Real-Time Aspects, the JPL Perspective
History of Differential GPS at JPL

• 1995 white paper on WADGPS (Tom Yunck, et al.)

• 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

Vertical error in real-time solution on October 22, 1998

- Dual freq. 47 cms RMS
- Single freq. 124 cms RMS

Vertical difference with truth (meters) vs. time (minutes)
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
Flight Path of DC-8, Mar 31, 2003

Real-Time Position Error of DC-8, Mar 31, 2003

Altitude Profile of DC-8, Mar 31, 2003

- East (8.8 cms r.m.s.)
- North (6.7 cms r.m.s.)
- Vertical (5.9 cms r.m.s.)

Real-Time Aspects, Berne 2004, IGS
NASA’s Global Differential GPS System

Developed under the NASA Advanced Information Systems Technology Program

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

NASA’s global real time network

Terrestrial and airborne users

Up link

Internet

TDRS

Broadcast

Space users
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
true global reach:
• open Internet

• 3 Inmarsat satellites with global coverage up to latitude ±75° (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

mean RSS per day
[01-APR-2002 to 23-AUG-2003]

Mean: 25.5  Mean: 26.9  Mean: 27.1
Std Dev.: 5.6  Std Dev.: 6.3  Std Dev.: 4.5

Mean: 19.2  Mean: 17.8
Std Dev.: 5.8  Std Dev.: 2.5

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- rtg up to 05-Oct-2002
- rtg up to 15-Feb-2003
- rtg for 03Jan01-01Feb15
- rtg for 03Feb01-03Mar15
- rtg for 03Apr01-03Aug23

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Real-Time Aspects, Berne 2004, IGS
JPL RTG vs FLINN orbit diff:
daily mean, median RSS of HCL differences for all SVN

Jan-Dec, 2003

- mean RSS
- median RSS
- median RSS (trend)

HCL diff [cm]

2003 [day]

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GDGPS Real-Time UTPM Estimates

GDGPS real-time - IGS Rapid ypole (0.23 mas rms)

GDGPS real-time - IGS Rapid xpole (0.28 mas rms)

GDGPS real-time - IGS Rapid LODR (0.05 msecs rms)
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
estimated wet zenith troposphere delay at Tidbinbilla, Australia using GOA II

- with JPL FLINN orbits and clocks
- with GDGPS real-time orbits and clocks

rms difference is 0.49 cms

days past 03dec21
Real-Time time transfer accuracy is consistent with that of positioning: nanosec level for dynamic platforms; 0.1 nanosec level for static platforms.

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 than 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
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 must 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.
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

- OK
- Missing
- Failed Rng Ck

PRN 23 groundtracks on 01 Jan 2003

Real-Time Aspects, Berne 2004, IGS
SVN 23 on January 1 2004 (cont)

Real-time 1 sec clock error

Clock error (m)

GPS Time (HH:MM)

0 5 10 15 20

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