NASA

software of the year

AWARD

IGDG

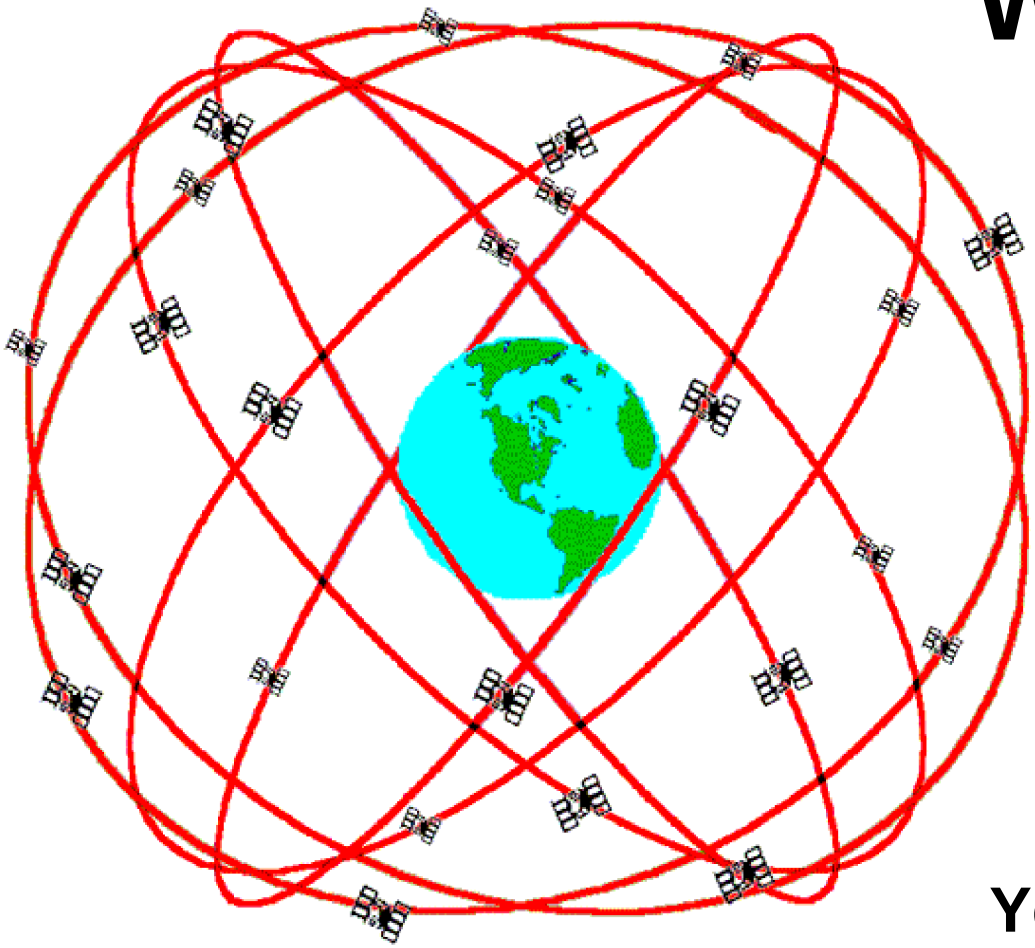
Internet-based Global Differential GPS

http://gipsy.jpl.nasa.gov/igdg

Overview of Talk

- What is this GPS stuff anyway ?
- GPS is good.
  - SA (selective availability) turned off 5/2/00
- But Differential GPS is better.
- And Global Differential GPS really good.
  - JPL's background in GPS and DGPS
  - Current world-wide capabilities
  - Future plans

What is GPS ?



GPS Nominal Constellation
24 Satellites in 6 Orbital Planes
4 Satellites in each Plane
20,200 km Altitudes, 55 Degree Inclination

Funded by U.S. DOD

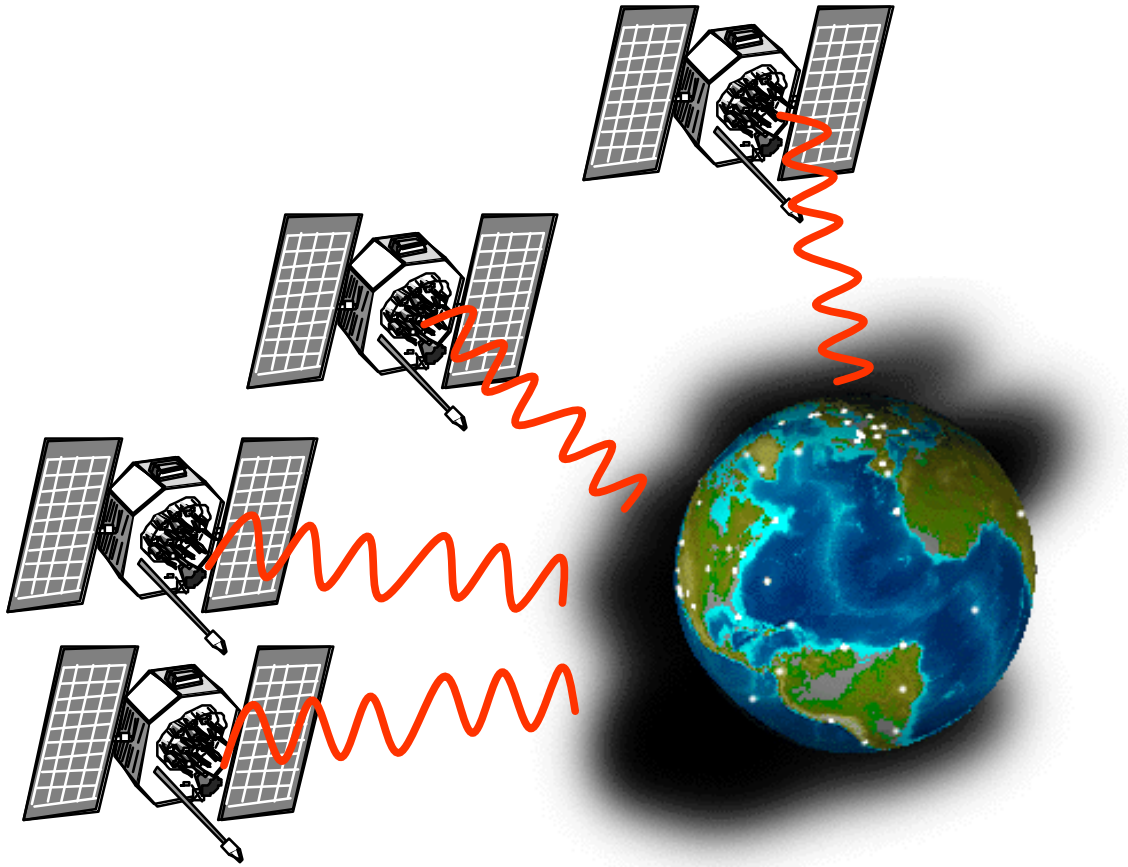
Operated by USAF at Schriever AFB in Colorado Springs

Yet thousands of civilian applications with millions of world-wide users !

http://www.colorado.Edu/geography/gcraft/notes/gps/gps.html

GPS Primer

User observes (at least) 4 measurements and solves for position (xyz) and time (t)

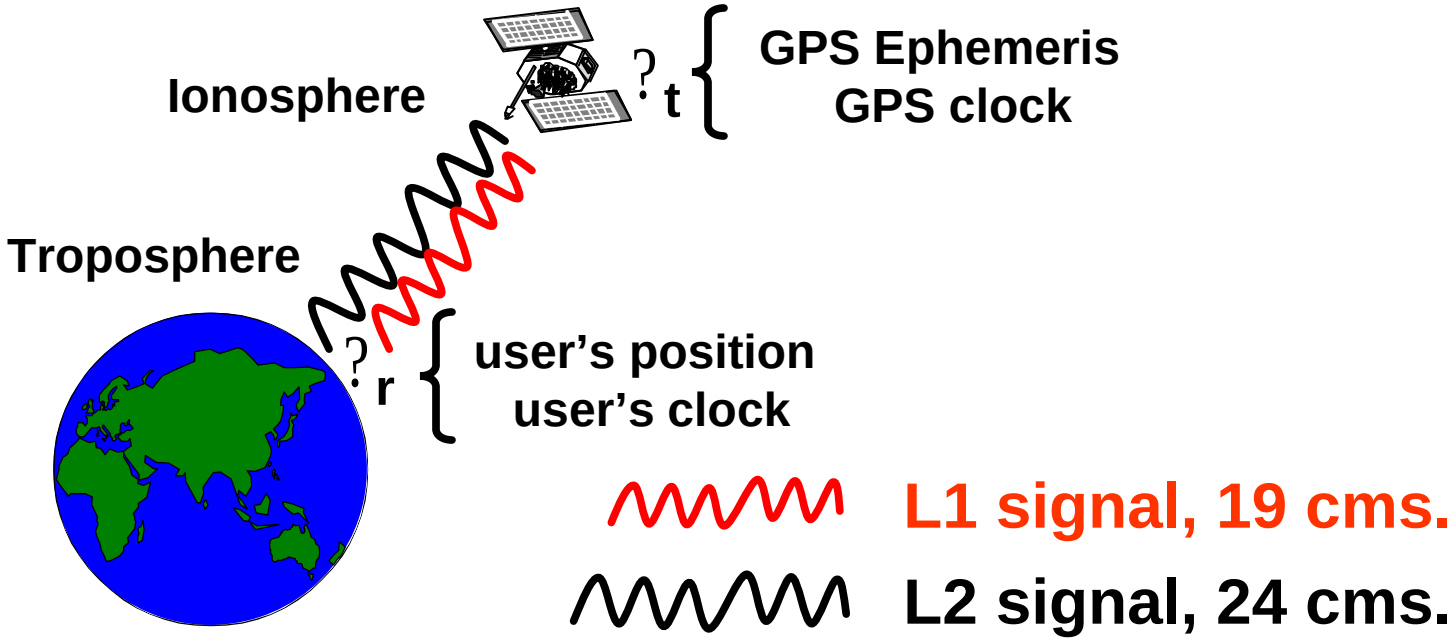


http://www.aero.org/publications/GPSPRIMER/

User Error Sources

$$R = c(?_r - ?_t) + Trop + Iono + ?_{big}$$

$$? = c(?_r - ?_t) + Trop - Iono + Bias + ?_{small}$$



Stand Alone GPS is Good

- **SA GPS clock dithering (~25 meters) turned off 5/2/00, 9:05 PM local time**

It's rare that someone can press a button and make something you own instantly more valuable, but that's exactly what's going to happen today. All the people who bought a GPS receiver (…) are going to find that they're suddenly 10 times more accurate as of midnight tonight.
- Dr. Neal Lane, Director of the Office of Science and Technology

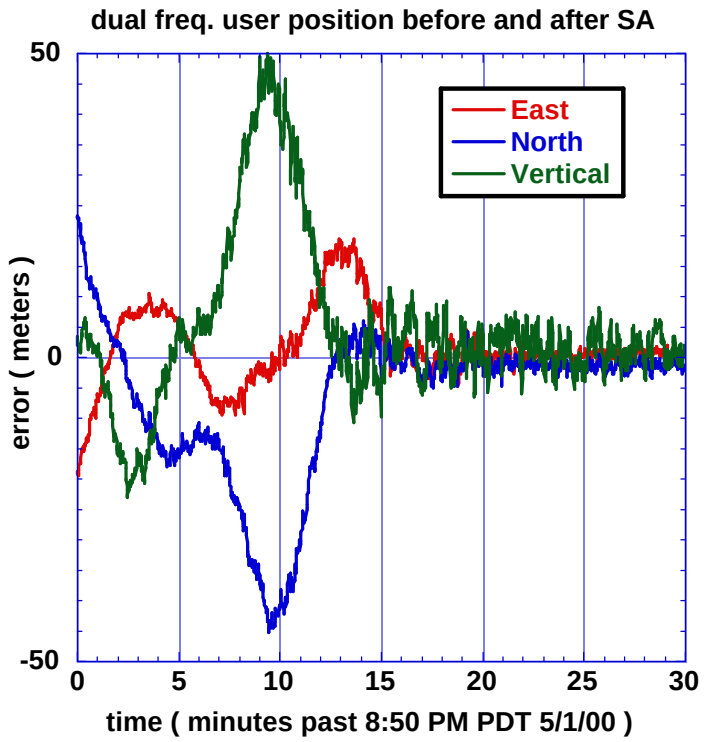
- **Winners**
  - **folks who bought receivers from K-mart**
- **Losers**
  - **differential GPS providers**

After SA Off

rms. accuracy of stand alone GPS receivers

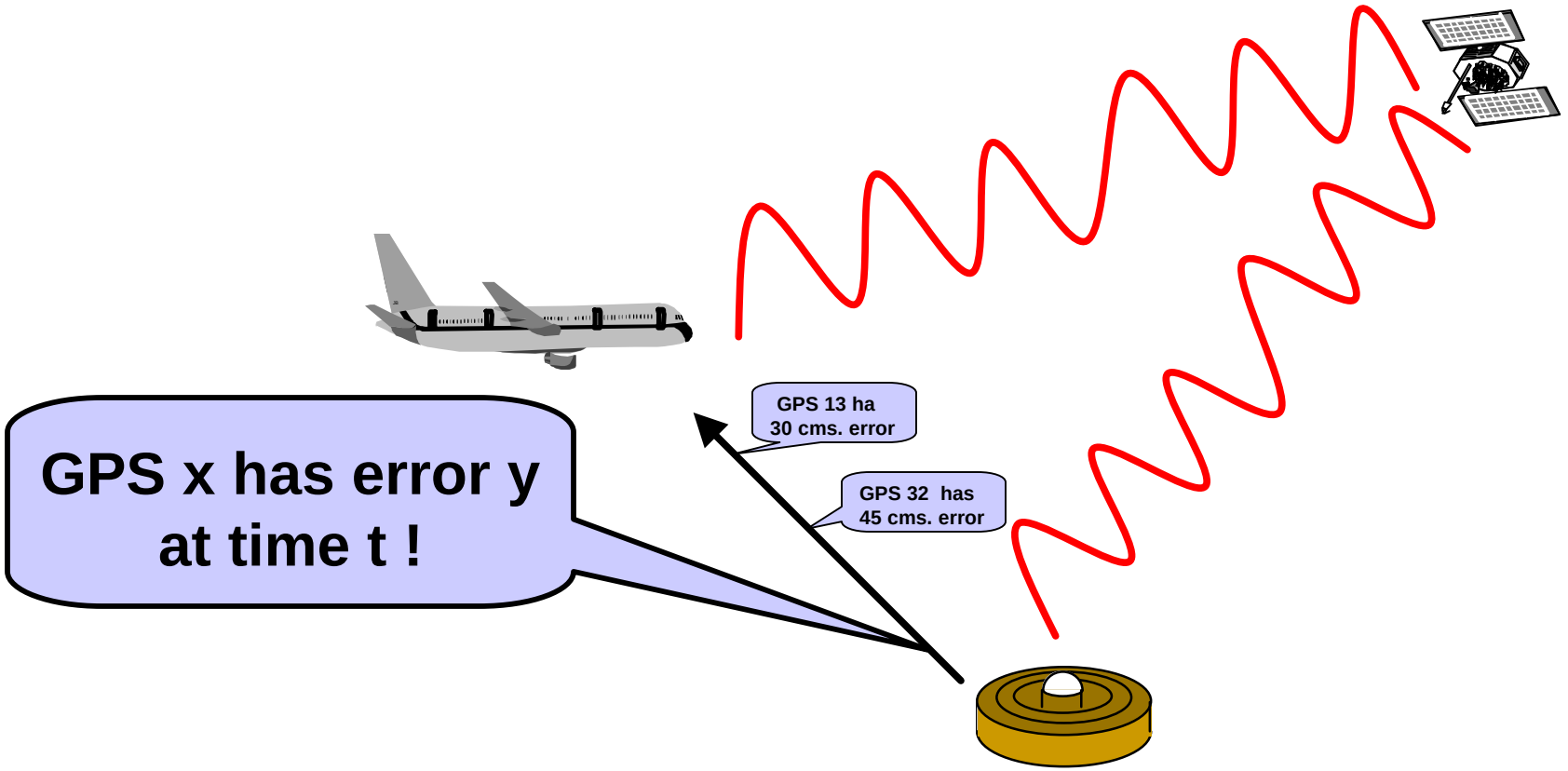
- **single frequency**
  - 1-5 meters horizontal
  - 10-25 meters vertical
- **dual frequency**
  - 1-2 meters horizontal
  - 3-4 meters vertical

- **dual freq. w/ SA on**
  - 15-20 m. horizontal
  - 40-50 meters vertical



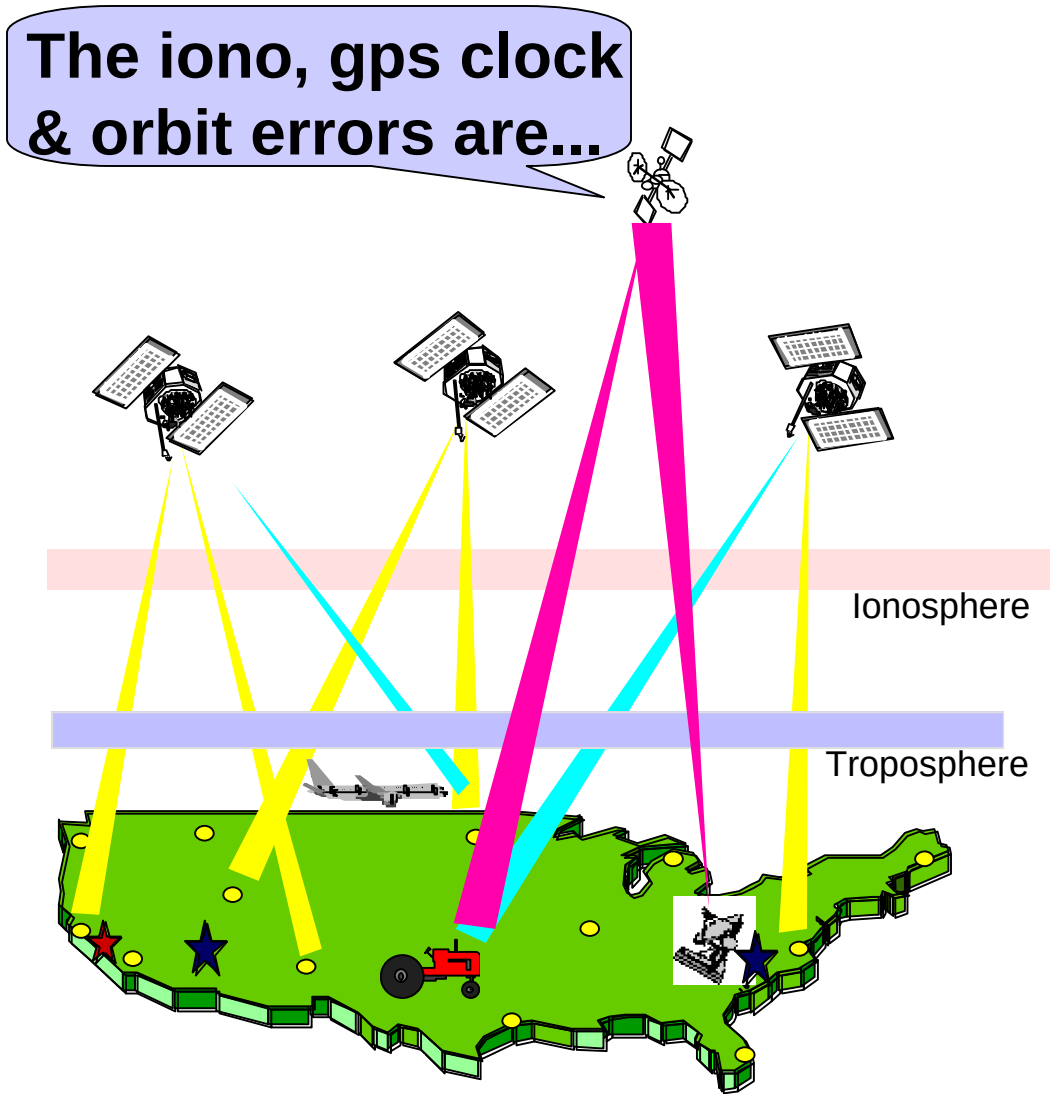
Differential GPS is Better

Accuracy of measurement domain differential degrades as distance from the reference receiver(s) increases



static antenna at known location

WADGPS One Step Better



State-space approach using a network of reference receivers to solve for error sources.

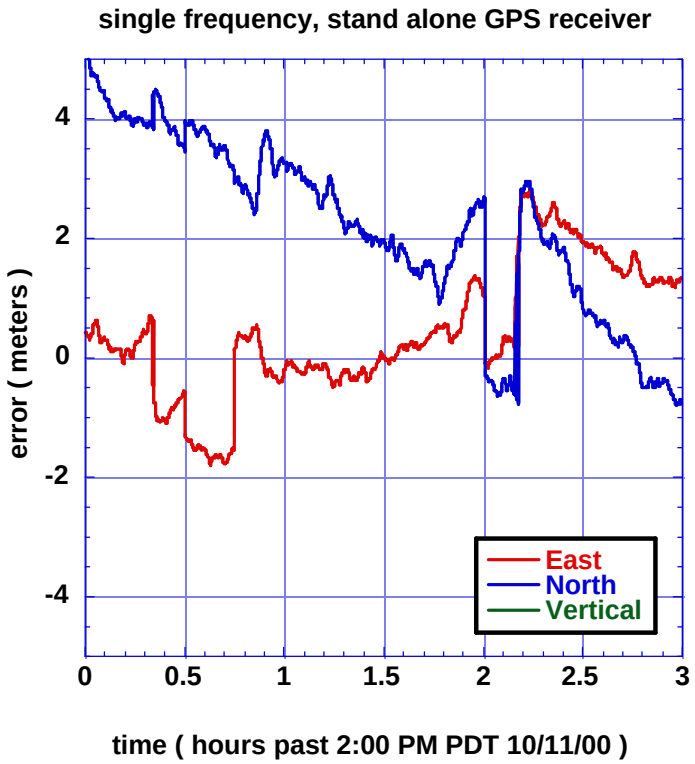
Accuracy independent of distance from a particular reference receiver.

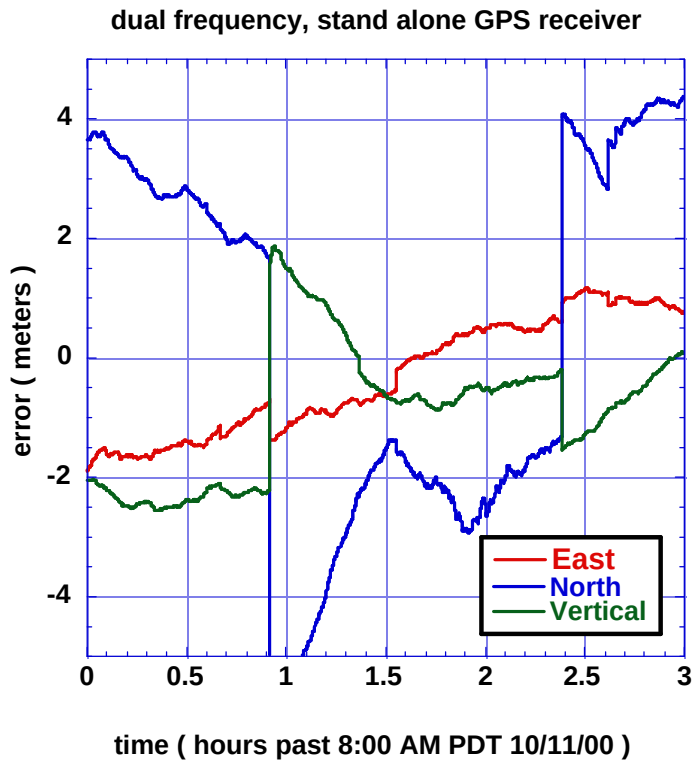
For Example:

Same signal, split 5 different ways

- **Single frequency, stand alone**
- **Dual frequency, stand alone**
- **DGPS, measurement domain**
- **WADGPS, state-space domain**
- **IGDG, Global Differential GPS**

Stand Alone Receivers



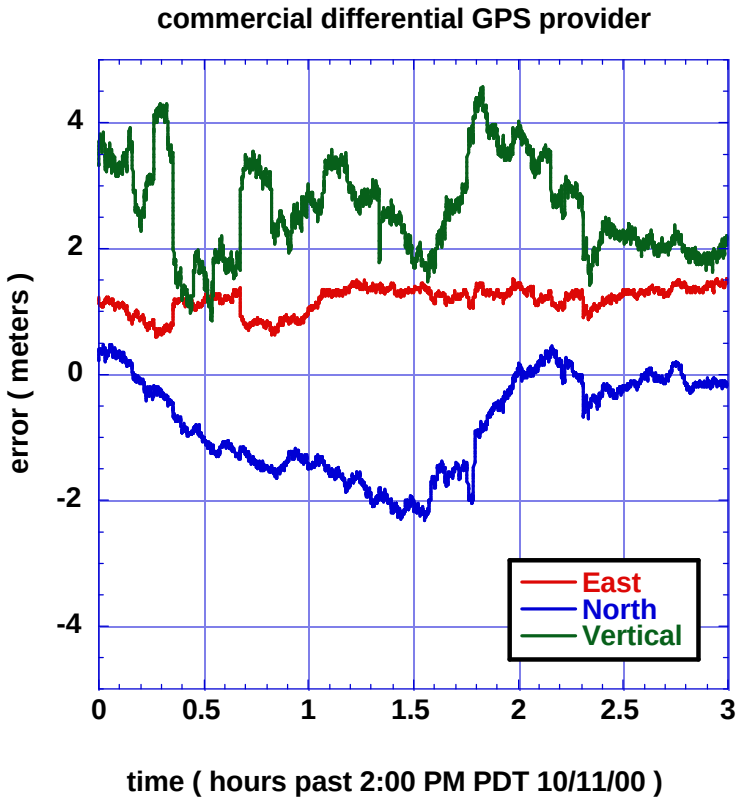


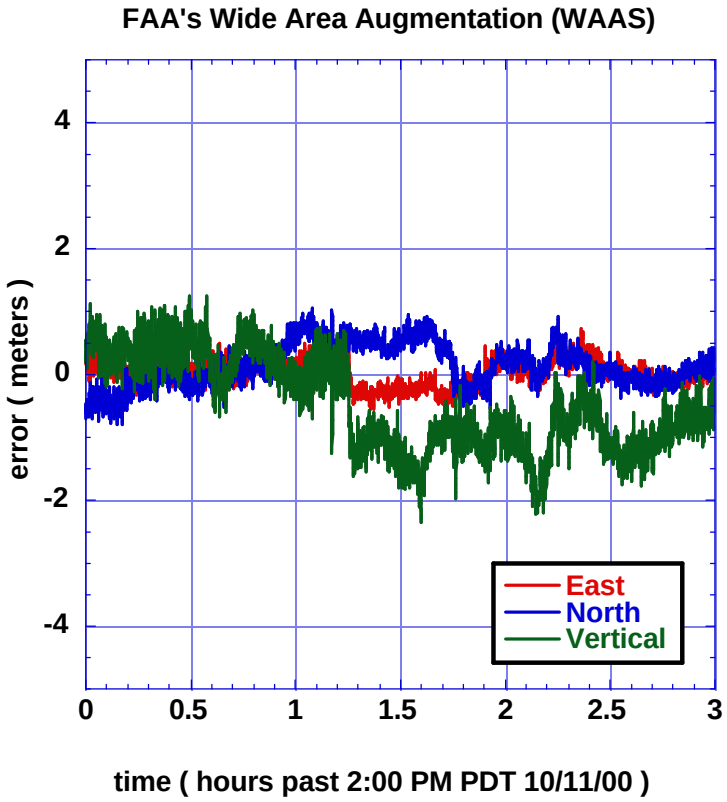
rms. accuracies

East	1.2 m
North	2.6 m
Vertical	23.6 m

East	1.5 m
North	1.0 m
Vertical	3.2 m

DGPS and WADGPS



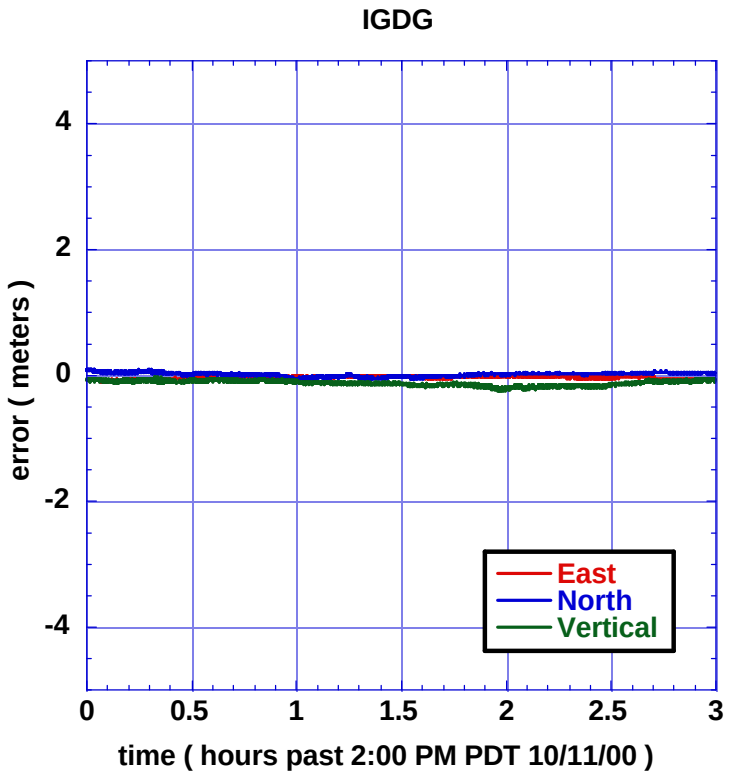


rms. accuracies

East	1.2 m
North	1.1 m
Vertical	2.8 m

East	0.2 m
North	0.4 m
Vertical	0.9 m

Global Differential GPS



rms. accuracy

East	4 cms
North	4 cms
Vertical	13 cms

Why is accuracy better ?

- always observing GPS s/c
  - –no rise/set events
- we're really-really good at GPS orbit determination

How We Got There

- **1995 white paper on WADGGPS**
- **1996 provide core s/w for Satloc's WADGPS services**

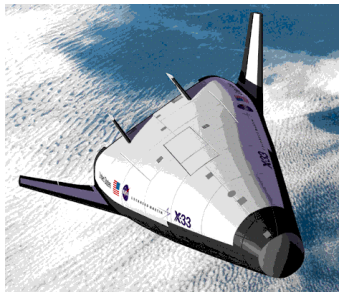
Demonstrated 30-40 cms rms. horizontal and sub 50 cms rms. vertical accuracy

- **1996 prototype for FAA's WAAS**
  - **Software licensed by Raytheon**
  - **Sole means of airplane navigation in year 2003 (?)**
  - **Clones of system licensed for Japan's MSAS,...**

Enabling Software, part 1

- **rtg (real-time GIPSY)**
  - **Contains state-of-the-art models**

    http://gipsy.jpl.nasa.gov/igdg/system/od/index.html



—Can be embedded in real-time user equipment

- **VxWorks**

But we need data too

- Data was provide to us by Satloc
- Use existing JPL owned and operated global GPS receivers
  - Code based on DC-8 flight code
- Use the open Internet
  - Better long term reliability w/ open Internet through redundancy
  - Its FREE !
- TCP vs. UDP

Enabling Software, part 2

- **rtnt (real-time Net Transfer)**

  Input data

  – Interfaces w/ receiver and edits data locally

  – Compresses GPS data

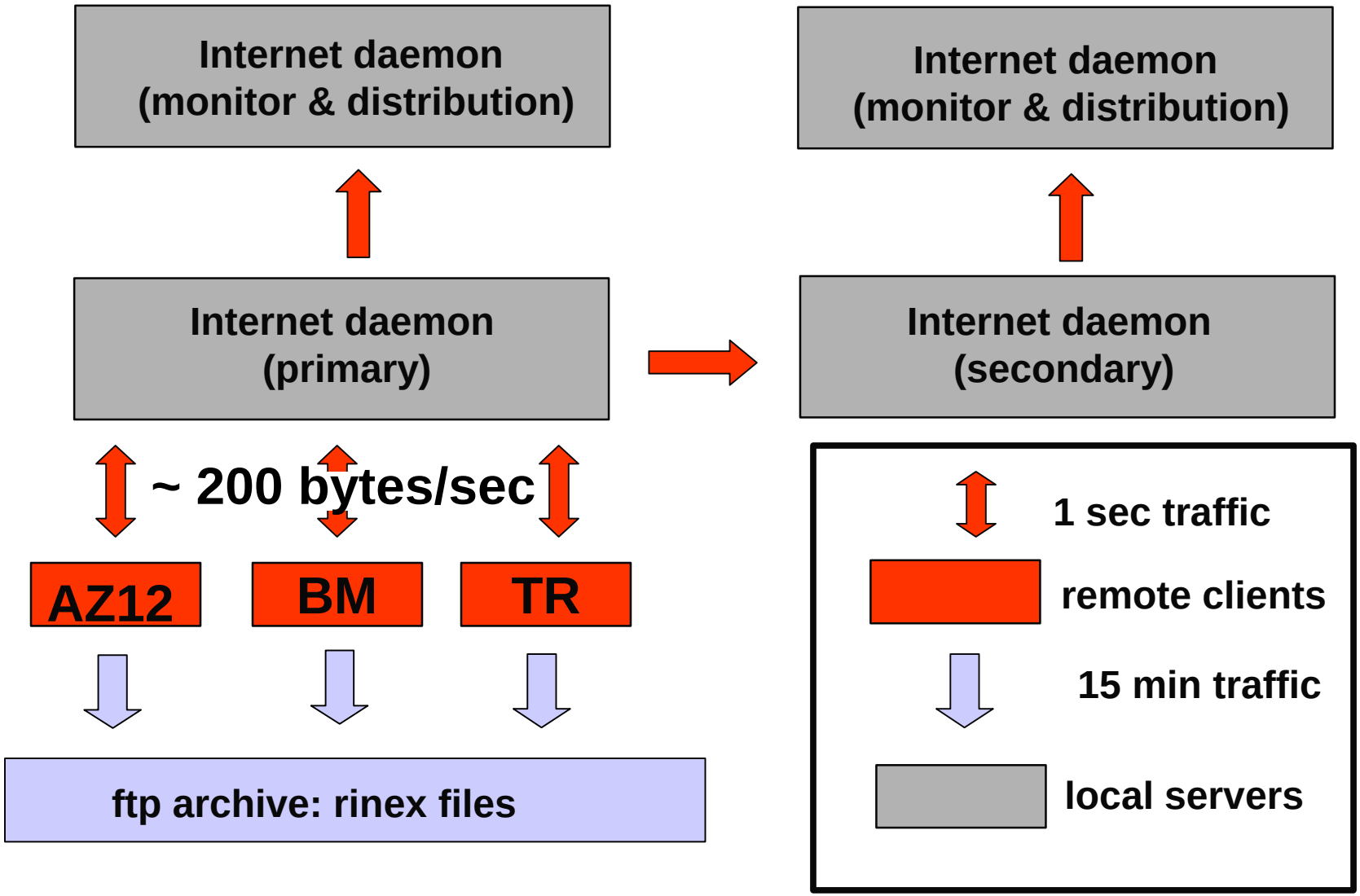
    - **Data resolution supports LEO atmospheric occultations**

  – Returns data at 1 Hertz over open Internet

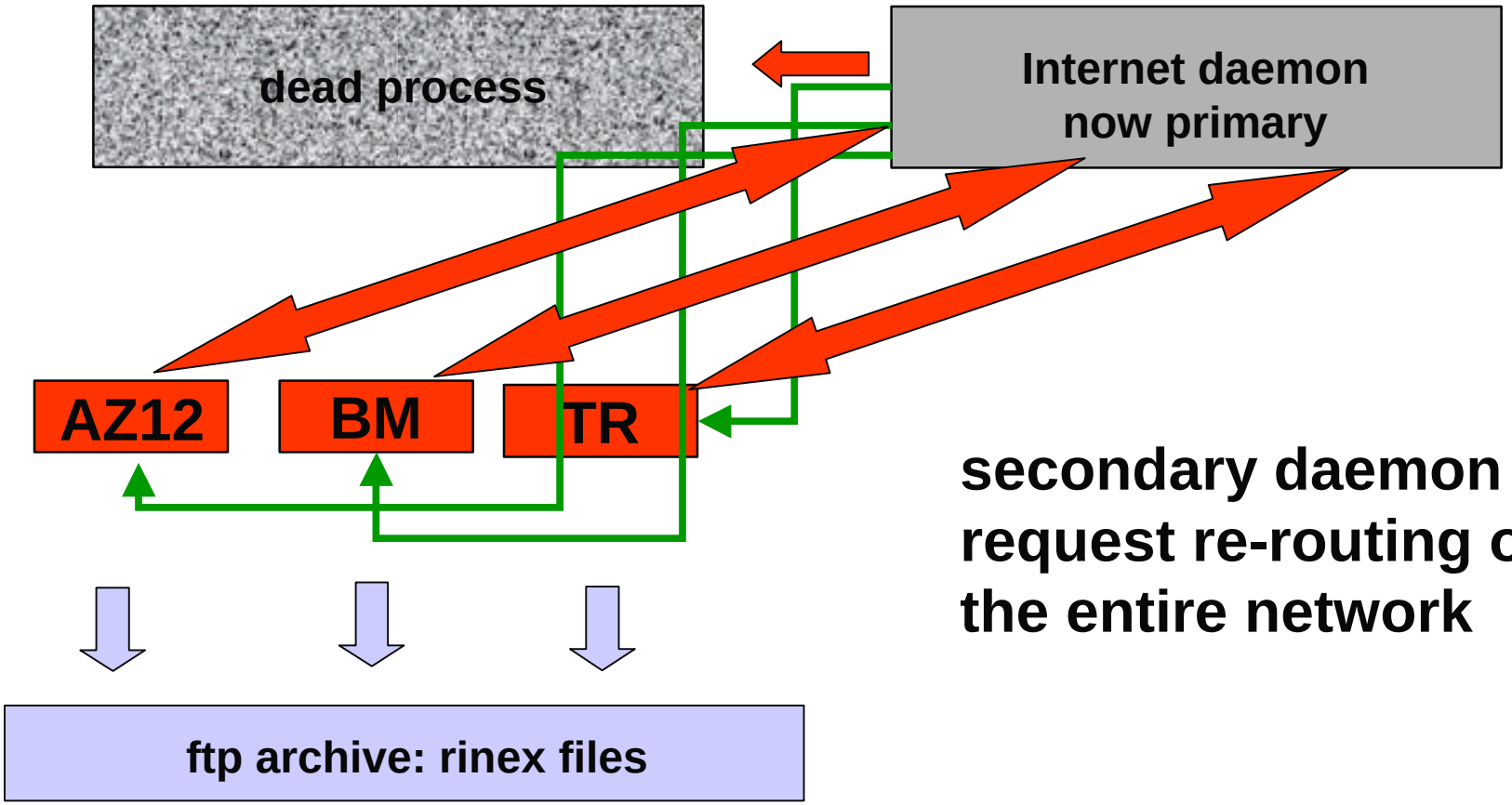
  Output estimates

  – Provides users with differential corrections

Overview of rtnt

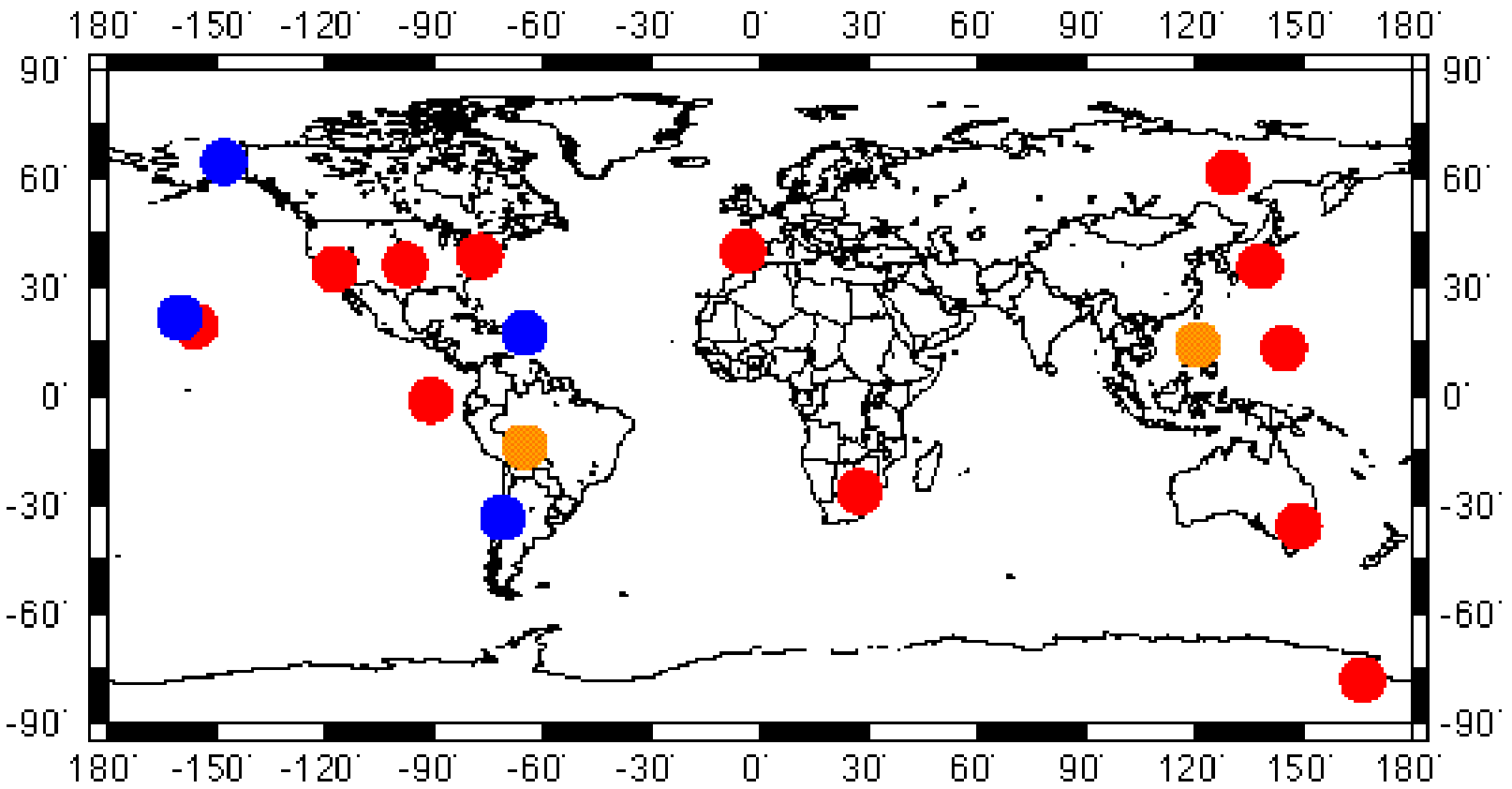


Backup Server Operations



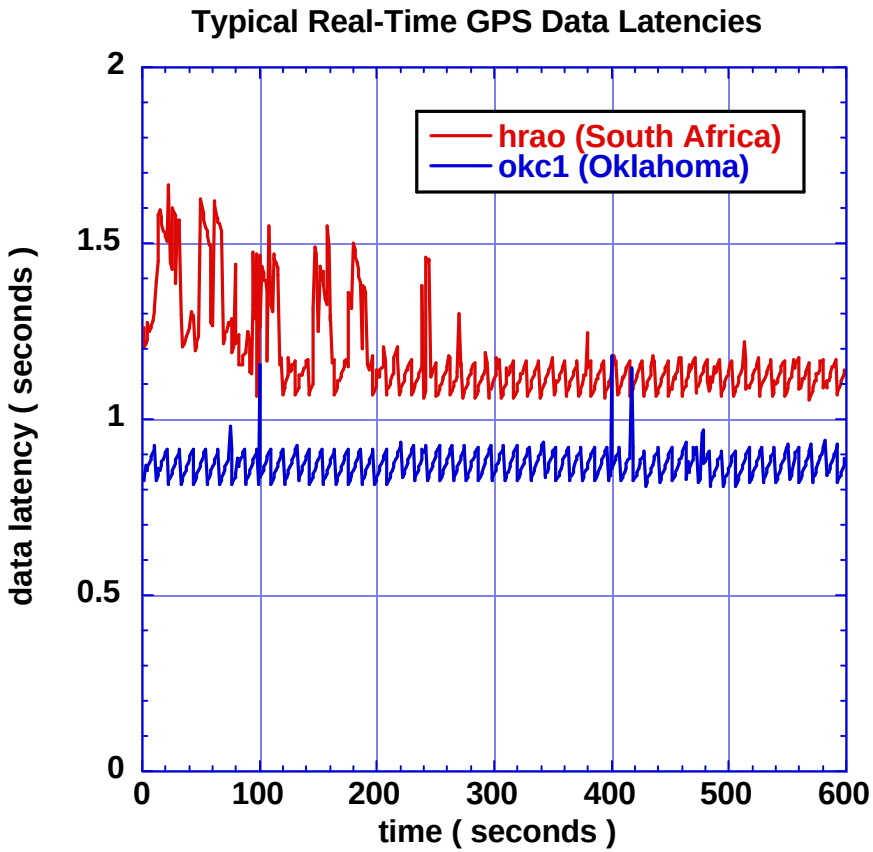
secondary daemon may request re-routing of the entire network

Current Global Network



AOA Benchmarks Turbo-Rogues Ashtech Z-12s

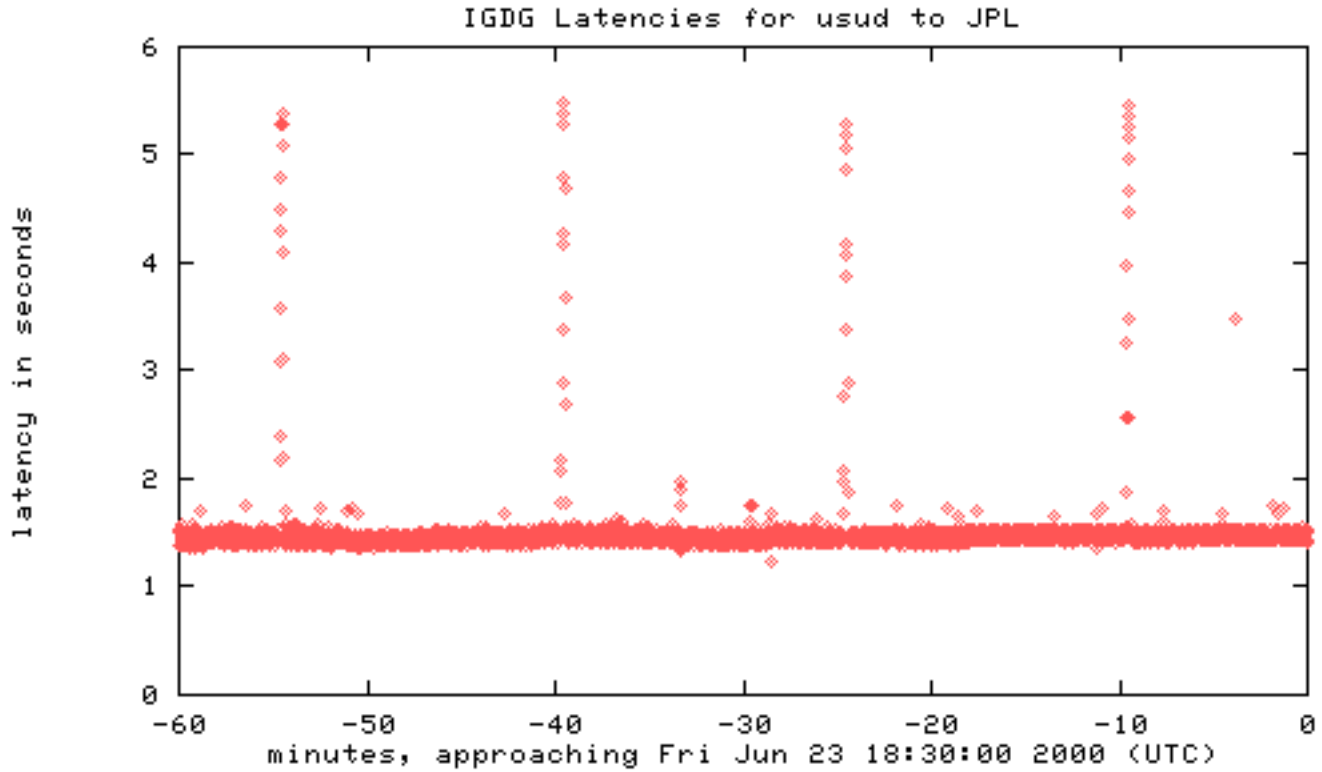
Data Latencies



6 Hour Philippines Test (Worst Case)

< 2 sec 93.4%
< 3 sec 97.0%
< 4 sec 97.7%
< 5 sec 97.9%
< 6 sec 98.0%

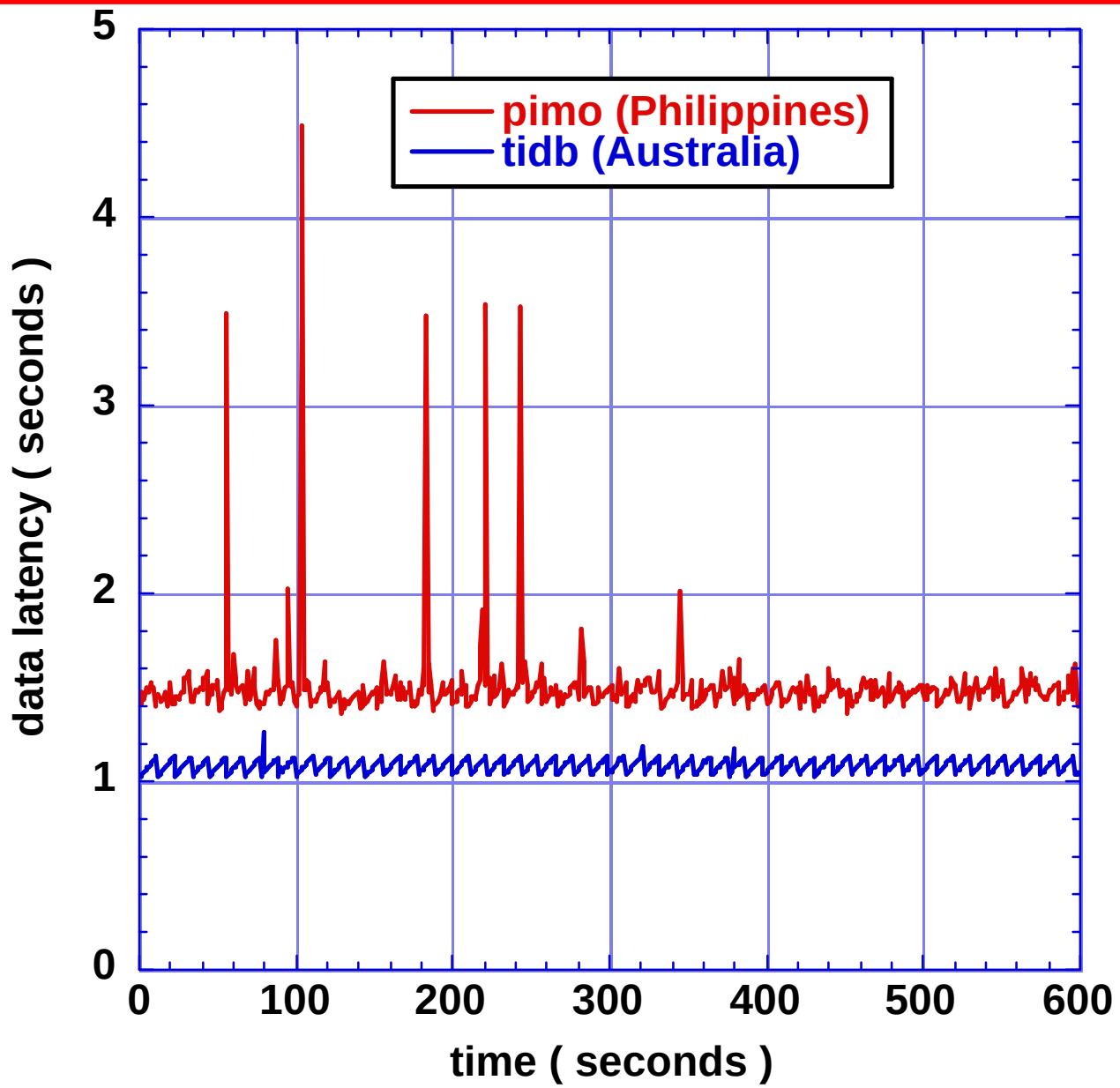
Data Latencies



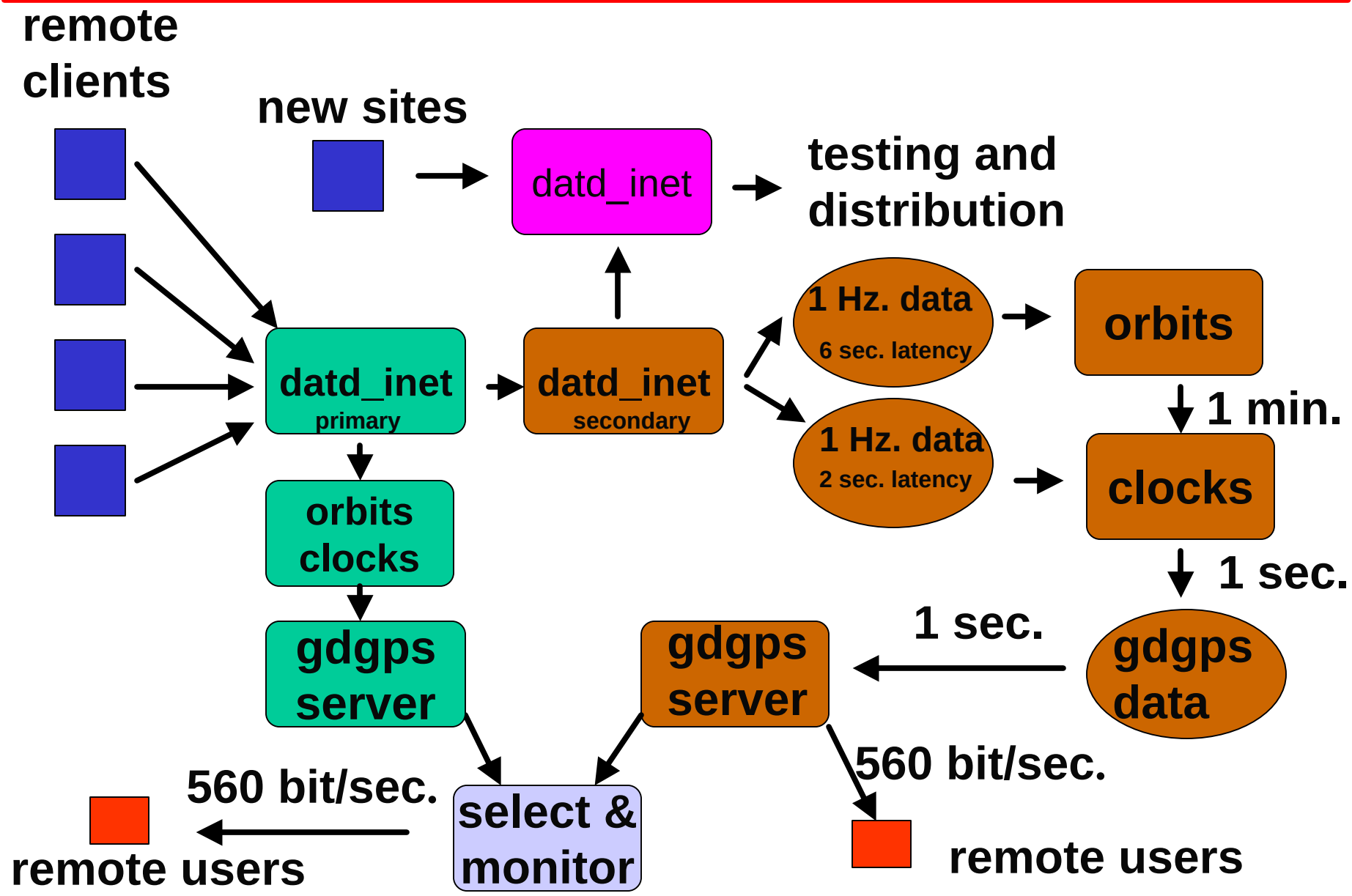
from IGDG Network Montior:

http://gipsy.jpl.nasa.gov/igdg/demo/index.html

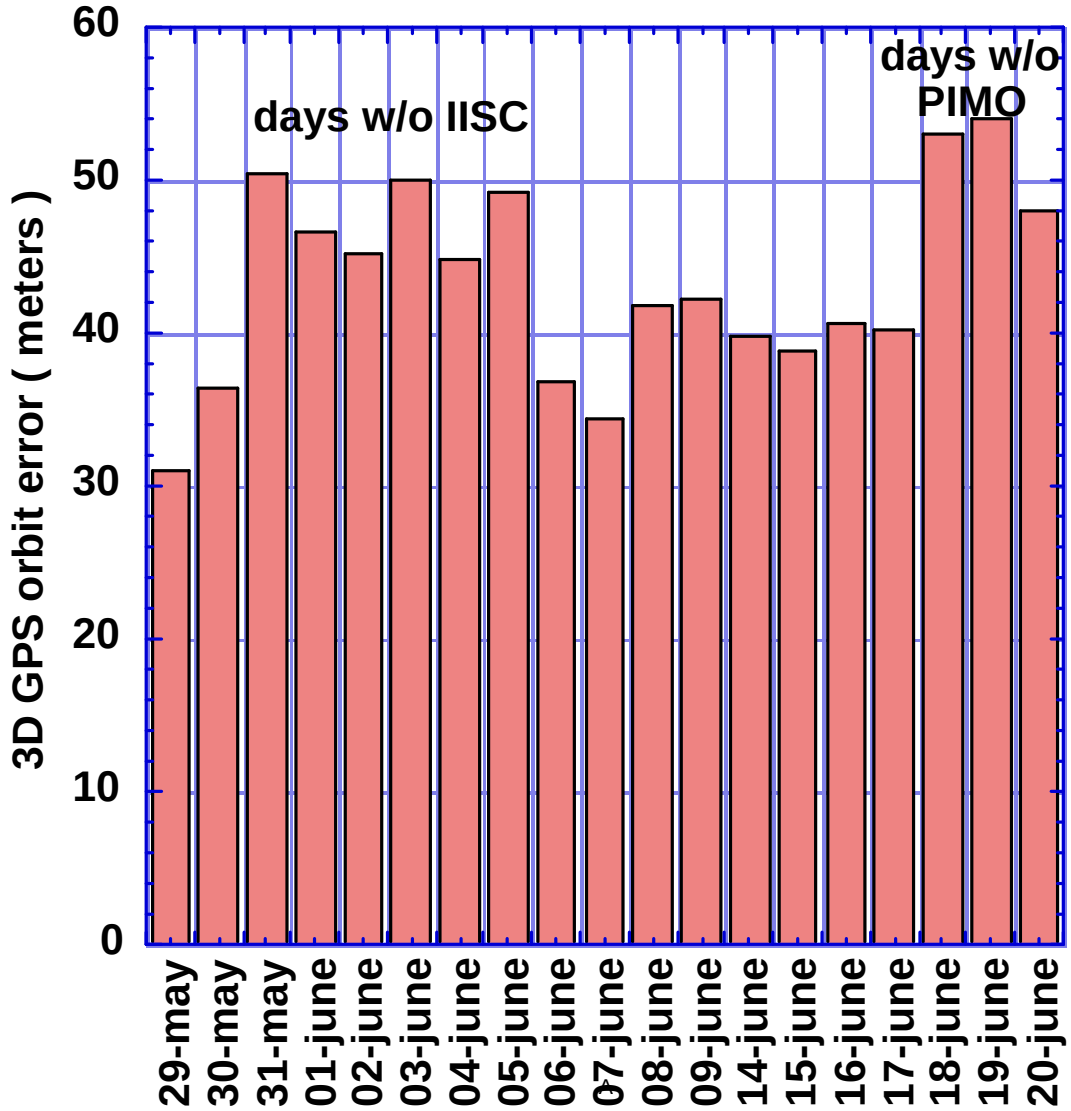
Typical Real-Time GPS Data Latencies



s/w overview


remote clients
new sites
datd_inet
testing and distribution
1 Hz. data
6 sec. latency
orbits
1 min.
datd_inet
primary
datd_inet
secondary
1 Hz. data
2 sec. latency
clocks
1 sec.
orbits clocks
gdgps server
1 sec.
gdgps server
gdgps data
560 bit/sec.
560 bit/sec.
select & monitor
remote users
remote users

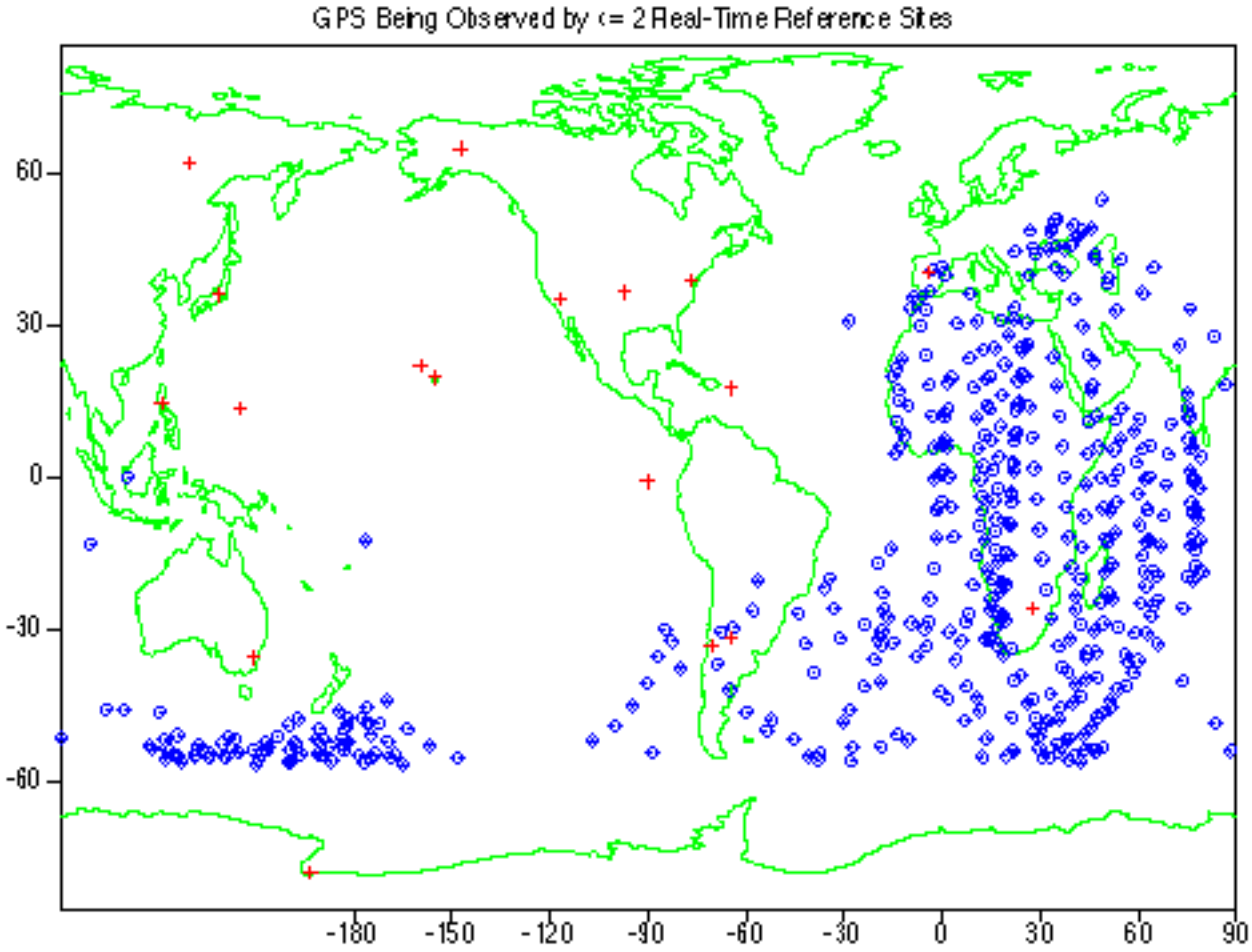
Residual GPS Orbit Errors



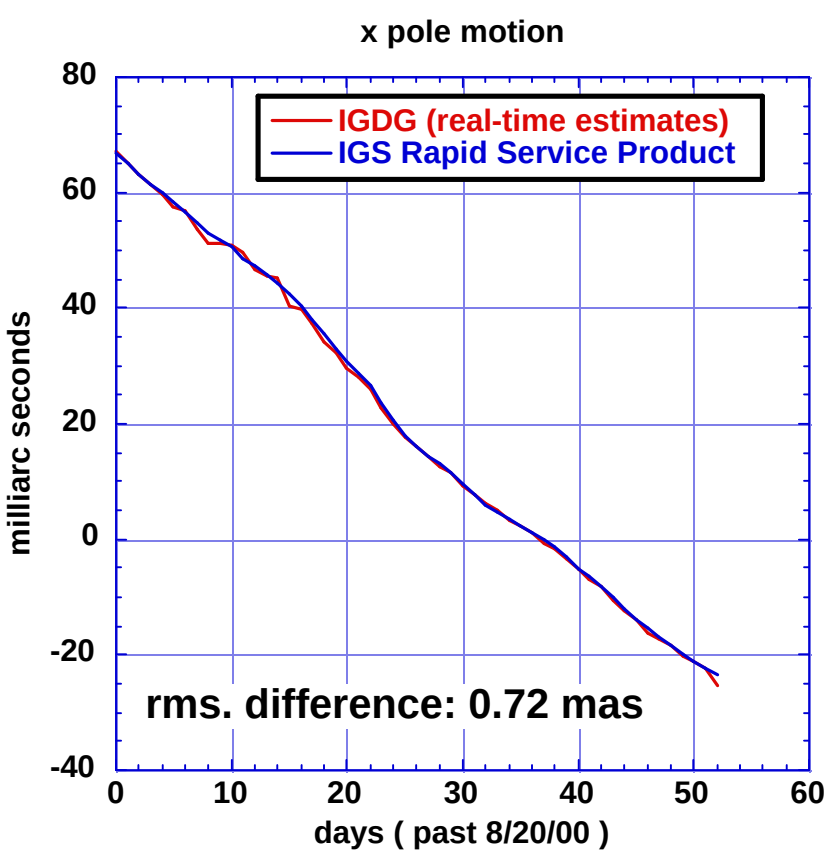
- 2x better than GPS Master Control
- Even w/o IISC, routine daily orbits are now better than 40 cms.

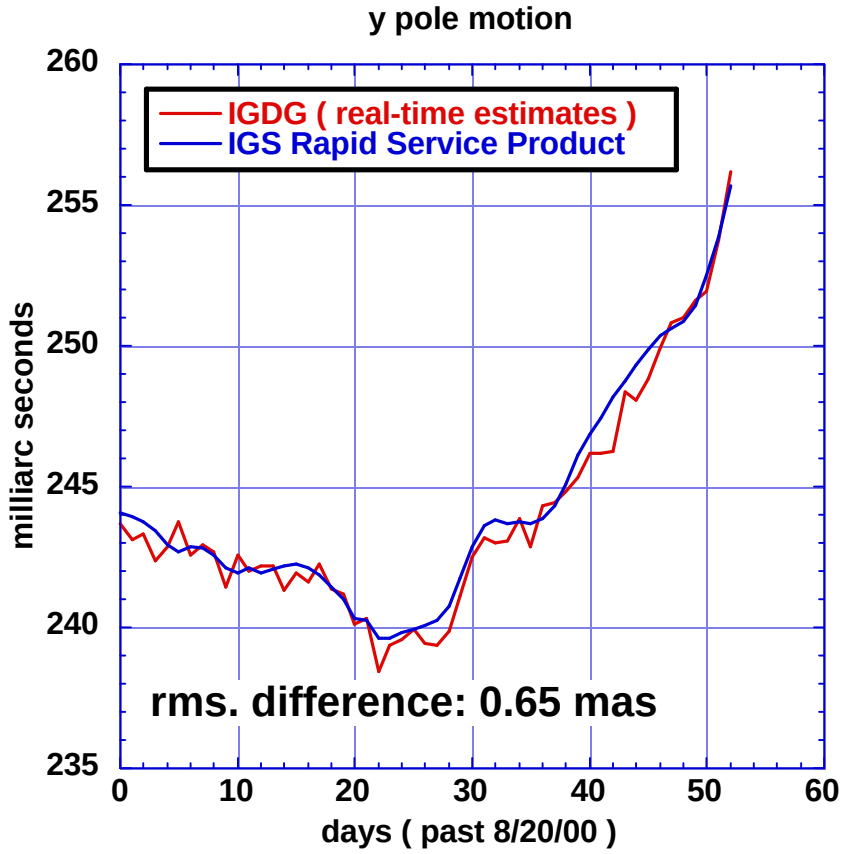
Holes in Current Network

GPS observed by less than 3 ref. sites, 10/12/00



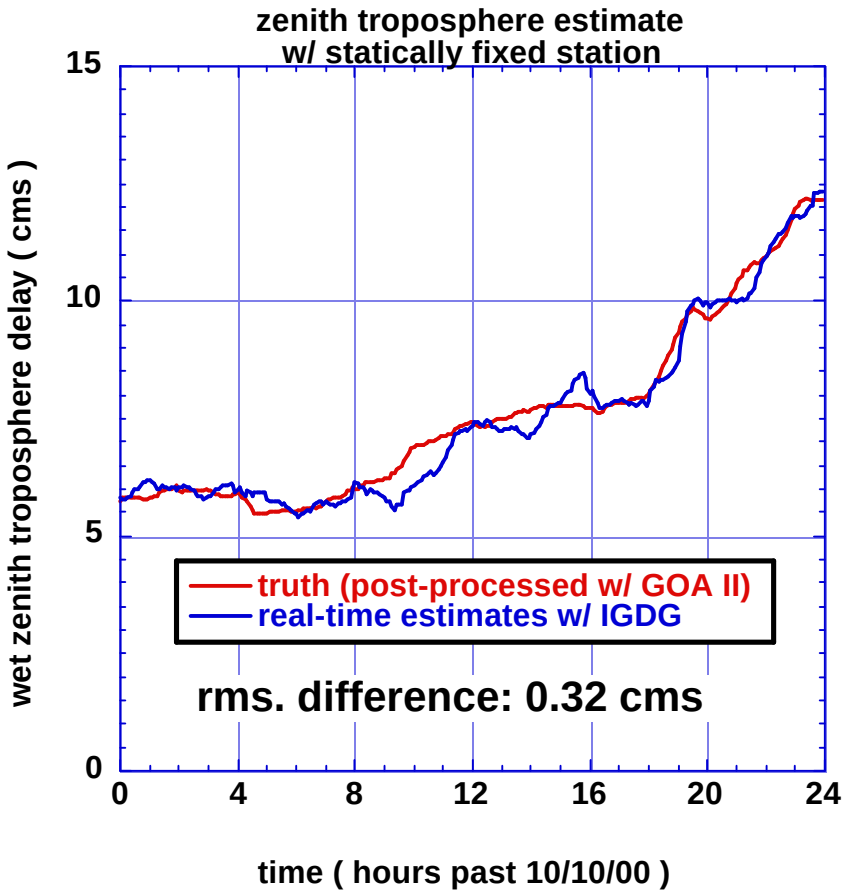
Real-Time Polar Motion

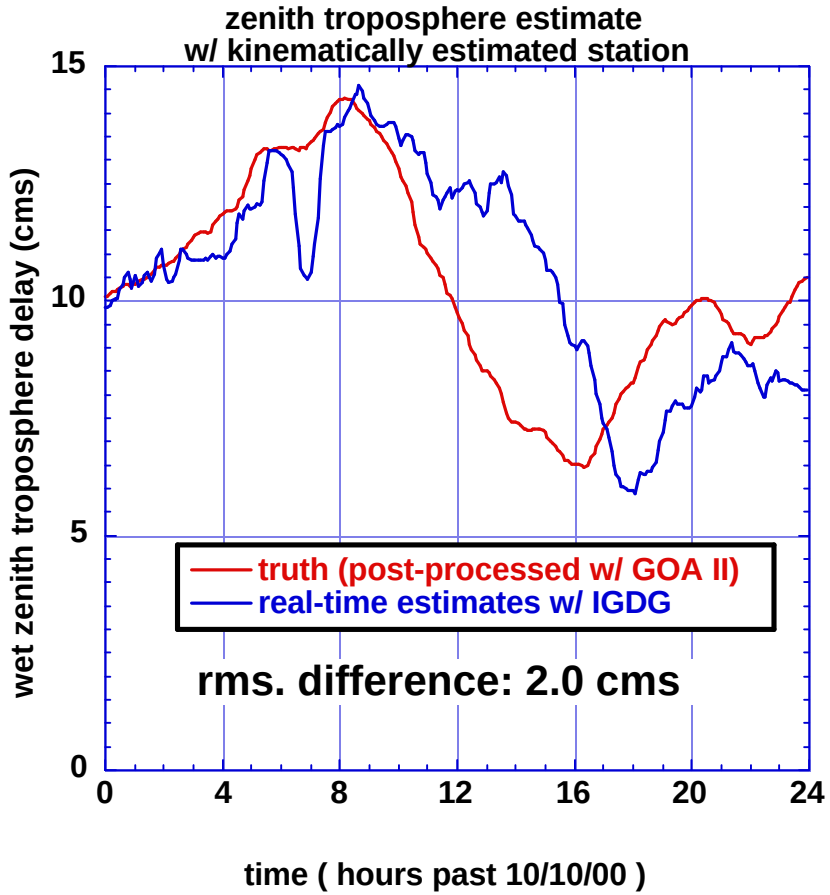




1 mas ~ 3.1 cms at R_{earth}

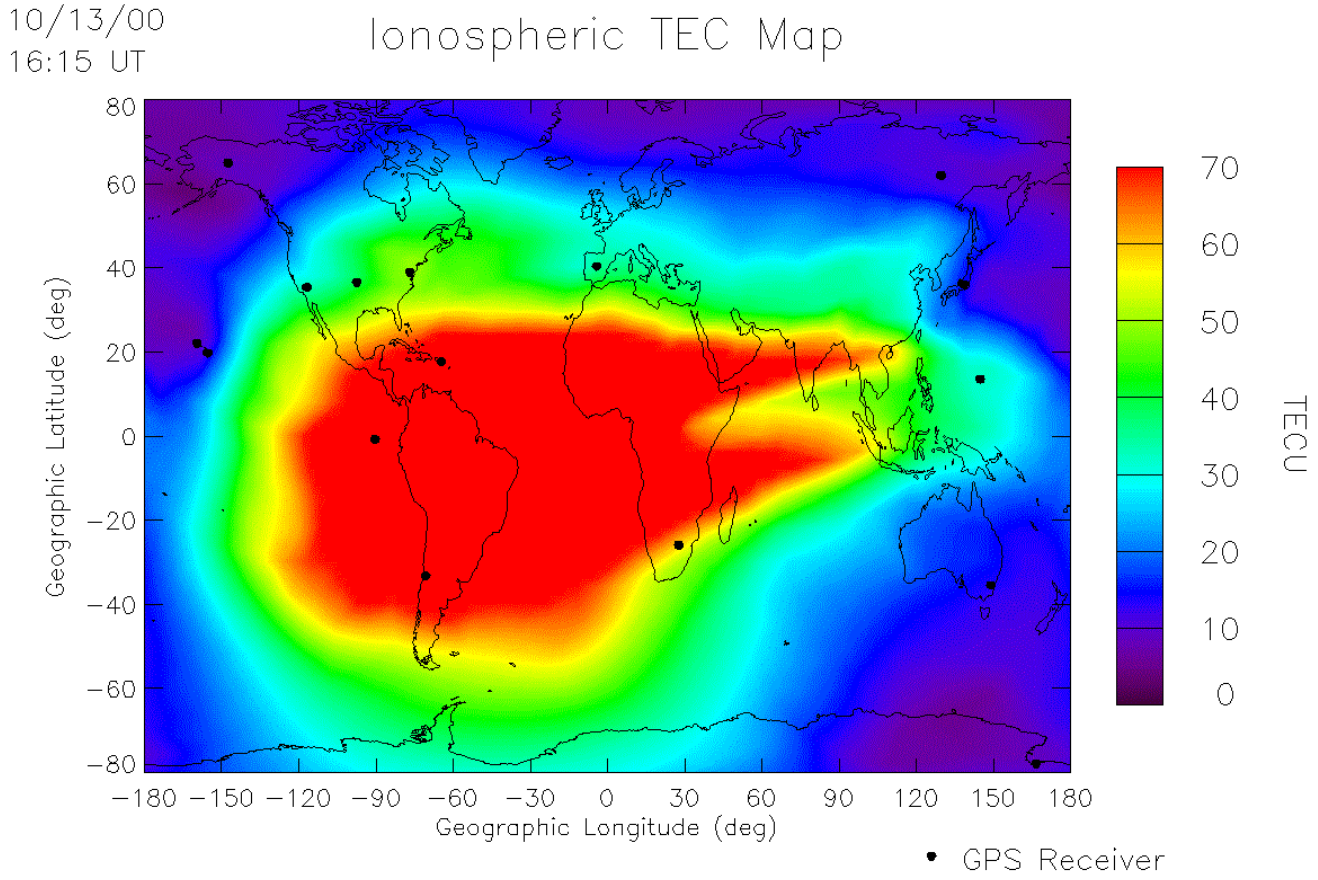
Real-Time Troposphere





Real-Time Ionosphere

9:15 AM PDT **http://heath.jpl.nasa.gov/vwall**



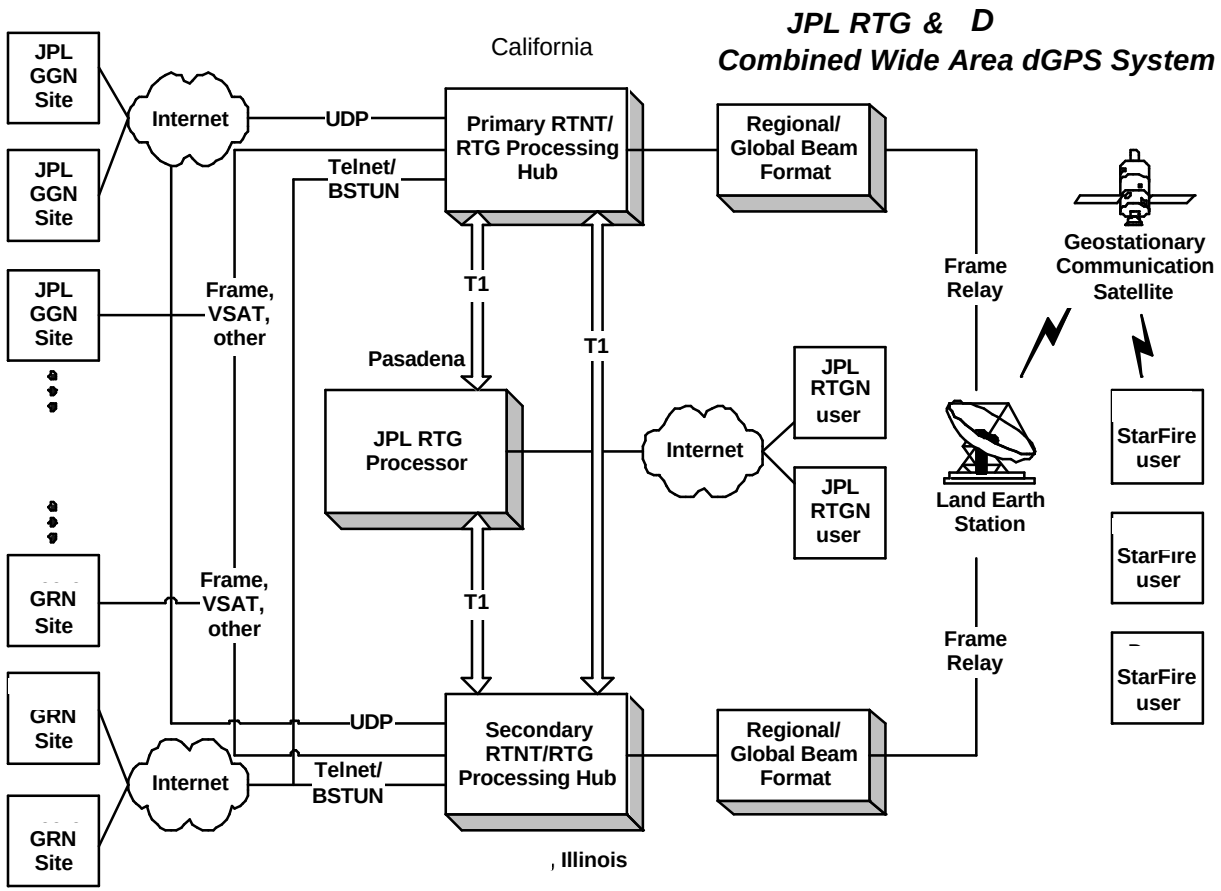
Implemetation of IGDG

- **$1.4M to implement a NASA differential service (AIST NRA)**

Advance Information System Technology

- **Cell-phone positioning w/ company G.**

- **Licensing agreement w/ company D.**



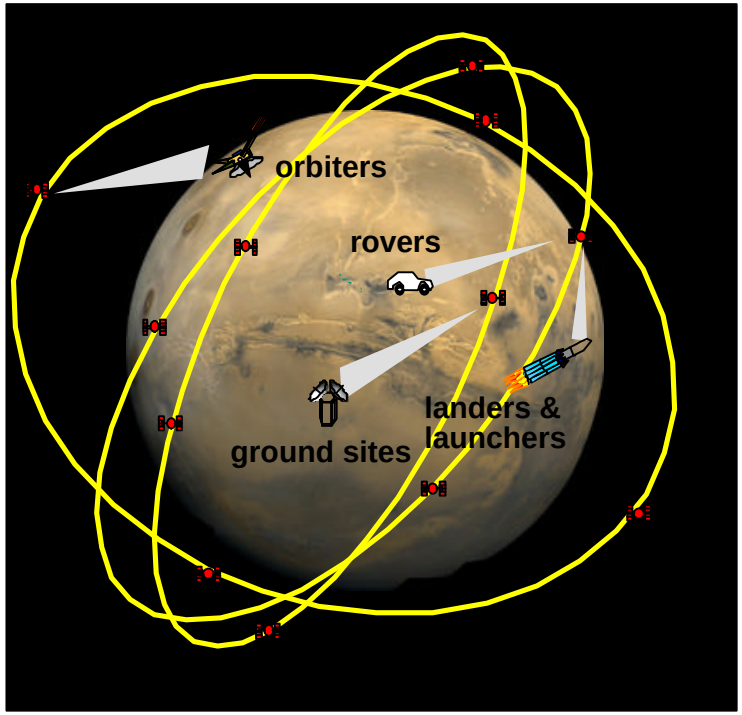
Applications

- Enables autonomous operations in Earth orbit
  - Save $M/year/mission on ground operations (e.g. Topex)
- Enables timely monitoring and response to natural hazards
  - volcanoes, earthquakes
- Operational weather forecasting
  - timely ground data for Champ, COSMIC atmospheric occultation
  - real-time troposphere estimates
- Support AirSAR, X33/RLV
- Commercial impact
  - precision farming
  - construction
  - off-shore oil operations and cabling
  - surveying

Non-GPS Applications

ST5

MARS



Summary

Real-time positioning anywhere on earth

Capability		JPL GDGPS	GPS (USAF)	Others (WADGPS services)
Coverage:	Global	Yes	Yes	No
	Seamless	Yes	Yes	No
	Usable in space	Yes	Yes	No
Real-Time Accuracy:	Kinematic applications	**10 cms horizontal 20 cms vertical**	5 m	~ 1 m
	Orbit determination	**1-5 cms** using dynamics to smooth	1 m	N/A
Dissemination method		Internet/Broadcast	Broadcast	Broadcast
Targeted users		Dual-frequency	Dual-frequency	Single-freq.

Unattended operations, 24/7, twice redundant

Robust development system for planetary navigation