Networks for robust Civil Signal Performance Monitoring & RFI Detection

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Primary Goal: Situational Assessment of Threats to GPS Service

Threats include:

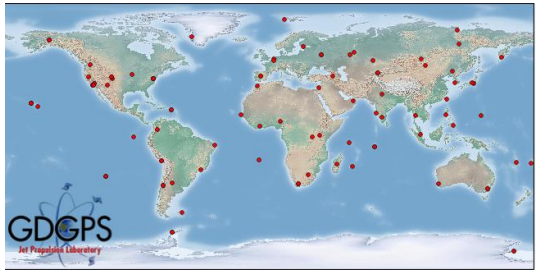
- Integrity failures
- Jamming
- spoofing (ranging signals and broadcast)

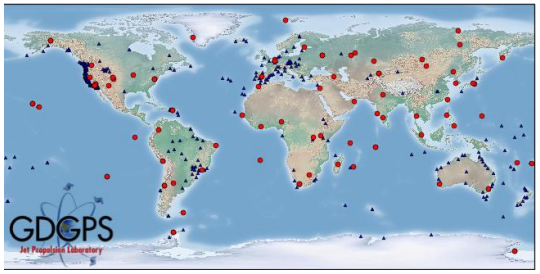
Approach:

- Use global and dense regional real-time monitoring networks ; exploit the inherent resiliency of GPS
- Apply classical and novel monitoring techniques; big data mining

Beneficiaries:

- Responsible agencies (for example, DHS, DOT)
- Connected users (for example, power grids, communications grids)



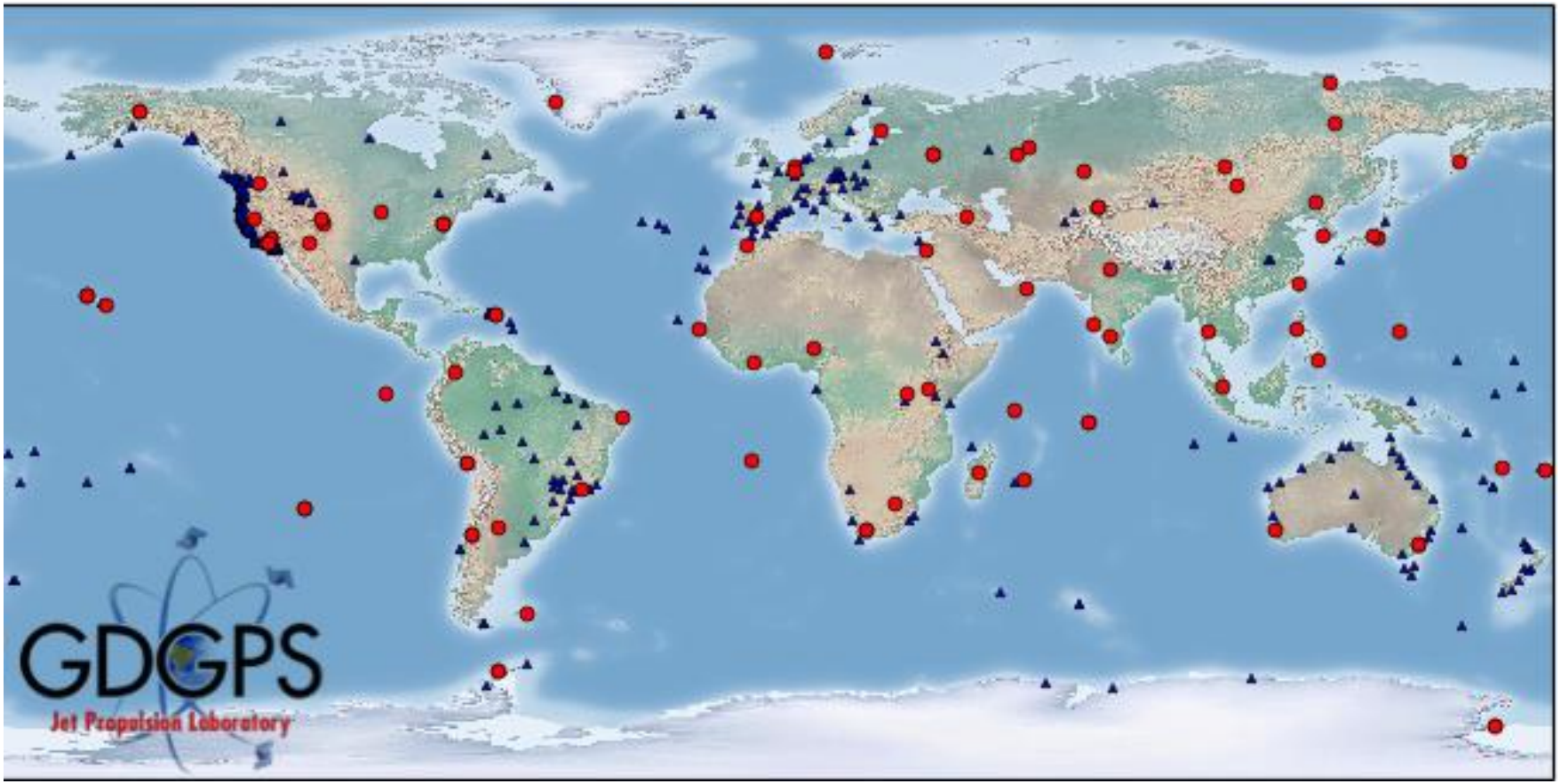


The Foundation: Extremely Redundant Global Real-Time Tracking Network

80+ global tracking sites deployed, controlled, operated, and maintained by JPL's GDGPS System

- Hardware and software fully owned and controlled by JPL
- Decades of site stability, quality, and continuity
- **20-fold** observation redundancy enable strong majority voting schemes

Hundreds of contributed sites operated by a variety of partners, U.S. and foreign agencies (e.g., NSF, BKG, GA) provide additional level of redundancy and density of coverage

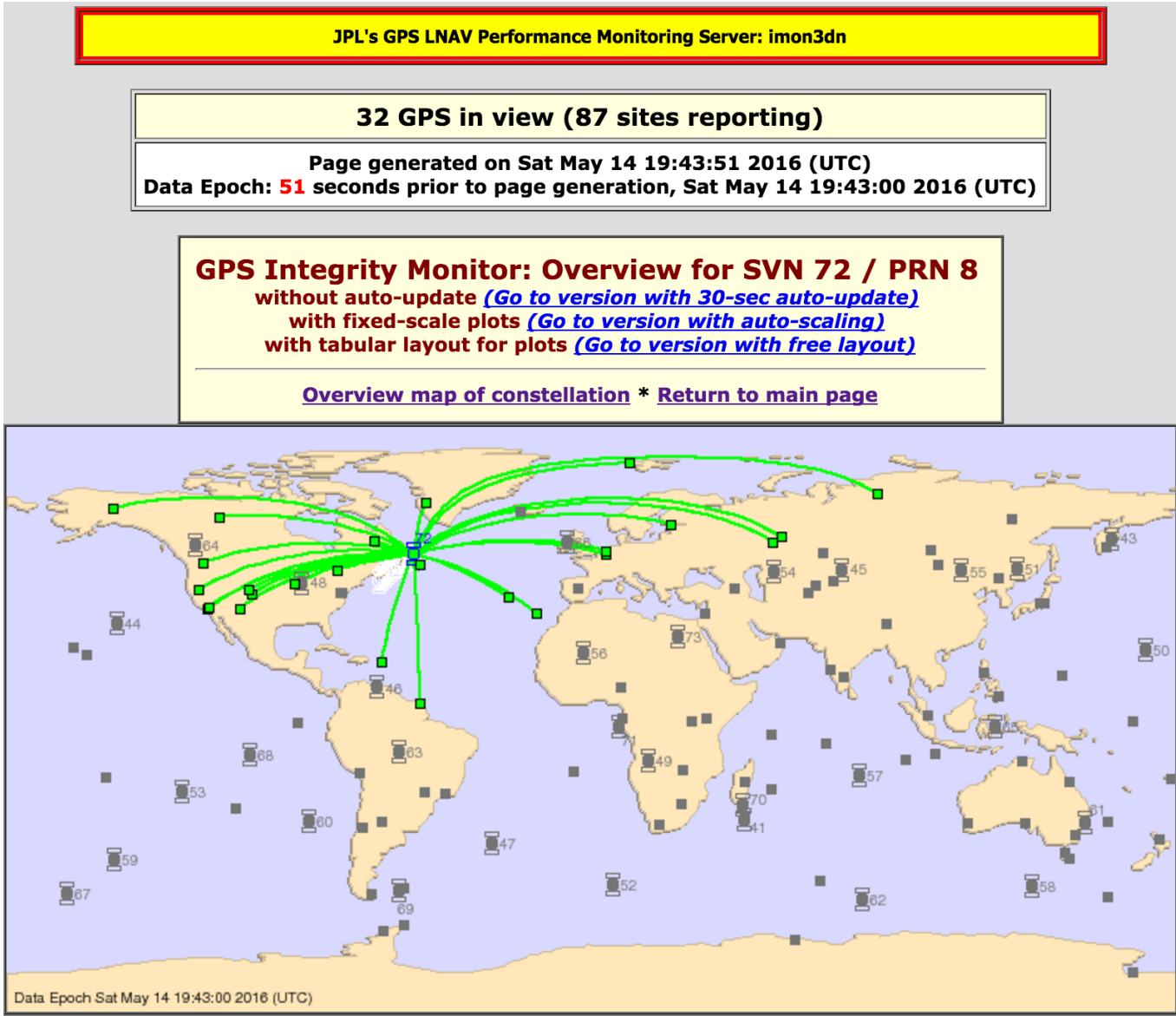


Large Footprint of GPS Satellite Signals is key to Resiliency of the GDGPS System

Flying at 20,000 km altitude, GPS satellites are viewed from a very large geographical area

- To spoof GDGPS one has to spoof many sites across multiple continents

- A live demonstration of the GDGPS System resilience to spoofing was successfully carried out for the U.S. Air Force during the early phase of the OCX project



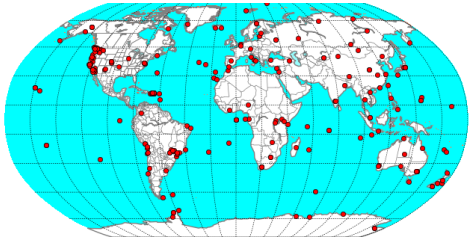
Screenshot of GDGPS CNAV monitoring website for 2SOPS

Reliable and Accurate Orbit Determination Operation Enables Integrity Monitoring

Robust architecture extends beyond the tracking network

- Redundancy extends to data hubs, computers, processes, communication channels, customer access points
- Automatic quality control and fail-over mechanism for all processes and products

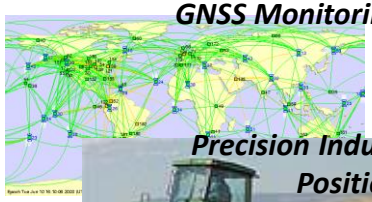
Real-Time Tracking Network (200+ sites)



Measurements

Triple Hot Redundant Operation Centers

Products, Services



Fundamental products should be unimpeachable:

- Real-time orbit and clock states (Currently being performed by GDGPS with RTGx, the OCX navigation software)
- Real-time navigation message (majority voted)

Real-time integrity monitoring (and augmentation) can now be performed

Integrity Monitoring on a Global Scale

Globally uniform performance metrics for the first tier situational assessment for GPS service

- Signal quality
- Broadcast ephemeris correctness
- Broadcast ephemeris accuracy

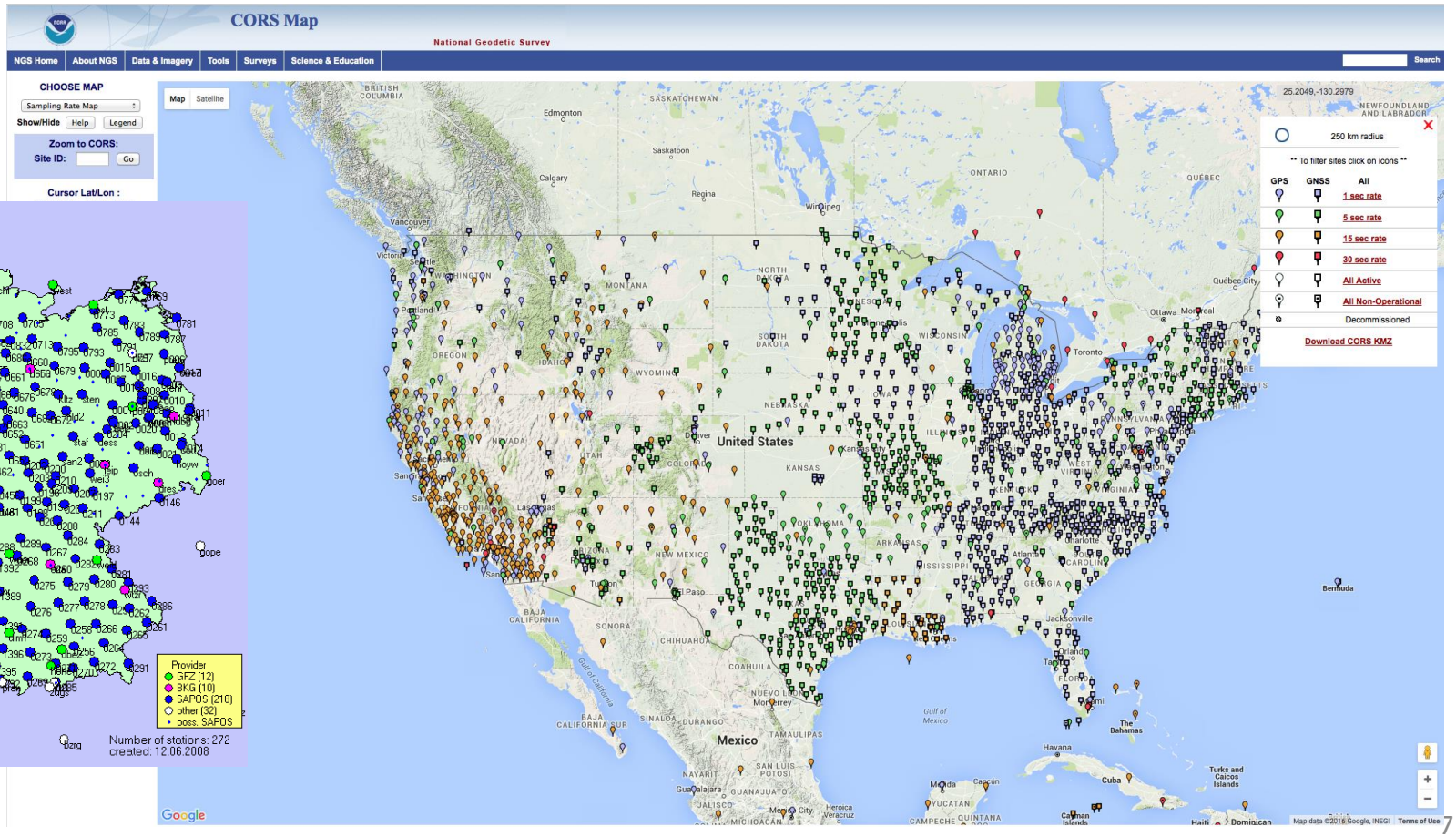
The UTC broadcast error of January 26, 2016 would have been caught within 1 min by GDGPS, had we been commissioned to perform full Civil Signal Monitoring

SERIAL #	REQ. #	SUB-REQ. #	REQUIREMENT	SOURCE NAME	SOURCE SECTION	REQ. CLASS	DIFFICULTY
	3.2.4.0	-	**Verification of Navigation Message** **Detection-time requirement: within 1 minute following transmission**				
	3.2.4.1	-	Verification of L1 C/A Navigation Message				
85	3.2.4.1	a	Verify the GPS time scale is within one microsecond of the Coordinated Universal Time (UTC) when adjusted by the leap second correction.	IS-GPS-200	3.3.4	NAV	E
96	3.2.4.1	l	Verify that UTC parameters are correctly set as specified in IS-GPS-200.	IS-GPS-200	20.3.3.5.2.4	NAV	E
97	3.2.4.1	m	Verify that the absolute value of the difference between the untruncated week number (WN) and truncated leap second week number (WNt) values does not exceed 127 when ΔtLS and ΔtLSF differ.	IS-GPS-200	20.3.3.5.2.4	NAV	E
98	3.2.4.1	n	Verify that the reference time for UTC is correctly set.	IS-GPS-200	20.3.3.5.2.4	NAV	E
99	3.2.4.1	o	Verify that the UTC parameters provided via L1 C/A navigation message are updated by the Control Segment at least once every 6 days.	IS-GPS-200	20.3.3.5.1.6	NAV	E

Monitoring Jamming and Spoofing Require Dense Local Networks

Dense CORS networks in the U.S., Europe, Japan, and elsewhere offer wealth of high-quality data that can be mined for situational assessment of *user experience*

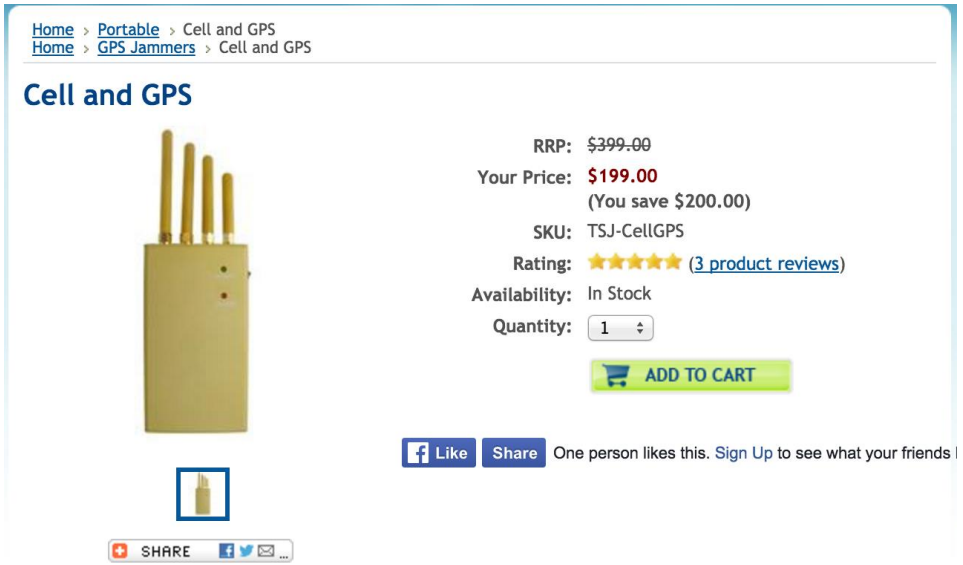
- Many already provide real-time streaming measurements; some upgrades may be needed
- Sites are static with locations known to millimeters
- Patterns of tracking performance can be well-characterized
- GDGPS currently monitors hundreds of U.S. and global sites for earthquake detection



Jamming and Spoofing Situational Assessment

Jamming situational assessment:

- Monitor SNR and available satellite signals, and correlate data geographically
- In densely covered area it may be possible to locate the jammer using time-of-arrival measurements and other techniques
- Thousands of sites can be centrally-monitored to provide a coherent, consistent situational assessment on a national scale



Spoofing situational assessment:

- Verify received navigation message to detect ephemeris spoofing (either by RF or IP)
- Compare link SNRs against established patterns to detect spoofing
- Perform positioning and compare to mm-accurate database; correlate patterns locally

In-situ data processing can reduce outgoing data to position solutions and SNR only, facilitating cost-effective communications

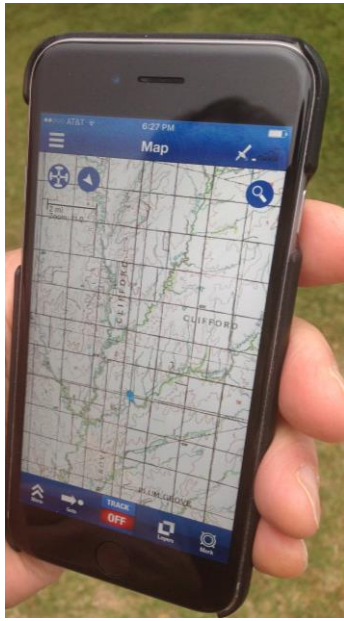
Investigate Crowd Sourcing and Big-Data Mining for the Ultimate RFI Situational Awareness

Millions of GPS receivers are connected via mobile wireless devices, and a massive amount of data could be mined for RFI situational assessment

Key GPS tracking metrics, such and SNR are typically available to the application layer, and can be retrieved by Apps or by the lower level OS

Central processing can receive data directly from the App, or via the A-GPS providers, E-911 service providers, wireless carriers, location service providers

Many technical challenges for effective data mining: chipset performance variability, antenna performance depends on orientation, obstructions,…



However, attempts to mine positioning data from mobile devices show initial promise

- For example, USGS crowdsourcing earthquake early warning (Minson et al,. Sci. Adv. 2015;1:e1500036 10 April 2015)

RESEARCH ARTICLE

GEOPHYSICS

Crowdsourced earthquake early warning

Sarah E. Minson,[1,2] Benjamin A. Brooks,[1]* Craig L. Glennie,[3] Jessica R. Murray,[1] John O. Langbein,[1] Susan E. Owen,[4] Thomas H. Heaton,[2] Robert A. Iannucci,[5] Darren L. Hauser[3]

10.1126/sciadv.1500036

Conclusions

***Existing* GPS tracking networks, technologies, and operational capabilities enable effective and low cost GPS integrity monitoring and RFI situational assessment**

- Existing and proven GDGPS system can provide a low-cost monitoring, to complement its current and anticipated civil signal monitoring services

Explore innovative big-data mining approaches to crowd-source GPS tracking metrics from millions of mobile wireless devices for high resolution assessment of threats to GPS service

Consider installing reference sites near sensitive areas such as airports

GPS situational assessment capabilities can be extended to other GNSS constellations, reference networks are being upgraded to track all GNSS

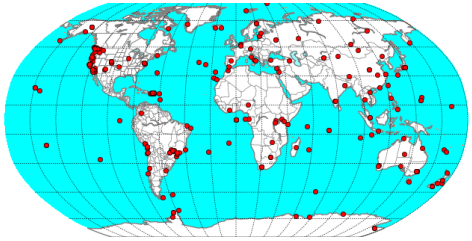
- JPL's GDGPS System already tracks and monitors GLONASS, BeiDou, and Galileo on a global scale

The Global Differential GPS (*GDGPS*) System

Providing mission-critical, real-time services, 24/7, since 2000

Full GNSS capabilities: GPS, GLONASS, BeiDou, Galileo

Real-Time Tracking Network (200+ sites)



Measurements

Triple Hot Redundant Operation Centers

Products, Services

GNSS Monitoring

Precision Industrial Positioning

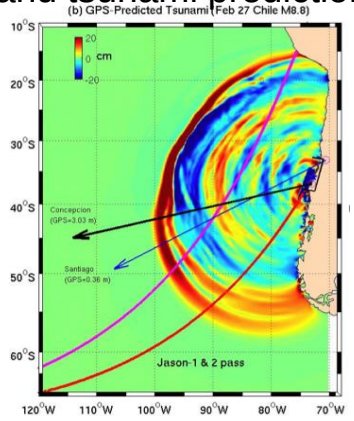
Personal Geolocation

Prototype system and testbed for Next Generation GPS Control Segment (OCX)

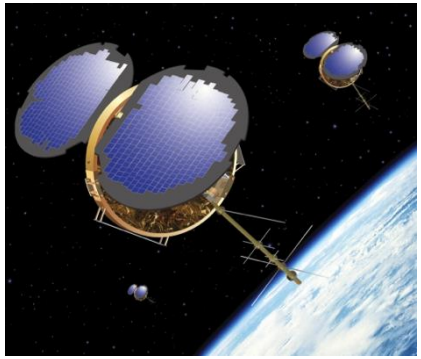
Time-critical environmental monitoring services

Repeat path interferometry with UAV-SAR

Earthquake monitoring and tsunami prediction



GNSS navigation data for Radio Occultations



Space weather monitoring