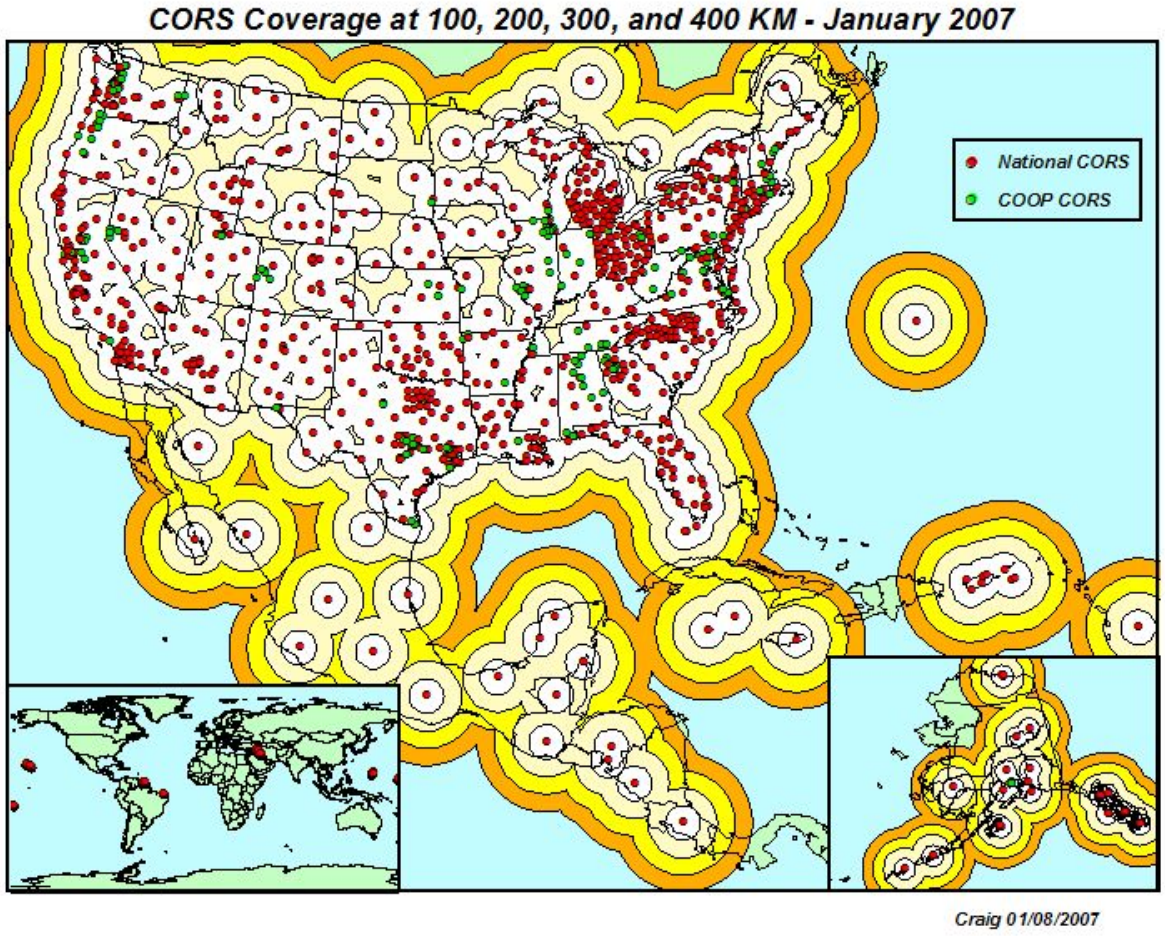
Report on the
7th Annual CORS Users Forum
Fort Worth, Texas
September 25, 2007

Photo from Fort Worth rodeo on 22 September 2007.

NOAA's National Geodetic Survey (NGS), in cooperation with the U.S. Coast Guard and the U.S. Department of Transportation, organized a CORS (Continuously Operating Reference Station) Users Forum on September 25, 2007. The Forum was an integral part of the 47th Civil GPS Service Interface Committee (CGSIC) meeting September 24-25, 2007 at the Hilton Hotel in Fort Worth, Texas. The Institute of Navigation's GNSS Conference convened September 25-28, 2007 in the Fort Worth Convention Center.

The U.S. CORS network is comprised of numerous subnetworks operated by more than 190 organizations. Together, these networks include more than 1,200 sites—each containing a geodetic quality, dual-frequency, GPS receiver—and these networks are collectively growing at a rate of approximately 200 sites per year. NGS and its partners collect, process, and distribute data from the CORS sites on a continuous basis in support of numerous activities, including land surveying, navigation, GIS development, construction, remote sensing, environmental monitoring, weather forecasting, satellite tracking, geophysics, and time transfer.



Agenda

1:30 **Welcome**
Richard Snay, NOAA's National Geodetic Survey

1:35 **CORS: Overview and Status**
Giovanni Sella, NOAA's National Geodetic Survey

1:55 **EarthScope's Plate Boundary Observatory: Status Update**
Greg Anderson, UNAVCO, Inc.

2:15 **OPUS: The Online Positioning User Service**
Gerald Mader and Neil Weston, NOAA's National Geodetic Survey

2:35 **Surveying Green Light: Impact of Space Weather**
Joe Kunches, Mihail Codrescu and Time Fuller-Rowell
NOAA's Space Weather Prediction Center

2:55 **On-GRID: Resources and Support for High-Precision Real-Time GNSS Networks**
Gavin Schrock, Washington State Reference Station Network

3:15 **Real-Time Positioning and the Role of the NGS**
William Henning, NOAA's National Geodetic Survey

3:35 **Question & Answer Session with Panel of the Speakers**

3:55 **Break**

4:05 **Interactive Sessions within Small Discussion Groups**
Group A: Real-Time Positioning from the Network Administrator's Perspective
Facilitators: Pam Fromhertz & Giovanni Sella
Group B: Real-Time Positioning from the User's Perspective
Facilitators: William Henning & Mike Londe
Group C: OPUS and Ionospheric Models
Facilitators: Rick Foote, Gerald Mader, & Joe Kunches

5:00 **End of Forum**

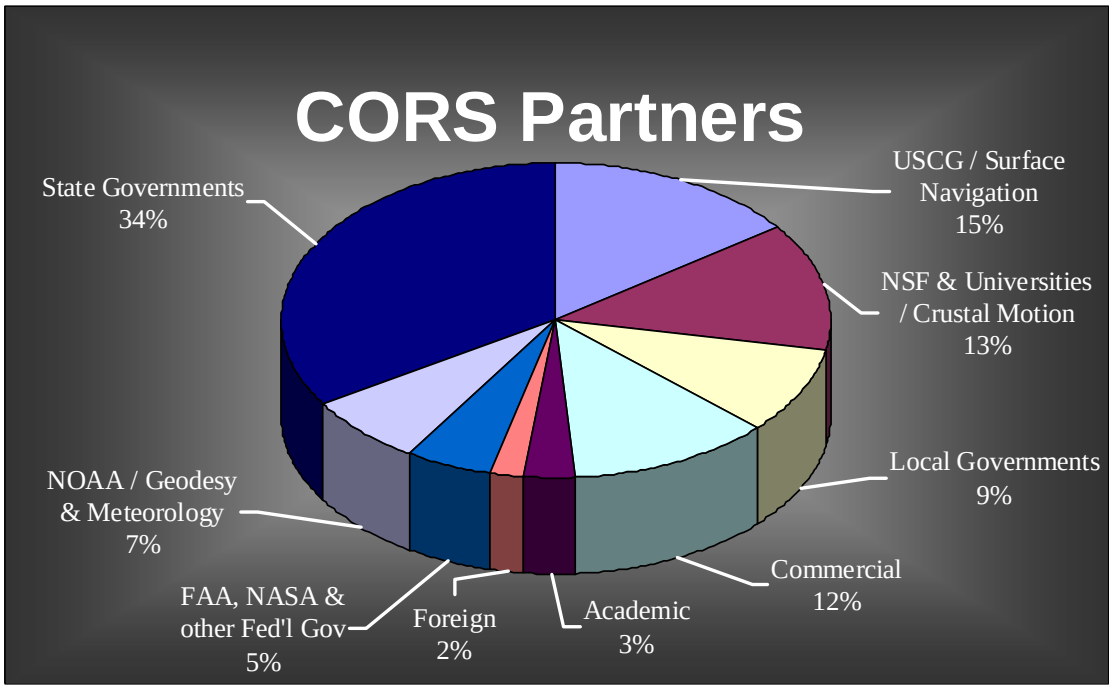
The PowerPoint files for each of the six formal presentations may be viewed and/or downloaded at http://www.ngs.noaa.gov/CORS/ . Click on "General Information" and then on "Presentations".

CORS: Overview and Status
Giovanni Sella, CORS Program Manager
NOAA's National Geodetic Survey

CORS users are currently downloading ~400 Gigabytes of data per month via anonymous FTP and ~100 Gigabytes per month via the UFCORS utility.

The CORS-West data facility, located in Boulder, Colorado is now operational, and it is collecting, storing, and distributing GPS data from all CORS sites in parallel with the CORS-East data facility located in Silver Spring, Maryland. Users may obtain CORS data from CORS-West via anonymous FTP at wwwest.ngs.noaa.gov. NOAA's National Geophysical Data Center operates the CORS-West data facility.

The Department of Commerce recognized OPUS as its showcase E-gov service in 2006.



CORS partners have been upgrading CORS sites they operate, many with L2C and GLONASS capabilities. NGS will soon start to make these L2C and GLONASS observables available.

Many CORS partners are aggressively moving toward real-time GNSS operations.

NGS released OPUS-RS (rapid static) in January 2007. The utility allows users to submit as little as 15 minutes of GPS data to NGS, whereby NGS will compute accurate positional coordinates for the location where the data were collected. OPUS-RS has since performed an average of 3,700 solutions per month.

NGS now produces GPS orbits that agree within 1 cm of the IGS orbits obtained by combining the NGS orbits with those produced by several other IGS Analysis Centers.

NGS will serve as the IGS Analysis Center Coordinator for a four-year period starting January 2008.

NGS will re-analyze all IGS and CORS data collected since 1994 to obtain consistent positional coordinates and velocities for all sites. Also, daily GPS orbits will be recomputed as part of this project. The re-analysis will incorporate recent innovations in GPS processing technology. In particular, it will use absolute calibration results for GPS receiving antenna, as well as calibration results for GPS broadcasting antennas.

OPUS, currently used by more than 3,000 people per month, performs an average of 17,000 solutions monthly.

The U.S. Coast Guard is upgrading the NDGPS sites. In particular, they are replacing the original Ashtech antennas with Trimble Zephyr antennas.

The CORS network now contains over 1,200 sites, with a backlog of an additional 400 sites. A host of internal NGS software/hardware problems has delayed NGS from incorporating these 400 sites into the CORS network. NGS plans to begin reducing this backlog soon.

NGS assisted in establishing a seven-station CORS network in Benin at the request of the Millenium Challenge Corporation of the U.S. State Department and in collaboration with UNAVCO, Inc.

NGS is now establishing four CORS sites in Ethiopia to support a U.S. Agency for International Development project on land privatization.

NGS is also establishing a CORS in the British Virgin Islands.

NOAA's US-TEC space weather program became operational in FY2007. US-TEC uses CORS data to calculate the distribution of total electron content in the ionosphere for assisting aviation and telecommunication activities.

NOAA's GPS-Met program provides a model of the wet zenith delay caused by water vapor in the troposphere across CONUS. This program will transition to operations starting in FY2009.

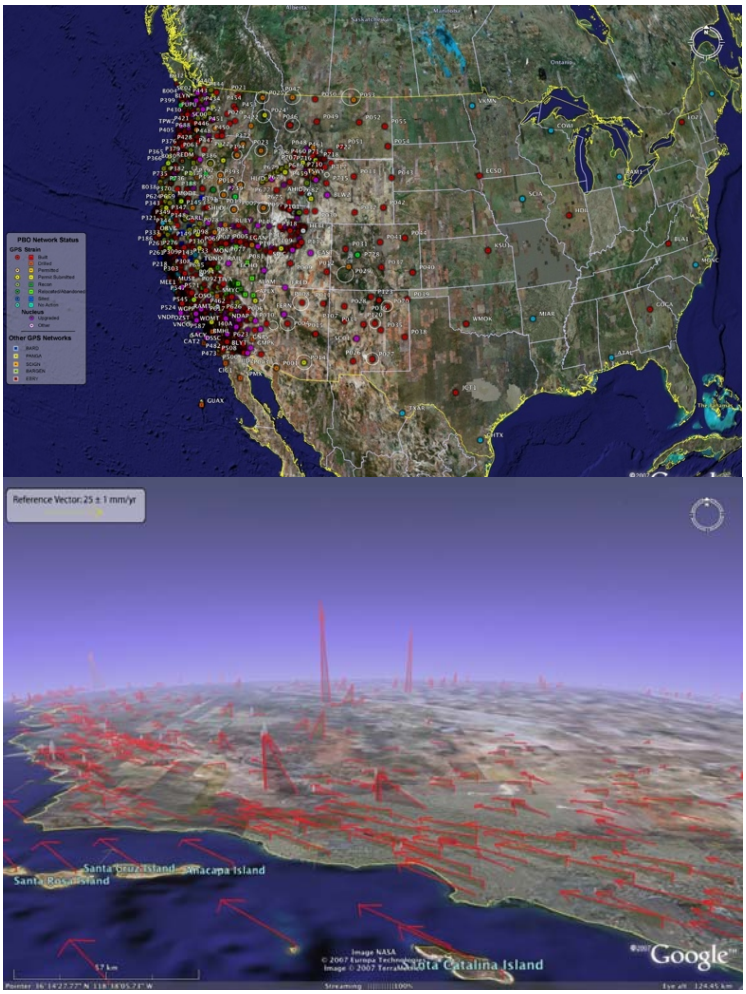
EarthScope's Plate Boundary Observatory: Status Update

Greg Anderson, PBO Data Products Manager
UNAVCO, Inc.

EarthScope is funded by the National Science Foundation and conducted in partnership with the U.S. Geological Survey.

EarthScope is being constructed, operated, and maintained as a collaborative effort with UNAVCO, IRIS, and Stanford University, with contributions from NASA and several other national and international organizations.

EarthScope's Plate Boundary Observatory (PBO) will include a network of approximately 1,100 continuous GPS sites to monitor crustal motion in western CONUS and Alaska.



Top Figure: Current PBO Network in CONUS
Bottom Figure: GPS-derived 3-dimensional velocities

To date:

- 889 of 1100 continuous GPS stations have been built
- 47 of 108 strain stations have been built
- 40 of 103 seismic stations have been built
- 8 of 28 tiltmeters have been built.

In its first four years of operations, EarthScope has captured

- 2 significant earthquakes
- 2 volcanic crises
- 3 episodic tremor and slip events.

GPS data products include:

- Raw & RINEX data for individual sites
- Site metadata and logs
- SINEX solution files
- Time series of day-to-day estimates of positional coordinates
- Site velocities

Users downloaded a Terrabyte of data in 2006.

Information on a PBO site is available at
http://pboweb.unavco.org/stations/XXXX
where XXXX denotes the site's 4-character ID.

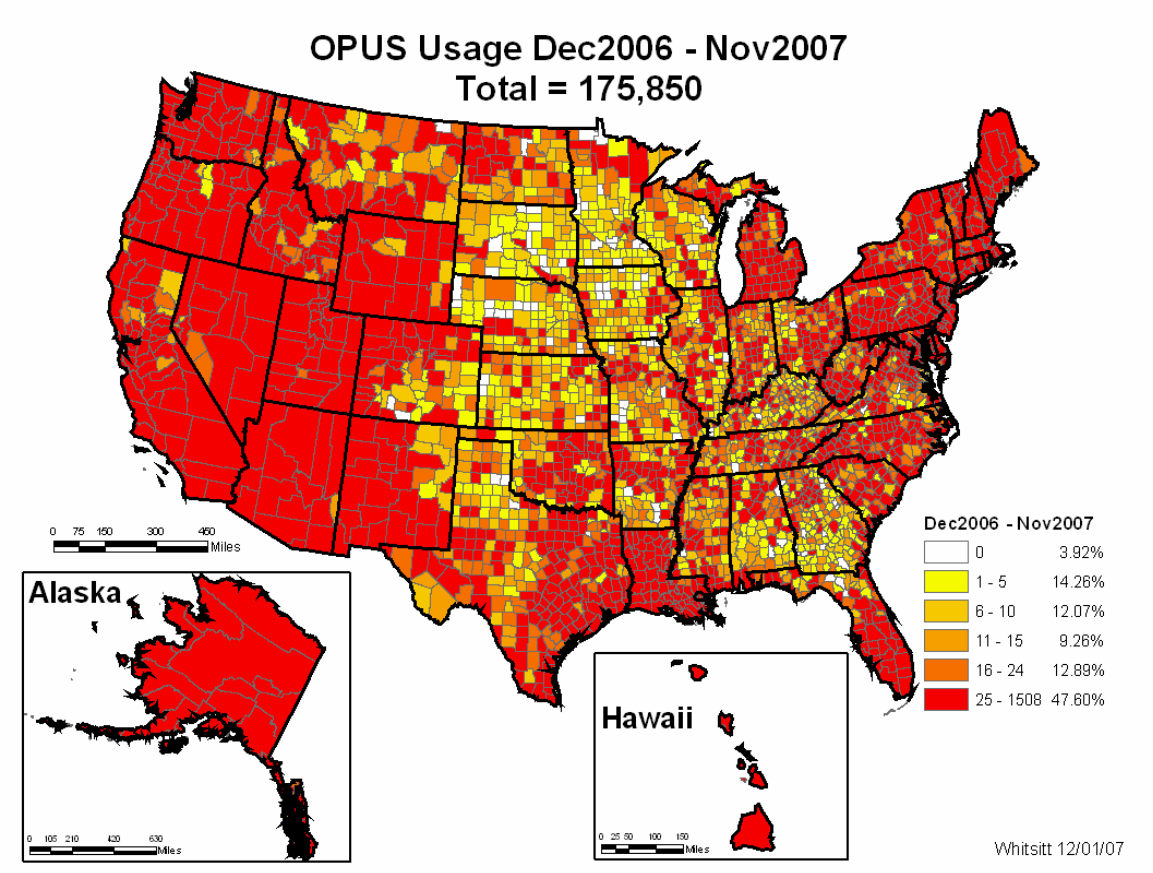
UNAVCO is streaming GPS data for selected sites via the Internet using the NTRIP software. See http://pboweb.unavco.org/rtgps .

OPUS: The On-Line Positioning User Service

Gerald Mader and Neil Weston
NOAA's National Geodetic Survey

NGS introduced OPUS in 2001 as a tool to enable users to submit their GPS data to NGS. NGS automatically processes these data with data from nearby CORS to calculate accurate positional coordinates for the location where the submitted data were observed. NGS then emails the resulting coordinates to the user within minutes after the time when the data were submitted.

Thus far, over 29,000 users have successfully submitted data to OPUS, and OPUS has performed over 600,000 solutions.



In January 2007, NGS released OPUS-RS (rapid static). The OPUS-RS version allows users to submit as little as 15 minutes of GPS data, whereas OPUS guidelines suggest that users submit at least two hours of data. The OPUS-RS algorithm was developed by researchers at the Ohio State University and was refined by Charles Schwarz of NGS. The algorithm can obtain accurate results for a relatively short observational session by interpolating the ionospheric and tropospheric refraction delays from nearby CORS to the location where the user collected his/her GPS data.

NGS hopes to release OPUS-DB (data base) within the next few months. This flavor would allow a user to archive his/her OPUS-generated coordinates in a publicly available data base maintained by NGS.

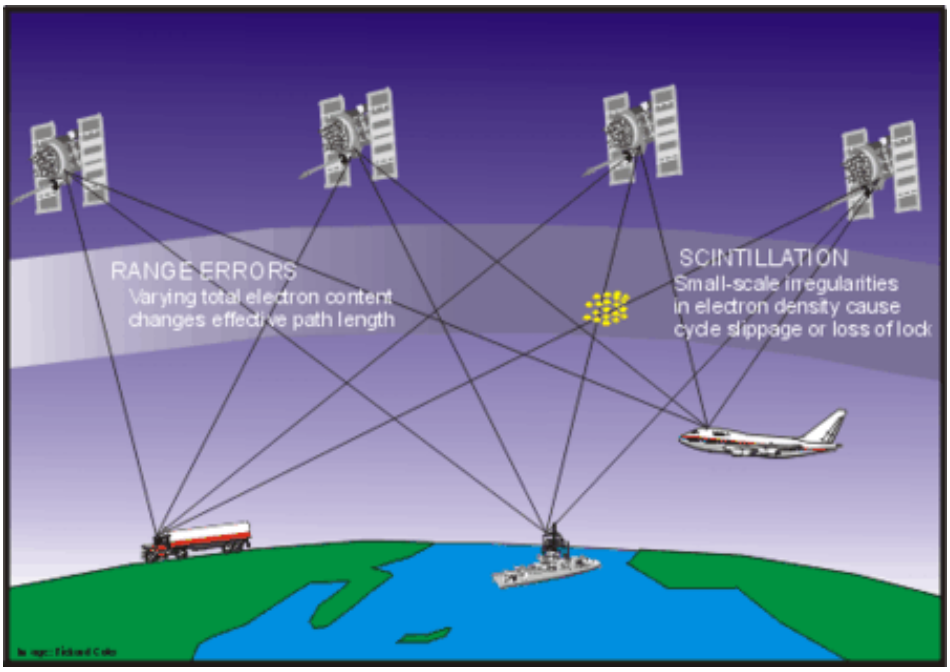
NGS is also working to develop OPUS-Projects and OPUS-Mapper. The former would assist a user to manage a GPS data-collection project. OPUS-Projects, in particular, would simultaneously process GPS data from several sites and/or from several observational sessions, together with CORS data, in a rigorous least squares adjustment. This utility will include features to assist management of field operations and management of the GPS data.

OPUS-Mapper would enable a user to submit single-frequency GPS range observables to be processed automatically by NGS. OPUS-Mapper is being designed for users with less strict accuracy requirements than those associated with GPS carrier-phase observables.

Surveying Green Light: Impacts of Space Weather
Joseph Kunches, Mihail Codrescu, and Tim Fuller-Rowell
NOAA's Space Weather Prediction Center

The ionosphere is the largest source of error for autonomous GPS and the second largest for differential GPS.

The ionosphere is that part of the upper atmosphere where free electrons occur in sufficient density to have an appreciable effect on the propagation of radio frequency electromagnetic waves. Its lower boundary is at ~60 km, and its upper boundary is at ~1000 km.

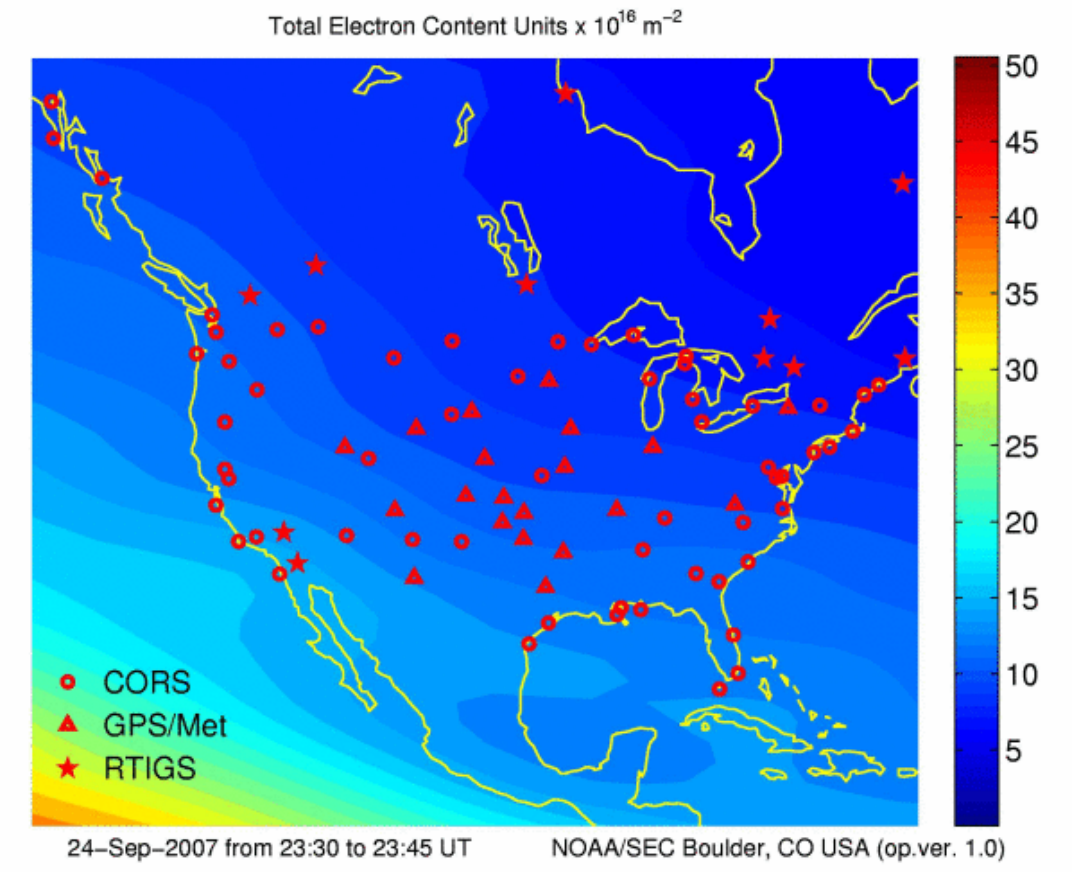


The ionosphere introduces a variable time delay in the propagation of signals from the GPS satellites to the receiver and calculating the time delay is critical for achieving accurate positional coordinates. The delay calculations require modeling the electron density along the path of the signal.

Proposal by NOAA's Space Weather Prediction Center (SWPC):

- Provide a web-based customer application for providing ionospheric correctors from a user-specified list of options
- User submits a RINEX file
- SWPC either uses the "best available" model to evaluate corrections to the GPS observables or a user-specified model (US-TEC, GAIM, IRI, rtIRI,…)
- Return RINEX file to user with corrections inserted
- Next version of RINEX format will include place for corrections.

As part of their US-TEC (total electron content) project, SWPC provides real-time ionospheric maps showing the distribution of total electron content over CONUS once every 15 minutes. This project currently uses data from about 100 CORS.



The US-TEC estimate for the "slant path" total electron content has an uncertainty < 3 TEC units (equivalent to about a 45-cm delay at L1 frequencies).

The US-TEC estimate for the vertical total electron content has an uncertainty < 2 TEC units (equivalent to about a 30-cm delay at L1 frequencies).

SWPC goals

- Improve US-TEC so that the slant path total electron content uncertainty is < 2 TEC units, and the vertical total electron content uncertainty is < 1 TEC unit.
- Provide TEC forecasts for CONUS: at one hour with uncertainties as good as above specifications; at three hours with uncertainties less than 3 TEC units; and at six to 12 hours.
- Provide GPS user tools, including color-coded regional maps of ionospheric disturbance, and support for vendors to produce color-coded maps for specific applications.

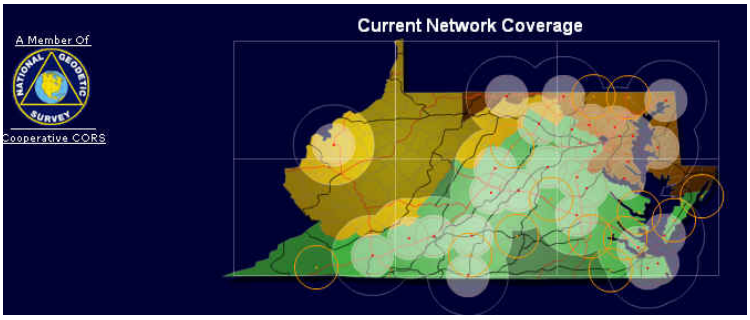
The next solar maximum is predicted to occur around 2012.

OnGRID: Resources and Support for High-Precision Real-Time GNSS Networks
Gavin Schrock, Washington State Reference Network

OnGRID was founded to develop, on the national level, a program to assist locally or regionally driven initiatives in the establishment, maintenance, and operation of real-time GNSS infrastructure networks to serve the widest possible range of public and private sector interests.

Issues facing real-time GNSS network developers:

- Reference system issues, consistency of coordinates from one network to another
- Outreach & education issues (the *American Surveyor Magazine* has been publishing a series of articles on topics concerning the operation of a real-time GNSS network)
- Business model boiler plates, including user agreements and partner agreements
- Communications and IT guidelines
- Cost-benefit analyses
- Policy considerations



Real-Time Positioning and the Role of the NGS
Bill Henning, NOAA's National Geodetic Survey

Why real-time networks (RTN) are becoming popular:

* No time is lost setting up and breaking down a base station
* No "baby sitting" the base station, therefore labor cost is reduced
* No base station means with two rovers, the project is completed in half the time
* No reconnaissance/recovery of passive control required
* NO DISTANCE CORRELATED ERROR—Atmospheric, ephemeris corrections for the site of survey. Errors degrade gracefully outside of the network
* RTNs CAN BE SEAMLESSLY CONNECTED TO THE NATIONAL SPATIAL REFERENCE SYSTEM

This means:

- Regional Inter-GIS compatibility
- Continual accuracy and integrity monitoring
- Easy datum adjustment/change updates
- Overlapping RTNs give the same results!

The proposed role of NGS in support of RTNs:

- The NGS should provide real time RTCM data streams (via NTRIP) from a subset of the National CORS network—perhaps in a horizontal grid with 200-km spacing. These data streams will aid in the establishment, validation, and monitoring of the RTNs by network administrators. NO CORRECTORS WILL BE BROADCAST.
- NGS encourages the institutions providing real-time positioning services to use the NGS-provided raw data in their operations to:
  (1) SUPPLEMENT the data from other GNSS base reference stations, and
  (2) use the positional coordinates and velocities of the GNSS stations contained in the NGS real-time network as FIDUCIAL VALUES for the positional coordinates and velocities of other real-time GNSS stations.
- The NGS could ASSESS AND ACCREDIT proposed or even current RTN reference station sites for obstructions, multipath, positional integrity—in short, for anything that might affect optimal performance of the RTN.
- Initial RTN reference station coordinates are produced by the individual RTN administrator. However, promulgated coordinates and velocities for the corresponding GNSS base reference stations should be compatible with the National Spatial Reference System at the level of 2-cm Horizontal and 4-cm (ellipsoid) height.
- Automated processes will enable RTN administrators to push daily data for all RTN reference stations to the NGS where a specific version of OPUS-DB will position the stations and archive the resulting coordinates.
- Three National CORS **that are part of the RTN** will be used as control stations for this OPUS-DB processing. Then, 60 day plots will be developed to graphically depict the scatter of predicted daily coordinates for each and every reference station.
- Additionally, NOAA/NGS could stream satellite ephemerides, satellite clock parameters, iono and tropo models, and even crustal motion models for public use.

- The NGS, continuing its role in support of accurate, reliable positioning, would study temporal macro variations in positions (seasonal, daily, ocean loading, atmospheric loading, subsidence, tectonic, etc.) and would study phenomena affecting accurate positioning (satellite orbits, refraction, multipath, antenna phase centers, geoid, etc.)
- *The NGS will not stream data that is being streamed via NTRIP by another organization.*

NGS is in the process of creating three documents to support real-time positioning:

*** "NGS User Guidelines for Single Base GNSS Real-Time Positioning"**
Draft finished and in review

* **"NGS User Guidelines for GNSS Real Time Positioning in RTN"**
to be completed in FY 2008-9

*** "NGS Guidelines for GNSS RTN Administrators"**
to be completed in FY 2009

Discussion Group A:
Real-Time Positioning from the Network Administrator's Perspective
Facilitators: Pam Fromhertz & Giovanni Sella
Recorder: Casey Brennan

Participants: Karen Van Dyke, Jim Richardson, Anthony Searle, Gunnar Hedling, Gavin Schrock, Ken MacLoed, Lienhart Troyer, Eric Gakstatter, Mike Cloud, Bob Twilley, Steve Schmidt, Andre Fuegner, George Weber, Greg Anderson, Ken Bays, Casey Brennan, Pam Fromhertz, Richard Snay, Giovannia Sella

Pam: What are we doing in today's meeting vs. tomorrow's meeting: Some overlap, but we expect different people, so we want to be sure and capture input from today's group. Let's take some questions…

Giovanni: This is more of a group about people running real-time networks vs. just how NGS will be involved.

- What have been some of the hurdles for the international people? Funding has been an issue in Australia, as has communications. There are areas where it is not possible, even with satellites. We would like to hear more about how you use cell phones to transfer data.

- IT issues: Just getting the IT department to understand the idea behind it. Convincing them that it is not a security issue. It took some time, but once they were on board and realized it was not a security issue, they were big supporters.

  From a manufacturing point of view, Leica has issues with international manufacturers, so they had their IT folks write a white paper to allay fears, and it was helpful to them. Since written by IT folks, it speaks the language IT people understand.

- Administrators run the network and often become a helpdesk, but they might not be capable of answering the questions. Often the dealers of the equipment are not very familiar with the equipment and cannot provide much support. The network administrators should not be the person who answers all the questions. Manufacturers need to help, or documentation needs to be available.

- How are the data being served up by the administrator? NTRIP has a number of supporters. One administrator reported that all his customers were capable of receiving NTRIP.

- Communications issues: In Washington State, a variety of options exists. Satellites have been reliable, and data has had good latency. Cell phones are the preferred communication option (easy, cheap), but there are holes in coverage. In the United Kingdom, they have relay stations. 700mghz radio repeaters for emergency can be used. For under $5K, you can have a simple satellite connection in the really extreme areas. Satellite dishes seem to work best.

- When you talk about latency, how important is it? Does .9 seconds vs 1.5 seconds matter?

I hear anything more than two seconds is the max. Mobile phones have one second latency. If you have both people using mobile phones, you have two seconds latency right there. In some applications latency is less important. Five seconds might be ok. For stuff like high speed navigation, you need good latency. For stuff like earthquakes you need good latency. If it is more like rapid static, it might not be as important. In some cases, you get dropped if you have more than two seconds of latency. In some cases, you do not see your latency. It depends on the equipment. One person reported problems with data links being more of a problem than latency. If you go down into a valley, you might lose your connection. Data link is a huge issue.

Stream data even if there is slow latency, as anything is better than nothing. Some will take data with five seconds of latency, if they can, because it is better than nothing. Much of the software was developed in a time when the data was streamed over the air. Now, it is streamed in different formats (Internet, satellite, etc.), so we have had to update the equipment software.

We have our own communications network, so we don't have to deal with latency. We use CORS coordinates for our real time network.

- How many folks only give ellipsoidal heights? (None.)
  We tell people they need to use a geoid model and need to occupy benchmarks to do a calibration.

  How many folks think it is an issue to not be able to have a geoid model?
  It works. It is just another step that we will have to do. Height Mod is critical to this. Folks hate using real time and then having to occupy benchmarks—it defeats some of the purpose.

- Is there user interest in older versions of the RTCM formats?
  We try to get users to use the latest format, namely, RTCM 3.0.

  Is this an issue with equipment, or a user wants to use older stuff?
  There will always be older receivers. If they want to use receivers that use only RTCM 2.1, you can't lock people out. The network can produce multiple streams. You can't dictate to people what they will use.

  There are other reasons to encourage people to move to RTCM 3.0. It is so much more compact, the bandwidth is just better. But, you can encourage people to do so, or you can rule by fiat. And the latter is not such a great idea.

  RTIGS is a more compact format. It's more an international thing and is not used as much in the United States.
  There are so many formats—BINEX, Non-visible VRS, CMR, CMR+ 2.0. Some people are locked into RTCM 2.3. We would very much encourage people and manufacturers to move to RTCM 3.0. For scientific applications, the resolution is so much better in RTCM 3.0.

- Equipment interoperability is a question. Trimble network, Leica rovers, does it make a difference? Are manufacturers doing stuff to optimize their rovers on their own network? Will a Leica network not work with Trimble receivers? Some say it is not a problem, and then some engineers say it is a problem.

From a manufacturer's perspective, one manufacturer stated they do lots to test their equipment with other manufacturer's equipment. They optimize their rovers to work with their equipment. They test the equipment of other manufacturers, but test their own equipment more than anyone else's.

There is a concern that some equipment people will do stuff to make sure their equipment will work better on their own network with proprietary stuff.

- As administrators, are there standards, guidelines, best practices, that you have been using? Are there standards you are looking for?
  No comments.

- One stated he tested things himself. He would use published CORS positions, and check the various equipment in various networks. Sometimes, we would have different coordinates than what was published for CORS sites, and we had to just go with that for internal consistency. That bothered some of our users, but we just had to go with it.

Discussion Group B:
Real-Time Positioning from the User's Perspective
Facilitators: Bill Henning and Mike Londe

Participants:

Steve Hampton	Texas DOT
Peter France	Trimble Mapping/GIS
Dan Norin	National Land Survey of Sweden
John Vasquez	Texas DOT
Marc Cheves	The American Surveyor magazine
Mike Londe	Bureau of Land Management
Bill Henning	NOAA's National Geodetic Survey

Discussion Group C:
OPUS and Ionospheric Models
Facilitators: Rick Foote, Gerald Mader, & Joe Kunches

Participants:
Francine Coloma of NOAA's National Geophysical Data Center
Knute Berstis, David Gietke, Rick Foote, Gerry Mader, and Dru Smith of NGS
Shawn Weisenburger of Trimble
Richard Langley of the University of New Brunswick, Canada
DeLane Meier of North Dakota Dept of Transportation

The following questions were considered:

What improvements would you like to see in OPUS?

Will you use the new XML output feature in OPUS to reformat the results and create customized reports?

Are you interested in OPUS-DB—for improving the coordinates of existing marks in the NGS Integrated Database or inputting new marks into this database?

Are you aware of methods of improving the OPUS solutions? For example, by viewing the extended output available from OPUS and looking for CORS stations with questionable coordinates, by reviewing their 60-day plots?

NGS is proposing to make OPUS usage available around the world. Would you use OPUS outside of the United States?

Dru Smith asked Professor Langley if he knew of any problems that Canada experienced with allowing their PPP utility to be used globally. Prof. Langley was not aware of any such problems.

Shawn Weisenburger said that Trimble would like to use whatever ionosphere model was developed, so that they could incorporate it into their software.

DeLane Meier said that he would like to have a better idea of how selecting CORS stations in OPUS-RS will affect results (ex: distance from Rover), and why user selected CORS stations cause OPUS-RS runs to fail quite often.

How would OPUS and OPUS-RS function if some of the NDGPS sites were de-commissioned?

Can we get atmospheric conditions at the selected reference stations to help determine accuracy of the autonomous point?

Also, DeLane thanked all the people at NGS for making the work of surveyors easier and more accurate.