A New Centimeter-Level *Real-Time Global* Navigation and Positioning Capability with GPS

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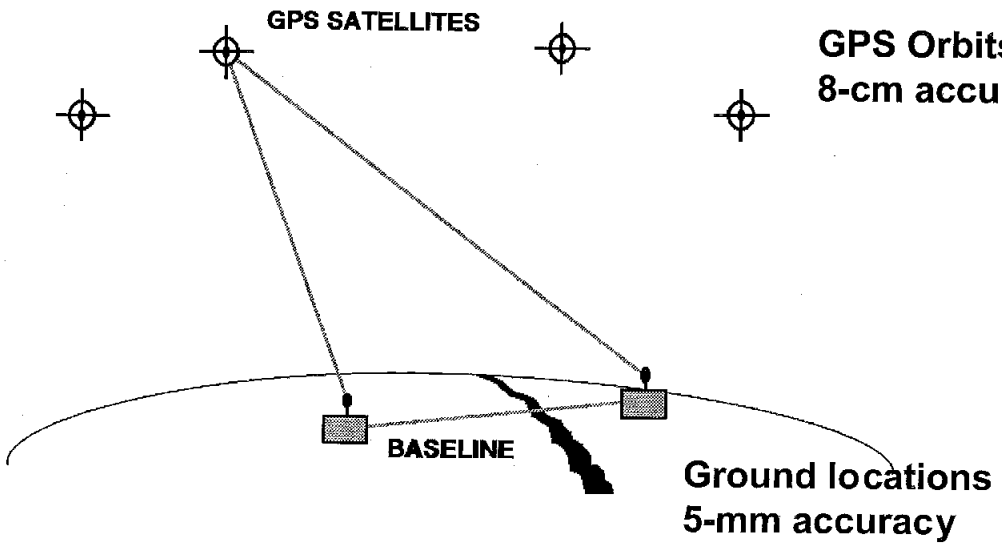
JPL

Overview

- NASA/JPL has developed a new, very precise, global, GPS-based capability for real-time terrestrial and space platform navigation
- The system has been demonstrated on Earth's surface
  - x10 more accurate than other real-time GPS-based systems
  - Space demo likely within one year
- Advantages of the new system for Earth science remote sensing
  - Enables new science products
    - Onboard generation of science data products in real-time
    - Sensor control and reduction of data transmission bandwidth
  - Enables improved environmental forecasting
  - Autonomous and intelligent platform control
  - Operations cost savings -- reduce/eliminate ground processing costs
  - Technology transfer and commercial partnership -- new paradigm for global GPS network

Global Positioning System (GPS) Measurements Applied to Geophysics and Natural Hazards

- NASA contributes about one-quarter of the ≈ 250 GPS tracking stations in the International GPS Service (IGS) global network
- Analyses of their data (non real-time) is interpreted in terms of tectonic plate motions and geodynamics
- High density deployment of GPS sites contributes to the assessment of earthquake hazards (southern California map)



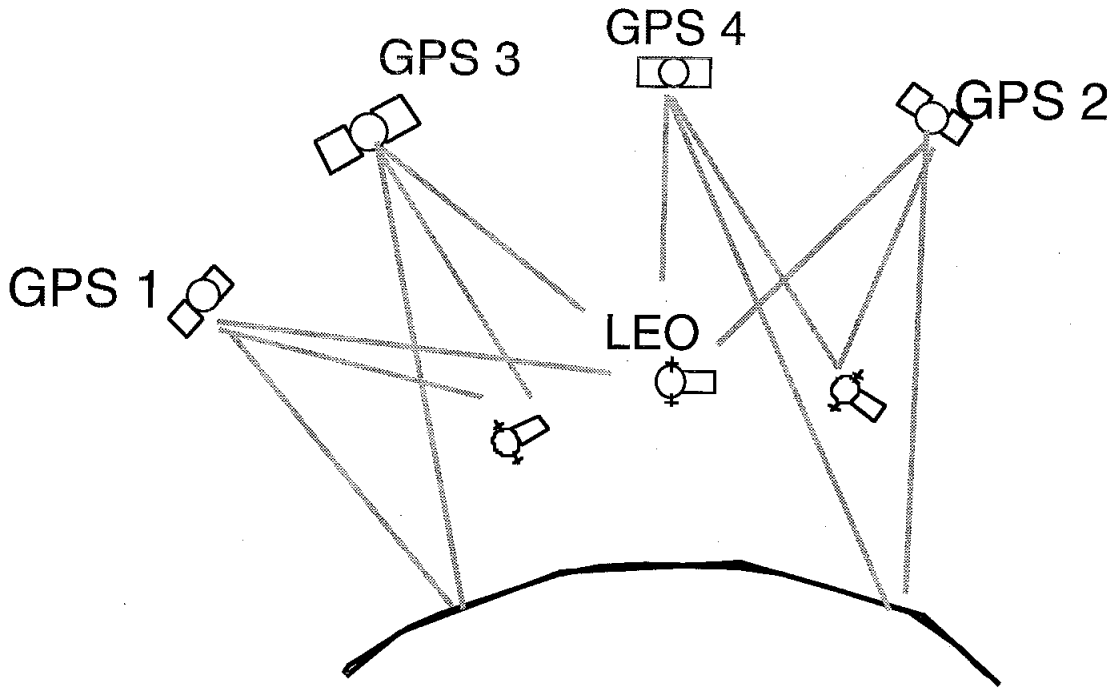
GPS Orbits
8-cm accuracy

Ground locations
5-mm accuracy

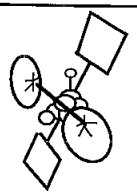
IGS Global Network

Precision LEO Positioning and Timing

- **GPS tracking maintains constant and precise knowledge of relative spacecraft positions & clocks**

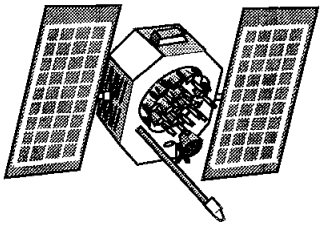


Demonstrated Orbit Accuracies With GPS



Geostationary
36000 km altitude
(TDRS, INMARSAT)

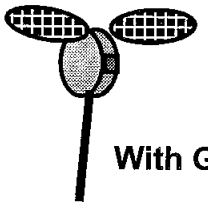
15 m
ground-based tracking



GPS

20000 km
altitude

8 cm (< 40-cm real-time)
operational automated processing

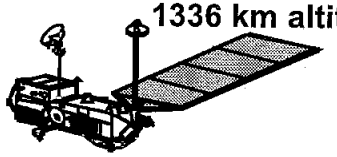


MicroLab/GPSMET
730 km altitude

With GPS < 10 cm

TOPEX/POSEIDON

1336 km altitude

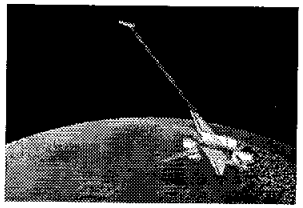


With GPS: < 2 cm radial accuracy

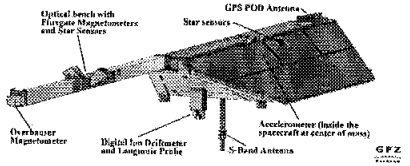
operational automated processing

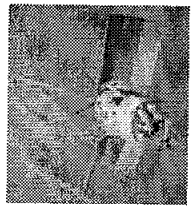
Recent (2000) JPL Blackjack Flight GPS Receiver Results

Shuttle Radar Topography Mission (SRTM): 230-km alt
45-cm orbit accuracy



CHAMP: 470-km alt
< 10-cm orbit accuracy



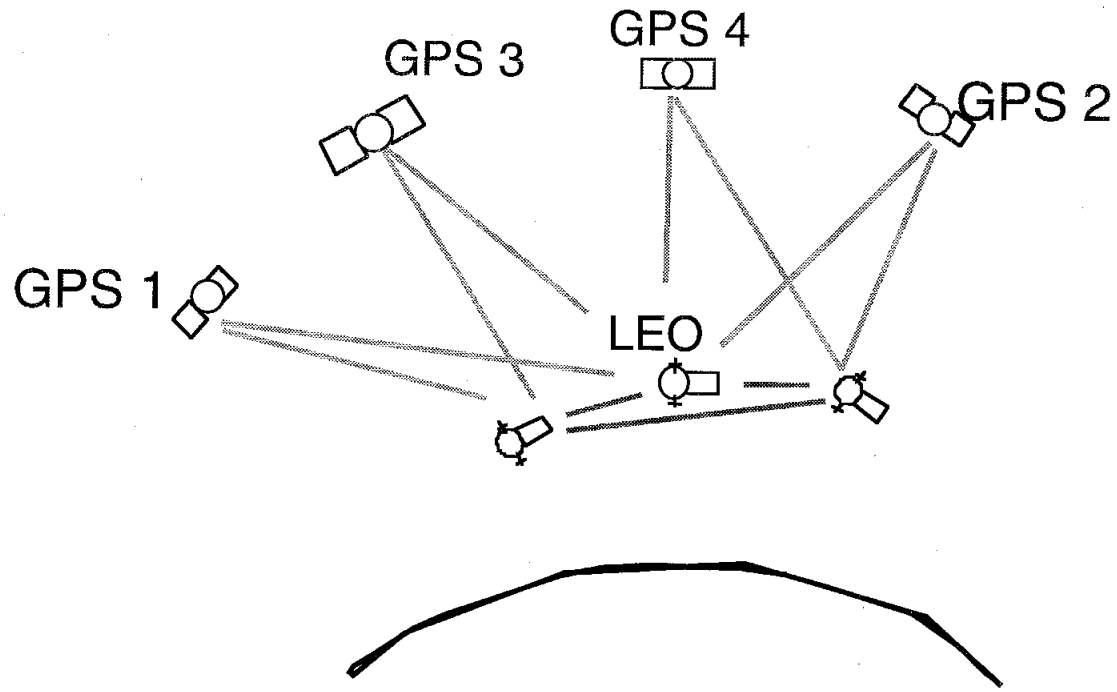


SAC-C: 705-km alt
< 10-cm orbit accuracy

FUTURE GOAL: < 1-cm Orbit Accuracy for LEOs

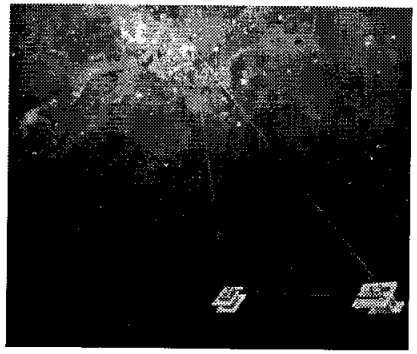
Precision Spacecraft Positioning and Timing

- **GPS and/or LEO cross-link tracking maintain constant and precise knowledge of relative spacecraft positions & clocks**

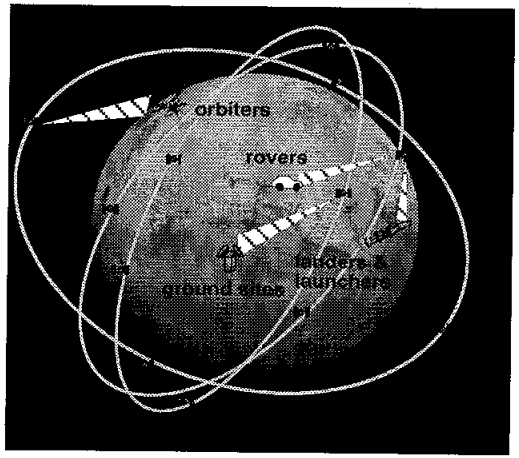


JPL Spacecraft Cross-Link Sensors Under Development for Space Deployments in 2001-2005

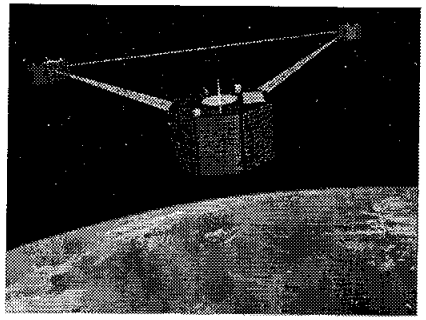
GRACE: JPL GPS Receiver with integrated camera and K-band spacecraft-spacecraft tracking, to provide 1-micron accuracy measurement of range change to improve knowledge of the Earth's gravity field by several orders of magnitude



ST-3: Precision (1-cm) formation flying



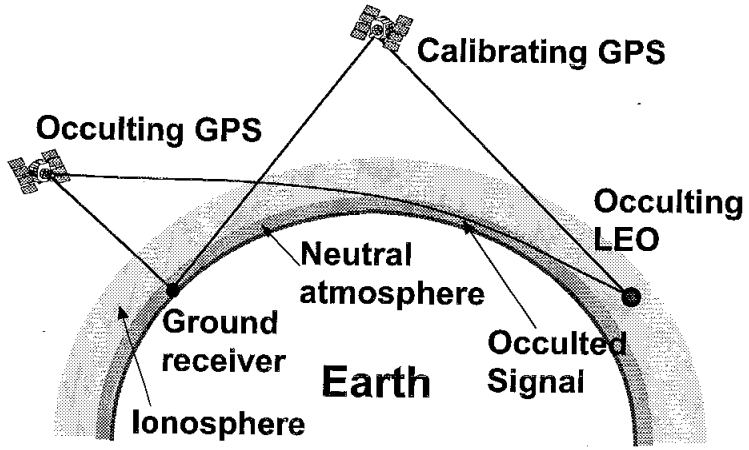
Mars Network Node: Integrated Navigation and Telecommunications



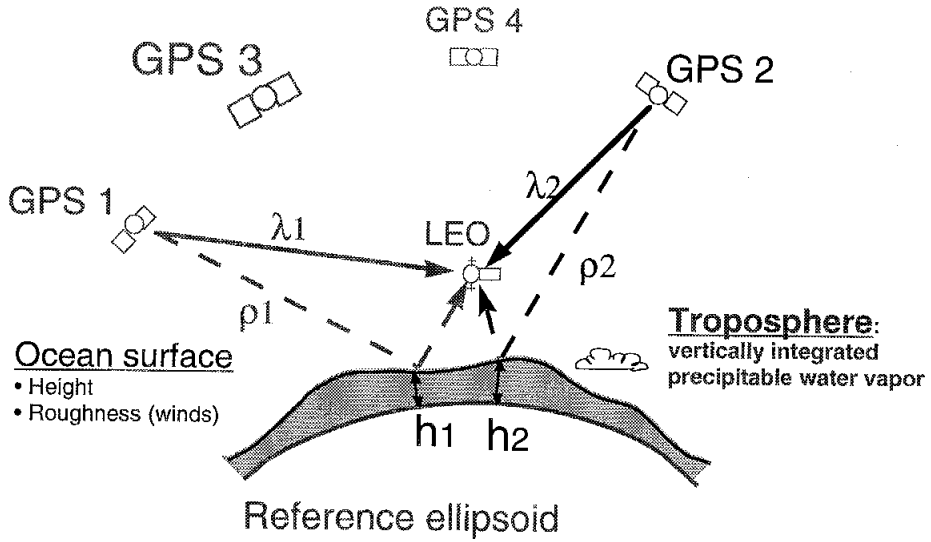
ST-5: GPS-based Constellation Communications and Navigation Transceiver (CCNT) for cross-link ranging and inter-spacecraft telecom in constellation of spacecraft in GEO-transfer elliptical Earth orbit

BACKUP SLIDE

Novel Science Applications



Atmospheric and Ionospheric Remote Sensing and Science



Bi-Static Ocean Reflectometry

Motivation for Real-Time GPS

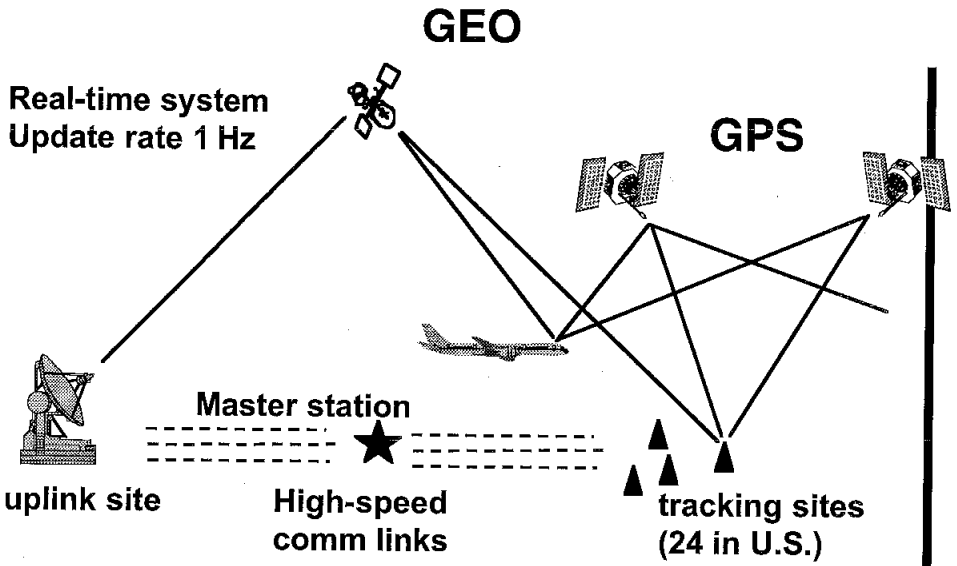
- New operations paradigm for remote sensing with inividual spacecraft and/or constellations
  - Old: track spacecraft one by one, downlink sensor data sets to ground, analyze and process data in extensive ground operations
    - Relatively costly; significant latencies to science products
  - New: treat spacecraft & ground receivers as an extended sensor network, with real-time onboard processing/operations enabling high level of autonomy
    - Dramatically reduces recurring costs and downlink requirements
- Enables new science products and capabilities
  - Real-time onboard science instrument pointing/control in response to events (volcanoes, earthquakes, storms, floods etc.)
  - Precise orbit control
    - Ground track repeats, SAR navigation, cooperative sensor pointing from multiple spacecraft or aircraft (formation flying or platform ensembles)
  - Enables improved environmental forecasting
    - Tactical oceanography (science, agriculture, fishing, marine navigation, and natural hazard monitoring)
    - Atmosphere occultation processing for weather nowcasting
    - Natural hazard monitoring (volcanic inflation, earthquakes)

Motivation for Real-Time GPS (cont.)

- Example: orbit determination operations for Topex/Poseidon
  - $100K/yr for GPS-based precise orbits (1-day latency)
  - $Millions/yr for formal ephemeris operations (laser ranging etc.)
  - Delay to get science products: days to weeks
- New concept: real-time cm-level orbit knowledge available for onboard science data record generation
  - Finished or preliminary science products available in real- or near-real time
  - Exploits powerful embedded processor in Blackjack GPS receiver (PowerPC)
- Operational processing of GPS occultation data from LEOs a key beneficiary due to huge raw data volumes and need for minimal latency for assimilation into operational weather forecasting models

Task: GPS Wide Area Augmentation System (WAAS) Implementation

California Institute of Technology

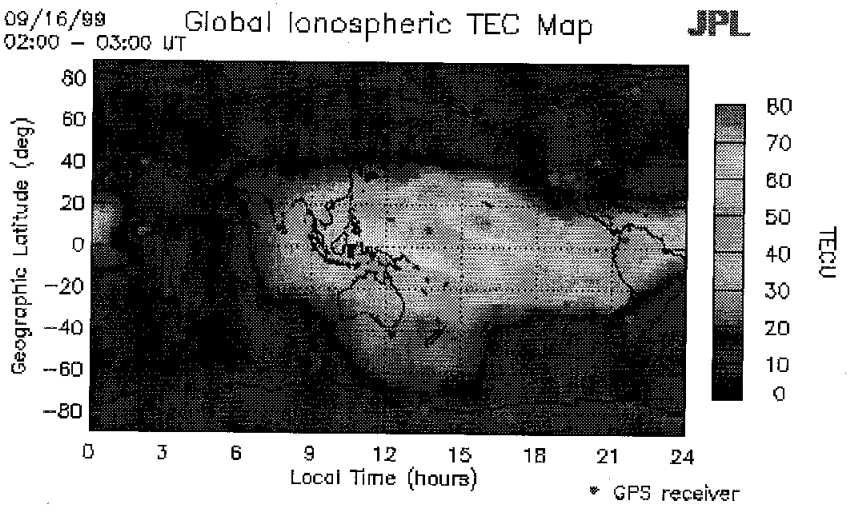


Task Purpose/Objectives:

- Deliver real-time software prototype to DOT/FAA for new GPS-based precision navigation system (WAAS) for aviation.

Major Products and Deliverables:

- Real-time software for GPS orbits, clocks, and ionosphere maps
- New GPS and safety algorithms



Customer Relevance:

- Improve airline navigation accuracy by orders of magnitude; enhance aviation safety in U.S.
- Save $12B+ in next decade in fuel and airport costs

NASA Relevance:

- Real-time, autonomous space navigation
- Onboard science data product generation
- Real-time natural hazard monitoring
- Pathfinder for the Mars Network Infrastructure.

Real-Time GPS Technology Development Progression at JPL

1995 White Paper (WADGPS)
Real Time GIPSY (RTG)

1996 RTG is licensed to SATLOC
RTG is licensed to Raytheon (WAAS)

1997 NASA-FAA Inter-Agency Agreement

1998 2nd RTG license to Raytheon (MSAS-Japan)

1999 Internet-based Global Differential GPS (IGDG)

2000 Global Differential GPS with IGDG operational

IGDG wins NASA Software of the Year Award

Initial ground positioning
Demonstrated 50-cm (97)

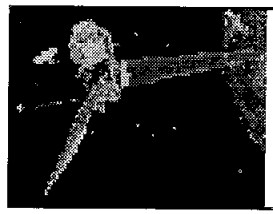
Automobile positioning
Demonstrated 80-cm (98)

Aircraft real-time Wide Area Differential navigation:
NASA SAR plane (98)
and FAA/WAAS (99)

Demonstrated 40-cm vertical 30-cm horizontal (98)

Internet-based Global Differential (IGDG) (00)
Real time ground positioning
Demonstrated 10 cm horizontal, 20 cm vertical accuracy

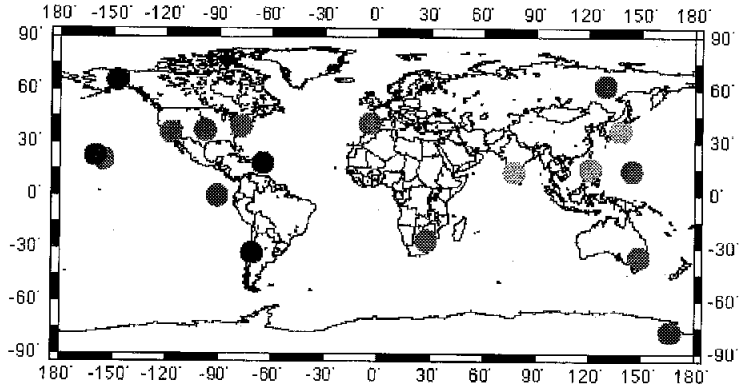
X-33/RLV IGDG real-time positioning demo (01)
Goal: sub-meter accuracy



Real-time autonomous positioning and navigation for Earth orbiters (00-01)
Goal: sub-10-cm accuracy

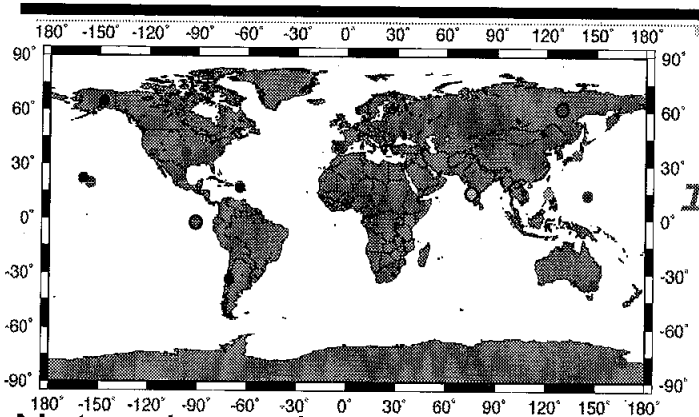
Precise Real-Time Global GPS Navigation

- **JPL has established a global, real-time, GPS ground network**
  - **Real-time user accuracies: 8 cms RMS horizontal, 20 cms RMS**
    - **~ 10 times better than best available commercial and military systems**
  - **30-40 cms 3D (RSS) global GPS orbits, in real-time**
  - ***Winner of the 2000 NASA Software of the Year Award!***
  - **NASA, DoD and commercial applications being studied, including:**
    - **X33/RLV navigation (X33 flight demo planned)**
    - **Automated LEO navigation and onboard science data product generation**



AOA Benchmarks Turbo-Rogues Ashtech Z-12s

JPL's New Global Global Capability Supports 10-20 cm User Accuracy, Anywhere, Real-Time



Network receivers running IGDG

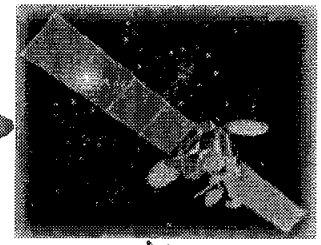
JPL processing center running IGDG

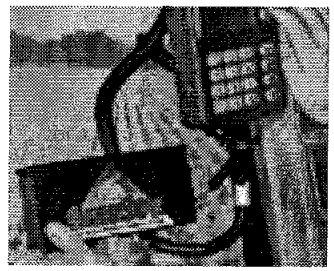
Internet

Broadcast

Internet

Broadcast





Remote user running IGDG

Revolutionary new capability:
decimeter real time positioning, anywhere, anytime

Capability		JPL's IGDG	Un-augmented GPS	Others (WADGPS services)
Coverage:	Global	Yes	Yes	No
	Seamless	Yes	Yes	No
	Usable in space	Yes	Yes	No
Accuracy:	Kinematic applications	0.1 m horizontal 0.2 m vertical	5 m	> 1 m
	Orbit determination	0.01 – 0.05 m (goal)	1 m	N/A
Dissemination method		Internet/broadcast	Broadcast	Broadcast
Targeted users		Dual-frequency	Dual-frequency	Single-freq.

For more info:
http://gipsy.jpl.nasa.gov/igdg

Summary

- **A significant advance in real-time GPS technology has been achieved**
  - **Decimeter real-time global navigation accuracy**
  - **Few-cm real-time low-Earth orbit determination may be realized within a year or so**
  - **Enable new Earth science capabilities**
  - **Real-time operations enable sensor-web type architectures for extended ground+space platform networks with extensive connectivity**
  - **Anticipate lower operations costs in connection with remote sensing on space platforms, and new operations paradigm incorporating near-real time delivery of science data to PIs**