; documentation should include contact information.

6. Daily GPS positions and derived products for continuous GPS stations

Strategies and software for processing GPS data to obtain daily position estimates are well-established. USGS conducts automated processing and analysis that provides daily position updates and derived products (e.g., velocities, offsets) for continuous GPS (CGPS) stations in the western U.S. and New Madrid region. Starting in March 2015 routine daily processing and creation of derived products for USGS EHP-supported CGPS networks with data that are generally available at least daily (through real-time telemetry or automated remote downloads) will no longer be supported for cooperating networks; these activities will be carried out by the EHP. Results will be available through the USGS website. For non-continuous and/or manually downloaded networks this website will link to each cooperator's website where users can obtain the same information as provided by USGS. This approach meets the goals of minimizing duplication of effort, promoting consistency among processed solutions and derived products, and simplifying users' access to processed results.

7. Alinement array data

Network operators shall measure existing sites in northern California at approximately one year intervals (unless the operator and the EHP agree that measurements can/should be made more or less frequently). Creep measurements and estimated long-term creep rates, as well as uncertainties on individual measurements and rates must be provided in graphical and numerical form (downloadable ascii files) in a timely manner via the operators' website and Open File Report updates. Measurement techniques, data reduction methods, units for data and derived quantities, and time-tag conventions should be clearly stated; documentation should include contact information.

8. Continuity of operations plan

Network operators should develop a written plan for continuity of operations following an earthquake and for the earthquake response activities they anticipate carrying out. As appropriate, plans should address response activities related to recovery of field operations, communications, and IT capabilities. Operators should outline plans for data acquisition and sharing, processing and analysis, and distribution of any derived products. Plans should describe anticipated interactions or interdependencies with other networks, institutions, or organizations in the context of maintaining operations following an event. Following earthquakes of $M \geq 5.5$ or any smaller events that produce measurable signals within a network, operators must provide a summary report on their response activities, observed signals, any technical problems encountered, and corrective actions to be taken. The report is to be submitted to the EHP Geodesy Coordinator within 2 months of the event.

USGS/EHP Data Management Standards for Geodetic Monitoring Operations

Following is a summary of required practices described above.

- Carry out maintenance of field instrumentation including, but not limited to, data acquisition, telemetry, and power as applicable to ensure data integrity and accessibility.
- Conduct quality control and report data quality metrics.
- Provide up-to-date station metadata, using IGS log sheet for any CGPS stations.
- Maintain a website through which station information, metadata, and data quality metrics are provided.
- Make data available through publically accessible, routinely maintained archives in standard formats (for GPS, raw and RINEX). For GPS networks, if the cooperator does not maintain such an archive data must be archived with UNAVCO.

- If operating your own publically accessible data centers also participate in the Geodesy Seamless Archive (GSAC).
- If applicable, ensure that RINEX header information is complete and correct.
- Archive data daily for stations whose data are acquired (by real-time telemetry or automatic download) at least once per day and archive all other data within 1 month of data collection or download. For GPS networks, if the cooperator does not maintain such an archive data must be archived with UNAVCO.
- Use a minimum sampling rate for GPS data of 1 sample/30 sec.
- Maintain an Ntrip caster to provide public access (either directly or by real-time rebroadcasting by another institution) to real-time GPS data streams in standard formats (RTCM3, BINEX for GPS) for any USGS EHP-supported stations that produce such data.
- Provide processed position solutions and derived products that parallel those provided by the USGS for any non-telemetered (manual download) GPS networks.
- If applicable, measure alinement arrays at approximately one year intervals unless a different survey frequency has been agreed upon.
- If applicable, provide alinement array data tables and plots annually.