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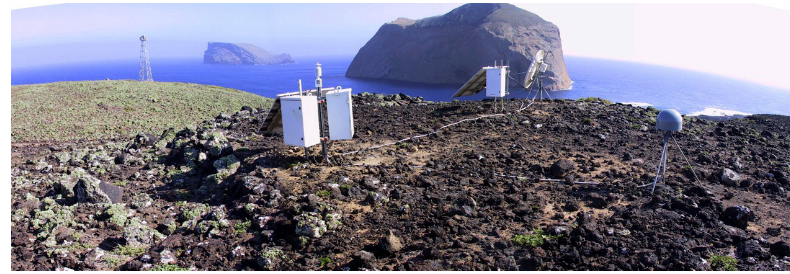
Puerto Vallarta, Jal.



HUAX GPS station, Isla Guadalupe, Mex.

TLALOCNet: a continous GPS-Met infrastructure for the study of the earthquake cycle, tectonics, subsidence and atmospheric processes in Mexico.

E. Cabral-Cano *Instituto de Geofísica, Universidad Nacional Autónoma de México.*
B. Marquez-Azúa *Centro de Estudios Estratégicos para el Desarrollo , Universidad de Guadalajara.*
H. de Dios *Coordinación General de Tecnologías de la información – Universidad de Guadalajara.*
D. Adams, *Centro de Ciencias de la Atmosfera, Universidad Nacional Autónoma de México.*
C. DeMets, *University of Wisconsin-Madison.*
K. Feaux *UNAVCO, Inc.*
A. Fernández-Alcántara. *Dirección General de Cómputo y de Tecnologías de Información y Comunicación, Universidad Nacional Autónoma de México.*
G. S. Mattioli *UNAVCO, Inc.*
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Y. L. Serra *University of Arizona.*

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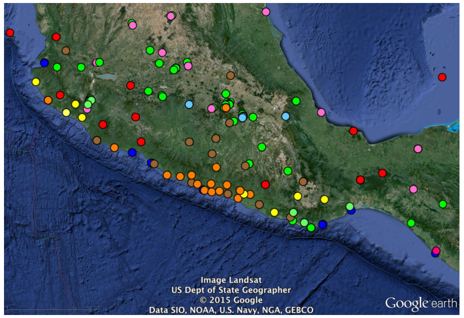
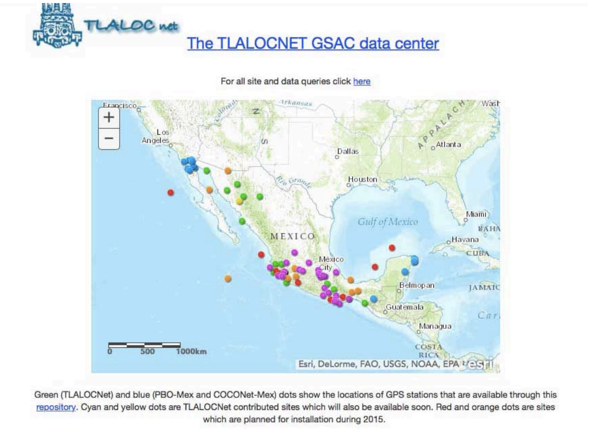
Overview



1st part

- GPS basics
- TLALOCNet project description
- GPS network development in Mexico
- Examples of some GPS applications



2nd part

- Is GPS Big Data?
- Big Challenges for Mexican GPS data holdings

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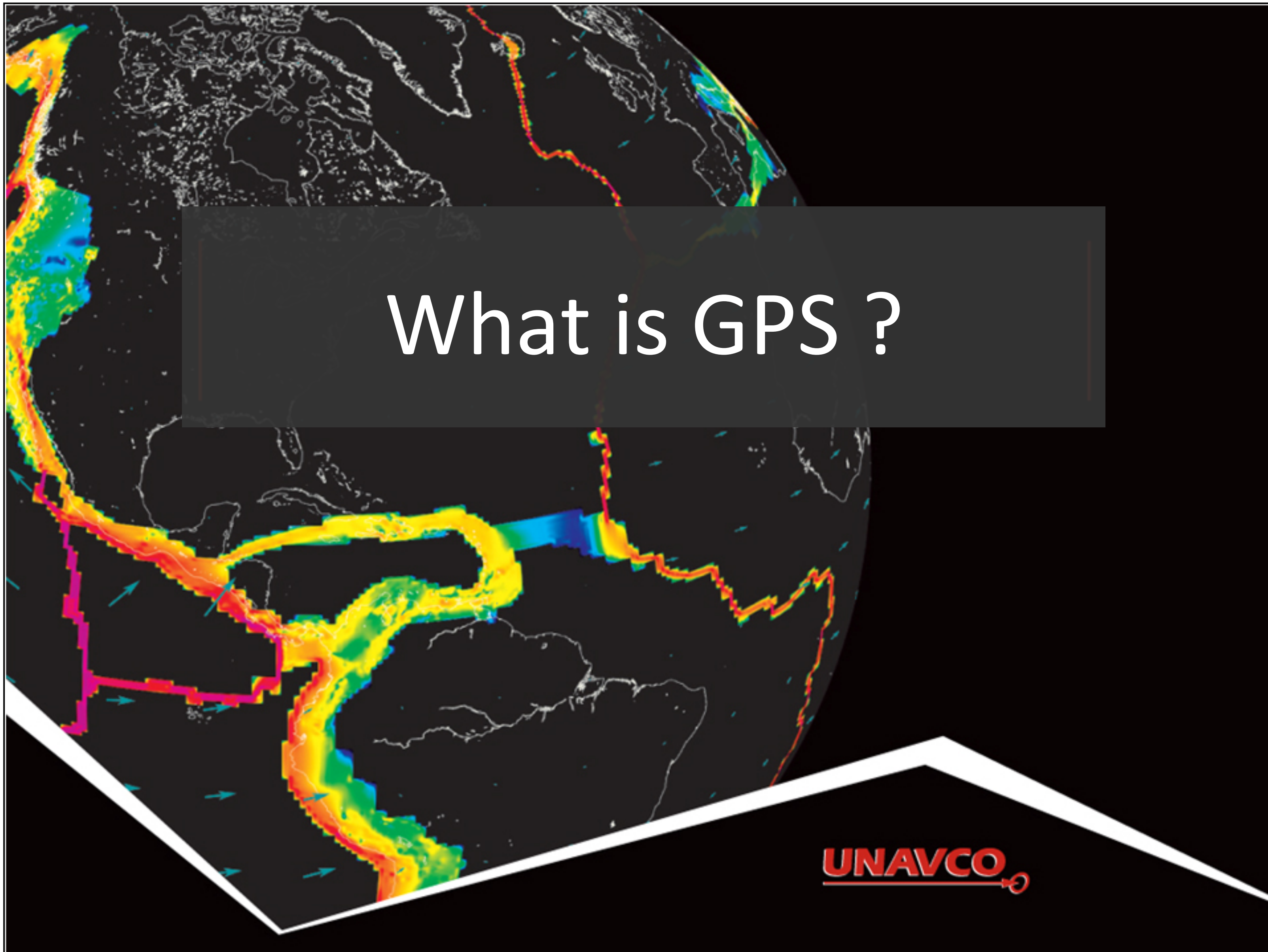
What is GPS ?



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GPS receiver

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GPS receiver

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GPS receiver

So is GPS really important?

There are very few advances in satellite geodesy in the past 5 decades that have been so transformative of both geodesy and our everyday as the Global Positioning System (GPS) and its newer versions which are now collectively known as Global Navigational Satellite Systems (GNSS).

These advances have made possible precise geodetic positioning to everyone with a smart phone

GPS satellite

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GPS are now available at very low cost for any consumer and its use is so widespread that few people realize the great complexity, the large logistical effort and the science behind these apparently simple device such as:

- Precise satellite ephemeris
- Ultra-stable clocks
- Very well calibrated atmospheric corrections
- Even relativistic time corrections

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The transformative nature of this technology is best demonstrated by the fact that even 50 years ago, there were so many places on Earth where you could not position yourself with a precision better that 500m. Let alone anyone with no prior geodetic and cartographic knowledge.

But nowadays, anyone can determine and let other people know his position with decimeter precision, in real time, in any place on Earth using a very small GPS device which in most cases are embedded in all sort of mobile devices.

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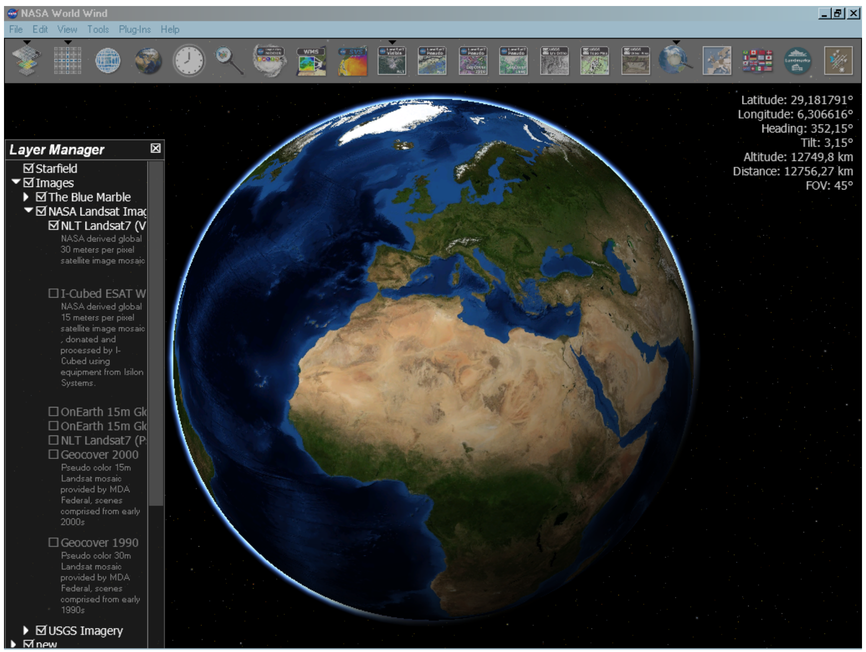
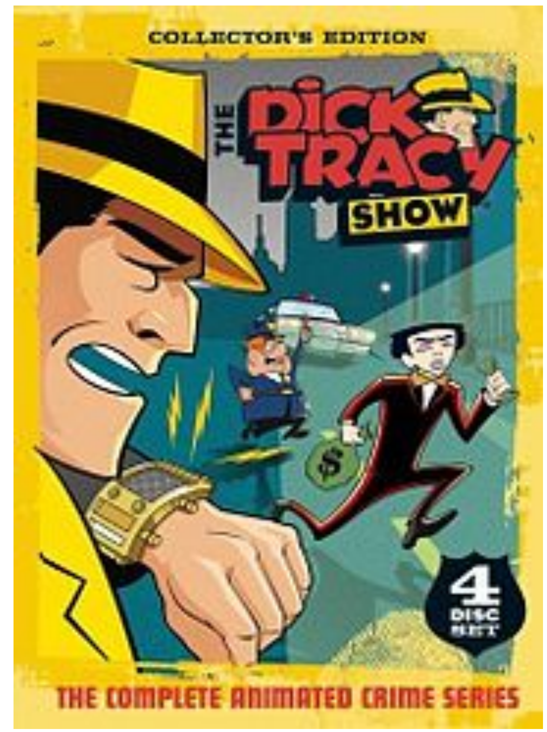
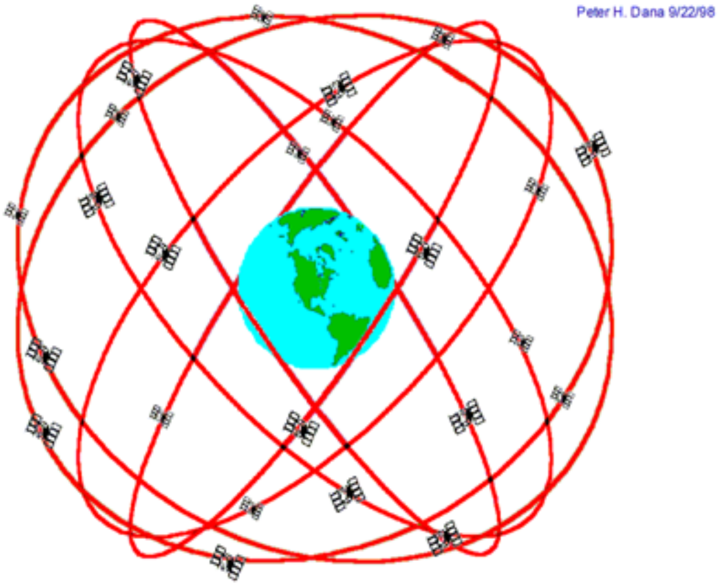
This "democratization" of geodesy has been fueled by all sort of cheap mobile devices, the proliferation of free access cartography and Virtual Globes (e.g. Google Earth, Bing, World Wind, etc) and the interconnectivity that empowers any person with tools that were the realm of science-fiction just a few years ago.



World Wind virtual globe JPL NASA



The Global Positioning System



- 24-32 satellites
- 20,200 km altitude
- 55 degrees inclination
- 12 hour orbital period
- 5 ground control stations
- Need 4 satellites to be accurate
- Each satellite passes over a ground monitoring station every 12 hours

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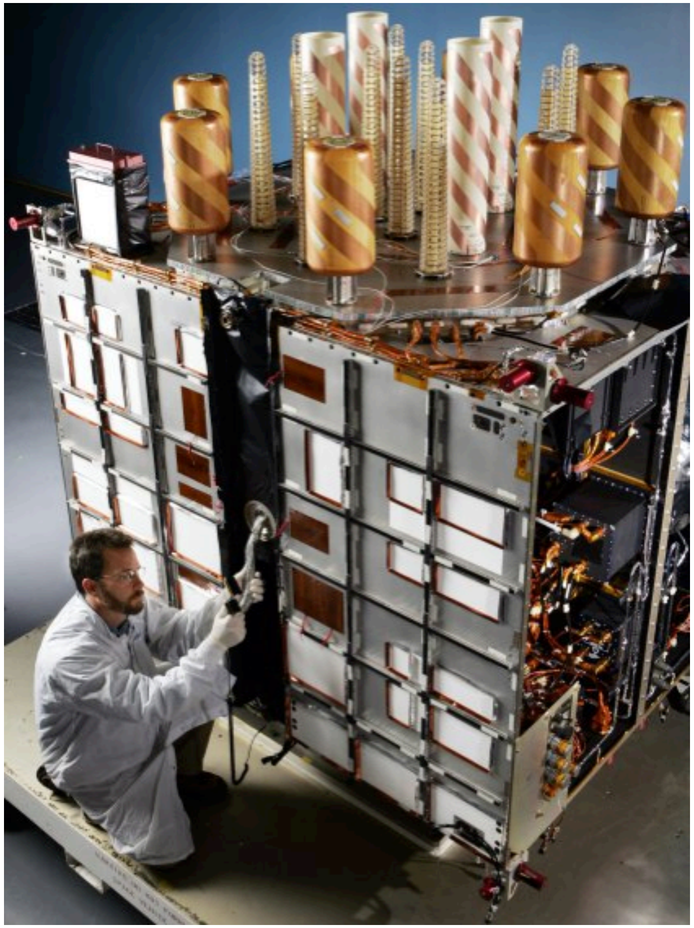
GPS Satellites



Images from Lockeed-Martin (http://www.lockheedmartin.com/products/GPS/)

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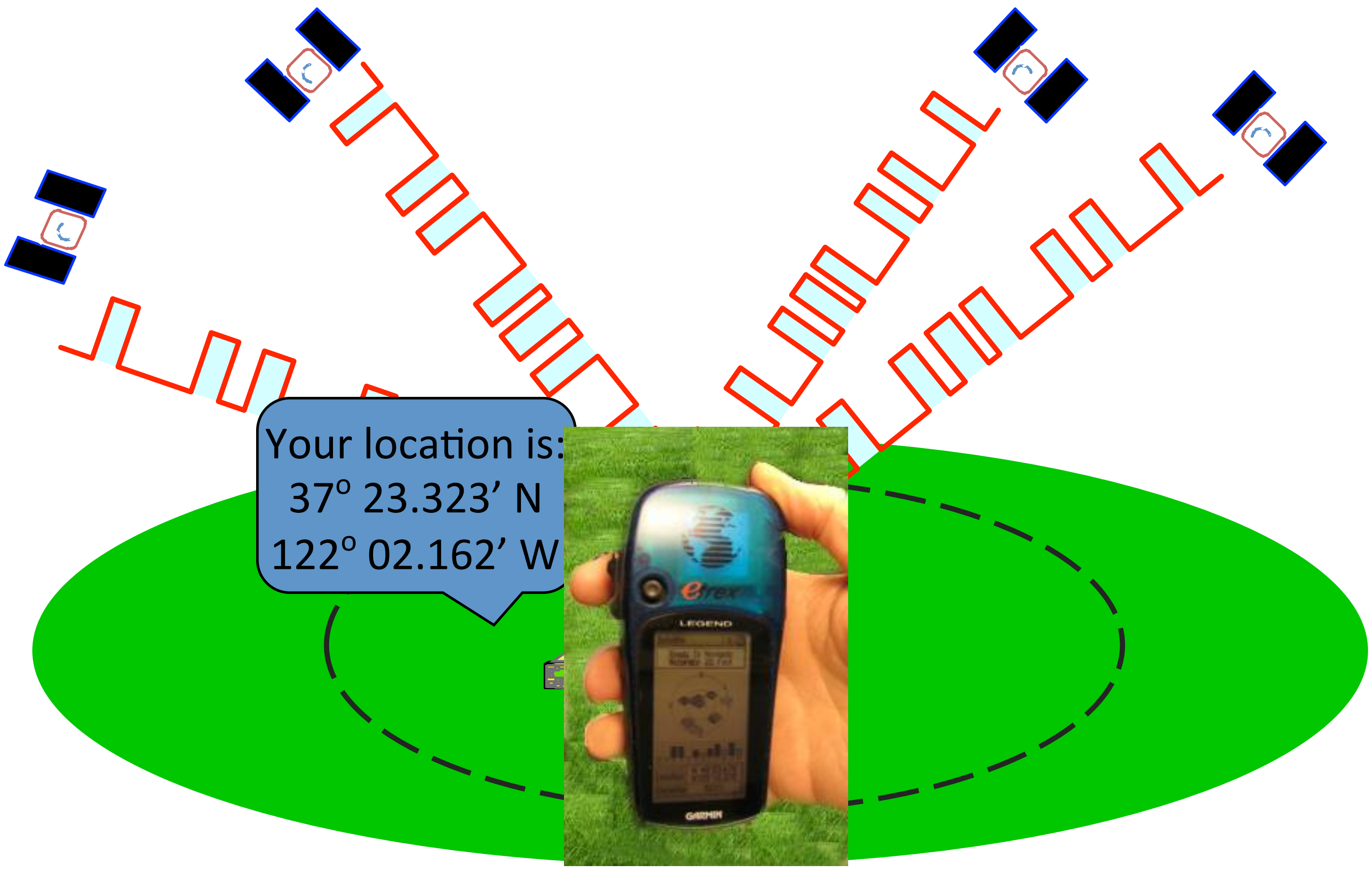
Consumer-grade GPS accuracy

- Horizontal: +/- 10 m (30 ft) error
- Vertical: +/- 15 m (45 ft) error



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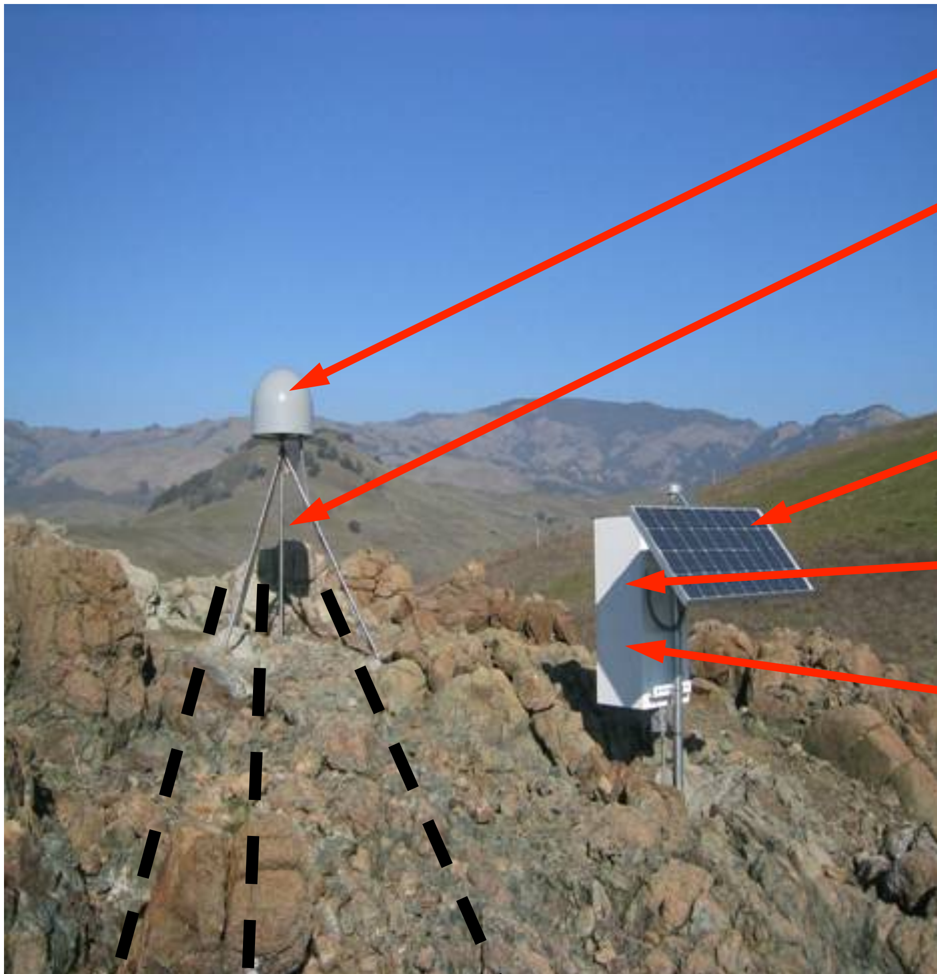
Anatomy of a High-precision Permanent GPS Station



GPS antenna inside of dome

Monument solidly attached into the ground with braces.

If the ground moves, the station moves.

Solar panel for power

Equipment enclosure

- GPS receiver
- Power/batteries
- Communications/ radio/ modem
- Other geophysical instrumentation

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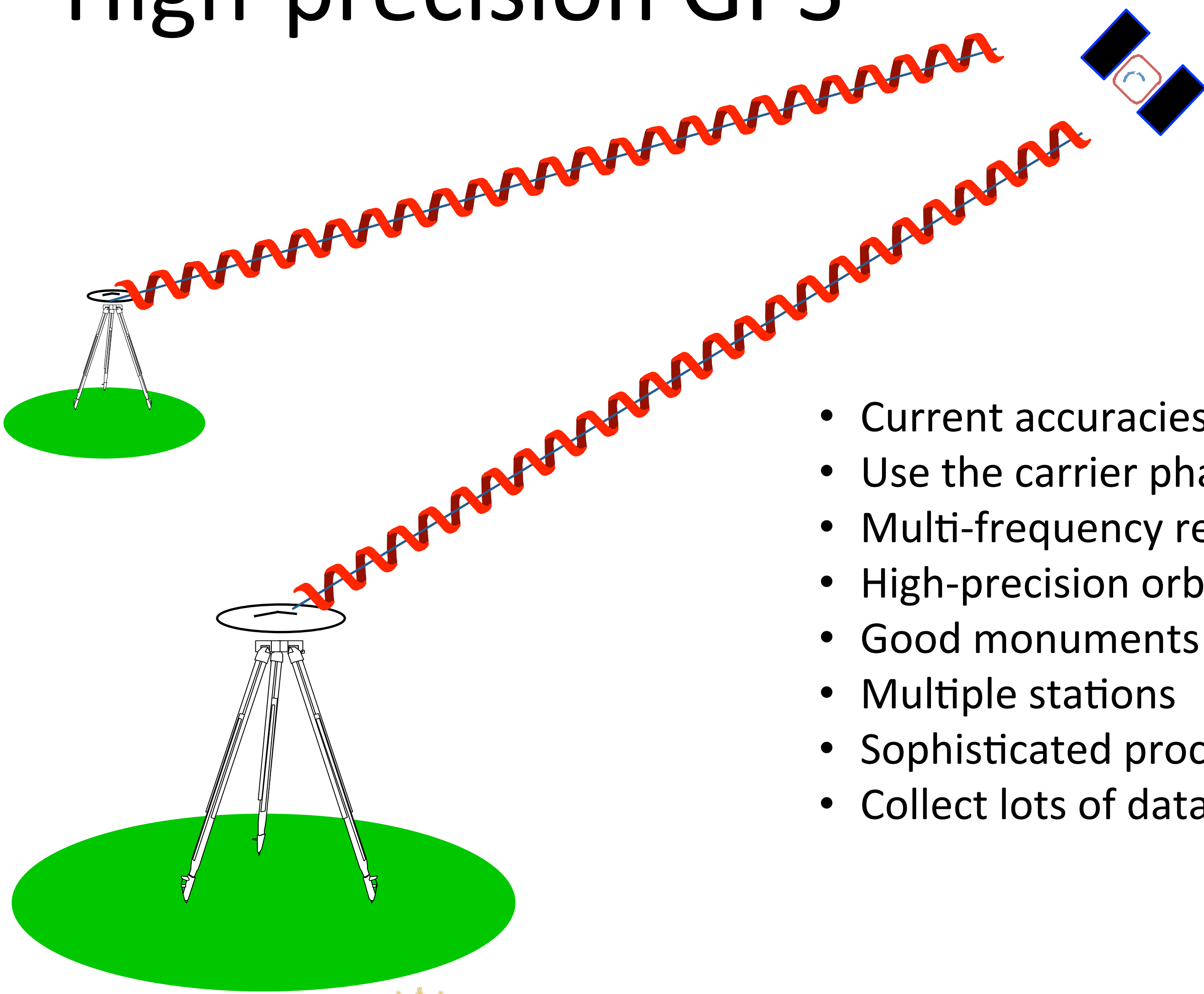
High-precision GPS



- Current accuracies sub-cm.
- Use the carrier phase
- Multi-frequency receivers
- High-precision orbital information
- Good monuments
- Multiple stations
- Sophisticated processing software
- Collect lots of data (Big data??)

GPS & atomic clocks

Each GPS satellite has 4 atomic clocks, to be sure that one is always working. Each costs ~$100,000, and is accurate to 1 billionth of a second (1 nanosecond).

http://www.kowoma.de/en/gps/satellites.htm

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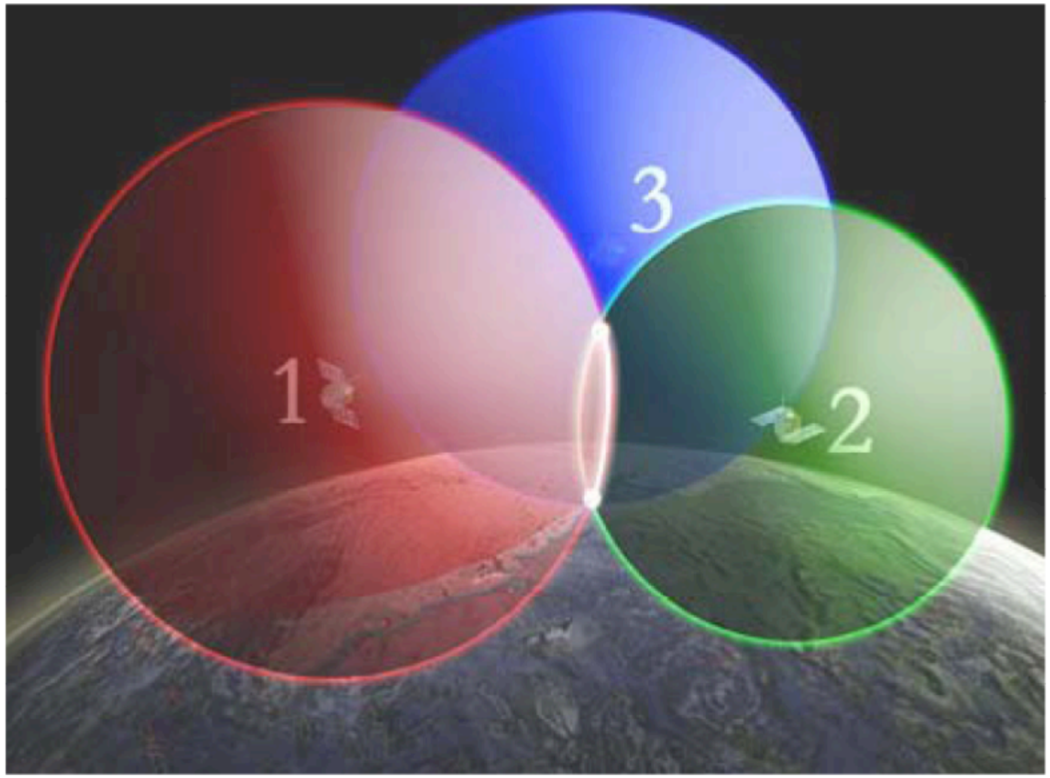
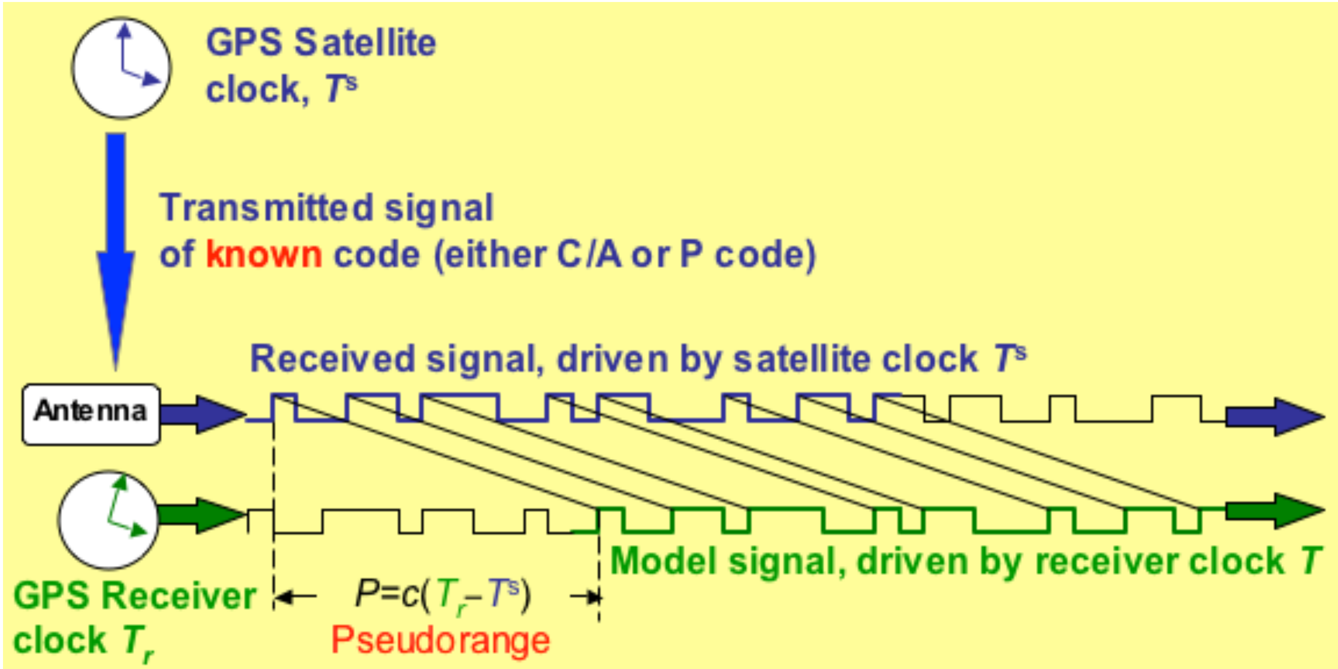
How actual location is determined



- Receiver position is triangulated using at least 3 satellites,
- 4th needed to adjust the receiver's time.

How satellite-receiver distance is measured

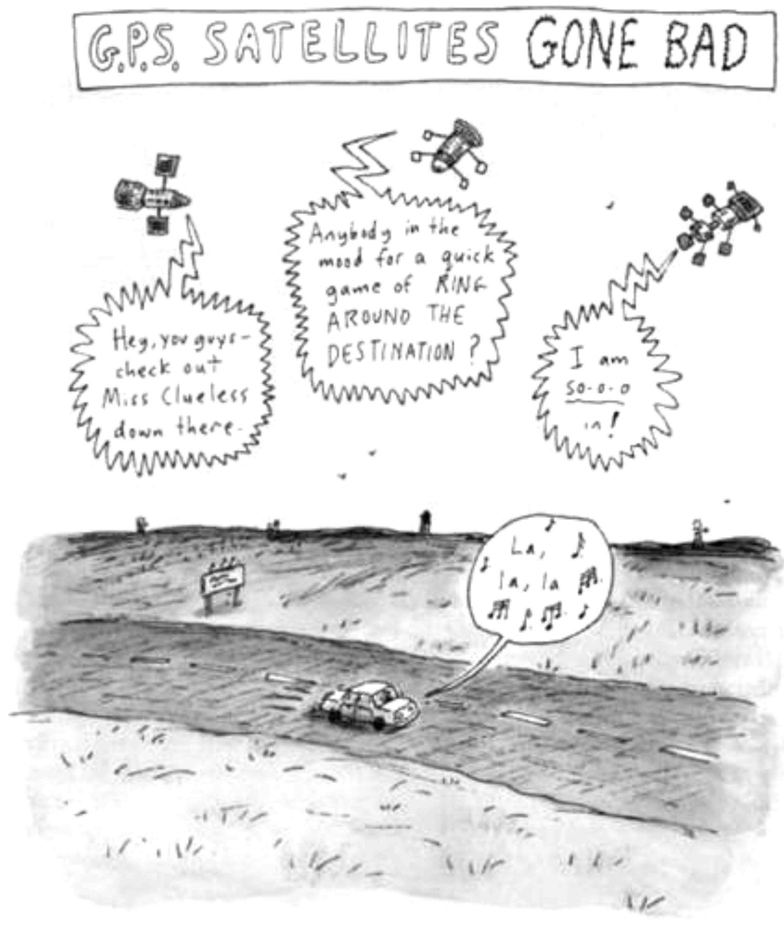


- Radio signal from satellite tells GPS receiver the satellite-clock time and provides the most recent corrections to the satellite's position relative to Earth (ephemeris)
- GPS receiver compares the satellite-times to receiver-time to determine the distance to each satellite

Sources of Error

Some GPS Error Sources

- Selective Availability
- Satellite orbits
- Satellite and receiver clock errors
- **Atmospheric delays**
  - Ionosphere
  - Troposphere
- **Multi-path**
- **Human errors**



The New Yorker, Roz Chast

Other sources of error

Morning Mix

Driver follows GPS off demolished bridge, killing wife, police say

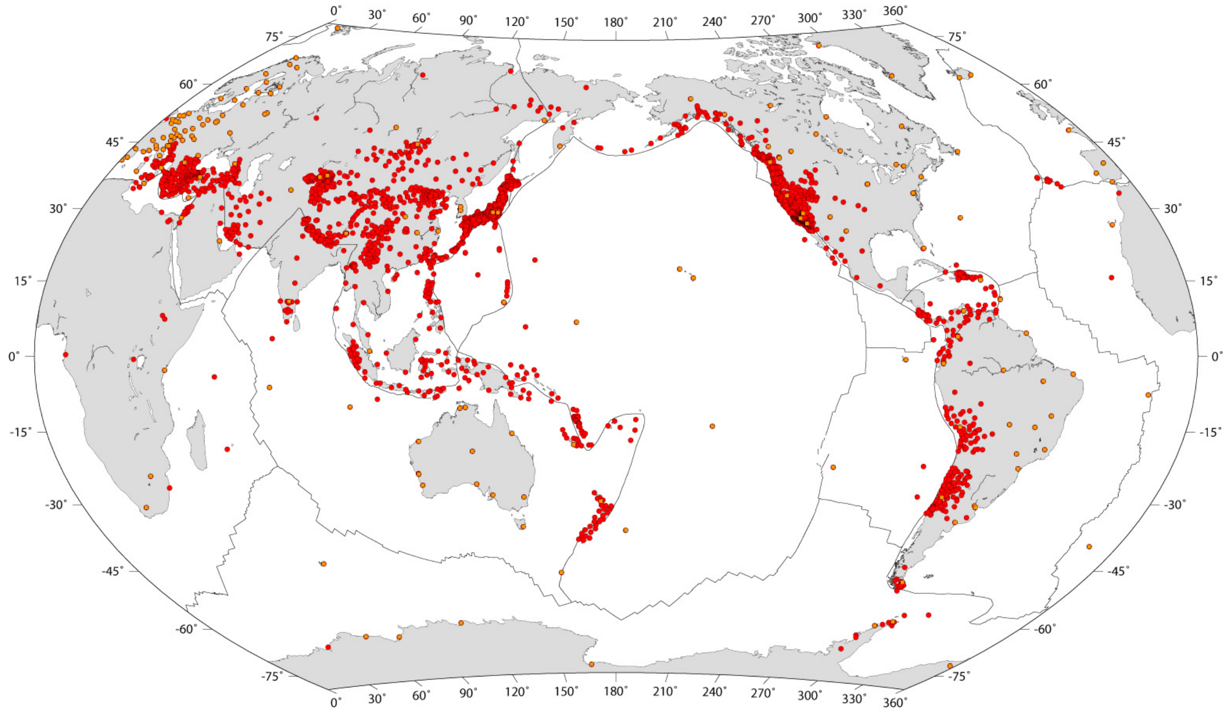
By Peter Holley March 31 Follow @peterjholley

A man following his vehicle's GPS navigation drove the couple's car off a partially demolished bridge. (Ken Davidson/Northwest Indiana Gazette)

A Chicago woman was killed after her husband followed their car's GPS navigation off a partially demolished bridge that has been closed since 2009, according to reports.

Zohra Hussain, 51, died after their Nissan Sentra fell more than 37 feet off the old bridge and burst into flames. She was unable to escape, the Lake County coroner's office said, according to the Times of Northwest Indiana.

GNSS/GPS stations globally



http://gsrm.unavco.org/data/images/1.2/sites.jpg

- >4000 stations (open data access) with more added all the time
- Some data freely available, some not
- GNSS = Global Navigation Satellite System

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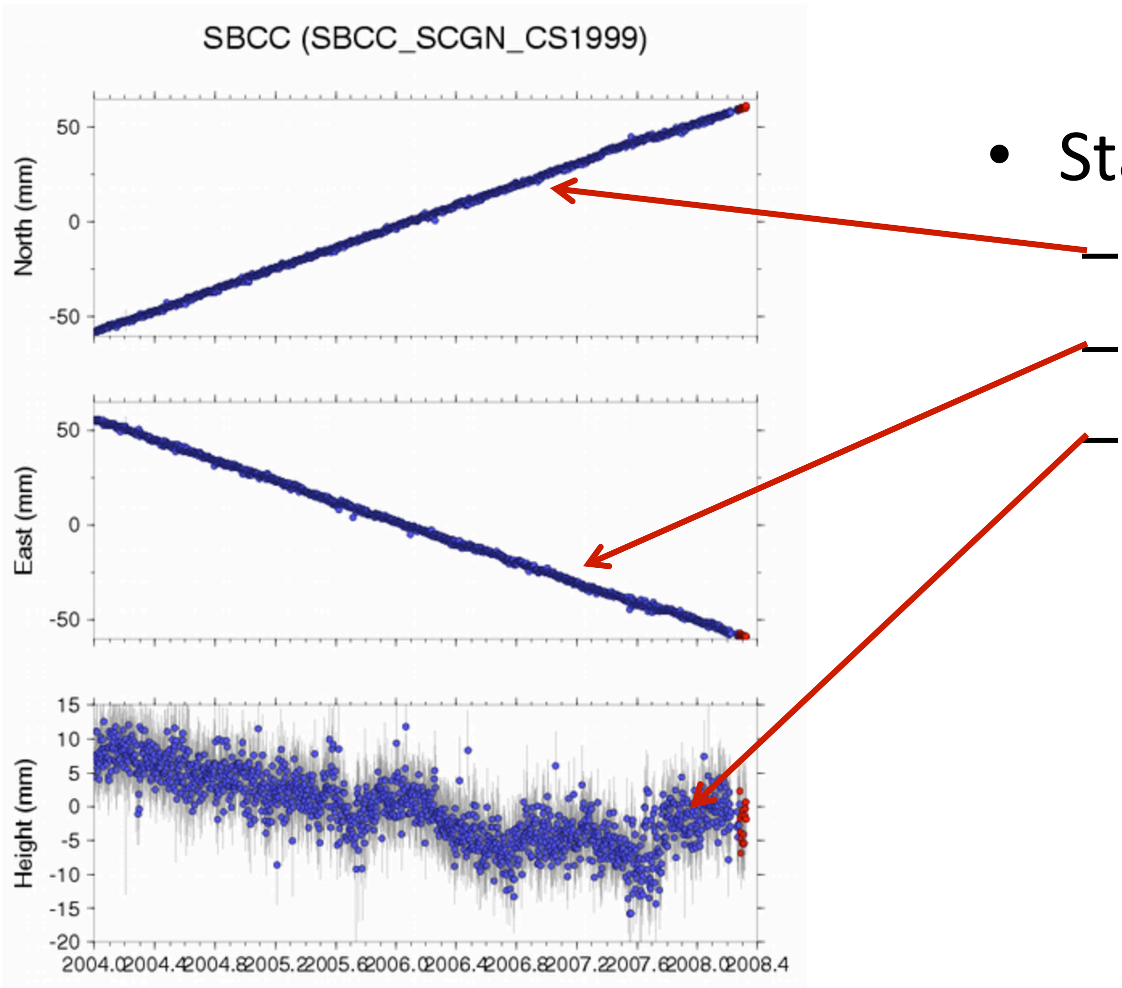
Example: using GPS velocities to understand plate motions

Two PBO stations in California

- Twenty-nine Palms, (BEMT)
- Mission Viejo (SBCC)

GPS time series data



http://pbo.unavco.org/station/overview/SBCC

- Station position over time
  - North-South
  - East-West
  - Up-Down

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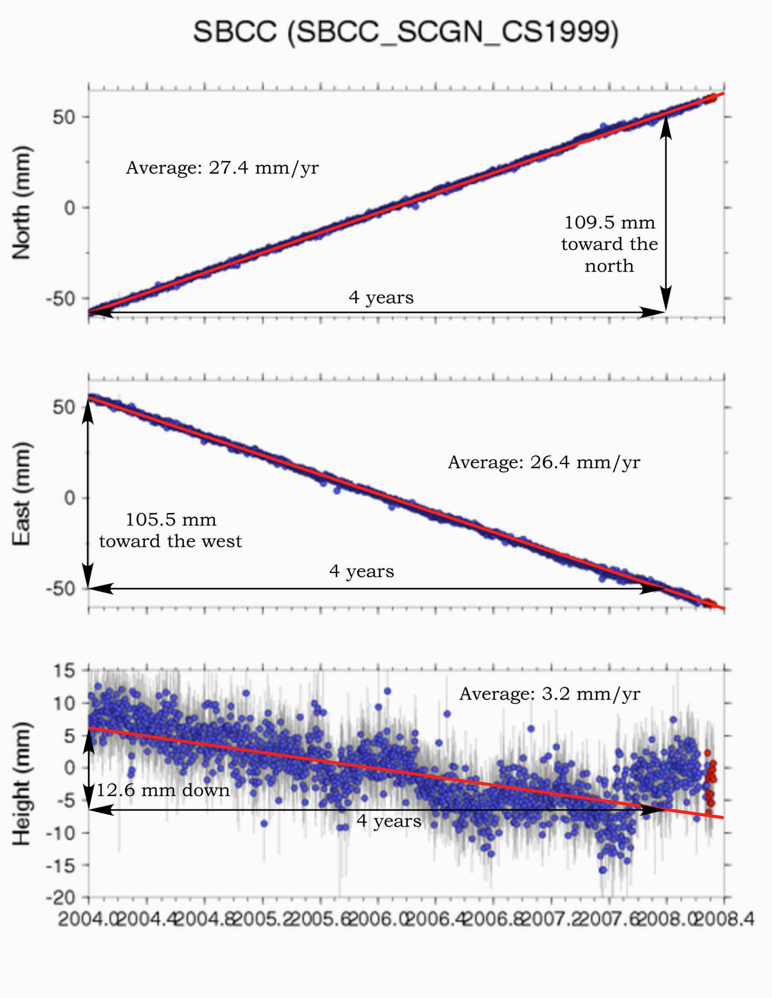
GPS time series data



http://pbo.unavco.org/station/overview/SBCC

- From the changing position velocity can be calculated using slope (rise-over-run)

Map view of velocity

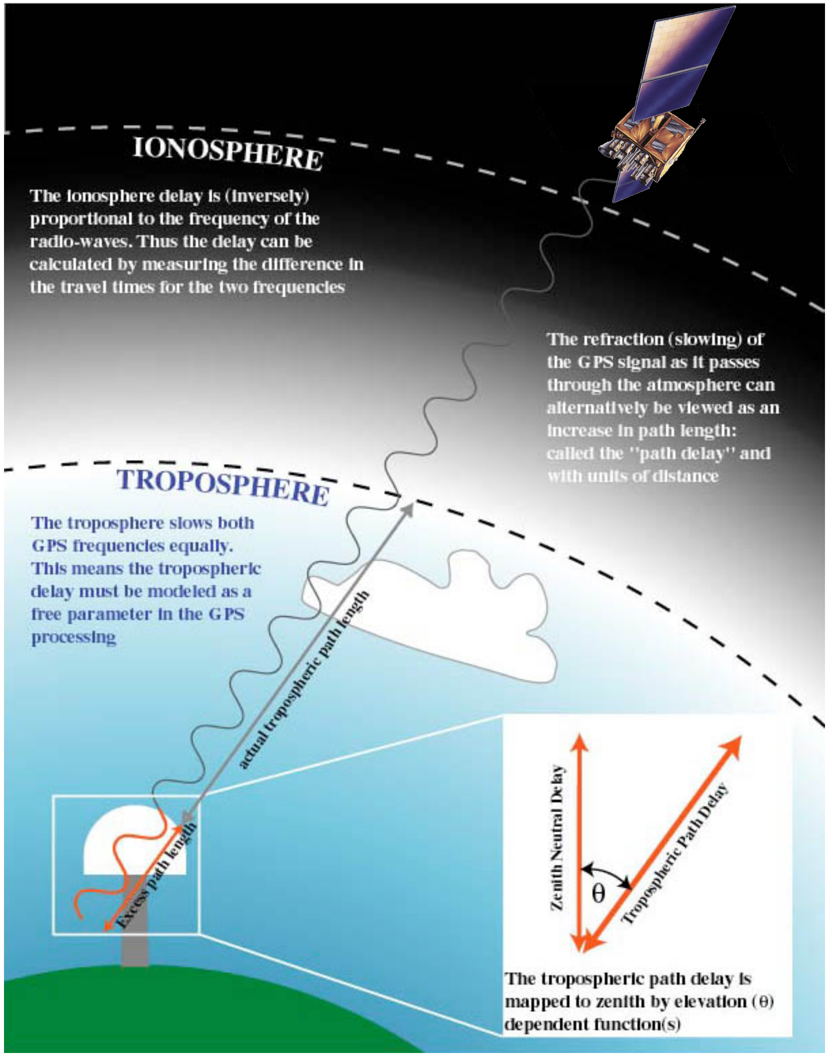
Two different velocities

Same process yields much slower velocity at BEMT

San Andreas Fault!

20 mm/yr

GPS-Met Applications for atmospheric research



The transmission velocity of an electromagnetic signal through the Earth's atmosphere is delayed as a function of the amount of water vapor preset in it.

For precise GPS positioning this needs to be estimated, however this same atmospheric noise can also be used to determine the integrated water vapor content in the lower part of the atmosphere, which is a very useful parameter for atmospheric modeling.

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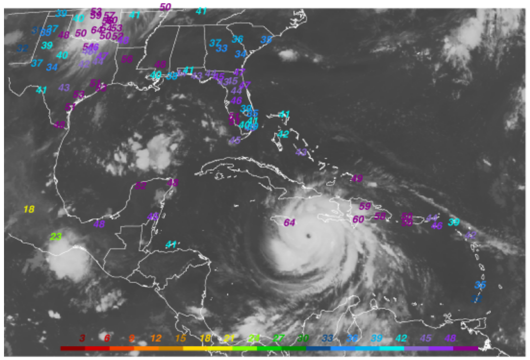
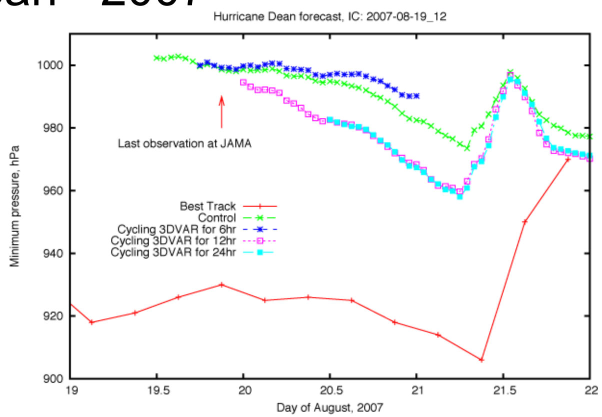
Hurricane forecast and precipitable water vapor derived from GPS-Met

Dean - 2007

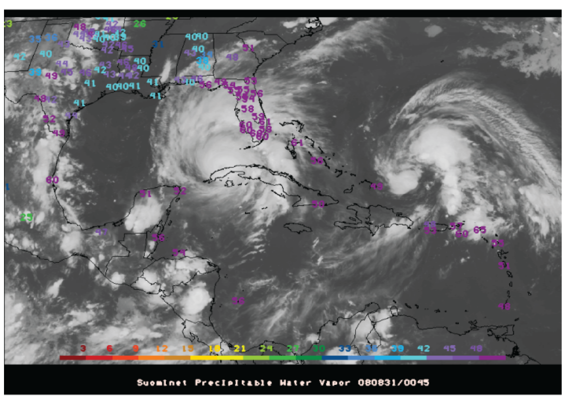


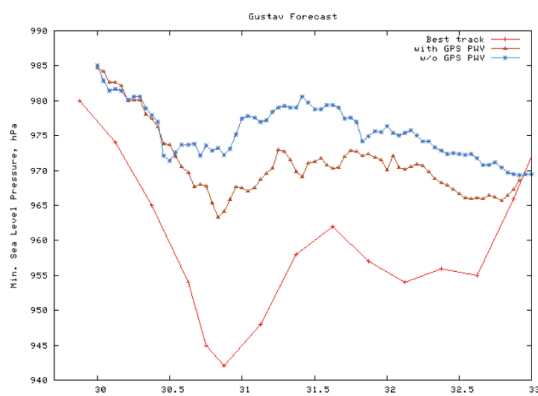
Suominet Precipitable Water Vapor 070819/1345



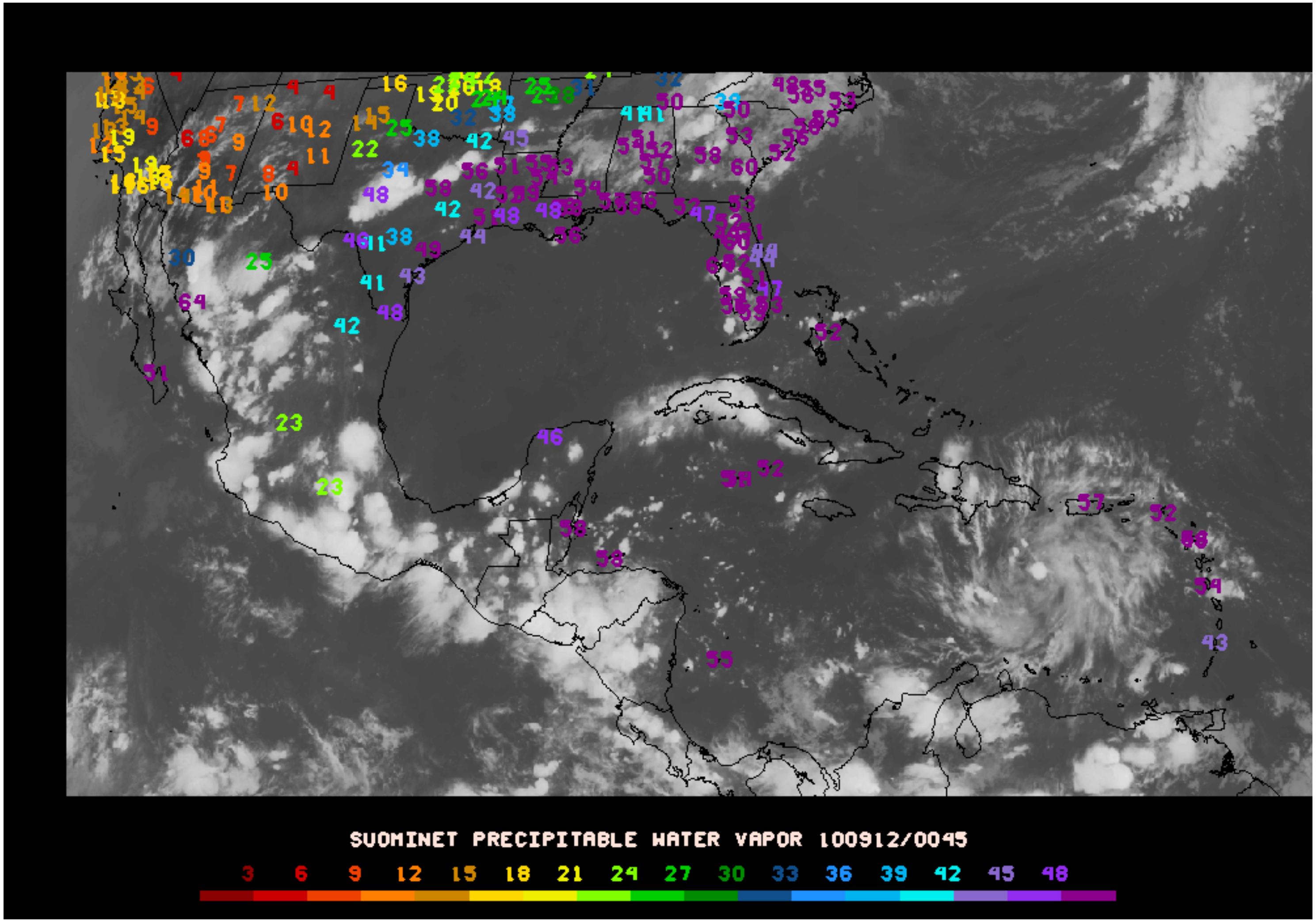
The GPS-Met network in the Caribbean has been successfully used to forecast hurricane intensification

Gustav - 2008





Hurricanes Karl and Igor



Precipitable water vapor for hurricanes Karl and Igor

Timeline of GPS infrastructure in México (1985-1999)

- 1985-1989 First Baja California campaign sites in Cabo San Lucas, Loreto and Mazatlan (*F. Suárez, CICESE; T. Dixon JPL*)
- 1993 INEGI's Red Geodésica Nacional Activa: 15 permanent sites for cadastral use.
- 1993-1995 Northern Baja California network; **First permanent research GPS site in México** CICE/CIC1 (*F. Suárez, CICESE; T. Dixon, JPL. NASA funded*).
- 1995 Jalisco block first GPS observations (*O. Sánchez, UNAM, B. Márquez-Azúa, U de Guadalajara J. Stock, CalTech, and C. DeMets, U. Wisconsin. NSF funded*).
- 1996 Popocatepetl Volcano. One of the earliest volcano installations supported by UNAVCO (*T. Dixon, U. Miami, E. Cabral-Cano. UNAM. NASA funded*).
- 1998-99 Guerrero network (*V. Kostoglodov, S. Krishna, O. Sánchez UNAM, Conacyt funded*).
- 1999 Northwestern Mexico network (*J. González, F. Suarez, CICESE, SOPAC, U. Arizona, UNAVCO*).
- 1999 First GPS colocated on Tide gauge station in Manzanillo (*SOEST-Hawaii*).
- 1999 L1 network in Popocatepetl (*T. Dixon, U. Miami, E. Cabral-Cano. UNAM, C. Meertens UNAVCO. NASA funded*).

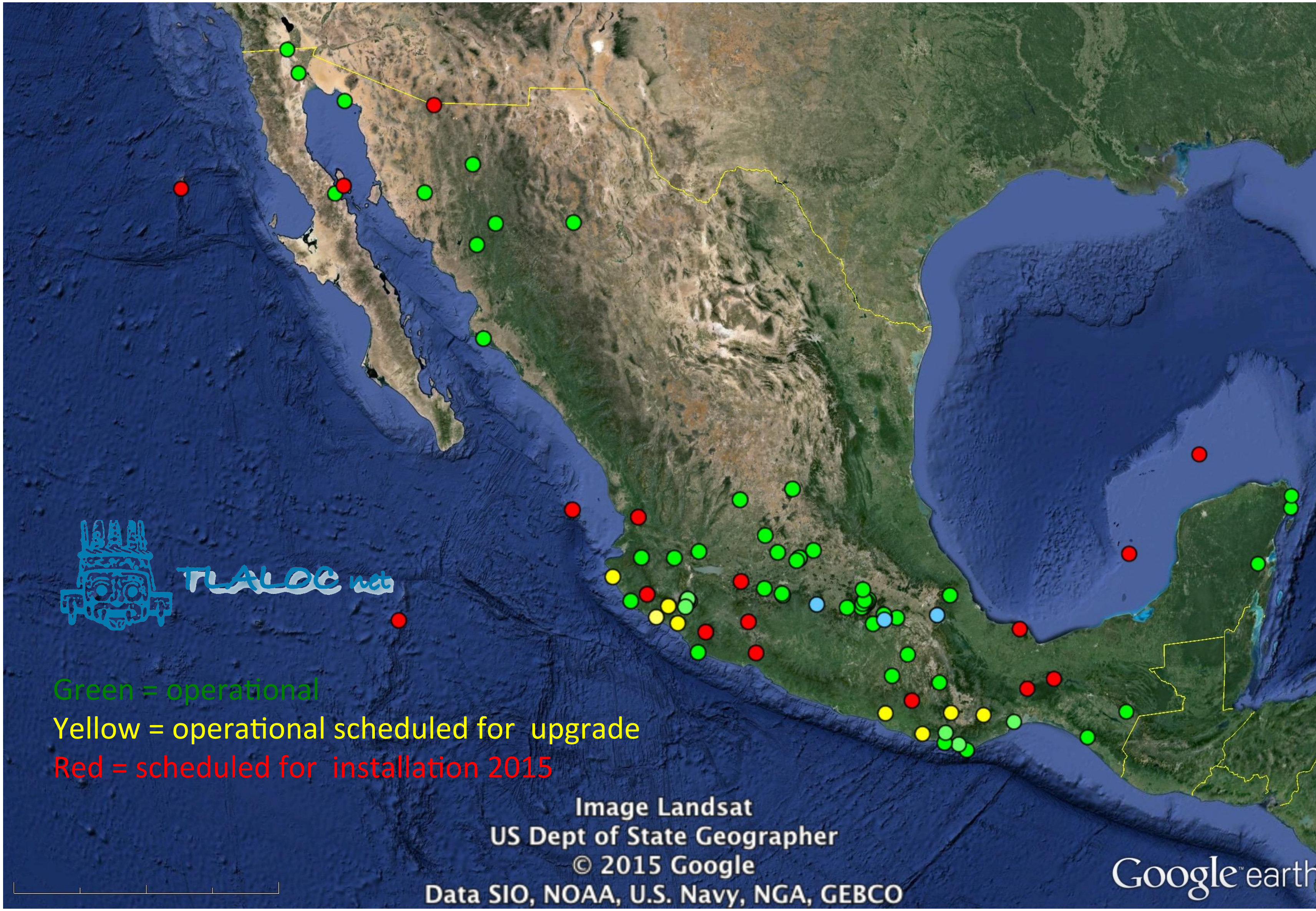
Timeline of GPS infrastructure in Mexico (2000-2006)

- 2001 Suominet sites installed. First atmospheric application in México.
- 2001 Oaxaca network first phase (*E. Cabral-Cano, UNAM, C. DeMets, U. Wisconsin NSF and Conacyt funded*)
- 2002 Northwestern Mexico network densification (*J. González, F. Suarez, CICESE, R. Kurinski, R. Bennett, U. Arizona, UNAVCO, SOPAC*)
- 2003-2004 Guerrero densification *(V. Kostoglodov, UNAM, K. Larson, T. Lowry, NSF and Conacyt funded*).
- 2004 Mexico city subsidence network (*E. Cabral-Cano; UNAM funded*)
- 2004 North American Monsoon Experiment (*U. Arizona, NOAA, U. Sonora, UCAR*)
- 2004 Upgrade of INEGI's Red Geodésica Nacional Activa with new receivers.
- 2005-2007 WAAS coverage expanded with 5 sites in Mexico (*FAA and SENEAM funded*)
- 2006 Second phase of the Jalisco-Colima network (*B. Márquez-Azúa, U. de Guadalajara, C. DeMets, U. Wisconsin*).
- 2006 Oaxaca network second phase, colocation of 9 broad-band seismometers (*C. DeMets, U. Wisconsin, M. Brudzinski, Miami U., E. Cabral-Cano, UNAM. NSF and UNAM funded*)

Timeline of GPS infrastructure in Mexico (2007-2015)

- 2007-2008 Central Mexico subsidence network in Mexico City, Morelia, Celaya, Queretaro and Aguascalientes *(E. Cabral-Cano, UNAM. UNAM and Conacyt funded*).
- 2009 Southern Baja California network (*T. Melbourne, C. Washington U.*)
- 2009 G-Gap France-Mexico project. Guerrero network densification and seismic mini-arrays (*V. Kostoglodov, UNAM, M. Campillo, A. Walpersdorf, , N. Cotte U. Grenoble*)
- 2010 Northern Baja California densification after the Mexicali Valley Earthquake (*CICESE and UNAVCO funded*)
- 2010 Volcán de Fuego de Colima network (*E. Cabral-Cano, H. Delgado and A. Arciniega, UNAM; Conacyt-Foncicyt funded*)
- 2012 COCOnet-Mexico (UNAVCO-UNAM collaboration).
- 2014 Servicio Mareográfico Nacional colocates GPS with tide gauges (UNAM-Geofisica-CCA)
- 2014 TLALOCnet GPS-met network: densification and upgrades of current stations (NSF-UNAM funded)
- 2015 COCOnet-Mexico tide gauge stations

- April 2015, there are 156 cGPS stations throughout México.



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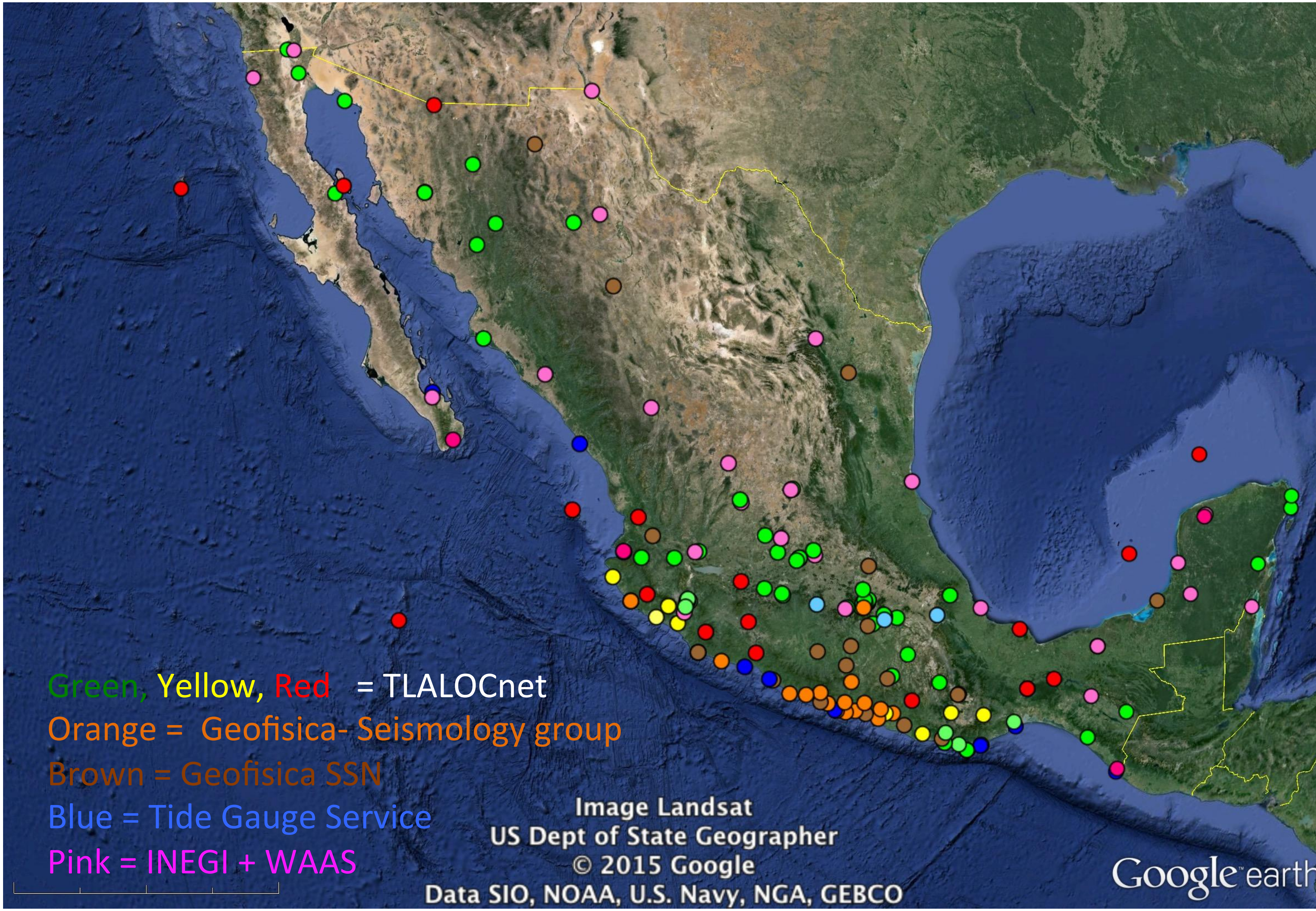

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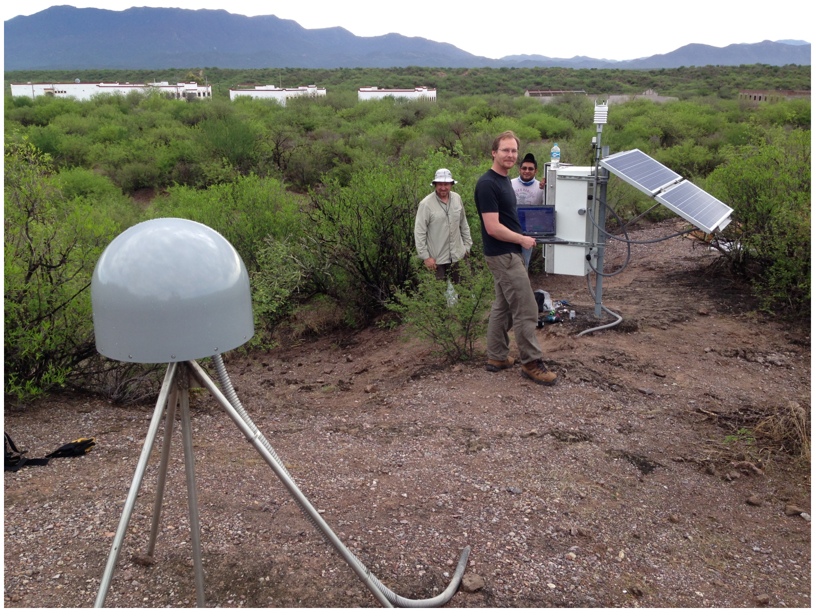
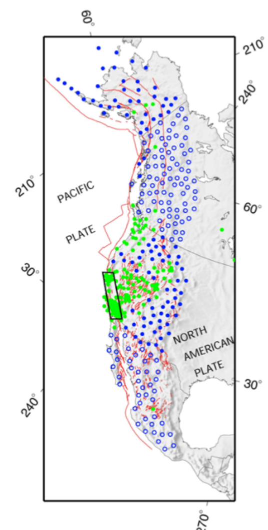
TLALOC net

TLALOCNet is a continuous GPS-Met network in Mexico for the study of earthquake cycle, tectonics, ground subsidence and atmospheric processes in Mexico. TLALOCNet links existing GPS infrastructure in the rest of North America and Central America, the Caribbean and northern South America to create a continuous, federated network of networks spanning from Alaska to South America.





From EarthScope Science Plan ca. 2002.

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Hardware

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Telecommunications

VSAT station in Bahia de los Angeles, BC.

3G cellular modem

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Monumentation and Power

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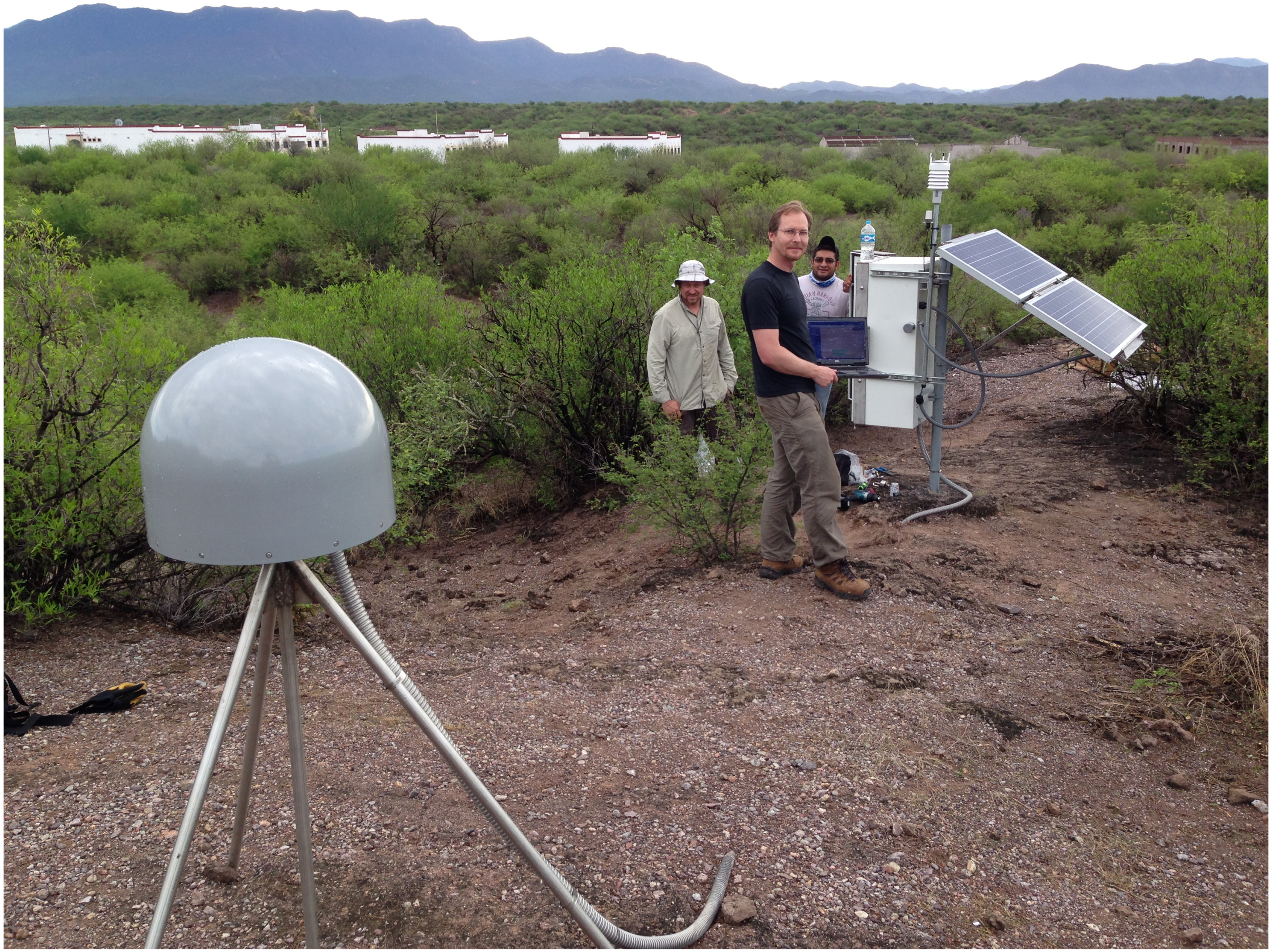
Monumentation and Power



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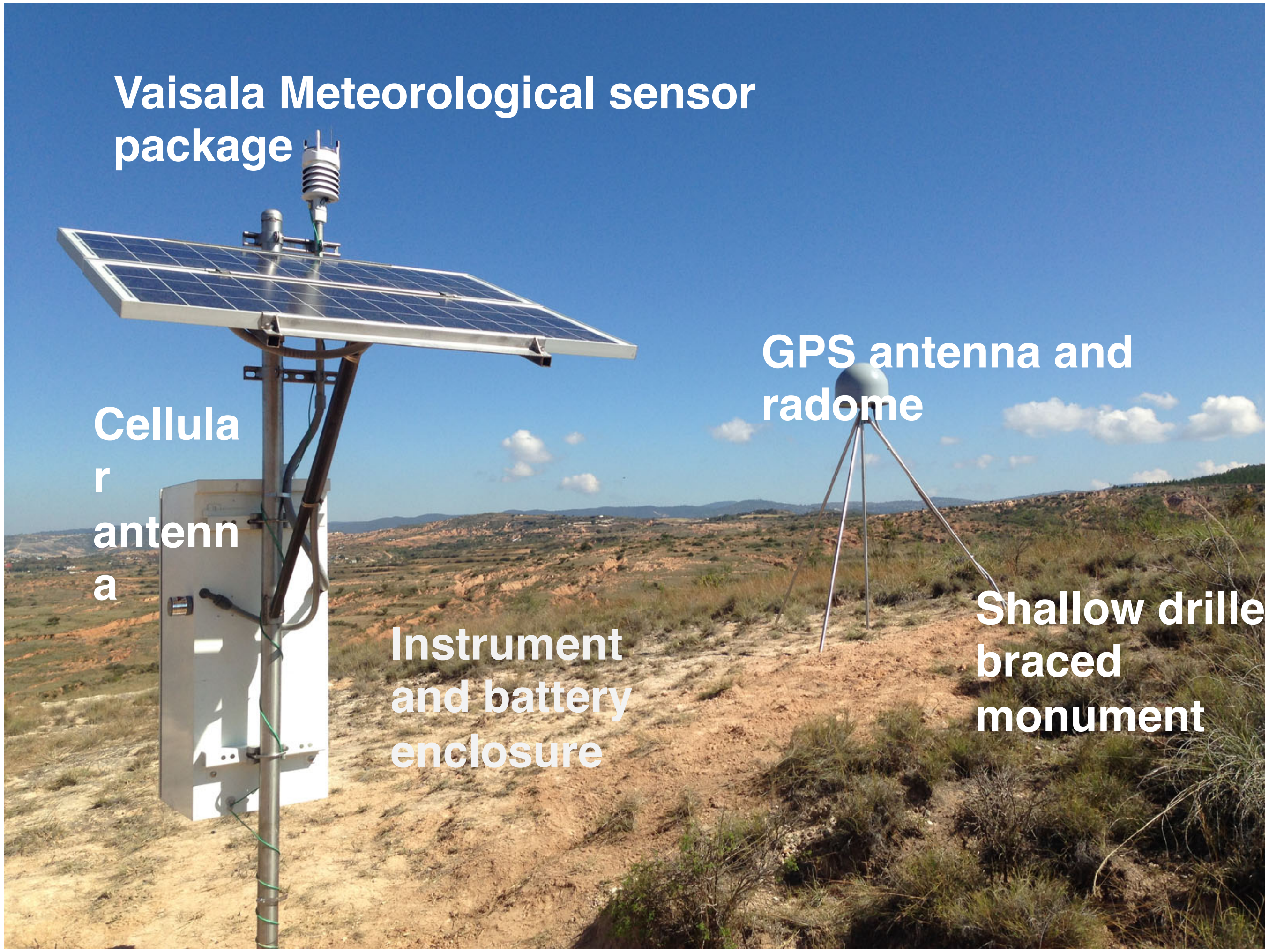
TLALOCnet GPS-Met station hardware TNNX Nochixtlán, Oaxaca.



TLALOCNet stations telecommunication requirements

The limitations for setting up a GPS station are:

- Satellite visibility
- Security
- Telecommunications potential
- Rock outcrop of other suitable solution

Other factors

- Reliable power (usually via a photovoltaic solution)
- Hardened telecommunications (if used for early warnings or during crises
- High availability/low latency telecommunications.

TNBA station, BC.

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Telecommunication challeges

- For real time applications the GPS station telecommunications are of key importance.
- Federal programs aimed for Internet/digital inclusion can be a great asset for all geophysical observational efforts, but the collaboration between Mexican federal agencies and the academia is hard to initialize.
- Moreover, telecommunication fees are the single largest cost for mid to large term operations and one of the hardest to justify on (usually) short term scientific projects.
- CUDI could play a facilitator role into this situation and help pave the road for a more collaborative participation in these Internet inclusion programs.

TLALOCNet Data Flow

UNAVCO Data Center

TLALOCNet Data Center

Daily 15-second GPS and Hourly 15-second MET
Raw Files
Real-time stream in some stations
1 and 5HZ files for large events

Open Raw and RINEX Files

Tlaloc users

The TLALOCNET GSAC data center

For all site and data queries click here

Green (TLALOCNet) and blue (PBO-Mex and COCONet-Mex) dots show the locations of GPS stations that are available through this repository. Cyan and yellow dots are TLALOCNet contributed sites which will also be available soon. Red and orange dots are sites which are planned for installation during 2015.

The TLALOCnet data center (*http://tlalocnet.udg.mx*)

<<GSAC>> | Web Services for Geoscience Data

Querable, open data access data (GPS+Met, real time streams) to all TLALOCnet and other contributed GPS networks in Mexico based on GSAC.

- The TLALOCNet data center, started operations in March 2015
- Serves as seamless archive for discovery, sharing and access to TLALOCNet GPS-Met data, and other academically operated cGPS-Met sites throughout Mexico.

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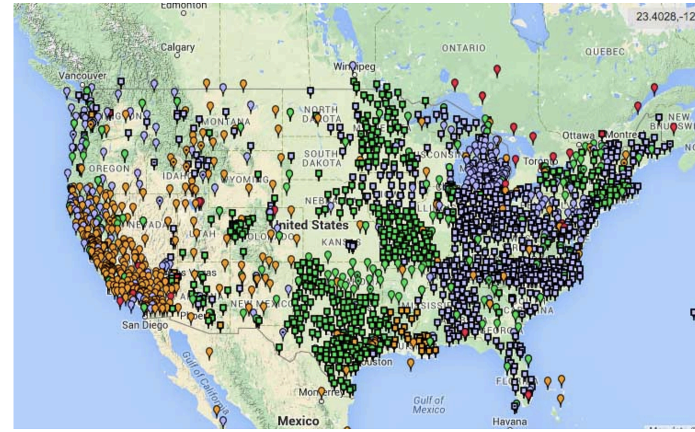
Is GPS Big data ?



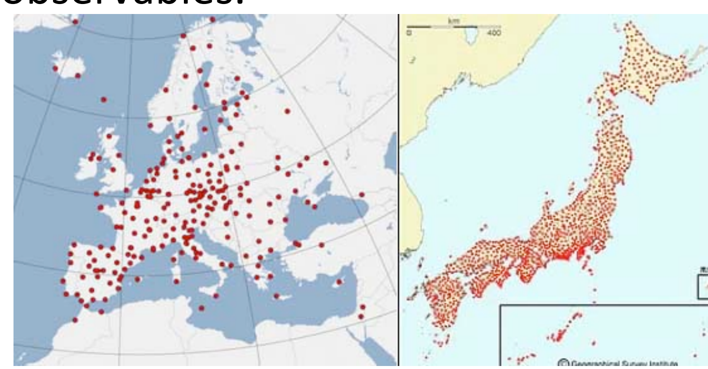
PBO/NGS-CORS GPS network

- GPS research in Earth and Space Science need big
- number of data collectors (cGPS/GNSS stations).

- Long term observations (specially in Geodesy) by a large number of spatially distributed sites is the core of GPS-based research in solid earth, atmospheric and space weather.

Big data needs Big repositories (open and free)

- The TLALOCNet data center (***http://tlalocnet.udg.mx***) is the first Mexican community effort for perpetual archiving of GPS-Met observables.



EUREF and GEONET GPS networks

TLALOC net UNAVCO geOFISICA UNAM

CUDI 2015
REUNIÓN DE PRIMAVERA
21 AL 24 DE ABRIL
Puerto Vallarta, Jal.

GPS (Big?) Numbers

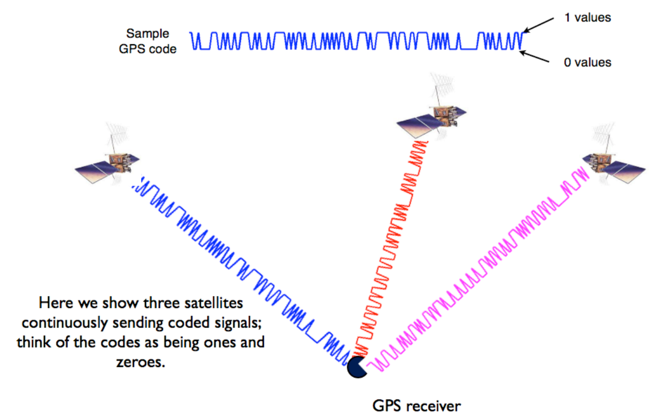
GPS observables (@ 1 GNSS constellation - GPS)

Each station @ 15 sec (standard rate for daily solutions)
10 pseudoranges/satellites/epoch average x 4 x 60 x 24 = **55,760** pseudoranges/day/station

Each station @ 1Hz (standard rate for continous real-time solutions)
10 pseudoranges/satellite/epoch average x 60 x 60 x 24 = **864,000** pseudoranges/day/station

Each station @ 5Hz (current best rate seismogeodesy, epoch-by-epoch solution for large displacement events such as earthquakes)
10 pseudoranges/satellite/epoch average x 300 x 60 x 24 = **4'320,000** pseudoranges/day/station

- Data archiving at 1-5 Hz only during large deformation events.
- Current GPS receivers can store @ 20 Hz but limitation is in the last-mile connectivity (most sites are at rural locations).
- Current GPS receivers can observe 2 GNSS constellations (GPS + GLONASS and in the next years Galileo and others will be available).



The receiver is going to try to decrypt each of the GPS signals separately.

http://xenon.colorado.edu/spotlight/index.php?action=kb&page=42

We are throwing away data and archiving only a small fraction of the GPS observables.

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The TLALOCNet data center

The TLALOCNET GSAC data center

For all site and data queries click here

Green (TLALOCNet) and blue (PBO-Mex and COCONet-Mex) dots show the locations of GPS stations that are available through this repository. Cyan and yellow dots are TLALOCNet contributed sites which will also be available soon. Red and orange dots are sites which are planned for installation during 2015.

(based on UNAVCO's Geodetic Seamless Archive Centers - GSAC)

Collaborative effort UdeG - UNAM

Server on-line on ***March 11, 2015***.
First advertised on Mar 27, 2015.

Stations	**52** average 3.57 years/site Oldest operating site 2007, but will ingest data from sites operating since 1996
Data holdings	**72,828** file holdings (obs, nav and met), total **19'209,264 KB** (Hatanaka compact + Z compressed)

Data served

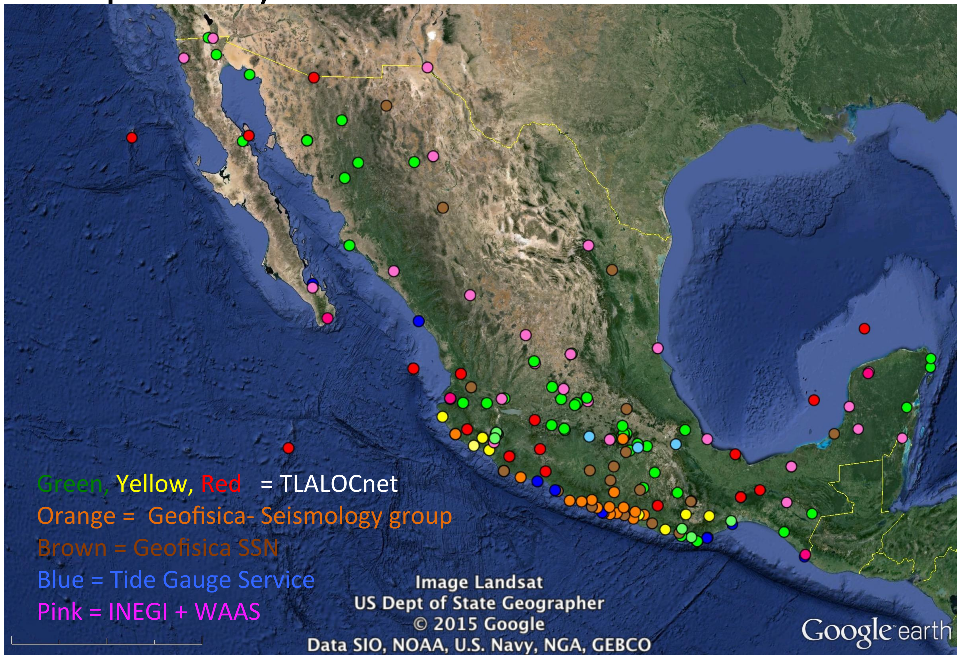
March,2015	**14,931,196 KB**	68,233 files
April, 2015	**2,897,563 KB**	3,640 files

TLALOC net · NSF · UNAVCO · UNAM · Geofisica UNAM · CUDI 2015 Reunión de Primavera 21 al 24 de Abril Puerto Vallarta, Jal.

Overall Mexican GPS holdings (INEGI + academic)

Sites **156** continuous sites
28 INEGI
128 other academic
First cGPS sites: 1994 (INEGI), 1996 (academic)

Data holdings ~**182,000** (obs) files (not including INEGI's)
136'500,000 KB (Z compressed) total



Academic + INEGI GPS networks in Mexico

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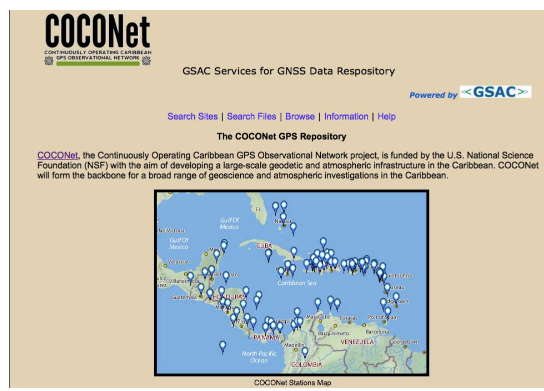
Other similar GSAC repositories

Currently 16 different GDAC-based geodetic repositories.
capability to run federated repostories in "seamless" archive where data holdings may be geographically dispersed

Federated" GSAC repository which, while maintaining the independence of each individual GSAC repository, allows for merged or joint searches of all the collaborating GSACs at once.

A federated GSAC doesn't stores any data from the collaborating individual GSAC repositories, but instead dynamically queries two or more participating GSAC repositories

NASA-Goddard GSAC



COCONet GSAC

RING GSAC

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GPS data growth perspectives

Expand number of Mexican cGPS sites

currently **156** GPS sites throughout Mexico
expected ~**200** sites by 2017

World-wide			~**4,000** cGPS stations	
Japan	377,000 km^2	GEONET (1994->)	~**1,200** cGPS stations	0.31 $x10^3$ km^2/station
USA	9,147,000 km^2	PBO (2003 ->)	~**1,300** cGPS stations	7.03 $x10^3$ km^2/station
Mexico	1,972,000 km^2		~**150** cGPS stations	13.14 $x10^3$ km^2/station

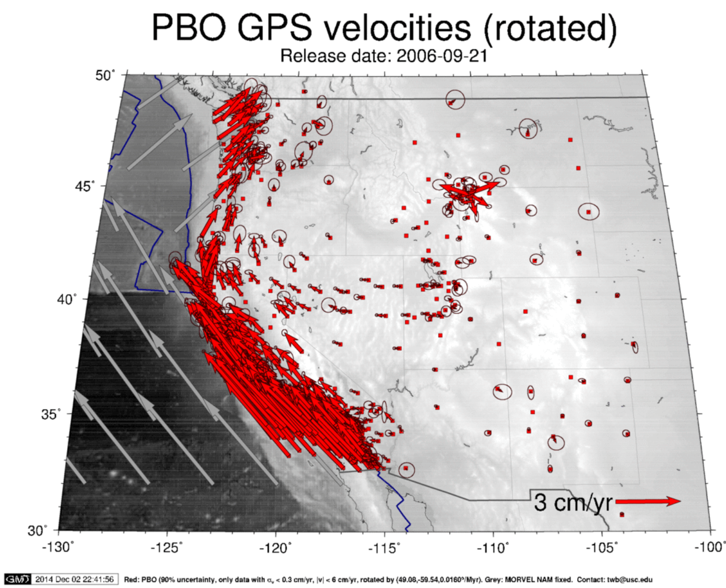
Mexico would need **300 - 2,900** stations to reach a comparable coverage density.

Increase sampling rate archived

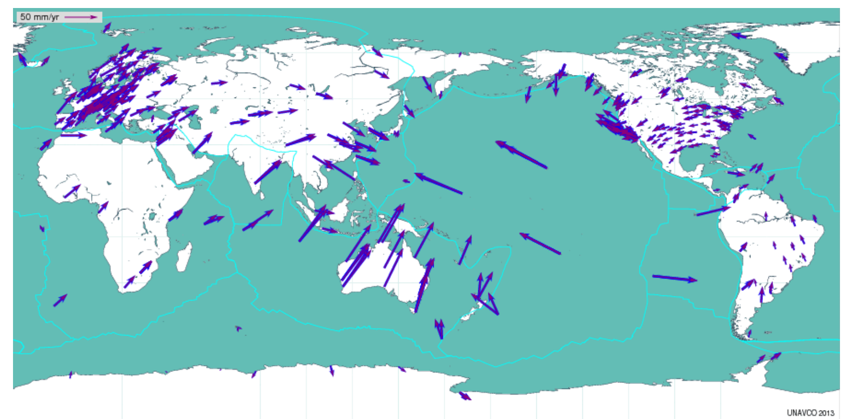
- Currently only 15 sec.
- Receiver capabilities can log @ 20Hz (**300x** more), but we only record @ 5Hz with on-demand scheme for large seismic events
- Only GPS constellation signals. No plans yet for full GNSS (GLONASS, Galileo, etc) constellations.
- Archiving 5Hz data + 3 GNSS constellation = **225x** increase in data holdings size from current levels

Why are geodetic data centers important?

- New realizations of global reference frameworks
- Reprocessing with new software versions (e.g. Gipsy 6.2 -> 6.3; decrease noise levels)
- Reprocessing for new orbits (e.g. no-fiducial -> no-net-rotation)
- Reprocessing globally distributed GPS stations needed every ~2 yrs.



Velocities of GPS sites in a North America fixed reference frame. (Credit: T. Becker.)



The International Terrestrial Reference Frame (ITRF) (Create your own maps on UNAVCO's Jules Verne Voyager.)

Global-wide reprocessing of GPS data holdings (decimated to 30 sec)

~10 million days of historic data

- 85,000 hours (8 months) CPU time @ 20 CPU's
- 1,440 hours (2 months) @ distributed high-throughput environment processing 45,000-100,000 station days.

+ QC solutions (also time consuming and in occasions an artesanal process)
+ value added products (time series plots, velocity maps, global strain maps etc)

Reprocessing entire Mexican GPS data holdings (decimated to 30 sec)

~180,000 days of historic data

- 40 seconds average processing time per daily Rinex file (@ 3GHz single CPU)
- 2020 hours (84+ days) of continuous CPU time to process the 182,000 Mexican non-INEGI Rinex files.
- 505 hours (21 +days) (@ 4 3GHz CPUs)

+ QC solutions (also time consuming and in occasions an artesanal process)
+ value added products (time series plots, velocity maps, global strain maps etc).

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Big Challenges for Mexican GPS data holdings

Scientific

- Fully operational needs, 24x7.
- No data-gaps desired in time series.
- GNSS is the cornerstone for many future-envisioned early-warning systems (e.g. seismogeodesy, Tsunami, space weather).

National infrastructure

- Early-adoption is not coded on Mexican (government) DNA?.
- GPS networks have become part of the national infrastructure in any country.
- Mexican federal agencies have yet to realize this situation.
- Several Early-warning systems are based on GPS-networks.

Technological

- If we want to take the next step into GPS densification, the last mile connectivity is a key-issue. Need fast high availability and low-latency connectivity.
- Our latest efforts are based on cellular data connections. OK for hourly/daily file downloads, real-time streams are less than optimal.
- Synergy with *México conectado*?.
- **CUDI should play a higher-profile role and serve as a link between science applications/ academia and the relevant federal government entities.**

Big Challenges for Mexican GPS data holdings (cont.)

Financial

- Aim for perpetual archiving.
- How to secure long term funding? ... CONACYT's legal framework imposes requirements but has no clear funding provisions yet.

Educational

- No formal training on best practices for Big Data curation and archiving.
- **Geoscience-IT opportunities ??.**

Historic value

- GPS observations can't be reproduced; time dependency.
- Geologic processes need very long time series for proper analysis or to lower uncertainty.

Are we a Big dysfunctional family?

- Group collaboration and data exchange has been hard to encourage.
- Still poor collaboration with applied and research IT areas.
- National (Mexican) repositories legislation geared towards "papers" rather than "data".
-
- Are they made for fiscal responsibility and transparency or for ethical purposes or for true science advancement?.
- Poor recognition in scientific performance reviews; maybe minting DOI's for data collections will help to overcome this situation?.
- Open data philosophy has still not permeated throughout many scientific activities.
- Very few examples of federal agencies with free and openly accessible repositories. CONACyT has no clear mandate for open data.
- Networking efforts within our communities may have been misguided. Should be not within own realm but with other areas.
- **Diversity should be our strength not our weakness.**

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Thanks so much for your attention