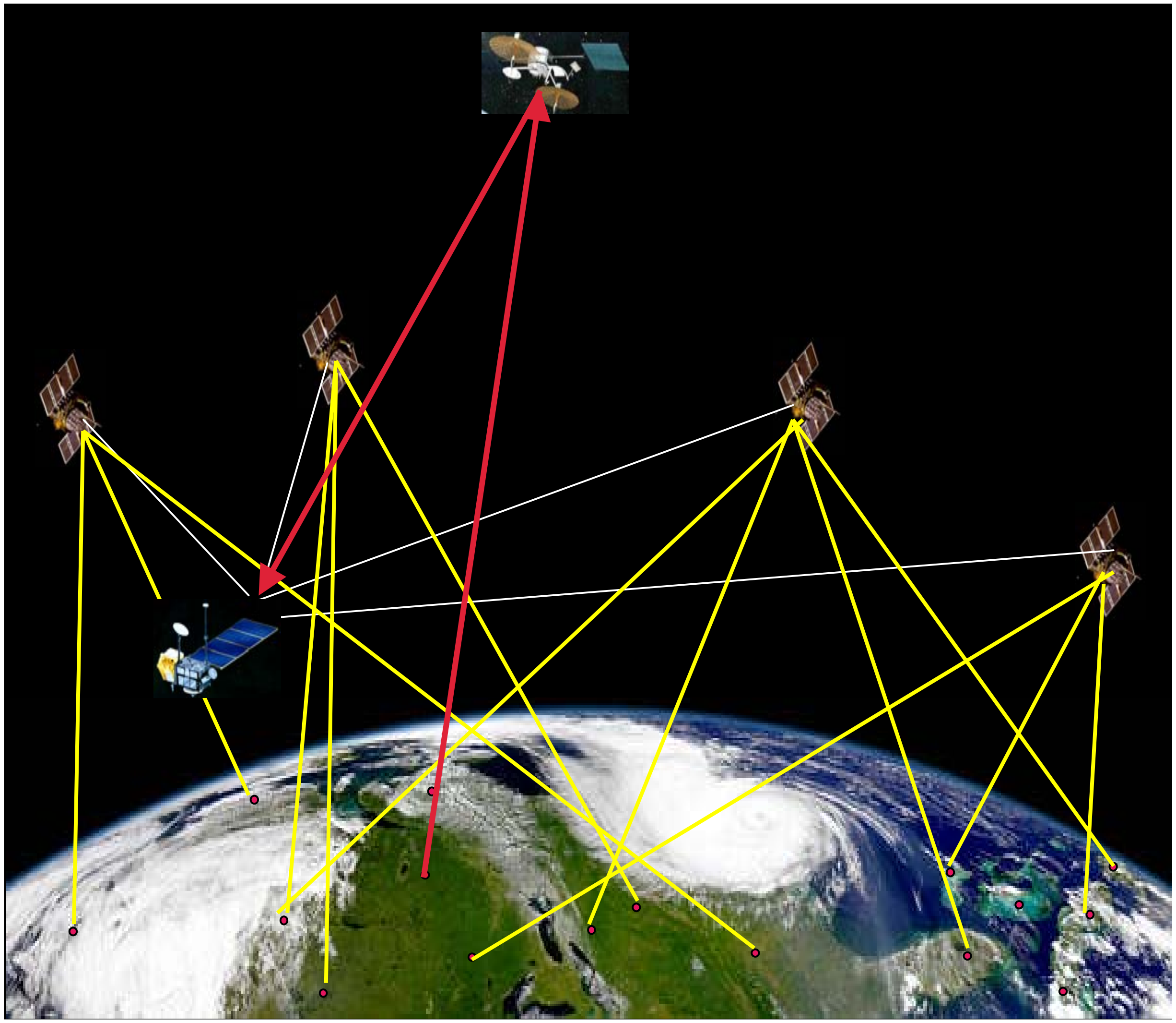
Real-Time Aspects, the JPL Perspective

Global Differential GPS

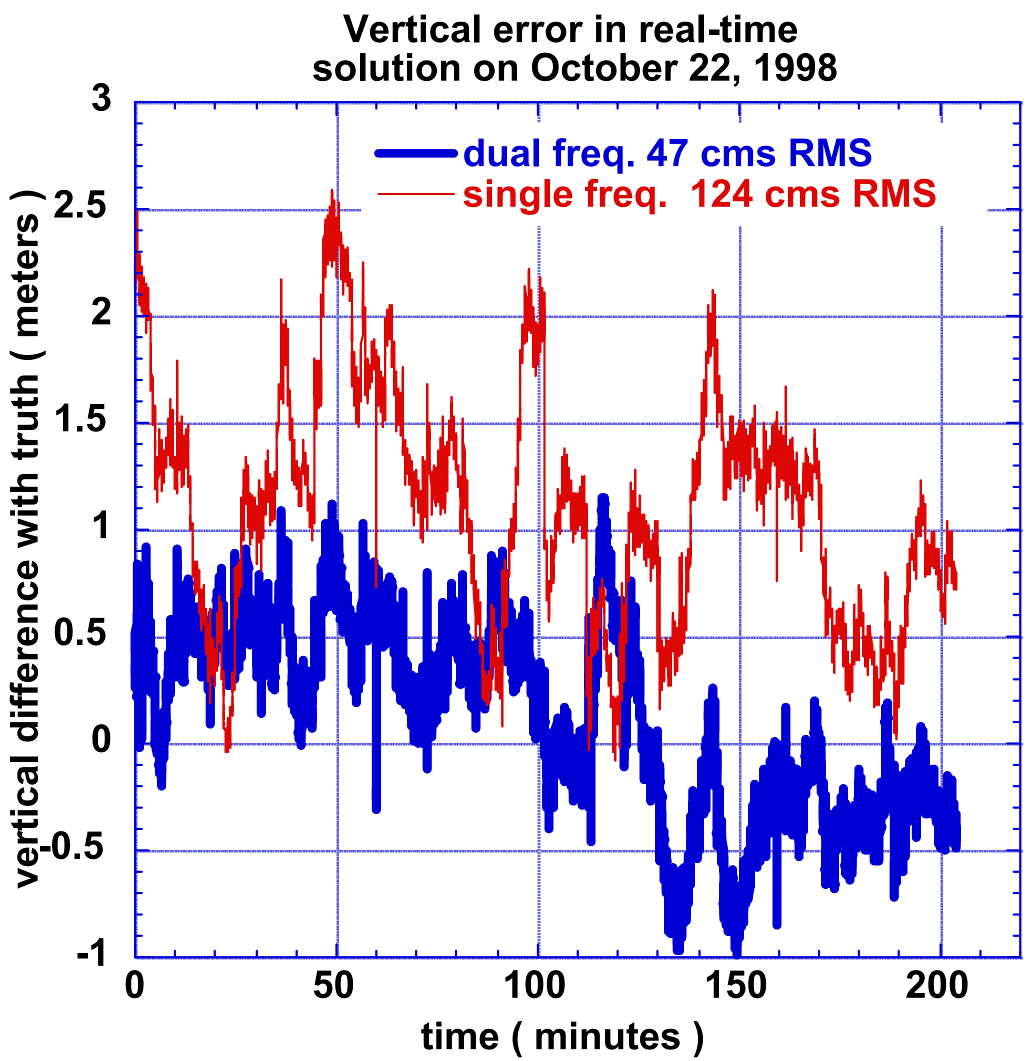


History of Differential GPS at JPL

- **1995 white paper on WADGPS (Tom Yunck, et al.)**
  "A Prototype WADGPS System for Real Time Sub-Meter Positioning Worldwide," Proceedings of ION GPS 96, Kansas City, Kansas, September, 1996.
- **1996 provide core s/w for Satloc's WADGPS**
  - Selected as prototype for FAA's WAAS (US)
  - Software licensed by Raytheon

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

DC-8 AirSAR Flight Tests



Jan 2000 ION talk, Anaheim

An Internet-Based Global Differential GPS System, Initial Results

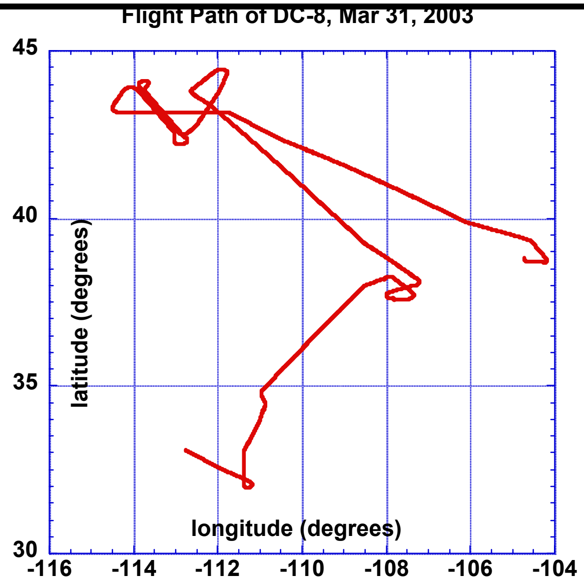
- Real-Time Data
  - 15 Global Stations
- Dual-Freq. User Positions, Anywhere (Internet)
  - Horizontal < 10 cm bias, Sigma < 5 cm
  - Vertical < 20 cm bias, Sigma < 10 cm

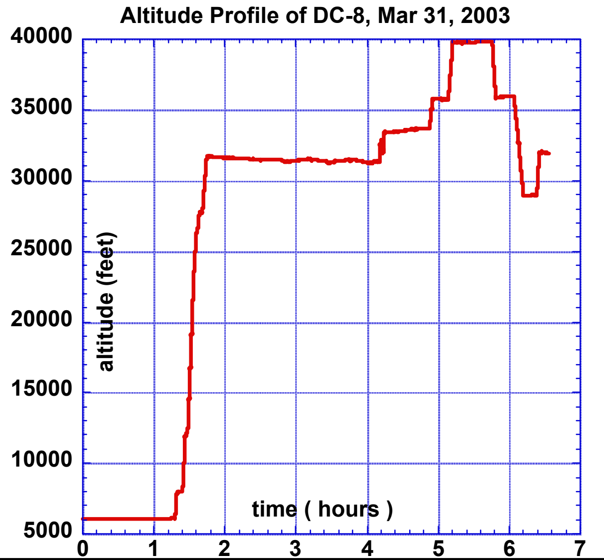
… and 4 years later

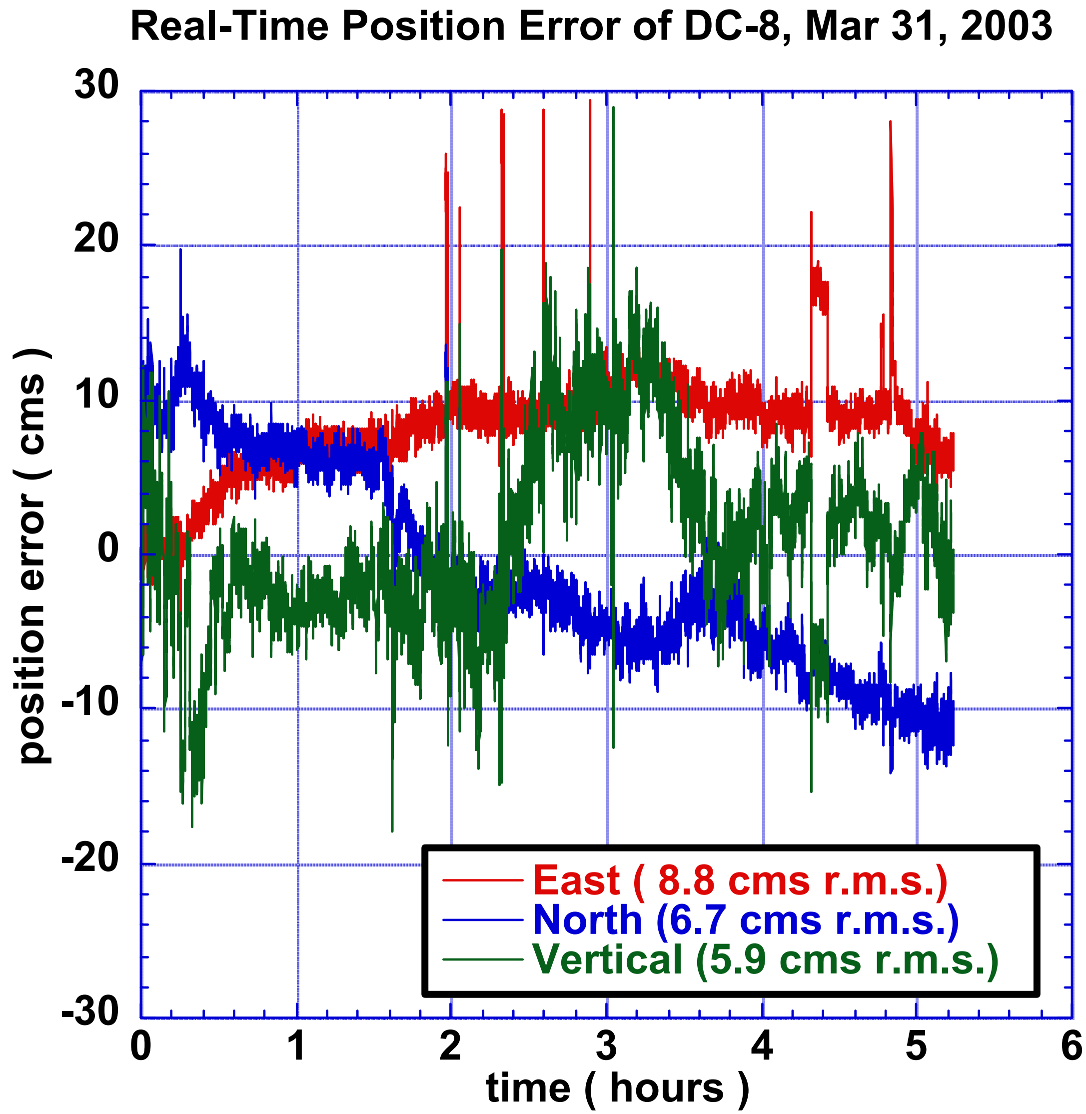
- Continue to refine techniques and algorithms
  - Earth radiation model in real-time orbit determination
  - 6 different solar pressure models
  - Adaptive weighting to control long-term clock biases
  - Two-stage filter implementation for PPP end user

- Improve on robustness of the network and infrastructure
  - Two independent operation centers with redundant computer infrastructures
  - Dual pathways for raw observables

DC-8, Colorado Springs, CO to EAFB, CA







NASA's Global Differential GPS System

GDGPS Operations Center

TDRS

Internet

Iridium
Inmarsat

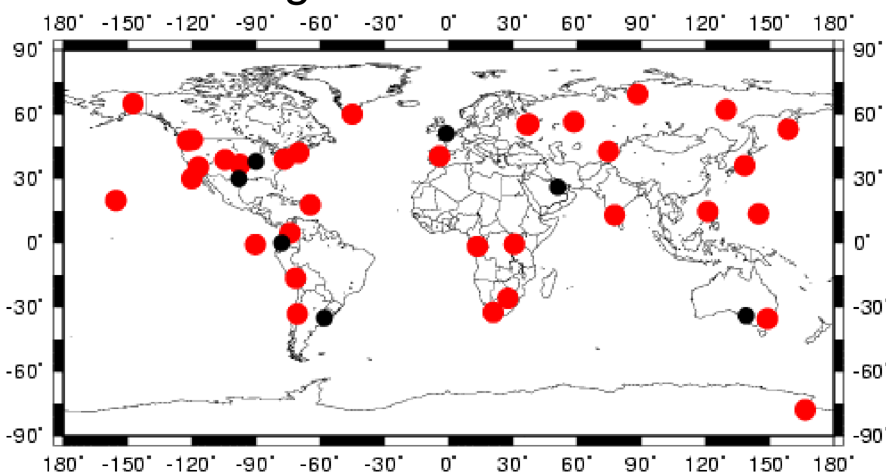
Uplink

Terrestrial and
airborne users

Internet

Broadcast

NASA's global real time network



Space users

Developed under the NASA Advanced Information Systems Technology Program

For more information see: http://galia.jpl.nasa.gov/igdg

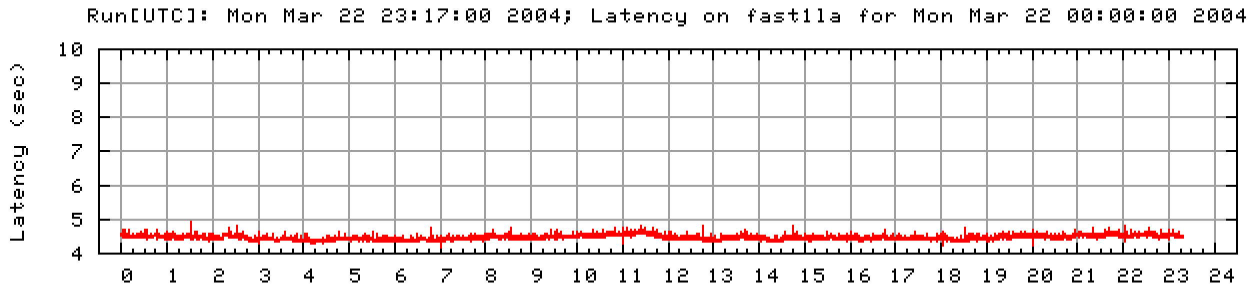
GDGPS Correction Latency Monitor

JPL RTG GDGPS Correction Message Latency: gmon1la

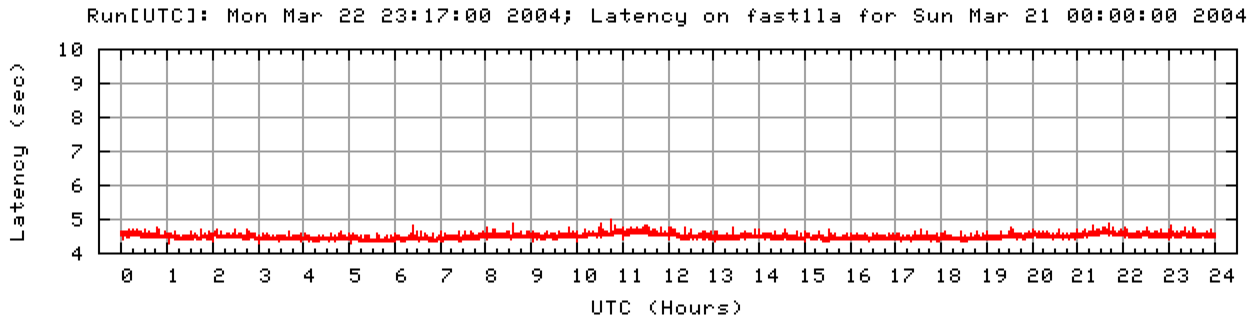
Last run: Fri Jan 23 16:17:00 2004 (UTC)

4-sec Latency Monitor host=fast1la (15-days):

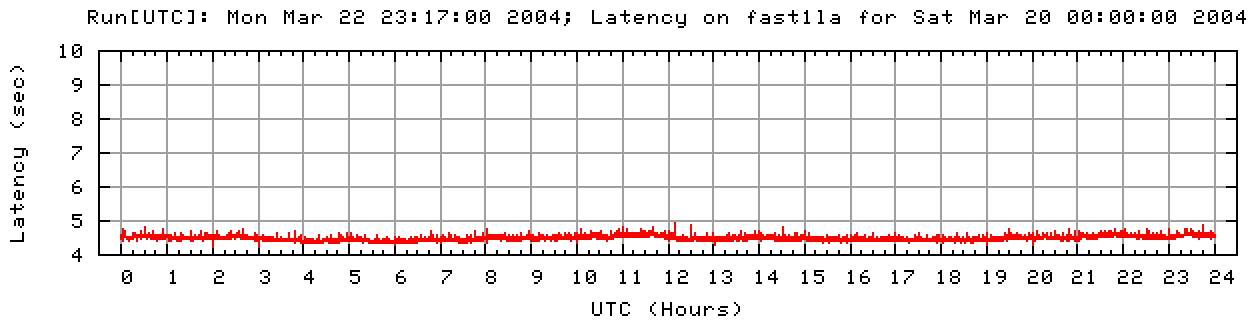
Day 1:



Day 2:

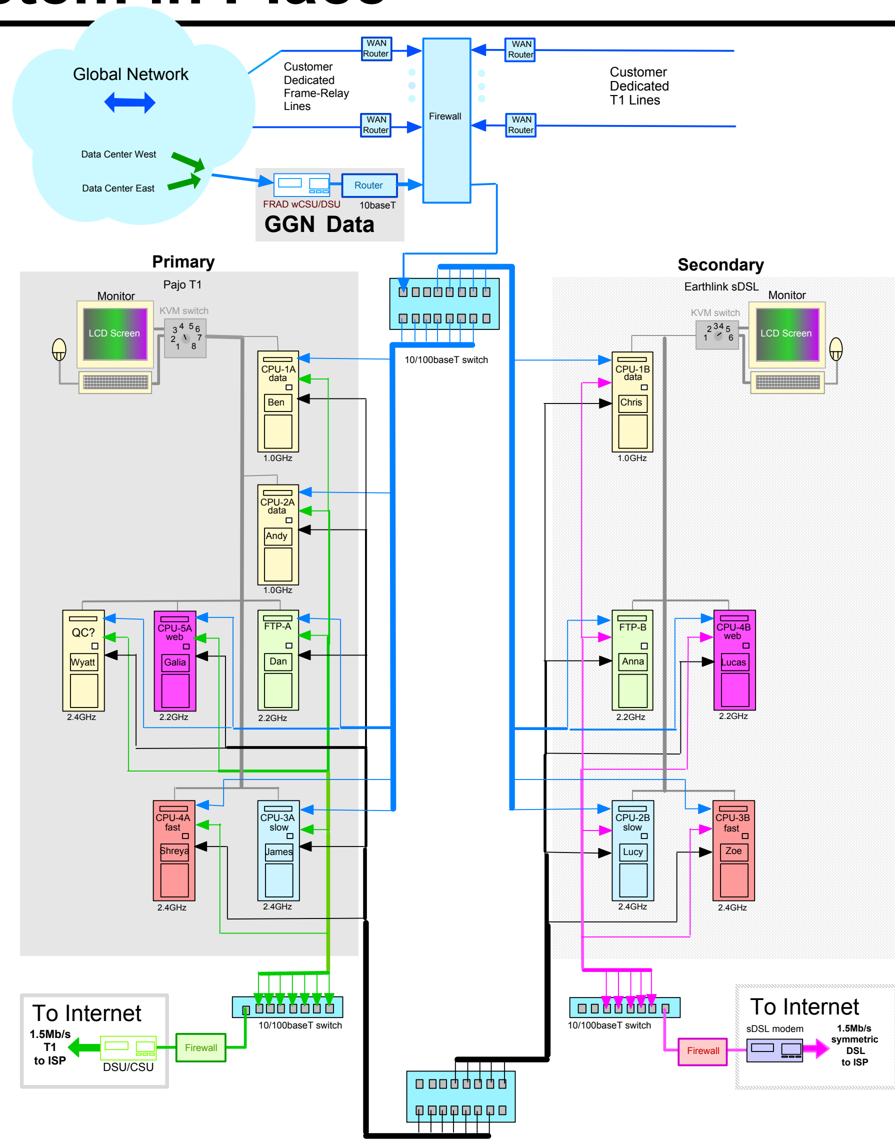


Day 3:



Mature and Reliable Ground Operations System in Place

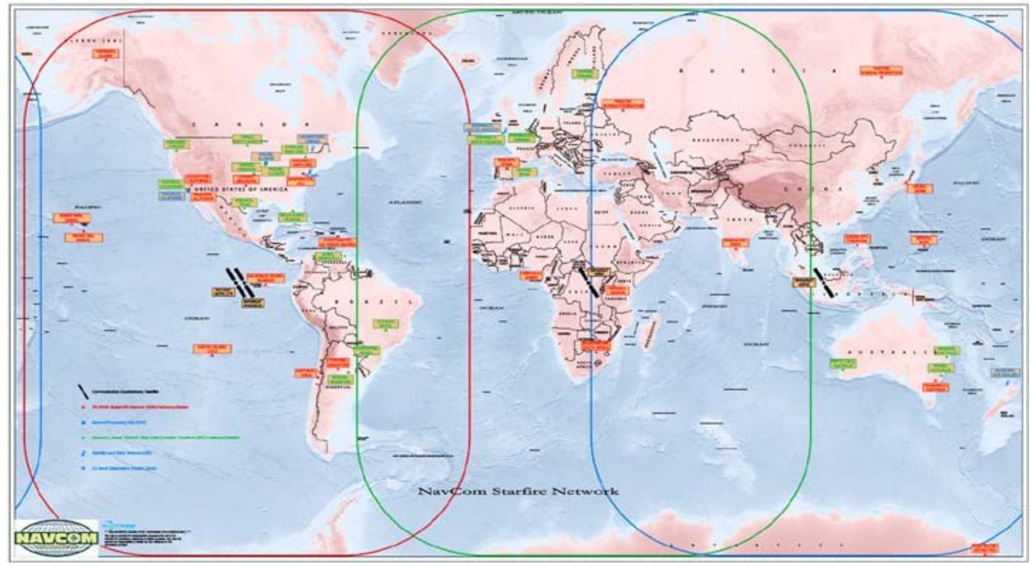
- Reliability through redundancy
  - No single points of failure
  - Dual data stream accumulators
  - Numerous reference sites
    - 66 and growing
  - Multiple reference clocks
    - USNO & AMC
  - Redundant correction processes
- Automatic (unmanned operations)
  - fault detection
  - data rerouting
- Integrity monitoring
- Web monitoring in the public domain
- **99.99% reliability since 2000**

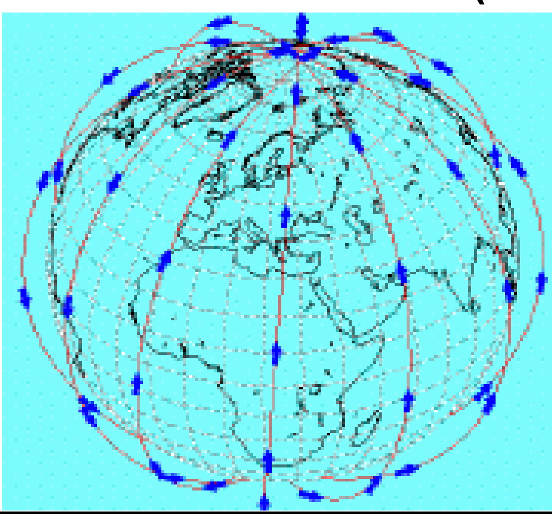


Communication Relay Systems

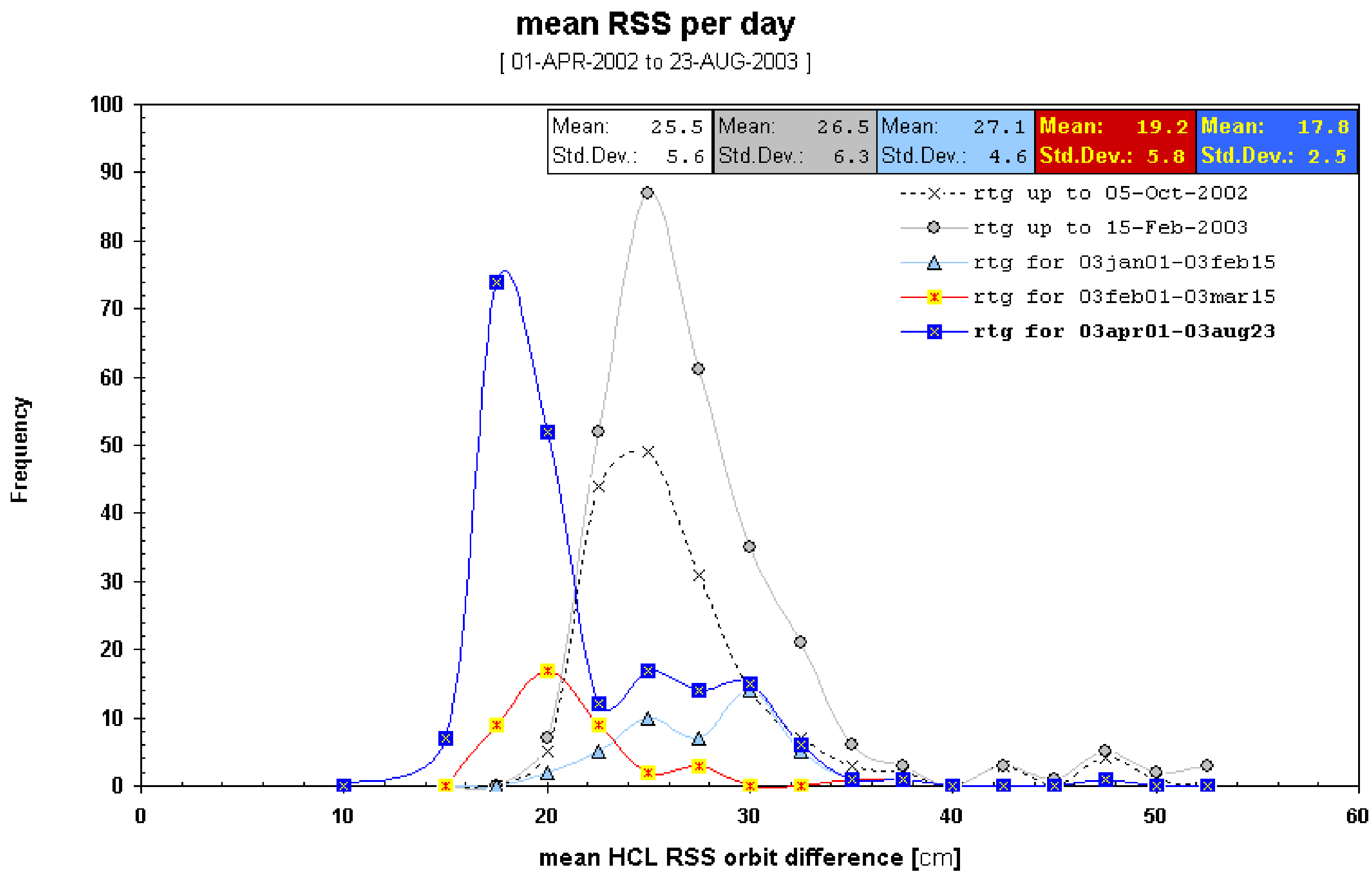
true global reach:

- **open Internet**
- **3 Inmarsat satellites with global coverage up to latitude ±75º (operated by Navcom, et al.)**
- **Iridium telephone modems provide internet access globally (including the polar regions)**
- **future TDRSS broadcast (S-band)**



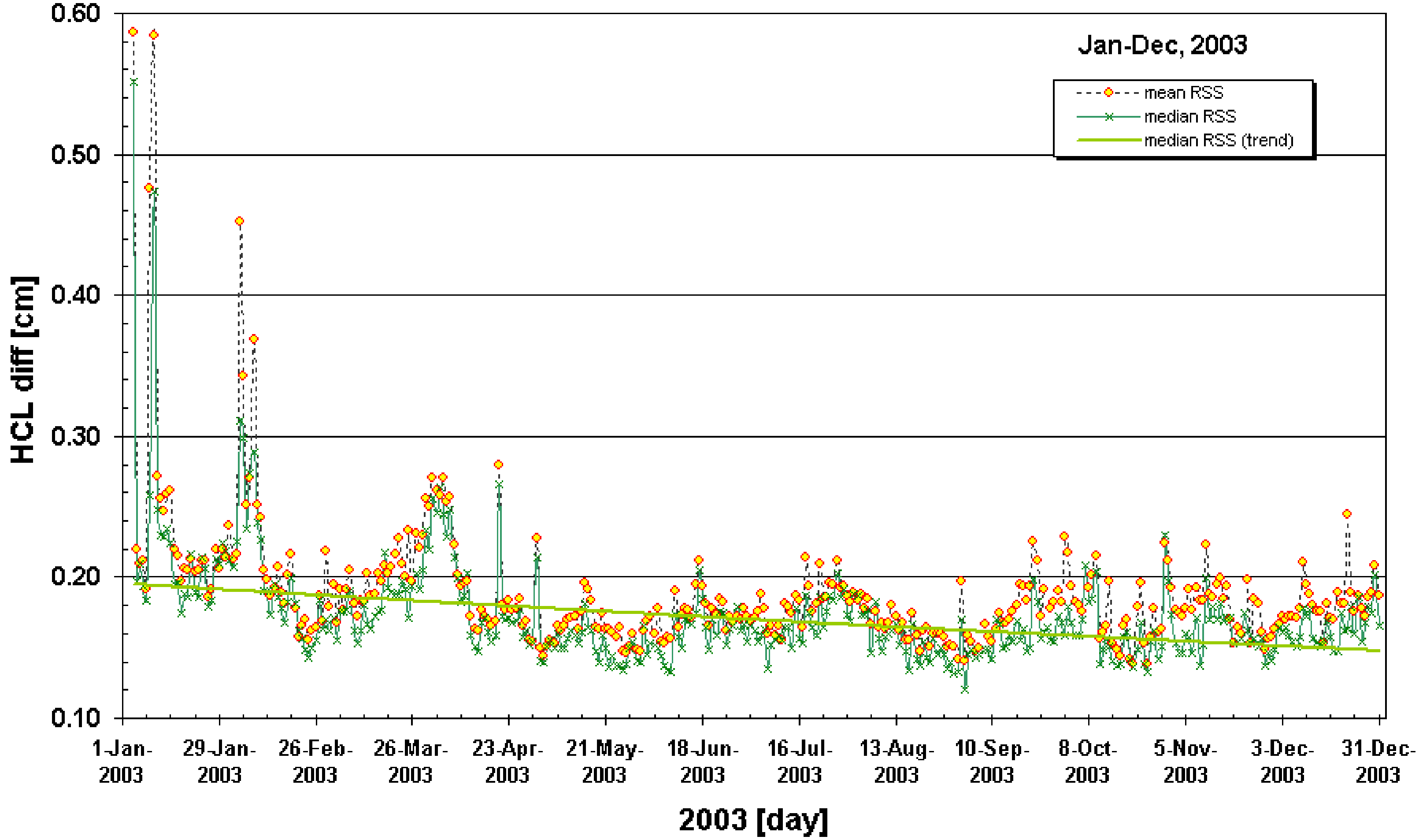


RTG HCL Orbit Differences to FLINN Orbits

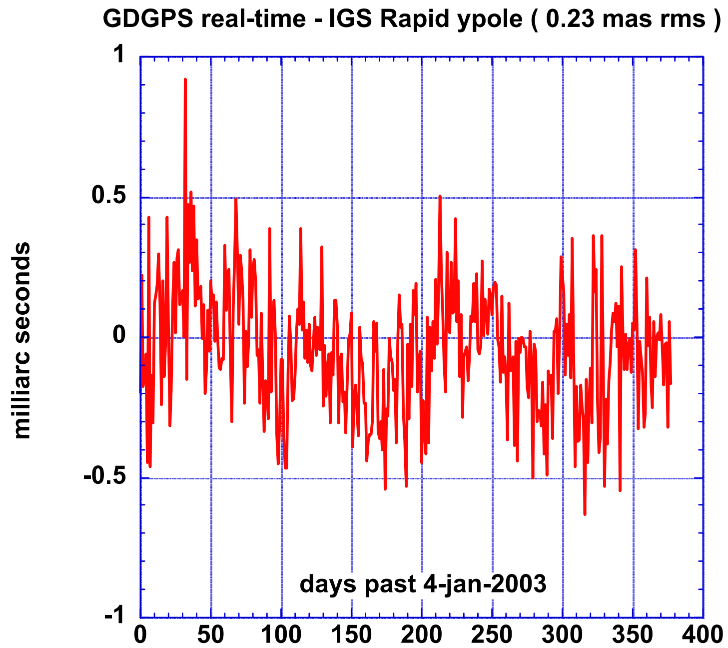


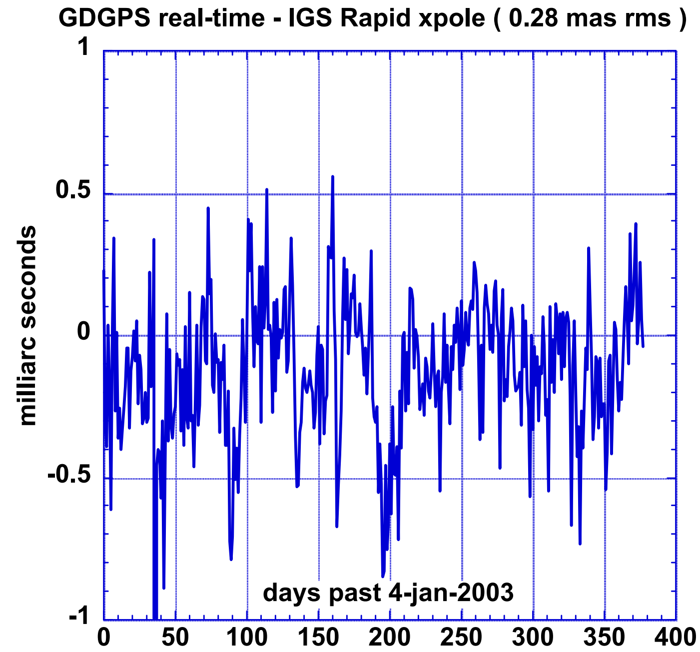
JPL RTG vs FLINN orbit diff:

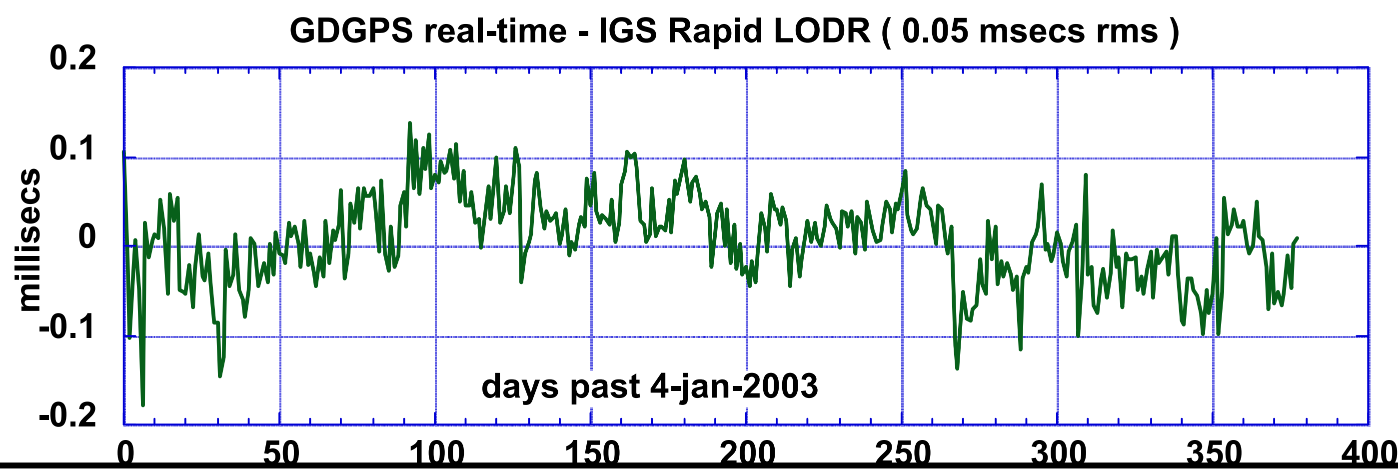
daily mean, median RSS of HCL differences for all SVN



GDGPS Real-Time UTPM Estimates

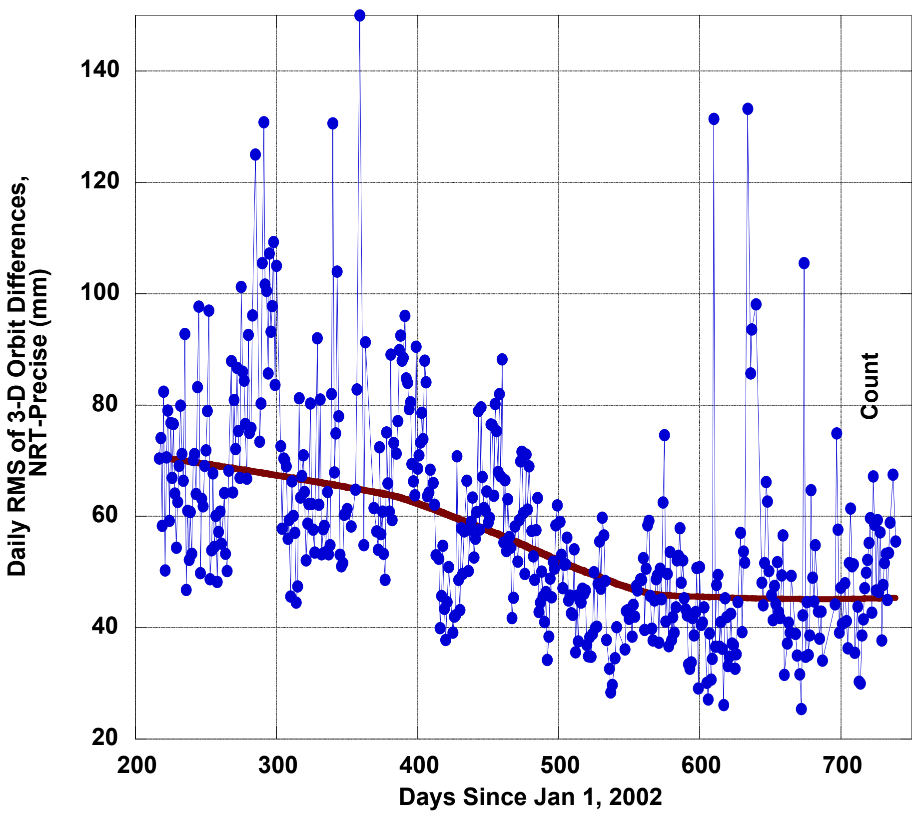




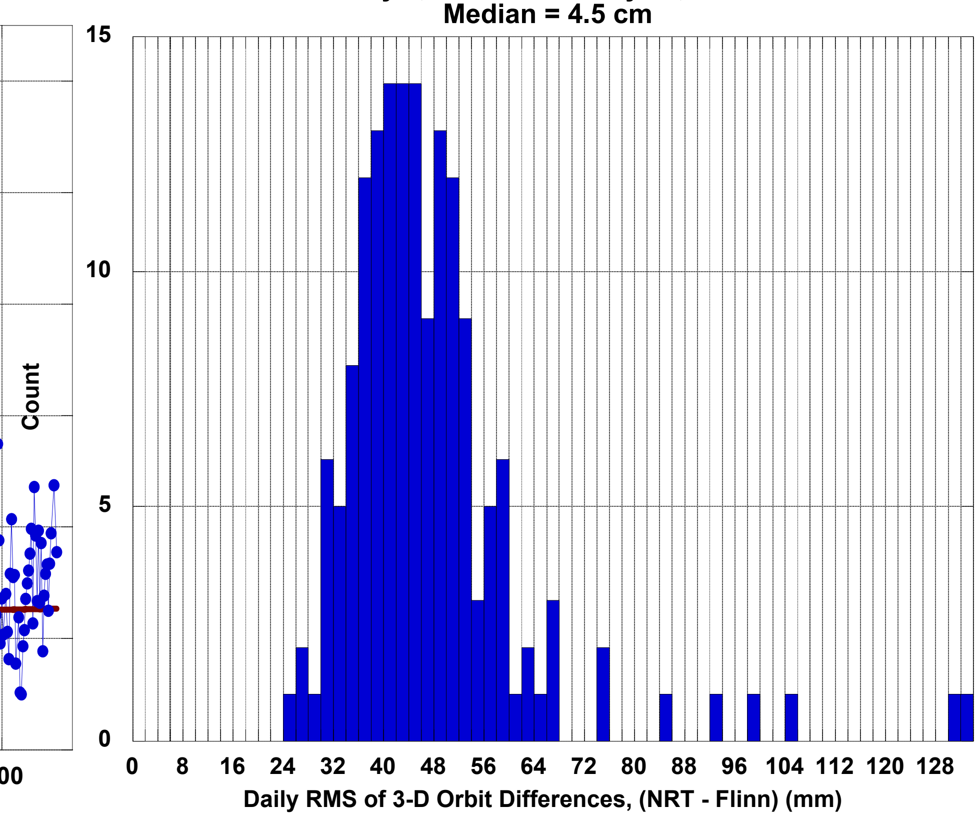


Orbit Determination with GDGPS Products

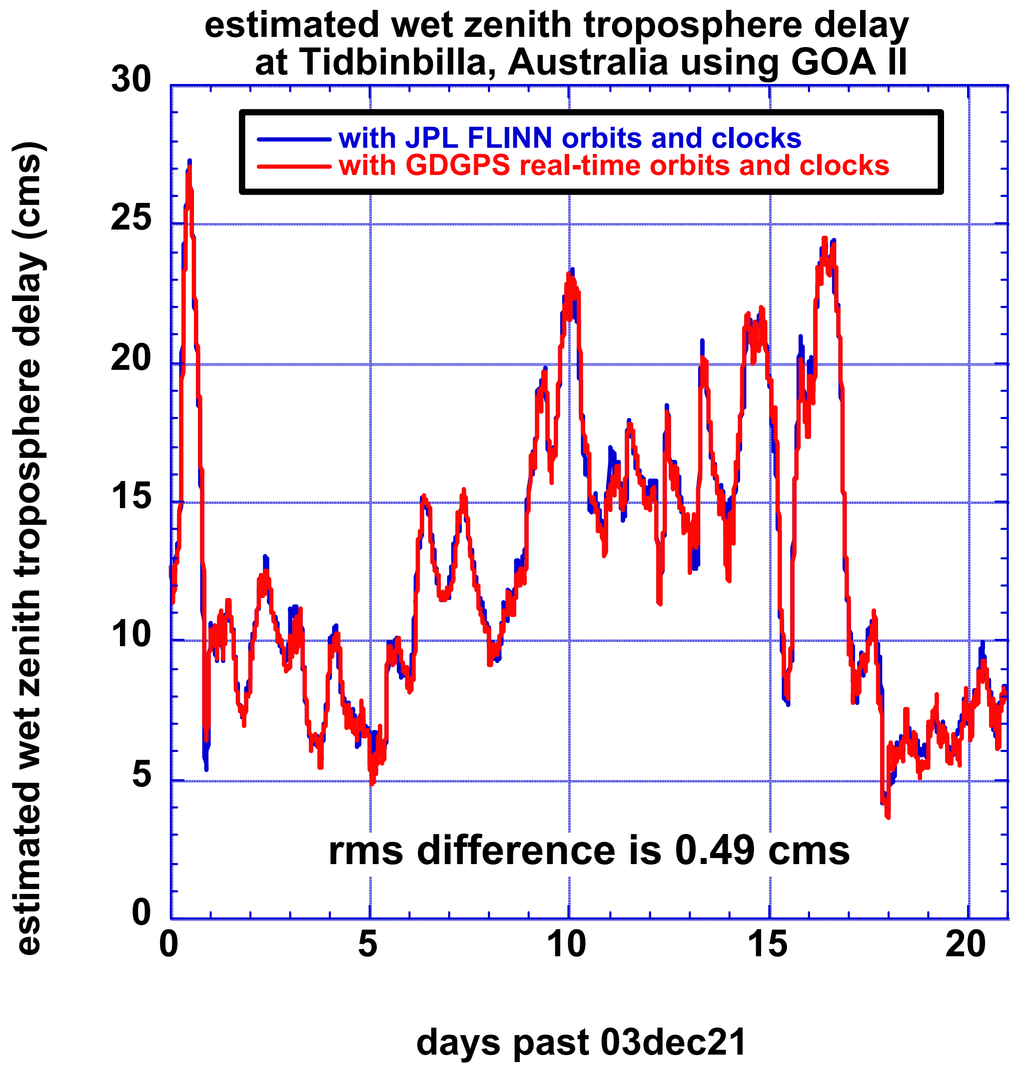
3-D Differences Between NRT and Precise (Flinn) GPS-based Jason-1 Orbits



Histogram Based Only on Data from
July 4, 2003 to January 10, 2004
Median = 4.5 cm



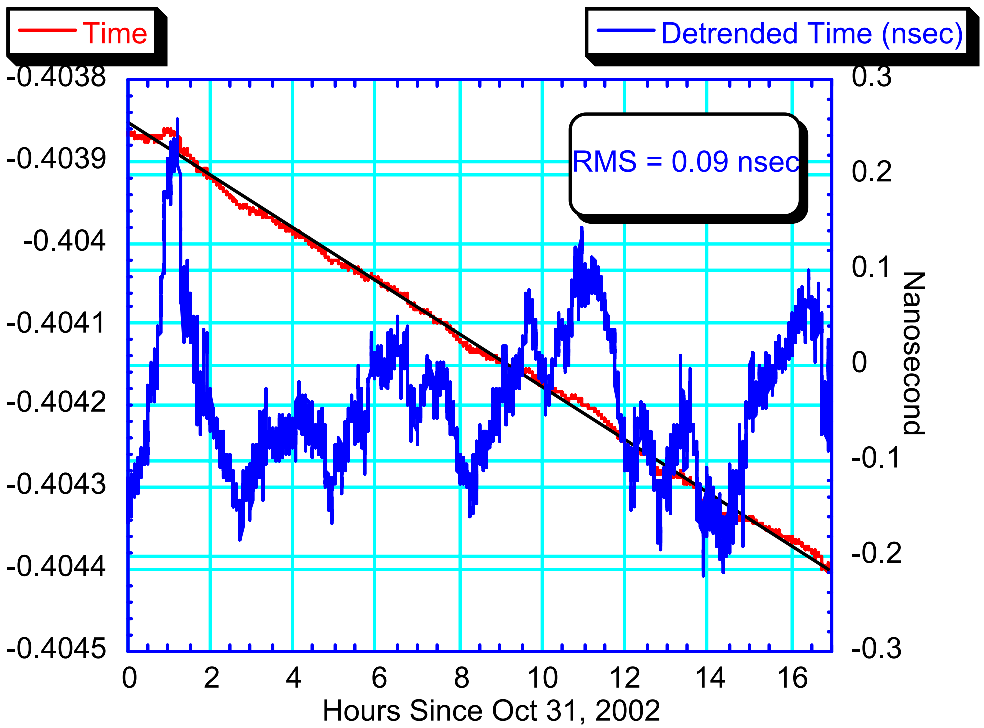
Troposphere with GDGPS Products



Time Transfer Capabilities

Real-Time time transfer accuracy is consistent with that of positioning:
nanosec level for dynamic platforms; 0.1 nanosec level for static platforms

Time Transfer from USNO to JPL Maser
Position held fixed



An order of magnitude improvement compared to unaided GPS

Centralized vs. Distributed

- Centralized architecture approach
  - \+ Ease in providing data to end-users in common format
  - – Data (re)transmission provided by central authority
    - Single implemented architecture is not a robust approach
    - Single-path nature of central relay does not provide robustness
      - – And a mesh of relays provides no more redundancy then obtaining the data from a distributive architecture
  - – End-users of real-time data stream are unknown
- Distributive architecture approach
  - \+ Direct access to accumulating organizations
    - They are closer to the data
    - Likely to have provided multiple access points
  - \+ RTWG has proposed a common data format and method for universal access of available streams
  - \+ Precludes need to relay data through IGS centers
    - Avoids potential of data in infinite loop
  - \+ Distributes cognizant knowledge

Contribution to the IGS Prototype

JPL does not support
- centralized architecture
- redistribution of JPL data through relay

JPL supplies IGS formatted data available from 3 network sources
- supports both UDP and TCP clients
- provides 5 data streams from 3 continents
  Goldstone CA, Madrid Spain, Tidbinbilla Australia
  AMC1 (Colorado Springs), DLF3 (Delft University)

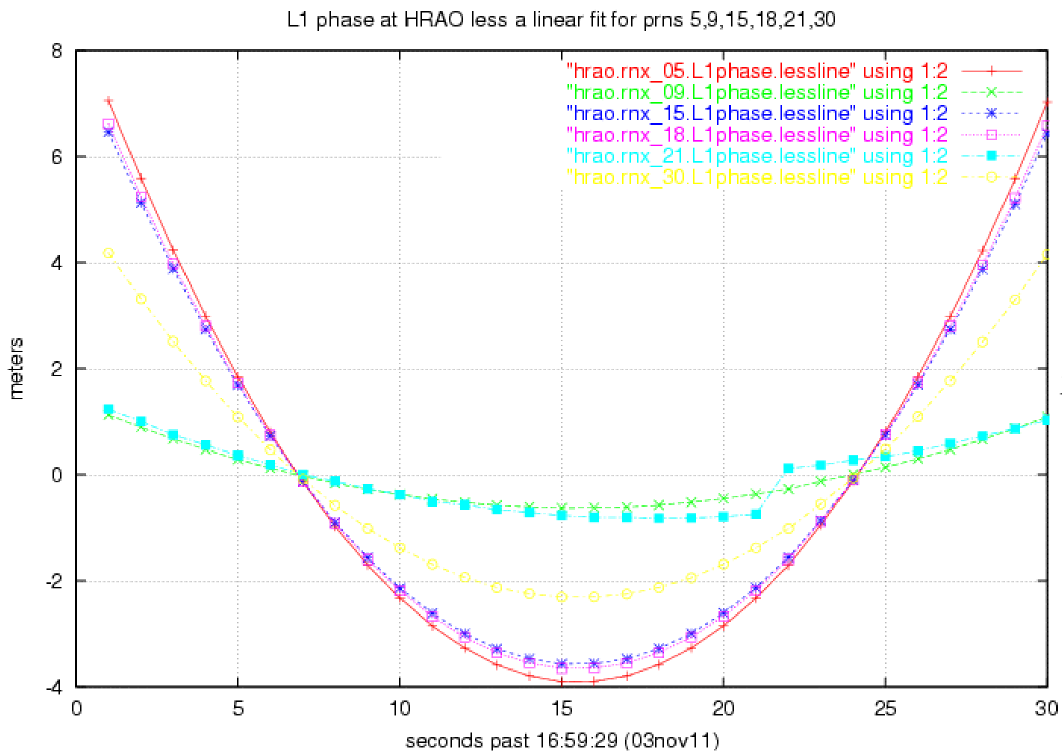
JPL supports
- open environment for technology development
- data exchange among IGS members
- distributive architecture

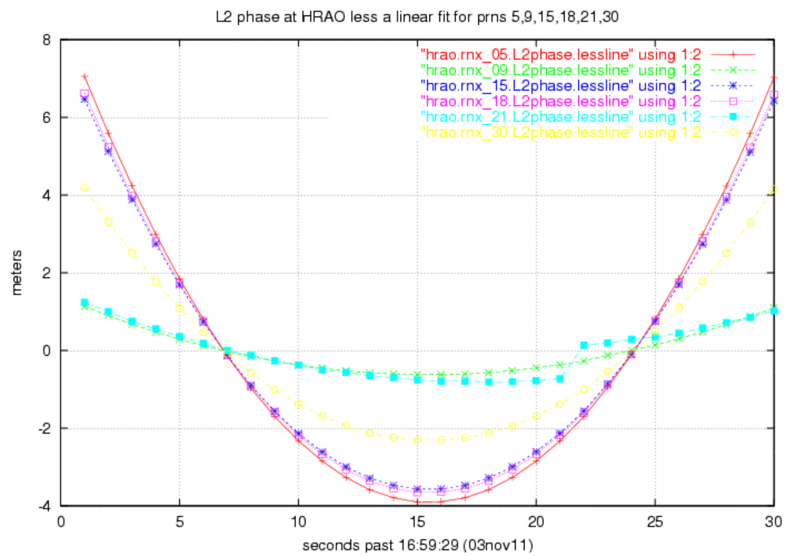
Summary

- some lessons learned
  - Data <u>must</u> be robustly edited in-situ
  - Monitor, monitor, monitor
  - Expect the unexpected
- GDGPS has evolved into an operational, highly reliable service since our first claims of 10/20 cms in Y2000
  - Combined NASA and commercial resources have allowed us to remain economically viable
- more to do
  - Data authentication for GPS monitoring
  - Improve orbit models, yaw rates in shadow and noon-turns
  - End-user initial convergence issue
  - Need to reduce long term and short term GPS clock biases

results of one missed cycle slip

- **80 cm jump in PRN21 clock 03nov11 16:59:51**
- **9 out of 10 stations reported innovations failures in the filter, only HRAO data passed.**





Data editing is difficult and unreliable without data continuity

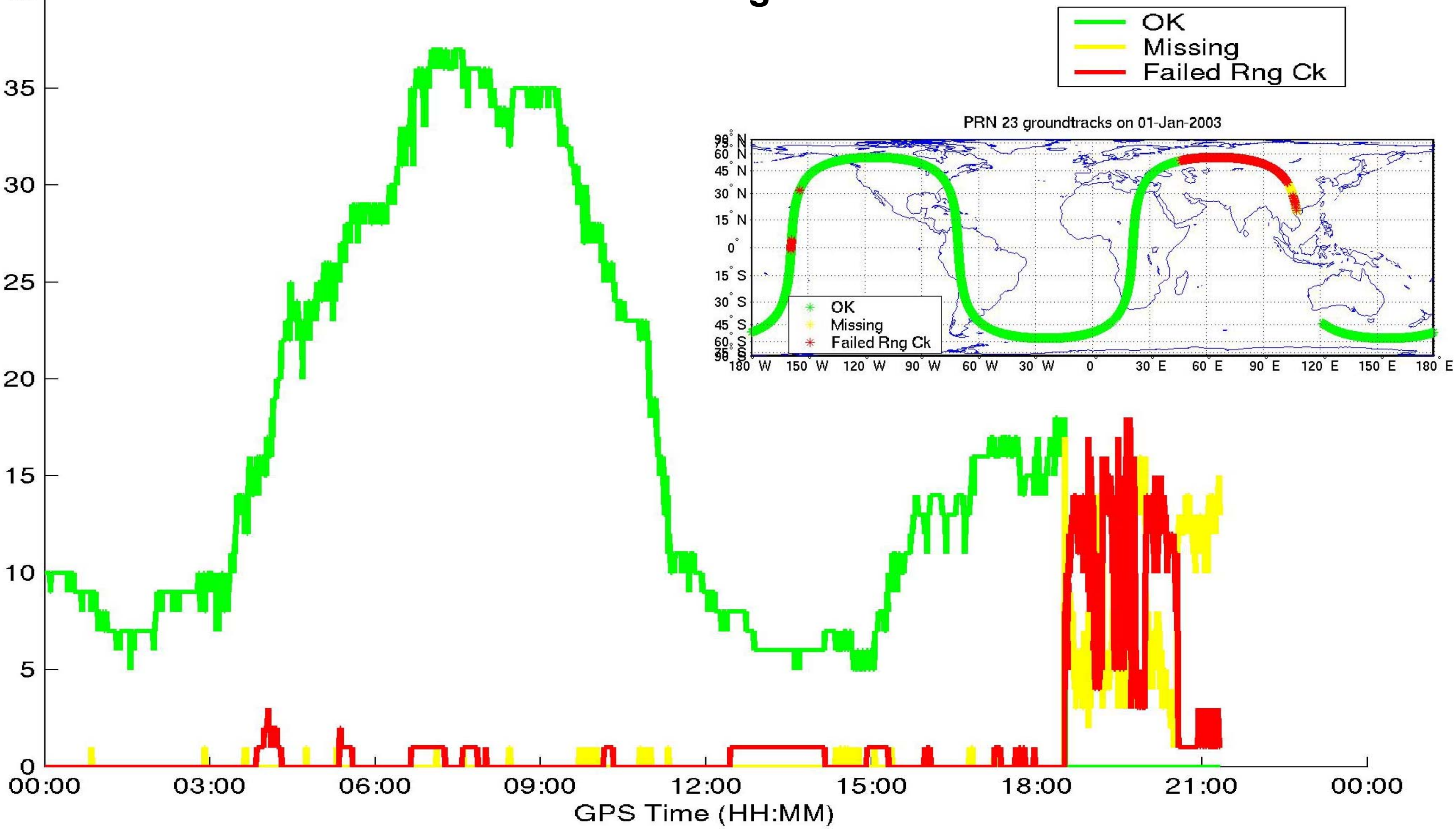
QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

Acknowledgement

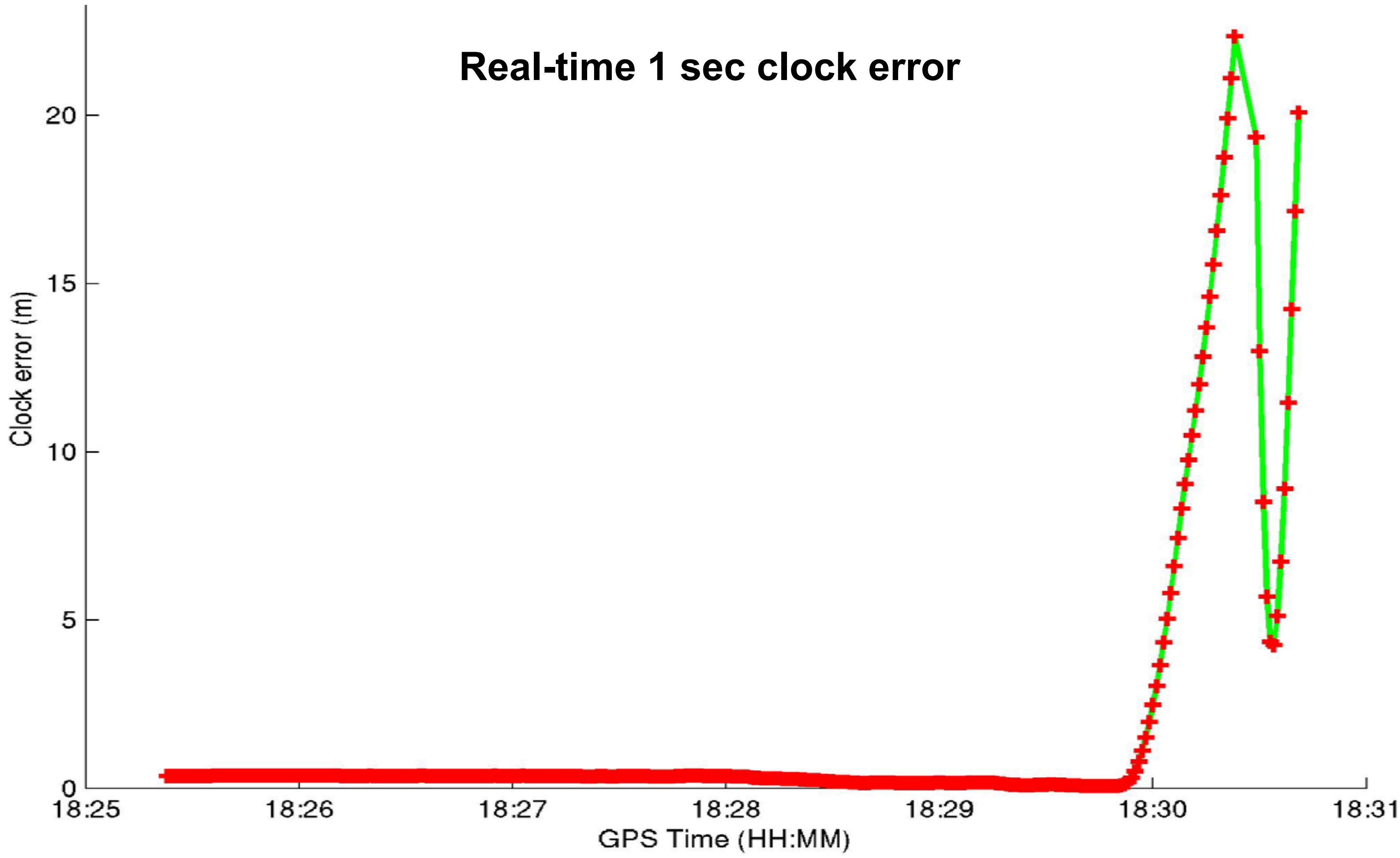
The work described in this paper was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration

GDGPS Integrity Monitoring

Number of GDGPS sites tracking SVN 23



SVN 23 on January 1 2004 (cont)



Unique Processing Techniques

- **two-stage filter implementation**
  - **lag filter applies the correctors optimally to the data.**
  - **real-time filter services the data using the covariance and estimates from the lag filter.**
    - **NCT 0.06 to 0.08 seconds latency**
    - **Ashtech 0.4 secs. latency**