The NASA Global Differential GPS System (GDGPS) and The TDRSS Augmentation Service for Satellites (TASS)

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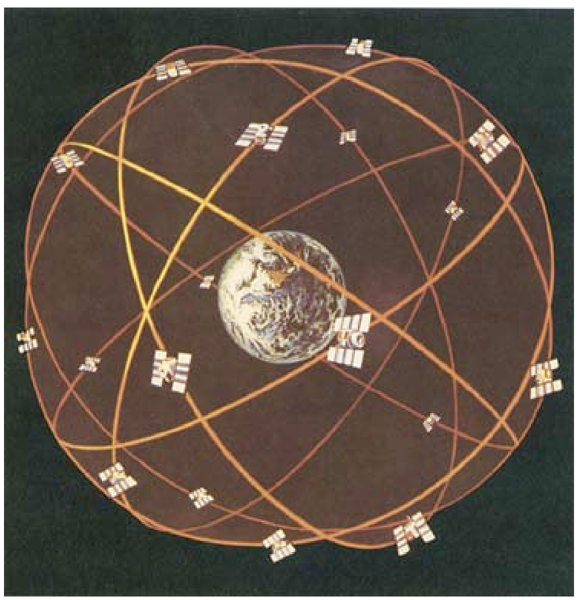
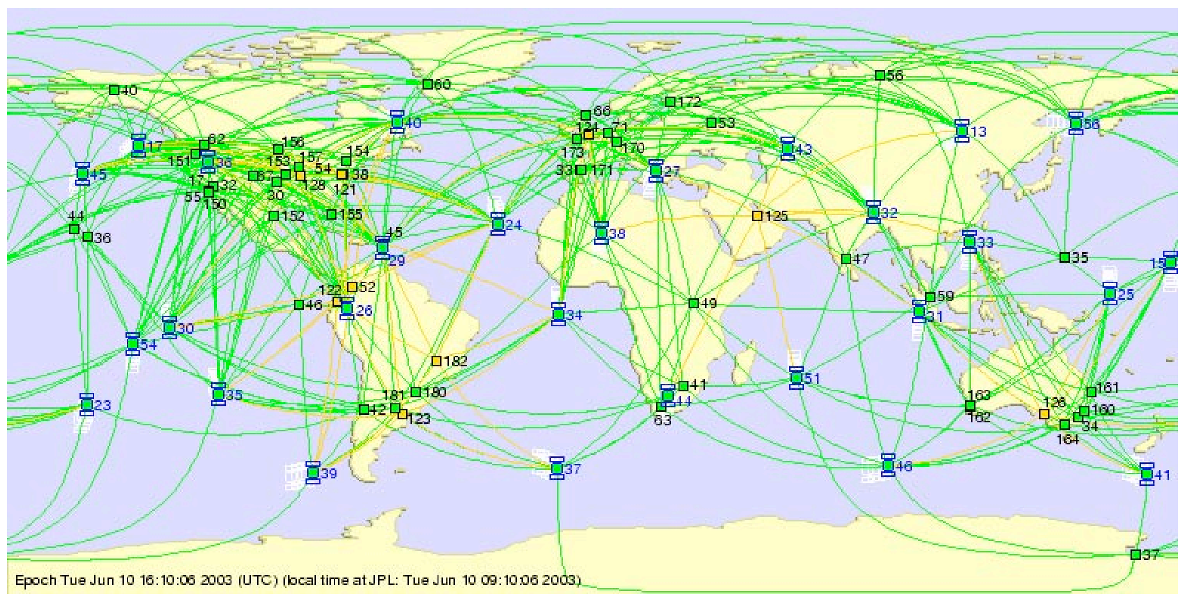
NASA





NASA's Global Differential GPS System


Terrestrial and airborne users

Land lines

Iridium
Inmarsat

GDGPS Operations Center

Uplink

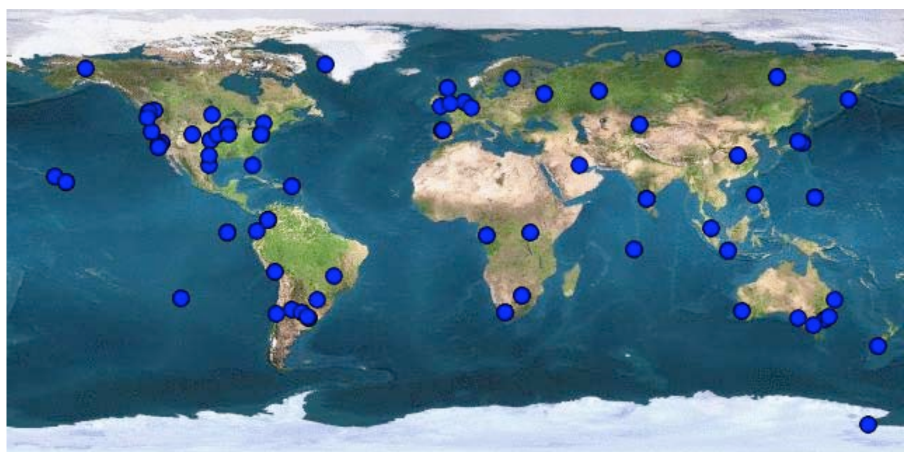
TDRS

Frame

Internet

Broadcast

GDGPS real time network



Space users

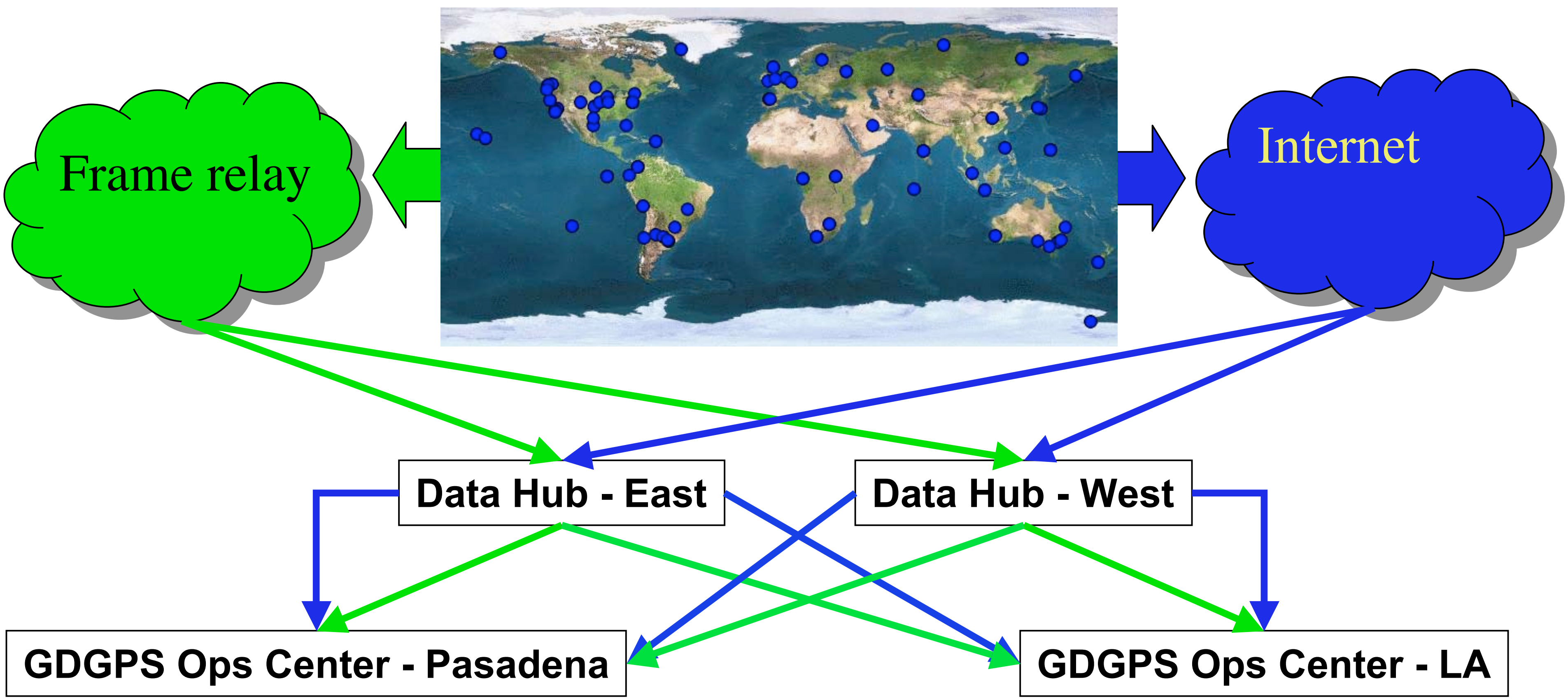
Fully operational since 2000

For more information see:

http://www.gdgps.net/

Robust Network Architecture

- Reliability through redundancy: **No single points of failure**
- Architecture integrates **dedicated comm lines** with multiple **internet channels**
- Automatic fault detection and data rerouting ensures redundancy even during failures
- USNO Master Clock provides system reference time through two sites



Mature and Reliable Ground Operations

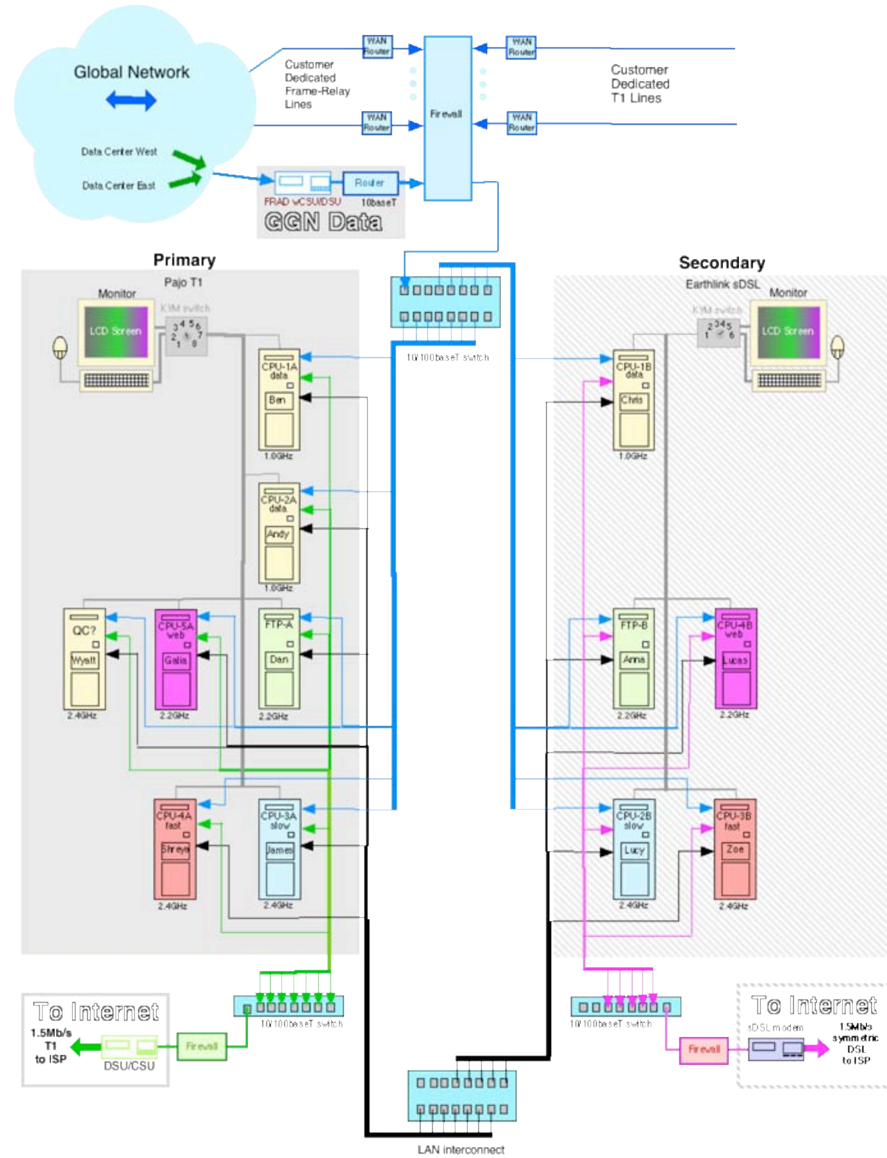
- Triple redundancy for high reliability even during system maintenance

- Multiple user access channels
  - Secure leased lines
  - VPN
  - Open internet
  - Modems

- Global reach
  - Iridium
  - Inmarsat
  - TDRSS (for space applications)

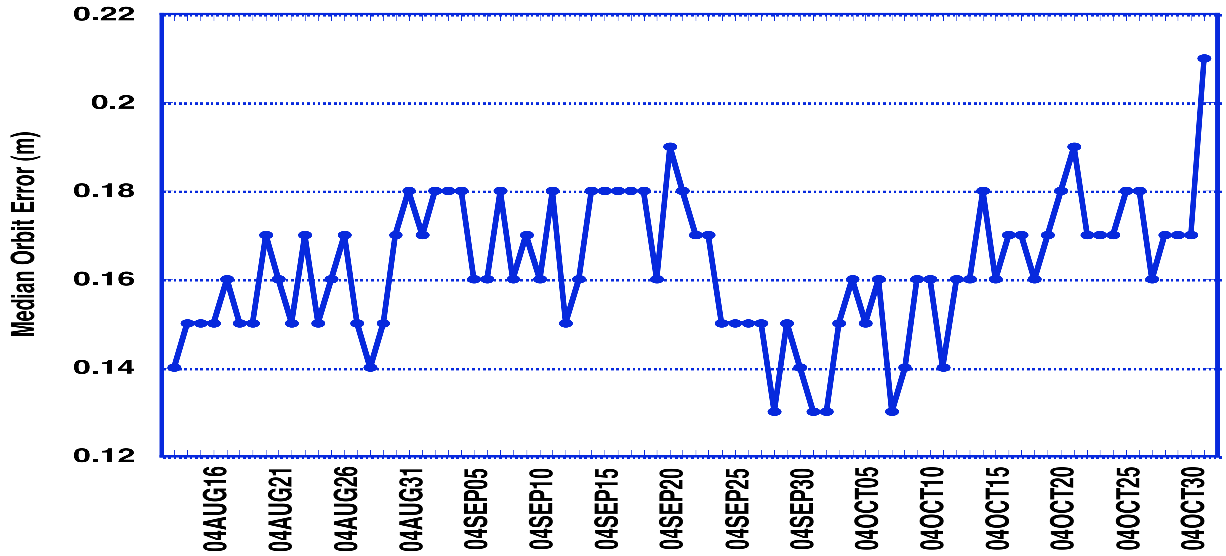
- Continuous Web monitoring in the public domain

- **99.999% reliability since 2000**

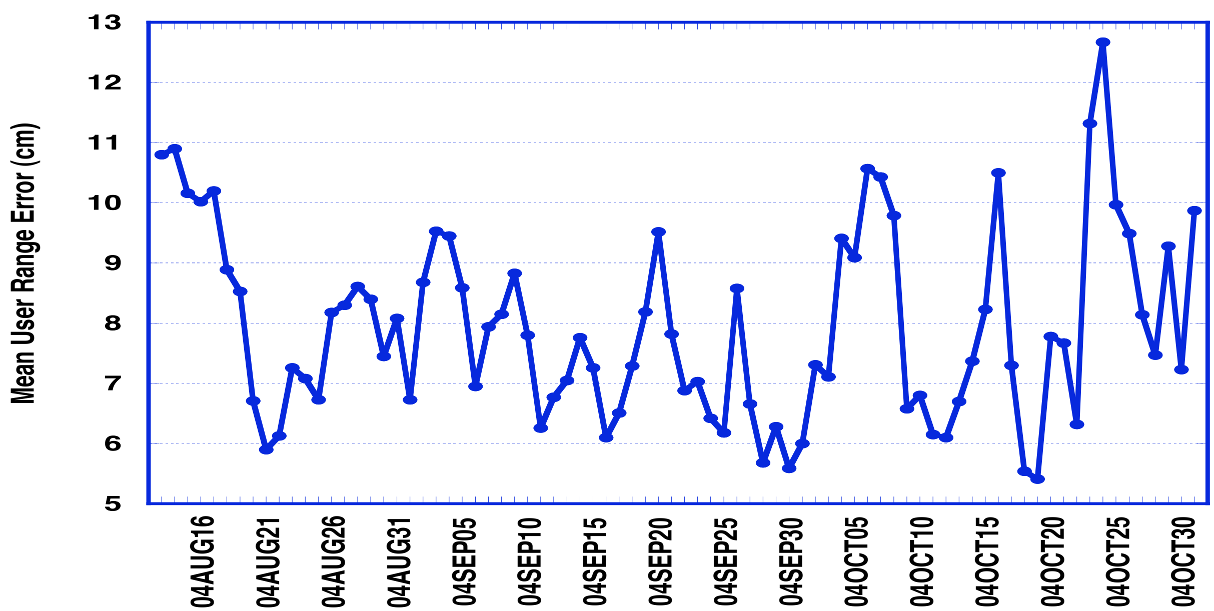


GDGPS Ephemeris Accuracy

Median daily 3D RMS orbit error

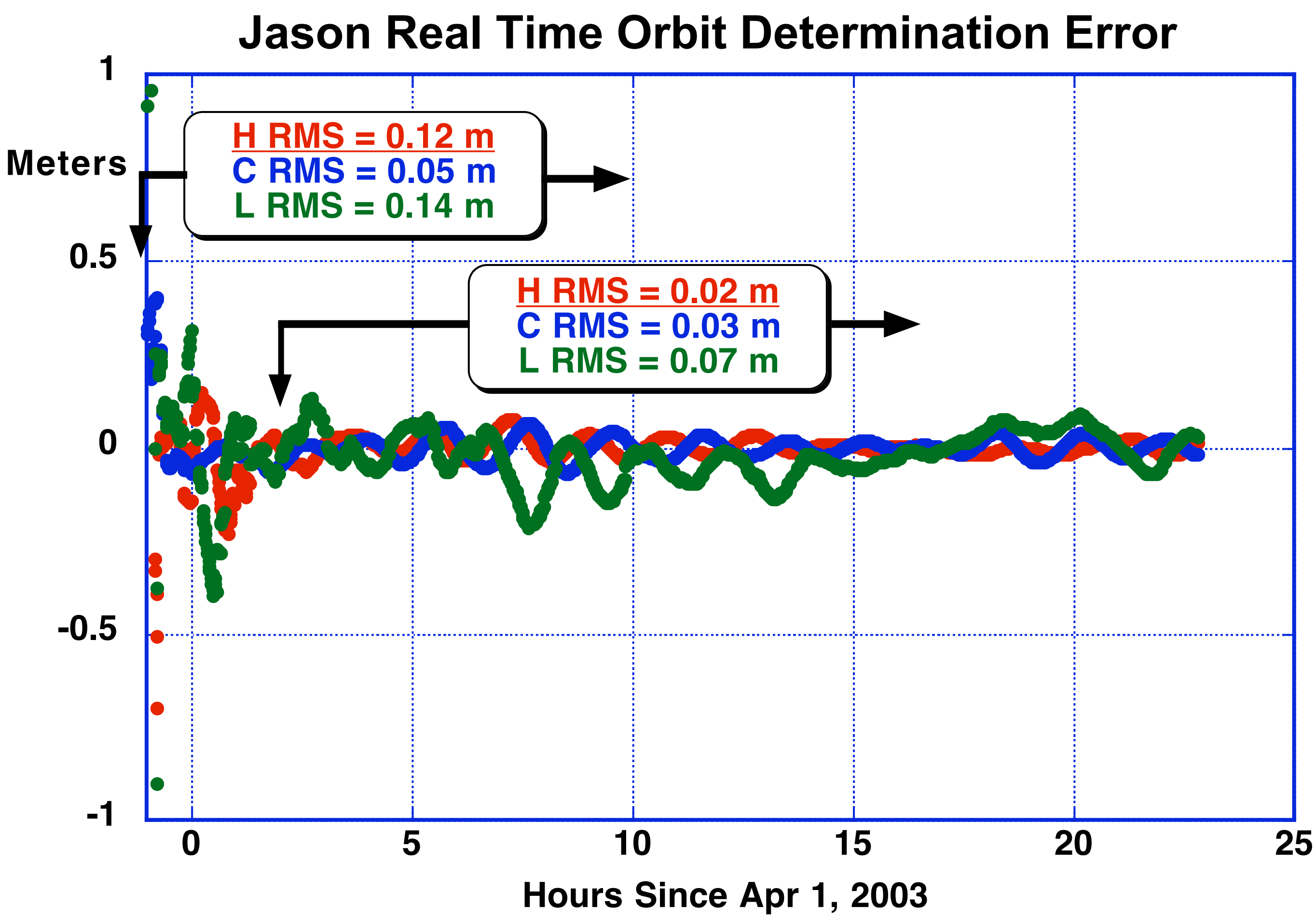


Mean daily user range error (URE)



Jason: Real Time Science Quality Orbits

Jason-1: Radar altimeter for precise oceanography at 1300 km altitude



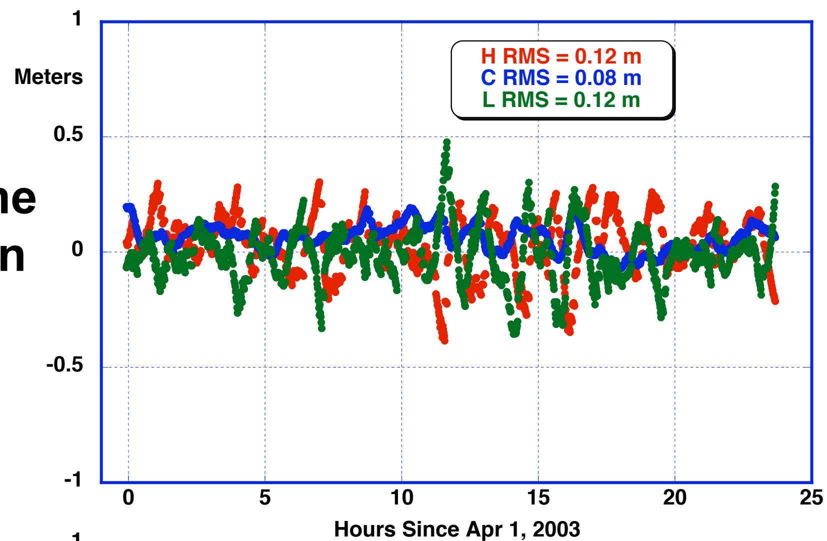
Science requirement: 2.5 cm RMS radially

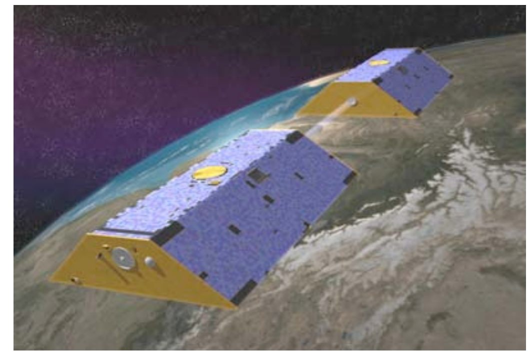
Truth: sub-cm RMS accuracy for radial coordinate

GRACE: Challenging Dynamic Environment

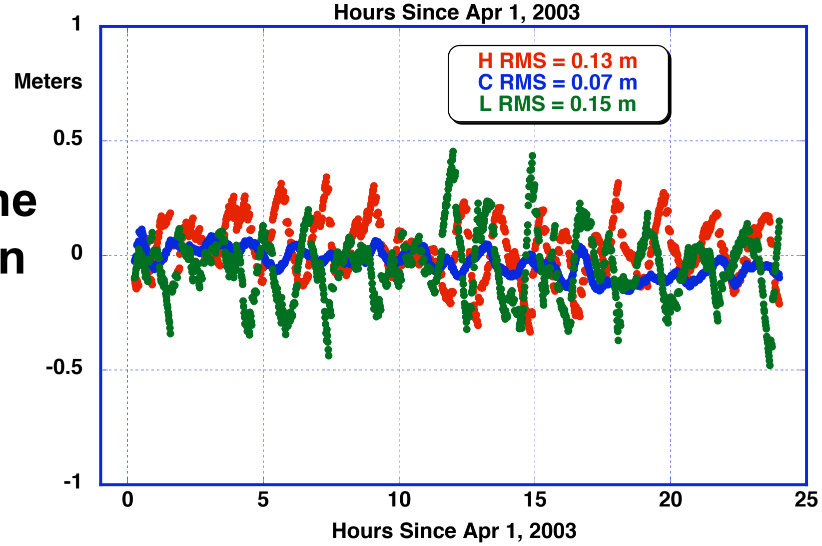
GRACE: Twin satellites with cross-link ranging for gravity recovery at 480 km altitude

GRACE A Real Time Orbit Determination Error





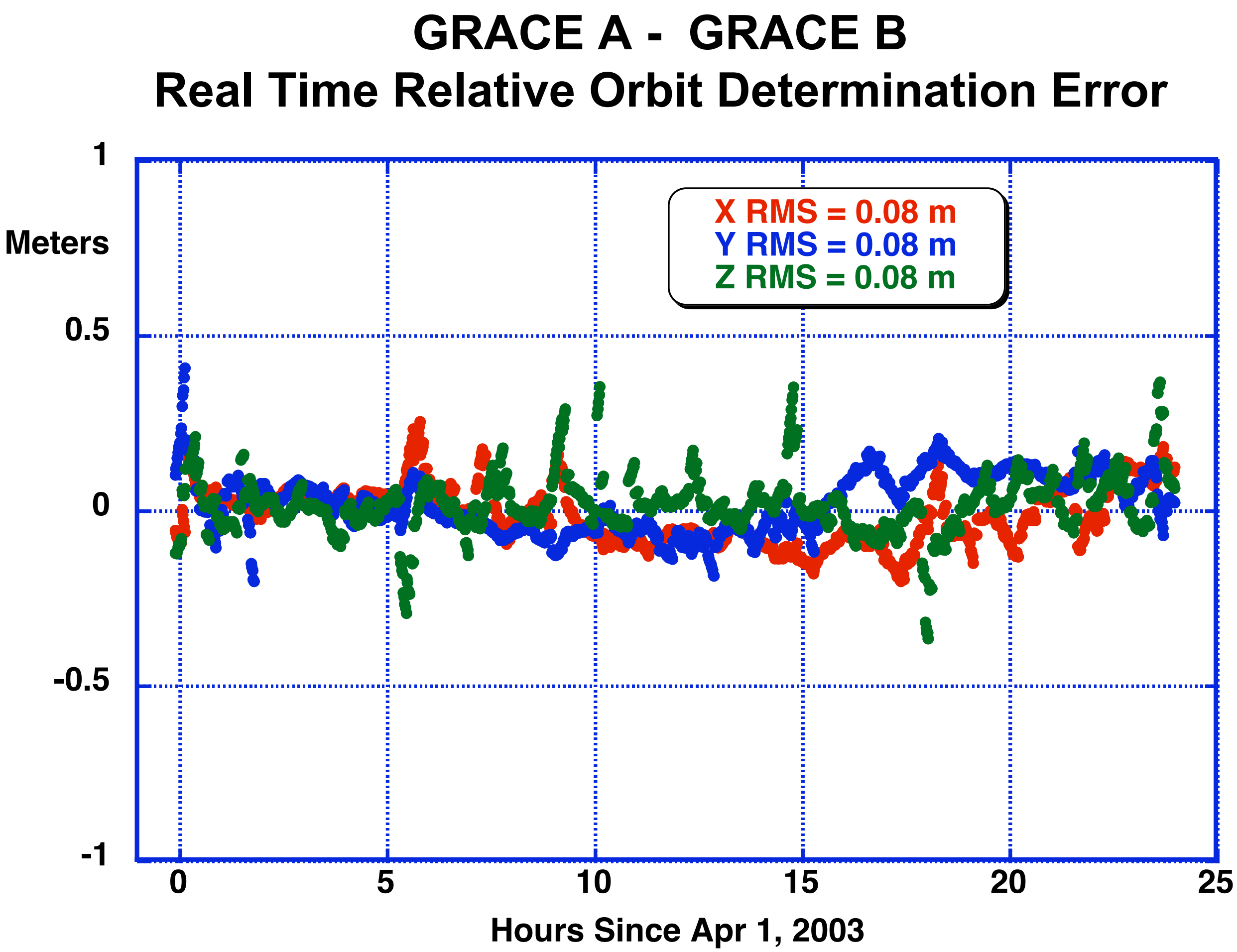
GRACE B Real Time Orbit Determination Error

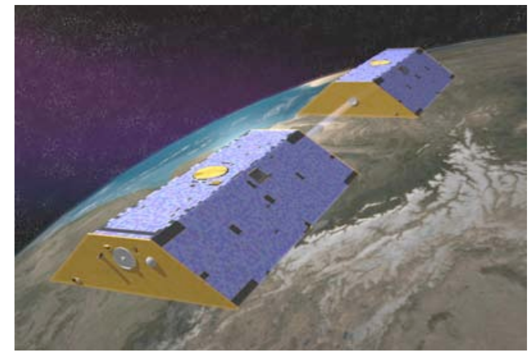


Truth: 2-3 cm RMS Accuracy for all coordinates

GRACE: Relative Positioning

GRACE: Twin satellites with cross-link ranging for gravity recovery at 480 km altitude

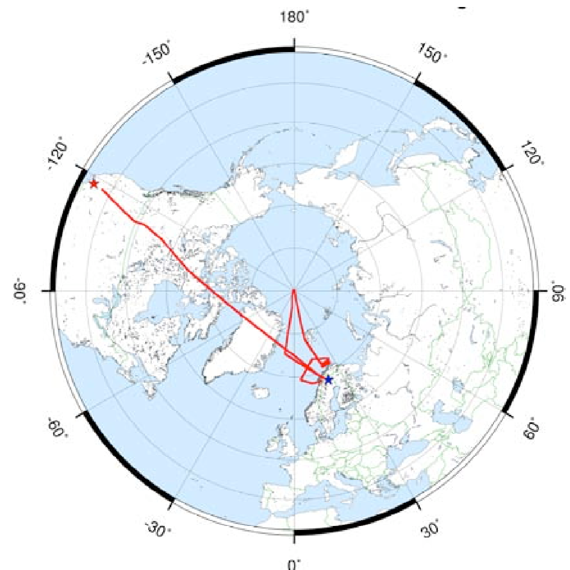




Truth: 2-3 cm RMS
Accuracy for
all coordinates

Precision Positioning for Airborne Applications

Extensive flight tests
- North America, February - September 2002: NASA DC-8 AirSAR
- Greenland, May 2002: NASA P-3 LIDAR
- Sweden, polar region, February 03: NASA DC-8
- North America, August 2003: Proteus UAV (first attempt at repeat pass with GDGPS)



Performance validation by comparisons with:
- Post processing (precise orbits + smoothing)
- Independent local area differential techniques
- Laser ranging

Consistent Accuracy:
10 cm RMS Horizontal
20 cm RMS Vertical

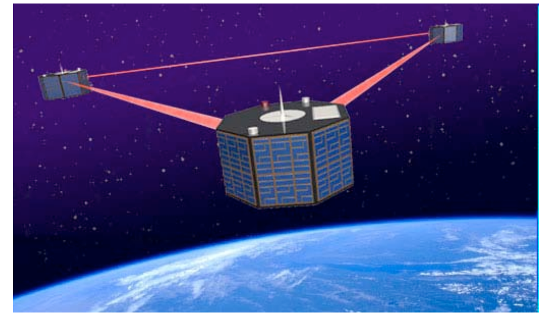
GDGPS aviation payload

PROTEUS HALE AIRCRAFT (SCALED COMPOSITES)

Gold Standard for Accuracy and Reliability

- Broad array of real-time products and services
- Seamless global coverage
- Unparalleled accuracy on the ground, in the air, and in space

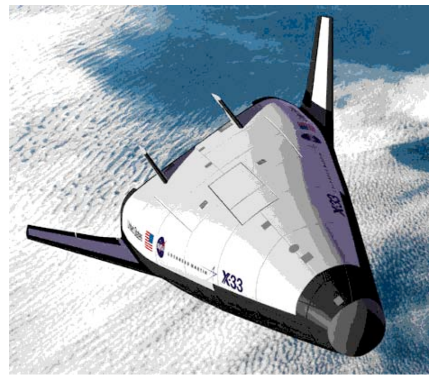
Value of GDGPS and TASS to NASA and Society



- Autonomous operations in Earth orbit to enable smart sensor webs
- Onboard science processing to reduce communications bandwidth
- Repeat pass SAR interferometry and long-baseline interferometry
- Low cost formation flying

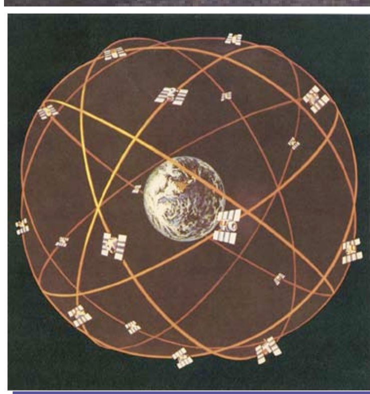
- Enable extending GPS infrastructure to the Moon via TDRSS

- Safe proximity operations for NASA missions
- Safe landing for next generation shuttle
- GPS integrity for Shuttle



- Timely monitoring and response to natural hazards
- NRT sea surface height

- Airborne science, UAV ops
- Dryden plans to offer GDGPS services on all platforms

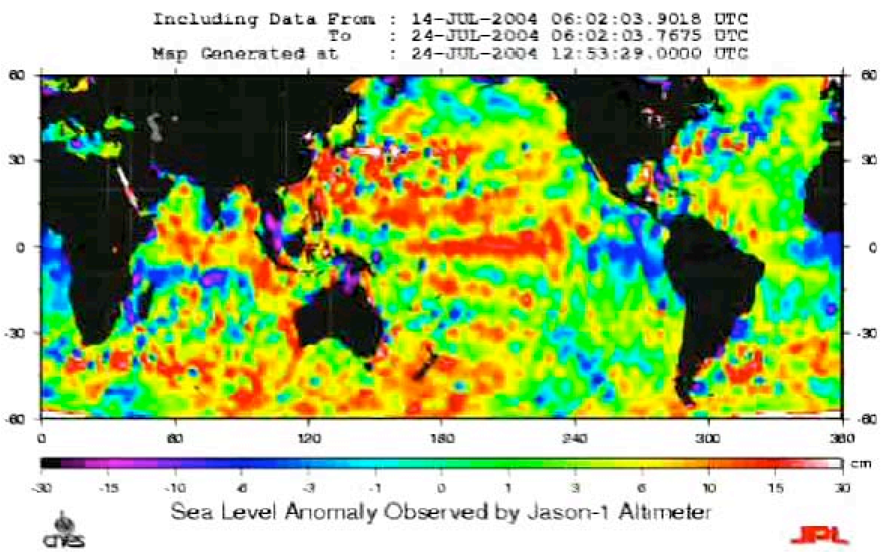


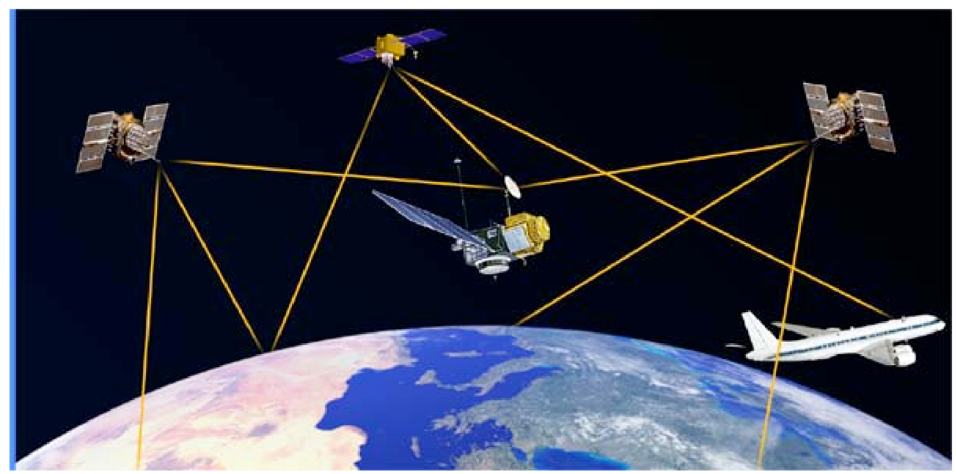
Many global security applications
- GPS integrity monitoring
- GPS enhancements

Many commercial applications

Support for NASA Missions and Projects

- Media (tropo, iono) calibration at DSN sites in support of time-critical operations
  - MER EDL, Cassini orbit injection
- Pre-processor for all of JPL’s operational GPS orbit determination
- Rapid LEO POD analysis after orbit insertion, configuration changes, maneuvers
- Real time on-board positioning for AirSAR radar system calibration
- UAV-SAR on-board, real-time positioning for flight control of repeat pass interferometry
- Near-real time Jason orbit determination and sea surface height

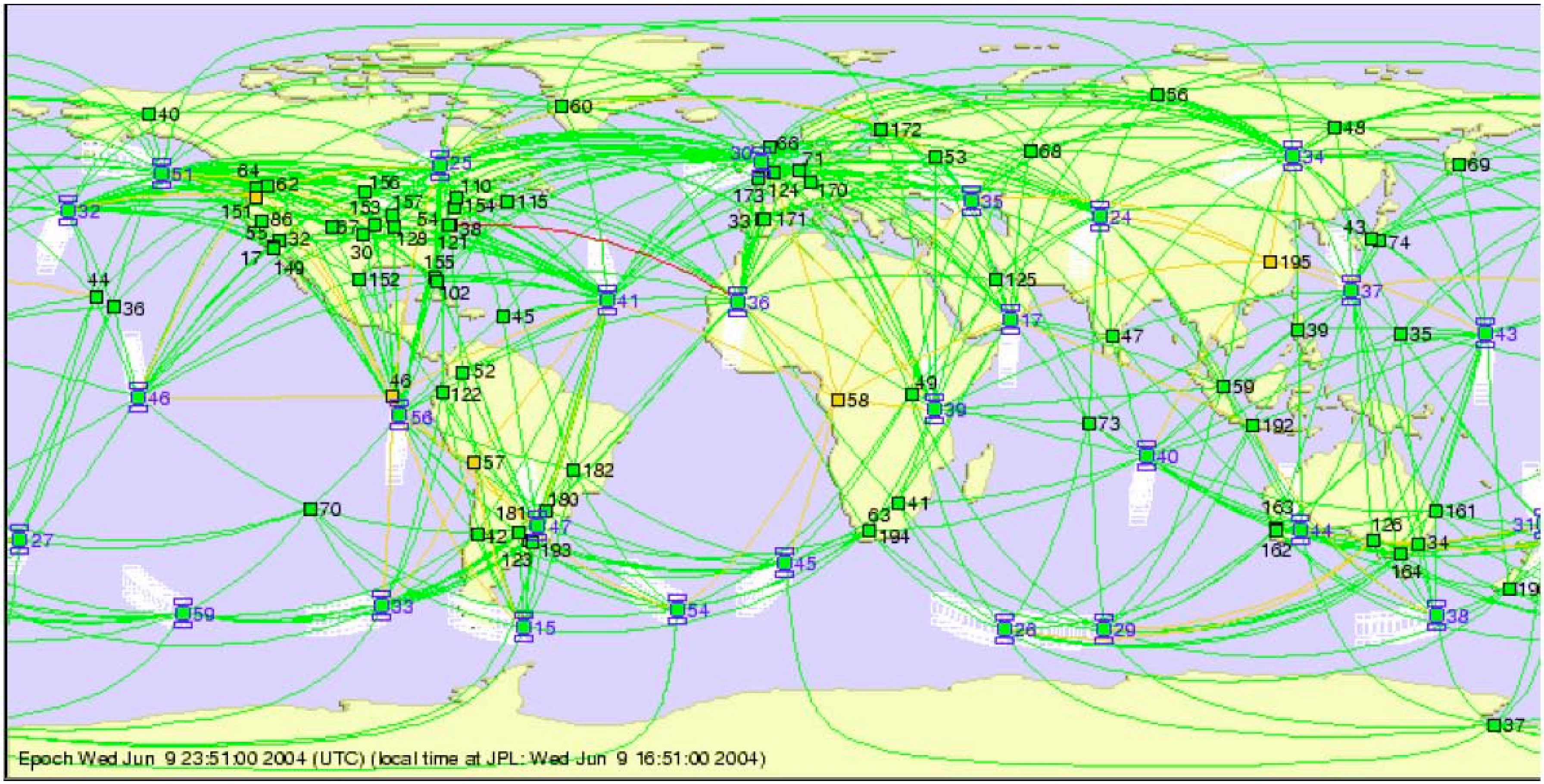




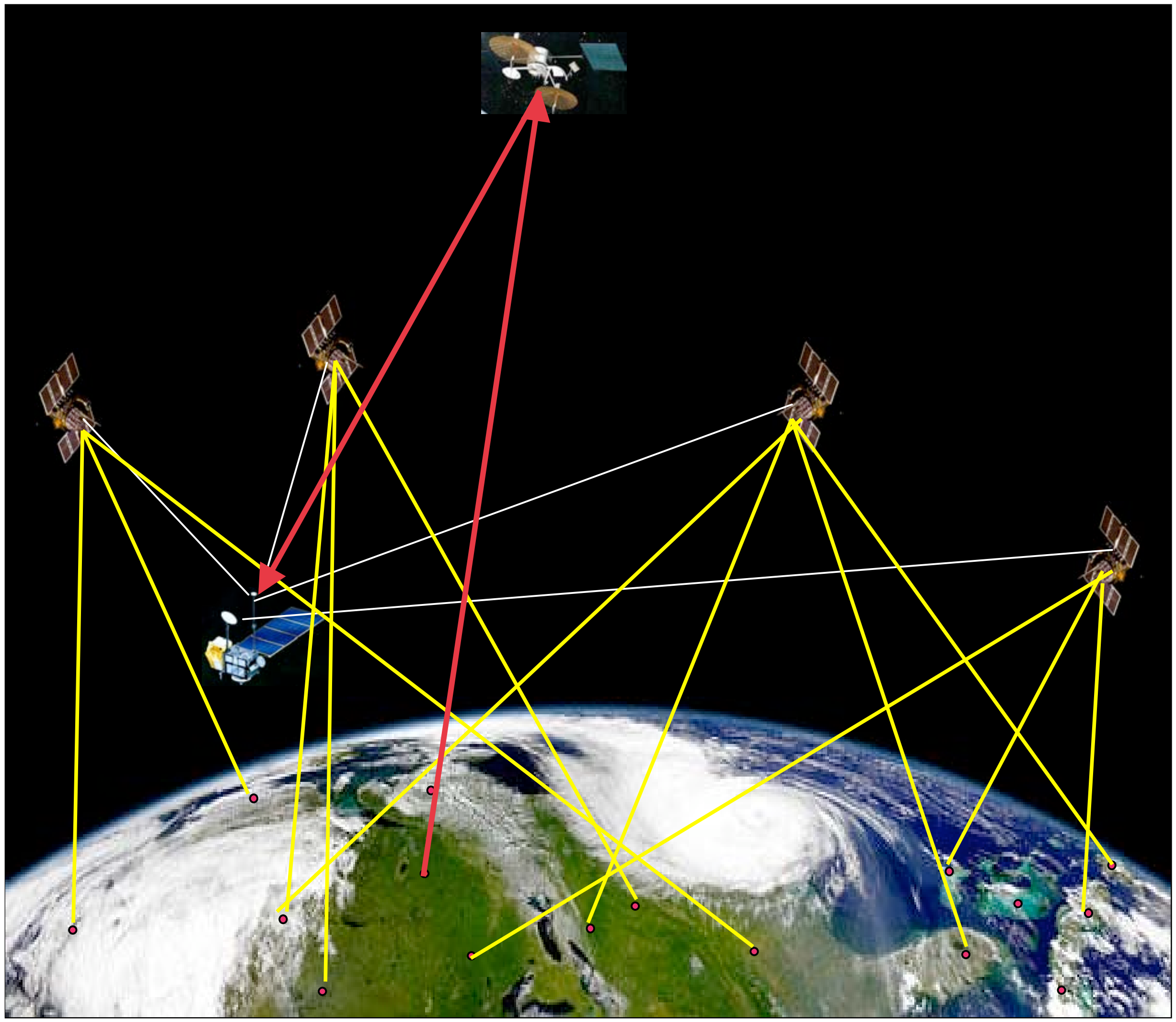
Uniquely Powerful GPS Monitoring

The NASA Global Differential GPS system is providing real-time global GPS performance/integrity monitoring services to operational GPS at the U.S. Air Force

With more than 70 real-time tracking sites, the GDGPS System tracks each GPS satellite by at least **9 sites**, and by **18 sites** on average, enabling robust, real-time GPS performance monitoring with **4 sec** to alarm



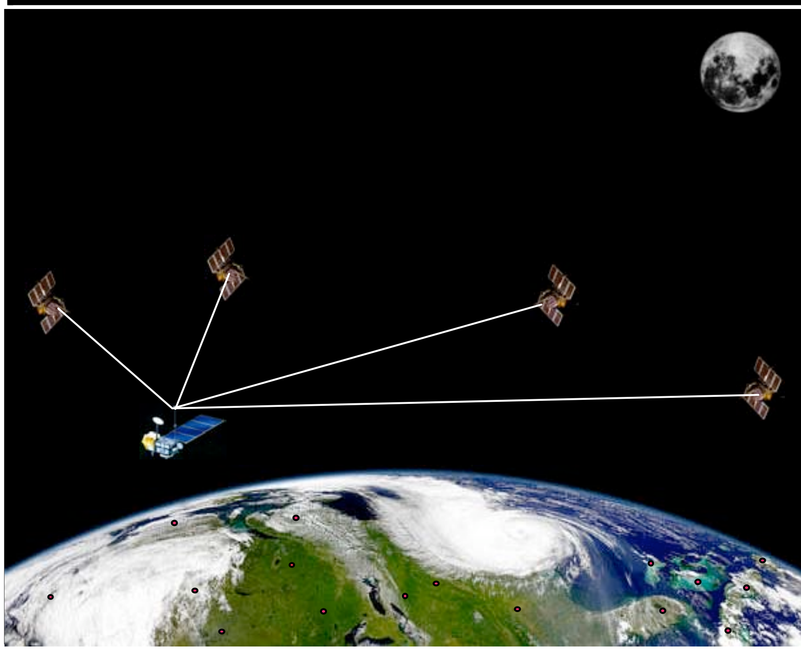
TDRSS Augmentation Service for Satellites (TASS): Integrating NASA's Ground and Space Infrastructures

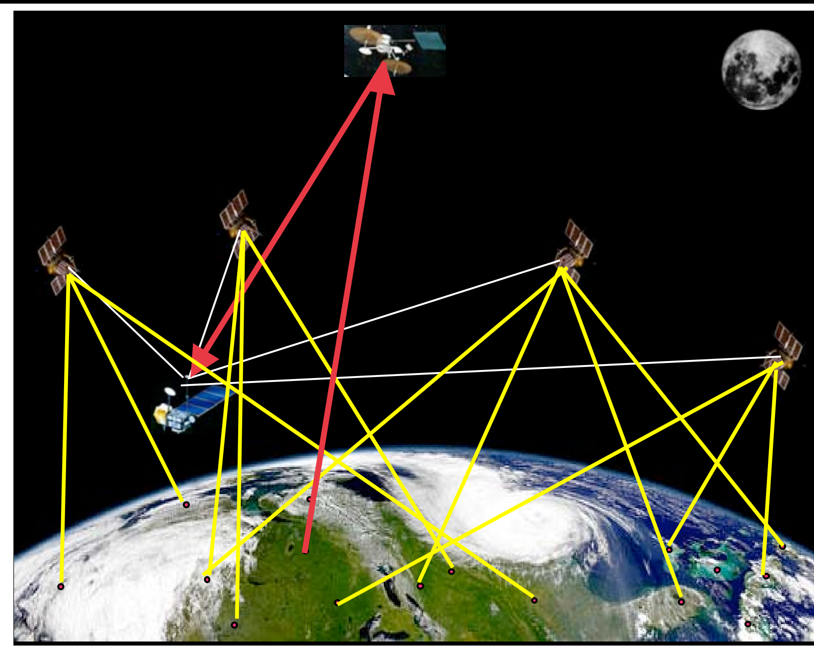


Revolutionary New Capabilities in Orbit

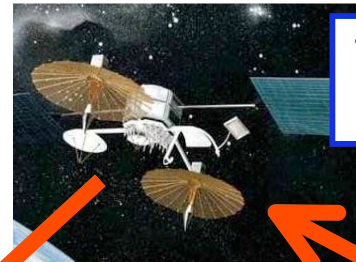
Enabling precise autonomous operations near earth

	State of the Art (unaugmented GPS)	**GDGPS**
Real-time orbit determination	1-5 meters	**0.1 - 0.3 m**
Real-time time-transfer	~10 nsec	**~1 nsec**
Integrity **(GPS malfunction flags)**	Not available	**Included**





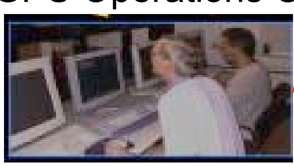
TASS Architectural Components



TDRS
- 3 element array for wide beam

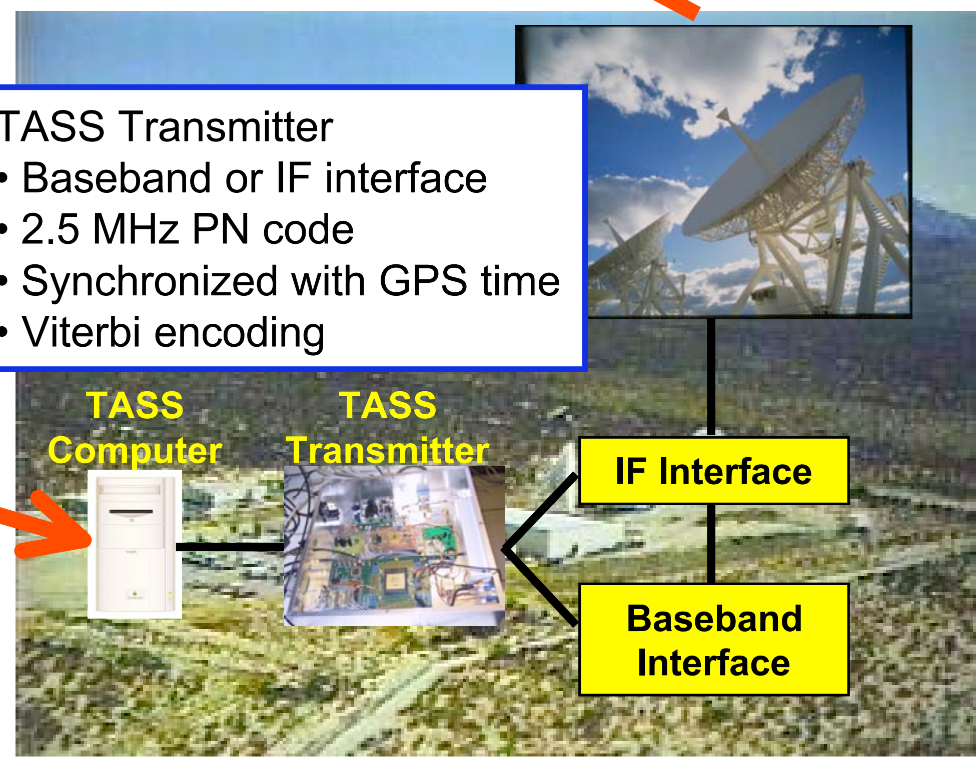
TASS message
- 0.5 Hz GPS corrections
- 5 sec integrity alarms
- Earth orientation
- Solar flux
- Data authentication

GDGPS Operations Center

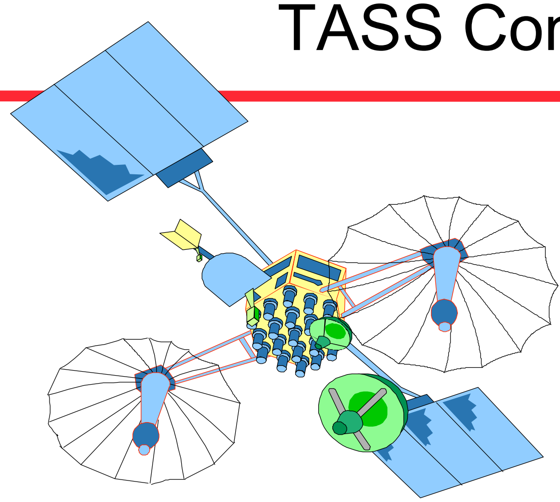


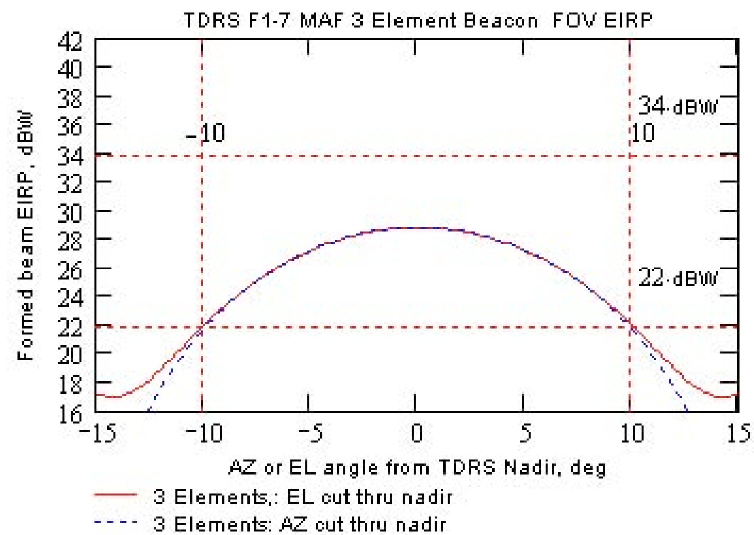
GDGPS Network

TASS Transmitter
- Baseband or IF interface
- 2.5 MHz PN code
- Synchronized with GPS time
- Viterbi encoding

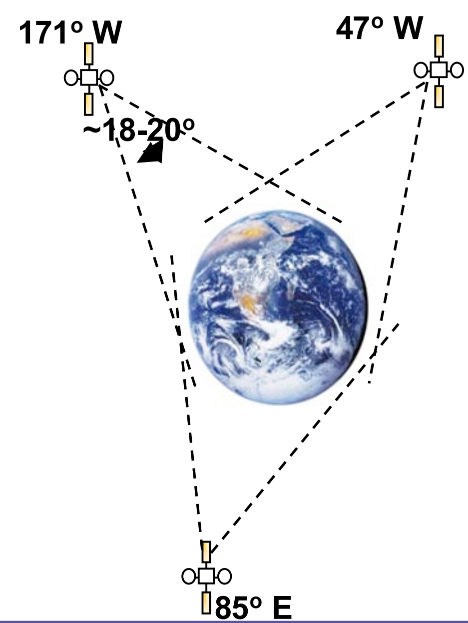


TASS Configuration





- New TDRSS global beam designed
  – Element phasing controlled via upload commands
  – Fixed beam ~ ± 9 - 10 º ; covers altitudes to ~ 1000 km
- 24 x 7 S-band broadcast from three TDRS will provide global coverage
- Multiple Access broadcast
  – 2.5 MChips/sec PN code modulated / BPSK data stream
  – Unique PN code per TDRS synchronized with GPS
  – 512 bps data rate including rate 1/2 FEC
- Next Generation TDRS will be more capable
  – Wider beam for better polar coverage
  – Stronger signal



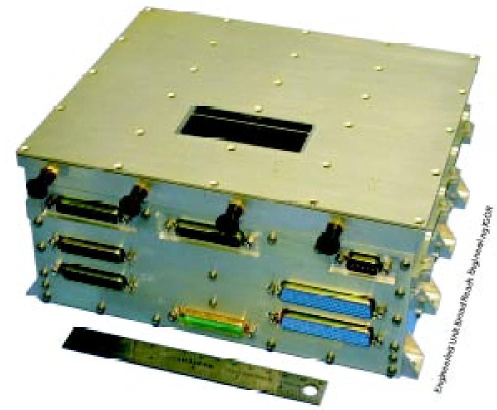
TASS Broadcast Message

- Unique PN code per satellite enables ranging to TDRS
- TDRS ephemeris broadcast
- 256 bps (512 sps with rate 1/2 Viterbi encoding)
- GPS orbit and clock corrections at 0.5 Hz
- Integrity info at 1 Hz with 5 sec latency
- Earth orientation and solar flux to enable autonomous orbit prediction and planning
- Supports encryption and authentication

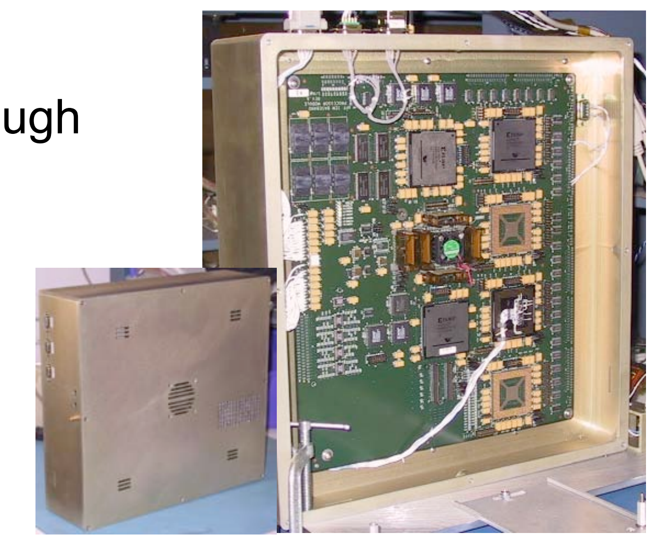
				Detail for block #'s 1-31										
Field	Number of bits	Qty		Max values	Scale Factor		Range	Unit	Resolution		Has sign bit?	Has NAN value?	Default or NAN	Meaning
Preamble	8	1					TBD				No	No	Always defined	Message synchronization preamble
Message block #	5	1		31			0-31		1		No	No	Always defined	Corresponds to PRN #
Time tag	11	1		2047			0-1799		1		No	No	Always defined	GPS time modulo 30 mins (1800 sec)
TDRSS ID	3	1		7			0-3				No	No	Always defined	TDRSS Satellite ID
IODE	8	1		255			0-255		1		No	No	0	Issue Of Data, Ephemeris
Orbit X, Y, Z	12	3	+/-	2047	128	+/-	15.9921875	m	0.0078125	m	Yes	Yes	-0 or 100000000000	Orbit correction to the ECEF X, Y, Z position from the broadcast ephemeris, at time tag
Orbit X, Y, Z dot	6	3	+/-	31	8192	+/-	0.00378418	m/s	0.00012207	m/s	Yes	Yes	-0 or 10000	Rate of change of the X, Y, Z orbit correction at time tag
Meter clock	7	1	+/-	63	1	+/-	63	m	1	m	Yes	Yes	-0 or 1000000	Meter-level clock correction
Cm clock	8	16	+/-	127	128	+/-	0.9921875	m	0.0078125	m	Yes	Yes	-0 or 1000000	Cm-level clock correction. PRN's 1-16 on even seconds and PRN's 17-31 on odd
Integrity bits	16	1		65536	1		0x0000 - 0xFFFF		1		No	No	0x0000	16-bit word with each bit representing the health of the PRN's not represented with the current cm-level clocks. 1 if unhealthy, 0 otherwise.
CRC	16	1					TBD							
		256		Total bit count										

TASS Receiver Development

Two receiver configurations have been developed:



- Integrated GPS/TDRSS receiver
  - Modified COSMIC BlackJack (BRE IGOR) by replacing one antenna channel with s-band front-end
  - Real Time GIPSY embedded in CPU
  - Receiver has redundant sides; second ‘side’ can be used for real time POD concurrently with occultation tracking on first side



- TDRSS receiver, CPU and software as a ‘second box’
  - GPS data received from a separate GPS receiver through a serial port
  - Based on the Autonomous Formation Flyer baseband processor board with S-band front-end
  - Fully reconfigurable FPGA; PowerPC 750
  - Real Time GIPSY (RTG) software

TASS Tests

Carried out successful tests of TASS prototype signal in space

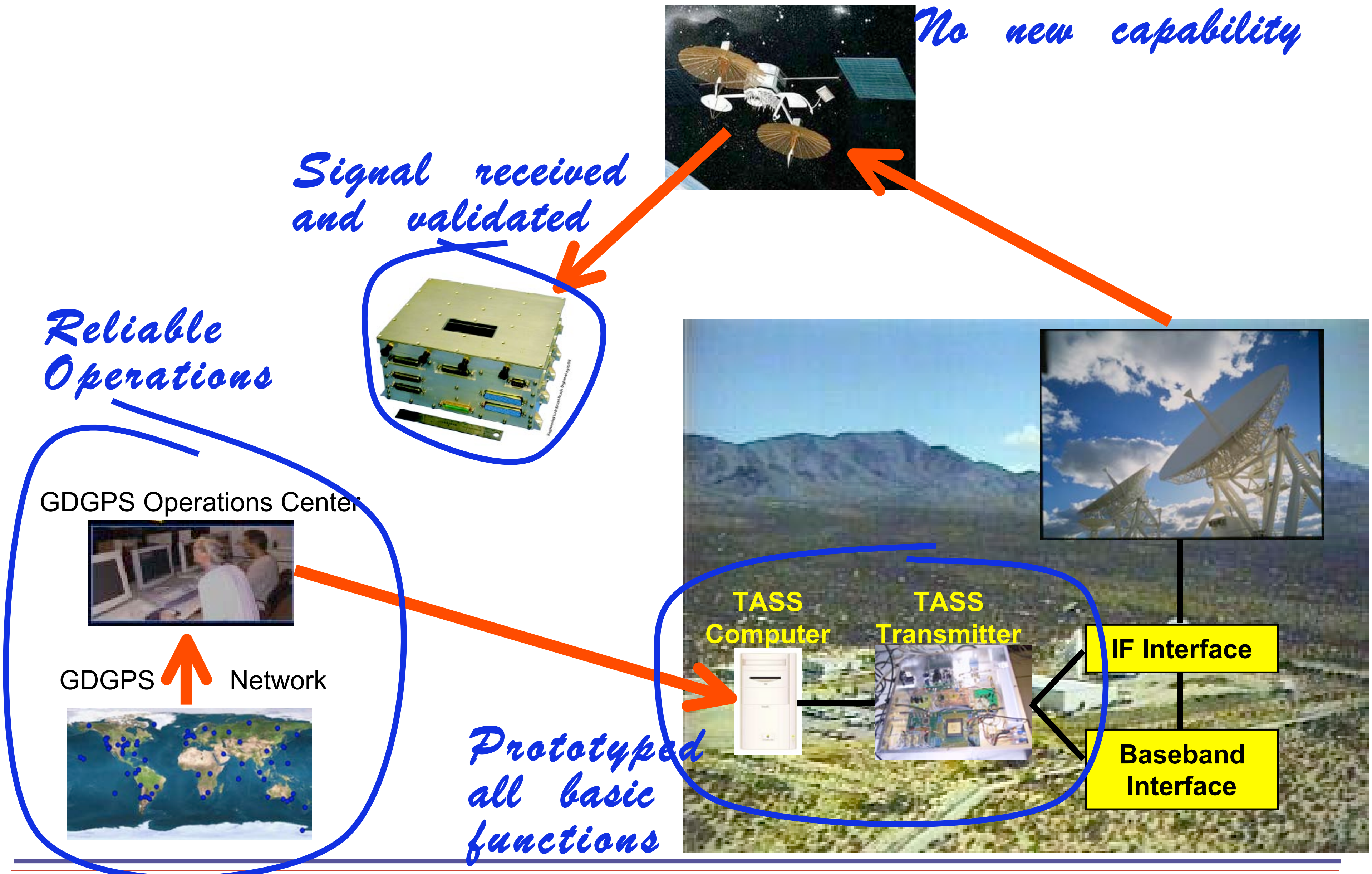
- Validated all major system capabilities
- Successfully received and tracked carrier phase
- Successfully received and tracked the PN ranging code
- Real-time data streaming from JPL
- End-to-end GDGPS data authentication
- Viterbi encoding/decoding
- Validated both IF and baseband interface options for the TASS transmitter at WSC
- Validated link budget
- Validated end-to-end latency (7 sec)

Not tested yet

- Off-boresight tracking
- Data encryption
- Dynamic user
- Long term stability and reliability

The TASS prototype transmitter

TASS Status: Prototype System validated (TRL-5)



Tentative TASS Development Schedule

- Near-continuous signal in space from one TDRS - mid 2005
- Service from two TDRS satellites - 2006
- Full service from three TDRS satellites - 2007 or as necessary